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Environmental Assessment of the Alaskan Continental Shelf

Annual Reports of Principal Investigators for the year ending March 1978

Volume VII. Effects

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF INTERIOR
Bureau of Land Management

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Outer Continental Shelf Environmental Assessment Program
Boulder, Colorado

October 1978

U.S. DEPARTMENT OF COMMERCE
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ACKNOWLEDGMENT

These annual reports were submitted as part of contracts with the Outer Continental Shelf Environmental Assessment Program under major funding from the Bureau of Land Management.

EFFECTS

Contents

EFFECTS OF OILING ON TEMPERATURE REGULATION IN SEA OTTERS

by

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Yearly Progress Report
Research Unit No. 71
Outer Continental Shelf Energy Assessment Program
NOAA Contract No. 03-7-022-35130
Period Ending April 1, 1978

I. SUMMARY OF OBJECTIVES, CONCLUSIONS AND IMPLICATION WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT.

A. The objective of this study was to measure effects of crude oil contamination on sea otters through studies on the changes in the animal's metabolic rate and subcutaneous temperatures before and after contact with oil. A second objective was to attempt to rehabilitate the otters after crude oil contamination.

B. Conclusions:

The study has shown that small amounts of crude oil contamination have large effects on the metabolic rate of sea otters. Light oiling of approximately 25% of the animal's pelt surface area resulted in a 1.4X increase in metabolic rate while immersed in water at 15°C. Furthermore, when the oil was removed by detergent, the animal's metabolic rate increased 2.1X while immersed in water at 15°C. Of the two animals studied both contracted pneumonia and one died.

C. Implications:

Any contact with oil at any time of year would have a profound influence on the health of individual sea otters through increases in the animal's thermal conductance and the subsequent increase in metabolic rate. It is probable that death may follow from pneumonia or hyopthermia depending upon the amount of the animal's fur fouled. Rehabilitation of oil-fouled sea otters would be very costly requiring holding facilities to keep the animals for at least two weeks. Even if adequate facilities were available the success rate of rehabilitating oil-fouled sea otters is likely to be rather low.

II. INTRODUCTION:

A. General Nature and Scope of Study.

This project represents an extension of studies that began with the investigations of diving and feeding behavior, and thermoregulatory effects of oil pollution in fur seals (Kooyman et al., 1976a). In this species, which relies on fur for insulation against cold sea water, the effects of oiling were profound. It is thought, but not measured, that sea otters are even more dependent on their fur for insulation.

It is predicted that oil will have an impact on sea otters through increasing their maintenance costs due to increased heat loss in air and in water as a result of pelage contamination. The magnitude of this increase will also vary between neonates and adults. External oil may also impair their diving and feeding abilities. Kenyon (1974) noted that malnutrition was common in contaminated fur seals. Finally we would anticipate direct metabolic effects of ingested oil. This proposed research will continue physiological research on sea otters, and will include an analysis and evaluation of other studies on the effects of oil pollution on sea otters. The results will provide an answer to such questions as well as help in providing basic information on the general aspects of respiration in all marine mammals. Furthermore, determination of the characteristics of diving, and measurements of the energetics involved will help to provide general information on the energy requirements of the various marine mammals and their different modes of propulsion.

B. Specific Objectives:

1. Energy requirements of normal sea otters at various water temperatures.
2. Energy requirements of sea otters after oiling.
3. Appropriate procedures for rehabilitating oiled sea otters.
4. Energy requirements of washed sea otters and time required for complete recovery.
5. At sea behavior and energetics of sea otters.
6. At sea behavior after oiling.

Information of this kind will provide a data base from which the assessment of any kind of oil contamination, or other activity which may alter the nature of the otter's food sources can be derived. In addition, relative to oil contamination the difficulties and costs of protecting from oiling, and the rehabilitating of oiled otters can be estimated.

C. Relevance to problems of petroleum development:

The sea otter is a conspicuous faunal element of many nearshore communities in Alaska and California where offshore oil development and transportation is either underway or planned. As fur bearers they are among the marine mammals most likely to be affected by oil. Furthermore, the California sea otter population has been determined to be a threatened population by the Department of the Interior due primarily to the threat of an offshore oil spill. By measuring the physiological responses of individual animals to surface contamination, the present research effort provides basic information from which the impact of an oil spill within the sea otter's range can be predicted.

III. CURRENT STATE OF KNOWLEDGE

The effects of oil spills on marine mammals have been reviewed recently by Geraci and Smith (1977), and by Davis and Anderson (1976). From both these sources it appears that hair bearing marine mammals (either adult or immature) are not usually killed by simple surface contact with oil. However, fur-bearing marine mammals (either young or adult) are much more susceptible, and may be killed by such contact.

Our previous study has shown that small amounts of crude oil have a large effect on thermal conductance of fur-bearing pelts, and no effect on nonfur-bearing pelts. In living fur seals light oiling of approximately 30% of the pelt surface area resulted in a 1.5X increase in metabolic rate while immersed in water of various temperatures. Furthermore, this effect lasted at least two weeks.

Preliminary research by Siniff, Johnson and Williams (1977) indicates that crude oil contamination of live sea otters results in death under certain circumstances. However, their investigation was of a limited nature and no conclusions can be made from their study. Metabolic rates of immersed sea otters have been measured previously (Morrison, Rosenmann and Estes, 1975; Iverson and Krog, 1973) and are useful only in comparisons with control animals used in the present study.

IV. STUDY AREA

Laboratory experiments were done at the Physiological Research Laboratory, Scripps Institution of Oceanography, University of California at San Diego, California. All sea otters were collected from Monterey, California with the assistance of the California Department of Fish and Game. Field studies on wild sea otters are planned for July, 1978 in Prince William Sound, Alaska.

V. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

A. Metabolic Rates During Immersion

Sea otters were held for several months at the Physiological Research Laboratory. A total of five female sea otters have been maintained over the last year. One female was transferred to Sea World, San Diego, when she indicated signs of pneumonia which resulted in chronic lung damage.

The sea otters were weighed wet on a platform beam balance just prior to the metabolic run. Soon after weighing all animals were placed in the metabolic test chamber specially designed for these studies. The chamber, which was 151 cm long, 84 cm wide, 84 cm deep and which held about 1400 liters of fresh water, was constructed of styrofoam sheets (about 95 cm thick) which were coated with wood and fiber glass for strength. The lid of the chamber was fastened tightly over a neoprene gasket and the box was filled with fresh water to 2 cm above the lip of a 30 x 60 cm lucite dome projecting above the chamber top. Opposed ports in the lower portion of the dome functioned as intake and exhaust for air drawn through this air space. The rate of air flow was measured with a Wright respirometer. Humidity was determined with a dial hygrometer, and barometric pressure was measured with an aneroid barometer.

Air temperature and water temperature of the box were measured with thermocouple probes, one of which was placed at the mouth of the air intake and the other on the upper portion of the chamber wall about 2 cm below the lid. Water was slowly, constantly and uniformly stirred in the box by means of a series of outlet and inlet manifolds. Water temperature usually varied less than 0.5°C. Readout of the thermocouple probes was with a Bailey Batt 4 coupled to a digital voltmeter which made possible the reading of temperatures to 0.1°C.

Deep body temperatures were obtained by inserting an encapsulated radio transmitter down the esophagus of anesthetized animals. The transmitter signal was received on a standard FM broadcast receiver modified by Konigsberg Instruments, Inc. to demodulate the pulsed interval ratio to an analog voltage which was then measured on an oscilloscope.

Subcutaneous temperatures were taken by surgically implanted radio transmitters. The pulse rate of the transmitter varied with temperature. The signal was received on a standard AM radio and the pulses were counted and converted to temperature readings.

A sample of the exhaust from the dome was drawn through a glass "U" tube filled with drierite, two "U" tubes containing CO_2 absorber, and a final "U" tube of drierite before entering the sensing cell of an AEI O_2 analyzer. In those experiments with oiled or washed animals a "U" tube of 4-12 mesh activated charcoal preceded the first drierite "U" tube. This material absorbed all oil fumes.

The AEI O_2 analyzer signal was continuously recorded on a 25 cm chart recorder adjusted to record from 19-21% full scale. At 60-minute intervals the inlet air sample was checked, and the instrument's reference cell adjusted if it had drifted. Once a session the analyzer was calibrated by flushing the sensing cell with outside air.

The plotted curves of O_2 concentration changes were smoothed by eye and the difference in O_2 concentration from the intake and exhaust were determined every minute. The averages for 60-minute intervals were collated. Appropriate factors for correction of gas volumes to STPD were incorporated into a computer program, and oxygen consumption rates were calculated on a Data General Corporation, Nova 2, computer.

Sea otters were oiled by first putting them lightly to sleep with gas anesthesia (Halothane). This was accomplished by placing the sea otter's head in a plastic mask and flowing gas through the mask at a known concentration. Gas flow rate and concentration were maintained with a Bird MK 5 respirator and fluotec vaporizer. Prudhoe Bay crude oil was then brushed over the back of the animal from the base of the skull to the tail. About 60 ml of oil was brushed onto the fur. The rest of the animal was left oil-free. This process took no more than 15 minutes. After oiling the animals were permitted to swim in a clean pool of sea water for 30 minutes before the metabolic test.

Upon completion of the metabolic test the animals were anesthetized and cleaned with Amberlux detergent. Cleaning took 30-45 minutes.

VI. RESULTS

To date a total of 43 control metabolic measurements have been made on four sea otters at water temperatures of 5, 10, 15, 20, 25 and 30°C (Table 1 and Fig. 1). The sea otters appear to have a thermal neutral zone between 10°C and 30°C, with the lower critical temperature between 5 and 10°C (Fig. 1).

Oiling experiments have been conducted on two sea otters, once on otter D and twice on otter B. The subcutaneous and core body temperatures for the three oiling experiments can be seen in Table 2. The average metabolic rate of otter B increased 22% after oiling ≈ 30% of her dorsal surface with 38 mls of crude oil. After washing, her metabolic rate increased 102% above the control rate (Fig. 2). Eight days after oiling her metabolic rate returned to normal. In the second experiment 50% of otter B's back was oiled with 60 mls of crude oil. After oiling there was a 69% increase in her normal metabolic rate. After washing her metabolic rate was 125% above normal and was still 33% higher than normal after 14 days. In the third oiling experiment 50% of the dorsal surface of otter D was oiled with 60 mls of oil. Her average metabolic rate increased 36% after oiling and 111% after washing. After washing, the sea otters' furs appeared wet and the animals were observed shivering. The lower subcutaneous temperatures observed in oiled pelt areas agree with the increased thermal conductance of oiled fur.

After the first oiling otter B recovered in our normal holding facility. However, after the second and third oiling experiments the washed otters were incapable of completely grooming their fur into its normal condition.

Forty-eight hours after washing, otter B had groomed only her upper torso and the fur on her lower abdomen was totally wetted. Furing this time she was constantly shivering. The water temperature of our holding tank was 16.7°C. Due to constant shivering and the inability of otter B to groom herself properly, she was removed from the holding tank and placed in a small tub filled with 25-30°C water. The tank was left filled for three hours and then drained and left empty for 1-2 hours and then filled again. This procedure was carried out for 24 hours. After the 24 hour period the otter had managed to successfully groom her entire body and was returned to our regular holding tank where she continued to groom normally and was not observed to shiver again.

Two weeks after oiling otter B, we took a routine blood sample and measured a white blood cell count of 16,500 cells/mm^3. The normal white count is around 8,000 cells/mm^3. Otter B was when transferred to Sea World for veterinary care, where they diagnosed pneumonia. Otter B recovered after treatment with antibiotics. When she was returned to the Physiological Research Laboratory 100 days after oiling, her fur was matted and her metabolic rate was 71% greater than normal.

After washing otter D we put her into a tank of warm water (26-30°C). However, unlike otter B, she would not groom. Over the next six day period we put her into cold water then warm water and then let her dry. She did attempt to do some grooming but was unsuccessful in restoring the air layer into her fur. On the sixth day after oiling we transferred her to Sea World, where they diagnosed initial signs of pneumonia. Five days later she died (11 days post oiling). A necropsy was conducted and revealed gross inflammation of the lung resulting from acute pneumonia.

VII DISCUSSION

The lower subcutaneous temperature beneath oiled fur agrees well with the increased thermal conductance of excised oiled pelts by Kooyman et al., 1976a. The lower subcutaneous temperature under the oiled fur indicates that the fur has lost some of its insulating quality. In order to compensate for the localized loss of insulation the peripheral circulation was probably reduced resulting in a lower subcutaneous temperature, thereby lowering the heat loss to the environment.

The mean standard metabolic rate for the immersed four sea otters studied of 11.3 ml O_2/min · kg compares well with the 14.2 ml O_2/min · kg measured in Alaskan sea otters by Morrison, Rosenmann and Estes (1974). The standard metabolic rate of these sea otters is 2-3X the predicted standard metabolic rate for a terrestrial mammal of equal size. Elevated metabolic rates of immersed marine mammals have been observed by others (Irving and Hart, 1957; Kooyman et al., 1976a; Miller et al., 1976; Morrison et al., 1974). Similarly elevated metabolic rates have also been recorded for immersed penguins (Kooyman et al., 1976b). The changes in the sea otter's metabolic rate after oiling and washing parallel those previously observed in live fur seals and in excised pelts (Kooyman et al., 1976a). In both studies the post wash condition was twice the control. The fact that the fur becomes wet to the skin after washing seems to indicate that the natural fur oils have been removed along with the crude oil.

If this hypothesis is correct, it takes the fur a minimum of eight days to recover its natural oils. During the first oiling experiment the reduced thermal stress from the warmer holding-tank water (20.7 - 1st oiling, 16.7 - 2nd oiling) probably allowed otter B to recover without special handling. The fact that in 2 of the 3 oiling experiments the sea otters contracted pneumonia is not surprising. Sea otters appear to be especially susceptible to pneumonia. The cause of death in many wild sea otters has been attributed to pneumonia (Morejohn, Ames, Lewis, 1975). Any rehabilitation of oil fouled sea otters would require veterinary supervision and warm water holding facilities to decrease the chance of death by hypothermia or pneumonia prior to release of the sea otters into the wild. It may not be possible to treat large numbers of fouled sea otters successfully. Especially when we consider the amount of food sea otters require (25-30% of their body weight daily).

The matted fur and high average metabolic rate of otter B after returning from Sea World may not be entirely due to the oiling and washing. Otter B was maintained in a tank flushed with chlorinated sea water. It is possible that the chlorine also removed some natural fur oils causing the fur to mat. This hyopthesis is further supported by two facts. Otter B's metabolic rate was 17.8 ml O_2/kg · hr just before she went to Sea World and was 23.0 ml O_2/kg · hr upon her return. The matted fur extended into areas which were not oiled or washed (even the hind flippers were matted). However, the only conclusion that can be made is the fur became matted as a result of the rehabilitation process.

VIII. CONCLUSIONS

Crude oil contamination over small areas of the sea otter's fur causes noticeable increases in their heat loss and metabolic rate. Oiled sea otters had metabolic rates 1.4X normal. Removal of the crude oil by washing with a detergent resulted in metabolic rates that were 2.3X normal. Crude oil contamination of wild sea otters would probably cause significant thermal stress and could lead to hypothermy and/or pneumonia resulting in death. Rehabilitation of large numbers of sea otters would require sophisticated pre-existing facilities and would be extremely expensive if at all possible.

IX. NEEDS FOR FURTHER STUDY

Five areas which deserve further study are: the consequences when crude oil is left on sea otter fur; how well the sea otter survives the increased energy demands of oil contamination; do wild sea otters avoid oil slicks; what are the natural oils in sea otter fur and can we successfully replace the oils after washing.

X. SUMMARY OF JANUARY - MARCH QUARTER

1. Scientific Party

    a. Dr. Gerald Kooyman - Principal Investigator

    b. Daniel Costa - Project Coordinator

    c. Randall Davis - Assistant in data analysis and experimental runs.

    d. Michael Bergey - Animal Caretaker

    e. Noel du Celliee Muller - Volunteer

    f. Darrell Lee - Southwest Fisheries Center Paid Volunteer

    g. William Owens - Volunteer

2. Methods

    The laboratory analysis is described in the final report.

3. Data Collected

    a. The oiling experiment reported for otter D was during January.

    b. Eight control measurements were conducted on otter J who was collected on 12/30/77. An oiling experiment was planned for otter J, but it was cancelled when we discovered she was pregnant.

    c. Otter S was collected from Monterey, California with the assistance of the California Department of Fish and Game on 20 April, 1978. We are preparing to begin metabolic measurements on her as soon as she becomes accustomed to captivity and the metabolic chamber.

XI. AUXILIARY MATERIAL

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B. Oral Presentations

Symposium on Offshore Drilling
Sponsored by Association of Monterey Bay Area Government.
Gerald L. Kooyman - Panel Member Marine Mammal Authority. April, 1978.

C. Papers Published

Costa, D. P. 1978. The Sea Otter; its interactions with man. Oceanus. Spring Issue (In press).

SUBLETHAL EFFECTS OF PETROLEUM HYDROCARBONS AND TRACE METALS, INCLUDING BIOTRANSFORMATIONS, AS REFLECTED BY MORPHOLOGICAL, CHEMICAL, PHYSIOLOGICAL, PATHOLOGICAL, AND BEHAVIORAL INDICES

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Submitted as the Annual Report
for Contract #R7120819
Research Unit #73
OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM
Sponsored by
U. S. Department of the Interior
Bureau of Land Management

April 1978

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I. SUMMARY OF OBJECTIVES, CONCLUSIONS, AND IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

A. SUMMARY OF OBJECTIVES

The overall objective of this program was to assess potential effects of petroleum operations on marine organisms indigenous to Alaskan waters. There were several primary objectives of this research unit (OCSEAP RU 73) during the contract period. These were to define and evaluate: (1) the alterations in structure of eggs, larvae, livers, and tissues of fish after petroleum exposure; (2) the importance of skin and epidermal mucus in metabolism and disposition of petroleum hydrocarbons in salmonids and flatfish; (3) the uptake, metabolism, and elimination of petroleum aromatic hydrocarbons by salmonids, demersal fish, and shrimp; (4) the effects of toxic trace metals on the metabolism of aromatic hydrocarbons by salmonids and flatfish; (5) the enzymes (aryl hydrocarbon monooxygenases) that metabolize and detoxify or activate aromatic hydrocarbons in a variety of aquatic species; (6) the physiological and embryological effects of aromatic hydrocarbons on early life forms of invertebrates; (7) the pathological effects of exposure of flatfish to crude petroleum-contaminated sediment; (8) the effects of exposures to petroleum on disease resistance of salmonids; and (9) the behavioral responses of vertebrate and invertebrate species exposed to petroleum hydrocarbons.

B. SUMMARY OF CONCLUSIONS

The conclusions of this program are summarized according to disciplinary areas of study. Several aspects of the studies have been completed while others are continuing.

Morphology

In our previous studies on morphological alterations of fish tissues after petroleum exposure, a number of potentially deleterious changes were observed. Further studies were performed this year to look at cellular changes in different species and in species previously examined but exposed under different conditions. Liver changes observed in fish exposed to petroleum repeatedly involved alterations in lipid and glycogen levels and an increase in endoplasmic reticulum. The metabolism of the fish, therefore, was changed as a result of oil exposure; the consequences of these alterations in terms of survival are not known.

In addition, investigations were expanded to early developmental stages of fishes in order to detect particularly sensitive species.

Lenses were found to hydrate and may eventually form cataracts in rainbow trout (Salmo gairdneri) chronically exposed to a high level of petroleum in their diet. Seriously impaired vision is the final result. Cataractous lenses can be easily identified in the field and should be considered as one of the criteria for monitoring the long-term impact of petroleum on fish populations.

Chemistry

Our results demonstrate that skin of salmonids and flatfish is actively involved in the uptake and discharge of naphthalenes and their metabolites, and that skin exhibits a tendency to preferentially retain metabolic products of hydrocarbons. Starry flounder (Platichthys stellatus) can have four times as much hydrocarbon metabolites as parent hydrocarbons in the skin one week after an exposure, thereby indicating extensive metabolism of the hydrocarbon. Completed work presented evidence for the role of mucus in the excretion of naphthalene and its metabolites in fish, and suggests that such exudates must be considered along with other routes of elimination which lead to the recycling of petroleum and metabolic products in the marine environment. It appears that skin and epidermal mucus play an important role in accumulation, discharge, and retention of hydrocarbons and their metabolites in fish.

The findings that starry flounder extensively metabolize polycyclic aromatic hydrocarbons to their metabolic products showing clearly that analyses of parent hydrocarbons in tissues of such fish would not give a clear picture of the extent and effect of petroleum pollution on the demersal fish.

Coho salmon (Oncorhynchus kisutch) readily incorporate 1-methylnaphthalene (1-MN), from dietary exposure, into the liver, brain, kidney, muscle, and blood. Coho salmon and starry flounder, which are exposed to 2.7 and 0.4 ppb of 1-MN, respectively, in flowing seawater, will bioconcentrate substantial amounts of this compound. A trend toward increased accumulations of 2,6-dimethylnaphthalene (2,6DMN) and its metabolites at 4° compared to 13°C was indicated, but not established statistically. The administration of 2,6-DMN to coho salmon results in accumulations of conjugated and non-conjugated hydroxy derivatives of 2,6-DMN in tissues.

Results show that cadmium or lead in seawater can influence naphthalene metabolism in starry flounder. In livers from both cadmium- and lead-exposed flatfish, the amount of the metabolite 1,2-dihydro-1,2-dihydroxynaphthalene in the liver was significantly lower ($P<0.05$) than in the control livers. Also, cadmium exposures did not significantly ($P<0.10$) alter the level of the dihydrodiol in livers of coho salmon. The data also indicate that large differences in the levels of naphthalene metabolites in the liver occur between starry flounder and coho salmon.

Completed work revealed that highly variable activities of aryl hydrocarbon monooxygenases (AHM) are common to hepatic tissues of vertebrate species and visceral tissues of the tanner crab tested (Chionoecetes sp.). Negligible or no activities of the monooxygenases are associated with gastropods (Fusitriton sp.) and molluscs.

Physiology

The work on physiological effects of petroleum hydrocarbons lead to the following conclusions: No biological exchange of the tritium label takes place, and purified, tritiated compounds are appropriate for metabolic studies. Naphthalene adversely affects the fertilization and early embryology of mussels and oysters at concentrations as low as 1 ppb. The metabolic products of naphthalene formed by spot shrimp (Pandalus platyceros) appear to include naphthol, a dihydrodiol, naphthyl sulfate and a glucuronide.

Pathology

English sole (Parophrys vetulus), rock sole (Lepidopsetta bilineata), and starry flounder took up substantial levels of aromatic hydrocarbons when exposed to Prudhoe Bay crude-oil-contaminated sediments. English sole in contact with sediments having over 500 ppm (dry wt) total extractable petroleum hydrocarbons (TEPH) for one month developed liver abnormalities consisting of severe hepatocellular lipid vacuolization (HLV) and hematological changes. When exposed to oiled sediment for over 4 mo, the number of fish not gaining weight was significantly higher (P=0.05) than for control fish on uncontaminated sediment. Also, after 4 mo a small number of oil-exposed fish, but no control fish, became severely emaciated.

The effect of long-term peroral exposure to Prudhoe Bay crude oil (PBCO) (up to 1 part per thousand added to diet for up to 16 mo) on host defense mechanisms and disease resistance in rainbow trout, was assessed using a variety of in vitro and in vivo tests of immunocompetence. The results were that essentially no adverse changes were found after oil exposure. However, a reduction in spleen/body weight ratio was demonstrated in oil-exposed fish. The significance of this reduction is not clear as no consistent decreases in erythrocyte or leukocyte-thrombocyte numbers were found in spleens from oil-exposed fish. Additionally, no decrease in the same hematological parameters was shown for anterior kidney nor for peripheral blood.

Behavior (including aspects of reproductive biology)

Upstream migration of spawning adult salmon was inhibited by the presence of a model mixture of petroleum hydrocarbons in the water at concentrations of 0.7 ppm and higher. Salmon migrating early in the run were more responsive to the presence of hydrocarbons than those migrating late in the run.

Exposure of adult salmon to subavoidance concentrations of a model mixture of petroleum hydrocarbons resulted in a delay of return to their "home" stream, but did not alter their ability to return.

Exposure of mature dorid nudibranchs to a seawater-soluble fraction of Prudhoe Bay crude oil for 1 to 14 days at concentrations of 10 ppb and greater resulted in a decrease in their reproductive success by: (a) a reduction in capacity to locate other individuals of the same species for mating; (b) a decrease in quantity of eggs deposited; and (c) disruption of ontogenetic development.

C. IMPLICATIONS WITH RESPECT TO OCS OIL AND GAS DEVELOPMENT

Research findings from this program have clear implications with respect to petroleum effects on aquatic species and consequently to OCS oil and gas development. Most of the research studies were designed as laboratory experiments with emphasis on oil exposures of aquatic organisms contained in flowing-seawater holding tanks. The degree to which laboratory results can be directly applied to natural events remains a considerable problem. In the absence of a capability for testing target species directly under natural conditions, models, such as those used in the present studies, and representative test situations, must be applied.

Changes in the structure of certain cells of fish exposed to petroleum indicate potentially deleterious effects. Alterations in metabolism reflected by abnormalities in the liver and possible defects in vision from lens pathology could affect survival of wild fish. These changes are consistent, distinct, and potentially severe enough to be useful as one means of evaluating effects of oil spills on fish.

Results from the study of exposure of coho salmon and starry flounder to ppb levels of 1-MN imply that low concentrations of alkylated naphthalenes in areas of petroleum operations could result in substantial increases in hydrocarbon burdens of these compounds and their metabolites in fish. Furthermore, the data suggest that increases in body burdens of alkylated naphthalenes may not be related in a major way to temperature of surrounding waters in exposed fish.

The ability of fish to metabolize alkylated naphthalenes, with subsequent accumulations of metabolites, suggests cause for concern because related studies using mammalian systems show that metabolites of certain polynuclear aromatic hydrocarbons comprise one group of toxic factors which can lead to neoplasia and other deleterious biological changes.

The studies on the effects of lead and cadmium on naphthalene metabolism in starry flounder showed lower concentrations of the dihydrodiol of naphthalene in fish exposed to cadmium and lead than in unexposed fish. Cadmium affected coho salmon similarly. This suggests that lead and cadmium interfere with the biotransformation of naphthalene. The observed differences in dihydrodiol concentrations in liver could be due to partial inhibition of the metabolism of naphthalene or to increased rates of excretion of the dihydrodiol from the liver. The findings indicate that starry flounder, under lead and cadmium stress, may have altered capacity to metabolically respond to a petroleum challenge.

Knowledge of the AHM activities and factors affecting them for various species suggests which species may accumulate and/or metabolize aromatic hydrocarbons from petroleum exposures.

The low concentration (1 ppb) of hydrocarbon that produces adverse effects on the fertilization and early embryology of the selected molluscs used in this study indicates the incompatibility of the simultaneous presence of petroleum hydrocarbons and gametes in the water. This is of considerable importance since the gametes of most commercial species of molluscs and of many commercially important vertebrate species are exuded directly into the water where fertilization takes place. The resultant larvae are also partially vulnerable as members of the plankton community.

The presence of several metabolites in the spot shrimp exposed to naphthalene and the facility that these animals have for accumulating naphthalene and metabolites allows a direct route for these compounds to be concentrated and passed to higher trophic levels. The question of the transfer of potentially toxic metabolites through the food web becomes increasingly important in studies such as these with invertebrates.

English sole, and probably most other Pleuronectidae, exposed to sediment containing levels of Prudhoe Bay crude oil hydrocarbons of approximately 400 ppm or higher for several months appear to be at risk for developing pathological alterations, including liver abnormalities and other conditions associated with weight loss.

There is no evidence, however, from experiments conducted this year that an increased incidence of bacterial infections in salmonid fish would result from dietary exposure to PBCO.

The threshold concentration of monoaromatic hydrocarbon components of PBCO which inhibited adult salmon upstream migration was 0.7 ppm. However, depending upon time of migration and environmental factors such as temperature and water siltation, significant reduction in migration may be evident only at hydrocarbon concentrations greater than 2-3 ppm. Considering the high volatility of monoaromatics and their low proportion in PBCO (0.98% of total components), it appears doubtful that a sufficient concentration of these hydrocarbons would be frequently attained in the environment for a period of time necessary to seriously inhibit upstream spawning salmon migration.

Adult salmon exposed to subavoidance concentrations of monoaromatic hydrocarbons for 8-22 hr showed a two-day delay in return to their home stream. Although the significance of what appears to be a short delay is unknown, it is important to recognize that salmon migration is correlated with a variety of reproductive physiological and environmental parameters, and at certain critical periods a disruption in migratory timing may impair spawning success.

Chronic exposure at low ppb concentrations of the salt water-soluble fraction of PBCO can potentially result in deleterious effects on certain marine invertebrate populations. Evidence for this was obtained in this year's laboratory studies on reproductive processes of a dorid nudibranch, and last year's experiments on feeding behavior of spot shrimp. There were notable effects on both species at 10-20 ppb, and distinct reductions in these behavioral and reproductive activities at 300 ppb.

II. INTRODUCTION

A. GENERAL NATURE AND SCOPE OF STUDY

The responses of marine organisms to environmental contaminants are reflected in a number of changes detectable at population and organismal levels, as well as at cellular, subcellular, and molecular levels. The general scope of this study is to evaluate effects at various levels by investigating morphological, chemical, physiological, pathological, and behavioral changes in subarctic and arctic marine animals exposed to petroleum hydrocarbons and trace metals.

B. SPECIFIC OBJECTIVES

In the multidisciplinary approach used in this study, there is a series of objectives to evaluate the effects of petroleum on marine organisms.

The series of specific objectives performed during the current reporting period of April 1, 1977 to March 31, 1978 are as follows:

Morphology

To identify the effects of petroleum on fish eyes, livers, eggs, and larvae. Also, to establish, using a variety of exposure situations and selected species of both benthic and pelagic fish, which tissues are the most obviously and consistently structurally altered by petroleum exposure.

Chemistry

Naphthalene Metabolism in Fish Skin and Mucus

To evaluate the importance of fish skin and its accessory structures in accumulation, metabolism, and excretion of petroleum constituents. Specific objectives of the study were to determine concentrations of hydrocarbons and their metabolites in skin and mucus of salmonids and flatfish exposed to radioactively labeled naphthalenes in diet, in flowing water, or via intraperitoneal injection.

Metabolism and Disposition of Naphthalene in Flatfish

To conduct initial studies to determine extent of metabolism and disposition of naphthalene in several species of flatfish.

Biotransformation of Methyl-Substituted Naphthalene in Fish

To determine (a) the uptake and levels of accumulation of 1-methylnaphthalene (1-MN) in tissues of force-fed coho salmon, (b) the uptake and bioconcentration factors of 1-MN in tissues of coho salmon and starry flounder exposed to 1-MN under flow-through conditions, (c) effects of a change in temperature (4° vs. 13°C) on levels of accumulation of 2,6-DMN and its total metabolites in coho salmon, and (d) the nature of metabolism of 2,6-DMN in coho salmon.

Influence of Cadmium and Lead on Naphthalene Metabolism

To determine the effects of lead and cadmium on the metabolism of naphthalene in marine organisms and to identify the affected pathways for metabolism of naphthalene.

Activities of Aryl Hydrocarbon Monooxygenases (AHM) in Different Species

To measure the specific activities of AHM in different marine species from Norton Sound and the Chukchi Sea.

Physiology

To determine if the differences noted in the metabolic profiles of vertebrates and invertebrates exposed to carbon-14 and tritium labels of the same compound are due to exchange of the tritium labels or are caused by impurities in the labeled compound.

To determine the physiological and embryological effects of naphthalene on the gametes and larvae of the oyster (Crassostrea gigas) and the mussel (Mytilus edulis).

To identify the metabolites formed by spot shrimp (Pandalus platyceros) exposed to a seawater solution of naphthalene.

Pathology

Pathological Changes in Flatfish from Exposure to Oil-Contaminated Sediment

To determine the frequency and nature of pathological changes occurring in flatfish as a result of exposure to oil-contaminated sediments.

Effects of Petroleum on Fish Disease Resistance

To assess the effects of petroleum hydrocarbons on host defense mechanisms and disease resistance of salmonid fish.

Behavior (including aspects of reproductive biology)

Vertebrate

To determine whether the following occurs: (a) juvenile salmon avoid water containing petroleum hydrocarbons, (b) petroleum hydrocarbons introduced into "home" stream water inhibits the upstream spawning migration of Pacific salmon, and (c) exposure of migrating adult Pacific salmon to petroleum hydrocarbons reduces the frequency or alters the timing of their returning to the "home" stream.

Invertebrate

To determine if the seawater-soluble fraction of Prudhoe Bay crude oil (a) inhibits chemotaxis related to reproductive behavior of the dorid nudibranch (Onchidoris bilamellata), and (b) interferes with dorid nudibranch egg deposition and development.

C. RELEVANCE TO PROBLEMS OF PETROLEUM DEVELOPMENT

When petroleum is transported in or obtained from coastal or offshore areas, inevitably petroleum hydrocarbons and associated trace metals escape into the marine environment. These materials, at some levels, have a potential for producing critical damage to marine resources. This damage by crude oil components can take several forms (Blumer, M., Testimony before Subcommittee on Air and Water Pollution, Senate Comm. on Public Works, Machias, Maine, 8 Sept. 1970):

1. Direct kill of organisms through coating and asphyxiation.
2. Direct kill through contact poisoning of organisms.
3. Direct kill through exposure to water-soluble toxic components of oil at some distance in space and time from the accident.
4. Destruction of the generally more sensitive juvenile forms of organisms.
5. Incorporation of sublethal amounts of oil and oil products into organisms resulting in reduced resistance to infection and other stresses. Also, this may result in failure to reproduce.
6. Destruction of the food sources of higher species.
7. Exposure to long-term poisons, e.g., carcinogens.
8. Low-level effects that may interrupt any of the numerous events necessary for the feeding, migration, and propagation of marine species and for the survival of those species which stand higher in the marine food web.
9. Contamination of marine food resources to make them unfit for human consumption.

Studies of OCSEAP Research Unit 73 are largely concerned with indirect, long-term effects of petroleum such as those detailed in items 4, 5, 7, and 8. These effects are much more difficult to detect and evaluate than those related to acute exposures, but may over a period of time have even greater impact on marine biota.

III. CURRENT STATE OF KNOWLEDGE

A resume of the current state of knowledge relevant to the several disciplinary areas of study covered in this report is given below.

MORPHOLOGY

Studies on the morphology of fish exposed to petroleum hydrocarbons address problems of structural changes at cellular and subcellular levels. We are, by such studies, able to detect changes which may be useful in assessing long-term effects of petroleum and which are indicators of potential physiological damage.

In addition to our own contributions summarized in this report and the papers reviewed in the previous Annual Report (RU 73/74, 1977), there have been two papers published this year which relate to our particular research direction. A recent paper by Payne et al. (1978) describes the pathological changes in a marine fish (cunner: Tautogolabrus adspersus) after exposure to Venezuelan crude oil in a flow-through system for 6 mo. There were significant differences in the lens diameter, testicular/somatic index, and the plasma chloride levels between control and experimental fish. The changes in lenses parallel the lens size increases that we have reported in freshwater fish exposed to petroleum in their diet (Hawkes 1977) even though the type of fish and exposure conditions were different in the two studies.

A study of another fish species, Fundulus heteroclitus, which was exposed to a major spill in 1969 in Wild Harbor marsh, Massachusetts, compared the ultrastructure of the liver cells of fish of the same species from nearby Sippewissett marsh which had no petroleum contamination (Sabo and Stegeman 1977). In 1975, six years after the spill, the levels of petroleum in the tissues of Fundulus were as high as 75 ppm (Burns 1975). The 1977 study of Sabo and Stegeman, eight years after the spill, showed notable ultrastructural differences between liver lipid and glycogen levels in the exposed and unexposed fish and an increase in the endoplasmic reticulum of the exposed fish.

CHEMISTRY

Polycyclic aromatic hydrocarbons such as naphthalene are prominent components of water-soluble fractions (WSF) of petroleum. Many investigations have been carried out on the acute toxicity of WSF of petroleum, and of some individual hydrocarbons, to a variety of marine organisms (Craddock 1977). Most studies concerning biochemical effects of polycyclic aromatic hydrocarbons on aquatic organisms have focused on accumulation of the hydrocarbons in whole organisms and to a lesser extent in specific tissues (Varanasi and Malins 1977). In the last few years an increasing interest has developed in the ability of aquatic organisms to convert aromatic hydrocarbons to their electrophilic metabolites (Payne 1976, Pedersen et al. 1976, Philpot et al. 1976, Gruger et al. 1977), which are shown to be potentially mutagenic in mammalian systems (Sims and Grover 1974). The hepatic tissues of many aquatic organisms contain hydrocarbon metabolizing enzymes such as aryl hydrocarbon monooxygenases (AHM). Moreover, it was recently shown by Lee et al. (1976), Sanborn and Malins (1977), and Roubal et al. (1977a) that metabolic products of polycyclic hydrocarbons tend to persist in the tissues of most aquatic organisms (e.g., crab, shrimp larvae, fish) even when the parent hydrocarbon is almost completely discharged.

A survey of the literature (Varanasi and Malins 1977) shows that the skin of fish, a primary site of contact with the environmental pollutants, has been largely overlooked in studies concerning the fate and effect of petroleum in aquatic environments. Considering that certain fish (e.g., Pleuronectidae) frequently develop epidermal neoplasia (Wellings et al. 1976) whereas others rarely do, studies to investigate the role of skin in hydrocarbon metabolism in different species of fish are of considerable interest. Furthermore, studies with mammalian systems have demonstrated that skin of some mammals possesses an ability to metabolize polycyclic hydrocarbons to potentially mutagenic and carcinogenic compounds (Sims and Grover 1974). Correlations have been drawn between the carcinogenicity of the hydrocarbons and the extent of their interactions with nucleic acids of skin in mice (Brookes and Lawley 1964).

Coho salmon and starry flounder are capable of bioconcentrating a wide spectrum of hydrocarbons (Roubal et al. 1978). Moreover, studies of the individual metabolism of benzene, naphthalene, and anthracene in coho salmon gave rise to hydroxylated and conjugated compounds, which are typical of mammalian metabolism. For example, formations of 1-naphthol, a naphthalene dihydrodiol, and several conjugates of 1-naphthol in salmon were quantitated (Roubal et al. 1977). Although individual metabolites of anthracene in coho salmon were not identified, the separation scheme that was employed established that conjugated derivatives were present together with non-conjugated derivatives. Moreover, it was shown (Roubal et al. 1977a, 1978) that both the number of fused benzene rings and the degree of alkylation of aromatic compounds are factors which influence levels of accumulated aromatic hydrocarbons in coho salmon and starry flounder (Roubal et al. 1978). That is, increases in alkylation and ring structure tend to increase retention of aromatic hydrocarbons in marine organisms within certain, yet undefined, limits.

Our current findings indicate that other factors are involved in hydrocarbon incorporation and accumulation; that is, competition between individual hydrocarbons in complex mixtures (e.g., water-soluble hydrocarbons of crude oil) exist in hydrocarbon accumulation. For example, results of recent work showed that 1-MN, a constituent of crude oil, is bioconcentrated to substantially greater levels when coho salmon and starry flounder are exposed to 1-MN alone than when exposed to it in a WSF of crude oil. These findings suggest that significant differences in accumulations are likely to occur, depending on whether the organisms are exposed to a single compound or to that compound in a complex mixture. Also, it is likely that the composition will influence to a significant degree the accumulation of the individual hydrocarbon components.

The effect of temperature on accumulation of individual hydrocarbons in fish is unclear. The work by Collier et al. (1978) has shown that lowering of the temperature from 10° to 4°C resulted in higher levels of naphthalene in several organs of coho salmon after 16 hr of exposure. However, this situation for 2,6-DMN and its metabolites was not shown to be valid after statistical treatment of the data.

The extensive review by Varanasi and Malins (1977) clearly points out that petroleum hydrocarbons can induce metabolic activity in aquatic species. Studies with _Fundulus heteroclitus_ from clean water and oil-polluted water indicated that petroleum contamination induced higher levels of mixed function oxidase activity in fish.

Heavy metals are known to interfere with metabolic processes. Dawson et al. (1977) found that Morone saxatilus, when exposed to 5 ppb cadmium for 90 days, had significant reduction in activity of both aspartate aminotransferase and glucose-6-phosphate dehydrogenase. Lead has been shown to inhibit α-amino levulinic acid dehydratase (ALA-D) activity in fish at concentrations as low as 10 ppm (Hodson 1977).

Rats that have been exposed to cadmium had significant reductions in the levels of the cytochromes P-450 and b_5, and aniline hydroxylase activity was decreased by 32% (Krasng 1977). This suggests that metals, such as cadmium and lead, might alter the activity of aromatic hydrocarbon monooxygenases (AHM) and thus the ability of fish to transform and excrete petroleum components.

There is considerably more information available now about activities of AHM in aquatic organisms than there was 2-3 yrs ago. Payne and Penrose (1975) found that petroleum induces the AHM in tissue homogenates from liver and gills of brown trout (Salmo trutta) and capelin (Mallotus villosus). Hepatic AHM activity was higher in fish taken from petroleum-contaminated sites than in fish taken from "clean" control sites (Payne 1976, Kurelec et al. 1977). Gruger et al. (1977) showed that young coho salmon exposed to 150 µg/ml of a seawater-soluble fraction of Prudhoe Bay crude oil (PBCO) for 6 days exhibited a significant induction of the hepatic AHM system, but that 1 µg/g of PBCO in food did not affect the AHM system after 68 days of feeding the oil to young salmon in fresh water.

Preliminary results from the present research indicates that starry flounder exposed to sediment, which was contaminated with PBCO, exhibited significant increases in hepatic AHM activity, while no effect on AHM activity was found for English sole and rock sole that were similarly exposed (McCain and Hodgins, unpublished). Hepatic AHM activity for starry flounder were found to be considerably higher for fish taken from the highly industrial area of Puget Sound than for fish taken from the mouth of the Columbia River (Gruger and Folmar, unpublished).

Evidence is rapidly accumulating to suggest that all vertebrate marine organisms possess the AHM system, although there are other organisms which do not seem to have AHM activity in the principal tissues examined. Buhler and Rasmusson (1968) reported aniline hydroxylase activities for 17 species of fish. Payne (1976) demonstrated benzopyrene hydroxylase activity in some invertebrates, but "attempts to induce the enzymes in representative echinoderms, crustaceans, and mollusks have been unsuccessful." The stripped mullet (Mugil cephalus), the sardine (Clupea pilchardus), and Blennius pavo, among several other fish species, were reported to exhibit activity of benzo(a)pyrene monooxygenase, but the benthic protochordate, Macrocosmos sulcatus, did not show a measurable hepatopancreatic AHM activity (Kurelec et al. 1977). Bend et al. (1977) reported activities of benzo(a)pyrene hydroxylase for nine species of marine vertebrates, including dogfish shark (Squalus acanthius) and winter flounder (Pseudopleuronectes americanus). Little or no activity was found for lobsters (Panulirus argus and Homarus americanus) and the blue crab (Callinectes sapidus) (Ibid.). On the other hand, considerable activity of epoxide hydrase, as measured with styrene 7,8-oxide and benzo(a)-pyrene 4,5-oxide, was found for the lobsters, blue crab, rock crab (Cancer irroratus), clam (Mya arenaria), and mussel (Mytilus edulis) (Ibid.). The present research adds nine more species, including the tanner crab (Chionocetes sp.), to the growing list of aquatic organisms which possess AHM activity (Gruger and Folmar, unpublished).

Other studies have indicated that strains of the same species, each geographically and genetically distinct, may exhibit different capacities for benzo(a)pyrene hydroxylation (Pedersen et al. 1976). In a given species, too, there may be little or no capacity to induce the benzo(a)pyrene hydroxylation or a moderate capacity for induction (Ibid., Payne 1976). Numerous xenobiotic compounds found in marine environments are known inducers of AHM activities in marine species (Gruger et al. 1977). Hence, the simultaneous presence of petroleum and other xenobiotics largely precludes the use of AHM activity as a means to monitor for the presence of petroleum.

PHYSIOLOGY

Studies of the planktonic organisms to date have concentrated on the uptake and depuration of hydrocarbon by organisms, including some larval species, as well as the identification of organisms that metabolize hydrocarbons (Lee 1975, Sanborn and Malins 1977). One recent study quantified the transfer of benzene through a single step in a larval plankton food chain (Eldridge et al. 1978). There are no studies to date that identify the metabolites formed by planktonic organisms and the cycling of these metabolites through a planktonic food chain.

PATHOLOGY

During the past year very little additional published information concerning the long-term effects of oil on marine fish has appeared (See Annual Report, RU 73/74, 1977). At a recent symposium (October 1977) concerned with oil pollution in northern marine environments, Payne et al. (1977) reported that male cunner (Tautogolabrus adspersus), exposed to a surface slick of Venezuelan crude oil for 6 mo developed slight histopathological abnormalities in the testes. This observation was supported by the lower testes-somatic index in oil-exposed (0.81) vs. control (1.33) fish. In addition, as is stated elsewhere in this report (See Chemistry section), pleuronectids may be at high risk to the impact of oil exposure because of their tendency to bioaccumulate and metabolize high concentrations of petroleum-derived aromatic hydrocarbons in their tissues (Roubal et al. 1978, Varanasi et al. 1978).

There is a growing volume of experimental evidence indicating that petroleum hydrocarbons and associated trace metals inhibit disease resistance mechanisms in various animals (Stjernswärd 1974, Kripke and Weiss 1970, Koller et al. 1975, Koller and Kovacic 1974, Cook et al. 1975) and in fish (Robohm and Nitkowski 1974). The results of our preliminary experiments (See Annual Report, 1977), however, suggested that there was no gross alteration in natural disease resistance in salmon following a short-term exposure to PBCO. In subsequent studies (which are reported below) we have examined immunocompetence and adaptive immunity in salmonids following a long-term exposure to PBCO and likewise have been unable to demonstrate any adverse changes. On the other hand, the recent work of Roubal et al. (1978) has demonstrated that selected flatfish species bioaccumulate hydrocarbons to a much greater extent than do salmonids. It is not presently known whether this increased bioaccumulation could lead to detrimental changes in the mechanisms of natural and acquired disease resistance in flatfish, or whether or not the lower petroleum accumulation by salmonids accounts for the lack of effect of petroleum on disease resistance of salmonids.

BEHAVIOR (including aspects of reproductive biology)

Behavioral reactions in response to chemical cues, and the development of eggs and larvae, are among the most sensitive of biological processes of marine organisms to disruption by petroleum hydrocarbons. Such disruptions at exposure concentrations in the low ppb range have been noted among marine organisms as diverse as bacteria, algae, and invertebrates (Johnson 1977). For vertebrates, however, behavioral responses such as avoidance of petroleum hydrocarbons and changes in activity patterns during hydrocarbon exposure have been generally observed only at high ppb and low ppm concentrations (Patten 1977). It is difficult to use much of the current information to predict the reactions of marine organisms to specific petroleum hydrocarbon concentrations, since most of the published data is in terms of volume or weight of oil added, and not based on analysis of actual hydrocarbon concentrations in waters or tissues, and because different experimental procedures were used in different studies.

IV. STUDY AREA

All experiments, with the exception of field studies on salmon homing, were conducted either in laboratories or in fish holding facilities at NWAFC, Seattle, and at the NWAFC's saltwater field station at Mukilteo, Washington, on representative subarctic marine and anadromous species.

V. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

MORPHOLOGY

Several species of flatfish and salmonids were exposed to Prudhoe Bay crude oil (PBCO) in the diet and/or the water-soluble fraction of PBCO in the water. The design of each experiment is detailed in other parts of this report as the fish were shared among several investigators in order to obtain data from several disciplines; specific exposure parameters will be described for each target tissue in the Results section.

Techniques for preparing tissues for morphological studies were consistent throughout the study and entailed taking replicate samples from three fish of skin, gill, and intestine for scanning electron microscopy (SEM) and skin, gill, liver, intestine, and kidney for light microscopy (LM) and transmission electron microscopy (TEM). In certain studies lens tissue was sampled for both SEM and TEM. The tissues were excised and fixed in 0.75% glutaraldehyde, 3% formalin, 0.5% acrolein in 0.1 M sodium cacodylate buffer with 0.02% $CaCl_2 \cdot H_2O$, 0.02 M s-collidine, and 5.5% sucrose (Hawkes 1974). The tissues designated for LM or for TEM were post-fixed in osmium tetroxide in the same buffer, dehydrated in an ethanol series, and embedded in plastic. Sections were cut at 0.5 μm, stained with toluidine blue or a trichrome (MacKay and Mead 1970) for LM. For TEM, sections were cut with a diamond knife and stained with lead citrate and uranyl acetate and examined with a Philips EM-301 electron microscope. For SEM, samples were dehyrated after the initial fixation, critically point dried, coated with gold-palladium, and examined with an AMR-1000 scanning electron microscope.

CHEMISTRY

Hydrocarbon Analyses

Samples of water, sediments, and biological tissues were analyzed by procedures developed by the NOAA National Analytical Facility (NAF) at the Northwest and Alaska Fisheries Center, Seattle. Water from aquaria, which contained fish exposed to seawater-soluble fractions of Prudhoe Bay crude oil (PBCO) and model mixtures of aromatic hydrocarbons in flow-through systems, were analyzed for paraffinic and aromatic hydrocarbons. The same types of hydrocarbons were analyzed in the sediments and tissue samples from several experiments. In certain cases, NAF handled the entire samples from extraction stages to instrumental analyses, while in other cases extractions were performed by the investigators and the extracts were submitted to NAF for instrumental analyses. The methods and procedures were essentially those reported by MacLeod et al. (1976) with procedural improvements as time went on.

Drums containing 55 gal of PBCO were obtained at various times for use in research by investigators in this and other OCSEAP Research Units. Analysis of hydrocarbons in a random sample of the crude oil was carried out by using methods employed for API reference oils (Pancerov 1974). A naphtha content was determined by weighing the fraction from a short-path distillation that distilled between room temperature (26°C) and 210°C/763 torr, with a final pot temperature of 310°C. The pot residue (9.33 g) was taken up in *n*-pentane and centrifuged to recover a pellet, which was again extracted with *n*-pentane, and the second pellet was weighed to obtain the proportion of insolubles in the oil (ASTM method D-893-69). The pentane-soluble substances (in 25 ml reduced volume) were used to quantitate the polar substances, the saturated hydrocarbons, and the aromatic hydrocarbons.

The latter separations were achieved by adsorption chromatography through two interconnected columns, which consisted of an upper column of Attapulgite clay and a lower column of silica gel that was layered with a specific proportion of the clay. Polar substances were eluted from the upper column in benzene:acetone, 1:1 (vol/vol); saturates from the lower column were eluted in 250 ml of *n*-pentane. Deviation from the prescribed method was made in that the aromatics were gravimetrically quantitated, rather than calculating a weight difference of eluted substances from total quantity chromatographed, by recovering the substances which eluted from the silica gel with methylene chloride. The benzene-acetone solvent was evaporated at <66°C on a rotory evaporator. Methylene chloride and *n*-pentane were evaporated in streams of nitrogen while heating the mixtures to 40°C. The *n*-paraffins and aromatic hydrocarbons were determined by capillary gas chromatography (GC) and by GC/mass spectrometry, by NAF.

Analyses of Hydrocarbon Metabolites

Metabolites of naphthalene and 2,6-dimethylnaphthalene (2,6-DMN) were separated and identified by thin-layer chromatographic procedures, such as those reported by Roubal et al. (1977) and Jerina et al. (1970), and by high pressure liquid chromatography (HPLC), such as reported by Collier et al. (1978). Radioactively-labeled naphthalenes were used and quantitations of metabolites from HPLC separations were made by liquid scintillation spectrometry, employing either a Packard Tri-Carb Model 3003 or Model 3255. Where possible, pure compounds were purchased for use as reference standards; these included 1-naphthol, 2-naphthol, naphthyl sulfate (potassium salt), and 1-naphthyl-β-glucuronic acid (sodium salt). 1-Naphthyl-α-glucoside and N-acetyl-S-(1-naphthyl)-cysteine were provided by Professor E. Boyland of the London School of Hygiene and Tropical Medicine. A sample of 1,2-dihydro-1,2-dihydroxynaphthalene was synthesized and provided by L.L. Grant of the Northwest and Alaska Fisheries Center. Radiochemically labeled metabolites of naphthalene were obtained in rat urine, which was used in dual-labeling (tritium and carbon-14) experiments to quantitate the recovery of metabolites involved in studies of cadmium (and lead) interactions with PAH metabolism (see below).

Naphthalene Metabolism in Fish Skin and Mucus

Rainbow trout (150 ± 50 g), coho salmon (150 ± 50 g), and starry flounder (100 ± 25 g) were acclimated to experimental temperatures for a period of two to three weeks prior to treatment.

Exposure Regime

Force-feeding study. Rainbow trout were mildly anesthetized with tricaine methane sulfonate (50 μg/l) and each were force-fed a #5 gelatin capsule containing 74.6 μCi (sp. activity, 83.3 mCi/mmole) of tritium-1,4,5,8-naphthalene (Amersham-Searle, Arlington Heights, Illinois) dissolved in 250 μl of salmon oil. Similarly, starry flounder were fed 87 μCi of tritiated naphthalene and seawater-adapted coho salmon were fed 4.7 μCi of carbon-14 labeled 1-methylnaphthalene (sp. activity 2 mCi/mmole). The capsules were kept frozen and carefully inserted with a glass plunger through the esophagus and into the stomach. The end of the capsule was snipped off prior to feeding to facilitate release of the contents in the gastrointestinal tract. The fish were then placed in aquaria supplied with continuously flowing fresh or sea water. Four fish were sampled at each time period of 4, 16, 24, 48, and 168 hr after the initiation of exposures. Water samples were taken at each time interval and used to determine concentrations of naphthalene and metabolic products which may have accumulated from excretions.

Injection study. Mildly anesthetized rainbow trout were injected intraperitoneally with 40 μl of salmon oil containing 94.6 μCi of the tritiated naphthalene and starry flounder were injected with 75 μCi of tritiated naphthalene. The fish were kept under the conditions described above until the sampling times at 4, 16, 24, 48, and 168 hr after injection.

Water-immersion study. A stock solution was made by dissolving 30.1 mg (20 mCi) of the tritium-labeled naphthalene and 37.7 mg of radioactively cold naphthalene in 7 ml of 95% ethanol and subsequently diluting it with distilled water (0.942 l). A glass aquarium was filled by a simultaneous addition of fresh water and refrigerated stock solution, and 12 rainbow trout were added. In order to maintain constant temperature in the test and control aquaria, the incoming water was first directed to an overhead box containing cooling coils. The chilled water in the overhead box was oxygenated by a slow bubbling of oxygen through an air stone. With the help of a peristaltic pump, the cold, oxygenated fresh water (flow rate of 600 ml/min) was mixed with the refrigerated stock solution (flow rate of 2 ml/min) before entering the test aquarium. Control fish received similarly treated water without the naphthalene. Temperature of both the exposure and the control tanks was 10° ± 1°C during the experiment, and oxygen levels in both tanks were 12 ± 2 ppm. Fish were sampled at intervals of 24, 48, and 72 hr. Water samples were taken at the end of each time interval and were analyzed for radioactivity. The concentration of naphthalene in the exposure aquarium was 9.2 ± 1.8 ppb during the entire exposure period. At the end of 72 hr, the remaining test fish were transferred to another aquarium containing fresh water for an additional period of 72 hr.

Analytical Methods

Fish were killed by a blow to the head and epidermal mucus was collected as described previously (Varanasi et al. 1978). Extreme care was taken not to abrade the skin. A 3 x 10 cm piece of skin was excised from each side of the fish and rinsed several times with water to remove residual mucus and adsorbed naphthalene. (This was especially important for samples from the water-immersion study.) The remaining skin, excluding headskin and fins, was also removed from several fish to obtain total weight of skin. A small section of skin was blotted dry, weighed, and placed in a graduated centrifuge tube for digestion. Another section of skin from the same sample was scraped with a scalpel to remove the scales and epidermis. Scales with attached epidermal layer and the remaining skin were analyzed separately for radioactivity. Concentrations of naphthalene and its metabolites in the skin were determined and compared with the concentrations in the livers of the rainbow trout; the determinations were made in collaboration with Collier and Malins (1977). Concentrations of naphthalene and its metabolites in liver, skin, bile, mucus, and blood of starry flounder were also measured as described elsewhere (Varanasi and Gmur 1978).

Each tissue was tested for concentrations of naphthalene and total metabolites by a modification of previously described procedures (Roubal et al. 1977a). Briefly, the modified procedures were as follows: Each sample (≈100 mg) was placed in a centrifuge tube into which 3 ml of hexane and 2 ml of 4 N-NaOH were added. The tubes were held at room temperature for 20 hr. Upon complete digestion, known aliquots of the hexane layer and aqueous layer were transferred to scintillation vials and weighed. One ml of solution containing 4 N-HCl was added to the aqueous phase to facilitate solubilization. To these solutions, 15 ml of InstaGel (Packard Instrument Co., Downers Grove, Illinois) was added prior to measurement of radioactivity by liquid scintillation spectrometry. Background values for tritium activity were measured by a similar procedure using control tissue samples. Radioactivity in the hexane layer provided values for concentration of naphthalene and radioactivity in the aqueous layer provided values for total metabolites.

Analysis of the tritiated naphthalene in aquarium water in the beginning of the water-immersion study showed that virtually all tritium activity was associated with the hexane layer, thereby indicating that the radioactivity was virtually all (>99.8%) in the form of parent hydrocarbon. Average variation in our measurements was assessed by testing some samples of skin in triplicate.

Metabolism and Disposition of Naphthalene in Starry Flounder

Starry flounder (100 ± 20 g) were each fed a gelatin capsule containing 87 μCi of tritium-labeled naphthalene (sp. activity, 198 mCi/mmole) in salmon oil and were maintained in flowing seawater at 10° ± 1°C. Samples of epidermal mucus, dorsal skin, liver, and blood were taken from four fish at 8, 24, 48, and 168 hr after the initial treatment. Concentrations of naphthalene and its metabolites (expressed as naphthol) in each tissue were determined by previously described methods (Varanasi et al. 1978a).

Biotransformation of Methyl-substituted Naphthalene in Fish

The accumulation of 1-MN in coho salmon was determined following force-feeding as well as by flow-through exposure. In the force-feeding study, coho salmon were maintained in running seawater at ambient temperature (10°-11°C) at the Mukilteo facility. Each fish (six fish per test; 258 ± 56 g of undetermined sex) received a capsule containing 5.14 μCi (sp. activity, 1.3 mCi/mmole) of 1-methylnaphthalene-1-C-14 in salmon oil. Fish were sampled at 4, 16, 24, and 48 hr from the time of force-feeding. Brain, blood, liver, kidney, and composites of light and dark muscle were collected and digested individually in alkali using the digestion procedure of MacLeod et al. (1976). Digests were extracted with hexane and the radioactivity in extracts was determined by scintillation counting using the procedures of Roubal et al. (1977a).

In the flow-through exposure study, coho salmon (14.8 ± 3.0 g of undetermined sex) were exposed continuously to 2.7 ± 0.5 ppb of nonradioactive 1-MN in flowing seawater at ambient temperature (10° to 11°C), using the flow-through equipment of Roubal et al. (1977b). Four fish were used for each test. Light and dark muscle (composite samples), gills, and liver, were analyzed individually using the procedure of MacLeod et al. (1976) for four exposed fish and four control fish per analysis. Following exposure for four weeks of fish to 1-MN, the fish were maintained in hydrocarbon-free water in order to monitor depuration of 1-MN from tissues. Tissue workup and analysis were conducted as described above.

Similarly, starry flounder (23 ± 12 g, undetermined sex) were exposed to 0.4 ± 0.1 ppb of 1-MN in the flow-through system over a 5-week period. Following the exposure, the fish were transferred to hydrocarbon-free water and analyzed for losses of 1-MN in tissues over a 3-week period. Light and dark muscle tissues, livers, and gills from three exposed fish and three control fish were used for each data point and analyzed individually. The analytical scheme was the same as that used for salmon.

Bioconcentration values were calculated by dividing the concentration of hydrocarbons and metabolites found in tissues by the corresponding concentrations found in the water.

In the study on the possible dependence of temperature on the accumulation of 2,6-DMN and its total metabolites in tissues of coho salmon, the fish were first acclimated in temperature-controlled aquaria (4° ± 0.2°C or 13° ± 0.1°C) for two weeks prior to receiving 2.16 μCi (sp. activity, 2 Ci/mmole) of tritium-labeled 2,6-DMN (randomly labeled) in salmon oil by force-feeding. Seventy-two hours after the force-feeding, the liver, kidney, gall bladder, brain, blood, light muscle, dark muscle, and digestive tract were removed and digested individually using the procedure of MacLeod et al. (1976), followed by the analysis of the parent hydrocarbon and its total metabolites using the procedures of Roubal et al. (1977a). The experiment was repeated; however, samples of the digestive tract were not analyzed in the second experiment. The 72-hr period for tissue analysis was based on earlier work which showed that substantial accumulations occurred at 72 hr of metabolites of naphthalene when naphthalene was used as the test substance.

Metabolites of 2,6-DMN in tissues of coho salmon and a single male rat were examined chromatographically using the extraction procedures and TLC methods described by Roubal et al. (1977a). The rats were dosed with both radioactive and nonradioactive 2,6-DMN, and used to provide reference compounds for the purpose of isolating metabolites in amounts sufficient to detect colorimetrically with TLC. Rf values from TLC were then compared with those determined radiometrically for metabolites in fish.

Influence of Cadmium and Lead on the Metabolism of Naphthalene

The influence of lead on hydrocarbon metabolism was investigated by exposing fish to the metal in seawater while simultaneously feeding them a model control diet or a diet with a mixture of polycyclic aromatic hydrocarbons (PAH) in Oregon moist pellet, so as to activate xenobiotic metabolism systems. Then, the fish were injected with carbon-14-labeled naphthalene, in order to permit detection of possible metabolic conversions of PAH in relation to metal exposure. The species used were starry flounder and coho salmon.

The fish were exposed for 4 weeks to 200 ppb of divalent lead or cadmium ions in seawater. The test animals were fasted for 48 hr before an intraperitoneal (ip) injection of carbon-14 naphthalene. Twenty-four hours after the injection, the fish were dissected, and the liver and bile were collected. In some of the metal exposures, the fish were fed a 334 ± 4 ppm mixture of aromatic hydrocarbons (phenanthrene at 107 ppm, 2-methylnaphthalene at 128 ppm, and 2,6-dimethylnaphthalene at 99 ppm) in Oregon moist pellets during the week prior to the ip injection. The livers were homogenized, and naphthalene metabolites were extracted into ethyl acetate by the procedure of Thomas et al. (1978). The mixture of extracted metabolites was then separated by HPLC and the resultant chromatographic fractions were analyzed by liquid scintillation methods to identify the HPLC elution position and quantity of each metabolite. The identity of each metabolite was made on the basis of retention time on the HPLC columns.

The procedures used in the studies of metal-binding proteins with cadmium-109 and cytosolic distribution of the cadmium and lead were presented in April 1977 Annual Report of this research. The procedure for quantitation of protein content in samples of cytosol were according to Lowry et al. (1951).

Activities of Aryl Hydrocarbon Monooxygenases in Different Species

Fresh fish, crabs, and snails were collected during NOAA cruise no. MF-77-1 of the Miller Freeman, and livers and whole organisms (crab and snail) were frozen and held at -60°C during transit (from Alaska to Seattle) and in the laboratory prior to analyses. The specimens (115 total) were collected during January 25 to February 10, 1977, in areas northeast of Kodiak (57°30'-58°30' N lat. x 149°-152° W long.), and arrived in Seattle on June 16, 1977. An accidental thawing of an original 567 specimens, collected during September 1976 from the Norton Sound and Chukchi Sea areas, with destruction of the AHM systems under study, required us to take advantage of the next available cruise to Alaska waters to obtain the aforementioned samples as replacements.

Specific activities of aryl hydrocarbon monooxygenases (AHM) were measured using tritium-labeled benzo(a)pyrene as the substrate for the AHM. The procedures employed were a modification of those by De Pierre et al. (1975). The temperature and pH of the AHM assays were optimized for fish, i.e., 25°C and pH 7.5, and preformed NADPH (tetrasodium salt; Sigma Chemical Co.) rather than an NADPH-generating system was used in the assay incubation reaction.

A typical assay reaction of 2.1 ml contained 0.67-mM-NADPH, 1.4 mM-$MgCl_2$, 50 μl of enzyme source (25 mg protein/ml), 20 μl of an acetone solution of 3.2 mM-tritiated benzo(a)pyrene (0.96 μCi), and 60 mM-Tris HCl buffer. The enzyme source was a 20% (wt/vol) homogenate of liver (or other tissue) in cold 0.25 M-sucrose solution that was separated as a supernatant fraction from cellular debris by centrifugation at 9,000 x g (or 10,000 x g) for 20 min. The reaction mixtures were shaken for 10 min at 25° ± 0.2°C before initiation of reactions by the addition of the tritiated benzo(a)pyrene. Duplicate reactions were shaken at 25°C in 15 x 125 mm open culture tubes in subdued light. Time of incubations was 20 min. During the work up of reactions, two hexane extractions were employed, in contrast to a single extraction according to De Pierre et al. (1975), that resulted in better agreement among assays and less variation in assay blanks. Quench corrections for liquid-scintillation counting of tritium was done for each assay by automatic external standardization. Protein content of the enzyme source was determined by the method of Lowry et al. (1951).

Analyses of benzo(a)pyrene monooxygenase activities were carried out on livers of Pacific cod (Gadus macrocephalus) which were found to have pseudobranchial tumors. The fish were collected during the Miller Freeman cruise in Alaska, and were part of another OCSEAP project (R.U. 332).

Additional analyses of hepatic AHM activities were determined as naphthalene monooxygenase, according to procedures of Nilsson et al. (1976). These analyses were for starry flounder and coho salmon.

PHYSIOLOGY

The sperm and eggs from artificially spawned mussels were placed in 400 ml seawater solutions containing tritiated naphthalene at concentrations of 100, 10, and 1 ppm and in uncontaminated seawater. Each test and control condition was triplicated. Two milliliter samples were removed from each container at 30 min and 1, 2, 3, 6, 12, and 24 hr, and were preserved in 5% buffered formalin solution. Water samples were taken at each time period for determinations of the naphthalene concentration. Specimens in the biological samples were counted and the developmental stages identified using a compound microscope.

Sperm and eggs of oysters were separately exposed to a seawater solution of tritium-labeled naphthalene at two concentrations (10 and 1 ppb) for 15 min and the complementing gametes were added. In addition, fresh gametes were introduced into solutions of naphthalene with concentrations of 10, 1, and 0.1 ppb and one solution of uncontaminated seawater. Biological samples of 2 ml were taken from each solution at varying intervals for 48 hr and were preserved in 5% buffered formalin for future analysis. Water samples were taken at each time period to determine the concentration of naphthalene. The specimens in the biological samples were counted and the stages identified using a compound microscope.

Tritium- and carbon-14-labeled naphthalene were administered in a waterborne solution, under the flow-through conditions described by Sanborn and Malins (1977), to 150 shrimp and 24 coho salmon fry. The shrimp were removed after 12 hr, washed, and prepared for each specific analysis. Six salmon fry were sacrificed and the viscera removed. The visceral samples were extracted for HPLC analysis.

Adult shrimp and coho salmon fingerlings were exposed to a seawater solution of either purified carbon-14- and tritium-labeled naphthalene or unpurified carbon-14- and tritium-labeled naphthalene. After 12 hr the animals were washed in clean seawater and prepared for each specific analysis. The cephalothorax from three shrimp were combined to give duplicate samples from each test condition. The viscera were removed from three coho salmon for analyses of metabolites from each test condition. The metabolites from each test condition were separated into fractions using HPLC, and the fractions assayed for radioactivity. Metabolites were tentatively identified by retention times from HPLC.

PATHOLOGY

Pathological Changes in Flatfish from Exposure to Oil-Contaminated Sediment

Four-Month Experiment

Sediment was collected from a beach near Sequim, Washington. It had no detectable aromatic hydrocarbons, and contained iron, copper, and zinc in concentrations of 1,210.0, 11.5, and 9.0 mg/kg (dry wt), respectively. Particle-size analyses showed that 87% of the sediment particles were between 0.18 and 0.84 mm in diameter. A 0.2% (v/v) mixture of Alaskan crude oil and sediment was prepared using a cement mixer. This sediment was placed in a specially constructed aquarium (See Annual Report, OCSEAP RU 73, 1976) to a depth of 5 cm. After rinsing the sediment overnight by allowing seawater to flow through the tank, the experimental fish were added. An equal amount of uncontaminated sediment placed in a similarly designed aquarium at the same depth was used for control fish. Thirty-five English sole were placed in each aquarium.

After adding the fish to the sediment-containing aquaria, the aquaria were examined daily for: dead or moribund fish, the number of fish lying uncovered on the surface of the sediment, and the general level of swimming activity. The temperature ranged from 7° to 9°C with an average of approximately 8.5°C, and the average salinity was 27 ppt.

Hydrocarbon analyses of sediment and fish tissue were performed by the NOAA National Analytical Facility using a modification of procedures described by MacLeod et al. (1976) which involved gravimetric determination of total extractable hydrocarbons and gas-liquid chromatography (GLC) for alkanes and arenes. By subtracting the concentration of total extractable hydrocarbons in the control sediment from the level of extractable hydrocarbons in the oil-contaminated sediment, the value of total extractable petroleum hydrocarbons (TEPH) was determined. Samples of oil-contaminated sediments (about 400 g/sample) were taken immediately after mixing, and at 2, 7, 16, 30, 51, and 148 days after being placed in the aquarium.

At 11 days and at approximately 1, 2, 3, and 4 months of exposure to the sediments, 3 fish from each group were sacrificed and tissue samples were subjected to histological, morphological, hematological, and chemical analyses; and the length and weight of each fish were measured. For histological examination of each fish, pieces of gill, skin, gastrointestinal tract, kidney, liver, and eye lens were removed and preserved in appropriate fixatives. Specimens to be examined by light microscopy were embedded in paraffin, sectioned, and stained by a variety of histochemical stains and methods. Procedures used for electron microscopic examinations of tissues are described elsewhere (See Morphology section).

Hematological tests performed included the following: hemoglobin concentrations by the cyanomethemoglobin method, hematocrit, total red blood cell and leukocyte counts.

Samples of muscle, skin, and liver of the fish were analyzed for petroleum hydrocarbons by GLC (MacLeod et al. 1976). Muscle samples from each fish were analyzed individually, and skin and liver samples from the three fish in each of the two groups were pooled. Tissue samples were frozen at -20°C immediately after they were taken and thawed just before chemical analysis.

Two-Weeks Experiment

Flatfish were exposed to oil-contaminated sediment in 10 gal glass aquaria supplied with flowing seawater. Three aquaria contained 4 liters of contaminated sediment (a 0.2% v/v Alaskan crude oil and sediment mixture) and three aquaria had 4 liters of untreated sediment. Three flatfish species were used in these tests--English sole, starry flounder, and rock sole. For each species, two aquaria were used; one containing oiled sediment (test) and one containing untreated sediment (control). Twelve fish of the appropriate species were placed in each aquarium. The fish of each species were of similar length and weight.

Fish were sacrificed at 0 time (fish used at this time were in addition to the 12 used per aquarium) and at 7 and 14 days. Tissue specimens were collected for histology (light and electron microscopic examination) and hydrocarbon analyses. Blood was drawn for hematological tests. Also, the livers from three to four fish from each of the six groups were removed and used in AHM activity assays (See Chemistry methods for details). Sediment samples were collected for hydrocarbon analyses (total extractable hydrocarbons and gas-liquid chromatography) at 0 times, and at 1, 8, and 15 days after oiled-sediment was added to the aquaria.

Effect of Petroleum on Fish Disease Resistance

A series of laboratory studies employing a variety of *in vitro* and *in vivo* assays of immunocompetence were conducted to determine if a relatively long-term exposure to petroleum hydrocarbons affects defense mechanisms in salmonid fish. Comparisons were made among groups of rainbow trout, *Salmo gairdneri*, which were maintained on diets containing (1) a high level of PBCO (1,000 ppm), (2) a low level of PBCO (10 ppm), or (3) no PBCO (control) for 10 to 16 mo prior to testing (depending on date of test).

In an initial experiment, groups of rainbow trout maintained under the three exposure regimes were parenterally immunized (injected) with a heat-killed vaccine prepared from the marine fish pathogen, *Vibrio anguillarum* and subsequently challenged with varying concentrations of the living organisms. The isolate of *V. anguillarum* used, strain RG 75-834, was obtained from the Alaska Department of Fish and Game; it was isolated from a moribund coho salmon, at Halibut Cove Lagoon, Alaska, at a water temperature of 10°C. This isolate was maintained on 50% seawater cytophaga medium and its taxonomic identity was confirmed by biochemical and DNA homology techniques (Schiewe et al. 1977). Bacteria for vaccine preparation and challenge were cultivated in 2% trypticase soy broth (BBL) supplemented with 1% NaCl.

Fish were challenged 21 days after immunization by subcutaneous injection of 0.1 ml volumes of late log phase bacterial cultures at the posterior base of the dorsal fin. Groups of fish were held at 10°C in fresh water and monitored for 21 days for mortality. All dead fish were examined by bacteriological culture techniques in order to reisolate the test bacterium and confirm the cause of death. LD-50 values were calculated by the procedure of Reed and Muench (1938) and compared.

In vitro indices of immunocompetence used to compare disease resistance between oil-exposed and control fish included (1) determination of the number of antibody forming cells, (2) measurement of serum agglutinating antibody levels, (3) measurement of polyclonal lymphoid cell activation and, (4) measurement of response following mitogenic stimulation.

Numbers of antibody forming cells in anterior kidney and splenic tissues of high-oil-exposed and control fish were determined by a modified Jerne plaque assay (Chiller et al. 1969). Fish were immunized against trinitrophenol conjugated with lipopolysaccharide (LPS) from *Escherichia coli* B. Plaque formation was assayed on a lawn of sheep red blood cells (SRBC) coated with LPS which was immobilized in a dilute agarose matrix. Once-frozen rainbow trout sera were employed as sources of complement.

Serum agglutinating antibody levels were compared between high-oil-exposed and control fish by the microdilution technique (Microtiter, Cooke Engineering Co., Alexandria, Va.). Fish were immunized against V. anguillarum, and 21 days later 10-fold serial serum dilutions were tested for agglutinins. Fish were held at 15°C to optimize antibody formation.

For polyclonal lymphoid cell activation assays, peripheral blood leukocytes from high-oil-exposed and control fish were incubated with purified protein derivative (PPD) prepared from tubercle bacillus. Activity was quantified by measurement of plaque forming ability on lawns of SRBC's immobilized in a matrix of dilute agarose.

Degree of mitogenic stimulation was compared between high-oil-exposed and control fish under assay conditions previously described by Etlinger et al. (1976). Briefly, leukocyte cultures prepared from peripheral blood were assayed for lymphocyte proliferation following incubation in the presence of the plant-derived mitogenic substance concanavalin A (Con A). Stimulation was quantified by measurement of the incorporation of ^{3}H-thymidine in the proliferating cellular DNA.

Early in the course of these investigations it was noted that a group of oil-exposed RBT had reduced spleen size compared to that of controls. Since antibody forming leukocytes had been previously identified as one of the cellular components of the spleen (Chiller et al. 1969), this condition was further examined. Spleen weight to body weight ratios were measured and cellular composition with respect to total numbers of erythrocytes and leukocytes-thrombocytes were determined. These same hematological parameters were also determined for anterior kidney tissue homogenates and peripheral blood.

BEHAVIOR (including aspects of reproductive biology)

Vertebrate

The experimental design for studies on salmon avoidance of petroleum hydrocarbons and their disruption of homing performance was as follows: First, tests with juvenile coho salmon were conducted at the NWAFC laboratory, Seattle, in a Y-shaped choice chamber to determine minimal concentrations of hydrocarbons in water that are avoided. The results of these tests were then to be used as a guideline for application to a choice situation using homing adult coho salmon in a field test at Chambers Creek, Washington. The concentration of hydrocarbons in the water determined to be less than adult homing salmon avoided at Chambers Creek was then to be applied in another field test with migrating coho salmon at Tulalip, Washington. The Tulalip experiment simulated exposure of salmon to a sub-avoidance concentration of hydrocarbons for 8-24 hr, and tested the resultant effect on homing behavior.

Both laboratory and field test situations employed model mixtures of aromatic hydrocarbons and a water jet eductor for mixing the hydrocarbons with water. The model mixture used in the laboratory and Tulalip studies contained over 94% by weight of the aromatic hydrocarbons found in the WSF of PBCO (Roubal et al. 1977); this mixture was modified for the Chambers Creek studies (See Table 1). For generating a water-hydrocarbon mixture, water was forced through a 1/2 inch eductor at flow rates of 12 to 16 l/min and a pressure of 80 to 95 psi. The model mixture was introduced into the vacuum port of the

TABLE 1. Composition of model mixtures of aromatic hydrocarbons

Hydrocarbon	Percent by volume	
	NWAFC and Tulalip tests	Chambers Creek[a]
Benzene	7.87	7.87
Toluene	56.99	56.99
Ethyl benzene	2.01	6.96
m- and p-Xylene	9.62	23.34
o-Xylene	16.17	4.84
1,2,4-Trimethylbenzene	7.34	--

[a] Modified model mixture commensurate with cost considerations. In this mixture a "purified" commercial xylol containing ethyl benzene was employed. Xylol does not contain trimethylbenzene.

eductor at flows of from 0.0034 to 105 ml/min. For low hydrocarbon concentrations a calibrated repeating syringe pump was used; at high flows the eductor vacuum served as a pump and the model mixture flow was regulated by a calibrated metering value. The reduced pressure in the vacuum port of the eductor vaporized the model mixture prior to mixing with water. The efficacy of this solubilizing system was tested in the laboratory Y-choice chamber and is shown in Figure 1. Considering the similarity between calculated and GC analysis values, the concentration of aromatics in the laboratory Y-choice chamber tests were based on the calculated values, i.e., the amount of model mixture introduced per minute and water flow rate. In the field studies, desired hydrocarbon concentrations for particular tests were determined by calculated values; however, data analysis relied in GC analytical values. Replicate water samples were taken at the end of each field test for GC analysis. Extraction of water samples for analysis followed standard procedures as outlined by NAF (1978).

Avoidance of Hydrocarbons by Juvenile Salmon

An all-glass, Y-shaped choice chamber was used to evaluate juvenile salmon avoidance of aromatic hydrocarbons. The average length of coho salmon used in these tests was 6 cm. The Y-chamber consisted of equal 140 cm length arms 15 cm in width. The base of the Y, which served as a holding area, was 48 cm long and 16 cm in width, and had a 10 cm tall stand-pipe drain at the foot. A perforated Teflon gate separated the base and each arm from one another. Water from a common source was split and directed through identical, valved flow meters, and then either directly to the designated control arm of the Y, or to the test arm via an eductor for introduction of aromatic hydrocarbons. Water flow rates into each arm were equal, and the arm receiving hydrocarbons and the control arm were periodically alternated.

Between 50 and 60 salmon were placed in the Y-holding area for fifteen minutes before introduction of hydrocarbons in one arm. The Teflon gate was then raised to allow fish access to either arm, and after one hour the gate lowered and the number of fish in each arm counted. Avoidance of aromatic hydrocarbons was evaluated statistically by the chi-square test on the assumption that if salmon could not discriminate between treated and untreated

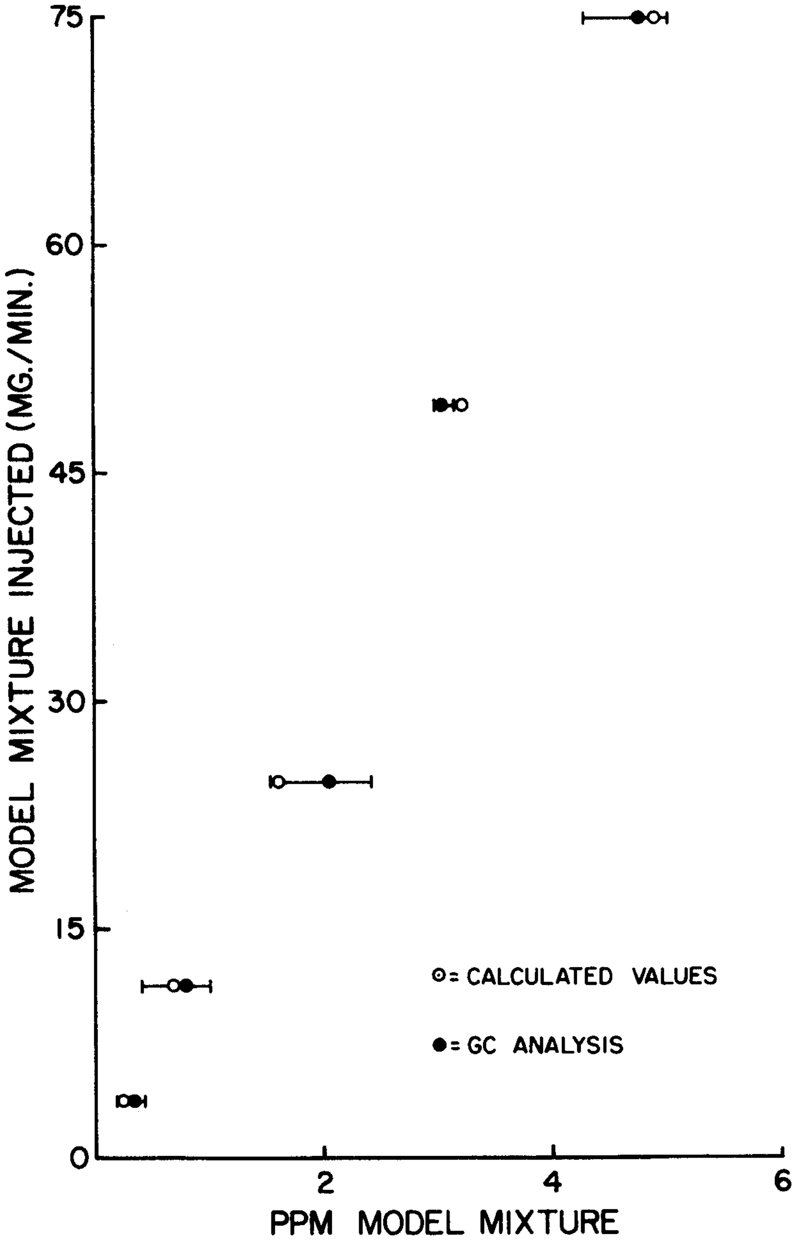

FIGURE 1. Amount of model mixture injected into eductor solubilizer and ppm of aromatic hydrocarbons present in the water as calculated from water flow and GC analysis. Horizontal bars represent range of GC values from 3 replicate water samples.

water, then they would enter each arm of the Y with an expected frequency determined by control tests.

Avoidance of Hydrocarbons by Adult Salmon

A field study assessing adult salmon avoidance of petroleum hydrocarbons was conducted on Chambers Creek which enters southern Puget Sound near Steilacoom, Washington (Fig. 2). At the mouth of Chambers Creek is a 35 m wide tidewater dam with fish ladders on each side of a central spillway--one ladder served for testing salmon avoidance, the other ladder as control (Fig. 3). A trap at the head of each ladder afforded a count of all salmon migrating past the dam.

An aromatic hydrocarbon-water mixture generated in an eductor was piped to the center of the dam spillway where it was then diverted to the top of either the right or left fish ladder. A diffuser pipe at the head of each ladder provided dispersion of the hydrocarbon-water mixture across the width of each ladder, and further mixing took place in the ladder turbulence. The fish ladders were similar except for water flow, of which the right ladder had 54% of the left ladder. At the end of each test the number of salmon in the traps at the head of each ladder were counted and placed upstream--traps were also emptied before the start of each test.

Effect of Hydrocarbons on Salmon Homing Ability

Jack coho salmon (males which mature and return to spawn one year early) were captured in a trap at the head of a tidewater fish ladder on the Tulalip Indian Reservation, Tulalip, Washington (Fig. 4). The salmon were divided into control and experimental groups, tagged, and held for 8-22 hr in 800 l fiberglass tanks with a seawater flow of 16 l/min to each tank. Water delivered to the test tank first passed through an eductor where it was mixed with a model mixture of aromatic hydrocarbons. The hydrocarbon-water mixture was introduced into the bottom of the circular test tank, and water outflow was via a central standpipe, thus affording equal dispersion of hydrocarbons throughout the water column. After exposure, both control and test fish were transported to one of two release sites 4.7 and 1.6 km distant from the home stream. Salmon migrating up the Tulalip fish ladder were monitored for tag returns throughout the duration of the run. Water samples for GC analysis were taken from the experimental and control tanks at 4 hr intervals during the exposure period.

Analysis of the Tulalip data indicated that the number of test fish in a tank had an inverse relation to the concentration of hydrocarbons in the water (Table 2). Thus, the results of these tests are presented in ppb/fish:

$$\frac{\text{(Calculated concentration) - (GC analysis concentration)}}{\text{Number of fish in tank}}$$

The ppb/fish figure is an instantaneous value, and not related here to tissue concentration.

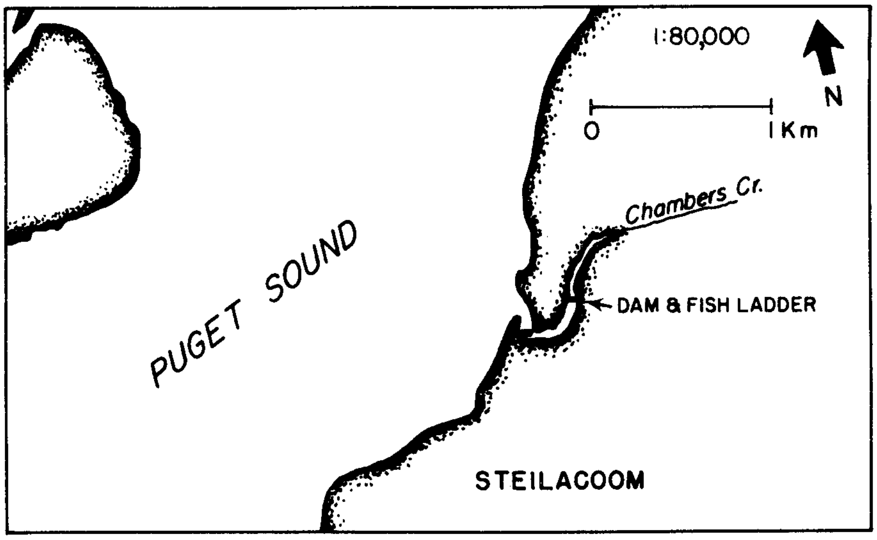

FIGURE 2. Map of area and Chambers Creek field test site for study on homing salmon avoidance of aromatic hydrocarbons.

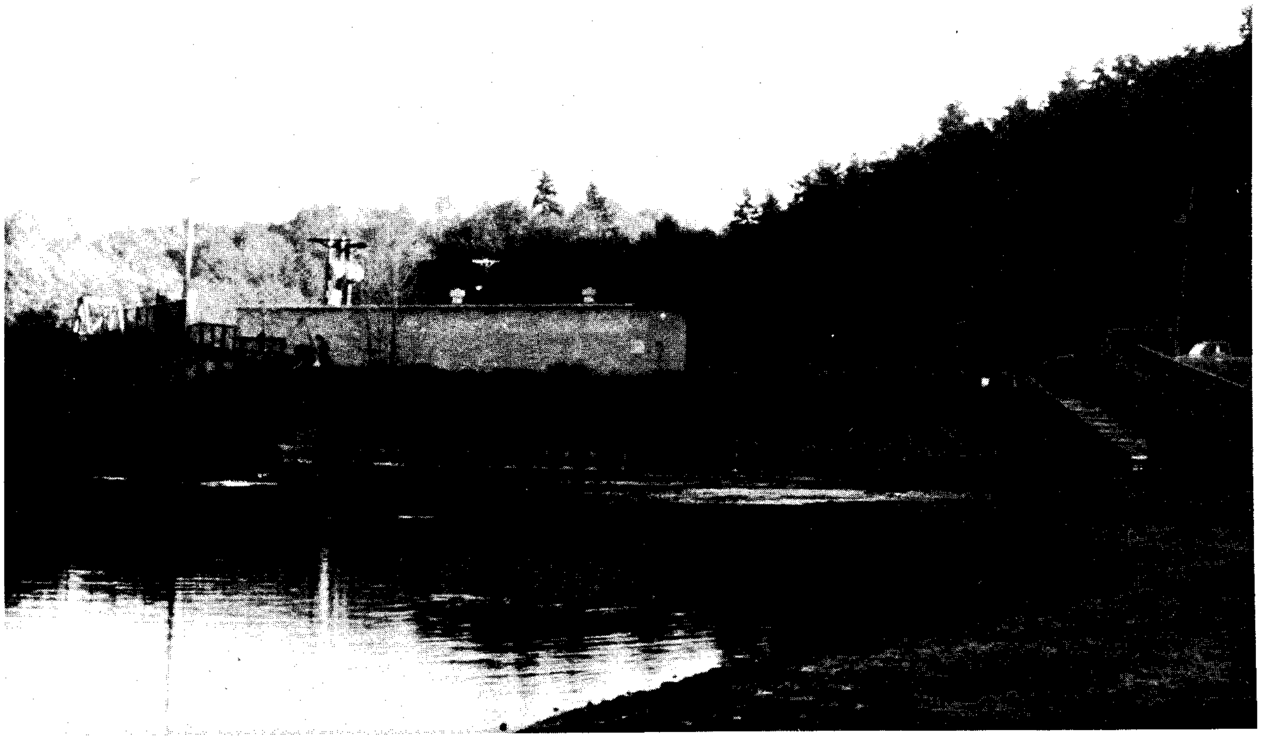

FIGURE 3. Dam and fish ladders at Chambers Creek. Photograph taken at low tide. Mean high tide during study period covered the lower 2/3 of the spillway.

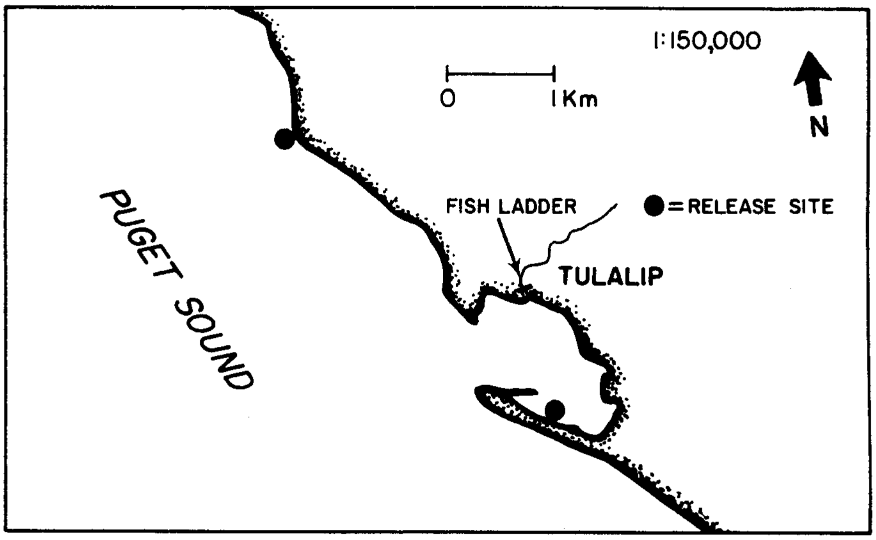

FIGURE 4. Map of area and release and recovery locations for study on disruption of homing ability of migrating adult salmon by aromatic hydrocarbons.

TABLE 2. Concentration of aromatic hydrocarbons in water as determined by calculated values and GC analysis in relation to number of fish (N)

N	Hydrocarbon concentration (ppb)		ppb/fish
	Calculated	GC analysis[a]	
0	1500	1723	--
12	1020	378	54
25	960	154	32
52	2200	214	38
65	2100	24	32

[a] Average of replicate samples taken at 4 hr intervals.

Invertebrate

Effect of Petroleum Hydrocarbons on the Mating Behavior of Dorid Nudibranchs

Adult dorid nudibranchs were exposed to the SWSF of PBCO for 1 to 3 days in 2,000 ml flow-through aquaria with a seawater flow of 250 ml/min and a temperature of 13.6° ± 0.6°C. The SWSF was generated by a method described by Roubal et al. (1977), and to obtain different hydrocarbon concentrations in each aquarium the SWSF flows were diluted by mixing with untreated seawater. Water samples were collected daily from each aquarium throughout the 3-day exposure period for GC analysis of hydrocarbon concentration.

Following SWSF exposure, the nudibranchs were assayed in "untreated" seawater for a chemotactic behavioral response consisting of movement out of the "T" chamber in a choice apparatus (Fig. 5). The "stimulus" chamber contained an aggregate of four control nudibranchs. The "stimulus" and "blank" chambers were periodically alternated and thoroughly washed between tests to remove mucus. A positive response denoted selection of the arm leading to the stimulus chamber; a negative response denoted movement toward the blank arm. The time required for the test nudibranch to make a choice was also recorded, and defined as the duration between entering the vertical arm of the "T" fitting to emergence from one of the horizontal arms. If a nudibranch did not move into the "T" fitting, or failed to reappear from one of the horizontal arms within 10 mm from start of test this was considered as no movement.

Effect of Petroleum Hydrocarbons on Dorid Nudibranch Egg Deposition and Development

The exposure system for this study was identical to that described above. There was, however, a difference in determining the petroleum hydrocarbon concentration in each aquarium. Over the 2 week exposure period five equally spaced water samples for GC analysis were taken from the solubilizer headbox. Hydrocarbon concentration in each aquarium was calculated from the average SWSF concentration in the headbox and the amount of SWSF diluted with untreated salt water (Table 3).

Twenty dorids with a total weight of 2.1 g were placed in each aquarium. The first egg masses laid were placed in rearing cages in the aquaria. Replicate egg aliquots (2-3 mm^2) from these masses were taken daily 5 days per week

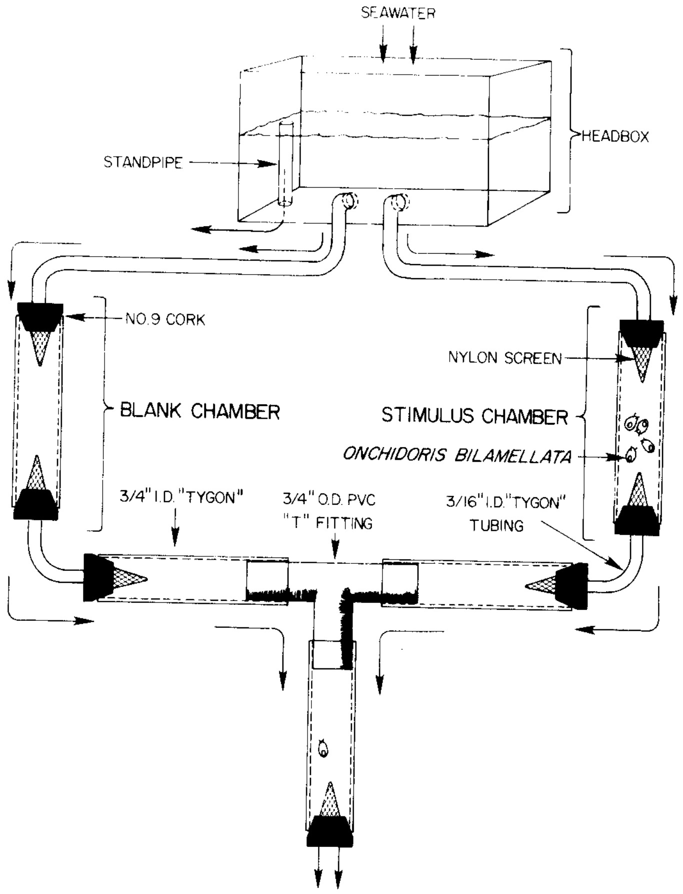

FIGURE 5. Testing apparatus for chemotactic response of dorid nudibranch. Choice chamber is "T" fitting in lower center of diagram.

and fixed in buffered preservative (Hawkes 1974, with addition of 17 g "Instant Ocean" per liter of buffer). In addition, eggs laid each day were collected and weighed, and a count was made of dorids that were present in mating aggregations.

Analysis of ontogenetic development was conducted with light microscopy. Eggs in an aliquot sample were counted and each egg assigned to one of the 11 categories given in Table 4.

TABLE 3. Concentration of petroleum hydrocarbons in test aquaria as determined from GC analysis of headbox SWSF and respective dilutions

Aquaria	Water flow ml/min			SWSF concentration
	Untreated	SWSF	Total	($\bar{x}$ ppb + range)
1	250.0	0.0	250	0 (control)
2	242.8	7.2	250	8
3	226.0	24.0	250	27
4	0.0	250.0	250	278 ± 180[a]

[a] Average hydrocarbon concentration and range applicable to aquarium 4 only.

TABLE 4. Description of nine stages of dorid nudibranch development, and two categories of abnormality

Category	Characteristic
1-cell	
2-cell	
4-cell	
Blastula	Ball of readily distinguishable cells.
Gastrula	Embryo assumes oval shape, individual cells not distinguishable.
Pre-veliger I	Velum begins development with small cilia evident.
Pre-veliger II	Lobes of velum well developed with clearly visible cilia. Shell covering up to half of embryo, but without coil.
Veliger	Shell usually covering all of embryo, with fully developed coil.
Hatched	No evidence of embryo present.
Moderate abnormality	Recognizable embryo, but malformed or with extra cellular material in the capsule.
Severe abnormality[a]	No recognizable embryo and often no capsule present.

[a] This abnormality may be a result of non-fertilization rather than teratogenesis.

VI. RESULTS

MORPHOLOGY

Liver

English sole were exposed to 400-700 ppm PBCO in sediments for 27 days (See Pathology section). With both LM and TEM, vacuolization of the liver was moderate to heavy in petroleum-exposed fish and light to moderate in controls. Transmission electron microscopy revealed that, in severely affected fish, a major proportion of the cell volume was occupied by vacuoles containing glycogen and aggregates of lipid droplets as large as 10 μm in diameter (Figs. 6 and 7). The lipid is highly osmiophilic and appears electron dense in the micrographs.

Another difference between control and experimental fish was the organization and amount of rough endoplasmic reticulum (RER) in the hepatocytes. There was both proliferation of the RER and apparent alignment of the membranes around the nucleus in concentric layers (Figs. 6 and 7). There was no evidence of changes in other organelles and no general liver necrosis.

Lens

Studies on enlargement and opacity of lenses from petroleum-treated salmonids have continued since the initial observation that rainbow trout fed PBCO (1 g/kg food) for 8 mo developed enlarged abnormally soft lenses (Hawkes 1977). Very recently (this present quarter), we sampled trout that had been fed this high dose for 3 yr. Sixty percent of the experimental fish (3 of 5 examined) had cataracts and none of the controls had abnormal lenses. This information is included here because of its pertinence to the current topic.

We have pursued several approaches to accruing more information about the relationship of petroleum exposure and lens changes. One approach was to establish whether the size increase was the result of stimulated growth of lens fibers. Counts of fiber numbers in control and experimental animals showed that there was no proliferation. In the cortical lens region there were about 6.5 fibers per 1000 μm^2 area in both experimental and control fish.

We then asked if the increase in lens dimension was the result of hydration especially since the lenses grossly appeared extremely soft and deformable. We approached this problem with an in vitro study of normal lenses to ascertain if hydration could account for the observed changes. In 5 hr, lenses in distilled water increased 64.3% in volume and stayed at that size until they began to disintegrate. Preliminary data on the amount of water in normal and experimentally hydrated lenses revealed that a change of about 20% in lens water content results in about 40% change in lens volume. We do not yet know how small a change in osmotic pressure can cause hydration nor the time parameters of such a change but the hydration experiments did reveal that, under some conditions, lenses can very rapidly respond to osmotic gradients.

Our next approach was to inquire if the lens changes could be the result of petroleum acting directly on the lens or some type of systemic change which caused a failure in osmoregulation. The target organ could be the kidney, for example. A laboratory study, therefore, was designed to determine the uptake of naphthalene, a hydrocarbon which has been shown to damage rabbit lenses (Van Heyningen and Pirie 1967), into the lens and other tissues of the rainbow

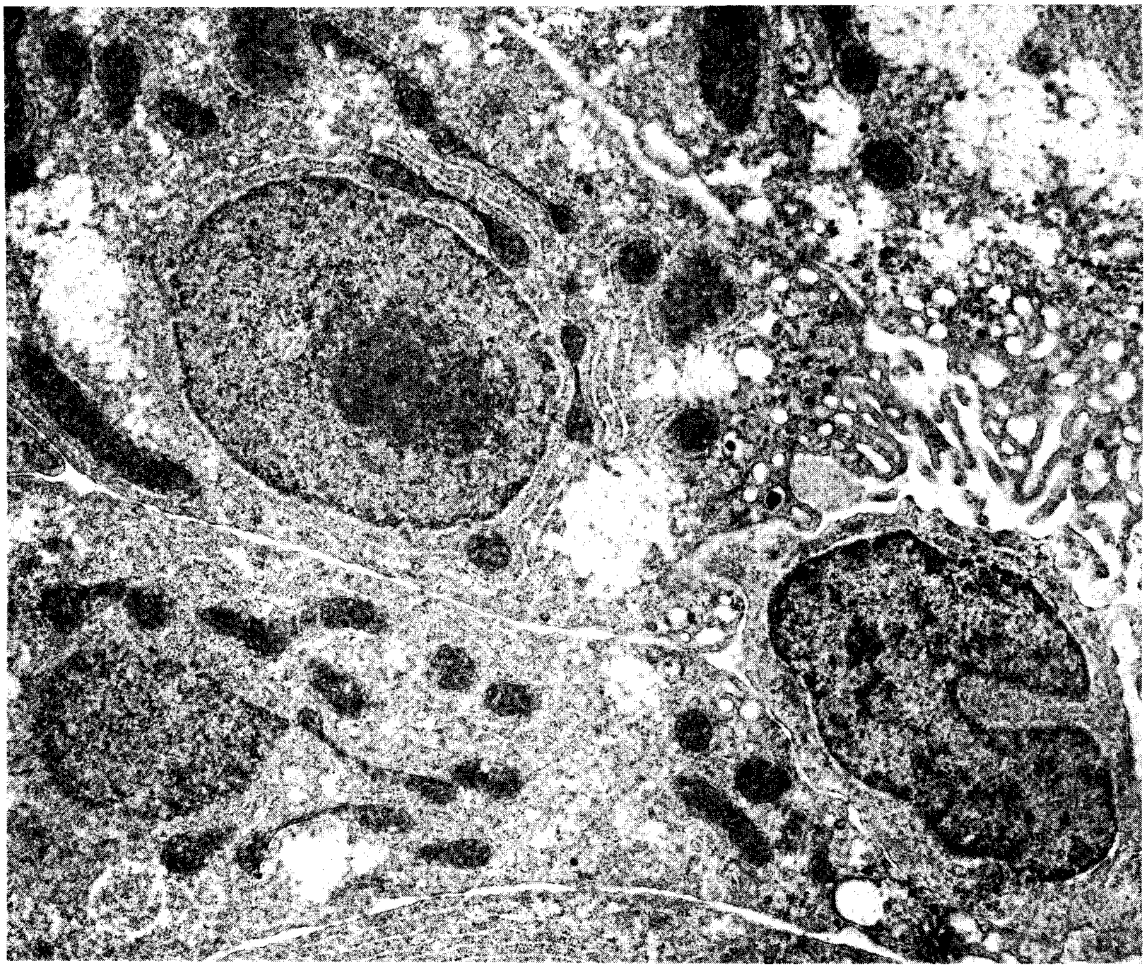

FIGURE 6. Transmission electron micrograph of liver cells from an unexposed English sole. X 9,860.

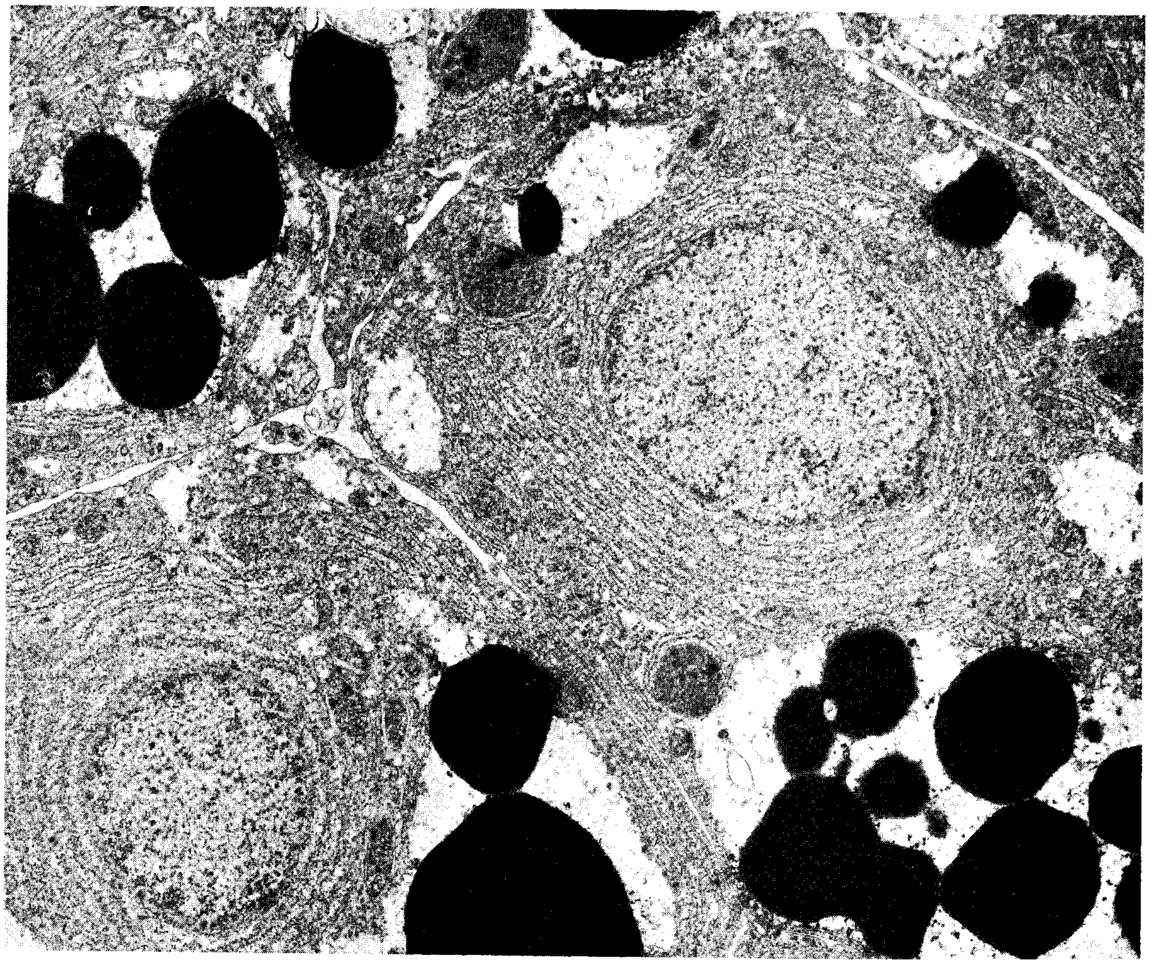

FIGURE 7. Comparison TEM of English sole liver from petroleum exposured fish. Note the electron dense lipid vacuoles and whorls of endoplasmic reticulum surrounding the nucleus. X 12,600.

trout. Fourteen test fish, each weighing about 100 g, were each fed a gelatin capsule containing 47 mg (73 ± 5 μC) tritiated naphthalene. Samples of blood, liver, kidney, vitreous humor, and lenses were taken from two fish sacrificed at 16, 24, 40, 48, 70, 168, and 204 hr after exposure (Fig. 8). The counts from each tissue peaked at different times between 24 and 48 hr. The kidney reached maximum concentration before any other organs but at about 4 times fewer counts/mg than the blood and liver. By 70 hr activity in all organs tested had dropped to baseline levels but the kidney and lens had another lesser peak at 168 hr. In addition, samples of crystalline lenses were taken from 17 species of rockfish and flatfish in the Gulf of Alaska in an ongoing effort to establish data on normal lenses of fish which might be exposed to petroleum after an oil spill. Both benthic species, which might be exposed to petroleum in sediment, and pelagic species, which might encounter surface petroleum or subsurface water-soluble fractions, are being sampled. A comparative study of the organization of normal lens fibers in representative species of both pelagic and benthic fish is nearing completion.

We were contacted in March, 1977 about an unusual occurrence of blindness in coho salmon in rearing pens near Squaxin Island, Puget Sound, Washington. A known source of diesel fuel spillage from a marine engine was indicated as a possible causative agent.

Water and tissue samples were collected on 4/28/77 and additional water and sediment samples were taken by divers on 5/3/77 at 4 depths and in two locations. Both samplings were done after the release of diesel fuel under circumstances as had occurred intermittently during the prior 3 mo except that some repairs had been done on the engine before the second sampling. A total of 96 water samples and 300 tissue samples were taken. Selected water samples were processed and analyzed by NAF.

The water samples from 4/28/77 contained hydrocarbons typical of suspended oil as evidenced by the presence of n-alkanes as well as the water-soluble fraction. The amount corresponds to about 9 ppm of fuel oil as calculated for C_{17} and C_{19}. Samples taken on 5/3/77 also contained petroleum hydrocarbons but at 20 times lower concentration than the original sample.

The muscle and liver/gall bladder samples showed the presence of benzene and naphthalene and their alkyl-substituted homologs at very low levels. The muscle tissue samples contained about 200 ng/g dry weight of xylene, about 70 ng/g methylnaphthalene, and about 30 ng/g phenanthrene. Other specific compounds were present at concentrations less than 5 ng/g. The liver and gall bladder samples showed xylenes at 400-500 ng/g and other compounds were below 6 ng/g.

In addition, bacteriological studies were done on five fish: kidney tissue was plated on trypticase soy agar and were negative for *Aeromonas salmonicida*, the agent of furunculosis and for *Vibrio anguillarum*, the bacterium causing marine vibriosis. There was also no evidence of kidney disease nor any other infectious disease. Neither was there evidence of eye flukes or any infectious eye condition.

The "blind" fish had cloudy appearing eyes, readily apparent from visual inspection. The cornea appeared normal. There was an obvious cloudy zone ranging from 1-3 mm in diameter on the anterior surface of the lens. In addition the entire lens periphery was soft and deformable.

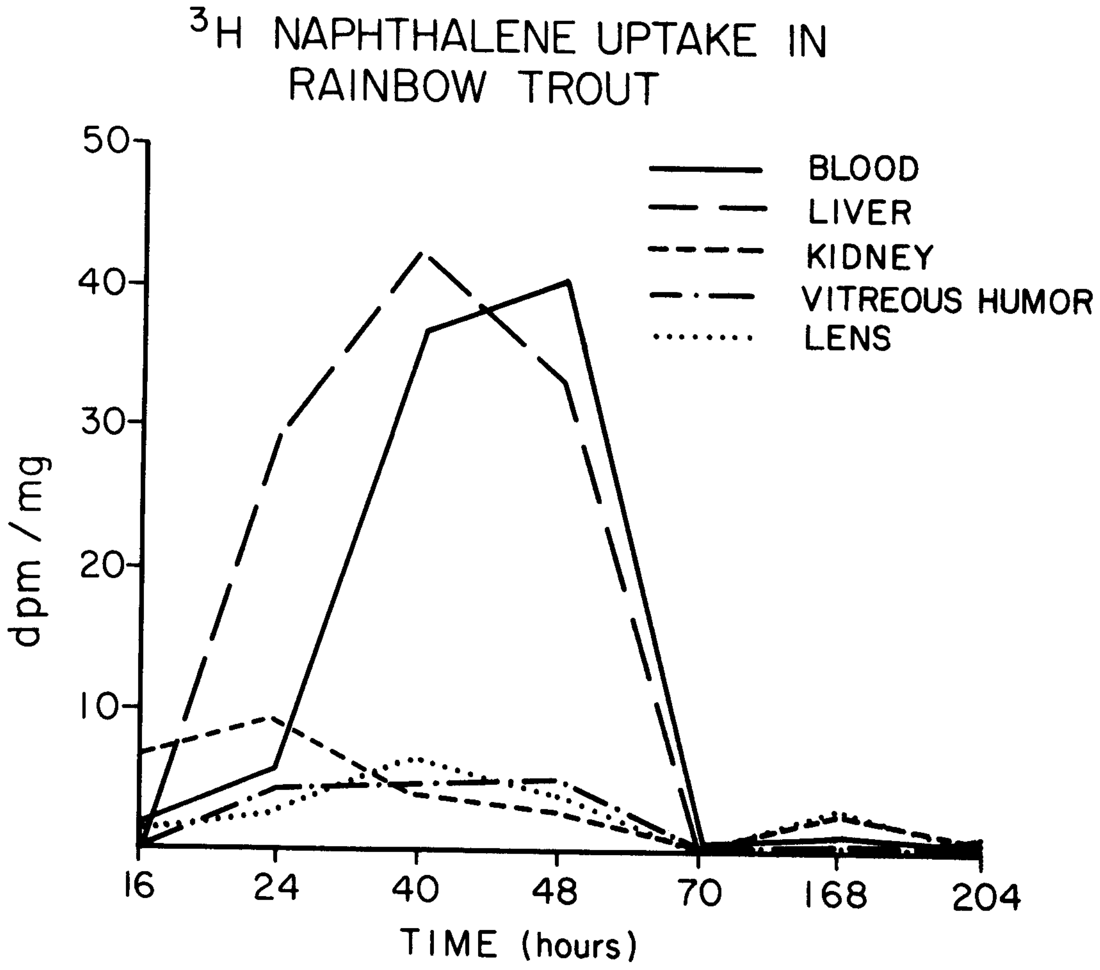

FIGURE 8. Uptake of tritiated naphthalene in rainbow trout tissues.

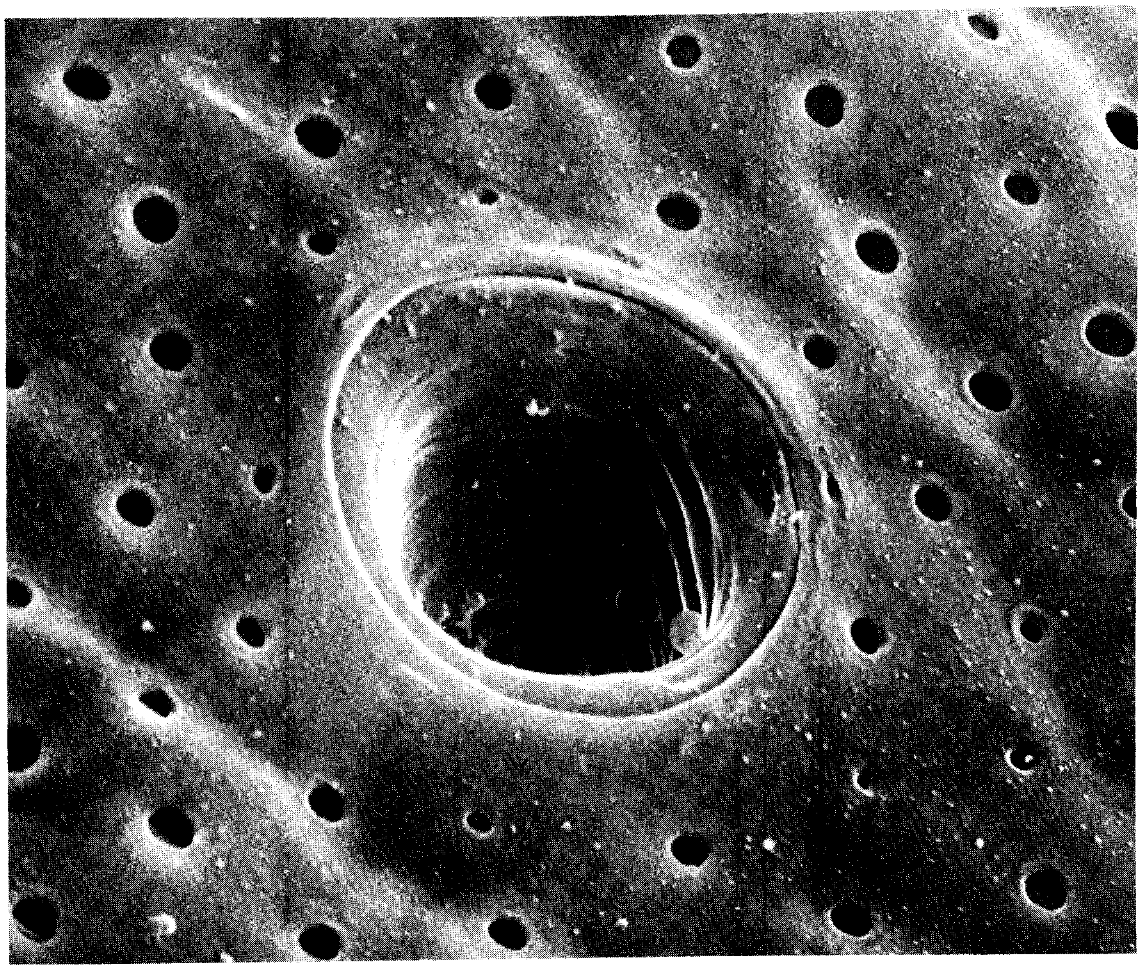

FIGURE 9. Micropyle and surrounding egg surface of a starry flounder egg with SEM. X 8,280.

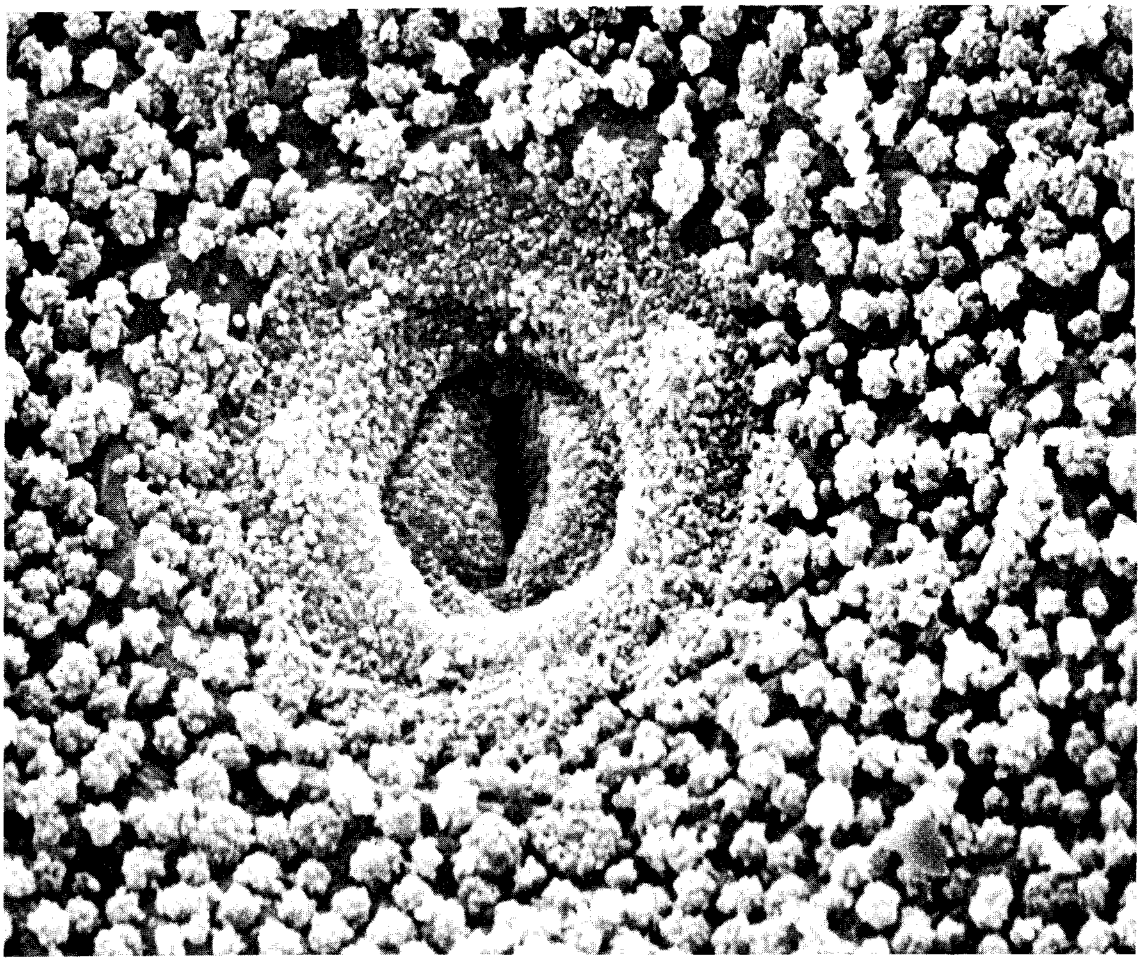

FIGURE 10. SEM of the micropyle of a sculpin egg. Note the elaborately decorated surface as compared with the starry flounder. X 3,850.

Fish Eggs and Larvae

Samples of fertilized and unfertilized eggs of several species of both benthic and pelagic fish have been observed with SEM. The site of sperm penetration, the micropyle, is of particular significance with respect to petroleum and potential inhibition of fertilization either by possible adherence of petroleum to the micropyle and surrounding region thereby damaging the egg membrane or by directly damaging the sperm at the time of fertilization.

The egg surface and micropilar structures of different species are vastly diverse. Some surfaces are relatively smooth with recessed pores (Fig. 9) and some have elaborate excrescenses (Fig. 10). Pink salmon eggs, which have an even-surface were collected, fertilized in the exposure solutions for 3-1/2 min, rinsed, and returned to petroleum for 1 hr and transferred to clean water at the Auke Bay, NMFS laboratory, Alaska. Exposures were accomplished with solutions of toluene, naphthalene, or water-soluble fractions of Prudhoe Bay crude oil. Specimens for microscopic analysis were sampled from two doses each of naphthalene (15 and 4.8 ppm) and the SWSF (9.6 and 4.8 ppm) of PBCO at the following sequence of exposure: 15, 30, 45 sec; 1, 3, 10 min; 1, 5, 8, 24, 29 hr; 1, 2 weeks. No morphological changes were observed on the surface of eggs nor in the embryos of petroleum-exposed individuals.

CHEMISTRY

Naphthalene Metabolism in Fish Skin and Mucus

Skin

Force-feeding Study. Skin of S. gairdneri, which were fed 74.6 μCi (114 μg) of tritium-1,4,5,8-naphthalene, contained 35 ppb of naphthalene and 4.7 ppb of the metabolites 4 hr after the treatment (Table 5). Concentrations are expressed both as ppb (ng/g) and as dpm/mg of dry tissue, where dpm is radioactivity as disintegrations per minute. Concentrations of the metabolites in ppb were calculated using the molecular weight of naphthol. The concentrations of both naphthalene and its metabolites in the skin of the test fish increased rapidly with time and reached maximum values of 322 and 16.6 ppb, respectively, at 24 hr, and subsequently the values declined to 10.3 and 2.5 ppb, respectively, at 168 hr (Table 5).

Several samples of skin from each fish were analyzed to assess variability within measurements on the same fish. These values reflected variations in our analytical technique as well as variations in concentrations, if any, in the skin samples from different areas of the body. These values were statistically compared with values obtained for variability among measurements on different fishes using the F-test (Sokal and Rohlf 1969). The results show that there was a highly significant added variance component in measurements among fish as compared to measurements on the same fish ($P<0.001$). The data (Table 5) on changes in concentrations of naphthalene and its metabolites with time in the skin were statistically treated and both curves fitted a lognormal probability distribution function. Eberhardt and Gilbert (1973) have used this distribution in studies on food chain and contaminant kinetics. Statistical treatment of the present data revealed that the rates of change in concentrations of naphthalene and its metabolites (Table 5) in the skin of the force-fed fish were significantly different ($P<0.05$) from each other. For example, up to 24 hr after the treatment, naphthalene concentration increased more rapidly than the metabolites (Tables 5 and 6) and thus at 24 hr, 95.6% of the total radioactivity in the skin was represented by naphthalene. However,

TABLE 5. Concentrations of naphthalene and its metabolites in skin and epidermal mucus of rainbow trout (Salmo gairdneri) exposed to naphthalene via force feeding[a,b]

Time elapsed after treatment (hr)	SKIN			
	Naphthalene		Metabolites[c]	
	dpm/mg	ppb	dpm/mg	ppb
4	51.3±18.3 (10)	35.0	6.1±1.8 (12)	4.7
16	250±29.8 (12)	173	20.0±2.0 (16)	15.6
24	465±46.1 (7)	322	21.3±1.8 (7)	16.6
48	109±18.7 (13)	75.5	8.0±1.4 (13)	6.2
168	14.9±1.1 (11)	10.3	3.2±0.6 (9)	2.5
	MUCUS			
4	2.9±1.0 (4)	2.0 [.01]	89.8±7.6 (3)	69.9 [.46]
16	18.7±3.1 (4)	12.9 [.09]	107±23.4 (4)	83.3 [.55]
24	64.4±53.9 (2)	44.6 [.29]	167±7.6 (4)	130.0 [.89]
48	65.1±33.2 (4)	45.0 [.30]	151±39.9 (4)	117.6 [.78]
168	42.2±30.2 (4)	29.2 [.19]	51.3±31.4 (4)	41.2 [.27]

[a] Fish were force-fed 74.6 μCi of [^{3}H]-1,4,5,8-naphthalene and samples were taken from 4 to 5 fish at each time interval. Concentration of both naphthalene and metabolites in water was less then 0.01 ppb at all times.

[b] Mean±S.E.M.; values in parentheses represent number of individual measurements including duplicate measurements on samples from the same fish. All concentrations are given on dry weight basis. Because epidermal mucus contained as much as 99.34% of water, concentrations in brackets are also given on wet weight basis.

[c] Concentration of metabolites was calculated using molecular weight of naphthol. The data fitted lognormal distribution and the pdf is given by:

$$f(\chi;\alpha,\mu,\sigma)= \frac{1}{(\chi-\mu)\sigma 2\pi} \quad \exp - \frac{1}{2\sigma^2} [\ln(\chi-\alpha)-\mu]^2$$

Where α is a location parameter, μ is a scale parameter, and σ is a shape parameter. For example, the data for skin in this experiment yielded parametric values of: α=5, μ=4.064, and σ=1.738 (naphthalene); α=1, μ=1.766, and σ=1.371 (metabolites).

TABLE 6. Various parameters showing patterns of accumulation and release of naphthalene and its metabolites in skin of rainbow trout *(S. gairdneri)* exposed to naphthalene.

Mode of exposure[a]	Time (hr)	Total radioactivity (μCi) in skin	Relative percentage[b]		% Administered dose in total skin	$[^3H$ in skin/^3H in liver$]$[c]	
			Naphthalene	Metabolites		Naphthalene	Metabolites
Force-feeding	4	0.06	89.4	10.6	0.08	0.05±0.01 (4)	0.09±0.02 (4)
	16	0.31	92.6	7.4	0.41	0.46±0.12 (4)	0.09±0.02 (4)
	24	0.65	95.6	4.4	0.87	0.52±0.10 (3)	0.17±0.06 (3)
	48	0.16	93.2	6.8	0.21	0.51±0.10 (4)	0.20±0.08 (4)
	168	0.03	82.4	17.6	0.03	0.51±0.12 (4)	0.10±0.01 (3)
Injection	4	0.20	95.4	4.6	0.21	0.13±0.05 (3)	0.10±0.03 (3)
	16	0.43	97.2	2.8	0.45	0.38±0.08 (3)	0.25±0.15 (3)
	24	0.38	95.4	4.6	0.40	0.34±0.12 (3)	0.26±0.03 (3)
	48	0.22	90.0	10.0	0.23	0.14±0.04 (2)	0.29±0.10 (3)
	168	0.04	84.9	15.1	0.04	0.19±0.06 (2)	0.12±0.03 (2)
Flowing water							
Exposure	24	0.53	95.3	4.7	--	0.84±0.32 (2)	0.13±0.04 (2)
	72	0.99	84.2	15.8	--	0.80±0.21 (2)	0.72±0.58 (2)
Depuration	72	0.20	48.0	52.0	--	0.51±0.40 (2)	1.23±0.27 (2)

[a] Details of exposure conditions are given in footnotes under Tables 5, 9, and 12.

[b] Relative percent of naphthalene and metabolites are based on dpm/mg values given in Table 5, 9, and 12.

[c] Values for radioactivity (dpm/mg dry wt) associated with naphthalene and metabolite fraction of each skin sample was divided by a corresponding value for the liver of the same fish. Numbers represent mean of three or four ratios ± S.E.M. Values in parentheses indicate number of individual fish. (Varanasi *et al.* 1978)

subsequently naphthalene concentration declined more rapidly so that at 168 hr, the metabolites represented 17.6% of the total radioactivity in the skin (Table 6).

To assess the importance of skin in uptake and accumulation of hydrocarbons in fish, concentrations of naphthalene and its metabolites in skin were compared with corresponding values for liver, which is an active site for hydrocarbon metabolism. Each value of radioactivity (dpm/mg, dry weight) associated with naphthalene in the skin was divided by the corresponding value for the liver of the same fish. Mean values of three or four such ratios for each time interval are given in Table 6 for rainbow trout. Similar ratios were also calculated for the metabolites in skin and liver of the same fish. At 4 hr after the treatment (Table 6), 1 g (dry weight) of skin contained 5% of naphthalene and 9% of the metabolites present in 1 g of the liver. However at 16 hr, relative concentration of naphthalene in skin was as much as 46%. The ratio [tritium in skin/tritium in liver] for naphthalene remained more or less constant thereafter. This ratio for the metabolites remained about the same throughout the experiment.

Total skin excluding headskin and fins comprised 5% of the body weight of our test fish. At 4 hr after the initial treatment, skin of the rainbow trout contained 0.08% of the administered dose of which 10.6% was attributable to the metabolites (Table 6). The maximum value for % administered dose in the skin was 0.87 at 24 hr. The skin contained only 0.03% of the administered dose at 168 hr after the treatment. At this time, the metabolites comprised 17.6% of the total radioactivity in skin.

Skin of saltwater adapted coho salmon contained substantial amounts of 1-methylnaphthalene (931 ppb) and its metabolites (86 ppb) at 24 hr after force-feeding of 4.73 μg of carbon-14-1-methylnaphthalene. At 24 hr the skin of the test fish contained 4.1% of the administered dose, of which 7.1% was attributable to the metabolites. At 48 hr, as much as 38.5% of the total radioactivity in the skin was represented by the metabolites; however, only 0.3% of the administered dose remained in the skin (Table 7).

Skin of starry flounder fed 56 μg contained 68 ppb of naphthalene and 25 ppb of metabolites at 24 hr (Table 8). At 24 hr 0.4% of the administered dose was present in skin and at 168 hr 0.02% remained. When comparing these data with those obtained for rainbow trout, it should be noted that starry flounder were kept at 12°C and rainbow trout were maintained at 8°C. The 4° difference in temperature may have an important effect on the levels of total radioactivity found in skin. At 168 hr, 78% of the total radioactivity in the skin was attributable to the metabolites (Table 8).

Injection study. Skin of rainbow trout injected intraperitoneally with 94.6 μgCi (145 μg) of tritium-1,4,5,8-naphthalene at 8°C contained 114 ppb of naphthalene and 6.2 ppb of the metabolites at 4 hr after the injection (Table 9). Maximum value of 244 ppb of naphthalene was reached at 16 hr following the injection and subsequently declined to 19.1 ppb at 168 hr. The concentration of metabolites continued to increase in the skin reaching a maximum value of 14.4 ppb at 48 hr and then decreasing to 3.8 ppb at 168 hr.

These data (Table 9) also fit a lognormal distribution probability function and it was calculated that rates of change in concentration of naphthalene and its metabolites in the skin of injected fish were significantly different from each other ($P<0.001$). As in the force-feeding study, both the rates of initial increase as well as subsequent decline of naphthalene concentration in the skin of the injected fish were greater than the rates of increase and decline of metabolites. Hence, the relative proportion of the

TABLE 7. Concentrations of 1-methylnaphthalene and its metabolites in skin and epidermal mucus of saltwater adapted coho salmon (<u>Oncorhynchus kisutch</u>) force-fed 1-methylnaphthalene[a,b]

Time elapsed after treatment (hr)	Skin		Mucus	
	1-Methyl-naphthalene ppb	metabolites ppb	1-Methyl-naphthalene ppb	metabolites ppb
4	347± 93[d,e]	91±16	n.d.[h]	152±100 [4.1][f]
16	767±290	118± 4	289±112 [7.8]	367± 68 [9.9]
24	931±320	86±30	--[g]	--
48	72± 31	45±31	135 [3.6]	693±100 [18.6]
168	--	--	n.d.	n.d.

[a] These results are provisional. Experiment is still in progress.

[b] Fish were fed 4.73 μCi (336 μg) of [^{14}C]-1-methylnaphthalene.

[c] Concentration of the metabolites was calculated using molecular weight of 1-methylnaphthol.

[d] All concentrations are given on dry weight basis; values represent Mean±S.E. (Sokal and Rohlf 1969).

[e] Concentration of either 1-methylnaphthalene or metabolites in water has less than 0.1 ppb.

[f] Concentrations in brackets are given on a wet weight basis because epidermal mucus contained 97.31% water.

[g] Not done.

[h] Not detected.

TABLE 8. Concentrations of naphthalene and its metabolites in skin and epidermal mucus of starry flounder (<u>P. stellatus</u>) exposed to naphthalene via force-feeding[a,b]

Time elapsed after treat-ment (hr)	Skin		Mucus	
	Naphthalene ppb	Metabolites ppb	Naphthalene ppb	Metabolites ppb
4	30±15	24±3	10±4	41±10
24	68±40	25±7	14±7	30±8
48	15±3	20±4	3±1	12±3
168	2±1	7±1	1±0.5	4±1

[a] Fish were force-fed 56 μg of ^{3}H-naphthalene at 12±1°C.

[b] See footnotes given under Table 5.

TABLE 9. Concentrations of naphthalene and its metabolites in skin and epidermal mucus of rainbow trout (Salmo gairdneri) exposed to naphthalene via intraperitoneal injection[a,b]

Time elapsed after treatment (hr)	Skin			
	Naphthalene		Metabolites[c]	
	dpm/mg	ppb	dpm/mg	ppb
4	164±98.5 (3)	114	7.9±0.5 (3)	6.2
16	353±2.7 (3)	244	9.9±1.4 (3)	7.7
24	306±151 (3)	212	14.7±0.2 (3)	11.4
48	168±28.9 (2)	116	18.5±3.6 (3)	14.4
168	27.6±13.5 (3)	19.1	4.9±0.4 (3)	3.8
	Mucus			
4	18.2±9.3 (3)	12.6	174±49.6 (2)	135
16	4.8±4.8 (3)	5.4	90.8±20.6 (3)	70.7
24	2.3±2.3 (3)	1.6	110±11.0 (3)	85.8
48	n.d. (3)	n.d.	n.d. (2)	n.d.

[a] [^{3}H]-1,4,5,8-naphthalene (94.6 μCi) was injected intraperitoneally in each fish and samples were taken at designated time intervals from a total of three fish. Concentration of both naphthalene and metabolites in water was less than 0.01 ppb at all times.

[b] Mean ± S.E.M; values in parantheses represent number of individual measurements. All measurements are given on dry weight basis, because epidermal mucus contained as much as 99.34% of water.

[c] Concentration of metabolites was calculated using molecular weight of naphthol.

[d] None detected

metabolites increased steadily and comprised as much as 15.1% of the total radioactivity in the skin of fish at 168 hr (Table 6).

Skin of starry flounder injected with 75 μg of naphthalene at 12°C contained 70 ppb of naphthalene and 15 ppb of the metabolites at 24 hr and 11 ppb of naphthalene and 4 ppb of the metabolites at 168 hr (Table 10).

At 24 hr, skin of the rainbow trout from the injection study contained 0.4% of the administered dose (Table 6), and as with the force-fed fish, these fish contained only 0.04% of the administered dose in skin at 168 hr. It should be noted that maximum concentrations of naphthalene and its metabolites in the livers of the injected and force-fed rainbow trout were reached at 4 and 16 hr, respectively, and maximum values for % administered dose were 0.34 for the injection study and 0.29 for the force-feeding study. At 168 hr liver contained less than 0.04% administered dose in both experiments. Starry flounder from the injection study contained 0.4% of the administered dose at 24 hr and 0.06% at 168 hr (Table 11).

TABLE 10. Concentrations of naphthalene and its metabolites in skin and epidermal mucus of starry flounder (P. stellatus) exposed to naphthalene via intraperitoneal injection[a,b]

Time elapsed after treatment (hr)	SKIN		MUCUS	
	Naphthalene ppb	Metabolites ppb	Naphthalene ppb	Metabolites ppb
24	70 ± 35	15 ± 3	1.2 ± 1	60 ± 41
168	11 ± 3	4 ± 0.4	ND	ND

[a] Fish were injected with 75 μg of ^{3}H-naphthalene at 12° ± 1°C.
[b] See footnotes given under Table 5.

Water-immersion study. Rainbow trout were exposed to 9.2 ± 1.8 ppb of tritiated naphthalene (sp. activity, 37 mCi/mmole) in flowing water for 72 hr. Because of some mortalities, the sample size in this experiment (Table 12) was smaller than in the force-feeding and injection studies. However, results yield interesting information on the accumulation of naphthalene and its metabolites in skin and liver of the fish exposed continuously to very low levels of water-borne naphthalene.

Skin of the test fish accumulated substantial concentrations of both naphthalene and metabolic products (Table 12). Interestingly, concentrations of naphthalene in the skin reached a maximum (4,230 ppb) after 48 hr of exposure, began to decline (2,100 ppb) during the remaining 24 hr of exposure, and continued to decline (223 ppb) for 72 hr during depuration (Table 12). Concentrations of the metabolites in skin continued to increased throughout the exposure period reaching a value of 441 ppb at the end of 72 hr of exposure. Levels of naphthalene and its metabolites were 223 and 272 ppb, respectively, after 72 hr of depuration (Table 12).

In the water-immersion study, skin is in direct contact with the hydrocarbon. This fact raises the possibility that a certain degree of hydrocarbon adsorption may contribute to high values obtained for naphthalene concentrations in skin. However, it should be noted that the skin samples from this

TABLE 11. Various parameters showing patterns of accumulation and release of naphthalene and its metabolites in skin of starry flounder (*P. stellatus*) exposed to naphthalene

Mode of exposure[a]	Time (hr)	Relative percentage[b]		% Administered dose in total skin	[^{3}H in skin/^{3}H in liver][c]	
		Naphthalene	Metabolites		Naphthalene	Metabolites
Force-feeding	8	56	44	0.10	0.03 ± 0.01 (4)	0.37 ± 0.11 (4)
	24	73	28	0.40	0.08 ± 0.02 (4)	0.15 ± 0.02 (4)
	48	43	57	0.08	0.06 ± 0.02 (4)	0.16 ± 0.04 (4)
	168	22	78	0.02	0.13 ± 0.01 (4)	0.10 ± 0.01 (4)
Injection	24	82	18	0.40	0.02 ± 0.01 (3)	0.10 ± 0.04 (3)
	168	76	24	0.06	0.06 ± 0.01 (3)	0.03 ± 0.01 (3)

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[a] Details of exposure conditions are given in footnotes under Tables 8 and 10.

[b] Relative percent of naphthalene and metabolites are based on dpm/mg values given in Tables 8 and 10.

[c] Values for radioactivity (dpm/mg dry wt) associated with naphthalene and metabolite fraction of each skin sample was divided by a corresponding value for the liver of the same fish. Numbers represent mean of three or four ratios ± S.E.M. Values in parentheses indicate number of individual fish.

TABLE 12. Concentrations of naphthalene and metabolites in skin of rainbow trout (Salmo gairdneri) exposed to water-borne naphthalene[a,b]

Time (hr)	Skin			
	Naphthalene		Metabolites[c]	
	dpm/mg[d]	ppb	dpm/mg	ppb
Exposure				
24	740±189 (2)	1,270	36.4±14.4 (2)	70.7
48	2,459 (1)	4,230	74.7 (1)	145
72	1,222±258 (2)	2,100	227.8±110.7 (2)	441
Depuration[e]				
72	130±81 (2)	223	140.9±47.6 (2)	272

[a] Fish were exposed to $[^{3}H]$-1,4,5,8-naphthalene mixed with cold naphthalene (9.2±1.8 ppm; 581 dpm/mg) in flowing water.

[b] Mean ± S.E.M.; values in parentheses represent number of individual measurements including duplicate measurements on samples from the same fish. All concentrations are given on dry weight basis.

[c] Concentration of metabolites was obtained using molecular weight of naphthol.

[d] Correction is made for the dilution of ^{3}H naphthalene with cold naphthalene and values are based on specific activity of 83.0 mCi/mMole to facilitate comparison with corresponding values for the force-feeding and the injection studies.

[e] During depuration, concentration of naphthalene in water was less than 0.02 ppb. (Varanasi et. al. (1978).

experiment were rinsed repeatedly and thoroughly prior to the measurements. Moreover, the scales and epidermal layer was completely removed from the skin samples, and the remaining skin was analyzed for concentrations of both naphthalene and its metabolites. It was found that skin minus scales and epidermal layer contained an average of 65% naphthalene and 75% of the metabolites present in the whole skin. For comparison, similar measurements were made on the skin of the fish from the injection study in which the naphthalene concentration in surrounding water was less than 0.01 ppb. The skin samples, from which scales with epidermal layer were thoroughly removed, contained an average of 57% of naphthalene and 60% of metabolites. Thus, it appears that adsorption of the hydrocarbon did not contribute significantly to total concentrations measured in the skin of fish from the water-immersion study. Nevertheless, during the exposure to water-borne naphthalene, ratios of radioactivity in skin versus liver for these fish were notably higher (Table 6) than corresponding ratios for both force-feeding and injection studies.

Data in Table 6 demonstrate that relative concentrations of metabolites in skin of fish from the water-immersion study increased with time. At the end of the exposure, 15.8% of the total radioactivity in skin was attributable to the metabolite fraction, and after 72 hr of depuration, the metabolites constituted as much as 52% of the total radioactivity.

Mucus

Results in Table 5 show that at each sampling time, epidermal mucus of rainbow trout fed naphthalene (74.6 μCi) contained considerably larger concentrations of metabolites than parent hydrocarbon. Epidermal mucus is generated when epithelial mucin released by the mucous cells comes in contact with surrounding water; therefore, concentrations of aromatic compounds calculated on a dry weight basis would more closely approximate the actual concentrations of these compounds in epithelial mucin. However, because epidermal mucus of rainbow trout contained more than 99% water, concentrations of naphthalene and its metabolites are also given on a wet weight basis in Table 5. Concentrations of both naphthalene and its metabolites in the mucus initially increased and reached maximum values of 45 and 130 ppb (based on dry weight), respectively, 24 hr after the force-feeding, and then declined to 29.2 and 41.2 ppb, respectively, at 168 hr. The data fit lognormal distribution, and using a one-tailed F-test of homogeneity of variance, it was calculated that rates of changes in concentration of naphthalene and metabolites in the mucus of the force-fed fish were not significantly different from each other.

As in rainbow trout, epidermal mucus of saltwater coho salmon, which were force-fed 1-methylnaphthalene, contained relatively higher concentrations of the metabolites than the parent hydrocarbon--up to 48 hr after the initial treatment (Table 7).

Epidermal mucus of starry flounder fed naphthalene contained 14 ppb (dry weight) of naphthalene and 31 ppb of the metabolites at 24 hr. During the entire exposure period, the mucus contained higher concentrations of the metabolites compared to naphthalene (Table 8).

Epidermal mucus of the rainbow trout in the injection study contained larger concentrations of metabolites than naphthalene at each time interval after the initial injection. Concentrations of the hydrocarbon and the metabolites varied randomly with time. The mucus of the test fish contained 12.6 ppb of naphthalene and 135 ppb of metabolites 4 hr after the injection. Naphthalene was not detected in the test fish after 24 hr. Metabolites were present in mucus for the first 48 hr; however, at 168 hr the metabolites were not detected in the mucus (Table 9). The data in Tables 5 and 9 reveals that there is no correlation between either relative proportions or rates of change of concentrations of naphthalene and metabolites in skin and mucus of the test fish.

In the water-immersion study, concentration of naphthalene (11.2 ± 2.1 ppb, wet weight) in the mucus of the test fish approximated the concentration of naphthalene (9.2 ± 1.8 ppb) in water. During depuration when concentration of naphthalene in water was less than 0.02 ppb, the epidermal mucus contained 0.3 ppb of naphthalene (45.5 ppb based on dry weight) and 2.2 ppb (330 ppb, based on dry weight) of the metabolites.

Metabolism and Disposition of Naphthalene in Flatfish

Starry flounder, each fed tritiated naphthalene (56 μg), were maintained in flowing seawater at 12° ± 1°C. Maximum concentrations of naphthalene (2,100 ppb, dry weight) were reached in liver at 8 hr and in blood (100 ppb) and dorsal skin (67 ppb) at 24 hr after the feeding. The concentrations of metabolites, expressed as naphthol, reached maxima at 24 hr in liver (190 ppb), blood (80 ppb), and skin (25 ppb) (Fig. 11). Subsequently, concentrations of both naphthalene and metabolites declined; however, the hydrocarbon concentrations declined more rapidly. Accordingly, at 24 hr, liver, blood, and skin contained 16, 44, and 27%, respectively, of total radioactivity in the form of metabolites; whereas, at 168 hr, the values were 81, 87, and 75%, respectively (Varanasi and Gmur 1978) (Fig. 12).

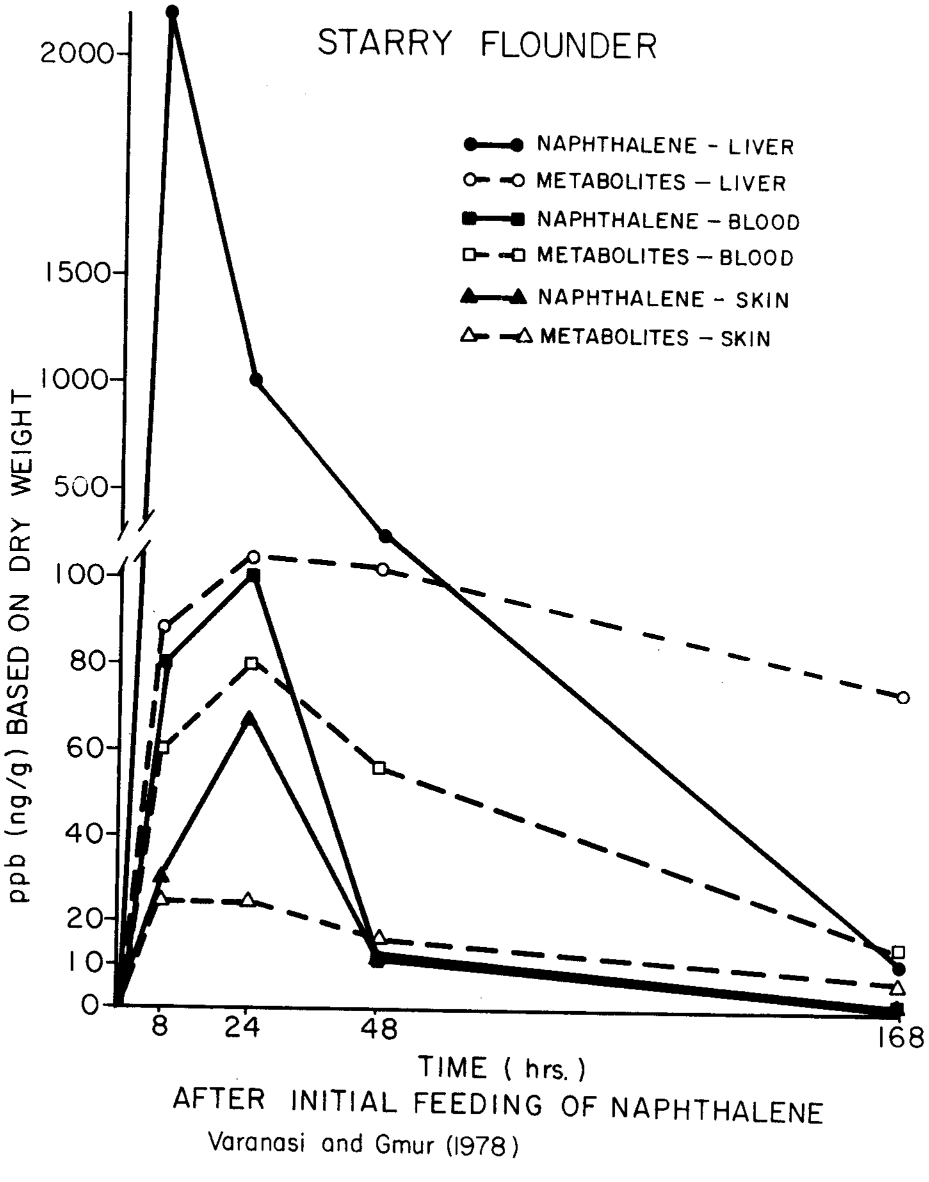
Biotransformation of Methyl-substituted Naphthalenes in Fish

The data for the incorporation of carbon-14-labeled 1-MN in organs and blood of coho salmon, which received this compound by force-feeding, are presented in Table 13 on the basis of dry weight of sample. The maximum accumulation of 1-MN at a concentration of 260 ± 40 ng/g occurred in blood at 4 hr after the time of force-feeding, and remained at about that concentration until after 24 hr from force-feeding. Beyond 24 hr, this concentration in blood markedly decreased.

Organ and muscle tissues exhibited maximum concentrations for 1-MN between 16 and 24 hr. For example, a maximum concentration of 1-MN of 3700 ± 130 ng/g occurred in the brain at 16 hr. In the other tissues examined, the maximum concentrations of 1-MN were observed in 24 hr, with values of 3000 ± 440, 2000 ± 340, and 1000 ± 220 ng/g for liver, kidney, and muscle, respectively.

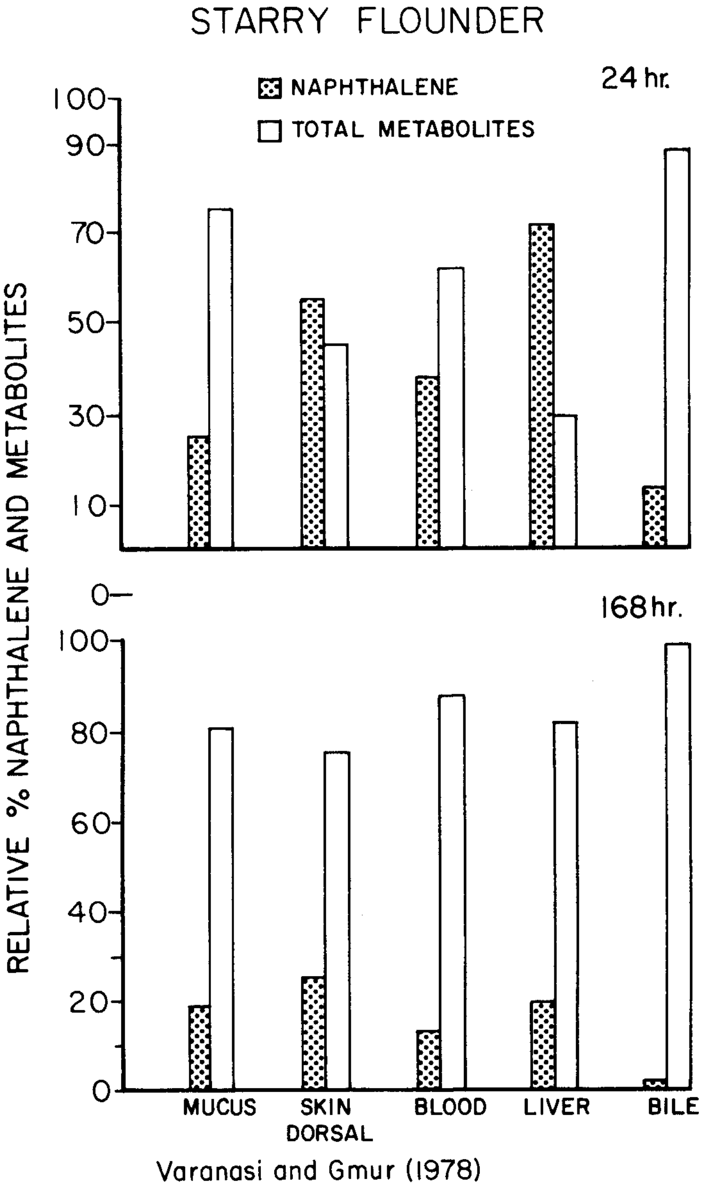
Data for a detailed quantitative examination of the accumulation and bioconcentration of 1-MN in gills, liver, and muscle of coho salmon and starry flounder exposed to 1-MN in the water column are presented in Tables 14 and 15, respectively. The highest concentration of 1-MN in tissues of coho salmon after one week of exposure was found in the gills (1.3 ± 0.41 ppm). Throughout the exposure, the concentration of 1-MN in the gills underwent a gradual increase. At the end of a 4-week exposure, the concentration of 1-MN in the gills was 8.1 ± 1.7 ppm, which was substantially greater than the concentration in the liver.

A gradual increase in the concentration of 1-MN was noted in livers of both species over the course of the exposures (Tables 14 and 15). In starry flounder, however, there was a sudden increase in the concentration of 1-MN in



Varanasi and Gmur (1978)

FIGURE 11. Concentrations of naphthalene and its metabolic products in tissues of starry flounder fed ^{3}H-naphthalene.



Varanasi and Gmur (1978)

FIGURE 12. Time-dependent changes in the relative % of naphthalene and its metabolites in tissues of starry flounder fed tritiated ^3H-naphthalene.

TABLE 13. Effect of time after force-feeding of 1-methylnaphthalene (1-MN) on the concentration of 1-MN in tissues of coho salmon (Oncorhynchus kisutch)

	HOURS AFTER FORCE-FEEDING 1-MN[a]			
Tissue	4	16	24	48
	ng/g dry weight[b]			
Brain	350±34 (0.007±0.001)	3700±130 (0.061±0.002)	3000±880 (0.054±0.021)	350±40 (0.006±0.001)
Blood	260±40 (1.5±0.57)	250±60 (1.5±0.55)	210±40 (0.45±0.052)	65±10 (0.24±0.040)
Liver	80±10 (0.10±0.024)	1500±460 (0.93±0.33)	3000±440 (1.3±0.19)	250±15 (0.32±0.068)
Kidney	230±130 (0.60±0.028)	670±210 (0.34±0.13)	2000±340 (0.41±0.10)	270±65 (0.069±0.018)
Muscle	120±10 (0.50±0.047)	390±80 (1.6±0.57)	1000±220 (6.7±1.01)	100±10 (1.1±0.16)

[a] Each fish was administered 5.14 nCi 1-MN-^{14}C.

[b] Average concentration values ±s.e.m. for six fish. Percent of administered dose given in parentheses.

muscle tissue after 2 weeks of exposure. The concentration of 1-MN in muscle of both species appeared to rise at a gradual rate over the final two weeks of the exposure (Tables 14 and 15).

When the exposure of coho salmon to 1-MN in the water column was terminated, accumulations of 1-MN in tissues were not detected after a two-week depuration period. The limit of detection was 0.03 ppm of 1-MN in tissue samples.

Starry flounder, which were exposed to 0.4 ppb of 1-MN in flow-through water, readily accumulated 1-MN as shown by the data of Table 15. Moreover, after two weeks of exposure, bioconcentration values for 1-MN in starry flounder liver were substantially greater than those for salmon; e.g., bioconcentration values for starry flounder and coho salmon were 15,500 and 560, respectively, at 3 weeks of exposure. Once exposure of starry flounder to 1-MN was terminated, concentrations of accumulated 1-MN in muscle underwent a substantial reduction over the period of depuration (Table 15). After a three-week period, the concentration of 1-MN in muscle tissue was below the limit of detection.

The data from duplicate experiments are presented in Table 16 for temperature effects on the concentrations of 2,6-dimethylnaphthalene (2,6-DMN) and its total metabolites in organs of coho salmon, which were force-fed tritium-labeled 2,6-DMN. Considering the typical wide variations in accumulations of hydrocarbons in individual organs, the experiments agree quite well.

In the case of 2,6-DMN and its metabolites, a comparison of the data for accumulated radioactivity, expressed as percent of administered dose, in the

TABLE 14. Concentration of 1-methylnaphthalene in tissues of coho salmon during and after seawater flow-through exposure to this hydrocarbon[a]

Tissue	Exposure time, weeks 1	2	3	4	Depuration after one week[b]
	μg/g dry weight				μg/g dry weight
Muscle	0.27±0.06[c] (100)	2.3±1.1 (1190)	3.8±1.3 (1400)	5.8±1.0 (2150)	1.0±0.04 (370)
Liver	0.16±0.03 (60)	0.90±0.24 (300)	1.5±0.90 (560)	4.6±1.1 (1700)	0.40±0.12 (150)
Gill	1.3±0.41 (490)	1.3±0.26 (1150)	5.0±2.1 (1850)	8.1±1.7 (3000)	2.50±0.50 (930)

---

[a] Fish exposed to 2.7 ± 0.05 ng/g 1-methylnaphthalene in flow-through seawater.

[b] The concentration of 1-methylnaphthalene was below the limit of detection at the end of 2 weeks.

[c] Bioconcentration factors are shown in parentheses.

TABLE 15. Concentrations of 1-methylnaphthalene in tissues of starry flounder during and after seawater flow-through exposure to this hydrocarbon[a]

Tissue	Exposure time, weeks 1	2	3	4	5	Depuration time[b] 1 wk	2 wk
	μg/g dry tissue					μg/g dry tissue	
Muscle	0.30±0.14 (750)[d]	0.10±0.06 (250)	2.8±0.08 (7000)	3.1±0.11 (7750)	4.2±1.8 (10000)	NA[c]	0.8±0.20 (2000)
Liver	0.91±0.25 (2280)	3.4±1.4 (8500)	6.2± 0.91 (15000)	NA	9.4±2.1 (23500)	1.2±0.48 (3000)	
Gills	0.97±0.41 (2430)	1.0±0.11 (2500)	ANP	ANP[e]	ANP	ANP	ANP

---

[a] Fish were exposed to 0.4 ± 0.1 ng/g 1-methylnaphthalene in flow-through seawater.

[b] The concentration of 1-methylnaphthalene was below the limit of detection in muscle after 3 weeks of depuration; it was below detectable limits in liver after two weeks of depuration.

[c] NA - not analyzed.

[d] Bioconcentration factors are shown in parentheses.

[e] ANP - analysis not possible.

TABLE 16. Effect of environmental temperature on the distribution of 2,6-dimethylnaphthalene and total metabolites in tissues of coho salmon[a]

Tissue[b]	Experiment No.	Compound analyzed	TEMPERATURE OF AQUARIUM WATER			
			13°C		4°C	
			pCi/mg dry wt	% admin. dose	pCi/mg dry wt	% admin. dose
Liver	1	DMN[c]	23±15	0.16±0.087	15±10	0.18±0.12
		M[d]	13±3.3	0.12±0.017	17±3.1	0.18±0.048
	2	DMN	18±8.7	0.12±0.052	21±7.7	0.25±0.071
		M	10±5.4	0.10±0.043	20±8.1	0.28±0.13
Kidney	1	DMN	21±7.7	0.072±0.016	24±13	0.081±0.040
		M	16±10	0.061±0.033	7.1±3.8	0.039±0.025
	2	DMN	18±8.0	0.051±0.021	24±10	0.080±0.033
		M	20±7.8	0.078±0.026	15±4.4	0.087±0.014
Gall bladder	1	DMN	32±17	0.023±0.019	56±22	0.017±0.006
		M	190±42	0.67±0.16	NA[e]	NA
	2	DMN	26±9.8	0.020±0.00	36±17	0.018±0.004
		M	160±70	0.050±0.020	NA	NA
Brain	1	DMN	13±2.8	0.02±0.0	NF[f]	NF
		M	1.9[g]	<0.01[g]	NF	NF
	2	DMN	8±1.9	0.013±0.004	5.0±3.1	0.008±0.006
		M	NA	NA	NA	NA

TABLE 16. (continued)

Light muscle	1	DMN	1.7±0.36	0.46±0.12	2.7±1.4	0.48±0.20
		M	1.0[g]	0.10[g]	2.1±0.34	0.13±0.03
	2	DMN	3.0±0.44	0.97±0.015	3.8±0.90	0.95±0.38
		M	1.3±0.30	0.087±0.075	2.8±0.49	0.18±0.027
Dark muscle	1	DMN	14±6.0	0.25±0.11	23±11	0.37±0.17
		M	1.9±0.30	0.038±0.004	2.3±0.30	0.046±0.006
	2	DMN	10±5.1	0.20±0.10	15±2.1	0.30±0.030
		M	2.8±0.045	0.056±0.006	3.1±0.87	0.062±0.017
Digestive tract	1	DMN	210±91	6.3±2.4	645±210	13±5.6
		M	21±3.1	0.61±0.12	21±4.0	0.91±0.19
	2		NA	NA	NA	NA

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[a] Each fish received 2.16 µCi of ^{3}H-2,6-DMN by force-feeding.
[b] Tissues were analyzed 72 hr after force-feeding.
[c] DMN, 2,6-dimethylnaphthalene.
[d] M, total metabolites of 2,6-dimethylnaphthalene.
[e] NA, not analyzed.
[f] NF, not found, less than twice background level for scintillation counting.
[g] Single sample value.

livers from fish maintained at 4° and 13°C show that average values are statistically the same at both temperatures. When absolute values of percent of dose for accumulated 2,6-DMN and its total metabolites from the other tissues and individual organs were examined statistically, no significant differences in levels of accumulations were evident due to effects of temperature.

Two metabolites of 2,6-DMN in organs of coho salmon exhibited TLC Rf values identical to those given by trans-3,4-dihydro-3,4-dihydroxy-2,6-dimethylnaphthalene and 3-hydroxy-2,6-dimethylnaphthalene (Table 17). Also, metabolites of 2,6-DMN with these same Rf values, were isolated from the urine of the rat. Moreover, conjugated metabolites of hydroxylated 2,6-DMN, with Rf values corresponding to those for the glucuronide of 1-naphthol, the sulfate of 1-naphthol, and the mercapturate of 1-naphthol were also detected (Table 19) in both the salmon and the rat. The available evidence suggested the conjugates formed in exposed salmon are the corresponding glucuronide, sulfate, and mercapturate of a monohydroxylated 2,6-DMN.

Influence of Lead and Cadmium on Naphthalene Metabolism

The HPLC chromatograms (Fig. 13) reveal a species difference in the distribution of naphthalene metabolites found in the livers of coho salmon and starry flounder. The 1,2-dihydro-1,2-dihydroxynaphthalene was the only significant metabolite found in starry flounder liver. In contrast, coho salmon had detectable amounts of the dihydrodiol, glycoside (?), glucuronide, naphthyl sulfate, and naphthol. At 24 hr after intraperitoneal injection of carbon-14-labeled naphthalene, the concentration of the dihydrodiol in non-PAH-fed starry flounder was approximately ten times greater than in non-PAH-fed coho salmon liver on an equivalent weight basis.

The gall bladder (bile) from the coho salmon showed a diversity of metabolites, with the glucuronide, naphthyl sulfate, the dihydrodiol, glycoside (?), and naphthol being the principal naphthalene metabolites observed. In starry flounder, the principal metabolite from bile was the dihydrodiol, along with naphthol and lesser amounts of a compound believed to be a glycoside (Fig. 13).

The data in Table 18 show that PAH-fed starry flounder had a significant depression ($P<0.05$) in the concentration of the 1,2-dihydro-1,2-dihydroxynaphthalene in the liver associated with the exposures to cadmium and lead. At 24 hr after intraperitoneal injection, the concentration of dihydrodiol was decreased 36% by lead-exposure and 63% by cadmium-exposure. In the case of starry flounder which had no PAH in their diet, the effect of metals on changing the dihydrodiol concentration in the liver was much less. Lead had no apparent effect; and the 20% depression observed for cadmium was not significant at the 90% statistical level. However, cadmium-exposed coho experienced a 31% depression in the concentration of dihydrodiol present in the liver, but the statistical confidence was low ($P<0.10$).

In coho salmon which had been fed PAH, the concentration of the dihydrodiol in livers of lead-exposed fish, on a whole organ basis, was not significant compared to control-fed salmon (Table 18).

TABLE 17. Rf values from thin-layer chromatographic analyses of metabolites of 2,6-dimethylnaphthalene in the urine of rats and in the gall bladder and liver (composite sample) of coho salmon[a]

Standard compound	Rf value standard colorimetric	Rf values of metabolites							
		RAT				COHO SALMON			
		System A		System B		System A		System B	
		Radio-metric	Colori-metric	Radio-metric	Colori-metric	Radio-metric	Colori-metric	Radio-metric	Colori-metric
Unknown								0.47	
Trans-3,4-dihydro-3,4-dihydroxy-2,6-dimethylnaphthalene	0.54[b]			0.54	0.54			0.56	
3-Hydroxy-2,6-dimethylnaphthalene	0.85[b]			0.85	0.85			0.85	0.85
1-Naphthyl-β-glucuronic acid	0.29[c]	0.24	0.29			0.23			
1-Naphthyl mercapturic acid	0.38[c]	0.38	0.38			0.38			
1-Naphthyl sulfate	0.58[c,d]	0.55	0.58			0.52			
1-Naphthyl-α-glucoside	0.60[c,d]								

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[a] Rats received ^{3}H-labeled and nonlabeled 2,6-dimethylnaphthalene (in separate experiments) by intraperitoneal injection. Fish received ^{3}H-labeled and nonlabeled 2,6-dimethylnaphthalene (in separate experiments) by force-feeding.

[b] System B: p-Dioxane:benzene:acetic acid (25:90:4, v:v:v) using Merck silica gel TLC plates.

[c] System A: Top layer from 1-butanol:conc. NH_4OH:H_2O (40:10:50, v:v:v) using Quantum LQD segmented TLC plates.

[d] 1-Naphthyl sulfate and 1-naphthyl glucoside overlap in System A.

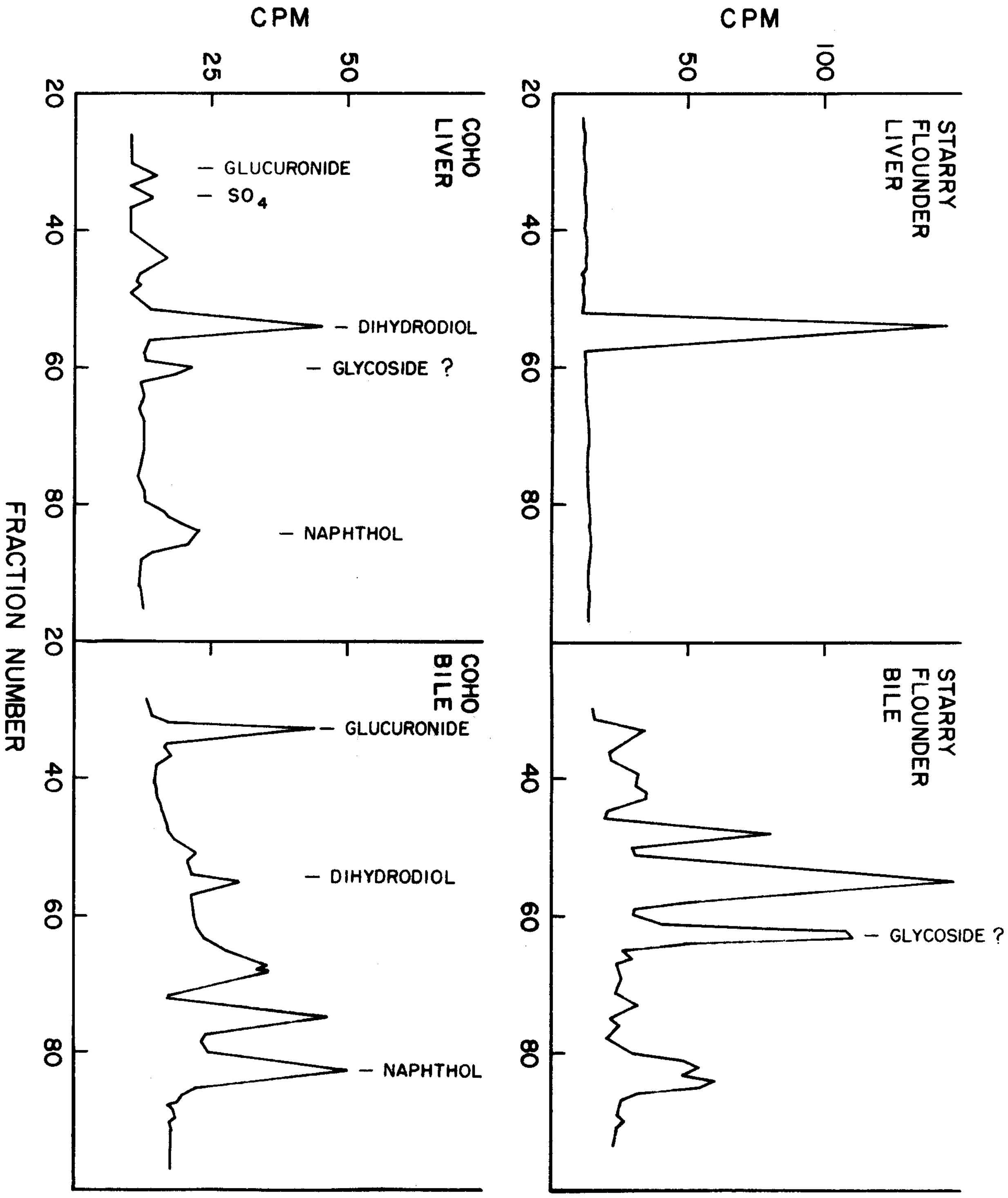

FIGURE 13. Distribution of metabolites of carbon-14 naphthalene in the bile and liver of starry flounder and coho salmon.

TABLE 18. Concentrations of the 1,2-dihydro-1,2-dihydroxynaphthalene in livers of metal-exposed fish

Species[a]	Exposure group Control (x 10^{-3}) μg/g	 Pb (x 10^{-3}) μg/g	 Cd (x 10^{-3}) μg/g
Starry flounder (PAH)[b]	11.5 ± 1.9	7.3 ± 2.6[c]	4.3 ± .8[c]
Starry flounder	15.1 ± 4.2	16.1 ± 4.3	11.8 ± 4.8
Coho salmon	1.40 ± .23	1.94 ± .77	0.96 ± .22[d]
Coho salmon (PAH)[b]	.56 ± .23	.72 ± .23	

[a] Fish exposed to 200 ppb of metal for 4 weeks.
[b] Groups of 10-12 fish fed 330 ppm of petroleum aromatic hydrocarbons during the week before i.p. injection of naphthalene.
[c] Statistically different from controls ($P<0.05$).
[d] $P<0.10$ with respect to controls.

Cadmium-109 and Lead-210 Injection Studies

Table 19 gives the distribution of Cd-109 in gill, kidney, and liver cytosol after i.p. injection of Cd-109. The gills exhibited a marked change in Cd-109 distribution after exposure to Cd. In unexposed coho salmon 3 hr after injection, only 9% of gill cytosolic Cd-109 was bound to CdBP (cadmium-binding proteins, 700 daltons); this increased to 55% in coho salmon which had been exposed for two weeks to 200 ppb Cd. This change is clearly demonstrated in Figure 14, as the amount of Cd-109 bound to proteins of molecular weight greater than 12,000 decreases dramatically.

The liver had the highest concentration of Cd-109 present in the cytosol and the highest percentage of Cd-109 bound to CdBP.

At 3 hr post injection, 79% of the total cytosolic Cd-109 in the liver was bound to CdBP in normal coho salmon. This percentage went to 89% at 48 hr post injection. The distribution of Cd-109 in a typical liver cytosolic fraction is illustrated in Figure 15.

The injection studies with Pb-210 revealed no significant concentrations of lead with any specific protein fraction in the cytosol of the gills, liver, and kidneys. The Pb-210 cytosol profile corresponded with cytosolic protein profile, which suggests that lead is probably nonspecific in binding with cytosolic components. A typical distribution of lead in liver is shown in Figure 16. The distribution of Pb-210 is similar in the cytosolic fractions of the gills and kidney.

Activities of Aryl Hydrocarbon Monooxygenases in Different Species

The analytical results of activities of the aryl hydrocarbon monooxygenases (AHM) enzymic systems are reported for marine organisms from Alaska, as follows: 15 samples of flathead sole (Hippoglossoides elassodon), 14 of arrowtooth flounder (Atharesthes stomias), 4 of butter sole (Lepidopsetta isolepis), 19 of Pacific cod (Gadus macrocephalus), 15 of pollock (Theragra chalcogramma), 24 of rock sole (Lepidopsetta bilineata), and 8 of tanner crab (Chionoecetes sp.). The data are presented in Tables 20-27, respectively.

TABLE 19. Distribution[a] of cadmium-109 in coho salmon (Oncorhynchus kisutch) cytosols from gill, kidney, and liver at 3, 24, and 28 hours after intraperitoneal injection[b]

Sample	Treatment	Sampling time hr	Cd bound to high MW fractions (>55,000 daltons)	Cd bound to CdBP fractions	Cd bound to remaining fractions	Cd in cytosol
			ng ^{109}Cd/mg cytosolic protein			
GILLS	Seawater only	3	16.0	2.0	3.7	21.7
		24	14.4	5.3	3.1	22.8
		48	29.3	14.0	14.0	57.3
	200 ppb Cd in seawater[c]	3	9.5	16.3	3.8	29.6
		24	16.8	17.3	5.4	39.5
ANTERIOR KIDNEY	Seawater only	3	9.6	10.1	8.6	28.3
		24	9.1	9.2	7.5	25.8
		48	20.0	40.0	20.7	80.7
	200 ppb CD in seawater[c]	3	7.8	5.6	3.1	16.5
		24	11.8	11.8	6.5	30.1
POSTERIOR KIDNEY	Seawater only	3	18.3	21.2	23.5	63.0
		24	30.1	23.9	29.4	83.4
		48	-[d]	55.6	-[d]	149.0
	200 ppb Cd in seawater[c]	3	5.3	29.5	3.7	38.5
		24	16.1	42.8	11.1	70.0
LIVER	Seawater only	3	12.6	67.5	5.2	85.3
		24	49.0	46.2	7.8	103.0
		48	24.3	167.4	8.5	200.2
	200 ppb Cd in seawater[c]	3	5.6	73.8	3.1	82.5
		24	16.0	6.0	5.2	27.2

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[a] Cytosolic fractions were separated by gel filtration chromatography.

[b] Fish were maintained at 10°C during exposures to cadmium-109.

[c] Fish were exposed to 200 ppb cadmium in seawater for 2 weeks prior to intraperitoneal injection of (32 μg) cadmium-109.

[d] Analytical samples of the collected fractions are not available.

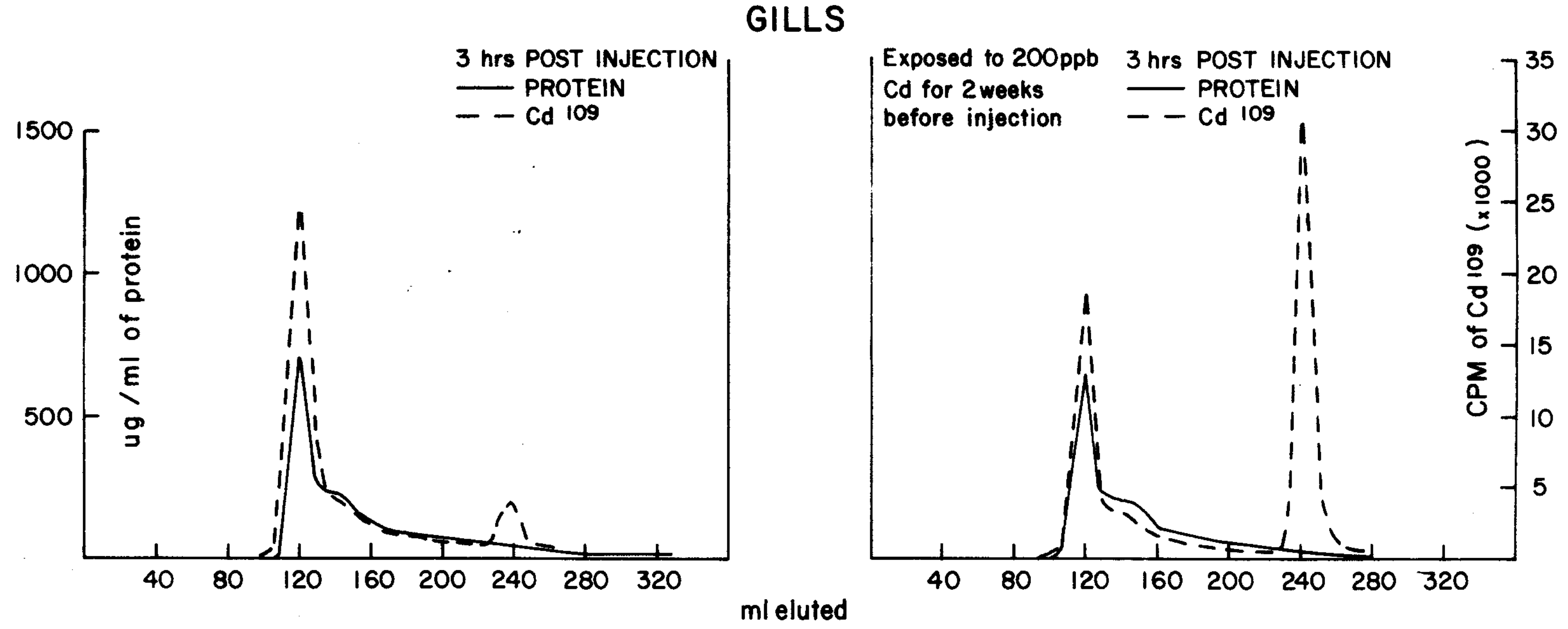

FIGURE 14. Distribution of cadmium-109 in coho salmon gill cytosol.

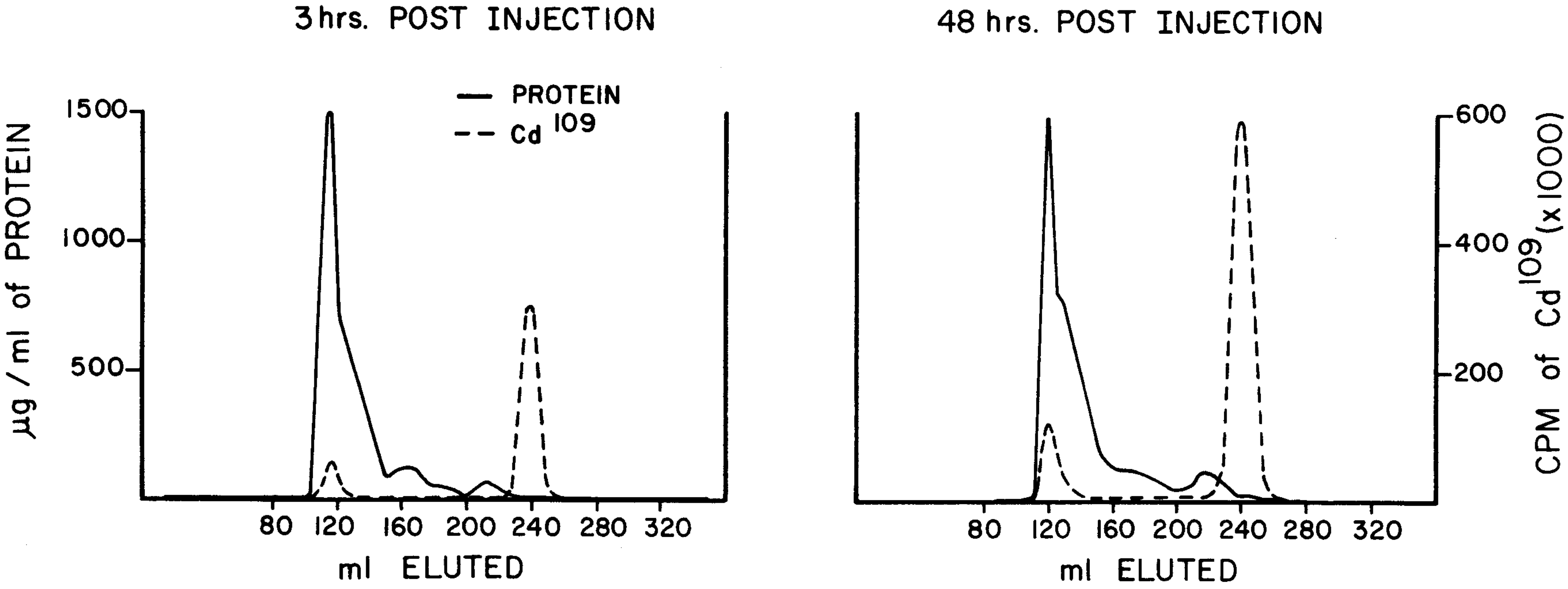

FIGURE 15. Distribution of cadmium-109 in coho salmon liver cytosol.

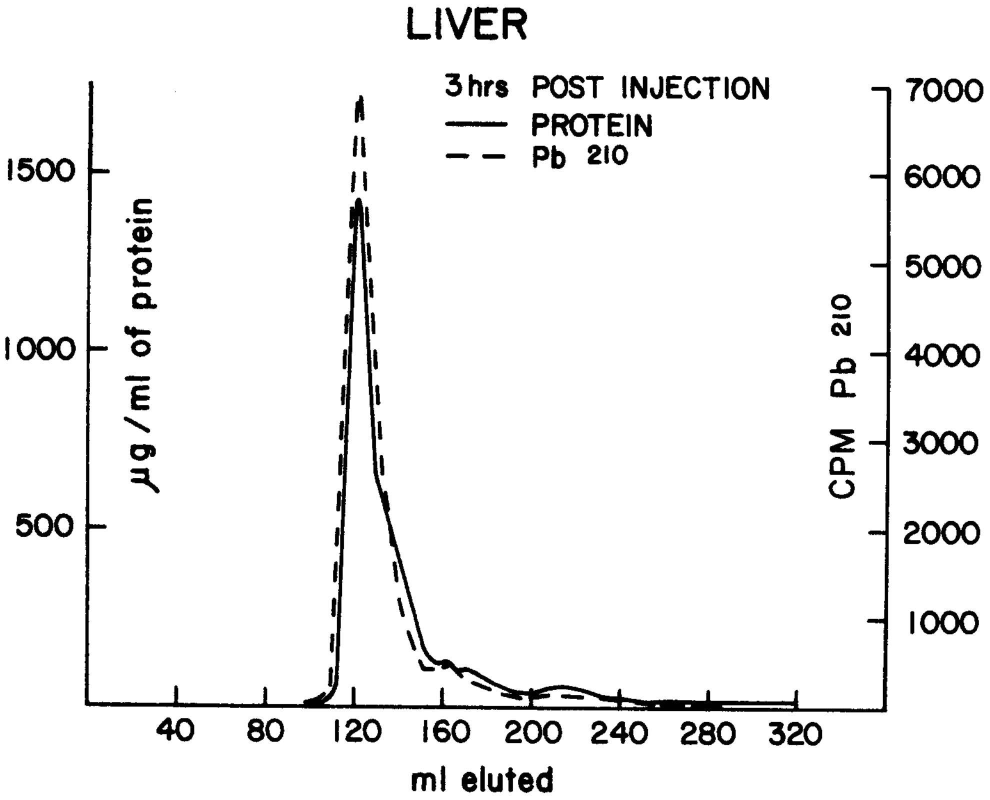

FIGURE 16. Distribution of lead-210 in coho salmon liver cytosol.

In general, the activities of AHM are given in two ways: as specific activity in nmoles of products of benzo(a)pyrene formed (per 20 min) per mg of protein in the enzyme sources and as nmoles of products formed (per 20 min) per whole liver (or tissue sample). The latter is proportional to the capacity of the organisms to metabolize the PAH. The specific activities of hepatic AHM for the finfishes ranged in values from 0.006 to 0.927, and values for the crab viscera AHM ranged from 0.005 to 1.03 nmoles/mg protein. In addition, hepatic AHM for a single Pacific Ocean perch (Sebastodes alutus) from Alaska had a value of 0.031.

Four samples of the snail, Fusitriton sp., were found to have no detectable activity of benzo(a)pyrene monooxygenase in whole body samples.

Starry flounder taken from Puget Sound were found to have specific activities of hepatic benzo(a)pyrene monooxygenase of 27.0 ± 6.9 (values ranged from 14 to 42). The same species from the Columbia River mouth had specific activities of naphthalene monooxygenase of 0.30 ± 0.25 (values ranged from 0.02 to 0.84).

Activities of hepatic benzo(a)pyrene monooxygenase for Pacific cod, which had pseudobranchial tumors, were indistinguishable from the activities found for "normal" Pacific cod. The data for the tumor-bearing fish are given in Table 27, which shows a mean value of 0.31 for the AHM activity that is essentially the same as the mean value of 0.33 from Table 23.

Temperature and pH optima for analyses of benzo(a)pyrene monooxygenase were determined for microsomal preparations (pellets from 105,000 x g/60 min differential centrifugations) for Pacific cod, rock sole, and starry flounder. The temperature profiles indicated maxima activity at 25°, 25°, and 28°C, respectively, for the three species. The profiles of pH for the monooxygenase reactions showed two maxima, 6.9-7.0 and 7.4-7.5, for the three species, with monooxygenase activity generally greater at pH 7.5 than at pH 6.9-7.0.

Hydrocarbon Analysis of PBCO

The results of the analysis of an aliquot of PBCO from a 55 gal drum are presented in Table 28. The proportion of isoparaffins and cycloparaffins were calculated from the difference between the amount of n-paraffins found in the total saturates fraction and the total proportion of saturates found in the oil. The analysis of aromatic hydrocarbons revealed naphthalenes as the major components with decreasing proportions of phenanthrenes and anthracenes, dibenzothiophenes, benzenes, fluorenes, and biphenyls and acenaphthenes, in that order.

PHYSIOLOGY

The concentrations of naphthalene that cause a change in the early embryology of mussels and the changes that are induced by naphthalene were studied using the gametes from artificially spawned adults. Mussel gametes were combined in separate solutions containing 1, 10, and 100 ppb naphthalene. The survival of the resulting larvae, after 24 hr, was 27, 32, and 2%, respectively, for the three exposures compared to 69% survival for controls. In the 100 ppb solution, 24% of the exposed eggs were unfertilized compared to 3% of the controls. The highest concentration produced abnormal embryological development in 25% of the animals after 1.5 hr of exposure, compared to 2% of the controls. After 24 hr all of the larvae exposed to 10 ppb naphthalene

TABLE 20. Examinations of flathead sole (*Hippoglossoides elassodon*) for activity of hepatic aryl hydrocarbon monooxygenase (AHM)[a]

Haul No.[b]	Fish sample Weight g	Length cm	Sex	Liver Weight g	AHM activity[c] Units/mg protein	Units/liver
1	108.6	24.2	M	0.36	0.056	1.56
1	122.1	23.7	M	1.28	0.109	9.97
1	182.3	27.5	M	0.96	0.108	3.04
1	129.0	26.0	M	1.15	0.142	11.6
1	112.0	25.2	M	1.30	0.462	36.6
1	141.5	26.3	M	1.24	0.298	26.4
1	177.4	27.0	F	2.12	0.146	22.3
1	339.5	33.5	F	3.38	0.069	18.6
1	157.3	26.9	F	1.87	0.201	28.0
1	219	30.5	F	2.94	0.256	50.1
56	273	31.0	F	3.15	0.072	18.7
56	256	30.8	F	2.70	0.236	36.4
56	153	25.5	M	1.78	0.927	79.1
56	266	31.1	F	2.97	0.100	172
56	172	27.0	F	1.86	0.149	17.4
		AHM activity, highest value =			0.927	172
		AHM activity, mean (±s.d.) =			0.222 (±0.223)	35.4 (±42.6)
		AHM activity, lowest value =			0.056	1.56

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[a] The fish were taken on cruise no. MF-77-1 of the *Miller Freeman* in areas northeast of Kodiak, Alaska. Cell-free supernatant fractions (9,000 x g/20 min) of 20% homogenates in 0.25 M-sucrose were used for AHM analyses.

[b] Refers to station of cruise ship during sampling.

[c] One unit of AHM activity is one nmole of benzo(a)pyrene products formed per 20 min at 25°C with the cofactors and substrate present at the prescribed concentrations. Specific activity of AHM is the units of activity per mg of protein used in the analysis.

TABLE 21. Examination of arrowtooth flounder (Atharesthes stomias) for activity of hepatic aryl hydrocarbon monooxygenase (AHM)[a]

Haul No.[b]	Fish sample			Liver	AHM activity[c]	
	Weight g	Length cm	Sex	Weight g	Units / mg protein	Units / liver
22	467	36.5	M	2.60	0.067	13.3
22	243	29.5	M	1.70	0.031	3.86
22	703	42.5	F	4.40	0.065	18.0
22	795	42.8	F	4.48	0.080	27.0
22	707	41.2	F	3.08	0.117	29.7
22	194	27.0	F	0.80	0.044	2.88
22	171	26.5	F	1.42	0.0069	0.77
56	99	23.7	M	0.50	0.060	2.47
56	103	24.2	M	1.13	0.083	6.73
56	129	25.7	M	1.25	0.051	4.33
56	106	24.6	M	1.17	0.024	2.02
56	114	25.0	M	1.24	0.145	15.0
56	305	32.0	M	3.13	0.030	6.54
56	100	23.6	M	0.77	0.080	5.54
		AHM activity, highest value =			0.145	29.7
		AHM activity, mean (±s.d.) =			0.063	9.87
					(±0.037)	(±9.39)
		AHM activity, lowest value =			0.0069	0.77

[a,b,c] Same as in Table 20.

TABLE 22. Examination of butter sole (Lepidopsetta isolepis) for activity of hepatic aryl hydrocarbon monooxygenase (AHM)[a]

Haul No.[b]	Fish sample			Liver	AHM activity[c]	
	Weight g	Length cm	Sex	Weight g	Units / mg protein	Units / liver
30	218	29.0	F	1.49	0.162	14.0
30	309	32.3	F	1.69	0.064	7.14
30	209	28.2	F	1.52	0.072	9.46
30	239	29.3	F	2.30	0.233	32.4
		AHM activity, highest value =			0.233	32.4
		AHM activity, mean (±s.d.) =			0.133	15.8
					(±0.080)	(±11.4)
		AHM activity, lowest value =			0.072	7.14

[a,b,c] Same as in Table 20.

TABLE 23. Examination of Pacific cod (<u>Gadus macrocephalus</u>) for activity of hepatic aryl hydrocarbon monooxygenase (AHM)[a]

Haul No.[b]	Fish sample			Liver	AHM activity[c]	
	Weight g	Length cm	Sex	Weight g	Units / mg protein	Units / liver
43	1190	47.5	F	5.12	0.063	15.7
43	1084	46.7	M	2.78	0.272	28.4
43	582	37.4	F	3.40	0.106	15.3
43	1230	49.0	M	3.40	0.209	35.9
43	1088	46.2	M	4.72	0.276	53.6
43	407	34.2	M	3.40	0.306	35.2
43	648	40.5	F	3.88	0.340	52.6
43	1095	47.5	F	4.28	0.178	30.8
43	997	46.5	F	3.08	0.034	6.13
43	1053	45.0	M	3.0	0.232	33.5
54	779	42.5	M	3.0	0.520	92.0
54	725	42.5	M	1.63	0.353	32.8
54	715	41.6	F	5.5	0.093	31.7
54	494	36.6	F	2.73	0.148	20.8
54	1102	47.4	F	3.73	0.122	23.4
54	655	40.5	M	2.78	0.863	127
54	1233	49.2	F	4.27	0.501	71.3
54	1802	53.2	M	5.10	0.875	169
54	810	44.2	F	2.85	0.713	79.3
		AHM activity, highest value =			0.875	169
		AHM activity, mean (±s.d.) =			0.326 (±0.257)	50.2 (±41.6)
		AHM activity, lowest value =			0.034	6.13

[a,b,c] Same as in Table 20.

TABLE 24. Examination of pollock (*Theragra chalcogramma*) for activity of hepatic aryl hydrocarbon monooxygenase (AHM)[a]

Haul No.[b]	Fish sample			Liver	AHM activity[c]	
	Weight g	Length cm	Sex	Weight g	Units / mg protein	Units / liver
26	659	45.1	F	9.11	0.582	170
26	664	44.3	F	5.00	0.088	10.9
26	531	41.3	M	2.90	0.235	19.6
26	736	45.8	F	7.90	0.188	51.2
26	521	39.6	M	4.82	0.047	2.9
26	812	46.8	F	5.92	0.087	11.1
26	474	38.3	M	4.10	0.655	19.9
26	606	40.8	M	5.35	0.006	6.3
54	155	29.0	F	2.04	0.266	17.1
54	138	27.6	M	2.50	0.164	7.9
54	212	31.0	F	3.56	0.148	12.6
54	239	32.2	F	2.97	0.205	11.6
54	101	25.2	M	3.23	0.111	6.2
54	135	26.5	M	2.60	0.232	19.7
54	88	24.5	M	1.58	0.077	3.1
		AHM activity, highest value =			0.655	170
		AHM activity, mean (±s.d.) =			0.206 (±0.184)	24.7 (±41.9)
		AHM activity, lowest value =			0.006	2.9

[a,b,c] Same as in Table 20.

TABLE 25. Examination of rock sole (Lepidopsetta bilineata) for activity of hepatic aryl hydrocarbon monooxygenase (AHM)[a]

Haul No.[b]	Fish sample			Liver	AHM activity[c]	
	Weight g	Length cm	Sex	Weight g	Units / mg protein	Units / liver
7	116	22.9	F	0.36	0.287	6.2
7	397	33.1	M	2.92	0.114	22.8
7	471	33.1	F	3.47	0.075	17.9
7	130	23.4	M	0.60	0.087	3.8
7	134	24.0	F	0.93	0.213	15.4
7	312	29.8	F	2.03	0.017	2.6
36	688	38.0	F	5.05	0.039	20.6
36	770	39.3	F	3.47	0.006	1.9
36	667	37.0	F	4.86	0.118	53.0
36	304	28.5	F	2.00	0.024	4.1
36	288	30.3	M	1.55	0.081	9.4
36	915	40.0	F	5.93	0.041	27.5
36	280	31.2	M	1.26	0.223	19.0
36	243	28.8	M	1.72	0.104	14.7
36	221	28.8	F	1.12	0.216	18.5
36	163	25.6	F	1.00	0.376	26.1
36	293	30.0	F	2.20	0.031	5.2
55	410	35.2	F	2.75	0.535	99.3
55	275	28.6	F	2.62	0.400	81.7
55	191	26.0	F	1.70	0.281	40.9
55	348	31.5	F	2.97	0.687	169
55	160	24.2	M	1.25	0.382	50.3
55	500	34.0	F	6.50	0.211	112
55	184	25.5	M	2.17	0.574	99.7
AHM activity, highest value =					0.687	169
AHM activity, mean (±s.d.) =					0.213 (±0.192)	38.4 (±43.4)
AHM activity, lowest value =					0.006	1.9

[a,b,c] Same as in Table 20.

TABLE 26. Examination of female tanner crab (Chionoecetes sp.) for activity of aryl hydrocarbon monooxygenase (AHM) in visceral organs[a]

Haul No.[b]	Weight of organ sample g	AHM activity[c] Units/mg protein	AHM activity[c] Units/organs
57	0.95	1.031	[d]
57	1.0	0.439	[d]
57	1.0	0.005	[d]
57	1.0	0.118	[d]
57	1.0	0.259	[d]
57	10.13	0.038	30.8
57	4.07	0.005	2.28
57	5.90	0.083	56.6
	mean (±s.d.) =	0.247 (±0.350)	30 (±27)

[a,b,c] Same as in Table 20.

[d] Only aliquots were analyzed, not entire viscera, so data based on entire organs are unavailable.

TABLE 27. Examination of hepatic AHM activities of Alaskan Pacific cod (Gadus macrocephalus) which had pseudobranchial tumors

Code No.	Fish sample Weight g	Fish sample Length cm	Hepatic AHM activity[a] nmoles products/mg protein
A514	364	33.0	0.257
A515	382	33.5	0.198
A516	410	33.6	0.249
A517	453	35.0	0.599
A518	637	39.5	0.252
		mean (±s.d.)	0.311 (±0.163)

[a] AHM as benzo(a)pyrene monooxygenase. Assay condition described in Methods.

TABLE 28. Organic composition of Prudhoe Bay crude oil used in research

n-Paraffin distribution[a]	Wt %
n-C$_{10}$	0.03
n-C$_{11}$	0.08
n-C$_{12}$	0.15
n-C$_{13}$	0.21
n-C$_{14}$	0.27
n-C$_{15}$	0.30
n-C$_{16}$	0.28
n-C$_{17}$	0.28
n-C$_{18}$	0.25
n-C$_{19}$	0.25
n-C$_{20}$	0.23
n-C$_{21}$	0.23
n-C$_{22}$	0.22
n-C$_{23}$	0.20
n-C$_{24}$	0.18
n-C$_{25}$	0.16
n-C$_{26}$	0.13
n-C$_{27}$	0.11
n-C$_{28}$	0.08
n-C$_{29}$	0.04
	4.0

Major oil fractions[b]	Wt %
Naphtha (to 210°C)	18.6[c]
Saturates	48.9
Aromatics	19.4
Polars	13.8
Insolubles	1.4
	102.1

Saturate-type compounds[a]	Wt %
n-paraffins	4.0
Pristane	0.18
Phytane	0.14
Unresolved components	44.6
	48.9

Aromatic-type compounds[a]	Wt %
Benzenes	0.24
Indans/Tetralins	0.04
Naphthalenes	1.11
Biphenyls/Acenaphthenes	0.25
Fluorenes	0.29
Phenanthrenes/Anthracenes	0.34
Pyrenes/Fluoranthenes	0.05
Chrysenes/Benzanthracenes	0.01
Benzpyrenes/Perylenes	0.00
Benzothiophenes	0.00
Dibenzothiophenes	0.59
Unresolved components	16.49
	19.4

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[a] Determined by capillary gas chromatography.

[b] Determined gravimetrically.

[c] Naphtha fraction includes low-boiling saturates and aromatics, which are not determined by gas chromatography.

had reached the "straight hinge" stage. No animals at the other concentrations or the controls developed to straight hinge larvae.

The decrease in fertilization demonstrated in the mussel experiments and the relative effect naphthalene has on sperm and egg function were further explored using oyster gametes. The oyster sperm exposed to 10 ppb and 1 ppb resulted in 14 and 9% unfertilized eggs, respectively, while only 5% of the exposed eggs were unfertile at each exposure concentration. This compares to 4% unfertile in the control eggs.

The possibility of the biological exchange of tritium was explored using HPLC analysis of shrimp tissues after exposure of the animals to carbon-14 and tritium-labeled naphthalene. The HPLC data from the shrimp exposures gave carbon-14 to tritium ratios ranging from 7.6×10^{-3} to 1.6×10^{-2} for naphthalene and two metabolic products when unpurified compounds were used. Purified compounds gave ratios of carbon-14 to tritium of from 2.3×10^{-2} to 1.6×10^{-2} for the same metabolites and parent hydrocarbon.

The HPLC data was further analyzed to determine the metabolites formed by adult spot shrimp that have been exposed to purified naphthalene. The HPLC data from the exposed adult shrimp indicate the presence of metabolites whose retention times are consistent with naphthalene, naphthol, a dihydrodiol, naphthyl sulfate, and a glucuronide.

PATHOLOGY

Pathological Changes in Flatfish from Exposure to Oil-Contaminated Sediment

Four-Month Experiment

The TEPH in the surface (1 to 2 cm) of the crude-oil-contaminated sediment decreased from 700 to 400 μg/g (dry wt) during the first 30 days of the experiment. After this initial decrease, the concentration of TEPH in the surface of the sediment remained at 414 ± 120 μg/g (dry wt) for the remainder of the experiment. The most abundant aromatic hydrocarbons and their concentrations in this sediment during the first 30 days are presented in Figure 17.

Several aromatic hydrocarbons were detected in liver, skin, and muscle tissue of oil-exposed fish analyzed after 11 days of exposure (Fig. 18). Fish analyzed at 27 and 51 days had detectable levels of aromatics only in liver tissue. Aromatic hydrocarbons were found only in the tissues from oil-exposed fish. The identities of these compounds were confirmed by mass spectrometry. 1-Methylnaphthalene, 2-methylnaphthalene, and 1,2,3,4-tetramethylbenzene were the most abundant aromatic hydrocarbons detected in the livers during the first month of exposure. Significant amounts of only the latter benzenoid hydrocarbon were found after 60 days.

Tissues from fish exposed to oil for 11 days had concentrations of several alkanes (C-11, 13, 17, 26, 27, 28, and 31) as much as fivefold higher than tissues from the control fish. At 27 and 51 days, however, the levels of alkanes in oil-exposed fish were not significantly different from the levels found in control fish.

Both groups of fish lost weight during the first 2 mo of the experiment, with the oil-exposed group losing more than the controls (Fig. 19). After this period, the control fish began to regain weight, and at 4 mo only 27% of the controls weighed less than at 2 weeks. The oil-exposed group was slower in their recovery from this initial weight loss, and at 4 mo 69% of these fish weighed less than they did initially. The numbers of fish gaining and

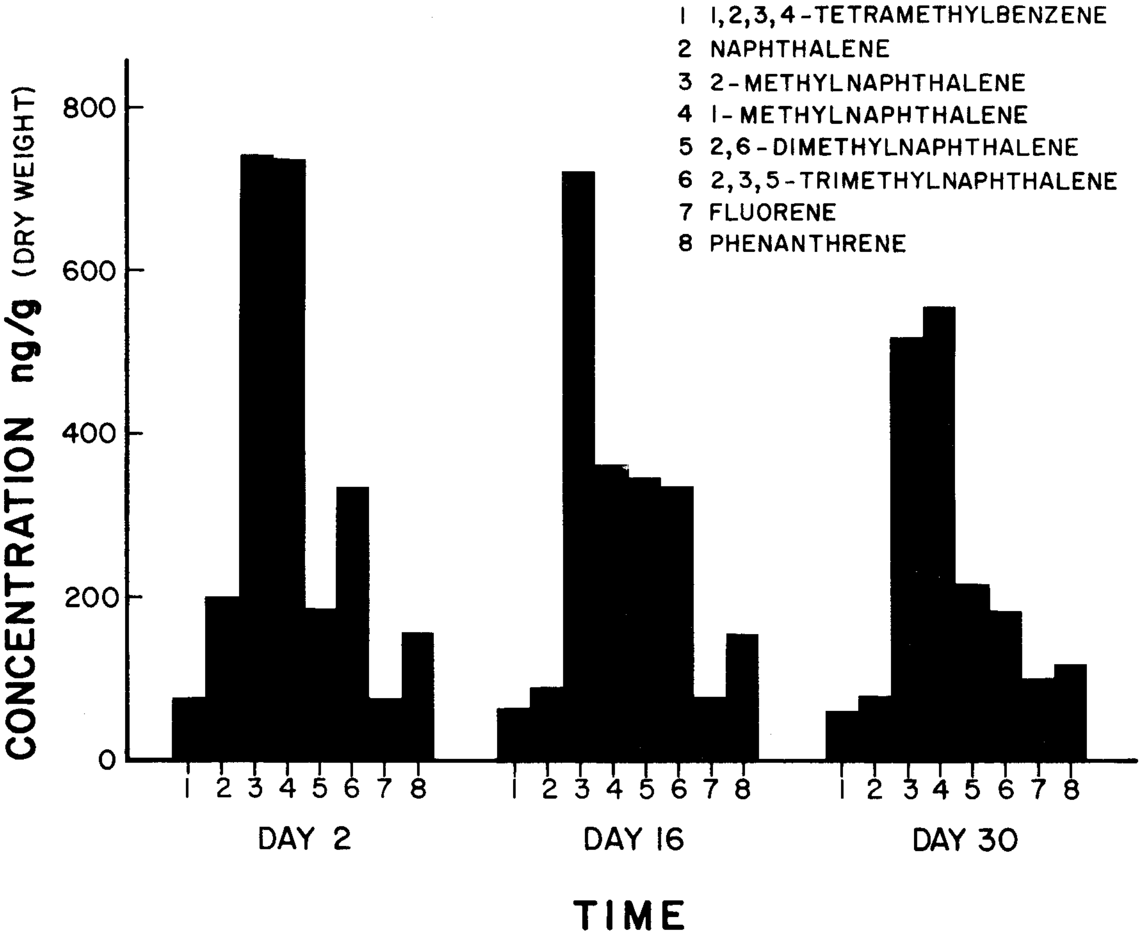

FIGURE 17. The concentrations of the 8 most abundant aromatic hydrocarbons in oil-contaminated sediments after 2, 16, and 30 days in the flow-through seawater aquaria.

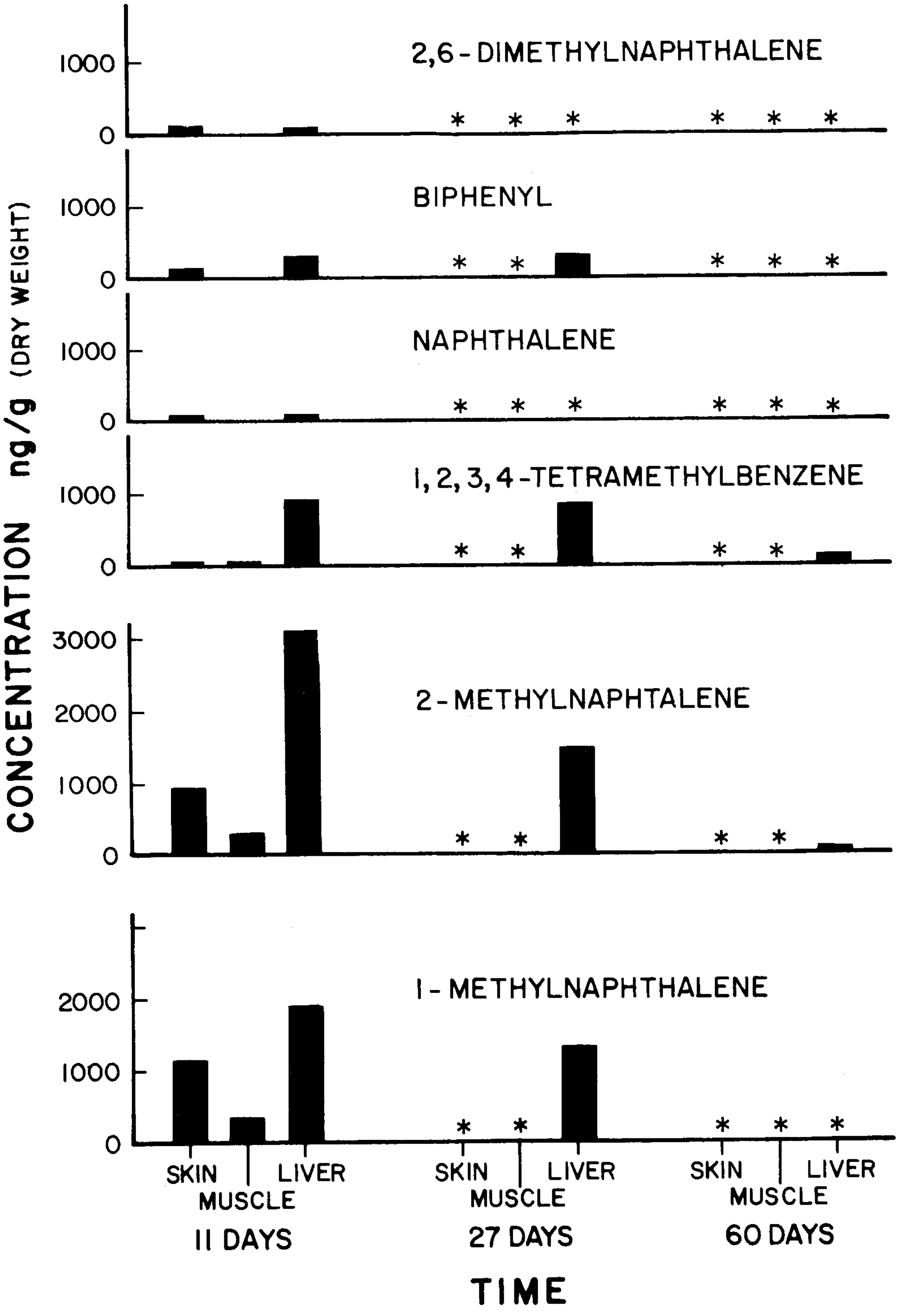

FIGURE 18. The levels of aromatic hydrocarbons in the tissues of English sole exposed to oil-contaminated sediment for various times (*, indicates not detected).

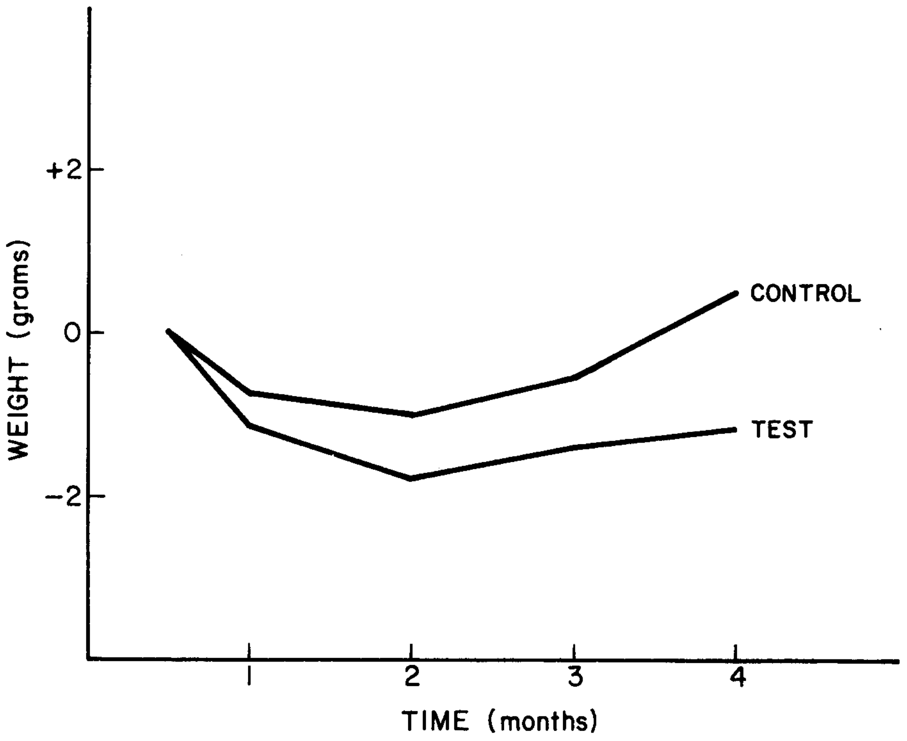

FIGURE 19. Weight changes in oil-exposed (test) and control English sole over a period of 4 months. Each observation at monthly intervals represents the average change (g) from weights at 2 wk for 16 test and 15 control fish.

not gaining weight after 4 mo were significantly different ($P=0.05$) between control and exposed groups.

During the first 4 mo of the experiment, there were no mortalities in either group. However, shortly after the 4th mo, 1 fish died and 2 fish were moribund in the oil-exposed group. All three of the fish were extremely emaciated but with no signs of microbial infection.

Although no marked histological differences between spleen, kidney, intestine, fins, gills, or skin of fish in each group were observed, the livers of the oil-exposed group had abnormalities which, in the more severe form, were not found in controls. Because sample sizes were small and some control livers had abnormalities, the observed differences between the two groups are presently considered to be tentative. During the first 27 days of exposure, when levels of PAH were highest in the livers, all 6 test fish examined histologically had slight-to-severe hepatocellular lipid vacuolization (HLV), with 3 fish having the severe form (greater than 95% of the cytoplasm being composed of lipid vacuoles) (See Morphology section). In this same period, 3 control fish had normal livers and 3 had moderate HLV. For the remainder of the experiment, both groups had approximately the same numbers of fish with normal livers and with livers having slight to moderate HLV; however, 2 additional test and no control livers had severe HLV. There was no apparent relationship between severe HLV and the emaciation observed in oil-exposed fish.

The gills of both the oil-exposed fish and the control fish were mildly infested with parasites including trichodinid ciliates, microsporidia, flagellates, and trematodes. Trichodinid infestation was most common, affecting 70% of the oil-exposed and 58% of the control fish; this difference was not statistically significant.

Slight but consistent behavioral differences were observed between the two groups of fish. The oil-exposed group appeared to be less active than the control group (i.e., the average of the number of fish out of the sediment in the control aquarium per day was higher than that of the test aquarium). Also, the oil-exposed group did not feed as well as the controls, as was evidenced by larger amounts of uneaten food following feeding.

During the first month of the experiment, oil-exposed fish had significantly higher ($P<0.01$) hematocrits (20.6 ± 1.7%) and hemoglobin levels (5.5 ± 0.7 mg/dl) than the controls (16.8 ± 0.9% and 4.2 ± 0.2 mg/dl). By 2 mo, however, these values in the oil-exposed fish (18.8 ± 0.8% and 4.6 ± 0.1 mg/dl) were not significantly different from controls (15.7 ± 5.6% and 4.8 ± 1.1 mg/dl). The other hematological tests (total RBC and leukocyte counts and differential leukocyte count) resulted in similar values for both groups.

Two-Week Experiment

Concentrations of TEPH in the sediment in each of the aquaria containing oiled sediment were initially approximately 520 µg/g (dry wt), and decreased to approximately 70 µg/g (dry wt) after 7 days and to 37 ± 11 µg/g (dry wt) by 14 days.

As yet, only the skin and muscle tissues of control and oil-exposed fish at 7 and 14 days have been analyzed for aromatic hydrocarbons (Table 29). English and rock sole skin contained similar levels of methylnaphthalenes, while the starry flounder had detectable levels of only 1-methylnaphthalene (36 ng/g dry wt).

TABLE 29. Concentrations of aromatic hydrocarbons in tissues of English sole, rock sole, and starry flounder exposed to oil-contaminated sediment for two weeks

Compound	SKIN			MUSCLE		
	English sole	Rock sole	Starry flounder	English sole	Rock sole	Starry flounder
	ng/g (dry wt) in tissue					
2-methyl-naphthalene	52	160	--[a]	46	20	--
1-methyl-naphthalene	46	116	36	11	42	--
Biphenyl	30	--	--	--	--	--
2,6-dimethyl-naphthalene	27	--	--	--	25	--

[a] --, not detected.

TABLE 30. Activity of hepatic aryl hydrocarbon monooxygenase (AHM) for flatfish exposed to petroleum-contaminated sediment

Species	Sample[a]	AHM activity[b]		Statistics, t-value
		Range	Mean ±s.d.	
Starry flounder	Exposed (3)	0.173-0.349	0.244±0.093	3.491
	Control (4)	0.057-0.121	0.072±0.034	(P<0.05)
English sole	Exposed (4)	0.197-0.582	0.378±0.158	2.171
	Control (4)	0.356-1.54	0.936±0.489	(N.S.)
Rock sole	Exposed (4)	0.144-1.02	0.624±0.368	0.517
	Control (4)	0.216-0.827	0.500±0.306	(N.S.)

[a] Number of samples analyzed are shown in parentheses.

[b] Hepatic AHM as nmoles of products/mg protein. Analyses performed at 25°C for 20 min on 9,000 x g supernatant fraction of a 20% homogenate of liver in 0.25 molar sucrose solution with tritiated benzo(a)pyrene and required cofactors (DePierre et al. 1975).

Histological examination of liver, heart, spleen, intestine, kidney, gonad, gill, skin, olfactory epithelium, and fin revealed no detectable differences between control and oil-exposed fish. Hematological tests demonstrated that after 14 days, oil-exposed starry flounder and English sole had significantly ($P<0.01$) higher hematocrits (22.3%) and whole red blood cell counts (3.38×10^6 RBC/mm^3) than did control (16.4% and 2.76×10^6 RBC/mm^3).

Both control and oil-exposed rock sole and English sole tolerated the 14-day experiment with no visible abnormalities. However, 3 oil-exposed and 2 control starry flounder died during the experiment from undetermined causes.

Assays for AHM activities in livers of fish after 2 weeks exposure demonstrated significantly higher ($P<0.05$) activity in only the oil-exposed starry flounder livers (Table 30). No significant difference was observed between oil-exposed and control English sole and rock sole.

Effect of Petroleum on Fish Disease Resistance

Mortality patterns among immunized and control groups of PBCO-exposed, V. anguillarum-challenged rainbow trout are presented in Figure 20. LD-50 values calculated from these data (Table 31) show that no difference existed in disease resistance. All immunized oil-fed and control fish survived bacterial challenge at a comparable level, which was, in all cases, higher than survival of nonimmunized controls.

The results of experiments in which antibody formation was assessed after long-term exposure to PBCO are shown in Tables 32 and 33. The ability to form antibodies, reflected by agglutination titer (Table 32), appears to slightly decline as a result of oil exposure; however, the difference is not statistically significant. The number of antibody-forming cells in the spleens and anterior kidneys (Table 33) did not differ between high-oil exposure and control groups. An increase was observed in the low oil-treatment group, but it is not clear whether this difference reflects stimulation or simply individual variation due to a limited number of observations.

Results of the mitogenesis and the polyclonal activation tests (Tables 34 and 35, respectively) likewise suggest that long-term exposure to PBCO does little to alter these responses. Peroral exposure to 1,000 ppm PBCO for 10 mo neither reduced the mitogenic effect of Con A nor affected polyclonal activation of lymphoid cells by PPD.

Comparison of the ratio of spleen to body weight in high-oil-treated versus control fish showed that a significant difference did exist (Student's t test, $P<0.05$) between the two groups. The average ratio of spleen weight (in mg) to body weight (in g) for control fish was 0.69 while the ratio was 0.49 for the PBCO-exposed group. Preliminary evidence had suggested that this reduction could be correlated with a reduced number of splenic leukocytes-thrombocytes (See Quarterly Report 1977). However, comparisons of erythrocyte and leukocyte-thrombocyte counts from homogenates of splenic and head kidney tissues from a larger sample of fish failed to substantiate any differences (Table 36). Furthermore, comparison of erythrocyte and leukocyte-thrombocyte counts from peripheral blood showed essentially no differences between oil-exposed or control groups (Table 37).

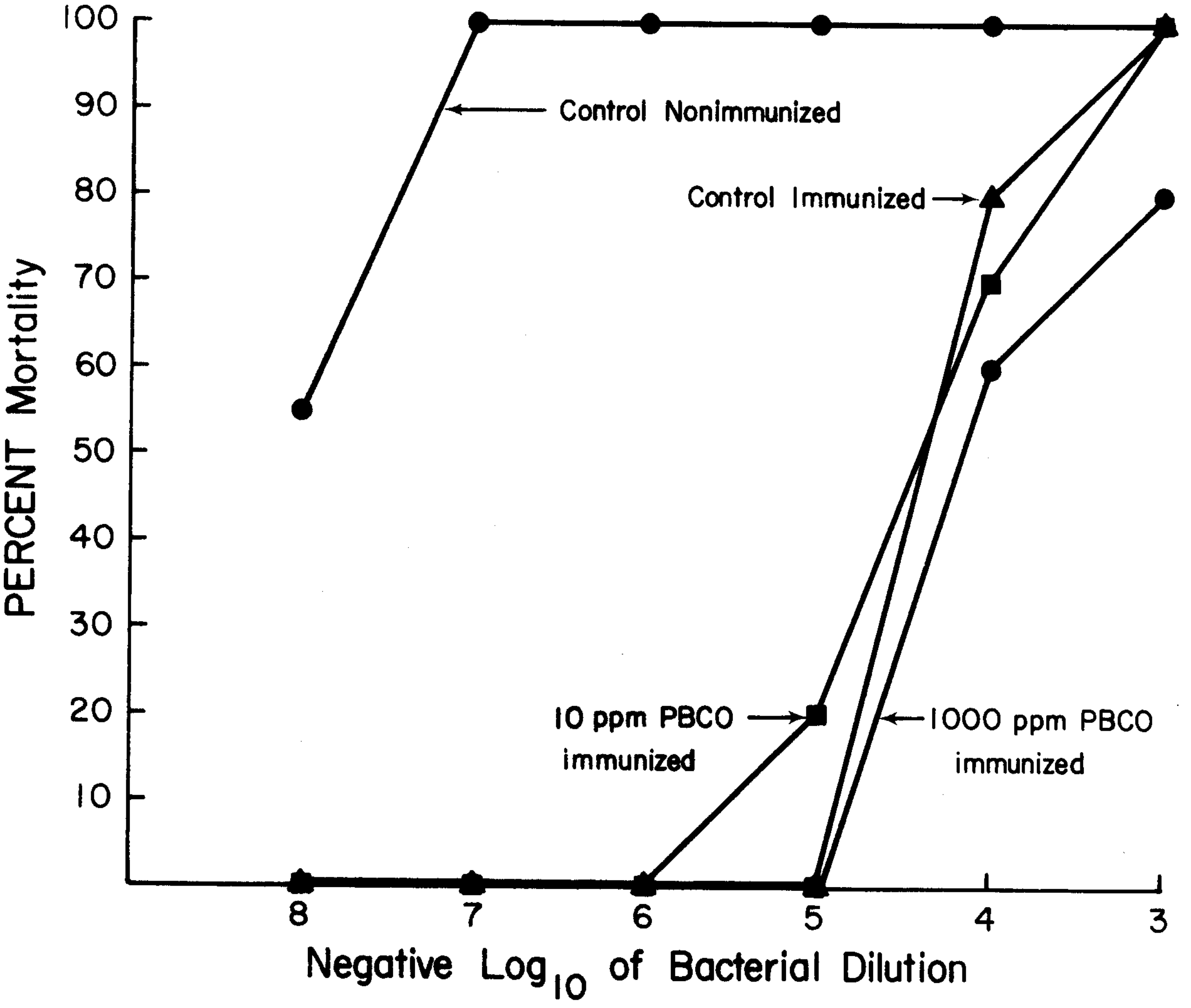

FIGURE 20. Mortality patterns among oil-exposed and control rainbow trout challenged with *Vibrio anguillarum*. Each point is based on a 10-fish group.

TABLE 31. LD_{50} values for oil-exposed and control rainbow trout immunized against *Vibrio anguillarum* and challenged with live bacteria

Group	Concentration of PBCO in diet	Dilution of *V. anguillarum* to give LD_{50}[a]
Immunized	1,000 ppm (high)	$10^{-4.4}$
	10 ppm (low)	$10^{-4.4}$
	None (control)	$10^{-4.4}$
Non-immunized	None (control)	10^{-8}

[a] LD_{50} based on original suspension of 2.3×10^9 *V. anguillarum* per ml.

TABLE 32. Effect of long-term peroral exposure to PBCO on antibody formation in rainbow trout. Antibody formation was assessed by measuring agglutinating antibody titer to *V. anguillarum* bacterin 21 days after immunization. Results represent the geometric mean titers ($\log_2$) of 10 fish from each exposure regime

Level of PBCO added in diet	Mean antibody titer against V. anguillarum bacterin
High (1,000 ppm)	4.3
Low (10 ppm)	5.2
None, immunized	5.7
None, non-immunized	<1

TABLE 33. Effect of long-term peroral exposure to PBCO on antibody-forming cells in rainbow trout. Antibody formation was assessed by determining the number of plaque-forming cells per 10^6 lymphoid cells in a modified Jerne plaque assay. Results represent a 5-fish pool from each exposure regime

Source of lymphoid cells	Number of plaque forming cells/10^6 lymphoid cells		
	PBCO exposure		
	High (1,000 ppm)	Low (10 ppm)	Control
Anterior kidney	275	3,556	107
Spleen	193	577	218

TABLE 34. Comparison of stimulation indices of concanavalin A (Con A)-induced mitogenesis of splenic leukocytes in fish exposed to PBCO and controls

Fish No.		Stimulation index[a]	
		PBCO-exposed (1,000 ppm)	Control
1		14	27
2		13	12
3		23	36
4		10	23
	Average	15	23

[a] Stimulation indices represent the ratio of ^{3}H-thymidine incorporation by 10^6 Con A treated leukocytes/^{3}H-thymidine incorporation by 10^6 nontreated leukocytes (Etlinger et al. 1976).

TABLE 35. Effect of long-term exposure to Prudhoe Bay crude oil (PBCO) on polyclonal activation in rainbow trout peripheral blood leukocytes by purified protein derivative of the tuberculin bacillus[a]

Fish No.		No. of PFC/10^6 lymphoid cells	
		PBCO-exposed (1,000 ppm)	Control
1		10	8
2		10	10
3		32	26
	Average	17	12

[a] Activation was quantified by determination of the number of plaque forming cells (PFC) per 10^6 lymphoid cells in a modified Jerne plaque assay.

TABLE 36. Comparison of mean erythrocyte (rbc) and leukocyte-thrombocyte (wbc-t) counts from homogenates of spleen and anterior kidney of low-oil-exposed (10 ppm in diet for 15 mo) and control rainbow trout. Values are expressed as cells/mg of homogenate and each value represents a mean of at least 10 fish. Number in parentheses is standard deviation

Group	Anterior kidney		Spleen	
	rbc	wbc-t	rbc	wbc-t
Oil-exposed	400 (134)	600 (316)	1400 (346)	750 (209)
Control	260 (100)	530 (83)	1100 (409)	1000 (259)

TABLE 37. Effect of Prudhoe Bay crude oil (PBCO)-exposure (high) on peripheral red blood cell and leukocyte-thrombocyte counts in juvenile rainbow trout

	Exposure	
	1,000 ppm PBCO	Control
No. of red blood cells[a]	1.2×10^6	1.4×10^6
No. of leukocytes-thrombocytes[a]	4.1×10^5	4.2×10^5

[a] Values expressed are cell per mm^3 and represent the average of 10 fish.

BEHAVIOR

Vertebrate

Avoidance of Hydrocarbons by Juvenile Salmon

Results of laboratory Y-choice chamber tests are shown in Figure 21. There was no statistically significant difference between the number of coho choosing the control arm and the number choosing the arm where model mixture was present in the water at hydrocarbon concentrations tested (up to 4.5 ppm). More recent Y-choice chamber tests indicate that avoidance of the model mixture by juvenile coho salmon occurs only at concentrations of 10 ppm and higher.

The laboratory avoidance tests with juvenile salmon were conducted up to the time the adult coho began migrating upstream at the field avoidance test site. As the Y-choice chamber data did not show a significant difference between tests and controls at any specific concentration, an arbitrary decision was made to initiate the field avoidance tests starting with a model mixture concentration of 1-2 ppm.

Avoidance of Hydrocarbons by Adult Salmon

Control data for the Chambers Creek field tests (i.e., percent salmon migrating to the right or left fish ladder) were collected from trap catches 7 days before the tests began, between tests, and for 5 days following the tests. Over 4,200 salmon passed the tidewater dam when hydrocarbons were not present in the water, and of those 57% chose the right-side ladder. Another 2,240 salmon migrated during the test periods when hydrocarbons were present in the water (Table 38).

Of the total number of salmon migrating up the two fish ladders during the experimental period (29 Sept. to 5 Dec. 1977) 95% were coho salmon, and the remainder were pink (O. gorbuscha, 3.7%), chum (O. keta, 0.8%), and chinook (O. tshawytscha, 0.5%). For analysis, the salmon run was divided into three segments, early, middle, and late. The early part of the run (29 Sept.-28 Oct. 1977) is characterized by high water temperatures (11°-12°C), low water flow, and an average of 2.9 fish per hour migrating up the ladders. The middle group covers a 10-day period from 29 Oct. to 7 Nov. 1977, in which water temperatures dropped 1°-2°C, numbers of fish increased to 8.2/hr, and high water flows contained silt. The last part of the run was from 8 Nov. to

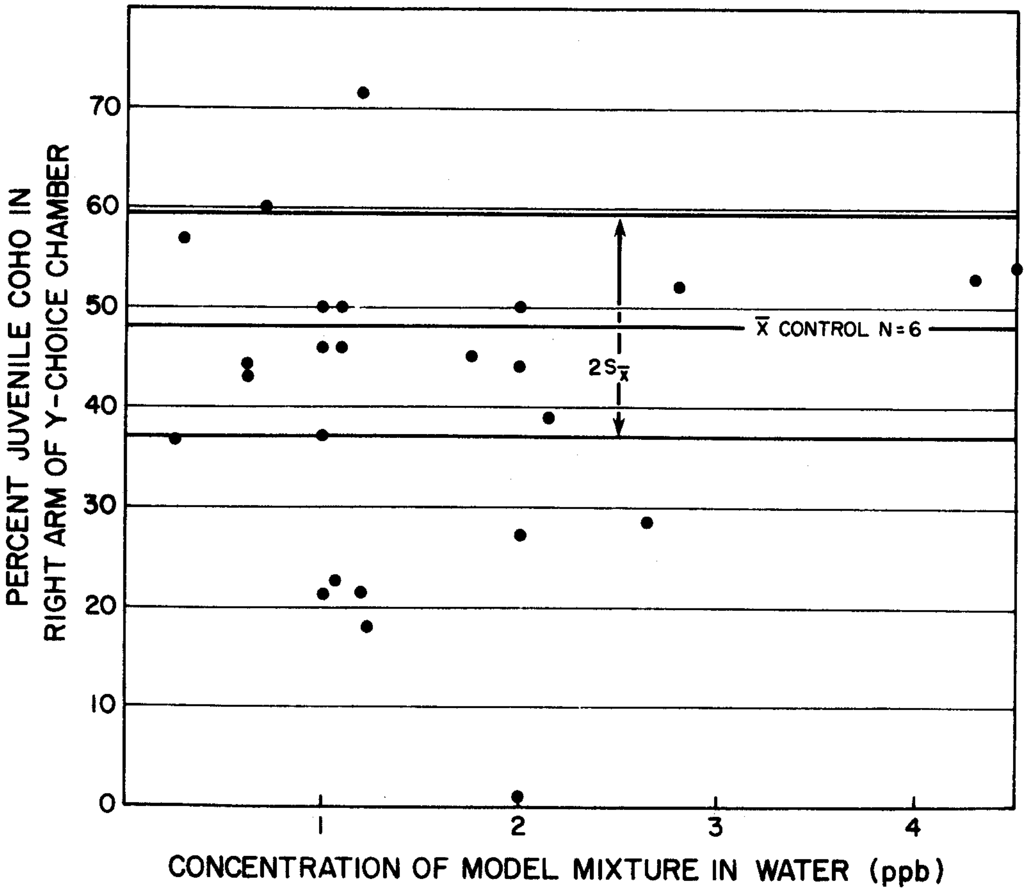

FIGURE 21. Percent juvenile coho salmon moving into the right-hand side of a Y-choice chamber in relation to concentrations of aromatic hydrocarbons present in the right arm water. (An additional 12 tests were conducted with model mixture in the left arm; results are similar to above, but with less variability).

TABLE 38. Results of tests conducted at Chambers Creek on avoidance of aromatic hydrocarbons by migrating adult salmon[a]

Date	Test period (hr)	Fish/hr		% Fish		Hydrocarbon concentration in ladder (ppb)	
		Left	Right	Left	Right	x̄ top ± range	Middle
Control	--	--	--	43.1	56.9	--	--
7 Oct	17.5	1.3	1.3	50.0	50.0[b]	600 ± 8	--
10 "	19.0	1.2	1.9	37.9	62.1[b]	299 ± 22	314
12 "	15.0	0.9	0.0	100.0	0.0[b]	2361[c]	2227
14 "	18.0	1.6	0.8	65.9	34.1[b]	770 ± 65	611
18 "	15.0	0.5	0	100.0	0.0[b]	2779 ± 89	2054
20 "	15.0	0.2	0.3	42.9[b]	57.1	610 ± 26	--
24 "	15.5	1.9	0.7	73.2	26.8[b]	682[c]	565
26 "	14.0	1.5	3.9	28.0[b]	72.0	787 ± 1	--
28 "	17.0	0.5	0.2	72.7	27.3[b]	667 ± 29	368
2 Nov	22.0	6.0	4.8	55.5	44.5[b]	1740[c]	1211
2 "	6.0	12.3	5.5	69.2	30.8[b]	4361 ± 703	3915
8 "	18.5	2.3	0.8	75.0	25.0[b]	2051 ± 49	1931
10 "	5.0	4.2	9.8	30.0[b]	70.0	1883 ± 113	--
11 "	7.0	5.4	3.0	64.4	35.6[b]	1924 ± 261	1590
12 "	16.0	4.6	3.9	54.7	45.3[b]	1337 ± 14	1087
12 "	4.5	5.6	2.2	71.4	28.6[b]	2498 ± 12	2248
13 "	6.0	9.5	0.7	93.4	6.6[b]	3748 ± 110	3715
15 "	5.0	14.0	11.2	55.6	44.4[b]	529 ± 54	--
16 "	5.0	13.8	6.2	69.0	31.0[b]	2188[c]	2105
17 "	19.5	3.4	4.2	45.0	55.0[b]	176 ± 1	175
18 "	20.0	1.7	1.3	56.7	43.3[b]	1525 ± 68	1477
18 "	6.0	3.3	0.2	95.2	4.8[b]	5031 ± 164	3924

[a] Data on fish/hr and % fish ascending the right or left fish ladder was derived from counts of fish in traps at the head of each ladder. Concentration of aromatic hydrocarbons was determined by GC analysis from water samples collected at the end of each test. Tests terminated during high tide prevented collection of water samples from the middle of the ladder.

[b] Indicates fish ladder into which aromatic hydrocarbons were introduced during test.

[c] No replicate water sample collected for GC analysis.

5 Dec. 1977. During this period water temperature was 9°-10°C, water flow high, but not silty, and numbers of fish declined to 5.4/hr.

The results of avoidance tests when the model mixture was introduced in the right-hand ladder are shown in Figure 22.

The results indicate that salmon migrating in the early part of the run were much more responsive to hydrocarbons in the water than those which migrated later. At hydrocarbon concentrations of 2-3 ppm the entire run of early migrants was depressed, whereas, this same concentration present in the water during the late run only caused 50% avoidance in the test ladder.

The results of GC analysis from water samples collected during different segments of the run are not consistent. During the early run, with water temperatures at 11°-12°C, and little silt, GC analysis of hydrocarbons in the water averaged 37% of the calculated amounts of model mixture introduced. During the late run with water temperatures at 9°-10°C and again little silt results of GC analysis were 61% of the calculated value. For the middle run, hydrocarbon concentration by GC analysis was 85% of the calculated amount of model mixture introduced. Water flow in mid-run had a high silt content of the water suggests that the aromatic hydrocarbons introduced into the water were adsorbed onto suspended particles. This adsorption reduced volatilization of aromatics from the water and there were resultant greater concentrations as determined by GC analysis. More importantly, under these conditions the hydrocarbons were probably less available to the fish and thus the avoidance response was not as pronounced as experienced with similar hydrocarbon concentrations under clean water conditions.

Effect of Hydrocarbons on Salmon Homing Ability

Based on results of the Chambers Creek experiments, in the first 5 tests at Tulalip on jack coho, these fish were exposed to calculated subavoidance concentrations of 1 ppm and less; for the last 2 tests at Tulalip the hydrocarbon concentration was raised to 2 ppm.

Results of the tests at Tulalip are given in Table 39. There is no statistically significant difference between the return of control versus hydrocarbon-exposed fish.

Due to trapping difficulties approximately 40% of tagged coho may have returned 2 days earlier than recorded. For fish with exact known date of return (57% of test, and 62% of control), the difference between control and test fish was 2 days (7.8 for control, and 9.6 for test coho). Figure 23 shows the differences in days returning (known dates of return only) between control and test fish plotted against the relative exposure concentrations. This data suggests that the delay in return of exposed salmon is directly proportional to hydrocarbon concentration (the correlation coefficient is significant at $P<0.05$).

Invertebrate

Effect of Petroleum Hydrocarbons on the Mating Behavior of Dorid Nudibranchs

As shown in Table 40 control nudibranchs displayed a marked preference for an aggregate of conspecifics in the stimulus arm of the testing apparatus. (When considering only dorids which displayed overt behavior, 94% responded positively to the stimuli.) For nudibranchs exposed to the SWSF of PBCO there was a definite reduction in movement toward the aggregate. There was no

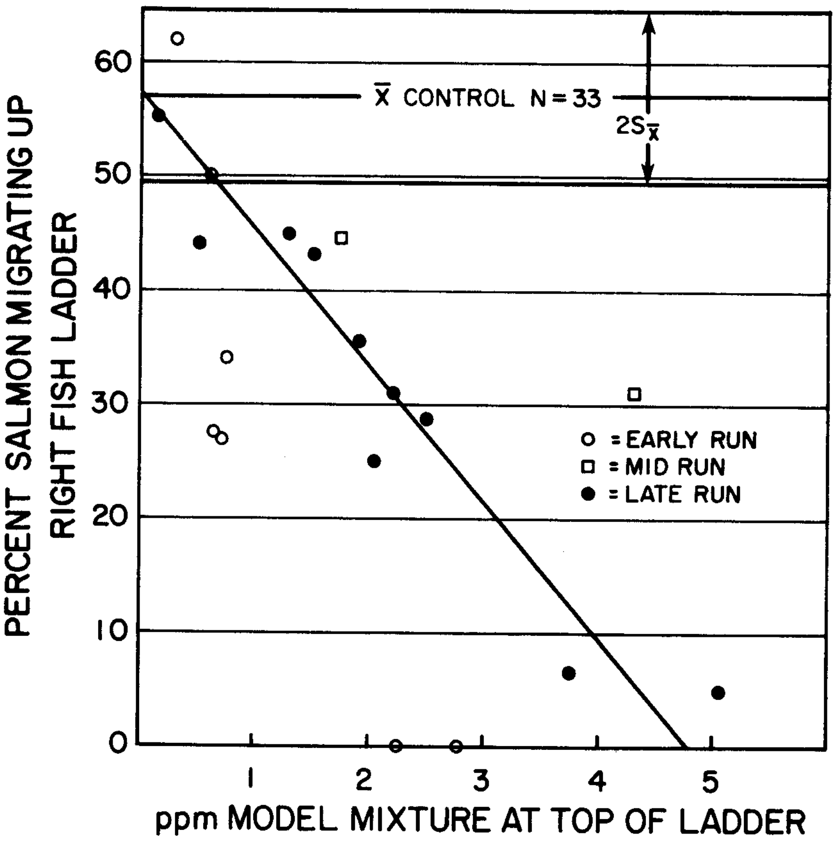

FIGURE 22. Percent adult salmon migrating up the right-hand side fish ladder at Chambers Creek in relation to concentrations of aromatic hydrocarbons in the right ladder water. Regression line is fitted to data collected during the late run.

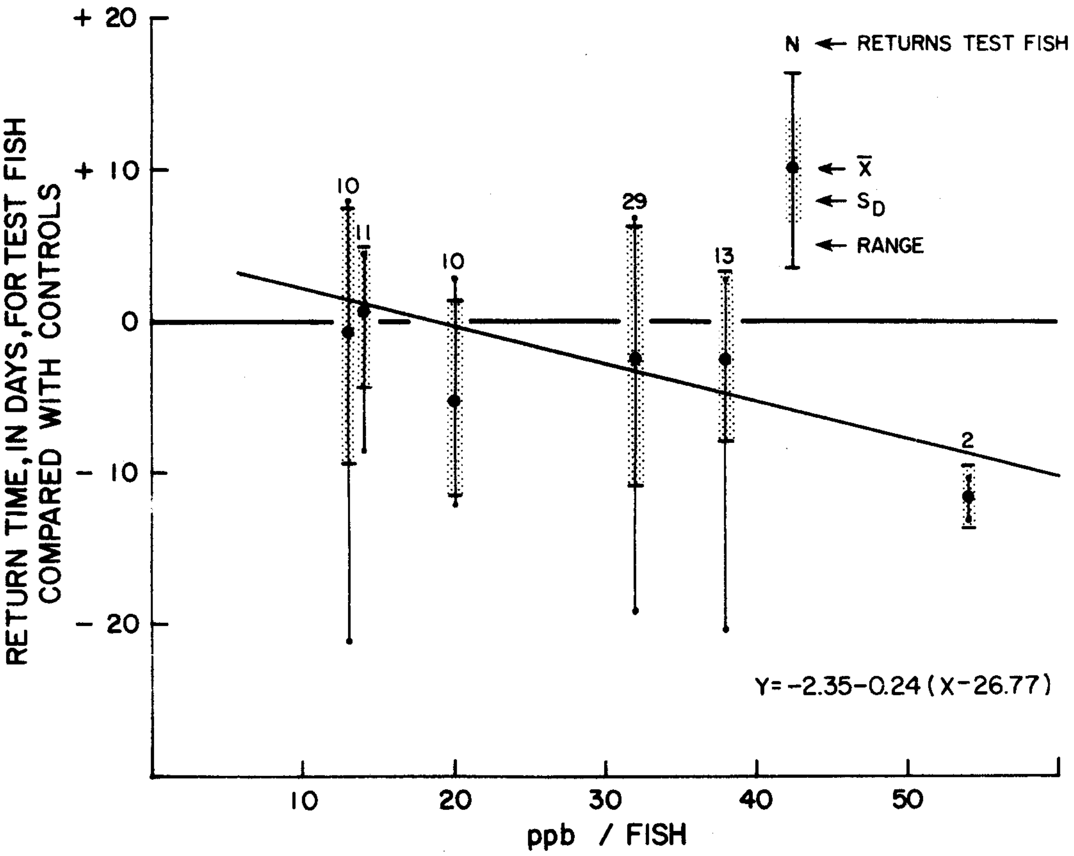

FIGURE 23. Difference in days to return of coho salmon exposed to sub-avoidance concentrations of aromatic hydrocarbons as compared with return of respective control group. (The ppb/fish are relative values of exposure.)

TABLE 39. Release and recovery data for jack coho salmon at Tulalip following exposure to subavoidance concentrations of aromatic hydrocarbons

Release date	N released		km transported	ppb fish	Return (%)	
	Control	Test			Control	Test
21 Oct	23	23	4.7	14[a]	61	70
22 Oct	42	12	4.7	54	64	33
28 Oct	55	44	1.6	20[a]	44	41
31 Oct	62	66	1.6	13[a]	27	40
3 Nov	26	25	1.6	32	58	36
4 Nov	64	65	1.6	32	44	45
6 Nov	52	52	1.6	38	44	37

[a] Estimate based on amount of model mixture introduced in water, number of fish exposed, and extrapolation of hydrocarbon concentration as determined by GC analysis of water samples.

apparent direct relation between concentration and chemotactic response in either the 1-day or 3-day exposure groups. The positive response percentage for the pooled 1-day exposure group was statistically compared with the positive control percentage using an arcsin transformation test for equality of two percentages (Sokal and Rohlf 1969). The results from the 1-day exposed animals are significantly different from controls (P=0.05). Upon pooling data from both the 1- and 3-day exposure groups there is an equal distribution of nudibranchs which moved either toward the blank or stimulus arm in the test apparatus. For these tests the 50-50 distribution is interpreted as random movement.

Of the exposed animals which did not move the pooled data is similar to controls; however, there is an indication that nudibranchs exposed to the SWSF for 3 days may have reduced mobility. This is counterbalanced by comparisons of average times required for the test animals to complete the behavioral assay which did not differ between control and SWSF-exposed groups.

Effect of Petroleum Hydrocarbons on Dorid Nudibranch Egg Deposition and Development

Onset of dorid oviposition was delayed 3 days at the highest hydrocarbon concentration (278 ppb), and the total weight of eggs deposited and average number of aggregations per day was reduced (Table 41). If the number of dorids which appeared to be actively participating in oviposition is considered, then the average weight of eggs laid per dorid was the same for all test groups. The delay in egg laying for the high exposure group was not a factor in total weight of eggs deposited, since all groups had sharply declined oviposition by the end of the experiment.

Tables 42-45 show, for control and three groups exposed to SWSF, the percent of normally developing eggs found in each of six to eight ontogenetic stages, and the percent with abnormal development. Replicate egg samples taken from each group, commencing with day of deposition, were combined. Groups exposed at the two lower levels of exposure (8 and 27 ppb) showed no evidence of developmental retardation; but there was an increase in percent of

TABLE 40. Chemotactic responses of control and SWSF-exposed dorid nudibranchs to an aggregate of reproductive conspecifics.

Days SWSF exposure (ppb±range)	Response			Time for choice min:sec	
	N pos. (5)	N neg. (5)	No movement (5)	pos.	neg.
Control	16 (84.2)	1 (5.2)	2 (10.5)	3:57	6:07
1 day at:					
(13±3)	5 (62.5)	3 (37.5)	0	3:28	3:04
(61±18)	5 (62.5)	2 (25.0)	1 (12.5)	3:04	3:27
(420±243	5 (62.5)	3 (37.5)	0	4:18	5:26
Total (SWSF)	15 (62.5)	8 (33.3)	1 (4.2)	3:52	4:00
3 day at:					
(13±3)	1 (11.1)	6 (66.7)	2 (22.2)	3:50	5:01
(61±18)	2 (25.0)	4 (50.0)	2 (25.0)	2:15	4:09
(420±243)	4 (57.1)	3 (42.9)	0	3:38	2:45
Total (SWSF)	7 (29.2)	13 (54.2)	4 (16.7)	3:33	4:08
TOTAL SWSF exposed	22 (45.8)	21 (43.8)	5 (10.4)	3:42	4:04

TABLE 41. Effect of seawater-soluble fraction (SWSF) on aggregation and egg deposition of dorid nudibranchs

Exposure concentration of SWSF (ppb)	Day eggs laid	No. egg masses laid 1st day[a]	Egg weight over 14 days (mg)	Wt. eggs per dorid (mg)	Average no. of aggregations per day
Control	1	16	938	10.1	1.8
8	1	14	832	8.3	1.9
27	1	10	821	10.2	1.4
278	4	5	516	10.7	0.9

[a] Each exposure group contained 20 mature nudibranchs with an average total weight of 2.1 g.
Number of egg masses laid on first day of oviposition constitute number of egg masses from which samples were taken for ontogenetic analysis.

abnormalities with increasing hydrocarbon concentration. At 278 ppb, developmental delay was evident, with some eggs never advancing beyond the celled stage, and the incidence of abnormalities was nearly 50%. A comparison of data from the control group and the group for the highest level of exposure is shown in Figure 24.

Examples of moderate and severe abnormalities are shown in Figure 25. Of the severe abnormalities, 100% in the group exposed to 278 ppb were a result of non-encapsulation, as compared to 12 and 18% of the severe abnormalities being non-encapsulated in the 27 and 8 ppb SWSF-exposure groups. Moderate abnormalities were distributed throughout all developmental stages; however, in the high exposure (278 ppb) group, moderate abnormalities occurred predominately in the first four stages of development. The result of moderate abnormal development on hatching and larval viability is unknown.

TABLE 42. Percent of dorid eggs in each ontogenetic stage and percent abnormal for control group

Post-lay days	No. eggs sampled	ONTOGENETIC STAGE						Abnormalities	
		Blastula (%)	Gastrula (%)	Pre-veliger I (%)	Pre-veliger II (%)	Veliger (%)	Hatch (%)	Moderate (%)	Severe (%)
1	180	99.4	0.6						
2	260	22.7	71.9					4.6	0.8
4	216		52.8	47.2					
5	217			98.6				0.9	0.5
8	624				3.8	95.4		0.2	0.6
9	465				12.7	87.1		0.2	
10	275*	0.4			7.6	41.5	50.0	0.1	0.4
11	NA						100.0		

* Replicate sample hatched; consider number hatched equal to number observed.

TABLE 43. Percent of dorid eggs in each ontogenetic stage and percent abnormal for group exposed to 8 ppb SWSF

Post-lay days	No. eggs sampled	ONTOGENETIC STAGE							Abnormalities	
		Cell stage 1 (%)	Blastula (%)	Gastrula (%)	Pre-veliger I (%)	Pre-veliger II (%)	Verliger (%)	Hatch (%)	Moderate (%)	Severe (%)
1	316	2.5	50.3	45.3					1.3	0.6
2	295	1.7	14.6	58.9					3.1	21.7
4	521	0.2		49.5	48.2				1.3	0.8
5	384	1.6		26.8	68.5				2.9	0.2
8	609	0.2				1.0	97.9		0.9	
9	NA							100.0		
10	241*					39.4	2.3	50.0	1.7	6.6
11	132*					47.0	2.3	50.0	0.7	
12	NA							100.0		

* Replicate sample hatched; consider number hatched equal to number observed.

TABLE 44. Percent of dorid eggs in each ontogenetic stage and percent abnormal for group exposed to 27 ppb SWSF

		ONTOGENETIC STAGE									
Post-lay days	No. eggs sampled	Cell stage		Blastula (%)	Gastrula (%)	Pre-veliger		Veliger (%)	Hatch (%)	Abnormalities	
		1 (%)	2 (%)			I (%)	II (%)			Moderate (%)	Severe (%)
1	264	2.3	0.8	62.1	34.1					0.7	0.3
2	368	1.9			95.4					2.4	
5	454	2.0					81.1			13.2	3.7
6	318				0.3		51.6			15.4	32.7
7	392	1.8					42.1	49.0		5.6	1.5
8	272						1.5	61.8		3.6	33.1
9	288	1.0					17.4	71.5		10.1	
10	277	3.3				13.0	62.8	2.5		7.2	11.2
11	NA								100.0		

TABLE 45. Percent of dorid eggs in each ontogenetic stage and percent abnormal for group exposed to 278 ppb SWSF

		ONTOGENETIC STAGE								Abnormalities	
Post-lay days	No. eggs sampled	Cell Stage			Blastula (%)	Gastrula (%)	Pre-veliger		Veliger (%)	Moderate (%)	Severe (%)
		1 (%)	2 (%)	4 (%)			I (%)	II (%)			
1	149	28.2	5.4		4.7					51.0	10.7
3	179	12.5	4.5							29.5	53.5
4	344	24.1	2.3			20.1				3.2	50.3
5	294	47.6	3.1	0.3		5.1	32.7			7.8	3.4
6	164	15.9	0.6			5.5	18.3			9.8	49.9
7	395	17.7	0.5		2.0	44.6	10.8	4.1		17.0	3.3
8	528	43.0	4.7			8.0	14.0	21.0		8.5	0.8
9	385	4.7	1.6		1.3	8.5	1.6	10.6	9.3	48.6	13.8
10	291	8.9	0.7			2.8	2.4	6.5	14.8	49.1	14.8

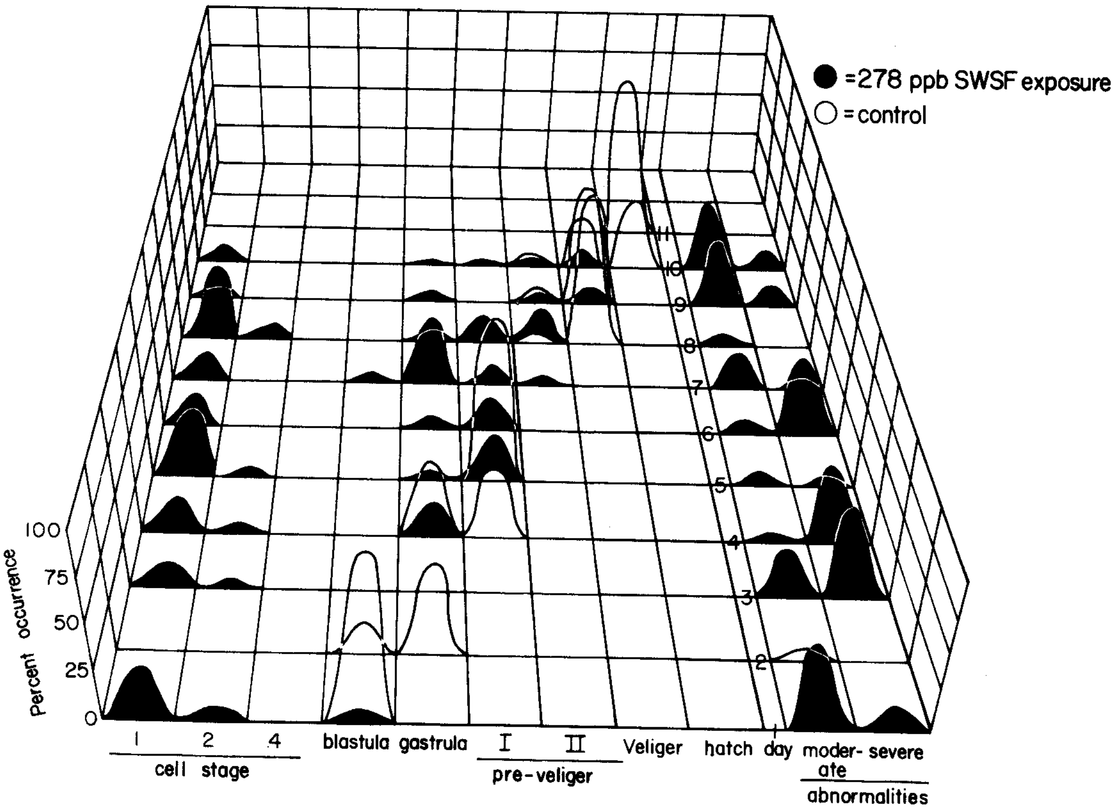

FIGURE 24. Percent of dorid eggs in each ontogenetic stage and percent abnormal for control and 278 ppb SWSF-exposed groups. Data are from Tables 42 and 45 (percentages less than 2 in any category are not shown).

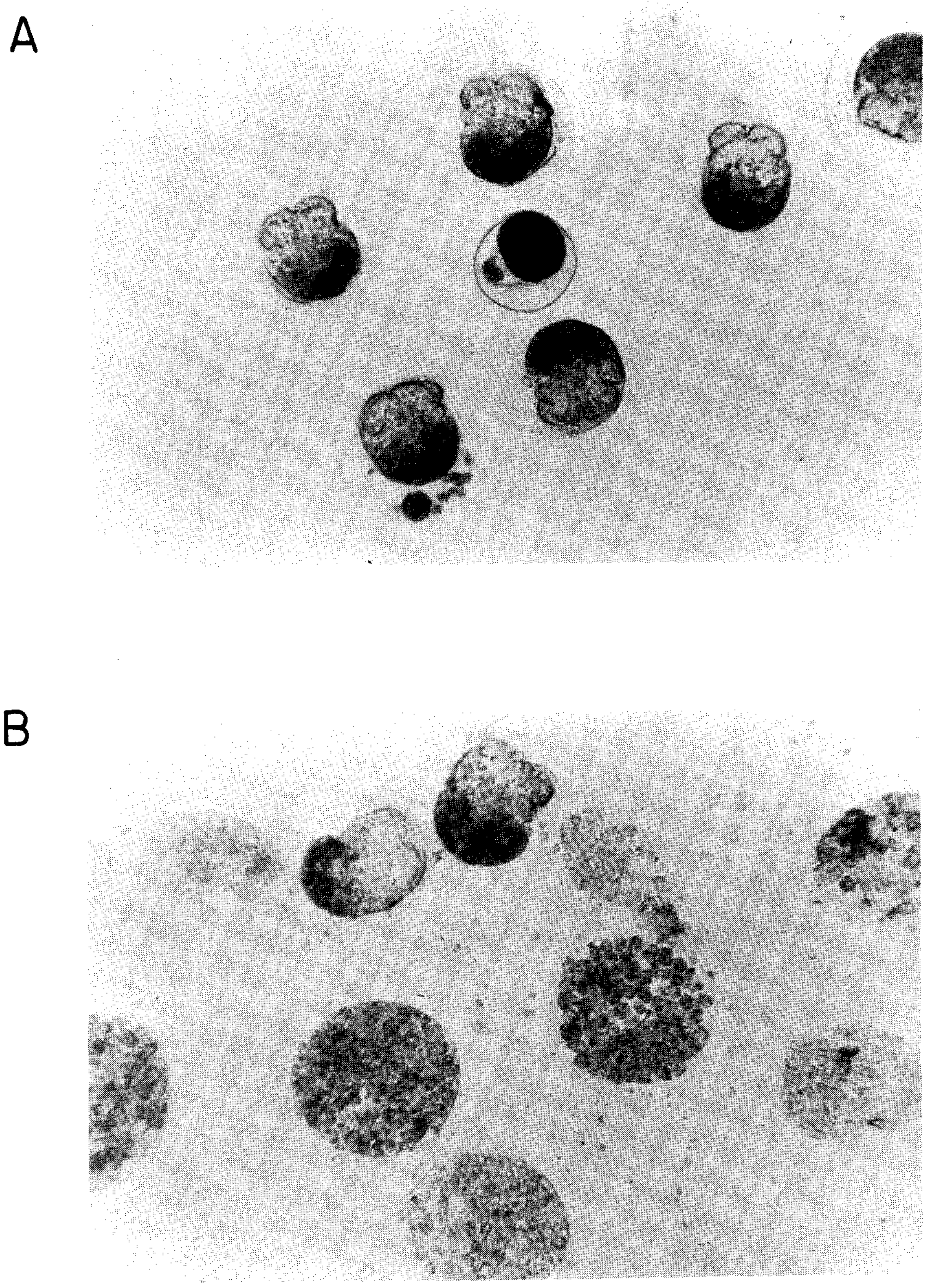

FIGURE 25. Developmental abnormalities during ontogenesis of dorid nudibranchs exposed to the SWSF of PBCO. Each photomicrograph (40 x) is from one egg mass. A. Ten days after oviposition at SWSF exposure concentration of 8 ppb. There are five normally developing eggs in the pre-veliger II stage and two with "moderate" abnormalities represented by additional material within the egg capsule. One of the eggs with "moderate" abnormalities remains in the one-celled stage. B. Same level and duration of exposure as above. There are two normally developing eggs in the pre-veliger II stage and the remainder have "severe" abnormalities including lack of capsule for three eggs.

VII. DISCUSSION

MORPHOLOGY

Ultrastructural studies have focused on lens and liver tissues and on eggs and larval fish. Lens damage in fish is potentially very deleterious because of possible blindness or reduced vision and consequent survival difficulties. One component of petroleum, naphthalene, has long been known as a causative agent in cataract formation in rabbits (Van Heyningen and Pirie 1967) and other animals (Grant 1962). It is not known if naphthalene or other petroleum components act directly on the lens or produce a systemic change which results in an osmotic imbalance and subsequent lens hydration. What is clear from our studies is that lenses do, indeed, hydrate and eventually form cataracts when trout are fed high levels of petroleum.

The mechanism of lens damage is unknown in the trout. However, the uptake of tritiated naphthalene by the lens suggests that lenses could be directly damaged by petroleum-related compounds rather than only indirectly affected through systemic failure in osmoregulation. It is certainly possible that a number of metabolic products of tritiated naphthalene were available to the trout lens by 40 hr after ingestion. In rabbits fed naphthalene, more than half of them developed opacities in the lens (Van Heyningen and Pirie 1967).

Additional evidence of lens abnormalities in fish exposed to different petroleum products and by routes other than feeding include a recent study on cunner, which were exposed to an oil slick of Venezuelan crude oil for 6 mo and had enlarged lenses (Payne et al. 1978). The levels of petroleum in the water were not reported.

The eye pathology, i.e., cataracts, of penned salmon at Squaxin Island occurred in a quasi-field situation. In this case, the precise history of exposure is not known and the evidence for petroleum as the primary causative agent is based on the absence of known bacteriological agents, the presence of petroleum in both the water and tissues of the affected fish, and the similarity of structural lens changes in the salmon with those of previously studied laboratory-exposed trout. These data are circumstantial but warrant consideration of lens pathology in future field and laboratory studies.

The most notable and consistent liver change is in the endoplasmic reticulum of hepatocytes. In previous studies the proliferation of this organelle has been described in several species of teleosts exposed to petroleum under both laboratory (Hawkes 1977) and long-term field conditions (Sabo and Stegeman 1977). The papers of the previous studies also reported depletion of lipid and glycogen deposits in the liver. In the experiments with flatfish reported here, lipid appeared to increase in livers from petroleum-exposed fish.

The flux of lipid to either side of normal may have some relationship to a threshold stress level in the organism. For example, the marine invertebrate Onisimus responds in an opposite manner to different concentrations of petroleum: with low levels, its metabolic rate is depressed but as the petroleum concentration is increased, the metabolic rate returned to the same level as the control or increased considerably over the control (Percy and Mullin 1975).

Studies are continuing in which flatfish are being exposed to petroleum at different concentrations and exposure conditions. In addition, studies of effects of petroleum on various physiological parameters are planned. By correlating liver alterations with evaluations of function, a clearer picture of the significance of various liver changes and abnormalities should emerge. A potentially significant observation on the eggs sampled after the Argo Merchant spill was that tiny petroleum globules adhered to the egg surface (personal communication, Anne Longwell, NMFS, Milford Laboratory; See also Gross and Mattson 1977). The variations in surface morphology that we have reported may play a role in how much petroleum sticks to an egg surface and, secondly, in how much exposure a specific species of fish experiences.

Moderate exposure to water-soluble petroleum components for a brief duration did not detectably affect the surface structure of pink salmon eggs. However, all embryos were dead by 17 days when pink salmon eggs were maintained in fresh water containing less than 1 ppm tritiated naphthalene. Uptake of the isotope was slow but continuous until the eggs died (S. Rice, personal communication).

Other species are very sensitive to low levels of petroleum: cod (Gadus morhua) exposed to the water-soluble fraction of crude oil at 0.015-3.5 ppm showed abnormal embryogenesis (Kuhnhold 1974). In addition, it is known that the larvae of some species are far more sensitive to petroleum than the embryos (Kuhnhold 1972, Rice et al. 1975).

CHEMISTRY

Naphthalene Metabolism in Fish Skin and Mucus

The present results show that within a few hours of naphthalene exposure, significant concentrations of both naphthalenes and their metabolites were present in the skin of coho salmon, starry flounder, and rainbow trout, regardless of the mode of exposure, salinity of medium, or nature of the compound. Moreover, comparison of our results with those obtained for liver of rainbow trout (Collier and Malins 1977) and starry flounder (Varanasi and Gmur 1978) reveals that the pattern of uptake and release of naphthalene and its metabolites in skin was similar to that observed for the liver. Our results show that in all three experiments, naphthalene concentrations in skin declined more rapidly than the concentrations of metabolites of naphthalene. This result, demonstrating a tendency of skin to preferentially retain metabolites, is in agreement with findings of Sanborn and Malins (1977), Lee and coworkers (1976), and Roubal et al. (1978). These workers have shown that the parent hydrocarbon was more rapidly discharged either directly or via biotransformation to its metabolic products and that small but detectable concentrations of metabolites persisted in tissues (e.g., liver, gall bladder) of crustaceans and fish over a long period. Whether metabolic products detected in the skin of our test fish arise from the direct transport of these compounds in blood to the skin and/or from biotransformation of naphthalene by aryl hydrocarbon monooxygenases that may be present in the skin remains to be seen. It should be noted that in the injection and force-feeding experiments, maxima in concentrations of both naphthalene and its metabolites in the skin were preceded by the corresponding maxima in the livers. It appears therefore that injected or ingested naphthalene was first transported to the liver and subsequently transported to the skin via the blood stream.

Radioactivity in the skin of rainbow trout, relative to liver, was the highest for the water-immersion study and was the lowest for the injection study. It appears that when fish were exposed continuously to low concentrations of naphthalene in water, large amounts of naphthalene were taken up by the fish, as evidenced by high concentrations of naphthalene and metabolites present in the skin and the liver of test fish. Compared to results from water-immersions, smaller concentrations of this hydrocarbon were taken up by the fish exposed to a single, large dose of naphthalene either via force-feeding or via i.p. injection. Whether continuous administration of small amounts of hydrocarbons mixed in the diet would result in accumulation of high concentrations comparable to those found in the fish from the water-immersion study remains to be assessed.

Very little is known about the pattern of uptake and release of hydrocarbons in the skin of aquatic animals. Recently Guiney et al. (1977) reported that skin of rainbow trout accumulated as much as 20% of the body burden of carbon-14 labeled 2,5,2',5'-tetrachlorobiphenyl and that release of this compound from the skin was very slow. It is apparent that a markedly different pattern of accumulation and release is exhibited by the skin of salmonids and flatfish when exposed to polycyclic aromatic hydrocarbons such as naphthalene. Recently, Roubal et al. (1978) reported that, compared to salmonids (Oncorhynchus kisutch), flatfish (Platichthys stellatus) exposed to WSF of petroleum accumulated considerably higher concentrations of low molecular weight aromatic hydrocarbons in liver and muscle. Our results (Varanasi et al. 1978, Varanasi and Gmur 1978) showing that compared to salmonids, skin of starry flounder contained significantly higher proportions of metabolic products are of interest in view of the fact that P. stellatus and other flatfish are highly susceptible to epidermal neoplasia.

Epidermal mucus of fish may serve as a physical and immunological barrier to pathogenic organisms (Harris and Hunt 1973). It is also believed to be associated with osmoregulation (Jakowska 1963) and is an important factor in controlling the swimming speed of the fish (Rosen and Cornford 1971). Our results from the force-feeding and injection studies, showing that naphthalene and its metabolic products were present in epidermal mucus of rainbow trout for several days after the initial exposure to naphthalene, suggest an additional role for epidermal mucus of fish; namely, in the excretion of xenobiotics. Epidermal mucus of fish exists in a continuous state of flux; that is, small amounts of mucus are continuously sloughed off and renewed. Therefore, the presence of naphthalene and more importantly, the metabolites of naphthalene in the mucus of the test fish for several days strongly suggests that epidermal mucus of salmonids is involved in excretion of hydrocarbons and their metabolites. The relative importance of epidermal mucus in the excretory mechanisms of fish would depend on the rate of discharge of these compounds from the mucus into the surrounding water as well as on the turnover or sloughing rate of the mucus itself. Varanasi and Markey (1978) reported that the presence of certain metals in water induces increased production of mucus in fish, thereby accelerating turnover of the mucous layer. Whether hydrocarbons exert such an influence on mucous production in fish is not known; however, it has been observed that copious amounts of mucus were produced by soft-shell clams exposed to No. 2 fuel oil in water (Stainken 1975).

Metabolism and Disposition of Naphthalene in Flatfish

The results show that demersal fish such as starry flounder exposed to dietary naphthalene accumulate considerable concentrations of naphthalene in various tissues and are able to extensively metabolize aromatic hydrocarbons (Varanasi and Gmur 1978). One week after the feeding, all tissues examined contained higher concentrations of metabolites compared to the naphthalene concentrations. It appears that a tendency exists in starry flounder to retain in key tissues metabolic products in preference to the parent hydrocarbons.

Biotransformation of Methyl-Substituted Naphthalene in Fish

The work on the uptake and accumulation of carbon-14-labeled 1-MN was originally planned with the intention of analyzing tissues for both unmetabolized 1-MN and its total metabolites. However, considerably more time was required to have the radioactive 1-MN synthesized than was expected, thereby leaving only enough time to complete an analysis of the parent compound in tissues before continuing the rest of the planned investigations.

The data show that 1-MN force-fed to coho salmon is readily incorporated into tissues. The data reinforce our earlier contention that alkyl-substitution of the parent aryl hydrocarbon is one factor governing the levels of hydrocarbon accumulation in tissues (Roubal et al. 1977a). For example, the present results show that the accumulation (percent of administered dose) of 1-MN is 5-10 times greater than that reported previously for naphthalene under comparable experimental conditions.

Coho salmon were also exposed to 1-MN via the water column. The purpose of such a study was to assess the uptake and accumulation of an aryl hydrocarbon under conditions where its entry is primarily via the gills. Starry flounder were included in this study.

When coho salmon were exposed to ppb levels of 1-MN in a flow-through seawater system, measurable amounts of 1-MN were present in the gills, liver, and muscle tissue within a week. The results of the present study show that tissues of salmon accumulated substantially more 1-MN over the course of the exposure period than did those from salmon exposed to a comparable concentration of 1-MN from a WSF of crude oil (Roubal et al. 1978). For example, the concentration of 1-MN in muscle of salmon exposed only to 1-MN was 32-times the concentrations of 1-MN in muscle of fish exposed to the WSF, after a two-week exposure.

Once exposure of coho salmon to 1-MN is terminated, the accumulations of 1-MN decreased to below detectable limits within a period of a week. In this regard, the results of the present work are no different from those reported previously for exposure of salmon to a WSF. The data suggest that the levels of accumulations of the hydrocarbons are greater when the organisms are exposed to the compounds individually than when exposed to the same compounds in a complex mixture under comparable conditions.

Analyses of tissues from starry flounder exposed to a concentration of 0.4 ppm 1-MN in a flowing seawater system, which contained about 1/10 of the 1-MN used in the salmon exposures, revealed bioconcentration values or factors that were 2.1 to 28-times greater than the factors for salmon. Comparable results were noted earlier when coho salmon and starry flounder were both exposed to the same concentration of 1-MN in a flow-through exposure using a WSF of crude oil (Roubal et al. 1978). Overall, the data indicate that starry flounder have a high propensity to accumulate and bioconcentrate hydrocarbons from the water column, a tendency which may make them particularly prone to damage from petroleum exposure.

The quantitation of hydrocarbons accumulated by gills of fish has proven difficult. This is especially true in the case of starry flounder; however, the reasons for poor analyses are not completely understood. Some gill samples proved impossible to analyze quantitatively, as indicated in Table 15.

Collier et al. (1978) have observed that the environmental temperature is one factor which controls naphthalene accumulation in tissues of coho salmon; there was significantly more naphthalene accumulated in fish maintained at 4° than at 10°C after 16 hr of exposure. It was important to determine whether the same correlation existed for tissues of salmon exposed to 2,6-DMN at the two temperatures. The results were inconclusive. Levels of 2,6-DMN and its total metabolites were found in individual salmon to exhibit such wide variations as to render it impossible to show statistically whether or not a difference existed. The experiment was repeated with the same results. Thus, no clear delineation of the effect of temperature on the levels of accumulated 2,6-DMN and its total metabolites has yet been made.

With regard to the fate of hydrocarbons in marine organisms, it is an historical fact that early work on the fate and effects of petroleum hydrocarbons in the marine environment centered only on the hydrocarbons themselves, with no consideration for the role of metabolites in such studies. However, as our understanding of the fate and effects has increased, more emphasis is being given to petroleum hydrocarbons metabolism in marine organisms (Malins 1977, Roubal et al. 1977a). This change in perspective stems primarily from the fact that significant amounts of metabolites are formed and retained in exposed marine organisms and because such compounds are known to be cytotoxic in animal systems.

Previously, we had shown that the same metabolites of naphthalene are formed in coho salmon (Roubal et al. 1977a) as in rats (Terriere et al. 1961). Accordingly, it was important to determine if the same held true in the case of 2,6-DMN. We have shown that coho salmon convert 2,6-DMN to both non-conjugated and conjugated hydroxylated derivatives. We have made tentative identifications for the glucuronide, mercapturate, and the sulfate and/or glycoside of 2,6-DMN. Also, metabolites with the same rf values by TLC were detected in the urine of rats which received 2,6-DMN. However, neither exact quantitation nor conclusive proofs of structure have yet been made for metabolites of 2,6-DMN in coho salmon. We suspect that the metabolic processes in fish are generally similar to those which occur in mammals, and that profiles of metabolites of 2,6-DMN in the rat have much in common with metabolite profiles obtained from fish.

Influence of Lead and Cadmium on Naphthalene Metabolism

The results indicate that starry flounder are capable of converting naphthalene to the 1,2-dihydro-1,2-dihydroxynaphthalene in the liver to a greater extent than coho salmon. The ability to more extensively metabolize aromatic hydrocarbons is important in that the bottom-dwelling starry flounder may suffer long-term exposures as a result of contacts with crude oil which has been incorporated in sediments. The naphthalenic dihydrodiol was the only significant metabolites in the flounder liver and was the principal metabolite in bile. The presence of the dihydrodiol infers that the principal metabolic pathway in the liver for the conversion of naphthalene is via aryl hydrocarbon monooxygenase to form an epoxide which subsequently undergoes hydration by microsomal epoxide hydrase. The presence of significant amounts of naphthol and some conjugated metabolites in the bile suggests that these metabolites are rapidly transported from liver to the bile.

In contrast to flounder, coho salmon had detectable levels of metabolites other than the dihydrodiol in the liver. The data reveal that starry flounder, which have been exposed to PAH, can have significantly lower amounts of the dihydrodiol of naphthalene present in the liver when exposed to lead or cadmium. These results suggest that lead and cadmium may also affect the metabolism of other aromatic hydrocarbons. At present, it cannot be stated whether the presence of lead or cadmium in fish inhibits the conversion of naphthalene to the epoxide or inhibits the subsequent hydration of the epoxide by epoxide hydrase.

Alternatively, the metals may affect the transport of the dihydrodiol out of the liver. These findings imply that lead and cadmium can influence the disposition of petroleum aromatic hydrocarbons in marine fish.

Lead-210 and Cadmium-109 Injection Studies

The results of the cytosol distribution studies with Cd-109 shows that in key organs of coho salmon, i.e., liver, gills, and kidney, a major fraction of the Cd-109 is bound to CdBP. In coho salmon that have been challenged by cadmium in seawater prior to intravenous injection of Cd-109, a higher percentage of cytosolic Cd-109 was bound to CdBP than was found for fish with no prior cadmium exposure. These findings indicate that fish exposed to cadmium ions responded by an induction of the metal-binding protein. The increase in the percentage of cytosolic Cd-109 bound to CdBP in the gills, after cadmium exposure, suggests that the CdBP in the gills might act as a defense against waterborne cadmium. However, despite the presence of low molecular weight proteins (CdBP) for binding cadmium, the arctic and subarctic organisms examined thus far still show a significant tendency to accumulate this metal in cellular proteins of high molecular weight (>55,000 daltons).

The findings indicate that accumulated cadmium in fish, resulting from ppb exposures, can alter cellular proteins and may perturb cellular biochemical processes. Whether these perturbations are deleterious to the viability of organisms is an important question for consideration.

As with mammalian systems, there appears to be no specific structural cytosolic fraction of the kidney, liver, and gills of coho salmon that has a high affinity for lead. The similarity in the cytosolic distribution of lead and protein in liver, kidney, and gills, suggests that lead is nonspecific with regard to binding to cytosolic components.

Activities of Aryl Hydrocarbon Monooxygenases in Different Species

Activity of the xenometabolism system of AHM was found in eight out of nine species taken from Alaskan waters. The exception was a gastropod or snail (Fusitriton sp.). Other results have suggested that the mussel (Mytilus edulis) has little or no AHM activity when whole body tissue samples were analyzed (Gruger and Wekell, unpublished). The absence of AHM activity in an organism is strong evidence to suggest that aromatic hydrocarbons will accumulate in the organism without the presence of metabolites.

Pacific cod had the largest mean value of specific activity of hepatic AHM and the largest mean number of units of AHM in the entire liver samples than were found for the other species taken from Alaska. The species with the next largest AHM activities were flathead sole, rock sole, and tanner crab. The arrowtooth flounder had the lowest, but significant, activities of hepatic AHM.

As seen from the data in Tables 20 to 26, there are great differences in hepatic AHM activities among individual organisms. Such widespread variations seem common among other aquatic species (Bend et al. 1977, Gruger et al. 1977b, Payne and Penrose 1975, Pedersen et al. 1976). The present work showed as much as two and three orders of magnitude differences in specific activities for a single species (cf., pollock and tanner crab). A wide range of activity values for a single species may preclude the utilization of the organisms for monitoring pollution from petroleum.

Indications from published data suggest that the hepatic AHM is inducible in marine species exposed to petroleum in seawater; however, other non-petroleum xenocompounds in the environment are likely to induce the enzyme. Thus, it is possible that the wide spread in AHM activities found in the present work reflects differences in exposures to AHM-inducing xenocompounds among the sampled organisms. For example, the values of AHM activities found for starry flounder from Puget Sound, an area surrounded by high industrialization, were two orders of magnitude greater on the average than for starry flounder from the possibly less contaminated mouth of the Columbia River. On the other hand, published data show that a species may or may not exhibit induced AHM activity depending on which species strain is examined (Pedersen et al. 1976).

The finding of more than one pH optima in the AHM activity analyses suggests that there is a complex enzymic system which contains more than a single pH-sensitive component. There is little that we understand about the AHM system aside from the presence of an electron-transport system, i.e., cytochrome P-450, and the arene oxide intermediates in the aryl monooxygenase-catalyzed reactions (Bend et al. 1977, Malins 1977).

PHYSIOLOGY

Mussel and oyster gametes and the resultant larvae are physiologically and embryologically sensitive to naphthalene in concentrations as low as 1 ppm. The major effect at low concentrations is a reduction in survival of the larvae. At higher concentrations, sperm is affected and results in a decrease in fertilization of eggs. Embryological abnormalities also are more prevalent at concentrations greater than 1 ppb. All of these factors indicate a reduction in the ecological fitness of petroleum-contaminated mollusc gametes and their resulting larvae in relation to aromatic hydrocarbon exposure.

The apparent increase in rate of formation of straight hinge larvae at the 10 ppb exposure level is unexplained at this time. The effect that the increased rate might have at a later period in the larval development or adult history is also unknown.

The carbon-14 to tritium ratios found in the metabolism of the purified naphthalene in shrimp indicates that there is no difference in this ratio after biochemical change of the parent compound, and thus no tritium exchange takes place *in vivo*. The unpurified compounds do indicate differences in the ratio of carbon-14 to tritium for different metabolites. The disparity is attributed to the presence and metabolism of different impurities in each of the labeled compounds.

The lack of evidence of biological exchange of the tritium-label in naphthalene is justification for the use of such labeled compounds with higher specific radioactivities than is possible with carbon-14 and it thus allows the subsequent use of lower concentrations of naphthalene for chronic exposure experiments. A higher radioactivity will permit the detection and quantitation of metabolic products at low concentrations in planktonic invertebrates. However, it is apparent that the hydrocarbon must be radiochemically pure in order for the interpretation of the metabolic fate of the compound to be meaningful.

The presence of a broad spectrum of metabolic products indicates the presence of a moderately complex biochemical detoxification (or toxication) system in the spot shrimp. The toxicities of metabolites retained in the shrimp are unknown at this time. The retention of specific metabolites in organisms after a period of depuration, the toxicity of individual metabolites, and the transfer of the metabolites through other trophic levels remains to be explored.

PATHOLOGY

Pathological Changes in Flatfish from Exposure to Oil-Contaminated Sediment

Four-Month Experiment

Exposure of English sole to crude-oil-contaminated sediments under laboratory conditions appeared to result in two principal, generalized pathological effects. Exposed fish tended to have greater weight losses leading in some cases to emaciation and morbidity; and their livers during the first month of exposure had a higher frequency of severe abnormalities.

The mechanisms underlying the greater loss of weight in oil-exposed versus control fish are not understood. Oil-exposed fish clearly did not eat as much as controls. The lower food intake may have been caused by crude-oil-induced damage to the chemosensory system. Although olfactory tissues were not examined histologically in this study, Gardner (1975) reported epidermal hyperplasia, metaplasia, and necrosis in the olfactory organs of Atlantic silverside (Menidia menidia) exposed to seawater-soluble and insoluble fractions of crude oil. The cumulative effects of stress resulting from captivity and oil exposure were also probably very important. That oil-exposed fish experienced a greater degree of stress than did control fish during the first month of the experiment is suggested by the higher hematocrit values and hemoglobin levels in the oil-exposed group. Both increases may have resulted from a decrease in blood volume in test fish, which is a common response of fish to stress (Fletcher 1975). Our observation that control fish also lost weight during the initial period of this experiment argues against the implication that crude oil was the sole cause of weight loss in exposed fish. Nevertheless, the fact that one exposed fish died and two were extremely emaciated and moribund combined with the statistically significant differences in weight between the two groups after 4 mo exposure strongly suggests that this apparent effect of oil exposure should be investigated further.

A more direct relationship between oil-exposure and severe liver abnormalities was inferred, however. The most severe cases of HLV in exposed fish livers were observed during the first month, when significant levels of aromatic hydrocarbons were found in these same livers. The frequency of severe HLV and the tissue concentrations of aromatic hydrocarbons declined during the remainder of the experiment.

Further evidence for a correlation between exposure of marine fish to pollutants and development of extensive HLV has also been reported in English sole from a polluted urban estuary (McCain et al. 1977); in Microstomus pacificus and Glyptocephalus zachirus from Coal Oil Point, an area in Southern California with a natural oil seep (K.V. Pierce, NMFS, Seattle, Washington, personal communication); and in spot (Lepostomus xanthurus) exposed to polychlorinated biphenyls (PCBs) (Couch 1975). Couch (1975) suggested that severe HLV in marine fish is a nonspecific liver lesion induced by a variety of pollutants.

In summary, this multidisciplinary experiment has demonstrated the uptake and tissue distribution of aromatic hydrocarbons by English sole and has provided preliminary evidence that long-term exposure to oil-contaminated sediments causes detrimental effects on this species. These effects included an increased stress response and liver abnormalities during the initial month of the experiment, when concentrations of petroleum hydrocarbons in the sediment were highest; and a gradual loss of weight during the remainder of the experiment. Additional experiments are presently being performed to further define these possible pathological effects of oil on flatfish.

Two-Week Experiment

Due to the rapid loss of hydrocarbons from the sediment during this experiment which left only about 40 μg/g (dry wt) in the sediment, conditions during this experiment are not directly comparable with the first two weeks of the 4-month experiment. In the latter, there were approximately 500 μg/g dry wt) TEPH in the sediment at 2 weeks. Nevertheless, the 2-week test did satisfy one of the principal objectives of this study, that is, it was demonstrated that English sole, rock sole, and starry flounder all accumulate aromatic hydrocarbons in petroleum from sediment, although there are indications that distinct species differences may exist.

The reason for the rapid loss of TEPH in this experiment was largely due to the use of small (10 gal) aquaria with a resulting higher ratio of fish per volume of sediment. The movement of the fish presumably agitated the sediment, allowing for a more rapid washing away of the adsorbed oil.

Also, the level of TEPH in the sediment may have been too low to induce detectable changes in the AHM activities in the livers of the three species; although, the livers from oil-exposed starry flounder did have significantly higher levels than controls. Another interpretation, however, may be that there are distinct differences between the species in the levels of AHM activity induced.

Effect of Petroleum on Fish Disease Resistance

The results of our tests designed to assess the effect of petroleum hydrocarbons on host defense mechanisms and disease resistance in salmonid fish failed to identify any marked alteration. A reduced spleen size, however, was noted in oil-exposed fish. While little is known about the function of the spleen in fish, it has been demonstrated that certain splenic leukocytes produce antibodies in response to antigenic stimulation (Chiller et al. 1969). Antibodies against infectious agents are a major form of host defense in man and are believed to play a similarly important role in fish. Whether the observed reduction in spleen size would, under certain conditions, limit antibody formation is not known. Regardless, our data did not show that following antigenic stimulation there was any difference in the relative amount of circulatory antibody nor in the number of antibody forming cells of oil-exposed versus control rainbow trout. Furthermore, bacterial challenge of oil-exposed and control trout resulted in no differential mortality.

BEHAVIOR (Including aspects of reproductive biology)

Vertebrate

Results of tests assessing effects of aromatic hydrocarbons on inhibition of the upstream spawning migration of Pacific salmon show wide variability. This variability is apparently partially attributable to both time of migration and environmental factors. Salmon migrating early clearly avoided hydrocarbons in the water at concentrations of 0.7 ppm. For salmon migrating late, distinct avoidance (50% reduction in migrants) was not noticeable at concentrations less than 2 ppm. At the time when particulate organic and inorganic matter was present in the water along with the hydrocarbons even higher concentrations of aromatics were required to inhibit migration.

The response of salmon migrating late is probably more reflective of the time frame in which avoidance of aromatic hydrocarbons would be detrimental to spawning success because of the advanced state of maturity of the fish. Whether or not similar relationships between hydrocarbon concentration and avoidance hold for estuaries and farther offshore is not known. However, movement of salmon into the fish ladders at Chambers Creek occurs predominantly at high tide, and at high tide only the top 1/4 to 1/2 of the fish ladders are exposed. Thus, the tests represent avoidance of hydrocarbons under estuarial rather than strictly freshwater conditions.

In capture-exposure-transport-release study conducted at Tulalip, the time to return for fish exposed to hydrocarbons was on the average 2 days later than for controls. Observations on salmon made during exposure to sublethal concentrations of aromatic hydrocarbons indicate a reduced level of activity which may account for this difference.

In the Tulalip tests the concentration of hydrocarbons in the water as it entered the holding tank was either 1 or 2 ppm depending upon the test series. Since the number of salmon exposed in each test was not constant, the concentration of hydrocarbons available to each fish was calculated and expressed as an instantaneous value of ppb/fish. If these instantaneous values are considered representative of the uptake of hydrocarbons by each fish there appears to be a direct relation between ppb/fish and delay in return to the home stream. In a natural environment it is doubtful if the density of salmon would be as great as in the exposure tanks at Tulalip. Therefore, under natural conditions, the amount of aromatic hydrocarbons available to each fish would be greater and the ppb/fish higher than calculated in these tests. The average two-day delay in return of hydrocarbon-exposed salmon to Tulalip may, thus, be a conservative estimate.

Invertebrate

The movement of a nudibranch toward an aggregate of other mating conspecifics is thought to be a chemotactic response mediated by a sex pheromone. As little as one day of exposure to the SWSF of PBCO at a concentration of less than 15 ppb significantly decreased the percentage of nudibranchs responding to the aggregate. This effect of SWSF exposure appears to involve the chemoreceptive system and is not a general narcosis as evidenced by equal rates of movement for both SWSF-exposed animals and control animals.

As a follow-up concerning the effect of the SWSF of PBCO on dorid mating behavior the effect of the SWSF on egg-laying and embryonic development was also studied. At the highest exposure level (278 ppb) egg deposition and development were retarded, and approximately half of the eggs laid were either not encapsulated or showed other abnormalities. At lower levels of exposure (28 and 8 ppb) the effect of the SWSF on egg development was reduced accordingly.

Interference with the reproductive processes of dorid nudibranchs by the SWSF of PBCO can occur at several different levels. First, by disruption of the chemotactic responses necessary to form mating aggregations. Second, by disruption of the egg-laying process as noted by the lack of egg encapsulation, and delay in egg deposition. Also, under control conditions there is a distinct pattern of spacing between eggs in the eggs mass; this pattern becomes distorted in eggs laid during SWSF exposure. Thirdly, eggs exposed to the SWSF show retarded development and increases in abnormalities.

It is important to reemphasize that these disruptive effects on the reproductive biology of dorid nudibranchs occurred at hydrocarbon concentrations in the low ppb range.

VIII. CONCLUSIONS

MORPHOLOGY

Lenses hydrate and may eventually produce cataracts in fish exposed to high levels of petroleum. Seriously impaired vision may be the final result. Cataractous lenses are easy to identify in the field and should be considered as one of the criteria in monitoring the impact of petroleum on fish populations.

Liver tissue reflects exposure to contaminants in both its biochemistry and morphology. The liver changes which involve alterations in glycogen or lipid deposits and proliferation of the endoplasmic reticulum have been observed in flatfish exposed to petroleum-contaminated sediments as well as in trout exposed to Prudhoe Bay crude oil in their diets.

Pink salmon eggs showed no abnormalities in structure or development when exposed to moderate doses of naphthalene or the WSF of Prudhoe Bay crude oil for 1 hr. This does not rule out possible effects from the higher molecular weight petroleum fractions which could adhere to intertidal pink salmon eggs, or effects from longer exposures, as has been reported elsewhere.

CHEMISTRY

Naphthalene Metabolism in Fish Skin and Mucus

Our results demonstrate that skin of salmonids and flatfish is actively involved in the uptake and discharge of naphthalenes and their metabolites and that skin exhibits a tendency to preferentially retain metabolic products of hydrocarbons. A possibility exists that similar to mammalian skin, the skin of some species of fish may possess an active aryl hydrocarbon monooxygenase system, and that the tendency to accumulate certain amounts of electrophilic metabolites of aryl hydrocarbons may be related to high incidence of skin pathology in some species. A notable finding was that in starry flounder four times as much metabolites as parent hydrocarbons were present in the skin one week after the exposure, thereby indicating extensive metabolism of naphthalene.

Evidence presented for the role of mucus in the excretion of naphthalene and metabolites in fish suggests that such exudates must be considered along with other routes of elimination which lead to the recycling of petroleum and metabolic products in the marine environment (Varanasi et al. 1978, Varanasi and Gmur 1978). It appears that skin and epidermal mucus play an important role in accumulation, discharge, and retention of hydrocarbons and their metabolites in fish. This fact should be taken into account when considering overall metabolism and excretion of xenobiotics in aquatic organisms.

Hydrocarbon Metabolism in Flatfish

Studies to determine the extent of metabolism of hydrocarbons in flatfish reveal that starry flounder extensively metabolize polycyclic aromatic hydrocarbons to their metabolic products showing clearly that analyses of parent hydrocarbons in tissues of such fish would not give a clear picture of the extent and effect of petroleum pollution on the demersal fish.

Biotransformation of Methyl-Substituted Naphthalene in Fish

Coho salmon readily incorporates 1-methylnaphthalene (1-MN) via the digestive tract. Coho salmon and starry flounder readily incorporate 1-MN from the water column. Bioconcentration of 1-MN in both species were substantial in the tissues examined. In particular, starry flounder sequesters large amounts of 1-MN; for example, the concentration of 1-MN in the liver reached a value which was 25,000 times that in the water after 5 weeks of exposure to this compound. The ability of starry flounder to bioconcentrate hydrocarbons to high levels and actively convert them to metabolites raises a concern for this species in areas of petroleum development.

The findings also suggest that significant differences in accumulations are likely to occur, depending on whether the organism is exposed to a single compound or to that compound in a complex mixture. Thus, the overall composition of the petroleum mixture is influential in the degree of accumulation of individual hydrocarbons in that mixture.

Additional work will be required in order to ascertain that greater concentrations of 2,6-dimethylnaphthalene and/or its metabolites are accumulated in fish at 4°C compared to 13°C.

Influence of Cadmium and Lead on Naphthalene Metabolism

Coho salmon are able to respond to cadmium challenge by preferentially binding the metal to the cadmium-binding protein; however, it appears that when this binding capacity is exceeded through metal-related stresses, the cadmium tends to attack high molecular weight proteins. At this stage, damage may occur to membrane structures and other matrices. It has been established in the present work that coho salmon possess a defense mechanism, via the cadmium-binding protein, against low-level cadmium exposures as may possibly be associated with petroleum operations in the arctic and subarctic regions.

Activities of Aryl Hydrocarbon Monooxygenases in Different Species

A wide variety of marine vertebrates and crab species are recognized to possess the enzyme system of aryl hydrocarbon monooxygenase, and that certain shellfish, particularly gastropods and mollusks, are either without the enzyme system or possess the monooxygenase activities below detectable levels. Also, the widely variable activity values of the monooxygenase for each species imposes limitations on the application of measured activities for monitoring petroleum pollution. In addition, we conclude that a variety of marine species will readily convert aryl hydrocarbons to metabolites, but the question remains as to the extent that these organisms retain toxic metabolic products.

PHYSIOLOGY

The presence of naphthalene at concentrations as low as 1 ppb reduced the viability of gametes and larvae of mussels and oysters. This reduction in viability compromises the ecological fitness of these organisms.

There is no biological exchange of tritium in tritium-labeled naphthalene. However, hydrocarbons that are not radiochemically pure will give differing results between carbon-14 and tritium labels when analyzing the metabolic fate of naphthalene by HPLC.

The complex metabolic system demonstrated in adult spot shrimp provides an effective detoxification (or toxification) mechanism for the shrimp. However, it also creates a wide range of metabolites and intermediate compounds that are available to higher trophic level organisms.

These conclusions indicate some of the possible consequences of petroleum exploration and allows some insight into both the long- and short-term physiological and embryological effects which may result from petroleum development. The low levels of naphthalene in seawater at which the viability of larval molluscs is reduced gives a hint of the possible consequences of the concurrence of hydrocarbons with the gametes and larvae of the many invertebrates and vertebrates that have planktonic stages.

PATHOLOGY

Pathological Changes in Flatfish from Exposure to Oil-Contaminated Sediment

English sole, and probably most other Pleuronectidae, exposed for long periods to sediments contaminated with levels of petroleum hydrocarbons well within the range of concentrations (greater than 400 ppm) reported to occur as the result of oil spills are likely to develop two general types of pathological changes. One type of change may be an acute, and apparently reversible, response characterized by liver abnormalities and hematological changes. The other type may be a more chronic effect leading to weight loss and/or a general decline in condition.

Effect of Petroleum on Fish Disease Resistance

Long-term peroral exposure of rainbow trout to PBCO did not directly alter disease resistance as measured by *in vitro* and *in vivo* indices of immunocompetence. A reduction in the spleen size was observed in oil-exposed fish compared to controls, but the significance of this is not known.

BEHAVIOR (including aspects of reproductive biology)

Studies conducted this past year (March 1977-April 1978) have focused primarily on evaluating the effect of water-soluble petroleum hydrocarbons on some aspect of the reproductive phase in the life cycles of two types of marine organisms--Pacific salmon and an intertidal dorid nudibranch. The hydrocarbon concentrations (based principally on GC analysis of monoaromatics) and effects noted are given below. The exposure times for the dorid nudibranchs are 1 to 14 days, and for salmon 5 to 22 hr.

10-500 ppb: The SWSF of PBCO at concentrations in this range affected a variety of reproductive processes of the dorid nudibranchs. These include: (a) inability of a mature individual to locate mating conspecifics, (b) disruption and delay in egg laying, (c) retardation in rate of embryo development and increase in embryonic abnormalities.

500-1000 ppb: A model mixture of aromatic hydrocarbons, representative of the SWSF of PBCO, when introduced in the "home" stream water inhibited upstream spawning migration of salmon in the early part of the run.

1000-2000 ppb: Exposure of migrating salmon to aromatic hydrocarbons in this range resulted in an average delay of 2 days in timing of return to the "home" stream--this delay is considered a conservative estimate. There was no statistical difference in percent returning between hydrocarbon-exposed and control fish.

2000-3000 ppb: This concentration of hydrocarbons in "home" stream water caused inhibition of upstream spawning migration of salmon in the late part of the run.

IX. NEEDS FOR FURTHER STUDY

GENERAL COMMENTS

Ultimate needs in research to define effects from arctic and subarctic petroleum operations on marine organisms include studies in three major categories: (1) impacts on physiological processes from fresh versus weathered petroleum components should be determined quantitatively; (2) critical environmental parameters (e.g., temperature) which influence the impact of weathered petroleum should be characterized; and (3) impacts on the physiological processes should be related to the viability of organisms and ecosystems as reflected in altered behavior, growth and development, reproduction, and disease resistance of various species in different trophic levels.

Nearly all information available on biochemical conversions of components from petroleum in marine organisms is based on the hydrocarbons *per se*. An urgent need exists to enable us to understand more about the impacts of weathered petroleum and of the chemically or biologically transformed products of petroleum in marine organisms. Moreover, it should not be assumed that the low concentrations of petroleum in oceans occur only as free and uncomplexed molecules. It is important to study possible physico-chemical interactions of hydrocarbons and weathered products with macromolecules (e.g., proteins and nucleic acids), and to evaluate the metabolic fate and effects of such structures on marine life. In the quest for a better understanding of the biological effects of petroleum on marine organisms, very little has been accomplished in evaluating the extent to which aromatic hydrocarbons, heteroatom compounds, and weathered petroleum, and their metabolites are transported through the marine food web or the impact of the metabolic products on such fluxes. These matters warrant more consideration.

As a step in approaching the above needs, the following sections suggest some specific investigations.

MORPHOLOGY

Both low levels of petroleum and field exposure situations should be studied with respect to eye damage in fish.

Further investigations on eggs and larval fish stages are warranted from both laboratory data (Kühnhold 1972, 1974; Rice et al. 1975) and preliminary indications of petroleum damage to embryos collected after the *Argo Merchant* spill.

In every case, baseline data is sorely lacking: what is the normal structure of target fish tissues? what is the normal structure of eggs and larvae? We have filled some of these gaps and are currently working on others but continued careful attention must be focused on defining the nature and degree of normal variations.

Structural and ultrastructural studies should also be continued as part of a number of other ongoing and proposed laboratory experiments on effects of petroleum, in order to observe structural changes occurring and correlate them with concomitant functional alterations.

CHEMISTRY

Results of the studies carried out in our laboratories show clearly that metabolism and disposition of petroleum aromatic hydrocarbons should be continued using a variety of species and model compounds under different exposure conditions, in order to understand more clearly the resident times and concentrations of parent hydrocarbons and, more importantly, their metabolic products in tissues of fish. These studies should include identification and characterization of the metabolic products. These studies should also include different life stages of fish to evaluate the impact of petroleum pollution on the viability of species.

Environmental temperature and its effect on uptake and retention of polycyclic aromatic hydrocarbons in fish requires further investigation. Moreover, little is known about the percentages of the total body load (parent hydrocarbons and their metabolites) that are excreted via urine and feces, or are discharged from the body via the gills. Also, little is known about the rates of excretion via these pathways. New studies dealing with the metabolism of carcinogens such as benzopyrenes and the benzanthracenes (compounds present in crude oil) by fish need to be performed. Also, the binding of such hydrocarbons and/or their metabolites to biologically important macromolecules, such as DNA, need to be investigated.

The weathering of petroleum, after it is discharged into marine environments, is understood to cause changes in hydrocarbon composition and formations of oxidation products from aromatic hydrocarbons. Future studies are needed to elucidate potential biological and biochemical effects created by the exposures of marine species to components of petroleum that may remain in seawater following evaporative losses of volatile components and to those oxidation products (e.g., aryl carboxylic acids) formed from a weathered crude oil. Biochemical interactions between oxidized polycyclic aromatic hydrocarbons in exposed species may alter the metabolism of petroleum hydrocarbons and change the toxicity of petroleum in marine species.

PHYSIOLOGY

With the assurance that purified tritiated aryl hydrocarbons are appropriate and available for metabolic studies, the metabolism of the hydrocarbons by larval vertebrates and invertebrates and the transfer of corresponding metabolites through a planktonic food chain can be studied.

A study of the physiological and embryological effects of water-soluble fractions from petroleum and specific aromatic hydrocarbons on gametes and resulting larvae is also important, since many of the species of vertebrates and invertebrates exude their gametes directly into the water where fertilization and development takes place. Our data from the mussels and oysters indicates that very low concentrations of naphthalene may severely affect the fertilization and the early embryology of the larvae. Thus, the continued study of the short- and long-term consequences of petroleum hydrocarbon contamination of vertebrate and invertebrate gametes and larvae is very appropriate and desirable.

PATHOLOGY

During the present contract, the initial series of experiments concerned with the long-term effects of exposing adult flatfish to oil-contaminated sediments will be largely completed. Logical extensions of this research would include the following: (1) further define the early phases and ultimate significance of apparent pathological changes in adult flatfish resulting from oil exposure in order to determine if these changes can be used as indicators of the impact of oil exposure in spill situations; (2) investigate the effects of oil on the reproduction of flatfish, and on flatfish eggs and larvae; (3) determine if integrated physiological parameters, such as tests of performance (i.e., swimming ability, competence in predator/prey tests) can be used to estimate effects of oil exposure; and (4) examine flatfish associated with actual oil spills for histopathological and weight/length changes.

Laboratory research described in this report suggests that certain changes in the livers of oil-exposed English sole result after exposure to crude oil. If present and future experiments with various species of flatfish exposed to oil corroborate the finding of oil-related liver abnormalities, or if other pathological changes are identified, then these changes may be utilized in field studies of oil spills. However, certain characteristics of these changes need to be further defined before they can be used as indicators of impact of oil exposure, including threshold levels of petroleum hydrocarbon necessary to produce changes, the various steps in the pathological process and its progressions, the length of time the abnormalities persist during depuration, and the ultimate significance of changes on the survival and health of the fish.

Pelagic eggs and larvae of flatfish may be the life stages most sensitive to the effects of oil. An experimental procedure which could estimate this vulnerability would involve exposing flatfish eggs and larvae to SWSF of crude oil, raising the larvae until they are at least 6 months old, and monitoring them for pathological changes. Such pathological changes may include skeletal deformities, liver abnormalities, microbial or parasitic diseases, fin erosion, or skin lesions.

In addition, prespawning adult flatfish when exposed to oil may suffer impaired reproductive capability. Of special interest for evaluation would be the viability, and the morphological and histological characteristics of the offspring of oil-exposed adults. The technology for maintaining certain species of prespawning flatfish under laboratory conditions now exists.

Although the identification of histopathological changes in flatfish resulting from long-term exposure of oil is valuable for assessing the harmful effects of oil exposure, another important criterion would be how oil exposure might affect the performance of certain vital functions, such as swimming endurance or predator avoidance. Tests of these abilities have been applied successfully with salmonids exposed to stresses. The same tests should be applied to flatfish.

Another aspect of our work which could be considered for future research would be the examination of flatfish, and possibly other demersal fish species, associated with actual oil spills. By examining such fish using histopathological techniques and petroleum hydrocarbon analysis, a comparison between laboratory observations and the effects of oil spills on wild fish can be made. Also, sediment samples could be collected near the oil spills, taken to our laboratory, and tested for their long-term pathological effects on selected flatfish species.

Our studies to date on the effect of petroleum on disease resistance have employed only salmonid fishes as test animals. This choice was made because of their economic importance in North Pacific commercial and sport fisheries and because of their relative availability. Essentially, no adverse effects on disease resistance or immune response have been demonstrated in these species. Also, the many and varied species of North Pacific flatfish are of great economic importance. Intimate association by these fish with bottom sediments suggests a potential for high degrees of exposure to polynuclear aromatic petroleum hydrocarbons. In addition, there is recent evidence that flatfish bioaccumulate petroleum hydrocarbons to a much greater extent than do salmonid fishes (Roubal et al. 1978) and, therefore, may suffer substantial damage from petroleum. Proposed future studies will address the question of whether or not flatfish exposed to oil-contaminated sediment undergo impairment of disease resistance and immune responses.

BEHAVIOR

Based on observations made on salmon during exposure to petroleum hydrocarbons, and on results of experiments conducted on marine invertebrates over the past two years there are several responses which should receive further study.

Salmon, both adult and juvenile, exposed to ppb concentrations of hydrocarbons frequently demonstrated reduced activity. Though these were subjective observations, the degree of activity depression appeared marked enough in several instances to potentially jepardize their survival in, for example, predator/prey situations. Experiments designed to evaluate total performance of salmon following exposure to low concentrations of petroleum hydrocarbons can be assessed in a laboratory swimming chamber (Smith and Newcomb 1970). This approach has been applied successfully by Smith et al. (1972) to evaluate physiological parameters associated with exposure of salmon to polluted waters.

Detectable changes in chemical-mediated behavior and embryonic development of marine invertebrates exposed to 10-20 ppb of petroleum hydrocarbons demonstrated that certain physiological parameters were highly sensitive to disruption by petroleum components. Since these disruptive responses are noted at hydrocarbon concentrations which could reasonably be attained in the natural environment it is important to gain a phylogenetic perspective by continuing these studies on other invertebrate organisms and expanding them to larval vertebrate species.

X. SUMMARY OF FOURTH QUARTER OPERATIONS

SHIP OR LABORATORY ACTIVITIES

Ship or Field Trip Schedule

Physiology

Daily trips for 1-1/2 mo to catch gravid shrimp of four species. All other activities in the reported study were carried out at the NWAFC, Seattle, and the Mukilteo facility of NWAFC.

Scientific Party

The scientific party consists of scientists and technicial personnel in five major study areas. The overall supervision of the research is carried out by Dr. Donald C. Malins, P.I., Director of Environmental Conservation (EC) Division, NWAFC, Seattle, WA. The scientific party also consists of the following persons from the EC Division, NWAFC:

Morphology

Dr. Joyce W. Hawkes, Fishery Research Biologist; role of principal electron microscopist and investigator in charge of morphological studies.
Carla Stehr, Biological Aide; part-time assistant to Dr. Hawkes.
Suzyann Gazarek, Biological Aide; part-time assistant to Dr. Hawkes.

Chemistry

Neva L. Karrick, MS, Supervisory Research Chemist; Assistant Director, EC Division.
Dr. Edward H. Gruger, Jr., Research Chemist; role of principal investigator, and coordinator of analytical chemistry between study groups and NOAA National Analytical Facility (NAF).
Dr. William T. Roubal, Research Chemist; role of investigator responsible for work on biotransformations of petroleum hydrocarbons.
Dr. William L. Reichert, Research Chemist; role of investigator responsible for work on biochemical interactions of trace metal compounds and aromatic hydrocarbons in fish.
Dr. Usha Varanasi, Research Chemist; role of investigator responsible for work on hydrocarbon metabolism in fish skin and mucus.
Dr. William D. MacLeod, Manager, NAF; in charge of analytical services to the study.
Donald W. Brown, Assistant Manager, NAF; role of supervisor in charge of analytical services to the study.
Dr. Lawrence C. Thomas, Research Chemist, NAF; in charge of metabolite analytical research.
Victor Henry, Chemist, NAF; laboratory assistant to Dr. Thomas; isolation and recovery of petroleum hydrocarbons for analyses.
John S. Finley, Physical Science Technician; analytical assistant to principal investigators.
David A. Federighi, Chemist; assistant to Dr. Reichert.
Dennis Gmur, Chemist; assistant to Dr. Varanasi.
Andrew Friedman, Chemist; assistant to Dr. Roubal.

Physiology

Herbert R. Sanborn, M.S., Oceanographer; conducts physiological and embryological studies.
Cathy Short, Graduate student; assistant to H. Sanborn.

Pathology

Dr. Harold O. Hodgins, Fishery Research Biologist; principal investigator in charge of pathological studies.
Dr. Bruce B. McCain, Microbiologist; part-time investigator in charge of work on petroleum in sediments and their effect on flatfish pathology; co-investigator with Dr. Hodgins.
William D. Gronlund, M.S., Fishery Research Biologist; part-time assistant to Dr. McCain.
Kenneth V. Pierce, Fishery Research Biologist; part-time assistant to Dr. McCain.
Linda Rhodes, Biological Aide; part-time assistant to Dr. McCain.
Michael Schiewe, Fishery Research Biologist; conducts disease resistance tests.
Philip Scordelis, Biological Aide; part-time assistant to M. Schiewe.

Behavior

Douglas D. Weber, M.S., Fishery Research Biologist; role of principal investigator in charge of behavior studies.
Fred Johnson, M.S., Fishery Research Biologist; part-time assistant to D. Weber.
Laura Mumaw, Marine Biologist, Graduate student; assistant to D. Weber.
Desmond Maynard, Fishery Biologist; part-time assistant to D. Weber.
Teresa Schermann, Physical Science Technician; assistant to D. Weber.
Dr. Vyacheslav Konchin, Ichthyologist; exchange program, Moscow State University, U.S.S.R.; behavior studies.

Methods

The research is conducted through laboratory studies and generally not through field sampling. Most of the methods have been defined in previous reports. The methods not previously reported are as follows:

Chemistry

Two groups of starry flounder were fed tritiated naphthalene and one group was kept at 4° and another at 12°C until the time of sampling. Samples of liver, blood, skin, gall bladder, muscle, kidney, and mucus were taken as described previously. Some of the samples (liver) are analyzed for the concentration of naphthalene and its metabolic products whereas other samples are now being processed.

Methods for collecting urine, feces, and in trapping hydrocarbons and their metabolites discharged from gills of fish are being investigated.

A plexiglass chamber was constructed for holding live fish while collecting urine by cannulation, collecting feces by trapping, and trapping hydrocarbons and their metabolites discharged from the gills. Presently, the system is being tested using carbon-14-labeled naphthalene and tritium-labeled 2,6-DMN in force-feeding to trout. Preliminary results indicate that the chamber may have to be reconstructed in all-glass in order to reduce adsorption of hydrocarbons to the walls of the chamber. The method, generally, has great potential in metabolism studies.

Physiology

Longline pot fishing for shrimp was carried out. HPLC, LSC and GC were carried out on extracts from samples of water and animals, which were used in the physiological studies.

Pathology

Exposure of flatfish to oil-contaminated sediments. An experiment involving long-term exposure of English sole and rock sole to crude-oil-contaminated sediment was initiated using the same facilities and protocols described in the accompanying Annual Report with the following exceptions:

(a) Bottom sediment was collected from a beach at the Battelle Northwest Laboratories at Sequim, Washington. This sediment was much siltier than sediment used in previous experiment.

(b) A 0.5% (v/v) mixture of Alaskan crude oil and sediment was prepared.

(c) The aquarium with oiled sediment received 42 English sole (avg. wt. 20.5 g) and 41 rock sole (avg. wt. 12.3 g). The control aquarium received 41 English sole (avg. wt. 22.5 g) and 41 rock sole (avg. wt. 17.4 g).

(d) At 2 weeks after exposure, 3 fish of each species from both aquaria were sacrificed and tissues were used for chemical, hematological, histological, and ultrastructural analyses. At one-month intervals thereafter, 6 fish of each species from both aquaria (total of 24) will be sacrificed and analyzed simultaneously.

(e) Sediment samples of the top 2 cm of sediment were collected at "0" time just prior to adding the fish and at 2 weeks. Samples of circulating water and interstitial water were also collected at these times.

Sample Localities and Ship Tracklines

Physiology

Sample localities were at the Mukilteo facility and the Seattle facility of NWAFC.

Chemistry

Starry flounder, as test animals, were taken from the mouth of the Columbia River. Coho salmon were from a stock of two-year olds held at the Manchester facility, NWAFC.

Data Collected and Analyzed

Morphology

In an experiment with high doses of Prudhoe Bay crude oil (1 g per 1,000 g of food) in the diet of rainbow trout, fish were sampled after three years' exposure. Three of the five experimental fish had opaque areas in their lenses and none of the three controls had cataracts. The opaque lenses have been examined microscopically and the changes in fiber patterns parallel those of cataracts in mammalian lenses. Large areas of disrupted fiber morphology include amorphous, electron lucent deposits and disruption of fiber patterns and limiting membranes.

Chemistry

Preliminary data with trout indicate that about 10% of the administered radioactivity (2,6-DMN study) is excreted in the urine. More work needs to be done in order to perfect the trapping of feces and water-soluble products excreted from the gills. Presently, we are able to account for about 50% of the administered dose. Two metabolites tenetatively identified as a dihydrodiol of 2,6-DMN and a monohydroxylated derivatives of 2,6-DMN have been isolated from the urine. In the conjugate fraction, about 90% of the excreted radioactivity is tentatively attributed to the glucuronide conjugate.

The studies on the effects of lead and cadmium on aromatic hydrocarbon metabolism have been continued. Groups of starry flounder and coho salmon, which have been exposed to lead and cadmium, have been fed carbon-14 labeled naphthalene in salmon oil. At present, the samples are being processed and the data will provide information on the effect of metals on the metabolism of PAH accumulated via the diet.

The studies on the mutual effects of heavy metals (lead and cadmium) and petroleum hydrocarbons on fish egg development and viability have been initiated. Trial runs exposing herring eggs to lead, cadmium, cadmium and petroleum, lead and petroleum, and petroleum are being done to test experimental procedures.

Pathology

Exposure of flatfish to oil-contaminated sediments.

Number and type of samples:

- Blood for hematology (18)
- Sediment samples for hydrocarbon analyses (4)
- Tissue samples for hydrocarbon analyses (16)
- Tissue samples for histology (180)

Number and type of analyses:

- Hematology:
  - hematocrit (18)
  - hemoglobin (18)
  - total blood cell count (10)
  - differential white cell count (10)
  - microscopic examination of histological specimens (60)

Behavior

Activities in this quarter have been directed exclusively to analysis of data collected during the year, particularly the data collected during field studies of petroleum effects on salmon homing.

XI. AUXILIARY MATERIAL

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QUARTERLY REPORT

Contract No: R7120810
Research Unit No: RU-77
Reporting Period: January 1-March 31, 1978
Number of Pages: 2 + attached Processed Report

NUMERICAL ECOSYSTEM FOR THE EASTERN BERING SEA

Co-Principal Investigators

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U.S. Department of Commerce
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National Marine Fisheries Service
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March 1978

QUARTERLY PROGRESS REPORT

Reporting Period: January 1 - March 31, 1978

Project Title: Numerical Ecosystem Model for the Eastern Bering Sea, RU-77

I. Highlights of Quarter's Accomplishments

The DYNUMES III was used to study the nature and magnitudes of natural fluctuations of herring and other pelagic fish stocks and the effects of environmental anomalies (see attached report). Preliminary studies on the effects of oil spills on biological components are awaiting updates of distributions and abundances of biological components from other RU's (see VII below). The optimization and documentation of the numerical model is in progress.

II. Task Objectives

To prepare a relatively complete ecosystem model for the eastern Bering Sea for evaluation of the possible effects of offshore oil development on the marine ecosystem.

III. Field and Laboratory Activities

A. Ship or Field Trip Schedules

None

B. Scientific Party

Dr. Taivo Laevastu, Co-Principal Investigator (part-time)

Pat Livingston, Fisheries Biologist (part-time)

C. Methods

Modeling techniques previously reported.

IV. Results

(see attached report)

V. Preliminary Interpretation of Results

(see I and IV above)

VI. Auxiliary Material

N/A

VII. Problems Encountered/Recommended Changes

In our previous quarterly report we requested some action by OCSEAP offices which would enable us to update the inputs to our model and assume that the OCSEAP fish, benthic, plankton, nutrient and modelling review scheduled for April will serve this purpose.

In addition to our request for space-time distributions and abundances of organisms, we would like to receive all technical data and/or estimates of possible magnitudes of disastrous accidents of oil exploration/exploitation which might affect any components of the marine ecosystem. We need these as inputs to our model to simulate and study quantitatively their possible effects on the overall marine ecosystem.

The following was submitted as part of this report:

Laevastu, T. and F. Favorite (1978), "The Control of Pelagic Fishery Resources in the Eastern Bering Sea (A numerical ecosystem study of factors affecting fluctuations of pelagic fishery resources with emphasis on herring)", Northwest and Alaska Fisheries Center, NMFS, Seattle, Washington 98112, Processed Report, 64 pp.

ANNUAL REPORT

EFFECTS OF PETROLEUM EXPOSURE ON THE BREEDING ECOLOGY OF THE GULF OF ALASKA HERRING GULL GROUP (*Larus argentatus* x *Larus glaucescens*) AND REPRODUCTIVE ECOLOGY OF LARGE GULLS IN THE NORTHEAST GULF OF ALASKA

BY

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Research Unit #96

National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Environmental Research Laboratories
Boulder, Colorado

April 1, 1978

Reporting Period: April 1977 - March 1978

Summary of Objectives, Conclusions and Implications with Respect to OCS Oil and Gas Development

This report is an investigation of primary and potential secondary effects of gas and oil development on large gulls (Larus) in the northeast Gulf of Alaska.

Our research objectives are: to determine threshold levels of petroleum exposure effects to gull reproduction under field conditions; to test alteration of incubation behavior and ability to produce second (replacement) clutches following experimental mortality due to petroleum exposure; to analyze gull population ecology in order to determine factors influencing "normal" (e.g. control) reproductive success in other colonies in the northeast Gulf of Alaska; and to continue analysis of the previous data base on the reproductive ecology of large gulls in the northeast Gulf of Alaska.

Primary Effects

Our conclusions are: very small amounts of North Slope (Prudhoe Bay) Crude Oil exposure (20 μ) to gull eggs in the field, at early stages of incubation, lead to high embryonic mortality. Embryonic resistance to petroleum exposure increases with the duration of incubation. Mineral oil (control) in equivalent microliter doses causes no significant mortality.

Gull behavior is altered by the continued incubation of eggs dead from petroleum exposure. Adult gulls fail to respond with the normal production of replacement clutches, which normally follow clutch loss to natural causes. The combination of high egg mortality and alteration of adult behavior virtually eliminates gull reproduction in the experimentally oiled area.

Secondary Effects

Southern Alaskan gulls nest on a variety of habitats, ranging from bare cliff ledges in fjords, to flat gravel bars, and to sloping grassy meadows with nest site slopes extending from 0% to 50% slope.

Gull populations (argentatus-group) are flexible in internest distances and are not limited by available nesting space in their northeast Gulf of Alaska breeding sites.

Age of the female is suggested as the most important factor influencing clutch size in southern Alaskan colonies. Territory size is inversely related to clutch size because of the tendency of young, inexperienced gull pairs to nest on the periphery of the colony, in marginal sites, or in newly colonized areas, where internest distances are large. This has important implications for the growth of gull populations in that clutch size and fledging success of these populations will tend to increase over time, given sufficient sources of artificial food.

Gull populations reproduce within a very short period of time of each other in the northeast Gulf of Alaska. Within the individual colonies, 50% of the eggs are laid in just over one week. Egg and chick predation (mostly from other gulls) are the primary factors responsible for reproductive failure. Relative percentages of unhatched eggs under "normal" circumstances are low, ranging from 0-6%.

Comparative reproductive rates suggest coastal populations of argentatus and glaucescens are expanding at rates ranging from 4% per year at very large colonies to 12% to 30% per year in medium-sized colonies. Over a five year time-span, net population increase could be well over 20%. If these populations, which are exhibiting tendencies towards lag-phase population growth, enter geometric rates of progression as in Britain, Canada, Europe, and the Eastern United States, the result will be staggering increases in the numbers of gulls in the northeast Gulf of Alaska.

ACKNOWLEDGEMENTS

We are deeply indebted to Dr. Francis S.L. Williamson of the National Science Foundation for the opportunity to study gulls under the auspices of the Department of Pathobiology, The Johns Hopkins University. We are equally grateful to Dr. William J.L. Sladen, our faculty advisor, for his continuous encouragement throughout our stay at Hopkins. We also extend our sincere thanks to Dr. George E. Watson, Curator, Division of Birds, National Museum of Natural History, to Dr. I.L. Graves and to Dr. F.B. Bang of the Department of Pathobiology for sponsorship and guidance in planning this study, and for review of the manuscript of this report. The logistical support received from Dr. Neal Nathanson and the Division of Infectious Diseases, Department of Epidemiology, is sincerely appreciated. Dr. Storrs Olsen of the National Museum has aided with specimens and encouragement.

We are grateful to Dr. Calvin Lensink of the U.S. Fish & Wildlife Service, to Drs. Jay Quast, David Norton, Lois Killewich, and to Ms. Susan Anderson Swanner of the National Oceanic and Atmospheric Administration for approval and support of this study.

Special thanks go to Dr. Peter G. Michelson, University of Alaska; to Mr. M.E. "Pete" Isleib of Cordova, Alaska; and to Mr. Kenton D. Wohl of the Fish & Wildlife Service for assistance and suggestions. Dr. Ralph B. Williams (ret.) of Alaska Public Health Laboratories and Mr. Lloyd Morley (ret.) of the

Department of Environmental Health of the State of Alaska have provided long-term knowledge of gulls in Alaska. Dr. Frank Pauls of Alaska Public Health Laboratories assisted with technical equipment, and Mr. Randolph Bayliss of Alaska Department of Environmental Conservation in Valdez indicated significant gull concentrations. Mr. James King, U.S. Fish & Wildlife Service, reported important sightings of marked gulls and banding recoveries.

The research in this study was conducted in part for the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office of the National Oceanic and Atmospheric Administration Environmental Research Laboratories, Boulder, Colorado. This research was partially supported by the Bureau of Land Management through an interagency agreement with the National Oceanic and Atmospheric Administration, under which a multi-year program responding to needs of petroleum development is managed by the OCSEAP Office. The Frank M. Chapman and Mae P. Smith Funds of the American Museum of Natural History, and the National Park Service supported initial aspects of this investigation. The financial support granted through these agencies is gratefully acknowledged.

We also express our gratitude to the Staff of the Cordova and Yakutat Work Centers, U.S. Forest Service, in particular to Mr. Richard Groff, Mr. Ronald Quilliam, Mr. Rodney King, Mrs. Lynda Plant, Mrs. Kris Widdows, Mr. Benjamin Ames, Mr. Timothy Moerlin, Mr. Joel Schilmoeller, Mr. Michael Lettis, Mr. Thomas Somrak, Mr. Alan Macrae, and the Kenai Lake

Youth Conservation Corps for field time, logistical support, and cooperation. Mr. Stanley Senner and Mr. Robert Bromley of the University of Alaska were our colleagues in the field, and were of considerable assistance. Dr. James Morrow and Dr. George Muller of the University of Alaska provided important identification of gull food items.

Mr. Alex Brogle, Dr. Donald McKnight and Mr. Loyal Johnson of the Alaska Department of Fish & Game suggested areas for special study; Mr. Paul Arneson and Mr. David Kurhajec helped with field work. We thank Mr. and Mrs. Jerry Thorne, Mr. Norman Borseth, Mr. Richard Morgrey, Mr. Ralph Pirtle of Cordova, and the commercial fishermen of the Alsek River for special kindness, hospitality, and good advice. We thank Dr. George and Molly Hunt for a manuscript review, Mr. Robert Stein and Mr. James Audet of the National Oceanic Data Center for data formats, Mr. Galen Smith and Mr. Vincent Lamonte of The Johns Hopkins University Computing Center for programming and data products.

We are grateful for the assistance and hospitality of Mrs. Mildred Hayes, and for her long-term observations on the gull colony at Lake Louise.

CHAPTER 1

Objectives and Rationale of Petroleum Exposure

This research is addressed to the following task: an analysis of the effects of petroleum exposure on the breeding ecology, including incubation behavior and hatching success, of the Gulf of Alaska Herring Gull group (*Larus argentatus* x *Larus glaucescens*).

The devastating effects of massive oil spills on seabird survival are widely reported, but little is known of the effects of low-level oil pollution on avian reproduction (Grau et al., 1977). Previous studies of petroleum effects on seabird eggs suggest hatchability is markedly reduced (Gross; Birkhead et al, 1973; Patten & Patten, 1977). Rittinghaus (1956) and Hartung (1963, 1964, 1965) reported that marine birds contaminate eggs with oil from the environment and hatching success of eggs thus exposed to petroleum was markedly reduced even after extended periods of incubation. Abbott, Craig and Keith (1964) suggested that oil interfered with normal respiratory exchange through the eggshell, while Szaro and Albers (1976) found hatching success of eider (*Somateria mollissima*) eggs was significantly reduced by microliters of petroleum exposure, that is, very small quantities. Patten and Patten (1977) have recently found unweathered North Slope Crude Oil 22 times more toxic than equivalent amounts of mineral oil under field conditions. Grau et al. (1977) have confirmed in laboratory experiments that small amounts of bunker C oil significantly depress bird reproduction. Indeed, oil exposure has been used in the past to control gull populations along the Eastern Seaboard of the United States and in several western U.S. wildfowl refuges (Gross, 1950; R. King, USF&WS, pers. comm.).

In summary, literature on the effects of oil exposure on the reproduction of marine birds is limited. Studies that do exist suggest high toxicity of petroleum to eggs, and marked effects upon the reproductive productivity of females. Complete knowledge of the effects of petroleum exposure in various forms is needed to evaluate and predict the full impact of oil pollution on the annual productivity of marine bird populations.

This current research is to provide information on the effects of North Slope Crude Oil on the hatching success and incubation behavior of key seabird species nesting on Alaskan barrier islands in proximity to Valdez tanker lanes and offshore oil lease areas.

Species examined are Herring Gulls (Larus argentatus) and Glaucous-winged Gulls (Larus glaucescens), which are common inshore and marine scavengers nesting in colonies. The study sites are the largest gull colony in the northeast Gulf of Alaska, Egg Island, located 10 km SE of Point Whitshed and 20 km south of Cordova (60° 23' N, 145° 46' W), and Dry Bay, 75 km SE of Yakutat (59° 10' N, 138° 35' W).

Our research objectives are thus defined as:

1) to determine threshold levels of petroleum effects to gull reproduction under field conditions,

2) to test alteration of incubation behavior and ability to produce second (replacement) clutches following experimental mortality due to petroleum exposure,

3) to analyze gull population ecology in order to determine factors influencing "normal" reproductive success in other colonies in the northeast Gulf of Alaska, and

4) to continue analysis of the previous data base on the reproductive ecology of large gulls in the northeast Gulf of Alaska.

Note: North Marble Island (GBNM) study area and itinerary as in previous reports.

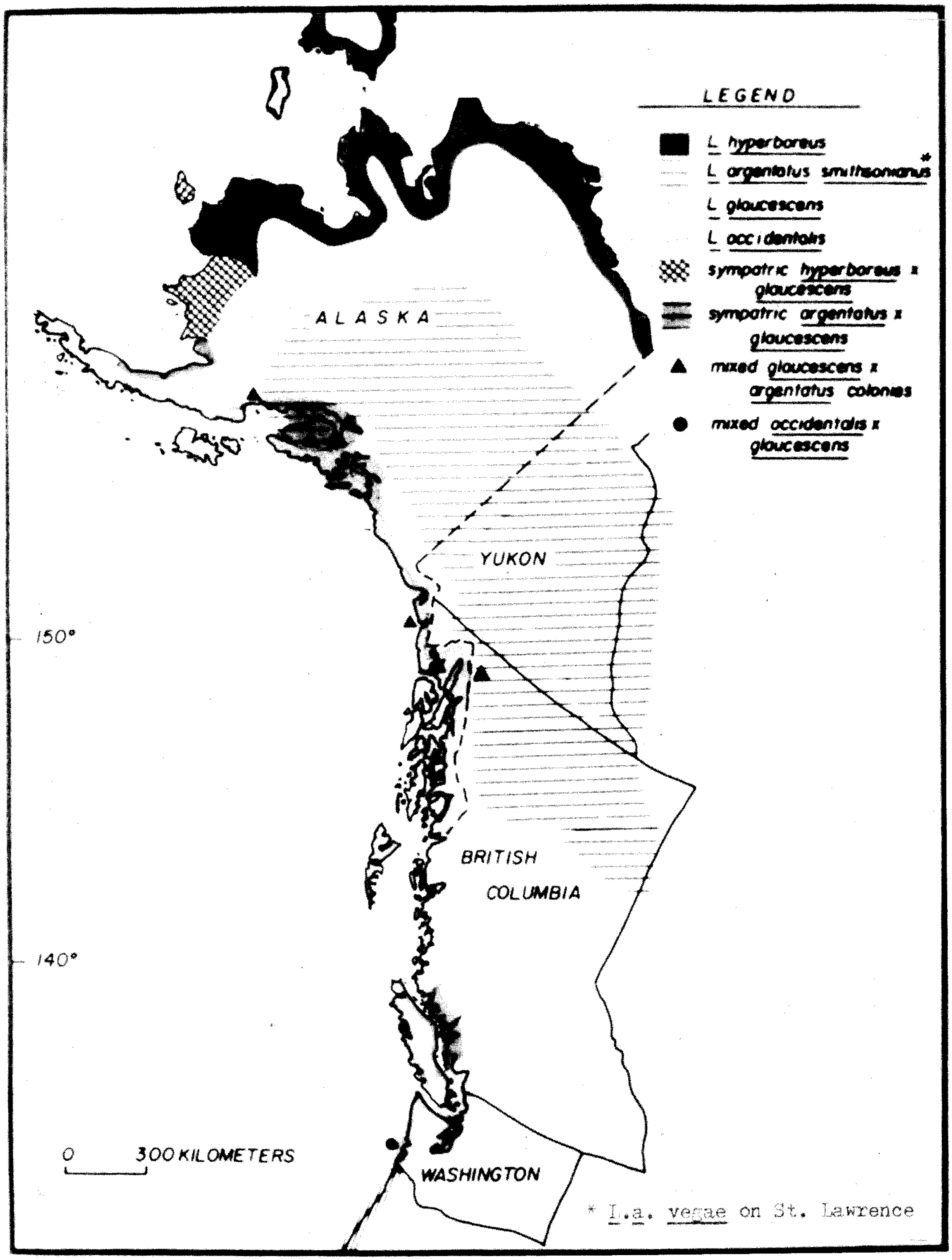


Figure 1 *PACIFIC NORTHWEST GULL DISTRIBUTION*

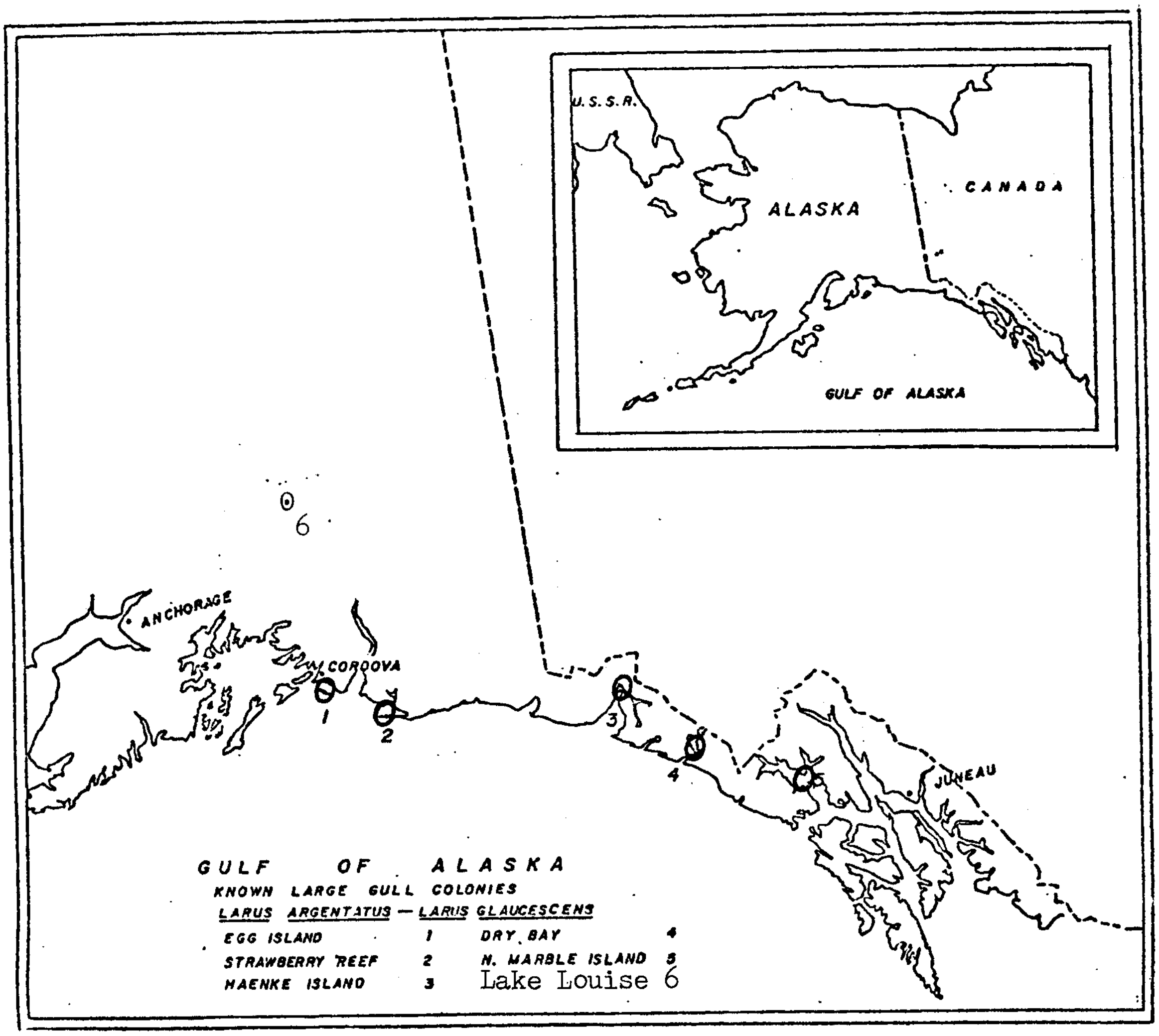


Figure 2. Map of the northeast Gulf of Alaska, showing known large gull colonies of the Larus argentatus - Larus glaucescens species group. (Inset: map of Alaska and northwest Canada showing Gulf of Alaska.)

Table 1

Southern Alaskan Study Areas

Colony	Coordinates		Large White-headed *Larus* Populations During Breeding Season	Aquatic Environment	Substrate/ Geology/ Slope	Dominant Vegetation
	N	W				
North Marble	58°40'	136°04'	*argentatus*, *glaucescens*	tidal bay	recently deglaciated (120 yrs) sloping island	*Hordeum* meadows
Dry Bay	59°08'	138°25'	*argentatus*, *glaucescens*	river delta/ coastal marine	shifting flat gravel bars	sparse alluvial/ maritime mix
Haenke Island	59°58'	139°32'	*glaucescens*	tidal bay	recently declaciated island cliff face	*Hordeum*/*Alnus* on cliff terraces
Strawberry Reef	60°13'	144°51'	*glaucescens*	brackish delta/ coastal marine	earthquake influenced low sandbar island	*Elymus*
Copper Sands	60°18'	145°31'	*glaucescens*	brackish delta/ coastal marine	"	*Elymus*
Egg Island	60°23'	145°46'	*glaucescens*	brackish delta/ coastal marine	"	*Elymus*
Cordova*	60°33'	145°45'	*glaucescens*, *hyperboreus*	tidal inlet	artificial urban environment	city dump
Lake Louise	62°20'	146°32'	*argentatus*	freshwater lake	sloping lake islet	*Calamagrostris* meadows

* Not a colony but a major feeding area (see text).

CHAPTER 2

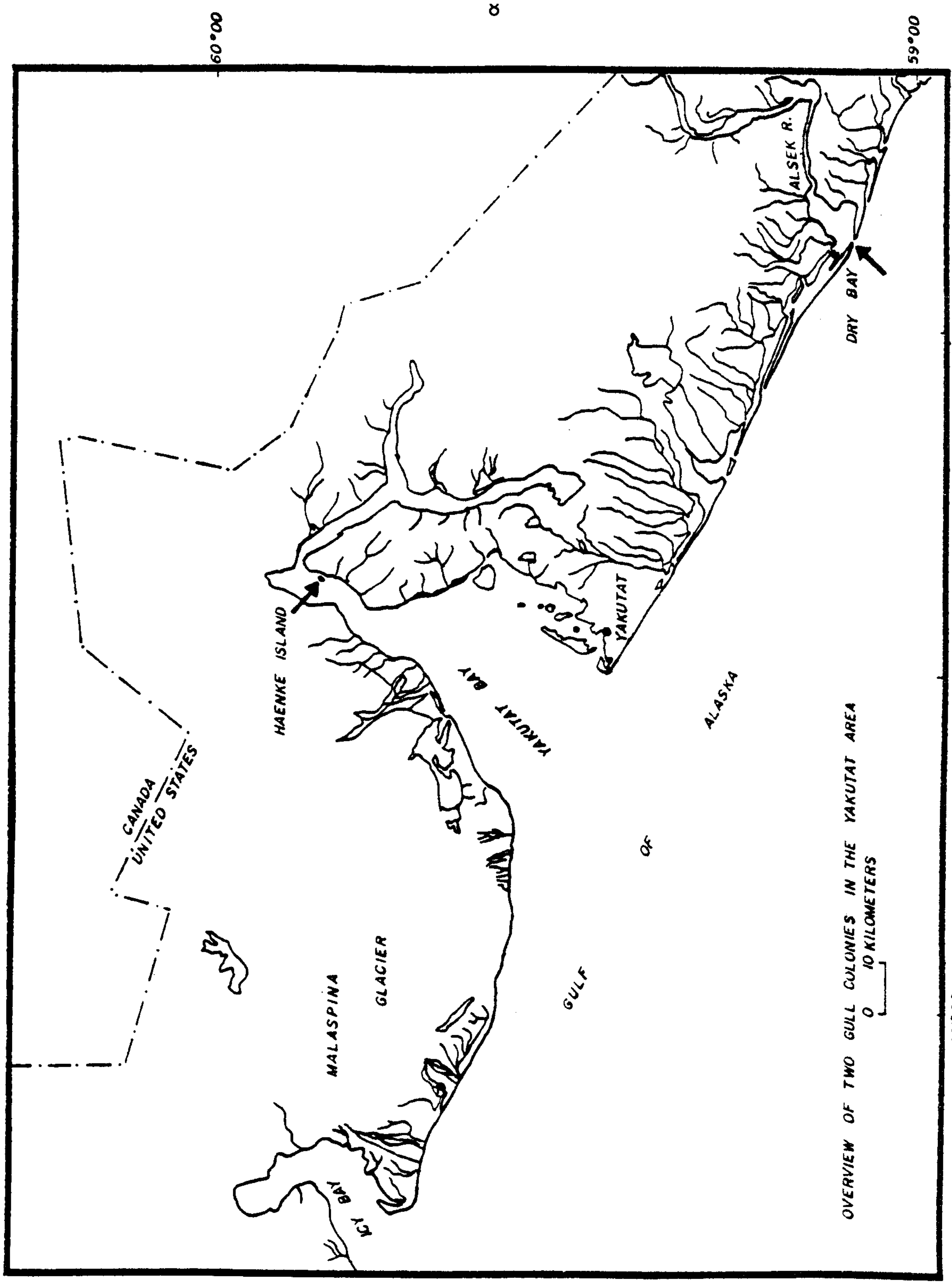
THE STUDY AREAS AND ITINERARY

I. Dry Bay

Dry Bay, a delta 25 km across on the northeast shore of the Gulf of Alaska, at the mouth of the Alsek River, 75 km SE of Yakutat, on the Malaspina Coastal Plain (59° 08' N, 138° 25' W) was named in 1869 by G. Davidson of the USC&GS because it appeared to be a shallow lagoon fed by silt-laden glacial streams (Orth, 1967) (Fig. 3). Small rocks, mud, grey clay, sand and gravel form the delta substrate. The general habitat classification is delta/river mouth, river shore. The islands and tributary streams at the Alsek River Delta are subject to considerable repositioning due to river action. Tide ranges from 1.0 to 1.3 m within Dry Bay.

Dry Bay has apparently not been glaciated but may have been the location of catastrophic flooding within the last 1000 years from glacially dammed lakes in the interior Yukon (Brogle ADF&G, pers. comm.). Dry Bay is a geologically active, earthquake-prone area. A minor earthquake caused the mouth of the Alsek River to shift 1 km to the west in 1975 (Ak. Geo., 1975).

The gull colony is located on flat gravel bars 4.8 km from the mouth of the river (Fig. 4). The Alsek level changes in relation to rainfall and snowmelt. Water temperature, + 3°C, supports ice floes from the Alsek Glacier, 28 km from the coast on the Alsek River. Gravel channels E and NE of the gull colony were empty during May 1977. The main river channel to the west was 2.5 m below the colony on 10 May, but the river rose 4-5 cm per day until mid-July, nearly flooding the colony. Some years much



OVERVIEW OF TWO GULL COLONIES IN THE YAKUTAT AREA
0 10 KILOMETERS
60°00
59°00
139°00
140°00
141°00
CANADA
UNITED STATES
ALSEK R.
DRY BAY
YAKUTAT
HAENKE ISLAND
YAKUTAT BAY
GULF OF ALASKA
MALASPINA GLACIER
ICY BAY

Figure 3

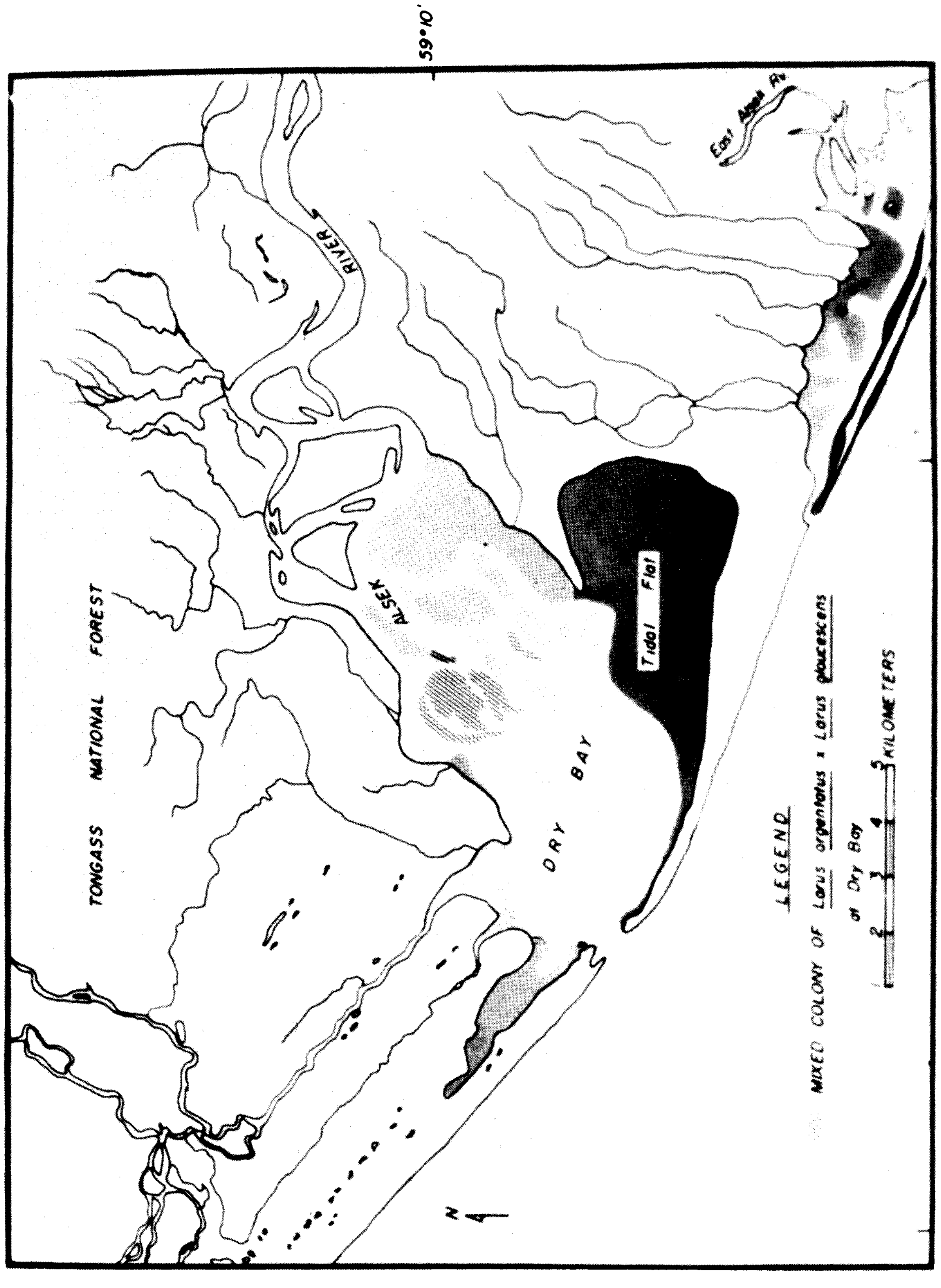

59°10'
TONGASS NATIONAL FOREST
ALSEK RIVER
East Alsek R.
Tidal Flat
DRY BAY
N
LEGEND
MIXED COLONY OF Larus argentatus x Larus glaucescens
at Dry Bay
1 2 3 4 5 KILOMETERS

Figure 4

higher flood stages, washing completely over the gravel islands, are reached in August (Mork, _viva voce_).

According to local fishermen, 1977 was a warm, dry spring, following an unusually mild, rainy winter. The formation of offshore high pressure ridges in May prevented intrusion of Gulf of Alaska low pressure systems. Mornings during May were usually calm, with afternoon winds 12-15 kph from the SW. Other seasons powerful southeast storms cover the delta with heavy rains or snow. Winds over 160 kph drive ocean waves over 20 m high onto the outer beach (Ak. Geo., 1975), inundating - washing over much of the delta.

The St. Elias Range (4130 m - 5800 m), along the coastline of the Gulf of Alaska, is a major influence on weather conditions in the Yakutat area (Ak. Geo., 1975). The Yakutat foreland lies between Yakutat and Dry Bay and is bounded to the north by the Brabazon Range (1180 m - 1770 m) and to the east by Mt. Fairweather (4519 m). These ranges capture water vapor from the Pacific Ocean with resulting annual precipitation of more than 338 cm on the Yakutat area. Snowfall ranges normally between 310 cm and 866 cm, with a mean around 570 cm, but in 1976-77 little snow fell due to unseasonably warm temperatures. Normal monthly temperature ranges from -3°C in January to +12°C in July (Ak. Geo., 1975).

A mixture of alluvial and maritime vegetation grows on the Dry Bay gravel bars, composed of mosses, various grasses, dwarf willow (_Salix arctica_), yarrow (_Achillea borealis_), river beauty (*Epilobium latifolium*), yellow lousewort (*Pedicularis palustris*), beach rye (*Elymus arenarius*), sedges (*Carex* spp.), beach pea (*Astralagus* sp.), black cottonwood (*Populus trichocarpa*), ($\leq$ 1 m), and scattered willow bushes (1 - 2 m) (*Salix* sp.). Gulls nesting on the most vegetated sections of the gravel bars use mud, *Epilobium* and *Salix* for nest construction. Red fescue (*Festuca rubra*) and river beauty (*Epilobium latifolium*) are dominant plant species in the gull colony by late June, although ground cover, especially in comparison to the other colonies investigated, is incomplete. Gull chicks are often exposed to aerial predators.

Parasitic Jaegers (*Stercorarius parasiticus*) and Common Ravens (*Corvus corax*) are occasional egg predators on the gull colony. The heavy eagle predation on gull chicks is especially noteworthy. A pair of eagles nested within a kilometer of the gull colony, and we observed spectacular, often successful eagle attacks on gull chicks throughout late June and July.

II. Haenke Island

Haenke Island, 1.6 x 1.0 km, was named in 1791 by Capt. Alessandro Malaspina for Thaddeus Haenke, botanist and naturalist with Malaspina's expedition (Orth, 1967). Haenke Island is located in Disenchantment Bay near the head of Yakutat Bay, 50 km NE of Yakutat, at the foot of the St. Elias Mountains (59° 58' N, 139° 32' W) (Fig. 3). Yakutat Bay is 30 km wide, relatively shallow, and bordered on the north and east by an abrupt range of mountains, including Mt. St. Elias, which reaches to 5800 m within

60 km of salt water (Fig. 3). The Malaspina Glacier, larger than the State of Rhode Island, lies immediately northwest of Yakutat Bay. The St. Elias Range and the Malaspina Glacier prevent influence of interior conditions in the area. The partially submerged glacial valley forming Disenchantment Bay opens southwest to the Pacific Ocean. The valley is closed to the northeast by the advancing Hubbard Blacier, which extends to within a few kilometers of Haenke Island (Fig. 5). The presence of vast bodies of ice within this geographically confined area exerts a depressing effect on the ambient temperatures around Haenke Island. Weather is often cold and wet even in summer. Moisture-laden air is forced to rise at the end of Disenchantment Bay over the Hubbard Glacier and against the mountains, depositing even greater amounts of moisture than on the Yakutat Forelands. The Hubbard Glacier is one of the notably few glaciers in Alaska to advance yearly, and now threatens to close Russell Fjord and form a freshwater lake (Ak. Geo., 1975).

The glacier once filling Yakutat Bay reached its maximum extent sometime in the Middle Ages and began to retreat about 600 years ago. The reasons for this retreat are obscure. The retreat went far behind the branches of the Yakutat Bay glacier, now the tidewater glaciers of Disenchantment Bay (Fig. 5). The ice then readvanced, reaching its largest extent during the 1700's. The Yakutat Bay glacier, best regarded as an expanded Hubbard Glacier, probably then extended slightly beyond Latouche Point, 10 km past Haenke Island. The glacier

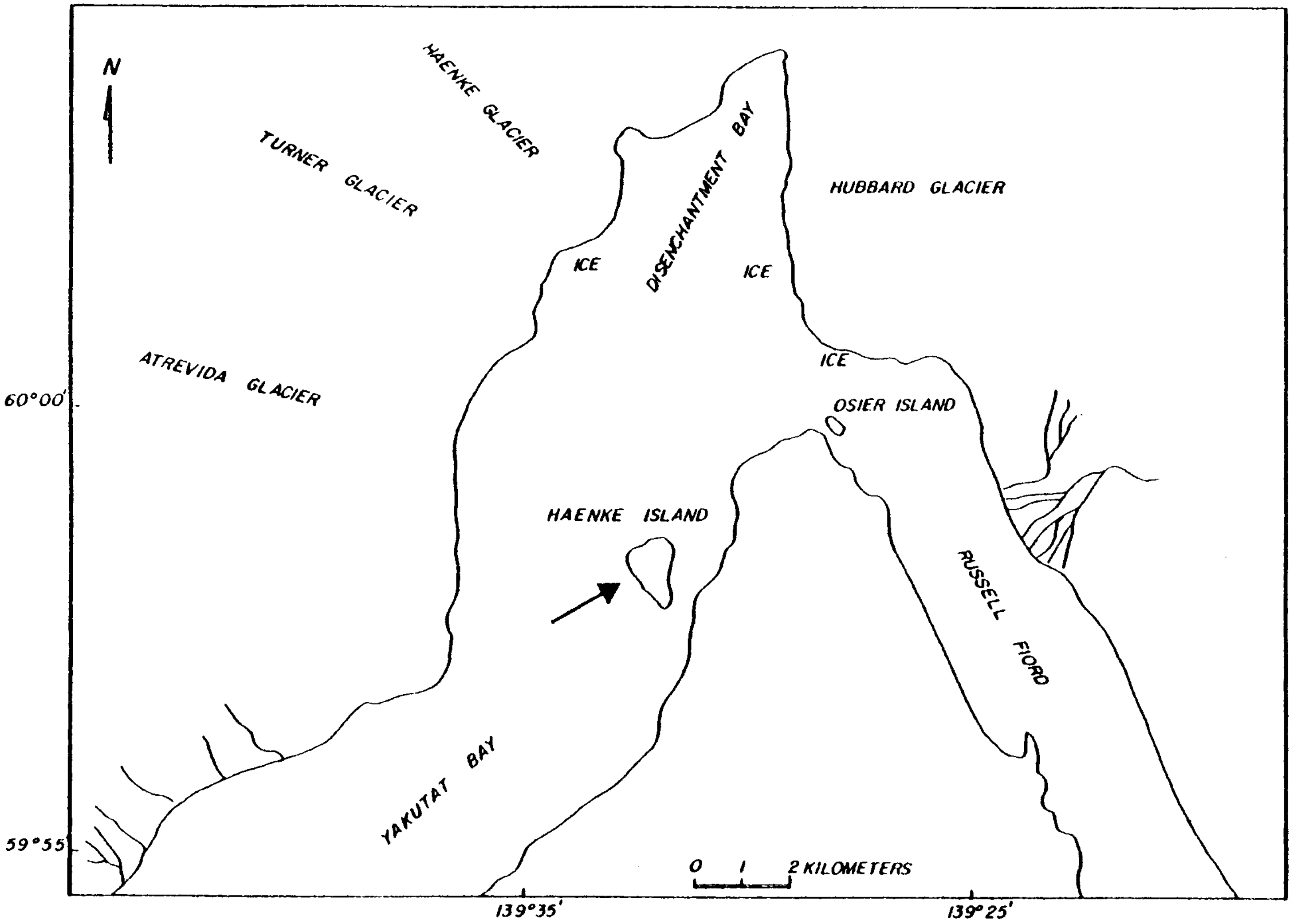


Figure 5. Map of Haenke Island and surroundings in Disenchantment Bay, near Yakutat Bay, 50 km NE of Yakutat, Alaska. Note the proximity of four major glaciers. The advancing Hubbard Glacier threatens to close Russell Fjord and form a freshwater lake. Haenke Island is located less than 1 km from the mainland.

again retreated to the vicinity of Haenke Island by the time of Malaspina and Vancouver in the 1790's. Their descriptions leave the exact position open to question (Ak. Geo., 1975). Haenke Island, similar to North Marble, is thus relatively recently deglaciated, but the exact date is uncertain due to the sporadic advances and retreats of the Hubbard Glacier.

Haenke Island, located less than 1 km from the mainland (Fig. 6) is often completely surrounded by pack ice from the Hubbard Glacier. The island, with little level ground, is covered with low, brushy vegetation dominated by alders, suggesting a relatively recent deglaciation. The east side of the island, facing the Hubbard Glacier, gradually slopes to an elevation of 75 - 100 m, and then drops precipitiously, forming a large westward-facing cliff, where 500 pairs of glaucescens breed on a series of narrow terraces. Alder (Alnus crispa), elderberry (Sambucus racemosa), currents (Ribes bracteosum), fireweed (Epilobium angustifolium) and mosses such as Rhytidiadelphus triquetrus vegetate unutilized portions of the cliff terraces.

Harbor seals (Phoca vitulina) are abundant around the island on the ice pack. The intertidal is rocky, with large boulders. Water surrounding the island is highly turbid with outwash from the Hubbard Glacier.

Figure 6. Haenke Island: Note ice pack and turbid outwash from the Hubbard Glacier. (National Ocean Survey aerial photograph)

III. COPPER RIVER DELTA

General Description

The largest gull colonies in the northeast Gulf of Alaska are located on sandbar islands off the Copper River Delta, near Cordova, Alaska. For millenia the Copper River has flowed from interior Alaska through the Chugach Mountains (2000 - 3000 m) to the Pacific Ocean. The river carries a naturally heavy load of silt, sand and gravel from the montaine erosion and glaciation of the higher peaks. This massive river system flows into the Gulf of Alaska south of Cordova, and drains the Scott, Sheridan and Sherman glaciers and other ice masses (USFS, 1975) (Fig. 7).

The town of Cordova (pop. 2000-5000) lies on the SE shore of Orca Inlet, oppiste Hawkins Island, close to the Chugach Mountains (60^{o} 33' N, 145^{o} 45' W) (Fig. 7). Cordova was named by Michael J. Heney, builder of the Copper River and Northwestern Railroad, about 1906. The name originated from "Puerto Cordova," given to what is now known as Orca Bay, by Senor Don Calvador Fidalgo in 1790 (Orth, 1967).

South of Cordova the Copper River and the confluent Martin River have deposited their sands and mud where they meet the sea. The suspended inorganic matter precipitates with the increasing salinity gradient, forming a 50 km wide delta. The rivers move across the delta, passing tidal mudflats, brackish sloughs and shallow ponds in sedge or grass marshes. Summers in the Copper Delta region tend to be cool and rainy while winters

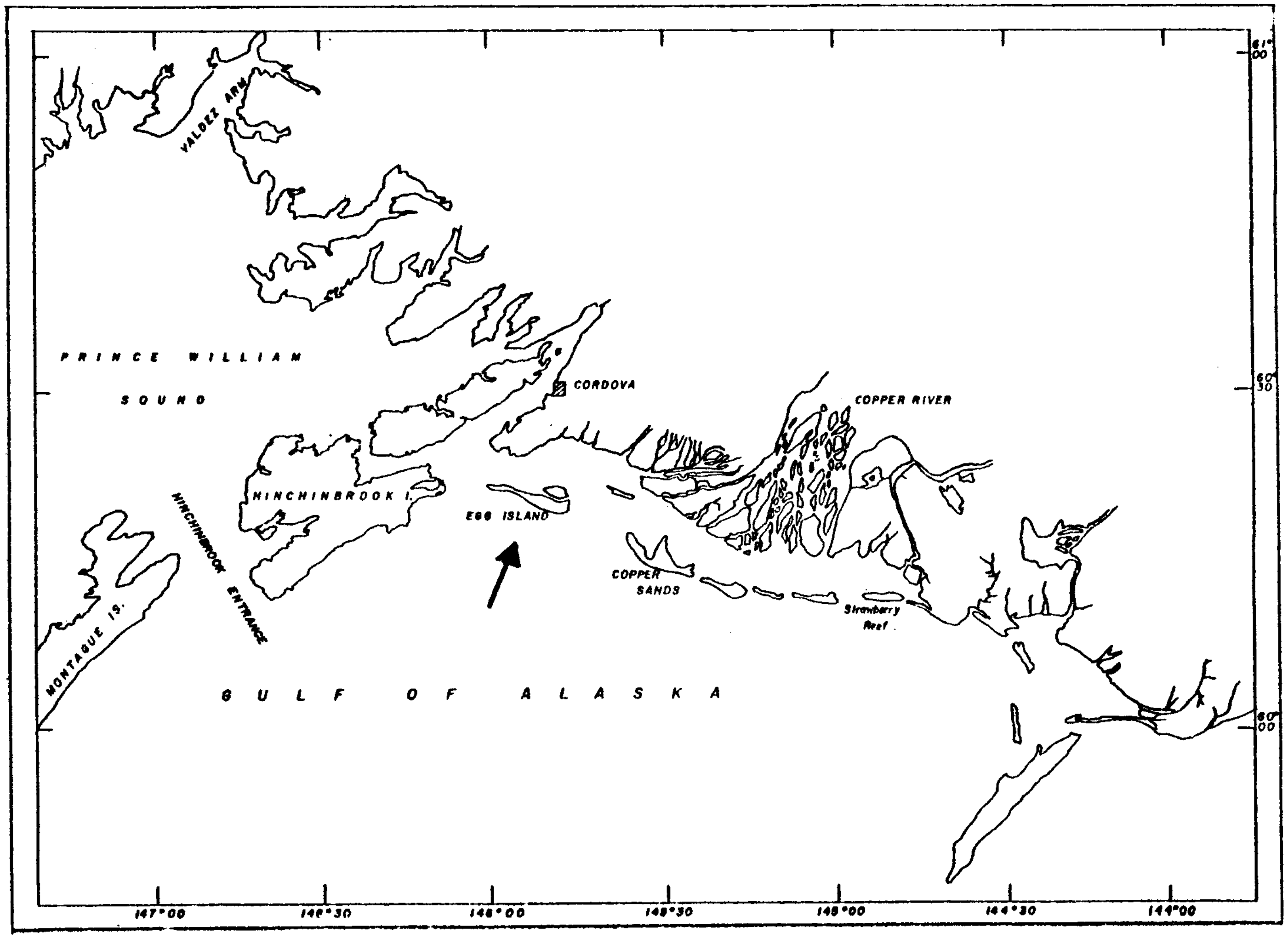


Figure 7. Map of the Copper River Delta region and Prince William Sound, showing location of Cordova, the Copper River, Egg Island (arrow), Copper Sands (S), and Strawberry Reef. Tanker traffic from Valdez will pass through Hinchinbrook Entrance. The area is highly vulnerable to oil spills.

bring extremely strong storms, intense cold, and high velocity interior winds.

The basic factors affecting climate in the Copper River Delta region are similar to those encountered at practically all points along the coastal area of southeastern Alaska (USDC, 1963). The climate is basically maritime, with nearby ocean areas modifying daily and seasonal temperatures within rather narrow limits. The area is exposed to frequent low pressure systems moving out of the Gulf of Alaska providing abundant precipitation. The high, rugged Chugach Mountains intensify precipitation from onshore movement of moisture-laden air. The Copper River Delta receives almost 250 cm of rain yearly. Maximum precipitation usually occurs from August through November. Average annual snowfall (317 cm) occurs mainly from November through March. The sky is rather persistently cloudy, averaging 80% coverage. The mean annual number of clear days is only 52 (USDC, 1963). High temperatures, usually encountered in early July, rarely climb above +27°C, while winter extreme low temperatures, reaching -35°C, are usually of short duration (USDC, 1963).

The Copper River Delta has been one of the most productive and important breeding and migration grounds for waterfowl on the North American continent (USFS, 1975). Millions of birds pass through the area in spring and fall, and tens of thousands of ducks, geese and swans remain to breed (Isleib & Kessel, 1973). Another indicator of the importance and productivity of the Copper River Delta is the extensive fishery on the "Copper Flats" for king salmon (Oncorhynchus tschawytscha), sockeye (O. nerka), and silver salmon (O. kisutch). The king and sockeye salmon migrate up the Copper River into the interior to spawn, while the silver salmon breed in the tributaries of the delta. A herring (Clupea harengus) fishery is increasing in nearby Prince William Sound. Eulachon (Thaleichthys pacificus) run up small streams of the delta. It is inevitable that this concentration of food resources should attract fish-eating birds.

A few kilometers off the mouth of the Copper River a series of low sandbar-dune islands forms a partial barrier to ocean storms. These islands have been formed by the deposition of sand and mud from the Copper River, and have been shaped by the counter-clockwise onshore currents of the Pacific Ocean.

Constant change is characteristic of the interface between land and sea, especially where rivers enter the ocean. Sandy islands are built up and eroded away in a relatively uninterrupted process. However, the Copper River Delta and surrounding area have been marked by sudden geological changes that have been extremely important in affecting local biota. Janson (1975) wrote of major earthquakes in the Copper Delta occurring at the end of the last century. The most severe earthquake recorded on the North American continent during modern times occurred in this area of Alaska in March 1964. The whole Copper River Delta including offshore islands was uplifted an average of two meters in a series of severe shock waves (USFS, 1975). The abrupt uplift disrupted the complex delta ecosystem and altered the balance between fresh and salt water. Nutrient input from salt water to the delta appreciably diminished; several species of intertidal invertebrates and nesting populations of ducks declined in numbers. Willows and alders began to replace grassy and sedgy marshes in areas of the delta. Certain tidal sloughs dried out (Scheierl & Meyer, 1976).

The sandbar barrier islands at the mouth of the Copper River underwent the same sharp geological forces as the delta itself, but due to the nature of the islands and the marine bird species using them, the resulting changes were quite different. Shallow salt-water channels between islets were eliminated, and new ridges of sand dunes formed, joining islets together. The actual land area of the barrier islands increased due to the upligt. The small breeding populations of waterfowl on the sandbar islands were not affected to the degree as those nesting on the delta itself because fresh water was limited on the islands even before the earthquake.

The gulls, which compose the largest breeding bird population on the outer islands, were influenced in the following manner. The long lines of dunes increased in height and area due to earthquake uplift and wind action. Plant succession began on newly formed dunes, with beach rye (Elymus arenarius mollis) forming scattered tufts on the sandy surface. The beach rye spread from the older high dunes covered with grassy meadows, where Elymus was the dominant plant species. Meadows encroach on dunes as succession continues.

Large colonies of gulls nest on these meadow-covered dunes. The actual area upon which the gulls can nest is increasing. A few alder (Alnus crispa), willows (Salix spp.) and cottonwood (Populus trichocarpa), however, are growing on the higher dunes of Egg Island; Strawberry Reef has scattered clumps of spruces (Picea sitchensis) as well as thickets of alders and willows. If this trend towards woody vegetation continues, in time the result could be displacement of nesting gull populations, but at the moment there are large areas of unoccupied meadows capable of supporting nesting gulls. The unifying characteristic of gull colonies examined thus far in this report is their geological and vegetational dynamism.

Overlying the vegetation and geological changes along the southern Alaskan coastline is the increasing human influence. Since the turn of the century successive tides of human influence have swept over Alaska. The most important development for gulls has been the rise of intensive fisheries. As an example, five important seafood packing canneries and fish-processing houses in Cordova provide a major food source to gulls in the form of salmon and crab offal. Gulls also feed at the open municipal dump at the edge of the harbor. The potential for discarded human food and industrial waste increases daily. Isleib (pers. comm.) sees an increasing gull population in the Cordova area to date. Our 1976 NOAA helicopter survey indicated 13,225 gull pairs nested on the sandbar barrier islands off the Copper River Delta (Table 2). This number is expected to increase with the development of offshore oil resources, since gull-associated problems of human waste and garbage disposal are not likely to decline.

TABLE 2

Nesting Gull Populations on Copper River Delta Sandbar Islands

29 June 1976 NOAA helicopter survey+

Sandbar Barrier Island	Population Estimate*
Egg Island	10,000 pairs
Copper Sands (N)	200 pairs
Copper Sands (S)	800 pairs
Kokinhenik Bar	a few pairs
Grass Island Bar	200 pairs
No Name Island	25 pairs among driftwood
Strawberry Reef	2,000 pairs

*estimated by groups of 50 individuals
Other mudflats and islets serve as loafing areas for large populations of immatures and adults which may or may not be breeding

+observers: Pattens

The discussion will now focus on four sandbar barrier islands of the Copper River Delta.

A. Egg Island, Copper River Delta

Egg Island, one of a dozen in Alaska, lies off the south coast 10 km SE of Point Whitshed and 20 km south of Cordova, at

60^{o} 23' N, 145^{o} 46' W. Egg Island, a local name probably due to abundance of gull eggs, was first reported by G.C. Martin of the USGS in 1906 (Orth, 1967). Prior to the 1964 earthquake, Egg Island was a series of sand dunes and bars off the mouth of Mountain Slough, Copper River Delta (Fig. 7). The total land area above mean high tide, as determined by Michelson (1973) from USGS quadrangle maps, was approximately 2.6 km^2. As of October, 1973, the time of Michelson's calculations, the sand dunes and bars had coalesced and built up one basic island totaling an estimated 36.3 km^2 (Fig. 8). Divisions between former sandbars are now arbitrary, depending upon tide, and the entire island can be inspected on foot. Hayes and Boothroyd (1975) have independently reported Egg Island has doubled in size since the 1964 earthquake, the apparent discrepancy resolved by different tidal levels.

The southeastern islet (sections 22, 27, 28; Fig. 10) is the largest, approximately 33.7 km^2, highest, 10 m above mean high tide, and most vegetated. Horsetails (Equisetum fluviatile), sedges (Carex spp.), and alkali grass (Puccinella nutkaensis) vegetate seasonal sloughs and marshy places on the lee of the dunes. Beach rye (Elymus arenarius), yarrow (Achillea borealis) and other forbs cover the high dunes. Several Sitka Spruce (Picea sitchensis) 2 m tall, with seedlings, grow on the northernmost islet (sections 21, 16). Clumps of Salix spp. are found in lower portions of sections 22 and 27. A long tidal slough partially separates sections 16 and 21 from the rest of the island.

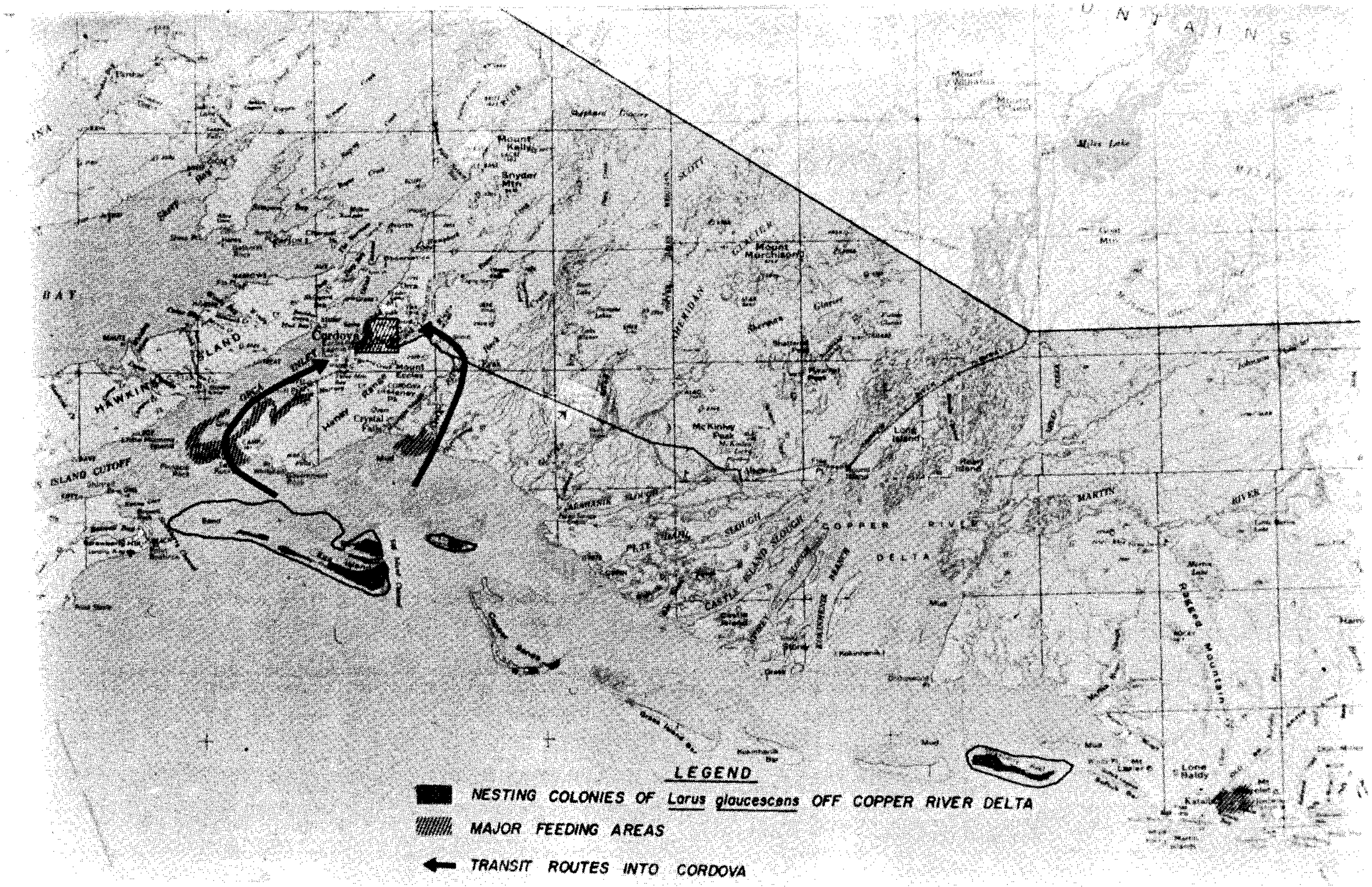

LEGEND
NESTING COLONIES OF Larus glaucescens OFF COPPER RIVER DELTA
MAJOR FEEDING AREAS
TRANSIT ROUTES INTO CORDOVA
Cordova
HAWKINS ISLAND
ISLAND CUTOFF
BAY
Mount Murchison
SHERIDAN
SCOTT
COPPER RIVER DELTA
MARTIN
RIVER
PETE DAHL
CASTLE ISLAND SLOUGH
Long Island
McKinley Peak
Crystal Falls
Mount Eccles
Miles Lake
Lone Baldy
Mount Kelly
Snyder Mtn
MOUNTAINS

Figure 8

Fig. 9. National Ocean Survey color aerial photograph of the east end of Egg Island, 9 July 1971, at low tide. New ridges of sand dunes have formed, joining the series of islets together. Scale 1:30,000.

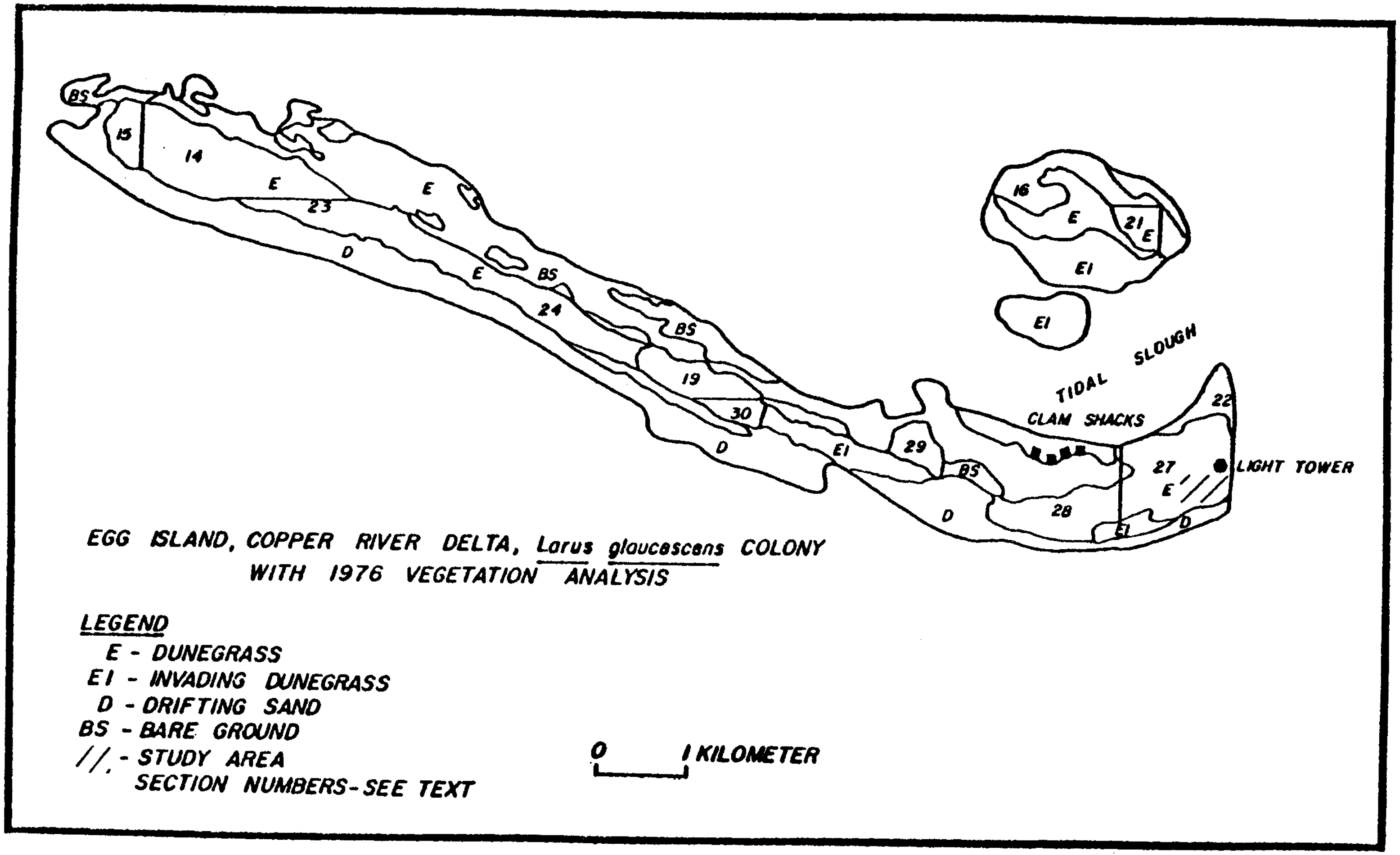

EGG ISLAND, COPPER RIVER DELTA, Larus glaucescens COLONY
WITH 1976 VEGETATION ANALYSIS
LEGEND
E - DUNEGRASS
EI - INVADING DUNEGRASS
D - DRIFTING SAND
BS - BARE GROUND
//, - STUDY AREA
SECTION NUMBERS - SEE TEXT
0 1 KILOMETER
TIDAL SLOUGH
CLAM SHACKS
LIGHT TOWER
BS
15
14
E
23
E
D
E
BS
24
BS
19
30
D
EI
29
BS
D
28
EI
D
27
E
22
16
E
21
E
EI
EI

Figure 10

Remains of at least six clam-digger shacks (pre-'64) are located in section 28 (Fig. 10). The clam-digging industry collapsed after the '64 earthquake (Thorne, viva voce). A U.S Coast Guard beacon light tower is now located in section 27 (Figs. 10 , 11) at 60° 216' N, 145° 451' W. A 100 m former tidal channel separates the two pre-1964 islets in sections 29 and 30 (Fig. 10). The former western islets (sections 14, 15, 19, 23, 24, and 30) are now a single high dune undergoing colonization by Elymus arenarius mollis (Fig.9). Driftwood, remains of fishing vessels, and other debris are scattered along the former storm-tide line, now at least a kilometer from the nearest salt-water (Michelson, 1973). Egg Island currently extends for 10 km along a series of dunes arranged on an E - W axis, containing the largest gull colony in the northeast Gulf of Alaska, approximately 10,000 pairs of nesting glaucescens. Changes on this island are nothing less than dramatic over the last dozen years. Quite recent earthquake activity ('64) is important in determining the structure of the island and the plant communities upon which the gulls nest.

B. Copper Sands and Strawberry Reef, Copper River Delta

Copper Sands (S), a bar 12 km long, is one of a series of barrier islands at the mouth of the Copper River. Copper Sands (S) lies 5 km ESE of Egg Island and 24 km SE of Cordova (60° 20' N, 145° 35' W; Fig. 7) offshore from the Malaspina Coastal Plain. Copper Sands is a local descriptive name reported

Figure 11. Composite color aerial photograph of the Egg Island study area, 60° 216' N, 145° 451' W, immediately SW of the USCG Beacon Light Tower, July 1976, from 335 m elevation. The vegetative cover (*Elymus arenarius mollis*) is most dense around the old drift logs marking the pre-'64 storm tide line. The entire lower portion of the photograph is a former wave-washed area. Nesting density of gulls is now highest in areas of most vegetative cover. Drift logs previously buried under several meters of sand, now exposed by the cutbank of Egg Island Channel, testify to the dynamic nature of the island. Photo courtesy of Mr. Robert Scheierl, Univ. Minn.

in 1951 by the USGS (Orth, 1967). Copper Sands has risen in elevation since the '64 earthquake, but shows much less vegetation than Egg Island, consisting of a series of unstabilized dunes extending from SE to NW. The gull colony of 800 pairs is located on three dunes covered with <u>Elymus</u> at the SE tip of Copper Sands (60° 18' N, 145° 31; W; Fig. 12 ; 13).

Copper Sands (N), a small, newly formed island less than a kilometer long, lies 2.5 km ENE of Egg Island off the mouth of the Eyak River. Copper Sands (N) did not exist before the '64 earthquake, but now contains several dunes with 150 pairs of <u>glaucescens</u> nesting in the <u>Elymus</u> (60° 24' N, 145° 37' W; Fig. 8). Other barrier islands between Copper Sands and Strawberry Reef at the east end of the delta support few nesting gulls due to lack of suitable vegetation, a result of intense scouring during sand storms blowing down the Copper River Valley during winter high pressure systems (Michelson, 1975; Isleib & Kessel, 1973). Gulls use unvegetated islands such as Kokinhenik and Grass Island Bar as resting areas (Fig. 8).

Strawberry Reef, 8 km long, the easternmost barrier island at the mouth of the Copper River, contains the second largest <u>glaucescens</u> colony on the delta (60° 13' N, 144° 51' W; Fig. 14). About 2000 gull pairs nest in the <u>Elymus</u> on Strawberry Reef, which is separated from the mainland by shallow tidal channels. The island is undergoing plant succession on recently uplifted areas, becoming more suitable to nesting gulls. Strawberry Reef, as Egg Island, consists of wide ocean beaches, unstabilized dunes, <u>Elymus</u>-covered dunes, and mud-flats, but differs by expanding thickets of spruce and alder.

Fig.12 . National Ocean Survey color aerial photograph of the southeast end of Copper Sands (S), 9 July 1971, at low tide. Gull colonies are located on the only three dunes covered with <u>Elymus</u> at the SE end of Copper Sands. Scale 1:30,000.

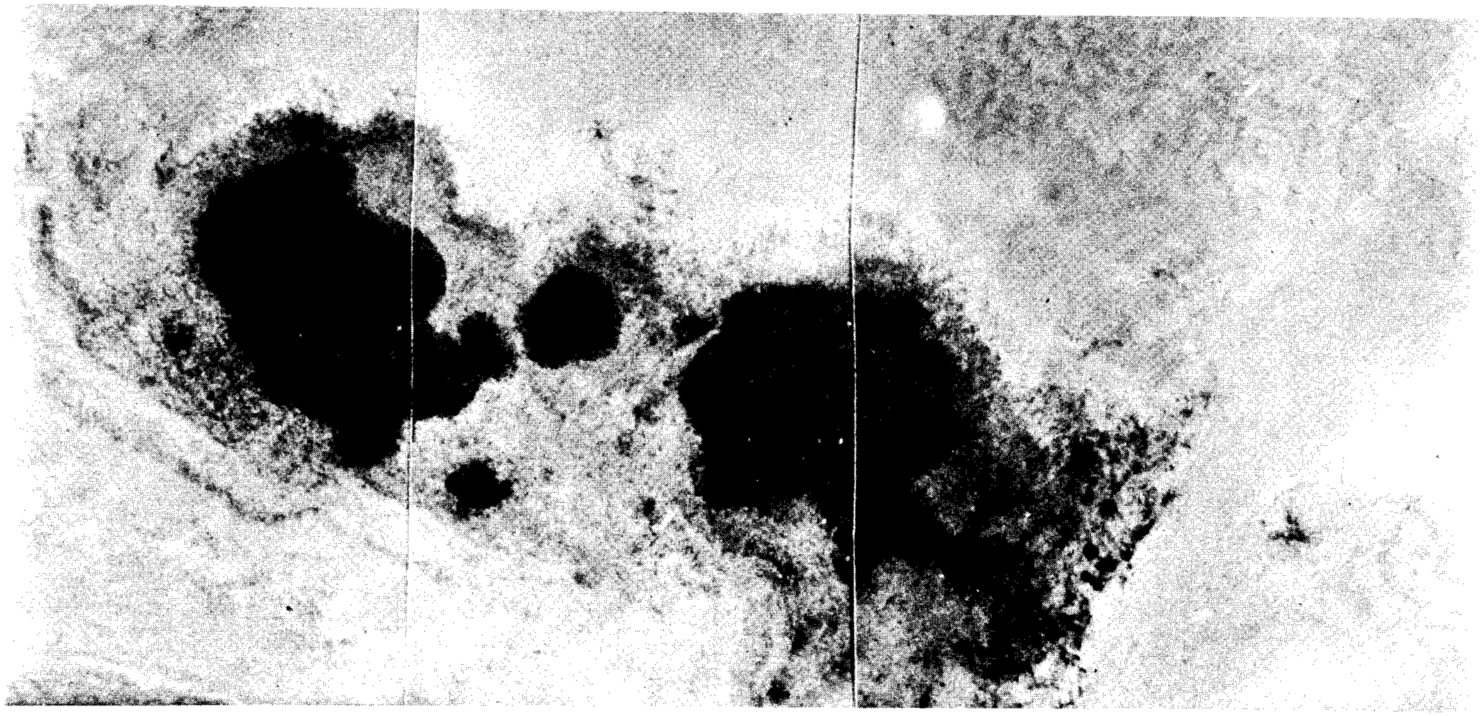


Figure 13. Composite color aerial photograph of two centrally located *Elymus*-covered dunes colonized by gulls at the SE end of Copper Sands (S), 60° 18' N, 145° 31' W. Copper Sands has much less vegetative cover than Egg Island and is inhabited by far fewer gulls.

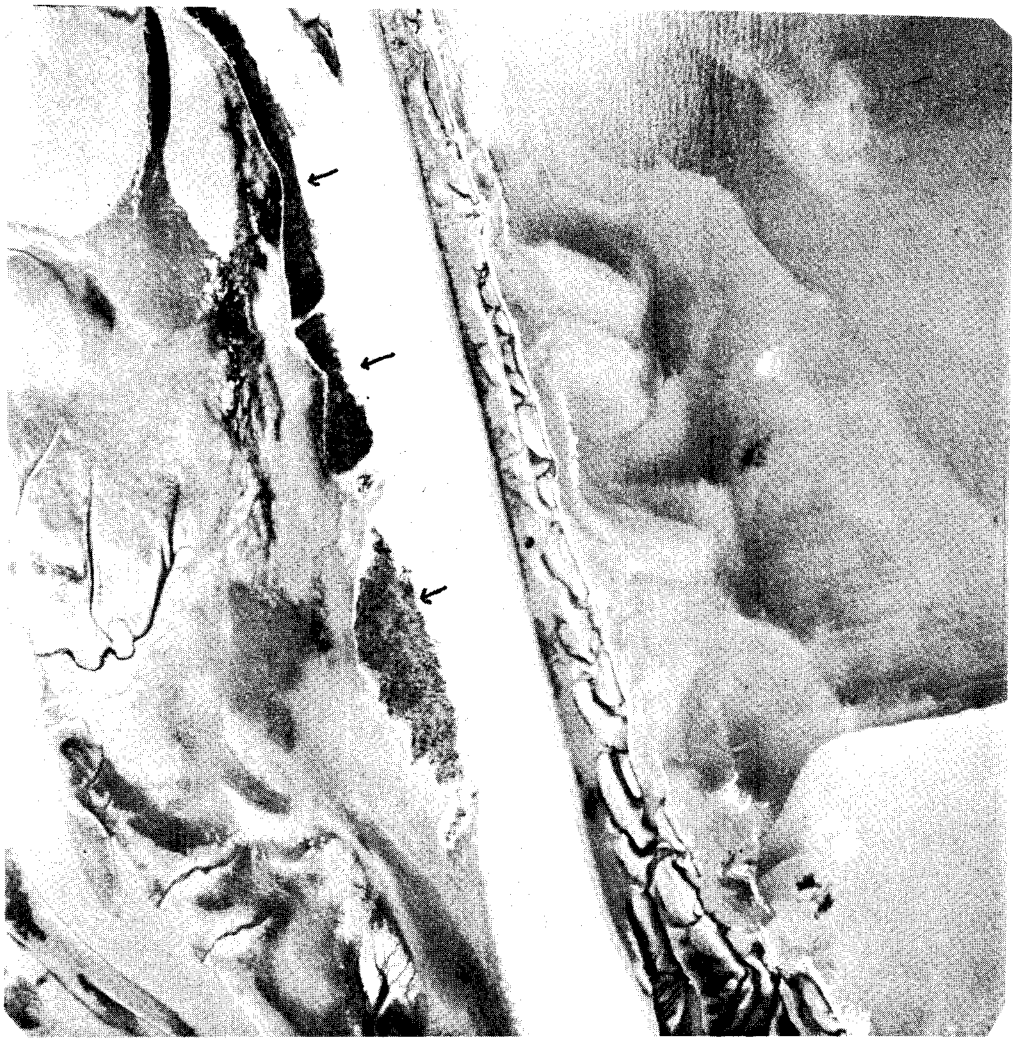


Figure 14 . National Ocean Survey aerial photograph of the central portion of Strawberry Reef, off the east end of the Copper River Delta, 20 July 1970, at high tide. Gull colonies are located on Elymus-covered dunes (arrows). Scale 1:30,000.

IV. Lake Louise

Lake Louise, 8 x 12 km, lies 51.2 km NW of Glenallen, Alaska, in the Copper River Basin of the south central Alaskan Gulkana district, at 62° 20' N, 146° 32' W. The name, of local origin, was reported by Capt. E.F. Glenn, USGS, in 1898 (Orth, 1967). Lake Louise drains through Susitna Lake and the Tyone and Susitna Rivers to Cook Inlet (Fig. 15).

An island gull colony lies 1 km from the west shore of this boreal lake, at 62° 18' 90" N, 146° 34', 00" W. The colony is situated on a steeply sloping rock (100 x 20 x 10 m, 0.36 hectare) under BLM jurisdiction, known locally as "Bird Island." The rocky island shoreline slopes to a wide, shallow, submerged shelf with shoals to the north, east, and west. A gravel spit, the length of which depends upon the lake level, forms the west end of the island (Fig. 16).

Prevailing winds at Lake Louise are southerly. Lake level in 1977, approximately 60 cm above 1976, was due to unusual north winds reducing drainage to Susitna Lake.

Bird Island, radically different in appearance from other spruce-covered islands in Lake Louise, shows evidence of heavy, long-term bird use. Vegetation, composed of lichens, grasses, resistant forbs, woody vines, bushes, and one dead spruce, indicates disturbed conditions. Nitrophilic lichen covers exposed rocks. Bent reed grass (*Calamagrostris canadensis*) forms tussocks on the steep slopes. Fireweed (*Epilobium angustifolium*) and cinquefoil (*Potentilla norvegica*) confirm early

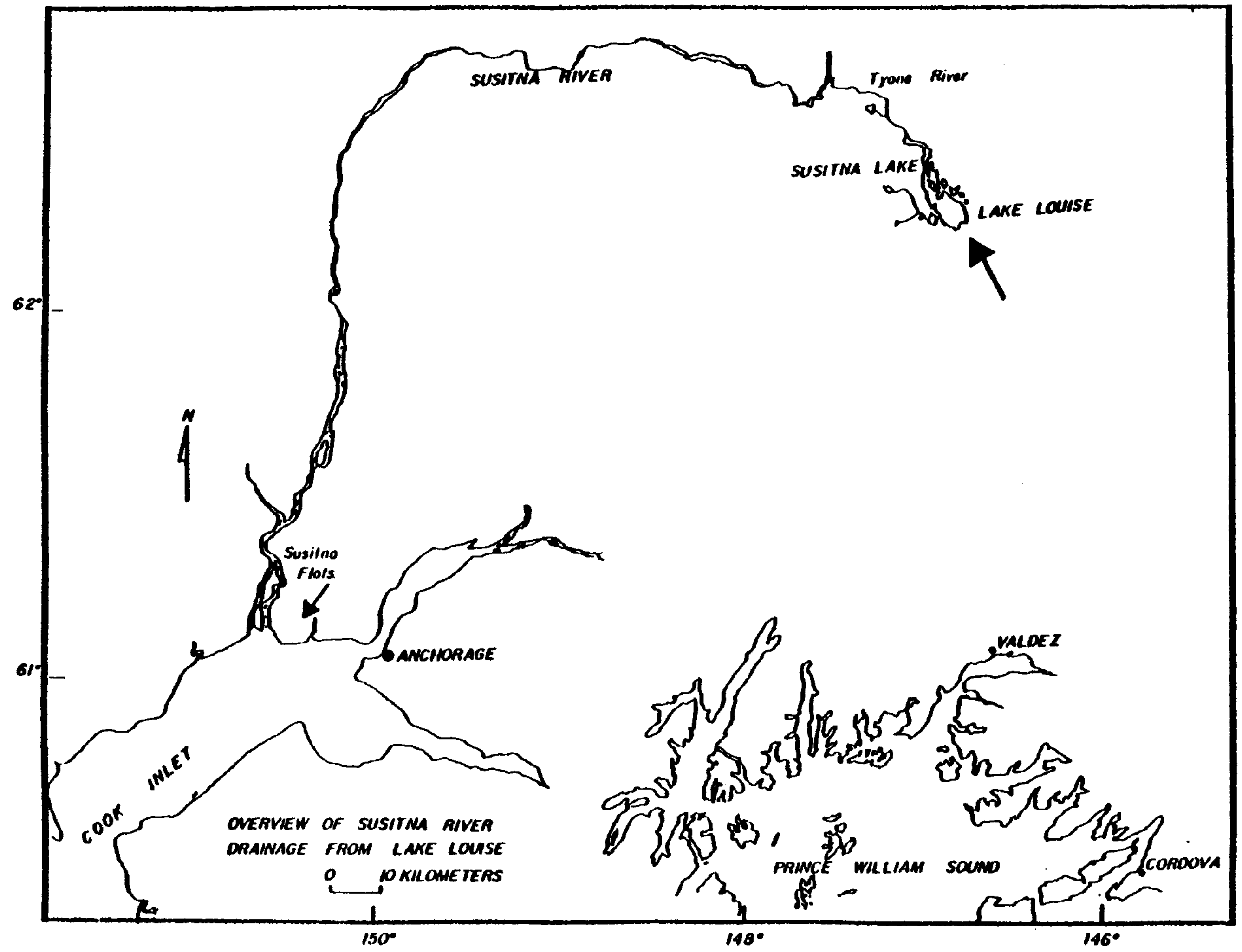


Figure 15. Overview of Susitna River drainage from Lake Louise to Cook Inlet, showing Prince William Sound, Cordova, Valdez, and Anchorage. Lake Louise and Susitna Flats are indicated by arrows. Williamson and Peyton (1963) investigated hybrid gull populations on the Susitna Flats.

successional stages. The air is pungent from the lowland herb Artemisia tilesii. Woody vines (Rubus sp.) and the wild rose (Rosa acicularis) grow on exposed southern sites. Willow bushes (Salix sp.) and three clumps of alder (Alnus crispa) vegetate the northeast slope, while one long-dead spruce stands at the island crest, surrounded by 14 active cormorant nests (Phalacrocorax auritus).

Living plants are absent in the peat formation along the island ridge subject to heaviest bird use. Photographs taken by Hayes (pers. comm.) 15 years ago show little change in island vegetation structure, in contrast to dynamic conditions in gull colonies previously examined. Hayes (pers. comm.) reports gulls and cormorants have inhabited Bird Island for living memory, probably centuries longer. This invites comparison with the biology of gulls on the south coast of Alaska, where change is explosive.

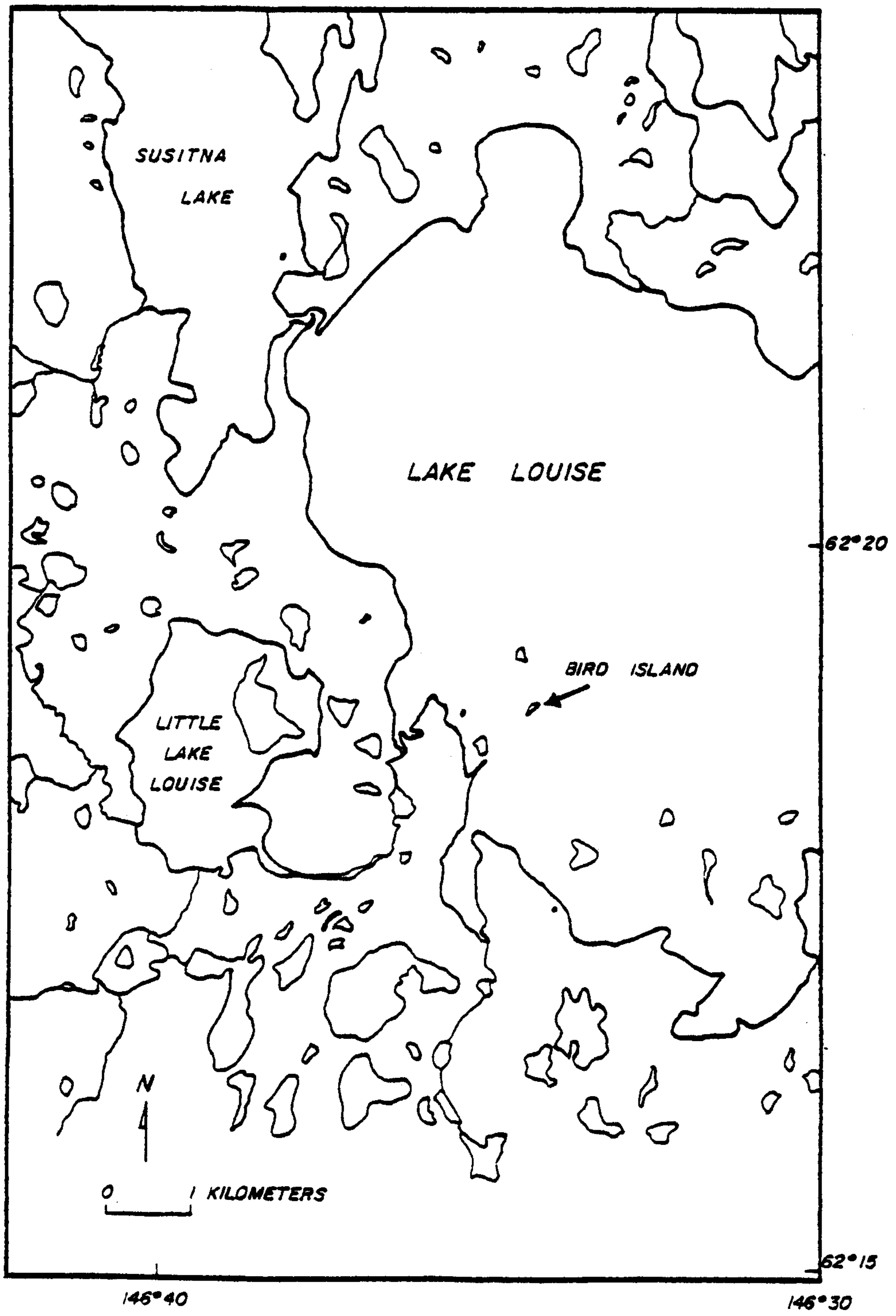


Figure 16. Overview of the Lake Louise area, showing Susitna Lake and Little Lake Louise. Bird Island (arrow) lies 1 km from the west shore of the lake and contains 77 pairs of *Larus argentatus smithsonianus*.

IV. A. Egg Island Itinerary

We spent two field seasons on Egg Island, beginning on 16 June and finishing on 23 August 1975 after most gulls had left. We began the 1976 field season on 20 May, and concluded on 18 August. After an initial aircraft survey of the island, we chose a study area southwest of the Light Tower. The study area was representative of island conditions and could be rapidly located. We spent considerable time examining the rest of the island.

The study area, next to Egg Island Light (60° 216' N, 145° 451' W -- identified on nautical charts), was located on the ocean slope of meadow-covered, partially stabilized dunes at the east end of the island (Figs. 9a,b, 10,11, 12a,b). We measured a 150 m square with a fiberglass tape in June 1975, intending to survey 100 nests. We flagged the boundaries of the study area and counted all nests. The final counts considerably exceeded original estimation: the study area contained 153 active nests in 1975 and 186 in 1976. The survey area remained identical from 1975 to 1976 except for erosion.

The southeast end of Egg Island, bearing the brunt of North Pacific storms, was radically altered by ten to thirteen meters of erosion in nine months (Sept. 75 - May 76). The Coast Guard Light Tower collapsed onto the beach and was replaced. Erosion three meters into the southeast edge of the study area certainly influenced colony structure, perhaps displacement accounting for the increased number of nests in 1976. Deposition of sand, according to the 'drumstick theory,' is now occurring at the thin western end of Egg Island, downstream of the longshore drift, slowly closing Strawberry Channel (Hayes and Boothroyd, 1975). Hayes and Boothroyd report "phenomenal changes" on Egg Island since the '64 earthquake. The uplifted areas and subsequent sand deposits are undergoing plant succession, becoming suitable for gull nesting, giving the gull population unlimited space (Fig. 9 , 10).

B. Yakutat Itinerary

We flew to the Yakutat area for an exploratory survey of gull colonies in June 1974, and first inspected Haenke Island near the Hubbard Glacier by charter boat. We collected adult gull specimens and examined the structure and vegetation of the Haenke Island colony on a 75 m cliff. We then flew from Yakutat to Dry Bay, mouth of the Alsek River, 75 km southeast of Yakutat. We located the Dry Bay colony on advice from ADF&G and local fishermen, and immediately realized many hybrid gulls nested at the site. We collected adult gull specimens, and made a preliminary analysis of the colony structure before returning to Glacier Bay.

We returned to Dry Bay in late June 1975, chartering from Yakutat to the Alsek River, and landing on an empty gravel channel on the gull island in the middle of the river. We completed several days more investigation before a severe storm caused the river to rise and parts of the island to flood, causing us considerable concern. We resolved to spend no more time on the island without some method of egress after the landing area next to the gull colony flooded. A passing fisherman in a skiff assisted us to another gravel island where our charter aircraft landed when the weather cleared.

We studied the Dry Bay colony through the 1977 field season, residing in the Forest Service Upper Alsek cabin, and visiting the gull colony by Zodiac inflatable skiff. We also worked the interior _argentatus_ colony at Lake Louise near Glenallen for several periods during the 1977 field season.

C. Lake Louise

We located the Lake Louise colony in August 1976 at the suggestion of Dr. Williamson, who had made a collection of adult gulls there some years before. We visited this colony in June, July, and August 1977, completing a reproductive study of the site by banding the chicks produced (Table 3).

CHAPTER 3

MATERIALS AND METHODS

I. Colony Selection and Investigation Dates

We selected North Marble, Dry Bay, Egg Island, and Lake Louise as principal locations for reproductive aspects of this study because of their relative importance as gull colonies in south central and southeastern Alaska. Each has distinguishing features and represents the major colony for large geographical areas. North Marble, recently deglaciated, is colonized by pioneering populations of both argentatus and glaucescens. Dry Bay supports a coastal hybrid colony astride a major river migration route to the Yukon. Egg Island contains the largest, still expanding, meadow-nesting glaucescens population in the northeast Gulf of Alaska. Lake Louise "Bird Island" has long been inhabited by migratory interior argentatus.

II. Reproductive Cycle

All nests to be studied were marked with forestry survey stakes at the beginning of each colony investigation. Each heavy wire survey stake had a bright vinyl flag attached. Since vegetation growth tended to obscure the flags by mid-season, each survey stake was marked with an additional sequentially numbered fluorescent vinyl streamer. We used a fiberglass meter tape to find the direct distance from every study nest to the center of the nearest neighboring nest. We left the nest survey stakes in position between field seasons and thus recognized nests from year to year. We measured nest site slope using a Brunton Survey Transit.

As part of each sequential visit through the gull colonies we recorded numbers of eggs and chicks from each nest site inspected in NODC Format 035 "Habitat I." Visits at North Marble averaged once every three days during incubation, and once every six days during the chick stage. Visits at Egg Island averaged once every three days during incubation, and once every three days during the chick stage. We visited the Dry Bay colony every other day.

The plumage and soft-part colors of both parents at each nest site studied at Dry Bay were ascertained using a 25x telescope and a color chart. Chicks hatching at Dry Bay were web-tagged with fingerling fish tags until large enough for banding, enabling knowledge of parents and nest site. Young chicks in other colonies were counted in the nest upon hatching. Older chicks in study areas other than Dry Bay were assigned to the nearest nest; such older chicks were marked at Egg Island with 2.5 cm aluminum bands with number codes which could be read vertically. The web-tagged chicks at Dry Bay, when nearly fledged, were banded with similar 2.5 cm aluminum bands, and an additional 2.5 lynnply plastic band with engraved codes in black alphanumeric characters on the opposite leg. The fledging success at Dry Bay was composed of known, marked individuals whose parentage had been previously established. At the end of the survey period each summer we made counts of fledged banded chicks for entire study areas. The results from North Marble and Dry Bay have been compared to Egg Island and Lake Louise.

III. Materials and Methods of Petroleum Exposure

Our methods include analysis of reproductive productivity at a series of nest sites marked with survey flags. Petroleum exposure to eggs is by drops from microliter syringes with repeating dispensers, with equivalent amounts of non-toxic mineral oil applied to a control sample. Reproductive success/mortality is compared to further controls of "normal" (unexposed) colonies adjacent to the experimental areas. The use of microliter syringes allows for precise manipulation of tiny amounts of petroleum exposure, which is in 20, 50, and 100 microliter doses at three (3) stages of incubation. Petroleum used is North Slope Crude Oil provided by NMFS Auke Bay Laboratory, with commercially available mineral oil as the control.

Experimental results are compared to the standards previously established for "normal" Alaskan gull reproduction (Patten, 1974; Patten & Patten, 1975, 1976, 1977). Egg loss through conspecific predation has been the principal factor influencing hatching success and fledging rate in previous studies.

IV. Marking Methods: Banding

To answer questions of migration routes and wintering areas, and to recognize chicks individually, we banded 5666 gulls during this project. Included in this total are 1300 flightless chicks (20-40 days old) in 1975, 2696 in 1976, and 1200 in 1977. These young gulls were banded on their left tarsi with U.S. Fish and Wildlife Service butt-end aluminum size 7A bands. All the 1975 young *glaucescens* were captured on Egg Island dunes. In 1976, we banded 2500 gull chicks on Egg Island, 95 chicks at Strawberry Reef, and 101 young at Copper Sands (S)--all *glaucescens*.

At the study site (150 m x 150 m) southwest of Egg Island Light, we captured during 1975 every *glaucescens* chick surviving to two weeks age. The 222 individuals were banded on the left tarsus with 1" tall, butt-end aluminum bands, with the reference numbers twice repeated vertically. We counted as fledged 157 of the 222 banded chicks in early August. Due to disappearance of chicks banded early in the 1975 field season, we did not band until chicks were nearly fledged (30+ days old) in 1976. This methods change was to reduce disturbance. We then counted as fledged those 208 *glaucescens* chicks banded in an intensive effort in late July.

At Dry Bay in 1977 we banded 25 known hybrid chicks, 1 known *argentatus* chick, and 403 other gull chicks assigned to *glaucescens*. Study area chicks were marked with web-tags, 2.5 cm aluminum bands, and orange lynnply 2.5 cm bands with engraved black alphanumeric codes (A001-A000), enabling individual recognition of the chicks, assigning them to parents and nest site of origin (Fig. 17).

A group of U.S. Forest Service volunteers assisted our research by banding 700 additional glaucescens chicks on Egg Island in 1977. We banded 71 of the 73 argentatus chicks produced at Lake Louise in early August 1977. All other gulls banded were trapped and released in the Cordova municipal dump.

V. Marking Methods: Color-dyeing

To investigate local and seasonal movements we color-dyed 141 gulls during this study. We marked 100 fledgling gulls with the black dye Nyansol B at the close of the 1975 field season on Egg Island (see Chick Stage, below). We captured 40 adult gulls and one third-year juvenile using snap-traps and a rocket net in 1975, 1976, and 1977. The adult gull and the light-colored juvenile were marked with a saturated solution of picric acid in isopropyl alcohol. This dye, a weakly acidic collagen stain, produced a brilliant yellow color on feathers which gradually oxidized to orange. The yellow dye clearly gave the best results, being visible until completely moulted about nine months later. The Nyansol B, also applied to the recently fledged juveniles in a saturated solution of isopropyl alcohol, was less satisfactory. The rapid sequential moults of the juveniles make them less suitable for color-dyeing except for very short-term studies.

We color-dyed the entire body plumage of the gulls in 1975. The results were striking, even from hundreds of meters

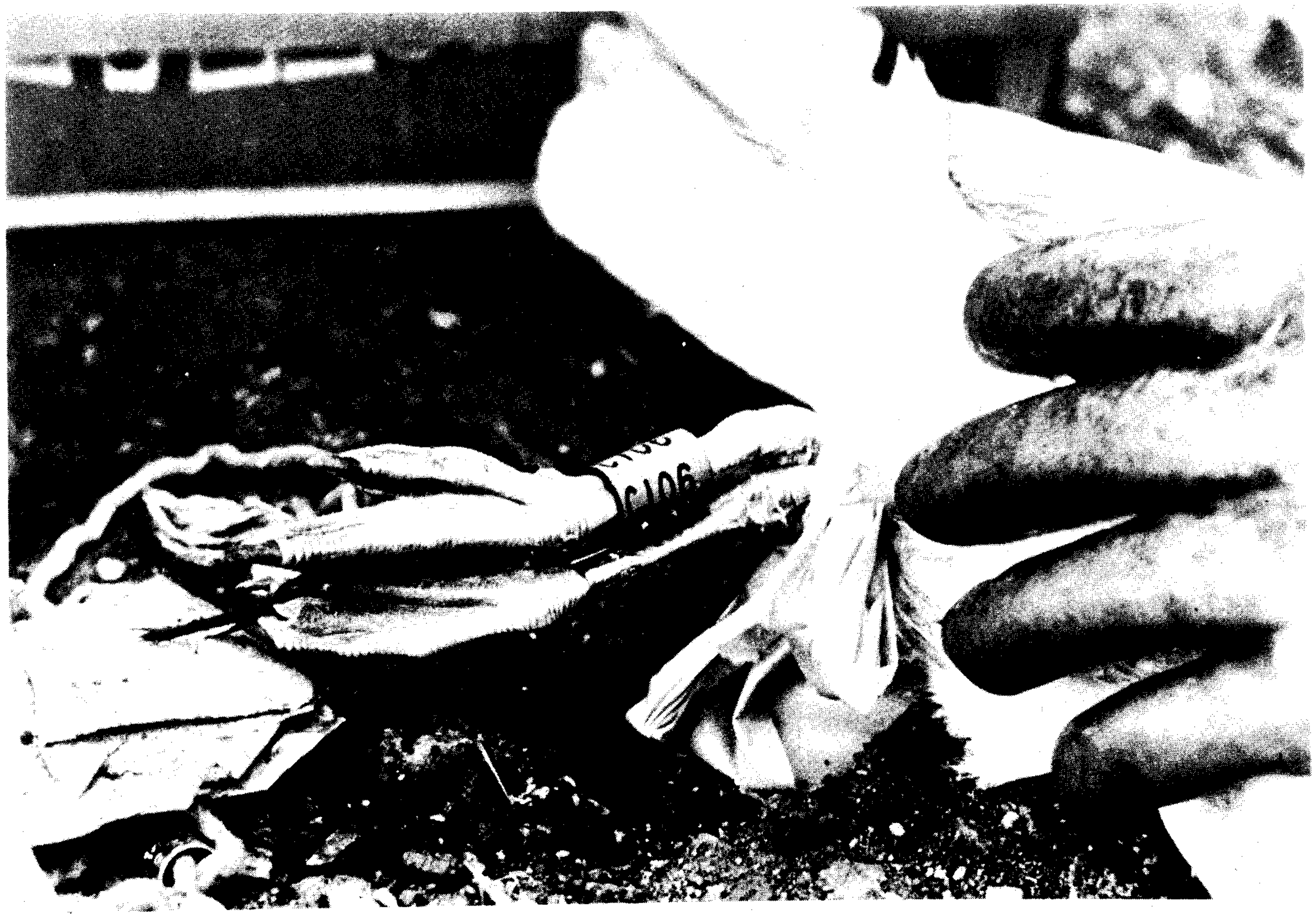


Figure 17. Color-marking studies. A 2.54 cm orange lynply tall tarsal band placed on adult *glaucescens*, with an engraved code for individual recognition. A Fish & Wildlife band has been placed on the other tarsus. Cordova, 1977

Figure 18. Color-marking studies. A color-dyed adult glaucescens marked with a saturated solution of picric acid in isopropyl alcohol. The dye is a weakly acidic collagen stain, which produced a brilliant yellow color on feathers. Cordova, 1977.

away, on the adult gulls. In 1976 we color-dyed adult gulls on their right side only in order to prevent duplication with Fish & Wildlife programs. We color-dyed the entire plumage of adult gulls again in 1977. Each year we avoided marking the orbital region of the head so as to not interfere with gull-to-gull individual recognition. We noted the dyed gulls freely intermingling with others once their plumage had dried (Fig. 18).

VI. Data Analysis

Numbers recorded as part of sequential visits through the gull colonies were entered on 80-column sheets and keypunched following the National Oceanic Data Center Format 035, File Type 'F' - Flat Colony Survey. A custom program written by Mr. Mark Miller of the University of Washington and modified by Mr. Galen Smith of Johns Hopkins Computing Center was used to compute clutch size, egg loss, hatching success, and fledging success for North Marble, Dry Bay, and Egg Island and to portray these variables graphically using the Cal-Comp System on the Johns Hopkins University DEC-system 10 computer.

VII. Study Skins

During this study we collected adult gulls from North Marble Island, Dry Bay, Haenke Island, Strawberry Reef, Copper Sands (S), Egg Island, and Lake Louise, for taxonomic verification, food habits, and serology. A representative series of study skins will be presented to the University of Washington, U. S National Museum, and the American Museum of Natural History.

Table 3

Principle Periods of Study in the Study Areas

Study Area	Periods of Study		
Glacier Bay	1971	17 July - 11 August	
North Marble Island	1972	15 May - 14 August	
North Marble Island	1973	27 April - 9 August	
Outer Coast of Glacier Bay National Monument	1974	23 May - 4 August	
Haenke Island	1974	14 - 15 June	
Dry Bay	1974	17 - 18 June	
Dry Bay	1975	28 June - 3 July	
Dry Bay	1977	4 May - 23 July	
Egg Island	1975	18 June - 18 August	
Egg Island	1976	20 May - 15 August	
Strawberry Reef	1976	29 - 30 June	
Copper Sands (S)	1976	1 July	
Lake Louise	1976	24 - 25 July	
Lake Louise	1977	9 - 10 June; 8 - 10 July; 1 - 3 Aug	
Cordova City	1975	June - August	at intervals
	1976	May - August	
	1977	April - Aug	

CHAPTER 4

RESULTS

A. General Timing of the Reproductive Cycle

1. Dry Bay

Gulls return in late winter from the continental shelf to feed and stage at the mouths of rivers in southern Alaska. Migration takes place in late spring through river valleys to interior Alaska and the Yukon. Early in March 5000 - 10,000 gulls feed on eulachon (*Thaleichthys pacificus*) at the mouths of the Italio, Dangerous and Alsek Rivers southeast of Yakutat (Quimby ADF&G, pers. comm.). Gulls also return to Dry Bay at the mouth of the Alsek River and some become territorial by early May, constructing scrapes and nests at traditional sites (we had marked 100 nests two years previously).

In early May 2000 - 5000 *argentatus* use open gravel areas at Dry Bay as loafing and staging sites prior to migration to the interior along the Alsek River, a natural passageway to the Yukon through the St. Elias Range (4000 - 6000 m). It is most likely at this time of population mixing prior to breeding that *argentatus* become paired with coastal *glaucescens*.

The Alsek is a known migration route, connecting coastal with interior populations of vertebrates (Streveler and Paige, 1971). We observed flocks of 15 - 45 gulls in 'V' formation at 60 - 200 m migrate up the Alsek River valley in both fair and foul weather from May until early June, well after the main migratory wave of other bird species passed. Locally nesting gulls remain quietly on territory while staging and migration continued through May. Herring Gulls appear in the Yukon by mid-May, at which time coastal gulls are beginning egg-laying. Median incubation dates at Dry Bay in 1977 were 24 May - 16 June.

Most gull chicks at Dry Bay hatched by the third week of June 1977, and fledged during the third and fourth weeks of July. Second year immatures appeared on loafing sites close to the main colony by early July 1977.

The general timing of the reproductive cycle at Dry Bay is variable within rather narrow limits depending upon weather conditions and snow cover. Brogle (viva voce) reported heavy snowfall and a late spring for the Yakutat area in 1975. Gulls laid most of their eggs at Dry Bay during the first week of June 1975, in contrast to 1977, when the spring was mild and early, and the gulls laid most of their eggs during mid-May. Dry Bay in 1975 can be further compared to Egg Island of that year. Dry Bay was two weeks delayed from the cycle at Egg Island, since the first eggs at the mouth of the Alsek River pipped at the end of June (Fig. 49). Thus Dry Bay exhibits variability between years approaching three weeks difference in timing of the reproductive cycle.

2. Egg Island

Color-dyed glaucescens from Egg Island leave the Cordova area in October and return in March. Isleib (pers. comm.) reports gulls in April at Egg Island on snow-covered nesting areas. Interior argentatus and hybrid argentatus x glaucescens are present in Cordova through the winters, especially around the canneries, where they are notably absent during the summers.

Breeding populations of glaucescens replacing wintering populations do not commence nest construction until snow melts, usually in late April (Isleib, pers. comm.).

Gulls began egg-laying on 20 May 1976 on Egg Island, and near that date in 1975. The first chicks hatched during the middle of June, and most chicks hatched during the last week of June both years. The peak time of fledging on Egg Island was the beginning of August. Most egg-laying thus took place in the last week of May 1975 at Egg Island, quite similar to 1976. The intervening winter was not especially mild, and snow remained in the lee of the dunes until late May. Thus both seasons were rather similar at Egg Island (Fig. 49).

Lake Louise

Mild winter weather (1976-77) did not skew Lake Louise gull phenology (Hayes, pers. comm.). A few argentatus typically forage for scraps during spring ice-fishing in February and March. Other argentatus arrive in April; most appear during the first week of May, representing a major portion of the migratory wave reported from the Gulf of Alaska by the Fish & Wildlife Service (Lensink, pers. comm.; Table 20). Lake Louise, usually frozen until late May, has loose pan ice which shifts with the wind until melting in early June. Gulls feed in leads along the shoreline until the lake opens.

Gulls begin breeding before the lake is free of ice. Hayes (pers. comm.) annually observes gull courtship on Bird Island by mid-May. Egg-laying occurs during the last week of

May and first week of June. Most eggs are incubated by the first week of June (Fig. 49). Chicks hatching in the last week of June and the first week of July fledge in early August, but remain in proximity to the island through the third week before distributing themselves around the lake.

Hayes (pers. comm.) reports a major gull emigration from Lake Louise in early September 1977; gulls were completely absent by mid-September. Some years Herring Gulls remain until late October when the lake surface freezes completely.

B. Results of Petroleum Exposure to Eggs

To determine threshold levels of petroleum exposure to gull reproduction, we conducted an oiling experiment in a colony at Dry Bay, mouth of the Alsek River, 75 km SE of Yakutat, Alaska. The oil experiment was carried out in an experimental area adjacent to controls known as 'A' and 'B' colonies. Receptors were a mixed group of Glaucous-winged x Herring Gulls (Table 4).

Table 4

Petroleum Exposure Parameters

Sample size		Dose	Date	Approx. Day of Incubation
10 nests	30 eggs	20ul	24 May	1
20 nests	60 eggs	50ul	1 June	8
20 nests	60 eggs	100ul	4 June	11

Petroleum Exposure Results

Table 5

Nests 1 - 10 Time: Onset of Incubation

Dose: 20µl	30 eggs	Date: 24 May	
9/30	=	30%	hatch
6/30	=	20%	"lost" (predated)
15/30	=	50%	failed to hatch

Table 6

Nests 11 - 30 8th day of Incubation

Dose: 50µl	60 eggs	Date: 1 June	
16/60	=	27%	hatch
14/60	=	23%	"lost"
30/60	=	50%	failed to hatch

early (1-2 days) chick mortality
3/60 eggs = 5%

Table 7

Nests 31 - 50 11th day of Incubation

Dose: 100µl	60 eggs	Date: 4 June	
41/60	=	68.3%	hatch
11/60	=	18.3%	"lost"
8/60	=	13.3%	failed to hatch

early (1-2 days) chick mortality
2/60 eggs = 3%

KNOWN EGG LOSS, DRY BAY 1977
EXPERIMENTAL AND CONTROL COLONIES

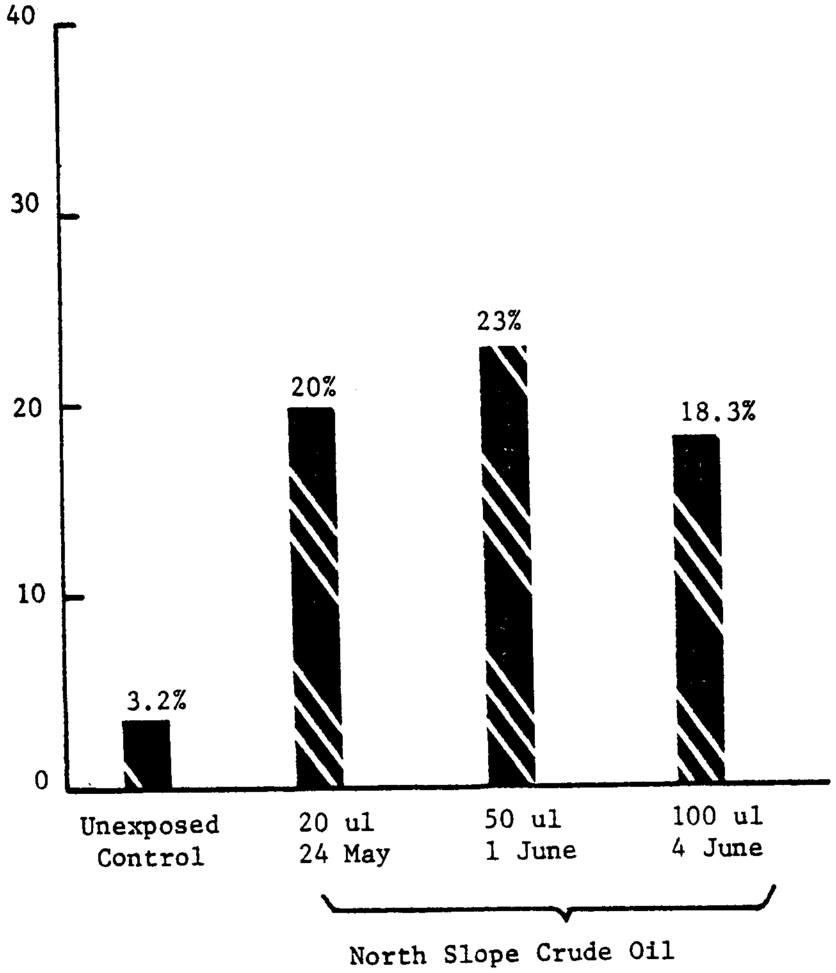


Figure 20

PERCENTAGE EGGS REMAINING IN NESTS (FAILED TO HATCH)
IN EXPERIMENTAL AND CONTROL COLONIES, DRY BAY, 1977

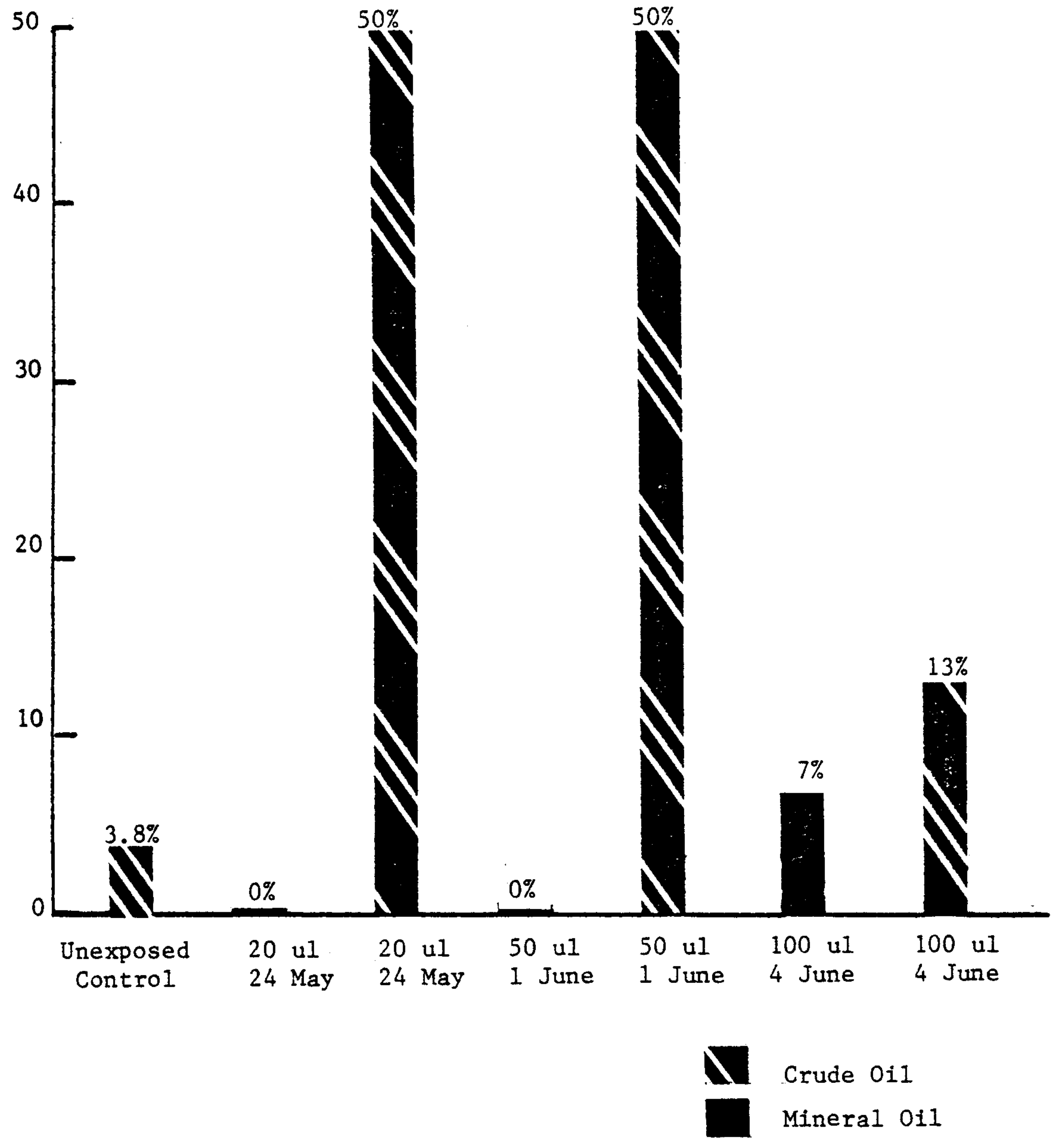


Figure 21

HATCHING SUCCESS, DRY BAY 1977
EXPERIMENTAL AND CONTROL COLONIES

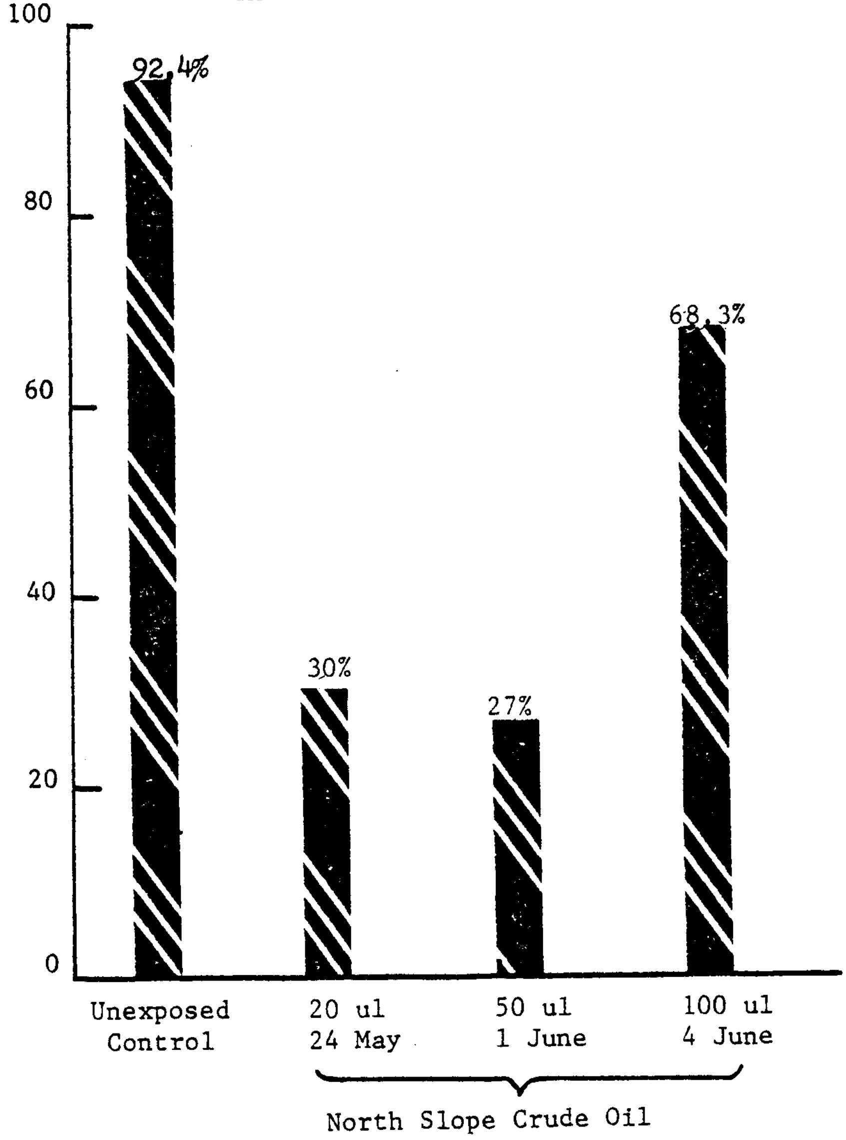


Figure 22

Table 8

Mineral Oil Experiment

7th day of incubation

Nest #	# Eggs	Dose in ul	Failed to Hatch (Eggs Remaining)	Chick Mortality (Known)
51	3	20	0	
52	3	20	0	
53	3	20	0	
54	2	20	0	
55	3	20	0	
56	3	50	0	
58	3	50	0	
59	2	50	0	
60	2	50	0	
61	3	100	0	
62	3	100	0	
63	2	100	0	
64	2	100	0	
65	3	100	1 died pipping	1 dead chick (5 days)
15 nests	40 eggs	3 different doses	mortality not significant	

Our conclusions from the above experiments are: very small amounts of North Slope Crude Oil exposure to gull eggs in the field, at early stages of incubation, lead to high embryonic mortality (Tables 5 , 6). Embryonic resistance to petroleum exposure increases with the duration of incubation (Table 7). Mineral oil in equivalent microliter doses causes no significant mortality (Table 8).

C. Results of Egg Petroleum Exposure on Incubation Behavior

To test alteration of incubation behavior and ability to produce second (replacement) clutches following experimental egg mortality due to petroleum exposure, we conducted the following experiment: at Egg Island, the largest gull colony in the northeast Gulf of Alaska, located 20 km south of Cordova, we chose our experimental and control areas to coincide with our established study site (RU #96 - 76). There were 75 nests in the experimental area, compared to 186 in the adjacent "normal" control colony. The experimental and control areas are located on the ocean slope of stabilized meadow-covered dunes at the east end of Egg Island in proximity to the U.S. Coast Guard Light Tower (Figures 9,10, 11).

Oil was delivered to completed clutches of three eggs at the tenth day of incubation. Fifty clutches (150 eggs) received 1 cc/egg surface application of North Slope Crude Oil, and 25 clutches (75 eggs) received the identical does of mineral oil. Both treatments were delivered by drops from calibrated syringes. The initial dose was selected to be well below the lethal level of oiling for adult waterfowl (7.0 - 3.5 gms) reported by Hartung (1963), but is nearly completely lethal for eggs. Most evidence of petroleum exposure <u>disappeared the next day</u> except for slight petroleum odor.

Observed clutch size in the oiling experimental area initially declined at a rate compatible with normal predation from other gulls (Fig. 23), but in July egg loss accelerated

OBSERVED CLUTCH SIZE

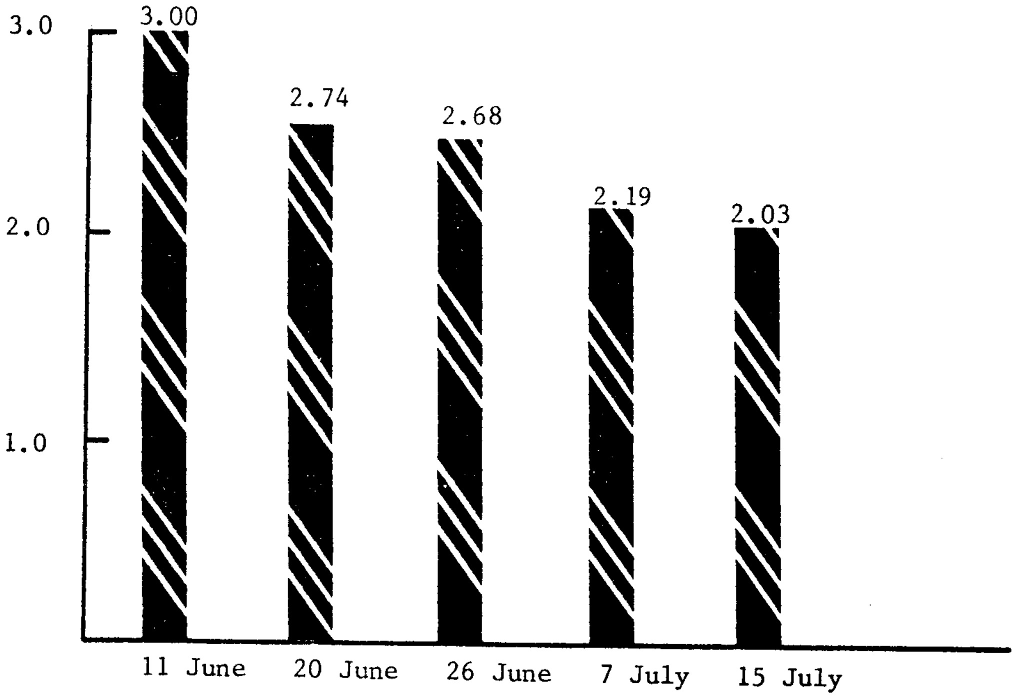


Figure 23. Observed clutch size in the oiling experimental area initially declined at a rate compatible with normal predation from other gulls.

due to adult gulls abandoning unhatched clutches after incubation prolonged 100% longer than normal. At this time we terminated the experiment. A month after hatching began in the adjacent control colony, 33% of eggs oiled with North Slope Crude and 24.4% of eggs to which mineral oil had been applied remained in the nests on 15 July. These figures can be compared to 2% of eggs in the adjacent control area remaining in nests at the end of incubation, a "normal" infertility rate (Figs. 24, 25).

Hatching success in eggs exposed to this nearly completely lethal dose of North Slope Crude was 0.67% (Fig. 26). Mineral oil applied in equivalent amounts to gull eggs led to a hatching rate of 14.6%. North Slope Crude Oil is thus calculated to be 22 times more toxic than equivalent amounts of mineral oil. Hatching success in the adjacent "normal" control colony was 77%; the normal range for these gulls in Alska is 67% - 77%. Adults continued to incubate almost all unhatched clutches at least 20 days longer than normal. Eggs opened at the close of the experiment were highly decomposed and no living embryos were found. Adult gulls nesting in the oiling area produced no more replacement clutches than the neighboring control colony (4.0% vs. 4.8%) (Figs. 28, 29).

Gull behavior is thus altered by the continued incubation of dead eggs. Adults fail to respond with the normal production of replacement clutches, which normally follow clutch loss to natural causes. The combination of high egg mortality and alteration of adult behavior virtually eliminated gull reproduction in the experimentally oiled area.

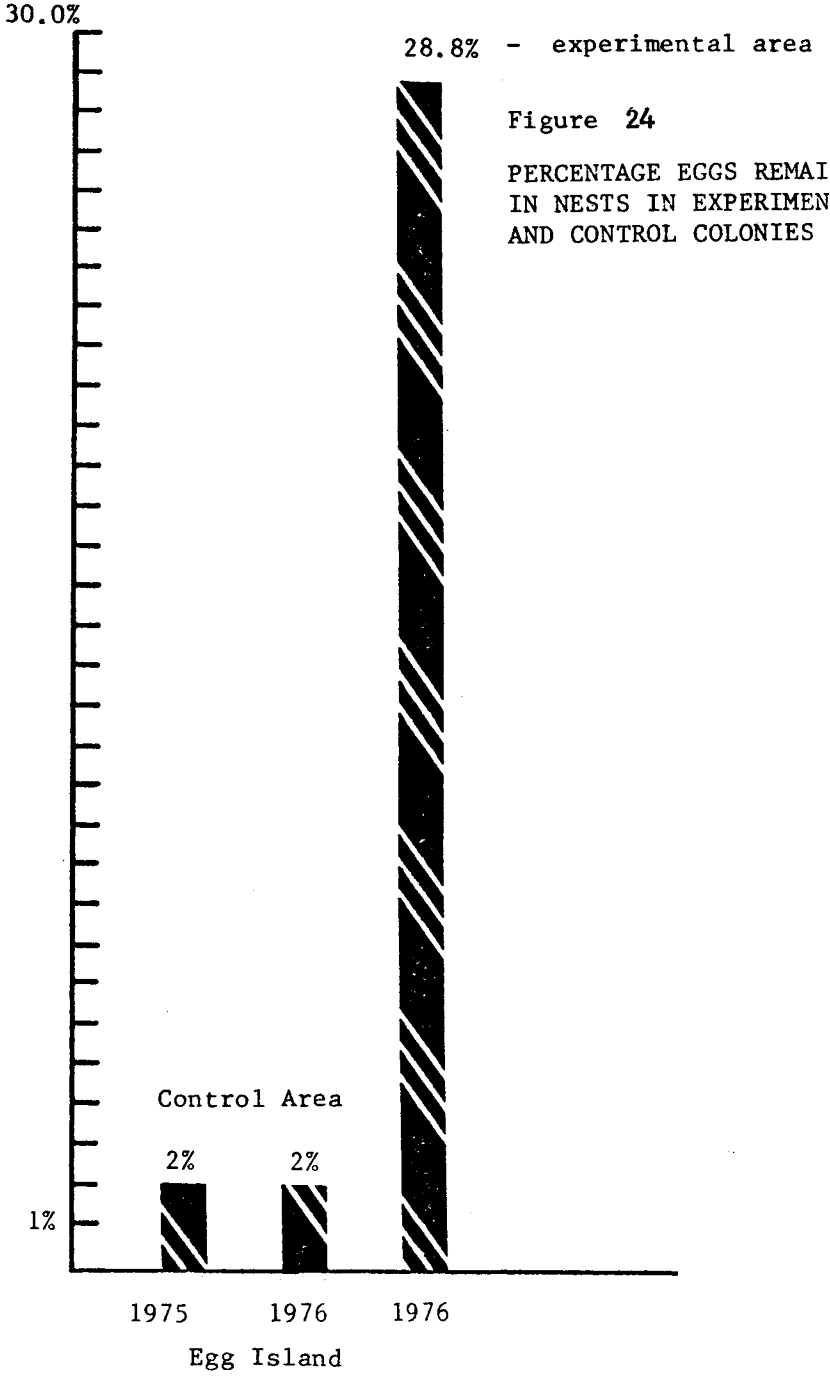


Figure 24

PERCENTAGE EGGS REMAINING IN NESTS IN EXPERIMENTAL AND CONTROL COLONIES

Figure 24. Percentage eggs remaining in nests at close of incubation or experimental period, experimental and control colonies, Egg Island, 1975-76.

Figure 25. A month after hatching began in the adjacent control colony, 33% of eggs oiled with North Slope Crude and 24.4% of eggs to which mineral oil had been applied remained in the nests.

Figure 25.

PERCENTAGE EGGS REMAINING IN NESTS WITH NS CRUDE OR MINERAL OIL

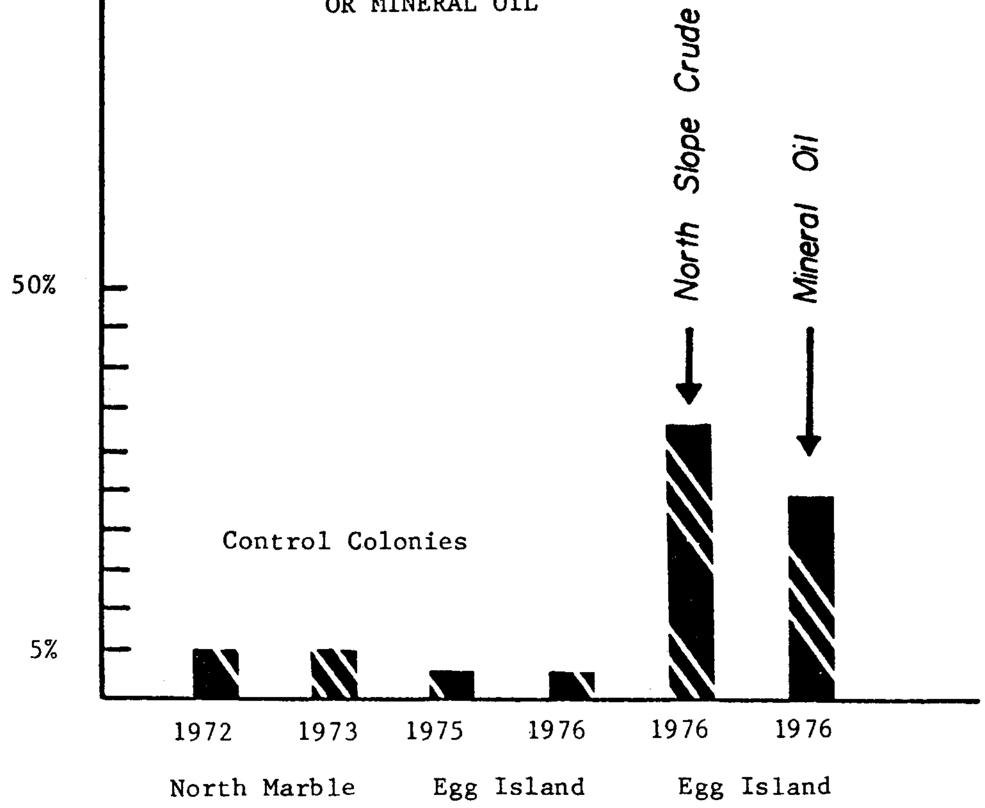


Figure 26

HATCHING SUCCESS

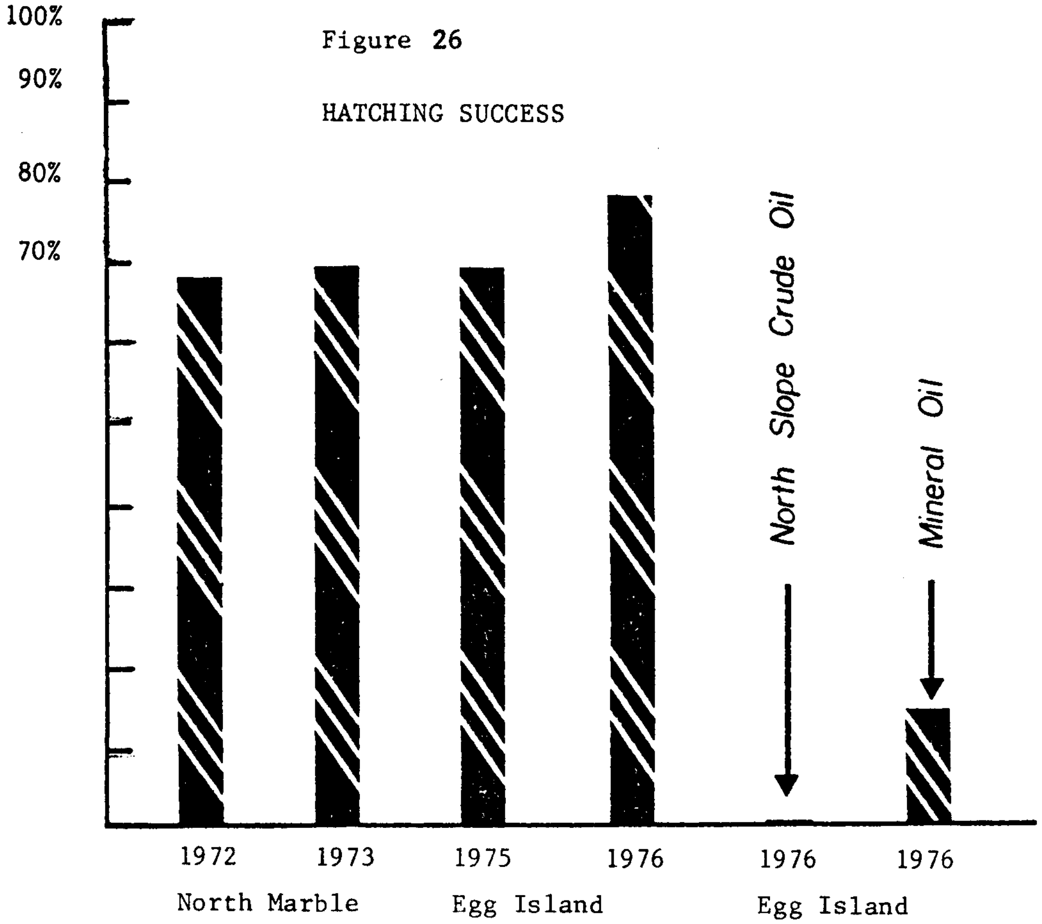


Figure 27

KNOWN EGG LOSS

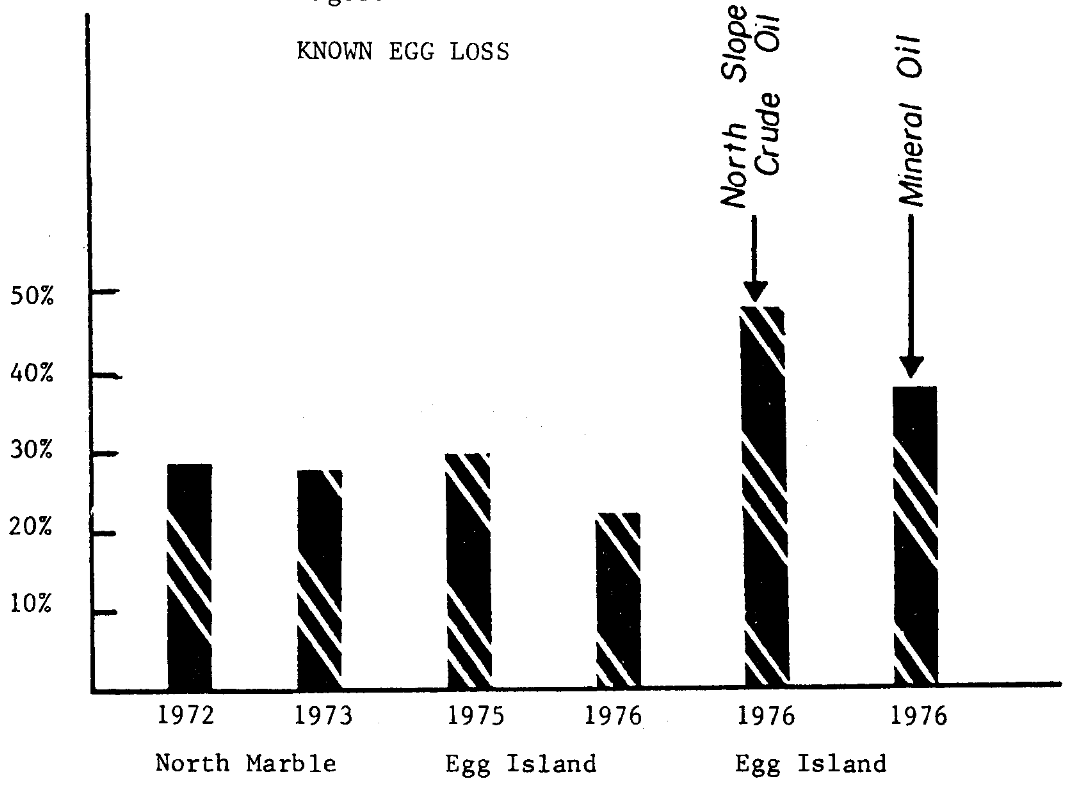


Figure 28

MEDIAN INCUBATION PERIODS, EXPERIMENTAL AND CONTROL COLONIES

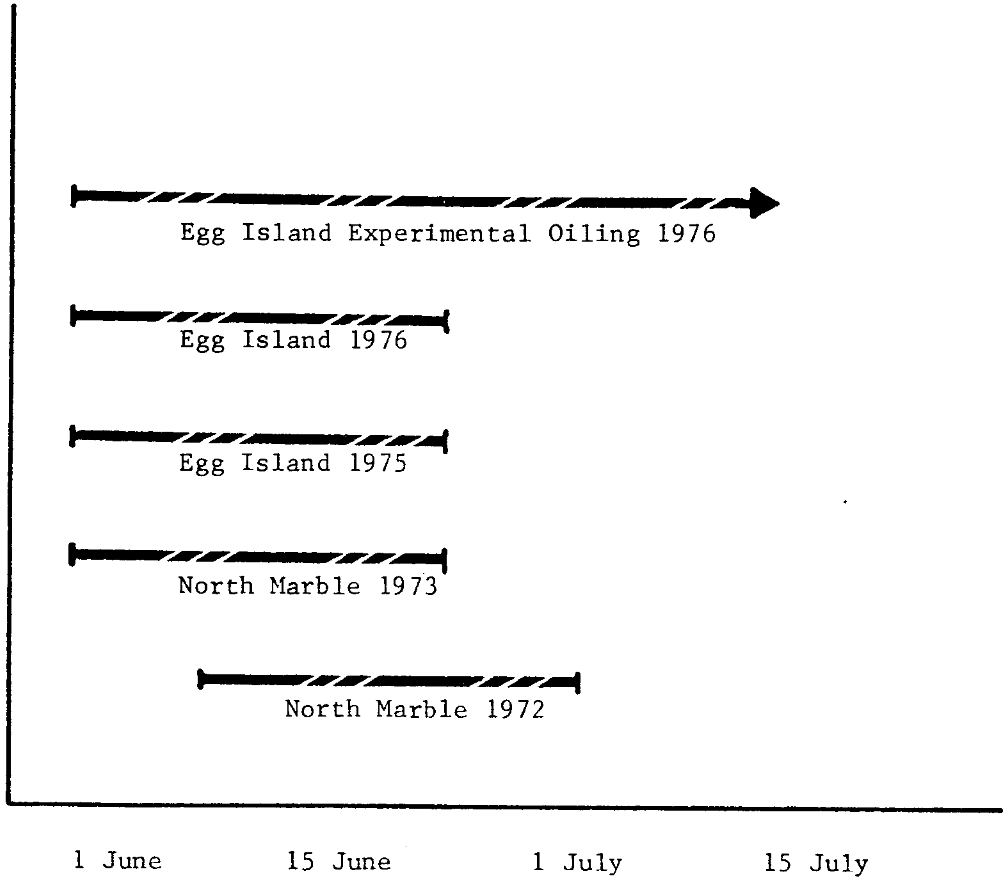
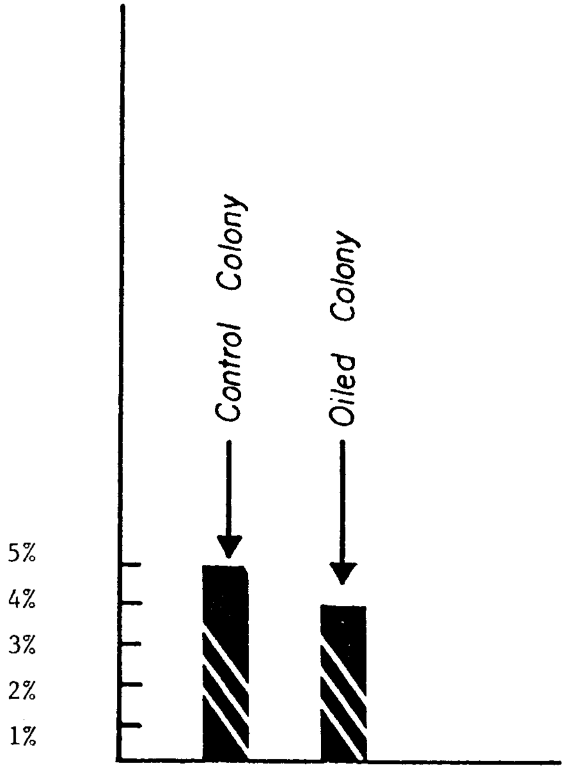


Figure 29

PERCENTAGE REPLACEMENT CLUTCHES, EXPERIMENTAL AND CONTROL COLONIES



D. Breeding Ecology

1. Nest Site Selection: Slope, Substrate and Cover

Southern Alaskan _argentatus_ and _glaucescens_ nest on a variety of substrates ranging from bare cliff ledges in fjords in Glacier Bay to flat gravel bars at Dry Bay to sloping grassy meadows at Egg Island, North Marble and Lake Louise.

Glacier Bay is rather interesting in this context . It is recently deglaciated; while not in the arctic, it approximates high arctic conditions in some areas. Smith (1966b) reported that _argentatus_ are present in small numbers at the heads of fjords around Baffin Island in the eastern Canadian arctic. We also found _argentatus_ in Glacier Bay in fjords close to glacier fronts; _glaucescens_ tend to concentrate in lower regions, more marine, in Glacier Bay, around the Marble Islands and the Beardslee Narrows. But _argentatus_ and _glaucescens_ also nest together on cliff faces near the glaciers. There are apparently insufficient isolating mechanisms in both nesting habitat selection and species recognition because they hybridize. From field notes of 24 July 1971, at William Field Cairn #3, 4 km from the front of Johns Hopkins Glacier, on the north side of Johns Hopkins Inlet, facing the glacier:

> "Sea cliffs. Cliffs several hundred meters long and several hundred meters high in near vertical slope. Sat for several hours--in fact all morning--observing birds from cairn #3. Noted Herring Gulls, Glaucous-winged Gulls, and some intergrades between them in the amount of black on the primaries. Herring Gulls have cat-yellow itis. Glaucous-winged have dark iris. All different amounts of black on wing-tips seen--some just very tips of primaries black, some with just ends and tips of primaries black, and some typical of usual Herring Gulls."

We also observed partially fledged chicks on ledges on the cliff face. In subsequent field seasons we found _glaucescens_ and _argentatus_ nesting together in Glacier Bay on low rocky islets, flat gravelly islets, and sloping grassy hillsides (Table 9 , 10).

Dry Bay, at the mouth of the Alsek River, south of Yakutat and northwest of Glacier Bay, provides different conditions. About 500 pairs of gulls nest on flat gravel bars near the river mouth. The low alluvial islands are washed by high waters following summer storms and snow-melt in the mountains. Vegetation as a consequence of unstabilized substrate plus periodic flooding is sparse and indicates a combined maritime and fresh-water influence. Japanese glass floats found on the gravel bars indicate winter storm tides flood Dry Bay with salt-water. The gull population, hybrids between _argentatus_ and _glaucescens_, reflects these mixed coastal and interior conditions. Vegetation cover is important for nest site selection, since nests are clumped near drift logs, willow bushes and grass patches. Gravel beds where gulls do not nest divide parts of the island colony at Dry Bay (Fig. 3 , 4). When melt-waters combine with heavy rainfall (as a summer storm follows days of sunshine), the river rises and fills the gravel beds. If gulls nested on these gravel beds or too close to the periphery of the island, their nests would be washed away under these conditions. Physical conditions subject to rapid changes influence nest site selection at Dry Bay and in colonies off the Copper River Delta (see Egg Island study area, _in_ Methods), but less so at North Marble and Lake Louise.

_L_. _glaucescens_ and _L_. _argentatus_ and hybrids must be flexible in nesting habitat selection due to the dynamic conditions in which they nest. _L_. _glaucescens_ and _L_. _occidentalis_ also nest in a variety of habitats when sympatric (Scott, 1971; Hoffman, 1976; see also Vermeer, 1963; Coulter et al., 1971).

Thousands of _glaucescens_ at Egg Island nest on stabilized meadow-covered dunes, usually in proximity to old drift logs or _Sambucus_ bushes

(Figs. 9, 10, 11). Slope of the dunes is shallow, averaging less than 3%. The highest dunes are only ten meters above sea level. Egg Island, as North Marble, has highest densities of nesting gulls on completely open meadows. Some sites on North Marble are precipitous, however, approaching 50% slope (Table 10). Gulls in both colonies tend to select breeding habitat where approaching predators can be easily detected. Few gulls nest in brush fringes on North Marble, but some glaucescens nest directly beneath bushes on Egg Island. Brush-nesting glaucescens are previously reported by Vermeer (1963) and Manuwal (pers. comm.) in Puget Sound. Tinbergen (1960) noted nesting argentatus react positively to bushes. Haycock and Threlfall (1975) observed argentatus in Newfoundland nesting in proximity to prominences such as boulders, trees or stumps. This form of nest site attraction may represent previous affinity for cliff-nesting. L. argentatus at Lake Louise nest on a grassy islet with similar slope and substrate to North Marble glaucescens, argentatus, and hybrids (Table 10).

According to Smith (1966), the Larus gulls around Baffin Island freely intermixed only during the few days after arrival in the Arctic, when they occurred together in flocks along the edge of the land-fast ice, and when they moved onto the cliff faces. Habitat separation may reduce the potentiality for mixed matings among gulls in the eastern Canadian Arctic. Knudsen (pers. comm.) is further investigating this topic in Baffin Island and New Brunswick. L. argentatus in the eastern Canadian Arctic tends to select a nesting place on small islets in flat marshy areas (Smith 1966). Despite selective pressure exerted by ground predators, argentatus has not colonized cliff faces. The isolating effect was apparently greatest in Smith's area between argentatus, and the cliff-nesting hyperboreus, thayeri and glaucoides kumlieni. In other areas, such as New Brunswick, Niagara Falls, N.Y., and the Lake Superior shoreline in Wisconsin, *argentatus* nest on cliffs (Emlen, 1963; Harris and Matteson, 1975; Andrle, 1976), and are otherwise plastic in nest site selection. Drury and Nisbet (1972) find *argentatus* in New England highly adaptable to changing circumstances, since the seashore is subject to continuous changes in detail.

Table 9

Nest Site Substrates in Colonies in southern Alaska, British Columbia, and Yukon

Colony	Species Composition	Substrate
Glacier Bay colonies:		
Johns Hopkins Inlet	mixed *argentatus - glaucescens*	bare cliff face
Sealer's Island	mixed *argentatus- glaucescens*	low rocky islet
Tlingit Point	mixed *argentatus - glaucescens*	flat gravelly islet
North Marble	mixed *argentatus - glaucescens*	sloping grassy hillsides
Dry Bay	mixed *argentatus - glaucescens*	flat alluvial gravel bars
Haenke Island	*glaucescens*	grassy cliff terraces
Strawberry Reef	*glaucescens*	*Elymus*-covered dunes
Copper Sands	*glaucescens*	*Elymus*-covered dunes
Egg Island	*glaucescens*	*Elymus*-covered dunes
Lake Louise	*argentatus*	sloping grassy islet
Dezadeash Lake Y.T.	*argentatus*	boreal lake forested islet shores
Atlin Lake, B.C.	*argentatus*	low rocky islet

Table 10

Nest Site Slope in Colonies in southern Alaska (% slope)

Colony	Species Composition	Mean	Range	S.D.	n
North Marble	mixed	16.2	1 - 48	15.7	9
Dry Bay	mixed	0	0	0	112
Egg Island	*glaucescens*	2.8	0 - 8	2.4	186
Lake Louise	*argentatus*	15.9	1 - 50	14.9	50

2. Territory Size

The definition of territory, as Hinde (1956) states, is "any defended area." This definition does not necessarily imply the defended area is sharply delimited, but in practice many workers on territory (references in Hinde, 1956) imply the existence of such borders by measuring territory size. Using the measure of territory for gulls defined by Harpur (1971), we calculated the area of each nesting territory as a circle with a radius half the distance to the nearest active nest. In reality, gulls do not defend neat circles. Actual territory size depends upon the stage of the reproductive cycle, expanding with hatching of chicks, and declining as chicks grow older (Hunt & Hunt, 1975). Nevertheless we have elected to use Harpur's measure because it is standardized and can be compared to other studies. The distance to nearest neighbor, upon which we calculate territory size, may be an important factor in determining gull chick survival (Hunt & Hunt, 1975).

Patten (1974) previously reported a mean territory size of 18 m^2 for the colony at North Marble, but territory size varied from sub-colony to sub-colony and from year to year (Table 12). At Dry Bay 'A' colony in 1975 mean territory size was 29.8 m^2, suggesting room for more breeding pairs (mean distance to nearest neighbor was 6.16 m^2). Mean territory size at Dry Bay 'A' colony in 1977 was quite similar, 30.9 m^2, with virtually the same number of pairs inhabiting the identical survey area. Dry Bay 'B' colony in 1977, which had not been previously surveyed, was less densely utilized, with a mean territory size of 48.51 m^2 and a relatively large internest distance of 7.86 m. Both 'A' and 'B' colonies produced well over one chick per nest to fledging (Table 11).

Table 11

Gull Reproductive Parameters, Dry Bay 1977

	Colony 'A' - 300 m x 50 m	Colony 'B' - 30 m in Ø
Clutch Size	2.94 (90 nests - 265 eggs)	2.86 (22 nests - 63 eggs)
Egg Loss	10 (3.8%)	7 (11.1%)
Infertile Eggs	8 (3%)	0
'Pipped' but failed to hatch	2 (.8%)	0
Hatching Success	245/265 (92.4%)	59/63 (93.6%)
Chick Loss	111/245 (45.3%)	31/59 (52.5%)
Chicks Fledged	134	28
Fledging Success	1.49 chicks/nest	1.27 chicks/nest
	or 50.5% chicks fledged/eggs laid	44.4% chicks fledged/eggs laid
	or 54% chicks fledged/chicks hatched	47.5% chicks fledged/chicks hatched

NOTES: 1 supernormal clutch of 4 eggs in 'A' colony, which hatched. (1/90 = 1.1%)

1 replacement clutch of 3 eggs in 'A' colony. (1/90 = 1.1%)

Chick loss was due mostly to sustained, heavy eagle predation (eagle nest within 2 km of the gull colony).

Chick loss was clearly the major factor influencing fledging success at Dry Bay in 1977.

Mean territory size on Egg Island in 1975 was 28.9 m^2. (mean distance to nearest neighbor was 6.06 m) (Table 12). Territory size, as at Dry Bay, remained practically identical the next season surveyed, but there were 20% more nests in the study area (30.2 m^2; mean distance to nearest neighbor 6.2 m^2). This suggests gull pairs distribute themselves due to social attraction at this density but clearly do not use all available space (weighed mean territory size for 1975 and 1976 was 29.6 m^2).

The migratory population of *argentatus*, breeding at the interior Lake Louise in 1977, showed a mean territory size of 13.5 m^2 and a mean internest distance of 4.3 m. 77 pairs bred in a relatively confined area of 0.36 hectare on a lake islet (Fig. 16; Table 12).

We found large differences in internest spacing and territory size for *glaucescens* breeding on grassy meadows on Egg Island and the mixed colony dominated by *glaucescens* at North Marble, also nesting on grassy meadows. Hybrid gulls nesting on gravel bars at Dry Bay and *glaucescens* on meadow-covered dunes on Egg Island had similar territory sizes (Table 12). Notable is the large territory size at both Egg Island and Dry Bay. The study area at Egg Island showed an increased number of pairs the second field season, while the Dry Bay colony did not. The *argentatus* nesting on the sloping grassy meadows at Bird Island at Lake Louise had small territory sizes, in sharp contrast to large portions of the meadows on Egg Island, not even colonized due to recent ('64) earthquake activity doubling the island surface area. This suggests interior *argentatus* are close to using all available nesting space, but other *argentatus*-group populations are flexible in internest distances and are not limited by available nesting space in their northeast Gulf of Alaska breeding sites. It is not unreasonable to expect increasing gull populations in coastal districts, with an increasing food supply due to human activities. This is especially true off the Copper River Delta.

Since territory, as expressed as a multiple of the distance to nearest neighbor, may be important in determining gull reproductive success, we have explored the influence of territory size by plotting various parameters against it. We have plotted mean clutch size, egg loss, chicks hatching, and chicks fledging against mean territory size by colony and by year. The results are presented in the following Figures: clutch size against territory size (Figs. 34, 35, 36, 37); egg loss against territory size (Figs. 45, 46, 47, 48); chicks hatching against territory size (Figs. 57, 58 , 59, 60) and chicks fledging against territory size (Figs. 65, 66, 67, 68).

3. Clutch Size

Clutch size is one of the important parameters determining the reproductive success of gulls. The seriousness of hatching failure, or chick loss, is partially determined by the clutch size. Reproduction can be maintained if the mean clutch size is sufficiently high before predation or other egg loss. A gull population with a higher mean clutch size can support a greater rate of hatching failure or chick loss than a population with a lower mean clutch size.

Clutch size in southern Alaskan gull colonies ranged from 3.0 to 2.1, both in North Marble Island colonies (Table 12). The weighted mean clutch size for the North Marble population, however, was quite high (2.80 in 1972; 2.96 in 1973). Only the Top Colony had a significantly lower clutch size compared to other sites in 1972 (2.1; $p < .05$, Duncan Multiple Range Test). This was correlated with significantly larger territory size (Table 12; Fig. 34). There were no significant differences between colony sites in 1973 in either clutch or territory sizes (Table 12; Fig. 35).

Dry Bay 'A' and 'B' colonies were not significantly different from each other in clutch size in 1977, nor were they significantly different from North Marble (1972-73), once again with the exception of the Top Colony in 1972 ($p < .05$, Duncan Multiple Range Test).

The interior <u>argentatus</u> population at Lake Louise had an intermediate mean clutch size of 2.7 and the smallest territories of any colony due to restricted nesting space (Table 12). The colony with the lowest mean clutch size, after the small, marginal Top Colony at North Marble in 1972, was Egg Island (Table 12). The plot of clutch size against average territory size on Egg Island (1975-76), compared to North Marble Island (Figs. 31, 32), showed territory sizes were larger on Egg Island but clutch sizes were smaller.

The conspicuous exception was the Top Colony on North Marble in 1972, which resembled Egg Island.

We suggest age of the female as the most important factor influencing clutch size in southern Alaskan gull colonies. Clutch size increased in the North Marble Island Top Colony as the females became older and more experienced. This influenced reproductive success as measured in chicks fledged. Territory size was inversely related to clutch size because of the tendency of young, inexperienced pairs to nest on the periphery of the colony, in marginal sites, or in newly colonized areas, where internest distances (upon which we calculate territory size) were larger. This has important implications for the growth of the Copper River Delta gull populations in that clutch size and fledging success of these populations may increase over time, given sufficient sources of artificial food (see below).

Table 12. Clutch Size, Number of Fledglings, and Territory Size in Southern Alaskan Gull Colonies, 1972-1977

Colony/Year		Number of Nests Examined	Mean Clutch Size	Mean Number of Fledglings	Mean Territory Size (m^2)
North Marble	1972				
East		94	2.8	1.8	14.3
West		36	2.9	2.2	18.3
North		20	2.8	1.5	32.7
Top		12	2.1	0.4	52.1
Total		162	2.8*	1.75*	20.2*
North Marble	1973				
East		104	3.0	1.6	14.0
West		60	2.9	2.2	12.5
North		15	3.0	1.7	36.1
Top		12	2.9	1.6	36.9
Total		191	2.96*	1.80*	16.7*
Dry Bay					
'A' Colony	1975	100	--	--	29.8
	1977	90	2.9	1.5	30.9
'B' Colony	1977	22	2.9	1.3	48.5
Egg Island	1975	153	2.4	1.0	28.8
Egg Island	1976	186	2.4	1.1	30.2
Lake Louise	1977	77	2.7	0.9	13.5

* weighted means

4. Egg-Laying

Gulls at North Marble, Dry Bay, Egg Island, and Lake Louise began to lay eggs in mid- to late May without regard to taxonomy. A remarkable degree of synchronization was apparent when comparing percentages of eggs found in sequential dates of observation through the nesting period (Figs. 38 , 39, 40). There was a strong tendency in these colonies for the majority of eggs to be laid in just over one week.

Egg-laying on North Marble was closely synchronized in all subcolonies, although most eggs were laid two weeks earlier in 1973 than in 1972. In 1972, 50% of eggs were laid in a seven day period in late May (Fig. 38). In 1973, 60% of eggs were laid between June 5th and June 7th. The evidence from North Marble indicated not only a colony-wide synchrony, but a synchronous egg-laying in four partially contingent colonies, suggesting the gulls on North Marble were acting as one large colony.

The Dry Bay colony demonstrated flexibility in timing of breeding from year to year, as at North Marble (see pp.52-3), but synchrony once the process began (Fig. 39). Gulls at Dry Bay laid 50% of eggs in an eight day period between May 15th and May 23rd, a pattern quite similar to North Marble.

The colony at Egg Island had 50% of eggs laid in just over one week, between May 30th and June 7th, similar to Dry Bay and North Marble (Fig. 38).

Incubation in Alaskan glaucescens did not begin until after the clutch of three was completed, usually about a week after the first egg was laid. Mean interval between eggs was two days (Patten, 1974). The onset of incubation at North Marble, Dry Bay, and in the Egg Island study areas was quite synchronized, and began immediately after the week in which most eggs were laid.

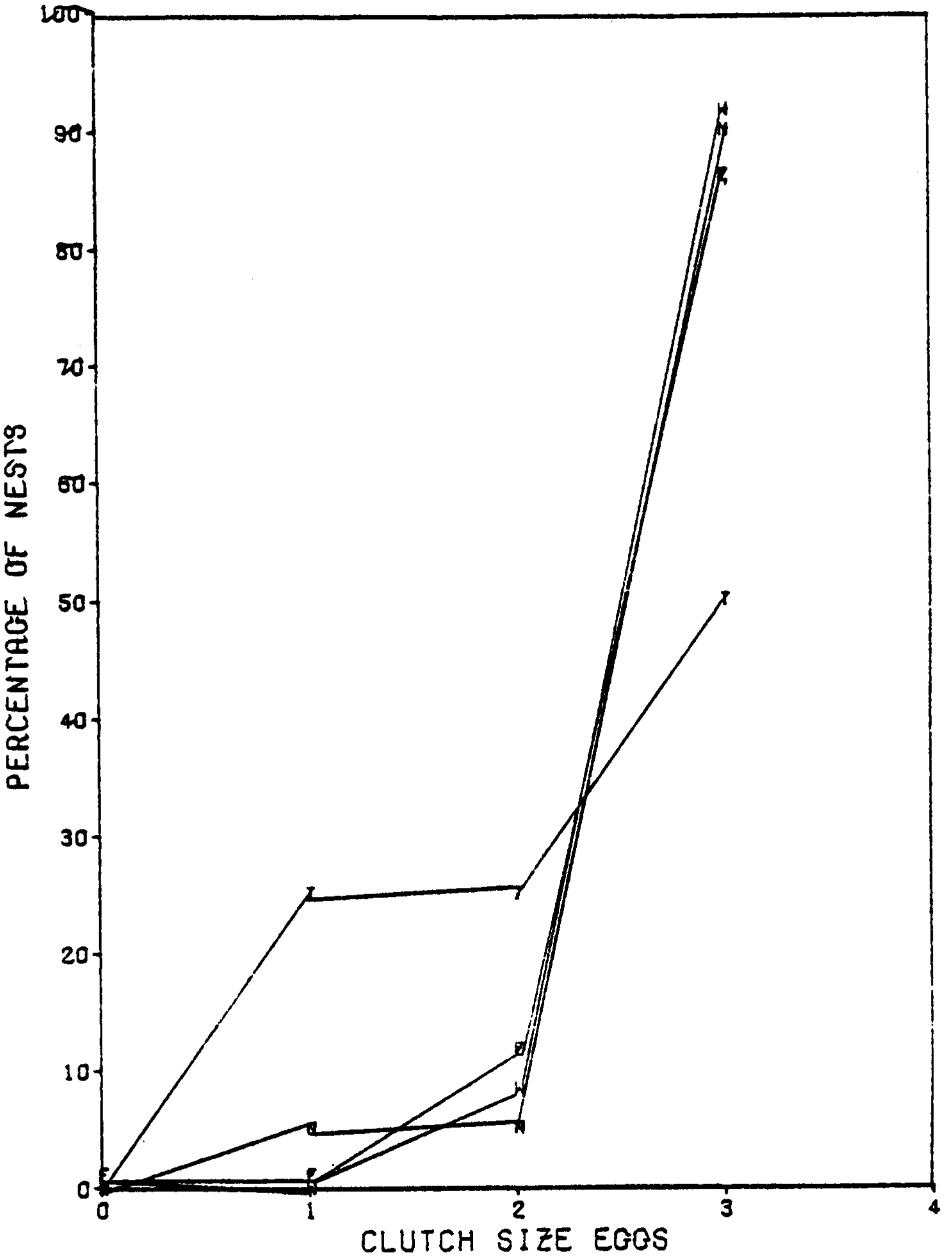


Figure 30. Clutch size plotted against percentage of nests, North Marble Island, 1972.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.
The Top Colony is different in clutch size; East, West, and North are similar.

The most likely explanation for the difference is young females laying for the first time produce smaller clutches.

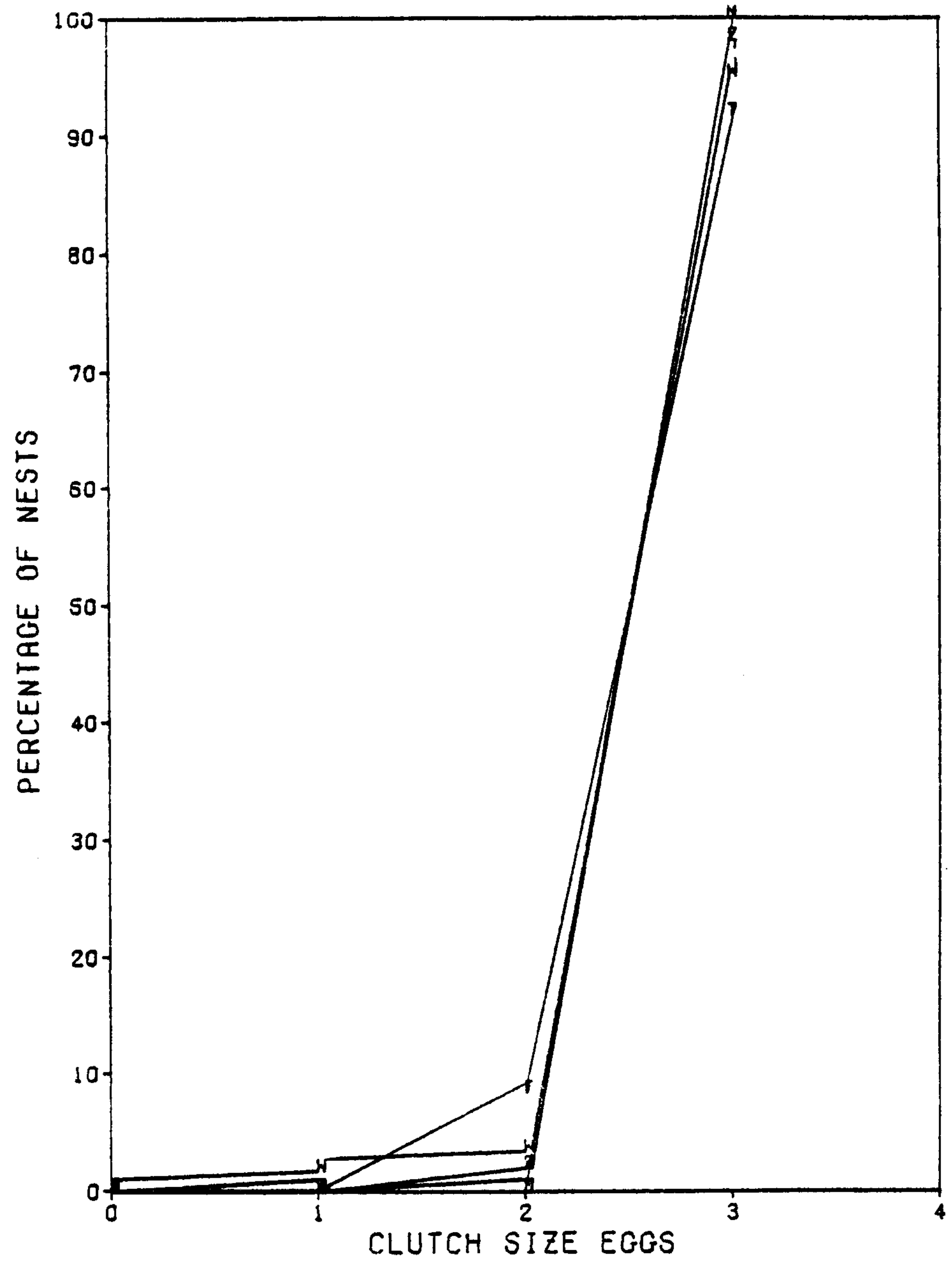


Figure 31. Clutch size plotted against percentage of nests, North Marble Island, 1973.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

All colonies show similar tendencies.

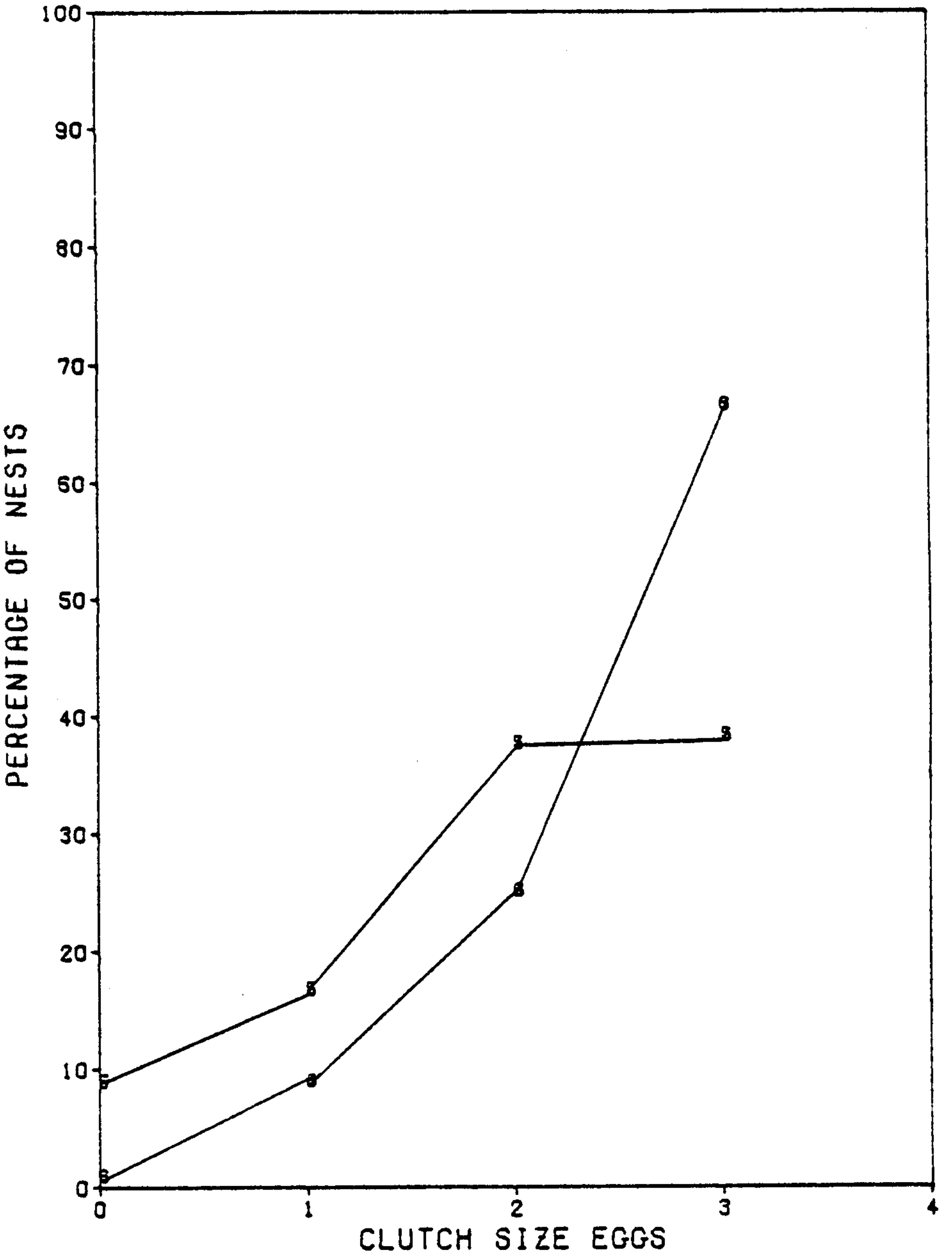


Figure 32. Clutch size plotted against percentage of nests, Egg Island 1975 - 1976. 5 = 1975 survey, 6 = 1976 survey.

Clutch size is smaller on Egg Island than on North Marble, probably due to the expanding population on Egg Island, with a higher percentage of young females producing smaller clutches. Egg Island most resembles the Top Colony on North Marble in 1972.

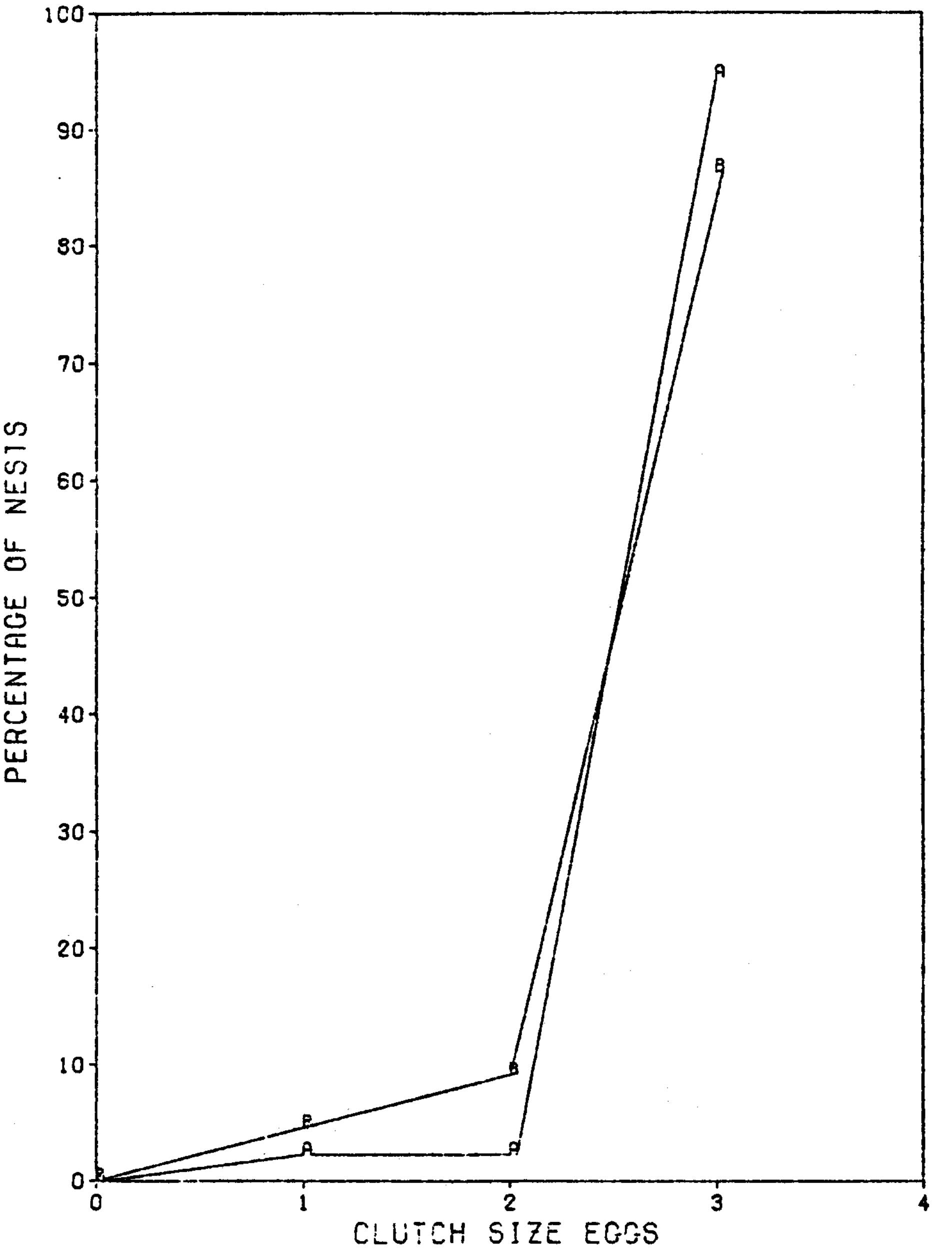


Figure 33. Clutch size plotted against percentage of nests, Dry Bay, 1977.
A = 'A' Colony, B = 'B' Colony

Both colonies are similar in clutch size and resemble clutch sizes on North Marble in 1973.

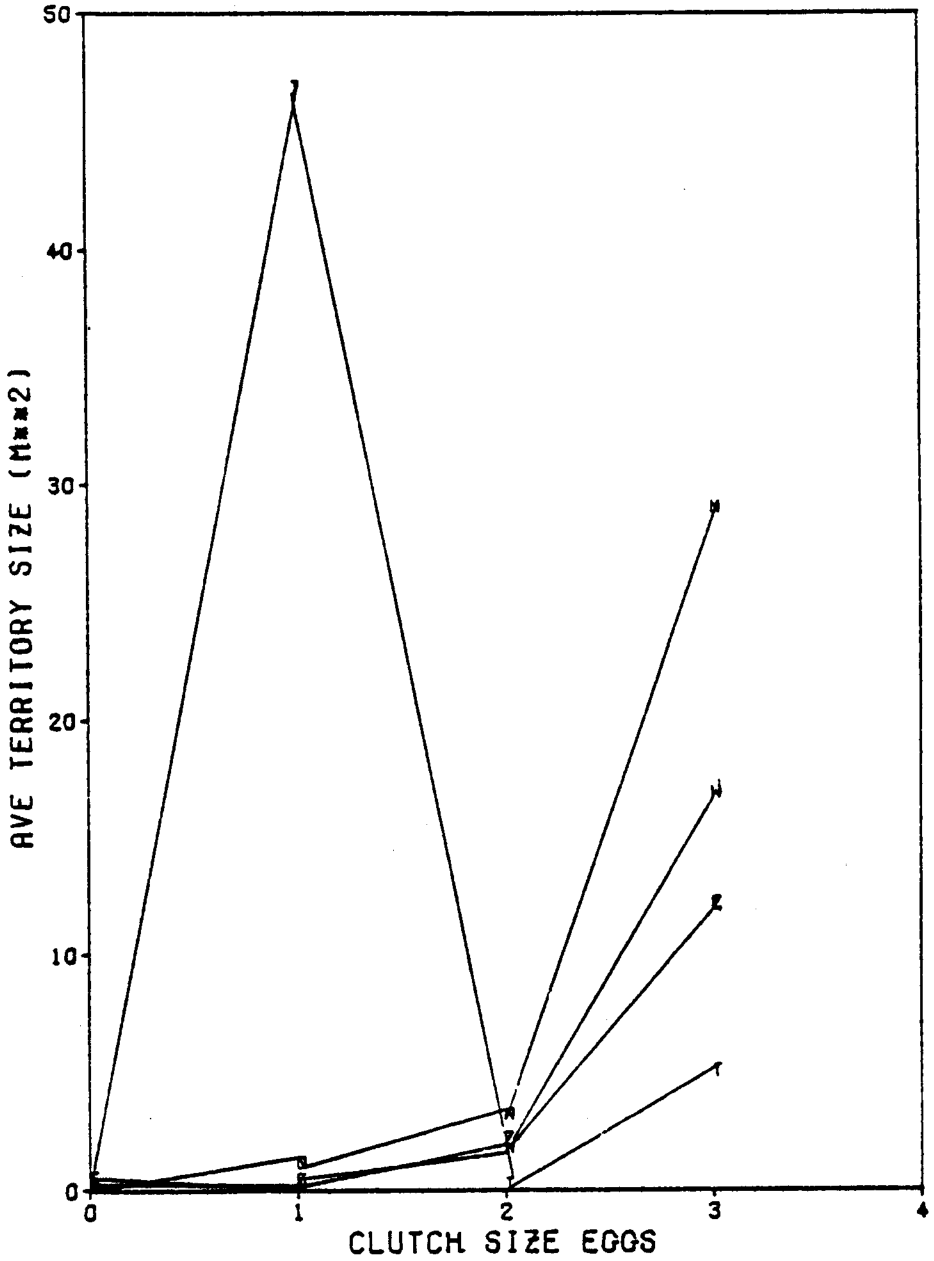


Figure 34. Clutch size plotted against average territory size, North Marble, 1972.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

East, West, and North Colonies show rather similar tendencies. Top Colony is strikingly different, with a large mean territory size and concurrent 1-egg clutches.

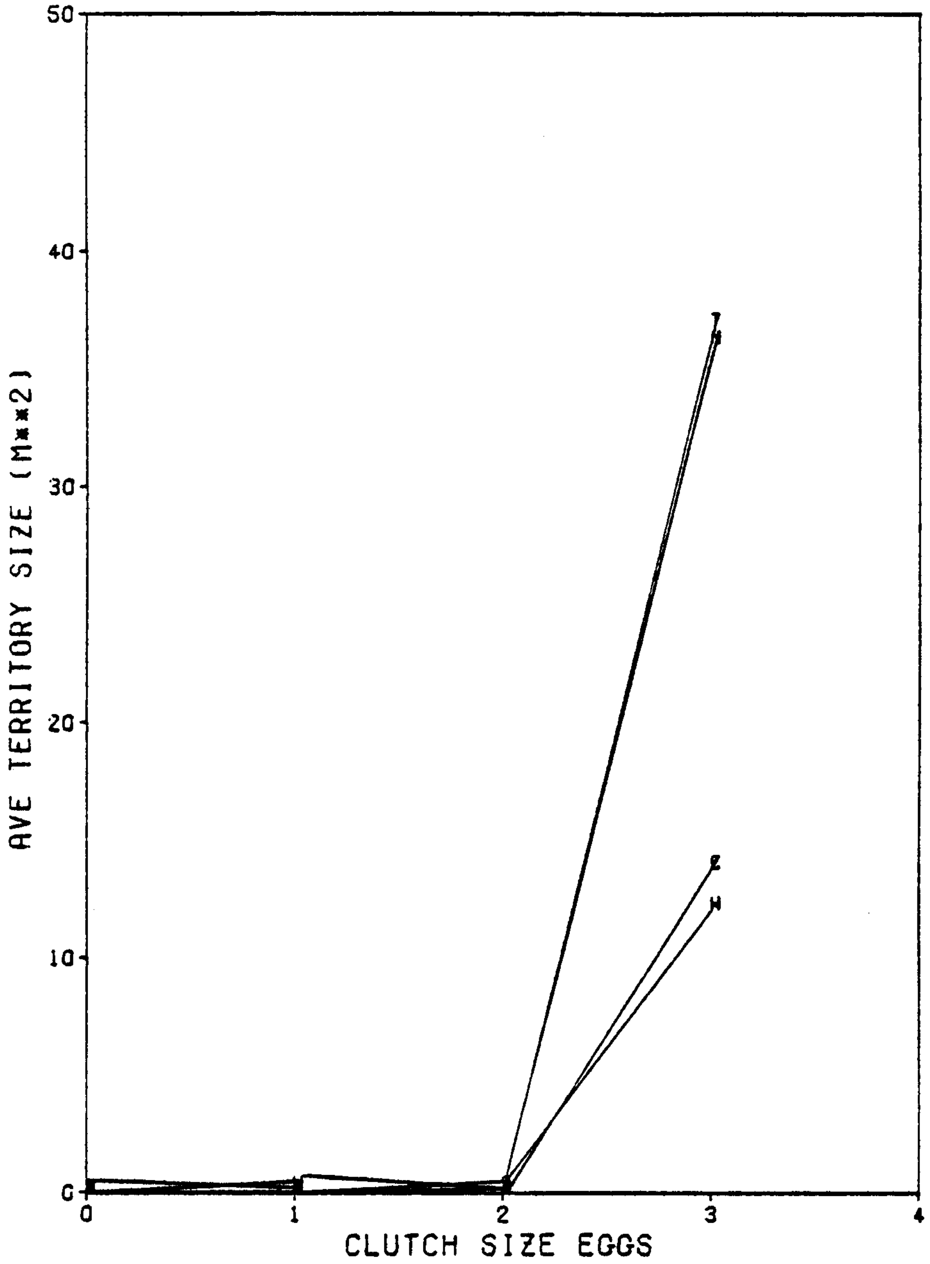


Figure 38. Clutch size plotted against average territory size, North Marble, 1973.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

East and West Colonies are close in average territory size, as are Top and North Colonies. However all colonies exhibit a high proportion of three-egg clutches.

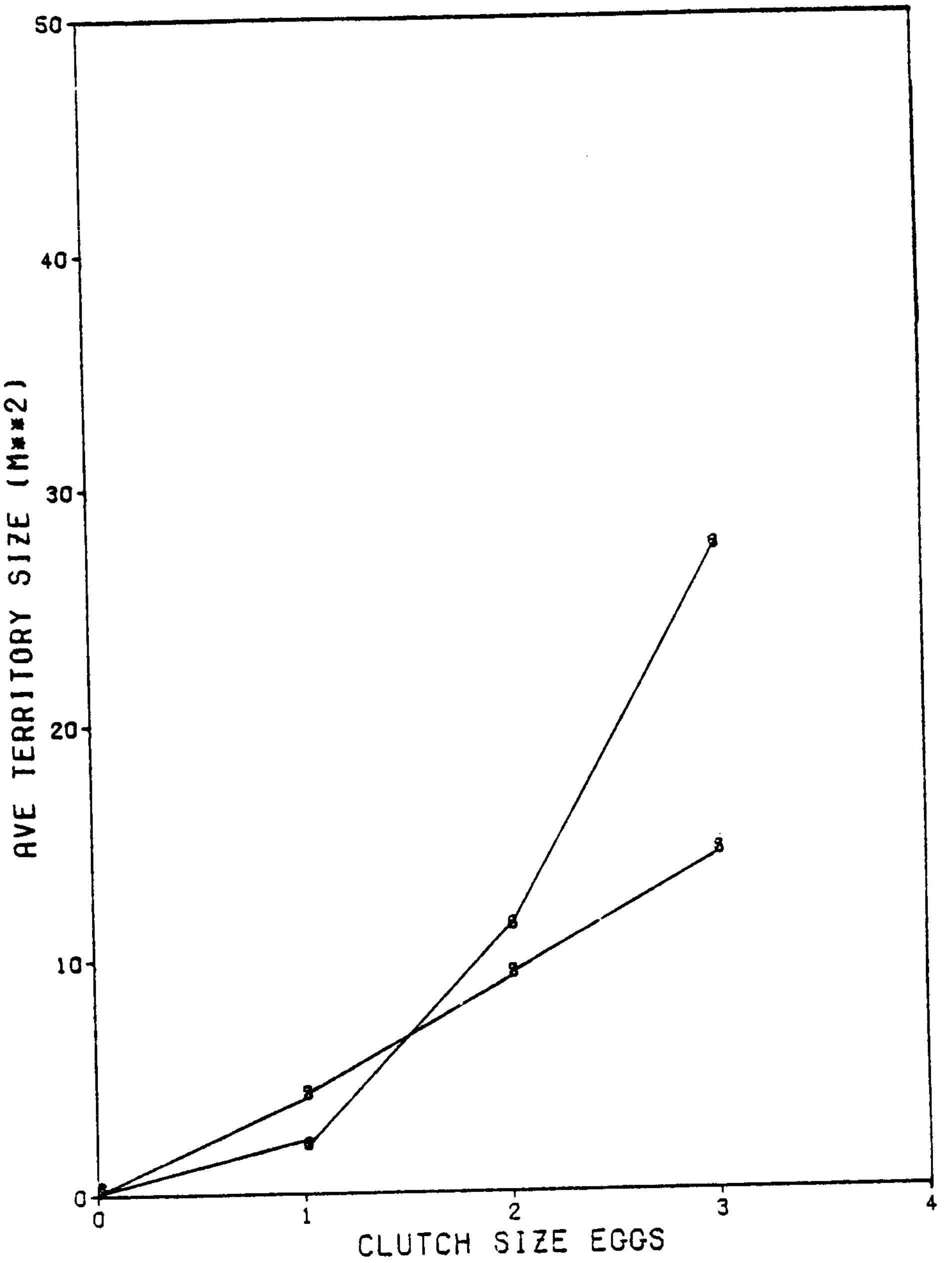


Figure 36. Clutch size plotted against average territory size, Egg Island 1975 - 1976.
5 = 1975 survey, 6 = 1976 survey.

Territory size is significantly larger on Egg Island compared to North Marble, with a smaller percentage of three-egg clutches and a greater proportion of one-egg and two-egg clutches. The conspicuous exception is the Top Colony in 1972 (Figure 6), with large territory size and high percentage of one-egg clutches.

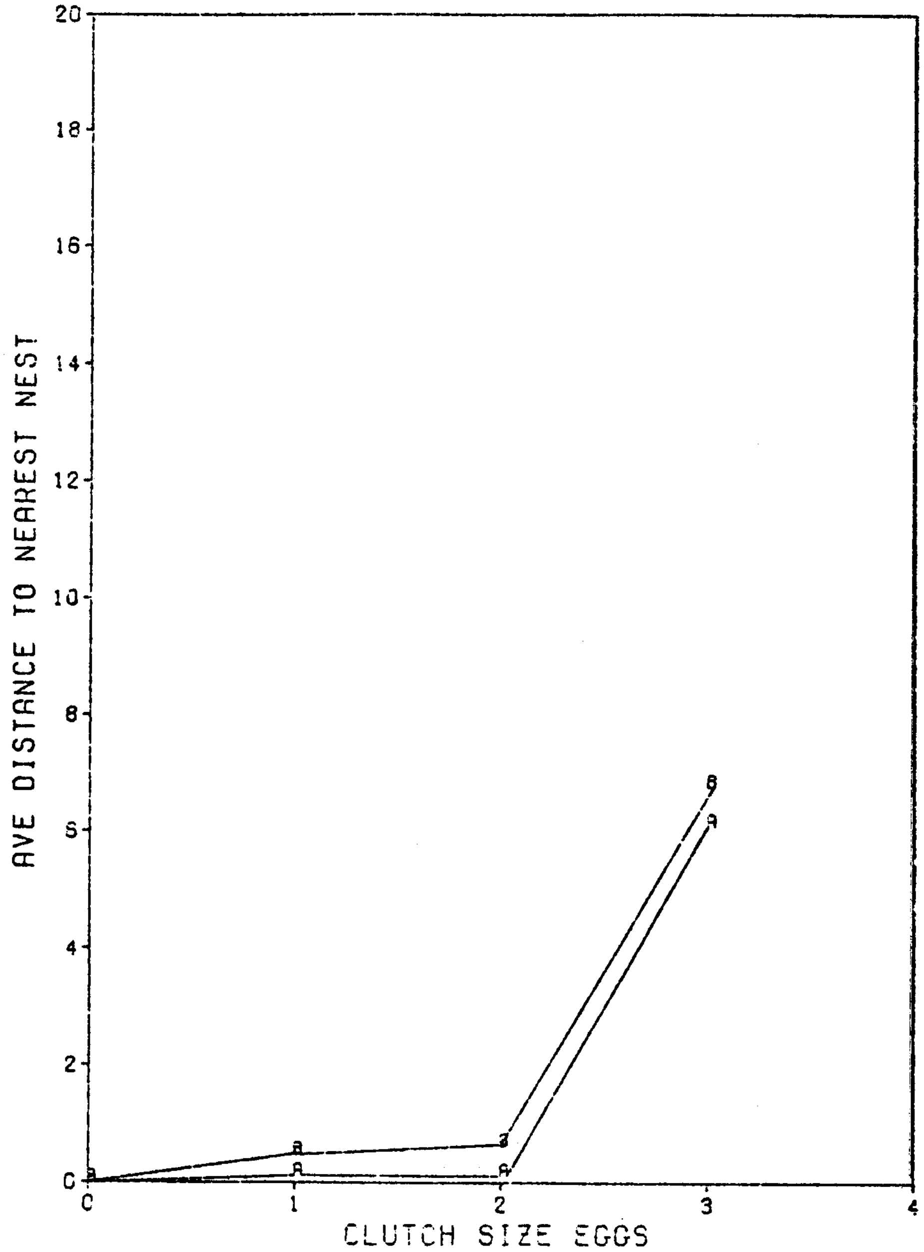


Figure 37. Clutch size plotted against mean distance to nearest nest, Dry Bay 1977.
A = 'A' Colony, B = 'B' Colony.

'A' and 'B' Colonies exhibit similar relationships in clutch sizes and distance to nearest neighbor.

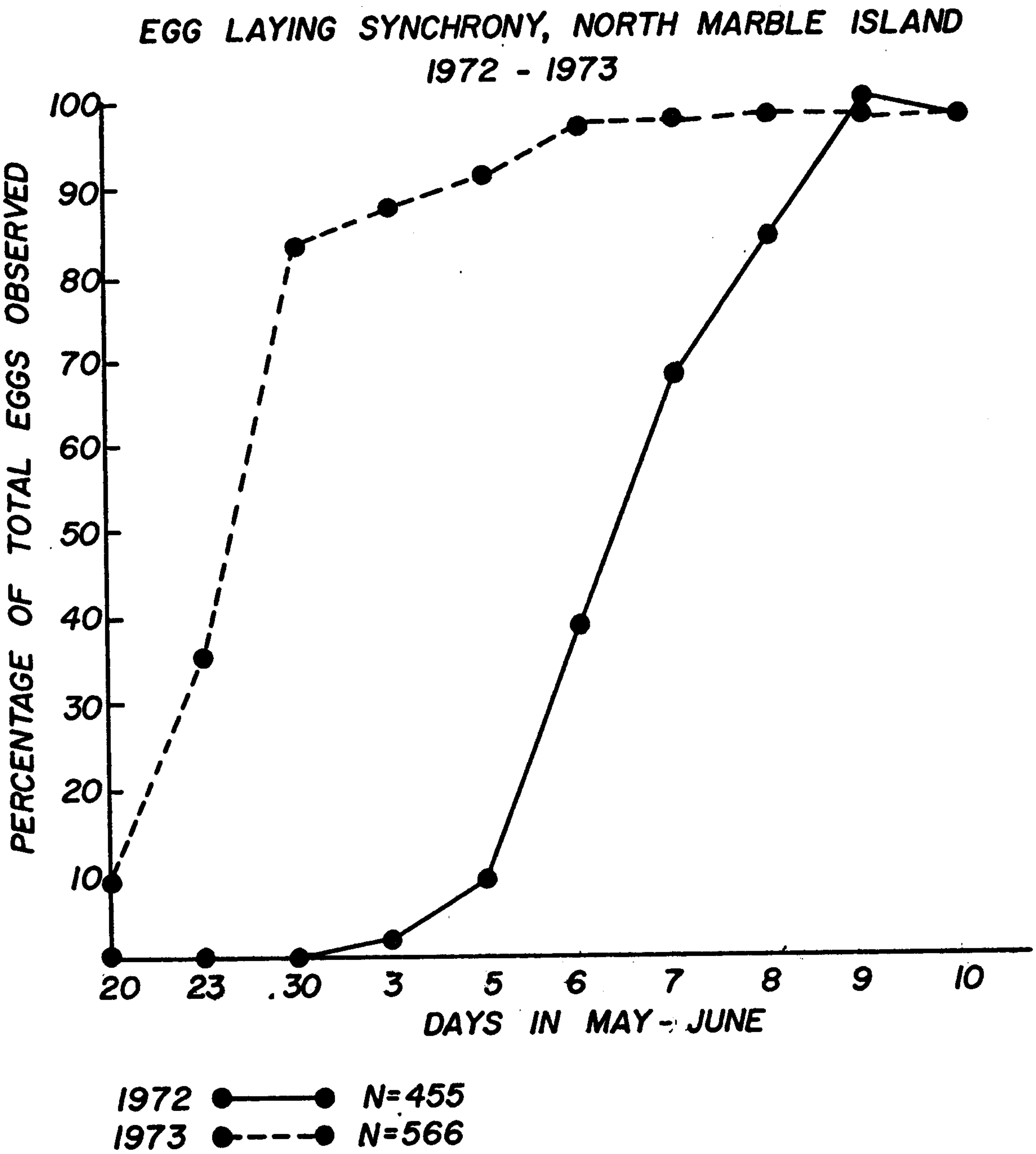

EGG LAYING SYNCHRONY, NORTH MARBLE ISLAND
1972 - 1973
PERCENTAGE OF TOTAL EGGS OBSERVED
100
90
80
70
60
50
40
30
20
10
20
23
.30
3
5
6
7
8
9
10
DAYS IN MAY - JUNE
1972 ●——● N=455
1973 ●- - - -● N=566

Figure 38

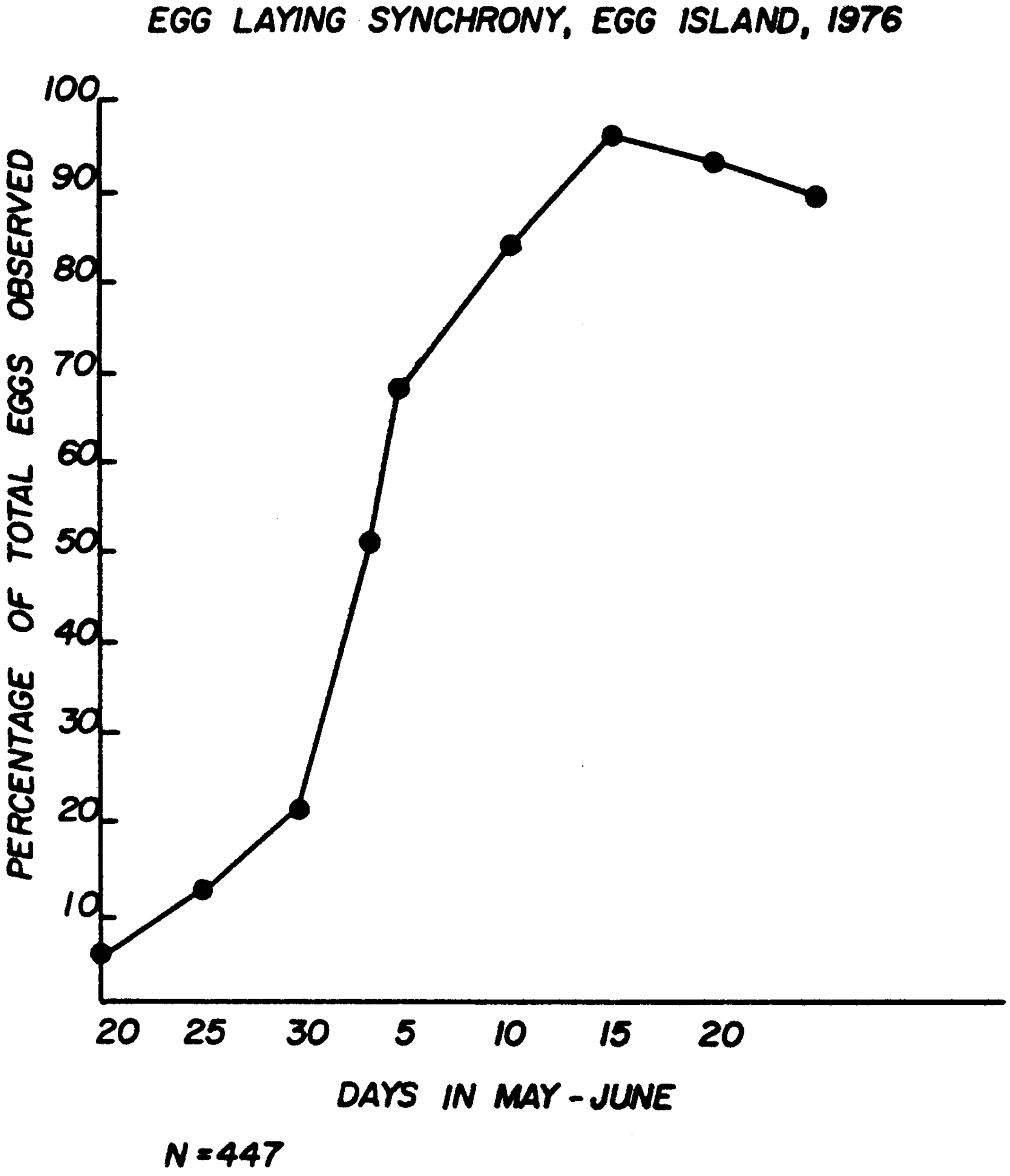

EGG LAYING SYNCHRONY, EGG ISLAND, 1976
PERCENTAGE OF TOTAL EGGS OBSERVED
100
90
80
70
60
50
40
30
20
10
20
25
30
5
10
15
20
DAYS IN MAY - JUNE
N = 447

Figure 39

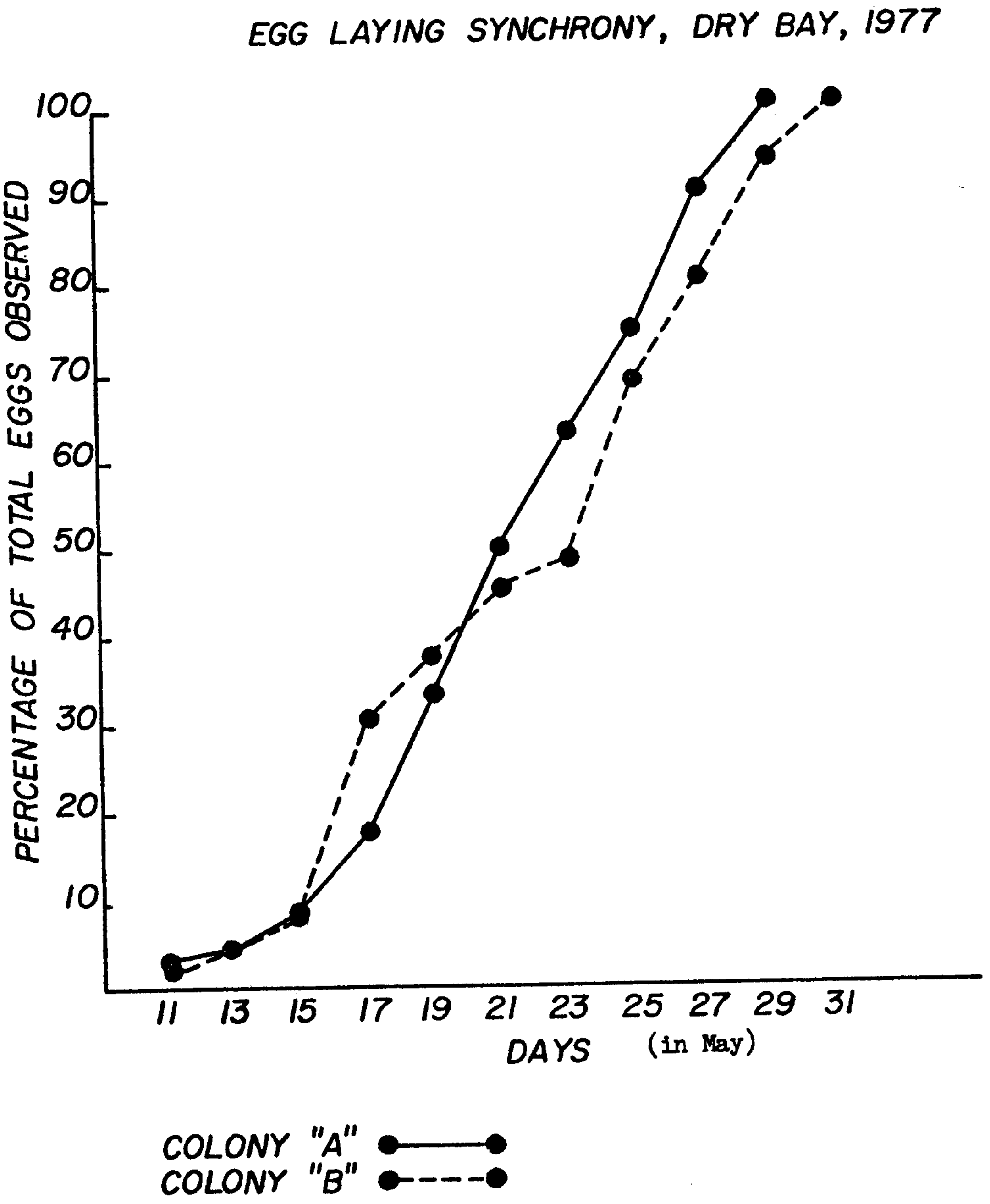

EGG LAYING SYNCHRONY, DRY BAY, 1977
PERCENTAGE OF TOTAL EGGS OBSERVED
100
90
80
70
60
50
40
30
20
10
11
13
15
17
19
21
23
25
27
29
31
DAYS (in May)
COLONY "A" ●——●
COLONY "B" ●----●

Figure 40

5. Hatching Failure

We attribute hatching failure in southern Alaskan gull colonies to three factors, using Paynter's (1949) formulation: (1) eggs disappearing (lost) from the nest during incubation; (2) eggs remaining in nests but not hatching (dying); and (3) eggs which pip but the chick dies before emerging. We consider lost eggs to be hatching failures because almost all egg loss was due to predation in which eggs were destroyed.

Loss of eggs through predation was the principle factor influencing hatching rate on North Marble (1972-73) and at Egg Island (1975-76) (Table 13). Results of the 1972-73 North Marble investigation indicated a 26-27% egg loss within a colony of 500 pairs (Table 13). Proportionate egg loss was similar from colony to colony at North Marble in 1972-73. Egg loss plotted against average territory size (Figs. 41, 45, 46) showed the following variations. The East and West colonies in 1972 were quite similar in percentage egg loss, while the Top colony had a high percentage loss of two eggs per nest. The North colony had a 20% complete clutch loss (3 eggs per nest). All colonies showed similar patterns of egg loss plotted against territory size in 1973 (Fig. 41, 42, 45, 46).

The plot of egg loss against average territory size for Egg Island showed a correlation between large territory size and loss of one or two eggs in 1976; egg loss in 1975 resembled the pattern on North Marble (1972-73). Total egg loss in the Egg Island study area (1975-76) was 26% (Table 13). These figures suggest a ±25% egg loss frequently occurs in gull colonies in the Northeast Gulf of Alaska. Natural predation is due to other gulls, ravens, crows and jaegers. Subsistence egging by fishermen and natives causes much higher rates of egg loss in certain areas, notably on Egg Island near Cordova.

Egg loss was significantly lower ($p < .05$) at Dry Bay in 1977, compared to either North Marble or Egg Island. The low rate of egg loss (3% to 11%), was due to few ravens and crows on the Alsek Delta (Table 13). Minor egg loss was due to jaegers and other gulls. Colonies 'A' and 'B' at Dry Bay showed quite similar percentage egg loss suggesting little relationship to distance to nearest nest (Fig. 48 ; Table 13). Dry Bay most resembled North Marble in 1973 in egg loss to predation (Figs. 48,46).

A minor cause of non-productivity on Egg Island, North Marble, Dry Bay, and Lake Louise was eggs remaining in the nests but not hatching (dying). Study of the few decayed eggs did not reveal developed embryos or specific reasons for mortality (as in Paynter, 1949). We tentatively concluded the eggs were infertile since the relative percentage of unhatched eggs was low (Table 13) and eggshells showed no signs of fragility or pesticide contamination.

The last cause of failure to hatch occurred when the chick pipped the shell but failed to emerge and died. There were only two cases in the Egg Island study area (1975-76); two each at Dry Bay and Lake Louise in 1977; and three cases on North Marble (1972-73). The rate at every colony was well below one percent of total eggs laid in the study areas (Table 13). These are not significant rates.

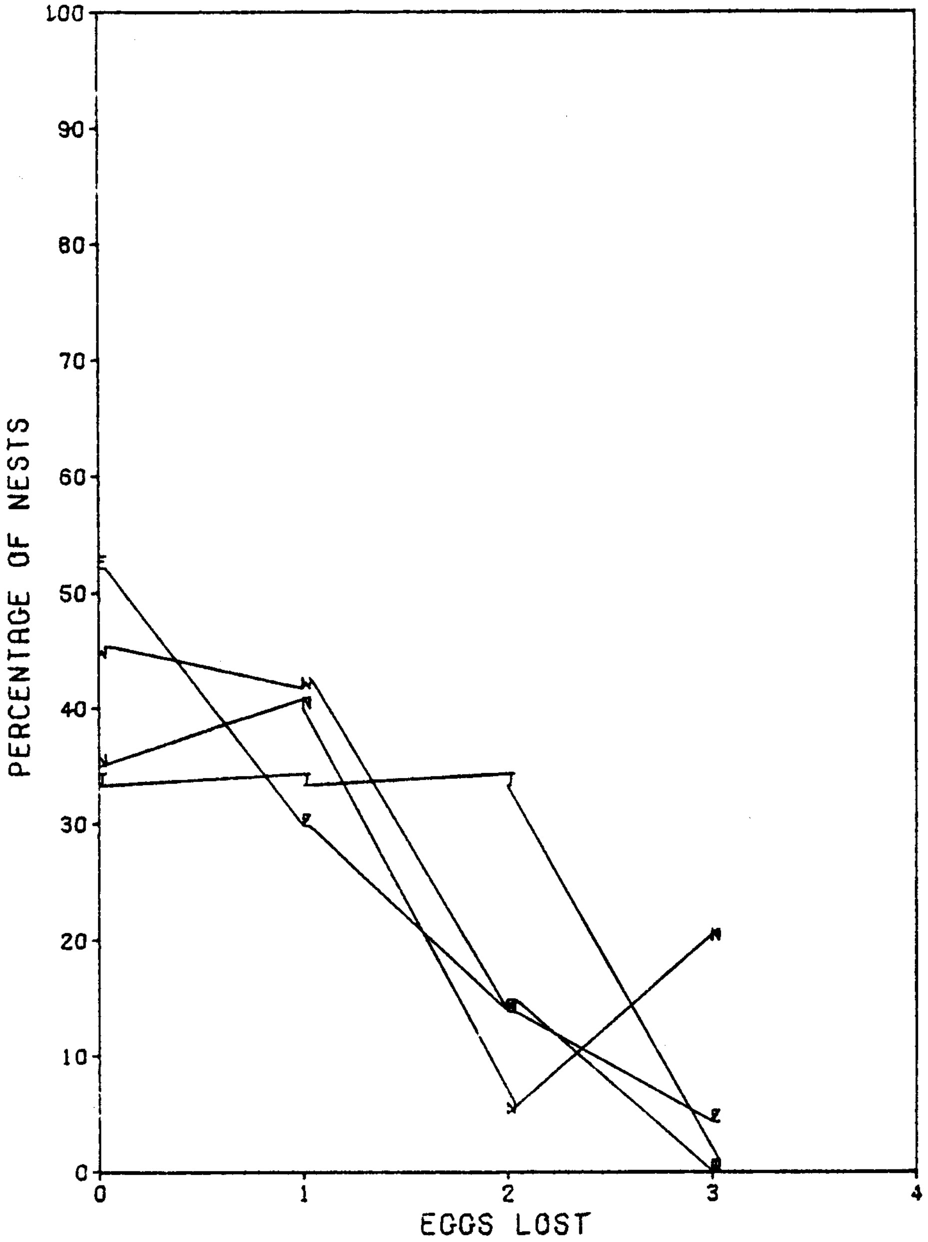


Figure 41. Eggs lost plotted against percentage of nests, North Marble, 1972.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

East and West Colonies are quite similar in percentage egg loss. Top Colony had a higher percentage 2-egg loss, and North Colony had 20% complete clutch loss.

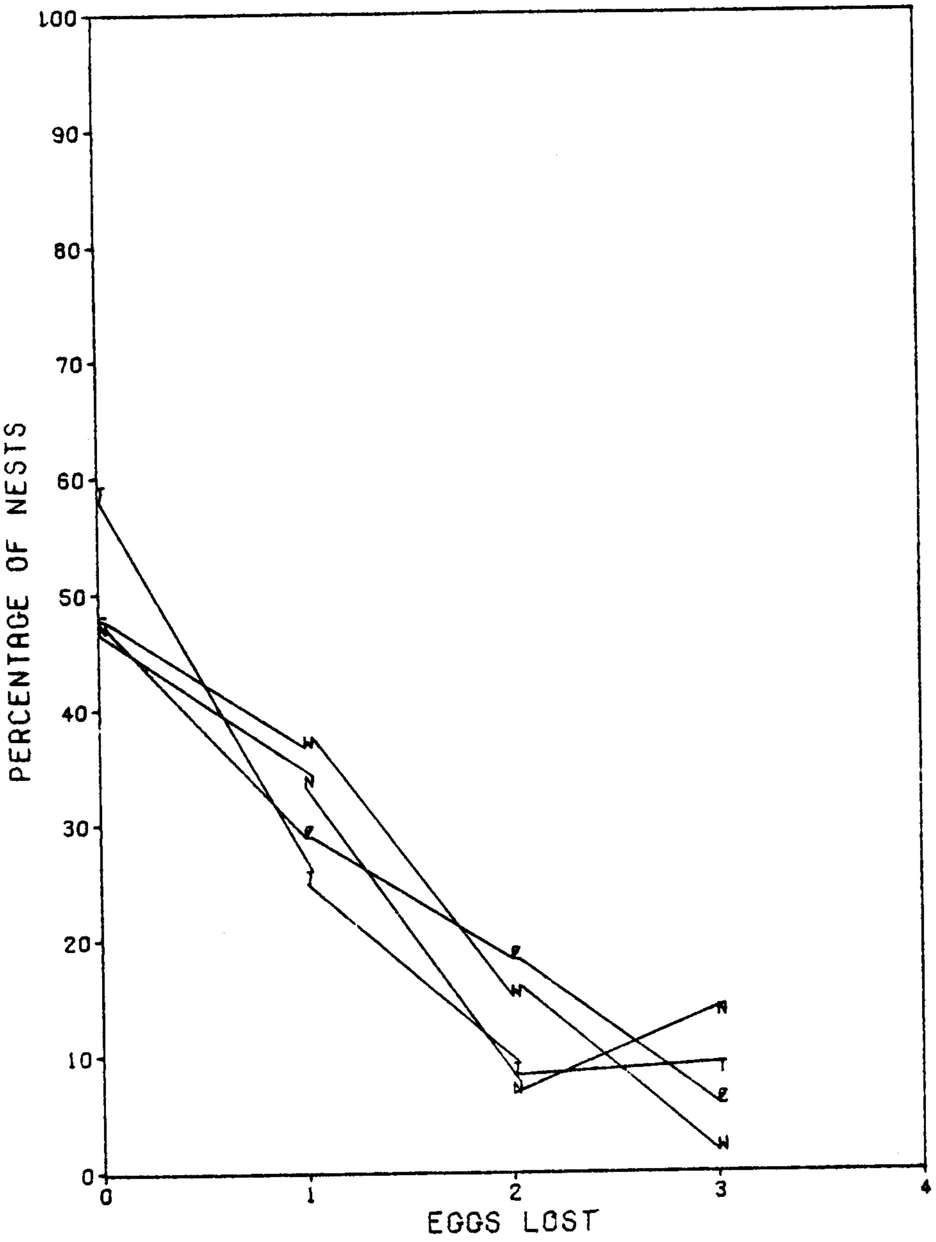


Figure 42. Eggs lost plotted against percentage of nests, North Marble, 1973.

All colonies show highly similar tendencies in eggs lost to predation. Predators are mostly conspecific adults.

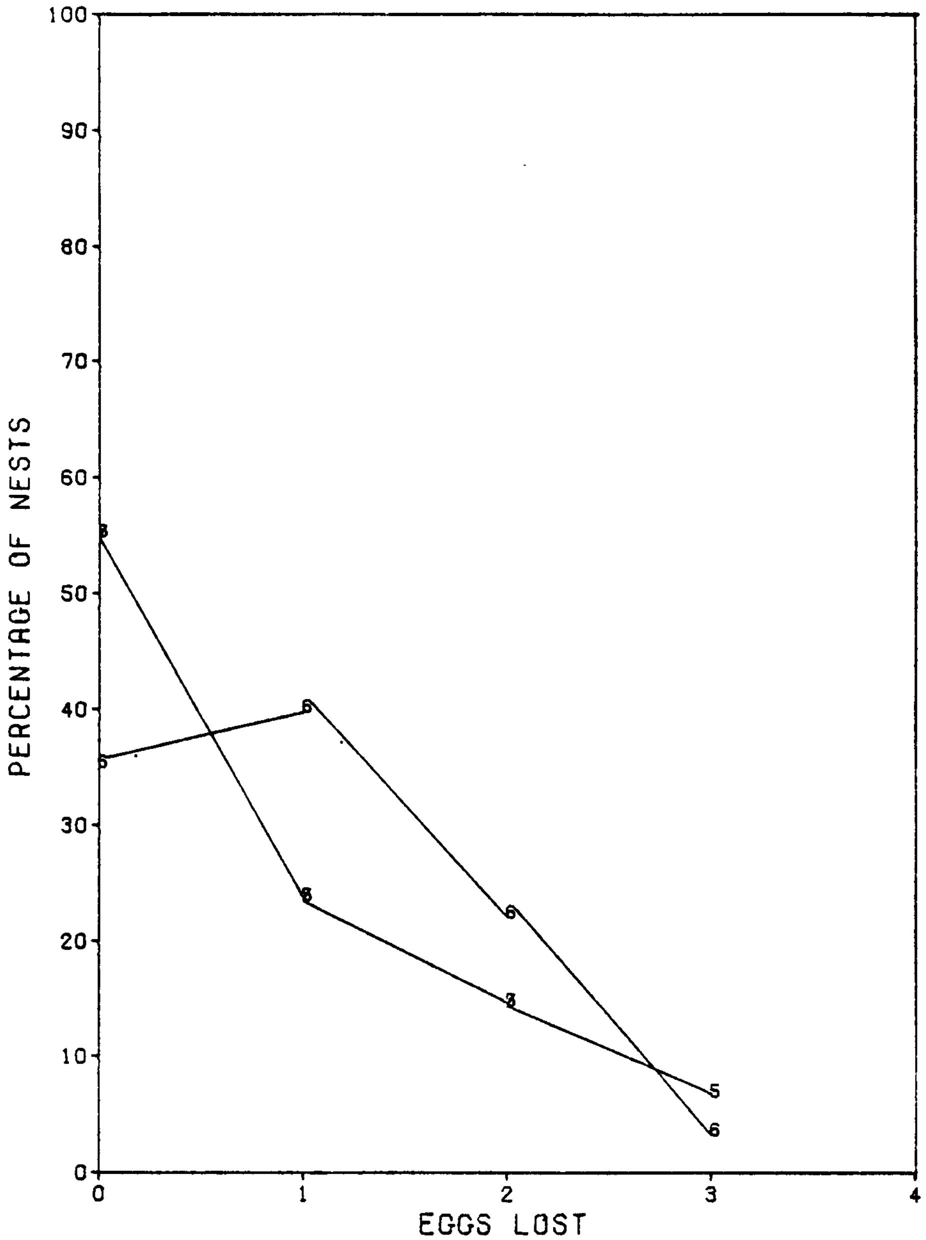


Figure 43. Eggs lost plotted against percentage of nests, Egg Island, 1975 - 1976. 5 = 1975 survey, 6 = 1976 survey.

Egg Island is similar to North Marble in egg loss to predation.

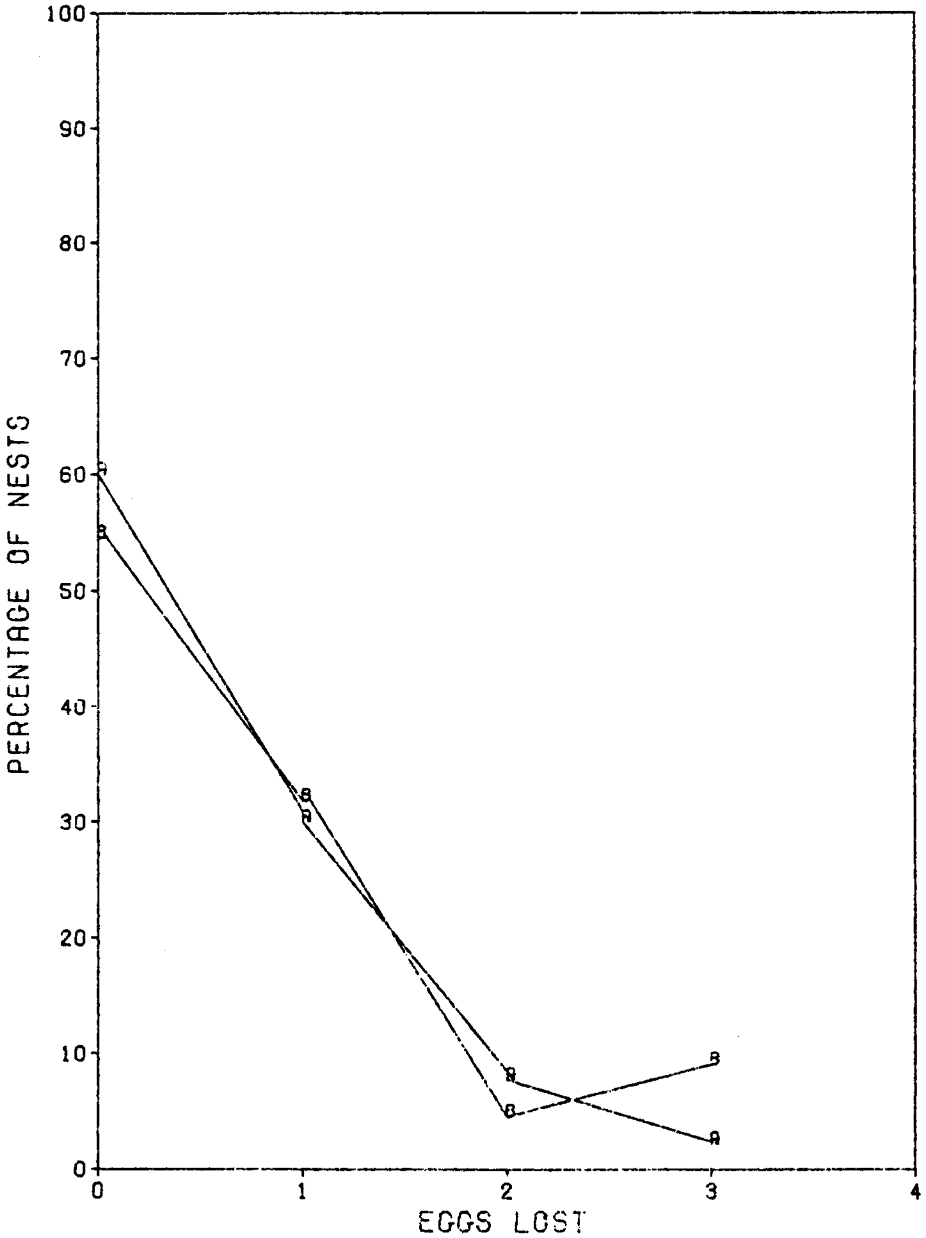


Figure 44. Eggs lost plotted against percentage of nests, Dry Bay, 1977.
A = 'A' Colony, B = 'B' Colony.

Eggs lost to predation at Dry Bay show a rate most similar to North Marble in 1973.

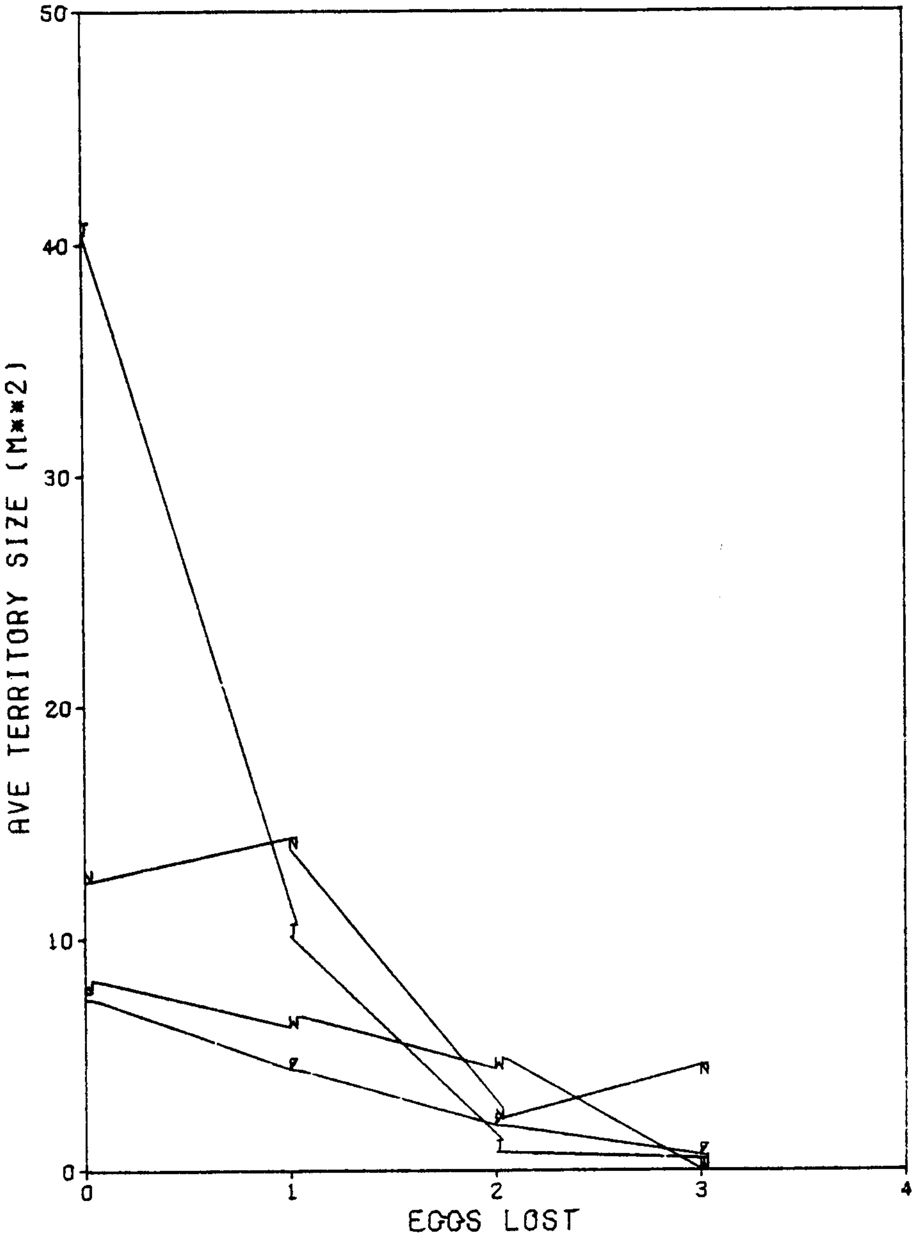


Figure 45. Eggs lost plotted against average territory size, North Marble, 1972. E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

Although Top Colony is significantly larger in average territory size, proportionate egg loss is similar to other colonies.

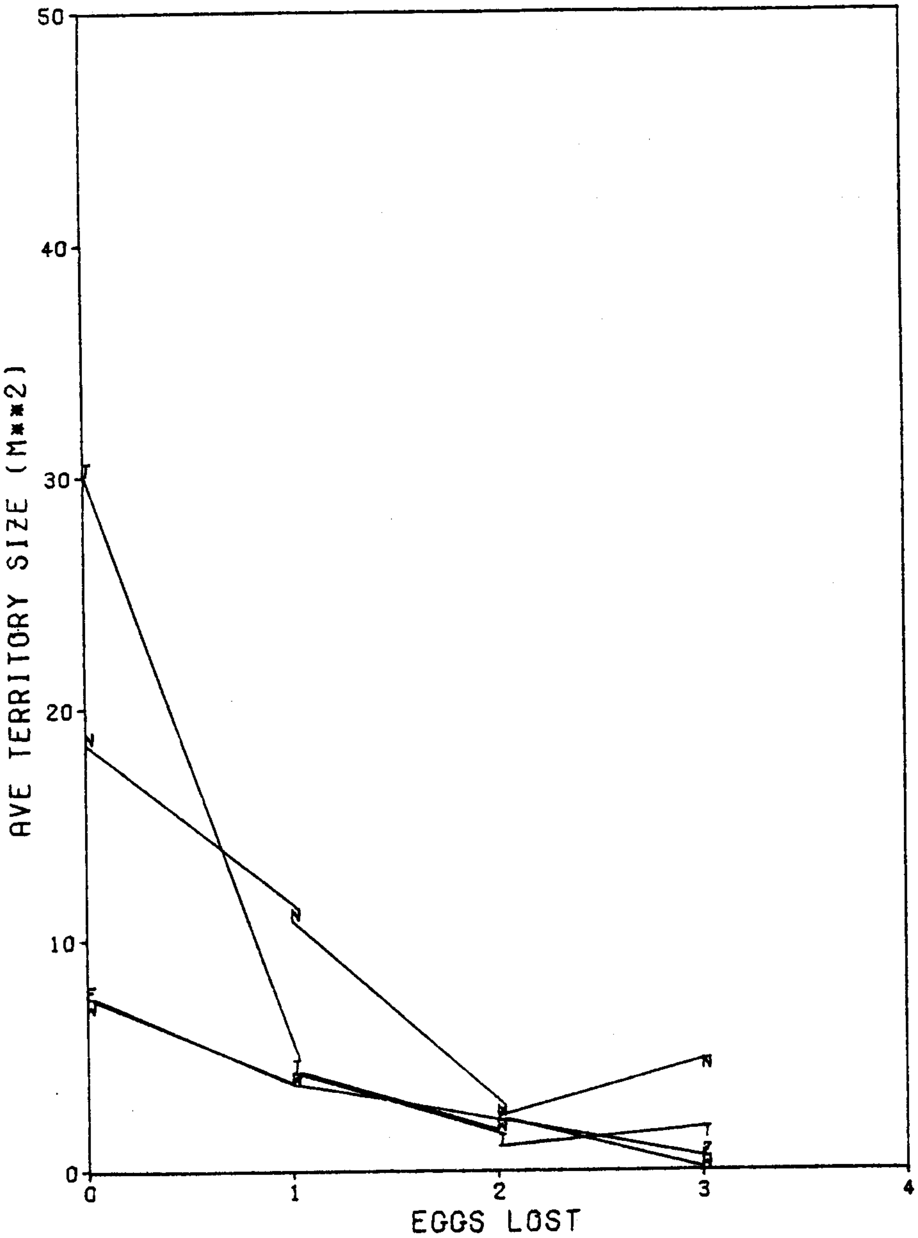


Figure 46. Eggs lost plotted against average territory size, North Marble, 1973.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.
All colonies show similar trends in eggs lost.

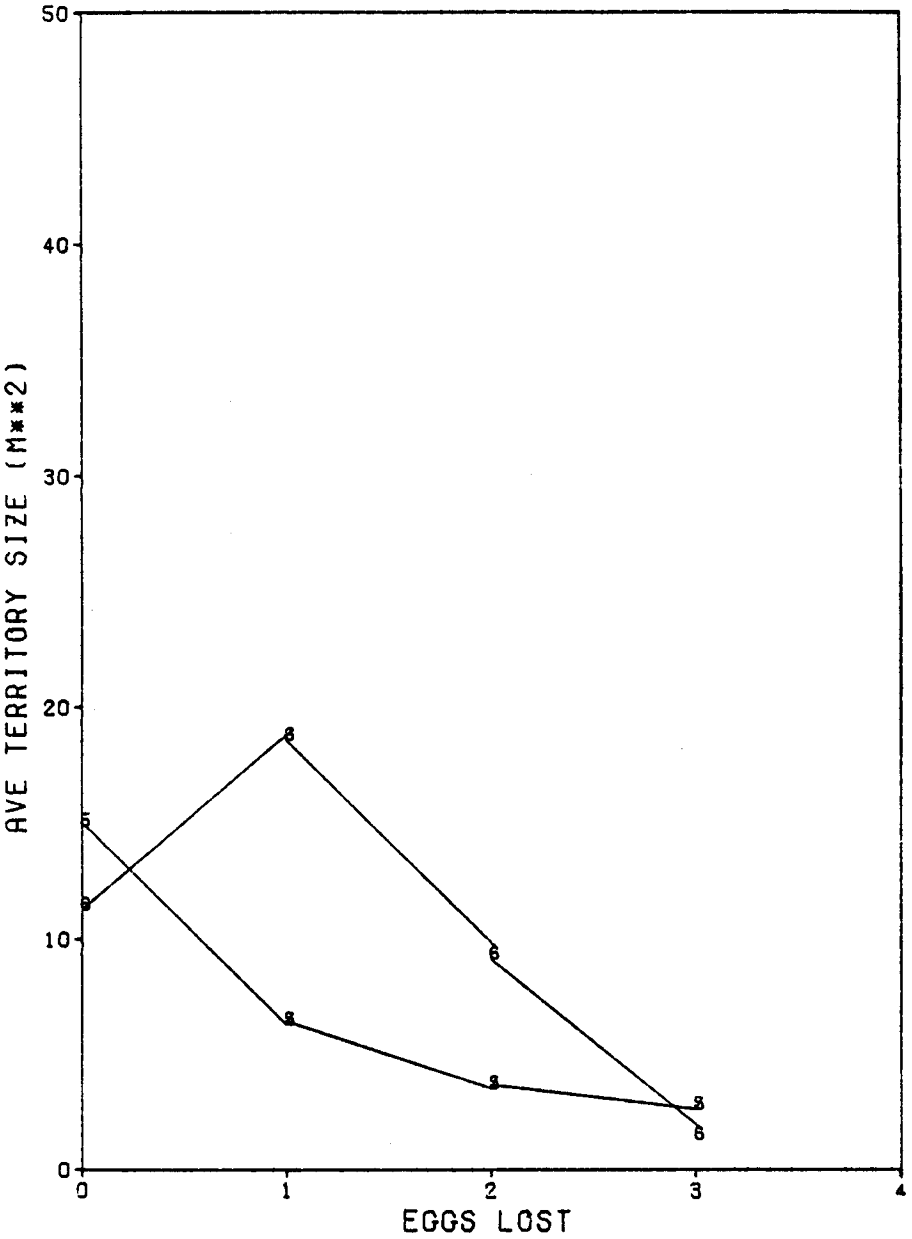


Figure 47. Eggs lost plotted against average territory size Egg Island, 1975 - 1976.
5 = 1975 survey, 6 = 1976 survey.

Gulls with larger territory sizes tended to loose one or two eggs in 1976.
Egg loss in 1975 resembled that of 1972 and 1973 on North Marble.

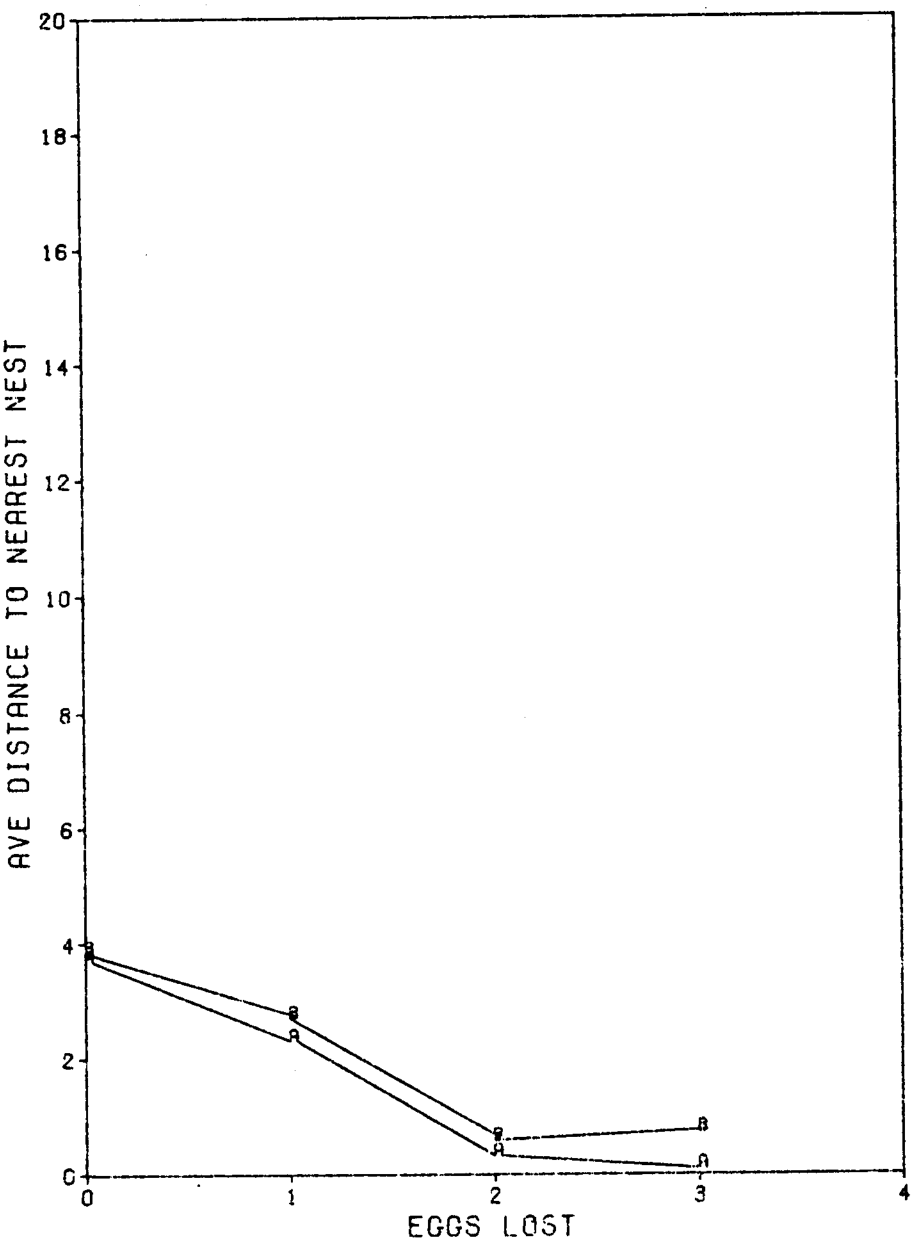


Figure 48. Eggs lost plotted against mean distance to nearest neighboring nest, Dry Bay, 1977. A = 'A' Colony, B = 'B' Colony.

'A' and 'B' Colonies show quite similar tendencies indicating egg loss is little influenced by distance to nearest nest.

Table 13

Numbers of "Lost," "Infertile" and "Pipped" Eggs Which Did Not Hatch in the Study Areas: Egg Island (1975-1976); North Marble (1972-73); Dry Bay and Lake Louise (1977)

Colony & Year	Total Eggs in Study Area	Lost Eggs	Infertile Eggs	Pipped, but did not Hatch
Egg Island (1975)	386	114 (29.5%)	8 (2.0%)	1 (1%)
Egg Island (1976)	447	104 (23.3%)	9 (2.0%)	1 (1%)
North Marble (1972)	455	125 (27.5%)	22 (4.8%)	2 (1%)
North Marble (1973)	566	150 (26.5%)	26 (4.6%)	1 (1%)
Dry Bay (1977) 'A'	265	10 (3.7%)	8 (3.0%)	2 (1%)
Dry Bay (1977) 'B'	63	7 (11.1%)	0	0
Lake Louise (1977)	211	N.A.	13 (6.2%)	2 (1%)

6. Incubation Period

An incubation period is defined as the time span between the beginning of incubation of an egg and the date of hatching. Gulls lay eggs spaced several days apart, but do not begin incubation until the clutch (usually three) is completed. Thus all the eggs in a clutch tend to hatch within a very short time of each other (1-2 days). Not only do eggs within the same clutch tend to hatch within a few days of each other, most of the chicks within a colony tend to hatch within a week of each other, under undisturbed conditions.

Onset of incubation varies by several weeks at an individual colony between years (Fig. 49). The onset of incubation on North Marble ranged from 29 May 1973 to 10 June 1972. The beginning of incubation in colonies at Egg Island and Lake Louise fell within this time range, despite nearly

INCUBATION PERIODS BY COLONY

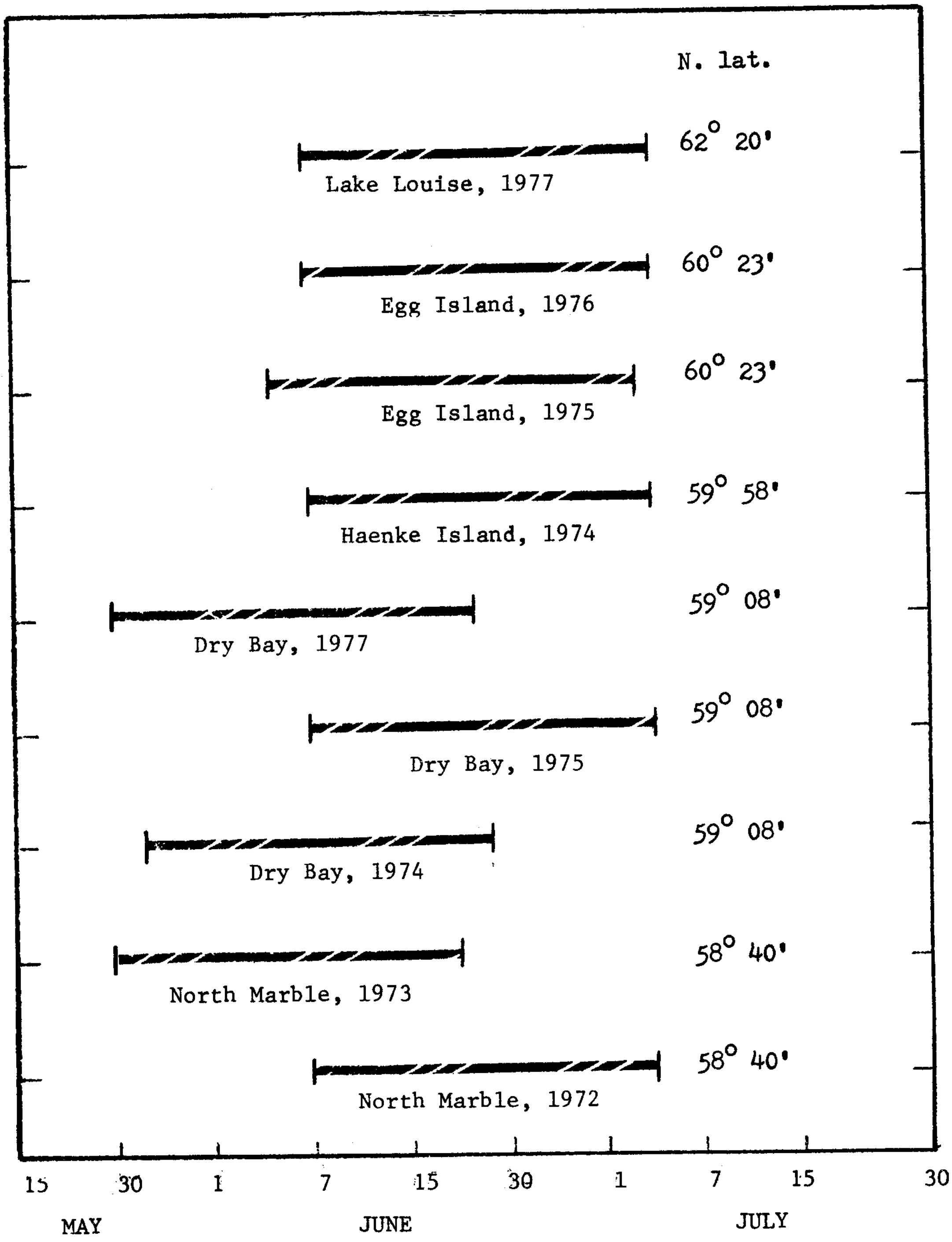


Figure 49

4^{o} change in latitude. This suggests that gulls along this entire stretch of coastline and interior breed at the same time (Fig. 49).

The beginning of incubation was synchronized at North Marble, despite the somewhat larger spread of egg-dates from colony to colony. The abrupt synchrony of chick hatching both years of the North Marble study reflected the synchronized onset of incubation (Fig. 50). Median dates from onset of incubation to hatching established an incubation period of 24 to 27 days on North Marble.

The wider spread of chick ages on Egg Island reflected less synchrony in onset of incubation as well as greater spread of egglaying following egg-collecting by humans (Figs. 49, 52). However, in the study site at Egg Island, 50% of eggs were laid by June 5th, and 50% of eggs hatched by June 30th, demonstrating a median incubation period of 25 days.

At Dry Bay, 50% of eggs were laid by 24 May, and 50% of eggs hatched by 19 June, demonstrating a median incubation period of 26 days. Similar incubation periods have been reported by Tinbergen (1960), Keith (1966), Schreiber (1970), Harpur (1971), and Vermeer (1963) for argentatus, occidentalis and glaucescens.

7. Chick Hatching

Synchrony is the tendency of a population of colonial birds to reproduce within a short period of time of each other. Synchrony is an adaptative anti-predator strategy.

Chick hatching was quite synchronous both years of the North Marble Island study. In 1972, 70% of the gull chicks hatched between 4 and 9 July; in 1973, 87% of the chicks hatched between 23 and 25 June. Chick hatching in 1973 at North Marble was two weeks earlier than 1972, a result

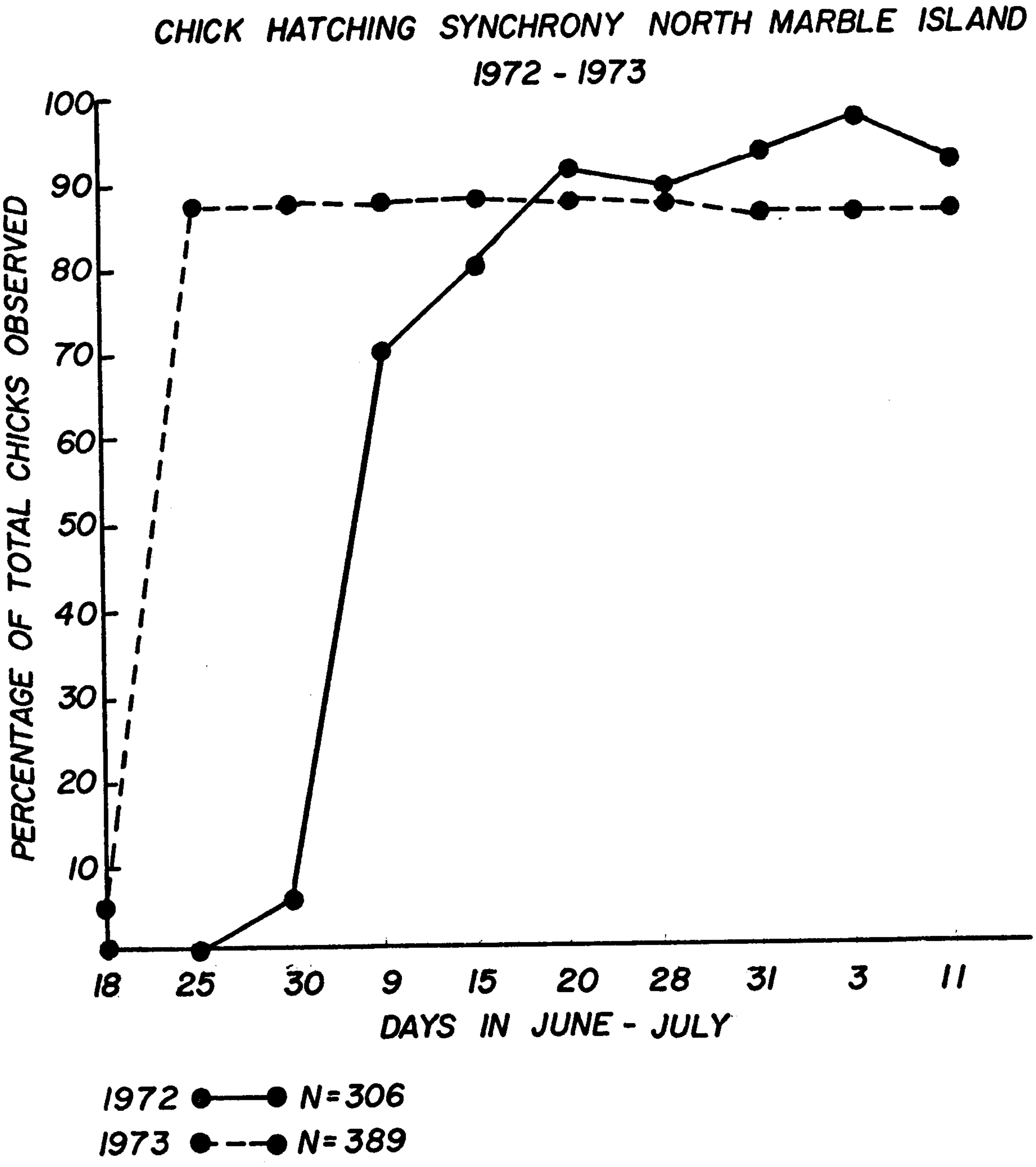

CHICK HATCHING SYNCHRONY NORTH MARBLE ISLAND
1972 - 1973
PERCENTAGE OF TOTAL CHICKS OBSERVED
100
90
80
70
60
50
40
30
20
10
18
25
30
9
15
20
28
31
3
11
DAYS IN JUNE - JULY
1972 ●——● N=306
1973 ●---● N=389

Figure 50

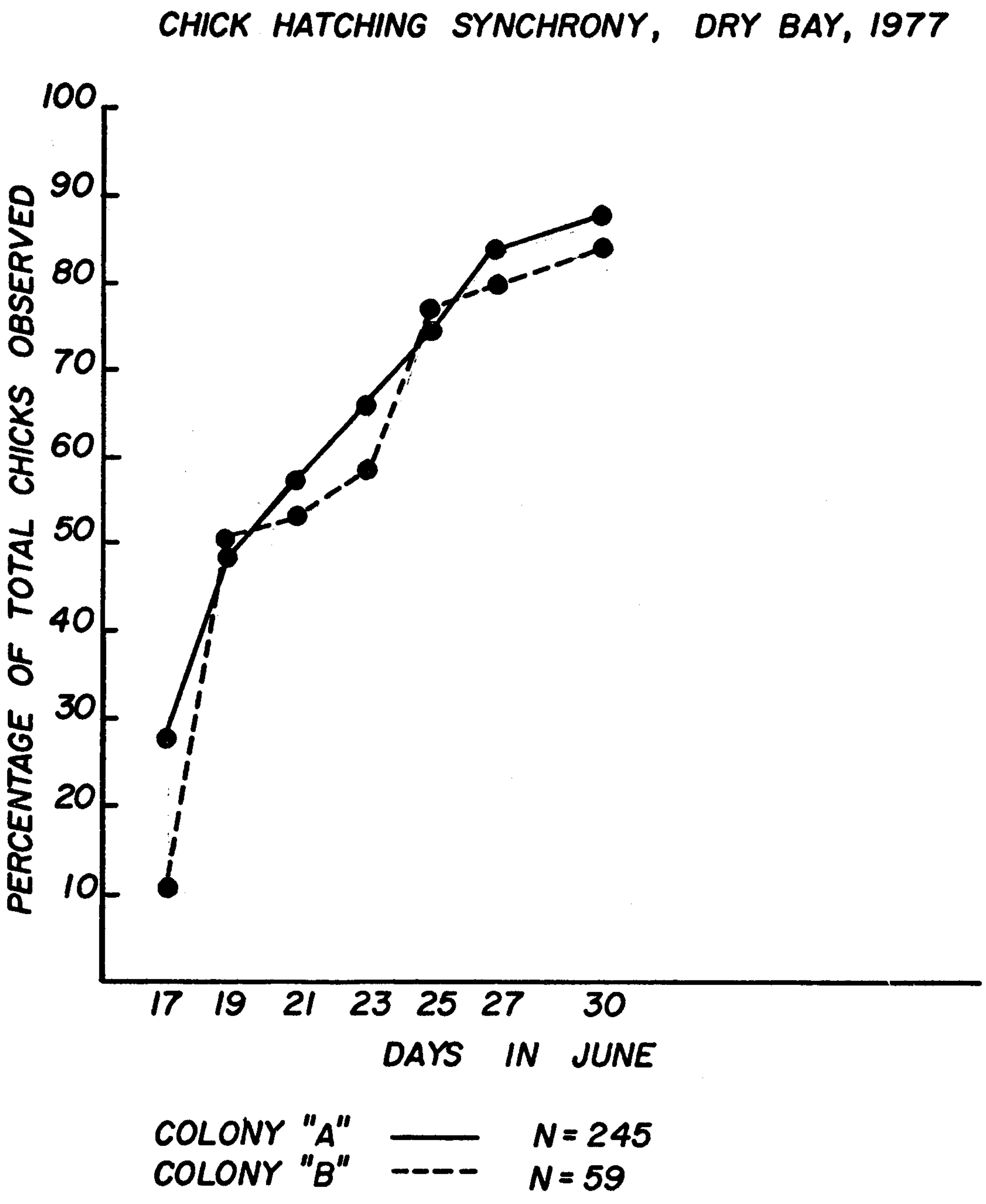

CHICK HATCHING SYNCHRONY, DRY BAY, 1977
PERCENTAGE OF TOTAL CHICKS OBSERVED
100
90
80
70
60
50
40
30
20
10
17
19
21
23
25
27
30
DAYS IN JUNE
COLONY "A" —— N=245
COLONY "B" ---- N=59

Figure 51

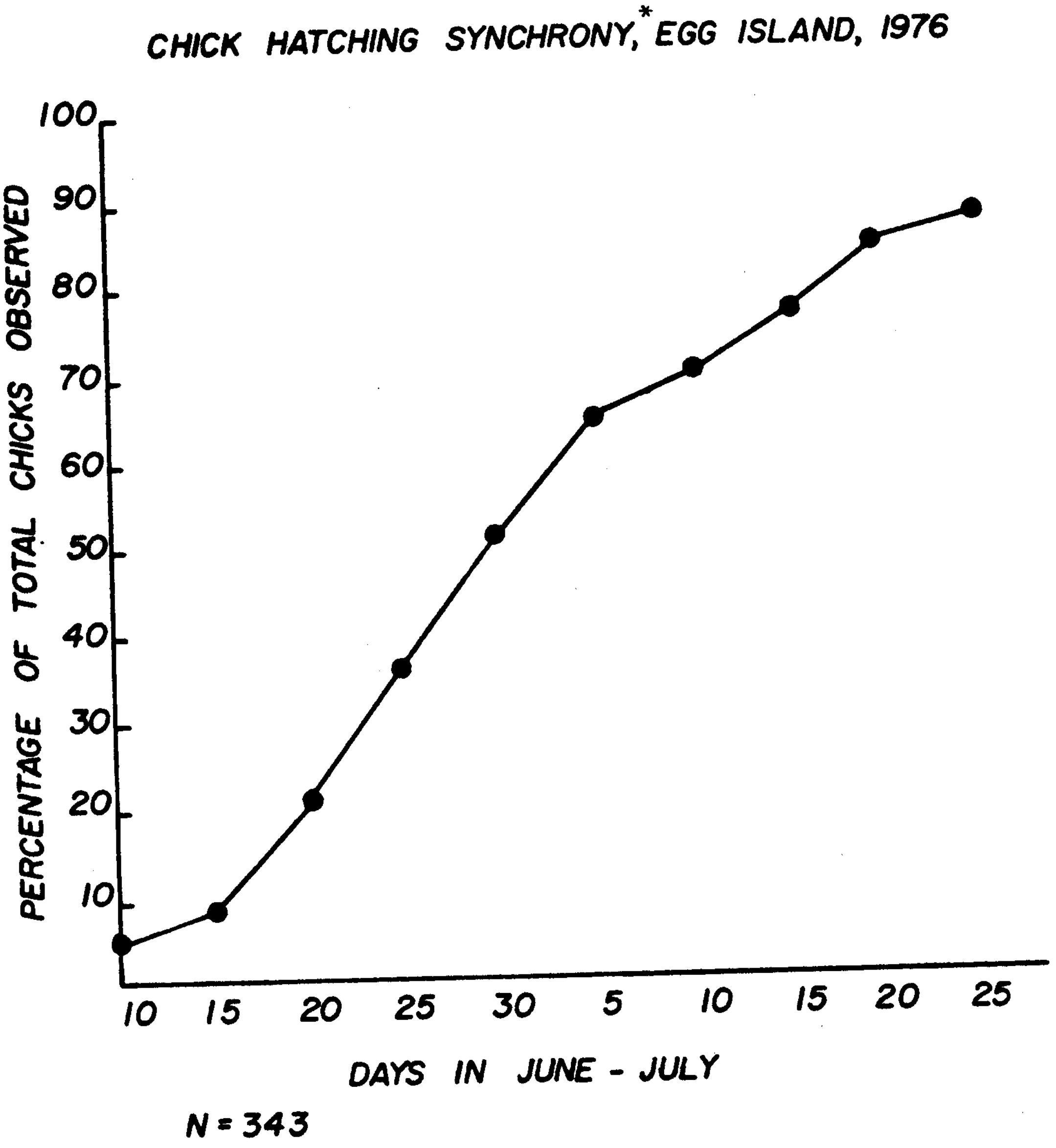


Figure 52

* The slope is nearly directly proportional to time.
Therefore synchrony is technically not correct.
"Phenology" would be correct. (See text for explanation.)

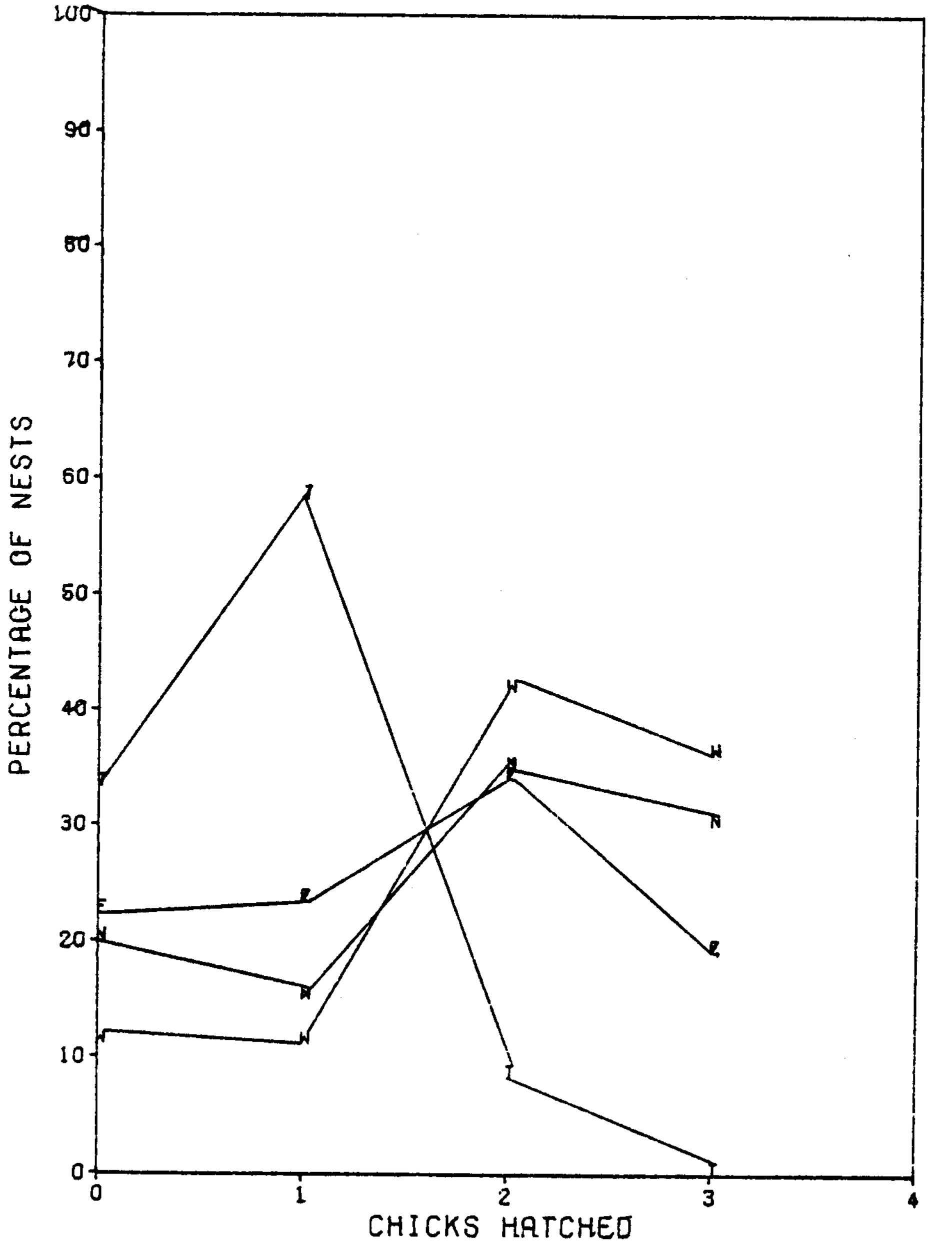


Figure 53. Chicks hatching plotted against percentage of nests, North Marble, 1972.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

East, West and North Colonies are quite similar in number of chicks hatching per nest. The Top Colony, due to smaller mean clutch size, produced fewer chicks hatching in proportion.

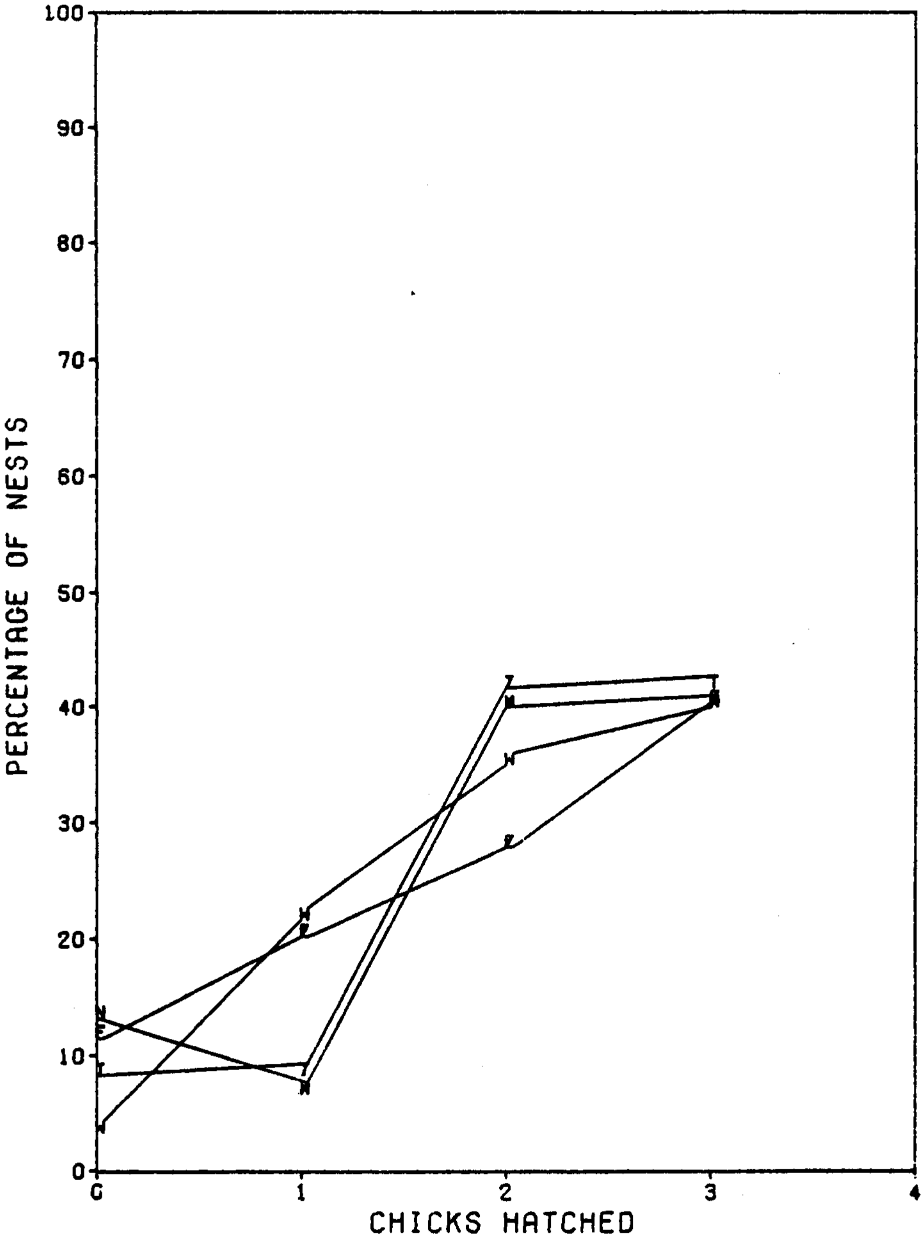


Figure 54. Chicks hatching plotted against percentage of nests, North Marble, 1973.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

All colonies show quite similar tendencies in proportion of chicks hatching due to similar mean clutch sizes and rate of predation.

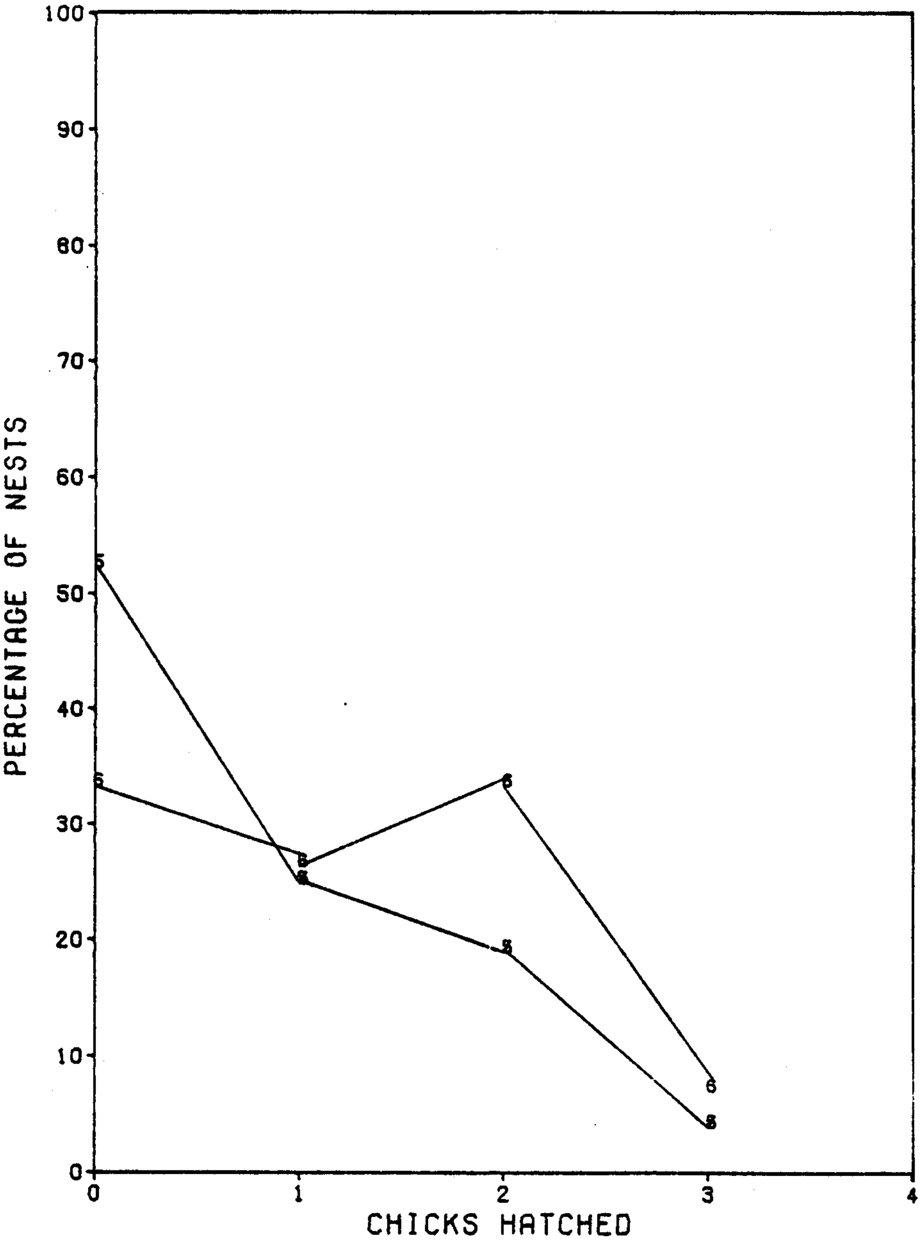


Figure 55. Chicks hatching plotted against percentage of nests, Egg Island, 1975 - 1976. 5 = 1975 survey, 6 = 1976 survey.

Egg Island, due to smaller mean clutch size, shows a reverse tendency in proportion of chicks hatching when compared to North Marble in 1973, but resembles the Top Colony on North Marble in 1972 (Figure 15), although not as extreme.

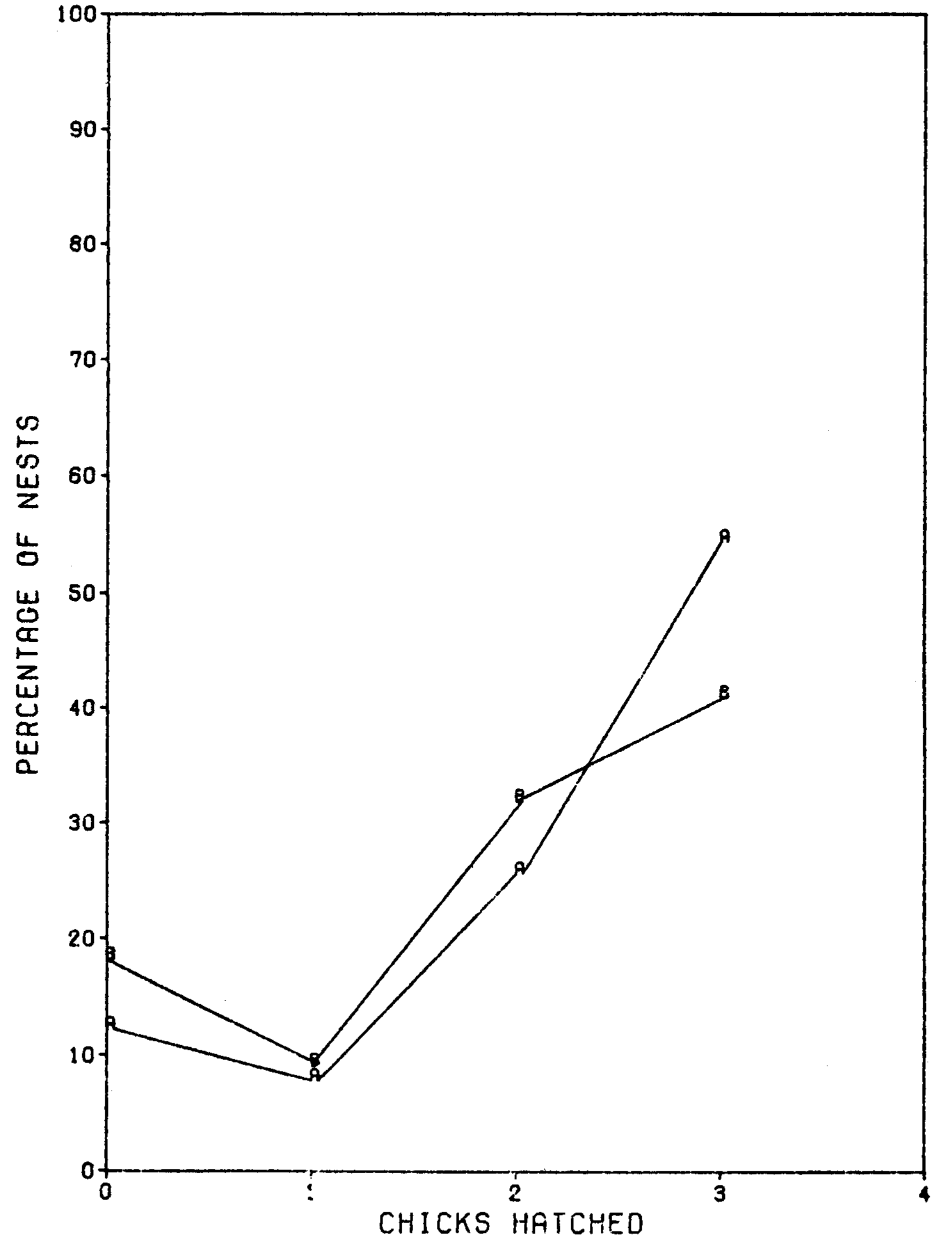


Figure 56. Chicks hatching plotted against percentage of nests, Dry Bay 1977.
A = 'A' Colony, B = 'B' Colony.

Dry Bay had the greatest percentage of chicks hatching in this study, due to largest clutch size and lowest rate of egg predation.

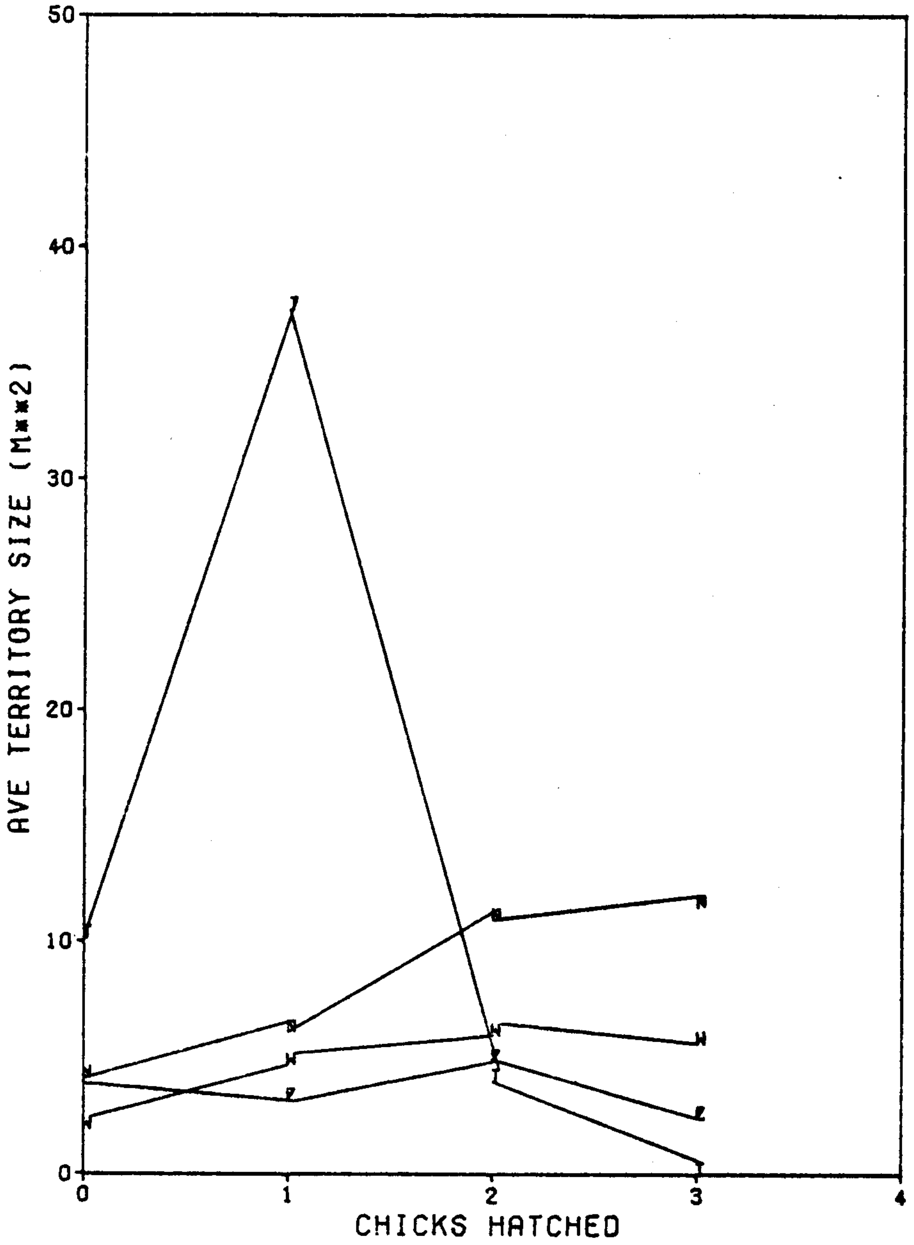


Figure 57. Chicks hatching plotted against average territory size, North Marble, 1972. E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

East, West and North Colonies are quite similar in number of chicks hatching in relation to average territory size. Top Colony is significantly different, with large territory size, smaller mean clutch size, and fewer chicks produced.

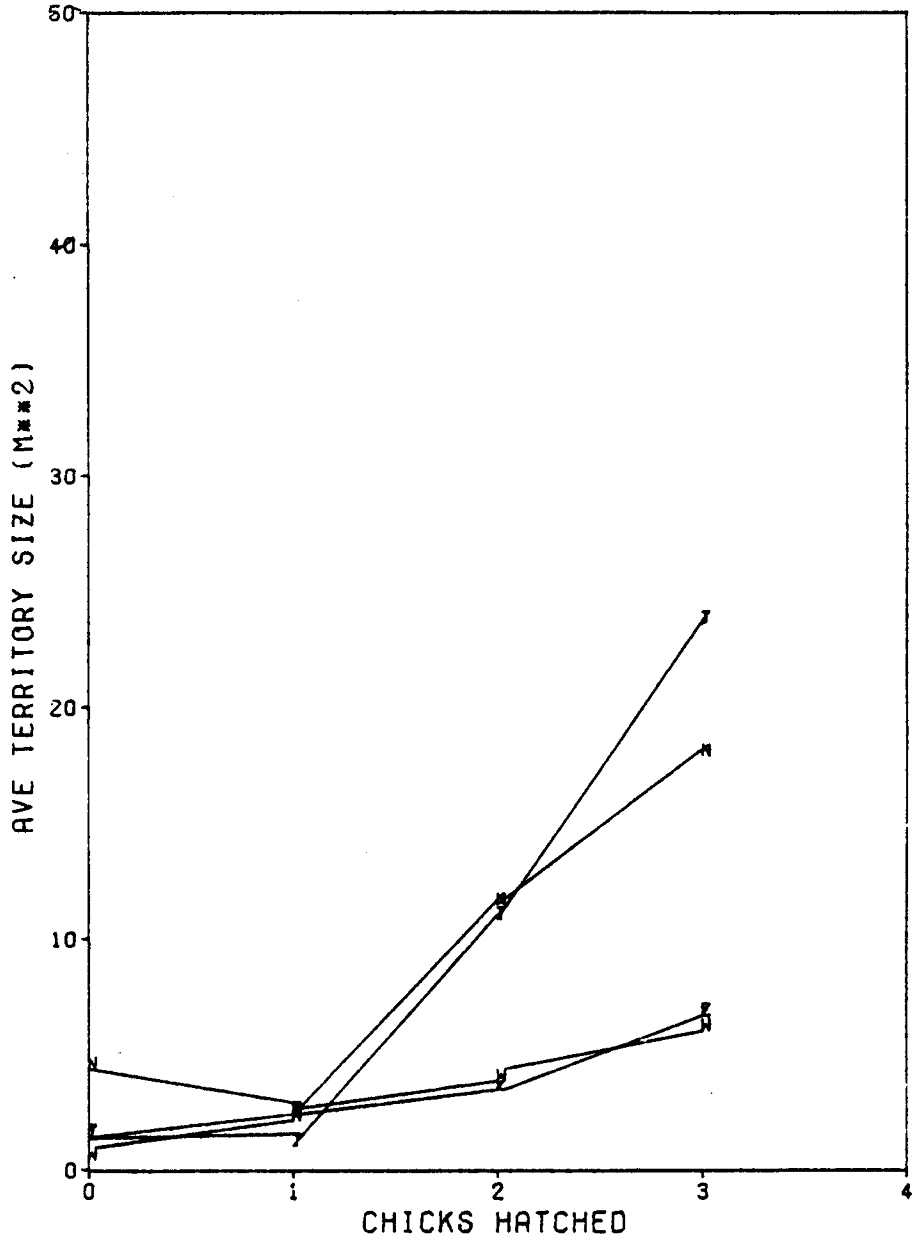


Figure 58. Chicks hatching plotted against average territory size, North Marble, 1973. E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

Top and North Colonies are similar in average territory sizes, as are East and West Colonies, but the two groups are different from each other, probably due to colony sizes. However, all colonies show similar tendencies in number of chicks hatched.

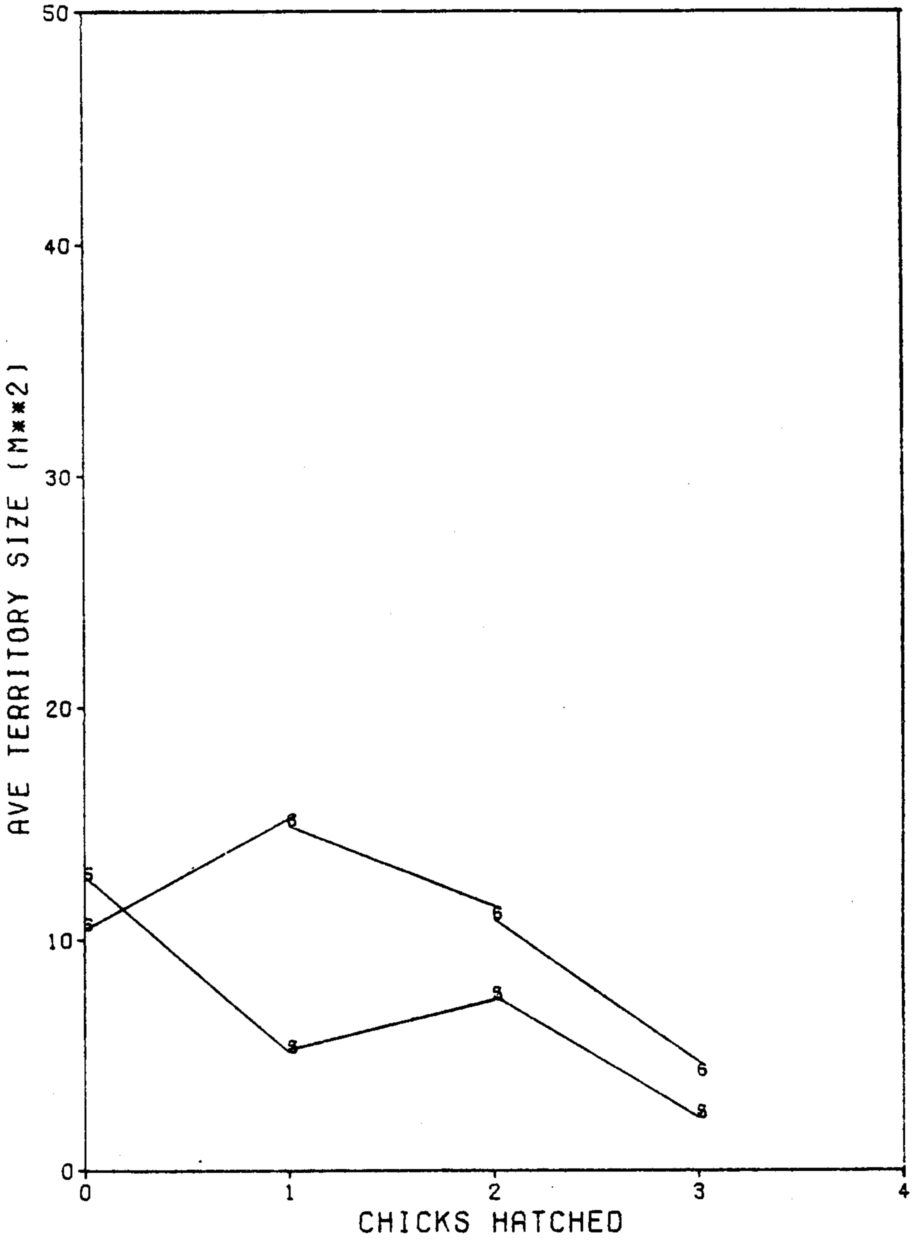


Figure 59. Chicks hatching plotted against average territory size, Egg Island, 1975 - 1976. 5 = 1975 survey, 6 = 1976 survey.

Average territory size on Egg Island in 1976 was larger than in 1975. Both years show a reverse trend from North Marble in 1973 due to smaller mean clutch size.

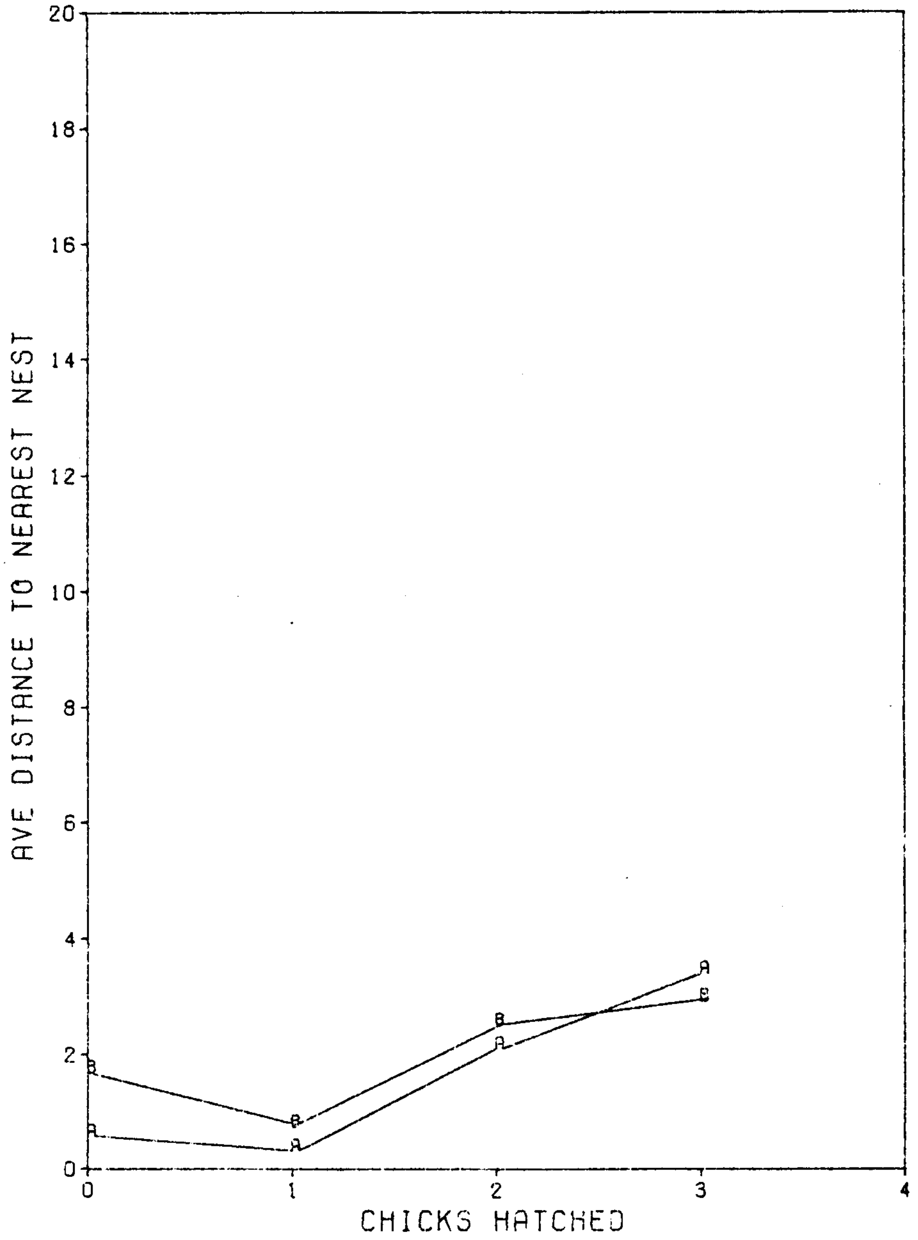


Figure 60. Chicks hatching plotted against mean distance to nearest nest, Dry Bay, 1977.
A = 'A' Colony, B = 'B' Colony.

Mean distance to nearest nest influenced number of chicks hatching per nest only slightly.

of a generally earlier breeding season, related to milder weather. Chick hatching was also more synchronous in 1973 (Figs. 49, 50).

Chick hatching was not synchronous at Egg Island in 1976. The increase in chick numbers was nearly directly proportional to time elapsed. Hatching for 50% of the eggs extended over 20 days, in contrast to the two to five day hatching period on North Marble. (Fifty percent of the eggs in the 1976 Egg Island study area were laid in one week.) Re-nesting and clutch replacement following subsistence egging by fishermen in early June was the most likely explanation for this spread of hatching (Figs. 39, 51).

Dry Bay in 1977 was intermediate between Egg Island and North Marble in rate of chicks hatching over time. Chick hatching was more synchronous than egg-laying (Fig. 40, 51) at Dry Bay; 50% of the eggs were laid in an eight-day period in late May, but 50% of the chicks hatched in a three-day period between 17 and 21 June. This suggests a more synchronized onset of incubation than synchronized egg-laying.

North Marble and Dry Bay colonies contained roughly the same number of pairs (about 500) and both were relatively undisturbed areas. Egg Island was a huge colony with disturbance. There was a tendency for groups of birds to breed at the same time, but the synchrony was disrupted by human intervention (egging).

8. Chick Mortality

Chick mortality in southern Alaskan gull colonies was divided into two classifications: chicks which were observed dead, and chicks which disappeared, were not counted as fledged, and which were presumed dead.

Observed chick mortality in southern Alaskan colonies was low, ranging from 3 to 12% (Table 14). North Marble Island had the highest rate of hatching failure, which was due to egg predation, but the rates of observed chick mortality and disappearance were the lowest of colonies examined, except for Lake Louise, where we have limited data due to restricted time available for investigation (Table 3).

Chicks which disappeared accounted for a high percentage of the chick loss at both Egg Island and Dry Bay. The figures ranged from 26% to 49% (Table 14). Egg Island, however, had the highest combined egg and chick mortality of coastal colonies studied (Table 15). High egg and chick mortality, added to low clutch size, meant Egg Island had the lowest total reproductive success (in chicks fledged per nest) of the three major coastal colonies examined. Total chick mortality on Egg Island (mean of both seasons) was 38%. The Egg Island situation represented disturbed conditions, with access by boatmen, picnickers, and dogs, which may have accounted for the large number of chicks which disappeared.

Hatching successes at Egg Island and North Marble were within 8% of each other (Table 14). Dry Bay had a much higher rate of hatching, due to a low rate of egg loss, and larger clutch size. Thus Dry Bay had more chicks hatching in proportion to other colonies (Table 14). However, chick disappearance was the main factor influencing chick mortality at Dry Bay in 1977 (Table 14).

The few chicks found dead on the sparsely vegetated gravel bars at Dry Bay in 1977 showed injury due to attacks by adult gulls defending territory. We believe eagle predation (observed on an hourly basis in late June and July) was the main reason for chick disappearance, and thus was the major factor influencing reproductive success in the gullery at Dry Bay. When the

Table 14

Percent Chick Mortality, Egg Island 1975-76; North Marble Island 1972-73; Dry Bay, 1977

Study Area	% Hatching	% Observed Mortality	% Disappeared	Fledged as % hatched
Egg Island 1975 (153 nests)	69	12	26	62
Egg Island 1976 (186 nests)	77	8	31	61
North Marble 1972 (162 nests)	67	5	2	93
North Marble 1973 (191 nests)	69	8	4	88
Dry Bay "A" 1977 (90 nests)	92	6.5	39*	54
Dry Bay "B" 1977 (22 nests)	93	3	49*	47.5

* heavy eagle predation noted.

Table 15

Hatching Success, Mortality, Reproductive Success Egg Island, 1975-76; North Marble Island, 1972-73; Dry Bay, 1977; Lake Louise 1977

Colony	Hatching Success (%)	Egg and Chick Combined Mortality (%)	Total Reprod. Success (%)
Egg Island (153-186 nests)	73	65	44
Dry Bay (22-90 nests)	93	51	49
North Marble (161-192 nests)	68	34	61
Lake Louise (77 nests)	N.A.	N.A.	35

low rate of egg loss, and the high rate of chick loss were combined, Dry Bay had an intermediate rate of mortality compared to other coastal colonies. Total reproductive success at Dry Bay was better than Egg Island, but less than North Marble (Table 15).

9. Fledging Success

We determined the median length of the fledging period to be 40-45 days on North Marble, similar to Dry Bay, Egg Island, and Lake Louise. Other investigators have reported similar fledging period for *argentatus* in Michigan (Keith, 1966), *occidentalis* in California (Schreiber, 1970; Harpur, 1971) and *glaucescens* in British Columbia (Vermeer, 1963).

At the end of the fledging period at each major colony in this study, we made counts to determine fledging success. Fledging success, while a difficult measurement (Keith, 1966; Schreiber, pers. comm.), is crucial in understanding the reproductive biology of these gulls.

When the number of chicks fledged in 1972 at North Marble was plotted against percentage of nests for four colonies, the East, West, and North Colonies formed a pattern (Fig. 61). The Top Colony was aberrant, with larger territory size (Table 12, Fig. 34), fewer chicks hatching Fig. 53), and fewer chicks fledging (Fig. 61). Territory size was not directly related to number of chicks fledging in the other colonies, since they were all within the same range (Fig. 61).

The situation on North Marble in 1973 was different. The East, West, and Top Colonies formed a pattern. Productivity was greater in the Top Colony; more chicks fledged. The increase in productivity was correlated with smaller internest distances, larger clutch sizes, and fewer eggs and chicks lost (Figs. 35, 46, 58, 62). The North Colony in 1973 exhibited the unusual, possibly artifactual, pattern. Disturbance associated with boat mooring may have caused nearly fledged chicks to emigrate earlier from the North Colony and not be counted as fledged.

At Dry Bay in 1977, both 'A' and 'B' Colonies fledged similar percentages of one chick per nest, but 'A' Colony had a greater reproductive output of two and three chicks per nest, which accounted for the better fledging success in Colony 'A' (Fig. 64). Mean distance to nearest nest showed little direct relationship to chicks fledging at Dry Bay in 1977 (Fig. 68).

Reproductive success (in chicks fledged per nest) was lower at Egg Island, compared to North Marble or Dry Bay, and was slightly higher than Lake Louise (Table 12). Egg Island exhibited a pattern similar to North Marble in 1972 when number of chicks fledged was plotted against percentage of nests (Fig. 63). On Egg Island, mean territory size was slightly, but not significantly, larger in 1976; productivity was also slightly, but not significantly, better than 1975. When territory size at Egg Island was plotted against number of chicks fledging per nest, the relationship was virtually the same for both study years (1975-76). Most nests fledged one chick (Fig. 67).

10. Summary of Fledging Rates

The fledging rate of 1.03 - 1.12 *glaucescens* chicks per nest on Egg Island is normal compared to other gull species (Table 16) but lower compared to a partially mixed *argentatus* - *glaucescens* colony at North Marble in post-glacial surroundings (1.77), due to the abundant natural food supply in the "unfilled" niche at Glacier Bay. The fledging rate of 0.95 *argentatus* chicks per nest at Lake Louise is sufficient to maintain a stable population, but also much lower than the highly mixed *argentatus* x

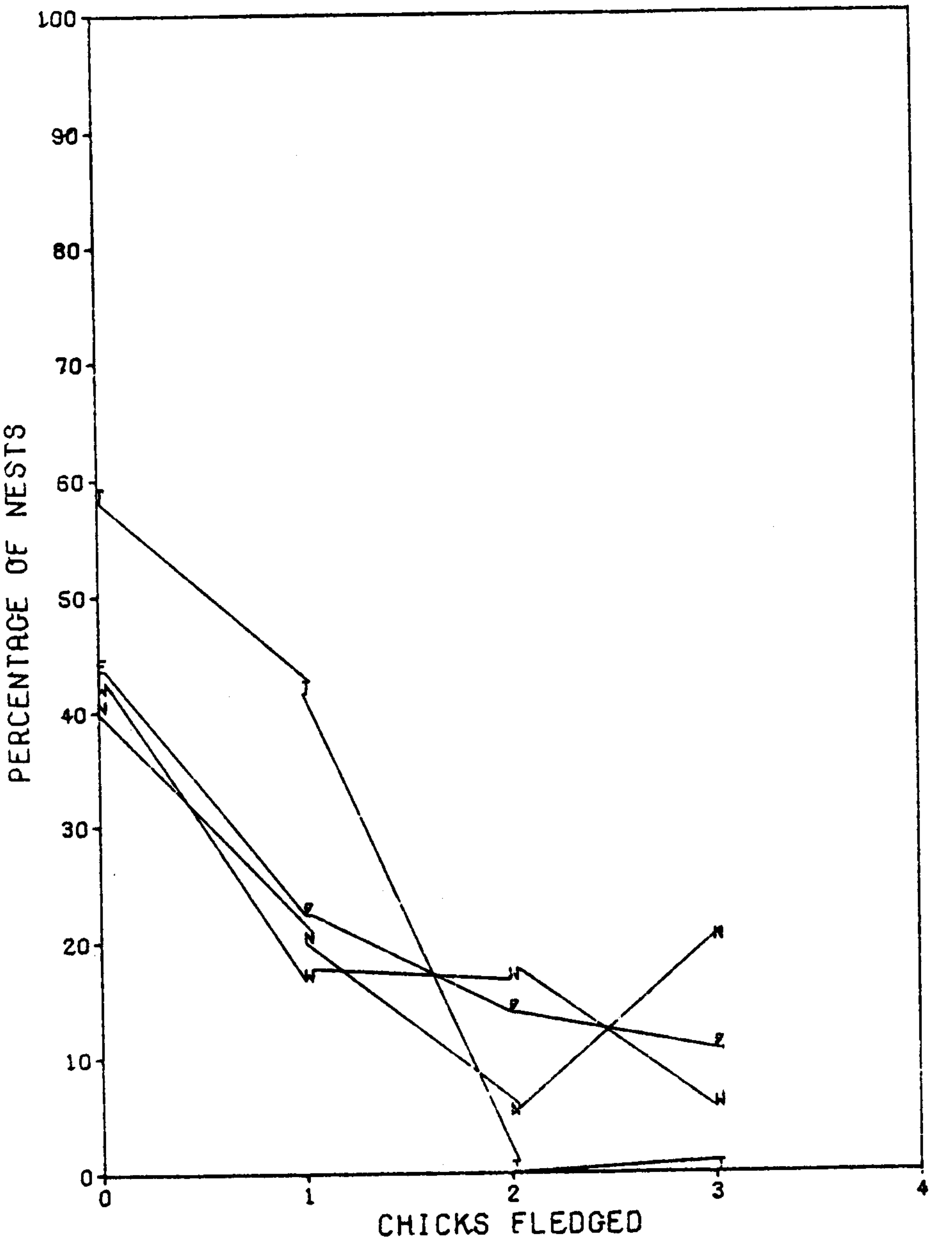


Figure 61. Chicks fledging plotted against percentage of nests, North Marble, 1972.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

Once again the East, West and North Colonies form a similar pattern and the Top Colony is aberrant, with large territory sizes, smaller clutches, fewer chicks hatching, greater chick loss, and fewer chicks fledging.

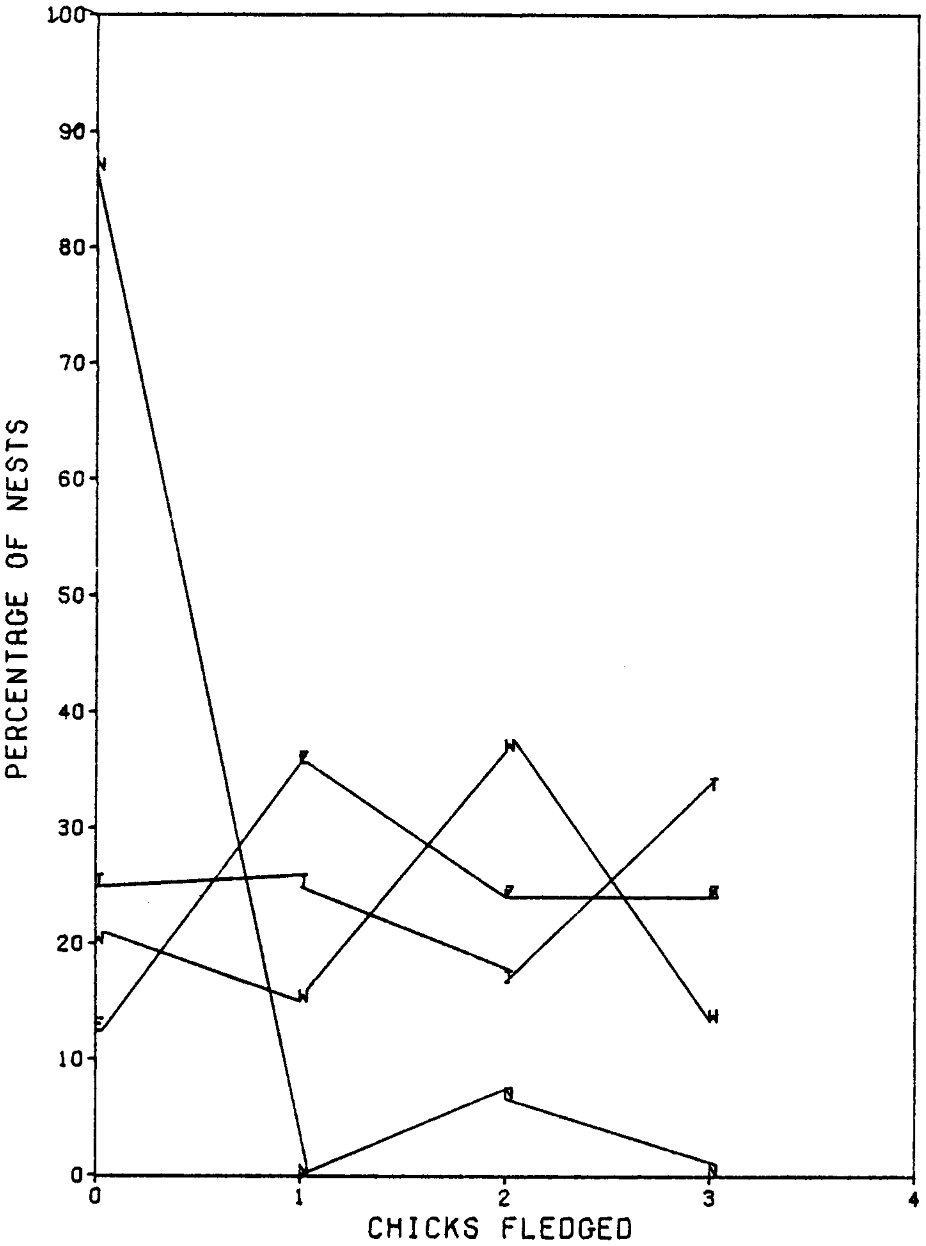


Figure 62. Chicks fledging plotted against percentage of nests, North Marble, 1973.
E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

The North Colony here presents an exception to the usual trend. The East, West and Top Colonies closely fluctuate around a mean, while the North Colony breaks the pattern, with many fewer chicks apparently fledged. This may be due to disturbance due to boat mooring near the colony, causing chicks to emigrate early.

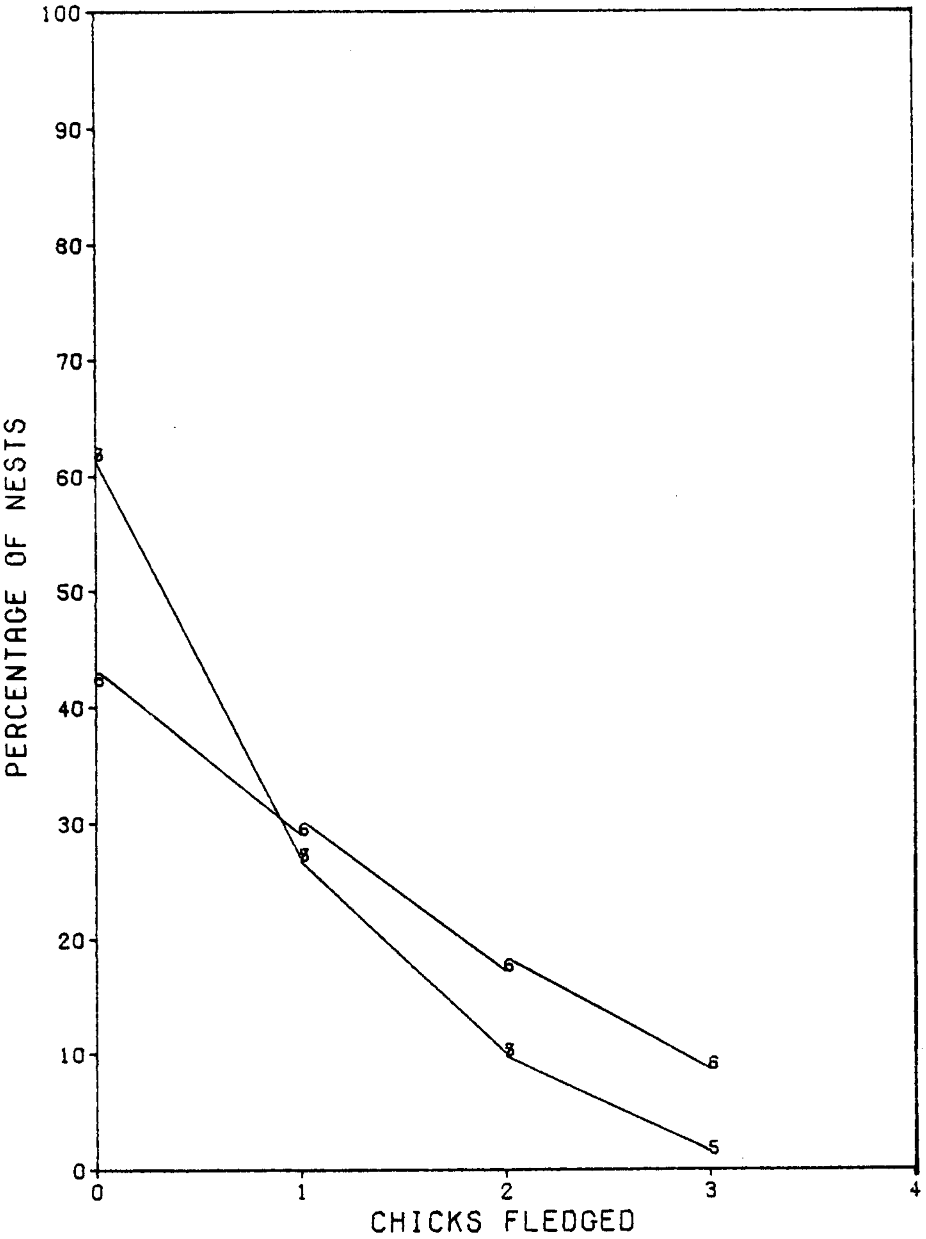


Figure 63. Chicks fledging plotted against percentage of nests, Egg Island, 1975 - 1976. 5 = 1975 survey, 6 = 1976 survey.

Egg Island gulls produce fewer chicks than those on North Marble, in proportion, but Egg Island resembles North Marble in 1972 in chicks fledged. The productivity on Egg Island is expected to increase as the proportion of experienced female breeders expands, given continued access to artificial food from human sources.

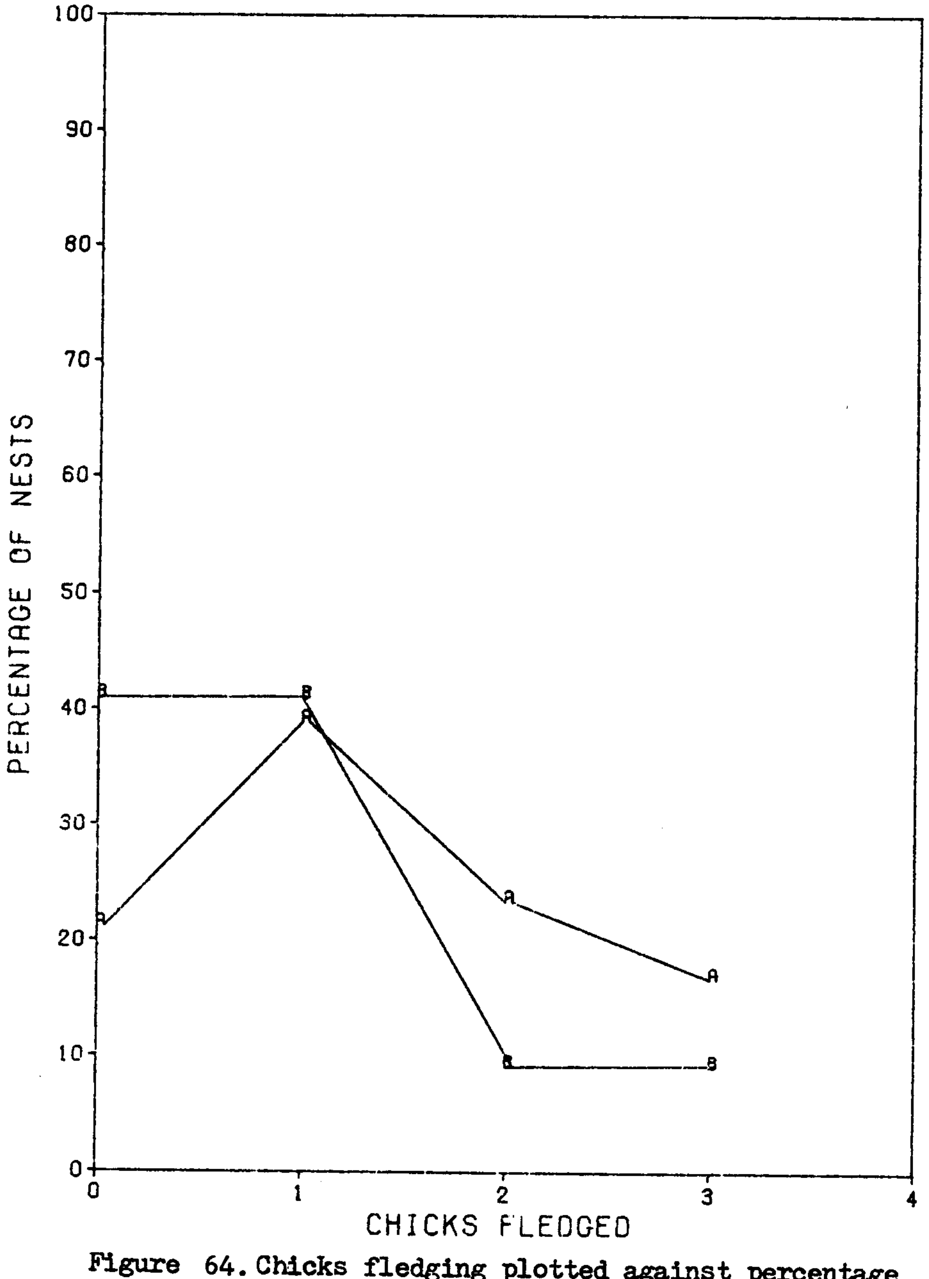


Figure 64. Chicks fledging plotted against percentage of nests, Dry Bay, 1977.
A = 'A' Colony, B = 'B' Colony.

Both 'A' and 'B' Colonies fledged similar percentages of one chick per nest, but 'A' colony fledged more two and three chicks per nest.

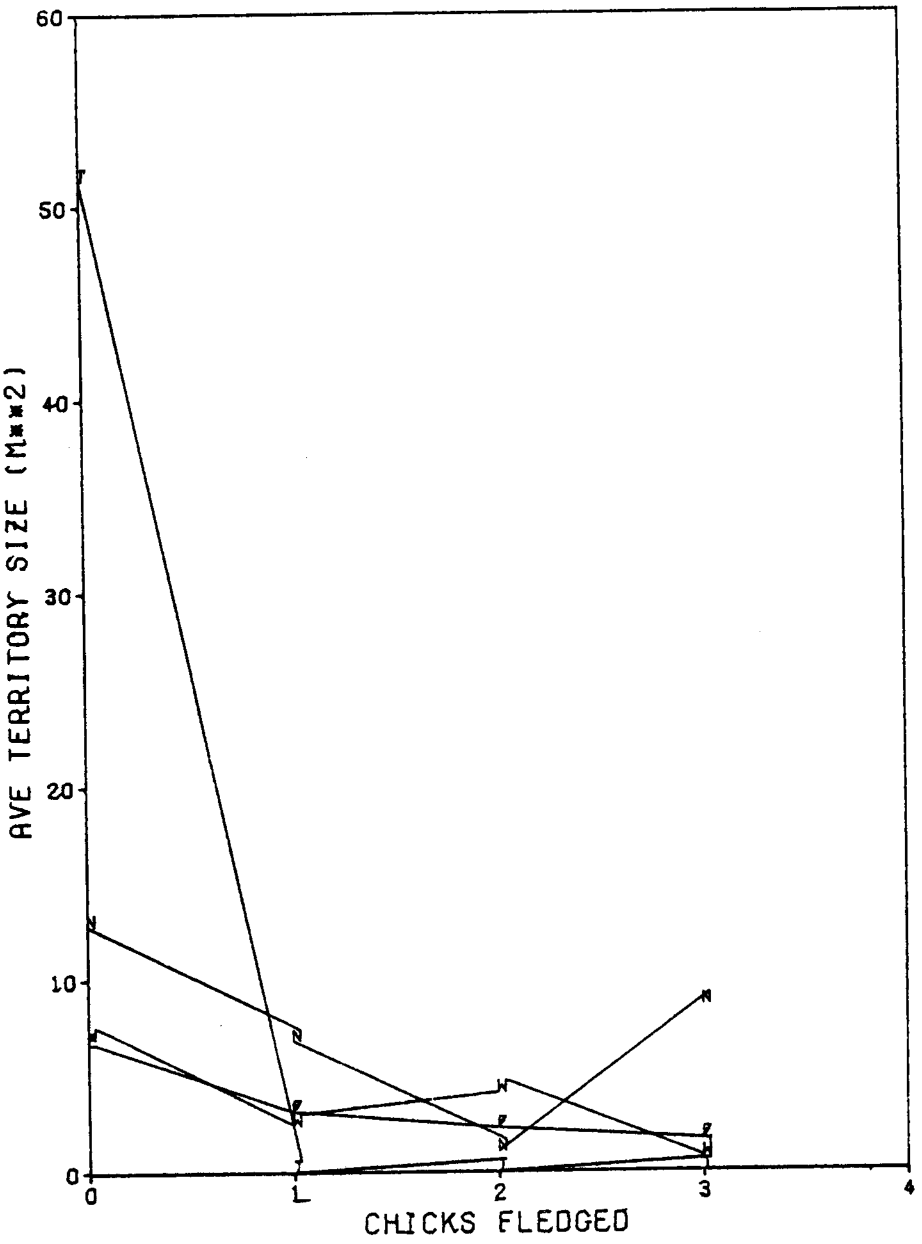


Figure 65. Chicks fledging plotted against average territory size, North Marble, 1972. E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

Gulls with large territory sizes and small clutch sizes in the Top Colony fledged no chicks. Only a few chicks survived from this colony this season. Territory size played only a moderate influence in chicks fledging in the other colonies, since they were all within the same general range.

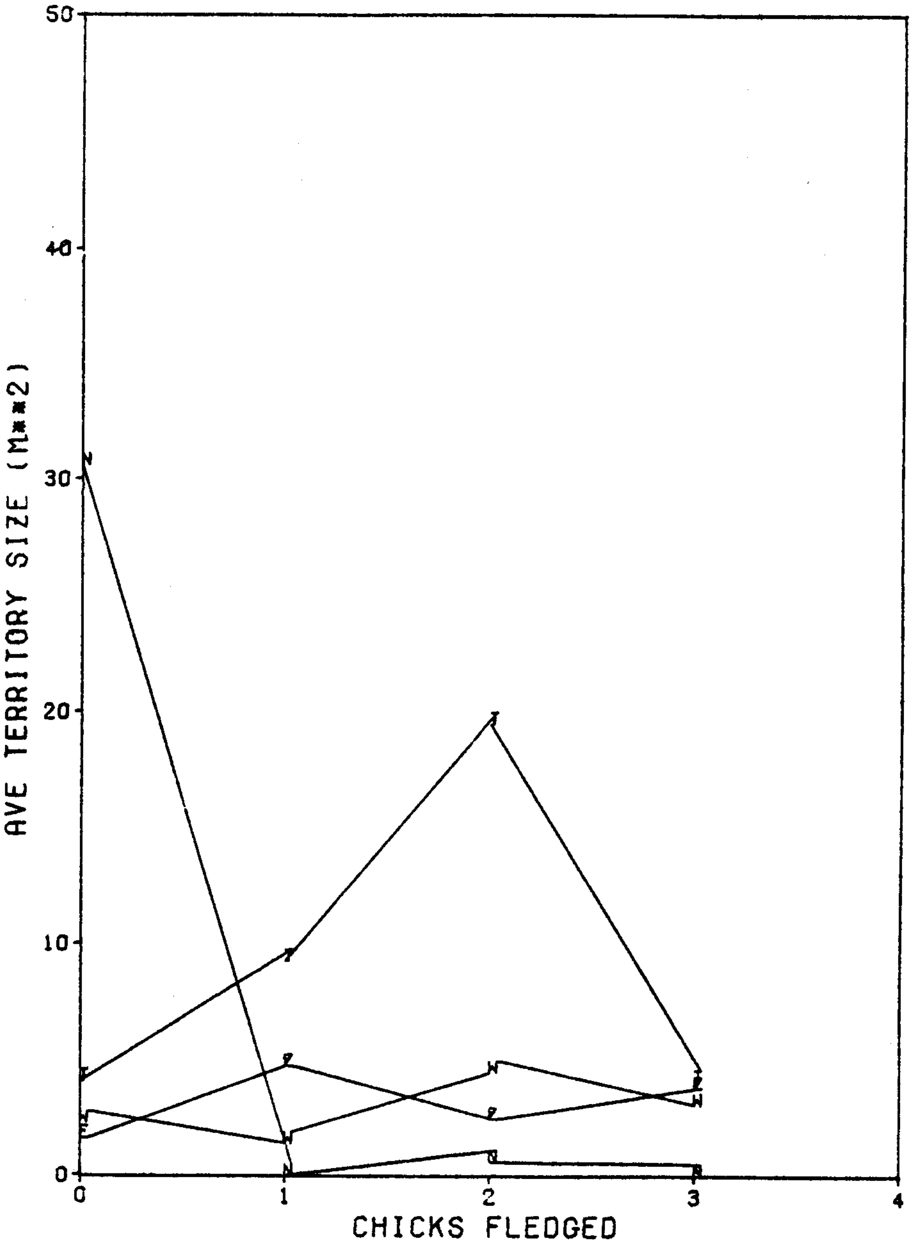


Figure 66. Chicks fledging plotted against average territory size, North Marble, 1973. E = East Colony, W = West Colony, N = North Colony, T = Top Colony.

Productivity was much greater in the Top Colony in 1973, with smaller average territory size, compared to 1972. The North Colony exhibits the unusual trend here, probably due to disturbance.

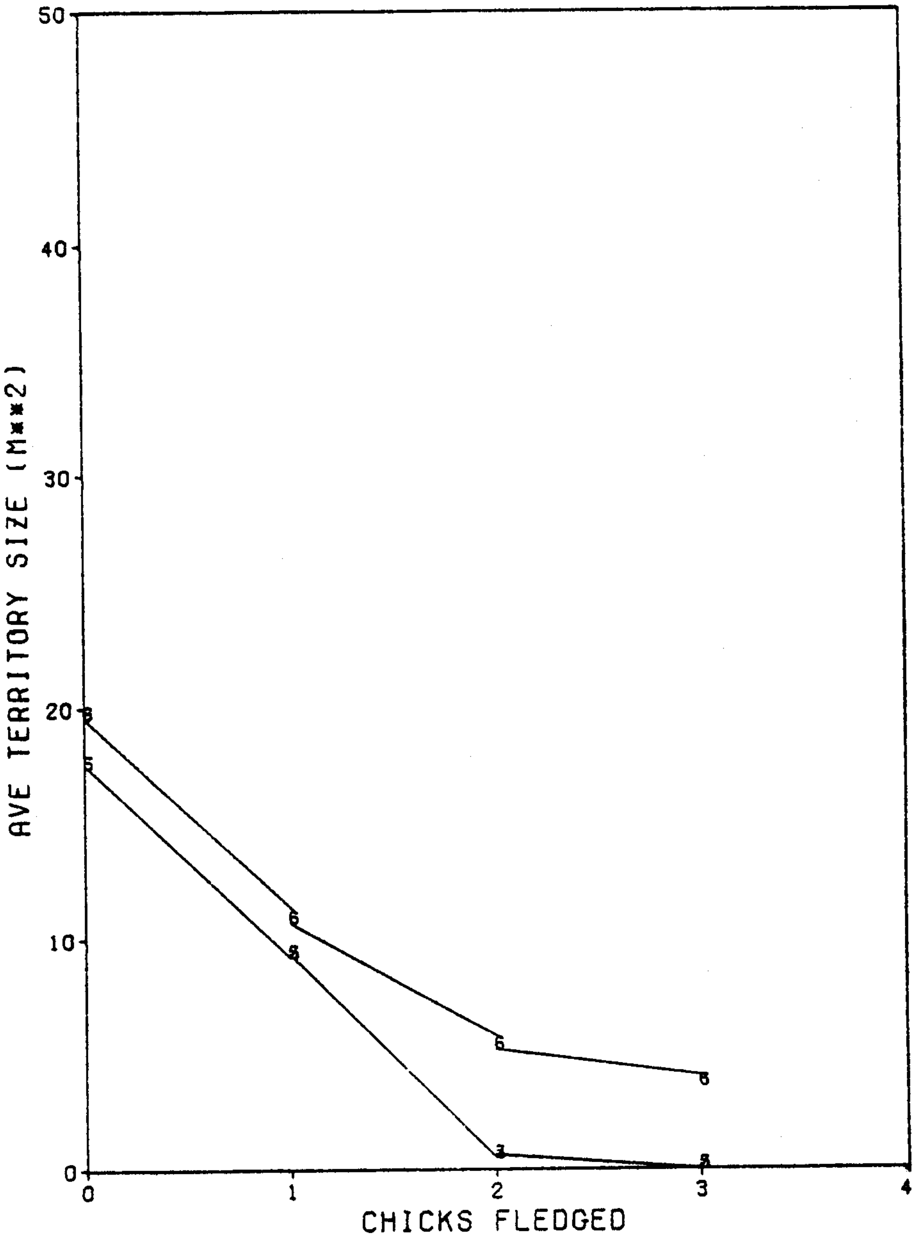


Figure 67. Chicks fledging plotted against average territory size, Egg Island, 1975 - 1976. 5 = 1975, 6 = 1976.

Territory size was slightly larger on the average in 1976, but productivity was also slightly better. However, both years the survey area shows a similar tendency, fledging mostly one chick per territory. Note larger territory size on Egg Island compared to North Marble (Figures 24, 25).

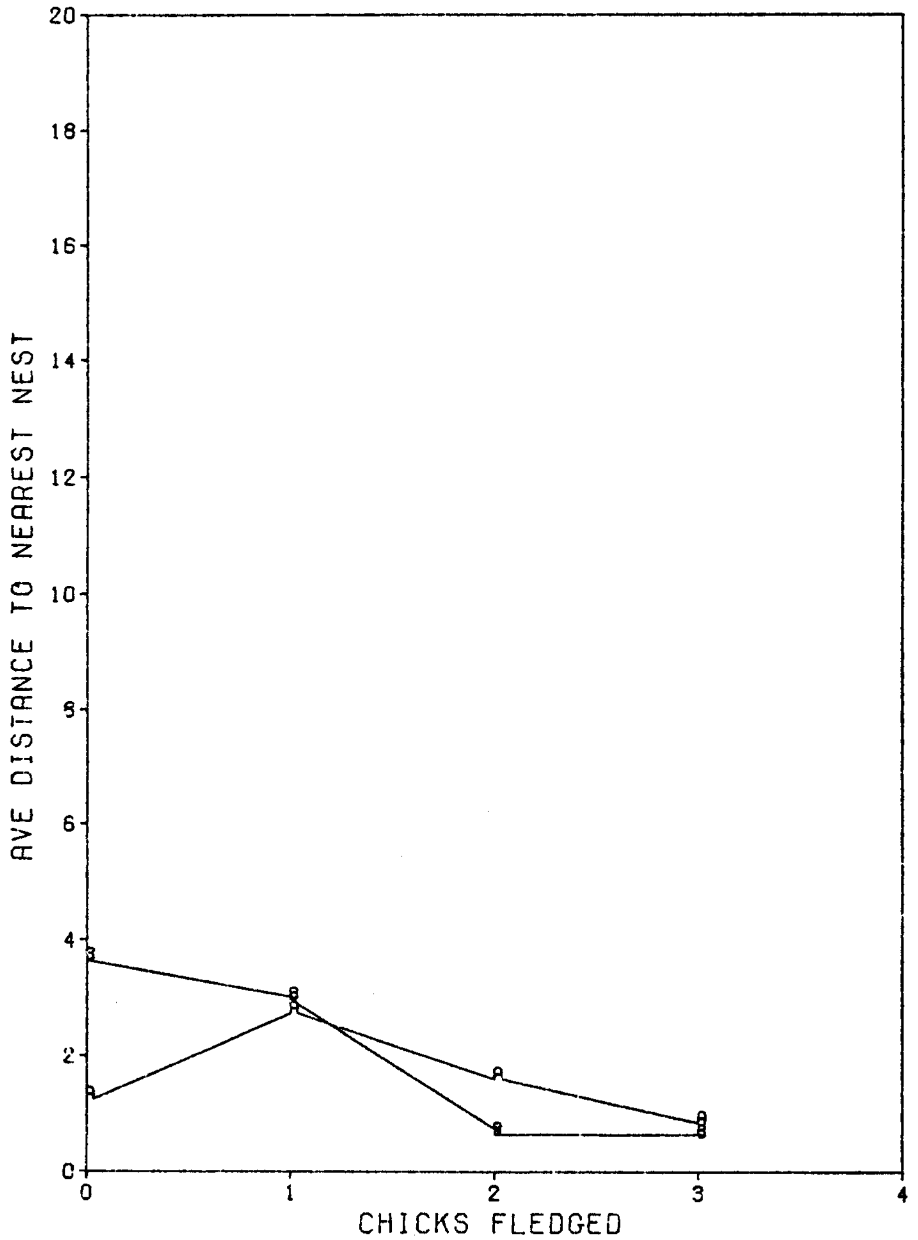


Figure 68. Chicks fledging plotted against mean distance to nearest nest, Dry Bay, 1977.
A = 'A' Colony, B = 'B' Colony.

Mean distance to nearest nest had little effect on chicks fledging per nest at Dry Bay in 1977.

glaucescens colony at Dry Bay (1.44) (Table 16; Fig. 70).

The expanding coastal populations of *glaucescens* and *argentatus* x *glaucescens* hybrids encounter relaxed selection pressures due to unlimited nesting space and abundant natural food in recent-post glacial and river delta environments. *L. argentatus* genes are entering coastal populations at Glacier Bay, Dry Bay, and the Susitna Flats near Anchorage at the mouth of the Susitna River.

Paynter (1949) reported a production of 0.92 chicks per nest sufficient to maintain a stable population of *argentatus* on Kent Island, New Brunswick, very close to that we discovered at Lake Louise. Ludwig (1966) found a recruitment rate of 0.63 maintained a stable population of *delawarensis* on the Great Lakes. *L. argentatus* studied by Ludwig increased on the Great Lakes between 1960 and 1965 at an annual rate of 13% with a mean fledging rate of 1.47, quite close to the production at Dry Bay (*argentatus* x *glaucescens*). The population growth of *argentatus* on the Great Lakes was due to the abundance of the alewife (*Alosa pseudohargenus*), a major food source. Populations of *delawarensis* on the Great Lakes increased during the same period at 30% per year with a mean fledging rate of 1.74 (Ludwig, 1966), practically identical to North Marble. *L. glaucescens* studied by Vermeer (1963) produced 1.35 chicks per nest per year. Harpur (1971) published fledging rates of 1.33 and 0.96 per pair of *occidentalis*. The highest mean fledging success in the literature is 2.00 chicks per nest reported by Coulter et al. (1971) for *occidentalis* on the Farallons. Other fledging successes, summarized by Keith (1966) ranged from 0.3 to 1.17.

The above comparisons indicate the coastal populations of *glaucescens* and *argentatus* are reproducing well. North Marble has a very high reproductive rate, indicating a population expanding at 30% per year. Dry Bay has a high reproductive rate, suggesting expansion of 12% per year. The large _glaucescens_ population at Egg Island, partially dependent upon artificial food in Cordova, is expanding at a rate of 4% per year, a "normal" pattern for gulls. For example, at this rate, in five years the 20,000 gulls breeding on Egg Island would number 24,333. This is over a 20% increase in five years, similar to conditions replicated in recent past in the eastern United States, due to the same reason, an increasing food supply due to man's activities. The Lake Louise population of _argentatus_, with limited nesting space and restricted food availability, is maintaining itself.

Table 16

Comparative Index of Gull Reproductive Success in Chicks Per Nest (Productivity)

Colony Location	Species	Chicks/ Nest	Reference
California	*L. occidentalis*	2.00	(Coulter et al., '71)
North Marble (1972-73)	mixed *glaucescens/ argentatus*	1.77	(Patten, 1974)
Great Lakes	*L. delawarensis*	1.74	(Ludwig, 1966)
Great Lakes	*L. argentatus*	1.47	(Ludwig, 1966)
Dry Bay (1977)	mixed *glaucescens/ argentatus*	1.44	(this paper)
British Col.	*L. glaucescens*	1.35	(Vermeer, 1963)
California	*L. occidentalis*	1.14	(Harpur, 1971)
Egg Island (1975-76)	*L. glaucescens*	1.08	(Patten & Patten, 1977)
Lake Louise (1977)	*L. argentatus*	0.95	(this paper)
New Brunswick	*L. argentatus*	0.92	(Paynter, 1949)
Michigan	*L. argentatus**	0.35*	(Keith, 1966)

* Population contaminated by DDT

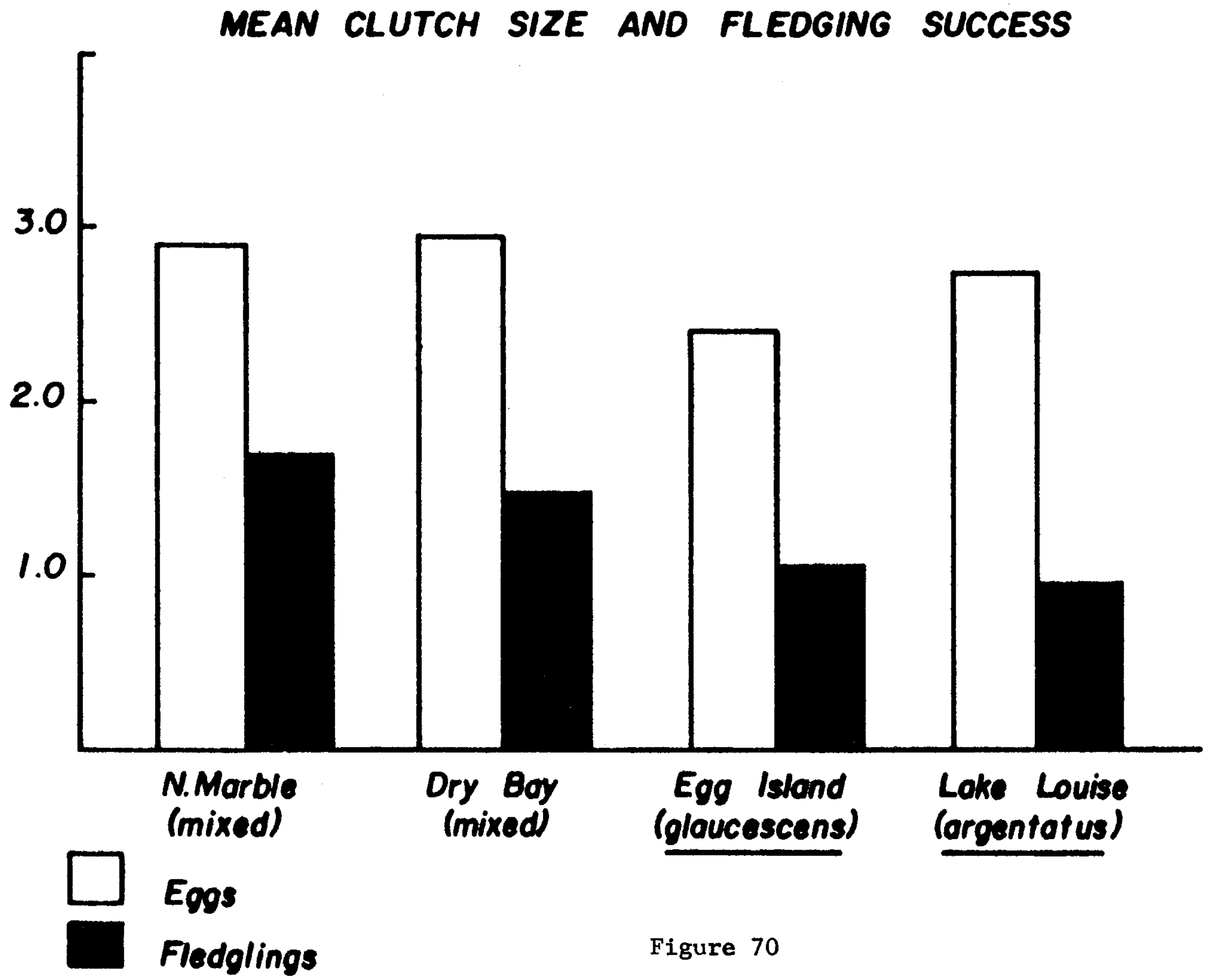

MEAN CLUTCH SIZE AND FLEDGING SUCCESS
3.0
2.0
1.0
N.Marble (mixed)
Dry Bay (mixed)
Egg Island (glaucescens)
Lake Louise (argentatus)
Eggs
Fledglings

Figure 70

E. Banding Results

The temporal sequence of band recoveries from Egg Island juvenile gulls first suggested strongly migratory tendencies. Additional recoveries now support the emerging migratory pattern of juvenile gulls originating on sandbar barrier islands off the Copper River Delta. Indications are that recently fledged juvenile gulls from Egg Island disperse explosively to Prince William Sound salmon streams within a month of fledging (cf. Moyle, 1966), and reach as far as Anchorage and Valdez before beginning migration south along the Pacific Coastline (Table 17; Fig. 71 ; Pearse, 1963). Band recoveries in January, from young gulls originating off the Copper River Delta, extend from Ketchikan, AK, to Puget Sound, WA. Several Egg Island juveniles, just over one year old, have been found in their second summer at Valdez. A color-dyed three-year old gull demonstrated lateral movement in July between Egg Island, off the Copper River Delta, and Middleton Island in the Gulf of Alaska (Fig. 72). More band recoveries of young gulls banded at Egg Island are from Valdez (25%) than any other location. Whether this represents environmental disturbances capitalized by gulls or simply concentration of human observers remains to be determined.

Table 17

Banding Recoveries of Juvenile Gulls from Egg Island

Location	Date	Reason
1. Valdez AK	22 Aug 75	aircraft strike
2. Valdez AK	22 Aug 75	aircraft strike
3. Valdez AK	29 Aug 75	dead on road
4. Anchorage AK	30 Aug 75	found dead
5. Copper Delta AK	1 Sept 75	eaten by eagle
6. Yakutat AK	- Oct 75	found dead
7. Juneau AK	4 Oct 75	shot by boy
8. Ketchikan AK	20 Jan 76	oiling
9. Vancouver BC	- Jan 76	found dead
10. Valdez AK	19 Jul 76	injury
11. Valdez AK	19 Jul 76	found dead
12. Cape Hinchinbrook AK	28 Jul 76	collected
13. Seward AK	5 Sept 76	found dead
14. Yakutat AK	8 Oct 76	found dead
15. Juneau AK	31 Oct 76	entangled
16. Olympia WA	23 Nov 76	no information
17. Petersburg AK	10 Dec 76	caught by dog
18. Harris Harbor AK	15 Jan 77	found dead
19. Prince Rupert BC	23 Jan 77	found dead
20. Rivers Inlet BC	-- Feb 77	found dead
21. Lake Tapps WA	-- Feb 77	shot
22. Ketchikan AK	3 Mar 77	hit by car
23. Valdez Arm AK	24 Aug 77	found dead
24. Cordova AK	31 Aug 77	trapped & released

Table 18

Banding Recoveries of Juvenile Gulls From Strawberry Reef, Copper River Delta

	Location	Date	Reason
1.	Vancouver BC	3 Feb 77	found dead
2.	Bainbridge Island WA	16 Feb 77	found dead

Note: Tables 17 & 18. Radiation to Prince William Sound region after breeding seasons and then strongly migratory tendencies exhibited by N - S chronological sequence of banding recoveries.

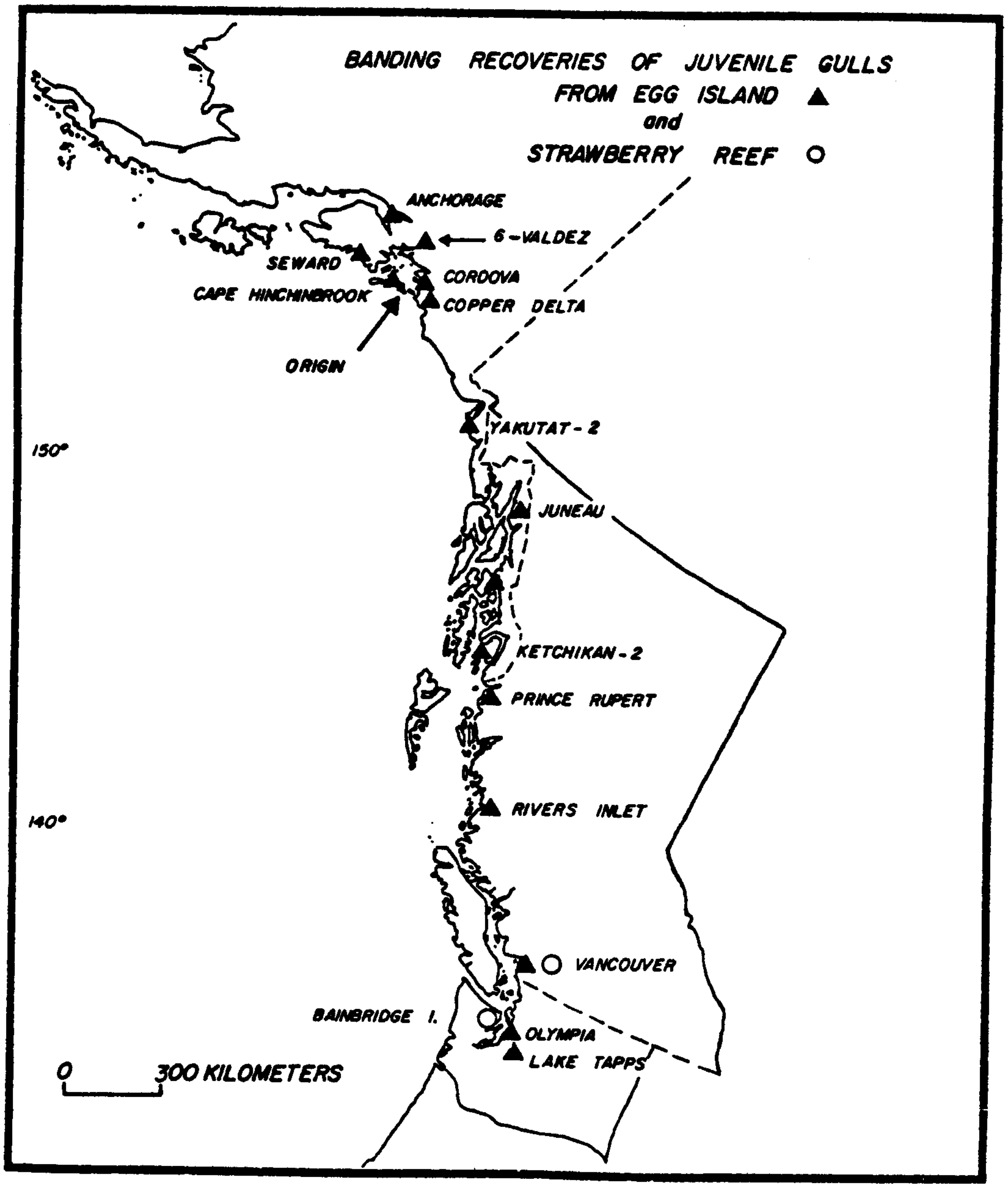

BANDING RECOVERIES OF JUVENILE GULLS
FROM EGG ISLAND ▲
and
STRAWBERRY REEF ○
ANCHORAGE
6-VALDEZ
SEWARD
CORDOVA
CAPE HINCHINBROOK
COPPER DELTA
ORIGIN
YAKUTAT-2
150°
JUNEAU
KETCHIKAN-2
PRINCE RUPERT
RIVERS INLET
140°
VANCOUVER
BAINBRIDGE I.
OLYMPIA
LAKE TAPPS
0
300 KILOMETERS

Figure 71

Table 19

Observations of Color-dyed Gulls (Adults)

	Location	Date	Activity
1)	Cordova docks-canneries	July-Aug 75 Sept-Oct 75	feeding
2)	Cordova dump	July-Aug 75 Sept-Oct 75	feeding
3)	Egg Island	July-Aug 75	breeding
4)	Eyak River, Copper Delta	Aug 75	resting
5)	Hawkins Island, Prince William Sound	Aug 75	flying
6)	Juneau	Sept 75	resting
7)	Cordova docks-cannieries	March 76	resting
8)	Egg Island	June 76	breeding
9)	Middleton Island,* Gulf of Alaska	July 76	resting
10)	Hartney Bay, Orca Inlet	Aug 76	feeding
11)	Cordova City Airport	Aug 76	resting
12)	Cordova dump	July-Aug 76 Sept-Oct 76	feeding

<u>Note</u> artificial food sources, winter absence, suggestion of migration pattern.

* third-year juvenile

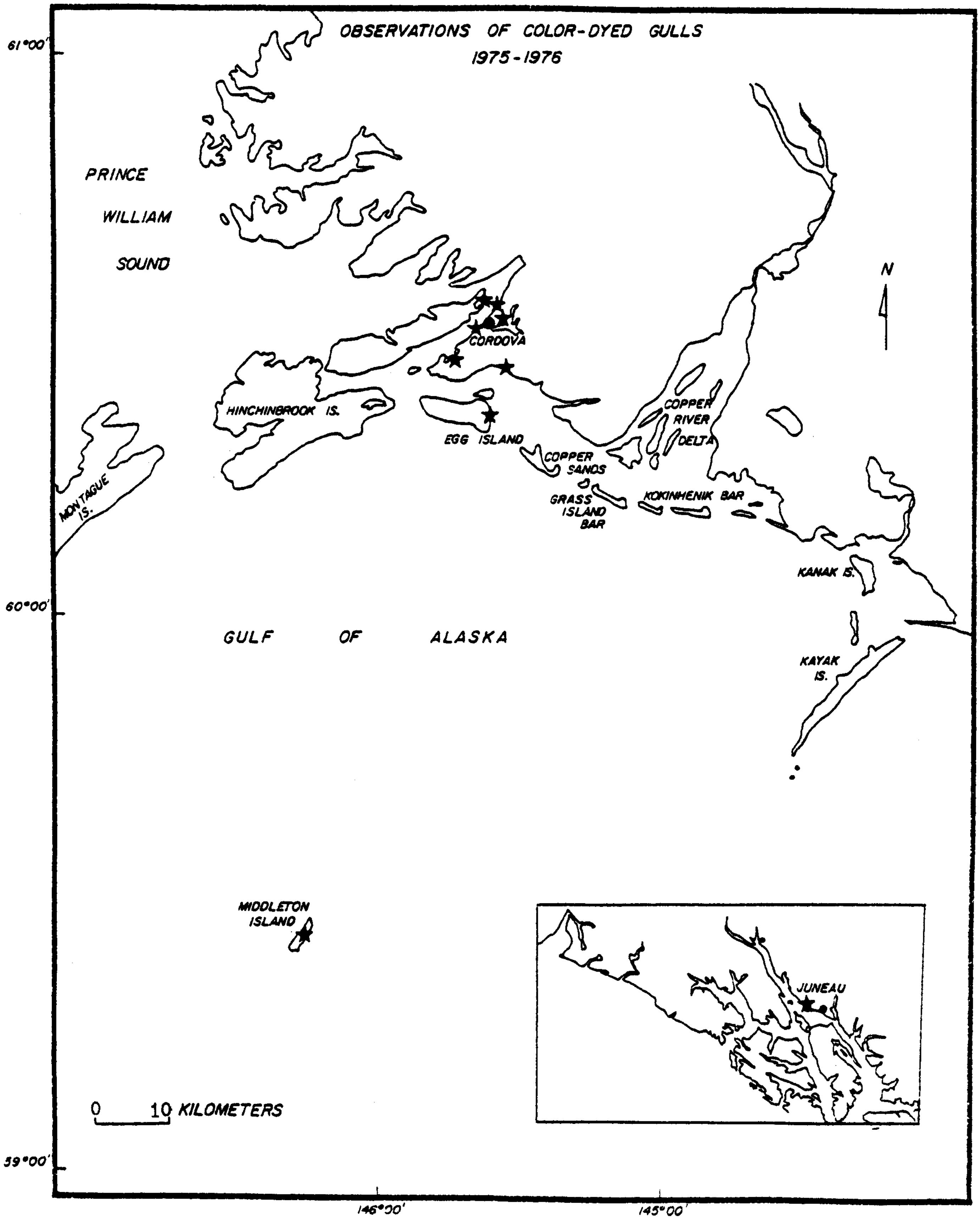

OBSERVATIONS OF COLOR-DYED GULLS
1975-1976
61°00'
60°00'
59°00'
146°00'
145°00'
PRINCE
WILLIAM
SOUND
N
CORDOVA
HINCHINBROOK IS.
EGG ISLAND
COPPER
RIVER
DELTA
COPPER
SANDS
GRASS
ISLAND
BAR
KOKINHENIK BAR
MONTAGUE
IS.
KANAK IS.
KAYAK
IS.
GULF OF ALASKA
MIDDLETON
ISLAND
JUNEAU
0 10 KILOMETERS

Figure 72

F. Wintering Areas of argentatus and glaucescens

A review of recent literature on wintering areas and F&WS observations of large gulls in the northeast Gulf of Alaska (Lensink, pers. comm.) amplifies banding and color-dyeing studies.

Isleib and Kessel (1973) suggest part of the northeast Gulf of Alaska glaucescens population winters offshore on the continental shelf. Isleib (pers. comm.) reports argentatus, glaucescens and other hybrids are common in the winter in the Cordova area, where argentatus and hybrids are quite uncommon during the summer. Hoffman (pers. comm.) also finds glaucescens, argentatus and hybrids offshore between Yakutat and Kodiak in November. These observations, with the results of color-dyeing studies showing Egg Island-Cordova adult glaucescens departing the Cordova area and returning in March, indicate major pelagie population shifts and migratory movements southward in fall and winter. (Table 19; Fig. 72).

The Fish & Wildlife Service / NOAA winter cruises (18 Jan - 13 Feb) find highest densities of seabirds in association with trawling operations 65 - 200 km east of Kodiak Island in waters over the continental shelf, or shelf break. Mean density in birds/km^2 for outer continental shelf regions is: British Columbia Shelf: 6.3; Southeast Alaska Shelf: 6.3; Northwest Gulf of Alaska 47.4; and Kodiak Basin: 35.2 (Lensink, 1977).

Larus glaucescens is among the most abundant species on NOAA/F&WS patrols (14-21 Feb; 7 Feb-4March). High numbers are consistently correlated with trawling operations of foreign-flag factory ships on the continental shelf. Larids occur in low but regular numbers in off-shelf areas. Apparently pure *glaucescens* predominate but a few *glaucescens* x *argentatus* hybrids and a very few typical *argentatus* are sighted off Canada and in the Gulf and Kodiak basins (Lensink, 1977).

Sanger (1973) and Harrington (1975) report pelagic *argentatus* and *glaucescens* 80 - 640 km off southern California from January to April. *L. argentatus* increase until mid-February, and then rapidly decrease from mid-March to mid-April. Gulls collected in April have enlarged gonads in near breeding condition. Further north, F&WS ship surveys in the northeast Gulf of Alaska find marked shifts in relative abundances of gulls indicating migration from more southern regions:

Table 20

Large Gulls Observed on Transects in the Northeast Gulf of Alaska (Lensink, pers. comm.)

Species	Number/km^2			
	Feb.	Apr.	May	June
Unidentified Gull	0	.08	.05	.07
Glaucous Gull	.02	.23	0	0
Glaucous-winged Gull	3.33	1.69	1.89	.19
Herring Gull	.03	.21	3.23	.41

The sharp increase and then decline in May of argentatus per km^2 represents a migration from more southern regions (e.g., off California) towards interior breeding localities in Alaska, B.C., and the Yukon (Table 20). Herring Gulls appear on interior lakes across Alaska in May just before spring break-up. Non-breeding argentatus may summer at sea, since inland lakes are not especially productive. Breeding pairs on inland lakes are more scattered than colonial and clutch size is smaller than coastal gull populations (Anderson, viva voce). Post-breeding adult gulls depart abruptly from interior lakes in late August or early September. Major rivers (Copper, Alsek, Taku, Stikine) provide migratory pathways to the sea.

The more gradual decline in glaucescens per km^2 from Feb. to June represents coastal breeders returning to colonies. From February to April pelagic glaucescens decrease by 50%. Gulls from Mandarte Island, B.C., are on site in February; gulls are present at North Marble in Glacier Bay in March (Streveler, pers. comm.) and appear on territories at Egg Island in April (Isleib, pers. comm.).

F&WS standing stock estimates of pelagic gulls exceed known breeding pairs in the NEGOA (Lensink, pers. comm.). Non-breeders and gulls originating from other than coastal NEGOA colonies comprise a large portion of the pelagic population. Offshore gull populations utilize food resources (including offal from foreign fisheries), reducing competition with onshore breeding populations.

G. Gull Food Habits

Continued access to food resulting from human activities will increase gull numbers in Alaska. This food supply is not likely to decrease with further industrial development in Alaska. Gene flow among gull populations will follow increasing numbers. Gulls exploit artificial food due to natural plasticity of food selection and dichotomy of foraging pathways. Gull populations in Alaska currently exhibit both food selection under natural conditions, and response to artificial food supply.

Glacier Bay

Alaskan gulls of the argentatus group under natural conditions show two major foraging pathways: first, gulls scavenge the intertidal in areas such as Glacier Bay, from the lowermost to the uppermost regions. The rise and fall of the strong tides in Glacier Bay exposes up to ten meters of a rocky, algae-covered zone. Gulls take a wide variety of food items, including cast-up larger fishes such as Gadidae, Scorpaenidae, Cottidae and Theragra, and invertebrates such as Mytilus, Thais, Balanus, and Pagurus (Table 21). Invertebrates are broken, dropped, pried open, or swallowed whole. Secondly, strong tidal currents in Glacier Bay cause upwelling of soil nutrients deposited in the waters by glaciation (Streveler and Paige, 1971). The nutrients support food chains producing small fishes. Gulls dive for small fishes, stooping from several meters to well beneath water surface, in areas of tidal disturbances, at river mouths, near surfacing whales (Jurasz, pers. comm.; Divoky, 1976), taking

Osmeridae, *Clupea harengus*, *Thaleichthys pacificus*, and small shrimp (*Pandalus*). Gulls take other small fishes (*Pholidae*) from rocky intertidal pools by stalking. Glacier Bay, representing the natural environment, a recently deglaciated "unfilled niche," provides excellent feeding for gulls.

Dry Bay

Gulls feed on outer sandy beaches and at river mouths between Yakutat and Cape Fairweather (cf. Patten & Patten, 1975, for similar observations at Dixon River in Glacier Bay National Monument). Dry Bay is an important feeding area for gulls, cormorants, mergansers, and seals. Eulachon (*Thaleichthys pacificus*), fed heavily upon by gulls, normally spawn in clear rivers in March and April, but a prolonged, late and heavy run continued until the end of May 1977 south of Yakutat, including Williams Creek, a tributary of the Alsek. Gulls also feed heavily on Pacific capelin (*Mallotus villosus*) spawning in the surf during summer high tides. Other gull foods include small crabs (*Cancer magister*) $\leq$ 4 cm, blackfin poacher (*Bathyagonus nigripinnis*), herring (*Clupea hargengus*) spawning on kelp in April and May, Pacific sandlance (*Ammodytes hexapterus*) and razor clams (*Siliqua patula*). The abundant 1977 eulachon may have accounted for the high clutch size and resultant good reproductive success in the gull colony at Dry Bay.

Salmon offal from Dry Bay Fish Co., a small processing plant, is currently a minor food source for gulls, bears and wolves. Dry Bay supported much heavier commercial fishing earlier this century and the resulting offal may have then supported more gulls. A railroad hauled fish from the Akwe River to a cannery at Dry Bay (Ak. Geo., 1975). The Alsek fishery included both drift and set gill nets (Brogle ADF&G, pers. comm.). Nothing is left of the cannery except pilings. An indian village existed at Dry Bay long before the cannery (Ak. Geo., 1975). Only a dozen fishermen now live along the lower Alsek from late May to October. Their impact upon the biota other than salmon is minimal.

Haenke Island

Alaskan gulls also exploit marine mammals under natural conditions (Divoky, 1976; Tuck, 1960). Seals, for instance, give birth on pack ice at Haenke Island near Yakutat and in Muir Inlet in Glacier Bay. Gulls (both argentatus and glaucescens nesting on nearby fjord cliffs) scavenge seal feces, stillborne pups, other carcasses, and placentae (Streveler & Paige, pers. comm.). Remains of seal placentae, lanugo hair, and ordinary seal hair form the most common item in gull castings and stomach specimens collected at Haenke Island in June (identification courtesy Mr. T. Eley, ADF&G).

The affinity of gulls for sewage has been previously discussed (Patten & Patten, 1977). This behavior may have originated from following marine mammals.

A long stretch of exposed, sandy beaches connects the fjordlands of Glacier and Yakutat Bays with Prince William Sound on the north.

Egg Island

The gull colony at Egg Island, at the end of the chain of sandy beaches between Glacier Bay and Prince William Sound, exhibits parameters of an expanding population as discussed above. The population is expanding for two reasons: a result of increase in nesting space, as plant succession follows earthquake uplift of island colonies, and availability of artificial food in Cordova in the form of offal and garbage.

Fish and crab processing plants in Cordova in 1972 discharged <u>2.6 million pounds of seafood waste</u> into Orca Inlet (USDI, 1976; underlining mine). EPA regulations require dumping of waste where material is not visible but in summers 1975-76-77 the gulls found the material highly visible, attracting huge foraging flocks (10,000 individuals per hour), notably during salmon-packing season (July-August). This is precisely when gulls feed young on Egg Island 20-30 km away. Color-dyed breeding birds from Egg Island join in these flocks with non-breeding adults and second and third-year juveniles. Gulls constantly interchange from Eyak Lake, Eyak River, and Orca Inlet to the colonies on sandbar islands at the mouth of the Copper River (Fig. 72). The gulls feed on circling swarms on the effluent hosed from the floors of the seafood processing plants, ground up and dumped from pipes at the ends of the wharves. Gulls also feed on detritus in the harbor and on fishing boats.

Newly fledged juveniles appear at the seafood plants in late July and early August. Fewer gulls are found in the area when the seafood plants are not processing, e.g., when ADF&G closes the season or when commercial fishermen strike. The Cordova municipal dump provides a more limited but more constant food supply and is used by fewer birds when effluent is available from seafood plants.

Lake Louise

Lake Louise, across Prince William Sound and 160 km into the interior from Cordova (Fig. 15), supports a small, now relatively stable population of argentatus. Fish, including lake trout (Salvelinus namaycush), greyling (Thallymus arcticus), burbot (Lota lota) and suckers (Catostomidae), form the most important part of the gull diet at this interior lake, since invertebrates are few in numbers and species. Gulls also scavenge fish scraps, refuse from State campgrounds, and garbage from a dump three km from the lake. Armed Forces recreation centers were located at Lake Louise until the mid-1960's, at which time the lake received heavier fishing pressure than at present. Poe (viva voce) stated his impression that gull nesting density on Bird Island is less now than a decade ago, when refuse and fish scraps were more readily available.

Gulls identified as argentatus are absent from the Cordova seafood plants during the summers, but Isleib and Kessel (1973) indicate they are common in the winter around the wharves. Most certainly these gulls originate from interior lakes such as Lake Louise, frozen in the winter.

Table 21

Known Gull Food Items

Colony/ Foraging Area	Glacier Bay	Dry Bay	Strawberry Reef	Copper Sands	Egg Island
Food items:					
Phylum Mollusca Class Pelecypoda	*Mytilus edulis*	*Siliqua patula*			*Siliqua patula* *Mytilus edulis* *Clinocardium nuttallii*
Gastropoda	*Fusitriton oregonensis* *Neptunea lyrata*				
Cephalopoda					*Octopus* sp.
Phylum Arthropoda Class Thoracica	*Balanus glandula*				
Decapoda	*Pagurus beringanus* *Hyas lyratus* *Chionoetes bairdi*	*Cancer magister*	*Pandalus borealis*		
Insecta					Tipulidae sp.
Phylum Echinodermata Class Echinoidea	*Strongylocentrotus drobachiensis*				

Table 22 (cont.)

Known Gull Food Items

Colony/ Foraging Area	Glacier Bay	Dry Bay	Strawberry Reef/ Haenke Island	Copper Sands	Egg Island	Valdez Cordova Yakutat Juneau	Lake Louise
Food items:							
Phylum Chordata Class Osteichthyes							
	Gadidae sp. *Theragra chalcogramma* *Cottidae* sp. *Hemilepidotus hemilepidotus*	*Ammodytes hexapterus* *Clupea harengus* *Bathyagonus nigripinnis* Thaleichthys *pacificus* *Mallotus villosus*		*Clupea harengus* Thaleichthys *pacificus*	*Clupea harengus* *Oncorhynchus* sp. (eggs) *Sebastes* sp. Thaleichthys *pacificus* Pholidae		*Salvelinus namaycush* *Thallymus arcticus* *Lota lota* Catostomidae
Class Aves							
	Larus glaucescens (eggs & chicks)				*Larus glaucescens* (eggs & chicks)		
Class Mammalia							
	Phoca vitulina (carcasses, placentae, feces)		*Phoca vitulina* (carcasses, placentae)		*Phoca vitulina* (carcasses)		
Food of Human Origin						garbage sewage salmon & crab offal	

Problems Encountered

No major problems encountered.

Recommendations for Future Research

The literature on effects of petroleum exposure to marine bird reproduction is highly limited, and the field is completely open for continued experimentation. Existing studies demonstrate marine bird eggs are highly vulnerable to minute amounts of petroleum, several orders of magnitude less than necessary to cause adult mortality. Egg mortality is a subtle variable, and not easily observed as is adult seabird mortality. Potential effects on marine bird reproduction would not be observed until the adult population "crashed" after some years of failure to reproduce.

Potential effects of petroleum exposure to seabird eggs hinge on transfer of petroleum during egg-laying or incubation. We are devising a protocol for capture of breeding adults, with subsequent artificial oiling, to test transfer to eggs. Necessary levels of contaminants needed to be established first, which we have now provided.

We are currently compiling information on petroleum effects on gull chick fledging success. We will carry out an expanded study of petroleum effects on gull chick viability during the 1978 field season.

Demonstrated effects to date have involved the use of unweathered North Slope Crude Oil. Petroleum encountered in the environment may or may not be weathered. The effects of weathered petroleum on marine bird reproduction are completely unexplored. Experiments should be designed and conducted in the field, first recapitulating experiments using "raw" petroleum, and then expanding upon that body of knowledge. The comparison should be enlightening, since most toxic components are apparently volatile, and the concentration should expect to decrease with duration of atmospheric exposure.

Recommendation to Regulatory Agencies

Our information to date indicates that because eggs of marine birds are so vulnerable to tiny amounts of petroleum, even low-level oil pollution near marine bird colonies would be highly undesirable.

Secondary Effects

Larus argentatus and relatives are, in general, rapidly reproducing "weedy" commensal species, highly adaptable to changing circumstances. Weeds as we know them are largely man-made and inhabit ecological niches that are directly or indirectly the results of human interference. Some of these niches are of definite types, and man creates these everywhere. The most important artificial niches for gulls are garbage piles, sewage outfalls, and fish offal. Two out of the three are secondary effects of gas and oil development. The experience in Britain has been that the secondary effects of petroleum development are more important than the primary effects.

The extrapolation of the British experience to the Alaskan situation is hypothetical, although highly suggestive. We have no data westward from Prince William Sound, although the primary gull species, glaucescens, is the same. North of the Alaska Peninsula, the main gull species shifts to hyperboreus, and the coastal environment becomes radically different.

Factors which limit the growth of the gull populations north of the Alaska peninsula probably do not come into effect during the breeding season, but during the winter. We do not know whether these gulls migrate, nor what their major sources of food are.

Gull populations in OCS areas other than the northeast Gulf of Alaska should be thoroughly investigated before generalizations concerning population changes can be considered valid.

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INFLUENCE OF PETROLEUM ON EGG FORMATION AND EMBRYONIC DEVELOPMENT IN SEABIRDS

by

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Submitted as the Annual Report for Research Unit 423
OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM
Sponsored by

U.S. Department of Interior
Bureau of Land Management
through the U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Bering Sea - Gulf of Alaska Project Office
P.O. Box 1808, Juneau, Alaska 99802

March 30, 1978

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I. Summary of objectives, conclusions and implications with respect to OCS oil and gas development.

A. Summary of objectives

The general objectives of the project were to appraise the effects that brief exposure to an oil spill would have on the reproduction of Cassin's Auklets (*Ptychoramphus aleuticus*) and on Western Gulls (*Larus occidentalis*) nesting on the Farallon Islands of California. These species are representative of many birds breeding in Alaska and the lower Pacific Coast states that are at risk from oil pollution during the reproductive period.

The specific objectives were to determine the effects of a single oral dose of bunker C fuel oil on the egg production, hatching success, fledging success, egg yolk structure, and yolk composition of Cassin's Auklets, and breeding pairs of auklets, dosing the female during the period of rapid yolk formation, and obtaining field data on reproductive success. Laboratory studies were designed to determine effects on yolk qualities and composition and embryonic changes in response to the oil, based on experience with the Japanese quail as a model bird.

Objectives in preparation for the 1978 breeding season included the following: (1) to increase the number of pairs studied in order to obtain more eggs laid during the period expected to be most critical, 2-7 days after dosing; (2) to prepare 270 wood nest boxes to permit easier, less disturbing access to the birds in addition to 130 natural burrows; (3) to obtain a supply of frozen euphausiids and develop methods for feeding the birds at the time of dosing; (4) to prepare Prudhoe Bay crude oil doses as one of the oils, the other being the bunker C used in 1977; (5) to use equal doses of the oils, at a higher level (1000 mg) than in 1977 (300 or 600 mg); and (6) to arrange to obtain as a byproduct of the study a set of normal auklet embryos after various periods of incubation.

B. Summary of conclusions

During the 1977 breeding season on Southeast Farallon Island, 251 female Cassin's Auklets were force-fed gelatin capsules that were empty or contained 300 mg or 600 mg bunker C oil. These birds and their eggs and chicks were observed throughout the breeding season, as were birds in a control group. No significant differences in laying, hatching or fledging success were observed among the four groups.

The field observation on the effects of the oil on gulls confirmed earlier results in which dosing was the principal problem. This year, capsules containing oil were coated with hydrogenated vegetable oil to lengthen time of capsule solution, and the capsules were sewn inside small squid. The gulls readily took the squid, but regurgitated it as soon as the oil was released from the capsule. Work with gulls was terminated.

Following the observations of gull behavior in regurgitating oil, auklets and other birds were also studied. The auklets began eliminating the oil at a mean time of 36 minutes after being fed. Adult Japanese quail (*Coturnix coturnix japonica*) reared in cages and adult, pen-reared mallards (*Anas platyrhynchos*) deprived of food for 16 hours were compared in their responses to oil with fed birds. It took fed quail 177 minutes to eliminate oil, while unfed quail took only 29 minutes. Mallards responded differently: feeding did not affect passage time. Three Black-footed Albatrosses (*Diomedea nigripes*) and 3 Common Murres (*Uria aalge*) were also dosed.

It took several hours for oil to pass in the albatross; the murres reacted violently within minutes by regurgitating and defecating oil.

Auklet eggs collected during the critical period of 2-7 days after dosing with bunker C oil were found to have normal yolk structure and appearance. Because chemical methods might be more useful than visual methods of detecting pollution, attempts were made to develop techniques of analysis using quail and chicken eggs, for eventual use with auklets. Yolks from oil-treated quail and chickens were found to differ from normal yolk in appearance and response to solvents. "Oil" yolks were lighter in color than normal. Denaturation and initial extraction of the thawed yolk with acetone resulted in a stringy texture as compared with the normal crumbly appearance. No major differences were found in phospholipid distribution or in ultra-violet absorption of extracts. Differences were detected in fluorescence of extracts prepared from "oil" and normal eggs after thin-layer chromatography of yolk extracts.

Gas chromatographic analyses of treated extracts of normal and "oil" eggs have been pursued vigorously but the results have not proved satisfactory. Preliminary observations of differences attributable to oil have not been confirmed.

C. Implications with respect to OCS oil and gas development

It is not possible to draw definitive conclusions from the results obtained during this first year of study in which auklets were dosed with small amounts of bunker C oil. However, under the conditions of the experiment, the oil did not cause any apparent adverse effects on reproduction of auklets such as those that were obtained when comparable doses were given to laboratory quail. This does not mean, of course, that oil is harmless to seabirds. Indeed, the experiment was designed to minimize general effects of oil and to maximize unique features of reproduction that might reveal subtle effects of oil instead of gross and multiple stresses such as those observed in massive spills. Furthermore, oil doses had to be given to the female several hours after the time of feeding, a condition that would be unlikely in the event of an inadvertent spill at a feeding area.

If auklets, gulls, or murres are subjected to foods contaminated by oil, they are likely to be able to deal with this oil by rapid elimination through the gut (auklets, murres) or by regurgitation (murres, gulls), and that oil will probably not constitute a hazard, provided other, noncontaminated food becomes available in a reasonable time.

The presence of spilled oil on the sea, from platform, pipeline, or tanker, constitutes a major hazard to birds in contact with that oil, as has been documented many times. Whether or not relatively small amounts of oil constitute a significant hazard to reproduction is unclear. The first year results do not support the worst fears that appeared possible from laboratory studies reported previously.

II. Introduction

A. General nature and scope of study

The responses of marine birds to contamination by petroleum are only partly understood. Massive coating of external surfaces results in their death, but what happens when seabirds ingest small amounts of oil preened from their feathers? This project was designed to determine reproductive responses of Cassin's Auklets and Western Gulls to small doses of bunker C oil ingested by females during the period of egg formation.

B. Specific objectives

The approach was to identify breeding birds, feed them a known amount of bunker C oil at the time when yolk was being formed, and then to follow the course of their reproductive activities. We sought to determine whether ingested oil affected the timing of egg laying, the number of eggs laid, the hatching success of eggs, and the growth and fledging success of chicks. We also sought to develop techniques whereby petroleum compounds could be detected qualitatively and quantitatively in the yolk of eggs.

C. Relevance to problems of petroleum development

It is known that many seabirds are killed by becoming oiled through contact with spills. The effects of sublethal contamination, especially in relation to reproduction, are not known. Because the reproductive period is one of vulnerability of adults and young, assessment of potential hazards to breeding populations is needed to evaluate the total impact of oil development and transport on avian species.

III. Current state of knowledge

Major oil slicks are relatively recent components of the marine environment, except in rare places such as Santa Barbara, California, where natural seeps occur. Seabirds, particularly the more susceptible diving and plunge-diving types (Ainley and Sanger MS), have not had contact with oil pollution long enough to have evolved or acquired defense mechanisms. Mortality of seabirds due to oiled plumage resulting from direct contact with oil slicks is thus becoming a frequent occurrence (see, for instance, Straughan 1970, 1971; Smail et al., 1972). Death in this situation has been attributed to hypothermic stress after the oil destroys the insulating properties of a bird's plumage. Ingestion of oil under these circumstances also affects intestinal absorption of water as at least one contributing cause of death (Crocker et al., 1975). In spite of information about bird survival following direct oiling, little is known about the possible effects of petroleum on physiological processes, especially reproduction, in birds. The present work is designed to evaluate the significance of oil ingestion in seabird reproduction.

Coating of laid eggs by oils can cause embryonic mortality, probably by limiting gaseous exchange through the shell (Rittinghaus 1956, Abbott et al., 1964, Hartung 1965), but also by a toxic effect of substances absorbed through the shell. Albers (1977) reported that as little as 1 μl of fuel oil reduced the hatchability of 8-day Mallard embryos that were being incubated artificially. Ingested substances can be deposited in eggs, usually in the yolk (Shenstone 1968), but we are only beginning to understand the mechanism and effects of such incorporations. Both fat and water-soluble materials, including drugs, pesticides, toxins, and dyes have been identified in the yolk.

A recently published study of the effects of bunker C oil on egg formation and hatchability in Japanese quail (*Coturnix coturnix japonica*), a pilot animal, showed that a single dose of 200 mg reduced egg production and drastically interfered with embryonic development, resulting in very poor hatchability for several days (Grau et al., 1977). It is not yet clear whether these effects represent incorporation of oil components in yolk or some indirect effect on intestinal or liver functions. Extension of this study to fractions of bunker C has shown that the primary effects lie in an isopentane-soluble fraction, not in the heavy residue. When experiments similar to these were carried out with Prudhoe Bay crude oil, fed at 400 and 800 mg levels, egg production and shell thickness were reduced, and therefore total reproduction was markedly affected, but the hatchability of fertile eggs was not reduced (Engel et al., 1977), in contrast to the results with bunker C.

Ingestion of petroleum hydrocarbons by seabirds and waterfowl can occur in several ways. First, a bird ingests oil while attempting to preen it from its plumage. Hartung and Hunt (1966) reported that a duck with 7 g oil on its feathers ingested 1.5 g of the oil during the first day after oiling or 2-3 g /kg body weight. Autopsies of heavily-oiled birds have disclosed oil in the alimentary tract, indicating that ingestion occurred during preening. At least twice during the past five years, up to 10% of Common Murres (*Uria aalge*), Pigeon Guillemots (*Cepphus columba*) and Western Gulls (*Larus occidentalis*) at their breeding grounds on the Farallon Islands have been counted with small amounts of oil on their feathers (PRBO Farallon Journal). In such instances significant amount of oil might be ingested through preening without the birds being sufficiently coated with oil to cause death. Second, a seabird might directly eat oil. Some species, for instance large gulls (*Larus*) and albatrosses (*Diomedea*), feed heavily at times on pelagic barnacles (*Lepas*) that attach themselves to objects floating on the sea (Miller 1940, Sanger 1973). The barnacles readily attach to oil globs with a hardened outer surface; such tar balls can in some areas be quite common (Heyerdahl 1971; Ainley, personal observation). If a bird finds barnacles on a small tar ball it might ingest the entire thing. Third, seabirds maintain fluid and salt balance by drinking seawater. They could conceivably drink water contaminated by oil. Finally, direct contact of skin with oil causes changes in tissue structure and permeability (Renden and Abbott 1973). We found recently that such contact will also affect yolk structure in the same way as does oral dosage. Similarly, we found that intraperitoneal injection of bunker C oil resulted in abnormal yolk structure (unpublished observations).

Smearing of as little as 1 ml of bunker C on the feathers and skin of the head and neck of quail resulted in formation of yolk with the same abnormal structure as was observed when 200 mg was given in a capsule by mouth. From this experiment it was not possible to determine whether the effect was a direct one on the skin, or whether the bird preened and thereby ingested the oil.

Recently developed approaches to the study of yolk structures and its relation to nutrition and other environmental factors have been made possible through new methods of fixation, staining and analysis of eggs (Grau 1976). After freezing whole eggs to alter lipoproteins, the yolk can be fixed in formalin and stained to reveal rings of yolk that can be related to the time the egg was laid. Frozen, unfixed yolks can be cut in half and material isolated from particular parts of the yolk can be analyzed chemically. Thus the composition of yolk deposited during a known period of 8-12 hours can be related to environmental pollution by oil or other materials without maintaining the female in captivity.

IV. Study area

The 1977 field studies were carried out on the Farallon Islands, which lie 45 km west of San Francisco, California (Figure 1). They are the site of the largest seabird breeding colony in the contiguous 48 states of the U.S. and a National Wildlife Refuge. Since 1968 the Point Reyes Bird Observatory (PRBO) has maintained a year round research station on Southeast Farallon, the largest island of the chain. Based on our 1977 studies, we concluded that Cassin's Auklet (*Ptychoramphus aleuticus*) would be our major study subject in 1978 (Figure 2). This bird is abundant at the Farallones, its ecology has been intensively studied there, it easily lends itself to the proposed studies and, lastly and very importantly, it is a member of that seabird family (the Alcidae) that world-round has been most heavily impacted by oil pollution. Furthermore, these auklets breed as far north as the Kodiak Island area of Alaska (Udvardy 1963) and thus occur in important lease areas (Figure 3). Study of the species at the Farallones will mean a minimum of logistics arrangements and problems.

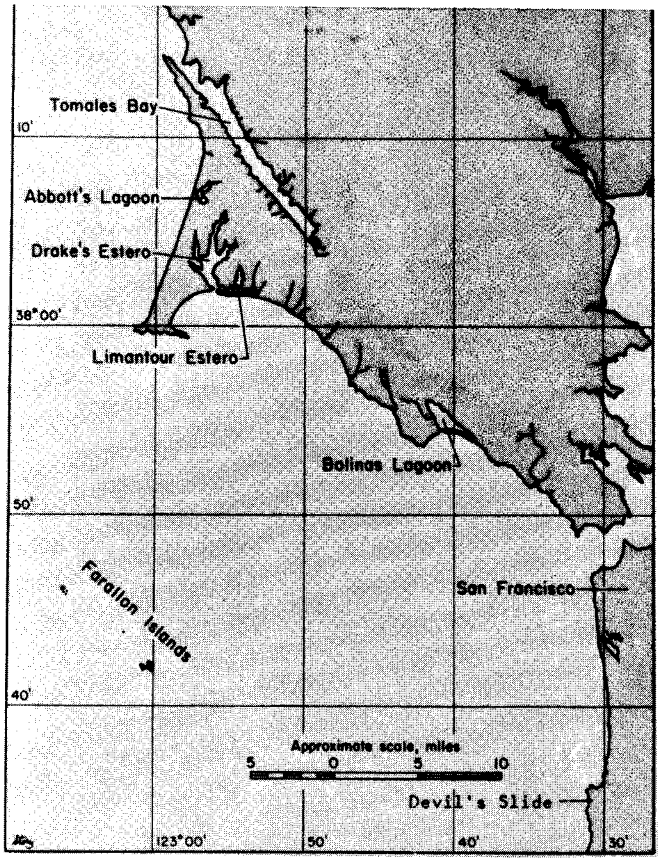

Figure 1. The Farallon Islands in relation to the California coast and San Francisco Bay. Southeast Farallon is the largest island.

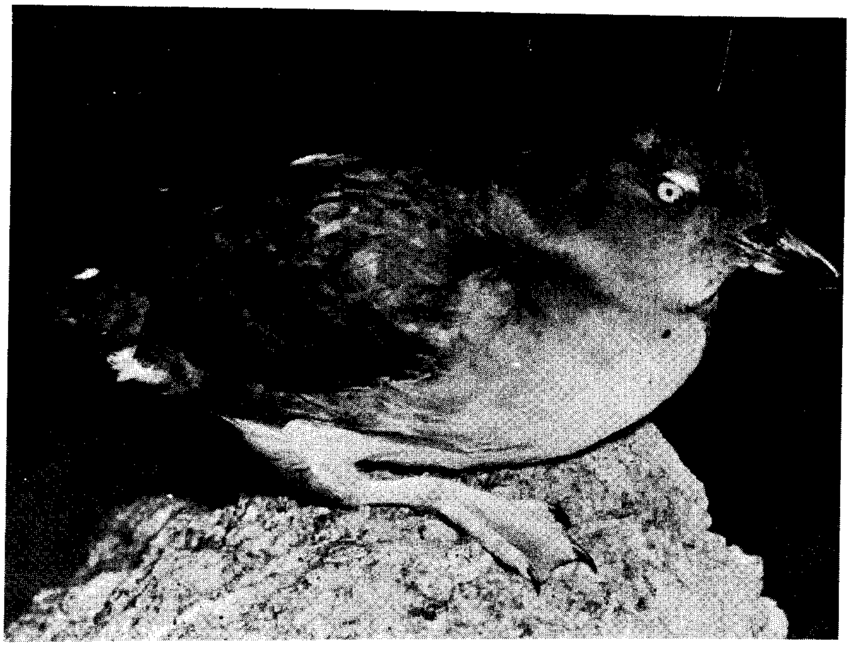

Figure 2. Adult Cassin's Auklet. (Photograph by Bill Parsons)

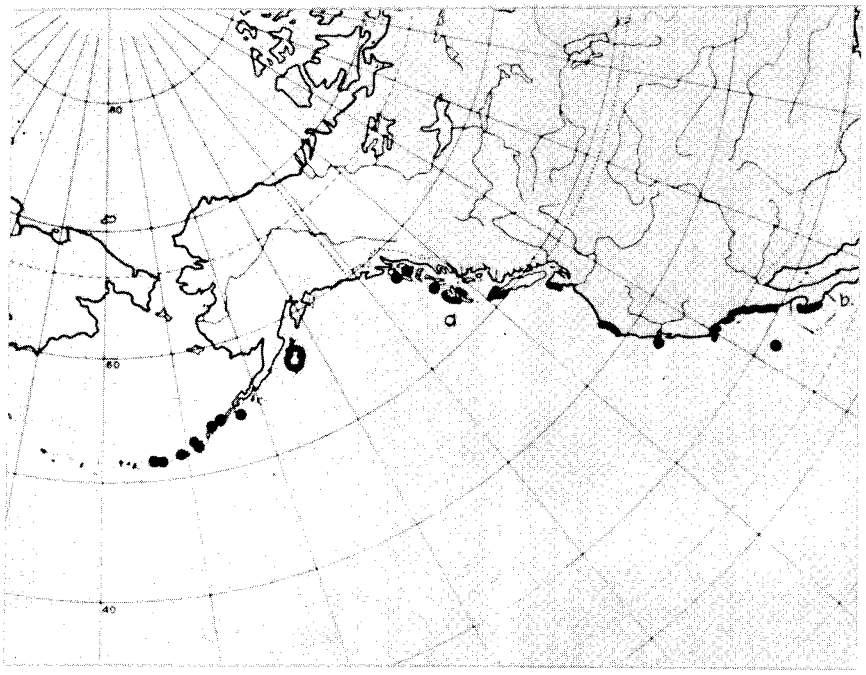

Figure 3. Breeding range of Cassin's Auklet (From Udvardy 1963).

Laboratory work was carried out in the Department of Avian Sciences, University of California, Davis, and in other analytical laboratories at Davis, especially in the Departments of Food Science and Technology and Physiological Sciences, where specialized equipment was available.

V. Sources, methods and rationale of data collection

Auklet field study. In January and early February 1977, 300 Cassin's Auklet burrows were selected and altered to allow human access. An additional 80 control burrows, studied since 1972 and in which birds were not given oil or capsules, were used to compare the effects of force feeding. Beginning in mid-March, all burrows were checked every other day until the first egg was found. On the night of 31 March we began our program of dosing at least 30 female auklets per night.

Each study burrow was checked until a pair of birds was found. We sexed the pair by measuring the bills with calipers. This method was proved reliable by analysis of specimens in museums. If the bill lengths were not distinctly different (an uncommon event), the bill depth was also measured. The bird with the smaller bill of each pair was assumed to be the female. She was force fed one of three possible experimental doses -- an empty capsule or a capsule containing 300 mg or 600 mg of bunker C. Both members of the pair were then returned to their burrow. The type of dose was alternated in sequence (600 mg, 300 mg, empty capsule) so that equal numbers of each treatment were administered each night. Dosing was completed on 7 April after eight successive nights of work.

All experimental burrows were checked daily for eggs through 14 April, after which they were checked every four days. The control burrows were checked every other day throughout the study. When an egg was found, the burrow was not checked again for 38 days (to determine incubation period and/or hatching weight) or 42 days (to determine hatching success). Hatching weight was measured to the nearest 0.5 gram with a Pesola spring scale which was checked daily for accuracy with an electronic balance. After hatching, at least 10 chicks from each group were weighed daily (when alone) until fledging, others were weighed beginning shortly before fledging and others were checked only to determine fledging success. In all comparisons of times, weights and success, only the first egg laid is considered and only if it was laid on at least the second day after a selected experimental dose was administered.

The following definitions apply to this study:

Incubation period is the first day the egg is found until the day before the chick is found free of its egg shell;

Nestling period is the first day the chick is found until the chick is fledged;

Hatching weight is the weight of a chick on the first day it is found (within 24 hours of hatching);

Fledging weight is the weight of a chick on the last day it is in its burrow before fledging;

Maximum number of eggs possible equals the number of females dosed minus the number of burrows that collapsed before an egg was laid;

Maximum number of eggs possible to hatch equals the number of eggs laid minus the number of eggs collected and the number of burrows collapsed, filled in, or where checking was discontinued.

During the late summer and fall of 1977, 270 wood nest boxes were constructed and put in place in S.E. Farallon Island. These box components were cut from exterior-grade 3/8" plywood, painted with dull green paint, and assembled on the island, according to the plan shown in Figure 4. The boxes appeared to be well accepted by auklets.

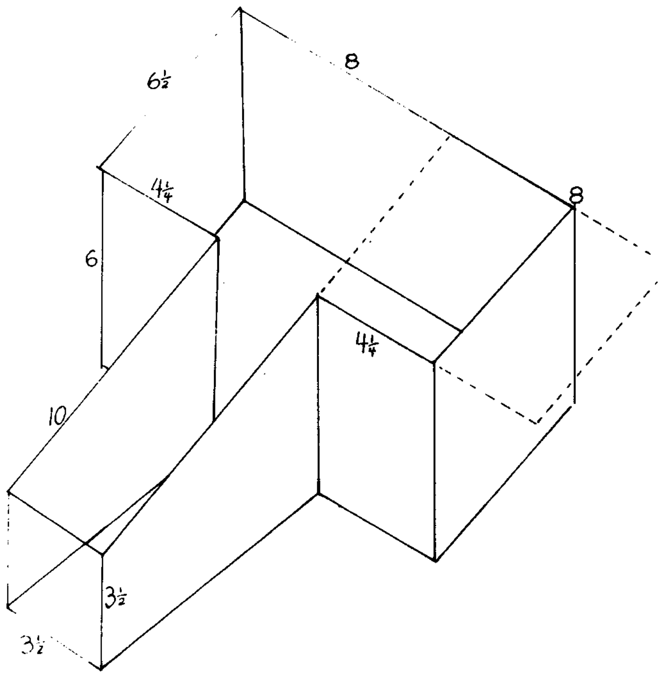

Figure 4. Diagram of wood nest box for Cassin's Auklets. Dimensions are given in inches. The floor is drained by drilled holes. The entrance tunnel and left part of the box are covered with a nailed-down cover. The right side has a removable cover. In use, most of the box is below ground level.

<u>Gull Field Study</u>. The field observations on the effects of the oil on gulls were based on the 1976 results. Dosing was the principal problem. In 1977, capsules containing oil were coated with hydrogenated vegetable oil to lengthen time of capsule solution, and the capsules were sewn inside small squid. The squid was hidden under a board to which a long line was attached, thus permitting the researcher to reveal the squid to the particular gull for which the dose was prepared.

A few gulls were snared and smeared with oil or were injected intraperitoneally with oil. In some nests, the first egg laid was covered with bunker C oil, and after the female incubated it overnight, thus coating the brood patch with oil, the egg was removed. Eggs laid subsequently were collected for chemical analysis and observation of yolk structure.

<u>Oil ingestion and elimination study.</u> To determine the time required for elimination of oil from the guts of auklets, birds were captured at random at night and placed in cardboard boxes covered with netting. The auklets were fed 600 mg of bunker C oil and observed until the oil was passed in their feces. Adult Japanese quail reared in cages and adult pen-reared Mallards deprived of food for 16 hours

(overnight) were compared in their responses to oil with fed birds. Black-footed Albatrosses and Common Murres that were being cared for in preparation for release were also dosed.

Structural and chemical examination of yolks. Auklet eggs collected during the critical period of 2-7 days after dosing with bunker C oil were frozen, fixed in formalin, and examined for structural changes such as those observed in eggs laid by quail after being dosed with bunker C oil (Grau et al., 1977).

Chemical studies utilized quail and chicken eggs for method development; most auklet eggs have been kept in storage until techniques are perfected.

Eggs of quail and chickens that had been given single doses of bunker C oil were treated and extracted, and various techniques were used to detect compounds that might be unique to petroleum-fed birds.

Analytical methods were based on the techniques of Ehrhardt (1972), Neff and Anderson (1975), and Warner (1976) including ultraviolet absorption and gas chromatographic analyses of saponified, florisil-treated extracts of yolk. Phospholipid distributions in yolks were based on standard methods of thin-layer chromatography after extraction with acetone followed by hexane-acetone (3:1)

Several methods of treatment were used for chemical analyses of yolks. For one method, a 500 mg sample of frozen yolk was dried in a vacuum oven at 60° for 8 hours, or alternatively, a sample of yolk that has been fixed in 4% formalin after freezing (Grau 1976) was used without drying. The sample was extracted by agitation in a beaker with 15 ml of petroleum ether, then with 15, 10, and 10 ml portions, and the extract was filtered into a flask. A mixture of 750 mg aluminum oxide G (E. Merck) and 750 mg silica gel (Absorbosil-3) both washed twice with petroleum ether, were added to the extract, shaken several times, filtered into a beaker, the solvent was evaporated, and transferred with isopentane to one spot on an activated silica gel plate scored with vertical grooves to prevent cross contamination. The plate was developed with isopentane: isopropanol: chloroform (100:1:0.2) and observed in ultraviolet light (254nm).

A recent modification was found to be useful for detecting eggs from oil-fed ducks (available through the courtesy of W. N. Holmes, University of California, Santa Barbara). The duck eggs were frozen and formalin-fixed as above. The slices of yolk (3mm thick) were dried in a vacuum at 60° for one hour, extracted with 25 ml petroleum ether, broken up with a glass rod, and extracted twice with 25 ml petroleum ether. The combined extracts were filtered through Whatmar No. 1 paper and the solvent evaporated at room temperature. Silica-gel, thin-layer plates predeveloped with chloroform and dried, were spotted with 5 μl on the solvent-free extract. The plates were developed with isopentane: isopropanol: chloroform (100:0.05:0.1) and observed in ultraviolet light (254nm).

Chickens were dosed with 1 gram bunker C and quail with 200 mg bunker C, and yolks of eggs collected 3-4 days later were frozen, fixed, sliced, and extracted with petroleum ether. Extracts and elutions from preparative thin-layer chromatographic plates were analyzed by gas-liquid chromatography, ultraviolet absorption, and spectrophotofluorometry. Some extracts were treated as were the ducks, above. Others were treated with activated florisil, and some of these were saponified with 5% potassium hydroxide in 95% extract at 80° for one hour, and reextracted with petroleum ether.

Gas liquid chromatography was carried out with a Hewlett-Packard model 1157A and Packard model 427 gas-liquid chromatographs equipped with flame ionization detectors. The columns were glass capillaries, 5 or 10 meters long, coated with SP2100 as the liquid phase. Programmed settings which started at 100° were increased 2° per minute to 250° or 290° and then held for 30 minutes. The injector and detector ports were kept at 290° or 300°. The carrier and makeup gases were nitrogen. A flow rate of 10m/sec with a 10 to 1 split ratio was used. Samples were dissolved in dichloromethane for injection. All GC work was done in the laboratory of Dr. W. G. Jennings, Department of Food Science and Technology, whose collaboration is gratefully acknowledged.

Ultraviolet absorption studies were performed with a Beckman Acta III Spectrophotometer, scanned from 205 to 327 nm, a 2nm/sec. Samples were dissolved in spectral quality solvents.

Spectrophotofluorometry used an Amino-Bowman instrument capable of scanning emission or excitation. For most work, excitation was set at 290 or 300 nm, and emission was scanned. Samples were dissolved in spectral-grade hexane or isopentane, or in reagent-grade petroleum ether in 2ml quartz cuvettes, and compared with suitable solvent controls.

VI. Results

Auklet study. The data for breeding success in each of the four auklet groups are summarized in Table 1. Chi square tests of the four groups in all possible combinations of two showed no significant differences between any two groups for either hatching or fledging success.

No differences were apparent in timing of egg laying following treatment for any of the three treatment groups (Table 2). However, when date of egg laying is considered (Table 3), there appeared to be a slight delay in onset of laying as the oil dosage was increased. This cannot be considered significant. Egg laying in the group given empty capsules and in control group were similar. The first egg for the control group was laid on 3 April, while the first eggs (after treatment) for the three groups dosed were -- empty capsule, 3 April; 300 mg, 5 April; 600 mg, 2 April (second egg in this group laid 7 April). The discrepancy in onset of egg laying disappeared within the first two weeks.

Samples of eggs that failed to hatch were taken to Davis for examination of egg contents. Most of the embryos were macerated or decomposed. No pattern of time or cause of death was found.

Gull Study. Gulls readily ate the squid containing its hidden oil capsule when the board hiding the squid was pulled away. As soon as the capsule dissolved and the oil was released, the squid, now covered with oil, was regurgitated, and was eaten by the mate or by another bird. Within a few seconds it was regurgitated again. Sometimes this was repeated several times. None of the 15 oil doses were actually ingested. Gulls that were snared and smeared with oil or injected intraperitoneally abandoned their nests. When first-laid eggs were smeared with oil and the female brooded it overnight, almost all the oil was removed from the egg, presumably to her brood patch. That egg was removed, as were subsequent eggs, for laboratory observations. No oil patches could be seen on the shell surface by observation under ultraviolet light, except on the egg that was originally smeared. Laboratory studies did not reveal any characteristic changes in yolk structure that could be attributed to oil. Chemical analyses have not been performed because of

Table 1. Breeding success of treated and control Cassin's Auklets - 1977

	Empty gelatin capsule	300 mg Bunker C	600 mg Bunker C	control
# of females dosed before first egg laid	86	84	81	-
maximum # of eggs possible to be laid	82	75	78	79
Total # of eggs laid	80	72	77	75
% eggs laid of possible maximum	98	96	99	95
# eggs laid 2-7 days after dosing	21	27	25	-
% eggs laid 2-7 days after dosing	26	38	32	-
maximum # of eggs possible to hatch	74	68	66	74
total # of eggs hatch	51	57	48	62
% eggs hatch	69	84	73	84
maximum # of 2-7 day eggs possible to hatch	19	26	23	-
# of 2-7 day eggs hatch	13	22	17	-
incubation period (days)	*38.9±1.6 N=10	*38.5±0.8 N=16	*38.9±1.2 N=12	38.4±0.9 N=55
hatching weight (grams)	*18.5±1.4 N=9	*20.0±1.9 N=14	*18.5±2.4 N=10	-
fledging time (days)	*43.0±3.8 N=9	*42.0±2.3 N=11	*44.0±1.9 N=11	41.0±3.1 N=48
fledging weight (grams)	*153.0±10 N=9	*149.0±12 N=12	*150.0±13 N=11	152.0±14 N=48
% fledging success	*90.0 N=10	*78.0 N=18	*85.0 N=13	87.0 N=55

* Data are for eggs laid 2-7 days after dosing only.

Table 2. Timing of egg laying by Cassin's Auklets following treatment

Dose	Total # eggs laid		Number of days between dosing and egg laying							
			2-7	8-13	14-19	20-25	26-31	32-37	38+	Un-known
Empty capsule	80	# of eggs	21	22	19	4	7	1	4	2
		% of total	26	28	24	5	9	1	5	3
		cumulative %	26	54	78	83	92	93	98	
300 mg Bunker C	72	# of eggs	27	18	12	8	1	3	0	3
		% of total	38	25	17	11	1	4	-	4
		cumulative %	38	63	80	91	92	96	96	
600 mg Bunker C	77	# of eggs	25	17	15	8	4	2	2	4
		% of total	32	22	20	11	5	3	3	5
		cumulative %	32	54	74	85	90	93	96	

Table 3. Cumulative percent of total number of first eggs laid by auklets

	Empty capsule (N=80)	300 mg Bunker C (N=72)	600 mg Bunker C (N=77)	Control (N=75)
April 1-2			1	
3-4	3			1
5-6	4	6		8
7-8	8	17	7	11
9-10	14	32	25	18
11-12	27	42	39	34
13-14	38	52	44	45

delays in adaptation of gas chromatographic methods to eggs. The attempts to dose gulls by capsule to observe reproductive effects were judged to be futile, and this part of the research was terminated.

Fate of ingested oil. Following the observations of gull behavior in regurgitating oil, auklets and other birds were also studied. The auklets began eliminating the oil at a meantime of 36 minutes after being fed (Table 4).

Adult Japanese quail and adult Mallards deprived of food overnight were compared in their responses to oil with fed birds, with the results shown in Table 4. It will be noted that fed quail took a mean of 177 minutes before eliminating oil while unfed quail took only 29 minutes. Mallards responded differently: feeding did not affect passage time.

Black-footed Albatrosses and Common Murres that were dosed were few and two of the albatrosses were found later to be infected by bacteria, but their responses appeared to be different from the other birds studied. The murres reacted violently to the oil dose.

If the same relationship between oil retention times in fed and unfed quail holds for fed and unfed auklets, fed auklets would be expected to retain oil for three hours before beginning to eliminate it. This would greatly extend the time of the auklet's exposure to oil and would expose the auklet at a time when it is actively absorbing nutrients. This may increase the toxicity of oil to both the auklet and any egg which it is forming at the time of exposure.

Structural examination of yolks. No characteristic features of yolk of dosed auklets could be detected, in contrast to our previous experience with quail, chickens, and geese (Grau et al., 1977). Tentatively, we attribute these results to elimination of the oil before an effect was obtained, but no substantiating data are available.

Chemical examination of yolks. Because petroleum hydrocarbons or their metabolites have not been reported to occur in avian yolk, and information of this kind would be important in evaluating responses of breeding birds to oil exposure, considerable effort has been made to determine whether oil components were present in eggs from birds fed oil. Most of the work has been done with quail and chickens fed bunker C: the former because of the known effects of oil on reproduction, and the latter because of the ease of obtaining samples. Yolks from Mallards fed crude oil-containing diets were also studied.

Ultraviolet visualization of the developed thin-layer plates indicated that there were differences between normal yolk and yolk from hens that had been fed oil. Control egg extracts exhibited a dull orange band close to the front. Frequently this was so faint that it could barely be seen. Eggs from oil-fed hens fluoresced bright blue in this region. This blue color faded rather quickly; after 4-5 hours it appeared orange. This faded "experimental orange" was brighter than "control orange". Some control quail eggs exhibited the blue fluorescence characteristic of experimental bird eggs, but this was not observed in control chicken or duck eggs.

No consistent difference in the lower part of the TLC plates has appeared in ultraviolet visualization. When exposed to sulfuric acid charring or iodine vapors, there was a very dark line at the front, a large dark "cloud" of material (which appeared translucent when unstained plates were held up to a light) just below the front, a large brown area below that, a fairly clean area about 2-3 cm above the

Table 4. Responses of several bird species to dosing with capsules containing bunker C oil

Species	Number of Birds	Time between dosing and			
		Regurgitation		Fecal Elimination	
		Mean	Range	Mean	Range
Cassin's Auklet[1] (Ptychoramphus aleuticus)	10	-	-	36 min	12-82 min
Western Gull[1] (Larus occidentalis)	15	*	0-35 min	-	-
Common Murre[2] (Uria aalge)	3	10 min	7-13 "	18 min	7-33 min
Black-footed Albatross[2] (Diomedea nigripes)	3	-		10 hrs	6-20 hrs
Japanese Quail[3]	6 fed	-		177 min	143-226 mi
(Coturnix coturnix japonica)	5 unfed	-		29 "	11-67 "
Mallard[3]	6 fed	-		52 "	20-145 "
(Anas platyrhynchos)	6 unfed	-		46 "	31-79 "

*Upon contact with oil. Some oil was hidden in bait.

1) Dosed on S.E. Farallon Island.

2) Dosed at International Bird Rescue Research Center, Berkeley, CA.

3) Dosed at University of California, Davis, CA.

We observed by aspiration that no food was present in auklet stomachs at night. This information, together with data on passage time of oil in fed and unfed quail and mallards indicates that if auklets are similar to quail, then oil may have passed through the auklets too quickly to affect their eggs.

The cooperation of Alice Berkner of the International Bird Rescue Research Center is gratefully acknowledged.

origin, and two or three dark bands on or above the origin. No differences were found between extracts of "oil" eggs and control eggs when sulfuric acid charring, iodine vapor exposure, or formalin sulfuric acid spray, which stains polynucleur aromatic compounds, were used.

Gas-liquid chromatographic analyses have been impaired by the presence of many nonvolatile or high boiling compounds in the extracts. These materials became baked on the glass walls of the splitter and decomposed at the high temperatures of the injector port. This necessitated dismantling the column set up, changing the splitter, and running programs at high temperatures which lowered column life and increased column bleed.

No consistent differences were found between experimental and control chromotographs from any of the extract. When the brightly fluorescent portion of some experimental thin layer chromatographs were eluted and compared with controls, there were, in four cases of experimental extracts, alkane peaks between C_{22} and C_{32}, but subsequent attempts to reproduce this failed. Similar chromatographs were produced with oil-spiked eggs; therefore, the earlier observations were probably caused by laboratory contamination. No C_{16} peaks were found by GC when yolk extracts were made after quail were given 200 mg hexadecane. Ultraviolet absorption measurements of extracts and TLC eluates did not show any differences between experimental and control eggs.

Spectrophotofluorimetry of eluates from the plates proved to be the only method by which quantative differences between experimental and control eggs were obtained. The shape of the spectra emitted over the range of 200-800 nm did not appear different between the two types of eggs. When excited at 290 or 300 nm, a broad peak appeared between 320 and 500 nm. Extracts of "oil" eggs showed a greater peak than control extracts. Some quail yolk extracts that emitted a blue fluorescence on TLC plates appeared to be identical in response to extracts from experimental (oil) yolks. Duck and chicken eggs have not exhibited this tendency. Current experiments are under way to determine if the blue fluorescence is a petroleum hydrocarbon or biogenic product.

Several auklet eggs from dosed and control birds have been extracted and examined for fluorescence, but no differences have been found. Because the number of eggs laid during the 2-7 day post-dose period was low, the results cannot be considered as conclusive.

VII. Discussion

An examination of Table 1 shows that most of our attention to hatching and fledging success, incubation period and fledging weight was directed to the group of eggs laid 2-7 days after dosing. Since yolk formation in the Cassin's Auklet eggs takes eight days (Roudybush and Grau 1977), we felt that the effects of various treatments would be most apparent in this group. However, no major differences were found. The incubation periods, fledging times and fledging weights are comparable in all groups and are also comparable with the findings of Manuwal (1972) from his studies on S.E. Farallon in 1969-71: mean incubation period -- 37.8 days (range 37-42; n=86); fledging time -- 41 days; fledging weight -- 158 grams. The hatching weight data for the three treatment groups are also comparable with each other and with Manuwal's figure of 21 grams.

Although there appeared to be a slight delay in the onset of egg laying with increased oil dose (Table 3), the effect cannot be considered significant. Delayed egg laying can be important to breeding success, however, since late breeders always do very poorly (PRBO unpublished data).

The procedures of bill measurement, dosing and checking for egg laying apparently did not cause birds to abandon their burrows, nor to affect experimental birds in other ways, when done in the manner used by us. All sixty birds (30 pairs) handled the night of 31 March were banded with numbered aluminum leg bands. Seventeen of those 30 burrows were checked on the night of 16 June. Of the 34 adults that could have been present in the 17 burrows, 29 adults were found in 16 burrows; only one burrow was vacant. Of the 29 adults, 28 were birds originally treated and banded. The one unbanded bird was with a banded female that had produced an egg that did not hatch. These data indicate that the auklets can tolerate well the level of disturbance to which we exposed them.

Some burrows in loose soil were destroyed by our activity. We also suspect that we caused some abandonment of eggs when we made repeated checks to determine exact date of hatching and hatching weight.

Definitive chemical analyses of auklet eggs for presence of oil components have been delayed until techniques are developed using quail and other laboratory birds. Development of suitable chemical methods has not progressed as rapidly as had been hoped. Differences in fluorescence of extracts after thin-layer chromatography are established for ducks and probably for chickens. Some quail give a false positive response; that is, some control quail that have not ever been exposed to oil show fluorescence. There have not been any false negative responses.

There are several possible reasons for failure to find petroleum hydrocarbons in yolk after birds were dosed with oil. Some of these are as follows:

(1) Hydrocarbons may act primarily on the gut, altering capacity to withstand stress.
(2) Hydrocarbons may be poorly absorbed, making identification in eggs difficult.
(3) Toxicity may be high, thus making difficult the detection of the small amounts needed to have an effect.
(4) Hydrocarbons may affect synthesis or metabolism of fluorescent compounds not usually present in chicken and duck eggs, thus increasing these compounds in the egg.
(5) Hydrocarbons may be easily volatilized from drying yolk or from TLC plates, thus possibly falling below detectable levels.

Problems encountered and proposed solutions. The major problem in the auklet study was related to elimination of oil by the birds before effects could have been caused. Preliminary indications are that Cassin's Auklets do not retain petroleum in their bodies, and so apparently suffer no detrimental effects in terms of breeding success. However, seabirds are far more likely to be exposed to petroleum while feeding at sea than while at their terrestrial breeding sites. In 1978, we therefore plan to feed some auklets small amounts of euphausiids (their normal diet) at the same time they are fed petroleum. The petroleum may be retained longer if food is also present in the stomach, as would be the case of birds exposed to oil while feeding at sea. We suspect that Cassin's Auklets coming ashore at night at the start of the breeding season may do so with empty or nearly empty stomachs.

The regurgitation responses of Western Gulls present such major problems that this part of the original plan will be abandoned for the present.

VIII. Conclusions

In this combined field and laboratory study of the effect of oil on reproduction, two dose levels of bunker C fuel oil were given orally by gelatin capsule to two randomly chosen groups of female Cassin's Auklets (*Ptychoramphus aleuticus*), and compared with a similar control group given an empty capsule. The field work was done on Southeast Farallon Island of California; the laboratory study of some of the eggs produced was done at Davis. There were 72-80 females per group, plus 75 controls that were not treated. Production of eggs, hatching success, chick weight, survival, and fledging were not affected by the treatments. This result was markedly different from effects on laboratory quail, which showed reduced reproductive success.

Attempts to dose gulls with bait enclosing capsules containing oil were unsuccessful, because the gulls regurgitated the bait as some of the capsule dissolved, in half an hour or less. Auklets were then dosed with oil to determine the fate of the dose. None regurgitated, but elimination in the feces was rapid, with a mean time of 36 minutes. Adult Japanese quail (*Coturnix coturnix japonica*) reared in cages and adult, pen-reared Mallards (*Anas platyrhynchos*) deprived of food for 16 hours were compared in their responses to oil with fed birds. It took fed quail 177 minutes to eliminate oil, while unfed quail took only 29 minutes. Mallards responded differently: feeding did not affect passage time. Three Black-footed Albatrosses (*Diomedea nigripes*) and 3 Common Murres (*Uria aalge*) were also dosed. It took several hours for oil to pass in the albatross; the murres reacted violently within minutes by regurgitating and defecating oil.

Auklet eggs collected during the critical period of 2-7 days after dosing with bunker C oil were found to have normal yolk structure and appearance. Because chemical methods might be more useful than visual methods of detecting pollution, attempts were made to develop techniques of analysis using quail and chicken eggs, for eventual use with auklets. Yolks from oil-treated quail and chickens were found to differ from normal yolk in appearance and response to solvents. "Oil" yolks were lighte in color than normal. Denaturation and initial extraction of the thawed yolk with acetone resulted in a stringy texture as compared with the normal crumbly appearance. No major differences were found in phospholipid distribution or in ultraviolet absorption of extracts. Differences were detected in fluorescence of extracts prepared from "oil" and normal eggs after thin-layer chromatography of yolk extracts. A bright blue fluorescence was found in eggs of chickens, ducks, and quail that had been fed oil.

Gas chromatographic analyses of treated extracts of normal and "oil" eggs have been pursued vigorously but the results have not proved satisfactory. Preliminary observations of differences attributable to oil have not been confirmed.

IX. Needs for further study

Discussed here is the second year of study on Cassin's Auklets, as well as an outlook for continuation in future years, in a project designed to assess some possible physiological effects on seabirds by short-term low-level exposure to oil slicks at sea. Preliminary laboratory work on quail and waterfowl showed that ingestion or cutaneous contact with less than a gram of oil resulted in lowered reproductive output. In the first year of NOAA funded work, the project was extended to seabirds in the field. We worked with bunker C oil in FY 1977. In FY 1978 we propose to compare crude oil with bunker C in their effects on reproductive success of Cassin's Auklets at the Farallon Islands. In following years we plan to compare the physiological responses of seabirds of different sex and to investigate whether oil on a seabird's skin has the same effect as it does in domestic fowl. The work will provide information to help assess the impact of oil pollution on breeding seabird populations.

It would be useful to extend this work to other seabird species, particularly alcids. In that case, work in Alaska would be necessary as large, accessible populations of other alcids are not present on the Farallons. Middleton Island is one site where work on murres and puffins may be possible. It appears, also, that it will be possible to extend the study of auklets into several new areas, to answer such questions as the following:

A. What are the effects of two or more doses of oil at various intervals, in terms of survival, egg formation, and reproductive success?

B. Does oil place a larger chronic burden on an auklet, which lays only one egg, than it does on a quail which lays many eggs, and thus has a mechanism for removing fat-soluble substances from its body?

C. What are the responses of male auklets to oil dosage, separate from and in addition to that of females?

D. Does external application of oil that simulates the effects of a spill have a major adverse effect on reproduction, or is such a direct effect primarily one of survival?

Answers to these and similar questions should yield data that will help to evaluate the magnitude of oil spill effects. Because only two or three variables can be studied each year, two or three additional years may be required to answer the question. In this connection it should be pointed out that this approach is unique as far as we know, and no comparable studies are in progress in the U.S., Canada, or Great Britain.

The cost per fiscal year would remain at approximately the present level, adjusted for inflation.

Major equipment is not anticipated.

We anticipate continued use of the Farallon Islands as an ideal field laboratory for these studies.

No changes in logistics are expected.

X. Summary of January-March Quarter

A. Ship or laboratory activities

1. Field trip schedule

   a. Periodic work throughout quarter by persons resident at the study site (Southeast Farallon Island)

   b. Special trip 22-25 February

2. Scientific Party

   a. Steve Morrell, Harriet Huber, Ron LeValley: PRBO

   b. Tom Roudybush: University of California, Davis

3. Methods

   Periodic examination of the prepared auklet burrows at Southeast Farallon during this quarter showed that they were being used by the birds. Similar checks of the artificial nest boxes revealed that they were being investigated by auklets, and we are confident that the boxes will be used for nesting.

   In February (22-25), techniques of feeding auklets before dosing were developed. Also, 1000 mg doses of Prudhoe Bay crude oil and bunker C fuel oil have been partitioned into 4 capsules for use when egg production studies begin in late March (see below).

   On 10 March we began daily checks of a portion of the study burrows/boxes to determine the onset of egg laying. To date (21 March) no egg has been laid. We consider this delay to be a response to continued warm (12°-13° C) water in the east North Pacific.

4. Sample localities: Southeast Farallon Island, San Francisco County, California

5. Data collected or analyzed

   None this quarter.

XI. Auxiliary Material

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B. Papers in preparation or print

None

C. Oral presentations

1. "Influence of petroleum on egg formation and embryonic development in seabirds."

   Seattle, Washington. 29 November - 1 December 1977.

2. "Reproductive responses of Cassin's Auklets to orally administered bunker C oil and eliminative responses in seabirds."

   Fourth Annual Meeting, Pacific Seabird Group, Victoria, B.C. 19-21 January 1978.

3. "Studies on seabirds at the Farallon Islands."

   Thirteenth Annual Meeting, Point Reyes Bird Observatory, Bolinas, CA. 5 February 1978.

ANNUAL REPORT

Research Unit #425

October 1977 - March 1978

COMPOSITION AND SOURCE IDENTIFICATION OF ORGANIC DETRITUS IN LOWER COOK INLET

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April 12, 1978

I. SUMMARY

The major purpose of Research Unit #425 is to describe some of the features and conditions relevant to the occurrence, production, and composition of organic detritus settling from the water to the bottom of lower Cook Inlet. This material, presumably, is an essential source of nutrition for the benthic community. Detrital particles may become coated with spilled oil or may sorb oil fractions, and provide a pathway for the transport of oil to the benthos.

This research was initiated in October 1977. The first of five observational periods was recently completed (March 24-26). No major conclusions are available. The purpose of the March cruise was to determine environmental conditions and phytoplankton population size in lower Cook Inlet shortly before the spring plankton bloom. In late March, chlorophyll concentrations were low indicating that the spring bloom was not in progress, and water characteristics reflected the general patterns of circulation documented elsewhere.

II. INTRODUCTION

A. General Nature and Scope of Study

The fluxes, composition, and sources of organic detritus reaching the benthic community in lower Cook Inlet will be estimated. Observations will be made at about one-month intervals throughout spring and summer 1978 of a suite of selected variables at seven stations along a transect from Kachemak to Kamishak Bays. Particle Interceptor Traps (PITs) will be deployed during these observational periods to collect sinking particles for various analyses. Variables measured include flux of particles settling to near bottom; plant pigments in the PITs and in the water column; organic carbon and nitrogen, and stable isotopes of carbon and nitrogen in particulate matter from the PITs; concentrations of phytoplankton species; primary productivity and related variables including nutrients, light, and water transparency; and salinity and temperature.

B. Specific Objectives

The objectives of this year's study are:

1. Define the seasonal composition and origin of the organic detrital material.
2. Determine the short- and long-term vertical fluxes of organic particles to the bottom.
3. Determine phytoplankton composition, standing stock, and productivity during the biologically active period of the year.
4. Test the feasibility for determination of sources of organic detritus by application of carbon and nitrogen isotopic composition.

C. Relevance to Problems of Petroleum Development

Offshore petroleum development in lower Cook Inlet will provide a potential source of contamination of the environment by accidental large spills and chronic low-level oil pollution. Such pollution would undoubtedly have a harmful effect on important commercial fisheries in lower Cook Inlet.

Benthic species harvested include snow, king, and Dungeness crab, shrimp, razor clams, and scallops. These are commercially harvested primarily within the rectangle bordered by Anchor Point, Kachemak Bay, the Barren Islands, and Kamishak Bay (Bureau of Land Management, Final Environmental Statement, 1976). Some primary king crab recruitment grounds are within this area in the Bluff Point-Kachemak Bay region. The adverse effects to these species from oil pollution are discussed in BLM (1976).

The larval stages of these and other benthic species are planktonic and rely on phytoplankton as food. Adults in the benthic community ultimately depend on organic production from phytoplankton and other plants. Phytoplankton grazed by zooplankton enters the detrital food web via fecal pellet deposition. Other cells enter the benthos by sinking directly. As small sinking particles, the cells and pellets may act to transport oil from the surface to the bottom.

Studies have indicated rapid removal and dispersal of surface oil by suspended particles. When oil enters seawater, emulsions of very tiny droplets can form. Some of the droplets become bound to particles by absorbtion and adsorbtion; they subsequently sink directly or are sedimented in fecal pellets after being ingested by zooplankton. Thus, ingestion and sorbtion act as precipitation mechanisms to transfer otherwise buoyant oil particles to the detrital food web (NOAA Special Report, 1977; Forrester, 1971 in NOAA; Conover, 1971).

Since lower Cook Inlet has a seasonally sustained high yield of phytoplankton, it can be assumed that their input of organic matter (fecal pellets and cells) to the benthos is considerable. The respective fraction of each is not known, but combined they can probably provide the means for transporting considerable amounts of oil to the bottom where it can undoubtedly impact the benthos.

In addition to the role of phytoplankton in transporting oil to the benthos, primary production can be affected by oil contamination and thus impact higher trophic levels. The impact on phytoplankton depends on oil and other contaminant concentrations, proximity of the cells to the contaminant, localized geography, species composition, and other variables. The species composition of a natural population can be significantly altered by oil contamination (Dunstan et al., 1975 and Lee et al., 1977). Other effects can include death, increased and decreased photosynthetic rates, decreased cell division rates, cell membrane damage, and other physiological abnormalities (Shiels et al., 1973; Gordon and Prouse, 1973; BLM, 1976; Hufford, 1971 in BLM, 1976). Surface oil can lower light levels to decrease photosynthesis and can interrupt gas exchange across the surface. Hufford (1971) in BLM (1976) states that photosynthesis can be decreased by 50 to 90% from lowered light levels and lowered cell division rates from phytoplankton under an oil spill. Drilling muds may contaminate phytoplankton and other biota due to the presence of toxic chromium and pipeline burial may resuspend contaminated sediments (BLM, 1976).

III & IV. CURRENT STATE OF KNOWLEDGE AND STUDY AREA

Generally, we know that runoff draining from the mountains and glaciers adjacent to upper Cook Inlet contains copious inorganic particulate matter. Currents carry this runoff out of the Inlet along the western portion resulting in highly turbid water in that region. Inflowing Gulf of Alaska water enters the Inlet and flows north along the eastern shore. The presence of a low-energy zone in the midchannel of the lower Inlet has been postulated.

This mean circulation pattern sets the basic environmental conditions which largely control the production of phytoplankton populations as observed during our previous study of primary productivity in lower Cook Inlet in 1976 (Larrance et al., 1977).

Phytoplankton standing stock and primary productivity are high in lower Cook Inlet. During our 1976 investigations, cell concentrations were greater than 10^6 cells/ℓ and primary production was as much as 7.7 $gC/m^2/day$ in May in Kachemak Bay. Mean primary productivity in lower Cook Inlet reached a peak of about 4.9 $gC/m^2/day$ in late May and decreased to about 0.7 $gC/m^2/day$ by late August (Larrance et al., 1977). BLM (1976) reports that photosynthetic rates in lower Cook Inlet range between 0.25 and 0.50 $gC/m^2/day$. The latter figures are averages for an extensive region including the Aleutian Islands and may be annual estimates. They appear to be somewhat low for lower Cook Inlet in any case.

The extremely high productivity in Kachemak Bay can be explained in part by the water circulation, or lack of it, and by a strong pycnocline development in that region. A gyre tends to keep local water entrained in outer Kachemak Bay and a constriction (Homer Spit) prevents rapid turnover of inner Kachemak Bay waters (Larrance et al., 1977; Evans et al., 1972; Knull and Williamson, 1969). The local permanence and stability of the water column (i.e., water is not advected either laterally or vertically) enhances conditions for a bloom. Elsewhere in lower Cook Inlet, strong tidal currents prevent pronounced local entrainment and stabilization of the water.

Phytoplankton populations in such embayments and locally entrained waters are particularly vulnerable to toxic contamination since clean water dilution by mixing will not occur. The Kachemak Bay area is of particular importance, also, because king crab zoea in that recruitment area undoubtedly rely on the local phytoplankton community.

There is an east to west transition across lower Cook Inlet with respect to magnitude and timing of maximum phytoplankton standing stock and productivity. Organic production by phytoplankton in 1976 was 0.1 to 0.5 as great in Kamishak as in Kachemak Bay, and maximum productivity and standing stocks occurred about two months later in Kamishak Bay. Midchannel values were as high as in Kachemak Bay, but occurred about one month later when the water column became slightly stable. Thus, the organic input to the detrital food web from phytoplankton has distinctly variable components with respect to season, magnitude, and locale in lower Cook Inlet.

V. SOURCES, METHODS AND RATIONALE OF DATA COLLECTION

A field program consisting of sediment trap deployment, intensive water column sampling, and primary productivity measurements has been developed to address the stated objectives. Five cruises are tentatively planned through the spring and summer of 1978 to correspond to the period of highest biological production. The selection of sampling sites was influenced by studies conducted in 1976 (Larrance et al., 1977). The timing and degree of biological activity differed from east to west across lower Cook Inlet as a partial function of variable water column stability and light attenuation by suspended particulates. Therefore, a 7-station transect running east-west has been chosen to study the variable input of pelagic material to the benthic communities of Cook Inlet. Stations will be occupied at and between Kachemak and Kamishak Bays (fig. 1).

Sediment traps, moored near the bottom (fig. 2) at three sampling sites, will be recovered after several days to provide minimum estimates of the input rate and composition of suspended particles reaching the sea floor. Aliquots will be withdrawn from the sediment traps for the following analyses:

a. plant pigments - chlorophyll a and pheopigments.

b. microscopic examination of major sedimented components including phytoplankton cells, zooplankton fecal pellets, macrophyte debris, etc.

c. ratios of stable carbon and nitrogen isotopes.

d. total particulate matter and total particulate carbon.

A. Sampling and Analytical Methods

Station sampling will begin following deployment of sediment trap moorings. Routine CTD-rosette casts will be made to obtain temperature and salinity profiles. Water samples will be collected from several depths with 5-liter PVC Niskin bottles. Aliquots withdrawn from these samplers will be used to measure various biological and chemical parameters. Subsamples for phytoplankton species determination will be preserved in acetate buffered formalin and returned to the laboratory for analysis by inverted microscope techniques (Lund, Kipling and LeCren, 1958). Plant pigments will be analyzed aboard ship using fluorometric methods (Lorenzen, 1966). Seawater samples for determination of dissolved inorganic nutrients will be frozen and returned to the University of Washington

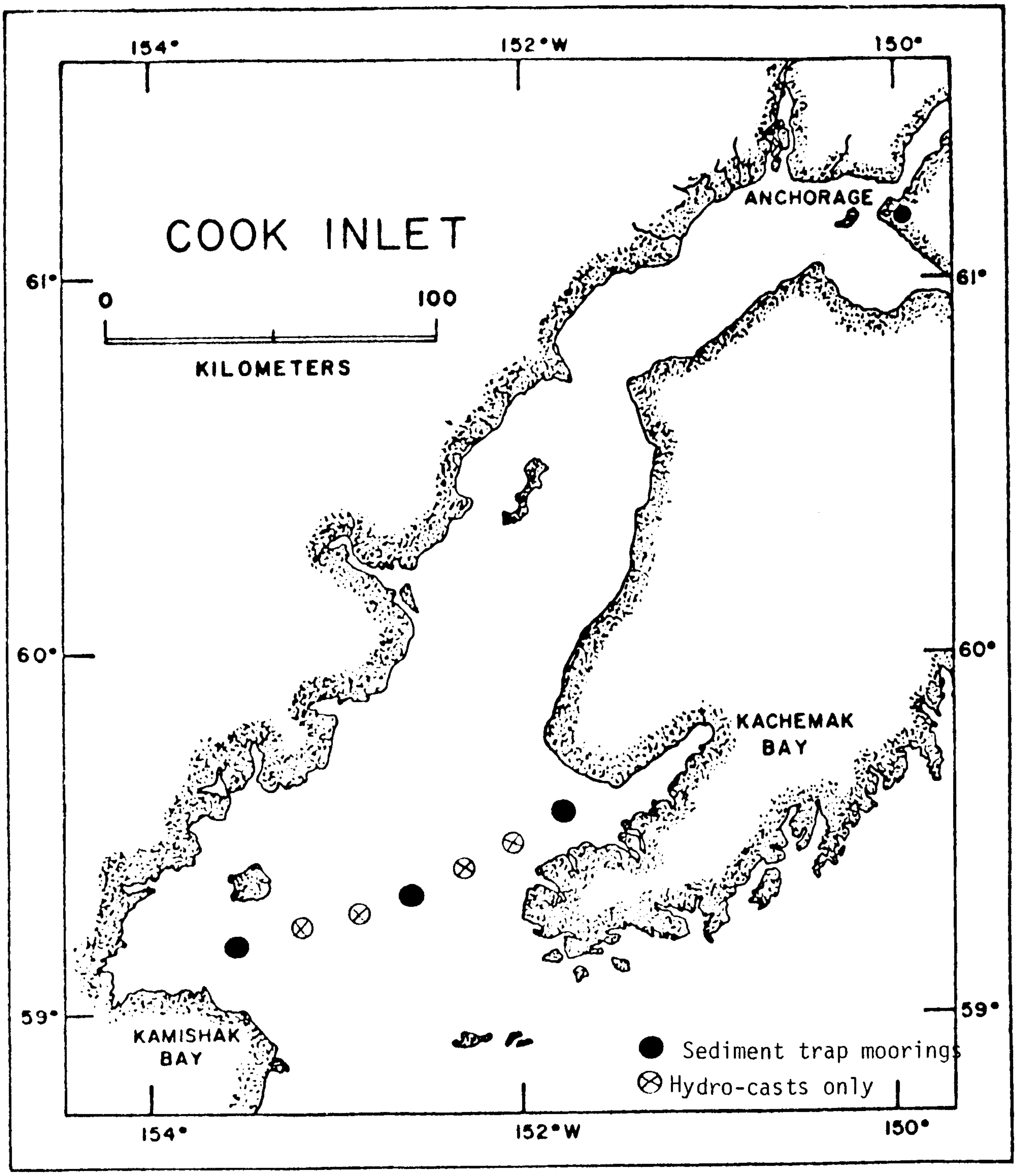

Figure 1. Station locations, Organic detritus studies,RU425, FY 1978.

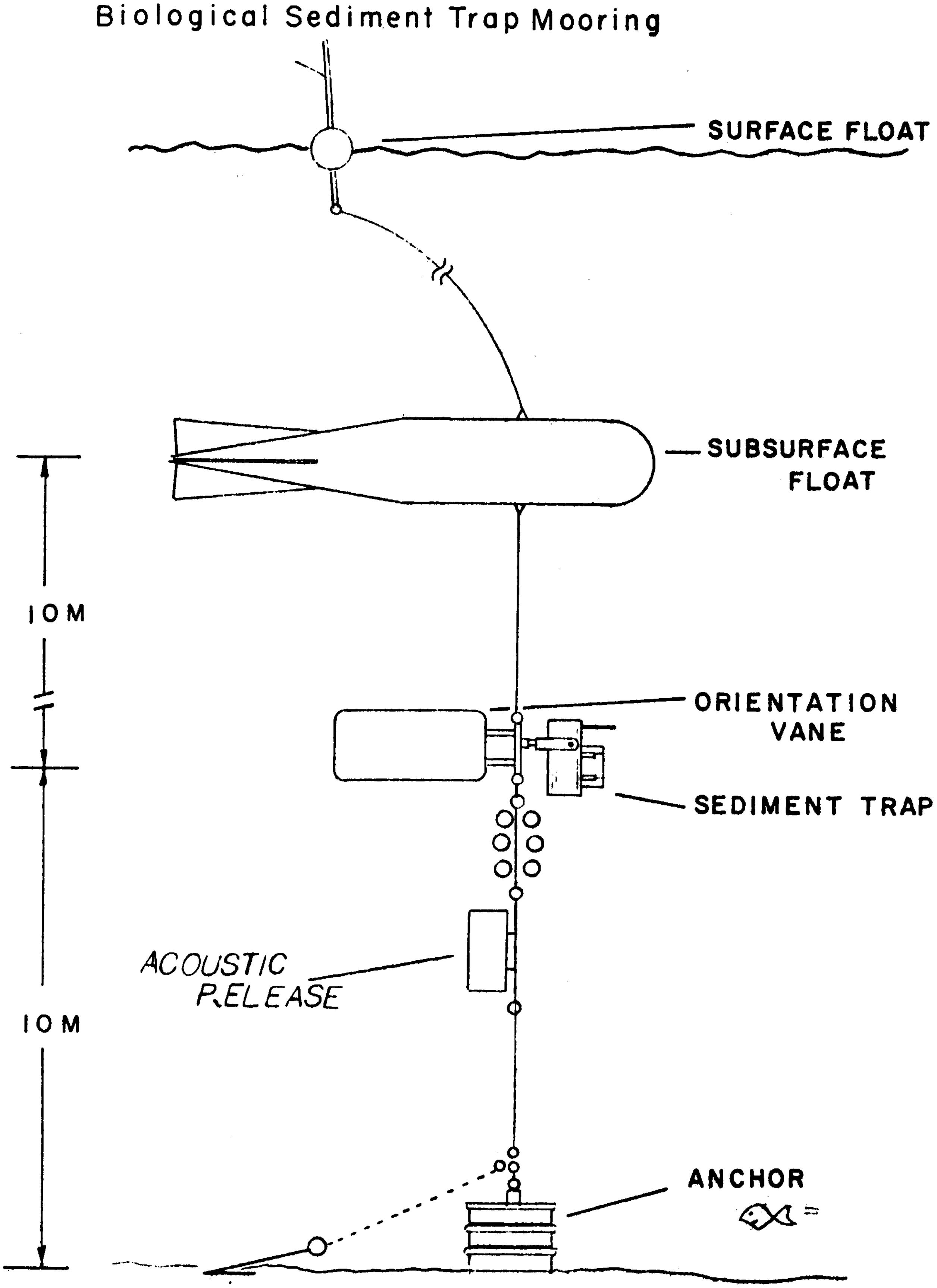

Figure 2. Mooring array for sediment traps, RU 425, FY 1978.

Department of Oceanography for analysis by Auto Analyzer methods (Strickland and Parsons, 1972). Half-day primary productivity experiments will be conducted using standard carbon-14 methodology (Strickland and Parsons, 1972). Total particulate matter will be measured by filtering subsamples through preweighed 47 mm 0.4 μm Nuclepore filters. The filters will be washed with de-ionized water, dried in a dessicator, and reweighed in the laboratory. Total particulate carbon will be determined by filtering through precombusted silver filters. Filters will be rinsed in de-ionized water, dessicated, frozen, and analyzed by the micro-Dumas combustion method, employing a Hewlett Packard C-H-N analyzer (Sharp, 1974). During each cruise, sunlight will be continuously monitored with a Lamda Instruments quantum sensor sensitive to light in the photosynthetically active region (approx. 400-680 nm).

Material recovered from sediment traps will be collected for analysis of plant pigment content, total particulates, carbon and nitrogen isotopes, total particulate carbon, organic carbon, and microscopic inspection using methods adapted from those described in this proposal.

B. Isotopic Analysis

Organic carbon and nitrogen (e.g., sediments and tissue) must be first converted to CO_2 and N_2 prior to isotopic analyses. This is accomplished in a high temperature combustion furnace in the presence of oxygen (Craig, 1953; Cline, 1973). Undesirable reaction products such as carbon monoxide (CO) and nitrous oxide (N_2O) are converted to CO_2 and N_2 in appropriate oxidizing and reducing furnaces. Carbon monoxide is readily converted to CO_2 at the surface of hot cupric oxide; nitrous oxide is readily reduced to N_2 at the surface of hot, clean copper. Since the combustion and conversion reactions may isotopically fractionate the product, care must be exercised that the original substrate carbon and nitrogen be converted to CO_2 and N_2.

After conversion to CO_2 and N_2, the samples are analyzed isotopically on an isotope-ratio mass spectrometer. Because the relative abundances of the isotopes of carbon and nitrogen are different (see above), the isotope mass spectrometer is usually designed for specific analysis.

The mass spectrometer measures the C^{13}/C^{12} and N^{15}/N^{14} ratio directly and compares it to a standard reference material. The results are usually expressed in delta-notation:

$$\delta C^{13} = \left| \frac{(C^{13}/C^{12})_{sample} - (C^{13}/C^{12})_{std}}{(C^{13}/C^{12})_{std}} \right| \times 1000,$$

$$\delta N^{15} = \left| \frac{(N^{15}/N^{14})_{sample} - (N^{15}/N^{14})_{std}}{(N^{15}/N^{14})_{std}} \right| \times 1000.$$

The standard for carbon is usually prepared from a cretaceous belemnite (PDB) or a suitable working standard compared to it. The standard for nitrogen is atmospheric N_2, which has been shown to be globally uniform (Sweeney et al., 1976). The respective precisions for δC^{13} and δN^{15} are around $\pm 0.1^{\circ}/_{\circ\circ}$; the precision being somewhat better for carbon.

VI. RESULTS

One set of observations was made March 24-26 which describes conditions prior to the spring phytoplankton bloom. Chlorophyll a concentrations were low, ranging from 0.2 mg m^{-3} in Kamishak Bay to 0.5 mg m^{-3} in Kachemak Bay. At all stations, salinity and temperature were uniform in the water column.

Cold, less saline water ($1^{\circ}C$, $31.2^{\circ}/_{oo}$) was found in Kamishak Bay with a cross channel gradient in temperature and salinity. Temperature and salinity in Kachemak Bay were $4^{\circ}C$ and $31.9^{\circ}/_{oo}$. The 1% light depth was 5 m in Kamishak Bay and 24-27 m at mid-channel and in Kachemak Bay. The preliminary data are presented in Table 1.

Table 1. Plant Pigments and Water Transparency, Lower Cook Inlet, March 24-26, 1978

Station	Lat.(N)	Long.(W)	Chlorophyll a (mg/m^2)	Pheopigments (mg/m^2)	1% Light Depth (m)
1	59°33'	151°35'	25.2	11.2	24
2	59°30'	151°58'	22.5	10.2	26
3	59°27'	152°22'	17.1	8.2	26
4	59°23'	152°40'	26.2	13.2	23
5	59°20'	153°00'	23.0	14.8	17
6	59°17'	153°20'	7.2	5.6	5
7	59°14'	153°40'	7.1	6.2	5

VII & VIII. DISCUSSION AND CONCLUSIONS

The preliminary data are consistent with expected conditions before the spring phytoplankton bloom and with the general circulation pattern described. Too little data are available for an analysis.

IX. NEEDS FOR FURTHER STUDY

The needs for further study can be ascertained at the completion of the present study.

X. SUMMARY OF JANUARY-MARCH QUARTER

A. Ship and laboratory activities

1. Ship schedule
   - a. Dates: March 23-27, 1978
   - b. NOAA ship SURVEYOR
2. Scientific party

   Jerry Larrance, PMEL - Chief Scientist
   Alexander Chester, PMEL - Oceanographer
3. Field methods

Standard casts were made at each station using SURVEYOR's CTD/ Rosette system with 5-ℓ Niskin bottles. Samples were drawn for phytoplankton species analysis and preserved in 1% formalin. Nutrient samples were drawn and immediately frozen for return to Seattle where they will be analyzed at the University of Washington. Water samples were drawn and immediately analyzed fluorometrically for chlorophyll a and pheopigments

At three stations (one per day), primary productivity experiments were conducted. After inocculation with $H^{14}CO_3$, two light bottles from each of eight light depths were exposed to natural light screened by neutral density light filters from local apparent noon until sunset. One dark bottle from each depth was also incubated. The light bottle incubator was placed on the SURVEYOR's helipad where it was free from shadows and it was supplied with a continuous flow of seawater. A quantum sensor was placed beside the incubator to measure incident photosynthet- iccally active radiation. The values were continuously recorded on a strip chart during the entire cruise.

Water transparency was measured using a Secchi disk at every station when daylight was sufficient. The light depths for productivity sampling were calculated from the Secchi depths.

4. Station locations are listed in Table 1 and shown in figure 1.
5. Data collected. The observations made are summarized in Table 2.

Table 2. Summary of Observations

Observation	Number
CTD Casts	21
Plant Pigments	190 samples and analyses
Nutrients	72 samples
Phytoplankton	49 samples
Primary Productivity	3 stations, 24 depths, 72 samples
Water Transparency	15
Incident Light	3 days (continuous)

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RESEARCH TO DETERMINE THE ACCUMULATION OF ORGANIC CONSTITUENTS AND HEAVY METALS FROM PETROLEUM-IMPACTED SEDIMENTS BY MARINE DETRITIVORES OF THE ALASKAN OUTER CONTINENTAL SHELF

by

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ANNUAL REPORT
to the

National Oceanic & Atmospheric Administration
OCSEAP Office
P. O. Box 1808
Juneau, Alaska

Contract No. 2311102778
April, 1978

LEGAL NOTICE

PREFACE

For the past 22 months, individuals in the Battelle Marine Research Laboratory at Sequim, Washington, have been studying the bioavailability of petroleum hydrocarbons and trace metals from petroleum-impacted sediments. Since our study is relevant to petroleum development of the Alaskan Outer Continental Shelf, Prudhoe Bay crude oil was used as a test oil. Our test animals were cold-water species of the Pacific Northwest, similar to those found on the Alaskan shelf. Results of our investigation will be found in three publications, which will be available in 1978. The majority of the information contained in this report has been extracted from these manuscripts which are available in pre-print form for researchers interested in more details.

PUBLICATIONS

Anderson, J. W., G. Roesijadi and E. A. Crecelius. 1977. Bioavailability of hydrocarbons and heavy metals to marine detritivores from oil-impacted sediments. Paper presented at the OCSEAP Review-Workshop, Seattle, Washington, October, 1977.

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Roesijadi, G. and J. W. Anderson. 1978. Condition index and free amino acid content of *Macoma inquinata* exposed to oil-contaminated marine sediments. *In*: 1977 Symposium on Pollution and Physiology of Marine Organisms. Georgetown, S. C., ed. by Winona and F. J. Vernberg, Academic Press, New York (in press).

CONTENTS

LIST OF TABLES AND FIGURES

ABSTRACT

During FY1977 and 1978, experiments were conducted to examine the bioavailability of petroleum hydrocarbons and trace metals from petroleum-impacted marine sediments. The feasibility of using bivalve condition index and free amino acid pool as indicators of stress due to petroleum exposure was also tested. Prudhoe Bay crude was the test oil in all experiments.

When simultaneously exposed to 600 μg/g oil in sediment for 40 days in the field, detectable levels of hydrocarbons were present in two deposit-feeding species, *Phascolosoma agassizii* and *Macoma inquinata*, but not in *Protothaca staminea*, a filter-feeder. These results suggest that mode of feeding is a determinate factor in the availability of sediment-sorbed hydrocarbons to benthic animals. Tissue magnification of hydrocarbon concentrations above those in or on sediments was not observed.

Additional short-term experiments with ^{14}C-labeled specific aromatic hydrocarbons in the laboratory indicated that ingestion of contaminated sediment resulted in negligible uptake of 2-methylnaphthalene by *Macoma inquinata*. Methylnaphthalene released from sediment to seawater appeared to be the primary contributor to tissue concentrations of this compound. Uptake of ^{14}C-phenanthrene, -dimethylbenzanthracene, and -benzo(a)pyrene, however, exhibited components which could be attributed to both direct uptake from sediment and uptake from seawater. Magnification factors showed that hydrocarbons were concentrated from seawater but not from sediment. Long-term exposure indicated that uptake of ^{14}C-benzo(a)pyrene by *M. inquinata* was linear for at least six weeks. No indication of a steady-state tissue concentration was observed.

Both free amino acid content and condition index of *Macoma inquinata* were sensitive to stress, as they showed significant reductions, compared to control animals, during field exposure to oiled sediment.

Compared to sediment concentrations, nickel, copper, zinc, and manganese were elevated in *Phascolosoma agassizii*, and nickel, zinc, and selenium in *Macoma inquinata*. Other compounds were present at levels similar to or lower than those of sediment. Exposure to oil-contaminated sediment did not appear to affect trace metals content of either species. Individual variation of trace metals content in *M. inquinata* was relatively low. Coefficient of variation for all elements ranged from 5 to 20%. Use of neutron-activated natural detritus in exposures of *Macoma* provided a closer examination of low levels of four trace metals (Co, Eu, Sc and Zn). Determinations of total gamma-activity and these specific isotopes on shells and in tissues at various intervals showed that little if any of the metals were taken up from oiled and non-oiled detritus.

Recent research with a mud-ingesting polychaete, *Abarenicola pacifica*, indicates that this species takes up and retains more phenanthrene than naphthalenes. With this organism and our experimental system, it has been possible to detect behavioral modifications, ingestion (= egestion) rate reduction, and decreases in phenanthrene content of sediment after passage through the gut.

INTRODUCTION

With increasing petroleum utilization and transport, there has been a concomitant increase in the amount of petroleum hydrocarbons that enter the marine environment. Charter *et al.* (1973) estimated that the total influx of petroleum to the oceans exceeds 3×10^6 tons per year. Numerous studies have now been conducted on interactions between oil-contaminated seawater and marine organisms. Considerable information is available on the toxicity, uptake, and depuration, metabolism, and physiological effects of these compounds (Anderson *et al.*, 1974; Neff *et al.*, 1976a; Malins, 1977; Anderson, 1977). Although it is known that hydrocarbon levels are elevated in marine sediments in the vicinity of petroleum inputs such as oil spills (Blumer *et al.*, 1970; Gilfillan *et al.*, 1976), sewage effluents (Farrington and Quinn, 1973), and refinery operations (Wharfe, 1975), little is known about the effects of oil-contaminated sediments on benthic organisms. Shaw *et al.* (1976) reported increased mortalities of clams *Macoma balthica* exposed to oiled sediment, while Rossi (1977) and Anderson *et al.* (1977) found little or no uptake of naphthalenes from oil-contaminated mud or detritus by a polychaete. Furthermore, there is no information regarding interactions between marine organisms and trace metals from oil-impacted sediments.

Our study has been concerned with the bioavailability of petroleum hydrocarbons and trace metals from petroleum-contaminated marine sediments using diverse experimental approaches. Two species were emphasized as test organisms in the first 18 months of the study: a detritivorous clam, *Macoma inquinata*, and a sediment-ingesting sipunculid, *Phascolosoma agassizii*. A filter-feeding clam, *Protothaca staminea*, has been used in some studies to provide a comparison between detritivores and filter-feeders. We have conducted preliminary studies with a mud-ingesting polychaete, *Abarenicola pacifica*, which provides several experimental advantages. Exposures utilized sand, mud, and detritus (from natural sources) under laboratory and field conditions. Several analytical techniques were employed to quantify hydrocarbons in animal tissues and sediment: ultraviolet and infrared spectrophotometry, gas chromatography, high-pressure liquid chromatography, and liquid scintillation spectrometry. Trace metals were analyzed by x-ray fluorescence or neutron-activation analysis.

To date, we have conducted experiments to examine the following: (1) comparison of bioavailability of petroleum hydrocarbons from sediment in benthic deposit- and filter-feeders; (2) uptake of specific aromatic compounds from sediment in short-term experiments, differentiating between the relative importance of uptake from sediment versus seawater; (3) long-term uptake of specific hydrocarbons from sediment; (4) condition index and free amino acid content of oil-exposed clams, and (5) uptake of trace metals from oil-contaminated sediment. The results are presented in this report. Prudhoe Bay crude oil was the test oil in all experiments.

INFLUENCE OF FEEDING TYPE OF BIOAVAILABILITY OF PETROLEUM HYDROCARBONS FROM SEDIMENT

Benthic organisms are represented by species which exhibit diverse feeding modes. When considering the problem of uptake of material from sediment, it is reasonable to presume that organisms which feed directly on sediment or detritus would have a greater opportunity for accumulation from sediment than species which do not. We tested this hypothesis by exposing filter-feeding, detritus-feeding, and sediment-ingesting species to oil-contaminated sediment in a field experiment, then analyzing the organisms for tissue hydrocarbon concentrations. The clams *Protothaca staminea* and *Macoma inquinata* and sipunculid *Phascolosoma agassizii* were chosen as test species representative of the respective feeding modes listed above.

Details of experimental procedures have been described in our 1977 Annual Report and Roesijadi *et al*, (1978a). The results are presented in Table 1.

Concentrations of total petroleum hydrocarbons (IR) in exposure sediment were 887.4 ppm initially, then declined to 443.8 and 420.6 ppm at 40 and 60 days, respectively. The decreases can probably be attributed to microbial- and photo-oxidation of hydrocarbons as well as their release to the surrounding seawater. Although our exposure concentrations were relatively high, even higher levels have been reported after actual oil spills.

Accumulation of petroleum hydrocarbons was considerably higher in the deposit-feeders, *Macoma inquinata* and *Phascolosoma agassizii*, than in the filter-feeder *Protothaca staminea* (Table 1), indicating that deposit-feeding benthic animals are more likely to take up such compounds from contaminated sediment than are filter-feeders. At the 40 day sampling interval (Table 1),

Table 1. Aliphatic and diaromatic hydrocarbons in samples[1] of *Phascolosoma agassizii*, *Macoma inquinata*, and *Protothaca staminea* exposed to oil-contaminated sediment.

Species	Treatment	Hydrocarbon Concentrations (µg/g wet weight)					
		Saturates C_{12}-C_{28}	N	MN	DMN	Total[2] Diaromatics	Total Hydrocarbons measured
P. agassizii	Control	<0.10	<0.005	<0.005	<0.01	<0.02	<0.12
M. inquinata		<0.10	<0.005	<0.005	<0.01	<0.02	<0.12
P. staminea		<0.10	<0.005	<0.005	<0.01	<0.02	<0.12
P. agassizii	40 day exposed	1.90	<0.005	0.23	0.60	0.83	2.73
P. agassizii		0.73	<0.005	0.01	0.15	0.16	0.89
M. inquinata		0.69	<0.005	0.06	0.89	0.96	1.65
P. staminea		<0.10	<0.005	<0.005	<0.10	<0.02	<0.12
P. agassizzi	60 day exposed	1.48	0.01	0.06	0.18	0.25	1.73
M. inquinata		0.54	0.02	0.27	2.39	2.68	3.22
M. inquinata		3.62	0.02	0.26	1.96	2.24	5.86
P. staminea		0.10	<0.005	0.02	0.16	0.18	0.28
M. inquinata	60 day exposed 7 day depurated	0.35	<0.005	0.03	0.96	0.99	1.34
		0.15	<0.005	0.02	0.20	0.22	0.37
P. staminea		0.03	<0.005	<0.005	<0.01	<0.02	0.03
		0.02	<0.005	<0.005	0.01	0.01	0.03

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[1] Each sample consisted of 2 to 4 pooled individuals; clams were shucked prior to extraction.

[2] Total diaromatics include naphthalene (N), methylnaphthalenes (MN), and dimethylnaphthalenes (DMN).

hydrocarbon levels in *Protothaca staminea* were below our detection limits, while those in *M. inquinata* and *Phascolosoma agassizii* ranged between 1 to 3 ppm combined aliphatics and diaromatics. Relative contributions of the two fractions were similar for both species. Aliphatics averaged 1.1 ppm, and total diaromatics averaged 0.7 ppm. The diaromatics consisted of the alkylated forms, particularly the di- and tri-methylnaphthalenes. Naphthalene was not detected. At 60 days (Table 1), hydrocarbon concentrations in *Macoma* were higher than those at 40 days, primarily due to increases in levels of di-methylnaphthalenes. The apparent increase in uptake between 40 and 60 days is difficult to explain; however, we have observed a similar phenomenon with benzo(a)pyrene uptake from sediment by *M. inquinata*. At the 60 day sampling, *Protothaca staminea* also contained a small amount of petroleum hydrocarbon, approximately 0.3 ppm combined aliphatics and total aromatics (Table 1). Transfer of exposed *M. inquinata* and *Protothaca staminea* to clean seawater for one week resulted in significant depuration of both saturate and aromatic hydrocarbons from clam tissue (Table 1).

For comparative purposes, we exposed *Protothaca staminea*, the filter-feeder to 0.02 - 0.03 ppm Prudhoe Bay crude oil dispersed in seawater for 60 days in a continuous-flow bioassay system. The results indicated that tissue hydrocarbon levels were considerably higher than those in the exposure seawater and were consistent with previous reports on the uptake of petroleum hydrocarbons from seawater by marine bivalves. Approximately 11 ppm aliphatic and total aromatic hydrocarbons were present in clam tissue, with a distribution pattern similar to that described above for animals exposed to oil-contaminated sediment.

It is evident from our study that the feeding type of benthic organisms is an important factor in the bioavailability of hydrocarbons from sediment.

Both the aliphatic and diaromatic petroleum hydrocarbons on or in marine sediments are more readily taken up by detritivores than filter-feeders. However, the extent of accumulation was relatively low compared to initial sediment hydrocarbon concentrations. Since concentrations in tissue of both *Phascolosoma agassizii* and *Macoma inquinata* increased during the 60 days of the experiment, the long-term implications for bioaccumulation cannot be adequately defined at the present time. In a study using oiled sediment similar to that reported here, concentrations in sediment of docosane, naphthalene, and phenanthrene exhibited exponential decreases with approximate half-times of 40 days. Our IR analyses also indicated a decrease of petroleum hydrocarbons with exposure time. Thus, it would appear that animals in our experiment were accumulating hydrocarbons during a period which coincided with release of these compounds from sediment.

UPTAKE OF ^{14}C-LABELED AROMATIC HYDROCARBONS BY *MACOMA INQUINATA* IN SHORT-TERM EXPERIMENTS

Our efforts consisted of short-term (1 week) experiments to survey the relative uptake of various aromatic hydrocarbons from oil-contaminated sediments. The objective was to screen several compounds in an attempt to identify those which may have greater significance with respect to bioavailability from marine sediments. We selected *Macoma inquinata* as a test species, since preliminary observations indicated that this clam is an active detritus-feeder. The test compounds were 2-methylnaphthalene, phenanthrene, chrysene, dimethylbenzanthracene, and benzo(a)pyrene.

Clams were collected from intertidal regions of Sequim Bay, Washington, and held at the Marine Research Laboratory of Battelle-Northwest, Sequim, Washington. Holding tanks contained raw, flowing seawater of about 10°C and 30°/₀₀ and sediment obtained from the vicinity of the clams' natural habitat.

Detrital material which settles out of our flowing seawater system was collected and filtered onto No. 42 Whatman filter paper. Fifteen grams were weighed and suspended in approximately 30 ml Prudhoe Bay crude oil dissolved together in 1 ml ethyl ether were added to the suspended detritus, mixed thoroughly by shaking, then filtered onto No. 42 Whatman filter paper. The contaminated detritus was used in exposures. Stock solutions of ^{14}C-hydrocarbons were tested for radioisotope purity by thin-layer chromatography and autoradiography. Measurements by infrared spectrophotometry (IR) indicated approximately 2,000 μg/g total hydrocarbons in the detritus.

Since oil-contaminated sediments can release hydrocarbons to the surrounding water, it was necessary to consider the possibility of uptake of solubilized, as well as sediment-bound, hydrocarbons. Therefore, some clams were placed on the bottom of exposure aquaria containing the contaminated detritus, while others were placed in a nylon-mesh (Nitex) basket suspended in the water column above the detritus. The first group fed directly on the detritus, and the latter served as a control for uptake from the water. Seven-day exposures were conducted in all-glass aquaria containing detritus and 3 ℓ of 0.45μ filtered seawater. At the end of exposure, some individuals from the bottom and suspended basket were removed for immediate extraction, while the remainder were transferred to clean seawater for a 24-h gut purging period.

Net uptake from sediment, i.e., the amount of hydrocarbon ingested and present in clam tissue at the end of the exposure period, can be calculated as follows:

Net uptake = Concentration in clams on bottom - concentration due to seawater uptake - concentration in gut contents + concentration lost from tissue during gut purging.

If uptake is primarily due to absorption of solubilized hydrocarbons, then the value for actual uptake would be essentially zero or negative.

Seawater samples were taken prior to the addition of clams and at 1, 2, 4, and 7 days. Detritus was sampled initially and at 7 days. All samples were analyzed by liquid scintillation spectrometry and corrected for quench. Additional experimental details are described in our 1977 Annual Report.

The results are summarized in Table 2. There was no measurable uptake of the diaromatic 2-methylnaphthalene from sediment. Uptake from seawater could account for the entire amount of this substance in clam tissue. Higher molecular weight compounds possessed an uptake component associated with net uptake from sediment. Comparison of net uptake from seawater indicated that both sources contributed similar amounts to the tissue burden of polyaromatic hydrocarbons. Magnification factors indicated that hydrocarbons in sediment were not as readily accumulated by clams as hydrocarbons in seawater. Sediment magnification factors were typically less than 0.1, while seawater magnification factors ranged from 3.2 to 420. Furthermore, seawater magnification factors exhibited a correlation with molecular weight of the aromatic compound, increasing with increasing size of compound. Such a correlation is undoubtedly related to the lipid vs. water solubilities of the compounds. Thus, larger molecular weight compounds which are more lipophilic would tend to have a greater affinity for animal tissues than smaller compounds. Sediment magnification factors did not exhibit such a trend.

Table 2. Uptake of ^{14}C-polyaromatic hydrocarbons from sediment by *Macoma inquinata*. Clams were exposed to sediment containing 2000 ppm crude oil spiked with 10 μC of the hydrocarbon indicated in the table.

Parameter	2-Methyl-Naphthalene	Phenanthrene	Chrysene	Dimethyl-Benzanthracene	Benzo(a)pyrene
Net Uptake From Sediment[1] (μg/g)	0	0.096	0.308	0.297	0.059
Uptake From Seawater (μg/g)	0.048	0.038	0.297	0.856	0.037
Sediment Magnification Factor[2]	0	0.056	0.029	0.039	0.057
Seawater Magnification Factor[3]	3.2	5.89	105	295	420

[1] Calculated As Indicated in Text

[2] Sediment Magnification Factor = Net Uptake/Geometric Mean Concentration In Sediment

[3] Seawater Magnification Factor = Uptake From Seawater/Geometric Mean Concentration In Seawater.

UPTAKE OF ^{14}C-AROMATIC HYDROCARBONS BY *MACOMA INQUINATA* IN A LONG-TERM EXPERIMENT

We examined long-term uptake of phenanthrene, chrysene, and benzo(a)pyrene from sediment by *Macoma inquinata*. Since short-term experiments, already described, indicated a low level of accumulation of these compounds by *M. inquinata*, it was necessary to determine if prolonged exposure would also produce similar results.

Clams were collected in the intertidal region of Sequim Bay and held in the laboratory in flowing seawater of approximately 10°C and 30°/₀₀. Exposures were conducted in compartmentalized sediment trays already described. Each compartment was filled with 3 kg clean sand and placed in holding tanks with flowing seawater and a simulated diurnal tidal flux. Cement blocks held the trays at a level that prevented "high tide" from overflowing the upper edges of the sediment trays. "Low tide" completely drained seawater from the trays through fiberglass mesh bottoms. Therefore, the only water flux in the exposure trays occurred through the tray bottoms as the trays drained and filled. Twenty clams were placed in each compartment. Six exposure and one control trays were prepared.

Contaminated detritus was prepared as described for short-term experiments. At "high tide" approximately 25 g of suspended detritus was added to each compartment and allowed to settle on the surface of the sand containing clams. Clams and sediment were sampled at 3, 7, 14, 28, and 42 days of exposure. Each sampling period entailed removal of all clams and one sediment core from a compartment. Half the clams and the sediment core were extracted and analyzed immediately. The remaining clams were transferred to clean seawater for 24 h to allow purging of gut contents, then analyzed.

During the course of exposure, the detritus which had settled onto the surface of the sand penetrated into interstitial spaces as a result of the tidal fluxes. Since it was impossible to separate detritus from sand at sampling intervals after day 3, counts for core samples were used as a measure of hydrocarbon content. For purposes of comparison, initial counts for detritus were corrected to account for the total sediment load (= detritus + sand), assuming uniform distribution of the detritus in sand. These values could then be directly compared to values for core samples.

For phenanthrene and chrysene, ^{14}C-radioactivity was also separated into parent compound and metabolite fractions using a procedure described by Roubal *et al.* (1977).

Concentrations of radioactivity in sediment are described in Figure 1. Initial concentrations were similar (~ 1.0 x 10^4 dpm/g) for phenanthrene, chrysene, and benzo(a)pyrene and exhibited an apparent two-component exponential decrease with time. Phenanthrene, the smallest compound, decreased at a faster rate than chrysene or benzo(a)pyrene. Final sediment ^{14}C concentrations were two orders of magnitude less than initial levels with phenanthrene and approximately one order of magnitude less with chrysene and benzo(a)pyrene. In all three cases, loss rates were relatively rapid.

Behavior of ^{14}C-radioactivity in tissue of exposed clams was different for the three compounds and apparently related to relative solubilities (Figure 2). With all three compounds, exposed clams took up an initial high dose measured at either two or three days of exposure. This initial uptake was probably associated with the high levels in the initial exposure detritus on the sand surface and active filtration of this highly contaminated material. With time, however, the detritus percolated into the underlying sand substrate as described earlier. Tissue concentrations of ^{14}C-phenanthrene radioactivity steadily

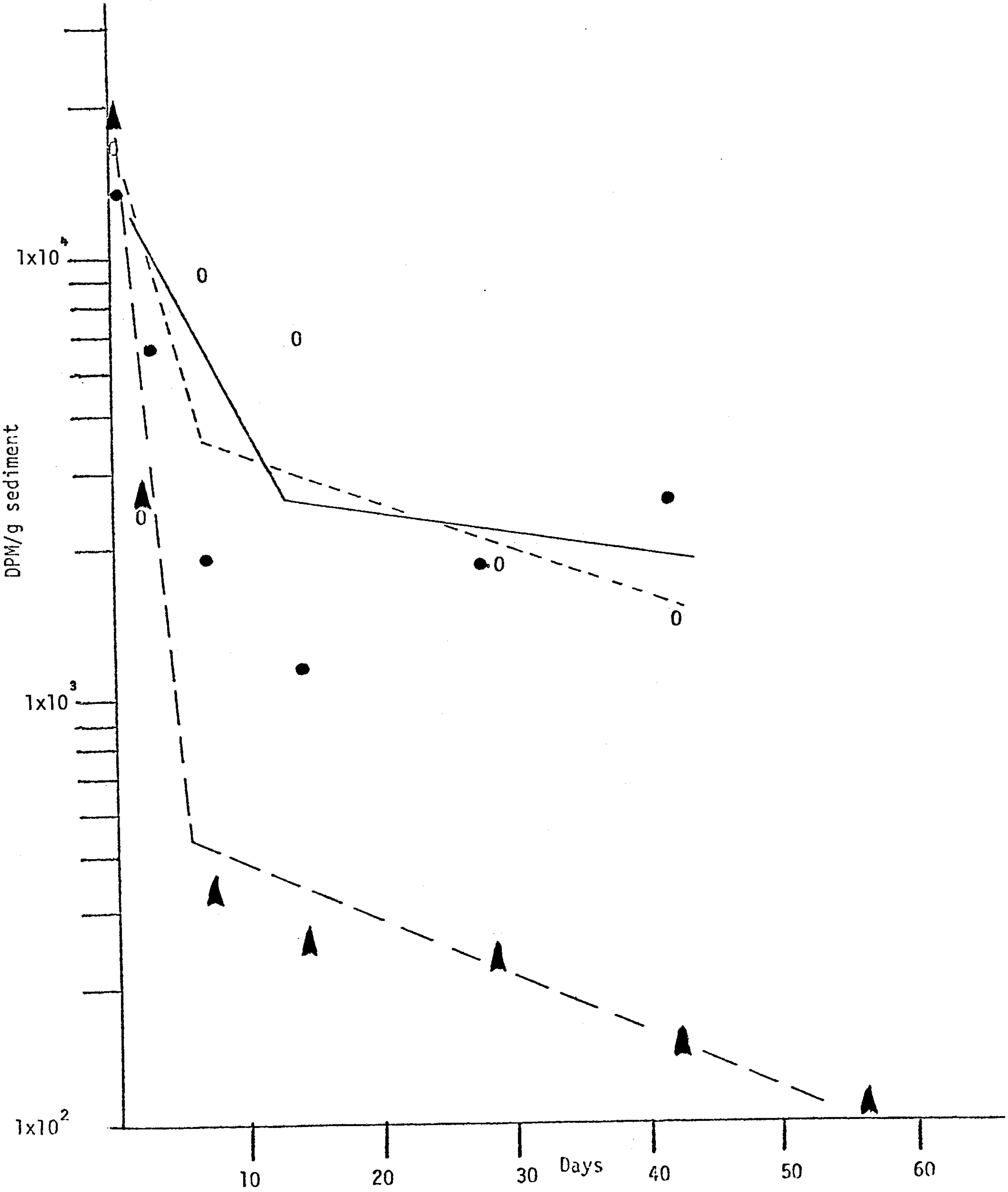

FIGURE 1. Radioactivity in sediment at intervals during exposure of clams to ^{14}C-phenanthrene, -chrysene, or -benzo(a)pyrene. Legend: triangles and short dashes = phenanthrene; open circles and short dashes = chrysene; closed circles and solid lines = benzo(a)pyrene.

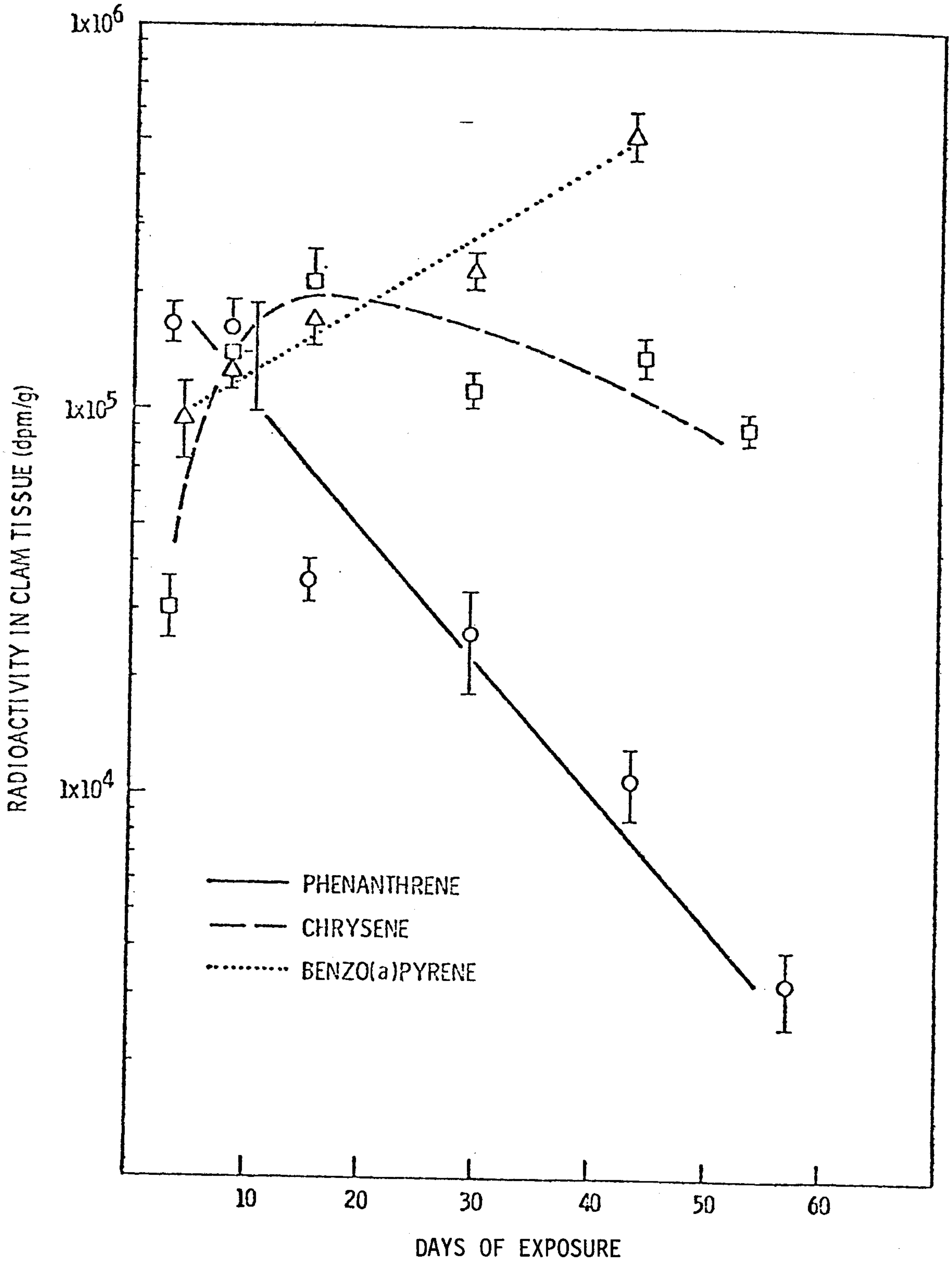

Figure 2. Radioactivity in clam tissue at intervals during exposure to HC-phenanthrene, -chrysene, or -benzo(a)pyrene.

declined with subsequent exposure indicating an initial high uptake followed by depuration. Tissue ^{14}C-chrysene concentrations increased up to day 14, then began to decline after that time. ^{14}C-benzo(a)pyrene in tissue, however, continued to increase throughout the duration of the experiment (42 days in this case). These observed differences are probably associated with the relative solubilities of the three compounds in water and lipids. For example, net uptake as presented in Figure 2 can be described as follows:

$$\text{net uptake} = \text{influx} - \text{efflux.}$$

Therefore, net uptake is positive when influx exceeds efflux and negative when efflux exceeds influx. The kinetics of benzo(a)pyrene radioactivity uptake is clearly representative of the former case, while phenanthrene kinetics is representative of the latter. Chrysene possessed a positive net uptake during the early stages of the exposure then tissue concentrations began to decrease. Since benzo(a)pyrene was the most lipophilic compound of the three, phenanthrene the most hydrophilic, and chrysene intermediate; it appears that the relative affinities of the three compounds for clam tissue, probably the lipid pool, was associated with the behavior of these compounds in our experimental system.

Separation of ^{14}C-radioactivity for phenanthrene and chrysene into parent and metabolite fractions indicated a difference in the behavior of these compounds in both sediment and clam tissue. For example, the fraction of phenanthrene radioactivity present as parent compound in sediment decreased at a faster rate than that for chrysene (Table 3), indicating that phenanthrene was a less stable compound in our exposure system. Furthermore, the fraction of phenanthrene radioactivity in clam tissue associated with parent compound decreased from 97.1 to 44.5% of the total radioactivity over the 56 day exposure period. For chrysene, almost all the radioactivity in clam tissue was still associated with the parent compound at the end of exposure.

Table 3. Percent of total radioactivity present as parent compound.

Compound	Time (days)	Sediment	Tissue
Phenanthrene	0	98.4	-
	2	83.5	97.1
	7	36.6	87.1
	14	35.3	80.6
	28	17.4	60.2
	42	27.2	51.2
	56	17.7	44.5
Chrysene	0	90.4	-
	2	94.7	98.4
	7	78.1	96.2
	14	63.0	95.8
	28	72.0	93.9
	43	67.4	94.7
	52	24.6	95.8

It is obvious that degradation of phenanthrene in sediment occurred at a faster rate than for chrysene, and that the relative contributions of metabolites of phenanthrene increased with time in clam tissue. Chrysene metabolites in tissue were negligible. Microbes and photo-chemical oxidation as well as loss to the seawater were probably responsible for the turnover of these compounds in sediment. At the present time, there is no evidence to suggest that marine bivalves possess enzymatic systems which can degrade aromatic hydrocarbons. Therefore, phenanthrene metabolites present in clam tissue may have originated in the sediment and were subsequently taken up by clams.

DISTRIBUTION OF ^{14}C-RADIOACTIVITY IN TISSUES

The analytical chemistry associated with determining the rates of uptake, level of accumulation and fate of ^{14}C-labeled aromatic hydrocarbons derived from exposing intertidal detritivores to oil contaminated substrate requires the solution of two analytical tasks. These tasks are, A: analysis of polyaromatic hydrocarbons in oil and, B: in tissue.

In the first task, high pressure reverse phase liquid chromatography (HPLC) employing ultraviolet and fluorescence detection systems is being used to determine the concentrations of chrysene and benzo(a)pyrene in Prudhoe Bay crude oil (PBC) which are two of three compounds used in the accumulation studies. Isolation of a polyaromatic enriched fraction from the crude oil utilizes aspects of a procedure described by Pancirov *et al.* (1975). The concentration of phenanthrene in PBC, the third compound to be used in these studies, has been determined by capillary gas chromatography. Since these compounds are present in PBC oil, these data are needed to relate levels of radioactivity to amounts of each of these compounds (specific activity) to which the organisms are exposed as a function of time.

Reverse-phase HPLC has previously been used in a method to characterize impurities associated with benzo(a)pyrene degradation (Clarke, 1976), and we have recently used this technique to determine the radio-purity of all three substrates used in these studies. Phenanthrene and chrysene undergo no significant chemical degradation under prolonged storage, however, benzo(a)pyrene showed the presence of about 4% impurities and, therefore, will have to be verified by silica gel chromatography prior to each experiment to assure that no degradative chemical artifacts are introduced to invalidate radioactivity analysis.

In the second task, a method is being developed to monitor the uptake and fate of ^{14}C-phenanthrene, chrysene and benzo(a)pyrene in tissue of intertidal detritivores. The method will allow us to account for the formation of metabolites or conjugates which are of interest in future studies. Conventional tissue digestion techniques such as that described by Warner (1976) cannot be used in the method because of potential degradation of metabolites or conjugates. Therefore, initial preparation includes homogenization of tissue samples in an organic solvent. Removal of high molecular weight components (biogenic) from the tissue extracts is necessary to reduce separation interferences and minimize quenching effects. Gel permeation chromatography incorporates a modified version of a method described by Keuhl *et al.* (1978). Samples isolated from this system containing initial substrate and any associated metabolites or conjugates are further fractionated by reverse-phase HPLC, and the amount of radioactivity associated with parent hydrocarbon substrate and metabolites are determined using liquid scintillation counting.

UPTAKE OF HYDROCARBONS FROM MUD BY *ABARENICOLA*

Work has begun on *Abarenicola pacifica*, a polychaete which presents several advantages for the assessment of bioavailability of petroleum hydrocarbons or other pollutants from muddy sediment. *A. pacifica* occupies an L-shaped burrow constructed in mud. The anterior 2/3 of the animal normally lies in the deep horizontal portion of the burrow (the gallery or head shaft) about 10 cm below the surface, while the posterior 1/3 lies in the vertical tail shaft. Undulating movements of the body, especially the tail, bring in currents of water for respiration and, to some extent, for feeding. Micro- and meio-organisms suspended in the respiratory current are filtered on the walls of the end of the head shaft and are ingested together with the surrounding sediment. The resulting excavation, as well as the hydraulic abrasion of the respiratory current, cause a subsidence of the sediment lying over the animal's anterior end. Thus, material lying on the surface of the sediment can, over a period of several days, be drawn down to the level of the head shaft and be ingested. At intervals the posterior end of the animal is raised to the upper end of the tail shaft, and feces are deposited around the opening in a characteristic pattern.

As a result of this mode of life, materials adsorbed onto sediments may be presented to *A. pacifica* via several routes. Materials that remain attached to sediment may be ingested directly. Materials that are given off into the water column may be taken up through the respiratory current or be incorporated into suspended food organisms which will then be eaten. Furthermore, sediment at all levels above the head shaft is subject to ingestion. Since the fecal material from individual worms can be easily collected, it is possible to analyze changes in pollutant material resulting from passage through the digestive tract.

Preliminary investigations have been conducted with a small number of these organisms to determine whether they respond to hydrocarbon contamination by avoiding it. For this purpose, four plastic boxes with Nitex mesh bottoms were divided into two compartments by a teflon sheet. Clean sediment from the worms' habitat was placed in one half of each tray. The other half was filled with sediment into which 1000 ppm PBC oil had been stirred with a motor driven impeller. The teflon sheets were removed, one worm was introduced into each box at the dividing line between clean and oiled sediment, and the boxes were placed in tanks with flowing seawater. The location of the worms after feeding could be determined by the location of the fecal casts surrounding the tail shafts. Initially, two of the four worms moved into the oiled mud and two into clean mud. After ten days, one worm moved from the oiled to the clean mud, and one had moved in the opposite direction. Three weeks later however, all the animals had moved into the unoiled halves, and they remained there until the termination of the experiment (35 days).

The uptake and release of naphthalenes by *Abarenicola* from contaminated sediments were studied by mixing PBC with substrate at a high (H) concentration of 1000 ppm and at a low (L) concentration of 100 ppm. Worms were exposed to the sediment, either directly (D) by being placed in trays entirely filled with the contaminated sediment, or indirectly (I) where they were in a 2 cm deep layer of unoiled mud overlain by a 5 cm layer of oiled mud. The four combinations of conditions are designated as HD, HI, LD, and LI. The oil-mud mixtures were placed in mesh-bottomed trays in running seawater for four hours and flushed twice by changes in water level before the worms were placed in them. The trays were then placed in clean running seawater.

At intervals of several days, a tray was removed and the worms it contained were washed free of surface contamination with a stream of distilled water.

The intestinal tract of each animal was removed, slit opened and freed of its contents by flushing with distilled water. The cleaned guts, body wall and part of the coelomic fluid of each animal were frozen together at -80°C in teflon-lined, hexane-washed, centrifuge tubes and saved for later analysis. Tissue samples were taken at 1, 4, 7, 14, and 22 days of exposure. Worms exposed to HI conditions for eight days were moved to clean sediment for depuration of one and eight days. Frozen tissue samples were thawed and analyzed for naphthalene, methylnaphthalenes, and dimethylnaphthalenes contents by UV spectrophotometry (Neff and Anderson, 1975). Samples of sediment and fecal casts were taken for IR analysis of total hydrocarbons.

The results of this set of experiments are summarized in Table 4. As might be expected, the average concentration of tissue naphthalenes was highest under HD conditions, less in HI, still less in LD, and lowest in LI. As much as 3 ppm total naphthalenes was present in the HI *Abarenicola* in four days. Under those conditions in which a time course of accumulation and depuration was followed, a plateau appeared to be reached within a few days of exposure and loss of naphthalenes following transfer to clean sediment was rapid, leading to a 90% decrease in concentration within eight days. The concentration of naphthalenes in the sediment could not be measured directly due to its high organic content, but calculation based on an unpublished analysis of PBC indicated that the highest tissue concentration reached was of the same order of magnitude as the sediment concentration but somewhat lower. Since the preliminary flushing of oiled sediment undoubtedly removed an unknown proportion of the naphthalenes, it is not possible to say whether a tissue magnification effect exists.

IR spectrophotometry indicated that the total hydrocarbon content of the H and L sediments, when corrected for the endogenous hydrocarbons of the native

Table 4. Uptake of naphthalenes (N + MNs + DMNs) by *Abarenicola pacifica* exposed to oiled mud. The UV technique (Neff and Anderson, 1975) showed that control tissue produced a background fluorescence of 0-0.2 ppm naphthalenes. All values listed are ppm total naphthalenes and means are shown for each interval.

Condition	Exposure (days)					Depuration (days) after 8 days exposure	
	1	4	7	14	22	1	8
High Concentration (471 ppm)							
In oiled mud[1] (Direct)					2.15		
					4.23		
					3.19		
Below oiled mud[2] (Indirect)	1.46	1.44	1.09	2.6		0.99	
	2.16	2.57	4.20	1.99		0.90	0.43
	1.81	3.46		1.60		0.39	0.22
	1.81	2.49	2.65	2.06		0.76	0.32
Low Concentration (52 ppm) In oiled mud (Direct)	0.58						
	0.63	0.99					
	1.03	0.60	0.93				
	0.75	0.80	0.93				
Below oiled mud (Indirect)	0.36	0.66					
	0.53	0.54	0.73				
	0.34	0.77	0.37				
	0.41	0.56	0.55				

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[1] The polychaetes were completely surrounded by oil contaminated mud.

[2] The animals were initially in a 2 cm deep layer of clean mud overlain by a 5 cm layer of oiled sediment.

substrate (68 ppm), differed by a factor of ten (471 and 52 ppm, respectively). The average absolute value of the added oil, measured by IR methods, was one half of the calculated value measured by volume. Few fecal casts were produced by worms in the D sediment. Their hydrocarbon content (HD = 538 ppm; LD = 145 ppm) closely matched the total average content of the sediment surrounding the worms. Fecal casts collected from I worms had lower average contents (HI = 171 ppm; LI = 93 ppm).

Uptake of another aromatic compound was studied under conditions that allowed direct comparisons between sediment, tissue, and fecal concentrations. In this experiment sediment containing 1000 ppm PBC, to which ^{14}C-labeled phenanthrene had been added at 85% of its endogenous concentration, was placed in ten U-shaped tygon tubes, 40 cm long. The tubes were suspended in flowing seawater and one worm was placed in each. Feces were collected daily from plastic trays surrounding the ends of the tubes. After twelve days the sediment and surviving worms were removed. The radioactivity of sediment, worms, and feces were measured by liquid scintillation, following extraction of phenanthrene by a modification of the method of Warner (1976). Contaminating material was rinsed from the worms' exteriors and their gut lumens with ethanol, assuring that only the phenanthrene incorporated into the tissues was measured. Interstitial water was extracted from the sediment by centrifuging for 20 minutes at 29,000 g, followed by passage through a .45μ Millipore filter. Control animals were placed in similar tubes containing unoiled sediment, such that survival and fecal cast production could be compared.

Several differences between the controls and experimentals are noteworthy. During the 12 days, one control and five exposed animals died. The exposed animals appeared to be in more distress since their tails were seen to protrude from their burrows 20 times versus 3 times for the controls (Table 5). This

Table 5. Effects of oiled mud on the feeding and behavior of *A. pacifica*. Mud contained a calculated concentration of 1000 ppm PBC oil of which 0.56 ppm was phenanthrene.

Response	Controls	Exposed
Survival	90%	50%
Tails projecting outside of tubes (no. of events)	3	20
Fecal casts produced	31	17
Mean weight of casts/g live tissue	1.25g	0.92g
Mean fecal production	0.5g/day/g tissue	0.2g/day/g tissue

behavior, which is clearly non-adaptive in the field, is never seen under natural conditions. On the other hand, two of the control worms and none of the exposed left their tubes.

The rate of feeding was lower in the exposed group, which produced 17 fecal casts in 11 days, among seven animals which either survived or produced at least one cast (Table 5). Nine control animals in the same categories produced 31 casts. It is of interest that only three of the experimental group produced casts during the first week of exposure, and two of these failed to survive, indicating that cessation of feeding in the early stages of oil contamination may be a protective response.

There is a clear effect of oil on the rate of turnover of sediment by *Abarenicola pacifica* populations, as the control group produced 0.5 g feces/day/g live weight of animal, and the exposed only 0.2 g. The difference is partly due to the lower rate of cast production by the exposed and partly from the lower average size of the casts, .92 g/g live weight versus 1.25 g for the controls (Table 5).

The average concentration of phenanthrene within the tissues of the exposed worms was higher than that in the surrounding sediment, though of the same order of magnitude, with the highest concentration of any found in the body of a dead worm (Table 6). The tissue concentration was not affected by the rate of feeding, as the same level, corresponding to a total (endogenous plus labeled) level of about 80 ppb, was found in an animal that had produced no fecal casts as in one that had passed more than its own body weight in sediment through its intestinal tract.

It may be conjectured that high concentrations of petroleum hydrocarbons can enter *A. pacifica* by direct contact with water and surrounding sediment as

Table 6. Uptake of ^{14}C-Phenanthrene from oiled mud by *A. pacifica*. 100 µC of ^{14}C-Phenanthrene (1.57 mg) was added to 3.2 g of PBC (1.86 mg phenanthrene) and this was mixed with 3.2 kg of mud.

Compartment	Mean ^{14}C-activity (dpm/g)	Concentration (ppm) mean ± S.D.	Number of Samples
Mud	38,400	0.56 ± 0.14	9
Whole worm (survivors)	53,200	0.80 ± 0.19	5
Whole worm (deaths)	84,000	1.25	2
Body wall	38,500	0.57	1
Gut	115,000	1.72	1
Feces	9,790	0.16 ± 0.09	12
Interstitial water	80	0.0013	7

well as through ingested material, though the level of phenanthrene in interstitial water was two to three orders of magnitude less than that in the sediment (Table 6). Further experimentation is being planned to determine the relative importance of these routes.

There is some evidence that the digestive tract does play a significant role in the response of *A. pacifica* to petroleum since the gut of one animal, which was analyzed separately, had three times as high a concentration as the remaining tissue. Furthermore, the phenanthrene content of the feces in nearly all cases was substantially lower than that of the ingested sediment, indicating that it had been metabolized into a more soluble form during its transit through the gut.

UPTAKE OF TRACE ELEMENTS FROM OIL-CONTAMINATED SEDIMENT

In last years Annual Report, data were presented on the concentrations of trace elements in Prudhoe Bay crude oil, test sediments and detritus and tissues exposed to clean or oiled substrate. The crude oil was analyzed by neutron-activation analysis, and all other samples were characterized by x-ray fluorescence. Both *Phascolosoma agassizii* and *Macoma inquinata* were used in these studies, and between 14 and 22 different trace elements were determined in the experimental substrates and tissues. Trace metals of biological significance which were determined include V, Cr, Ni, Cu, Zn, Pb, Sr, As and Hg. To determine variability between individual *Macoma*, replicate analyses (3-10 samples) were conducted and values for two standard errors were generally 10% of the mean or less (Table 7). The exposure of *Macoma* in laboratory or field experiments to clean and oiled substrate did not produce concentrations of any trace elements in the tissues which were above normal variations. The data generated in FY1977 for both *Macoma* and

Table 7. Analysis of trace elements in *Macoma inquinata* by x-ray fluorescence. Estimation of sample variability.

Element	Sample size[1]	Concentration (μg/g) $\bar{X} \pm 2$ S.E.
P	10	4,651 ± 686
S	10	15,374 ± 591
Cl	10	53,859 ± 3,695
K	10	13,504 ± 245
Ca	10	2,003 ± 140
Ti	10	23.7 ± 9.5
V	3	3.58 ± 0.45
Cr	5	3.92 ± 0.60
Mn	10	9.136 ± 1.043
Fe	10	315.2 ± 31.3
Co	4	2.497 ± 0.442
Ni	10	3.282 ± 0.391
Cu	10	8.108 ± 0.374
Zn	10	195.2 ± 12.5
Ga	10	n.d.[2]
Hg	10	n.d
Se	10	3.177 ± 0.188
Pb	3	0.815 ± 0.680
As	10	10.319 ± 0.368
Br	10	262.5 ± 17.8
Rb	10	n.d.
Sr	10	29.59 ± 2.46

Phascolosoma suggested that within the limits of the analytical approaches utilized, these organisms were not exhibiting uptake of trace metals from oiled substrate.

Since the possibility existed that the x-ray fluorescence techniques may not be detecting small changes in the tissue content of certain heavy metals, we suggested the use of radio-labeled detritus and oil which would be produced from neutron-activation of these substances. By generating gamma-emitting isotopes from the metals contained in the oil and associated with the detritus, very small amounts of isotopes transferred from these substances to the detritivores could be measured. In the fall of 1977 (FY1978), samples of oil and detritus were subjected to neutron-activation, and the products were measured for isotope content and activity. Because the concentration of metals in the oil was so low (Table 8) and the specific metals present did not lend themselves to use in this experimentation, the activated oil was not utilized.

The detritus, however, did possess at least four gamma-emitting isotopes, which exhibited activities and half-lives suitable for use in experimentation. In January of 1978, a preliminary experiment was conducted to evaluate the uptake of isotopically-labeled heavy metals by the clam, *Macoma inquinata*. Activated natural detritus was mixed with fresh cold detritus (1:10), and the mixture was "aged" in seawater at 10°C for four days. The final product was then filtered on #42 Whatman paper, and divided into two halves. The oil-impacted portion received a calculated 2000 ppm of PBC contamination by the methods described earlier under hydrocarbon exposure. The non-oiled portion received only one ml of ether used as a carrier in the oiled sample. These two samples of activated detritus were placed on the bottom of two separate

Table 8. Trace element concentrations in Prudhoe Bay Crude oil Samples represent oil from two different barrels and were analyzed by neutron activation analysis.

Element	Concentration (μg/g)	
	Sample 1	Sample 2
Na	<0.06	0.097
Mg	<30	<33
Al	<0.5	<0.5
Cl	<1	0.95
K	<4	<1.4
Sc	<0.001	<0.001
V	20.9	18.0
Cr	<0.21	<0.15
Mn	<0.04	<0.02
Fe	<1.6	<1.7
Co	0.018	0.017
Cu	<5	<3
Zn	0.31	0.31
As	<0.03	<0.01
Se	--	<0.3
Br	5.73	2.75
Rb	<0.06	<0.08
In	<0.005	<0.003
Sb	<0.002	<0.002
Cs	<0.002	<0.001
Ba	<23	<8
La	<0.01	<0.01
Sm	<0.002	<0.001
Eu	<0.001	<0.001
Tb	<0.007	<0.006
Ta	<0.04	--
Hg	<0.03	<0.03
Th	<0.008	<0.006

5-liter aquaria and low aeration was supplied. Ten marked clams were placed on the substrate of each tank, and then a basket containing an additional five clams was suspended in the water column above the other animals. The exposure continued for one week and there was an additional depuration period of two days. During the exposure, water and clam samples were counted at 1, 3, and 7 days, and animals were also counted after depuration. It was possible to utilize a small number of animals since they could be counted alive and placed back in the aquarium. The same groups of five individuals were counted together, and the configuration within the counting chamber was kept constant. After the one week exposure and final counting at Sequim for total gamma activity, five of the ten animals on the bottom of each aquarium were transferred to clean water with clean detritus for two days depuration. The remaining five in each group were removed from the shell, and both tissue and shell were sent to Richland for detailed analyses. The same procedure was used on the 2-day depurated groups and the two groups of five suspended above the detritus. The determinations of total gamma activity and specific isotope content of the various groups and samples are shown in Tables 9 and 10.

During the one week exposure, the oiled detritus decreased in total hydrocarbon concentration from 1755 ppm to 1138 ppm. The gamma activity associated with the water above the detritus (both oiled and non-oiled) was primarily in solution and was of significant magnitude, except on day 3 (Table 9). Counts generally present in the 200 ml samples were about twice as high as those found in the clam tissues after seven days of exposure to detritus (200). Clams suspended above the substrate, where activity could only be obtained from the water and very fine suspended particles, exhibited rather consistent counts between 34 and 79. The shells of clams living on the bottom of both aquaria (oiled and unoiled detritus) possessed a total of 35 counts/g (per 40 min.).

Table 9. Uptake of total gamma-labeled trace metals from detritus by *Macoma*. Values are counts per 40 minutes per gram (tissue) or per 200 ml (seawater).

Type of Sample	Sample Interval (days) Exposure 0	1	3	7	Depuration (after 7 days exposure) 2
Seawater (200 ml)					
Filtered (0.5μ)	370	432	23	440	
Unfiltered	473				
Filter	268				
Macoma					
On Detritus					
With oil		109	141	200	45
Without oil		230	59	172	52
Above detritus					
With oil		79	54	68	27
Without oil		68	34	55	23
Shell only				35	28

Two days of depuration in clean water and detritus reduced all counts, including those clams on and above detritus, with and without oil and shells, to a range of 23 to 52 (Table 9). Since the shell alone gave a count of 28, it is apparent that uptake by clam tissue was extremely small if present at all.

Samples taken on the seventh day of exposure and after two days of depuration were analyzed for content of specific radioisotopes (Table 10). It is clear that the detritus contained sufficiently high amounts of these four isotopes to provide the organisms with an opportunity to exhibit uptake. ^{60}Co was found in the water at higher counts than the other metals, but these only represented 1% of the detritus activity and the Zn in water represented about 4% of detrital activity. There are no apparent differences in the activity of clams between the oiled and non-oiled groups, but the sub-groups living above the detritus both exhibited lower activity. Depuration for two days reduced the levels of activity to those of the clams living above the substrate, which is approximately equal to that associated with the shell of those living on the detritus.

It is interesting to note that when the Zn counts in the tissues are converted by use of the Zn specific activity, the amount of Zn accumulated by *Macoma* represents only about 0.1% of the total Zn found in freshly collected animals. These findings make two facts apparent. First, no other means of analysis would ever detect uptake of Zn at this very low level; and secondly, a short depuration reduces tissue levels to approximately the same activity associated with shell material. These findings agree with our 1977 report, which indicates that trace metals are probably not available from sediments, even in the presence of oil.

We feel that the question of trace metals availability from oil-impacted sediment is fairly well answered. However, we plan one final experiment using

Table 10. Uptake of Specific Radio-Labeled Trace Metals from Detritus by *Macoma*. Values are counts per 1000 minutes per gram detritus or tissue and per 200 ml seawater.

	Isotopes			
	^{152}Eu	^{60}Co	^{46}Sc	^{65}Zn
Detritus (after 7 days)				
With oil	25,984	13,456	14,528	1,216
Without oil	17,038	17,038	9,656	913
Seawater (200 ml)				
Filtered on Day 7				
With oil	0	131	1	41
Without oil	14	173	7	28
Filter				
With oil	6	1	9	7
Without oil	8	6	5	<1
7-day *Macoma*				
With oil				
On detritus	101	70	55	16
Above detritus	10	13	4	7
Without oil				
On detritus	81	65	48	13
Above detritus	7	11	4	8
2-day Depuration (on detritus)				
With oil	15	19	8	7
Without oil	23	26	10	13
Shell only				
7-day Exposed <u>on</u> detritus				
With oil	39	24	22	7
Without oil	50	28	23	8
7-day Exposed <u>above</u> detritus				
With oil	16	9	8	5
Without oil	13	9	7	4
2-day Depurated (on detritus)				
With oil	37	22	20	7
Without oil	10	10	10	4

detritus containing a larger number of isotopes and higher specific activity. The results of this last study, if in agreement with earlier findings, should provide ample information for evaluating trace metal transfer from oiled substrates.

CONDITION INDEX AND FREE AMINO ACIDS OF *MACOMA INQUINATA* EXPOSED TO OIL-CONTAMINATED SEDIMENTS

Our study has shown that both condition index and certain free amino acids in *Macoma inquinata* were significantly altered by exposure to oil-contaminated sediments (Tables 11 and 12). Adequate sample size was an important factor in demonstrating statistically significant reductions in condition (Table 11). The reduction in condition index in exposed clams, although small (~10%), provided evidence of a deterioration in nutritional state. A decrease in bivalve condition index is an indication that affected clams may have been in a state of negative-energy balance; in other words, metabolized energy exceeded energy consumed as food. Utilization of endogenous storage products such as tissue protein, lipid, and carbohydrates may have been necessary to provide the balance of the energy for metabolism under such conditions (Gabbott, 1976). Condition index of oysters and mussels have been closely correlated with tissue glycogen content (Walne, 1970; Gabbott and Stephenson, 1974; Gabbott and Bayne, 1973).

Using the criteria proposed by de Wilde (1975) for *Macoma balthica*, a value of >10 represents good condition, ~8 moderate, and <6 poor. If these criteria are applicable to *M. inquinata*, the clams in this study possessed mean values for condition index which ranged from good to moderate. Condition in bivalves is known to undergo seasonal variations which are reflective of reproductive and nutritional state (Walne, 1970; Trevallion, 1971; de Wilde, 1975). Periodic sampling of clams from our collection site during the course

Table 11. Condition index of *Macoma inquinata* exposed to oil-contaminated sediment in the second experiment. Exposure was conducted in the field only. (From Roesijadi and Anderson, 1978).

Treatment	Sample size (n)	Condition index
Control	91	8.92 ± 0.18 (S.E.)***
Exposed	50	7.46 ± 0.28

*** Significant at $p<0.001$; Student's _t_ test of this study indicated that condition index of our experimental clams, especially those used in field exposures, were out of phase with the natural population. In general, clams in this study possessed lower condition index than those collected freshly at the times of experiment termination (13.79 ± 1.63 and 17.01 ± 0.78 for experiments 1 and 2, respectively). Thus, experimental manipulation also was a factor which influenced condition index of clams in this study. The effect of oil-exposure on condition was, therefore, either additive or synergistic with general experimental conditions.

Since arginine, lysine and threonine are considered to be essential amino acids (Mahler and Cordes, 1971), decreases in these substances in oil-exposed clams were also suggestive of alterations in nutritive state. Increased utilization of these amino acids, possibly in protein sythesis, by oil-exposed clams or a decrease in their ingestion with food may have accounted for our observations. The large decrease in glycine content in our oil-exposed clams was consistent with previous studies which examined free amino acid levels in marine animals subjected to pollutant or natural stresses (Jeffries, 1972; Roesijadi *et al.*, 1976; Bayne *et al.*, 1976). As a consequence of the decrease in glycine, the taurine:glycine ratio was elevated in oil-exposed clams (Table 12). The actual values of 0.54 ± 0.06 (S.E.) for control clams and 0.89 ± 0.19 (S.E.) for exposed clams in this study were not directly comparable to those reported by Jeffries (1972) or Bayne *et al.* (1976) since taurine levels in *Macoma inquinata* were much lower than those in the bivalves *Mercenaria mercenaria* and *Mytilus edulis* used in the other studies. Although taurine:glycine ratios may prove useful in identifying bivalves which have experienced stressful environmental conditions, it is evident that the cause of the change in the ratios is due primarily to alterations in glycine content. This pattern has been consistent in the studies conducted to date. Examination of glycine metabolism would certainly be useful in understanding this apparent stress response.

Table 12. Free amino acid content of *Macoma inquinata* exposed to oil-contaminated sediment in the second experiment. Conducted in the field only. (From Roesijadi and Anderson, 1978).

	Concentration (μ moles/g)		
Amino acid	Control	Exposed	
Alanine	22.53 ± 1.82 (S.E.)	16.80 ± 2.02 (S.E.)	
Arginine	6.89 ± 0.40	4.56 ± 0.73	*
Aspartate	1.44 ± 0.17	0.90 ± 0.27	
Glutamate	2.72 ± 0.22	2.21 ± 0.19	
Glycine	70.25 ± 4.51	43.56 ± 4.99	**
Histidine	0.28 ± 0.03	0.22 ± 0.04	
Isoleucine	0.37 ± 0.02	0.32 ± 0.04	
Leucine	0.63 ± 0.05	0.48 ± 0.05	
Lysine	0.59 ± 0.04	0.41 ± 0.04	**
Methionine	0.20 ± 0.03	0.13 ± 0.02	
Phenylalanine	0.22 ± 0.02	0.19 ± 0.02	
Proline	0.57 ± 0.04	0.74 ± 0.25	
Serine	4.09 ± 0.41	3.24 ± 0.39	
Threonine	1.16 ± 0.05	0.87 ± 0.07	**
Tyrosine	0.37 ± 0.03	0.33 ± 0.03	
Valine	0.54 ± 0.04	0.44 ± 0.16	
Taurine	37.06 ± 1.94	35.08 ± 2.39	
Total	150.57 ± 8.15	110.48 ± 8.24	**
Taurine:Glycine	0.54 ± 0.04	0.89 ± 0.12	*

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* Significant at $p<0.02$, Student's *t* test

** Significant at $p<0.01$, Student's *t* test

CONCLUSIONS

There appears to be a tissue accumulation pattern associated with the molecular weight of the petroleum hydrocarbon, which is probably dependent on relative partitioning coefficients. From other studies it seems that tissue retention times, while animals are in clean water, increase with the size of the hydrocarbon, and the number of side chains (alkylation). In other words, depuration time increases in the approximate order of: naphthalene, > methylnaphthalenes > dimethylnaphthalenes > phenanthrene > methyl- and dimethylphenanthrenes > chrysene > benzo(a)pyrene. No single study with one organism and one type of system has been conducted to produce these data, but the basic pattern appears to exist.

We must assume that tissue retention time for a given compound is independent of the route by which an organism received the contamination. There is some evidence that hydrocarbons entering via food may be retained longer, but there is no reason to believe that there are differences associated with water, interstitial water and sediment routes. Therefore, once the hydrocarbons reach the tissue the rates of release (by various means) should be dependent upon relative solubilities in tissue lipids vs. tissue water (and subsequently surrounding water). The rapid uptake and short-term retention of naphthalenes we have observed in these and earlier studies are probably explained by uptake from water. In a relatively short time,sediments give up (release) naphthalenes to the interstitial water and this compartment eventually exchanges with the overlying water column. If we assume that this is also the sequence of events for higher molecular weight compounds, then the majority of our findings may be explained by differences in the rates of equilibration between sediment-sorbed and water-born hydrocarbons. This line of thought leads to the conclusion that all uptake observed was via the water (including interstitial water), and ingestion of contaminated particles does not result in significant tissue contamination. This hypothesis would appear to be strengthened by the data on trace metals. These substances were not accumulated by the two test species, even though sediments contaminated with oil were ingested. Either the metals were bound tightly to the particles or there was merely an exchange taking place which resulted in no net uptake.

Our most recent research with the burrowing polychaete, *Abarenicola*, produced results which indicate that uptake from ingested mud does occur. Those animals which fed on oiled substrate in the early stages of exposure did not survive,and the one digestive tract which was analyzed exhibited higher accumulation than the body wall. Since the concentration of ^{14}C-activity in interstitial water was about two orders of magnitude less than the mud,it is difficult to explain the mortality and uptake merely on a basis of the interstitial water. It will be easier to assess the significance of the various routes of uptake when our analyses include a separation of parent hydrocarbons and metabolites. It is possible that a portion of the activity observed in the gut was metabolic products, since polychaetes possess higher levels of detoxification enzymes in their gut than other tissues.

During both laboratory and field exposures of *Macoma* to oiled sediment, the condition index of the organisms decreased to a greater extent than occurred in clean substrate. When the sample size was large enough to overcome individual variability, both condition index and free amino acid content of *Macoma* was shown to be affected by oil contamination. Experimental manipulation alone reduced conditon index below that of freshly collected animals, which indicates that a better knowledge of site and seasonal variability must be gained and experimental design should be improved. These parameters, which reflect the energy balance of the species, have been shown to be valid and sensitive measurements for the study of pollutant effects.

The results of various aspects of our research under NOAA/BLM funding through the OCSEAP program have been submitted and accepted for publication by three different publishers (Roesijadi, Woodruff and Anderson, 1978; Roesijadi, Anderson and Blaylock, 1978; Roesijadi and Anderson, 1978). The full references for these manuscripts are listed in the literature cited section and copies of the papers are on file at the OCSEAP offices of Juneau, Alaska and Boulder, Colorado.

The application of information obtained in these studies would appear to be relatively straightforward. It is important to understand the interactions between oil, sediments and benthic organisms, once petroleum has reached the substrate. Present evidence indicates that hydrocarbons bound to sediment particles are not directly available to deposit/detritus-feeding organisms. Leaching from sediment would appear to be controlled by the water solubility of the specific compound, physical-chemical factors in the environment, and microbial activity. The physical energy of the environment would control release rates,and the dilution volume available when release occurs will control the extent of uptake by benthic organisms. Even when tissue uptake is relatively low the condition of organisms may be reduced, probably from decreased feeding on contaminated substrate. The recovery of a single generation in oiled substrate or the recovery of a specific benthic habitat would also be controlled by the physical-chemical and microbiological factors in that environment. Not all of those assumptions are sufficiently validated by scientific investigations, but if future studies are designed to fill the information gaps, we will be in a position to predict the fate and effects of petroleum hydrocarbons in marine sediments.

RECOMMENDATIONS AND FUTURE DIRECTION

There is a need to continue sediment studies to test the hypotheses proposed above regarding the factors controlling sediment recovery after oiling. While generating these data, we can also determine the effects of sediment-sorbed hydrocarbons on infaunal species and the rates and routes of hydrocarbon uptake. Field experiments should be designed to answer a number of questions simultaneously, thus saving time and money. With careful planning, coordination and separate funding,a large field experiment in the Alaskan environment could be conducted, using the combined expertise of many OCSEAP investigators to describe the physical, chemical, microbiological and biological parameters associated with the presence of oil on sediments. Such field experiments could either be centered around an application of oil on the interdial zone or a spill in the nearshore environment.

Variability between types of marine sediments and species of benthic organisms are such that additional data are required to determine the extent of these differences and the controlling factors. We intend to look more closely at fine (mud) sediments and to utilize a deposit feeding polychaete in these studies. It is likely that hydrocarbons will be retained longer in this system, and that we will be able to separate hydrocarbon inputs via sediment from those in the interstitial water. Condition index and free amino acids appear to be good indicators of effects on bivalves, but only the latter can be used on soft body animals and it may not be useful. While toxicity from water exposure may be linked to tissue accumulation, effects of oiled substrate may be primarily related to reduced feeding on contaminated detritus and/or sediment. Since highly contaminated substrates are often non-toxic to benthic species in the short-term, we may need to determine the levels of sediment contamination that interfere with normal energy intake over the long-term. While trace metals were not accumulated in our experiments, we will utilize neutron-activated detritus once more to study exchange rates for metals and to look more closely for uptake.

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ANNUAL REPORT

Research Unit No.: 467
Contract No.: 03-6-022-35193
Reporting Period: 1 April 1977-31 March 1978
Number of Pages: 318

BEAUFORT SEA BARRIER ISLAND-LAGOON ECOLOGICAL PROCESS STUDIES

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31 March 1978

This Annual Report of the Beaufort Sea Barrier Island-Lagoon Ecological Process Studies is an interim presentation of research. The reports of program research and the synthesis and interpretation of results are therefore incomplete. Detailed presentations of such aspects of the program as the use of modeling and interpretive comparisons of the system under study with similar systems in other areas are lacking; they will be more fully treated in subsequent reports.

Research efforts in oceanography, geomorphology, sedimentology, and primary production and nutrient dynamics are not reported herein except as integral parts of the Overview and Synthesis section. Although research units in these disciplines are associated with the Barrier Island-Lagoon Program, they are contracted separately to NOAA/OCSEAP and the research is reported in detail elsewhere according to the requirements of each of their Research Units.

BEAUFORT SEA BARRIER ISLAND-LAGOON
ECOLOGICAL PROCESS STUDIES

Section I

OVERVIEW AND SYNTHESIS

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31 March 1978

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ACKNOWLEDGEMENTS

This annual report is the first opportunity to thank the many people who have provided ideas, support, labor, and enthusiasm. Any project of this size, carried out over a two-year period, requires a series of supportive services that are individually only a part of the effort, but as a group determine success or failure. We apologize to any individuals we have forgotten from the following list of contributors.

BLM: Nancy Maynard, Gary Hufford, Edward Hoffman

NOAA: Roy Overstreet, Doug Wolfe, Rudy Engelmann, Wanda Power, Jane Ludka, Merle Gibson, Dean Dale.

Arctic Project Office, Fairbanks: Toni Johnson, Ted Flesher.

Naval Arctic Research Laboratory, Pt. Barrow: Dan Brooks, Terry Hall.

Oliktok DEW Station: Ken Jenkins.

LGL Limited, Edmonton: Vicky Aziz, Wayne Bennett, Tim Byers, Rick Barss, Eric Tull, Alan Birdsall, Jeff Green, Phil Lulman, Lori Burke, Bill Koski, Bill Fricker.

LGL Limited, Toronto: Helen Stallard, Dennis Thompson, Aaron Sekerak, Michael Bradstreet.

LGL Limited-U.S., Inc.: Benny Gallaway, Pam Snodgrass, Randall Howard.

University of Washington: Roger Anderson, Frank Carsey, Tom Kozo.

University of Alaska: George Mueller, Ken Coyle, Stuart Rawlinson, Mike Sweeney, Brian Matthews, Sathy Naidu, Doug Schamel, Jan Cannon, George West.

Texas A and M University: Chris Mungall.

McGill University: Max Dunbar, Grant Ingram.

Canadian Wildlife Service: John Kelsall.

Northern Alberta Institute of Technology: Don Pattie, Trudy Dyck.

During the modeling workshops, Carl Walters, Ray Hilborn, Sandy Buckingham, Randall Peterman, Mike Staley and others at the Institute of Animal Resource Ecology, University of British Columbia, have provided unique insights that have influenced the direction and integration of the project.

Jim Helmericks of Colville Station provided excellent aircraft support and hospitality.

A number of LGL employees have made essential contributions to the project. Gary Searing, Lew Haldorson and John Richardson contributed to the research design and participated in the field program. John Richardson applied his unique talents to editing the report. Scotty Roxburgh and Geoff Clarke were an important part of the field crew. Tom Wetmore participated in the field and carried out the data analyses and management. Rob Dillinger was responsible for invertebrate sample analyses and contributed many ideas. Maya Spies provided logistic support from LGL's Fairbanks office and helped in many aspects of report production. Rick Dressler prepared the figures for the report. We reserve special thanks for Jean Erwin, who coordinated report production and typed much of the report. She was assisted by Gail Wylie. Both Jean and Gail worked efficiently for extremely long periods during preparation of this report.

Finally, we would like to thank Herb Curl, Gunter Weller and Dave Norton. This research has benefited in a variety of tangible and intangible ways from their direction and support.

PREFACE

In response to recent increasing national needs for energy, moves have been made to accelerate the exploration of the U.S. Outer Continental Shelf (OCS) lands for oil and gas development. The Bureau of Land Management (BLM) of the Department of the Interior, under authority of the Outer Continental Shelf Lands Act of 1953, is responsible for leasing areas of the Continental Shelf for mineral development, and for regulating that development. The National Environmental Policy Act of 1969 (NEPA) requires an assessment of development impact for all proposed federal projects whose implementation would potentially alter the quality of the human environment. To fulfill NEPA requirements, BLM arranged for the National Oceanic and Atmospheric Administration (NOAA) to evaluate the impact of planned OCS development.

As a direct outgrowth of NEPA's mandate and BLM's needs, NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP) created an assessment plan for the Alaskan continental shelf. Environmental investigations funded under this plan normally have addressed one or more of the following areas of study:

1. Contaminant Baselines--a determination of the pre-development distribution and concentration of potential contaminants that are commonly associated with oil and gas development,
2. Sources--a determination of the nature and magnitude of the contaminant inputs and the environmental disturbances that may be assumed to accompany exploration and development on the Alaskan continental shelf,
3. Transport--a determination of the ways in which contaminant discharges move through the environment, and the manners in which they are altered by physical, chemical and biological processes,
4. Reconnaissance--a determination and characterization of the biological populations and ecological systems that are subject to impact from petroleum exploration and developments,
5. Effects--a determination of the effects of hydrocarbon and trace element contaminants on individuals, populations and ecological systems, and

6. Hazards--the identification and estimation of the potential hazards to petroleum exploration and development that are posed by the environment.

In addition to the above types of studies, OCSEAP's research planners have recently proposed a "process study" approach, containing elements of both (4) and (5) above, to provide a more effective assessment of the impacts associated with petroleum exploration and development. This type of study was designed to investigate the physical and biological processes that importantly regulate the structure and function of nearshore ecosystems and, in turn,to determine how potential oil and gas development activities might interfere with these processes. Processes, broadly defined as the patterns of change that are governed by natural laws and that recur in time and space, are exemplified by such phenomena as water circulation, land form erosion, sediment transport, and migration and feeding activities of fish and birds. The following requirements for the design and implementation of an ecological process study were established:

1. The research approaches must be interdisciplinary.
2. The research programs must be mission-oriented and must deal with specific potential impacts of OCS development. Particular attention should be given to effects that are potentially irreversible.
3. The studies should focus on ecosystem processes that are sensitive to impact and that contribute to the welfare of important organisms.
4. Frequent meetings between the principal investigators and the OCSEAP planners and a strict schedule for the flow of information must be made an integral part of the program.
5. The program results must be presented in a way that can be readily assimilated and utilized by BLM decision-makers.

The Beaufort Sea Barrier Island-Lagoon study, which is described herein, is such an ecological process study that is being conducted as part of OCSEAP in the Beaufort Sea coastal zone.

SUMMARY OF RESEARCH AND ITS IMPLICATIONS

This study of a coastal area of the Beaufort Sea in Alaska analyzes the critical system processes (patterns of change) to provide information that can be used to assess the impacts of activities related to petroleum development. The primary objective of the program is to improve the understanding of natural processes that support organisms considered important to society and that are sensitive to the effects of human activities. A secondary objective is to develop procedures whereby the effects of development activities on these processes can be evaluated.

Program management and planning were the responsibility of LGL Limited-U.S., Inc.; a major emphasis of this management and planning has been on interdisciplinary coordination. Periodic workshops that emphasized systems simulation modeling as an integrative procedure have provided the basic communication and planning framework.

The design of the research programs was unique in the following aspects:

1. Within the context of the contractual obligations, biologists established the research objectives of all the disciplines.
2. Research was concentrated on those ecosystem processes that (a) supported organisms identified to be of special interest to society, and (b) were judged to be directly vulnerable to the impact of projected development activities.

The Simpson Lagoon-Jones Islands area was selected as the study site because (1) it was a reasonably typical island-lagoon system of the Beaufort Sea coast, (2) prior human disturbance to the area was relatively limited, (3) it was reasonably accessible, and (4) some baseline data for the area were available. The area is a shallow lagoon bounded by barrier islands. Many of the islands are composed solely of sand and gravel; the larger ones, however, are covered by tundra. The area is extensively used during the summer by several important species of birds and fish.

The research conducted in 1977 in the disciplines of geology, oceanography, and ecology has provided many important new findings relevant to the assessment of impacts of OCS petroleum development. The key results are summarized as follows:

1. Nearshore currents, which are predominantly generated by wind, flow parallel to the coast at about 3% of the wind speed.
2. Approximately one-fifth of the volume of Simpson Lagoon is replaced each day under normal wind conditions; if strong winds prevail, however, the lagoon may flush as rapidly as once per day.
3. Lagoon waters in summer are usually warmer and less saline than the adjacent marine waters; lagoon salinities and temperatures are highly variable both temporally and spatially (except that vertical differences are small). Natural or artificial landforms that bound the lagoon (e.g., the ARCO causeway) have considerable local effects on water temperatures and salinities.
4. Most or all of the barrier islands appear to be relict mainland features whose large-grained materials (gravels) are not replaceable by presently-occurring processes. The expected lifetimes of tundra covers on the larger islands (under present erosive forces) are a few hundred years or less; the islands will exist as sand-gravel barriers for a longer time. Lagoon substrates are continually being replenished by sands and silts supplied from elsewhere.
5. As a result of normal coastal retreat and lake-bed subsidence (which leads to the coalescing of coastal lakes), it is expected that new lagoon systems will be created (perhaps in a matter of a few centuries) from the mainland adjacent to the present lagoon.
6. The amounts of organic detritus input into the Simpson Lagoon area from coastal erosion and from river discharges are probably of the same order of magnitude.
7. Observations by divers showed that the biomass of epibenthic organisms (the primary food source of birds and fish) in the lagoon was about two to three orders of magnitude greater than had previously been estimated (based on conventional sampling techniques) for Beaufort Sea lagoon systems.
8. The epibenthic organisms that are preferred as food by fish and birds were very much more abundant than the daily consumptive needs of these vertebrate predators.
9. Circumstantial evidence suggested that the shallow nearshore waters are annually repopulated by an immigration of epibenthic organisms from deeper nearshore areas.
10. Epibenthic organisms concentrated in and on the organic detritus that blanketed the lagoon bottom. It is suspected that this detritus, most of which appears to be terrestrially-derived, may provide a major energy source to these invertebrates.

11. The abundant species of anadromous fish--arctic cisco, arctic char and least cisco--concentrated in shallow lagoon areas (and less commonly in marine areas) that were very near the shorelines; the tendency for abundant marine species--fourhorn sculpin and arctic cod--to concentrate in these areas was less evident.
12. The diets of the important fish species were primarily epibenthic invertebrates (amphipods and mysids); they were similar to the diets of the same fish species in other nearshore areas of the Beaufort Sea, and very similar to the diet of the oldsquaw--the major bird consumer in Simpson Lagoon.
13. Fish populations do not appear to be limited by natural factors in nearshore Beaufort Sea waters during summer.
14. The greatest use of the lagoon system by birds occurred in August and September. At this time the area was heavily used by migrating and molting seaducks (primarily oldsquaws), by staging shorebirds (primarily phalaropes), and by transient populations of gulls and terns. Spring migrants made little use of the lagoon system.
15. For all bird species except the traditional island nesters, nesting densities on the barrier islands were lower than occur in similar mainland habitats. Predation by arctic foxes caused most bird nests on the islands during 1977 to fail.
16. Birds ate mostly aquatic invertebrates--amphipods, mysids, copepods and isopods. The dominant consumer, the oldsquaw, ate virtually the same foods as did most fish.
17. Patterns of bird use of the nearshore region varied among species and seasons; certain bird species were highly concentrated in specific habitats, such as along island beaches or on gravel portions of islands.

The implications of these research findings to petroleum development in the nearshore zone include the following:

1. Nearshore currents and water quality parameters (salinity, temperature, etc.) will probably be modified (at least locally) by major changes in the landforms that bound the system. Whether the birds and fish will ultimately be affected by such changes is not yet known.
2. Coarse-grained materials (gravel) removed from barrier islands and nearshore waters will probably not be replaced by natural processes; fine-grained materials (sand and silt) will probably be replaced by sediment transport. The extent to which alterations of existing landforms (e.g., islands) will have permanent adverse effects on the living organisms is not yet clear.

3. Shoreline stabilization practices that reduce the organic detritus input into nearshore waters could conceivably affect the fish and birds by reducing the availability of an important energy source. This hypothesis has yet to be tested.
4. Introduction of contaminants (e.g., oil) into nearshore systems could directly affect birds (and perhaps fish), or could indirectly affect both birds and fish by affecting the epibenthic invertebrates--their primary food source.
5. Because the supply of epibenthic organisms appears to be large relative to the food requirements of the birds and fish that feed on them, moderate reductions in the food source as a result of development may have little affect on the fish and birds.
6. Because both fish and epibenthos migrate into and within the nearshore zone, construction of barriers such as causeways should take account of the requirements of these organisms for passageways. Little is currently known about the migration pathways of epibenthic organisms, and almost nothing is known about the responses of epibenthos or fish to a blockage of their normal corridors of movement.
7. Development activities in and near islands and lagoon systems should proceed with the knowledge that birds, which are more or less susceptible to various types of disturbances, utilize the islands, shorelines and lagoons most extensively from mid-summer to early fall. The sensitivities of birds to specific activities are determined by the habitat requirements and behavioral responses of each species. Potential indirect effects of development, such as the likelihood that arctic foxes would concentrate on islands, should also be considered.

INTRODUCTION

Early in 1976, the NOAA-OCSEAP Research Planning Committee sent selected research organizations a request for a proposal to develop an interdisciplinary ecological process study in a coastal area of the Alaskan Beaufort Sea. The study was to be conducted in two distinct stages: an in-depth information review and research planning stage, which would be followed by an active research program to collect and integrate the existing data and to conduct new field research. In May 1976 a contract was awarded to LGL Limited-U.S., Inc. to develop a research plan (Phase I), and subsequently to conduct the planned research (Phase II).

General Nature and Scope of Study

This program was designed to be a closely-integrated research investigation of the physical and biological processes in a barrier island-lagoon system on the Alaskan Beaufort coast. The program was to identify the processes that are sensitive to impacts and important to those ecosystem components (organisms) that are of particular concern to society; these processes were to be studied as a means of assessing the impacts of development upon these components. A significant factor that affected the research program was the need to extrapolate the approach and findings of the study to assist in the assessment of impacts in other OCS areas.

At the outset NOAA-OCSEAP identified the general types of processes in the barrier island-lagoon environment that they viewed as important in the context of the objectives of the program, and that they therefore required to be studied. These were processes that related to (1) the biology of the system, (2) the oceanography and nearshore circulation, and (3) the dynamics of the coastal land-form features (geology). The disciplinary limits of the program were thereby established, and this permitted the subsequent selection of qualified specialists as principal investigators to design and implement the appropriate studies. Subsequently during the course of research planning, specific processes which were to be studied within each discipline were identified (see Research Design, page 8).

Objectives and Rationale

Because this program was, in essence, an experimental undertaking, an implied objective of the program was to test the viability of the process analysis approach to impact assessment. Three specific research objectives of the program were stated by NOAA; these objectives and an amplification of each are as follows:

1. *To identify and analyze those components and processes that contribute significantly to the structure and productivity of the nearshore ecosystem.*

   It would be impossible to study all of the components and processes that occur in the barrier island-lagoon ecosystem. The scope of this objective was accordingly narrowed during the course of the research planning to include only the identification and analysis of those systems processes (and their associated components) that were essential to the life-support of the species that had been identified as "important" and that were likely to be altered as a consequence of development. "Important" species were defined to be those birds, fish and/or mammals that were a significant constituent of the fauna of the area to be studied and that (1) had significant commercial or recreational value, (2) were important to the subsistence of local residents, and/or (3) were otherwise "high profile" and therefore of major concern to society and to decision-makers. This objective was addressed during the 1976 planning program and the 1977 field and analysis programs; modifications to the list of important components and processes were made as a consequence of findings made during the 1977 programs.

2. *To evolve mechanisms whereby the "important" components and processes can be evaluated for their reaction to man's activities.*

   Most impact assessments have been based on speculation that is tied to established facts. The purpose of this objective is to make this process more accurate. This objective would be addressed by the generation of a series of hypotheses that would be capable of being tested, that would be relevant to impact assessment, that would be cost-effective from the point of view of impact assessment, and that could ultimately lead to more accurate speculation about the consequences of development.

3. *To determine the feasibility of detecting and quantifying the temporal changes in "important" ecosystem components and processes.*

   Testing of hypotheses about reactions of ecosystem components and processes to man's activities usually requires quantification of change. Changes in values or levels of ecosystem components or in the rates at which processes occur are normal, even in the absence of man's influence. Changes caused by human activities thus are often difficult to separate from normal temporal variations. In order to determine whether a specific component or process can be used to measure impact, it is essential to determine the feasibility of measuring changes in the component or process with sufficient precision to quantify both the normal range of variability and the perturbations of such normal variability that are caused by man. Aspects of this objective addressed to date concern documentation of spatial and temporal variability in components and processes so far identified as "important", and development of effective measurement procedures.

Relevance to Impact Assessment

System processes differ from population parameters in two ways that relate to impact analysis; each of these ways offers an advantage over conventional methods of impact assessment (i.e., assessment via baseline studies and population monitoring):

1. Man's activities usually assert themselves as impacts through alteration of support processes rather than through direct obliteration of segments of populations. A characterization of process rates and mechanisms, rather than a compilation of baseline data, will therefore enable scientists to speculate more effectively about the manner in which development may alter populations.
2. We suggest that the characteristics of processes are temporally and spatially more conservative than are baseline population parameters. As a result of this relative constancy the process information is more broadly applicable than is baseline survey data, and may consequently be more freely extrapolated to questions concerning development impacts in other areas. Environmental data collected at other times and places can also be used more effectively in a process analysis context, thereby ensuring the maximum use of existing data.

PROGRAM MANAGEMENT AND PLANNING

The Barrier Island-Lagoon Program is under the general management of LGL Limited-U.S., Inc. (LGL), which, in conjunction with its Canadian affiliate (LGL Limited), has been responsible for the course and direction of the program since the award of the initial contract. As a first step in responding to the contractual requirement of detailed program planning, LGL developed the program framework and identified the general research needs.

Principal investigators for the various research fields that had been identified were selected from the staff of LGL and, on the basis of proposals submitted, from various universities. With one exception, investigators with university affiliations came into the program under separate contracts with NOAA-OCSEAP (Table 1); their annual reports are submitted separately according to the terms of their respective contracts. Dr. C.J. Walters *et al.* were under subcontract with LGL. Despite the contractual segregation among disciplines, the research data were shared among investigators, and this report is an overview and synthesis of all research.

Chronology

Although the planning and research phases of the program have been contracted separately, the two emerged as one continuing effort. A discussion of the sequence of program events (Table 2) follows.

In June 1976 an initial background document was prepared[1]; it outlined the proposed program within the context of a brief regional environmental description based on existing literature. This document was submitted to NOAA-OCSEAP and to other selected scientists for their information and review. In late July a meeting was convened in Edmonton,

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[1] Reports submitted as part of this program are listed in Appendix I.

Table 1. OCSEAP Research Unit Numbers, Disciplines and Affiliations of Principal Investigators Participating in the Barrier Island-Lagoon Program in 1977.

Principal Investigators	Ru No.	Discipline	Affiliation
J.C. Truett	467	Project Director	LGL Limited
S.R. Johnson	467	Ecology (Birds)	LGL Limited
P.C. Craig	467	Ecology (Fish)	LGL Limited
W.B. Griffiths	467	Ecology (Invertebrates)	LGL Limited
C.J. Walters *et al.*	467	Systems Modeling	Univ. of Br. Col.
J.B. Matthews	526	Oceanography	Univ. of Alaska
J.C.H. Mungall	531	Oceanography	Texas A & M Univ.
P.J. Cannon/S. Rawlinson	530	Geology	Univ. of Alaska
A.S. Naidu/M. Sweeney	529	Geology	Univ. of Alaska
D.M. Schell*	527	Nutrient Dynamics/ Primary Production	Univ. of Alaska

*Schell's research effort did not become a part of this program until late in 1977; research performed is correspondingly preliminary.

Table 2. Sequence of Research Activities, Information Product Submissions, and Meetings, Barrier Island-Lagoon Program, June 1976-April 1978.

Year	Month	Activity	Data Product or Meeting
1976	June	Background Document Preparation	
	July		Background document[1] Planning workshop[3]
	August	First Draft Research Plan; Preparation and Review	
	September		Draft Research Plan[1]
	October	Second Draft Research Plan	Research Plan[1]
	November		Modelling and Integration Workshop[3]
	December		
1977	January	Detailed Preparation for Field Research	Report of First Modelling Workshop (1-3 December 1976) and Revised Research Plan[1]
	February		
	March		
	April		Modelling and Integration Workshop[3]
	May	Field Research	
	June		
	July		Quarterly Progress Report[2]
	August		
	September	Data Analysis, Annual Report Preparation	Post-field Season Seminar[3]
	October		Seminar Report[2]
	November		Quarterly Progress Report[1]
	December		Modelling and Integration Workshop[3]
1978	January		Quarterly Progress Report[2]
	February		Report of Modelling Workshop[2]
	March		
	April		Annual Report[2]

[1] Report submitted to NOAA/OCSEAP, Boulder, Co.

[2] Report submitted to Arctic Project Office, Fairbanks, Alaska.

[3] Workshop or seminar.

Alberta, for a discussion of the incipient research plan. Attending were representatives from OCSEAP and from LGL, consulting scientists who had reviewed the above background document, and a systems modeler from the University of British Columbia. Following this preliminary planning workshop, and partially in response to ideas that were generated therein, a draft research plan was submitted to NOAA on 8 September 1976. The draft plan was followed on 12 October by a second draft that had been revised in response to comments from OCSEAP.

A first modeling and integration workshop was held on 2-4 December 1976 to assemble the principal investigators who had been identified prior to that time and to create a preliminary systems model on which to structure the forthcoming research program. As a result of that workshop and the associated modeling exercise, the research plan was further revised and was submitted to OCSEAP on 17 January 1977. Preparations were then begun for the 1977 field season. Final research plans were completed during the course of a second modeling and integration workshop in April 1977.

Field research commenced in early May 1977 and extended to late September. A seminar was held at the OCS Project Office in Fairbanks on 12 September near the end of the 1977 field research effort. Following a preliminary analysis of the season's research data, a third modeling and integration workshop was held on 6-8 December to revise the existing model using 1977 field research data, and to begin coordinated planning for 1978 research. Efforts since the third workshop have been directed to a detailed analysis of the field research data, the production of this annual report, and, to a lesser extent, the planning of the 1978 field research program.

Workshops

Workshops have served as focal points for continued research planning. The workshops have functioned specifically to accomplish the following:

1. the promotion of general communication among principal investigators, project managers, and NOAA and BLM planners and administrators,
2. the provision of a mechanism for critical examination and revision of research task priorities,
3. the preparation and refinement of the computer simulation of systems processes, and
4. the assembling of principal investigators to plan an integrated field research effort.

Workshops were held at the University of British Columbia in Vancouver, B.C., in December 1976, April 1977 and December 1977. The December workshops emphasized the preparation and updating of the simulation model (see Modeling section to follow) and served to increase the general understanding of the research program and the system under study. Emphasis in the April workshop was on continued general communication, on a re-examination of research priorities in light of the most recently available information and on the planning of research activities for the coming field season.

Research Design

Throughout the program, biologists have assumed the responsibility for establishing the general objectives of all disciplines (Fig. 1). The physical disciplines functioned as internal service groups, and their research was designed to provide information that was needed by the biologists.

Detailed interdisciplinary research planning is essential for a program such as the present one, where biological organisms, which are heavily dependent upon physical processes, are the ultimate focus of interest. The identification of processes and interdisciplinary data needs occurred largely during the course of the workshops. At these times a cross-reference or matrix system was used to depict the data that each investigator required from the others; Table 3 is a generalized summary of major items in the matrix. As shown in this table, few data were required by the oceanographers or geologists from either the biologists

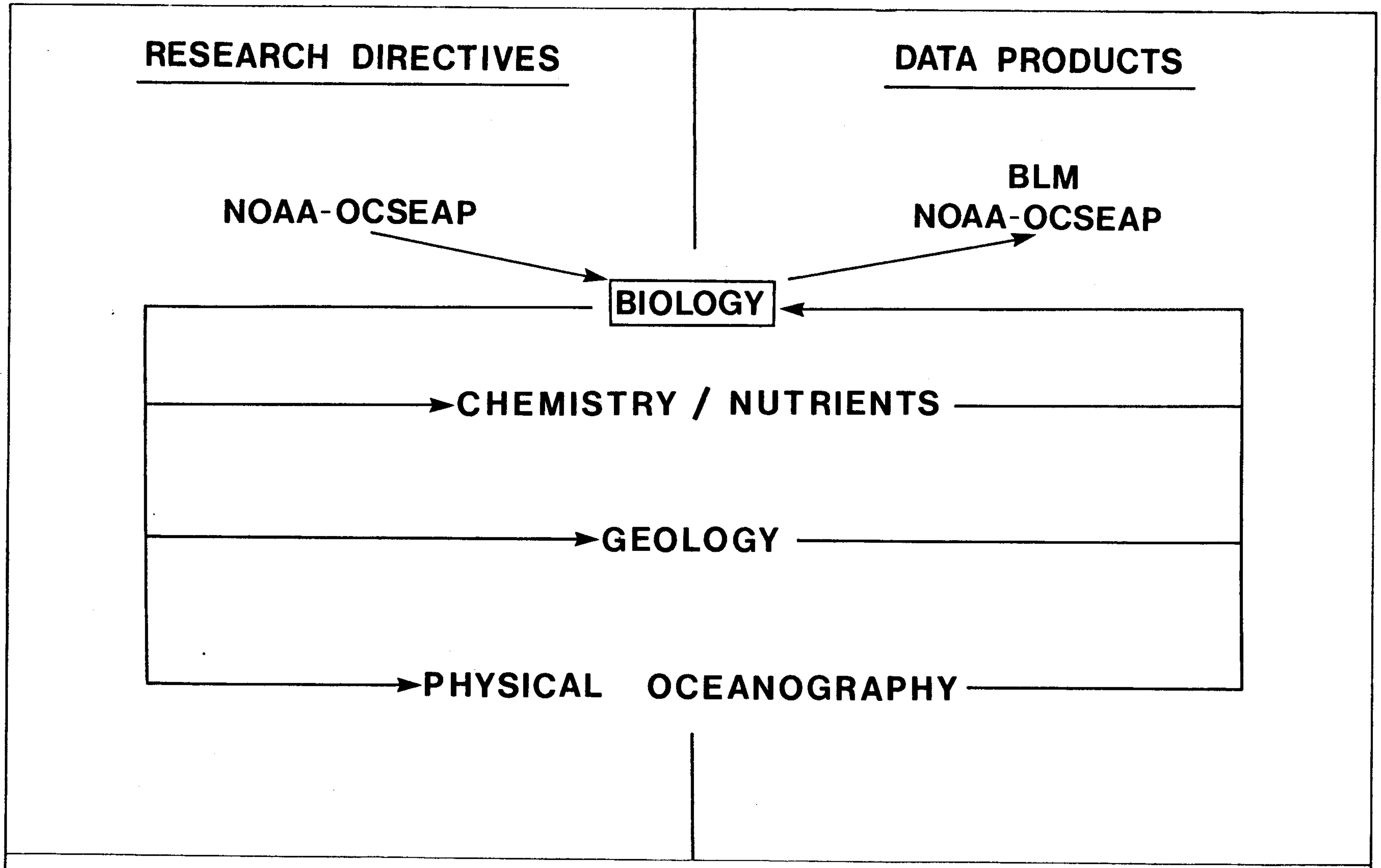

Fig. 1. Information Flow Among Disciplines, Barrier Island-Lagoon Program.

Table 3. Generalized Cross-reference System Used for Identifying Interdisciplinary Information Needs During the Research Planning, Barrier Island-Lagoon Program. (Data to be provided within disciplines are enclosed by dashed lines).

Data to / Data from	Oceanography	Geology	Invertebrate Biology	Fisheries Biology	Ornithology
Oceanography	1. Wind data collection 2. Current measurements 3. Sea level measurements 4. Temperature-salinity measurements		1. Water mass exchange characteristics 2. Temperature-salinity measurements in space and time 3. Current speeds	1. Temperature-salinity measurements in space and time 2. Water mass exchange characteristics	1. Water mass exchange characteristics
Geology		1. Sequential aerial photo interpretation 2. LANDSAT imagery 3. Ground-based measurements and interpretation	1. Organic detritus input 2. Permanence of barrier islands, lagoons	1. Permanence of barrier islands, lagoons	1. Extent of coastal inundation by storm surge 2. Coastal landform dynamics, permanence
Invertebrate Biology			1. Invertebrate samples in space and time 2. Temperature-salinity measurements to accompany samples	1. Invertebrate distribution in space and time 2. Results of fish stomach analysis 3. Invertebrate biomass and turnover rate estimate	1. Invertebrate distribution in space and time 2. Results of bird stomach analysis 3. Invertebrate biomass and turnover rate estimate
Fisheries Biology			1. Fish abundance in space and time 2. Consumption rates of invertebrates by fish	1. Fish samples in time and space 2. Temperature-salinity measurements to accompany samples 3. Fish diet 4. Fish parasites and human harvest 5. Fish tag returns	1. Fish food selectivity and consumption rates
Ornithology			1. Bird abundance in space and time 2. Consumption rates of invertebrates by birds	1. Bird food selectivity and consumption rates	1. Bird survey data re distributional and habitat use 2. Bird movement in space and time

or from each other; most of the interdisciplinary data were required by biologists from physical scientists. The biologists specified the types of physical process information that they required in order to clarify the biological dependencies that they were to investigate. The physical scientists (oceanographers and geologists) then designed or modified their research plans accordingly.

The primary consideration in defining research tasks was to ensure that the research efficiently addressed the ultimate goal of assessing the impacts on designated resource components. A structured approach for establishing research priorities was provided through the following steps, some of which depart appreciably from conventional approaches:

1. System components (organisms) of particular interest to society were identified at an early stage in the program. Research efforts were thereafter directed solely toward clarifying the environmental dependencies of these organisms in light of expected changes that might be caused by development. The "components of interest" were found to be predators, which are situated ecologically near the top of the food chain.
2. Food-chain and habitat dependencies of these predators were evaluated in a step-wise fashion that began with the predators themselves and moved down the food chain, (Fig. 2). Because the method forces investigators to look at only those energy transfers and habitat-use factors that are necessary to the life-support of the "important" organisms, it promotes research efficiency. (Conventional "ecosystem" studies have usually "looked upward" from the presumed energy base in an attempt to trace the food chain lines within an extremely complicated array of energy transfers, few of which directly regulate the vertebrate populations.)
3. Research was designed to address processes likely to be significantly affected by development activities. The most recently-available information on present-day technology was used to delineate those processes.

Modeling

A systems modeling team at the University of British Columbia provided a unique service to the Barrier Island-Lagoon Program. Through use of a computer simulation model of the system, they helped to establish

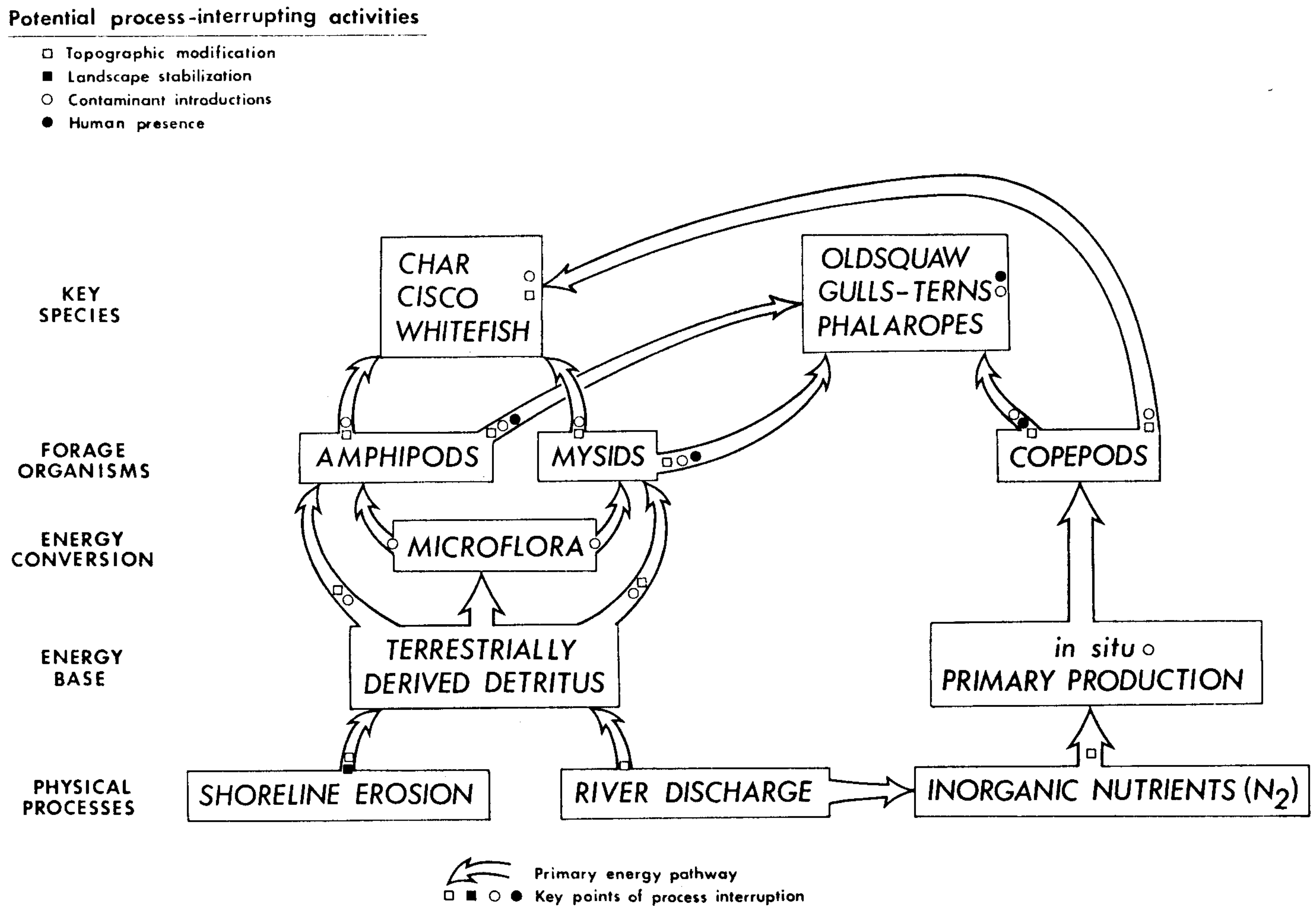

Fig. 2. Known and Suspected Critical Energy Pathways That Support the Key Species in the Area of Simpson Lagoon, Alaska. Places where energy pathways and system components are likely to be affected by OCS development activities are shown.

an interdisciplinary communication format within which research planning (and evaluation of results) were facilitated. The functions of the modeling exercises were as follows:

1. *Construction of the simulation model.*

   The first function of the modeling workshops was to construct a simulation model. To do so, each disciplinary specialist explained to a modeler how the processes within his discipline operated and what information he required from other disciplines in order to predict the operations of processes within his discipline. The modeler then translated the description of these relationships into a series of equations, which formed the simulation model. Important gaps in the understanding of the system were revealed when the "current concepts" of the disciplinary specialists proved to be incomplete. This situation usually occurred when the model of the dynamics of a discipline required input (usually from another discipline) that was not available.

2. *Organization of existing information and assessment of its completeness through operation of the simulation model.*

   Once the modelers had produced a functioning model that approximately simulated the "current concept" of the operations of the system, the existing data were organized and provided to the modelers and actual simulations of the system were run. The initial inability of the model to approximate the real system indicated to the disciplinary specialists and the modelers the presence of additional errors in their "current concept" of the system and pinpointed areas where the existing data were inadequate or inaccurate. On the first run of the model, for example, the lagoon quickly filled in with detritus and sediments. This process, whereby the model is repeatedly used to test the evolving "current concept" of the system, is the primary value of the modeling workshops as a research planning tool.

3. *Provision of a common focus for determination of research priorities.*

   It became evident at the outset that communication among disciplines was difficult because of differences among the scientists in their perceptions of the roles of their research and hence in their opinions concerning research priorities. The matrix (Table 3) and the model forced the investigators to place all of the research needs in a common format that tended to reduce these differences.

4. *Definition of appropriate temporal and spatial limits to research.*

Considerable effort was expended during the first two workshops to define the appropriate time scales for the research and modeling efforts, and to define the limits of the study area. With respect to the time scale, the effort was to determine the maximum time interval between samplings that would result in an acceptably low probability that an important change or event would be missed. Such a determination was necessarily a subjective determination; not surprisingly, different disciplines were found to require different time scales.

It was important to define the study area so that the research could be applied to a system with some integrity. That is, the limits to the study area should be chosen such that, to the extent possible, the area is a logical unit wherein a maximum number of processes occur solely within the system and a minimum number and complexity of input and output phenomena cross the study area boundaries.

5. *Use of the simulation model to design research.*

The sequence of steps followed to design research was similar at each workshop session. Following an initial exercise to precisely define the program goals (problem definition) and to identify the interdisciplinary information requirements, the development of quantitative submodels was begun. Four submodels were created or (at later workshops) refined; each simulated processes within a particular discipline (oceanography, geology, aquatic biology and ornithology). Once the submodels were connected into an overall computer simulation, the simulation was used to explore the sensitivity of the system to changes in the values and functional relationships that were assigned to important processes. If it was found that a small change in a particular variable or relationship resulted in a major impact on the way in which the model functioned, then that variable or process was considered to be of high priority in the research planning effort. Similarly, if it was found that the system did not respond over a wide range of values of a particular variable or over a variety of assumed functional relationships, then that variable or process was not considered to have a high priority.

The model is intended, in the future, to be used to simulate the effects of perturbations that result from particular aspects of outer continental shelf development. Such a use has been considered in the design of the model but it has to date only been implemented to a limited extent at the workshops.

STUDY AREA

Study Area Selection

The OCSEAP planners desired that the Barrier Island-Lagoon Study focus its attention on a representative barrier island-lagoon site on the Alaskan Beaufort Sea coast. Ideally this site would have the following characteristics:

1. It should, as much as possible, typify other barrier island-lagoon systems so that data from other areas that applied to the processes under consideration could be used in the study and so that research findings from this study could be extrapolated to other areas.
2. It should have been comparatively little disturbed by past human activities, so that the processes to be studied would be representative of a relatively "natural" situation.
3. It should be relatively accessible in order to minimize logistics support costs.
4. It should have previously been the focus of research so that a partial data base would already be available.

Four areas along the Alaskan Beaufort Sea coast were initially evaluated as potential study sites. Considered as candidates were Elson Lagoon and the Plover Islands (in Naval Petroleum Reserve No. 4), Simpson Lagoon and the Jones Islands (about 30 km west of Prudhoe Bay), Challenge-Flaxman Lagoon and the Maguire-Flaxman Islands (near the Canning River delta), and Kaktovik Lagoon and Barter Island (in the Arctic National Wildlife Range).

The Simpson Lagoon-Jones Islands area (Fig. 3) was selected over the other areas for several reasons, including the variety of habitat types that the area appeared to contain relative to the diversity found at other sites, its nearness to efficient logistics support, and the amount of background data available for the site.

Because of the extreme variability among the physical parameters from place to place along the Alaskan Beaufort Sea coast, it became obvious that no system could be considered "typical". The selected area appeared to be relatively heterogeneous with regard to its physical characteristics. It contained elements that seemed representative of the variety that exists along the northern coastline of Alaska; in this respect it may be of more value than a relatively homogeneous site. By addressing the diversity of physical habitats available for study at Simpson Lagoon, greater potential existed for extrapolation of the data to a variety of coastline situations.

Although the extensive installations of the Prudhoe Bay oil field are only a short distance (about 30 km) to the east of the area and a Distant Early Warning (DEW) station and air strip are located at Oliktok Point, no major communities or settlements are in the immediate vicinity of Simpson Lagoon. Several cabins (some seasonally occupied) and a landing area are present along the mainland coast of Gwydyr Bay.

Logistics problems for field studies appeared to be relatively minimal. The area is 30-40 km west of the Deadhorse jetport, which has both helicopter and fixed-wing aircraft support and scheduled air services from Fairbanks.

A considerable amount of scientific data was available for the Simpson Lagoon area on both its physical and biological parameters. A number of recent and on-going studies have been funded through state and federal organizations and by private corporations.

Site Description

The major research effort was carried out in the immediate vicinity of Simpson Lagoon; subsidiary oceanographic and geological sampling efforts were made as appropriate in the adjacent Gwydyr Bay-Return Islands

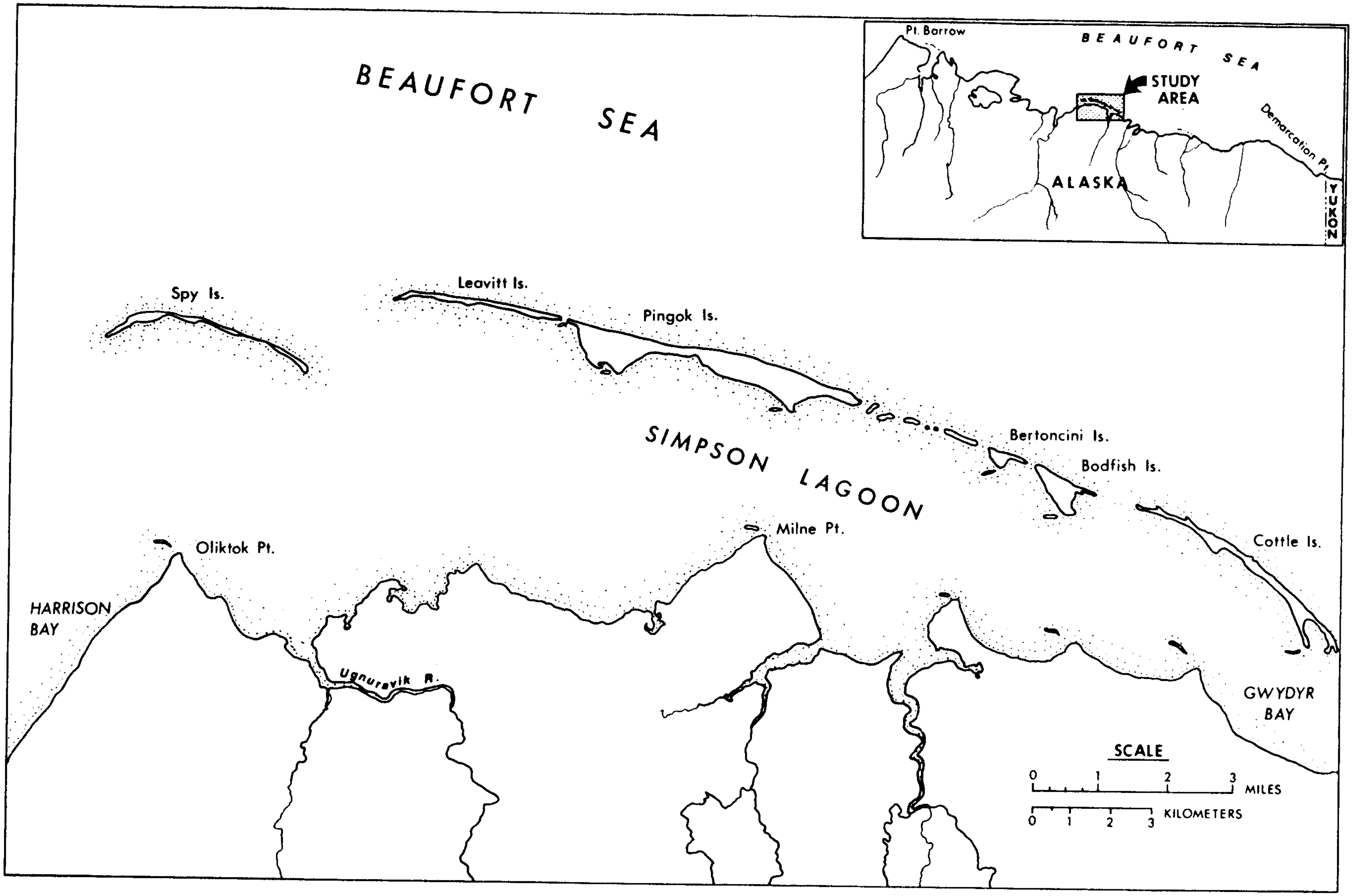

Fig. 3. Simpson Lagoon Study Area on the Beaufort Sea Coast of Alaska, 1977.

area to the east.

One river, the Ugnuravik River, discharges into Simpson Lagoon; two rivers, the Sakonowyak and the Kuparuk rivers (from west to east), discharge into Gwydyr Bay. The Colville River, to the west of the study site, and the Sagavanirktok River to the east exert a more peripheral influence on the system. Lagoon waters are up to approximately 4 m deep, but most are less than 2.5 m (Fig. 4). Prevailing currents are from east to west, but periodically reverse their course under strong winds from the west. Lagoon waters freeze to a depth of approximately 2 m by late winter, at which time under-ice salinities are very high (up to 60 ppt); salinities rapidly decline to brackish during the course of breakup in early summer, then gradually increase during the open-water season. Lagoon bottoms are silt or sand covered by a thin layer of detritus.

The mainland and the larger islands have a surface of tundra vegetation overlying peat deposits. Other islands are surfaced with sands and gravels.

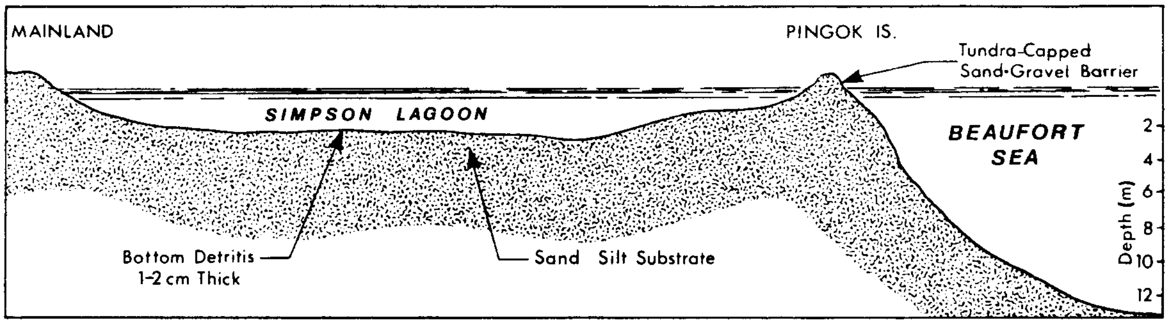

Fig. 4. Cross Section of Simpson Lagoon.

CURRENT STATE OF KNOWLEDGE

The general processes that operate in the Simpson Lagoon area appear to be similar to those that prevail in other areas along the Alaska Beaufort Sea coast. The data from other studies in this region are therefore useful as background material. These data are summarized below; more details concerning previous investigations are provided in the individual research reports.

Oceanography

During the open water period the nearshore currents of the southern Beaufort Sea are extremely variable and are strongly influenced by local winds. Northeasterly and northwesterly winds are responsible for predominantly westward-flowing and eastward-flowing currents, respectively; the northeasterly winds and westward-flowing currents predominate. Tides are of secondary importance to wind in controlling currents. Very complex patterns occur in the nearshore circulation; these patterns are related to bottom topography. It has been suggested that nearshore water masses are transported along the coast and generally remain within nearshore areas.

Freshwater discharge from mainland streams strongly affects nearshore oceanographic processes. Salinities, temperatures, nutrient levels and sediment loads of nearshore waters are greatly modified during summer because of this stream discharge. Rivers, most of which freeze to the bottom in winter, begin to flood in late May or early June. Open water forms first in the areas near river mouths because it is here that the warm fresh water melts the sea ice. Floodwaters may extend several kilometers out to sea over the shorefast ice; these waters eventually drain downward through cracks and holes in the ice. Sixty to eighty percent of the annual discharge of most rivers occurs from the last week of May to late June. Flows rapidly decrease during the course of the summer; they are minimal by the time freeze-up begins.

During severe on-shore summer storms, high waters that are generated by the winds can cause the inundation of considerable portions of both the barrier islands and the nearshore mainland. At such times wave action resuspends detritus and bottom sediments and accelerates erosion of coastal features. The barrier islands interfere with wind and wave action in the lagoon system, but the effects of wind and waves in exposed coastal waters are limited only by the edge of the ice pack and by concentrations of ice floes.

Geology

The nearshore region of the Alaskan Beaufort Sea is shallow and is occupied by irregular discontinuous chains of barrier islands that skirt about 50% of the coastline. The islands, which are generally parallel to the mainland, are characteristically low (1-1.5 m above sea level) and narrow (0.1-2.0 km wide); they range in length from a few hundred meters to 15 km. Most of the islands and the beaches of all the islands are composed of coarse sands and gravels; a few islands are covered by tundra vegetation. Offshore shoals (which are similar in cross-section to the barrier islands) and offshore bars exist on the seaward sides of the barrier islands and along some stretches of exposed mainland coasts. The bottoms of nearshore areas are roughened by the gouging action of ice floes and icebergs; this gouging occurs less commonly in the shelter of island chains and on the shoreward side of offshore shoals.

Because of wave and tidal action, the mainland coastline retreats 1-2 m annually, and the island margins are eroded and reworked. This erosion is cataclysmic in nature; most occurs during the course of infrequent storms. At such times large amounts of organic material (tundra mat and underlying peat) and inorganic sediments are transported from coastal landforms to benthic substrates.

Most inorganic sediments in the lagoons and other nearshore areas are the size of silt; gravels occur sparingly. The poorly-sorted characteristics of the sediments indicates that currents and wave action are extremely variable in their competency to resuspend and transport sediments. The organic carbon content in the sediments appears similar among some nearshore habitats, where it is higher than in adjacent marine areas.

Sediments are continually being introduced to nearshore areas via river floodwaters and coastal erosion. Much of the annual river discharge to nearshore areas is over the ice. It is possible that significant amounts of the suspended sediment load are subsequently transported away from the delta regions by movements of the ice and deposited elsewhere; this possibility is currently in dispute. Wind-generated waves and currents produce a net westerly longshore sediment transport, which results in westerly island migration and the formation of offshore bars. Sediment sinks (areas where sediments accumulate) are thought to occur at particular locales in nearshore waters but the detailed locations and characteristics of these sinks are unknown.

Ecology

The following summary of current knowledge of ecological parameters and processes includes brief discussions of nutrients, detritus, primary production, aquatic invertebrates, fish and birds. Field studies of nutrients, detritus and primary production were not a major part of the 1977 program; discussions of these parameters are included, however, because they provide important background in order to understand the rationale and results of the research program. They will be addressed more fully by research in 1978.

Nutrients, Detritus and Primary Production

Nitrogen and/or phosphorus are the nutrients that probably limit primary production in nearshore waters. River discharge is evidently the major source of these nutrients, but an important supply of nitrogen may also be contributed by erosion of peat from the coastal tundra into nearshore waters. Existing evidence suggests that nutrients are rapidly assimilated following their entry into nearshore waters in early summer.

Organic detritus, which is presumably an important energy source for the nearshore ecosystem, is contributed via two processes--coastal tundra erosion and river discharge. The relative amounts of detritus contributed from these two sources are unknown, as are the transport and depositional patterns of the detritus after it enters nearshore waters.

Primary production in nearshore waters occurs as pelagic (water column) production, mainly in summer; as an ice-associated phenomenon in spring; and as benthic algal production. The majority of the production is thought to be contributed by pelagic phytoplankton and under-ice algae, whereas production by benthic algae is probably relatively insignificant.

Aquatic Invertebrates

Investigations of aquatic invertebrates in the southern Beaufort Sea have concentrated largely on benthos, particularly infaunal species. Extensive data on most nearshore epibenthic species are lacking, and the existing information is largely taxonomic in nature. Characterizations of the structure and functional ecology of nearshore benthic communities are based on very limited data.

The nearshore shallow-water benthic community is composed mainly of crustaceans, polychaetes and molluscs. The species diversity, biomass and numbers of benthic organisms (infauna and epifauna) all appear to increase seaward from the shore (at least seaward of barrier islands); these trends are probably caused by greater stresses on the shallow areas as a result of effects of waves and ice. The more common invertebrate species are widely distributed along the arctic coast.

Fish

Over thirty species of fish have been found in nearshore habitats along the Beaufort Sea coastline. Areas of greatest diversity of fishes occur in the deltas of the largest rivers. Despite this variety, only three anadromous species (arctic cisco, arctic char, least cisco) and two marine species (fourhorn sculpin, arctic cod) account for the majority of fish collected in nearshore waters. The anadromous species are the most important users of the area in terms of their abundance, utility to man, and apparent dependence on the nearshore environment. These anadromous fish are the primary catch of fisheries located along the Alaska Beaufort coast near Barrow, in the Colville River delta, and at Barter Island. Marine fish, especially the arctic cod, are important to certain arctic birds and mammals, but little specific information about these fish is available from Beaufort Sea waters.

Use of nearshore waters by fish is restricted to the short open-water season. After spring breakup, anadromous and marine species invade the shallow, relatively warm and brackish coastal waters to feed on an abundant invertebrate food resource. Anadromous fish entering coastal waters are usually either immature fish or mature fish which will not spawn for another year. Fish movements during this period are complex. Tagging studies show that some anadromous fish may travel considerable distances along the coastline before turning to their overwintering sites in rivers. Fish utilization of offshore marine waters is not well known, although andromous fishes probably do not account for a significant portion of the fish fauna in the deeper, colder, and more saline waters.

Birds

Approximately 100 species of birds use the Beaufort Sea. Because coastal regions of the Beaufort Sea are completely ice-covered during winter, the water-associated birds of the area are necessarily migrants that are absent during winter. During portions of the summer significant fractions of the total North American populations of a number of species are present in the coastal lagoons, bays and marshes of the Beaufort Sea coast; these species include yellow-billed, red-throated and arctic loons; brant; oldsquaw; common and king eiders; glaucous, Sabine's and Ross' gulls; jaegers; arctic terns; and red and northern phalaropes. Some of these birds occur in the Alaskan Beaufort zone only during migration, but others also nest, molt, feed or accumulate fat reserves there.

Three major migrations of waterbirds occur in the nearshore areas--spring migration, a mid-summer molt migration, and fall migration. The spring migration begins in May and is complete by mid-June. Because most of the lagoon systems are ice-covered until July, significant use of the nearshore areas by migrating birds occurs only during the mid-summer molt migration and the fall migration, not during spring migration.

In late summer, male seaducks concentrate in large flocks in particular locations; there they molt their flight feathers and become flightless. The bays and lagoon systems along the coast of the Beaufort Sea are particularly important summer molting areas for oldsquaws.

Some nearshore areas are important as nesting and feeding sites. Several species of waterbirds (brant, eiders, gulls, terns) nest on the barrier islands and to a lesser extent on mainland spits and beaches. Some of these birds, plus other birds such as oldsquaws that normally nest inland, feed with their young in shallow nearshore waters in mid-and late summer. During the molt period and during fall pre-migratory staging, many waterbirds feed along shorelines and in lagoons and other nearshore areas in order to accumulate fat reserves for their southward migration.

PROGRAM RESEARCH

Each disciplinary research effort was oriented toward supplying data that would permit a coordinated interdisciplinary approach to the general program objectives. Research during the first year (1977) was designed primarily to respond to the first program objective (i.e. the identification and analysis of components and processes of the ecosystem). Responses to the full implications of the second objective (generation of mechanisms to evaluate impact) and the third objective (determination of feasibility of measuring change) are evolving as a consequence of the continuing analyses of the results of the studies concerning ecosystem components and processes.

Research studies were designed to respond to the program objectives either directly by identifying or quantifying the components or processes of the system or indirectly by providing data to the other disciplines that would enable them to respond to the program objectives. Summaries of the objectives, research methods and results of each major discipline are presented below. The disciplines included are oceanography (RU 526 and RU 531), geology (RU 529 and 530), and ecology (RU 467 and RU 527).

Oceanography

Objectives

The objective of the oceanography study was to characterize the nature and rates of water exchange both between coastal (estuarine) and marine systems and among coastal areas, primarily by the use of circulation models.

Rationale

An important hypothesis is that the lagoon and/or the nearshore area in general are systems that are distinct from adjacent areas and that are therefore unique in their habitat qualities (e.g., temperature, salinity and nutrient regimes). A knowledge of the water circulation patterns is critical to the testing of this hypothesis and helps to answer related questions concerning input, transport and deposition of pollutants, nutrients and detritus.

Methods

The primary method used to characterize the nearshore circulation and water exchange was to construct models and to test and refine these models by incorporation of field measurements. The field data were also used to interpret the local dynamics of circulation on a scale that was too small to incorporate into the model. To date the model has only been used to investigate the effects of steady winds on the lagoon waters under the assumption that tidal and river influences on water exchange are small by comparison. Volume flows through the lagoon entrances and estimates of lagoon water exchange rates have been calculated.

Field measurements were concentrated at the eastern and western ends of the lagoon system; one additional series of measurements was taken along the length of the lagoon. The site-specific data that were collected were chiefly conductivity, temperature, salinity and (where appropriate) depth, wind and waves. Continuously-recording current meters moored at the eastern and western entrances to the lagoon provided data on current speeds and directions.

Results

Research findings were as follows:

1. An essentially linear relationship existed between current and wind speeds; the mean current speed as determined by measurements at various depths was approximately 3% of the wind speed regardless of whether the wind blew from an easterly or westerly direction.

2. The model showed that, under typical wind conditions, approximately 1/5 of the lagoon volume is apparently replaced per day; under relatively strong winds the lagoon flushes almost daily.
3. Salinity and temperature values can change rapidly at nearshore sites; daily changes of 15 ppt salinity and 6°C temperature were common.
4. Temperatures were coldest farthest from the mainland shore throughout the length of the lagoon.
5. The ARCO causeway at the east end of the lagoon system has a strong local effect on water salinity and temperature. Temperature and salinity differences across the causeway were as high as 7°C and 18 ppt, respectively.
6. Meaningful variations of salinity and temperature with depth were rare.

Geology

Objectives

The objectives of the geological investigations were (1) to investigate the origin and evolution of coastal land forms so that the consequences of removing, reshaping or stabilizing topographic features could be evaluated, and (2) to quantify the inputs of terrigenous materials (materials that originate on land) so that contributions of energy in the form of organic detritus to the system could be estimated.

Rationale

Because the topographic features of coastal areas appear to affect the quality of these areas as fish and bird habitat, the permanence or the regenerative capability of such features is important in light of potential development-caused changes. It is therefore critical to know how these landforms originated, whether the formative processes are continuing and what the nature and rates of the present-day erosive processes are. If terrigenous organic input to the nearshore environment provides a key source of energy (as appears likely) it is important to know how erosion affects the input rates of this material.

Methods

Methods used included the following:

1. Analysis of LANDSAT imagery to identify the points of introduction of river sediments and detritus and the extent of input of these materials to the system during spring thaw.
2. Interpretation of historical and recent vertical aerial photographs to calculate the landform erosion rates and to estimate the extent of landscape inundation by storm surges.
3. Low-altitude reconnaissance flights to corroborate the aerial photo interpretations.
4. Ground reconnaissance to observe and document the geological and geomorphic features.
5. Analysis of sediment core samples from the area to reconstruct the geological and depositional history.
6. Analysis of the mineral and carbon contents of substrate samples to evaluate the points of origin and the transport characteristics of the substrate materials.

Input volumes of detritus from coastal erosion were calculated by using annual horizontal erosion rates (estimated from sequential photos) and average thicknesses of tundra and peat (measured during the course of ground reconnaissance). Amounts of detritus deposited over the ice by river flooding in the spring were estimated using LANDSAT imagery and low-altitude reconnaissance to map the areal extent of detritus coverage.

Distributions of particle sizes in the nearshore sediments were a key to the transport and depositional regimes of the area. Composition of the clay minerals of substrate samples was interpreted to determine the points of sediment origin and the sediment transport trajectories, and, indirectly, to evaluate the contribution of sediments to the forming of nearshore landforms. Horizontal distributional characteristics of organic carbon in nearshore substrates were used to infer sources and trajectories of detritus.

Results

Important findings of the geological investigations were as follows:

1. Tundra-covered islands, as well as most sand and gravel islands, are relict mainland features. With the passage of time they have become isolated from the mainland by the enlargement of freshwater thaw lakes that have coalesced to form lagoons.
2. The tundra cover of the mainland and larger islands is continually being eroded away; in recent decades, the tundra has eroded horizontally at rates of approximately 1.2 and 1.7 m per year from mainland and island margins, respectively.
3. The expected lifetimes of tundra on the larger islands in the Jones Island group under present erosive forces are of the order of a few hundred years or less; the islands will remain as sand or gravel barriers for a longer but undetermined length of time.
4. Thawing and lake bed subsidence, as they presently occur, lead to the coalescing of coastal lakes. As present barrier island-lagoon systems disappear through island erosion, it is expected that similar systems will form from the coastal mainland by this coalescing of coastal lakes. The time required for the formation of new lagoon systems is possibly of the same order of magnitude as the time required for the existing systems to disappear.
5. The amount of organic detritus input into Simpson Lagoon from coastal erosion is estimated to be about the same order of magnitude as that from river input.
6. Most of the coarse materials (gravels) on the islands were deposited in place as erosion removed the tundra covers of the islands, but these materials may be locally transported and re-worked. The finer-grained clastics (sands, silts and clay-sized particles), especially at the island margins, are partially supplied from elsewhere by longshore transport.
7. Coastal areas that are subject to inundation by storm surges may extend up to a few kilometers inland in low-lying areas but are normally much narrower. The islands that lack tundra could be completely inundated during periods of maximum storm surge.
8. Lagoon bottoms may be categorized into two major substrate types--sandy (>50% sand) and muddy (>50% mud). Sandy substrates are found largely in very shallow areas adjacent to lagoon margins, where wind-generated turbulence resuspends and removes the fine-grained particles. Muddy substrates are characteristic of the deeper less turbulent lagoon bottoms.

9. The organic carbon content of the bottom sediments progressively decreases northward across the lagoon. Thus there is a positive correlation between organic detritus abundance and nearness to the postulated source of the detritus (e.g., eroding tundra bluffs).

Ecology

Objectives

The objectives of the ecological program were (1) to document the processes that supply nutrients and energy to the coastal zone biota, (2) for selected "important" fish and bird species, to investigate those habitat and feeding dependencies that are sensitive to impact, and (3) to investigate the habitat and feeding dependencies of the invertebrates that serve as the food base for the above species of fish and birds.

Rationale

Fish and bird populations are the environmental constituents of the barrier island-lagoon system that are of principal concern to society and are therefore the primary focus of this study. Marine and terrestrial mammals are also of concern to society, but the study area is not of major importance to these populations, so relatively little effort was directed toward mammals. Invertebrates are the primary food source of "important" fish and birds, and alterations in the invertebrate populations would potentially affect populations of their consumers. The processes that supply food (energy and nutrients) to these birds, fish and invertebrates accordingly govern their distribution and abundance. Because development-related perturbations to animals frequently act via an alteration of energy or nutrient sources or via an alteration of habitat, a clarification of the food and habitat dependencies of "important" birds, fish and supporting invertebrates is needed in order to assess the impacts of development.

Methods

Nutrient Dynamics and Energy Sources. A major program effort to study nutrient dynamics and energy sources has only recently commenced. The methods in use to evaluate the mechanisms of nutrient assimilation and energy supply include (1) a sampling program for ice algal production and (2) analytical techniques for determining the sources of carbon in the tissues of selected organisms. Ice-core and sub-ice water samples are being taken in spring 1978 to quantify the production and the spatial distribution of ice algae; these samples are being obtained in spring when ice thicknesses are maximum; they will then be analyzed to yield a total nitrogen budget. The method proposed to evaluate the utility of detrital carbon to invertebrates (and, indirectly, to vertebrates) is an analysis of tissue samples of these organisms to determine the proportions of "old" (from terrestrial peat) or "new" (from recent pelagic production) organic materials in their tissue; C^{14} dating techniques and carbon isotope ratios will be used to estimate this tissue "age".

Aquatic Invertebrates. Techniques for the study of aquatic invertebrates included both field and laboratory methods. Invertebrate collections were made at representative habitat sites at intervals throughout the open-water season by conventional sampling methods (nets, trawls); additional underwater observations were also made in representative habitats by a SCUBA diver. Laboratory analyses included the processing of invertebrate samples and contents of bird and fish stomachs, which contained largely invertebrates. Analysis procedures emphasized the determination of species composition, relative and absolute biomasses, and to a lesser extent densities. The composition of invertebrate samples was compared to the composition of the stomach contents of birds and fish in order to evaluate the feeding selectivities and overlaps of those vertebrates. The estimated available food energy provided by major groups of invertebrates was compared to the estimated energy requirements of major consumers of invertebrates in the system.

Fish. Fisheries research methods included field sampling methods designed to provide spatial and temporal information about fish utilization of nearshore areas, and laboratory analysis techniques to determine the population, age and sex structure of the fish, their physiological condition, and their diet. Representative habitat types (which corresponded to those sampled for invertebrates) were sampled regularly between mid-June and late September. A variety of capture techniques was used to ensure the effectiveness of the sampling effort. Catch data were used to assess species composition, relative abundances of different species, and catch per unit effort. Laboratory analyses included length and weight measurements, age determination by examination of otoliths, state of maturity relative to spawning capability, condition as determined by index of fatness, and stomach content examination. The degree of diet overlap among the various major fish species and between fish and birds was evaluated.

Birds. Methods used for determining bird feeding dependencies and habitat utilization patterns included (1) observations to document migration through the area, (2) ground surveys to quantify the amount, locations and success of nesting in the area, (3) aerial surveys to document the patterns of habitat utilization, and (4) collections of birds for laboratory determination of diet and condition. Observations of migration were made directly by noting the passage of birds through the study area, and indirectly (in spring only) via the Oliktok Distant Early Warning (DEW) radar. Observers recorded the temporal and spatial distributions of flying birds (by species or species group) and the general use of the lagoon and adjacent land surfaces by migrants. Radar showed the extent of concentration in the study area relative to adjacent seaward and landward areas. Ground-based surveys were used to determine use by birds of the barrier islands and mainland beaches for nesting, resting and feeding. Low-altitude aerial surveys of the area were used to determine the distribution of and habitat use by the larger birds in the area through the course of the summer. Samples of selected key species (oldsquaw, red and northern phalaropes, and glaucous gull) were periodically collected for stomach content analysis (% volume basis) and fatness, sex and age determinations.

Results

Aquatic Invertebrates. Investigations of the aquatic invertebrates in the Simpson Lagoon area showed the following:

1. Epibenthic forms comprised a large portion of the lagoon invertebrate biomass; the biomass and density of epibenthic fauna both appeared to be dominated by mysids and amphipods.
2. Use of conventional sampling techniques (nets and trawls) caused drastic underestimations of the abundance of highly mobile species (e.g., amphipods, mysids); reliable estimates for these groups were only obtained through observations by a diver.
3. Densities of mobile epibenthic species varied widely in space and time.
4. The standing crop estimates of invertebrates that were selected as food by birds or fish were 1-2 orders of magnitude above the daily consumptive capacity of these predators, and the ratio tended to increase during the course of the summer.
5. Biomass estimates for zooplankton (pelagic invertebrates) were similar to those reported from other relatively productive Arctic seas. After the ice breakup, the biomass of these animals increased rapidly to a fairly constant level, which prevailed until freeze-up.
6. A marine copepod that was commonly collected at the marine offshore sampling station was not found in the lagoon samples; its distribution suggests that extensive and rapid exchanges do not occur between marine and lagoon water masses.
7. Migration of mysids and amphipods from the ocean to the lagoon may help to recolonize the lagoon annually following breakup.

Circumstantial evidence suggested that some of the epibenthic invertebrates may consume the terrestially-derived detritus that blankets the lagoon floor.

Fish. Fisheries research in the Simpson Lagoon area showed the following:

1. Few species of fish (13) were caught, and only five species (arctic cisco, arctic char, least cisco, fourhorn sculpin and arctic cod) were abundant.

2. Smaller (younger) individuals of anadromous species were more abundant in nearshore areas than had been recorded in earlier studies, probably because a greater variety of collection methods was used in this study than in most previous work.
3. Different sampling gear produced very different results concerning the occurrence and relative abundance of the various fish species.
4. During the open-water season, fish utilized lagoon areas to a much greater extent than they did offshore areas; fish were most numerous (especially the anadromous species) immediately adjacent to the shorelines, and particularly to the mainland shoreline.
5. Food habits of fish in nearshore areas were very similar among the various species; primary foods were epibenthic invertebrates (largely amphipods and mysids) and zooplankton.
6. Diets of key fish species were very similar to the diets of most of the key bird species.
7. Diets of fish in Simpson Lagoon were generally similar to the diets of the same species at other Beaufort Sea locations.
8. Neither predators nor parasites appeared to limit the populations of fish in nearshore waters of the Beaufort Sea.

Birds. The ornithological investigations in the Simpson Lagoon area showed the following:

1. The peak of spring migration for most birds was late May and early June; migrants moved eastward on a broad front and made little use of nearshore areas. The westward molt migration of seaducks peaked twice, once in early July (oldsquaws) and once in late July (eiders); during the early peak, male oldsquaws made moderate use of water-filled cracks in the lagoon ice as well as water in open shoreleads. Molt migration of eiders occurred after breakup, and only small fractions of the Beaufort Sea populations used the study area. Fall migration exhibited a wide temporal variation among species; of the abundant species, phalaropes, arctic terns and brant had left the area by early to mid-September, but oldsquaws and glaucous gulls increased in abundance from mid-summer until at least 20 September.

2. For all bird species except the traditional island nesters (common eiders, brant, glaucous gulls, arctic terns), nesting densities on the barrier islands were lower than would be expected in similar mainland habitats.
3. Predation by arctic foxes caused the failure of most of the fifty active nests found on the islands bordering Simpson Lagoon.
4. Large numbers of oldsquaws used the lagoon during the course of the annual feather molt and during the fall pre-migration period. It was estimated that over 50,000 molting birds occurred in Simpson Lagoon at peak periods of the molt in August; at one time in late September, over 100,000 staging oldsquaws were estimated to be present in the lagoon.
5. Shorebirds, most of which were red and northern phalaropes, congregated in large numbers to feed along mainland and island beaches during pre-migration staging in mid-August.
6. Arctic terns were relatively abundant transients in late summer, but few nested in the study area.
7. The diet of oldsquaws was composed largely of mysids and amphipods and was very similar to the diets of arctic cisco, arctic cod, and fourhorn sculpin. Oldsquaws presumably fed near the lagoon bottom where these organisms were most abundant.
8. Glaucous gulls were associated with shorelines on the study area and opportunistic in their feeding habits; their diets were composed largely of isopods and amphipods with lesser amounts of fish and birds.
9. Phalarope diets were composed primarily of copepods, amphipods and mysids; these birds were apparently relatively specialized in their feeding dependencies, and were narrowly concentrated along shorelines while feeding.

SYNTHESIS AND DISCUSSION

As stated earlier, this program is designed to be an integrated research effort concentrating on critical ecosystem processes that are likely to be affected by outer continental shelf development. This section synthesizes the findings of the program research efforts (Oceanography, RU 526 and RU 531; Geology, RU 529 and RU 530; Primary Production/Nutrient Dynamics, RU 527; and Ecology, RU 467) and discusses the implications of the research findings to the assessment of impacts likely to accompany petroleum exploration and development. In the following sections each major process that is being studied is discussed, its importance to birds or to fish is described, the manner in which activities associated with outer continental shelf development might affect the process is discussed, and the manner in which the findings of specific Research Units have contributed to an understanding of the process is shown.

Geological Processes

A major hypothesis of the program is that the topographic (geological) configuration of the nearshore system (i.e., the existence of lagoons bordered by barrier islands) has an important influence on the quality of the nearshore area as habitat for fish and birds. This hypothesis is being tested by oceanographic and ecological investigations. Geologists are concurrently studying the formative processes of existing landscapes to evaluate the probability that landscape alterations associated with development (e.g., island removal) will be naturally "mended".

The geological findings suggest that limited reshaping of sand or gravel barrier islands by man may simulate natural processes, that stabilization of barrier islands may interrupt their normal reshaping patterns, and that materials removed from barrier islands may be largely irreplaceable by natural processes. The findings also suggest that lagoon bottom materials are more readily replaceable than are island materials, provided that their sources (river discharge, eroding shorelines) and their transport mechanisms (nearshore current and wave action) remain unaltered.

Oceanographic and Ecological Processes

The types of oceanographic and ecological processes important to the support of fish and birds are presented in Table 4 in the context of the activities related to outer continental shelf development that will possibly affect these processes. The following discussion shows how

Table 4. Potential Interactions Between "Important" Ecosystem Processes and Human Activities Associated With Outer Continental Shelf Development.

Type of Activity	Processes That Are Important to Birds and Fish and That Might Be Altered by Development-Related Activities.
<u>Topographic Modification</u> (Causeway construction; island construction, alteration or removal; subsea dredging.)	1. Nearshore circulation, water mass exchange patterns, and associated transport and depositional behavior of nutrients, food materials and contaminants. 2. Migrations of fish and epibenthos. 3. Special responses of fish and birds to physical and chemical habitat parameters (e.g., use of characteristic sites for resting or foraging).
<u>Erosion Prevention</u> (Island and/or Shoreline stabilization)	3. (See above). 4. Input of terrigenous organic material to the nearshore system.
<u>Introduction of Contaminants</u> (Discharges of petroleum, heavy metals, etc. into the system)	5. Physical and physiological responses of fish, birds and their food organisms to contaminants.
<u>Human Presence and Activity</u> (Noise and visual disturbance; increased hunting, fishing and harassment of wildlife; provision of scavenger or predator attractants.)	6. Behavioral responses of birds in their selection and use of foraging, molting, nesting and resting areas. 7. Mortality and stress patterns that result from hunting and fishing activities. 8. Predator-prey interactions

the program research has provided information required to understand these processes. Each process is considered separately; research contributions are noted by discipline.

Process #1: *Nearshore circulation, water mass exchange patterns, and associated transport and depositional behavior of nutrients, food materials and contaminants.*

Nearshore water circulation and exchange support or affect fish and bird populations in the following ways:

1. by delivering nutrients and/or foods to sites where they can be effectively utilized either directly, or indirectly via food chain conversions,
2. by delivering contaminants to areas and/or retaining them in areas where fish and birds are more or less vulnerable to their effects, and
3. by creating locally variable physical conditions (e.g., temperature/salinity regimes) that can have an important influence on the habitat quality for fish, birds and/or their foods.

Causeway construction, barrier island removal or subsea dredging could significantly alter the circulation pathways and water exchange rates in the nearshore zone. (RU 531, OCEANOGRAPHY, has provided evidence for such alterations by their measurements in the vicinity of the ARCO causeway at the east end of the lagoon system.) Whether the altered flow patterns would significantly affect birds and fish is not definitely known; refer to process #3 for a discussion of this question.

Research findings that relate to this process and the manner in which it might be affected by development are the following:

1. Fish and birds concentrate in shallow nearshore waters to feed (RU 467, ECOLOGY OF FISH AND AVIAN ECOLOGY sections).
2. The principal organisms that are consumed by fish and birds move in large numbers in summer to nearshore benthic environments (RU 467, INVERTEBRATES section).
3. Nearshore waters are characteristically warmer and less saline than the adjacent marine waters (RU 526 and RU 531, OCEANOGRAPHY; and RU 467, INVERTEBRATES section); fish abundance appears to be correlated with these higher temperatures and lower salinities (RU 467, ECOLOGY OF FISH section).

4. Circulation patterns are predominantly parallel to the coast; nearshore water masses and entrained materials usually move westward (but sometimes eastward), and usually flow at a speed of approximately 3% of the wind speed. Simpson Lagoon flushes about once every five days under "average" winds and one or more times per day under relatively strong winds (RU 526 and RU 531, OCEANOGRAPHY section).
5. The physical integrity of the nearshore system appears to be relatively great. The mixing of nearshore waters with offshore waters, for example, is sufficiently slow both to allow the temperature/salinity regimes of the two waters to remain different throughout the summer (despite drastically reduced freshwater inputs to nearshore areas in late summer) (RU 526 and RU 531, OCEANOGRAPHY section) and to cause marked differences between marine and lagoon populations of some neustonic invertebrates (e.g., a marine copepod that was commonly encountered offshore was not found in the lagoon) (RU 467, INVERTEBRATES section).
6. Organic detritus coats the lagoon bottom where it may provide a key energy source for invertebrates. It is probably resuspended primarily by wave action under the influence of strong winds; it then moves eastward or westward along the coast with the prevailing current (RU 526 and RU 531, OCEANOGRAPHY section). It is not yet known how motile invertebrates (i.e., those capable of independent movement, including many epibenthic invertebrates) are affected by water flow.

Process #2. *Migrations of fish and epibenthos*

Anadromous fish, and to a lesser extent epibenthic invertebrates, make characteristic seasonal migrations in nearshore waters. Fish leave the river systems in spring and migrate considerable distances along the coast to feed and fatten in summer before returning to their overwintering sites in the rivers. Less is known about the characteristics and purposes of movements of epibenthic organisms; each year they apparently repopulate the shallow nearshore areas that are frozen to the bottom in winter.

Although studies around the ARCO causeway near the east end of the Simpson Lagoon-Gwydyr Bay system have indicated that some fish pass that obstruction, the effects of obstructions on the normal movements of fish and invertebrates are not fully known. If construction of solid-fill connections between islands or of jetties that extend into the sea were to occur, disruptions to normal migration processes might ensue. Further clarification of the function and patterns of these migrations is needed.

Research findings concerning invertebrates and fish (RU 467) that relate to their migrations are the following:

1. Migration of mysids and amphipods from the ocean to the lagoon may occur very soon after the ice lifts from the lagoon bottom in early summer. These migrations may, in part, be active responses independent of water circulation patterns. The reasons for this invertebrate immigration are not known, but may be related to utilization by the invertebrates of a valuable food resource (possibly detritus) and/or a habitat that cannot be found elsewhere.
2. Fish, especially the anadromous species, use the shallow areas that are very near shorelines more intensively than they use other areas. Reasons for this preference of lagoon edges are not clear, but they may be related to water quality parameters, the use of the area by prey species and/or navigational processes.

Process #3. *Special responses of fish and birds to physical and chemical habitat parameters.*

Results of this study (RU 467, ECOLOGY OF FISH AND AVIAN ECOLOGY sections) indicate that fish and birds concentrate at specific sites within lagoons. Fish and staging phalaropes, for example, appear to prefer shallow areas that are very near coasts. Oldsquaws frequently occur in feeding concentrations near points of land that extend into the lagoon. Some island-nesting birds are very specific in their nesting-site requirements.

Causeway construction, artificial island construction or subsea dredging might alter nearshore habitats so that they would offer birds of fish either more or less of their required habitat. Whether the responses of these animals to such alterations would be positive, negative or nil would depend on the nature of the change in habitat and on functional relationships between the animals and their habitats. The effects of development activities might result directly from habitat modification (e.g., alterations to land or bottom surfaces or topographic configurations) or indirectly from various causes (e.g., alterations in water circulation and associated water quality regimes because of causeway construction).

Special habitat requirements of birds and fish that have been studied (RU 467, ECOLOGY OF FISH AND AVIAN ECOLOGY sections) are the following:

1. Intensive use of nearshore habitats by fish was possibly related to the relatively high temperatures and/or low salinities found in these areas compared to offshore areas. It is known from other studies that fish frequently respond physically, physiologically and behaviorally to slight differences in temperature and salinity, and it is suggested that waters in nearshore areas provide a more favorable environment for fish than do offshore waters.
2. Some birds (e.g., common eiders, arctic terns, glaucous gulls) prefer or require sand or gravel barrier islands or spits for nesting sites; specific micro-habitat features (e.g., presence of vegetation or driftwood) are sometimes also required.
3. Phalaropes appear to selectively forage on specific types of island and mainland beaches.
4. Oldsquaws feeding in the lagoon appear to concentrate near points of land. Reasons for such concentrations are uncertain.
5. The lagoon *per se* is an area of concentration of both fish and birds. The relative roles of physical habitat factors, food availability and other possible factors in causing concentrations are not clearly established. A general hypothesis under continuing investigation in RU 467 (all sections) is that shallow and protected lagoon habitats provide an environment that is particularly conducive to the development and efficient cropping of prey (invertebrate) populations.

Process #4. *Input of terrigenous organic material to the nearshore system.*

The evidence to date suggests that an important portion of the energy base of the nearshore ecosystem may be derived from terrestrial sources of detritus. Detritus may be an important food source (either directly, or indirectly via bacterial action) to epibenthic invertebrates, which in turn are the food source for many birds and fish. There are two major sources of detritus--the shoreline tundra mat and its underlying peat, and the discharge of the rivers.

Coastal development activities might directly retard or prevent erosion by stabilizing the land margins on mainlands and islands. Development activites might also indirectly affect erosion processes by causeway construction or other modifications of land forms that would alter the impacts of storm-generated tides and waves. A significant reduction of erosional input might affect both the organisms directly dependent on detritus and their consumers.

Research in this program has clarified two aspects of detritus input and distribution within the system.

1. RU 530 (GEOLOGY) investigations have provided realistic estimates of the rates of detritus input from coastal erosion.
2. RU 467 (ECOLOGY) investigations have shown that detritus exists as a fairly continuous, unconsolidated layer on the surface of the lagoon bottom, and that epibenthic invertebrates live largely in and on the surface of this detritus. The permanence of this detritus on the lagoon floor, the degree of its utility to invertebrates, and the means by which it is resuspended and transported have not yet been fully evaluated.

Process #5. *Physical and physiological responses of fish, birds and their food organisms to contaminants.*

Water-borne contaminants can have direct or indirect effects on living organisms. Oil on or in the water can pose a direct hazard to some organisms. It may cause direct mortality in waterbirds by reducing the buoyancy and the insulative value of their feathers; it has less potential to directly harm fish or motile invertebrates. The existing evidence suggests that petroleum products may accumulate in organisms but that food-chain magnification does not occur; other potential contaminants, such as heavy metals, however, may be further concentrated at each step of a food chain.

One of the primary concerns about outer continental shelf development relates to the consequences of possible oil spills in nearshore waters. Concern has also been expressed about the potentially adverse effects of heavy metals and other toxins that could be released in the course of drilling and production operations. The distribution and timing of contaminant releases, as well as their quantities, qualities and trajectories, will all influence the environmental impacts.

Information concerning the spatial and temporal use of habitat by animals is critical to a prediction of the impacts of contaminant releases;

RU 467 (ECOLOGY) provides such information for invertebrates, fish and birds.

1. Many important epibenthic invertebrates concentrate in nearshore areas during open water periods; their distribution patterns in other seasons are not entirely clear, but presumably they are more abundant in deeper marine areas in winter.
2. Fish utilize nearshore habitats in summer, concentrating in very shallow areas at the lagoon edges; most fish move into either freshwater streams (anadromous species) or deeper marine water (marine species) in winter.
3. Waterbirds use nearshore waters sparingly in spring and early summer, but much more intensively in August and September; at this time heavy use is made of lagoon waters by oldsquaws, and of lagoon and mainland beaches and shallows by phalaropes, gulls and terns.

Process #6. *Behavioral responses of birds in their selection and use of foraging, molting, resting and nesting areas.*

Waterbirds use nearshore waters, islands, and island and mainland shorelines for foraging, molting, nesting and/or resting. The nearshore shallow waters, as opposed to either offshore marine waters or mainland areas, uniquely fill these needs for a number of important bird species in the Beaufort Sea.

Birds are much more responsive to the visual and auditory stimuli that accompany development than are either fish or invertebrates. Impacts of these types of stimuli vary greatly with both the species of birds and the types of human activities, but a variety of activities (including aircraft overflights, ship and boat traffic, and the movement and noise of men and machines at drilling and production sites) have the potential to alter foraging behavior of birds, their molting, resting and nesting distributions, and (indirectly) their energetic status.

The research of RU 467 (AVIAN ECOLOGY section) has described the temporal and spatial distribution of birds in the nearshore zone. The degree of impact of development activities will vary according to the degree to which the seasonal and spatial aspects of such activities coincide with the patterns of bird distribution and activity.

Ornithologists specifically noted that

1. Low-altitude overflights by helicopter or small fixed-wing aircraft caused minimal disturbance to feeding and/or molting oldsquaw.
2. Susceptibility of nesting birds to disturbance by humans on the ground varied both among species and with the phase of the nesting cycle.

Process #7. *Mortality and stress patterns caused by hunting and fishing activities and/or harassment of wildlife.*

Direct mortality of fish and wildlife due to hunting and fishing by humans is sometimes a significant impact accompanying development--especially if development occurs in isolated regions where access has previously been limited and/or in areas where animal populations are highly concentrated.

The impacts of changes in hunting and fishing processes are already subject to a considerable amount of control by government regulation and they can be relatively well predicted on the basis of current knowledge; they were, therefore, not addressed by new research. A general consideration of the effects of existing hunting and fishing activities in the nearshore Beaufort Sea is possible on the basis of existing data; it should permit more knowledgeable speculation about the impacts of increased exploitation.

Presently there is limited harvesting of the bird and fish resources in the Alaskan Beaufort Sea nearshore zone. Hunting of bird species other than waterfowl is and probably will remain negligible because of protective regulations. Harvest of waterfowl, especially of oldsquaw--the primary species of concern in nearshore areas--also is minimal. RU 467 (ECOLOGY OF FISH section) shows that the existing fish harvest is mostly limited to several small commercial or subsistence operations. It is thought that current hunting and fishing pressures on fish and waterfowl in the nearshore zone can be sustained over the long term, but there is little quantitative information to support this supposition. Increased hunting and fishing pressures promoted by increased access could quickly cause an adverse effect, because the population levels and turnover rates of the fish may be too low to sustain heavy harvests, and because of the concentrating effect of the nearshore zone on both waterfowl and fish.

Process #8. *Predator-prey interactions.*

Some predators exert an important but widely-varying influence on their prey in the Alaskan Beaufort Sea nearshore region. Predator-caused mortality among bird species, for example, fluctuates extensively in both space and time. The survival of prey species depends on their success in avoiding predators to a sufficient extent that they can successfully maintain and reproduce their populations.

Development in the arctic typically creates situations that are attractive to some predators or scavengers. In the coastal regions, arctic foxes are at the same time both voracious scavengers and predators on nesting birds and their eggs and young. Arctic foxes frequently abound where development activities proceed; the availability of garbage and construction facilities subsidizes these predators by provision of food and shelter.

The potential for such subsidized populations of arctic foxes or other predators to adversely affect their traditional prey may be considerable. Some species of birds in the nearshore Beaufort Sea, for example, are thought to prefer or require islands as nesting sites; development on islands could conceivably encourage arctic foxes to continually inhabit the islands and thereby pose a menace to nesting birds.

Research (RU 467, AVIAN ECOLOGY) on the nesting success of birds on barrier islands has shown that the nesting success on some islands was relatively low because of arctic fox predation on eggs and young.

CONCLUSIONS

A summary of important conclusions follows:

1. Nearshore water masses move rapidly eastward or westward along the coast in response to prevailing west or east winds, respectively. The entire Simpson Lagoon may be flushed once per five days under average conditions, and daily under the influence of strong winds. Normal currents apparently do not cause appreciable flushing of either organic detritus or its associated epibenthic fauna; it is assumed that detritus may be resuspended and transported by storm action; effects of currents on epibenthos are not known.

2. It is suspected that extensive and continuous water mass exchange occurs among nearshore areas in summer, but that water mass exchange between lagoon and marine areas is more conservative.

3. Barrier islands are landform remnants once continuous with the adjacent coast, or, in the case of sand and gravel barriers not capped with tundra, composed largely of materials deposited in place as tundra-capped remnants were eroded. Sand-gravel barriers as well as beaches of tundra-capped islands may additionally be supplied with transported sediments of sand-grain size and smaller. New lagoon systems are continually being formed (on a time scale of centuries) as portions of the nearshore mainland erode away and coastal lake beds subside. Lagoon benthic substrates are predominantly of recently-introduced sediments, mainly sand and silt.

4. Organic detritus derived largely from terrestrial sources forms a thin amorphous layer on the lagoon floor; it is potentially an important indirect energy source for fish

and birds (see below). It appears that the detritus contribution from each of the two major sources--shoreline erosion and river discharge--may be of the same order of magnitude.

5. Motile epibenthic organisms (primarily amphipods and mysids) are the major foods of the important fish species and of oldsquaws, the dominant predators in the system. At least some of these invertebrates appear to migrate into the lagoon in early summer and leave as the lagoon freezes in winter. During their residence in the lagoon they live in and on the organic detrital layer on the lagoon floor and some may receive a major portion of their sustenance from detritus.

6. The energy available to the fish and birds in the form of the epibenthos remains at least one or two orders of magnitude greater throughout the summer than the daily consumptive requirements of the fish and birds, and the overlap in diets of fish and birds is high. Implications are that food is not a limiting factor to birds and fish while they are in nearshore waters.

7. The abundant anadromous fishes--arctic cisco, arctic char and least cisco--and less commonly the marine fourhorn sculpin and arctic cod concentrate in shallow lagoon areas that are very near shorelines, implying that they select these areas to facilitate migration and/or feeding. Nearshore shallows had warmer temperatures and lower salinities than deeper marine waters; these factors may, in part, account for the high usage of nearshore areas by anadromous species. Fish populations did not appear to be limited by natural factors in nearshore environments during summer.

8. The time of most intensive use of the nearshore system by birds was August and September. During this time migration and molting seaducks (primarily oldsquaws), staging shorebirds (primarily phalaropes), and transient arctic terns and glaucous gulls were the dominant users of the area. Spring migrants made little use of the lagoon system.
9. For all bird species except those which are known to nest on islands in preference to the mainland, nesting densities on the barrier islands were lower than would occur in similar mainland habitats. Arctic fox predation on bird nests on islands caused a high percentage of the nests to fail.

RECOMMENDED FURTHER RESEARCH

Research objectives recommended by investigators of RU 467 are summarized below; research recommended by investigators who are part of this program but under separate contract are presented in the annual reports of their respective Research Units. The objectives listed below were formulated during the course of the workshop held in December, 1977, based upon the best judgement of investigators at that time. In view of further analysis of research data since that date, research plans for 1978 are currently under revision and will be finalized during the course of the forthcoming workshop in April.

Avian Ecology

1. Evaluate the use of the barrier island-lagoon system by birds, primarily phalaropes during August, and oldsquaw during the staging, molting and molt-migration period from 21 June to 10 August and during the fall migration period from 25 August to 25 September.
2. Evaluate the importance of the gravel barrier islands to nesting eiders, brant, gulls and terns, including an evaluation of impacts of arctic fox predation on these island nesters.
3. Further evaluate feeding dependencies of phalaropes, glaucous

gulls, and oldsquaws by collecting only the number of birds required to show general similarities/differences between the 1977 and the 1978 diets.

Ecology of Fish

1. Determine temporal habitat utilization and preferences of important fishes in the lagoon and nearshore marine system; determine the characteristics of important habitat for these fishes.
2. Evaluate distributions and movements of fish in relation to temperature and salinity regimes and possibly other oceanographic parameters.
3. Evaluate general feeding dependencies of important fishes to compare with feeding dependencies found in 1977.

Invertebrates

1. Conduct quantitative sampling by divers, coupled with conventional sampling techniques, to estimate density and biomass of invertebrates in relation to habitat and time.
2. Carry out oxygen consumption experiments (micro-Winkler techniques) in the field to estimate energy consumption (digestion rates) of epibenthic species.
3. Sample invertebrate populations under the ice in April and during spring breakup in early June in various habitats to help clarify the overwintering and/or recolonization strategies of the epibenthic invertebrates.
4. Gather seasonal life history data (length, weight, sex and breeding condition) for important invertebrate species.

SUMMARY OF 4TH QUARTER OPERATIONS

1. Ship/Laboratory Activites.
   Laboratory analyses of invertebrate samples which were conducted during the course of the last quarter were continued for the first half of this quarter. See RU 467, Invertebrates section, for methods and results.
2. Problems Encountered/Recommended Changes.
   Not applicable.
3. Estimate of Funds Expended.
   Over 90% of contract funds have been expended.

Appendix I. Reports Submitted by LGL Limited-U.S., Inc. During the Course of the Barrier Island-Lagoon Program.

July 1976	Gallaway, B. and J. Truett. Background information for the Beaufort Sea Barrier Island-Lagoon Ecosystem Studies. Report submitted to NOAA-OCSEAP, Boulder, CO. 32 p.
Sept 1976	Truett, J. and B. Gallaway. Draft Barrier Island-Lagoon research plan. Submitted to NOAA-OCSEAP, Boulder, CO.
Oct 1976	Truett, J. and B. Gallaway. Barrier Island-Lagoon research plan. Submitted to NOAA-OCSEAP, Boulder, CO. 143 p.
Jan 1977	Truett, J., A. Birdsall, C. Walters, S. Buckingham, R. Hilborn, and R. Peterman. Report of the first modeling workshop (1-3 Dec 1976) and revised research plan. Submitted to NOAA-OCSEAP, Boulder, CO. 160 p.
July 1977	Truett, J. Quarterly progress report covering period 1 April to 30 June 1977. Submitted to OCS Arctic Project Office, Fairbanks, AK. 11 p.
Sept 1977	Spies, M. Report of the Post-Field Season Seminar held on 12 September 1977. Submitted to OCS Arctic Project Office, Fairbanks, AK. 13 p.
Oct 1977	Truett, J. Quarterly progress report covering period 1 July to 30 Sept 1977. Submitted to OCS Arctic Project Office, Fairbanks, AK. 13 p.
Jan 1978	Truett, J. Quarterly progress report covering period 1 October to 31 December 1977. Submitted to OCS Arctic Project Office, Fairbanks, AK. 7 p.
Jan 1978	Truett, J., C. Walters, R. Hilborn, M. Staley, S. Buckingham, and P. Kleiber. Report of the Modeling and Integration Workshop, 6-8 December 1977. Submitted to OCS Arctic Project Office, Fairbanks, AK. 26 p.

BEAUFORT SEA BARRIER ISLAND-LAGOON
ECOLOGICAL PROCESS STUDIES

Section II

AVIAN ECOLOGY IN SIMPSON LAGOON, 1977

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31 March 1978

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SUMMARY

In 1976, LGL Limited-U.S., Inc. initiated an interdisciplinary, process-oriented study of a barrier island-lagoon ecosystem on Alaska's Beaufort Sea coast. The general scope of the ornithological components of this study, which was sited in the Simpson Lagoon area, was to characterize the use of nearshore habitats by birds and to clarify those critical feeding and habitat dependencies that development is likely to affect either directly, or indirectly via process alteration.

The research program addresses four ecosystem uses/dependencies of birds--for migration, breeding, feeding and staging-molting. These uses are evaluated as they relate to barrier island-lagoon habitats and predicted development alterations of habitats.

Results

Migration Studies

Spring migration (late May to mid-June) was eastward over a broad front; major bird groups involved were loons, glaucous gulls, jaegers, pintails, oldsquaws, eiders and black brant.

The westward molt migration by male seaducks consisted of two peaks--movement of oldsquaws during early July, prior to breakup in the lagoon or in the sea, and movement of common and king eiders through the study area during the 21 to 25 July period, after the lagoon and sea ice had retreated. Oldsquaws made moderate use of shoreleads in lagoons and light use of cracks in the lagoon during the course of their migration; eiders made light use of lagoon habitats during the westward molt migration.

The fall migration by birds out of the Simpson Lagoon area was protracted and much less intense than either the spring or molt migration. Most oldsquaws and glaucous gulls had not begun their fall migration out of the study area when the field season was terminated on 25 September 1977. A major westward movement of adult and juvenile arctic terns occurred along the barrier islands during the third and fourth weeks of

August, at which time they congregated at gaps between the islands and along the spits and sandbars. A major movement of black brant occurred along the mainland coast during the last days of August and the early days of September. A westward movement of loons through the lagoon occurred during the last week of August and the first week of September.

Nesting Studies

Arctic foxes preyed heavily on eggs of birds which nested on the barrier islands, and (presumably because of the predation) densities of successful nests were relatively low. Indications were that in the absence of arctic foxes on gravel islands, the nesting potential for traditionally island-nesting species was high.

Molting and Staging Studies

An estimated 50,000 male oldsquaws concentrated in the lagoon between late July and mid-August to molt. Few molting oldsquaws used marine habitats. An estimated 106,000 female and juvenile oldsquaws were present in the study area during late September.

Juvenile northern and red phalaropes arrived to feed along the shorelines of the barrier islands and mainland during mid-August, especially concentrating along the seaward beaches of the barrier islands.

Glaucous gulls in the study area were also associated with shorelines; their distribution appeared to be related to the availability of food. During late June and in July, they were most abundant along mainland shorelines, but during August, they were most abundant along the lagoonside shorelines of the barrier islands. During September, the number of glaucous gulls increased dramatically in the study area, and they were most abundant along the seaward beaches of the barrier islands.

Feeding Studies

Oldsquaws ate primarily mysids and amphipods, and to a lesser extent, bivalves. They ate largely the kinds of foods which were most available; their diet was similar to that of the arctic cisco, the most common coregonid fish in the lagoon.

Oldsquaws were fattest during the late July to mid-August period of molt. Their fat reserves declined thereafter, which suggests that subcutaneous fat may play an important role during the molt period (e.g., for insulation and/or to satisfy maintenance energy requirements) and that this fat may be utilized after the molt to help meet the energy demands associated with feather replacement. To some extent oldsquaws concentrated around headlands or points of land in Simpson Lagoon where currents may concentrate invertebrate organisms consumed by oldsquaws and/or where they may seek protection from wind. Throughout the summer, the standing stocks of epibenthos used as food by oldsquaws apparently remained several orders of magnitude greater than the estimated per-day food requirements of the birds.

Glaucous gulls fed exclusively along shorelines in the study area and ate mainly isopods, amphipods, small fish and small birds. The relative proportions of the organisms they consumed bore little resemblance to the proportions of these same organisms at the locations where glaucous gulls were collected. Feeding overlap studies indicated that the diet of glaucous gulls was most similar to that of the four-horned sculpin. The highest densities of glaucous gulls were recorded along the seaward beaches of the barrier islands during the third week in September, when this species was feeding on hyperiid amphipods.

Phalaropes concentrating on coastal shorelines in August ate primarily copepods, small amphipods and small mysids. The proportion of these organisms in the diet of phalaropes were similar to the proportions of these taxa available to them. Both northern and red phalaropes are specialized shoreline feeders. Diets of red and northern phalaropes were very similar to each other and collectively were similar to diets of arctic char and least cisco.

Disturbance Studies

Data from other studies coupled with observations made during the course of this study showed that the vulnerability of birds to disturbance varies among species, habitats, and type of bird activity.

Table 1 gives a sensitivity/vulnerability matrix of important avian species, their habitats and the periods when they are concentrated and are therefore most vulnerable to development-related environmental activities.

Conclusions

General conclusions were that:

1. Bird activity was minimal while the nearshore areas remained frozen in early summer; potential impacts of development are therefore probably also low at this time except for those activities which would create open water.
2. Nearshore areas were used moderately by birds after breakup began but before the nearshore became completely ice-free.
3. Heaviest use of nearshore areas by birds occurred during the open-water season--August and September. Primary use of the area at this time was by molting and migrating oldsquaws, staging shorebirds, and staging glaucous gulls. Feeding activity in the area was intensive by all these birds. Potential impacts of development may, therefore, be most serious during this open-water season.

Table 1. Sensitivity/Vulnerability† Index For Various Species and Habitats in the Simpson Lagoon-Jones Island Area of Alaska. (Preliminary; based on 1977 data and general principles).

	HABITATS								
	Barrier Islands				Lagoon		Mainland Shoreline		Offshore Marine
Species	Tundra	Gravel	Oceanside Shorelines	Lagoonside Shorelines	Shallow Lagoon	Deep Lagoon	Entire Shoreline	Points of Land	
Oldsquaw				loafing* (25 July-30 Aug)	loafing* (25 July-30 Aug)	Feeding*** (open water season)		Shelter or* feeding	
Eider		nesting*** (1 June-30 July)							migration*** (1 May-5 June and 15 July-10 Sept)
Brant		nesting** (1 June-30 July)					migration* (25 Aug-5 Sept)		
Loon									feeding** (open water season)
Phalarope			during high density staging*** (10-20 Aug)	during high density staging** (10-20 Aug)			during high density staging* (10-20 August)		
Glaucous Gull		nesting* (1 June-30 July)	during high density staging* (15-30 Sept)	feeding/ staging* (30 Aug-30 Sept)	feeding* (25 July-30 Aug)				
Arctic Tern		nesting*** (1 June-30 July)		feeding/ staging* (15-30 Aug)	feeding* (15-30 Aug)				

* Sensitive/vulnerable.

** Very sensitive/very vulnerable.

***Critically sensitive/critically vulnerable.

† The term sensitive refers primarily to habitats and the term vulnerable refers primarily to species.

INTRODUCTION

The Alaskan Beaufort Sea, especially its coastal lagoons and barrier islands, is an important area to many species of water-associated birds. During a portion of the year, significant fractions of the total North American populations of a number of species are present in the coastal nearshore waters of the Beaufort Sea (Johnson *et al.* 1975). These include the following: brant, oldsquaw, common and king eiders; glaucous Sabine's and Ross' gulls; arctic terns; and red and northern phalaropes. Some of these birds occur in the coastal Beaufort Sea area only during migration, but others also nest, molt, feed and accumulate fat reserves there (Johnson *et al.* 1975).

General Nature and Scope of Study

In 1976, LGL Limited-U.S., Inc. initiated an interdisciplinary, process-oriented study of a barrier island-lagoon ecosystem on Alaska's Beaufort Sea coast. The general scope of the ornithological portions of this study, which was sited in the Simpson Lagoon area, was to

1. assess the importance to birds of barrier island-lagoon habitats in the Beaufort Sea,
2. determine the degree and nature of dependence by birds on these habitats, and
3. clarify those critical feeding and habitat dependencies that development is likely to affect either directly or indirectly via process alteration.

Specific Objectives

The research program addresses each of four ecosystem uses or dependencies of birds--migration, nesting, feeding and staging-molting. These uses are evaluated as they relate to barrier island-lagoon habitats and predicted development alterations of habitats with these objectives:

1. Determine the timing, routes, volumes and major species involved in the spring migration, molt migration and fall migration of birds through a barrier island-lagoon system.

2. Identify the key species of birds and obtain quantitative estimates of their seasonal abundance in the major habitat types present in the barrier island-lagoon system.
3. Obtain quantitative estimates of the density, relative nesting success and major predators of breeding birds in the typical barrier island-lagoon habitats.
4. Determine the major food organisms consumed by the key bird species during periods of their peak abundance in a barrier island-lagoon system.
5. Determine the relationships between feeding birds and their habitats; e.g., do key species select particular food organisms or do they simply eat in accordance with the relative availability of organisms present in feeding habitats.

Relevance to Impact Assessment

Plans for the development of petroleum resources in the coastal area of the Alaskan Beaufort Sea are proceeding rapidly. Activities affecting the coastal barrier islands and accompanying lagoon systems play a prominent role in the various development scenarios presented by the petroleum industry (OCS Arctic Project Office, Proceedings 2nd Beaufort-Chukchi Seas Synthesis Meeting, Barrow, Alaska, 1978). Federal and state authorities have expressed the desire that development proceed with minimum disturbance to bird populations that are of concern to society because of their aesthetic, sport or subsistence value.

Industrial activity following petroleum leasing of nearshore waters may potentially affect birds in two major ways:

1. By imposing direct mortality or stress (e.g., oiling of birds, disturbance caused by aircraft overflights, destruction of nesting habitat, or introduction of predators).
2. By interrupting key physical and biological processes (e.g., coastal erosion, water circulation, nutrient and invertebrate production and cycling, etc.) that currently enable birds to successfully use the area for migration, breeding, feeding, staging and/or molting, or that affect the degree of mortality or stress mentioned in (1), above.

CURRENT STATE OF KNOWLEDGE

Current knowledge of birds found in the Beaufort Sea area is reviewed by Johnson *et al.* (1975). Searing *et al.* (1975) presented results of aerial surveys of seabirds conducted in the Canadian Beaufort Sea in 1972 and 1974. Barry (1976) has presented a brief summary of all available information on seabirds found in the Canadian Beaufort Sea. Richardson *et al.* (1975) presented detailed information on the spring migration of birds along a portion of the Beaufort Sea coastline in the Yukon Territory and eastern Alaska. Gavin (1976) and Bergman *et al.* (1977) recently published the results of long-term studies of the avifauna of the Beaufort Sea coast of Alaska. The work by Bergman *et al.* (1977) was restricted to tundra locations on the mainland, whereas the observations by Gavin (1976) included the coastal barrier islands and lagoons.

Several published accounts describe the birds in the immediate vicinity of the Jones Islands-Simpson Lagoon area. Hall (1974, and unpublished data 1972) has provided an annotated list of the birds seen near Oliktok Point and in Simpson Lagoon from 12 June to 23 August 1971 and intermittently from 11 May to 27 November 1972. Gavin's (1976) report includes details of water bird production on the Jones Islands for the 6-year period 1970 through 1975. Divoky (1978) conducted ground and aerial surveys of nesting birds along all of the Jones Islands during 1976 and two aerial surveys of the Simpson Lagoon area. During 1977, Divoky (1978) conducted opportunistic shipboard surveys of birds in the Simpson Lagoon area and at this location collected a small sample of oldsquaws for stomach analyses. Schamel (1974) described some aspects of the spring migration, the molt migration of seaducks, and the densities of shorebirds, gulls, terns, jaegers and seaducks in a portion of Gwydyr Bay near Egg Island, approximately 15 km east of Simpson Lagoon. Bergman *et al.* (1977) reported the results of a five-year study of waterbird and wetland resources on the mainland coastal tundra near Storkersen Point, which is approximately 25 km east of the Simpson Lagoon study area. Similarly, Norton *et al.* (1975) reported on the ecological relationships of the inland tundra avifauna near Prudhoe Bay, approximately 40 km east of Simpson Lagoon. Derksen *et al.* (1977) conducted habitat analyses during 1977 and reported on waterbird populations at tundra locations in the western portion of the Naval Petroleum Reserve, west of the Colville River, Alaska. King (1977) has reported on extensive aerial surveys of birds on tundra habitats in the Naval Petroleum Reserve.

STUDY AREA

The study area chosen for intensive ornithological investigations was the Jones Islands-Simpson Lagoon system. For comparative purposes, intermittent investigations were also conducted in adjacent areas.

The Jones Islands have been defined as all islands, spits and bars from Spy Island to Cottle Island (6.4 km^2, Fig. 1). The tundra-covered portions of Pingok, Peat, Bertoncini, Bodfish and Cottle Islands occupy an area of 3.8 km^2, and are characterized by poor soils (Everett 1975) and tundra vegetation of low growth form (Spetzman 1959; Wiggins and Thomas 1962; Nieland and Hok 1975; Webber and Walker 1975). The remaining 2.6 km^2 of island habitat, located principally on Spy, Leavitt and Cottle Islands, is covered with gravel, sand and silt.

Simpson Lagoon has been defined as that area east of a line from the west end of Spy Island to Oliktok Point, and west of a line from the east end of Cottle Island to Beechey Point (Fig. 1). This area occupies approximately 160 km^2, of which approximately 102 km^2 is 2 m deep or deeper. The deepest known point in the lagoon, located immediately off the east end of Spy Island, is 4 m deep. A trough, varying in width from 0.3 km at the east end of the lagoon to 5 km at the west end of the lagoon, and varying in depth from 2 to 3 m, runs the length of Simpson Lagoon. The remaining 58 km^2 of lagoon area is shallower than 2 m; almost two-thirds of these shallow waters lie along the south shore of Simpson Lagoon. (Planimetry conducted on U.S. Dept. Commerce, Coast and Geodetic Survey Chart No. 9471, 4th edition, May, 1973.)

Also included within the study area is a 32 km x 20 m (0.64 km^2) strip of coastline that includes beaches, adjoining spits and adjacent sand bars along the mainland shoreline between Oliktok Point and Beechey

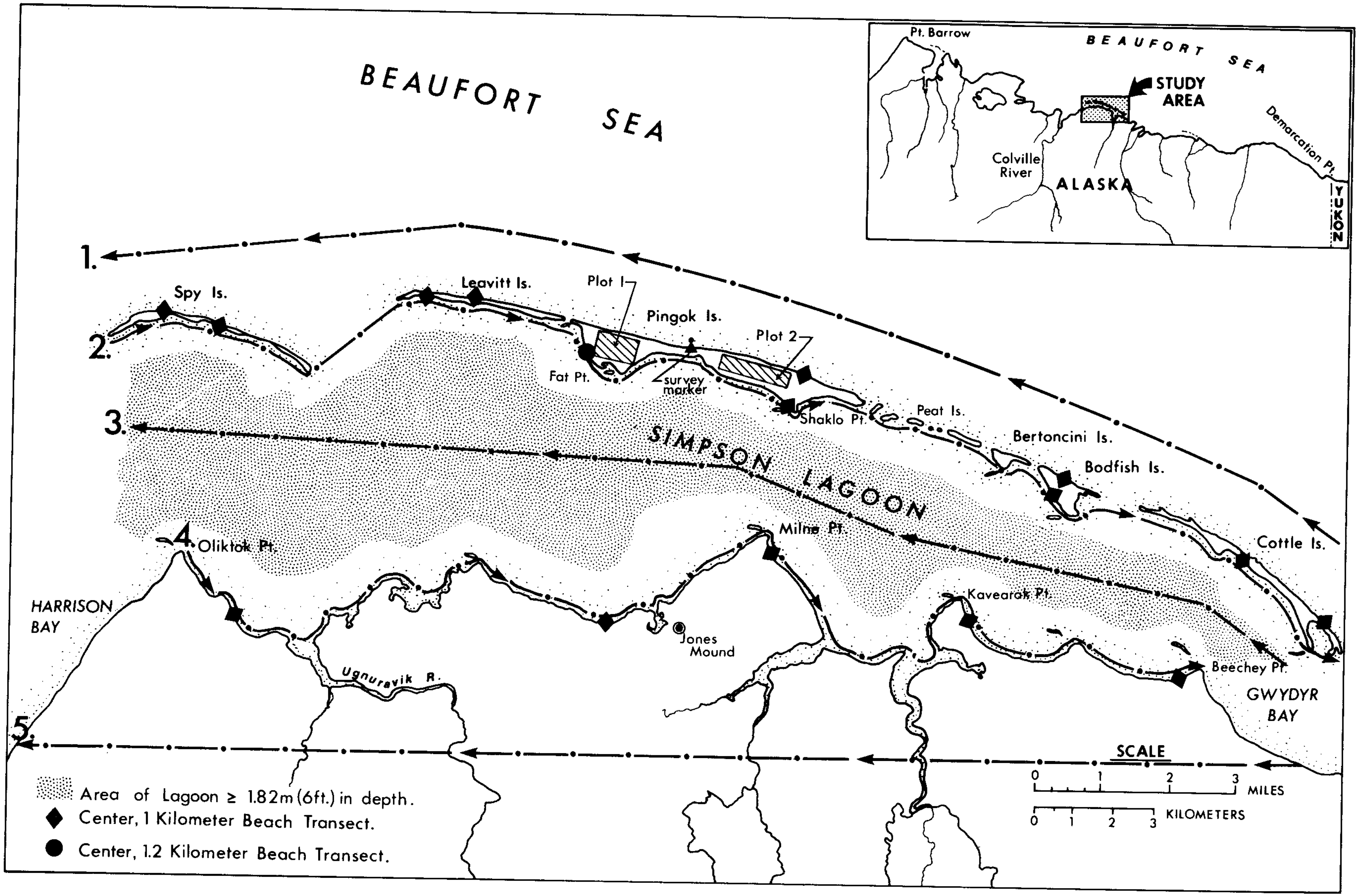

Fig. 1. Jones Islands-Simpson Lagoon, Alaska, Study Area.

Point. This strip includes most of the driftwood and debris along this portion of the Beaufort Sea coast.

In order to compare avian use of the barrier island-lagoon study area with avian use of adjacent marine and mainland areas, regular surveys were also conducted of two additional transects, one seaward and one landward of the study area. One of these was a 35 km x 0.4 km marine transect strip parallel to and approximately 2 km seaward from the Jones Islands. Another 35 km x 0.4 km transect strip was located approximately 4 km inland from the mainland shoreline between Oliktok Point and Beechey Point (Fig. 1).

METHODS AND RATIONALE OF DATA COLLECTION

Migration Studies

Detailed quantitative analyses of the migration watch and radar data are incomplete and not presented in this Annual Report, but will be presented in a conclusive report at a later date. In this section we describe or document methods used to study migration and in the "Results" we present three tables (Tables 3, 4 and 5) describing important species and events associated with migrations of birds through the study area. Three major migrations of marine-associated birds occur along the coast of the Beaufort Sea: spring migration, mid-summer molt migration and fall migration. During these migrations, birds usually occur in flocks and may be both spatially and temporally concentrated in certain lagoon habitats.

Spring migration occurs during a critical period because there is little open water in normal years. Under certain circumstances, high mortality can occur from natural causes (Barry 1968). An oil spill at this time into a natural or man-made area of open water might kill large numbers of waterbirds. Hence, our most intensive efforts (radar and visual) to monitor migrations through the barrier island-lagoon system were carried out during the spring.

The westward molt migration by male seaducks generally occurs during July. Except near Point Barrow, Alaska, the mid-summer molt migration is much less conspicuous than the spring migration. Fewer species and individuals are involved in this migration; furthermore, relatively small-scale movements occur in the coastal nearshore waters around barrier islands and lagoons at this time of year. Most coastal lagoon habitats remain predominantly ice-covered until mid-July, limiting the number of habitats that these migrating birds may occupy.

The westward fall migration out of the Beaufort Sea generally involves much less concentrated activity than either the spring or molt migrations. Although this migration involves more species than the molt migration, movements normally occur on a broader temporal and spatial scale within the coastal Beaufort Sea area. All coastal habitats are available to most fall migrants.

Since far fewer birds passed through barrier island-lagoon habitats during westward molt and fall migrations, these movements were not monitored as intensively as the eastward spring migration; only visual methods were employed during these westward migrations.

Spring Migration

Radar Monitoring. Radar data were recorded using the Oliktok Point, Alaska, DEW surveillance radar (70° 30'N, 149° 53'W). Radar data were obtained on a nearly continuous 24-hour basis on 18 May and from 26 May to 17 June 1977. The radar methods used consisted of time-lapse and still photography of the radar Plan Position Indicator (PPI) display. These methods were virtually identical to those used by Richardson *et al.* (1975) to study spring bird migration along part of the Canadian Beaufort Sea coast. That paper describes the radar, filming procedures and methods of quantifying numbers and directions of movement of birds.

Visual Migration Watches. Daily visual migration watches were conducted from 17 May to 15 June at Oliktok Point, and from 5 to 14 June at two sites on Pingok Island, both located 12 km NE of Oliktok (Fig. 1). At each site, one observer conducted watches on a regular schedule. Procedures during a migration watch are presented in Johnson *et al.* (1975), and methods of analysis are presented in Richardson *et al.* (1975).

At Oliktok Point, the migration watch was conducted atop a fuel storage tank from a level about 7 m above sea level (ASL). This location afforded good visibility in all azimuths except 205°-225° where buildings and radar apparatus 2000 m away partially obstructed visibility. The frozen lagoon surface was smooth. Binoculars (9x or 10x) and spotting telescopes (20-45 x zoom) were used. On clear days flying birds could often be detected and classified at least to major taxonomic category (i.e., loon, waterfowl, gull, etc.) at distances as great as 7-8 km.

Two migration watch posts on Pingok Island were located at the extreme western end of the tundra-covered portion of the island. One post was situated on the southwest shore and the other about 6 m ASL atop a building located about 40 m from the north shore (Fig. 1). The observer at the northern post recorded movements seaward of the barrier islands. Rough ice and pressure ridges obstructed visibility of low-flying birds beyond about 3 km seaward. The observer at the southern post recorded movements lagoonward of the island. The southern post was approximately 300 m south of the northern post, and although this post was not elevated, the lagoon surface was smooth and visibility was unobstructed to the mainland coast, approximately 7 km to the south.

Observers at all three posts maintained a daily schedule of three 2-hr watches: one in the morning, usually between 10:00 and 12:00 hrs Alaska Daylight Time (ADT); another during the afternoon, usually between 14:00 and 16:00 hrs ADT; and a third in the evening, usually between 20:00 and 22:00 hrs ADT. At all migration watch posts, observations were recorded with a portable tape recorder; this enabled observers to watch continuously. Data were transcribed from magnetic tapes, coded on standard forms and keypunched.

For purposes of analysis, definite or probable migrants were separated from local residents on the basis of behavior. Birds in sustained flight and that maintained an eastward (30°-150°) or westward (210° to 330°) course were included as migrants; those that were sitting, landing or taking off, or engaging in territorial behaviour were included in an "other" category (with those that flew north or south).

Mid-Summer Molt Migration

Data concerning the mid-summer molt migration of seaducks (oldsquaws, common and king eiders) were collected from 26 June to 25 July 1977. No use was made of radar during this period, nor was a rigid daily schedule of migration watches maintained. The amount of time devoted to migration watches depended on the factors listed below:

1. The prevailing weather conditions; if fog was present throughout the study area, no watches were conducted.
2. The demands of other duties associated with the ornithological program and sometimes judged to be of higher priority than migration watches.
3. The relative volume of bird migration noted during the course of duties (including migration watches) associated with the ornithological program.

During molt migration watches, one observer used the elevated north post on Pingok Island (as described above). He recorded all birds seen regardless whether they flew over the islands, lagoon or sea. Watches were usually conducted between 09:00 and 11:00 ADT and between 21:00 and 23:00 ADT. When weather permitted and the volume of migration dictated, longer and more frequent watches were conducted, as indicated below:

Date	Number of Hours	Time (ADT)
June 26	4	09:00-11:00; 21:00-23:00
July 2	4	15:00-16:00; 17:00-18:00; 19:00-20:00; 21:00-22:00
3	6	09:00-10:00; 11:00-12:00; 13:00-14:00; 15:00-16:00; 18:00-19:00; 21:00-22:00
4	5	09:00-10:00; 11:00-12:00; 13:00-14:00; 15:00-16:00; 18:00-19:00
7	1	09:00-10:00
12	2	21:00-23:00
13	2	09:00-11:00
14	2	09:00-11:00
15	4	09:00-11:00; 21:00-23:00
20	2	21:00-23:00
21	1	09:00-10:00

Date	Number of Hours	Time (ADT
(cont'd)		
July 22	2	21:00-23:00
23	4	09:00-11:00; 21:00-23:00
24	4	09:00-11:00; 21:00-23:00
25	2	09:00-11:00

In addition, all flocks or aggregations of birds seen during other research activities were recorded and included in the analysis of molt migration. Observations during watches were recorded on tape; additional observations were recorded in notebooks and also were coded for keypunching.

Definite or probable migrants were separated from local residents on the basis of the same behavioral criteria as in spring.

Fall Migration

Data concerning "fall" migration were collected from 21 August to 22 September 1977. Radar was not used. Watches were conducted by one observer from the elevated north post on Pingok Island using the same procedures as used during molt migration. Migration watches were usually conducted between 08:00 and 12:00 ADT and between 16:00 and 18:00 ADT.

Nesting Studies

Both Gavin (1976) and Divoky (1978) have presented estimates, based on primarily non-quantitative methods, of the numbers of waterbirds nesting on the Jones Islands. An accurate quantitative assessment of numbers of birds nesting on barrier island habitats can only be made by establishing and thoroughly searching plots or by systematically searching all available nesting habitats. Because of the large amount of tundra habitat available on Pingok Island (see "Study Area"), two large plots were established and studied on tundra portions of this island. The total area of all other barrier islands was completely surveyed.

Survey Methods

On 16-20 June 1977 two tundra plots, one covering 0.63 km^2 (Plot 1) and another covering 0.30 km^2 (Plot 2), were established on Pingok Island (Fig. 1). A compass and 100 m steel tape were used to designate and stake 100 m intervals within the plots. Between 20 June and 20 July, these two plots were surveyed for nesting birds twice, and all tundra habitats on Peat, Bertoncini, Bodfish and Cottle Islands (total area 0.87 km^2) were surveyed for nesting birds once. During surveys, two or three observers flushed birds from their nests by dragging a 50 m length of rope perpendicular to the direction of movement across the tundra. Most birds flushed in advance of the oncoming rope, although some did not flush until the rope passed over them.

From 21 to 24 June 1977, the locations and number of all territorial males (Π♂♂) of all species of birds seen on Plots 1 and 2 on Pingok Island were recorded.

The 2.6 km^2 of barrier island habitat covered by gravel, sand and silt was surveyed by searching along all the driftwood rows and in piles of debris where, in the Beaufort Sea area, species such as common eiders, glaucous gulls and arctic terns may nest (Schamel 1974; Divoky 1978).

When an active nest (a nest with at least one egg or young) was discovered, its position was mapped and a stake was placed at a given distance and direction from the nest. The stake was labelled, colored flagging tape was attached and the following information about the nest was recorded:

1. The presence or absence and behavior of any adult birds near the nest.
2. The number of eggs and/or young present in or near the nest.
3. A description of the substrate, nest material and cover near the nest.
4. Any evidence of predation or recent activity of predators near the nest site.

Nests constructed during previous years, destroyed nests and partially completed nests (including nest scrapes) were also recorded, and their positions mapped.

Molting and Pre-Migratory Staging Studies

Most waterfowl undergo a summer molt during which they simultaneously lose all of their flight feathers. Male seaducks migrate along specific traditional routes to specific locations where they concentrate into large flocks and undergo this molt (Salomonsen 1968). Hall (1974) and Gavin (1976) have previously suggested that Simpson Lagoon may be an important summer molting area for oldsquaws.

After they leave their tundra rearing areas and before they migrate out of the Beaufort Sea area, immatures of certain species of shorebirds also concentrate into large feeding flocks along the coastline. Connors and Risebrough (1976, 1977) have indicated that coastal locations in the western portion of the Beaufort Sea are important concentration areas for immature phalaropes. This process of pre-migratory concentration is called "staging". Any species that concentrated for a significant period of time in the Jones Islands-Simpson Lagoon study area was considered to be staging.

Specific survey programs and methods were designed to efficiently and accurately quantify the abundance and distributions of molting and staging birds in the study area.

Aerial surveys provide a method for rapidly and systematically recording numbers and distributions of medium-sized and large birds, such as oldsquaws, gulls, terns and loons, in a wide area. The aerial method is applicable over land, water and ice. Disturbance to birds caused by aircraft is of shorter duration than that caused by slow-moving waterborne craft and results are less biased by attraction to or repulsion from the survey vehicle.

Shoreline surveys from small boats were used to record numbers and distributions of small shoreline-associated birds such as phalaropes, sandpipers and plovers. (Because these surveys were restricted to shoreline areas, well away from major concentrations of seaducks present in the study area, disturbance to seaducks during boat surveys was thought to be minimal.) Gulls and terns, which also may associate with shorelines, especially when feeding, were also recorded during boat surveys. Hence, large shoreline-associated species such as gulls and terns were surveyed equally well from both aircraft and boats. Those large species associated with open water areas away from shorelines were surveyed most comprehensively from aircraft.

Aerial Surveys

Aerial surveys were conducted on seven occasions during 1977: 5 June, 20 June, 5 July, 28-29 July, 15 August, 30 August and 22 September. Each survey consisted of one flight along each of five permanent transect strips, each located in a different type of habitat (Fig. 1).

Transect 1 was over offshore marine habitat, approximately 2 km seaward of the barrier islands. Transect 2 was along the barrier islands. The aircraft was positioned directly over the center of the islands when the islands were narrower than the 400 m-wide transect strip. Along those portions of the islands that were wider than 400 m, the aircraft was maneuvered to a position about 100 m lagoonward of the south shoreline of the island. Transect 3 was along the deep central portion of Simpson Lagoon. Transect 4 was along the mainland shoreline of Simpson Lagoon; the aircraft was positioned 100 m lagoonward of the mainland shoreline. Transect 5 was over the mainland tundra, an average of 4 km inland of the south shore of Simpson Lagoon.

Aircraft flight procedures were standardized to the greatest extent possible. However, because it was necessary to use three different types of aircraft during the aerial survey program, including both fixed- and rotary-wing aircraft, variations in flight speed, observer visibility and aircraft seating position were unavoidable.

Except for the 28-29 July survey, a single aircraft was used to conduct a particular aerial survey on a single day. The 28-29 July survey was conducted over a two-day period and two different types of aircraft were used. A float-equipped aircraft was unavailable on 15 August so transects over open water were not surveyed on that date. Table 2 summarizes flight procedures by survey and transect.

On all surveys, both observers recorded into portable tape recorders all birds seen both on-transect (≤200 m from aircraft) and off-transect (>200 m from aircraft). The information recorded was of four types:

Table 2. Details of Seven Aerial Surveys Conducted in the Study Area During the Period 5 June to 22 September, 1977.

Transect #	Transect* Length (km)	General Habitat Type	Aircraft Type†						
			5 June	15 June	5 July	28/29 July	15 August	30 August	22 Sept.
1**	35.4	Offshore Marine	Bell 205	Bell 205	Bell 206	Bell 206	Not Surveyed	Bell 205	Bell 206
2**	37.0	Barrier Island	Bell 205	Bell 205	Bell 206	Cessna 206	Cessna 206	Bell 205	Bell 206
3**	30.6	Mid-lagoon	Bell 205	Bell 205	Bell 206	Bell 206	Not Surveyed	Bell 205	Bell 206
4**	32.2	Mainland Shoreline	Bell 205	Bell 205	Bell 206	Cessna 206	Cessna 206	Bell 205	Bell 206
5††	33.8	Inland Wet/ Dry Tundra	Bell 205	Bell 205	Bell 206	Cessna 206	Cessna 206	Bell 205	Bell 206

* Transects were 400 m wide; each observer surveyed an area within 200 m of one side of the aircraft.

† One observer was seated in a front seat and one in a rear seat, on opposite sides of the aircraft. In fixed-wing aircraft, the front observer was seated on the right side; in rotary-winged aircraft, the front observer was seated on the left. Bell aircraft had rotary-wings; Cessna aircraft had fixed-wings.

**Survey altitude was 30 m and survey ground speed ($\bar{x} \pm$ S.E.; n=26) was 155.4 ± 4.29 km/hr (96.5 ± 2.67 mph).

††Survey altitude was 15 m and survey ground speed ($\bar{x} \pm$ S.E.; n=7) was 88.8 ± 16.79 km/hr (55.2 ± 10.42 mph).

(1) systematic information about the transect, (2) systematic information about each bird sighting, (3) systematic information about the habitats below the aircraft at one-minute intervals, and (4) general remarks. All information except general remarks was numerically coded when transcribed later onto data forms. All transects were divided into 1-min intervals using a timing device. The timer was reset to zero at the start of each transect and it produced a sound at 1-min intervals audible to both observers. The general habitat type found within each 1-min interval was recorded by both observers, and the interval-number in which each bird was seen was recorded.

When counts of both observers were combined, it was possible to calculate an estimate of the density of birds per square kilometer.

Shoreline Transects

Shoreline transects were designed primarily to measure the distribution and abundance of shorebirds, gulls and terns along the three types of beaches common in the study area. During the third week of July, fifteen shoreline transects were established. Five transects were located along seaward shorelines of the barrier islands, five along lagoonward shorelines of the islands, and five along mainland shorelines (see Fig. 1). Each transect was 1.0 km long and 0.02 km wide (0.02 km^2). The start and end points of each transect were permanently marked by driving 2.5 m pipes approximately 0.5 m into the beach substrate approximately 10 m in from the shoreline. No markers were placed 10 m out from the shoreline; during the surveys of these transects, this distance was estimated by the surveyor.

Each of these shoreline transects was surveyed on 1, 16 and 24 August and on 1 and 14 September. Another shoreline transect, established along a lagoonward beach on the west end of Pingok Island (Fig. 1), was 1.2 km long by approximately 0.02 km wide and was surveyed more frequently--18 times from 2 August to 18 September.

During each survey, all 15 permanent transects were surveyed within one 8-hr period with the aid of 10 x 40 binoculars from a boat moving parallel to the transect. The boat was positioned approximately 50 m from the outer edge of the transect, and did not appear to disturb shorebirds along the shoreline. During most surveys, one observer operated the boat while a second systematically recorded into a portable tape recorder the following information about each transect and any birds sighted:

1. The date, transect number, observers, start and end time of the survey, weather and water conditions, and direction of travel.
2. The number of individuals of each bird species present on-transect (within 10 m of the shoreline) or off-transect (greater than 10 m from the shoreline).
3. The estimated distance of each bird or group of birds from the shoreline, and whether the birds were sighted on the beach or in the water.
4. The behavior of each bird or group of birds sighted on-transect or off-transect.

Feeding Studies

Studies of the feeding ecology of marine birds provide a key link in the interpretation of relationships among physical parameters, biological productivity, and distribution and abundance of marine birds in a barrier island-lagoon system. Specific questions regarding the age, sex, stage of molt, physical condition and identity of food organisms consumed by birds during the various stages of bird abundance and lagoon productivity can only be answered by a bird collecting program.

The primary purpose of the avian feeding ecology studies was to determine which food organisms comprised the important proportions of the diets of those species of birds most widely distributed and most abundant in the study area. During 1977 the key avian species were (1) oldsquaws, (2) red and northern phalaropes (generally treated as a single group), and (3) glaucous gulls. We chose a qualitative method (see Hynes 1950 and Griffiths *et al.* 1975) for assessing the relative importance of food taxa found in bird stomachs, and in bird feeding habitats, because this method combined the following advantages:

1. It is efficient and relatively accurate in estimating the relative volumes of particular food taxa.

2. It is easily used under field conditions and requires no special apparatus for measurement of organisms.
3. It does not give the potentially misleading impression of accuracy given by some other methods that measure stomach contents more precisely but make no better allowance for sampling problems and differential digestion rates.

Appendix Table 1 compares the diet of oldsquaws as determined by the qualitative Hynes point method and by a quantitative biomass measurement method. The Hynes point method tended to overestimate the percent of amphipods and underestimate the percent of unidentified material in the diet of oldsquaws. The biomass measurement method tended to underestimate the percent of fish in the diet of oldsquaws.

Collections of Birds and Habitat Samples

Between 17 June and 19 September 1977, 210 specimens of four avian species (oldsquaw, red and northern phalaropes, and glaucous gull) were collected in the Simpson Lagoon-Jones Islands area. During the last two weeks of June, seven oldsquaws were accidentally caught in gill nets set as part of the aquatic biology investigations; the stomach contents of these birds were retained. The remainder of the 203 specimens were collected with shotguns from 11 July to 19 September period. Samples of potential food organisms, hereafter called habitat samples, were collected from the various habitats in which birds were feeding when they were shot. These habitat samples were collected immediately after collecting the birds.

Oldsquaws. Initial observations suggested that in Simpson Lagoon, oldsquaws fed primarily in deep water away from the shallow resting and loafing areas in bays and along shorelines. Therefore, a small sample of oldsquaws (three birds) was collected from a large flock (approximately 500 birds) loafing along a shoreline. All three of these birds had empty stomachs. As a result of these generally qualitative observations, most oldsquaws and oldsquaw habitat samples were collected in relatively deep portions of Simpson Lagoon (average depth where 89 oldsquaws were collected was 1.5 ± 0.54 m).

The general procedures followed for collecting oldsquaws and oldsquaw feeding habitat samples were the following:

1. From a boat, a flock of Oldsquaws was located and watched to determine whether a significant proportion of the birds appeared to be feeding (diving). An estimate was made of the size of the flock.
2. With a speeding boat, the flock was entered as quickly as possible, an anchored buoy was dropped as the boat was slowed, and as many birds as possible were collected.
3. Dead and crippled birds were retrieved and labelled. To mitigate post-mortem digestion of any food items, the gut (proventriculus and gizzard) and esophagus of each dead bird was injected with absolute isopropyl alcohol. The esophagus of each bird was then plugged with a paper wad.
4. After returning to the buoy, habitat sampling was initiated.
    a. For each set of birds collected, two quantitative samples were obtained, one from the surface-water and another from the mid-water portions of the lagoon. This was accomplished by towing both a surface-supported neuston net and a submerged (1 m deep) macroplankton net (see RU 467, INVERTEBRATES section, for more details).
    b. For each set of birds collected, one qualitative sample from the lagoon epibenthos was collected. From a stationary boat in the area of the buoy, a macroplankton net was manually towed across the bottom of the lagoon for a distance of approximately 10 m and at a speed of approximately 0.5-1.0 m/sec.
    c. Habitat samples were immediately washed from the sampling nets into double labelled 227 ml (8 oz) bottles and preserved in 10% neutral formalin.

Phalaropes and glaucous gulls. Visual observations indicated that red and northern phalaropes and glaucous gulls fed almost exclusively in shallow areas (<1 m deep) along shorelines and in bays. Therefore phalaropes and glaucous gulls, and associated feeding habitat samples, were collected in these shallow areas.

Phalaropes are very tame birds and large flocks were easily approached on foot as they fed along shorelines. They were collected while feeding and the post-mortem handling procedures described for oldsquaws also apply to phalaropes.

Glaucous gulls fed either singly or in loose aggregations; they were not easily approached on foot. We watched from a boat offshore to ascertain whether they appeared to be feeding--if so, we approached as quickly as possible from a speeding boat. The exact location where the bird(s) were feeding was visually noted as we approached. If a bird was collected, the same procedures described for the post-mortem handling of oldsquaws were applied.

A single quantitative habitat sample was collected with a surface-supported neuston net at the shallow location where either phalaropes or glaucous gulls were collected. The net was attached by a line to a 3 m pole and was towed manually from shore over a distance of approximately 50 m at an approximate speed of 1 to 1.5 m/sec through waters that varied in depth from 10 to 50 cm. Habitat samples were treated as described for oldsquaws.

Laboratory Techniques

Within 24-hours of collection all birds were dissected and food items found in the esophagi and guts were preserved. The following procedures for measurement and dissection of birds were followed:

1. The unflattened length of the right wing of each bird was measured (accurate within 1 mm) and the weight of each bird (accurate within 1 g) was determined using a Pesola spring balance.
2. The condition of the plumage and the stage of molt were recorded.
3. The amount of subcutaneous and abdominal mesenteric fat was subjectively classified according to the OCS fat code: 1=none; 2=light; 3=moderate; 4=heavy; 5=excessively heavy. The thickness of subcutaneous fat present at a standard location near the midline on the right side of the breast of each bird was measured to the nearest 0.5 mm.
4. The sex organs of each bird were removed, measured and stored in Bouin's fixative solution. In females, the diameter of the largest ovum was measured to the nearest 0.5 mm. In males, the lengths and widths of both the right and left testes were measured to the nearest 0.5 mm.

5. The esophagus and gut (proventriculus and gizzard) were removed as a single unit from each bird. This unit was slit lengthwise and its contents were washed with 10% neutral formalin into a 227 ml double labelled bottle. Because of the small size of food items consumed by phalaropes and because some food items were difficult to wash from their esophagi and guts, these organs were preserved also.
6. The carcasses of collected birds were not preserved, but were used as bait in amphipod traps.

To assess the importance of each food taxon in the diet of each of the four key bird species it was necessary to sort by major taxon the preserved stomach contents and feeding habitat samples. An estimate was made of the volume of each major taxonomic group (e.g., amphipod, mysid, copepod, isopod, etc.) by assigning points (Hynes 1950; Griffiths *et al.* 1975). Our method for assigning points differed in one major respect from the modified "Hynes Point Method" described by Griffiths *et al.* (1975). We assessed the total volume of the stomach contents after instead of before it had been removed from the stomach and bottled.

Twenty points were assigned to the fullest stomach analyzed of a particular species of bird; a distended stomach was assigned 25 points. The fullness of each additional stomach from that species was subsequently gauged against the fullest stomach and a corresponding number of points was assigned. The total number of points thus assigned to each stomach was partitioned among the major invertebrate taxa present after the sample had been sorted, and after each major taxon had been bottled. No distinction was made between whole organisms and fractions thereof. Unidentified pieces of organisms were classified as such.

As noted above, feeding habitat samples for oldsquaw were collected using three different types of sampling techniques, each designed to sample a different strata of lagoon water. Two of these techniques were quantitative and the third (the epibenthic tow) was qualitative. Habitat samples for gulls and phalaropes were collected by yet another method. Therefore, volumes of materials sampled using the various methods were not directly comparable, and only relative volumes of different taxa were considered.

Twenty points were assigned to the total volume of each oldsquaw, phalarope and gull feeding habitat sample and then an appropriate proportion of the total 20 points was assigned to the various major taxa in the sample. Before the assignment of points was conducted, each major taxon had already been sorted and bottled. The two most important taxa (mysids and amphipods) present in the stomachs and habitat samples of key bird species were further sorted, identified to the species level and weighed (formalin wet weight). For a comparison, small samples (20 individuals each) of mysids and amphipods were randomly selected from all oldsquaw stomachs, and from all oldsquaw habitat samples; these individuals were measured to the nearest millimeter.

Further details of the sorting, counting and weighing procedures are described in RU 467, INVERTEBRATES section (this volume).

RESULTS

Migration Studies

Spring Migration

As previously noted, migration data from 1977 have not yet been analyzed in detail, so this section presents only a preliminary outline of the findings. Migration watches began at Oliktok Point on 17 May, and on this date four glaucous gulls were recorded flying east. On 18 May, the only date prior to 26 May when the radar was available, radar showed almost no eastward movement but a minor westward movement. Broad-front eastward movements of moderate density occurred on 26-28 May; westward movement was much less pronounced.

Both radar and visual data indicated that peak spring migration began on 28-29 May, and it continued until about 12 June according to visual observations. Loons, glaucous gulls, jaegers, pintails, oldsquaws, common and king eiders and black brant were the most commonly observed species during this migration (Table 3). During continuous time-lapse and intermittent polaroid photography of the radar PPI display, birds were detected regularly at distances up to 70 km, and occasionally up to 90 km, from Oliktok radar.

Table 3. List of All Avian Species Recorded During Migration Watches Conducted During Spring 1977 at Oliktok Point and Pingok Island.

Species	First Observed*	Number Seen†	Periods of Peak Abundance	Predominant Migration Direction	Peak Migration Rates (# Birds/Hour)**
Yellow-Billed Loon	3 June	27 (31)	3-9 June	East	0.74
Arctic Loon	9 June	39 (48)	9-13 June	East	1.27
Red-throated Loon	9 June	25 (27)	9-13 June	East	0.84
Unidentified Loons	2 June	285 (300)	3-13 June	East	3.98
Pomarine Jaeger	28 May	238 (316)	28 May-6 June	East	8.93
Parasitic Jaeger	29 May	85 (96)	29 May	East	6.07
Long-tailed Jaeger	7 June	6 (10)	11-14 June	East	0.19
Unidentified Jaegers	28 May	109 (151)	29 May-10 June	East	5.50
Black-legged Kittiwake	9 June	3 (3)	9 June	East	0.22
Glaucous Gull	17 May	701 (1142)	11-14 June	East	4.16
Herring/Thayer Gull	2 June	5 (9)	--	--	--
Mew Gull	13 June	2 (2)	--	--	--
Sabine's Gull	7 June	4 (5)	7-12 June	East	0.12
Unidentified Gulls	1 June	14 (19)	9-13 June	East	0.71
Arctic Tern	6 June	26 (51)	13-14 June	East	0.37
Mallard	5 June	5 (5)	--	--	--
American Wigeon	10 June	4 (7)	--	--	--
Green-winged Teal	10 June	3 (3)	--	--	--
Shoveler	7 June	7 (7)	--	--	--
Pintail	1 June	495 (1338)	5-12 June	Local (?)	23.06
Oldsquaw	28 May	2778 (3461)	2-10 June	East	175.33
Steller's Eider	4 June	2 (2)	--	--	--
Spectacled Eider	6 June	20 (26)	9-10 June	East	0.65
Common Eider	30 May	889 (962)	4-10 June	East	26.98
King Eider	30 May	553 (902)	1-10 June	East	13.28
Unidentified Eiders	2 June	323 (404)	9-14 June	East	6.74
Unidentified Diving Ducks	1 June	530 (708)	1-11 June	East	27.75
Unidentified Ducks	31 May	1032 (1535)	1-11 June	East	84.50
Lesser Snow Geese	10 June	22 (22)	10-11 June	East	0.65

White-fronted Goose	17 May	74 (201)	--	Local	--
(Black) Brant	31 May	626 (995)	10-12 June	East	14.77
Unidentified Dark Geese	3 June	256 (284)	5-10 June	East	14.32
Unidentified Geese	3 June	322 (353)	11-13 June	--	--
Whistling Swan	1 June	14 (16)	--	--	--
Unidentified Waterfowl	5 June	166 (295)	5-9 June	East	14.13
Red Phalarope	3 June	45 (79)	8-12 June	East	1.53
Northern Phalarope	12 June	2 (4)	--	--	--
Unidentified Phalarope	12 June	4 (4)	--	--	--
Common Snipe	24 May	1 (1)	--	--	--
Rufous-necked Sandpiper	2 June	1 (1)	--	--	--
Pectoral Sandpiper	6 June	13 (20)	7-12 June	Local	--
Baird's Sandpiper	31 May	26 (934)	3-7 June	Local	--
Dunlin	29 May	18 (22)	3-12 June	Local	--
Semipalmated Sandpiper	1 June	8 (8)	3 June	Local	--
Black-bellied Plover	1 June	6 (7)	1 June	Local	--
American Golden Plover	29 May	12 (19)	29 May-3 June	Local	--
Killdeer	12 June	1 (1)	12 June	--	--
Unidentified Plovers	2 June	1 (2)	--	--	--
Ruddy Turnstone	24 May	32 (48)	29 May-9 June	Local	--
Unidentified Shorebirds	29 May	84 (136)	29 May-11 June	East	2.60
Willow Ptarmigan	18 May	1 (1)	18 May	Local	--
Rock Ptarmigan	28 May	7 (7)	6 June	Local	--
Rough-legged Hawk	6 June	1 (2)	--	--	--
Short-eared Owl	31 May	2 (4)	--	--	--
Horned Lark	6 June	2 (2)	--	--	--
Unidentified Swallows	1 June	3 (3)	--	--	--
Black-billed Magpie	27 May	3 (3)	27-28 May	Local	--
Common Raven	25 May	9 (9)	31 May-3 June	Local	--
Snow Bunting	17 May	102 (102)	27 May-8 June	Local	--
Lapland Longspur	27 May	83 (100)	28 May-7 June	Local	--
Savannah Sparrow	2 June	2 (2)	2-3 June	Local	--
White-crowned Sparrow	24 May	2 (2)	24 May-3 June	Local	--
Slate-coloured Junco	29 May	1 (1)	29 May	Local	--
Unidentified Redpolls	31 May	6 (15)	13 June	Local	--

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* Dates of first observation include incidental records as well as records during migration watches.

† Numbers to left of parentheses are total birds seen migrating during the period of peak abundance. Numbers in parentheses are total birds seen (migrants and others) during all migration watches.

** Peak migration rate is number of migrants seen per hour during the date of peak movement.

Eastward movements visible on radar were invariably broad-front in nature, with birds visible over the North Slope, coast, lagoon, barrier islands and Beaufort Sea. Some birds observed visually on radar changed course to follow mainland or island shorelines, and radar often showed more birds over the barrier island-lagoon system than for inland or offshore; however, radar never showed an intense, narrow stream of birds along the mainland coast, lagoon, islands or elsewhere. This situation contrasts with that found along the coast of the northern Yukon in the spring of 1975 (Richardson *et al.* 1975), where radar often showed a narrow, concentrated stream along the coast, and where coastal visual observations recorded many more spring migrants than were seen in this study.

Visual observations revealed very little westward migration through the Simpson Lagoon area in 1977. However, radar sometimes revealed major westward movements, invariably broad-front and often extending far inland and offshore. The species composition of these flights remains uncertain, but some shorebird species probably contributed.

Early in the season no open water was available and waterbirds seen during migration watches all flew past, primarily toward the east. Runoff from the Kuparuk and other smaller rivers began to flow onto the lagoon ice on 7 June. Thereafter a few of the eastbound brant, eiders and oldsquaw occasionally landed on the runoff water near Oliktok Point, but apparently not near Pingok Island. Some of these few migrants that landed near Oliktok took off again within a few seconds or minutes; others remained for longer periods, particularly in the latter part of the spring migration season (mid-June). Flight directions of eiders also became less consistently eastward as the season progressed. No evidence of a return westward movement of jaegers was evident by the time spring migration watches ended on 15 June, in contrast to results in the Yukon in June 1975 (Richardson *et al.* 1975).

Visible eastward migration was noticeably less pronounced by 13-15 June than it had been earlier. However, radar showed that major broad-front eastward and westward movements continued--largely invisible during migration watches--until the last day of radar observations (17 June). Similar continuation of migration past the dates of peak visible movement was recorded in the Yukon in 1975. The composition of these late spring flights is largely unknown, but the paucity of visual sightings indicates that most of the birds involved must fly at high altitudes. There was no indication that these late spring flights were more concentrated over the barrier island-lagoon system than over the adjacent North Slope or Beaufort Sea.

Mid-Summer Molt Migration

The westward molt migration of male oldsquaws was first noted on 26 June and continued to approximately 24 July. Peak numbers were seen moving west from 2 to 4 July (Table 4). Most movements occurred along the lagoon shoreleads and over the fractured lagoon ice, but some movement was noted seaward of the barrier islands, over the frozen Beaufort Sea.

Observations during migration watches and other activities indicated that during the molt migration oldsquaws made moderate use of water-filled cracks in the lagoon ice and of the shoreleads around the perimeters of the barrier islands and along the mainland shoreline. A detailed quantitative analysis of habitat use by migrants has not yet been undertaken.

The westward molt migration of male common and king eiders was first noted on 1 July and continued until approximately 31 July. Most westward movement by eiders occurred after the lagoon ice had broken up and had been flushed westward, out of the study area (Simpson Lagoon began breaking up on 9 July and was virtually ice free by 11 July). Peak numbers of eiders were seen moving west from 21 to 25 July. Eiders made only light use of lagoon and nearshore marine habitats during molt migration.

Table 4 shows the chronology and magnitude of molt migration of three species of seaducks through the study area.

Fall Migration

Fall migration by waterbirds out of the coastal Beaufort Sea area first became evident during mid-August when large noisy flocks of adult and juvenile arctic terns were observed moving westward at high altitudes along the Jones Islands (Table 5). The fall migration of arctic terns had terminated by 30 August.

Table 4. Numbers of Oldsquaws and Eiders Sighted Flying Eastbound, Westbound and Other* During the Midsummer Molt Migration Through the Study Area.

Date	# of Oldsquaws			# of Common Eiders			# of King Eiders		
	Eastbound	Westbound	Other	Eastbound	Westbound	Other	Eastbound	Westbound	Other
June									
26-30	3	240	140	0	0	4	0	0	0
July									
1-5	61	1,373	264	0	16	1	2	51	2
6-10	20	4	126	0	12	0	0	0	0
11-15	2	571	1,722[†]	0	12	5	0	86	0
16-20	0	135	131	0	618	0	0	115	0
21-25	6	451	361	6	1,002	20	0	1,679	2
26-31	0	0	0	0	250	0	0	0	0
Total	92	2,774	2,744	6	1,910	30	2	1,931	4

*The "other" category includes birds flying north or south and birds present locally.

[†] The ice on the surface of Simpson Lagoon began to break up on 9 July and had departed the study area by 11 July. For a short period after that date, the number of locally flying Oldsquaws increased dramatically in the study area.

Flocks of pre-migratory staging phalaropes that were abundant in the Simpson Lagoon area during mid-August had departed by 30 August; only one flock of phalaropes (17 birds) was observed in the study area after this date, on 1 September, at Pingok Island. A peak of westward movement through the study area by black brant (and a smaller peak of westward movement by loons) occurred during the last days of August and the first days of September (Table 5). This migration occurred primarily along the mainland shoreline and appeared to be related to the occurrence of favorable tail winds (from the E or NE). It is not known whether brant (or loons) stopped in the study area during unfavorable head winds. During the aerial survey conducted on 30 August, all waterfowl observed were flying westward.

The numbers of glaucous gulls and oldsquaws present in the study area increased during September. Both of these species reached maximum abundance in the study area during the third week in September, when the field observations were terminated because the lagoon was beginning to freeze over. Thus, no direct information about fall migrations by these two species is presented. Table 5 summarizes the important species and events during fall migration of birds in the Simpson Lagoon area during 1977.

Nesting Studies

The numbers, densities and fates of nests of the various bird species that were found nesting in the study area are presented in Table 6. Fifty active nests were found, representing a total density of 11.4 nests/km^2. Of these 50 nests, 38 (21.1 nests/km^2) were found on the Pingok Island plots and the tundra-covered portions of the islands; many of these nests (18 of 38, or 10.0 nests/km^2) were of lapland longspurs. The remaining 12 nests (9.24 nests/km^2) were found on the portions of the barrier islands, spits and bars that were comprised of gravel and sand.

Based on the total number of nests found in the tundra-covered portions of the study area, the overall density of all species of birds nesting in this type of habitat was 21.1 nests/km^2. Similarly, the numbers

Table 5. List of Avian Species Recorded During Fall Migration, 1977, at Simpson Lagoon, Alaska.

Species	Number Seen*	Periods of Peak Abundance	Predominant Migration Direction	Peak Migration Rate (#birds per day)
Yellow-billed Loon	2 (5)	1 September	West	2
Arctic Loon	0 (25)	24 August-14 September	Local	-
Red-throated Loon	9 (17)	30 August- 1 September	West	7
Unidentified Loons	88 (332)	25 August- 6 September	West	20
Pomarine Jaeger	1 (5)	1 September	West	1
Parasitic Jaeger	0 (3)	22 August- 1 September	Local	-
Long-tailed Jaeger	0 (13)	24-31 August	Local	-
Unidentified Jaegers	1 (5)	30 August	West	1
Black-legged Kittiwake	0 (1)	19 September	--	-
Glaucous Gull	275 (1044)	28 August-15 September	West	200
Sabine's Gull	0 (2)	22 August	--	-
Arctic Tern	100 (380)	15-28 August	West	32
Pintail	11 (60)	24 August	East	11
Unidentified Scaup	0 (2)	18 September	--	-
Oldsquaw	1730 (114266)	27 August-21 September	West	1000
Common Eider	57 (57)	24-26 August	West	47
Unidentified Eiders	600 (600)	23-28 August	West	425
Unidentified Mergansers	300 (300)	23 September	West	300
Unidentified Diving Ducks	35 (110)	22 August- 6 September	West	20
Unidentified Ducks	373 (409)	27-29 August	West	333
White-fronted Goose	280 (288)	19-24 August	West	270
(Black) Brant	4638 (4686)	22 August- 6 September	West	2261
Unidentified geese	852 (908)	24-29 August	West	800
Red Phalarope	0 (27)	22-28 August	Local	-
Unidentified Phalaropes	28 (1143)	25 August	West	28
Long-billed Dowitcher	13 (78)	19 August	West	13
Unidentified Dowitchers	0 (12)	31 August	--	-
Pectoral Sandpiper	0 (6)	24 August- 2 September	Local	-
Dunlin	3 (310)	28 August	West	3
Sanderling	0 (8)	30 August- 2 September	Local	-

Semipalmated Sandpiper	0 (18)	19 August	--	-
Whimbrel	0 (1)	17 August	--	-
Black-bellied Plover	6 (181)	28-30 August	West	4
American Golden Plover	0 (27)	22-27 August	Local	-
Unidentified Plovers	7 (11)	22 August	West	7
Ruddy Turnstone	0 (30)	22-31 August	Local	-
Unidentified Shorebirds	29 (581)	21-28 August	West	6
Peregrine Falcon	0 (1)	22 August	--	-
Varied Thrush	0 (1)	7 September	--	-
Yellow Warbler	0 (1)	5 September	--	-
Snow Bunting	0 (64)	21 August- 2 September	Local	-
Lapland Longspur	0 (2)	22-24 August	Local	-

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*Numbers inside parentheses represent the total number of birds seen during migration watches and during incidental observations. Numbers to the left of those in parentheses represent the number of birds seen migrating during the period of peak abundance.

of territorial male (Π♂♂) birds recorded on tundra plots 1 and 2 on Pingok Island were 24.0/km^2 and 20.0/km^2, respectively.

Table 7 compares the species composition, numbers of nests and numbers of territorial males observed on the two census plots on Pingok Island; the total number of nests found in all tundra habitats throughout the study area is also shown.

No nests were found along the section of the mainland shoreline between Oliktok Point and Beechey Point; however two active nests (one common eider nest and one glaucous gull nest) were found on the Beechey Point gravel bar, and at least two active glaucous gull nests were present on the Oliktok Point gravel bar. These bars are separated from the mainland by water and are comprised of sand and gravel substrates similar to those found on the barrier islands.

Most nests were checked twice during the early summer in order to assess their fates (Table 6). However, probable fates of some nests are identified only on circumstantial evidence of fledging of young, desertion of eggs or young by adults, or predation on eggs or young by jaegers, gulls or arctic foxes. Approximately eight arctic foxes (1.2 foxes/km^2) were present on the Jones Islands after the ice retreated from the coasts of the islands in mid-July. Their distribution is shown below:

Island	Number of Foxes
Spy	2
Leavitt	1
Pingok	2
Bertoncini	1
Bodfish	1
Cottle	1

Fox predation accounted for a high proportion of nest failures on the Jones Islands during 1977. Foxes were observed searching for bird nests on the tundra on Pingok, Bertoncini and Bodfish Islands during 1977. Fox tracks and scats were abundant around active and inactive nests in all suitable nesting habitats along beaches and on the gravel portions of the barrier islands. Foxes probably preyed more heavily on birds during 1977

Table 6. Active Bird Nests Found During 1977 on the Jones Islands and on Adjacent Spits and Bars in Simpson Lagoon, Alaska.

	Type of Nesting Habitat				Fate of Nest				
	Tundra (3.9 km^2)		Gravel/Sand (2.6 km^2)		Successful*				
Species	Nests (#)	Density (nests/km^2)	Nests (#)	Density (nests/km^2)	Nests (#)	Density (nests/km^2)	Predated	Deserted	Other/ Unknown
Lapland Longspur	18	10.00†	0	0.00**	7	3.89	8	0	3
Willow Ptarmigan	1	0.56	0	0.00	0	0.00	0	0	1
Snow Bunting	4	2.22	2	0.77	3	1.32	0	0	3
Oldsquaw	0	0.00	2	0.77	0	0.00	1	1	0
Dunlin	3	1.67	0	0.00	0	0.00	0	0	3
Ruddy Turnstone	1	0.56	0	0.00	0	0.00	0	0	1
Baird's Sandpiper	8	4.44	0	0.00	1	0.56	3	0	4
American Golden Plover	1	0.56	0	0.00	1	0.56	0	0	0
Parasitic Jaeger	1	0.56	0	0.00	1	0.56	0	0	0
Common Eider	0	0.00	2	0.77	0	0.00	1	1	0
King Eider	1	0.56	0	0.00	0	0.00	1	0	0
Arctic Tern	0	0.00	3	1.15	0	0.00	2	0	1
Glaucous Gull	0	0.00	3	1.15	2	0.77	0	0	1
Total	38	21.13	12	4.61	15	7.66	16	2	17

* A nest was judged to be successful if evidence (many times only circumstantial evidence) suggested that some young from the nest had fledged.

† Density calculations are based on the 1.8 km^2 of tundra area surveyed during nest searches.

**Density calculations are based on the 2.6 km^2 of gravel/sand area surveyed during nest searches.

Table 7. A Comparison of Bird Densities on Two Tundra Plots on Pingok Island and on the Total Area of Tundra Surveyed During Nest Searches on the Jones Islands.*

Species	Pingok Plot 1 (0.625 km² tundra)				Pingok Plot 2 (0.300 km² tundra)				Total Tundra Surveyed During Nest Searches (1.80 km²)	
	Nest Searches		Counts of Π ♂♂		Nest Searches		Counts of Π ♂♂			
	# Nests	Density	#Π ♂♂	Density	# Nests	Density	#Π ♂♂	Density	# Nests	Density
Lapland Longspur	6	9.60	14	22.40	8	26.70	6	20.00	18	10.00
Willow Ptarmigan	-	-	-	-	-	-	-	-	1	0.56
Snow Bunting	-	-	-	-	-	-	-	-	4	2.22
Dunlin	-	-	-	-	3	10.00	-	-	3	1.67
Ruddy Turnstone	1	1.60	-	-	-	-	-	-	1	0.56
Baird's Sandpiper	2	3.20	1	1.60	-	-	-	-	8	4.44
American Golden Plover	1	1.60	-	-		-	-	-	1	0.56
Parasitic Jaeger	1	1.60	-	-	-	-	-	-	1	0.56
King Eider	-	-	-	-	-	-	-	-	1	0.56
Total	11	17.60	15	24.00	11	36.70	6	20.00	38	21.13

*Counts of territorial males (Π ♂♂) were conducted only on Plots 1 and 2 on Pingok Island. All densities are per km².

than during 1975 and 1976 because of the decline in the lemming population along the central Beaufort Sea coast during the winter of 1976 and the spring of 1977 (W. C. Hanson 1977, pers. comm.).

Molting: Oldsquaws

Pre-molt Period

Low densities of oldsquaws were present in the lagoon habitats on 5 and 20 June (Table 8). On these dates the highest density of oldsquaws recorded on any transect during an aerial survey was only 3.24 birds/km^2, and this transect was over tundra habitats on 20 June (Transect 5; see Table 8).

The 5 July aerial survey was conducted just after the peak of the male oldsquaw molt migration through the study area. The peak densities of oldsquaws during this survey, 26.23 and 21.63 birds/km^2, were recorded in the only areas of available open water: in the shoreleads around the margins of the barrier islands (Transect 2) and in the shoreleads along the mainland shoreline (Transect 4; see Table 8). Both the mid-lagoon area (Transect 3) and the nearshore marine habitat (Transect 1) remained ice-covered until 11 July and they therefore supported very low densities of oldsquaws (Table 8). Satellite imagery indicated that by 13 July, the ice had moved westward out of the coastal lagoon systems along the entire central Beaufort Sea coast, and that the ice seaward of the barrier islands had moved offshore, away from most of the barrier islands.

Male Molt Period

The aerial survey conducted on 28-29 July indicated that the area seaward of the barrier islands continued to support low densities of oldsquaws after the ice had retreated from this area (0.07 birds/km^2 on 29 July). However, the weighted average density of birds recorded in lagoon habitats (Transects 2, 3 and 4) had increased from 15.1 birds/km^2 on the 5 July survey to at least 321.1 (and possibly 566.1) birds/km^2 on the 28-29 July aerial survey (Table 9). The raw densities of oldsquaws

Table 8. Densities (Birds/km²)* of Oldsquaws Recorded in All Habitats During Aerial Surveys of Five Transects in the Jones Islands-Simpson Lagoon Area, 5 June to 22 September, 1977.

	Survey Date						
Transect	5 June	20 June	5 July	28/29 July	15 August	30 August	22 September
1	0.00	0.00	2.18	0.07	-	3.30	3.44
2	0.00	1.55	26.23	401.69†	811.31	73.05	21.63
3	0.00	0.00	2.85	501.14	-	184.60	928.05
4	0.23	0.85	21.63	516.39	161.94	68.04	220.01
5	2.58	3.24	1.92	1.18	5.81	0.00	0.00
Average	0.56	1.13	11.00	284.09	326.35	65.80	234.63

*All Oldsquaws recorded as 'On-Transect' (< 200m of each side of the aircraft), regardless of the habitat with which they were associated, have been included in these density calculations.

†Densities in the above table are lower than those that may be calculated from numbers presented in Table 9. In Table 9, the proportion of the total area surveyed that has been used in density calculations includes only lagoon habitats, and the numbers of birds that have been used in density calculations includes only those birds that we associated with lagoon habitats.

Table 9. Estimates of the Total Number of Oldsquaws Present in Simpson Lagoon During Each of Seven Aerial Surveys Conducted During the Period 5 June to 22 September.

Transect Number*	Area Represented	Date of Aerial Survey						
		5 June	20 June	5 July	28/29 July	15 August	30 August	22 September
2	22 km^2††	0 (0)†	65 (23)	1,127 (398)	14,284 (5,045)	33,951 (11,991)	419 (148)	841 (297)
3	102***	0 (0)	0 (0)	292 (35)	51,375 (6,165)	- (-)**	18,829 (2,271)	95,142 (11,417)
4	36†††	0 (0)	41 (11)	1,003 (269)	24,921 (6,687)	7,808 (2,095)	2,687 (721)	10,617 (2,849)
Total	160	0 (0)	106 (34)	2,422 (702)	51,375 (6,165)****	41,759 (14,086)	21,935 (3,140)	106,600 (14,563)
Mean Density		0.0	0.7	15.1	321.1††††	(261.0)††††	137.1	666.3

* Transect numbers 1 and 5 were seaward and landward, respectively, of Simpson Lagoon. Densities of oldsquaws on these transects were low and estimates have not, therefore, been calculated for these transects.

† Numbers in parentheses represent the total number of oldsquaws recorded 'on-transect' (<200 m on either side of the aircraft) in lagoon habitats only.

** Incomplete survey; transects 1 and 3 were not surveyed on this date.

†† Based on an areal coverage during the survey of 7.77 km^2 (37.0 km long x 0.21 km wide), and extrapolated over an area of approximately 22 km^2 (that portion of the northern region of the lagoon <1.82 m (6') deep).

*** Based on an areal coverage during the survey of 12.24 km^2 (30.6 km long x 0.4 km wide), and extrapolated over an area of approximately 102 km^2 (that portion of the lagoon >1.82 m (6') deep).

††† Based on an areal coverage during the survey of 9.66 km^2 (32.2 km long x 0.3 km wide), and extrapolated over an area of approximately 36 km^2 (that portion of the southern region of the lagoon <1.82 m (6') deep).

****Since the surveys of transects 2 and 4 were conducted on 28 July and that of transect 3 was conducted on 29 July, it is possible that some or all of the birds recorded on 28 July were also recorded on 29 July. We have, therefore, used the larger of the two estimates (the estimate from transect 3 rather than the sum of the values from transects 2 and 4), as a conservative total for the survey.

††††Minimum estimate.

recorded on the three lagoon transects on 28-29 July were very similar--401.7, 501.1 and 516.4 birds/km^2 for transects 2, 3 and 4, respectively--, but actual densities in the water along transects 2 and 4 (which included some land) were somewhat higher. Nonetheless, the high density in midlagoon is noteworthy, and because of the similar densities on all lagoon transects, the estimates for 28-29 July in Table 9 are not very sensitive to the specific weighting procedure.

The estimated total number of oldsquaws present in Simpson Lagoon during the 28-29 July survey was at least 50,000 birds--a substantial increase from the estimated total of 2,422 birds present on 5 July (Table 9). Based on the sex ratio of birds shot during the 29 July to 3 August collection period (Table 10), approximately 83% of the oldsquaws present in the study area at that time were males. This large population of male oldsquaws present in the study area, the considerable interval since the peak of migration and the abrupt decrease in the mean wing length of males from the 17 June-27 July collection period to the 29 July-3 August collection period (Table 10), indicated that the molt of male oldsquaws was well under way by 28-29 July.

Female oldsquaws are largely restricted to tundra nesting habitats during the early June to late July period. This may explain the low numbers of females present in lagoon habitats during the 17 June to 3 August period.

On 28 July, oldsquaws were concentrated at three locations along the south sides of the barrier islands in Simpson Lagoon (Fig. 2). A total of approximately 3,100 oldsquaws were recorded along the SE end of Spy Island. A similar number (3,065 birds) were seen midway along the south side of Leavitt Island, and a large group (5,200) was seen along the SE end of Cottle Island. On the same date (28 July) along the mainland shoreline, concentrations of oldsquaws were recorded NW of Oliktok Point (approximately 2,700 birds), SW of Milne Point (approximately 2,875 birds) and SW of Kavearak Point (approximately 1,225 birds)(Fig.2). During the survey of the mid-lagoon portion of the study area on 29 July, the largest concentrations of oldsquaws were recorded in the area between Beechey Point and the east end of Cottle Island (1,750 birds) and in the area between Kavearak Point and Bertoncini Island (4,575 birds) (Fig. 2).

Table 10. The Change in Adult Oldsquaw Wing Length, Weight and Subcutaneous Fat Thickness During the Premolt, Molt and Postmolt Periods at Simpson Lagoon, Alaska.

	Collection Intervals				
	17 June-27 July*	29 July-3 August	14-17 August	25-31 August	5-18 September
Male	Premolt	Molt	Postmolt		
Wing Length (cm)	23.1 ± 1.0 (n=13)	12.9 ± 2.0 (n=15)	19.3 ± 2.2 (n=10)	21.9 ± 1.1 (n=12)	22.8 ± 1.0 (n=7)
Weight (g)	869.3 ± 128.4 (n=13)	914.2 ± 64.7 (n=15)	879.0 ± 52.4 (n=10)	862.5 ± 72.1 (n=12)	949.3 ± 62.9 (n=7)
SubQ Fat Thickness (mm)	4.6 ± 0.9 (n=8)	5.6 ± 1.7 (n=10)	3.7 ± 1.5 (n=10)	3.2 ± 1.1 (n=12)	3.8 ± 1.7 (n=7)
Female	Premolt		Molt	Postmolt	
Wing Length (cm)	22.3; 21.1	20.6; 22.2; 20.5	13.9 ± 1.7 (n=5)	17.2 ± 3.3 (n=5)	20.8 ± 0.4 (n=12)
Weight (g)	653; 685	742; 699; 814	761.0 ± 88.8 (n=5)	737.0 ± 57.3 (n=5)	800.7 ± 62.9 (n=12)
SubQ Fat Thickness (mm)	heavy; light	8.0; 3.0; 2.0	3.5 ± 1.6 (n=5)	3.9 ± 2.0 (n=5)	2.4 ± 1.0 (n=12)
Sex Ratio† (♀/♂)	1/6.5 (n=15)	1/5.0 (n=18)	1/2.0 (n=15)	1/2.4 (n=17)	1/0.6 (n=19)

*Five male and two female Oldsquaws were accidentally caught in gill nets during the period 17 June to 27 June. These seven birds were salvaged and have been included in the wing length and weight calculations. All other birds were adults collected during the period 11 to 27 July.

†During the collection of birds no attempt was made to collect either males or females; hence, sex ratios are probably a true reflection of flock composition.

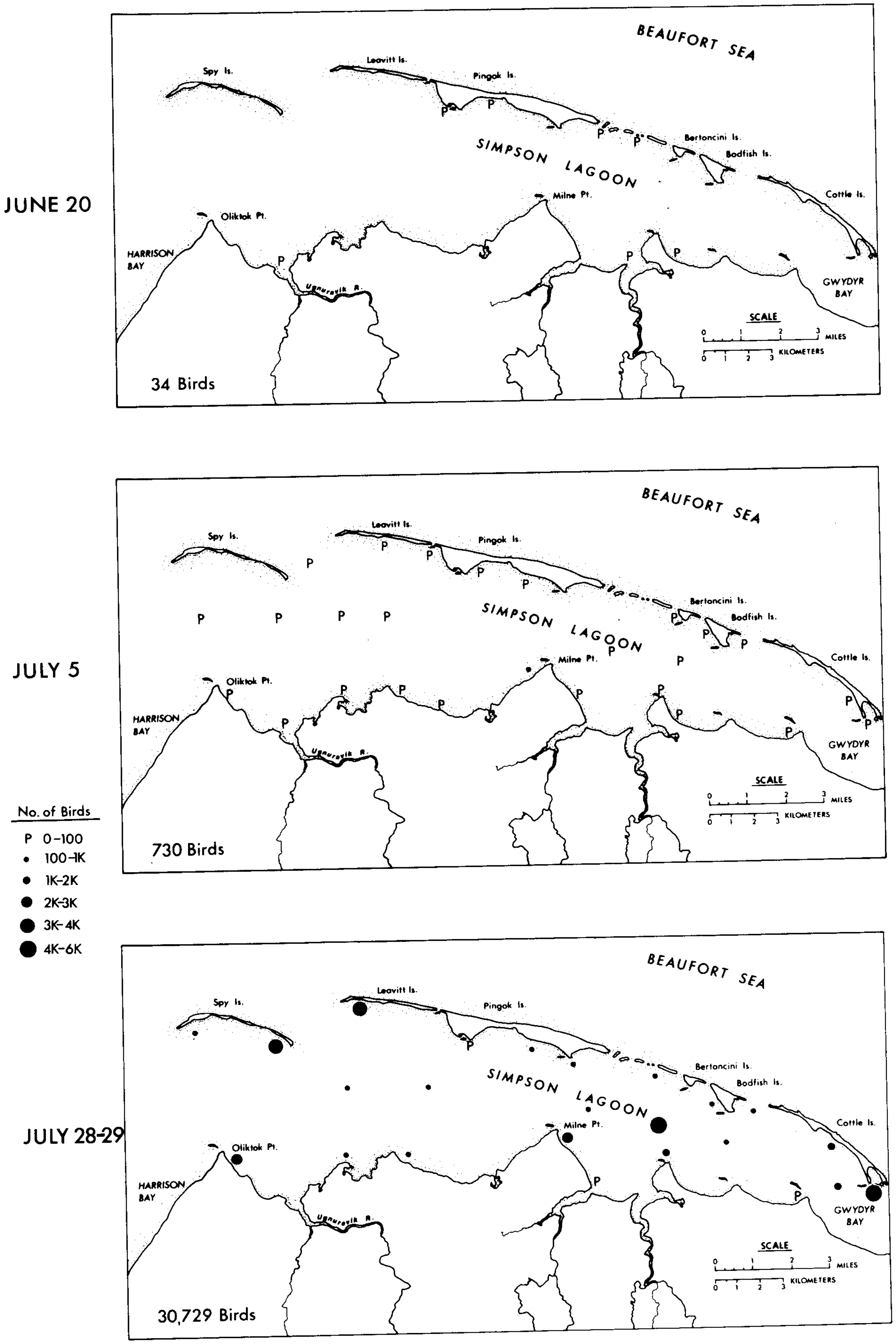
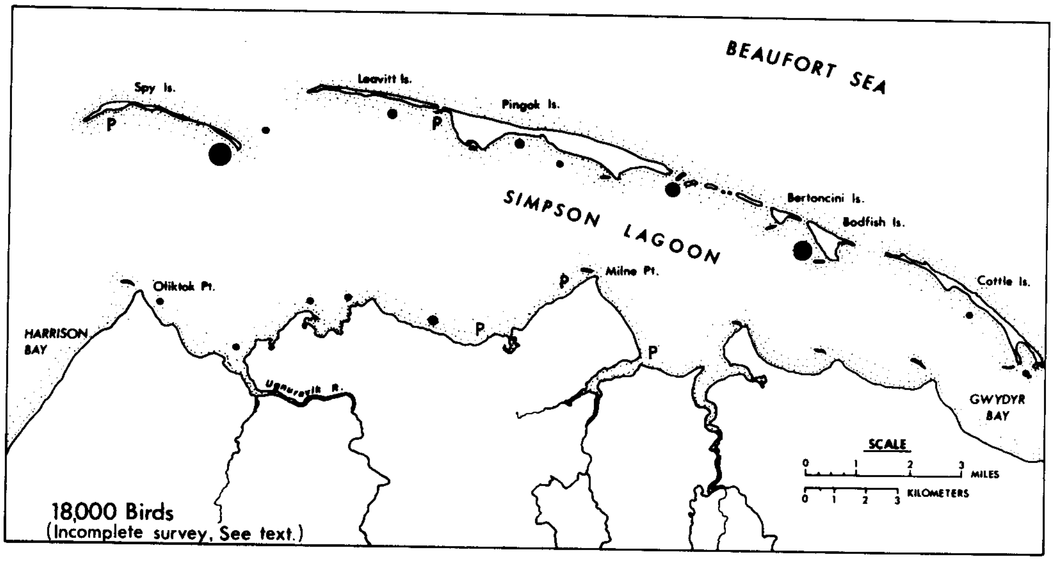
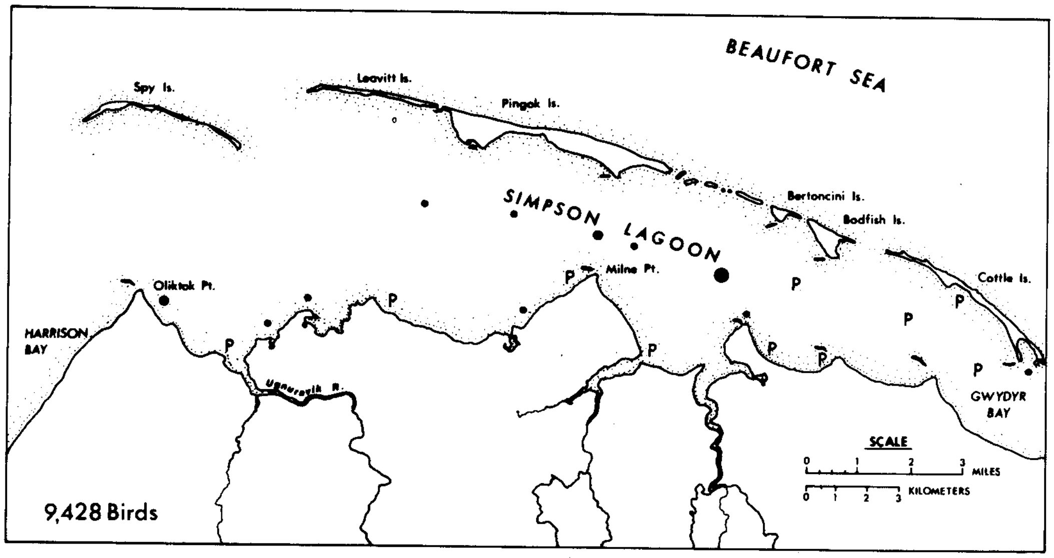


Fig. 2. Areas of Concentration of Oldsquaws in Simpson Lagoon during Aerial Surveys, 20 June through 22 September, 1977.

AUG.15



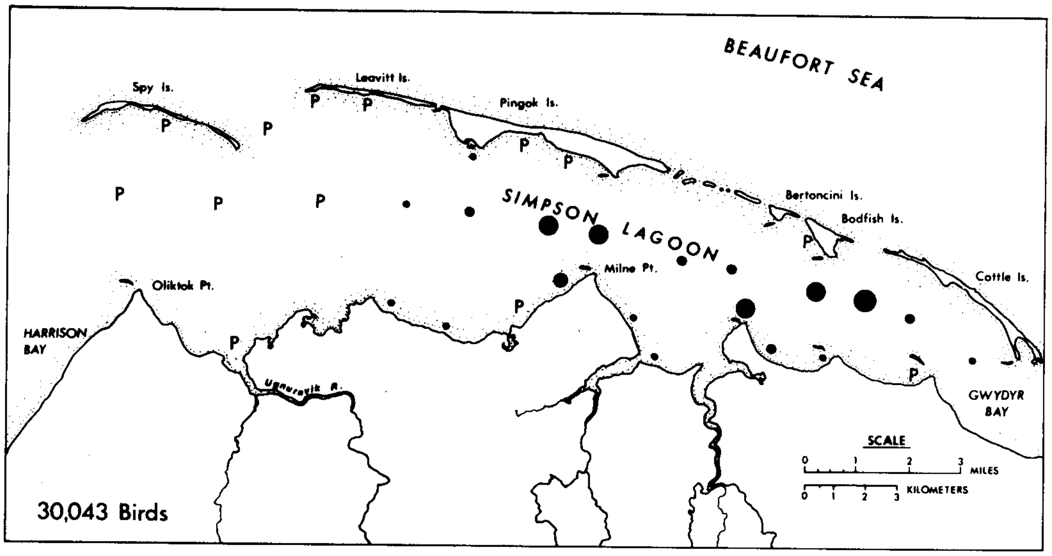
AUG.30



No. of Birds

P 0–100
• 100–1K
● 1K–2K
● 2K–3K
● 3K–4K
● 4K–6K

SEPT. 22



Although the weights of male oldsquaws collected in Simpson Lagoon did not significantly change throughout the summer (Kruskall Wallis $H=4.21$, d.f.=4, $n=57$, $P>0.02$--see Siegel 1956), the thickness of the subcutaneous fat layer on the males did vary significantly ($H=16.12$, d.f.=4, $n=51$, $0.01>P>0.001$) and was greatest (5.6 ± 1.7 cm; Table 10) during the 29 July-3 August collection period.

Female Molt Period

The ratio of female to male oldsquaws present in the study area was higher on 14-17 August than it had been on 29 July-3 August (Table 10). This shift in the sex ratio was probably a result of an influx of female birds, apparently failed breeders, from inland tundra locations. The greatly reduced length of the wings of the five females collected during the 14-17 August period (13.9 ± 1.7 cm) compared with those collected prior to this period (21.4 ± 0.86 cm), indicated that they had very recently molted their flight feathers (Table 10).

Post-molt Period

Although female oldsquaws were molting during mid-August, males had nearly completed replacement of their flight feathers by then (Table 10). The aerial survey conducted on 15 August was incomplete; overwater Transects 1 and 3 were not surveyed. On that same date, however, high densities of oldsquaws were recorded on the two lagoon transects that were surveyed--811.3 birds/km^2 on Transect 2, and 161.9 birds/km^2 on Transect 4 (Table 8). The estimated total number of oldsquaws present in the study area on 15 August, at least 41,800 birds, was smaller than the estimated total present during the previous survey on 28/29 July (at least 51,400 birds); however, had Transect 3 been surveyed on 15 August the total for that date would probably have been larger.

A large proportion of the oldsquaws present in Simpson Lagoon during the 15 August aerial survey were concentrated in waters immediately to the south of the Jones Islands. Approximately 4,600 oldsquaws were concentrated along the southeast portion of Spy Island. Approximately 1,800 birds were seen off the SW portion of Leavitt Island and over 1,200 oldsquaws were observed NE of Fat Point on Pingok Island (Fig. 2). Approximately 2,000 oldsquaws were observed NE of Shaklo Point, Pingok Island, and approximately 3,500 oldsquaws were seen SW of Bodfish Island (Fig. 2).

During the survey of Transect 4, along the mainland shoreline, only one major concentration of oldsquaws was noted on 15 August; approximately 1,500 birds were seen approximately 8 km SW of Milne Point (Fig. 2).

The density of oldsquaws recorded on tundra habitats during the 15 August survey was notably higher than that recorded there on 28 July (1.2 birds/km^2 on 28 July; 5.81 birds/km^2 on 15 August). This increase may be explained by the fact that female oldsquaws with broods were probably more common (or at least conspicuous) on tundra ponds on 15 August 1977 than they were on 28 July 1977 (Bellrose 1976; King 1977).

By late August, although female oldsquaws were still flightless, most males had regained flight (mean wing length=22.2 ± 1.2 cm; Table 10). Possibly related to this, there was a marked decline from 15 to 30 August in the number of oldsquaws observed in the study area (Tables 8 and 9). Raw densities on Transect 2 were 811.3 and 73.1 birds/km^2 on 15 and 30 August. Corresponding raw densities on Transect 4 were 161.9 and 68.0 birds/km^2. Similarly, the estimated total number of oldsquaws present in Simpson Lagoon had declined from at least 41,750 on 15 August to approximately 21,900 on 30 August. During the 30 August survey, relatively low densities of oldsquaws (73.1 birds/km^2) were recorded along the barrier islands where during the previous survey (15 August) very high densities (811.3 birds/km^2) had been recorded. This change in distribution may have been related to wind direction since during the 15 August survey the wind was from 135° and during the 30 August survey the wind was from 090° (Table 24). The largest concentration of oldsquaws seen during the 30 August survey was of approximately 2,775 individuals seen in the mid-lagoon area between Kavearak Point and Bertoncini Island. The only other large group of oldsquaws seen in the study area on this date was a concentration of 1,800 birds SE of Oliktok Point.

The sex ratios of oldsquaws collected during the 25-31 August period remained in favor of males (70.5%). No oldsquaws were recorded on tundra habitats during the 30 August survey. Apparently female and young oldsquaw had begun departing the tundra for coastal habitats; juveniles were collected in Simpson Lagoon for the first time during the 25-31 August collection period. The density of oldsquaws in nearshore marine habitats on 30 August was low (3.3 birds/km^2), and the few oldsquaws that were sighted on transect were associated with ice pans and chunks of ice that had drifted landward from the pack ice, located offshore from the barrier islands.

By 18 September, both sexes of adult oldsquaws as well as juvenile birds were capable of flight; of the 15 female oldsquaws collected during the 5-18 September collection period (Table 10), four were juveniles. Also noteworthy, is the fact that the sex ratio of adult oldsquaws collected in the lagoon during the 5 to 18 September period had shifted markedly in favor of females (female/male ratio=0.41 during 25-31 August; female/male ratio=1.71 during 5-18 September).

During the 22 September aerial survey, the weighted average density of oldsquaws recorded on the three Simpson Lagoon transects was 666.3 birds/km^2, a substantial increase from the average value of 137.1 birds/km^2 recorded on these same three transects during the previous survey on 30 August (Table 9). The density of oldsquaws recorded on Transect 3, in the mid-lagoon portion of the study area, was 928.0 birds/km^2--the highest single transect density of this species recorded during the entire study. The estimated total number of oldsquaws present in the study area during the 22 September aerial survey was 106,600 birds (Table 9). Approximately 90% of these birds (95,142) were present in mid-lagoon waters. No major concentrations of oldsquaws were observed along the southern margin of the barrier islands on 22 September. Over 90% (19,183 of 21,068) of all oldsquaws actually observed in the mid-lagoon area (including off-transect sightings) on 22 September were in the eastern half--east of a line from Jones Mound on the mainland to the survey marker at mid-Pingok Island. The largest concentration of oldsquaws observed during the 22 September survey (4,082 oldsquaws) was in the mid-lagoon region between

Kavearak Point and the west end of Cottle Island (Fig. 2). Other major concentrations of oldsquaws were seen in mid-lagoon waters between Milne Point and Shaklo Point on Pingok Island (approimately 3,000 oldsquaws) and in mid-lagoon waters between Milne Point and the survey marker at mid-Pingok Island (Fig. 2).

Of the 8,585 oldsquaws seen along the mainland shoreline of Simpson Lagoon, 93% (8,009) were observed in the eastern portion of the study area. Major concentrations along the mainland shoreline were noted SW of Milne Point (2,023 oldsquaws), SW of Kavearak Point (3,425 oldsquaws), and SE of Kavearak Point (1,631 oldsquaws).

The weights of oldsquaws collected throughout the season indicate that both males and females were heaviest during the mid-September collection period. In contrast, the subcutaneous fat layer of both male and female oldsquaws tended to be thinnest during this same mid-September collection period (Table 10).

Pre-migratory Staging

Shorebirds

Although phalaropes were not the only species of shorebirds observed in the study area during 1977, they were the most common shorebirds recorded and they were highly concentrated at certain shoreline locations in the study area during mid-August; therefore, phalaropes were considered key species. Other species of birds recorded on shoreline transects but thought to be of less relative importance than phalaropes, are shown in Appendix Tables 2 and 3.

The movement of juvenile phalaropes from rearing areas on tundra to coastal staging areas was first noted at Pingok Island on 1 August. On this date a total of 150 red phalaropes were recorded on 15 shoreline transects in the study area. No northern phalaropes were recorded during transect surveys in the study area until 3 August (Table 11). The average ratio of northern to red phalaropes recorded in the study area during the month of August was approximately 1/4. This ratio varied from 0/150 on 1 September, before northern phalaropes had arrived in the study area, to 1/2.8 on 16 August, during the peak of phalarope abundance to

Table 11. Numbers of Red and Northern Phalaropes Observed on Beach Transects in the Simpson Lagoon-Jones Island Area, 1 to 26 August 1977.

	August Date											Total
	1	2	3	6	8	12	14	16	23	24	26	
Number of Red Phalaropes	150	4	77	193	525	69	16	3470	262	1340	24	6130
Number of Northern Phalaropes	0	0	53	60	51	23	0	1220	52	40	17	1516
Northern/Red Ratio	0/150	0/4	1/1.5	1/3.3	1/10.3	1/3	0/16	1/2.8	1/5	1/33.5	1/1.4	1/4
Number of Transects Surveyed	15	1	1	1	1	1	1	15	1	15	1	53

1/1.4 on 26 August, the last date when both species were recorded in the study area. Seventeen red phalaropes (in winter plumage) were recorded on Pingok Island on 14 September; these were the last phalaropes seen in the study area during 1977.

During August and early September, densities of shorebirds differed significantly among the three types of transects surveyed (Friedman χ^2= 6.4, k=3, n=5, P=0.039--see Siegel 1956 and Table 12). Densities were usually highest along oceanside beaches of the barrier islands, intermediate along lagoonside beaches of the islands, and lowest along mainland beaches. Phalaropes were present along the mainland beaches only during mid-August, the period of their peak abundance in the study area.

During the month of August, red phalaropes accumulated a substantial amount of fat during the period of pre-migratory staging in the study area (Table 13). Northern phalaropes arrived in the study area substantially fatter than red phalaropes and no trend of increasing fatness was noted for this species.

All phalaropes collected for the feeding studies were juveniles. Sex ratios of both species of phalaropes varied greatly between collection periods (Table 13). For both species, the proportion of females was lower on 19-25 August than on 3-12 August, but the difference was not statistically significant for either species.

Terns and Gulls

Although a few arctic terns attempted to nest in the study area, all large groups of this species were transients. A large westward movement of arctic terns through the study area occurred during mid-August (Table 5 and 14). Peak numbers recorded during the 15 August aerial survey were along the barrier islands (Transect 2) where a total of 355 were observed. During this survey no arctic terns were observed in offshore marine habitats, in mid-lagoon habitats or in tundra habitats. During the entire study only three arctic terns were observed during aerial surveys along the mainland shoreline of the study area; all of these were seen on the 28 July aerial survey. Terns concentrated at several locations along the barrier islands during fall westward movements. The most notable of

Table 12. Average Linear Densities (Birds/km of Shoreline)* of All Shorebirds Recorded on Three Beach Types Surveyed During the Period 1 August to 14 September, 1977.

Date of Survey	Beach Type		
	Barrier Island Oceanside Beach (n=5)	Barrier Island Lagoonside Beach (n=5)	Mainland Beach (n=5)
1 August	5.0 (4.0)[†]	2.2 (1.2)	1.6 (0.0)
16 August	132.3 (131.8)	38.0 (32.8)	32.8 (29.8)
24 August	2.2 (0.0)	39.8 (32.6)	1.2 (0.0)
1 September	11.2 (0.0)	3.0 (0.0)	3.8 (0.0)
14 September	15.0 (0.0)	2.0 (0.0)	0.0 (0.0)

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*Beach transects were 1 km long x 0.02 km wide (10 m either side of the shoreline) = 0.02 km^2. Only those birds seen on-transect have been included in this table.

[†] Parentheses enclose the mean densities of all phalaropes (red, northern and unidentified phalaropes) recorded during each survey.

Table 13. Change in Fatness* and Sex Ratios of Red and Northern Phalaropes in Simpson Lagoon During August, 1977. All specimens were juveniles.

Species	August								
	3	4	5	6	12	19	21	23	25
Red Phalarope									
Fatness $\bar{x}$	2.4	2.1	2.4	2.3	2.7	3.0	3.2	4	3.3
S.D.	0.55	0.30	1.14	0.50	0.82	0.89	0.98	0	0.98
n	5	11	5	4	6	6	6	1	12
Sex Ratio ♂♂/♀♀	3/2	5/6	3/2	1/3	1/2[†]	6/0	4/1[†]	-[†]	5/5[†]
Northern Phalarope									
Fatness $\bar{x}$	-	3.5	3.5	3.0	3.4	-	4.5	3.8	4
S.D.	-	0.58	0.71	0	1.41	-	0.58	0.84	0
n	-	4	2	4	8	-	4	5	1
Sex Ratio ♂♂/♀♀	2/2	2/0[†]	2/0	1/1[†]	1/5[†]	3/1	3/1	1/0[†]	-

*Fatness classifications conform to OCS fatness codes: 2 = light fat; 3 = moderate fat; 4 = heavy fat; 5 = excessive fat.

[†] Some birds of undetermined sex were collected on this date.

Table 14. Total Numbers of Terns Recorded in All Habitats During Aerial Surveys of Five Transects in the Jones Islands-Simpson Lagoon Area, 5 June to 22 September, 1977.

Transect #	Survey Date						
	5 June	20 June	5 July	28/29 July*	15 August	30 August	22 September
1	0 (0)†	0 (0)	0 (0)	0 (0)	- (-)	5 (0)	0 (0)
2	0 (0)	7 (0)	22 (0)	23 (36)	355 (1)	109 (0)	0 (0)
3	0 (0)	0 (0)	0 (0)	0 (2)	- (-)	0 (0)	0 (0)
4	0 (0)	0 (0)	0 (0)	3 (0)	0 (0)	0 (0)	0 (0)
5	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Total	0 (0)	7 (0)	22 (0)	26 (38)	355 (1)**	114 (0)	0 (0)

* Transects 1 and 3 were surveyed on 29 July; transects 2, 4 and 5 were surveyed on 28 July.

† Parentheses enclose the number of Terns recorded off-transect (>200 m from either side of the aircraft). Numbers to the left of parentheses are birds seen on-transect.

**Minimum number.

these concentration areas were the east ends of Spy Island (about 220 observed on 16 August) and Pingok Island (maximum of 167 observed on 16 August).

The more detailed survey of barrier island shoreline transects on 16 August indicated that the number of arctic terns was greater along the lagoonside shorelines of the barrier islands (33.0 terns/km of shoreline) than along the oceanside beaches of the islands (2.2 terns/km) or the mainland beaches (no terns observed). Based on these numbers/km of shoreline, the estimated total number of arctic terns present along all shorelines in the study area at this time were as follows: Barrier Island oceanside shorelines, 67 arctic terns; barrier island lagoonside shorelines, 1,129 arctic terns; mainland shorelines, no arctic terns (Tables 15 and 16).

Only 109 arctic terns were observed during the 30 August aerial survey of the barrier islands. No arctic terns were recorded in the study area after 30 August.

During the entire aerial survey program, only two glaucous gulls were observed in the mid-lagoon portion of the study area; both of these birds were observed flying eastward over the frozen lagoon ice on 5 June. (Migration watches showed others migrating east over the mid-lagoon ice in spring.) Similarly, during the entire summer, four glaucous gulls was the largest number recorded during the survey of the mainland tundra transect (Transect 5). Twenty-six of the total 27 glaucous gulls recorded in offshore marine habitats were recorded on the 30 August aerial survey, and 25 of these birds were recorded off-transect, near the barrier islands.

The number of glaucous gulls recorded in shoreline habitats of the study area did not exceed 23 birds (1.6 birds/km^2; Transect 2; 5 July 1977) until 28 July. On this date a total of 98 glaucous gulls (3.5 birds/km^2) was recorded along the barrier islands (Table 17).

On 15 August, the density of glaucous gulls present along the barrier islands (7.5 birds/km^2) had more than doubled (an increase from 3.5 birds/km^2) since the previous survey. The 112 glaucous gulls seen along the barrier islands represented 88% of the total number recorded during the 15 August aerial survey. The mid-lagoon portion of the study area was not surveyed on 15 August, but in the area along the mainland shoreline

Table 15. Average Linear Densities (Birds/km of Shoreline)* of Gulls and Terns† Recorded on Three Beach Types Surveyed During the Period 1 August to 14 September, 1977.

Date of Survey	Beach Type		
	Barrier Island Oceanside Beach (n=5)	Barrier Island Lagoonside Beach (n=5)	Mainland Beach (n=5)
1 August	0.8 (0.6)	3.2 (1.0)	0.2 (0.2)
16 August	2.6 (0.4)	33.8 (0.8)	0.2 (0.2)
24 August	0.8 (0.8)	4.4 (4.4)	0.0 (0.0)
1 September	14.8 (14.8)	0.0 (0.0)	0.4 (0.4)
14 September	1.0 (1.0)	0.8 (0.8)	0.0 (0.0)

* Beach transects were 1 km long x 0.2 km wide (10 m either side of the shoreline) = 0.02 km^2. Only those birds seen on transect have been included in this table.

† Parentheses enclose the mean densities of all gulls (both glaucous and Sabine's gulls) recorded during each survey. To determine the linear density of arctic terns, subtract the density within the parentheses from the number immediately to the left.

Table 16. Estimated Numbers of Oldsquaws, All Shorebirds and All Gulls/Terns Present Along the Oceanside and the Lagoonside Beaches of the Jones Islands from Spy to Cottle Island, and Along the Mainland Beach of Simpson Lagoon From Oliktok Point to Beechey Point.

Date of Survey and Species	Beach Type		
	Barrier Island Oceanside Beach (30.5 km long)	Barrier Island Lagoonside Beach (34.2 km long)	Mainland Beach (32.2 km long)
1 August			
Oldsquaws	293	7296	0
All Shorebirds	153 (122)†	75 (41)	52 (0)
All Gulls/Terns	24 (18)**	109 (21) (14)	6 (6)
16 August			
Oldsquaw	18	14	0
All Shorebirds	4035 (4020)	1300 (1122)	1056 (960)
All Gulls/Terns	79 (6) (6)	1156 (27)	6 (6)
24 August			
Oldsquaws	0	8393	0
All Shorebirds	67 (0)	1361 (1115)	39 (0)
All Gulls/Terns	24 (24)	150 (150)	0 (0)
1 September			
Oldsquaws	0	342	19
All Shorebirds	342 (0)	103 (0)	122 (0)
All Gulls/Terns	451 (451)	0 (0)	13 (13)
14 September			
Oldsquaws	0	14	0
All Shorebirds	458 (0)	68 (0)	0 (0)
All Gulls/Terns	31 (31)	27 (27)	0 (0)

* Beach transects were 20 m wide, 10 m either side of the shoreline. Estimates are based on mean densities of birds recorded along 5 transects on each type of beach. Each transect was 1 km long.

† Parentheses enclose the estimated number of all phalaropes present along the beach type.

**Parentheses enclose the estimated number of glaucous gulls present along the beach type. Where two parentheses appear, the first refers to glaucous gulls and the second refer to Sabine's gulls.

the number of glaucous gulls had declined from the previously high density of 7.6 birds/km^2 to 1.1 birds/km^2 (from 98 to 14 birds seen on-transect).

By 30 August, the number of glaucous gulls observed in the study area had increased most markedly along the barrier islands (Transect 2), where a density of 25.6 birds/km^2 (377 gulls) was recorded. The number of glaucous gulls seen on this transect represented 95% (377 of 403 gulls) of the total number seen on-transect during this aerial survey. The estimated total number of glaucous gulls present along the barrier islands on 1 September (451 birds; see Table 15), based on the surveys of barrier island beach transects, was remarkably similar to the number recorded on- and off-transect during the 30 August aerial survey (421 birds, see Table 17). The shoreline surveys indicated that most gulls were along the seaward beaches of the islands.

The estimated total number of glaucous gulls present along the barrier islands on 14 September during the final beach survey, was 58 birds (Table 16). This number represented a substantial decrease from numbers observed and estimated for 30 August and 1 September.

During the period 18-20 September, the ponds and lakes on the mainland tundra of the North Slope froze over and no open water was available inland. The numbers of glaucous gulls (and oldsquaws, see above) present in the study area were higher during the 22 September aerial survey than on any other date during the entire study. In view of the low numbers of glaucous gulls present during the 14 September beach survey (Table 16), this increase apparently occurred during the period between 14-22 September. Of the 3,099 glaucous gulls observed on 22 September, approximately 92% (2,857 birds) were along the barrier islands (Transect 2; Table 17). This number represents a density of 192.0 glaucous gulls/km^2--the highest density of this species recorded during the entire study. On this date 240 glaucous gulls (13.5 birds/km^2) were recorded along the mainland shoreline.

Of the 28 glaucous gulls collected during the 16 July to 19 September period, eight were adult males and one was a two-year old male. Eleven female glaucous gulls, nine of which were adults, were also collected.

Table 17. Total Numbers of Glaucous Gulls Recorded in All Habitats During Aerial Surveys of Five Transects in the Jones Islands-Simpson Lagoon Area, 5 June to 22 September, 1977.

Transect #	Survey Date						
	5 June	20 June	5 July	28/29 July*	15 August	30 August	22 September
1	0 (0)†	0 (0)	0 (0)	1 (0)	- (-)	1 (25)	0 (0)
2	20 (0)	2 (0)	23 (0)	52 (4)	112 (0)	377 (44)	2857 (52)
3	1 (1)	0 (0)	0 (0)	0 (0)	- (-)	0 (0)	0 (0)
4	1 (1)	2 (0)	4 (1)	98 (1)	14 (0)	18 (0)	240 (5)
5	2 (1)	3 (0)	1 (3)	2 (0)	1 (1)	3 (0)	0 (0)
TOTAL	24 (3)	7 (0)	28 (4)	153 (5)	127 (1)	399 (69)	3097 (57)

*Transects 1 and 3 were surveyed on 29 July; transects 2, 4 and 5 were surveyed on 28 July.

†Parentheses enclose the number of glaucous gulls recorded 'off-transect' (>200 m from either side of the aircraft). Numbers to the left of the parentheses are birds seen on-transect.

The first one-year old glaucous gull collected, a female, was collected on 5 August. Another one-year old female glaucous gull was collected on 20 August and four juveniles of undetermined sex were collected on 8 September. Another juvenile glaucous gull, also of undetermined sex, and the final bird collected during the fall of 1977, was collected on 19 September.

Feeding Studies

Oldsquaws

Of the 91 oldsquaws collected as part of the feeding ecology investigations, 15 had empty stomachs and 18 had only unidentifiable material present in their stomachs. The average diet of the remaining 58 birds included, on a percent of total volume basis, 54.8% mysids and 18.5% amphipods (Table 18). The identifications of the three species of mysids and the major species of amphipods found in the stomachs of oldsquaws are presented in Appendix Tables 4 and 5. The remaining portions of the diet of oldsquaws consisted primarily of bivalves (7.7%), isopods (2.1%), small fishes (2.1%), and a relatively large proportion of unidentifiable material (14.6%) (Table 18).

Mysids appeared to be the predominant food item consumed by oldsquaws during all portions of the summer season in Simpson Lagoon. The mysid proportion of the stomach contents of oldsquaws was 65.2% in the early season, 34% during the mid-season, and 66.4% during the late part of the season (Table 18).

Copepods comprised a very minor proportion of the diet of oldsquaws throughout the season (Table 18). More bivalves were consumed during the early part of the season (16.3% of the diet) than during the mid-season period (6% of the diet). No bivalves were found in the stomachs of oldsquaws during the late season period (Table 18). A small amount of fish was consumed by oldsquaws during the late season period; this taxon did not appear in the diet of the oldsquaws earlier.

Table 18. A Comparison of Food Organisms Consumed by Oldsquaws Throughout the Season at Simpson Lagoon, Alaska.

Taxon	Early Season 19 June-3 August (n=20)		Mid Season 17-31 August (n=21)		Late Season 5-18 September (n=17)		Total Season 19 June-18 September (n=58)	
	Points*	% Total	Points	% Total	Points	% Total	Total Points	% Total
Mysids	108¼	65.2	56½	34.0	99	66.4	263¾	54.8
Amphipods	11½	6.9	53½	32.2	24	16.1	89	18.5
Isopods	10	6.0	0	0	0	0	10	2.1
Copepods	¼	0.2	1	0.6	0	0	1¼	0.3
Bivalves	27	16.3	10	6.0	0	0	37	7.7
Fishes	0	0	0	0	10	6.7	10	2.1
Unidentified	9	5.4	45	27.1	16	10.7	70	14.6
Total	166	100	166	99.9	149	99.9	481	100.1

*See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

Note: For a detailed description of the early, mid and late season diets of oldsquaws collected in Simpson Lagoon, refer to Appendix Tables 6, 7 and 8.

Griffiths and Craig (RU 467, INVERTEBRATES section) have discussed the limitations and biases associated with the various conventional marine zooplankton sampling equipment and sampling procedures. These problems should be considered when interpreting the following results of analyses of habitat samples.

Few mysids and amphipods were collected from the surface-waters of the lagoon (see Fig. 3, and Appendix Table 9), and oldsquaws probably did not feed in this layer. The predominant invertebrate taxa present in the surface layer were, on a percent of total volume basis, copepods (68.1%) and cnidarians (16.7%). Small proportions of amphipods (5.7%) and chaetognaths (3.3%) comprised most of the remainder of the organisms collected in this habitat (Fig. 3).

Copepods also represented almost two-thirds (64.4%) of the total volume of invertebrate organisms present in the mid-water habitat samples (Fig. 3 and Appendix Table 10); this proportion of copepods was similar to that found in the surface water samples. Mysids and amphipods both comprised larger proportions (11.7 and 9.4%, respectively) of the mid-water samples than of the surface samples. Cnidarians, chaetognaths and ctenophores comprised the major proportion of the remainder of the organisms present in mid-water samples (Appendix Table 10).

Copepods, mysids and amphipods comprised the major proportions (33.8, 28.1 and 27.5%, respectively) of the epibenthos samples (Fig. 3 and Appendix Table 11). Observations by a SCUBA diver at several locations in Simpson Lagoon, including a series of dives where approximately 300 oldsquaws had been feeding, similarly indicated that mysids and amphipods were the most conspicuous invertebrate organisms present in the epibenthos (RU 467, INVERTEBRATES section).

Because both mysids and amphipods, the organisms which comprised the major proportions of the diet of oldsquaws, were proportionately most abundant in the lagoon epibenthos, it is probable that oldsquaws fed from this habitat rather than from either the surface or the mid-water layers, where mysids and amphipods were relatively uncommon. Copepods are extremely small, and although they comprised one-third of the organisms collected from the epibenthos, they were not observed in the epibenthos by the diver. Presumably for the same reason, copepods did not comprise

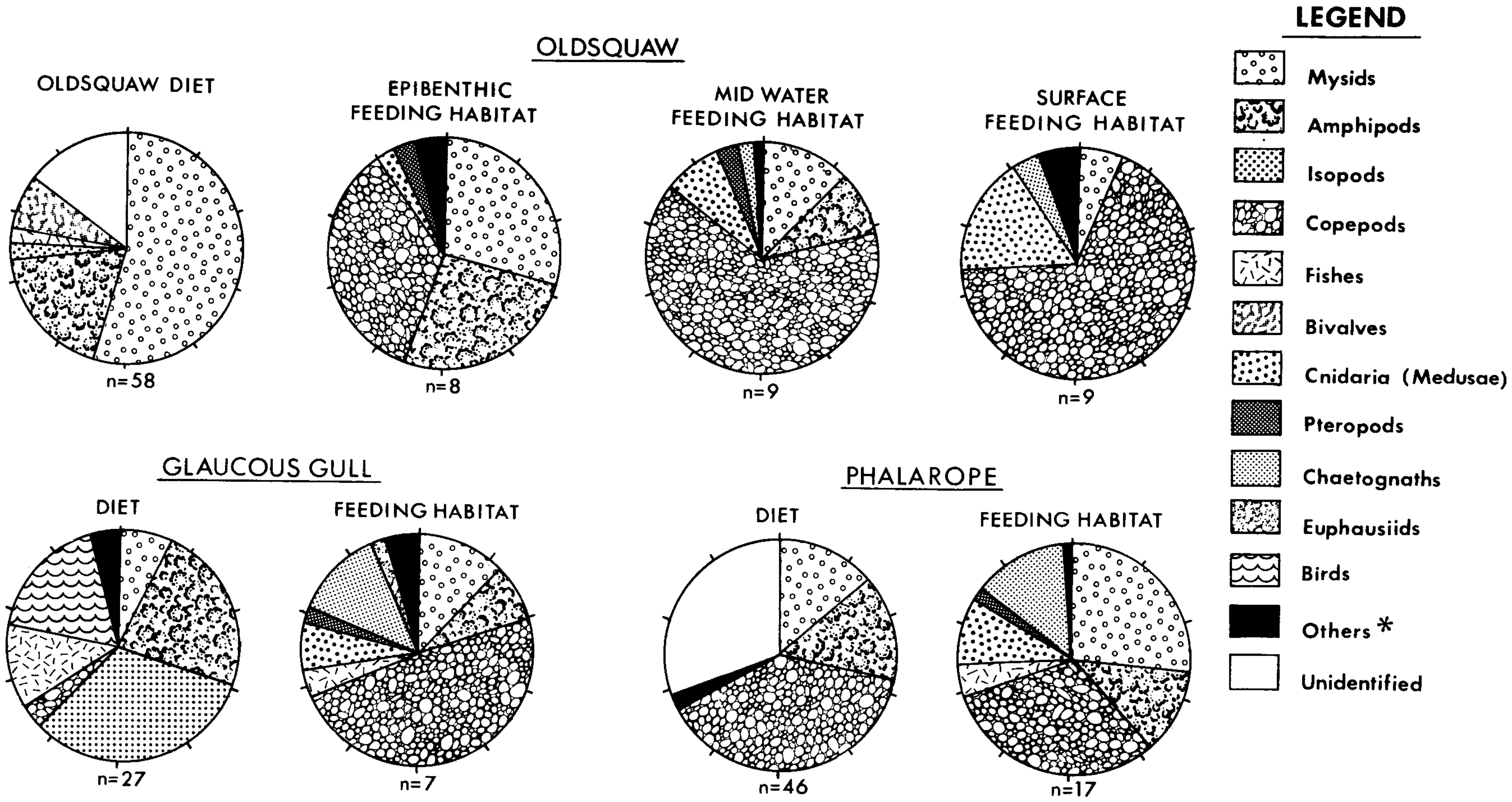

Fig. 3. A Comparison of the Organisms Present in the Diets of Oldsquaws, Phalaropes, Glaucous Gulls and the Organisms Present in Their Feeding Habitats.

*See Appendix Tables for a list of taxa in 'Others' category.

a significant proportion of the diet of oldsquaws (see Table 18 and Fig. 3). The very small proportion of copepods in the diet of oldsquaws may have been taken incidentally during the process of feeding on other epibenthic invertebrates.

Craig and Griffiths (RU 467, ECOLOGY OF FISH section) have examined the similarity of the stomach contents of the key bird and fish species present in Simpson Lagoon. The results of this analysis show that the diet of oldsquaws is very similar to the diets of arctic cisco (0.98 on a a similarity scale ranging from a low of 0.00 to a high of 1.00), fourhorn sculpin (0.96) and arctic cod (0.92), and less similar to the diets of the least cisco (0.80) and the arctic char (0.75).

Phalaropes

Of the 84 red and northern phalaropes collected in the study area during the 3 to 25 August period, 62 phalaropes had food organisms present in their stomachs when they were collected. Almost one-third (30%) of their stomach contents was unidentifiable material. The major components of the identifiable portion were copepods (40.2%), amphipods (14.0%), and mysids (14.0%). The remainder of the diet was comprised of very small amounts of fish (striated muscle), and small amounts of pteropods and insects (Fig. 3; Table 19).

Organisms collected from phalarope feeding habitats were in proportions similar to those found in phalarope stomachs (Fig. 3 and Table 19). Copepods comprised the largest proportion (31.1%), with mysids (26.1%) and amphipods (12.1%) also present in significant proportions. These data suggest that when phalaropes feed along barrier island and lagoon shorelines, they consume small organisms in approximately the same proportions in which they are present. However, chaetognaths comprised an estimated 12.9% of the food volume available in feeding habitats, but were not identified in the phalarope stomachs.

Comparisons of diets of major bird and fish species showed that the diet of northern phalaropes was most similar to that of arctic char (0.78), least cisco (0.74) and red phalaropes (0.74) (RU 467, ECOLOGY OF FISH section). The diet of red phalaropes was most similar to that of northern phalaropes (0.74) and fourhorn sculpins (0.57).

Table 19. A Comparison of the Organisms Found in the Stomachs and in the Feeding Habitat Samples of Phalaropes in the Simpson Lagoon Area of Alaska, 3 to 25 August, 1977.

Taxon	Point Assignment* for Phalarope Stomachs (n=46)	Point Assignment for Feeding Habitat (n=17)	% Total Points of Stomach	% Total Points of Habitat Sample
Mysids	37¾	36½	14.0	26.1
Amphipods	37¾	17	14.0	12.1
Copepods	108½	43½	40.2	31.1
Fish	0	6	0.0	4.3
Cnidaria (Medusae)	0	14	0.0	10.0
Pteropods	2	3	0.7	2.1
Chaetognaths	0	18	0.0	12.9
Euphausiids	½	1½	0.2	1.1
Decapod Larvae	0	½	0.0	0.4
Branchiopods	½	0	0.2	0.0
Insects	1¾	0	0.6	0.0
Unidentified	81	0	30.0	0.0
Total	269¾†	140	99.9	100.1

*See Griffiths *et al.* 1975 for a description of the points method of assessing the relative importance of food organisms.

† $\frac{\text{Total Points}}{n} = \frac{269\frac{3}{4}}{46}$ = 5.9 points average fullness of phalaropes stomach during this period.

Note: For a detailed description of the diet of phalaropes collected in Simpson Lagoon, refer to Appendix Table 12.

Glaucous Gulls

Of the 28 glaucous gulls collected during the 16 July to 19 September period, all but one was collected along the shoreline of a barrier island or the mainland; the one glaucous gull collected at a mid-lagoon location had an empty stomach. The diets of the remaining 27 glaucous gulls consisted largely of isopods (33.4% of volume), amphipods (22.8%), small birds (18.1%) and small fish (11.7%) (Table 20). Mysids and copepods comprised smaller proportions of the diet of glaucous gulls (6.7% and 3.1%, respectively). Euphausiids, bivalves, tunicates, hydroids and unidentifiable materials, all in small proportions, comprised the remainder of the diet. The diverse nature of the diet of this species, which included organisms ranging in size from small copepods and mysids to larger organisms such as isopods, small fish and small birds, suggests that glaucous gulls feed opportunistically along shorelines in the lagoons.

The relative proportions of invertebrate organisms collected in the shallow waters along shorelines in Simpson Lagoon where feeding glaucous gulls were collected bore little resemblance to the relative proportions of invertebrate organisms found in glaucous gull stomachs (Fig. 3; Table 20). The most conspicuous invertebrates found in glaucous gull feeding habitat samples were copepods (48.6%), chaetognaths (12.5%), mysids (11.8%), amphipods (8.2%) and cnidarians (6.8%). Isopods, which comprised 33.4% of the total diet of glaucous gulls, represented only 0.2% of the estimated total volume of the glaucous gull feeding habitat samples.

The analysis of dietary overlap in glaucous gulls and the key fish species found in Simpson Lagoon (RU 467, ECOLOGY OF FISH section) indicated that the diet of glaucous gulls was most similar to that of least cisco (0.64).

DISCUSSION

Migration Studies

Spring Migration

Radar and visual observations of spring migration detected broad-front movements of waterbirds along the central Beaufort Sea coast to

Table 20. A Comparison of the Organisms Found in the Stomachs and in the Feeding Habitat Samples of Glaucous Gulls in the Simpson Lagoon Area of Alaska, 16 July to 19 September.

Taxon	Point Assignment* for Glaucous Gull Stomachs (n=27)	Point Assignment for Feeding Habitat Samples (n=7)	% Total Points of Stomach	% Total Points of Habitat Samples
Mysids	13	16½	6.7	11.8
Amphipods	44	11½	22.8	8.2
Isopods	64½	¼	33.4	0.2
Copepods	6	68	3.1	48.6
Bivalves	1	0	0.5	0.0
Fish	22½	5	11.7	3.6
Cnidaria (Medusae)	0	9½	0	6.8
Pteropods	0	3	0	2.1
Chaetognaths	0	17½	0	12.5
Euphausiids	2	2¾	1.0	2.0
Decapod Larvae	0	¼	0	0.2
Tunicates	1	0	0.5	0.0
Tunicate Larvae	0	¾	0	0.5
Hydroids	½	0	0.3	0
Larvaceans	0	¼	0	0.2
Cumacean	0	1¼	0	0.9
Oligochaete	0	1	0	0.7
Ctenophore	0	2½	0	1.8
Birds	35	0	18.1	0
Unidentified	3½	0	1.8	0
Total	193†	140	99.9	100.1

*See Griffiths *et al.* 1975 for a description of the points method of assessing the relative importance of food organisms.

†$\frac{\text{Total Points}}{n} = \frac{193}{27}$ = 7.1 points average fullness of a glaucous gull stomach during this period.

Note: For a detailed description of the diet of glaucous gulls collected in Simpson Lagoon, refer to Appendix Table 13.

the limits of visual and radar detection. The period of spring migration in the Simpson Lagoon area during 1977 was nearly identical to that recorded during 1975 at a coastal location near the Alaskan-Yukon border. There was no indication that bird movements through the present study area were concentrated into one or more narrow 'streams' along the barrier islands, through the lagoon system or along the mainland shoreline, in contrast to results during spring 1975 near the Alaska-Yukon border (Richardson *et al.* 1975). Similarly, radar data from Oliktok in spring 1972 also showed broad front movement over and near the present study area (Flock 1973). The presence in the Simpson Lagoon area of a greater variety of potential leading lines, the more irregular configuration of the coast, and the greater width of the North Slope may all have contributed to the less concentrated nature of spring movement here than along the Yukon coast.

On the basis of visual observations during migration watches at Cape Dalhousie, in the Canadian Beaufort Sea, Barry (1976; Table 5) has estimated the total population of certain species of water birds present in this portion of the Beaufort Sea. A comparison of Barry's estimates of the total populations and the numbers observed migrating through the Simpson Lagoon-Jones Islands study area during the spring of 1977 is presented below:

Species	Estimated Total Eastern Beaufort Sea Population of Some Waterbirds*	Spring Migrants Simpson Lagoon 1977
Loons	37,850	406
Jaegers	19,200	573
Glaucous Gull	35,400	1,142
Arctic tern	2,300	51
Oldsquaw	1,130,250	3,461
Common Eider	549,120	962
King Eider	695,115	902
(Black) Brant	21,885	995
Total	2,491,120	8,492

*From Barry 1976; Table 5.

Even allowing for the facts that Barry's estimates are very general, that we usually could not record birds consistently at the far side of the lagoon, and that our observations covered only about 25% of the hours during the main 1977 spring migration period, it is apparent that only a small fraction of the Beaufort Sea populations of these species moved through Simpson Lagoon in the spring of 1977.

No open water existed in Simpson Lagoon or immediately seaward of the Jones Islands during peak days of the spring migration from 29 May to 7 June and no waterbirds made use of the ice-covered lagoon or nearshore marine habitats on these dates of peak movement. However, during the second week of June when river discharge water overflowed onto the surface of Simpson Lagoon some migrant birds, especially those migrating near the mainland shoreline, landed in lagoon waters. The earlier appearance of open water, during the peak of spring migration, whether due to some development-related activity at this coastal location or due to a natural cause, could cause birds to concentrate there.

The only major concentrations of waterbirds noted during the aerial surveys of the southeastern portion of the Beaufort Sea during early spring 1974 (Searing *et al.* 1975) and during early spring 1975 (Richardson *et al.* 1975) were restricted to areas of open water that were present there. Similarly, during an early May aerial survey of the open water area immediately west of Point Barrow, Alaska, G.Divoky (pers. comm. 1978) observed large numbers ($\sim 10^5$) of waterbirds concentrated there. A spill of oil or some other harmful pollutant into such areas could be catastrophic (Hartung 1967; Bourne 1968; Vermeer and Vermeer 1974; McEwen and Koelink 1975; Bourne 1976; Holmes and Cronshaw 1977). Techniques that could possibly be used to frighten birds from the more restricted areas of open water are discussed by Koski and Richardson (1976).

Mid-summer Molt Migration

The migration of male seaducks through the Simpson Lagoon area is not as spectacular as that near Point Barrow, Alaska (*cf.* Thompson and Person 1963; Johnson 1971; Timson 1976). The observed number of post-breeding male oldsquaws that moved through Simpson Lagoon during early July was approximately three orders of magnitude (10^3) less than the estimated 1.1 million oldsquaws that migrate into the southeastern Beaufort Sea during spring migration (Barry 1974).

The timing of the molt migration by male oldsquaws in Simpson Lagoon during 1977 was similar to that reported by others in Canada (Vermeer and Anweiler 1974; Gollop and Davis 1974) and Alaska (Schamel and Mueller 1976). Oldsquaws pass through Simpson Lagoon at a time when open water is restricted to shoreleads around the barrier islands and along the mainland shoreline, and cracks in the lagoon ice. The several thousand oldsquaws estimated to be present in Simpson Lagoon during the 5 July aerial survey were concentrated primarily in this system of shoreleads and cracks (Transects 2 and 4; Table 9). Precautions similar to those taken to avoid mortality of waterbirds during the spring migration period should also apply to the period of oldsquaw molt migration.

According to Thompson and Person (1963) and Barry (1974), slightly over one million eiders summer in the Beaufort Sea area. Approximately 700,000 of these are king eiders and the remainder are common eiders. Compared to the over one million eiders that pass Point Barrow during the post-breeding molt migration, the number of eiders that pass through Simpson Lagoon is small. The molt migration by eiders through Simpson Lagoon during 1977 occurred mainly during the third and fourth weeks of July; eiders were not observed to be concentrated in particular habitats in the study area during this period. The timing of the eider molt-migration during 1977 was similar to that in 1972 past Egg Island, near Prudhoe Bay, Alaska (Schamel 1974). According to Thompson and Person (1963), King (1970) and Johnson (1971), the molt migration of eiders past Point Barrow, Alaska, begins in the second week of July, and the peak of male movement at that location generally occurs a week later.

Most of the westward molt migration by eiders apparently occurs over marine habitats offshore from the barrier islands and coastal lagoons; far too few eiders were seen at nearshore locations during the period of molt migration to account for the numbers ($\sim 10^6$) that take part in this movement. Thus, the late July and early August period of molt migration appears not to be a critical period for eiders in the Simpson Lagoon area.

Fall Migration

In general, arctic terns begin their fall migration during mid-August and most birds of this species have departed the Beaufort Sea area by early September (Johnson *et al*. 1975). The timing of the fall migration by arctic terns along the Jones Islands during 1977 was approximately two weeks later than noted farther west on the Plover islands during 1976. At that location R. Boekelheide (pers. comm. 1978) recorded a peak movement of arctic terns during the first week of August. Connors and Risebrough (1977) noted that arctic terns and Sabine's gulls were abundant in the Point Barrow area during the second week of August, 1976.

Large flocks consisting of both adult and juvenile arctic terns with smaller numbers of adult and juvenile Sabine's gulls were observed feeding at specific locations in Simpson Lagoon during the fall migration period. Presumably, these species at least partly rely upon pre-migration feeding to accumulate fat reserves prior to their long southward migrations; locations in the study area where terns and gulls concentrate to feed may be important, and development-related activities should be made compatible with concentrations of these birds.

A peak of fall migration by black brant and a lesser peak of movement by loons occurred during a two-week period from the end of August to early September. The timing of the brant migration along the coast of the Beaufort Sea has been well-documented (for a review, see Johnson *et al*. 1975). The fall migration by this species during 1977 is within the range of dates described by others.

The extent to which brant utilized lagoon or shoreline habitats during their fall migration in 1977 is unknown; however, most of the brant migration occurred along the mainland shoreline so this species probably would be less affected by development activities on the barrier islands or in Simpson Lagoon than some other species. Nevertheless, a degree of caution should be exercised at mainland shoreline locations during periods of brant migration.

It is not currently known whether loons utilized lagoon habitats during their fall migration through the study area during 1977.

Nesting Studies

The number of nests found on the Jones Islands during 1977 was larger than that reported by Divoky (1978) for the same islands in 1976 and larger than that reported by Gavin (1976) for the same islands surveyed yearly for the six-year period 1970-1975. None of the species of birds that nested or attempted to nest on the tundra portions of the Jones Islands are unique to barrier islands. All of these tundra-nesting species have been reported nesting at mainland locations and, in most instances, in densities much higher than on the tundra portions of the Jones Islands (Table 21). In fact, the only tundra area in North America where lower densities of nesting birds have been accurately determined was a High Arctic site on Devon Island (Table 22).

Arctic foxes apparently accounted for most of the nesting failure and consequently for the low density of successful nests on the tundra portions of the Jones Islands. Foxes may have preyed more heavily on birds' eggs during 1977 than during the immediately preceding years because of the decline in the lemming population along the central Beaufort Sea coast during the winter of 1976 and spring of 1977 (W. C. Hanson, pers. comm. 1977). Lemmings are a major food item of arctic foxes in tundra habitats (Chesemore 1968). Although old lemming nests and skeletal material were found on the tundra on the Jones Islands, we captured no individuals during 960 trap nights on Pingok Island during the period 21 July to 19 September 1977.

Certain species nest on gravel portions of the barrier islands. The small number of nests of three species of birds--arctic terns, common eiders and glaucous gulls--found during 1977 were all on gravel portions of the barrier islands. Gravel substrates are most common on Spy, Leavitt and Cottle Islands. Arctic foxes apparently also preyed heavily on the eggs of these species during 1977 and the number of active nests found in these habitats was small (see RESULTS). However, the numbers of nest scrapes* and destroyed nests† found on the gravel barrier islands suggest

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*Depressions in the gravel or sand designating an early stage of nest establishment.

†Nests with down present and/or with missing eggs, broken eggs or egg shells present.

Table 21. A Comparison of Bird Nesting Density and Nesting Success in Similar Habitats at Prudhoe Bay, Barrow and the Jones Islands, Beaufort Sea, Alaska.

	Prudhoe Bay (Norton *et al.* 1975)		Barrow				Jones Islands (Present Study)	
			Norton (1973)		Myers *et al.* (1977)			
Species	Density (nests/km^2)	Success (%)*	Density (nests/km^2)	Success (%)*	Density (Plot^1) (Territories/km^2)	Density (Plot 2) (Territories/km^2)	Density (nests/km^2)	Success† (%)**
Dunlin	4.6	50	13.9	72	21.2	20.4	1.7	0
Baird's Sandpiper	-	-	24.8	39	4.6	-	4.4	13
Lapland Longspur	7.7	60	30.0	63	31.8	22.2	10.0	39
Snow Bunting	-	-	15.0	80	6.1	3.7	2.2	75
All Species	96.7	62	133.5	65	167	148	21.1	30

* Eggs hatched/eggs laid in that nest = %.

† A nest was judged to be successful if evidence suggested that some young from the nest had fledged.

**Nests with some young fledging/total nests of that species = %.

Table 22. A Comparison of Bird Nesting Density at Five Tundra Sites in Arctic North America.

Site	Latitude (°N)	Pairs or Nests/km^2	Source
Devon Island, Canada	76	2	Pattie 1977
Barrow, Alaska	71	134	Norton 1973
		167	Myers 1977
		148	Myers 1977
Prudhoe Bay, Alaska	70	97	Norton *et al.* 1975
Cape Thompson, Alaska	68	160	Williamson *et al.* 1966
Jones Islands, Alaska	70	21	Present Study

that, in the absence of arctic foxes, a greater potential exists for successful nesting by those species that are thought to be unique to barrier islands (Table 23).

Development activities on barrier island habitats should be planned with the knowledge that the gravel portions of barrier islands apparently have the highest potential for production of bird species thought to be uniquely associated with barrier islands.

Molting Oldsquaw Studies

The peak of the molt by male oldsquaws occurred during the period 29 July to 3 August. By that period, both Simpson Lagoon and the offshore marine areas north of the barrier islands had cleared of ice, thereby making available to oldsquaws large areas of open water. Prior to the molt period, densities of oldsquaws recorded during aerial surveys were highest in the only open water habitat available to them in the study area--in shoreleads around the margins of the barrier islands, in the shoreleads along the mainland shoreline, and to a lesser extent, in the cracks in the lagoon ice.

Throughout the 1977 open-water season, the lowest densities of oldsquaws were recorded in offshore marine and mainland tundra habitats, and the highest densities were recorded in the lagoon habitats. Similar use of lagoon habitats by molting oldsquaws has been noted by other investigators along the Beaufort Sea coast (Brooks 1915; Bartonek 1969; Bartels 1973; Hall 1974; Ward and Sharp 1974; Gollop, Black *et al.* 1974; Vermeer and Anweiler 1975; Barry 1976). However, densities of molting oldsquaws as high as those recorded in Simpson Lagoon during 1977 have not been recorded elsewhere.

According to Payne (1972), the energy requirements of molting birds increase because of increased metabolic costs for thermoregulation when feather loss reduces body insulation, and because of metabolic demands for feather replacement. In view of these facts, it is interesting that in Simpson Lagoon, the thickness of the subcutaneous fat layer in male oldsquaws was greatest during the period of molt when insulation afforded

Table 23. Numbers of Nest Scrapes and Destroyed Nests on Spy, Leavitt and Cottle Islands, 1977*.

Island	Species			
	Common Eider	Arctic Tern	Glaucous Gull	Total
Spy Island				
# Scrapes	72	41	0	113
# Destroyed Nests	15	-[†]	8	23
Leavitt Island				
# Scrapes	21	22	0	43
# Destroyed Nests	4	-	2	6
Cottle Island				
# Scrapes	11	0	0	11
# Destroyed Nests	3	-	4	7
Total				
# Scrapes	104	63	0	167
# Destroyed Nests	22	-	14	36

*The exact age of many nest scrapes and destroyed nests is unknown. Apparently some nests and nest scrapes may remain apparent for several years.

[†] Nests of arctic terns may be simple depressions in the sand or fine gravel; these nests are often indistinguishable from nest scrapes.

by feathers was reduced. The subsequent decrease in the thickness of this fat layer after the molt may have been a result of the increased metabolic demands during molt. Availability of shelter and a reliable food supply prior to and during the molt period may be important in increasing or maintaining adequate fat reserves during molt.

Although the effects of wind on the energy requirements of molting seaducks have not been investigated, the metabolic responses of other species to wind have been discussed by Stevens and Moen (1970), Gessaman (1973), Evans and Moen (1975) and Kelty and Lustick (1977). In general, the metabolic rate of a bird exposed to wind increases in proportion to the square root of wind speed. We found no consistent evidence that old-squaws sought shelter from the wind on either the north or the south sides of Simpson Lagoon (Table 24). However, oldsquaws may have concentrated around points of land in Simpson Lagoon on certain dates (see RESULTS, Fig. 2), presumably for protection from winds and because the oldsquaws need swim only a short distance to regain shelter after a shift in the wind direction from east to west. More data are needed to permit a quantitative evaluation of responses to wind.

The estimated number of oldsquaws in Simpson Lagoon on 30 August, after males of this species had regained flight, was reduced from estimated numbers during and immediately after the peak molt (28 July to 15 August). Although the male/female ratio remained relatively unchanged throughout August, apparently some oldsquaws had moved out of Simpson Lagoon by the end of that month. A dramatic increase in the estimated number of oldsquaws present in Simpson Lagoon had occurred by 22 September, immediately after lakes and ponds on the mainland tundra had frozen over. An influx of birds from tundra areas adjacent to Simpson Lagoon, or from areas east of Simpson Lagoon, may have accounted for this dramatic increase. During the westward fall migration out of the Beaufort Sea, many oldsquaws follow a coastal route similar to the route followed during eastward spring migration (Johnson *et al.* 1975). It is possible, therefore, that birds from the Canadian portion of the Beaufort Sea, or from areas farther east in the Canadian Arctic, may temporarily stop in Simpson Lagoon as they pass westward during late September. The majority

Table 24. Distribution and Abundance of Oldsquaws in Simpson Lagoon in Relation to Wind.

Survey Date	Survey Type	WIND		POSITION OF OLDSQUAWS					
		From Direction(°)	Speed (km/hr)	North Side		Middle		South Side	
				#	%*	#	%	#	%
5 June	Aerial	-	-	0	-	0	-	3	100
15 June	Aerial	-	-	23	68	0	-	11	32
5 July	Aerial	Calm	Calm	398	57	35	5	269	38
28 July†	Aerial	120	8	5,345	44	-	-	6,687	56
1 August**	Ground	090	24	4,583	46	-	-	5,347	54
14 August**	Ground	060	16	19,938	88	-	-	2,758	12
15 August†	Aerial	135	8	11,991	85	-	-	2,095	15
30 August	Aerial	090	5	148	5	2,271	72	721	23
22 September	Aerial	270	27	297	2	11,417	78	2,849	20

* Percent of the total number of Oldsquaws seen on and off transect on an aerial survey.

† Because of logistic difficulties, the middle portion of the lagoon was not surveyed on 28 July or 15 August.

**During counts of oldsquaws from positions on the ground (1 and 14 August), the lagoon was divided only into north and south portions.

of these late-arriving birds are juveniles and females, which explains the increased proportion of female oldsquaws and the presence of juvenile birds during the late September collection period (see RESULTS).

In summary, during the mid-summer period of molt, oldsquaws gather into large flocks and become completely flightless after the loss of their wing feathers. During this period, oldsquaws are relatively concentrated and sedentary, and are probably more vulnerable to waterborne pollutants and to disturbance than at any other stage of their life cycle; development-related activities in lagoon systems along the Beaufort Sea coast should be conducted with this fact in mind. A recent preliminary study in a lagoon system in the southeastern Beaufort Sea (Sharp 1978) suggests that stationary scaring devices would have limited usefulness in deterring molting oldsquaws from areas of possible contamination, but that slow-moving and low-flying helicopters may be useful to 'herd' both molting and flying oldsquaws away from areas where they concentrate, and hence away from areas of possible contamination.

Pre-migratory Staging of Shorebirds and Gulls

In the Simpson Lagoon area, phalaropes did not use coastal areas as spring staging sites, in contrast to results from the Point Barrow area (Connors and Risebrough 1977). Phalaropes were not abundant in the Simpson Lagoon-Jones Islands study area until August, when juvenile birds left rearing areas on the mainland tundra and arrived along barrier island shorelines to feed. In mid-August, during the peak of their abundance in the study area and coincident with peak abundance in the Point Barrow area (Connors and Risebrough 1977), phalaropes were abundant along all the shorelines in the study area. Throughout August, however, phalaropes were most abundant along the shorelines of the barrier islands (see RESULTS, Table 12). In the Simpson Lagoon area phalaropes fed primarily on marine copepods and other small marine invertebrates; the high densities of phalaropes along seaward beaches may be related to an abundance of food organisms, and especially copepods, at those locations.

Connors and Risebrough (1976) have shown that during 1975, the presence of feeding phalaropes along particular beaches in the Point Barrow area was related to wind direction. During 1976, however, Connors and Risebrough (1977) found no such relationship. In Simpson Lagoon, all surveys of shoreline transects were conducted on relatively calm days; therefore, our data are not comparable to those of Connors and Risebrough (1977). It is unclear, therefore, whether wind and waves concentrate invertebrates along windward beaches, where birds may more easily pick them from the clear marine water or from the shoreline substrates; or whether copepods simply are more abundant in marine than in lagoon waters, and phalaropes concentrate along barrier island shorelines because of an abundance of food organisms there.

Juveniles of certain other species of shorebirds such as white-rumped and semipalmated sandpipers also concentrate along coastlines after leaving tundra rearing areas (Parmelee *et al.* 1967). No white-rumped sandpipers were observed in the Simpson Lagoon area during 1977 and few juvenile semipalmated sandpipers were recorded in habitats other than mudflats and saltmarshes and brackish and freshwater ponds along the mainland coast.

Small numbers of glaucous gulls were present in the study area, mainly in exposed gravel areas along the barrier islands, until the 28 July aerial survey, the first aerial survey conducted after the ice had moved out of Simpson Lagoon and away from the seaward shoreline of the barrier islands. On this date, the largest proportion (approximately 63%) of the total number of glaucous gulls (158 birds) recorded in the study area was seen along the mainland shoreline (Transect 4), and there was also a marked increase along the barrier islands (Transect 2; Table 17). During early spring in the Beaufort Sea, anadromous fish species such as cisco, whitefish and arctic char leave their wintering areas in freshwater streams and rivers and, as soon as a sufficient amount of water is available, begin a migration along the coast (Craig and McCart 1976; RU 467, ECOLOGY OF FISH section). The presence of glaucous gulls along the mainland coast during the period just after breakup (breakup was complete on 11 July) may be related to the presence of migrating fish in this area. Fish appeared in the diet of glaucous gulls sporadically throughout the season, but the largest quantity recorded in an individual gull stomach was from a bird collected at a barrier island location relatively early in the season (16 July).

The consistent presence of glaucous gulls along the barrier islands throughout the open-water season is thought to be related to the more extensive feeding habitats available along the barrier islands. Ingolfsson (1967) has shown that in Iceland, the glaucous gull is more closely associated with intertidal or shoreline habitats than four other species of large gulls. Barrier islands provide both seaward and lagoonward shoreline feeding habitats. Furthermore, the presence of both marine and lagoon habitats in close proximity may provide a quantity of food organisms along the barrier islands not present along the mainland shorelines (RU 467, INVERTEBRATES section; Table 8).

Feeding Studies

Results of stomach analyses of oldsquaws and analyses of oldsquaw feeding habitat samples suggested that oldsquaws in Simpson Lagoon consumed invertebrates primarily from the epibenthos. Mysids (primarily *Mysis litoralis*) and amphipods (primarily *Onisimus glacialis* and *Apherusa glacialis*) were the main taxa in the oldsquaw stomachs and (along with copepods) feeding habitat samples. Epibenthic transect surveys by a SCUBA-equipped diver (RU 467, INVERTEBRATES section) provided corroborating evidence that mysids and amphipods were the most visibly abundant taxa of epibenthic invertebrates present at aquatic sampling stations in Simpson Lagoon and at a specific location where a flock of oldsquaws was observed feeding. The apparent concentrations of oldsquaws near points of land along the mainland coast and south of the barrier islands (see Fig. 2) may be related to the presence of high densities of food organisms that may be concentrated in these areas by currents--the currents that deposit sediments that form spits and sandbars at these same locations. At present, neither qualitative or quantitative data exist to support this speculation.

Craig and Griffiths (RU 467, ECOLOGY OF FISH section) have shown that the diet of oldsquaws in Simpson Lagoon during 1977 was very similar to that of the most common coregonid fish species present in the study area, the arctic cisco (*Coregonus autumnalis*). Similarly, the winter diet of oldsquaws in Lake Michigan was very similar to that of the major coregonid species present (*Coregonus clupeaformis*); there both oldsquaws and whitefish concentrated in areas where benthic invertebrates were most dense (Peterson and Ellarson 1977:88). The largest proportions of the diets of both the oldsquaw and the whitefish in Lake Michigan were comprised of the benthic amphipod (*Pontoporeia affinis*). Other studies of the feeding ecology of oldsquaws (Ellarson 1956; Cottam 1939) have indicated that in both the arctic breeding grounds and temperate wintering areas, crustaceans and especially amphipods, are the most conspicuous food organism present in the diet of this species.

The volume of both clams and fish in the stomachs of oldsquaws examined in Lake Michigan was low. Clams and fish were also present in the stomachs of oldsquaws collected in Simpson Lagoon. More clams were consumed by oldsquaws in Simpson Lagoon during the early part of the season (19 June to 3 August) than during later periods; fish did not comprise a significant proportion of the diet of oldsquaws in Simpson Lagoon during 1977 (see RESULTS, Fig. 3).

Table 25 gives a comparison of the mean lengths of three important species of invertebrates--*Mysis litoralis*, *Onisimus glacialis* and *Apherusa glacialis*--all of which were consumed by oldsquaws and all of which were found in oldsquaw feeding habitat samples. The organisms found in the stomachs of oldsquaws were significantly longer than those found in the oldsquaw feeding habitat samples. The limitations and biases of conventional sampling equipment and sampling procedures, as discussed by Griffiths and Craig (RU 467, INVERTEBRATES section), should be considered when interpreting these results. However, these length comparisons suggest that oldsquaws, when feeding on the lagoon epibenthos during 1977, may have selected larger mysids and amphipods.

Further evidence that oldsquaws may feed selectively is given by Rofritz (1977) for oldsquaws feeding in Milwaukee Harbor, Lake Michigan.

Table 25. A Comparison of the Sizes of Three Important Marine Invertebrates Taken From Oldsquaw Stomachs and Taken From Lagoon Epibenthic Habitat Samples.*

Taxon	Oldsquaw Stomach (length mm)	Epibenthic Sample (length mm)	U**	P
Onisimus glacialis	5.64 ± 1.15†	4.38 ± 1.68	77	<0.002
Apherusa glacialis	9.28 ± 1.65	5.70 ± 2.12	36	<0.002
Mysis litoralis	13.28 ± 2.59	10.74 ± 3.42	64	<0.002

* Habitat samples were collected at the locations where birds were collected.

† Mean ± standard deviation.

**Mann-Whitney U-test; n_1 and n_2 = 20.

Rofritz found that during January of 1972, oldsquaws fed almost exclusively on oligochaetes, even though molluscs and crustaceans were also present in the benthos where oldsquaws were feeding. Rofritz suggested that oldsquaws in Milwaukee Harbor may have selected oligochaetes as a food source because oligochaetes had a significantly higher caloric value per gram of body weight than did other benthic fauna present.

I calculate the daily existence energy requirements of an oldsquaw to be approximately 300 Kcal/bird-day. This is an approximate value based on data for scaup ducks provided by McEwan and Koelink (1973) and on general principles and equations provided by King (1974) and by Kendeigh *et al.* (1975). Based on data presented by Owen (1970), the coefficient of utilization

$$\frac{\text{metabolized energy}}{\text{gross energy intake}} \times 100$$

for oldsquaws was estimated to be 70%. This value was used to calculate $[(300 \text{ Kcal})\ (\text{bird-day})^{-1}/(0.70)]$ the daily gross energy requirement of approximately 430 Kcal/bird-day for an oldsquaw. The estimated number of oldsquaws present in Simpson Lagoon, as calculated from densities obtained from aerial surveys, varied from approximately 106 birds on the 20 June survey to approximately 106,000 birds on the 22 September survey. Griffiths and Craig (RU 467, INVERTEBRATES section) have compared the energy available in epibenthic mysids and amphipods in Simpson Lagoon during various periods to the daily energy requirements of the oldsquaws present at those times. Partly on this basis, and partly because the epibenthic standing crop tended to increase through the summer, they concluded that food was probably not a directly limiting factor for oldsquaw in Simpson Lagoon in the summer of 1977.

In the Simpson Lagoon area, 40% of the diet of phalaropes was comprised of copepods. Amphipods (13.9%) and mysids (13.9%) comprised most of the remainder. Similarly, copepods, amphipods and mysids comprised the largest proportions of organisms present in samples collected from phalarope feeding habitats.

In the Point Barrow area of Alaska, Connors and Risebrough (1977) found extreme variation both in the diets of red phalaropes and in the relative abundances of invertebrates present in areas where phalaropes were feeding. During 1975, copepods, decapod zoea (larvae) and chaetognaths comprised the major proportions of both the diets of red phalaropes and of plankton samples collected at locations where phalaropes were observed feeding (Connors and Risebrough 1976). During 1976, however, copepods were apparently less important as a food for red phalaropes in the Point Barrow area (Connors and Risebrough 1977); amphipods, decapod zoea and pteropods comprised the major proportions of the diet of red phalaropes during that year.

Copepods consumed by phalaropes in Simpson Lagoon were not systematically identified to species. However, cursory identifications made during sorting of major taxa indicated that calanoid copepods, primarily *Calanus* spp. and *Limnocalanus* spp., were the predominant taxa present in the stomachs examined as well as in the phalarope feeding habitat samples.

During a series of observations of the feeding behavior of phalaropes conducted on 5 August 1977, it was noticed that birds of both species were feeding on the small cnidarian (jellyfish) *Sarsia princeps*. Although jellyfish and other soft-bodied invertebrates such as pteropods (soft-bodied snails with highly reduced shells) collectively comprised 12.1% of the estimated total volume of phalarope feeding habitat samples, these soft-bodied invertebrates comprised a very small proportion of the stomach contents of phalaropes (see Appendix Table 12). Indeed, we found no trace in the phalarope stomachs of *Sarsia princeps*. Because of this difference between behavioral observations and results of stomach analyses, caution should be exercised when interpreting the results of feeding ecology studies of phalaropes (and other species) when visual observations do not accompany stomach analyses. The results of micro-bomb calorimetry determinations have revealed that *Sarsia princeps* represents a relatively significant amount of food energy (5.4 Kcal/g of ash free dry material) for an avian predator such as a phalarope (RU 467, INVERTEBRATES this volume, discusses the results of oxygen micro-bomb colorimetry trials).

The daily existence energy requirements of a single phalarope, based on equations given by Kendeigh *et al*. (1975) and King (1974), was calculated to be approximately 33 Kcal/bird-day. Assuming a coefficient of utilization of approximately 60% (Norton 1970), the total daily gross energy requirement of a single phalarope is 55 Kcal/bird-day. The estimated total number of phalaropes present in the study area, based on extrapolations of linear densities (birds/km of shoreline) along 15 shoreline transects surveyed during August (see RESULTS, Table 12), ranged from approximately 160 birds on 1 August to a peak of approximately 6,100 on 16 August, and decreased to approximately 1,120 on 24 August (Table 16). Thus, 3.4×10^5 Kcal/day (55 Kcal/bird-day x 6,100 birds) is the energy required in the form of copepods, small amphipods, small mysids and small jellyfish to maintain the total number of phalaropes present in the study area on 16 August. Quantitative estimates of the standing stocks (Kcal/m^2) of mysids and amphipods at stations along the north and south shorelines of Simpson Lagoon are given by Griffiths and Craig (RU 467, INVERTEBRATES section). If phalaropes are assumed to feed 0-20 m from shore, the energy available in mysids and amphipods present in lagoon feeding habitat is 1½-2 orders of magnitude more than daily energy requirements at the time of peak phalarope abundance.

It is clear that large numbers of phalaropes concentrate along shorelines in the Beaufort Sea to feed and accumulate fat reserves prior to southward migration. The results of color-marking studies of phalaropes near Point Barrow, Alaska (Connors and Risebrough 1977), suggest that a rapid turnover in the number of juvenile phalaropes present along shorelines occurs during late August. Thus, total numbers using an area may considerably exceed the maximum number seen at any one time. This information indicates that the Beaufort Sea may be an important area to significant fractions of the total populations of both red and northern phalaropes.

In relation to phalaropes, shorelines of barrier islands and areas directly adjacent to such shorelines appear to be most in need of protection from contaminants during the month of August. However, during mid-August, the period of peak phalarope abundance, precautions should be taken to protect all shorelines around barrier islands, spits and along the mainland.

No arctic terns were collected in the Simpson Lagoon study area during 1977. The only period when large numbers of arctic terns were present in the study area was during their fall migration, which lasted from approximately 15 to 30 August in 1977. During this period both adult and juvenile terns, with smaller numbers of Sabine's gulls, fed at locations between the barrier islands, where mixing of marine and lagoon waters produced turbulence. Both arctic terns and Sabine's gulls were observed picking invertebrates from the surface of the water in these areas; juvenile birds of both species were observed begging for food from adults. Several plankton tows conducted in these areas while birds were feeding indicated that mysids and amphipods were the two most abundant taxa present.

The diets of glaucous gulls in Simpson Lagoon consisted of a variety of shoreline invertebrates and vertebrates ranging in size from copepods to amphipods, tunicates, bivalves, isopods, small fish and small birds. In relation to the other key bird species examined (phalaropes and oldsquaws) glaucous gulls appear to have adopted an opportunistic feeding strategy along shorelines in the Simpson Lagoon area. Glaucous gulls feeding along coasts in Iceland also consumed a variety of food organisms ranging from small intertidal invertebrates to birds and fish (Ingolfsson 1967).

The distribution of gulls in the study area appears related to the distribution of their food organisms; the mainland shoreline was apparently preferred habitat shortly after breakup, possibly because of the presence of fish in this area; the lagoonward shorelines of the barrier islands were apparently preferred habitats during August, presumably because of the presence of isopods and mysids; the seaward shorelines of the barrier islands were apparently preferred habitats during September because of the presence of large hyperiid amphipods.

The existence energy requirements of a glaucous gull, calculated using formulae in King (1974) and Kendeigh *et al.* (1975), is approximately 390 Kcal/bird-day. Assuming a coefficient of utilization of 70%, the gross energy requirement is approximately 560 Kcal/bird-day. The energy requirements for the total number of glaucous gulls present along the barrier islands and in Simpson Lagoon, based on the total number of glaucous gulls recorded both on- and off-transect during aerial surveys conducted in these habitats (Table 17), increased from a low of approximately 1.34 x 10^3 Kcal/day on 5 June to 176.6 x 10^3 Kcal/day during the period of peak abundance on 22 September.

Avian Disturbance Studies

Scientifically credible, quantitative studies of disturbance, employing proper controls, are difficult to conduct. The very presence of an observer recording responses of organisms to various types of disturbance is a major source of error. Similarly, misleading anthropomorphic interpretations of responses by animals to disturbance are difficult to avoid. Experience has shown, however, that many species of birds accomodate relatively well to certain types of development-related activities (Schweinsburg 1974; Gollop, Goldsberry and Davis 1974a,b; Gollop, Black *et al.* 1974). Notable exceptions along the Beaufort Sea coast include snow geese approached by aircraft (at nearly any altitude) during the period of fall pre-migratory staging, which occurs from approximately 15 August to approximately 10 September (Schweinsburg 1974; Koski 1977); and aircraft overflights in the vicinity of certain species of ducks, such as eiders, during the period of egg laying and early incubation, which occurs from approximately 1 to 30 June (Barry and Spencer 1971; Schamel 1974; Korschgen 1977; Schamel, pers. comm. 1978).

Our experiences in Simpson Lagoon during the summer of 1977 suggest that molting and post-molting oldsquaws were little affected by such activities as systematic collecting with shotguns, by systematic disturbance from small boats moving across and through the lagoon, by systematic low-level aerial surveys from both helicopters and small fixed-wing aircraft, and by overflights of many other aircraft (Appendix Table 14). Oldsquaws did not leave the study area after such disturbances; nor did they cease to frequent certain areas of concentration around points of land on the mainland coast and along the south coast of the Jones Islands (see Fig. 2).

Ward and Sharp (1974) similarly found that molting oldsquaws were little affected by aircraft overflights near Herschel Island, Yukon Territory, during August 1973.

Feeding flocks of staging phalaropes showed little overt reaction to our collecting activities (shooting them with shotguns). Many flocks of phalaropes continued to feed while several birds from the flock were collected.

Glaucous gulls became wary of small boats after a number of encounters with biologists shooting at them from small boats.

CONCLUSIONS

Major conclusions of ornithological studies in 1977 are enumerated below:

1. Lagoon and nearshore marine habitats were largely frozen when spring migration occurred, and birds made minimal use of the area. Any open water created during this time by man's activities might attract large numbers of waterbirds and thereby increase their vulnerability to oil or other contaminants that might accumulate at such sites.
2. Male oldsquaws used shoreleads and cracks in lagoon ice during their molt migration in early July effectively concentrating themselves into habitats potentially vulnerable to contamination by oil. Male eiders largely bypassed Simpson Lagoon during their westward molt migration.
3. Common eiders, arctic terns and glaucous gulls nested almost exclusively on gravel surfaces of islands, whereas species and densities nesting on tundra portions of islands were unremarkable; it is concluded, therefore, that gravel-surfaced barrier islands are very important to these species and should receive protection during the course of development.

4. Simpson Lagoon was an extremely important area for staging and molting oldsquaws in August and September; an estimated maximum of 106,000 oldsquaws were present in the lagoon on 22 September 1977. Therefore, development should proceed there only with extreme caution during these months.

5. Shorelines were very important habitats to feeding shorebirds in August; seaward shores of islands were most important, lagoonward shores of islands were of intermediate importance, and mainland shores were of least importance. Shorelines were also important to glaucous gulls throughout the open-water season. Development activities that affect beach habitats during the open water season should therefore proceed with caution.

6. Glaucous gulls were opportunistic in their diets and feeding strategies; phalaropes and oldsquaws were more specialized. Standing stocks of epibenthic invertebrates, expressed as energetic equivalents, were apparently one to two orders of magnitude greater than the daily energetic requirements of key bird species.

RECOMMENDED FURTHER RESEARCH

Needs for further study are addressed in RU 467, OVERVIEW AND SYNTHESIS section: RECOMMENDED FURTHER RESEARCH.

SUMMARY OF 4th QUARTER OPERATIONS

Fourth quarter operations are summarized in RU 467, OVERVIEW AND SYNTHESIS section: SUMMARY OF 4th QUARTER OPERATIONS.

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APPENDIX

Appendix Table 1. A Comparison of the Percent of the Major Food Organisms Consumed by Oldsquaws as Determined by Biomass Measurements and by Estimated Total Volume.*

TAXON	% TOTAL WET WEIGHT		% ESTIMATED TOTAL VOLUME	
Mysids	47.4	(78.7)[†]	54.8	(64.2)
Amphipods	5.6	(9.3)	18.5	(21.7)
Isopods	1.0	(1.7)	2.1	(2.4)
Copepods	>0.1	(>0.1)	0.3	(0.3)
Fishes	Otoliths Only		2.1	(2.4)
Bivalves	5.9	(9.8)	7.7	(9.0)
Hydroids	0.3	(0.4)	0.0	(0.0)
Chaetognaths	>0.1	(>0.1)	0.0	(0.0)
Cumacean	>0.1	(>0.1)	0.0	(0.0)
Tunicates	>0.1	(>0.1)	0.0	(0.0)
Unidentified	39.8		14.6	
TOTAL	100.1	(100.0)	100.1	(100.0)

*The estimated total volume is based on methods described by Hynes (1950) and by Griffiths *et al.* (1975)..

[†] Numbers in parentheses represent the % of the total identifiable material; the 'unidentified' category has not been included.

Appendix Table 2. Mean Linear Densities (Birds/km of shoreline)* of Birds on Five Ocean Beach Transects, Five Lagoon Beach Transects, and Five Mainland Beach Transects Surveyed During the Period 1 August to 14 September, 1977.

	1 August			16 August			24 August			1 September			14 September		
	Ocean n=5	Lagoon n=5	Mainland n=5	Ocean n=5	Lagoon n=5	Mainland n=5	Ocean n=5	Lagoon n=5	Mainland n=5	Ocean n=5	Lagoon n=5	Mainland n=5	Ocean n=5	Lagoon n=5	Mainland n=5
All Loons	-	-	0.4	-	-	-	0.2	-	0.4	0.6	0.4	0.4	-	-	-
All Geese	-	-	-	-	-	-	-	-	15.0	-	-	6.4	-	0.4	-
Pintail	-	-	-	-	-	-	-	1.2	-	-	0.4	-	-	-	-
Oldsquaw	9.6	213.4	-	0.6	0.4	-	-	245.4	-	-	10.0	0.6	-	0.4	-
Eider	2.2	-	-	-	4.0	-	-	-	-	-	-	-	-	-	-
All Phalaropes	4.0	1.2	-	131.8	32.8	29.8	-	32.6	-	-	-	-	-	-	-
Other Shorebirds	1.0	1.0	1.6	0.5	5.2	3.0	2.2	7.2	1.2	11.2	3.0	3.8	15.0	2.0	-
Gulls/Terns	0.8	3.2	0.2	2.6	33.8	0.2	0.8	4.4	-	14.8	-	0.4	1.0	0.8	-
Jaeger	-	-	-	-	-	-	-	-	-	0.4	-	-	-	-	-
Lapland Longspur/ Snow Bunting	-	-	-	-	-	-	-	-	-	0.4	0.4	-	-	-	-
ALL BIRDS / TOTAL DENSITY	17.6	218.8	2.2	135.5	76.2	33.0	3.2	290.8	16.6	27.4	14.2	11.6	16.0	3.6	-

*Beach transects were 1 km long x 0.2 km wide (10 m either side of the shoreline) = 0.02 km^2. Only those birds seen on-transect have been included in this table.

Appendix Table 3. Numbers of Charadriiforms Sighted on a Frequently Surveyed Shoreline Transect on Pingok Island, Alaska.*

Date	SPECIES											
	Black-bellied Plover	Ruddy Turnstone	Pectoral Sandpiper	Baird's Sandpiper	Dunlin	Semipalmataed Sandpiper	Sanderling	Red Phalarope	North Phalarope	All Phalarope	Glaucous Gull	Arctic Tern
August												
2	-	-	-	1	2	29	-	4	-	4	-	-
3	-	1	-	5	1	2	-	77	53	130	-	-
6	-	7	-	1	-	-	-	193	60	253	1	3
8	-	18	-	1	-	1	-	525	51	686	-	1
10	-	5	-	-	-	-	-	-	-	338	3	-
12	-	1	3	6	1	1	-	69	23	116	-	-
14	-	11	6	3	29	6	-	16	-	16	-	-
23	-	-	2	-	13	-	-	262	52	364	-	60
26	2	-	2	-	7	-	1	24	17	41	6	15
28	-	-	-	-	-	-	-	-	-	-	-	-
31	4	-	-	-	9	-	3	-	-	-	1	26
September												
2	3	-	-	-	9	1	5	-	-	-	-	-
4	-	-	-	-	-	-	1	-	-	-	-	-
6	-	2	-	-	37	-	-	-	-	-	2	-
8	1	-	-	-	-	-	3	-	-	-	-	-
12	6	-	-	-	66	-	17	17	-	17	18	-
16	-	-	-	-	-	-	-	-	-	-	-	-
18	6	-	-	-	2	-	2	-	-	-	2	-

*This transect was located along the lagoonside shoreline of Pingok Island, south of the field camp (see Fig. 1). The dimensions of this transect 1.2 km x 0.02 km (0.024 km^2), were slightly different from other shoreline transects.

Appendix Table 4. The Mysid Diet of Oldsquaws Collected in the Simpson Lagoon Area of Alaska.

Taxon	Early Season (n=12) 24 June to 3 August				Mid Season (n=10) 17 to 31 August				Late Season (n=12) 15 to 18 September				Total Season (n=34) 24 June to 18 September			
	#*	%	wt†	%	#	%	wt	%	#	%	wt	%	#	%	wt	%
Mysis relicta	347	29.4	4.133	24.8	67	20.6	1.281	14.8	78	6.7	1.636	8.0	492	18.4	7.05	15.5
Mysis litoralis	245	20.8	3.632	21.8	50	15.3	0.435	5.0	529	45.2	4.588	22.6	824	30.8	8.655	19.0
Mysis oculata	0	0.0	0	0.0	0	0.0	0	0.0	2	0.2	0.004	<0.1	2	0.1	0.004	<0.1
*Mysis spp***	588	49.8	8.867	53.3	209	64.1	6.945	80.2	561	47.9	14.095	69.4	1358	50.7	29.907	65.6
TOTAL	1180	100.0	16.632	99.9	326	100.0	8.661	100.0	1170	100.0	20.323	100.1	2676	100.0	45.616	100.2

* The number of individuals of each taxon present in the stomach of the individual birds in the sample.

† Formalin moist weight of the total number of individuals of each taxon in the stomach of the individual birds in the sample.

***Mysis* spp = either *M. relicta* or *M. litoralis*

Appendix Table 5. The Amphipod Diet of Oldsquaws Collected in the Simpson Lagoon Area of Alaska, 24 June to 18 September, 1977.

	Early Season 24 June to 3 August (n=12)				Mid Season (17 to 31 August) (n=11)				Late Season (5 to 18 September) (n=10)				Total Season 24 June to 18 September (n=33)			
Taxon	#*	%	wt†	%	#	%	wt	%	#	%	wt	%	#	%	wt	%
Onisimus glacialis	46	63.0	0.311	50.1	26	5.2	0.334	10.4	44	45.8	0.385	18.7	116	17.4	1.030	17.5
Onisimus nanseni	1	1.4	0.073	11.8	3	0.6	0.020	0.6	0	0.0	0.000	0.0	4	0.6	0.093	1.6
Onisimus littoralis	0	0.0	0.000	0.0	1	0.2	0.079	2.5	0	0.0	0.000	0.0	1	0.1	0.079	1.3
Onisimus spp.	8	11.0	0.044	7.1	15	3.0	0.131	4.1	23	24.0	0.199	9.7	46	6.9	0.374	6.4
Gammarus setosus	12	16.4	0.149	24.0	1	0.2	0.037	1.2	4	4.2	0.056	2.7	17	2.5	0.242	4.1
Gammarus spp.	0	0.0	0.000	0.0	1	0.2	0.007	0.2	4	4.2	0.288	14.0	5	0.7	0.295	5.0
Gammaracanthis loricatus	5	6.8	0.043	6.9	1	0.2	0.020	0.6	3	3.1	0.075	3.6	9	1.3	0.138	2.3
Apherusa glacialis	0	0.0	0.000	0.0	446	89.4	2.525	78.8	2	2.1	0.002	0.1	448	67.1	2.527	42.9
Acanthostepheia behringiensis	0	0.0	0.000	0.0	4	0.8	0.048	1.5	2	2.1	0.013	0.6	6	0.9	0.062	1.1
Acanthostepheia incarinata	1	1.4	0.001	0.2	0	0.0	0.000	0.0	0	0.0	0.000	0.0	1	0.1	0.001	<0.1
Weyprechtia hueglini	0	0.0	0.000	0.0	0	0.0	0.000	0.0	4	4.2	0.168	8.2	4	0.6	0.168	2.9
Parathemisto libellula	0	0.0	0.000	0.0	0	0.0	0.000	0.0	9	9.4	0.873	42.4	9	1.3	0.873	14.8
Unidentified Amphipod	0	0.0	0.000	0.0	1	0.2	0.005	0.2	1	1.0	0.001	<0.1	2	0.4	0.006	0.1
Total	73	100.0	0.621	100.1	499	100.0	3.206	100.1	96	100.1	2.06	100.0	668	99.9	5.888	100.1

*The number of individuals of each taxon present in the stomach of the individual birds in the sample.

†Formalin wet weight of the total number of individuals of each taxon present in the stomachs of the birds.

Appendix Table 6. The Early Season (19 June to 3 August) Diet of Oldsquaws Collected in the Simpson Lagoon Area of Alasks, 1977, as Determined by Hynes Point Method.*

Taxon	Bird Number																				Total Points	% of Total Points	Total Points (Identifiable Items)	% of Total Points (Identifiable Items)
	2	5	6	8	9	10	13	16	18	19	20	24	26	28	29	36	39	40	41	42				
Mysids		2	3	5		3	1	10	21				¼	12	19			8	10	14	108¼	65.2	108¼	68.9
Amphipods			2½			½	1		2	½				1	1				2	1	11½	6.9	11½	7.3
Isopods		6			4																10	6.0	10	6.4
Copepods													¼								¼	0.2	¼	0.2
Fishes																					0	0.0	0	0.0
Bivalves					4		1							12				4	6		27	16.3	27	17.2
Unidentified	1		½				1				2	2	1			1	½				9	5.4	--	--
Total	1	8	6	5	8	3½	4	10	23	½	2	2	1½	25	20	1	½	12	18	15	166†	100	157	100

*See Griffiths *et al.* 1975 for a description of the points methods for assessing the relative importance of food organisms.

†$\frac{\text{Total Points}}{n} = \frac{166}{20}$ = 8.3 points average fullness of Oldsquaw stomach during this period.

Appendix Table 7. The Mid Season (17 to 31 August) Diet of Oldsquaws Collected in the Simpson Lagoon Area of Alaska, 1977, as Determined by the Hynes Point Method.*

	Bird Number																				
Taxon	97	99	100	101	104	107	111	112	140	141	157	158	159	160	161	162	163	167	168	172	173
Mysids	2		5			14	13	½	7	1	½		10½				3				
Amphipods						1			1		½			9	7½	9½			25		
Isopods																					
Copepods														1							
Fishes																					
Bivalves	1	1		1			5				1			1							
Unidentified		2		4	6						10	2	1½	4	2½	½		8		3	1½
Total	3	3	5	5	6	15	18	½	8	1	12	2	12	15	10	10	3	8	25	3	1½

*See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

† $\frac{\text{Total Points}}{n} = \frac{166}{21}$ = 7.9 points average fullness of oldsquaw stored during this period.

Appendix Table 7 (cont'd)

Taxon	Total Points	% of Total Points	Total Points (Identifiable Items)	% of Total Points (Identifiable Items)
Mysids	56½	34.0	56½	46.7
Amphipods	53½	32.2	53½	44.2
Isopods	0	0.0	0	0.0
Copepods	1	0.6	1	0.8
Fishes	0	0.0	0	0.0
Bivalves	10	6.0	10	8.3
Unidentified	45	27.1	-	-
Total	166†	99.9	121	100

Appendix Table 8. The Late Season (5 to 18 September) Diet of Oldsquaws Collected in the Simpson Lagoon Area of Alaska, 1977, as Determined by the Hynes Point Method.*

	Bird Number																				
Taxon	176	177	182	187	189	196	198	200	201	202	203	204	206	207	208	209	210	Total Points	% of Total Points	Total Points (Identifiable Items)	% of Total Points (Identifiable Items)
Mysids	10	10	3	3	¼	15	16	9		22	3				8			99¼	66.5	99¼	74.5
Amphipods			3	1			4	3		3			2		7		1	24	16.1	24	18.0
Isopods																		0	0.0	0	0.0
Copepods																		0	0.0	0	0.0
Fishes		10																10	6.7	10	7.5
Bivalves																		0	0.0	0	0.0
Unidentified					1				1			2	4	4		1	3	16	10.7	--	--
Total	10	20	6	4	1¼	15	20	12	1	25	3	2	6	4	15	1	4	149¼†	100	133¼	100

*See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

†$\frac{\text{Total Points}}{n} = \frac{149\frac{1}{4}}{17}$ = 8.8 points average fullness of oldsquaw stomach during this period.

Appendix Table 9. Invertebrates Present in the Surface Layer* Where Feeding Oldsquaws Were Collected.

Major Taxon	Early Season 29 July to 17 August (n=5)		Mid-Season 25 to 27 August (n=2)		Late Season 5 to 8 September (n=2)		Total Season 29 July to 8 September (n=9)	
	Points†	%	Points	%	Points	%	Total Points	%
Mysids	2¾	2.7	0	0.0	½	1.3	3¼	1.8
Amphipods	6¼	6.2	1	2.6	3	7.5	10¼	5.7
Isopods	3	3.0	0	0.0	0	0.0	3	1.7
Copepods	71½	70.8	22	56.4	29	72.5	122½	68.1
Cnidaria (Medusae)	16	15.8	12	30.8	2	5.0	30	16.7
Pteropods	1½	1.5	1	2.6	0	0.0	2½	1.4
Chaetognaths	0	0.0	3	7.7	3	7.5	6	3.3
Diptera	0	0.0	0	0.0	2½	6.3	2½	1.4
TOTAL	101	100.0	39	100.1	40	100.1	180	100.1

*The surface layer includes surface waters to a depth of 10 cm.

†See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

Appendix Table 10. Organisms Present in the Mid Water Layer* Where Feeding Oldsquaws Were Collected.

Major Taxon	Early Season 29 July to 17 August (n=5)		Mid-Season 25 to 27 August (n=2)		Late Season 5 to 8 September (n=2)		Total Season 29 July to 8 September (n=9)	
	Points[†]	%	Points	%	Points	%	Total Points	%
Mysids	15	15.0	1	2.5	5	11.9	21	11.5
Amphipods	5	5.0	9	22.5	2¾	6.5	16¾	9.2
Copepods	69	69.0	26	65.0	22	52.4	117	64.3
Fish	2	2.0	0	0.0	0	0.0	2	1.1
Cnidaria (Medusae)	3¼	3.3	3	7.5	7	16.7	13¼	7.3
Pteropods	2¼	2.3	1	2.5	2	4.8	5¼	2.9
Chaetognaths	2¼	2.3	0	0.0	2	4.8	4¼	2.3
Ctenophores	1	1.0	0	0.0	¼	0.6	1¼	0.7
Cumacea	¼	0.3	0	0.0	¼	0.6	½	0.3
Decapod larvae	0	0.0	0	0.0	¾	1.8	¾	0.4
TOTAL	100	100.2	40	100.0	42	100.1	182	100.0

*The mid-water layer was defined as the layer approximately midway between the epibenthos and the surface of the water.

[†] See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

Appendix Table 11. Invertebrates Present in the Epibenthos Where Feeding Oldsquaws Were Collected.

	Early Season 3 to 17 August (n=3)		Mid Season 25 to 27 August (n=3)		Late Season 5 to 8 September (n=2)		Total Season 3 August to 8 September (n=8)	
Major Taxon	Points*	%	Points	%	Points	%	Total Points	%
Mysids	22	36.7	16	26.7	7	17.5	45	28.1
Amphipods	17	28.3	14	23.3	13	32.5	44	27.5
Copepods	12	20.0	28	46.7	14	35.0	54	33.8
Bivalves	2	3.3	1	1.7	0	0	3	1.9
Cnidaria (Medusae)	1	1.7	0	0.0	3	7.5	4	2.5
Pteropods	2	3.3	0	0.0	3	7.5	5	3.1
Polychaeta Larvae	2	3.3	1	1.7	0	0.0	3	1.9
Ostracoda	1	1.7	0	0.0	0	0.0	1	0.6
Foraminifera	1	1.7	0	0.0	0	0.0	1	0.6
TOTAL	60	100.0	60	100.1	40	100.0	160	100.0

*See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

Appendix Table 12. The Diet of Phalaropes Collected in the Simpson Lagoon Area of Alaska, 3 to 25 August, 1977, as Determined by the Hynes Point Method.*

	Bird Number																									
Taxon	43	44	45	46	47	49	50	51	55	56	57	58	59	62	68	69	70	78	79	80	81	84	85	86	95	96
Mysids	¼									2		½													18	15
Amphipods				8¼	2							½	1½									5	5	12	2	
Bivalves																										
Pteropods														2												
Branchiopods																										
Euphausiids																										
Copepods						½	1	1	½		1				10¼	11	¼	6	5	4	13					
Insects															1											
Unidentified		½	2	¼		1						3	3½	4		8¾		6	5	10						
Total	¼	½	2	8½	2	1½	1	1	½	2	1	4	5	6	11¼	19¾	¼	12	10	14	13	5	5	12	20	15

*See Griffiths *et al.* 1975 for a description of the points method for assessing the relative importance of food organisms.

†$\frac{\text{Total Points}}{n} = \frac{269\frac{3}{4}}{46}$ = 5.9 points average fullness of phalarope stomach during this period.

Appendix Table 12 (cont'd)

	Bird Number																					
Taxon	114	115	116	117	118	119	130	131	132	142	144	145	147	148	149	150	151	153	154	155	Total Points	% of Total Points
Mysids																				2	37¾	14.0
Amphipods					½		1														37¾	14.0
Bivalves																					0	0.0
Pteropods																					2	0.7
Branchiopods											½										½	0.2
Euphausiids					½																½	0.2
Copepods		¼	¼			½		2	2	8		3½	½	½	2	8	2	10	15	½	108½	40.2
Insects	¼		½																		1¾	0.6
Unidentified	2	1	½	3	1	½	7	6	13			½	1½		1						81	30.0
Total	2¼	1¼	1¼	3	2	1	8	8	15	8	½	4	2	½	3	8	2	10	15	2½	269¾	99.9

Appendix Table 13. The Diet of Glaucous Gulls Collected in the Simpson Lagoon Area of Alaska, 16 July to 19 September, 1977, as Determined by the Hynes Point Method*.

Taxon	Bird Number																											Total Points	% Total Points
	12	21	22	30	48	54	65	73	82	103	113	121	122	142	156	169	175	183	184	185	186	190	192	193	194	195	211		
Mysids											1	8	2			2												13	6.7
Amphipods																	4	1	1		1	1	8		25		3	44	22.8
Isopods			16		10	3½	18	4								13												64½	33.4
Copepods		½															6											6½	3.1
Bivalves																								1				1	0.5
Fish	20									1					1													22	11.7
Euphausiids						2																						2	1.0
Tunicates																				1								1	0.5
Hydroids																										½		½	0.3
Birds				10										25														35	18.1
Unidentified		½				½			½								2											3½	1.8
Total	20	1	16	10	10	6	18	4	½	1	1	8	2	25	1	15	12	1	1	1	1	1	8	1	25	½	3	193†	100.0

*See Griffiths *et al.* 1975 for a description of the points method of assessing the relative importance of food organisms.

†$\frac{\text{Total Points}}{n} = \frac{193}{27}$ = 7.1 points average fullness of Glaucous Gull stomach during this period.

Appendix Table 14. Aircraft Sighted Flying in the Vicinity of the Simpson Lagoon-Jones Island Study Area, June through September, 1977.

HABITAT TYPE	Helicopter				Single Engine Fixed-Wing				Twin Engine Fixed-Wing				Unknown Fixed Wing				Total Aircraft				
	0-150*	150-300	300+	?	0-150	150-300	300+	?	0-150	150-300	300+	?	0-150	150-300	300+	?	0-150	150-300	300+	?	Total
June																					
Mainland Tundra	47			13	2			6	9	1	1	18	3			5	61	1	1	42	105
Lagoon	42			13	1			2	2	1	2	8	1			4	46	1	2	27	76
Barrier Island	41			9	2			3	5			3	1			2	49			17	66
Unknown				1				1				3				1				6	6
Total	130	0	0	36	5	0	0	12	16	2	3	32	5	0	0	12	156	2	3	92	253
July																					
Mainland Tundra	32			5	11	1		11	6			13	2			6	51	1		35	87
Lagoon	30			3	14			5	2			4	1			3	47			15	62
Barrier Island	30		2	5	12		1	6	2			3	1			2	45		3	16	64
Unknown	1			1								1	1			7	2			9	11
Total	93	0	2	14	37	1	1	22	10	0	0	21	5	0	0	18	145	1	3	75	224
August																					
Mainland Tundra	8			6	33			2	7		1	7	1				49		1	15	65
Lagoon	13			3	27	1		2		1	1	5					40	2	1	10	53
Barrier Island	15	3		10	30			5	6		1	8					51	3	1	23	78
Unknown				1				1				2						1		4	5
Total	36	3	0	20	90	1	1	10	13	2	3	22	1	0	0	0	140	6	3	52	201
September																					
Mainland Tundra	18			4	3			2					1			4	22			10	32
Lagoon	12	1		3	4			2				1			1	2	16	1	1	8	26
Barrier Island	20	1	1	3	8			1									28	1	1	4	34
Unknown	2			1			1					2				5	2		1	8	11
Total	52	2	1	11	15	0	1	5	0	0	0	3	1	0	1	11	68	2	3	30	103
Total Season																					
Mainland Tundra	105	0	0	28	49	1	0	21	22	1	2	38	7	0	0	15	183	2	2	102	289
Lagoon	97	1	0	22	46	1	0	11	4	2	3	16	2	0	1	9	149	4	4	60	217
Barrier Island	106	4	3	27	52	0	1	15	13	0	1	14	2	0	0	4	173	4	5	60	242
Unknown	3	0	0	4	0	0	1	2	0	0	0	8	1	0	1	13	4	1	1	27	33
Grand Total	311	5	3	81	147	2	3	49	39	3	5	78	12	0	2	41	509	11	12	249	781

*Altitudes recorded in meters. If an aircraft was observed flying at variable altitudes, the lowest altitude at which it was observed has been presented in this table.

BEAUFORT SEA BARRIER ISLAND-LAGOON
ECOLOGICAL PROCESS STUDIES

Section III

ECOLOGY OF FISHES IN SIMPSON LAGOON, 1977

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31 March 1978

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SUMMARY

The Simpson Lagoon fisheries program addresses the role of nearshore fishes in a barrier island-lagoon ecosystem on Alaska's Beaufort Sea coast. Study objectives were to identify important biological processes and habitats of fish, and assess their vulnerability to OCS petroleum development.

Simpson Lagoon and other nearshore habitats are used by fish for one overriding purpose, namely feeding on the abundant nearshore food supply. Each spring as the ice melts, anadromous and marine fishes invade nearshore waters and feed extensively on epibenthic invertebrates (organisms living on or near bottom substrates). The fish accumulate food reserves for spawning and/or overwintering requirements.

Although fish in the nearshore environment are abundant, species diversity is low; during this study, three anadromous species (arctic cisco, arctic char, least cisco) and two marine species (fourhorn sculpin, arctic cod) accounted for almost all fish captured.

Several factors influencing the numbers and distribution of fish were examined but predators, parasites and food were not considered to be limiting factors for fish inhabiting nearshore waters. It appears instead that populations of nearshore fishes, particularly the anadromous species used by man, are limited by factors operative outside the nearshore environment (e.g., overwintering areas in North Slope rivers). If this interpretation is correct, the implication is that, while nearshore habitats are essential feeding areas for fish, nearshore biological processes and habitats are less vulnerable to impacts of OCS petroleum development than other locations or stages in the life cycles of key fish species.

INTRODUCTION

General Nature and Scope of Study

The nearshore environment along the Beaufort Sea coastline provides essential habitat for several arctic fishes, particularly the anadromous species utilized by man. During the short arctic summer, large numbers of fish enter coastal waters and feed extensively on nearshore food resources. These fish must accumulate food reserves to support them through the arctic winter, and adult fish must reach a critical level of food reserves or they will not spawn (Bolotova 1976).

Ongoing petroleum activities at Prudhoe Bay and the recent construction of the trans-Alaska pipeline demonstrate the nature of demands industry makes on arctic water and gravel resources, and the subsequent disruptions of habitat and inevitable oil spills. As part of the program to assess the environmental impacts of offshore petroleum development, it is necessary to understand the utilization of nearshore habitats by anadromous and marine fish populations.

The present study examines nearshore fishes and their ecological role in a barrier island-lagoon complex along the Beaufort Sea coast to evaluate in what ways petroleum development may affect fish populations. It is part of a more comprehensive program designed to study ecological processes as a means of assessing impacts of petroleum development. (See RU 467, OVERVIEW AND SYNTHESIS section, for detail about general objectives of the program.)

Specific Objectives

Specific objectives of the 1977 program were to:

1. determine habitat utilization in time and space by key fish species,
2. assess food sources and feeding dependencies of fishes in nearshore waters, and
3. determine species composition and life history characteristics of fishes in the barrier island-lagoon ecosystem.

CURRENT STATE OF KNOWLEDGE

Petroleum discoveries in the arctic have prompted a variety of fisheries studies over the past decade. Craig and McCart (1976) summarized much of the research done prior to 1976; more recent studies include Bendock (1977) and Doxey (1977).

A general picture of fish use of nearshore waters has emerged, and topics such as species distribution, relative abundance, general food habits, age-length relationships and some basic life-history data have been adequately examined. Only recently has attention been paid to the problems of trophic relationships, limiting factors, location of overwintering areas, stock identification, effects of OCS petroleum development and resource management.

STUDY AREA

Simpson Lagoon, located between Prudhoe Bay and the Colville River delta on Alaska's North Slope (Fig. 1), is a large and partially enclosed body of water measuring approximately 35 km in length and 2.8-6.4 km in width. To the north, Simpson Lagoon is protected from direct ocean exposure by a chain of barrier islands in the Jones Island group. The two westerly islands, Spy and Leavitt, are composed of gravel and sand and lack any tundra cover. Of the remaining islands, Pingok, Peat, Bertoncini, Bodfish and Cottle have areas of tundra cover; however, the series of small unnamed islands between Peat and Bertoncini islands do not. The mainland forms the southern boundary of the lagoon and is characterized by slumping tundra cliffs (1.5-3.0 m in height) and narrow silt, sand and gravel beaches.

There are three principal pathways for water exchange into and out of Simpson Lagoon: (1) the far western entrance between Spy Island and Oliktok Point, (2) the large gap between Spy and Leavitt islands, and (3) the far eastern entrance between Cottle Island and Beechey Point. In addition, there are several small and shallow channels between the various islands.

The Colville River, Alaska's largest North Slope river, has surpri-

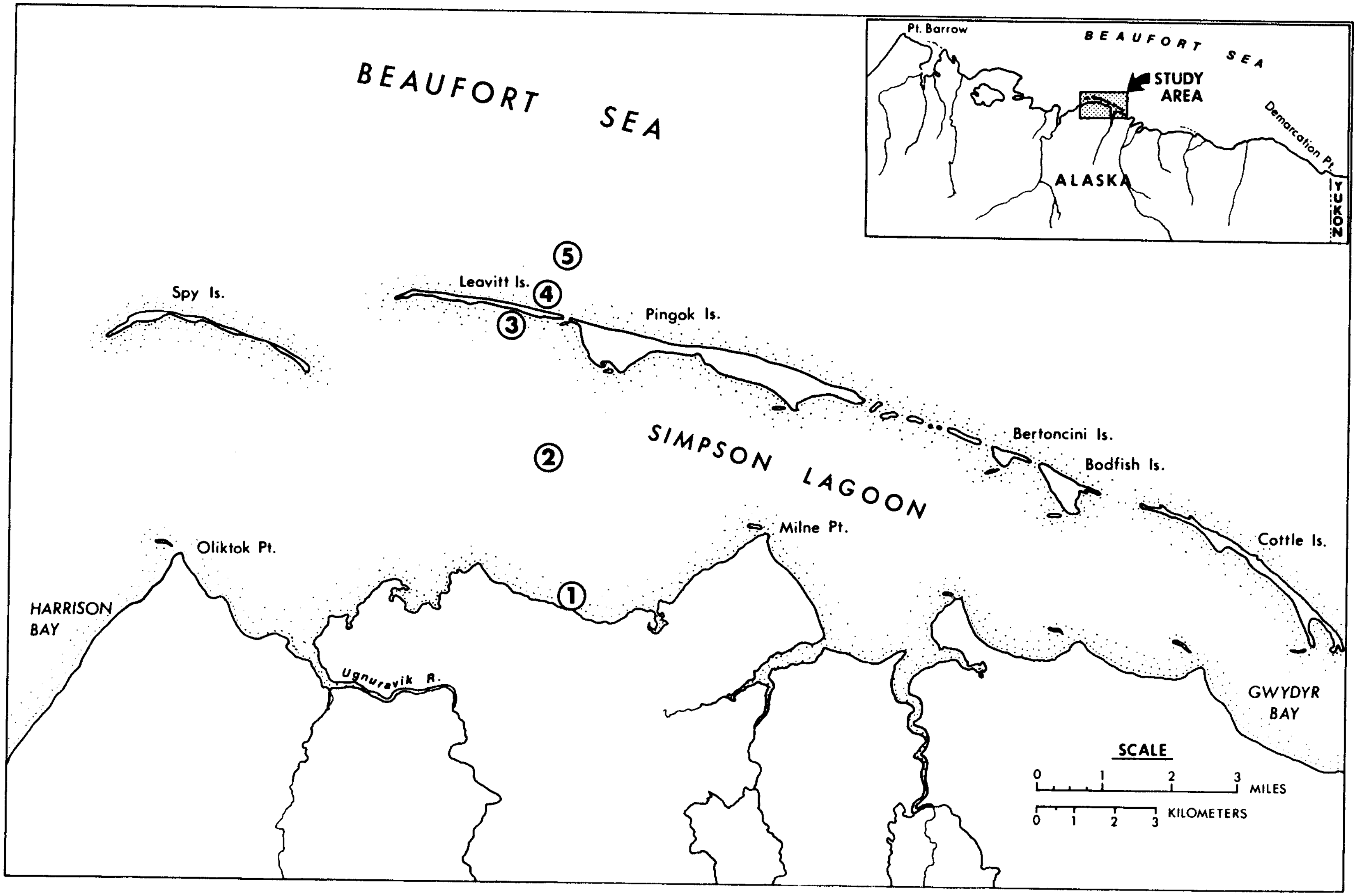


Fig. 1. Map of Simpson Lagoon Area in Alaska.

singly little direct hydrological influence on Simpson Lagoon despite its close proximity. During spring breakup in 1977, overflow from the Colville did not enter the lagoon, and for the remainder of the season prevailing nearshore currents tended to entrain the Colville's discharge to the west rather than through Simpson Lagoon, which lies to the east.

Simpson Lagoon is a shallow-water basin with an average depth of only 1-2 m and a maximum depth of 2.8 m; those water depths greater than 2 m are confined to an east-west channel through the lagoon center. Except for this central region, the lagoon freezes to bottom substrates during winter months. Outside Simpson Lagoon on the seaward side of Pingok Island, ocean depths drop to 2 m within 50 m of the shoreline and gradually drop to 20-25 m water depth 1 km offshore.

Simpson Lagoon waters are generally cool, brackish and well-oxygenated (see RU 467, INVERTEBRATES section, Appendix IV). During the open-water season in 1977 temperatures varied from -2 to 11°C, and salinities fluctuated from 2 to 31 ppt, but mid-summer values were typically 5-8°C and 20-27 ppt. The lagoon environment was warmer and less saline than non-lagoon waters on the seaward side of Pingok Island where mid-summer temperatures were 0-4°C and salinities 25-30 ppt. Dissolved oxygen concentrations remained high throughout the open water period.

The lagoon floor is uniformly flat and almost featureless. In most areas, a layer of detritus covered substrates of mud and sand. The detrital layer, which varied in thickness from 0.5-1.3 cm was not consolidated, but consisted of a flocculent, amorphous mass easily dispersed by storm-generated turbulence. Mysids and amphipods actively swam over the detrital layer, and numerous small holes in the detritus were further signs of animal activity.

A small degree of topographic relief along the lagoon floor is provided by shallow ice scours in the central portion of the lagoon and occasional piles of ice-rafted stones. These stones, which measure approximately 2.5 cm in width, serve as a base for attached algae. Other observed features of the bottom include occasional tundra clumps, irregularly spaced tunicates, and numerous stalked anemone-like animals.

In 1977, spring breakup in Simpson Lagoon began in early June. Flooding from the Kuparuk and Ugnuravik rivers, both to the east, covered approximately one-half of the lagoon ice on 8 June and an open-water lead began to form along the mainland shoreline. On 16 June, the ice around Pingok Island melted. Leads of open-water along the mainland and around island shorelines grew slowly, reaching widths of approximately 100 m on 5 July. One week later, the lagoon was 90% ice-free.

The initial stages of freeze-up in the lagoon were observed on 23 September, when slush ice formed in shallow, calm waters. Lagoon waters were open on 1 October and ice cover probably developed during the next two weeks.

METHODS AND RATIONALE OF DATA COLLECTION

In order to document fish use of Simpson Lagoon and identify important fish areas, the 1977 field program was designed to sample representative nearshore habitats in time and space during the open-water season. Five habitat types (Fig. 1) were sampled on a regular basis:

Station No.	Habitat Type	Water Depth (m)
1	mainland shoreline	0-1.2
2	lagoon center	2-2.5
3	island shoreline (lagoon)	0-1.2
4	island shoreline (ocean)	0-1.2
5	offshore ocean	8-10

The temporal sampling scheme consisted of (1) a spring breakup period (16 June-5 July) when samples were restricted to open water leads around Pingok and Leavitt islands, and (2) a summer period when samples were taken at approximately 10-day intervals at all Stations. Sampling ended 23 September, when lagoon waters were beginning to freeze. During each sampling period and at each location, the water column was sampled by a variety of techniques to insure adequate collection of fish present.

Methods of Capture

Gill Nets

Variable mesh, monofilament gill nets 45.7 m in length and 2 m in height were used. Each net contained five panels of the following mesh sizes (stretched): 2.5, 3.8, 5.1, 6.4 and 8.9 cm. In shallow waters at Stations 1-4, gill nets sampled the entire water column; both sinking and floating fill nets were used in deeper waters at Station 5.

Gill net sets were usually 24 hr in duration but varied from 10-120 hr according to ice and weather conditions. Total number of sets and days fished between 24 June and 18 September are listed below:

	Seasonal Totals	
Station	Gill Net Sets	Days Fished
1	10	10
2	10	19
3	10	10
4	7	10
5	7	10.5

Fyke Nets

Fyke nets had the following dimensions: 31 x 1.2 m lead net, 7.8 x 1.2 m wing nets, 4.7 m trap length (with two throats), 1.2 x 1.2 m trap mouth. Net material was #44/5 nylon with 2.5 cm stretched mesh. The fyke trap was generally situated in 1 m of water. Nets were checked daily and all fish were identified, measured and tagged, if possible.

During spring breakup, fyke nets were operated in open water leads along Pingok and Leavitt islands but catches were low. Permanent fyke net stations were established at Stations 1 and 3 on 25-27 July and operated almost daily until 22 September.

Faber Net

A modified Faber net (Faber 1968) was used to catch planktonic fish. Net dimensions were 0.5 m opening, 3 m length and 1.024 mm mesh. Each tow filtered approximately 81 m^3 of surface water (i.e. a 5 min two at 1.4 m/sec). Data are presented as the mean of two replicate tows at each sampling site.

Other Methods

Other methods were also used to sample fish (seines, otter trawl and SCUBA diving), but none was as successful as the fyke and gill nets. Our diver, for example, sighted only two fish during all dives.

Laboratory Analysis of Fish

Laboratory analysis included determination of fork or total length to the nearest millimeter, weight to the nearest gram, sex, age (otoliths) and maturity. Based on a field evaluation of reproductive condition, and aided by measurements of egg sizes or testes weights, fish were classified as "immature" (have never spawned), "mature spawner" (would have spawned in the year of capture), or "mature non-spawner" (had spawned previously but would not spawn again in the year of capture).

As an indicator of fish condition, the total weight of fat on the digestive tract of 33 arctic cisco was determined in the following manner. Intestinal fat (IF) was weighed together with the pyloric caeca (PC), which held a considerable amount of fat (PCF). PC weights were estimated by regressing IF against IF + PCF. An extrapolation indicated PC weights were about 7 g for fish under 350 g and 8 g for larger fish. This weight was subtracted from the initial figure to give weight of fat only.

Stomach contents were analyzed by the Points Method (Hynes 1950), which estimates the relative importance (number and biomass) of each food item in the diet. In this method, contents of individual stomachs are assigned 0-20 points based on fullness (25 points for distended stomachs). Organisms present in the stomach are then assigned a portion of the available points in accordance with their size and abundance. For each fish species, all points gained for each food item are summed and scaled to a percentage for each food group consumed by all fish examined.

Amphipods and mysids, which accounted for most of the fishes' diets, were further examined at the species level. Laboratory methods for counting and weighing (wet weights) these organisms are described in RU 467, INVERTEBRATES section.

The degree of food overlap betweel fish species was determined by the modified Morisita index (Horn 1966):

$$C = \frac{2 \sum_{i=1}^{S} X_i Y_i}{\sum_{i=1}^{S} X_i^2 + \sum_{i=1}^{S} Y_i^2}$$

where S is the total number of food categories, and X_i and Y_i are the proportions of food item i in the diets of species X and Y, respectively. The index C varies from 0, when the diets have no food items in common, to 1, when the diets are identical in kinds and proportions of food items. A value of 0.6 or greater is assumed to indicate a significant overlap (Zaret and Rand 1971).

RESULTS AND DISCUSSION

Species Composition and Relative Abundance

The most notable features of species composition and relative abundance in Simpson Lagoon are that (1) few species were caught and fewer still were abundant, (2) small anadromous fish were more abundant in nearshore waters than recorded in earlier studies, and (3) different sampling gear produce very different pictures of species' occurrence and relative abundance.

During the 1977 open-water season, thirteen fish species were collected in the study area:

Anadromous Species

1. arctic char (*Salvelinus alpinus*)
2. arctic cisco (*Coregonus autumnalis*)
3. least cisco (*C. sardinella*)
4. Bering cisco (*C. laurettae*)
5. humpback whitefish (*C. pidschian*)
6. broad whitefish (*C. nasus*)
7. ninespine stickleback (*Pungitius pungitius*)

Marine Species

1. fourhorn sculpin (*Myoxocephalus quadricornis*)
2. arctic cod (*Boreogadus saida*)
3. arctic flounder (*Liopsetta glacialis*)
4. capelin (*Mallotis villosus*)
5. smelt (*Osmerus* sp.)
6. snailfish (*Liparus* sp.)

10,807 fish were caught (85% were returned alive). Because of the variety of sampling methods used and the thoroughness of sampling efforts, it is felt that the above species list includes most species using the lagoon during the 1977 openwater season. These data account for most fish usage of the lagoon for an entire year, because much of the lagoon freezes to bottom substrates in winter, making residence impossible.

Although relative abundances of fish varied according to method of capture (Table 1), five species accounted for over 91% of all fish caught. Three anadromous fishes (arctic cisco, arctic char, least cisco) and two marine fishes (fourhorn sculpin, arctic cod) were the dominant species in the lagoon ecosystem. These species also characterize the fauna of nearshore waters along most of the Beaufort Sea coastline in Alaska (Craig and McCart 1976).

The fyke net data are of particular interest because the majority of fish caught by this method were small fourhorn sculpin, arctic cisco and arctic cod. These data and Bendock's (1977) study at Prudhoe Bay show that small fish are substantially more common in nearshore Beaufort Sea waters than indicated by earlier studies that relied on data obtained by gill nets (reviewed by Craig and McCart 1976).

Habitat Utilization in Time and Space

Spatial Pattern

Two prominent trends describe the spatial distribution of anadromous fish during the open-water season in the Simpson Lagoon study area: (1) most fish are found in nearshore rather than offshore marine locations and (2) fish numbers are highest along shoreline edges. These generalizations are somewhat less valid for marine fishes and it should be noted that species such as fourhorn sculpin and arctic cod are not restricted in distribution to nearshore waters.

The distribtuion of both anadromous and marine species changes during the winter period. In general, anadromous fish return to overwinter in coastal waters deeper than 2 m or in the deltas of the larger rivers.

Table 1. Relative Abundance of All Species Caught by Three Sampling Methods.

Fish Species	Gill Net (n*=781) %	Fyke Net (n=10,026) %	Faber Net (n=366) %
Arctic Cisco	56	15	0
Arctic Char	14	4	0
Least Cisco	12	2	0
Fourhorn Sculpin	9	70	0
Arctic Cod	0.1	8	83
Broad Whitefish	4	0.1	0
Humpback Whitefish	2	0	0
Bering Cisco	1	0	0
Capelin	1	0.02	0
Arctic Flounder	0.4	1	0
Ninespine Stickleback	0	0.2	0
Smelt sp.	0	0.2	0
Snailfish sp.	0	0.1	16.6
Sculpin sp.	0	0	0.5
% Anadromous spp.	89	21	0
% Marine spp.	11	79	100

*N equals number of fish caught.

Nearshore (Lagoon) Versus Offshore (Marine) Distribution. Concerning the first trend, the Simpson Lagoon data demonstrated a nine-fold difference in the numbers of fish caught in lagoon habitats compared to habitats on the seaward side of Pingok Island (Fig. 2, Table 2). The catch per unit effort (seasonal average for combined species) in the relatively warm, shallow and brackish waters of the lagoon was 14.7 fish/24-hr gill net set, in contrast to 1.6 fish/24-hr set in the colder and more saline offshore waters. This difference is accentuated substantially if "nearshore waters" are taken to mean all lagoon stations plus the seaward shoreline of Pingok Island, and "offshore waters" includes only samples taken 1-2 km seaward of Pingok Island in marine water 7-10 m deep. Then the comparison becomes 12.3 fish/24-hr set in nearshore waters and only 0.4 fish/24-hr set in offshore waters, a 30-fold difference in abundance of fish. The only fish taken at the offshore location were two snailfish, one fourhorn sculpin and one arctic cod. Anadromous species were absent from offshore catches. Anadromous fish remain in nearshore waters, foregoing the impressive oceanic migrations of some non-arctic salmonids.

Numbers of fish collected in plankton trawls were also greater inside the lagoon than offshore (Table 3). Arctic cod young-of-the-year, which comprised 83% of the Faber net catches (Table 1), were abundant at Stations 2 and 3 (130 and 119 fish/1000 m^3 seasonal averages), but less frequent at Station 5 (10 fish/1000 m^3). However, the extremely variable catch records indicate the need for a more extensive sampling program before the general significance of lagoon habitats for these fish is known.

For comparative purposes, densities of arctic cod young-of-the-year at other locations were as follows: 28 fish/1000 m^3, Chukchi Sea (Quast 1974); 10-60 fish/1000 m^3, Barter Island area (Griffiths *et al.* 1977); and 4-130 fish/1000 m^3, Canadian High Arctic (Bain *et al.* 1977; LGL, unpublished data).

The "Edge Effect". If only nearshore habitats are considered, it is apparent that fish are not uniformly distributed but are far more abundant along mainland and island shorelines than the lagoon center (Fig. 2).

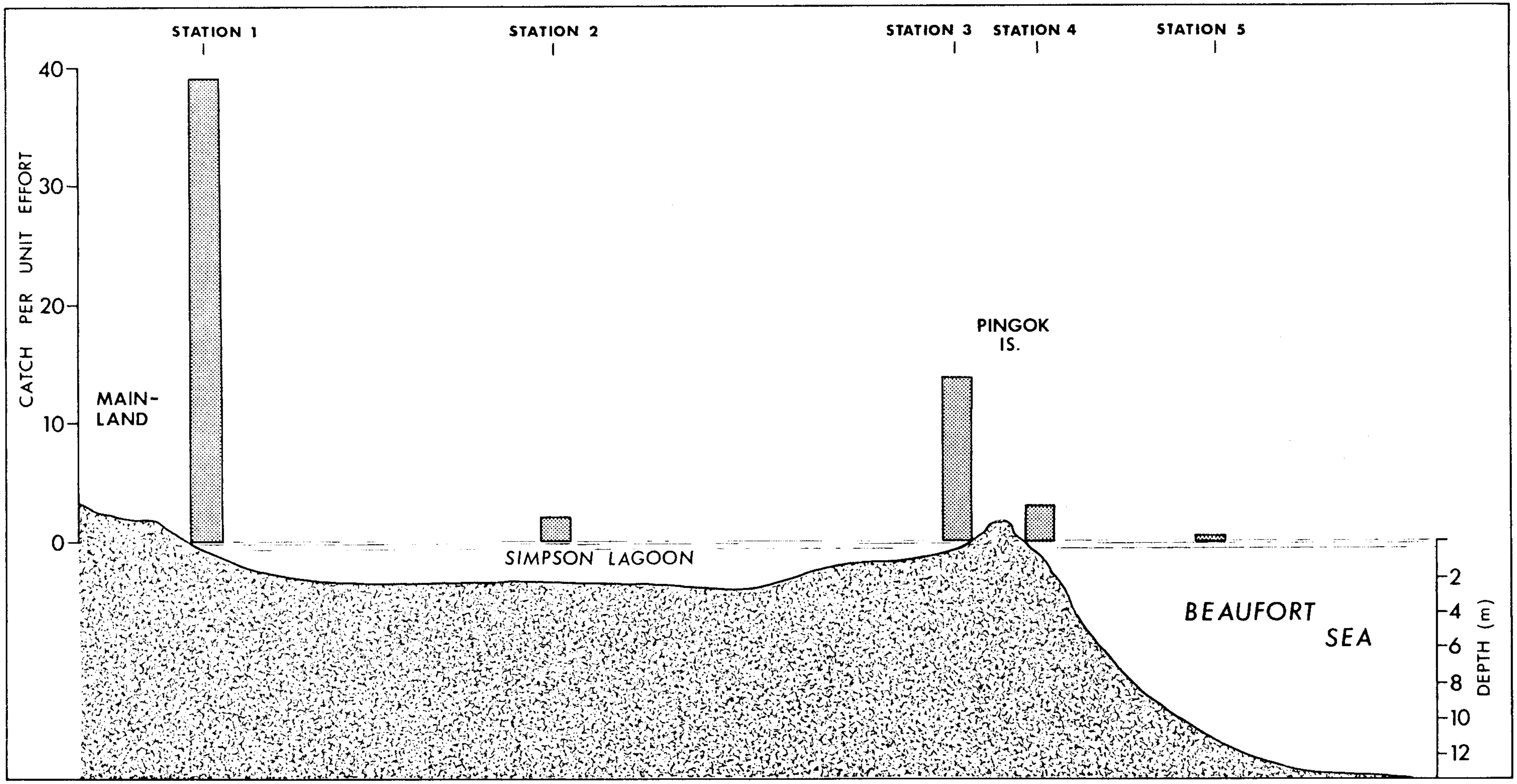


Fig. 2. Cross-Section of Simpson Lagoon Study Area Showing Relative Numbers of Fish Caught at 5 Sampling Stations. Numbers of fish represent a seasonal average for combined species caught in a standardized 24 hr gill net set.

Table 2. Comparison of Gill Net Data at Five Sampling Locations During Open Water Season, 1977. (See Fig. 2 for locations.)

Fish Species	Seasonal Averages of Fish Caught Per 24 Hour Gill Net Set at Stations				
	1	2	3	4	5
Arctic cisco	17	1	9	0.1	0
Least Cisco	8	0	1	0	0
Arctic Char	6	0.4	3	2	0
Fourhorn Sculpin	3	0.5	1	1	0.1
Broad Whitefish	3	0	0	0	0
Humpback Whitefish	2	0	0	0	0
Arctic Flounder	0.2	0	0	0	0
Capelin	0	0.1	1	0.1	0
Snailfish	0	0	0.1	0	0.2
Arctic Cod	0	0	0	0	0.1
Totals	39.2	2.0	15.1	3.2	0.4

Table 3. Seasonal Densities of Young-of-the-Year Arctic Cod Collected by Faber Net.[1]

Sampling Dates	No. Arctic Cod/1000 m^3 at Stations			
	1	2	3	5
11 July	-	6	0	-
22 July	-	50	0	0
31 July	-	0	31	0
14 August	-	855	694	0
25 August	0	0	0	0
5 September	0	0	6	0
14 September	0	0	99	62
Means	0	130	119	10

[1] Paired t-test on averaged data for stations 2 and 3 vs. station 5 gave $t=1.05$, $n=5$, $P>0.1$.

Most fish travel parallel to the shoreline along a surprisingly narrow corridor. It is common, for example, for gill nets attached to the shoreline to catch many fish while nets set only 100 m seaward of the shoreline catch few fish. The actual width of this migration corridor is probably variable, depending on factors such as the longshore nature of the coastline, underwater topography, etc. Furthermore, areas of fish concentration are not restricted to land edges during the spring breakup period since fish also follow ice leads and melting ice edges, which provide temporary topographic relief.

Why fish concentrate along shorelines is not understood, but there are several possibilities:

1. Predator Avoidance - improbable since predator densities are low (see "Other Organisms" in this section).
2. Food Abundance - not likely since available data indicate food is more abundant in deeper waters away from the shoreline (see section on Invertebrates).
3. Navigation Aid - perhaps shorelines are useful navigation aids since nearshore waters are frequently turbid.
4. Habitat Preference - perhaps fish prefer the slightly warmer and less saline shoreline waters (discussed below).

Another aspect of the "edge effect" shown in Fig. 2 is that the mainland shoreline appears to be used more extensively by fish than island shorelines. Data obtained by fyke nets (which generally catch smaller fish than gill nets) substantiate this difference (Table 4). An average of 160 fish/24-hr fyke net was caught at the mainland site compared to 104 fish/24-hr fyke net at the island site (lagoon side of Pingok Island). If the omnipresent fourhorn sculpin are excluded from these comparisons, the difference between sites is more apparent: 68 fish/fyke net (mainland) versus 10 fish/fyke net (island).

Thus, numbers of both large fish (gill net catches) and small fish (fyke net catches) are higher along the mainland shoreline than anywhere else in the study area. This may be a reflection of the fact that the mainland shoreline is, on the average, warmer and less saline than other

Table 4. Comparison of Fyke Net Data for Mainland and Island Sites, 8 August to 21 September 1977. During this period, nets were operated 36 days (mainland) and 30 days (island).

	Mean Catch in Fyke Net/24 Hour	
Fish	Mainland Shoreline (Station 1)	Island Shoreline (Station 3)
Fourhorn Sculpin	92	94
Arctic Cisco	36	6
Arctic Cod	15	4
Arctic Char	8	1
Least Cisco	5	0.03
Arctic Flounder	3	0.07
Smelt	0.6	0.07
Ninespine Stickleback	0.4	0.07
Broad Whitefish	0.3	0
Snailfish	0.1	0.03
Capelin	0	0.07
Total	160	105
Daily Range	(2-626)	(0-810)

nearshore habitats. Seasonal averages are shown below:

Station	Salinity Mean (range)	Water Temperature Mean (range)
1	17.5 (2-24)	6.3 (2.5-8.5)
2	21.4 (14-28)	4.9 (1.5-6.5)
3	24.1 (20-29)	4.3 (1-6)
4	25.9 (20-30)	1.3 (-0.5-4.5)
5	26.0 (22-30)	2.0 (0.4-4.5)

Two notes of caution are necessary in regard to the above discussion. First, although fish are concentrated along the shoreline, the lagoon center probably accommodates as many fish due to its relatively large size. The following calculation illustrates this point. From Table 2, the average number of fish in each meter of gill net (all nets were 45.7 m long) can be determined for each station. These stations represent particular types of habitat (mainland edge, lagoon center, island edge), and the extent of each habitat can be estimated along a cross section of the lagoon from the mainland to Pingok Island. Using these two sets of figures, the relative number of fish can be calculated for shorelines and lagoon center:

Station No.	Habitat Type	No. Fish per Meter of Gill Net	Estimated Length of Habitat Type Across Lagoon	Relative No. Fish in Habitat Type
1	mainland edge	0.86	200 m	172
2	lagoon center	0.04	5000 m	200
3	island edge	0.33	200 m	66

Though these calculations are rough, they show that a theoretical gill net drawn across the whole lagoon would catch 238 fish along combined shorelines compared to 200 fish in the center of the lagoon cross-section. It appears, then, that total number of fish in the lagoon center is similar to the total number of fish along the shoreline edges.

The second note of caution concerns the apparently greater importance of the mainland shoreline as a migration corridor than the barrier island shorelines. This difference may reflect the large (6 km) distance between the Pingok Island sampling site and the mainland coast. Perhaps this distance is too great for fish with strong shoreline orientation to traverse. Fish densities are probably higher around islands closer to the mainland.

Winter Distribution. Petroleum development can have a direct impact on arctic fish populations by damaging overwintering sites critical to fish survival. Some overwintering areas have already been subject to mechanical disturbance or de-watering associated with petroleum exploration and development activities (Bendock 1976). Although there has been continuing effort to identify where fish overwinter in North Slope rivers (Craig and McCart 1974; Bendock 1977), the degree to which fish use coastal areas for overwintering is virtually unknown.

Anadromous and marine fishes differ in their overwintering habits. In general, anadromous fish leave coastal waters and return to fresh water to overwinter in rivers or lakes. However, the possibility that anadromous fish might also overwinter in coastal areas needs examination. For example, circumstantial evidence suggests that some arctic cisco may overwinter in the brackish water channels or the seaward extension of the Colville Delta (see "Life-History Information" in this section). Marine species also vacate the shallow (<2 m) nearshore habitats, which eventually freeze to bottom substrates in winter. Presumably these fish move to deeper waters or overwinter in the deltas of large rivers. The Colville delta is used by fourhorn sculpin (Kogl and Schell 1975), but no other specific overwintering sites for marine species are known along the Beaufort Sea coastline in Alaska.

By late winter, Simpson Lagoon freezes solid except for a central channel, which may have 0.5 m of unfrozen hypersaline water. This kind of winter habitat appears unsuitable for fish, and if used at all, is probably used only by fourhorn sculpin.

Temporal Pattern

General features of the temporal distribution of fish in the study area are that (1) most fish use nearshore habitats only during the brief open water period, and (2) within this period, the local abundance of fish is a complex picture of day-to-day pulses and large-scale species movements over several-week periods.

Summer versus Winter Periods. Winter surveys were not conducted as part of this study in 1977. However, previous work provides general information about overwintering. Neither anadromous nor marine species overwinter in the shallowest coastal habitats (<2 m water depth) that are utilized so extensively during summer months. As noted previously, anadromous fish generally overwinter in rivers and lakes while marine fish overwinter in deeper (>2 m) coastal waters; when the ice melts, both anadromous and marine fish invade the shallow water zone. Some fish arrive with the first signs of spring breakup (approximately 5-20 June) and some are still present when surface ice forms on the lagoon in early winter (approximately 20 September-10 October). How long fish remain in the lagoon under ice cover is not known, but the main population movements of anadromous species returning to fresh water appear to be complete by the time of ice-over. Perhaps the marine species such as fourhorn sculpin linger in nearshore areas, since water depths below the ice remain adequate for fish passage for 1-2 months in early winter.

Open-Water Season. While nearshore ice may not completely disappear until early July, fish have already been migrating and feeding under the ice and in leads for up to several weeks. The present study and others (Griffiths *et al.* 1975, 1977; Bendock 1977) show that fish enter nearshore waters almost as soon as there is enough unfrozen water to swim in.

In Simpson Lagoon the first open water areas in the spring of 1977 were leads along mainland and island shorelines. When gill net sampling began in the lagoon-side lead off Pingok Island on 19 June, fish were already present and actively feeding. First capture dates for major species off Pingok Island are listed below:

19 June - fourhorn sculpin
22 June - arctic cisco
30 June - least cisco
3 July - arctic char
12 July - arctic cod

Salinities during this breakup period (16 June-3 July) at Pingok ranged from 2.1-6.0 ppt and water temperatures 0-4.5°C in areas where the fish were taken.

The arctic cisco was the most abundant species at Pingok during this early breakup period (Fig. 3). These individuals were primarily mature spawners, which may have overwintered in the nearby Colville Delta (see "Life-History Information"). It appears that spawners leave their overwintering areas at the first opportunity, feed voraciously in Simpson Lagoon for two weeks or so (all had stomachs packed full of amphipods and mysids), and then return to the Colville River by early July. During their sojourn in nearshore waters, most remain near the Colville Delta; very few spawners have been taken east of Simpson Lagoon in Alaskan Beaufort Sea waters (Craig and Mann 1974; Griffiths *et al.* 1977; Bendock 1977). On the other hand, juvenile and mature non-spawning arctic cisco were abundant in nearshore environments throughout the open-water season. Fig. 3 shows two major periods of activity, which probably represent migrations away from the Colville River in the latter half of July and back to the Colville in early September. This bimodal pattern was not observed at locations more distant from the Colville: Kaktovik Lagoon (Griffiths *et al.* 1977); Prudhoe Bay (Bendock 1977).

Fyke net catches of small arctic cisco (Fig. 4) suggest two points of interest: (1) there were movement peaks in late August and early September, perhaps indicating their return to the Colville, and (2) daily catches varied erratically, indicating that fish were passing by in pulses or schools rather than in a large, even migration.

The seasonal abundance of least cisco, when viewed in conjunction with the Prudhoe Bay data (Bendock 1977), is difficult to interpret. In Simpson Lagoon least cisco were abundant from late July until late August (Fig. 3), but in Prudhoe Bay their numbers increased through the summer with peak numbers in September. Though least cisco in the study area are

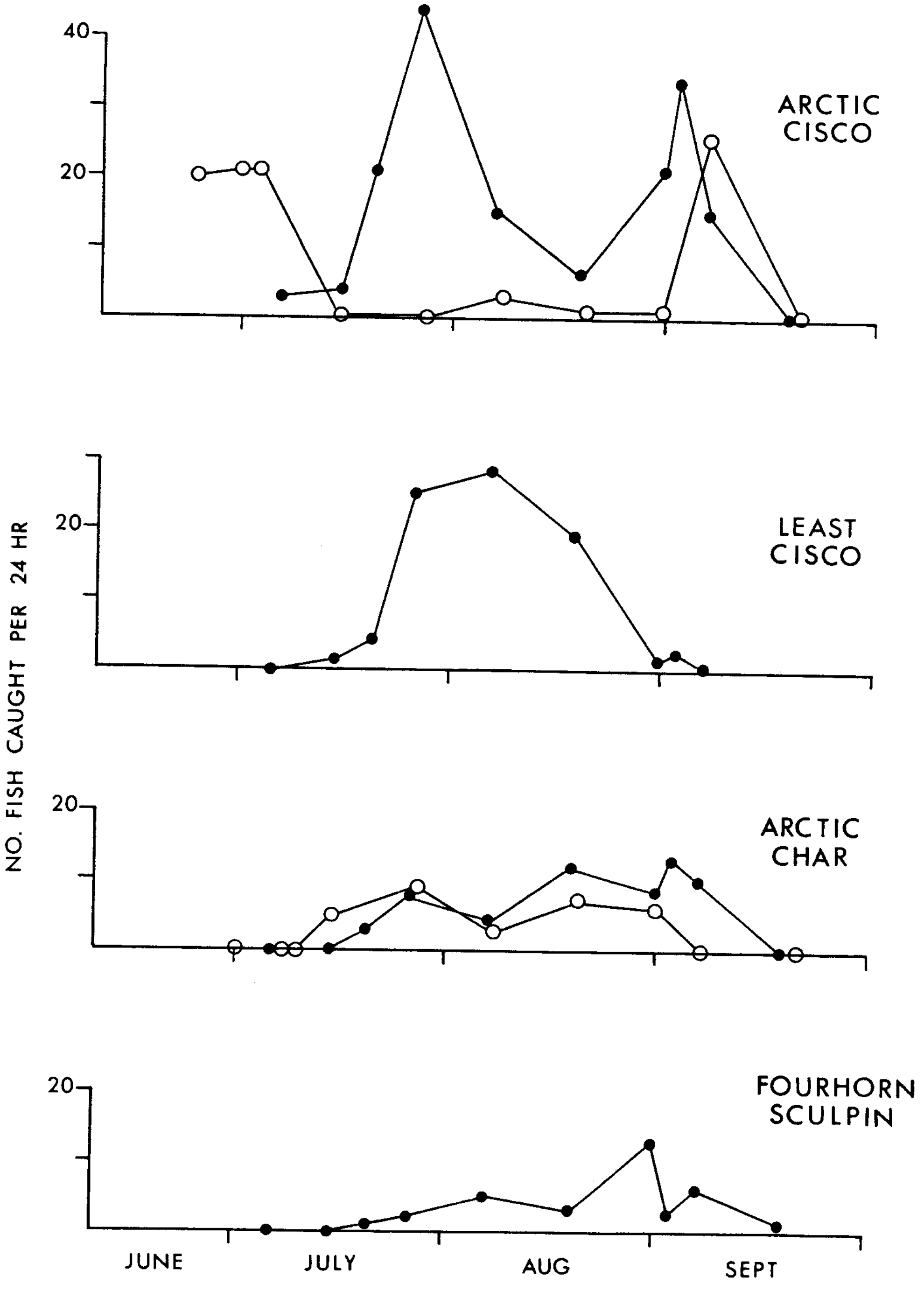


Fig. 3. Seasonal Abundance of Fish Caught by Gill Net at Station 1, Mainland (solid dots) and Station 3, Pingok Island (open dots), 1977.

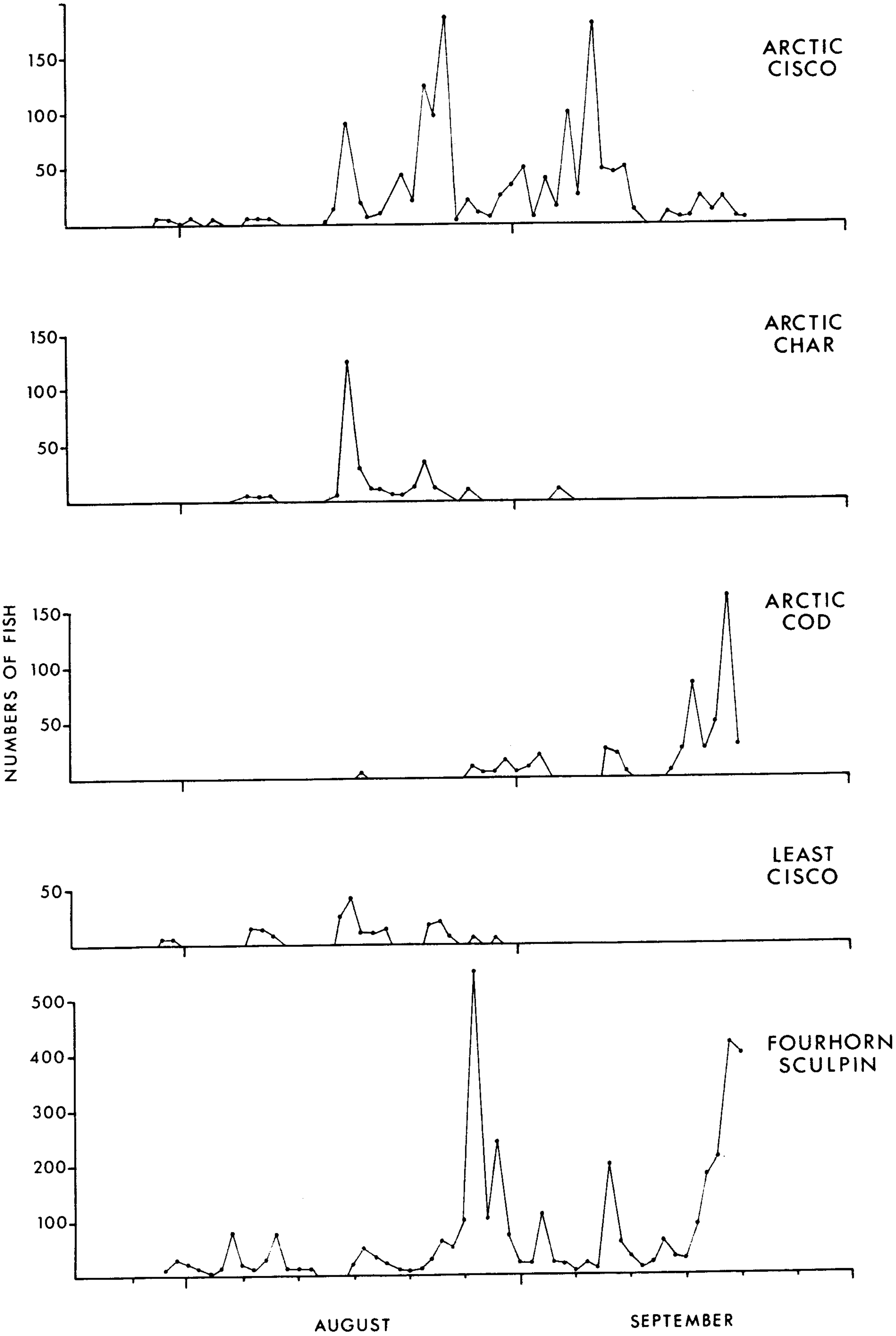


Fig. 4. Daily Fyke Net Catches at Station 1 (mainland shoreline) Which Operated From July 29 - September 21, 1977. Note that the ordinate scale for fourhorn sculpin differs from the others.

thought to be largely of the Colville stock (Bendock 1977), this species did not follow the more understandable movement patterns demonstrated by the closely related arctic cisco.

Arctic char showed similar abundance patterns at mainland and Pingok Island locations (Fig. 3). These fish apparently come from the Colville and Sagavanirktok rivers (see "Life History Information") and feed in Simpson Lagoon.

Large fourhorn sculpin were present in low numbers through most of the season (Fig. 3). Numbers of small fourhorn sculpin, which were by far the most frequently-caught species in the fyke nets (Table 1), varied dramatically as if these small fish were moving by in dense groups (Fig. 4).

Arctic cod increased in numbers as freeze-up approached (Fig. 4), which coincides with Bendock's (1977) findings in Prudhoe Bay. Arctic cod young-of-the-year were most numerous in Simpson Lagoon during the 14-20 August sampling period (Table 3), but seasonal trends are partly obscured by erratic catch data.

Movements versus Physical Factors. Due to large variations in day-to-day numbers of small fish taken in fyke nets (Fig. 4), a comparison was made between catch data and three features of the physical environment that fluctuated almost daily: salinity, water temperature and turbidity. These physical parameters were measured every 1-2 days at the Station 1 fyke net. Correlation coefficients were calculated for Station 1 data during the period 30 July-24 August (n=17-22 dates when measurements of physical variables could be directly compared to daily fish catches). Since each day's catch covered a 24-hr period, numbers of each species were compared to physical data collected both at the start and end of each 24-hr period.

In no case was there a significant correlation between fish numbers and the physical factors monitored. The highest correlation coefficient was only 0.5 and most were in the 0.1-0.3 range. It should be emphasized that more precise comparisons on a smaller time scale might reveal the importance of factors such as salinity to the distribution and movements of fish. For example, it was pointed out in the section "Spatial Pattern" that fish catches were highest at Station 1, where waters were significantly warmer and less saline than at all other stations.

Movements of Tagged Fish

A tagging program was initiated to determine the residency time of fish in Simpson Lagoon. During the 1977 open-water season, 221 large fish (>250 mm) were tagged with Floy dart tags and 2923 small fish (generally 100-250 mm) were tagged with metal opercular tags.

Only eight of the large fish were recaptured (Table 5), and none was recaptured in Simpson Lagoon despite a continued sampling program of fyke and gill netting. While these data suggest that individual fish spend relatively little time in the lagoon, the data are inconclusive because of the small numbers of fish tagged. Additional fish will be tagged during the next field season. The recaptures do, however, provide information on the coastal movements of nearshore fishes. Fish recaptured in Simpson Lagoon but tagged elsewhere are also shown in Table 5; these recaptures are further discussed in "Life History Information" since their principal value is to identify which rivers are the sources of the study populations.

Tag recaptures of small fish also provide some information on the movements of these fish and their residency time in Simpson Lagoon. Fish recaptured the day after tagging are not included since they may have entered the fyke net upon initial release. Fifteen small fish were recaptured: 13 fourhorn sculpin, one arctic flounder, and one arctic cod. The arctic flounder was recaptured 21 days later at the same site; the arctic cod two days later at the same site. For the fourhorn sculpins, the following numbers of days elapsed between tagging and recapture: 2 days (n=5 fish), 3(1), 5(3), 16(1), 19(1), 21(1), 24(1). All but two fourhorn sculpin were recaptured at the site where they were originally tagged; these two crossed the lagoon and were recaptured 19 and 21 days later at Pingok Island.

Table 5. Recaptures of Fish Tagged in This Study or By the Alaska Department of Fish and Game. Abbreviations: LSCS (least cisco), ARCS (arctic cisco), CHAR (arctic char), HMWF (humpback whitefish).[1]

		Tag Data		Recapture Data	
Species	Fork Length (mm)	Location	Date	Location	Date
LSCS	315	Simpson Lagoon	16 Aug 77	Colville Delta	31 Oct 77
LSCS	315	Simpson Lagoon	15 Aug 77	Colville Delta	31 Oct 77
LSCS	-	Simpson Lagoon	18 Aug 77	Colville Delta	25 Nov 77
LSCS	298	Simpson Lagoon	15 Aug 77	Near Barrow	24 Oct 77
LSCS	336	Prudhoe Bay	1 Aug 76	Simpson Lagoon	6 Aug 77
LSCS	319	Prudhoe Bay	1 Aug 76	Simpson Lagoon	23 Aug 77
LSCS	355	Prudhoe Bay	10 Aug 76	Simpson Lagoon	23 Aug 77
ARCS	321	Simpson Lagoon	16 Aug 77	Colville Delta	31 Oct 77
ARCS	298	Simpson Lagoon	15 Aug 77	Colville Delta	26 Oct 77
ARCS	365	Simpson Lagoon	15 Aug 77	Colville Delta	10 Nov 77
ARCS	308	Simpson Lagoon	15 Aug 77	Colville Delta	19 Nov 77
CHAR	533	Ivishak River	17 Sept 72	Leavitt Island	3 Aug 77
CHAR	649	Ivishak River	9 Sept 72	Leavitt Island	26 Jul 77
HMWF	400	Prudhoe Bay	16 July 76	Simpson Lagoon	25 Jul 77
HMWF	408	Prudhoe Bay	19 July 76	Simpson Lagoon	5 Aug 77

[1] All known recaptures of fish tagged in this study are listed. Only recaptures during this study are listed for fish tagged by Alaska Department of Fish and Game.

Trophic Relations

Food habits of fish species in Simpson Lagoon were surprisingly similar. The fish fed extensively on epibenthic invertebrates (organisms living on or near bottom substrates) and zooplankton. Diets of key fish species are described in this section, and these data are then compared to the diets of nearshore birds, the other major group of vertebrate predators in the lagoon ecosystem.

Data Analysis

Relative proportions of food items in fish stomachs were determined by the Hynes Point Method, and the diets of fish and bird species were compared using the Morisita overlap index (see METHODS).

Since fish diets may change seasonally, a composite estimate of their food habits was obtained by pooling and analyzing approximately equal numbers of samples collected during three periods of the 1977 open-water season: early summer (20 June-15 July), mid-summer (25 July-15 August), and late summer (1-20 September). For each of these sampling periods, 17-21 arctic cisco stomachs and 10-14 stomachs of each of four additional fish species were examined. Empty stomachs were not included in these analyses. Since the composition of food items in stomach contents of individual fish collected during any specific period did not vary greatly (Fig. 5), a sample of 10 stomachs appeared adequate to describe the relative proportions of major food items consumed during any one sampling period. It is therefore felt that the pooled data from the three time periods reflect the general diets of each fish species in nearshore waters. Additional arctic cisco stomachs were analyzed since the diet of this species was examined in greater detail.

It should be noted that samples used in dietary analyses were not selected on the basis of fish size, sample location or collection method; each of these factors has a potential influence on the kinds of foods eaten. Instead, the samples used are intended to reflect the habits of fish populations using Simpson Lagoon (described in "Life History Information"). (Medium- to large-sized fish of most species were predominant in the catch and in the samples used for stomach analyses.)

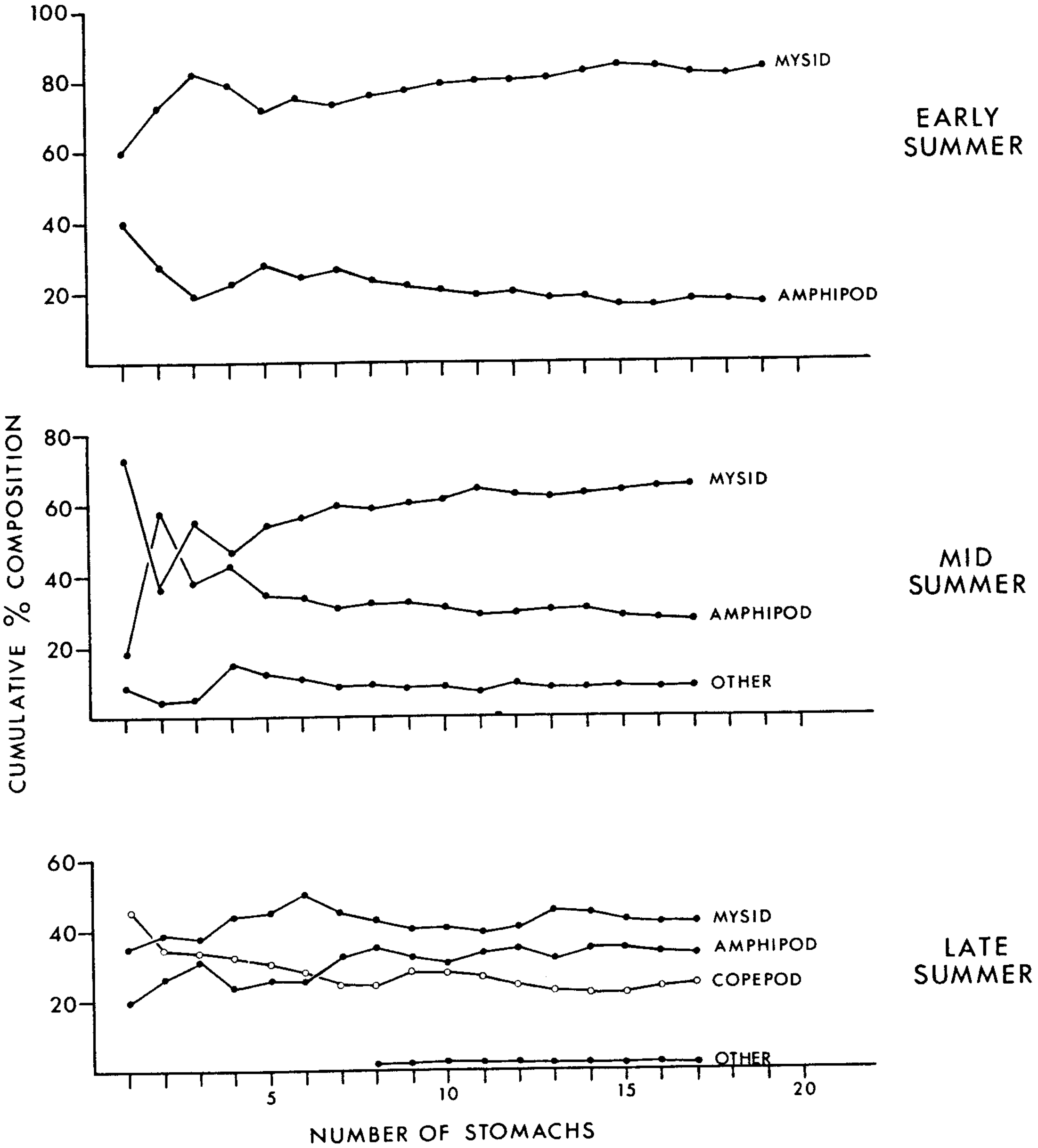


Fig. 5. Cumulative Percent Composition of Major Food Items in the Diet of Arctic Cisco Collected During Three Periods During the 1977 Open-Water Season.

General Food Habits

Mysids and amphipods were the most significant source of food for fishes in Simpson Lagoon in 1977. Although seven taxonomic groups of food items were recorded in fish stomachs, mysids and amphipods accounted for 74-90% of all food ingested by the five species considered (Table 6). Copepods, isopods and smaller fish were of secondary importance, and euphausiids and cumaceans were incidental food items. The abundances and distributions of these food groups in Simpson Lagoon are discussed in RU 467, INVERTEBRATES section.

The apparent similarity in fish diets--at least at the level of the broad taxonomic groups mentioned above--was confirmed by the Morisita overlap index, which compares the relative proportions of different food groups consumed by different predator species. Of the ten possible pairs of fish species, eight showed a high degree (≥ 0.6) of dietary overlap:

	Arctic Cisco	Arctic Char	Fourhorn Sculpin	Least Cisco	Arctic Cod
Arctic cisco	-	0.77	0.80	0.99	0.92
Arctic char		-	0.96	0.69	0.52
Fourhorn sculpin			-	0.72	0.58
Least cisco				-	0.93
Arctic cod					-

The diet of arctic cisco, for example, was very similar to diets of the other four fishes and virtually identical to the diet of least cisco (C=0.99). Only the arctic cod diet showed relatively little overlap with the diets of certain species--arctic char and fourhorn sculpin. The degree of dietary overlap between fishes in Simpson Lagoon is considerably higher than that reported for fish communities in non-arctic coastal areas (e.g., Zaret and Rand 1971; Obrebski and Sibert 1976; Kislalioglu and Gibson 1977). Some implications of this overlap analysis are presented in the following section, "Dietary Overlap".

Major food groups of arctic cisco were identified to the species level. These groups were the mysids and amphipods, which comprised 90% of the arctic cisco diet. Twelve amphipod species and three mysid species

Table 6. Major Food Groups Eaten by Five Fish Species, Simpson Lagoon, 1977.

Food Item	% Composition				
	Arctic Cisco	Least Cisco	Arctic Char	Fourhorn Sculpin	Arctic Cod
Mysid	66	61	32	33	71
Amphipod	24	16	55	43	3
Copepod	8	14	3	0	2
Isopod	1	0	0.3	12	4
Fish	0.1	0	5	10	0
Euphausiid	1	0	1	0	0.4
Cumacean	0	1	1	0	0
Unidentifiable	0	9	2	3	20
No. Stomachs Examined	57	30	30	35	30

were identified in stomach contents, although only two species in each group formed the bulk of the diet (Table 7). *Apherusa glacialis* and *Onisimus glacialis* accounted for 94% of the total weight of identified amphipods, and *Mysis litoralis* and *M. relicta* accounted for 99.9% of the total weight of identified mysids. A vast number of small mysids (*Mysis* sp.) were also eaten and it seems a safe assumption that these were the young of the identified species. A seasonal average of 18,297 (range 0-90,092) of these small mysids was found in each arctic cisco stomach.

The nature of the organisms eaten provides some indication of fish feeding habits. The major food items have an epibenthic distribution, at least during the open water period. SCUBA divers observed large numbers of mysids and amphipods concentrated within 10 cm of the lagoon bottom, and few were in the water column except during periods of storm-generated turbulence. These epibenthic invertebrates are active and some avoidance behavior was noted by the divers (some large mysids dived into the flocculent detrital mat). Fish apparently cruise along the lagoon bottom and feed on this abundant food supply. Secondary food groups, such as copepods, occur in the water column as well as near bottom substrates. Infaunal groups in Simpson Lagoon were an insignificant component of fish diets.

The food habit data obtained in Simpson Lagoon are generally similar to those recorded for the same fish species at other Beaufort Sea locations (Griffiths *et al.* 1975, 1977; Kendel *et al.* 1975; Bendock 1977). However, proportions of the taxonomic groups of food organisms consumed show annual and/or location differences.

Dietary Overlap: Fish and Birds

Food items of all key vertebrate predators in the lagoon ecosystem have been compared to help determine the ecological implications of invertebrate consumption in the lagoon. Comparisons have been made between five fish species (arctic cisco, arctic char, least cisco, fourhorn sculpin, arctic cod) and four bird species (oldsquaw, glaucous gull, northern phalarope, red phalarope). Specific foods and feeding habits of bird species are described elsewhere (RU 467, AVIAN ECOLOGY section).

Table 7. Species Composition of Amphipods and Mysids Eaten by 57 Arctic Cisco, Simpson Lagoon, 1977.

Food Item	Seasonal Average (n=57)		
	Number	Weight (g)	% Weight by Species
A. Amphipod			
Apherusa glacialis	107.3	0.69	62.4
Onisimus glacialis	90.8	0.35	31.6
Onisimus sp.	93.4	0.45	
Unidentified gammarid	46.8	0.1	
Gammarus setosus	2.3	0.04	3.6
Unidentified amphipod	2.7	0.02	
Acanthostepheia behringiensis	0.8	0.008	0.7
Onisimus littoralis	0.6	0.007	0.6
Parathemisto libellula	0.3	0.008	0.7
Acanthostepheia incarinata	0.1	0.001	0.1
Onisimus nanseni	0.7	<0.001	<0.1
Gammaracanthus loricatus	0.2	<0.001	<0.1
Gammarus sp.	0.3	0.001	
Monoculopsis longicornis	0.1	<0.001	<0.1
Weyprechtia pinguis	0.3	<0.001	<0.1
Apherusa sp.	0.1	<0.001	
Unidentified lysianassid	0.04	0.002	
Monoculodes sp.	0.02	<0.001	<0.1
Unidentified hyperid	0.02	<0.001	
Unidentified caprellid	0.02	<0.001	
			99.9%
B. Mysids			
Mysis litoralis	445.2	4.73	80.1
Mysis relicta	241.1	1.17	19.8
Mysis oculata	0.2	0.002	0.03
Mysis sp.	18,297.4	10.27	
			99.9%

The degree of food overlap among predators in Simpson Lagoon was high (Table 8). Of the 36 possible comparisons of pairs of predators, almost half (47%) showed that predators exploited similar ($C \geq 0.6$) taxonomic groups of food organisms. The similarity was greater among the fishes (80% of 10 possible fish pairs had $C \geq 0.6$) than among the birds (17% of 6 possible bird pairs). In comparisons between birds and fishes, the similarity between the diets of oldsquaws and all fishes was particularly evident.

The food overlap of the nine species of fishes and birds suggests that the feeding habits of all major predators in the lagoon ecosystem can be separated into three general patterns:

1. Epibenthic feeders (all fishes and oldsquaws).
2. Specialized shoreline feeders (phalaropes).
3. Opportunistic shoreline feeders (glaucous gulls).

When the number of predator species and the relative sizes of their populations are taken into account, it is clear that epibenthic feeding is the predominant feeding pattern in the lagoon ecosystem. The oldsquaw is the dominant avian species; it and the five fish species utilize the same general food resource, namely mysids and amphipods.

The food overlap between the dominant fish and bird predators, arctic cisco and oldsquaw, was examined in greater detail. As indicated in Table 8, the diets of these predators were nearly identical (C=0.98) in 1977. However, this high overlap value, based on pooled data collected during the open-water season, might mask seasonal differences in diet. Therefore, the data were separated into early, mid- and late summer periods. Specific collection dates and sample sizes are shown below.

Time Period	Arctic Cisco		Oldsquaw	
	Dates	n	Dates	n
early summer	22-24 June	19	19 June-3 August	12
mid-summer	3-13 August	17	17-31 August	9
late summer	30 August-7 September	21	5-18 September	12

Table 8. Food Overlaps of Fish and Bird Predators in the Lagoon Environment.

	Fish and Oldsquaw						Gull	Phalarope	
	Arctic Cisco	Arctic Char	Least Cisco	Fourhorn Sculpin	Arctic Cod	Oldsquaw	Glaucous Gull	Northern Phalarope	Red Phalarope
Arctic Cisco	-	0.77	0.80	0.90	0.92	0.98	0.30	0.44	0.50
Arctic Char		-	0.96	0.69	0.52	0.80	0.64	0.74	0.42
Least Cisco			-	0.72	0.58	0.80	0.64	0.74	0.42
Fourhorn Sculpin				-	0.93	0.96	0.25	0.41	0.57
Arctic Cod					-	0.92	0.18	0.16	0.33
Oldsquaw						-	0.31	0.38	0.39
Glaucous Gull							-	0.54	0.25
Northern Phalarope								-	0.74
Red Phalarope									-

Although the arctic cisco and oldsquaw samples each were collected during three time periods, the dates of corresponding time periods vary somewhat, partly due to availability of specimens.

Dissection and analysis showed that arctic cisco and oldsquaw consumed similar taxonomic groups of prey throughout the open-water season. Overlap indices during the three time periods were 0.95, 0.96 and 0.77 for the early, mid- and late summer periods, respectively.

Despite the high degree of dietary overlap between arctic cisco and oldsquaw, it is conceivable that they had, in fact, consumed different invertebrate species. To examine this possibility, principal prey (mysids and amphipods) of these two predators were identified to species and compared during the three previously described time periods. Totals of 13 amphipod species and three mysid species were recorded in arctic cisco and/or oldsquaw stomachs, and proportions (by weight) of these species were compared.

In general, the proportions of mysid and amphipod species in the diets of oldsquaws and arctic cisco were surprisingly similar. Seasonally averaged values of the food overlap index were 0.92 for mysid species and 0.98 for amphipod species. Even when the data were examined separately during the three time periods, food overlap was high in most cases: 0.77, 0.63 and 0.99 for mysids, and 0.89, 0.45 and 0.10 for amphipods during the early, mid- and late summer periods, respectively. Not only were the two dominant lagoon predators both exploiting lagoon epibenthos, but they were consuming the same prey species to a large degree.

The ecological implication of these data is that, in general, there is a lack of competition for food in the nearshore environment because the available food supply is not finely partitioned by the predators. If the food resource had been in limited supply, general ecological theory (Gause's Principal) holds that competition for food would be high and therefore we should observe specialized and non-overlapping feeding habits among predators. Since this was not the case, it implies that food in Simpson Lagoon was not in limited supply for the number of predators present during the 1977 open-water season. A second line of evidence that supports this finding is that the standing stock biomass of epibenthic invertebrates during the course of the summer was calculated to remain two to three orders of magnitude greater than the daily consumptive needs of birds and fish inhabiting Simpson Lagoon (discussed in RU 467, INVERTEBRATES section).

Other Organisms: Man, Predators and Parasites

With the possible exception of man, other organisms (predators and parasites) do not appear to limit population numbers of fish in nearshore waters of the Beaufort Sea. While man's exploitation levels have probably been fairly consistent over the years, the effects of this harvest on particular stocks of fish are not known, and indeed, the total annual catch is not well documented.

Human Use of Fish Resources

Anadromous fish, particularly cisco, whitefish and char, are the focal point of several fisheries along the Beaufort coastline in Alaska. Principal areas where fish are taken include (1) domestic fisheries near Barrow, the Colville Delta (Nuiqsut Village) and Barter Island (Kaktovik Village), (2) a commercial fishery in the Colville Delta (Helmericks), and (3) sport fishing at villages, DEW line stations and oil camps.

This information is of direct interest to the present study because all these fisheries catch at least some fish that pass through Simpson Lagoon during the open-water season. Tagging data (Table 5) and Bendock (1977) show that some fish passing through Simpson Lagoon or nearby Prudhoe Bay are caught in nets from Barrow to Barter Island, a distance encompassing much of the Beaufort coastline in Alaska. Therefore, these fisheries must be viewed as sources of mortality to the study populations.

At this stage, however, it is not possible to determine the effects of human harvest rates on Simpson Lagoon fish populations because (1) fish population sizes are not known, (2) harvest rates are not well documented and (3) proportions of "Simpson Lagoon fish" killed in the various fisheries are not known. The only good catch records available are those of the commercial fishery in the Colville Delta where the average harvest from 1964 to 1976 has been as follows:

Species	Average Catch Number	%
arctic cisco	37,284	65
least cisco	16,682	29
broad whitefish	2,816	5
humpback whitefish	701	1

These records (ADF&G 1977) exclude 1967 and 1969 when the fishery did not operate. The village of Nuiqsut also relies on fish in the upper Colville Delta, and a guess would be that the annual catch there is at least one or two times that of the commercial fishery.

Predators

Predation pressure on fishes in the nearshore environment appears to be surprisingly low. Although beluga whales, seals, birds and some fish are all known to feed on Beaufort Sea fish, predators tend to be scarce in areas where anadromous fish are abundant. And, when predators are taken in lagoons and other nearshore areas, stomach analyses show they often feed on invertebrates in summer, although ringed seals rely on arctic cod in winter (J. Burns, ADF&G, pers. comm.). (However, ringed seals in the Canadian High Arctic consume crustaceans as well as arctic cod in winter--K.J. Finley, LGL Limited, pers. comm.) Most fish recorded in whale and seal stomachs are marine species rather than the anadromous species of nearshore habitats.

Few potential predators were sighted in the Simpson Lagoon study area during the 1977 open-water season. Only 10-12 ringed seals were seen inside the lagoon and 75-100 beluga whales were seen outside the lagoon. Fish-eating birds were not abundant; ornithologists estimated the density of loons to be approximately 0.4 birds/km^2 in the whole lagoon system. Even potential fish predators such as arctic char fed infrequently on small fish in Simpson Lagoon (see "Trophic Interactions"). However, small fish may form a higher proportion of the diet of char and cisco at other coastal locations (Griffiths *et al.* 1975, 1977; Craig 1977).

In offshore areas the picture appears somewhat different. Although anadromous species are not present, predation might be an important limiting factor for some marine fish populations. The arctic cod, for example, is a favored food item for marine mammals, birds and other fish (Andriyashev 1954; Bain and Sekerak 1978).

Parasites (by L. Haldorson, Dept. Biol., University of California, Santa Barbara, California)

A preliminary examination of fish parasites was initiated during this study because parasite infections of coregonid fishes may cause deterioration in physical condition and reduce growth of fish (reviewed in Bauer 1970 and Lawler 1970), or affect the ability of fish to resist the environmental effects of chemical pollutants (Boyce and Yamada 1977; Perevozchenko and Davydov 1974 cited in Boyce and Yamada 1977). Therefore, arctic cisco, an ecologically and economically important fish species, was examined for potentially detrimental parasitic species. Specific objectives were to (1) evaluate the significance of parasitism in the energy budget of the fish population, (2) determine if parasite infections caused deterioration in fish condition, (3) determine if there is any period when parasites are especially prevalent and could be a factor affecting the ability of the fish to withstand additional stress, and (4) determine if these economically important fish hosted any parasite species potentially dangerous to man or other mammals.

Methods. Samples of 25 arctic cisco were collected under the ice in the Colville Delta (November 1976) and three times during the open-water season in Simpson Lagoon (30 June, 27 July, and 2 September 1977). These arctic cisco averaged 351 mm fork length (range 304-385, SD=21) and 551 g weight (range 265-801 g, SD=136). The gills and viscera were removed and preserved in 10% formalin and later examined for the presence of parasites. Condition factors for fish were determined by this equation:

$$C = \frac{\text{length (cm)}^3}{\text{weight (g)} \times 100}$$

Results. No parasites were found on the gills. The viscera were infected with three types of parasites that occurred in sufficient numbers to be of interest in terms of study objectives: (1) an adult tapeworm (*Diplocotyle olrikii*) (2) a tapeworm intermediate stage (*Diphyllobothrium* sp.), and (3) an adult acanthocephalan (unidentified).

The adult tapeworm, *Diplocotyle olrikii*, occurred in the lumen of the pyloric caeca and intestine. Bauer (1970) reports that in Russia this species infects fish in marine waters but perishes when the host migrates into fresh water. The pattern of infection in the study population (Fig. 6) coincides with that observation. Fish collected in the brackish lagoon waters during mid- and late summer periods were highly infected (84-92%) in contrast to those fish that had returned in early winter to fresh water in the Colville Delta (0% infection). Average number of tapeworms per fish (35.6) was highest on 27 July. These were small tapeworms about 1 cm in length, which grew to 3-4 cm by 2 September, though they were few in number by that time (5.7 per infection). Lawler (1970) reports that *D. olrikii* may retard fish growth and cause general deterioration, but apparently this requires much higher infection levels than found in this study.

A second tapeworm, *Diphyllobothrium* sp., occurred as a plerocercoid (first intermediate stage) on the stomach wall, pyloric caeca walls and mesenteric tissue. Most specimens measured 2-3 mm in diameter. This parasite probably matures in fish-eating birds, although there have been reports of *D. dendriticum*, a species infecting man, occurring in arctic cisco (Bauer 1970). It is possible, therefore, that this fish does harbor a harmful parasite, and eating the whole fish (including the stomach) could be dangerous. The infection level of this parasite does not appear high enough to adversely affect the fish (Fig. 6).

The acanthocephalan found in the intestine has not yet been identified. These adult parasites are "spiny-headed worms", 0.5-1 cm in length, which probably have a lagoon amphipod as their intermediate host. Acanthocephalan (*Echinorhynchus* spp.) infections have been reported to cause deterioration in coregonid fishes when infections of over 250 per fish occur; however, infections of 30 or less per fish have shown little effect

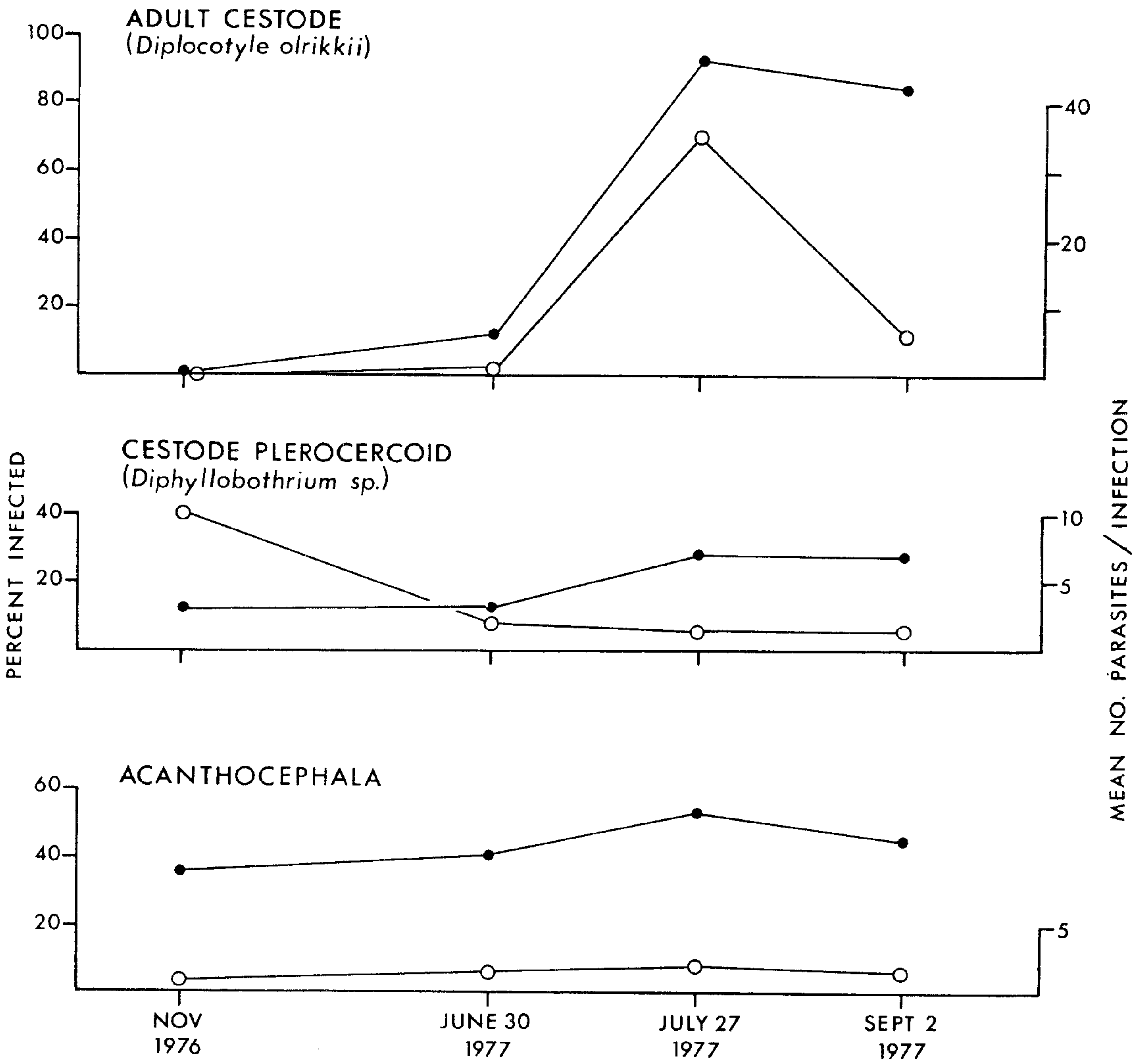


Fig. 6. Intestinal Parasites of Arctic Cisco From Simpson Lagoon and the Colville River Delta. Percent infection (solid dots) and mean number of parasites per infected fish (open dots) are indicated. On each date, 25 Arctic cisco were examined.

(Bauer 1970). Consequently, it seems likely that infection levels in the Simpson Lagoon samples are too low to be harmful (Fig. 6).

In general, the infection levels of all parasites in arctic cisco from Simpson Lagoon are low and do not appear to detrimentally affect the health of the fish. There was no significant correlation between the condition factor of a fish and its total intestinal parasite load at these levels of infection ($r=0.06$, $P>0.1$, $n=25$) during September, when parasite infections were maximum for the season.

Conclusions. On the basis of this survey three species of intestinal parasites, two cestodes and an acanthocephalan, appear to occur frequently enough to warrant evaluation in this study. Apparently none of these three occur at sufficient infection intensities to either affect the energy budget or decrease the condition or growth of the arctic cisco. Pending positive identification, the plerocercoid-stage cestode must be regarded as potentially dangerous to man or other mammals, such as dogs, that may eat the viscera. There is a marked seasonality in infection levels of the cestode *D. olrikkii*, with maximum infection levels from about mid-July until the fish enters fresh water. If parasite infections do increase the susceptibility of arctic cisco to other stresses, such as chemical pollutants, the population would be most vulnerable during this mid-July period.

Life History Information for Major Species

Age, length and maturity data for arctic cisco, least cisco, arctic char, fourhorn sculpin and arctic cod are presented in this section. Available data regarding freshwater sources of major anadromous species, the commercial fishery for arctic cisco in the Colville Delta, and the arctic cisco - Bering cisco species complex are also discussed.

Arctic Cisco

By several standards, the anadromous arctic cisco, *Coregonus autumnalis*, ranks as an important species in Alaska arctic waters. It is one of the most abundant and widely distributed fishes along the Beaufort Sea coastline, and it plays an important role in domestic and commercial fisheries from Barrow to Barter Island. These generalizations hold true for the Simpson Lagoon/Colville Delta study area where arctic cisco accounted for

- 63% of large anadromous fish caught in gill nets,
- 70% of small anadromous fish caught in fyke nets, and
- 41-94% of the commercial catch in the Colville Delta (ADF&G 1977).

Most, if not all, of the arctic cisco utilizing the Simpson Lagoon study area originate from the Colville River, the only river in Alaska known to support a major population of this species (Craig and McCart 1976). Nineteen fish tagged in Prudhoe Bay (Bendock 1977) and four fish tagged in Simpson Lagoon (this study) were recaptured in the commercial fishery in the Colville Delta. Recent surveys by the U.S. Fish and Wildlife Service (1978) report that a few arctic cisco have also been caught in two lakes west of the Colville (Teshekpuk Lake and an unnamed coastal lake), but it is not yet known whether these represent separate stocks or are merely areas used by Colville arctic cisco.

Available information on the biology of arctic cisco has been obtained largely as a result of coastal studies of the anadromous segment of the population (summarized in Craig and McCart 1976). Minimal data exist for the freshwater segment of this species. In the Colville River, for example, it is only known that (1) arctic cisco inhabit only the lower reaches of the Colville with none recorded as far upstream as Umiat (Alt and Kogl 1973; U.S. Fish and Wildlife Service 1978), and (2) "it is suspected that spawners enter the Colville Delta later in the summer and spawn in the lower reaches of the rivers" (Alt and Kogl 1973). The lack of information regarding spawning times and areas, overwintering areas and freshwater distribution of this species represents a major data gap.

Size Distribution. The prominent bimodality in the size distribution of arctic cisco collected in Simpson Lagoon (Fig. 7) results, in part, from the methods used to capture fish. Fyke nets caught mostly small arctic cisco 60-140 mm long, but gill nets caught larger fish 280-400 mm

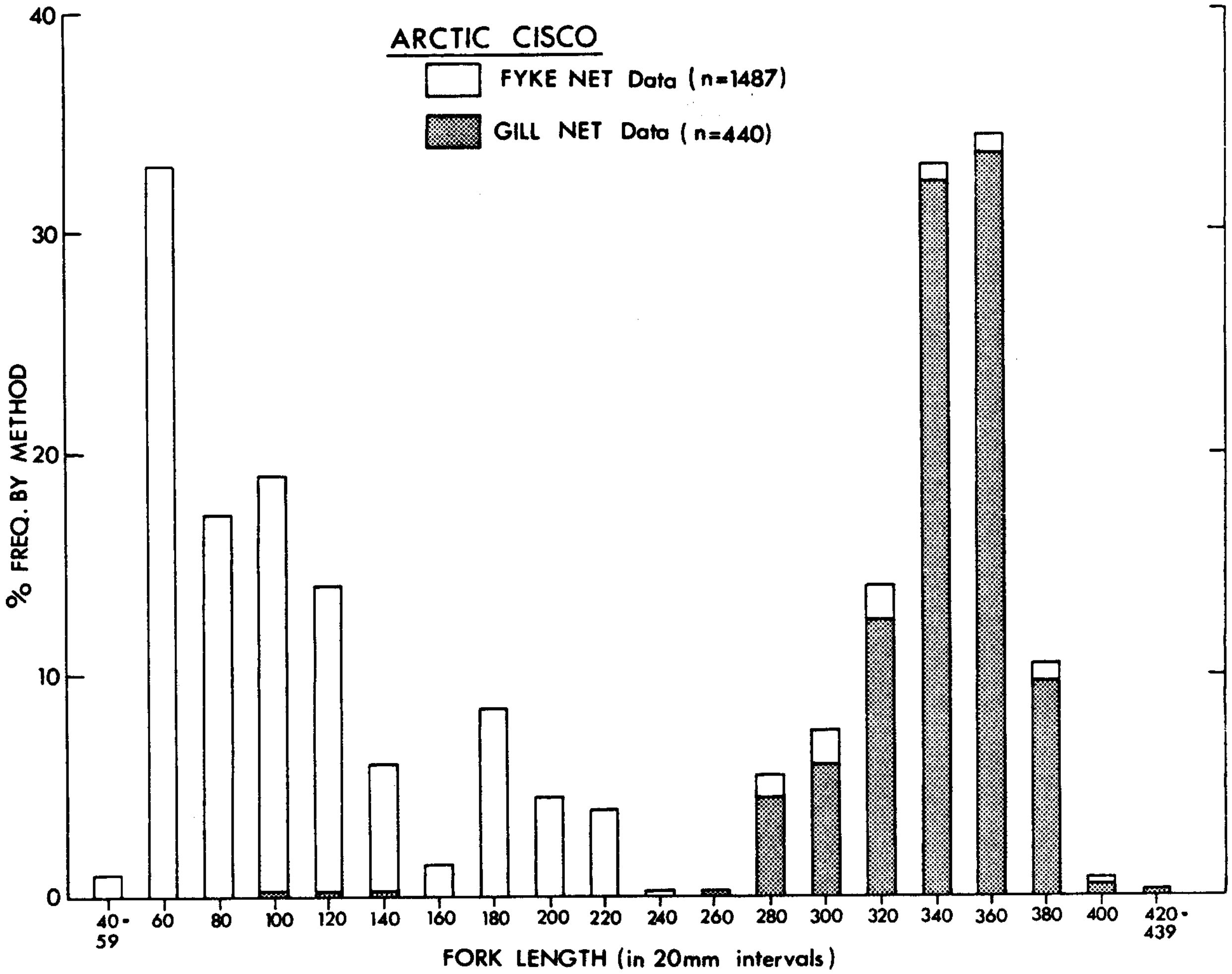


Fig. 7. Length-Frequency of Arctic Cisco in Simpson Lagoon, 1977.

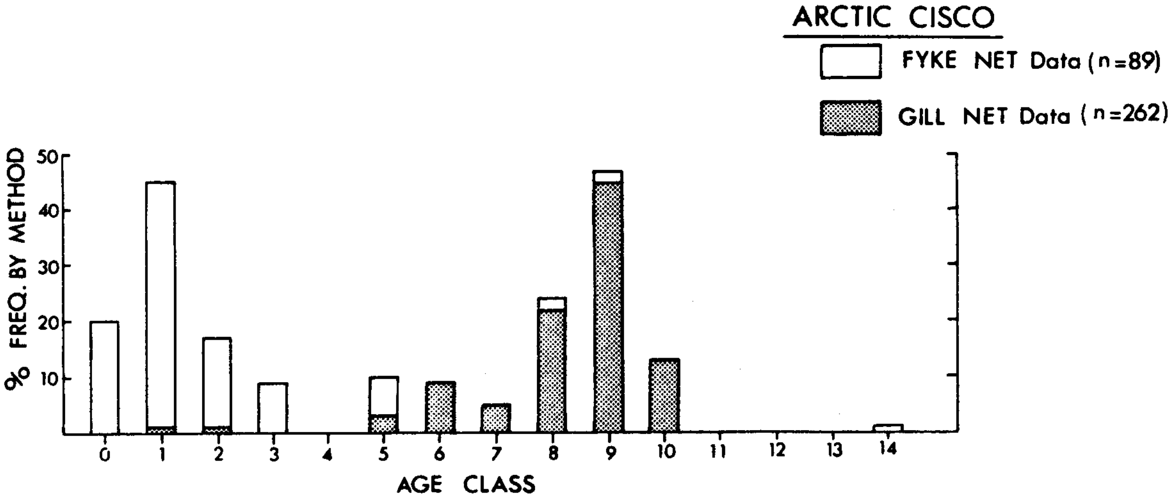


Fig. 8. Age-Frequency of Arctic Cisco Caught in Simpson Lagoon, 1977.

long. The former size group corresponds to juveniles ages 0-3 and the latter to older juveniles and mature fish ages 5-10 (Table 9). While sampling bias associated with these two capture methods may contribute to the apparent scarcity of the fish in the intermediate size ranges, the complete absence of age 4 fish in the total sample (Fig. 8) suggests that the bimodality in size may also be a consequence of a poor 1973 year class.

Fyke net data from this study and Bendock's (1977) study at Prudhoe Bay show that small fish are more common in nearshore Beaufort Sea waters than indicated by earlier studies that relied on data obtained by gill nets. Figure 7 clearly illustrates that variable-mesh gill nets underestimate numbers of small arctic cisco, even when gill net mesh sizes are as small as 1.25 cm (0.5 in) bar mesh.

Age at First Seaward Migration. Arctic cisco smolt at an early age. In 1977, some entered the brackish waters of Simpson Lagoon as young-of-the year, and age 1 fish were the most abundant age class of all arctic cisco caught by fyke net. Bendock (1977) reports that age 1 arctic cisco were also present in Prudhoe Bay, thus indicating that some small arctic cisco disperse at least 70 km from the Colville River. The proportion of juveniles that smolt at these early ages or remain in fresh water are not known.

Age, Growth, and Maturity. Ages of arctic cisco in Simpson Lagoon cover the known age range for the Colville population, ranging from 0-14, with a distinctly bimodal distribution (Fig. 8). Growth of the Simpson Lagoon fish (Table 9) is generally similar to that of other populations of this species along the Beaufort Sea coastline (*cf.* Craig and McCart 1976), For the 1977 study population, two growth phases are apparent (1) rapid growth for immature fish of ages 0-6, and (2) markedly slower growth as fish attain sexual maturity (Fig. 9).

Several differences were noted in the reproductive status of male and female arctic ciscos in Simpson Lagoon. Males tend to reach maturity one year earlier than females. Most males mature at ages 7-9, females at ages 8-10 (Fig. 9). Of those caught, 57% of the males and 46% of the females were mature fish. Proportions of males and females within the

Table 9. Age-Length Relationship (derived from otoliths) and Age-Specific Maturity of Arctic Cisco in Simpson Lagoon, 1977. Immature fish (I) and mature fish that would (S) or would not (NS) spawn in the year of capture are indicated.

					Maturity							
	Fork Length (mm)				Males				Females			
Age	n	mean	(range)	SD	n	% I	% S	% NS	n	% I	% S	% NS
0	18	73	(54-96)	11	-	-	-	-	-	-	-	-
1	40	112	(65-145)	15	23	100	0	0	7	100	0	0
2	15	155	(129-188)	22	7	100	0	0	6	100	0	0
3	9	175	(151-227)	23	7	100	0	0	2	100	0	0
4	0	-	-	-	0	-	-	-	0	-	-	-
5	14	293	(261-318)	15	5	100	0	0	6	100	-	0
6	24	310	(290-340)	16	7	100	0	0	17	100	-	0
7	13	348	(330-398)	20	7	57	43	0	7	100	-	0
8	63	352	(292-394)	21	36	47	53	0	27	73	19	8
9	121	364	(333-400)	16	63	6	71	22	54	22	24	54
10	35	368	(349-390)	10	17	0	58	42	17	0	65	35
11	0	-	-	-	0	-	-	-	0	-	-	-
12	0	-	-	-	0	-	-	-	0	-	-	-
13	0	-	-	-	0	-	-	-	0	-	-	-
14	1	410	-	-	1	1	100	0	0	-	-	-
Overall	352				173	43%	45%	12%	143	54%	20%	26%

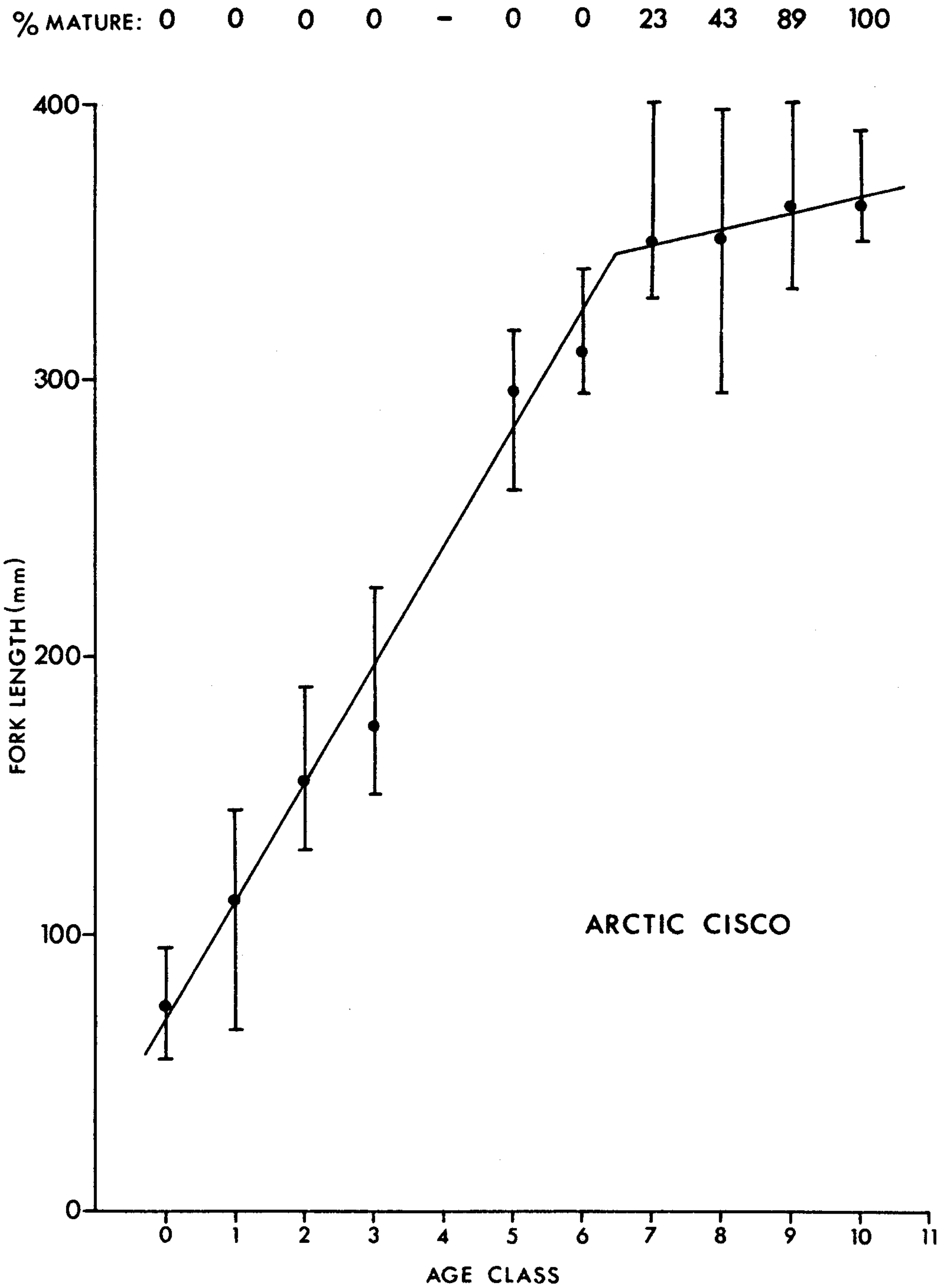


Fig. 9. Growth of Arctic Cisco in Simpson Lagoon, 1977. Mean, range and percent mature (sexes combined) are indicated for each age class.

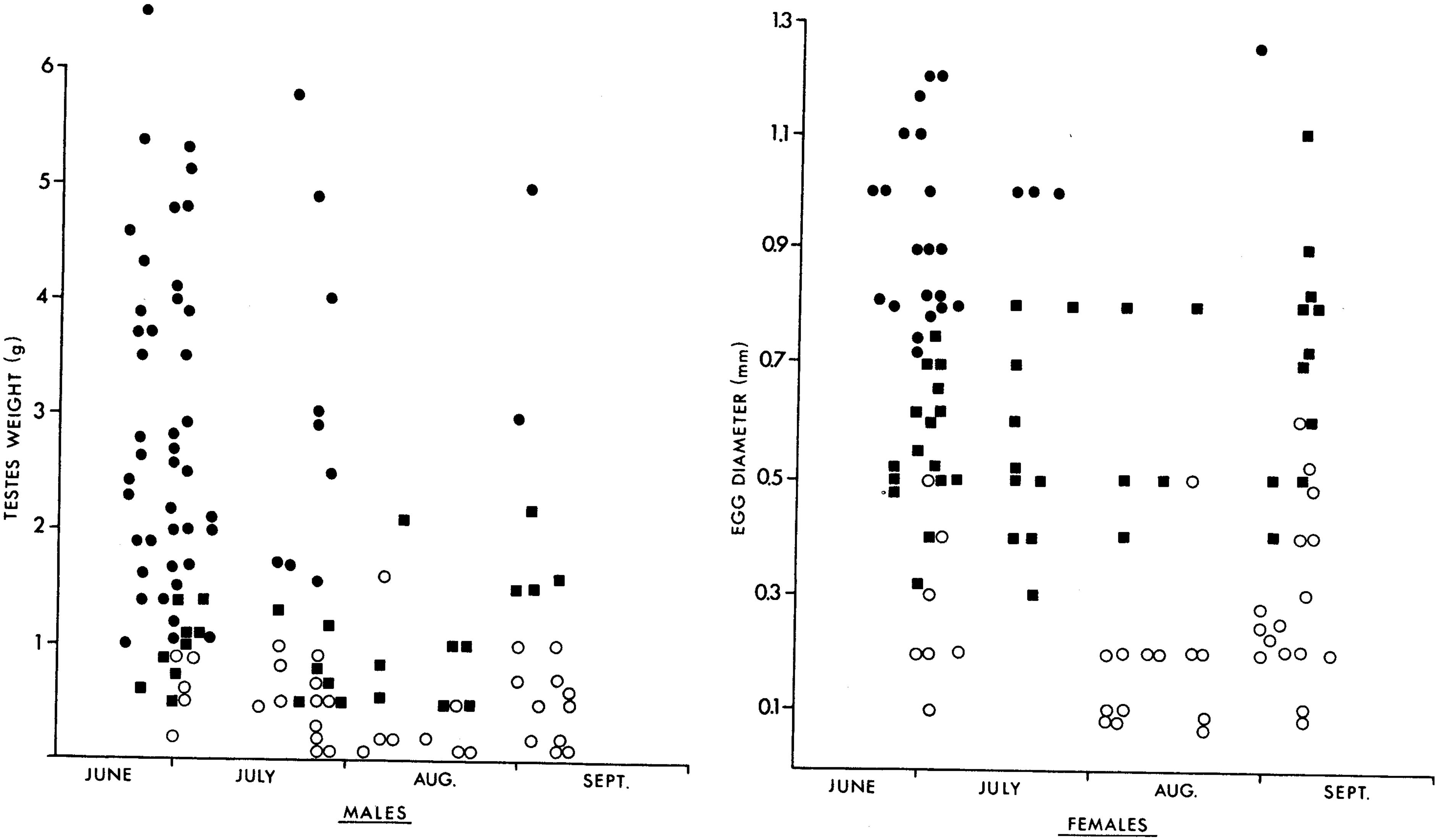
categories "mature spawner" (those that would spawn in the year of capture) and "mature non-spawner" (mature fish that would not spawn in the year of capture) also differed. Among the males, 79% were spawners and 21% were non-spawners; among females, 43% were spawners and 57% were non-spawners.

Seasonal patterns of egg sizes and testes weights (Fig. 10) indicate that

1. there is considerable overlap in reproductive conditions of fish visually judged to be immature, mature spawners or mature non-spawners, indicating a degree of subjectivity in field designations of reproductive status. Egg sizes of spawning arctic cisco are not known but are probably similar to those of least cisco: 1.4-1.9 mm (Mann 1974).
2. spawners are present in early summer, presumably returning to fresh water thereafter. The available evidence suggests that spawners are the first group to enter nearshore waters in the spring (see section on "Habitat Utilization"), but they do not travel far from the Colville River since few spawners have been taken at sites east of Simpson Lagoon in Alaska (Craig and Mann 1974; Griffiths *et al.* 1977; Bendock 1977). Most spawners return to the Colville by mid-July, whereas juveniles and mature non-spawners remain in coastal waters for a longer time.

Sex Ratio. Male and female arctic cisco in the Simpson Lagoon sample were present in almost equal numbers (n=529, 51.2% male, χ^2=0.32, P>0.5). The observation in other species (particularly arctic char) that females have a greater tendency to become anadromous is not apparent with arctic cisco.

Intestinal Fat and Speculations about Overwintering Areas. A common belief among fisheries biologists is that anadromous fish overwinter in fresh water during the prolonged arctic winter and feed very little during this time because of lowered metabolic needs and scarcity of prey. Thus, fish would tend to be in their poorest physical condition after surviving the winter and best condition after summer feeding in coastal waters. Hence, it was surprising that arctic cisco caught during the 1977 spring breakup in Simpson Lagoon were not thin, but healthy-looking, robust fish. As early as 30 June-2 July (two weeks before Simpson Lagoon was free of all ice), an abundance of fat along the intestinal tracts of the fish



ARCTIC CISCO

Fig. 10. Seasonal Patterns of Testes Weights and Egg Sizes for Arctic Cisco in Simpson Lagoon, 1977. Immature fish (open dots), mature spawners (closed dots) and mature non-spawners (squares) are indicated.

indicated that these fish had survived the winter with more than adequate food reserves, or had already had the opportunity to fatten up in the spring before entering the lagoon. Intestinal fat accounted for an average of 1.7% of the total body weight, and this early-season value was already one-half the total amount present by the end of the growing season:

		Intestinal Fat (%)	Fork Length (mm)		Weight (g)	
Date	n	Mean (Range)	Mean (range)	SD	Mean (Range)	SD
30 June-2 July	18	1.7 (0.9-3.4)	360 (339-383)	14	577 (463-723)	66
7 Sept.	15	3.6 (1.8-5.5)	369 (331-395)	17	664 (464-848)	103

Before making speculations based on these data, two pertinent facts must be considered: (1) Helmericks' commercial fishery caught arctic ciscos under the ice in the brackish waters of the Colville Delta in 1976 until mid-December when fishing ceased due to inclement weather, and (2) invertebrates ("shrimp") were active and abundant throughout the 1976-1977 winter in a hole opened up by crews on an exploratory drill rig just off the Colville Delta. It appears that arctic cisco are present in the delta well into winter and that food (probably mysids and amphipods) is available at this time and in this area. Thus, arctic cisco may spend the entire winter in brackish delta or nearshore coastal waters, and during this time feed on an apparently plentiful supply of under-ice invertebrates. Should this be the case, the idea that anadromous fishes must overwinter in fresh water may not be entirely correct. Some nearshore coastal waters, particularly around the mouth of the Colville River, may be important overwintering and winter-feeding sites for arctic cisco.

The Commercial Fishery in the Colville Delta. For comparative purposes, a sample of fish was purchased from Helmericks' commercial fishery in the Colville Delta. The sample consisted solely of arctic cisco caught the previous autumn (October-November 1976) under the ice in brackish delta waters. Subsamples were analyzed for reproductive status (n=59), age (n=31) and stomach fullness (n=34). Most of the arctic cisco were immature fish (86%); the rest were mature non-spawners. No mature spawners or spawned-out fish were present. The age distribution was as follows: age 5 (n=1), 6(17), 7(2), 8(9), 9(2). Empty stomachs were found in 35% of the fish.

It appears that during autumn the commercial fishery in the Colville Delta harvests the non-spawning segment of the arctic cisco population. Domestic fishing at the villages of Kaktovik (Griffiths *et al.* 1977) and presumably Nuiqsut (upper Colville Delta) also harvests the non-spawning segment of the same population. Effects of domestic and commercial fishing pressure on the Colville stock are not known.

Additional information on catch records for this fishery is presented in "Other Organisms: Man, Predators, and Parasites" in this report.

Bering Cisco

In his review of the *Coregonus autumnalis* complex, McPhail (1966) described the occurrence of two cisco species in Alaska and Northern Canada: the arctic cisco (*C. autumnalis*) and the Bering cisco (*C. laurettae*). The former is found along the Beaufort Sea coast while the latter occurs primarily along the Bering Sea coast. The species are almost allopatric, overlapping only between Point Barrow and the Colville River. The taxonomic status of *C. autumnalis* is reviewed below because data gathered during the present study are not compatible with the two-species concept.

McPhail found that a single meristic character, gill rakers, differentiated arctic cisco (26-30 gill rakers on the lower limb of the first arch) from Bering cisco (21-25 gill rakers on the lower limb of the first arch). Furthermore, when the cisco were subsequently divided into two groups on this basis, they were also found to differ significantly in mean numbers of lateral line scales and pyloric caeca. Most importantly, in the coastal area where these two groups overlapped, the frequency distribution of gill rakers remained bimodal, suggesting that the "two groups of *autumnalis* ciscos do not intergrade along the arctic coast in Alaska, but exist sympatrically and therefore, should be considered as valid species".

However, the 1977 Simpson Lagoon data do not substantiate the sympatric difference in gill raker counts. Simpson Lagoon is the easternmost coastal area where the two species co-exist, but gill raker counts at this location are as unimodal as one could expect in natural populations (Fig. 11). It is biologically unreasonable to divide the specimens compiled in Fig. 11 into two groups, with 24-25 gill rakers representing Bering cisco and 26-31 gill rakers representing arctic cisco.

While these data suggest that intergradation of gill raker numbers occurs, the data may simply indicate that, with increased sample sizes, the intraspecific range of gill raker numbers is larger than formerly reported. In any event, the Simpson Lagoon data indicate that the taxonomy of the *autumnalis* complex warrants a more through examination in the coastal zone where *C. autumnalis* and *C. laurettae* are sympatric.

Least Cisco

Several Beaufort Sea drainages in Alaska are known to support populations of anadromous least cisco (*Coregonus sardinella*), a common anadromous species along the Beaufort Sea coastline. Tagging data show that many least cisco in the Prudhoe Bay area originate in the Colville River (Bendock 1977), and three fish tagged in Simpson Lagoon were recovered in the Colville commercial fishery. Recent surveys (U.S. Fish and Wildlife Service 1978) also found least cisco were present in 27 lakes and 13 streams to the west of the Colville.

While tagging data indicate that most least cisco in Simpson Lagoon are from the Colville stock, one least cisco tagged in Simpson Lagoon on 15 August 1977 was recaptured at a fishing camp near Barrow (specific recapture site unknown) later in the fall. Perhaps this fish originated in a stream to the west of the Colville.

Despite the proximity of the study area to the Colville, least cisco were not abundant in Simpson Lagoon during the 1977 open-water season. Least cisco accounted for only 12% of all gill net catches and 2% of all fyke net catches (Table 1). The size range of the sample was 80-414 mm with most fish measuring 280-340 mm (Fig. 12). Fyke nets sampled a wider size range of fish than gill nets, but both methods caught primarily large fish. Small least cisco were not abundant in contrast to the numerous

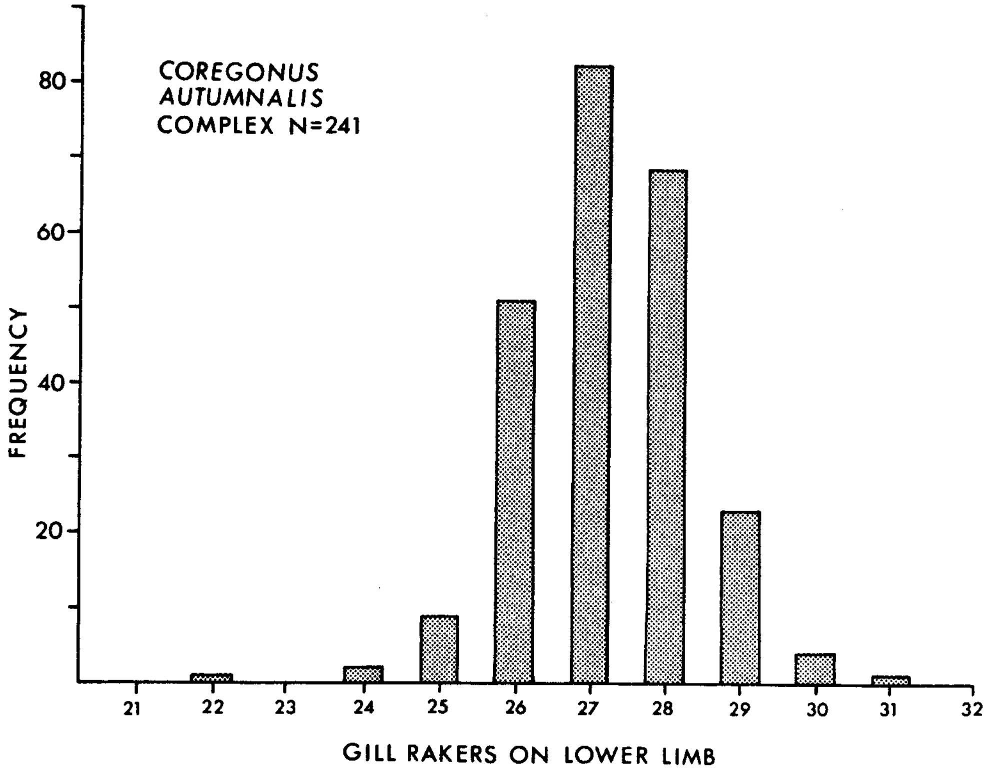


Fig. 11. Frequency Distribution of Number of Gill Rakers on the Lower Limb of the First Gill Arch, Simpson Lagoon, 1977.

small arctic cisco in the study area.

Though least cisco ages in the sample cover a wide range (Table 10), no fry or age 1 fish were present, and older fish aged 7-11 comprised most of the catch. The growth rate of these fish is generally similar to that reported for least cisco at other Beaufort Sea coastal locations.

Age at maturity was 7-8 for males and 7-10 for females. Among the females, 71% were mature (50% spawners and 50% non-spawners); 48% of the males were mature (87% spawners and 13% non-spawners). Seasonal development of egg sizes and testes weights for immatures, mature spawners, and mature non-spawners are illustrated in Fig. 13. Though there is great variability in the maturity data for least cisco reported in the literature, the 1977 Simpson Lagoon data are similar to those obtained at nearby Prudhoe Bay (Bendock 1977), and the seasonal patterns of egg sizes and testes weights are similar to those recorded at Kaktovik Lagoon (Griffiths *et al.* 1977).

Females were significantly more abundant than males in the 1977 Simpson Lagoon sample (n=121, 74% female; $\chi^2=28.8$, $P<0.001$). Several other coastal studies also report that female least cisco outnumber males; this indicates that females have a greater tendency than males to become anadromous (as in the case of arctic char).

Arctic Char

The arctic char, *Salvelinus alpinus*, is a characteristic species of both North Slope rivers and the Beaufort Sea coastline. It is a prized sport fish and is also important in native domestic fisheries. Life-histories for this species have recently been reviewed by Craig and McCart (1976) and Craig (1977).

Char caught in Simpson Lagoon during this study probably originated from several North Slope drainages, but it is likely that most are from the nearby Sagavanirktok River. This river supports one of the largest char populations on the Alaskan North Slope and tagging evidence shows that some Sagavanirktok char do, in fact, enter Simpson Lagoon; two char recaptured in the study area had been tagged in previous years by Alaska Dept. Fish and Game crews in the Ivishak River (Sagavanirktok drainage) (Table 5). Undoubtedly, some char in Simpson Lagoon are also from the

Table 10. Age-Length Relationship and Age-Specific Maturity of Least Cisco in Simpson Lagoon, 1977.

	Fork Length (mm)				Maturity			
					Males		Females	
Age	n	mean	(range)	SD	n	% Mature	n	% Mature
2	10	126	(95-154)	19	7	0	3	0
3	5	154	(128-180)	20	2	0	3	0
4	5	197	(163-260)	38	2	0	2	0
5	5	227	(188-291)	38	2	0	3	0
6	5	261	(229-297)	30	2	0	3	0
7	13	277	(239-320)	24	2	50	11	45
8	10	303	(279-320)	12	2	100	8	63
9	19	304	(268-380)	26	3	100	16	81
10	19	305	(263-354)	24	4	100	15	100
11	18	327	(288-399)	24	4	100	12	100
12	8	329	(302-346)	14	0	-	8	100
13	4	322	(305-331)	12	0	-	3	100
14	2	370	(328-412)	59	0	-	2	100
15	1	371	-	-	1	100	0	-
16	0	-	-	-	0	-	0	-
17	0	-	-	-	0	-	0	-
18	1	414	-	-	0	-	1	100
Overall	125				31	48%	90	71%

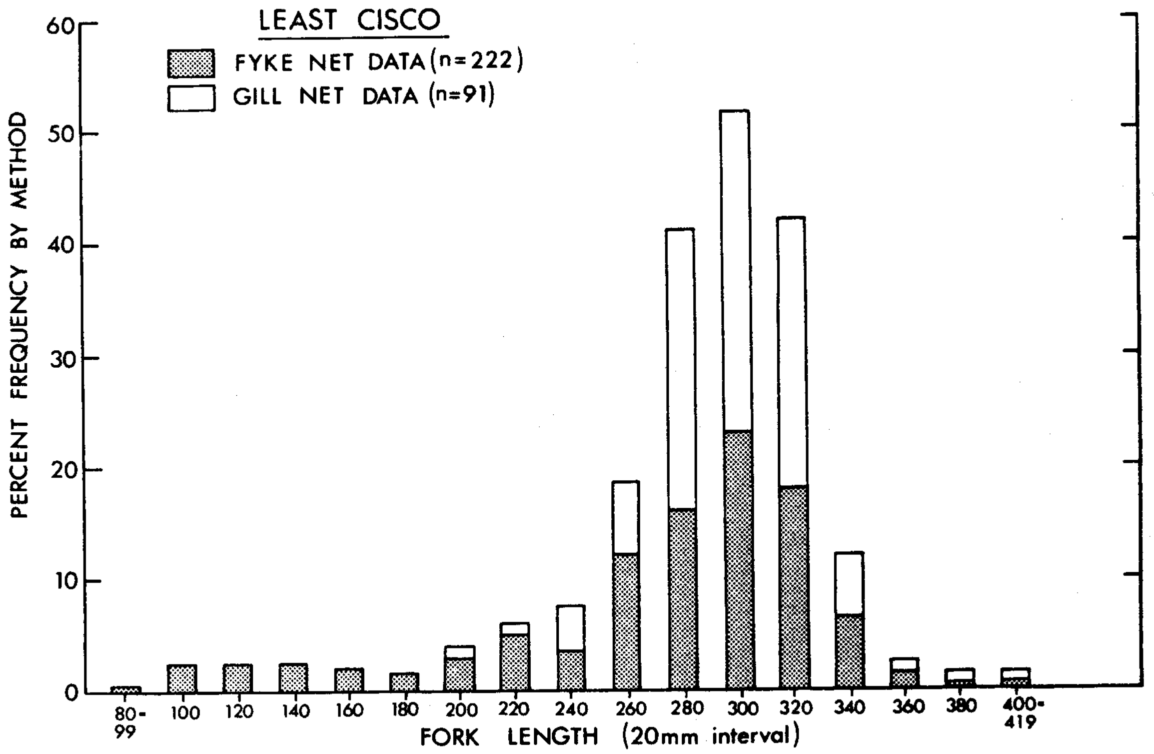


Fig. 12. Length-Frequency of Least Cisco Caught in Simpson Lagoon, 1977.

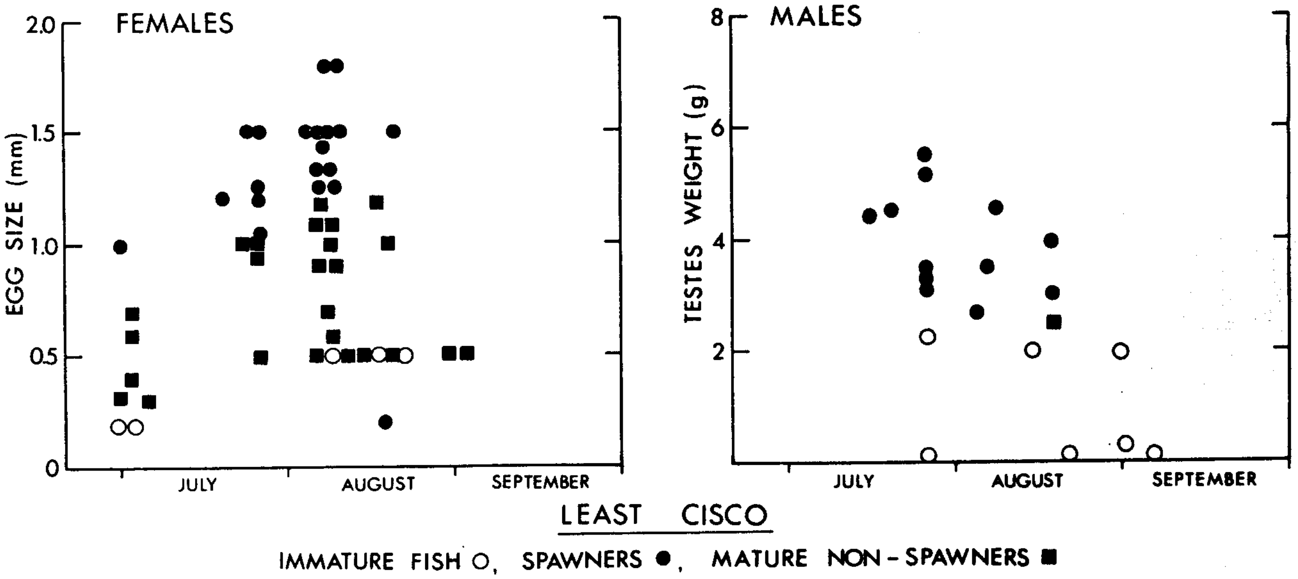


Fig. 13. Seasonal Changes in Egg Sizes and Testes Weights of Least Cisco Caught in Simpson Lagoon, 1977. Immature fish (open circles), spawners (closed circles) and mature non-spawners (■) are indicated.

Colville River, though the size of the Colville char population appears small (U.S. Fish and Wildlife Service 1978). Beaufort Sea drainages west of the Colville do not appear to support char populations (U.S. Fish and Wildlife Service 1978). These streams apparently lack groundwater habitats, which play an important role during char spawning and overwintering (Craig 1978).

Size Distribution. Fork lengths of char in Simpson Lagoon ranged from 120-703 mm. Fyke nets caught primarily small char 200-260 mm long, corresponding to juveniles aged 3-5. Gill nets also sampled this group of juveniles, but caught large char as well (Fig. 14). A distinctly bimodal size distribution is evident; since gill nets caught both small and large char, it is probable that intermediate-size fish were not present. These missing intermediate size classes correspond to fish ages 5-8, some of which would be first-time spawners. Their poor representation in Simpson Lagoon in 1977 may be due to weak year classes and/or an apparent tendency for some spawning char to remain in fresh water during the year they will spawn.

Age, Growth, and Maturity. From the standpoint of age, growth and reproductive condition, arctic char in Simpson Lagoon are generally similar to char taken in other coastal areas in Alaska and the Yukon Territory. The Simpson Lagoon char ranged in age from 3-15 (Table 11). Here, as in other areas, char younger than age 3 were generally absent in coastal waters since juveniles spend several years in fresh water before smolting. Char aged 4 and 10 were especially abundant in Simpson Lagoon.

Female char exhibit a greater tendency than males to become anadromous, thus accounting for the predominance of females in the sample (n=143, 71% female; $\chi^2=24.3$, $P<0.001$). Female char attain sexual maturity at ages 7-8, and males by age 9 (Table 11). Approximately half of the char in Simpson Lagoon were mature fish (51% of the females and 41% of the males were mature). Seasonal patterns in egg development for immature fish, mature spawners and mature non-spawners are shown in Fig. 15. Of the mature females, 46% were spawners and 54% non-spawners; of the males, 29% were spawners and 71% were non-spawners.

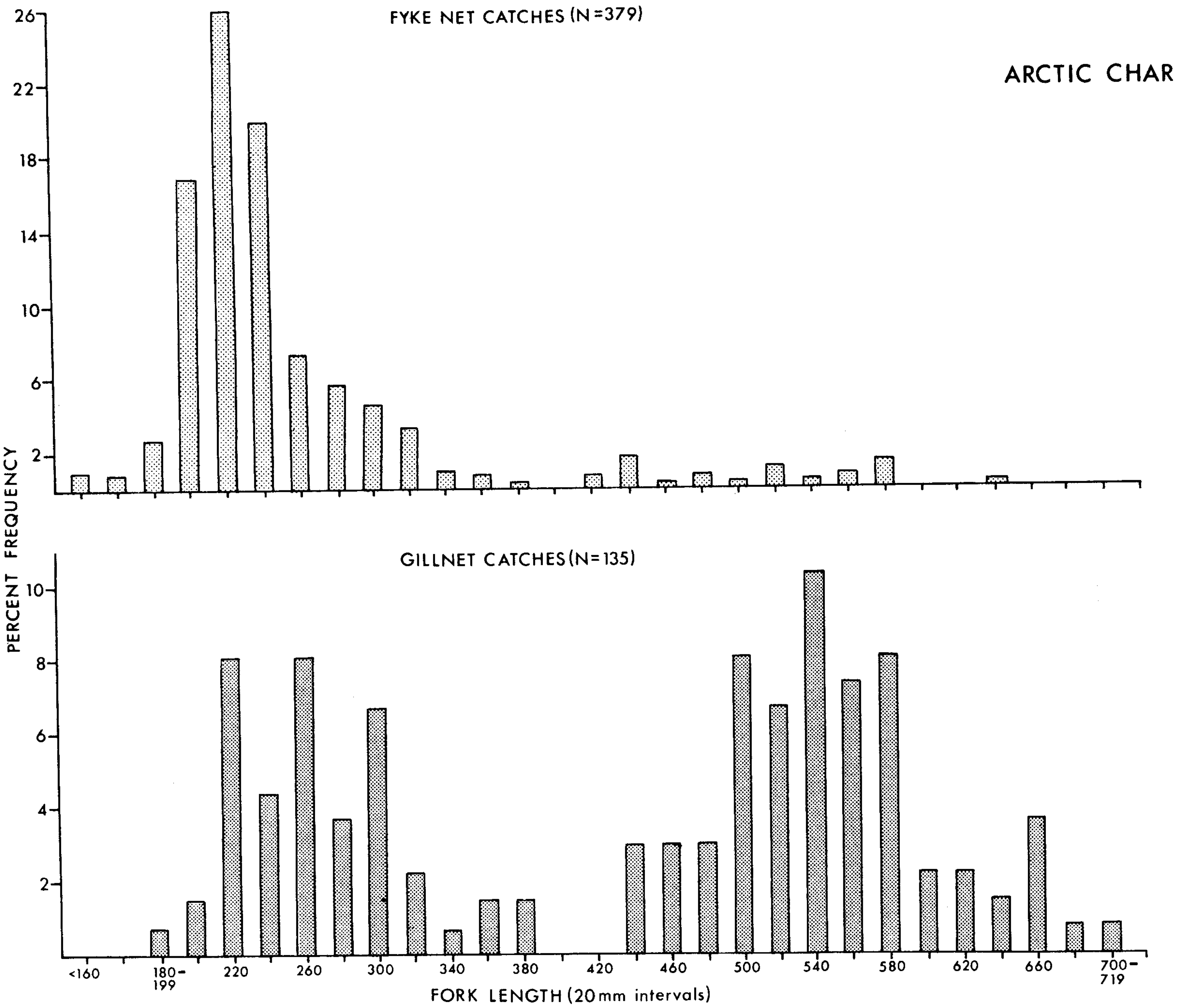


Fig. 14. Length-Frequency of Arctic Char in Simpson Lagoon, 1977. Gill net and fyke net data are presented separately.

Table 11. Age-Length Relationship and Age-Specific Maturity of Arctic Char in Simpson Lagoon, 1977.

	Fork Length (mm)				Maturity			
					Males		Females	
Age	n	mean	(range)	SD	n	% Mature	n	% Mature
3	14	233	(181-315)	34	5	0	9	0
4	31	254	(189-329)	35	9	0	19	0
5	18	298	(238-364)	33	7	0	11	0
6	5	356	(305-473)	70	3	0	2	0
7	5	390	(298-454)	63	0	0	5	40
8	5	507	(473-539)	30	0	0	5	100
9	9	524	(475-614)	47	1	100	8	100
10	21	554	(480-640)	42	7	100	14	100
11	12	586	(527-662)	46	3	100	9	100
12	6	582	(542-680)	51	2	100	4	100
13	5	608	(520-703)	79	2	100	3	100
14	2	643	(595-690)	67	1	100	1	100
15	1	668	-	-	1	100	0	100
Overall	134				41	41%	90	51%

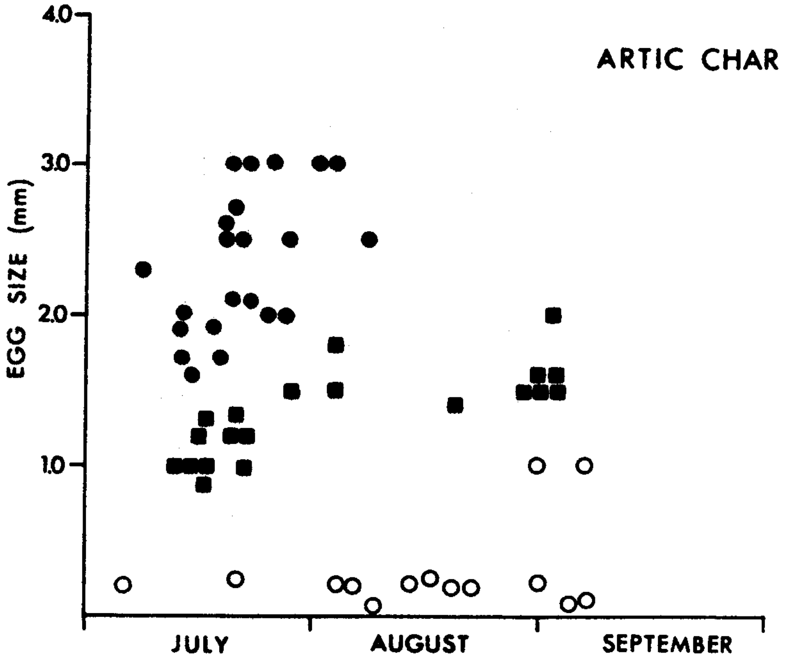


Fig. 15. Seasonal Pattern of Egg Development of Female Arctic Char in Simpson Lagoon. Immature fish (open dots), mature spawners (closed dots) and mature non-spawners (squares) are indicated.

Fourhorn Sculpin

Of all the marine fishes found along the Beaufort Sea coastline, the fourhorn sculpin (*Myoxocephalus quadricornis*) is typically the most numerous species. These demersal sculpins are taken in virtually all nearshore habitats, including the deeper waters not frequented by anadromous species.

Fourhorn sculpins in the 1977 Simpson Lagoon sample ranged in total length from 18-265 mm and their length-frequency distribution largely reflected the sampling methods used in this study. Seines collected young-of-the-year along the shoreline, fyke nets caught primarily intermediate-size sculpins, and gill nets caught large fish (Fig. 16). This bias in sampling methods accounts for some of the observed variations in size distributions of this species at other coastal locations where only one or two of the above-mentioned gear types were used to collect fish. It does appear, however, that large sculpins are less abundant in Simpson Lagoon than in areas to the east of the study area. Modal sizes of fish taken by gill net in Simpson Lagoon were 160-200 mm compared to 200-240 mm at Nunaluk Lagoon (Griffiths *et al.* 1975), Kaktovik Lagoon (Griffiths *et al.* 1977) and the outer Mackenzie Delta (Percy 1975). In addition, maximum sizes of fourhorn sculpins were smaller in Simpson Lagoon.

Fourhorn sculpin young-of-the-year averaged 21.4 mm in length (range 18-26 mm, n=50) on 3 August 1977. At this time, their distribution along the lagoon shore of Pingok Island was examined. Densities were determined by seining seventeen 20 m^2 plots (each plot was seined 1-3 times) at three distances from the shoreline:

Distance from Shore (m)	Water Depth (cm)	No. Plots Sampled	Fourhorn Sculpin Density (No./m^2) Mean (Range)
0-2	0-10	7	1.4 (0.1-3.5)
3-5	10-25	5	3.0 (0.4-7.2)
10-12	30-35	5	0.1 (0-0.2)

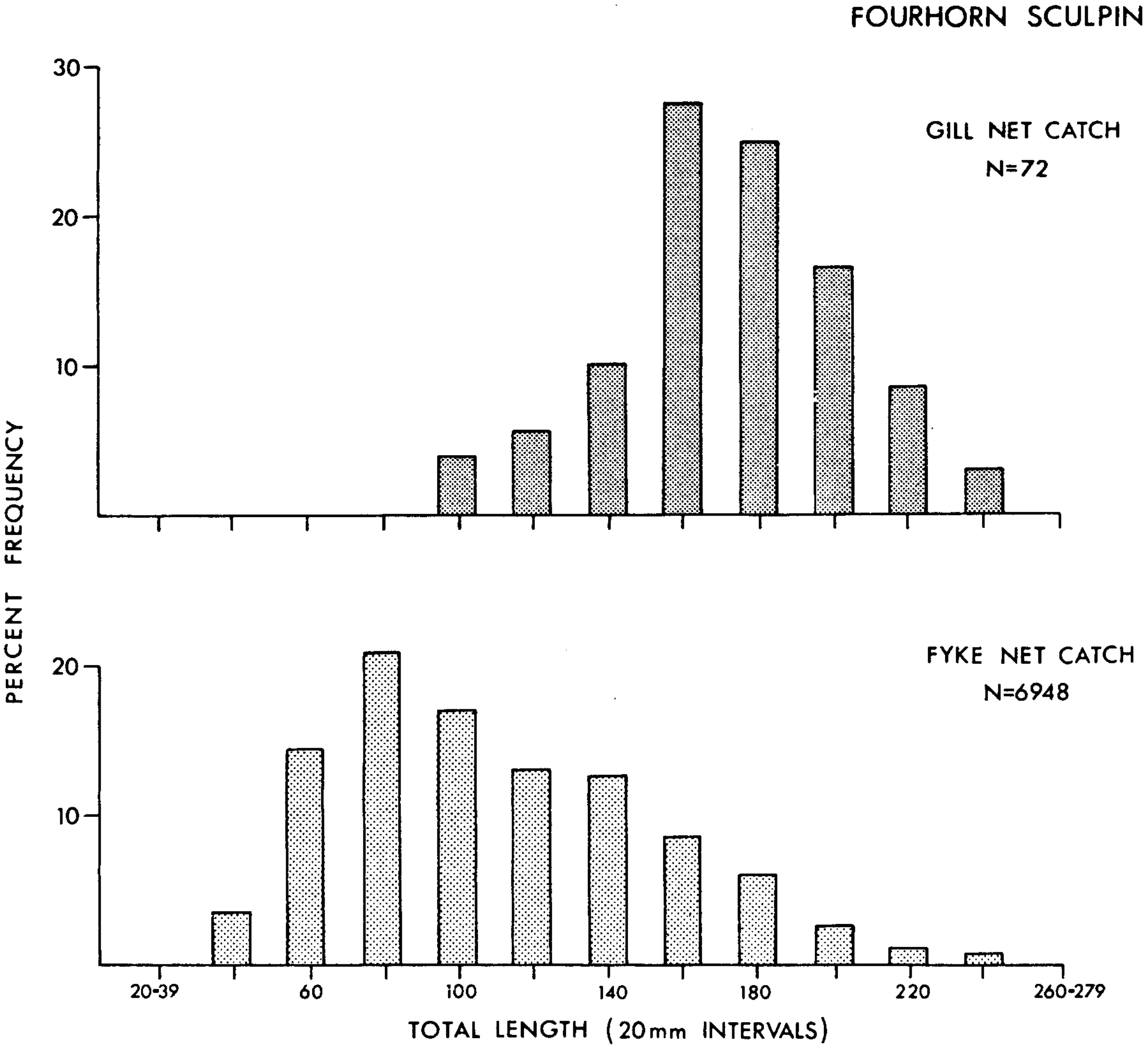


Fig. 16. Length-Frequency of Fourhorn Sculpin in Simpson Lagoon, 1977.

The capture data showed that the young-of-the-year were distributed close to the shore, with greatest densities recorded at 3-5 m from the shoreline.

Growth and maturity patterns of the larger fourhorn sculpins in Simpson Lagoon (Table 12) differed in several ways from patterns in Nunaluk and Kaktovik lagoons. Age-length relationships indicate a faster growth rate for the study population, and these fish reached sexual maturity 1-3 years earlier than those in Nunaluk or Kaktovik lagoons. Sexual maturity was determined on the basis of field examination, aided by a later analysis of growth trends in egg sizes and testes weights (Fig. 17). Some male fourhorn sculpins were mature as early as age 2 and all were mature by age 4. Although testes of the smallest mature males weighed only 1.0 g, these fish were judged to be mature because of the appearance of the gonads and relatively large proportion of the body cavity filled by the testes. These general criteria were also followed in the Nunaluk and Kaktovik lagoon studies (Griffiths *et al.* 1975, 1977). In the current study, female sculpins matured between ages 4-6 and appeared to spawn annually thereafter. Reasons for the accelerated growth and relatively early maturity in the study population are not known. Percy (1975) reports an even faster growth rate for fourhorn sculpins in the Mackenzie Delta.

As in studies elsewhere along the Beaufort Sea coast, more female than male fourhorn sculpins were caught in Simpson Lagoon (n=225, 67% female; $\chi^2=26.4$, $P<0.001$).

Arctic Cod

Described as a "key species in the ecosystem of the Arctic Ocean" (Quast 1974), the arctic cod (*Boreogadus saida*) is an integral element in the trophic pathways of the Beaufort Sea. Several studies have demonstrated that this fish is an important food item in the diets of arctic marine mammals, birds and other fish (Andriyashev 1954; Bradstreet 1977; Bain and Sekerak 1978). Coastal residents also catch arctic cod for human and dog food.

Although the distribution of this fish is usually associated with the occurrence of ice, catch data for Simpson Lagoon and other coastal locations (Griffiths *et al.* 1977; Bendock 1977) show that young-of-the-

Table 12. Age-Length Relationship and Age-Specific Maturity of Fourhorn Sculpin in Simpson Lagoon, 1977.

	Total Length (mm)				Maturity			
					Males		Females	
Age	n	mean	(range)	SD	n	% Mature	n	% Mature
1	55	63	(46-81)	8	7	0	22	0
2	46	94	(74-160)	15	15	20	26	0
3	34	134	(102-167)	17	14	86	20	0
4	31	169	(133-208)	17	10	100	21	71
5	31	193	(168-224)	14	10	100	21	95
6	24	211	(176-248)	18	2	100	21	100
7	5	222	(197-258)	25	0		5	100
8	3	236	(220-265)	25	1	100	2	100
9	1	226	-	-	1	100	0	-
Overall	231				60	65%	138	47%

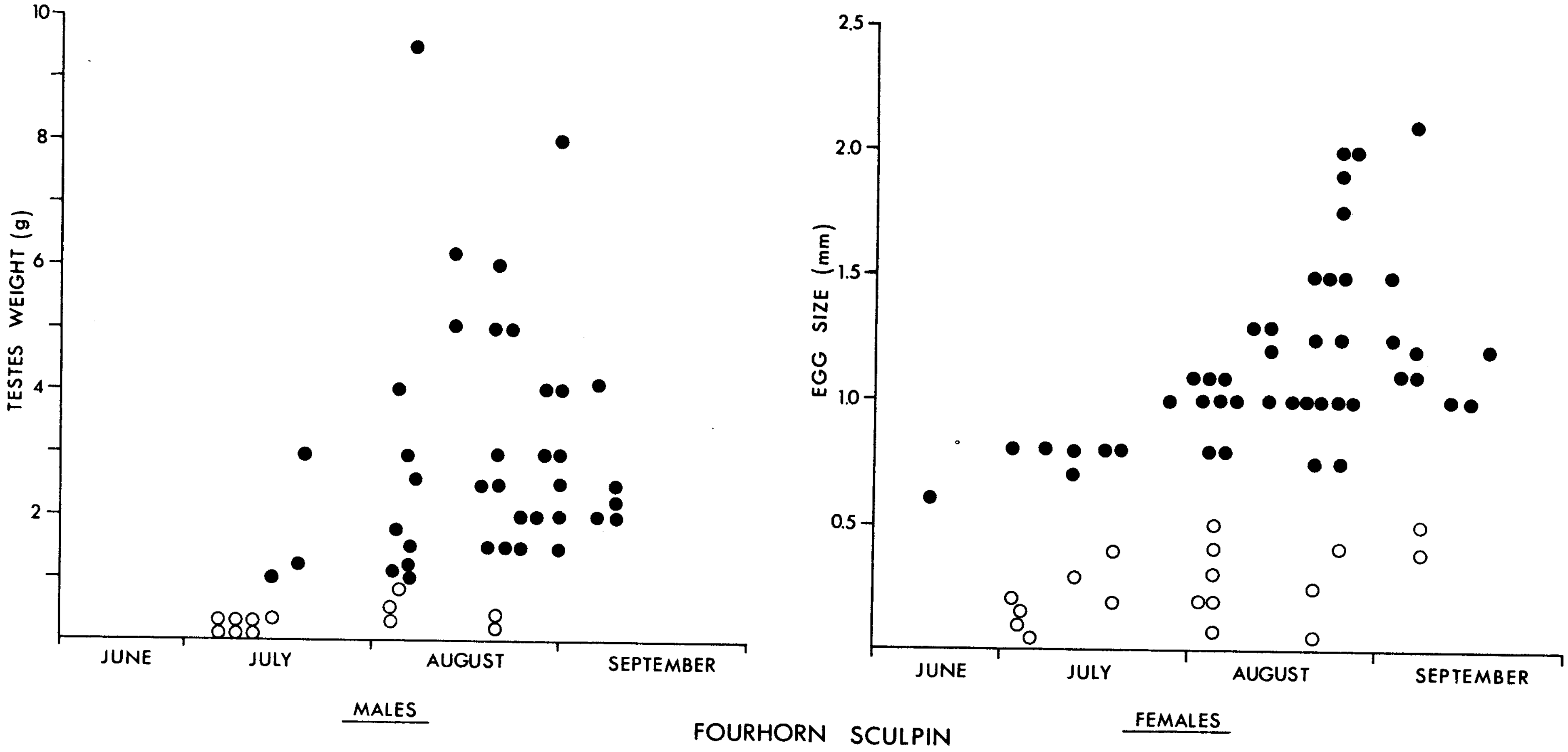


Fig. 17. Seasonal Changes in Egg Sizes and Testes Weights of Fourhorn Sculpin in Simpson Lagoon, 1977. Immature fish (open dots) and mature spawners (closed dots) are indicated.

year and juvenile arctic cod are often abundant in ice-free nearshore waters, but the significance of nearshore areas for rearing is not known. Spawning locations for cod in the Beaufort Sea are also not known, although spawning is thought to occur under the ice in coastal waters during winter (Andriyashev 1954). Much of the basic biology of this species remains undocumented.

Young-of-the-year arctic cod were caught in Faber trawls in Simpson Lagoon and in marine waters seaward of Pingok Island in 1977. Early catches (22 July) averaged 8.1 mm in length (range 6-11 mm, n=14 preserved specimens), whereas late season catches (14 September) averaged 19.0 mm (range 12-29, n=17 preserved specimens). Though young-of-the-year were common at times in lagoon waters (Table 3), Quast (1974) reports that they are found in abundance in offshore waters as well.

Fyke nets caught arctic cod 45-251 mm in length (Fig. 18) and 1-6 years old (Table 13). The growth rate of these fish is very similar to that of arctic cod caught in Prudhoe Bay (Bendock 1977). Most arctic cod caught in Simpson Lagoon were immature fish aged 1-3. Only 16% of the males and 11% of the females were judged to be mature. Youngest ages at sexual maturity were age 2 for males and ages 3-4 for females (Table 13). By mid-September, testes weights of mature males were 1.8-3.2 g, and egg sizes of mature females were 0.8-1.5 mm (Fig. 19). Andriyashev (1954) reports that eggs reach 1.6-1.8 mm by spawning time in December and January.

Females outnumbered male arctic cod in the study population (n=119, 74% female, χ^2=27.3, P<0.001).

CONCLUSIONS

1. Fish use of Simpson Lagoon: Anadromous and marine fishes repopulate Simpson Lagoon every summer. Large numbers of these fish invade the shallow, brackish and relatively warm lagoon waters from both freshwater and marine directions. In winter, much of the nearshore zone (<2 m water depth) utilized by fish freezes solid. Species diversity in this marginal habitat is low, characterized by a few

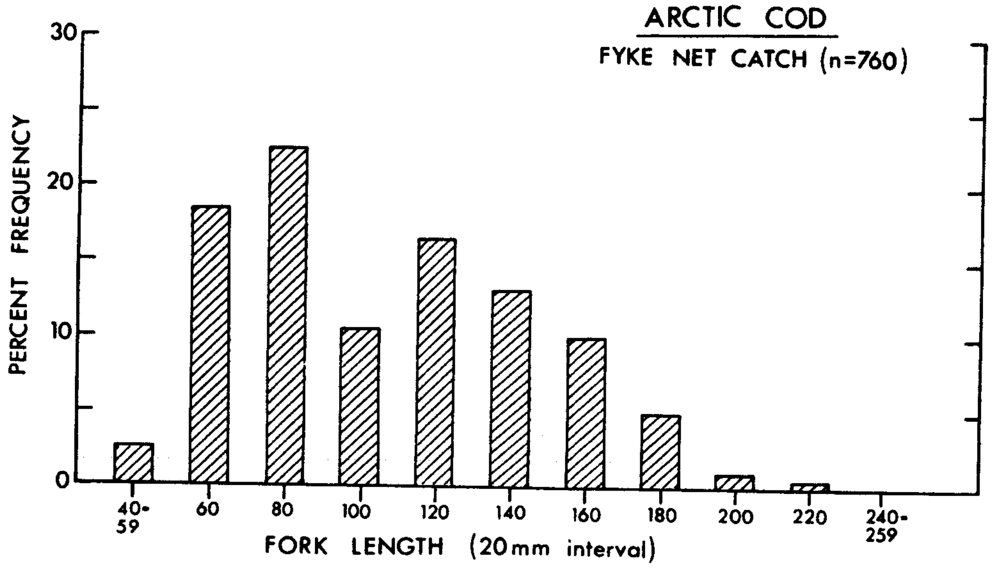


Fig. 18. Length-Frequency of Arctic Cod in Simpson Lagoon, 1977.

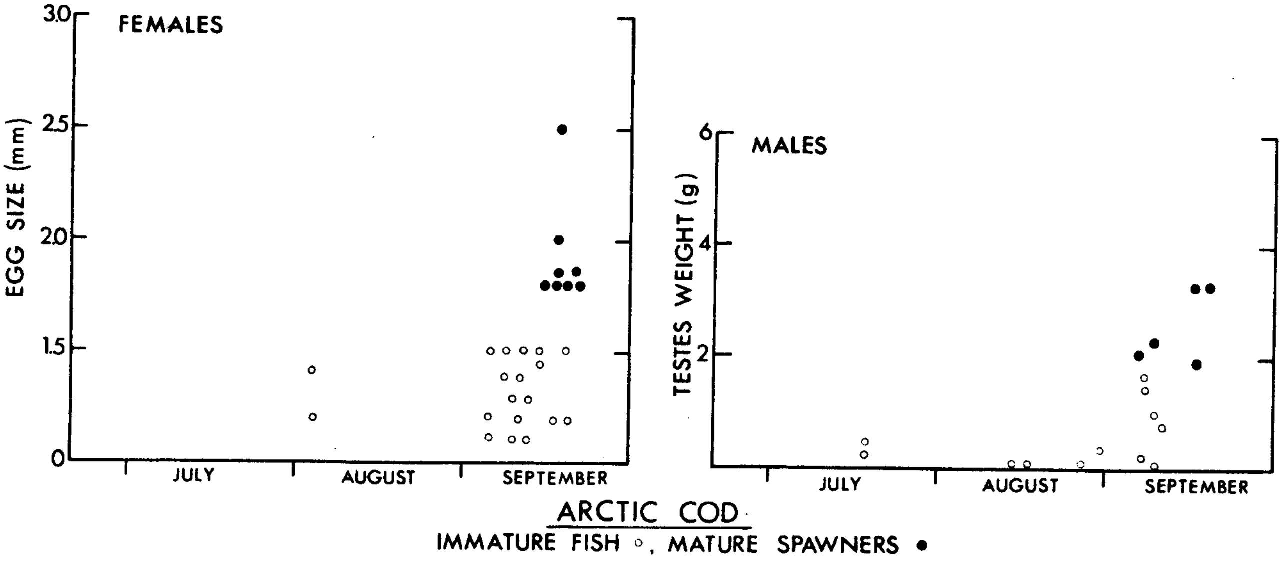


Fig. 19. Seasonal Changes in Egg Sizes and Testes Weights in Arctic Cod Caught in Simpson Lagoon, 1977.

Table 13. Age-Length Relationship and Age-Specific Maturity of Arctic Cod in Simpson Lagoon, 1977.

Age	Fork Length (mm)				Maturity			
					Males		Females	
	n	mean	(range)	SD	n	% Mature	n	% Mature
1	136	82	(54-129)	13	19	0	40	0
2	33	134	(106-171)	19	9	22	21	0
3	23	169	(150-193)	13	2	100	21	38
4	5	169	(138-195)	22	1	100	4	25
5	1	221	-	-	0	-	1	0
6	1	251	-	-	0	-	1	100
Overall	199				31	16%	88	11%

dominant species. Principal fishes in Simpson Lagoon were three anadromous species (arctic cisco, arctic char, least cisco) and two marine species (fourhorn sculpin, arctic cod). The lagoon served as an important feeding area for the young and/or adults of these species, and also as a migration corridor for the highly mobile anadromous fishes.

Fish utilize lagoon waters throughout the open-water season. Some arrive with the first signs of spring breakup (approximately 5-20 June), and others are present when ice forms on the lagoon surface in early winter (approximately 20 September-10 October). During summer months, the local abundance of juvenile and adult fish is a complex picture of day-to-day pulses and large-scale population movements over several-week periods.

2. Trophic relations: Fish fed primarily on epibenthic invertebrates in nearshore areas. Mysids (*Mysis litoralis*, *M. relicta*) and amphipods (*Apherusa glacialis*, *Onisimis glacialis*) were the most significant sources of food in 1977. Diets of the most numerous fish and bird species in the lagoon ecosystem (arctic cisco and oldsquaw) were similar. It appears that the epibenthic food resource in Simpson Lagoon was not in limited supply for the numbers of fish or bird predators present during the 1977 open-water season.

3. Influence of predation and parasites on fish populations: Populations of fishes in the nearshore environment do not appear limited by predation pressure or parasite loads. Mammal and bird predation tended to be negligible in areas where fish were abundant. Predation by piscivorous fishes was infrequent in Simpson Lagoon but may be more significant elsewhere. Parasite loads of arctic cisco were low and did not appear to detrimentally affect their health.

4. Importance of coastal fishes to man: Anadromous fish, particularly cisco, whitefish and char, are the focal point of several domestic, commercial and/or sport fisheries along the Beaufort Sea coastline. The Colville River is a major source of cisco caught in Alaskan nearshore waters. Harvest levels in most arctic fisheries are not well documented.

RECOMMENDED FURTHER RESEARCH

Needs for further study are addressed in RU 467, OVERVIEW AND SYNTHESIS section: RECOMMENDED FURTHER RESEARCH.

SUMMARY OF 4th QUARTER OPERATIONS

Fourth quarter operations are summarized in RU 467, OVERVIEW AND SYNTHESIS section: SUMMARY OF 4th QUARTER OPERATIONS.

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BEAUFORT SEA BARRIER ISLAND-LAGOON
ECOLOGICAL PROCESS STUDIES

INVERTEBRATES IN SIMPSON LAGOON, 1977

Section IV

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31 March 1978

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SUMMARY

The invertebrate investigations in the Simpson Lagoon area on the Alaskan Beaufort Sea Coast in 1977 were concentrated on those organisms identified as important food items to higher trophic levels (fish and birds). The main objectives of this year's research were to determine the seasonal and habitat distributions, abundances and biomasses of these important organisms.

Diver observations showed that mysids and amphipods were the most abundant invertebrate groups in Simpson Lagoon in terms of numbers and biomass. Analyses of stomach contents of key bird and fish species showed that mysids and amphipods were also the major food items of these vertebrates. Four species of mysids and 17 species of amphipods were collected during the course of the field season. Amphipod and mysid densities and biomasses varied widely within sampling localities and collection periods, indicating a patchy distribution. Large-scale movements of amphipods and mysids into, out of and within the lagoon appeared to occur during the open-water season. Most amphipods and mysids were associated with the peat detritus layer (derived from tundra erosion) that covered most of the bottom of the lagoon. This detritus may have provided these organisms with a direct or indirect source of food.

Traditional surface-operated sampling gear (trawls, nets) was found to cause dramatic underestimations of densities of epibenthic invertebrates, apparently because these organisms (amphipods and mysids) were able to avoid the trawls and nets. For these groups, density estimates made by a diver are considered far more reliable.

A major potential cause of insult related to OCS petroleum development might be contaminant (e.g., oil) introductions. Previous investigations have shown that invertebrate responses to oil are highly variable, but that adverse consequences do occur under some circumstances. In the nearshore environment, invertebrates could be affected by oil in the water column or (probably more critical to epibenthos) by oil on and in benthic substrates. Adverse impacts of oil on invertebrates might affect the fish and birds that depend on those invertebrates for food.

INTRODUCTION

Numerous authors have noted the importance of the Alaskan Beaufort Sea coast and its nearshore barrier island-lagoon systems as summer breeding, rearing and feeding areas for birds and marine mammals, and as feeding and rearing areas for anadromous and marine fish. Because of the petroleum exploration and development activities projected for the Alaskan Beaufort continental shelf, much concern has arisen regarding the effects of these activities on the nearshore marine environment.

The interdisciplinary study of which this report is a part was initiated to examine nearshore trophic relationships and to define important biological processes in a barrier island-lagoon system. The research program was designed to focus on the higher trophic levels (fish and birds) and then to progress down the food web to develop an understanding of key processes that supported these vertebrates. It was apparent from the inception of this program that lagoon invertebrates were the primary source of food for the important vertebrate species in the ecosystem and, therefore, that more information about the biology of key invertebrates was needed.

Objectives

The specific objectives of our invertebrate investigations are stated below:

1. To determine the importance of benthic and epibenthic invertebrates to the higher trophic levels (fish and birds) in Simpson Lagoon.
2. To determine temporal and spatial variations in abundance and biomass of important invertebrate groups.
3. To determine how the biomass and productivity of the important invertebrates related to the energetic needs of their consumers in Simpson Lagoon.
4. To examine the food habits of the important groups of invertebrates.
5. To gather seasonal life history information (length, weight, sex, breeding condition) for the important species of invertebrates.

Objectives 1-3 have been partially met by work conducted to date, and these aspects of the work are emphasized in this report. Additional analysis of samples and data collected in 1977, subsequent studies in 1978, and a full summary of relevant literature will address objectives 4 and 5 and refine the results pertaining to objectives 1-3. Particular emphasis will be given, in 1978, to diver-operated quantitative sampling procedures, since preliminary results from diver methods used in 1977 showed that the key invertebrate species are not reliably sampled by traditional techniques.

Relevance to Problems of Development: Effects of Oil on Invertebrates

Several studies of effects of crude oil on arctic marine invertebrates have been conducted. Percy (1976) found that *Boeckosimus* (*Onisimus*) *affinis* tended to avoid oil masses but succumbed if mixed in these masses; this species usually rejected oil-contaminated food. Bushdosh and Atlas (1977) observed similar responses using *Boeckosimus* (*Onisimus*) *affinis* and *Gammarus setosus* and noted that oil slicks overlying shallow nearshore areas, particularly barrier island-lagoons, would be detrimental because benthic amphipods would come into direct contact with the oil. Johnson (1977) noted that differences among species and life cycle stages in the permeability of crustacean exoskeletons to oil result in different responses and sensitivities to contaminants. Such differences in responses are difficult to catalogue at the present time, partly because of differences in the experimental procedures used by different workers, and partly because few oil toxicity studies have been conducted on arctic invertebrates. Thus, meaningful generalizations concerning oil effects on arctic marine organisms are difficult to formulate.

Oil contamination of the Simpson Lagoon barrier island-lagoon system might have serious effects on the epibenthic community. These effects could be either direct or indirect. If organisms came into physical contact with the oil the indications from the previous studies are that they might succumb. Effects on invertebrates of water-soluble and suspended components of oil in the water column would depend on the concentration of these components. On the other hand, organisms may leave the lagoon as a result of an avoidance behavior.

Oil entering a shallow lagoon would become mixed with bottom sediments and organic debris. Any repopulation of the lagoon from stocks of marine invertebrates offshore (Feder *et al.* 1976) would have to contend with an oil-contaminated substrate and food source. This could result in drastically reduced densities of epibenthic organisms, the effects of which might be felt to the top of the food web.

CURRENT STATE OF KNOWLEDGE

Prior to oil and gas development on the Alaskan Beaufort Sea coast, most benthic invertebrate studies were of a qualitative nature and, due to logistics difficulties, were conducted primarily in the vicinity of the Naval Arctic Research Laboratory at Point Barrow. MacGinitie (1955) conducted extensive survey work (species composition of the invertebrate community) in this area from 1948 to 1950. Several taxonomic studies have been reported for a variety of benthic organisms near Point Barrow: sponges (De Laubenfels 1953); polychaetes (Pettibone 1954); amphipods (Shoemaker 1955); molluscs (MacGinitie 1959); mysids (Holmquist 1963); and cumaceans (Given 1965). These taxonomic studies are relevant to this study since the same species of invertebrates are found along the Beaufort Sea coast to Demarcation Point. An extensive review of existing literature and unpublished data on the distributions, abundances and life histories of benthic organisms, with emphasis on the Alaskan arctic coast, has been compiled by Carey (1977). In addition, Feder *et al.* (1976) have published an excellent annotated literature review of benthic invertebrates in arctic regions in both Canada and Alaska.

With the discovery and development of oil and gas in both the Canadian and Alaskan parts of the Beaufort Sea, several quantitative studies of infaunal (organisms living in bottom substrates) and epibenthic (organisms living on or near bottom substrates) invertebrates were initiated. Crane and Cooney (1974) investigated the invertebrate fauna of Simpson Lagoon during late summer. They found that crustaceans, molluscs and polychaetes were the dominant members of the nearshore invertebrate community, that biomass increased seaward of the lagoon, and that the seasonal distribution of infauna was strongly influenced by bottom-fast ice (Crane and Cooney

1974; Crane 1974). However, as Feder *et al.* (1976) point out, the study was conducted over a short time period in August and it lacks information on seasonal variations of invertebrate distribution and biomass. More extensive work conducted by Feder and Schamel (1976) in the nearshore areas of Prudhoe Bay indicated that a low benthic biomass existed in that area, although the number and diversity of organisms increased with distance from shore. This seaward increase suggests the existence of a marine stock of invertebrates that is available to repopulate nearshore ice-stressed areas each spring (Feder and Schamel 1976; Feder *et al.* 1976).

Carey *et al.* (1974) sampled across the Alaskan Beaufort Sea continental shelf in depths ranging from 20 to >2000 m. The results of this study also indicate that species diversity and biomass increase with depth and distance from shore, at least beyond the 20 m depth contour to and just beyond the continental shelf break (Carey *et al.* 1974; Carey 1977). Wacasey (1975) reported similar findings in a study in the Canadian Beaufort Sea between Herschel Island and Cape Dalhousie, centered principally in the nearshore waters of the Mackenzie Delta. Wacasey found low diversity (<20 species per station) and low biomass (2 g/m^2) in most nearshore areas. However, biomass averages as high as 5 g/m^2 were found in protected bays and lagoons.

The awareness that specific groups of invertebrates are important to higher trophic levels has been steadily building. Numerous feeding ecology studies have shown that arctic epibenthic invertebrates, often including mysids, amphipods, isopods and copepods, comprise major components of the diets of fish, birds and mammals (Griffiths *et al*, 1975, 1977; Kendel *et al.* 1975; Stirling *et al.* 1975; Bradstreet 1977; Bendock 1977; Fraker *et al.* 1977; Searing 1977; Bain and Sekerak 1978). However, ecological information regarding the important epibenthic species is almost totally lacking. Moreover, concern is also expressed in this report and elsewhere (e.g., Buchanan *et al.* 1977; Thompson *et al.* 1978) that traditional sampling methodology may be inadequate to accurately monitor this important group of organisms.

STUDY AREA

A description of the study area and sampling stations is provided in RU 467, ECOLOGY OF FISH section. Fig. 1 indicates the location of principal sampling locations in the Simpson Lagoon study area.

METHODS AND RATIONALE OF DATA COLLECTION

A review of the literature shows that higher trophic levels in the Beaufort Sea coastal environment rely on epibenthic invertebrates as their principal source of food. Therefore, epibenthic invertebrates were selected as the focal point of the 1977 invertebrate program in Simpson Lagoon. The present study was designed to identify the trophically important groups of epibenthic invertebrates and to investigate their temporal and spatial variations during the course of the open-water season. Additional samples for estimation of zooplankton biomass were taken to provide input to the barrier island-lagoon ecosystem model.

Epibenthic invertebrates were sampled by otter trawl, Faber net and zooplankton net. Samples of all three types were collected at stations 1-6 (Fig. 1) during each of seven sampling periods (Table 1), ice and weather conditions permitting. However, only samples from Stations 1, 2, 3 and 5 have been analyzed for consideration in this annual report.

All invertebrate samples were preserved in 10% neutralized formalin and shipped to the laboratory for analysis. Weather permitting, all trawls and net tows were replicated and values presented are means for the two samples.

Appendix IV describes methods and results of preliminary analyses during 1977 of temperature, salinity, dissolved oxygen, turbidity, chlorophyll-a, ammonia and nitrate in and adjacent to Simpson Lagoon.

Otter Trawl

A small otter trawl was used to sample epibenthic invertebrates along the lagoon bottom. The trawl measured 4.9 m wide and 4.0 m long with 16 mm bar mesh nylon marquisette with a 6.5 mm bar mesh cod end. It was towed

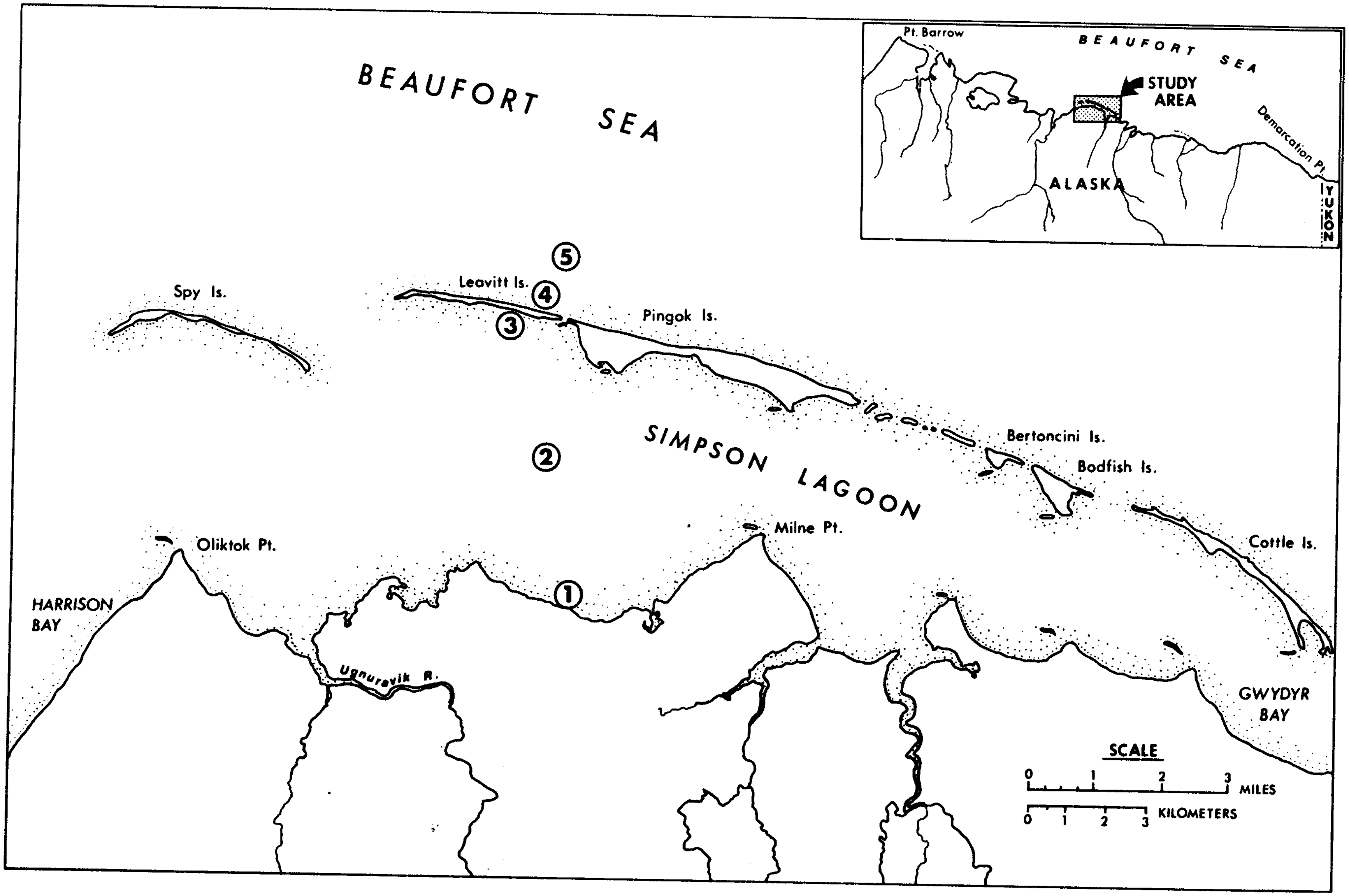

Fig. 1. Map of Simpson Lagoon Showing Locations of the Five Principal Sampling Sites.

Table 1. Dates of the Seven Sampling Periods in Simpson Lagoon 11 July-20 September, 1977.

Sampling Period	Date (1977)
I	11-15 July
II	22-30 July
III	31 July-7 August
IV	14-20 August
V	23 August-2 September
VI	4-9 September
VII	14-20 September

directly behind a boat for 3 min at a constant speed of 1.1 m/sec. Time was measured using a stopwatch, and the boat's speed using a Gurley current meter (direct readout model No. 665). Tow rope length varied from a ratio (length:depth) of 10:1 to 5:1, depending on water depth.

Faber Net

A 0.5 m diameter modified Faber net (Faber 1968) was used to sample ichthyoplankton and pelagic amphipods in surface waters of Simpson Lagoon. The 1.024 mm mesh net was towed 30 m directly astern of the boat for 5 min at a constant speed of 1.4 m/sec.

Zooplankton Net

A 0.25 m diameter zooplankton net (mesh size 0.239 mm) was used to sample zooplankton in surface waters of Simpson Lagoon. The net was towed at a constant speed of 1.1 m/sec by the side of the boat for 5 min.

Epibenthic Shore Transects

Prior to spring breakup, a hand-pulled 14 cm x 10 cm neuston net (mesh size 0.079 mm) was used to sample epibenthic invertebrates on transects parallel to the shoreline in open leads around the shores of Pingok Island. All tows were over a premeasured distance of 10 m.

Diver Transects

Diver transects, generally 25 m in length, were surveyed only on relatively calm, clear days when water turbidity was minimal and visibility was optimal. During the surveys of diver transects the following procedures were followed:

1. The diving location was selected within a standard sampling station.
2. The boat was anchored and a pre-dive equipment check was made. (The diver was suited before leaving the field camp.)

3. A 25 m length of rope was attached to the SCUBA tank pack and the diver entered the water.
4. The diver submerged and proceeded to swim along the predetermined transect near the lagoon bottom. An attendant in the boat monitored the safety rope and the progress of the diver.
5. At five locations along the transect the diver visually estimated the number and size of organisms of each major taxon present within an estimated 10 x 10 cm area of epibenthos. Organisms observed in the water column were also noted. During dives conducted on 4 August and thereafter, 35 mm photographs of the benthos were also taken.
6. After the diver had swam the predetermined distance, he returned to the boat and immediately dictated into a portable tape recorder the following information about the transect and organisms observed:
    a. the type of substrate present on the bottom, including the thickness and consistency of any detritus present,
    b. visibility and turbidity,
    c. the density and size (# organisms/100 cm^2) of organisms of various taxa present and their behavior.
7. Overall densities of major taxa on the transect were estimated from the mean of the minimum and maximum individual estimates, converted to a numbers/m^2 basis.

Energy Available to Consumers

Epibenthos biomass and energy (mysids and amphipods) present in August were determined in the following manner. Estimates of dry weight for the predominant size classes of organisms observed by the diver in Simpson Lagoon were taken from Bradstreet (1977). These dry weights were multiplied by the mean densities (numbers/m^2) of the types of organism observed by the diver to give estimates of grams dry weight/m^2. To then determine the amount of energy available to consumers, this value was converted to grams ash-free dry weight/m^2 by subtracting the percent ash, and then to Kcal/m^2 by multiplying by the energy content (Kcal/g ash-free dry weight). Percent ash and energy content were measured for *Mysis* spp. (mainly *M. litoralis* and *M. relicta*) and for two amphipod taxa--*Onisimus* sp. and *Gammaracanthus loricatus*. The mean of the values for the two amphipod taxa was assumed to apply to amphipods generally. Percent ash and energy content were determined by Dr. D.L. Pattie of the Northern Alberta Institute of Technology using microbomb calorimetry. This procedure was used to calculate Kcal/m^2 at each station where diving transects were conducted in August 1977.

The only available data concerning epibenthos from July and September were the otter trawl samples. The following procedure was used to correct these results for underestimations* of the biomass present and simultaneously to convert the results to an energy basis. For each of mysids and amphipods, and separately for each of stations 1-3, the July:August and September: August ratios of wet weights in trawl samples were multiplied by the August energy values (Kcal/m^2) previously estimated (see previous paragraph).

Laboratory Techniques

Sorting

All samples, including the contents of fish and bird stomachs (see RU 467, ECOLOGY OF FISH and AVIAN ECOLOGY sections), were sieved through a 1.024 mm mesh nylon screen, washed with water, and examined under a low-power binocular microscope. All whole or partial organisms were separated into major taxonomic groups (amphipods, mysids, etc.) and counted. Techniques for counting fragmented organisms were as follows:

1. Copepods: The total number of copepods was assumed to be the number of whole organisms plus the number of cephalothoraxes present.
2. Amphipods: Amphipod specimens were often in two parts (head plus peraeon, abdomen plus telson) or three parts (head, peraeon, abdomen plus telson). The sum of the numbers of whole amphipods and separate 'abdomens plus telsons' constituted the total number.
3. Mysids: The total number of mysids equalled the number of whole organisms plus the number of separate telsons.

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*The nature and extent of this underestimation is described below in "RESULTS AND DISCUSSION".

4. Polychaetes: Polychaetes were generally broken in half, so the total number present was assumed to be the number of whole polychaetes plus the number of anterior parts.
5. Medusae: The number of whole medusae plus the number of bells constituted the total number in the sample; fragmented bells were counted if over one-half the bell was present.
6. Bivalves: Similarly, the number of whole bivalves plus the number of partial shells (>1/2 of whole shell) constituted the total number of bivalves in the sample. Half shells were presumed to be from non-living individuals and were not counted.

If large numbers of individuals were present, the sample was first scanned for large or rare organisms and the remainder was then sub-sampled with a Folsom Plankton Splitter (following the methods of McEwen *et al.* 1954). The statistical reliability of the splitter was tested and no significant difference was found between specimen numbers in each of the chambers (Wilcoxon matched-pairs signed-ranks test: $n=10$ pairs, $P>0.05$).

Only those taxonomic groups (i.e. amphipods and mysids) that comprised significant portions of the diets of higher trophic level organisms were identified to species.

Biomass

For the determination of wet weights of epibenthic organisms (and stomach contents of fish and birds), taxonomic groups were separately strained through plankton netting (mesh size 1.024 mm), placed between two layers of absorbent paper and blotted dry. Samples were then weighed on a Mettler PT 200 balance accurate to ± 1 mg.

Zooplankton samples were not sorted into taxonomic categories, and each sample was weighed as a unit; at the present time only an overall biomass figure was needed for use in the ecosystem model.

Limitations and Biases

Sampling Techniques

Any study involving the capture of mobile organisms with trawls or nets contains inherent errors that should be taken into account. One source of error results from the natural avoidance behavior of the organisms (see "Results and Discussion" section). Swift-moving epibenthic invertebrates (amphipods and mysids) are able to avoid nets and trawls, but slow-moving or sessile organisms (isopods and tunicates) are not. Consequently, densities of the swifter organisms can be underestimated but estimates of the slower moving ones are relatively accurate. A comparison of this study's otter-trawl and diver-transect results demonstrates this error, for diver estimates of amphipod and mysid densities are two to three orders of magnitude greater than are estimates based on trawl data (see "Results and Discussion" sections)!

Differences in mesh size also introduce a source of error since small organisms may escape from large-mesh trawls and nets. Density estimates resulting from standard trawl and net sampling techniques may, therefore, be low, particularly for swift-moving organisms.

Laboratory Techniques

All wet weights calculated in this study were determined, as is conventional, from formalin-preserved samples. These wet weights must be considered approximate, since actual wet weights of crustaceans and some other invertebrates are significantly altered by preservation in 10% formalin (Conover and Lalli 1972; Bradstreet 1977; LGL Ltd. unpubl. data). The degree of weight alteration depends on the interval since samples were preserved according to taxon and size. For example, amphipods show changes of ± 5-20% in weight, depending on species, and copepods are reduced in weight by as much as 50-75% (LGL Ltd. unpubl. data).

RESULTS AND DISCUSSION

Investigations were focused on epibenthic invertebrates because numerous feeding ecology studies and our own field observations have shown these to be the major components in the diets of key vertebrate predators (fish and birds) in the lagoon ecosystem.

Comparison of Sampling Techniques

As previously described, data were obtained by two methods--by trawling and by SCUBA diver observation. This section compares the relative advantages of the two types of methods and then discusses the kinds of information most effectively supplied by each method.

Several studies of arctic marine invertebrates have indicated that a variety of sampling techniques are required to adequately sample the fauna in a particular area (MacGinitie 1955; Sparks and Pereyra 1966; Crane 1974; Crane and Cooney 1974; Feder and Schamel 1976; Feder *et al.* 1976; Griffiths *et al.* 1977). Dredges and grab samplers usually cause investigators to underestimate the densities of motile epibenthic invertebrates (mysids and amphipods), and trawl samples typically exclude inbenthic organisms (bivalves and polychaetes). Results from the present study indicate that trawl samples also dramatically underestimate densities of swiftly-moving epibenthic invertebrates. Comparisons of diver observations with trawl catches indicate that motile epibenthic invertebrates are able to avoid capture by trawls (Table 2). This avoidance behavior of amphipods and mysids was documented during this study (Table 3) as well as in other diver observation studies conducted by LGL in the Canadian high arctic (Buchanan *et al.* 1977; Thomson *et al.* 1978). Density estimates from diver observations are two to three orders of magnitude greater than those from trawl samples. Reasons for this drastic difference may include

1. the turbulence caused by the outboard motor in shallow water,
2. the boat shadow in all water depths, and
3. the trawl itself because of its slow speed and great disruptive action (churning up the peat layer).

Also, the mesh size of a trawl introduces errors, as small organisms can escape from the relatively large meshes commonly used. This is illustrated in Table 2, where the trawl used in this study (large mesh size) generally collected fewer organisms than the trawls (small mesh size) employed by Crane (1974) and Griffiths *et al.* (1977). However, while no directly comparable diver data are available for the studies of Crane and Griffiths *et al.*, even their small-mesh trawls collected far fewer mysids and amphipods

Table 2. Comparison of Densities (No/m^2) of Mysids, Amphipods and Isopods Collected in Trawl Samples and Observed During Diver Transects From Three Separate Studies on the Alaskan Beaufort Sea Coast.

Taxon	$\overline{X}$ range	Present Study, 1977[1] Simpson Lagoon		J. J. Crane, 1971[2] Simpson Lagoon			Griffiths et al, 1977[3] Kaktovik Lagoon		Present Study, 1977[4] Simpson Lagoon	
		Deep Lagoon (>2m)	Shallow Lagoon (<2m)	Deep Lagoon (>2m)	Shallow Lagoon (<2m)	Offshore Ocean	Deep Lagoon (>2m)	Shallow Lagoon (<2m)	Deep Lagoon (>2m)	Shallow Lagoon (<2m)
		No/m^2		No/m^2			No/m^2		No/m^2	
Mysid	$\overline{X}$	0.2	2.2	1.0	1.8	22.7	17.9	1.55	700	532.8
	range	(0.1-0.8)	(0.1-23.2)	(0.1-3.7)	(0.2-4.6)	(1.8-133.1)	(4.6-61.2)	(1.1-1.9)	(400.0-1100.0)	(12.0-1250.0)
Amphipod	$\overline{X}$	0.02	0.03	NT	NT	NT	1.98	0.8	188	188
	range	(0.0-0.04)	(0.003-0.05)				(0.5-2.4)	(0.5-0.9)	(150-250)	(0-400)
Isopod	X	0.002	0.007	0.002	0.060		0.68	0.16	only 3 seen on all dives combined	
	range	(0.001-0.004)	(0.001-0.04)	(0-0.11)	(0.003-0.38)		(0.20-1.92)	(0.07-0.23)		

[1] 4.88m Otter trawl 16mm bar mesh; 6.5mm bar mesh codend; approx. 936m^2 sampled.

[2] 2.0m benthic trawl 2.8mm strech mesh; approx. 900m^2 sampled.

[3] 1.0 benthic trawl 6.5mm strech mesh; 3mm strech codend, approx. 100m^2 sampled.

[4] Diver transects estimate of 10 cm^2 extrapolated to 1 m^2.

NT Data not taken.

Table 3. Summary of SCUBA Diver Observations in Simpson Lagoon 1977.

Station No.	Distance From Shore (m)	Date	Transect Length (m)	Water Depth (m)	Water Temperature (°C)	Visibility (m)	Substrate
1	50	04/08/77	50	1.0	10	0.3-0.6	- uniform sand, occasional pebbles, loose layer of detritus 0.3-0.6 cm thick on sand not consolidated into mat, loose drifting.
1	30	24/08/77	25	1.0	7	1.0-1.2	- uniform sand, occasional piles of stones, little detritus, only in depressions, very fine fibrous one ice scour 20-25 cm wide 5 cm deep
1	100	24/08/77	25	0.8	7	1.2-1.6	- fine sand no detritus, occasional pebbles, occasional tundra clumps (not associated with animals) along shallow sandbar
1	500	24/08/77	25	1.6	7	1.2-1.6	- fine sand, occasional pebbles, thin layer of detritus 0.3 cm thick (amorphous, fine silty)
1	1000	24/08/77	25	1.9-2.2	6	1.0	- mud/sand, detritus 0.3-0.6 cm thick (nonfibrous) occasional pebbles
2	mid-lagoon	04/08/77	25	2.0	7	1.2-1.6	- extremely uniform, flat, sand with layer of detritus 0.3-1.6 cm thick (flocculent and amorphous)
2	mid-lagoon	04/08/77	25	2.0	7	1.0	- sand with loosely consolidated detritus 1.3 cm thick some sign of ice scour 0.3-1.3 m in SW direction
2	mid-lagoon	24/08/77	25	1.9-2.2	4.5	3.0	- sand/mud, uniformly flat occasional depressions, detritus uniform 1.3 cm thick - old tundra clump above bottom also covered by detritus
2	mid-lagoon	24/08/77	25	1.9-2.2	4.5	3.0	- sand/mud, uniform flat, detritus uniform 1.3cm thick some algae filaments, 2-3 sticks on bottom, open clam shells (2-3/m^2) in detritus
3	20	21/08/77	25	0.6	-	1.0	- fine sand rippled by wave action no detritus
3	200	21/08/77	25	2.0	-	1.2	- grey mud with numerous stones embedded in bottom, detritus 1.3 cm thick
3	500	21/08/77	25	2.3	-	1.2-1.6	- soft mud, thick detritus layer 1.3-2.5 cm thick, some evidence of ice scour - small furrows and depressions

Table 3. Summary of SCUBA diver observations in Simpson Lagoon, 1977.

Mysids		Amphipods			
No/m²	Length (mm)	No/m²	Length (mm)	Behavior of Mysids and Amphipods	Other Organisms Observed
450 ± 70	6.4 1% 19.1	450 ± 70	3.2- 6.4	- mysids resting on detritus layer or above it no more than 5 cm above - both mysids and amphipods showed diver avoidance	- none observed
350 ± 70	6.4-12.7 10% 22.0	2 –	-	- mysids within 15 cm of bottom collected in detritus depressions showed rapid evasive action	- 1 small fourhorn sculpin
12 ± 4	6.4-25.4	0 –	-	- none observed	- none observed
150 ± 70	-	2 –	-	- mysids showed avoidance behavior	- 2 isopods 50 cm long
550 ± 70	6.4-25.4	250	6.4-12.7	- mysids and amphipods stayed within 30 cm of bottom	- numerous, turbelarians - 1-2 cnidarians
1100 ± 140	6.4-12.7	150 ± 70	-	- mysids showed avoidance - mysids and amphipods within 5.0-7.6 cm of bottom	- 2-3 cnidarians - turbelarians - small clams 2-3/m² 0.6-2.5 cm long
900 ± 140	6.4-12.7	150 ± 70	-	- mysids showed escape behavior, but amphipods did not	- 200-300 Oldsquaw ducks in area - 1 isopod skin - 8 tunicates/m²
400 ± 140	6.4-12.7 1% 19.1	200 -	6.4-12.7	- mysids and amphipods within 2.5-5.0 cm of bottom	- tunicates 4-5/m²
400 ± 140	6.4-12.7	250 ± 70	6.4-12.7	- mysids and amphipods 5.0-7.6 cm above bottom showed avoidance behavior	- 1 large fourhorn sculpin 200-220 mm - turbelarians 2-3/m² - tunicates 3-5/m²
1250 ± 353	6.4-12.7	150 ± 70	6.4-12.7	- mysids uniformly distributed - avoided diver	- several Clione
750 ± 353	6.4-19.1	250 ± 70	-	- mysids exhibited evasive action - a lot of activity in water column 30-60 cm from bottom	- 2-3 cnidarians - 2 Clione
750 ± 353	6.4-12.7	400 ± 140	-	- most mysids and amphipods within 15 cm of bottom, some 30-60 cm off bottom	- 4-5 cnidarians - 4-5 turbelarians

than divers found to be present during our study. For slow-moving or sessile epibenthic invertebrates (isopods and tunicates), trawl samples are thought to provide a more accurate density estimate than diver observations, because these organisms may have been obscured from the diver by the presence of the peat layer.

From the results of this and previous studies, it appears that grabs, dredges and in some circumstances diver-operated airlifts most effectively sample infaunal organisms; trawls, airlifts and known-area photographs are suitable for slow-moving or sessile epibenthic invertebrates; and diver observations and airlifts are most effective for sampling mobile epibenthic invertebrates. The type of gear used should, of course, depend on the specific objectives of sampling.

Diver Transects

Results of diver transects conducted in Simpson Lagoon during August 1977 at Stations 1, 2 and 3 are shown in Table 3. Water depth (0.6 to 2.3 m), temperature (4.5 to 10.0°C) and visibility (0.3 to 1.6 m) varied both within and among stations. Although bottom substrates varied from sand to fine sand/mud, most areas (except for raised sand bars and some nearshore regions) were covered by a layer of detrital material apparently derived from terrestrially-formed peat. This layer, which varied in thickness (0.3-1.3 cm), was non-fibrous, flocculent and amorphous in nature.

Observed densities of mysids (12-1100/m^2) and amphipods (0-450/m^2) varied widely with time and location. Generally, densities appeared highest in areas where peat was abundant. Amphipods and mysids were observed scurrying on or just above the surface of the peat layer and some avoided the approaching diver. Few amphipods or mysids were observed in the water column and few fish or slow-moving or sessile invertebrates were observed during the dives.

Diver observations have proved useful in the present study and other studies conducted in arctic waters in recent years. Reimnitz and Toimil (1977) used diving to study bottom types and processes and to make faunal observations on the inner continental shelf in the southern Beaufort Sea.

Lee (cited in Feder *et al.* 1976) conducted a series of dives in the Prudhoe Bay area and observed bottom topography and fauna in addition to operating an airlift for sampling benthos. Several under-ice and open-water invertebrate studies have been assisted by divers in the high arctic islands (Buchanan *et al.* 1977; Thomson *et al.* 1978). All these studies have shown that diver observations and/or diver operated sampling procedures have distinct advantages over surface-operated sampling gear. Advantages include the following:

1. Provision of direct observations of distributions and densities of both benthic and epibenthic invertebrates in a relatively undisturbed condition; observations of behavior patterns of epibenthic invertebrates; and observations on habitat partitioning by various groups of invertebrates.
2. Capability for a more accurate assessment of habitats (i.e. type of substrate, presence or absence of organic detritus, tundra clumps etc.),
3. Capability for selective sampling of particular groups or species by use of airlifts and hand-operated corers, trawls or nets.

Problems associated with diver operations include the following:

1. Diving operations are only feasible during the open water period (August-early September) unless special equipment is provided.
2. Diving observations are limited by visibility. This is a particular problem in the nearshore Beaufort Sea because of frequent periods of wind-generated turbulence.
3. Because of adverse weather and ice conditions, a successful diving program requires that divers be present for much of the open-water season to take advantage of occasional good diving conditions.

The deficiencies of a diving program can be mitigated by augmenting it with trawling techniques and by developing correction factors so that comparisons can be made between results collected with the different techniques.

Trophic Relationships

Results of feeding ecology studies of both fish and birds (see RU 467 AVIAN ECOLOGY and ECOLOGY OF FISH sections) have shown that mysids and amphipods are the most important groups in the diets of these predators. Since diver observations provided the most accurate estimates of densities of mysids and amphipods (see above section), the values obtained by divers were used in estimating the energy available in the form of mysids and amphipods at Stations 1, 2 and 3 in Simpson Lagoon during August (Table 4). The calculated energy values (Kcal/m^2) were then multiplied by July:August and September:August ratios of wet weights in trawl samples to estimate energy available in the form of mysids and, separately, amphipods at each station in each month of study (see "Methods" and Table 5). No conversions were attempted for Station 5 because diver operations were not conducted at this station.

Calculations of daily energy requirements of the key vertebrates present in the study area showed that oldsquaw ducks were the major energy consumers because of their relatively high numerical densities and energy needs (430 Kcal/bird-day; see RU 467 AVIAN ECOLOGY section). In contrast, the energy requirements of large and small fish are much lower due to their cold-blooded nature (est. 1-5 Kcal/fish-day).

A comparison of the energy available (as mysids and amphipods) to the daily energy requirements of oldsquaw ducks in Simpson Lagoon during 1977 is shown in Fig. 2 and Tables 5 and 6. Fish are not included in Fig. 2 since their low energy requirements, coupled with a rough estimate of their density, revealed a negligible energy demand compared to that of oldsquaw. At Stations 2 and 3 available energy increased as the season progressed; at Station 1 available energy was least in the first period but slightly higher in the middle than in the last period.

Results indicated that the energy available exceeded the daily requirement of oldsquaw ducks by one to two orders of magnitude. Although the rates of production, immigration and emigration of epibenthos are all unknown, the fact that the epibenthic standing crop increased over the season--despite cropping by oldsquaws, fish and other predators--suggests that food was not

Table 4. Estimates of Energy Available (Kcal/m^2) in the Form of Mysids and Amphipods in August Based on SCUBA Diver Observations.

Station	Organism	Mean (No/m^2)	Dry weight[a] (g/organism)	Ash free[b] Dry wt. (g/m^2)	Ash free[c] Dry wt. (Kcal/g)	Kcal/m^2 (August)
1	Mysid	302 ± 220[†]	0.003	0.78	5.47 ± 0.06[+]	4.27
	Amphipod	141 ± 204	0.005	0.49	5.37 ± 0.06	2.63
2	Mysid	700 ± 356	0.003	1.80	5.47 ± 0.06	9.85
	Amphipod	200 ± 50	0.005	0.70	5.37 ± 0.06	3.76
3	Mysid	917 ± 289	0.003	2.36	5.47 ± 0.06	12.91
	Amphipod	267 ± 126	0.005	0.93	5.37 ± 0.06	4.99

[†] Mean ± one standard deviation.

[a] Dry weight/individual organism from Bradstreet 1977, based on average length of 9.6 mm for both mysids and amphipods.

[b] Ash free dry wt. (g/m^2) calculated by subtracting % ash from dry (% ash calculated from microbomb colorimeter results, Dr. Pattie, N.A.I.T.: for mysids 14.16% ± 0.16%, for amphipods 29.84% ± 1.36%).

[c] Kcal/g ash free dry wt. are the mean of 3 best determinations from microbomb calorimeter results.

Table 5. Estimates of Energy Available (Kcal/m^2) in Simpson Lagoon Based on SCUBA Diver Observations: Otter Trawl Conversion Index (see Methods and Table 4).

STATION	ORGANISM	Early (July)		Mid (August)		Late (September)	
		Ash free dry weight (g/m^2)	(Kcal/m^2)	Ash free dry weight (g/m^2)	(Kcal/m^2)	Ash free dry weight (g/m^2)	(Kcal/m^2)
1	Mysid	0.32	1.75	0.78	4.27	0.59	3.22
	Amphipod	0.08	0.43	0.49	2.63	0.28	1.50
	(Total)	(0.40)	(2.18)	(1.27)	(6.90)	(0.87)	(4.72)
2	Mysid	0.39	2.13	1.80	9.85	2.50	13.66
	Amphipod	0.06	0.32	0.70	3.76	1.28	6.87
	(Total)	(0.45)	(2.45)	(2.50)	(13.61)	(3.78)	(20.53)
3	Mysid	0.86	4.70	2.36	12.91	172.80	945.22
	Amphipod	0.06	0.32	0.93	4.99	9.26	49.73
	(Total)	(0.92)	(5.02)	(3.29)	(17.90)	(182.06)	(994.95)

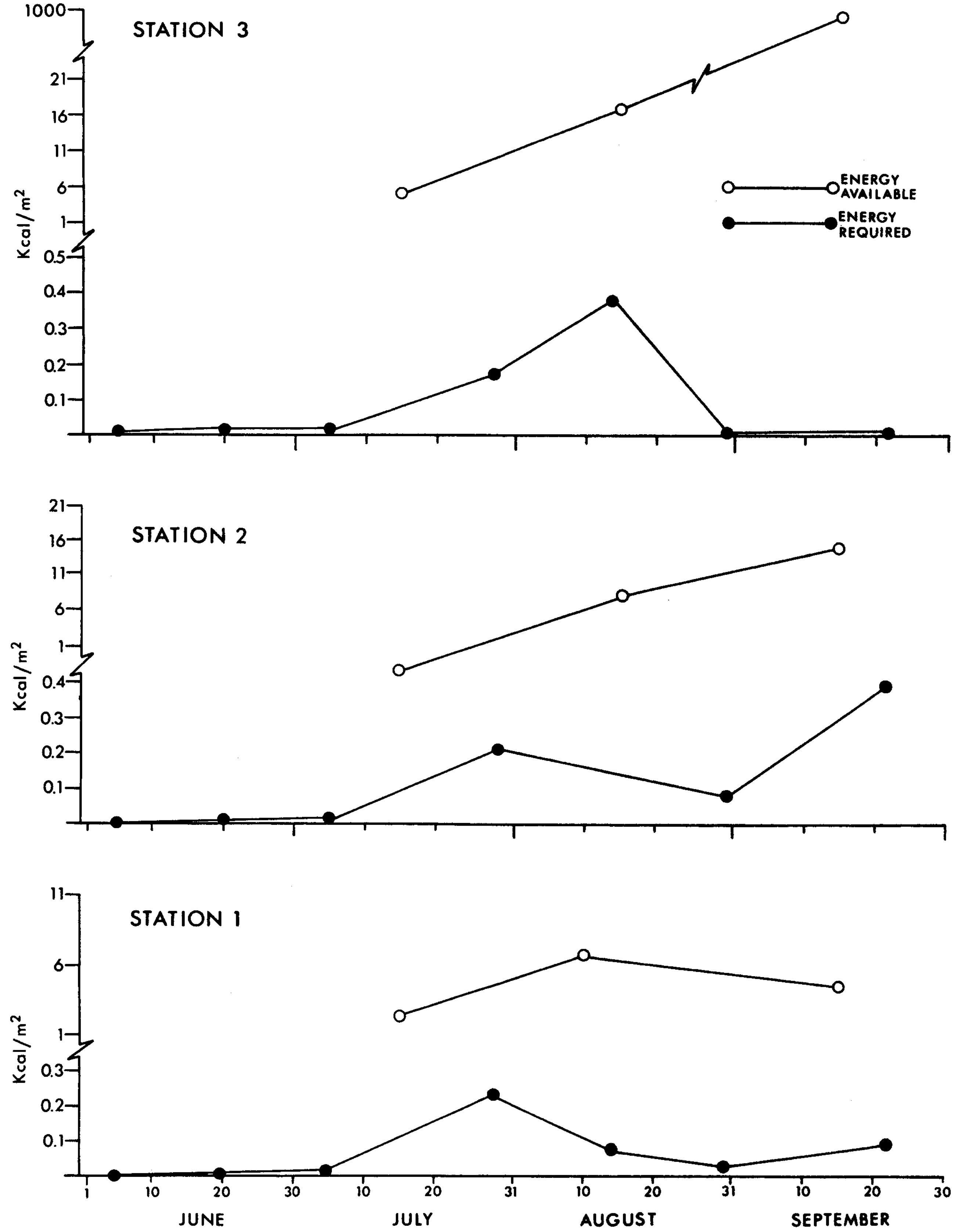

Fig. 2. Comparison of Energy Available in the Form of Amphipods and Mysids (Kcal/m^2) and the Energy Consumed Daily by Oldsquaw Ducks (Kcal/m^2 per day) in Simpson Lagoon, 1977.

Table 6. Estimates of Energy Requirements (Kcal/m^2) of Oldsquaw Ducks in Simpson Lagoon During 1977. Values are based on results of aerial surveys of birds conducted during the period 5 June to 22 September. A value of approximately 430Kcal/bird-day has been calculated as the daily gross energy requirements of an oldsquaw duck.*

Station	June 5		June 20		July 5		July 28/29	
	birds/m^{2}x10^{-5}	Kcal/m^{2}x10^{-3}	birds/m^{2}x10^{-5}	Kcal/m^{2}x10^{-3}	birds/m^{2}x10^{-5}	Kcal/m^{2}x10^{-5}	birds/m^{2}x10^{-5}	Kcal/m^{2}x10^{-7}
1	0.0	0.0	0.085	.365	2.163	9.301	51.639	222.05
2	0.0	0.0	0.0	0.0	0.285	1.225	50.114	215.49
3	0.0	0.0	0.155	.667	2.673	1.494	40.169	172.73

Station	August 15		August 30		September 22	
	birds/m^{2}x10^{-5}	Kcal/m^{2}x10-^{3}	birds/m^{2}x10^{-5}	Kcal/m^{2}x10^{-3}	birds/m^{2}x10^{-5}	Kcal/m^{2}x10^{-3}
1	16.194	69.634	6.804	29.257	22.001	94.604
2	____*†	____*†	18.460	79.379	92.805	399.062
3	81.131	348.863	7.305	31.41	2.163	9.301

*See RU 467 Avian Ecology section for details of results of aerial surveys of birds.

†No aerial survey in this type of habitat on this date.

a limiting factor for the higher trophic levels in 1977. This same conclusion was reached independently in a food overlap comparison of key vertebrate consumers (see RU 467, ECOLOGY OF FISH section).

Although fish and bird food in the form of epibenthic invertebrates was apparently superabundant, a decrease in its biomass by an order of magnitude accompanied by an increase in numbers of birds by the same factor would probably cause food to become a limiting factor in this sytem. Therefore, it should not be assumed that birds and fish are immune to effects of perturbations to their food source. It is not known whether oldsquaw ducks would select infaunal organisms (bivalves and polychaetes) in the absence of sufficient numbers of epibenthic invertebrates, or if they would leave the system to feed elsewhere.

The feeding ecology of the epibenthic invertebrates will be studied in the summer of 1978. Several sources of energy are available to organisms at this trophic level:

1. Primary Production. Phytoplankton production roughly estimated from standing crop measurements (chlorophyll-a--see Appendix IV) and empirically derived turnover rates averaged 0.30 $g/m^2/day$* or 27.0 $g/m^2/year$ assuming a 90-day open water period. It is emphasized that these values are only rough estimates (i.e. under ice productivity are not accounted for); they will be refined during 1978. However, assuming that they are correct and that there is a 10% conversion of this production by the next higher trophic level, then all of the primary production would be required to just meet the estimated metabolic requirements of the mysids and amphipods, to say nothing of the needs of zooplankton and the remaining epibenthic and infaunal organisms.
2. Organic Detrital Input. Preliminary indications are that some epibenthic invertebrates may feed on the peat (detritus layer) (Broad 1977); it is not known if they digest the peat itself or utilize the meiofauna living on the peat. Rates of detritus input to the lagoon from the river runoff and tundra slumping (estimated by RU 530, GEOLOGY) could theoretically* support a benthic standing crop of about 20-25 g/m^2 dry wt., assuming that an intermediate trophic level exists (e.g., meiobenthos) between detritus and epibenthos. This approximately equals the average standing crop estimate of epibenthic organisms recorded by the diver in Simpson Lagoon in 1977. Again, it is emphasized that these quantitative estimates are preliminary, and will be refined during 1978 studies.

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*Data from modelling and integration workshop submitted to OCS Arctic Project Office, January 1978. (See RU 467, Overview and Synthesis section Appendix I).

Trawl Samples

Otter trawl samples were taken throughout the open-water season, and trawling results are, therefore, useful for describing temporal and spatial composition of epibenthos. Since biomass rather than densities more accurately indicates the energy available to higher trophic levels, the components of trawl samples are expressed as percentages of total wet weight. The seven sampling periods have been grouped to form three main collection times: Periods I + II (11-30 July), Periods III + IV + V (31 July-2 September), and Periods VI + VII (4-20 September); these three periods are, for convenience, referred to as July, August and September below.

Invertebrates representing 15 major taxonomic groups were collected in the study area (Tables 7 and 8, Fig. 3). Four main groups of organisms (amphipods, mysids, isopods, tunicates) comprised the major portion of the biomass (86.9-99.9%) at all sample locations. Generally, the total number of taxonomic groups collected in the study area increased towards the ocean: Station 1 (9 groups), 2(12), 3(13), 5(13). Biomass was significantly higher at Stations 2, 3 and 5 than at Station 1 (Friedman X=7.8, $P<0.050$, $N=5$, $K=4$): Station 1 (28.7 g/trawl), 2 (92.3 g/trawl), 3 (302.8 g/trawl), 5 (118.3 g/trawl). The lower diversity and biomass of benthic invertebrates at Station 1 (shallow nearshore) is typical of nearshore arctic waters and has been attributed to disruption of the bottom by wave and ice-related phenomena (Ellis and Wilce 1961; Crane and Cooney 1974; Feder and Schamel 1976).

Invertebrate composition and biomass at each sampling station are described below. Seasonal changes in the invertebrate community (Table 7, Appendix I) will be described in more detail following the completion of the 1978 field program.

Station 1. Nine invertebrate taxa were collected at Station 1; the four taxa that constituted the majority of the mean biomass were isopods, mysids, tunicates and amphipods (Table 7, Fig. 3). Isopods and tunicates were the most abundant groups in early collections; as the season progressed, amphipods and mysids increased in importance. Biomass at Station 1 decreased sharply between July (56.0 g/trawl) and August (15.8 g/trawl) collections but stayed relatively constant thereafter.

Several of the results at Station 1 are surprising. Inbenthic organisms (bivalves) and slow-moving (isopods) or sessile (tunicates) epibenthic invertebrates were abundant although this area freezes to the bottom in winter. It was also surprising that the highest biomass at Station 1 occurred during the early period, shortly after ice breakup. The reasons for these findings may be related to the following:

1. Bivalves buried in the substrate may be adapted to withstand the water freezing to the bottom.
2. Isopods and tunicates may be carried toward shore by currents and/or wave action early in the season.
3. Lower biomass later in the season may have resulted from predation by fish and birds (anadromous fish, in particular, concentrated along this shoreline--see RU 467, ECOLOGY OF FISH section).

Station 2. Organisms representing 12 invertebrate taxa were collected at Station 2 during the open water season. Tunicates dominated in all three periods (85.6%, 68.3% and 35.3% of biomass, respectively), but mysids and isopods became almost as important by the last period (September); amphipods were a less important component here than at any of the other stations analyzed (Table 7). These results, and those at other stations should be interpreted with caution because of the known biases in trawl results (see above). The total biomass at Station 2 was lowest during early collections (July) (66.6 g/trawl), increased to a maximum during August (105.9 g/trawl) and was similar in September (104.3 g/trawl).

Station 3. Representatives of thirteen invertebrate taxa were collected at Station 3. Tunicates were most abundant in July and then sharply declined (82.1%, 36.5%, 4.6%); mysids showed the reverse trend (13.7%, 29.2%, 76.4%). Total biomass increased only slightly between July and August collections but was much higher in September (23.6, 30.6 and 854.2 g/trawl). The dramatic increase by September was mainly caused by the large influx of mysids (652.4 g/trawl). However, this increase may be a misleading sampling artifact since the results are based on a single sample.

Table 7. Seasonal Variation in Biomass (Wet weight g/trawl) of Major Taxon, Amphipod and Mysid Species Collected in Trawl Samples at Stations 1, 2, 3, 5 in Simpson Lagoon 1977. The season has been divided into three main periods: Early (sampling periods I, II); Mid (sampling periods III, IV, V); Late (sampling periods VI, VII). Each trawl collections sampled approximately 936m^2.

Major Taxon Amphipod and Mysid Species	STATION 1			
	Early (July)	Mid (August)	Late (September)	Seasonal Mean
	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl
Cnidarians	1.383	0.372	0.095	0.617
Priapulids	-	-	-	-
Bryozoans	-	-	-	-
Chaetognaths	0.017	0.010	0.006	0.011
Mysids				
Mysis oculata	-	-	-	-
Mysis litoralis	0.484	5.819	0.925	2.409
Mysis relicta	1.794	0.888	4.160	2.281
Mysis spp.	1.112	1.475	1.068	1.218
Neomysis rayii	-	-	<0.001	<0.001
Total	3.391	8.182	6.153	5.909
Euphausiids	-	-	-	-
Amphipods				
Paroediceros lycaneus	-	-	-	-
Parathemisto libellula	-	-	-	-
Hyperia medusarum	-	-	-	-
Hyperiid spp.	-	0.005	-	0.002
Onisimus glacialis	0.051	0.043	0.007	0.030
Onisimus littoralis	-	-	0.001	<0.001
Onisimus spp.	0.030	0.003	0.019	0.017
Apherusa glacialis	-	-	<0.001	<0.001
Gammarus setosus	0.175	0.769	0.280	0.408
Gammarus wilkitzkii	-	-	-	-
Gammaracanthus loricatus	0.260	2.305	0.446	1.00
Acanthostepheia behringiensis	-	-	-	-
Weyprechtia pinguis	-	0.006	0.024	0.010
Weyprechtia heuglini	-	-	1.024	0.341
Pontoporeia affinis	-	-	-	-
Monoculopsis longicornis	-	-	-	-
Monoculodes packardi	-	-	-	-
Atylus carinatus	-	-	-	-
Unidentified	-	-	-	-
Total	.516	3.131	1.801	1.816
Isopods	36.280	1.893	5.473	14.549
Copepods	<0.001	-	0.005	0.002
Cumaceans	-	-	-	-
Polychaetes	0.018	0.002	0.005	0.008
Bivalves	2.548	0.122	0.058	0.920
Decapods	-	-	-	-
Pteropods	-	-	-	-
Tunicates	11.854	2.080	0.633	4.856
Unknown	0.017	<0.001	-	0.006
Total	56.024	15.792	14.229	28.682
*No. of Trawl Samples	n=4	n=6	n=3	n=13

*Number of samples collected during each collection period (Early, Mid, Late) varied as ice and weather conditions prevented the collection of some samples.

Table 7. (cont'd)

Major Taxon Amphipod and Mysid Species	STATION 2			
	Early (July)	Mid (August)	Late (September)	Seasonal Mean
	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl
Cnidarians	0.965	0.335	0.295	0.532
Priapulids	-	0.009	-	.003
Bryozoans	-	-	-	-
Chaetognaths	0.005	0.021	-	0.009
Mysids				
Mysis oculata	-	-	-	-
Mysis litoralis	2.499	10.350	17.843	10.231
Mysis relicta	1.065	9.985	1.951	4.333
Mysis spp.	1.753	4.296	14.373	6.087
Neomysis rayii	-	-	<0.001	<0.001
Total	5.37	24.631	34.167	20.651
Euphausiids	0.005	0.013	0.080	0.033
Amphipods				
Paroediceros lycaneus	-	-	-	-
Parathemisto libellula	-	-	0.738	0.246
Hyperia medusarum	-	-	-	-
Hyperiid spp.	-	-	-	-
Onisimus glacialis	0.030	0.026	0.007	0.021
Onisimus littoralis	-	-	0.005	0.002
Onisimus spp.	-	0.021	0.055	0.025
Apherusa glacialis	-	-	<0.001	<0.001
Gammarus setosus	-	0.015	0.039	0.018
Gammarus wilkitzkii	-	-	-	-
Gammaracanthus loricatus	0.042	0.700	0.333	0.358
Acanthostepheia behringiensis	-	0.132	0.306	0.146
Weyprechtia pinguis	-	-	0.078	0.026
Weyprechtia heuglini	-	-	0.071	0.024
Pontoporeia affinis	-	-	-	-
Monoculopsis longicornis	-	-	-	-
Monoculodes packardi	-	-	-	-
Atylus carinatus	-	-	-	-
Unidentified	-	-	-	-
Total	0.072	0.894	1.632	0.866
Isopods	1.303	6.885	31.075	13.088
Copepods	0.005	0.008	-	0.004
Cumaceans	-	-	-	-
Polychaetes	-	0.007	-	0.002
Bivalves	1.938	0.776	0.225	0.980
Decapods	-	-	-	-
Pteropods	-	0.002	-	<0.001
Tunicates	57.017	72.324	36.850	55.397
Unknown	-	0.003	-	0.001
Total	66.627	105.008	104.324	91.566
*No. of Trawl Samples	n=3	n=5	n=3	n=11

*Number of samples collected during each collection period (Early, Mid, Late) varied as ice and weather conditions prevented the collection of some samples.

Table 7. (cont'd)

Major Taxon Amphipod and Mysid Species	STATION 3			
	Early (July)	Mid (August)	Late (September)	Seasonal Mean
	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl
Cnidarians	-	0.123	P	0.041
Priapulids	-	-	-	-
Bryozoans	-	-	-	-
Chaetognaths	0.078	0.043	-	0.040
Mysids				
Mysis oculata	-	-	-	-
Mysis litoralis	1.451	5.220	379.137	128.603
Mysis relicta	1.018	2.420	162.688	55.375
Mysis spp.	0.771	1.270	110.592	37.544
Neomysis rayii	-	-	-	-
Total	3.240	8.910	652.417	221.522
Euphausiids	0.053	-	-	0.018
Amphipods				
Paroediceros lycaneus	-	0.001	-	<0.001
Parathemisto libellula	-	-	0.624	0.208
Hyperia medusarum	-	-	-	-
Hyperiid spp.	-	-	-	-
Onisimus glacialis	-	0.289	3.227	1.172
Onisimus littoralis	-	0.015	0.014	0.010
Onisimus spp.	0.012	0.005	-	0.006
Apherusa glacialis	-	0.010	0.131	0.047
Gammarus setosus	0.050	1.117	-	0.389
Gammarus wilkitzkii	-	0.072	-	0.024
Gammaracanthus loricatus	0.209	0.930	36.190	12.443
Acanthostepheia behringiensis	-	0.396	1.577	0.658
Weyprechtia pinguis	-	0.001	-	<0.001
Weyprechtia heuglini	-	1.374	-	0.458
Pontoporeia affinis	-	0.001	-	<0.001
Monoculopsis longicornis	0.002	0.001	0.075	0.026
Monoculodes packardi	-	-	-	-
Atylus carinatus	-	-	-	-
Unidentified	-	0.013	0.212	0.075
Total	0.273	4.225	42.050	15.516
Isopods	-	5.297	120.000	41.766
Copepods	0.004	-	-	0.001
Cumaceans	-	0.003	0.040	0.014
Polychaetes	P	0.103	0.830	0.311
Bivalves	0.585	0.710	P	0.432
Decapods	-	0.003	-	0.001
Pteropods	-	0.020	-	0.007
Tunicates	19.412	11.236	38.900	23.183
Unknown	-	-	0.008	0.003
Total	23.645	30.673	854.245	302.855
*No. of Trawl Samples	n=3	n=6	n=1	n=10

*Number of samples collected during each collection period (Early, Mid, Late) varied as ice and weather conditions prevented the collection of some samples.

Table 7. (cont'd)

Major Taxon Amphipod and Mysid Species	STATION 5			
	Early (July)	Mid (August)	Late (September)	Seasonal Meal
	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl	Wet wt. g/trawl
Cnidarians	0.276	0.095	0.353	0.241
Priapulids	-	0.088	-	0.029
Bryozoans	0.005	0.023	-	0.009
Chaetognaths	0.025	0.042	0.096	0.054
Mysids				
Mysis oculata	-	-	0.049	0.016
Mysis litoralis	0.096	0.990	4.558	1.881
Mysis relicta	-	0.575	0.585	0.387
Mysis spp.	0.050	0.534	5.164	1.916
Neomysis rayii	-	<0.001	-	<0.001
Total	0.146	2.099	10.356	4.200
Euphausiids	-	.008	-	0.003
Amphipods				
Paroediceros lycaneus	-	-	-	-
Parathemisto libellula	-	-	17.612	5.871
Hyperia medusarum	-	-	-	-
Hyperiid spp.	-	-	-	-
Onisimus glacialis	-	-	0.125	0.042
Onisimus littoralis	-	-	-	-
Onisimus spp.	0.174	0.011	0.002	0.062
Apherusa glacialis	-	-	-	-
Gammarus setosus	-	0.114	0.034	0.049
Gammarus wilkitzkii	-	0.326	0.031	0.119
Gammaracanthus loricatus	-	0.924	0.297	0.407
Acanthostepheia behringiensis	0.215	5.693	1.618	2.509
Weyprechtia pinguis	0.092	0.074	-	0.055
Weyprechtia heuglini	-	-	-	-
Pontoporeia affinis	-	-	-	-
Monoculopsis longicornis	-	-	-	-
Monoculodes packardi	-	-	-	-
Atylus carinatus	-	0.033	-	0.011
Unidentified	-	0.001	0.014	0.005
Total	0.481	7.176	19.733	9.13
Isopods	1.680	227.518	79.428	102.875
Copepods	-	-	-	-
Cumaceans	-	0.002	0.055	0.019
Polychaetes	-	0.135	0.083	0.073
Bivalves	0.040	2.168	0.802	1.00
Decapods	-	.187	<0.001	0.062
Pteropods	-	-	0.287	0.096
Tunicates	-	-	-	-
Unknown	-	0.852	0.600	0.484
Total	2.653	240.393	111.793	118.280
*No. of Trawl Samples	n=2	n=5	n=3	n=10

*Number of samples collected during each collection period (Early, Mid, Late) varied as ice and weather conditions prevented the collection of some samples.

Table 8. Major Taxa (% of total wet weight) Collected in Trawl Samples at Stations 1, 2, 3, 5 Early (July), Mid (August) and Late (September) Collection Periods in Simpson Lagoon 1977.

MAJOR TAXA	STATION 1				STATION 2			
	Early (July)	Mid (August)	Late (September)	Seasonal† Mean	Early (July)	Mid (August)	Late (September)	Seasonal† Mean
Cnidarians	2.5	2.4	0.7	1.9	1.4	0.3	0.3	0.7
Priapulids	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1
Bryozoans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chaetognaths	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.0	<0.1
Mysids	6.1	51.9	43.2	33.7	8.0	23.3	32.8	21.4
Euphausiids	0.0	0.0	0.0	0.0	<0.1	<0.1	<0.1	<0.1
Amphipods	0.9	19.8	12.7	11.1	0.1	0.8	1.6	0.8
Isopods	64.8	12.0	38.5	38.4	2.0	6.5	29.8	12.8
Copepods	<0.1	0.0	<0.1	<0.1	<0.1	<0.1	0.0	<0.1
Cumaceans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polychaetes	<0.1	<0.1	<0.1	<0.1	0.0	<0.1	0.0	<0.1
Bivalves	4.5	0.8	0.4	1.9	2.9	0.7	0.2	1.3
Decapods	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pteropods	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1
Tunicates	21.2	13.2	4.5	13.0	85.6	68.3	35.3	63.1
Unidentified	<0.1	<0.1	0.0	<0.1	0.0	<0.1	0.0	<0.1
Total	100.0	100.1	100.0	100.0	100.0	100.1	100.0	100.1
g/trawl (mean)	56.0	15.8	14.2	28.7	66.6	105.9	104.3	91.6

Table 8 (cont'd)

MAJOR TAXA	STATION 3				STATION 5			
	Early (July)	Mid (August)	Late (September)	Seasonal[†] Mean	Early (July)	Mid (August)	Late (September)	Seasonal[†] Mean
Cnidarians	0.0	0.4	<0.1	0.1	10.4	0.1	0.3	3.6
Priapulids	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1
Bryozoans	0.0	0.0	0.0	0.0	0.2	<0.1	0.0	0.1
Chaetognaths	0.3	0.1	0.0	0.1	1.0	<0.1	<0.1	<0.1
Mysids	13.7	29.0	76.4	39.7	5.5	0.9	9.3	5.2
Euphausiids	0.2	0.0	0.0	<0.1	0.0	<0.1	0.0	<0.1
Amphipods	1.1	13.8	4.9	6.6	18.1	3.0	17.8	13.0
Isopods	0.0	17.3	14.1	10.5	63.3	94.6	71.0	76.3
Copepods	<0.1	0.0	0.0	<0.1	0.0	0.0	0.0	0.0
Cumaceans	0.0	<0.1	<0.1	<0.1	0.0	<0.1	<0.1	<0.1
Polychaetes	<0.1	0.5	0.1	0.2	0.0	<0.1	<0.1	<0.1
Bivalves	2.5	2.3	<0.1	1.6	1.5	0.9	0.7	1.0
Decapods	0.0	<0.1	0.0	<0.1	0.0	<0.1	<0.1	<0.1
Pteropods	0.0	<0.1	0.0	<0.1	0.0	0.0	0.3	0.1
Tunicates	82.1	36.6	4.6	41.1	0.0	0.0	0.0	0.0
Unidentified	0.0	0.0	<0.1	<0.1	0.0	0.4	0.5	0.3
Total	99.9	100.0	100.1	99.9	100.0	99.9	99.9	99.6
g/trawl (mean)	23.6	30.6	854.2	302.8	2.7	240.4	111.8	118.3

[†] Seasonal mean calculated from Early, Mid, and Late values from this table.

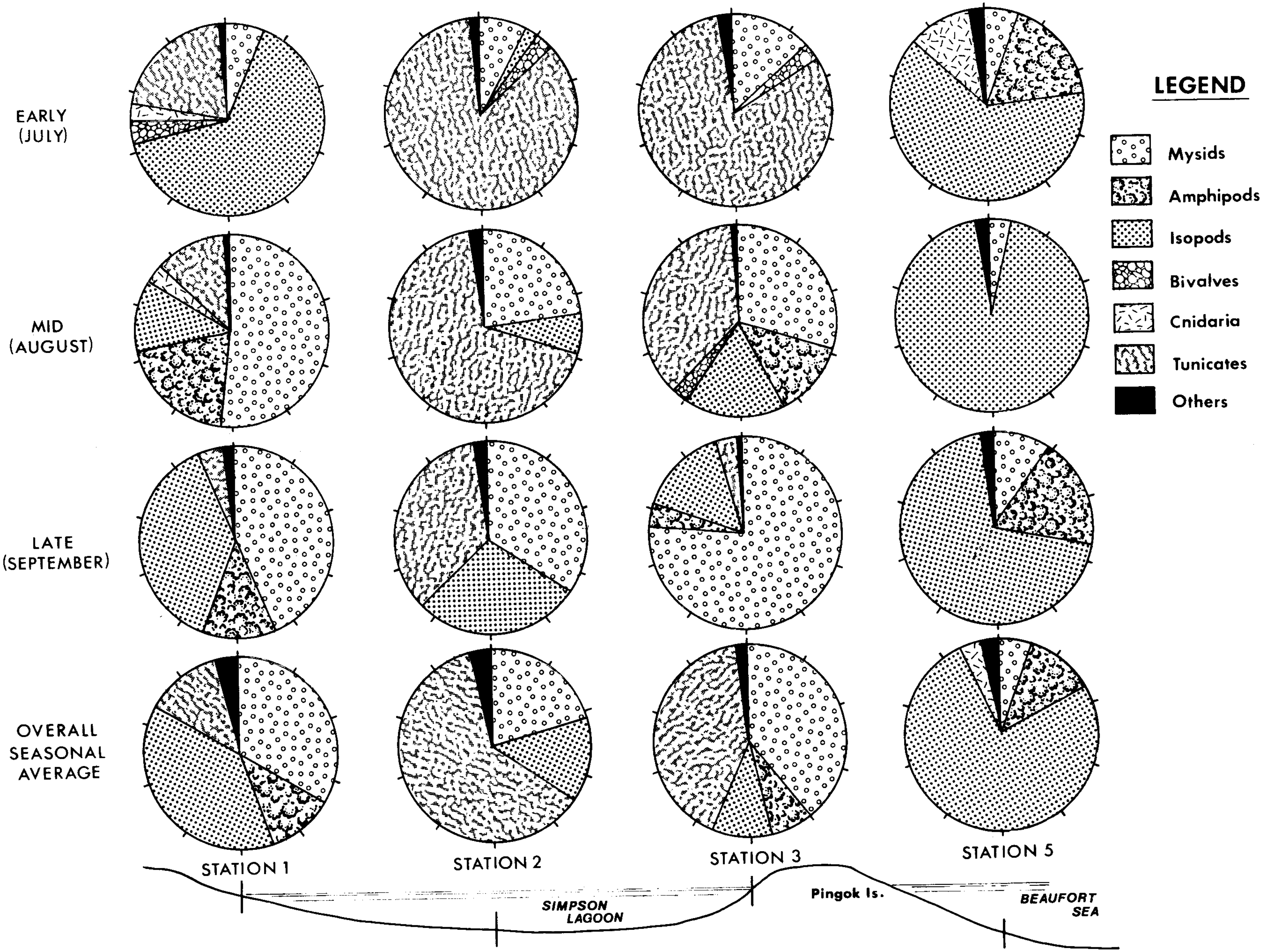

Fig. 3. Relative Wet Weights of Major Invertebrate Taxa in Trawl Samples, Simpson Lagoon, 1977. For numerical details, including composition of the 'Others' category, see Tables 7 and 8 and Appendix I.

Station 5. A total of 13 taxa were collected at this station during the open-water season; however 98.0% of the biomass was composed of only three groups (isopods, amphipods and mysids). Isopods were the most abundant group during all three collection periods, followed by amphipods. Total biomass at Station 5 varied substantially among collection periods: early (2.7 g/trawl), mid (240.4), late (111.8).

Major Taxonomic Groups of Invertebrates

In this section, general information about common invertebrate groups in Simpson Lagoon and more detailed information about key invertebrates (mysids and amphipods) are presented. The results and discussion of trawls and Faber hauls are discussed together, and are documented in Tables 7-12 and in Appendix I.

Mysids

Four species of mysids were identified from trawl samples during 1977; of these, *Mysis litoralis* and *M. relicta* were present in significant amounts (Tables 7, 9, Fig. 4). Most mysids identified as *Mysis* sp. belong to one of the identified species but were too small to have developed diagnostic characteristics. Crane (1974) identified *M. oculata* as the most abundant mysid in Simpson Lagoon, but in the present study *M. oculata* was recorded only once--at Station 5 in September. The discrepancy may be an artifact, since different taxonomic keys were used by Crane and ourselves, and they appear to be inconsistent.

Based on otter trawl samples of the epibenthos, the *M. litoralis* and *M. relicta* biomass ratio varied widely within stations and collection periods, however there was no significant difference among stations on a seasonal basis (Friedman X^2=5.16, P>0.10, N=5, K=4). No significant difference was found in *M. litoralis* biomass among stations on a seasonal basis (Friedman X=3.48, P>0.20, N=5, K=4), however, *M. relicta* was significantly more abundant at stations 1, 2 and 3 than at station 5 (Friedman X^2=9.96, P<0.05, N=5, K=4). Seasonally, there was no significant difference among stations in total mysid biomass (otter trawls) (Friedman X^2=4.92, P>0.10, N=5, K=4), however the biomass increased significantly throughout the season (Friedman X^2=6.5,

Table 9. Species Composition of Mysids (as % of total Mysid wet weight) and of Amphipods (as % of total Amphipod wet weight) Collected in Trawl Samples During Early (July), Mid (August), and Late (September) Collecting Periods in Simpson Lagoon 1977.

SPECIES	STATION 1				STATION 2			
	Early (July)	Mid (August)	Late (September)	Seasonal† Mean	Early (July)	Mid (August)	Late (September)	Seasonal† Mean
Mysid								
Mysis oculata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
M. litoralis	14.3	71.1	15.0	33.5	47.0	42.2	52.2	47.1
M. relicta	52.9	10.9	67.6	43.8	20.0	40.5	5.7	22.1
M. spp.	32.8	18.0	17.4	22.7	33.0	17.4	42.0	30.8
Neomysis rayii	0.0	0.0	<0.1	<0.1	0.0	0.0	<0.1	<0.1
Total	100.0	100.0	100.0	100.0	100.0	100.1	99.9	100.0
Amphipod								
Parathemisto libellula	0.0	0.0	0.0	0.0	0.0	0.0	45.2	0.0
Hyperia sp.	0.0	0.2	0.0	<0.1	0.0	0.0	0.0	0.0
Paroediceros lycaneus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.1
Onisimus glacialis	9.9	1.4	0.4	3.9	41.7	2.9	0.4	15.0
O. littoralis	0.0	0.0	<0.1	<0.1	0.0	0.0	0.3	0.1
O. spp.	5.8	0.1	1.0	2.3	0.0	2.3	3.4	1.9
Apherusa glacialis	0.0	0.0	<0.1	<0.1	0.0	0.0	<0.1	<0.1
Gammarus setosus	33.9	24.5	15.5	24.6	0.0	1.7	2.4	1.4
Gammarus wilkitzkii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gammaracanthus loricatus	50.4	73.6	24.8	49.6	58.3	78.3	20.4	52.3
Acanthostepheia berhingiensis	0.0	0.0	0.0	0.0	0.0	14.8	18.8	11.2
Weyprechtia heuglini	0.0	0.0	56.8	18.9	0.0	0.0	4.4	1.5
Weyprechtia pinguis	0.0	0.2	1.4	0.5	0.0	0.0	4.8	1.6
Pontoporeia affinis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monoculodes packardi	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Monoculopsis longicornis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atylus carinata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100.0	99.9	99.9	99.8	100.0	100.0	100.1	100.1

Table 9 (cont'd)

SPECIES	STATION 3				STATION 5			
	Early (July)	Mid (August)	Late (September)	Seasonal† Mean	Early (July)	Mid (August)	Late (September)	Seasonal† Mean
Mysid								
Mysis oculata	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2
M. litoralis	44.8	58.6	58.1	53.8	66.0	47.2	44.0	52.4
M. relicta	31.4	27.2	24.9	27.8	0.0	27.4	5.6	11.0
M. spp.	23.7	14.2	17.0	18.3	34.0	25.4	49.8	36.4
Neomysis rayii	0.0	0.0	0.0	0.0	0.0	<0.1	0.0	<0.1
Total	99.9	100.0	100.0	99.9	100.0	100.0	99.9	100.0
Amphipod								
Parathemisto libellula	0.0	0.0	1.5	0.5	0.0	0.0	89.3	29.8
Hyperia sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paroediceros lycaneus	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0	0.0
Onisimus glacialis	4.4	6.8	7.7	6.3	0.0	0.0	0.6	0.2
O. littoralis	0.0	0.4	<0.1	0.1	0.0	0.0	0.0	0.0
O. spp.	0.0	0.1	0.0	<0.1	36.2	0.2	<0.1	12.1
Apherusa glacialis	0.0	0.2	0.3	0.2	0.0	0.0	0.0	0.0
Gammarus setosus	18.3	26.4	0.0	14.9	0.0	1.6	0.2	0.6
Gammarus wilkitzkii	0.0	1.7	0.0	0.6	0.0	4.5	0.2	1.6
Gammaracanthus loricatus	76.6	22.0	86.1	61.6	0.0	12.9	1.5	4.8
Acanthostepheia berhingiensis	0.0	9.4	0.0	3.1	44.7	79.3	8.2	44.1
Weyprechtia heuglini	0.0	32.5	0.0	10.8	19.1	0.0	0.0	6.3
Weyprechtia pinguis	0.0	<0.1	3.8	1.3	0.0	1.0	0.0	<0.1
Pontoporeia affinis	0.0	<0.1	0.0	<0.1	0.0	0.0	0.0	0.0
Monoculodes packardi	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.2
Monoculopsis longicornis	0.7	<0.1	0.2	0.3	0.0	0.0	0.0	0.0
Atylus carinata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unidentified	0.0	0.3	0.5	0.3	0.0	<0.1	0.1	<0.1
Total	100.0	99.8	100.1	100.0	100.0	100.0	100.1	99.7

†Seasonal mean calculated from Early, Mid and Late values from this Table.

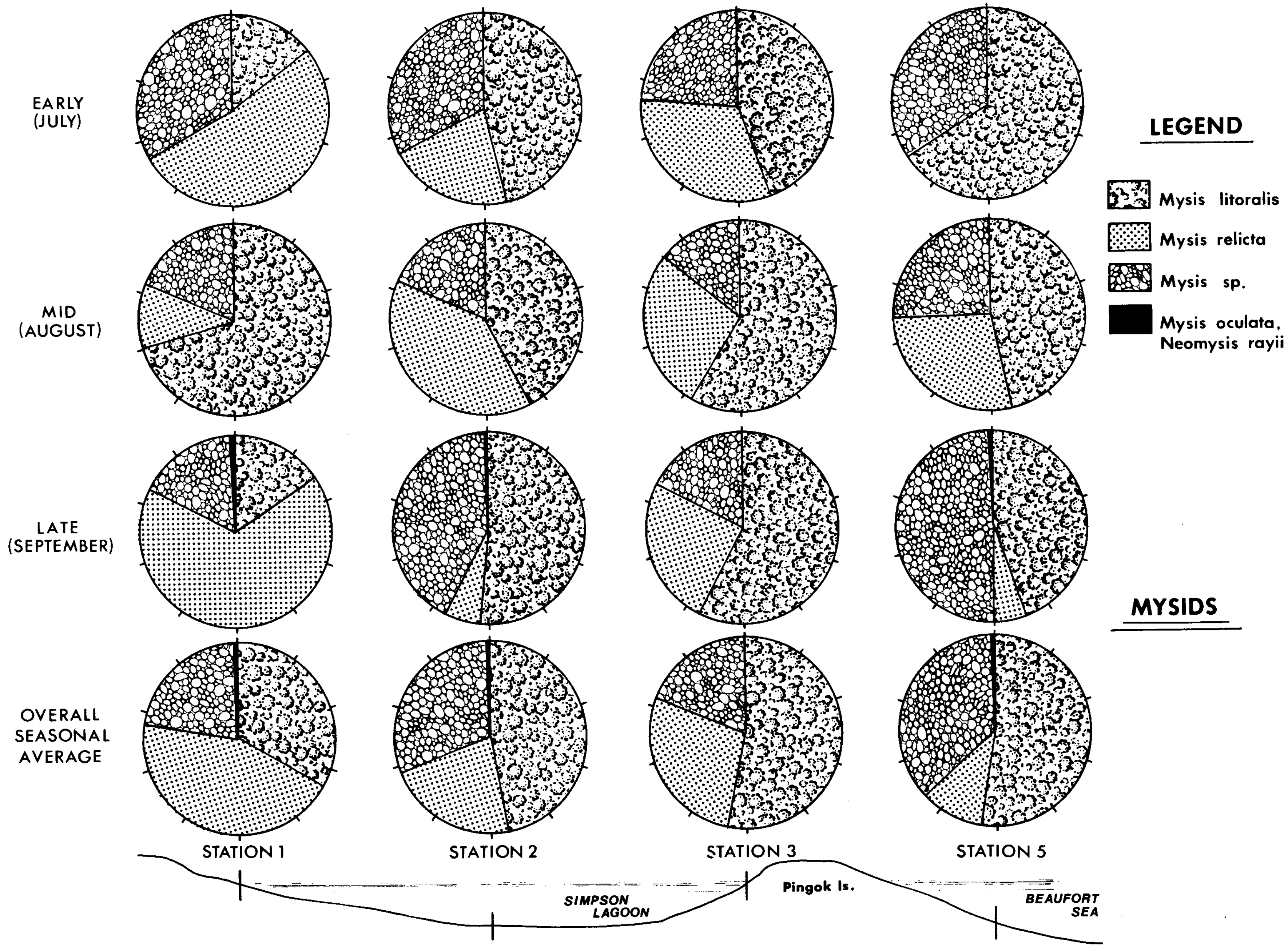

Fig. 4. Relative Wet Weights of Mysid Taxa in Trawl Samples, Simpson, Lagoon, 1977. For numerical details, see Tables 7 and 9 and Appendix I.

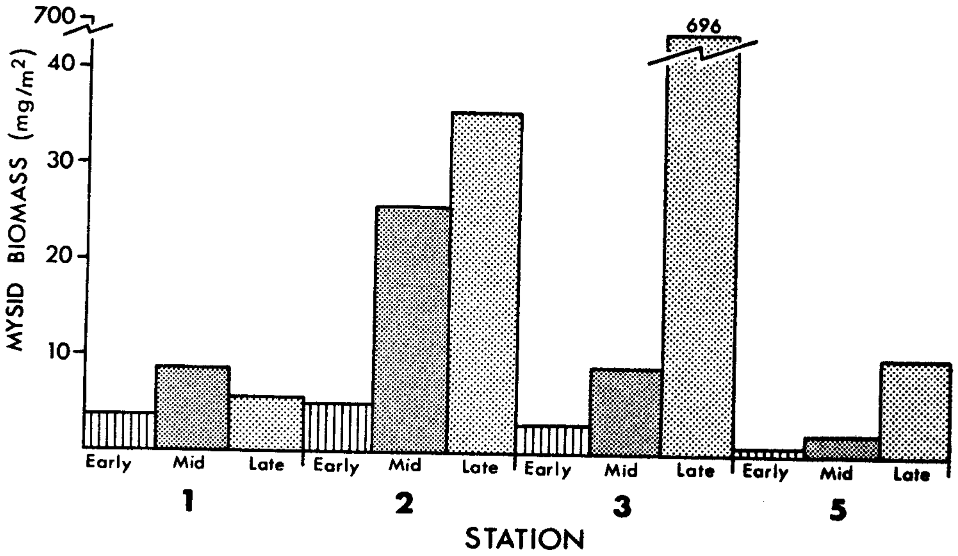

Fig. 5. Seasonal Variation in Total Mysid Biomass in Trawls at Stations 1, 2, 3 and 5 in Simpson Lagoon in 1977.

Table 10. Seasonal Variation of Amphipod Species and All Mysids (No/haul; wet weight g/haul) Collected in Surface Waters with Faber Net (mesh size 1.024 mm) at Stations 1, 2, 3, and 5 in Simpson Lagoon 1977. Season has been divided into three main periods: Early (sampling periods I, II); Mid)sampling periods III, IV, V); Late (sampling periods VI, VIII). Each Faber haul filtered approximately 80.7 m^3.

	STATION 1							
	Early (July)		Mid (August)		Late (September)		Mean	
Amphipod Species	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	$\bar{x}$ No/Haul	$\bar{x}$ Wet Wt. g/Haul
Parathemisto libellula	-	-	-	-	-	-	-	-
Hyperia medusarum	-	-	-	-	-	-	-	-
Hyperiid sp.	-	-	-	-	-	-	-	-
Onisimus glacialis	242.0	3.866	24.0	0.220	12.0	0.125	92.7	1.404
Onisimus littoralis	-	-	-	-	-	-	-	-
Onisimus sp.	-	-	-	-	1.0	0.001	0.3	<0.001
Apherusa glacialis	1.0	0.001	-	-	13.0	0.052	4.7	0.018
Gammarus setosus	-	-	1.0	0.002	1.0	0.001	0.7	0.001
Gammaracanthus loricatus	29.0	0.174	1.0	0.015	-	-	10.0	0.063
Acanthostepheia behringiensis	-	-	1.0	0.001	-	-	0.3	<0.001
Acanthostepheia incarinata	-	-	-	-	-	-	-	-
Gammarus wilkitzkii	-	-	-	-	-	-	-	-
Gammarus sp.	-	-	-	-	-	-	-	-
Weyprechtia pinguis	-	-	-	-	-	-	-	-
Pontoporeia affinis	11.0	0.113	-	-	-	-	3.7	0.038
Monoculopsis longicornis	-	-	-	-	-	-	-	-
Monoculodes sp.	-	-	-	-	-	-	-	-
Oedicerotid	1.0	0.001	-	-	-	-	0.3	<0.001
Atylus carinatus	-	-	-	-	-	-	-	-
Unidentified	-	-	1.0	0.003	-	-	0.3	<0.001
Total Amphipods	284.0	4.155	28.0	0.241	27.0	0.179	113.0	1.525
Mysid	845.0	10.700	73.5	0.45	225.8	2.61	381.4	4.587
*Total No. of Faber Hauls	n=1		n=2		n=4		n=7	

Table 10. (cont'd)

	STATION 2							
	Early (July)		Mid (August)		Late (September)		Mean	
Amphipod Species	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	$\bar{x}$ No/Haul	$\bar{x}$ Wet Wt. g/Haul
Parathemisto libellula	-	-	0.4	0.009	1.3	0.235	0.6	0.081
Hyperia medusarum	-	-	0.2	0.001	0.3	<0.001	0.2	0.001
Hyperiid sp.	-	-	-	-	-	-	-	-
Onisimus glacialis	23.8	0.065	5.8	0.032	52.3	0.588	27.3	0.228
Onisimus littoralis	-	-	-	-	0.7	0.007	0.2	0.002
Onisimus sp.	3.0	0.001	-	-	-	-	1.0	<0.001
Apherusa glacialis	8.5	0.041	19.2	0.039	8.0	0.025	11.9	0.035
Gammarus setosus	0.5	0.008	0.6	0.001	1.0	0.002	0.7	0.004
Gammaracanthus loricatus	0.5	0.002	1.2	0.011	-	-	0.6	0.004
Acanthostepheia behringiensis	-	-	5.0	0.046	-	-	1.7	0.015
Acanthostepheia incarinata	0.3	0.001	1.2	0.003	-	-	0.5	0.001
Gammarus wilkitzkii	-	-	-	-	-	-	-	-
Gammarus sp.	-	-	0.2	<0.001	0.3	<0.001	0.2	<0.001
Weyprechtia pinguis	-	-	-	-	-	-	-	-
Pontoporeia affinis	1.0	0.011	-	-	-	-	0.3	0.004
Monoculopsis longicornis	-	-	-	-	0.3	0.001	0.1	<0.001
Monoculodes sp.	0.2	0.001	0.8	0.001	-	-	0.3	0.001
Oedicerotid	4.0	0.006	-	-	-	-	1.3	0.002
Atylus carinatus	-	-	-	-	-	-	-	-
Unidentified	-	-	1.0	0.001	0.3	0.001	0.4	0.001
Total Amphipods	41.8	0.136	35.6	0.144	64.5	0.860	47.3	0.380
Mysid	173.5	1.192	825.4	6.542	30.0	0.403	343.0	2.712
*Total No. of Faber Hauls	n=6		n=5		n=3		n=14	

Table 10. (cont'd)

Amphipod Species	STATION 3							
	Early (July)		Mid (August)		Late (September)		Mean	
	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	$\bar{x}$ No/Haul	$\bar{x}$ Wet Wt. g/Haul
Parathemisto libellula	-	-	0.2	0.002	2.8	0.412	1.0	0.138
Hyperia medusarum	0.5	0.002	0.8	0.010	0.3	0.004	0.5	0.005
Hyperiid sp.	-	-	0.3	0.002	0.5	0.004	0.3	0.002
Onisimus glacialis	4.0	0.014	23.5	0.107	51.0	0.496	26.2	0.206
Onisimus littoralis	-	-	-	-	0.8	0.005	0.3	0.002
Onisimus sp.	-	-	0.3	0.001	-	-	0.1	<0.001
Apherusa glacialis	24.0	0.029	39.8	0.286	48.5	0.534	37.4	0.283
Gammarus setosus	0.5	0.001	6.8	0.012	6.0	0.007	4.4	0.007
Gammaracanthus loricatus	-	-	0.3	0.007	0.8	0.192	0.4	0.066
Acanthostepheia behringiensis	-	-	17.0	0.174	34.0	0.424	17.0	0.199
Acanthostepheia incarinata	-	-	1.0	0.003	-	-	0.3	0.001
Gammarus wilkitzkii	-	-	0.3	0.004	0.3	0.006	0.2	0.003
Gammarus sp.	-	-	0.5	0.001	-	-	0.2	<0.001
Weyprechtia pinguis	-	-	-	-	-	-	-	-
Pontoporeia affinis	-	-	-	-	0.3	0.002	0.1	0.001
Monoculopsis longicornis	-	-	-	-	-	-	-	-
Monoculodes sp.	-	-	0.3	0.001	0.5	0.001	0.3	0.001
Oedicerotid	-	-	0.2	0.001	-	-	0.1	<0.001
Atylus carinatus	-	-	0.2	0.001	-	-	0.1	<0.001
Unidentified	-	-	-	-	-	-	-	-
Total Amphipods	29.0	0.046	91.5	0.612	145.8	2.087	88.8	0.915
Mysid	0.0	0.0	97.2	1.833	141.8	2.153	79.7	1.329
*Total No. of Faber Hauls	n=2		n=6		n=4		n=12	

Table 10. (cont'd)

Amphipod Species	STATION 5							
	Early (July)		Mid (August)		Late (September)		Mean	
	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wt. g/Haul	No/Haul	Wet Wet. g/Haul	$\bar{x}$ No/Haul	x Wet Wt. g/Haul
Parathemisto libellula	-	-	1.2	0.204	17.0	2.367	6.1	0.857
Hyperia medusarum	0.5	0.003	0.4	0.002	-	-	0.3	0.002
Hyperiid sp.	-	-	0.4	0.001	1.0	0.005	0.5	0.002
Onisimus glacialis	0.5	0.003	14.6	0.193	0.7	0.001	5.3	0.066
Onisimus littoralis	-	-	-	-	-	-	-	-
Onisimus sp.	-	-	-	-	0.7	0.004	0.2	0.001
Apherusa glacialis	26.0	0.061	92.8	0.450	2.0	0.018	40.3	0.176
Gammarus setosus	-	-	4.8	0.114	-	-	1.6	0.038
Gammaracanthus loricatus	-	-	0.2	<0.001	-	-	0.1	<0.001
Acanthostepheia behringiensis	0.5	0.001	6.4	0.118	-	-	2.3	0.040
Acanthosetepheia incarinata	-	-	-	-	-	-	-	-
Gammarus wilkitzkii	-	-	-	-	-	-	-	-
Gammarus sp.	0.5	0.003	0.6	0.003	-	-	0.4	0.002
Weyprechtia pinguis	-	-	0.4	0.001	-	-	0.1	<0.001
Pontoporeia affinis	-	-	0.2	0.003	-	-	0.1	0.001
Monoculopsis longicornis	-	-	0.4	0.002	-	-	0.1	0.001
Monoculodes sp.	-	-	-	-	-	-	-	-
Oedicerotid	-	-	-	-	-	-	-	-
Atylus carinatus	-	-	-	-	-	-	-	-
Unidentified	-	-	-	-	0.7	0.003	0.2	0.001
Total Amphipods	28.0	0.071	122.4	1.091	22.1	2.398	57.5	1.187
Mysids	1.5	0.005	1.2	0.038	1.0	0.003	1.2	0.015
*Total No. of Faber Hauls	n=2		n=5		n=3		n=10	

*Number of samples collected during each main period (Early, Mid, Late) varied as ice, weather and shallow water conditions prevented the collection of some samples.

Table 11. Species Composition of Amphipods (as a % of total amphipod wet weight) Collected in Surface Water With a Faber Net. During the Three Collecting Periods in Simpson Lagoon 1977.

AMPHIPOD SPECIES	STATION 1				STATION 2			
	Early (July)	Mid (August)	Late (September)	Seasonal Mean	Early (July)	Mid (August)	Late (September)	Seasonal Mean
Parathemisto libellula	--	--	--	--	--	6.3	27.3	21.3
Hyperia medusarum	--	--	--	--	--	0.7	P	0.3
Hyperiid sp.	--	--	--	--	--	--	--	--
Onisimus glacialis	93.1	91.3	69.8	92.1	47.8	22.2	68.4	60.0
Onisimus littoralis	--	--	--	--	--	--	0.8	0.5
Onisimus spp.	--	--	0.6	<0.1	0.7	--	--	0.1
Apherusa glacialis	<0.1	--	29.1	1.2	30.2	27.1	2.9	9.2
Gammarus setosus	--	0.8	0.6	0.1	5.9	0.7	0.2	1.1
Gammarus wilkitzkii	--	--	--	--	--	--	--	--
Gammarus spp.		--	--	--	--	P	P	P
Gammaracanthus loricatus	4.2	6.2	--	4.1	1.5	7.6	--	1.1
Acanthostepheia behringiensis		0.4	--	<0.1	--	31.9	--	4.0
Acanthostepheia incarinata	--	--	--	--	0.7	2.1	--	0.3
Weyprechtia pinguis	--	--	--	--	--	--	--	--
Pontoporeia affinis	2.7	--	--	2.5	8.1	--	--	1.1
Monoculopsis longicornis	--	--	--	--	--	--	0.1	0.1
Monoculodes sp.	--	--	--	--	0.7	0.7	--	0.3
Oedicerotid	<0.1	--	--	<0.1	4.4	--	--	0.5
Atylus carinatus	--	--	--	--	--	--	--	--
Unidentified	--	1.3	--	<0.1	--	0.7	0.1	0.3
Total	100.0	100.0	100.1	100.0	100.0	100.0	99.8	100.2

Table 11. (cont'd)

AMPHIPOD SPECIES	STATION 3				STATION 5			
	Early (July)	Mid (August)	Late (September)	Seasonal Mean	Early (July)	Mid (August)	Late (September)	Seasonal Mean
Parathemisto libellula	--	0.3	19.7	15.1	--	18.7	98.8	72.2
Hyperia medusarum	4.4	1.6	0.2	0.6	4.2	0.2	--	0.2
Hyperiid sp.	--	0.3	0.2	0.2	--	0.1	0.2	0.2
Onisimus glacialis	30.4	17.5	23.8	22.5	4.2	17.7	<0.1	5.6
Onisimus littoralis	--	--	0.2	0.2	--	--	--	--
Onisimus spp.	--	0.2	--	<0.1	--	--	0.2	0.1
Apherusa glacialis	63.0	46.7	25.6	30.9	85.9	41.3	0.8	14.8
Gammarus setosus	2.2	2.0	0.3	0.8	--	10.5	--	3.2
Gammarus wilkitzkii	--	0.7	0.3	0.3	--	--	--	--
Gammarus spp.	--	0.2	--	<0.1	4.2	0.3	--	0.2
Gammaracanthus loricatus	--	1.1	9.2	7.2	--	P	--	P
Acanthostepheia behringiensis	--	28.4	20.3	21.8	1.4	10.8	--	3.4
Acanthostepheia incarinata	--	0.5	--	0.1	--	--	--	--
Weyprechtia pinquis	--	--	--	--	--	0.1	--	<0.1
Pontoporeia affinis	--	--	0.1	0.1	--	0.3	--	0.1
Monoculopsis longicornis	--	--	--	--	--	0.2	--	0.1
Monoculodes sp.	--	0.2	0.1	0.1	--	--	--	--
Oedicerotid	--	0.2	--	<0.1	--	--	--	--
Atylus carinatus	--	0.2	--	<0.1	--	--	--	--
Unidentified	--	--	--	--	--	--	0.1	0.1
Total	100.0	100.1	100.0	99.8	99.9	100.2	100.1	100.2

Table 12. Number of Amphipod Species Collected at Each Station During Each Collection Period in Trawl and Faber Samples.

Station	Period	Trawl Samples	Faber Samples
1	Early	4	5
	Mid	6	4
	Late	8	4
2	Early	2	8
	Mid	5	10
	Late	10	8
3	Early	4	4
	Mid	13	15
	Late	7	12
5	Early	3	5
	Mid	7	12
	Late	7	5

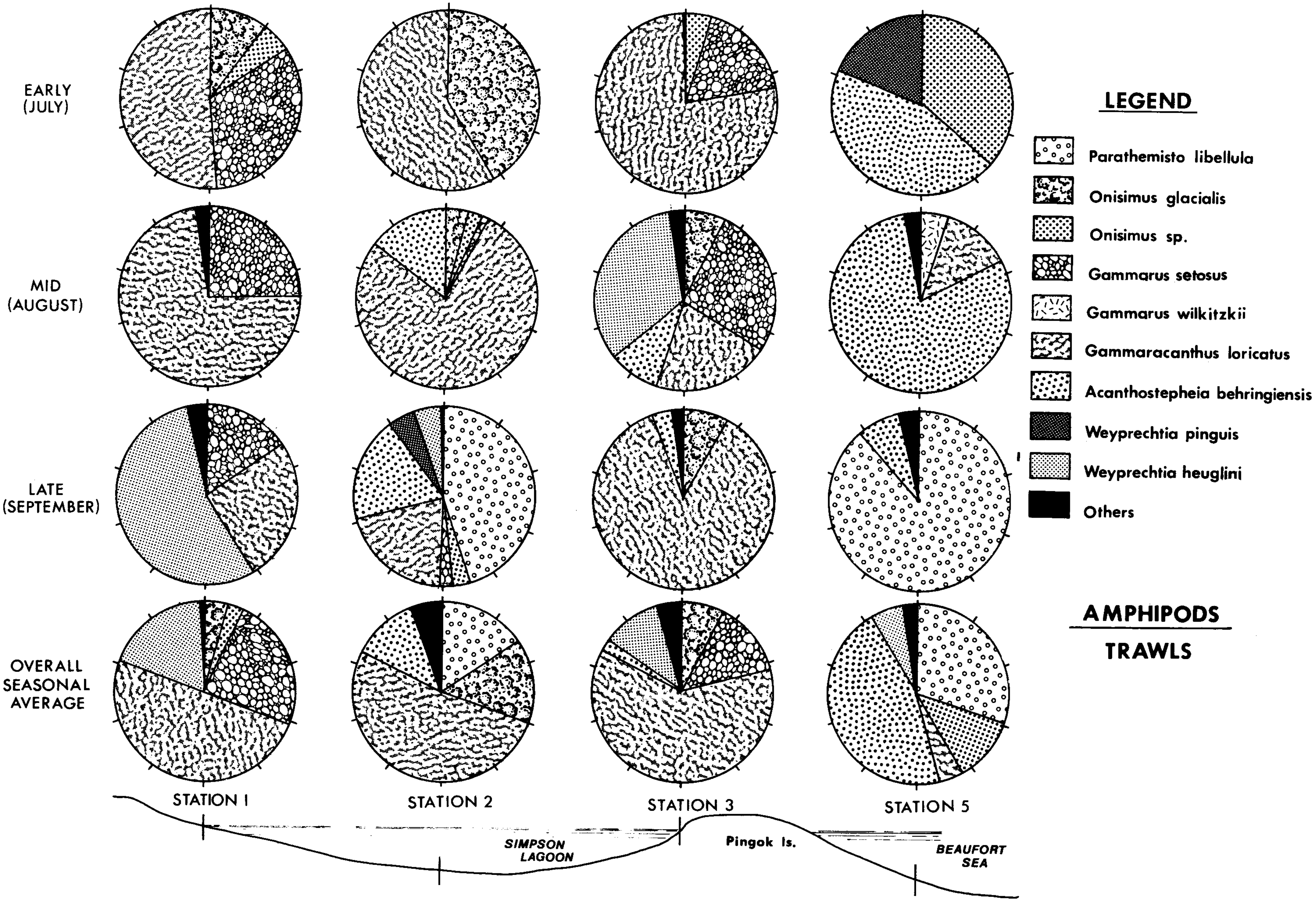

Fig. 6. Relative Wet Weights of Amphipod Taxa in Trawl Samples, Simpson Lagoon, 1977. For numerical details, see Tables 7 and 9 and Appendix I.

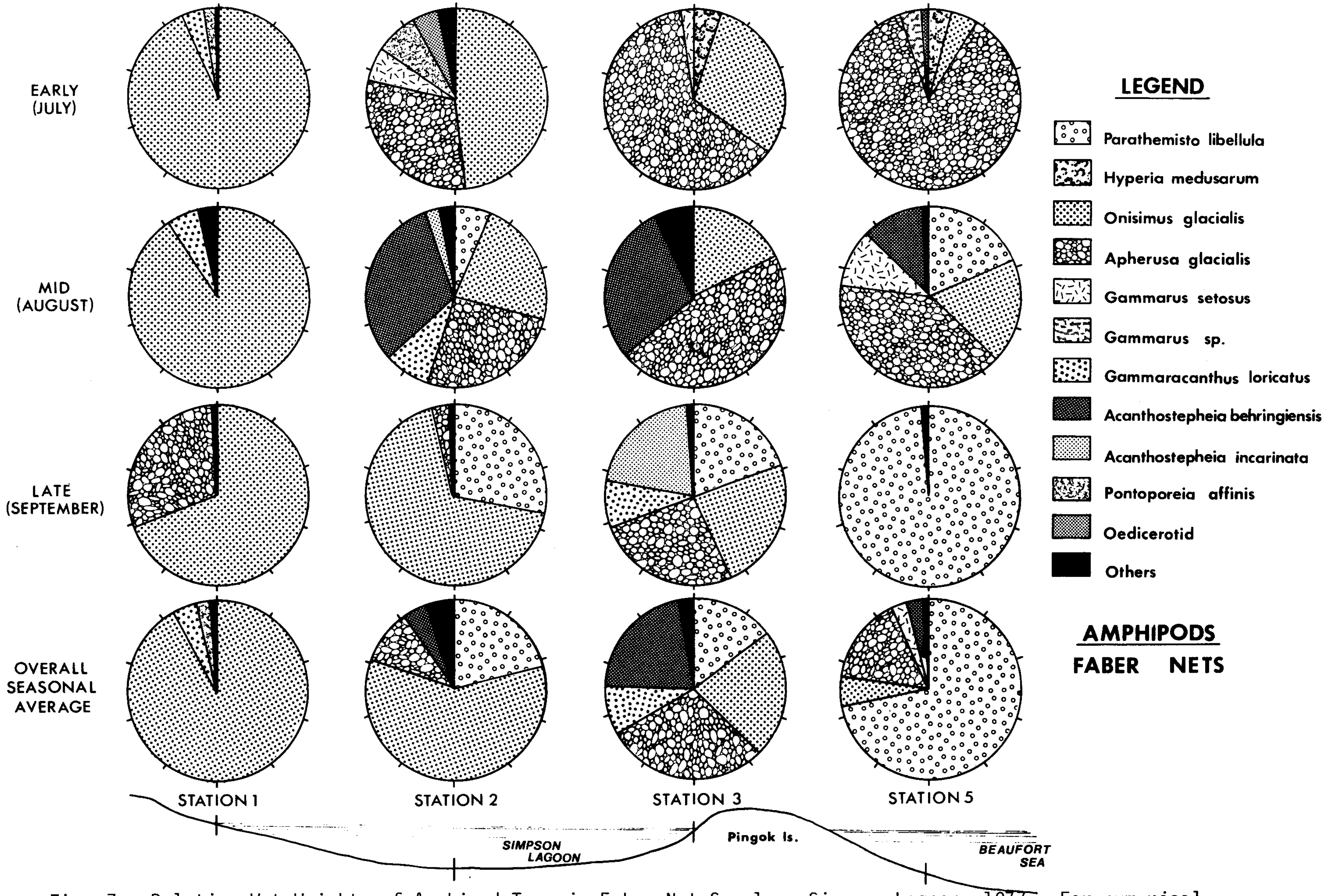

Fig. 7. Relative Wet Weights of Amphipod Taxa in Faber Net Samples, Simpson Lagoon, 1977. For numerical details, see Tables 10 and 11 and Appendix I.

$P=0.042$, $N=4$, $K=3$). Crane (1974), in contrast, recorded high mysid densities at Station 5-type areas (approx. 9-133 mysids/m^2). The discrepancy may be due to mesh sizes used (see comparison of sampling gear).

Results from the Faber hauls through surface waters also varied widely among stations and collection periods, with mysid biomass being significantly lower at Station 5 than at Stations 2 and 3 (Friedman $X^2=6.49$, $P<0.052$, $N=6$, $K=3$) (insufficient seasonal data from Station 1 to be included in the calculation). This probably reflects the diver observation (in the lagoon) that mysids concentrated near the bottom; few mysids were seen in the water column.

The high variability of trawl and Faber net results indicate that mysids are patchy in distribution within the lagoon. Diver observations indicate a similar range of variation (12-1100/m^2). Crane (1974) found mysids to be ubiquitous but patchy in distribution in Simpson Lagoon (range 66-4192/trawl) and in offshore Beaufort Sea waters (range 7744-120,000/trawl).

Mysis relicta (Loven) is widely distributed, from New York State to the high arctic islands (Johnson 1964). In Alaska, it is generally associated with fresh or brackish water but is also found in marine water (MacGinitie 1955; Holmquist 1963). In high arctic freshwater lakes, *M. relicta* has a two-year life cycle, with young being released from the brood pouch between May and July. Eggs develop in September and are carried over winter. *M. relicta* exhibits sexual dimorphism with mature females being larger than males (Lasenby and Langford 1972).

Mysis litoralis (Banner) is a circumpolar, arctic and subarctic species. Adults range in length from 12-29 mm. *M. litoralis* are tolerant of varying salinities but prefer marine water (Holmquist 1963).

Our information about the temporal and spatial distributions of mysids is consistent with previous information about habitats of particular species. *M. relicta*, a nearshore brackish-water mysid, was collected at lagoon stations in July, but was not found at Station 5 and then only in small quantities, until mid- and late collections. Conversely, *M. litoralis*, a marine species, was least abundant at Station 1 during early collections, reaching a peak in mid-summer and then declining in late collections. Generally, these results indicate movements of mysids into, out of, and within Simpson-Lagoon during the summer.

The fluctuations in mysid densities in the water column may be an artifact of lagoon shallowness (<3.0 m). During high winds, wave action in shallow lagoon waters resuspends the detritus layer and epibenthic invertebrates into the water column. At Station 5, where low mysid densities were common, the water was deeper (10 m) and presumably benthic environments were disturbed less by waves.

Amphipods

Seventeen species of amphipod were collected in trawl and Faber net samples in Simpson Lagoon in 1977 (Tables 7, 10). In general, the amphipod species collected in the present study were known from previous studies to occur along the Alaskan Beaufort Sea coast (MacGinitie 1955; Crane 1974; Feder and Schamel 1976; Feder *et al.* 1976). However, the species count is higher than reported in any previous nearshore study in this area, probably because we sampled over the complete open-water season (early June to late September).

The species composition and biomass of amphipods in trawl and Faber samples varied widely among stations and collection periods (Tables 7, 9, 10, 11, 12; Figs. 6, 7). In trawl samples *Gammaracanthus loricatus, Onisimus glacialis* and *Gammarus setosus* were common to all stations but only *G. loricatus* was collected at all stations and time periods. In Faber hauls the same three species plus *Apherusa glacialis* were common. *O. glacialis* was the only species found in all Faber samples, but *A. glacialis* was absent only during the mid-period at Station 1 (Table 10).

The variations in abundances, biomasses and species composition of amphipods collected at each station indicate a patchy distribution of epibenthic and pelagic amphipods in Simpson Lagoon and the nearshore areas. Diver observations also indicated that there was great spatial variability in densities of amphipods (range 0-400/m^2), as did the high standard deviations (>the mean) for samples collected by Crane (1974) in the same area. The patchy distribution of amphipods in arctic waters has been noted by numerous authors (MacGinitie 1955; Crane 1974; Feder *et al.* 1976; Griffiths *et al.* 1977).

Parathemisto libellula, which is typically a pelagic amphipod, was not collected in July, was present in August, and was most abundant in September. It was never collected at Station 1, and was most abundant at Station 5. Large numbers were washed up in windrows on the beaches during September. The occurrence of *P. libellula* and other hyperiids (marine pelagic amphipods) in Faber hauls and trawl samples at Stations 2 and 3 suggests that amphipods moved from the ocean into the lagoon. Periodically during the open-water season, plumes of marine water were observed moving into the lagoon through entrances between the barrier islands. Amphipods probably were carried into the lagoon with this water as well as with water entering the ends of the lagoon. However, *Parathemisto* apparently did not reach the nearshore mainland, since they were absent from Faber and trawl samples at Station 1.

Similar onshore movements of marine invertebrate species are suggested by Feder and Schamel (1976), who suggest that portions of offshore populations of these species may reoccupy nearshore areas during the open-water season.

Results of trawl and Faber net samples suggest movements of amphipods into, out of, and within Simpson Lagoon over the season. These movements are possibly augmented by wind-driven currents and storm surges, which provide a means of dispersal for adult and immature amphipods. The high flushing rate of the lagoon, 0.2 times/day on the average and 0.8 times/day during high winds (>20 knots) (RU 531, OCEANOGRAPHY) and typically in an east-west direction, may carry different species of amphipods into and out of Simpson Lagoon at various times through the season. Basically, two types of movements of amphipods into and out of the lagoon are postulated:

1. Movements parallel to the shore. Longshore movements might be a consequence of, or at least assisted by, wind-generated currents which typically move in an east-west direction during the open-water season.
2. Movements between shallow estuarine and deeper marine waters. During the open water period these movements may depend importantly on storm-driven wave and current action.

Although biomass estimates vary widely within stations and collections periods, there was no significant difference (Friedman X^2=5.8, P=148, N=3, K=4) among stations over the season, however total amphipod biomass increased significantly as the season progressed (Friedman X^2=6.5, P=0.042, N=4, K=3). Minimum amphipod biomass at all stations occurred during early collections, suggesting that migrations of amphipods into the lagoon, growth of the amphipods already present, or more likely some combination of the two, account for higher biomass of samples taken later in the season (Fig. 8).

Major Species of Amphipods

A brief discussion of each of the important amphipod species collected in trawl samples, Faber hauls and fish and bird stomachs in Simpson Lagoon follows.

Parathemisto libellula (Lichenstein). This species is ubiquitous in the Arctic, but in the Pacific it is found only in the Bering and Okhotsk Seas. It is predominantly carnivorous but also ingests some vegetable matter (Dunbar 1946). *P. libellula* is the largest member of the genus (up to 60 mm long) and is found in waters as deep as 2500 m (Shoemaker 1955). It has a two-year life cycle in arctic waters and spawns from September to May or June (Dunbar 1957). The young are brooded in the female's marsupium and are released when they reach a length of 2-3 mm. *P. libellula* did not appear in the oldsquaw diet until the September collections, at about the same time *P. libellula* first appeared in trawl samples. Glaucous gulls were observed feeding on windrows of *P. libellula* that had been stranded on the seaward side of Pingok Island in September.

Onisimus glacialis (G.O. Sars). This gammarid amphipod is pelagic, circumpolar and arctic in distribution (Ekman 1953). In Alaska this species seems to feed mainly on crustaceans, but also on diatoms, algae, worms and organic detritus (Broad 1977). In Lancaster Sound, N.W.T., this amphipod was generally associated with ice or in the upper 50 m of water (LGL Ltd. unpubl. data). This species was an important amphipod in the diets of both arctic cisco and oldsquaw ducks.

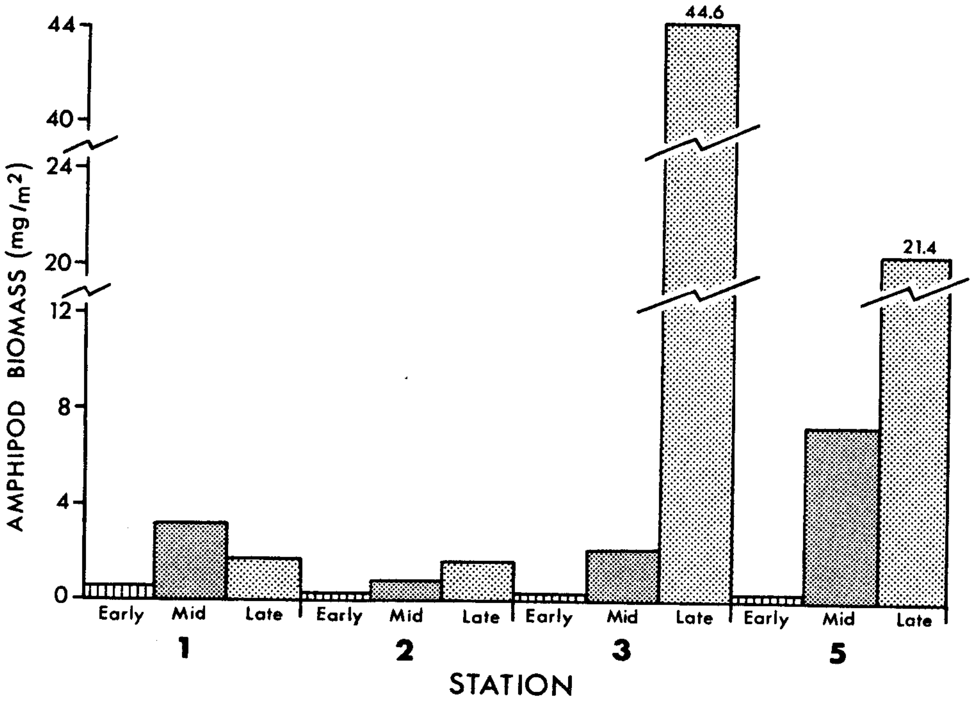

Fig. 8. Seasonal Variation in Total Amphipod Biomass in Trawls at Stations 1, 2, 3 and 5 in Simpson Lagoon in 1977.

Apherusa glacialis (Hansen). This pelagic amphipod is circumpolar, arctic-subarctic, and usually occurs in the upper layers of water (Dunbar 1957). In the Point Barrow region this species has been found associated with the underside of ice, but it also occurs from shallow water down to 300 m (Shoemaker 1955). Four oldsquaws collected on the ocean side of Pingok Island among many small ice pans had consumed large numbers of *A. glacialis*. Inspection of the undersurfaces of these small ice pans revealed swarms of *A. glacialis*. Arctic cisco also fed heavily on *A. glacialis* throughout the season.

Gammarus setosus (Dementieva). This circumpolar species is predominantly carnivorous (Steele and Steele 1970) and generally inhabits intertidal and shallow water (Ellis and Wilce 1961). *G. setosus* is euryhaline and can survive quite low salinity (Steele and Steele 1970). Only one brood is produced each year with young being released in early spring when plant production begins (Steele and Steele 1970). Broad (1977) speculates that this species feeds mainly on diatoms and organic detritus. Oldsquaw ducks and arctic cisco consumed *G. setosus* during the early collecting period (24 June-3 August) but thereafter their importance in the diets decreased.

Gammaracanthus loricatus (Sabine). This circumpolar amphipod was found from shallow water to 35 m at Point Barrow (MacGinitie 1955; Shoemaker 1955). Ellis and Wilce (1961) found *G. loricatus* in Admiralty Inlet (Baffin Island) under boulders and among rockweeds. This species is at times pelagic and is found on the underside of permanent ice in the Arctic Basin (Barnard 1969). *G. loricatus* is a hardy species and can tolerate great changes in salinity (MacGinitie 1955). Broad (1977) found this species to be omnivorous in feeding habit. This species appeared only incidentally in the diets of oldsquaw ducks and arctic cisco.

Acanthostepheia behringiensis (Lockington). This amphipod is a widely distributed arctic species and reaches lengths up to 37 mm (Shoemaker 1955). MacGinitie (1955) collected *A. behringiensis* at Point Barrow in water 3-4½ m deep. This species feeds mainly on diatoms but is probably omnivorous (Broad 1977). *A. behringiensis* was not an important food item in the diets of either oldsquaw ducks or arctic cisco.

Isopods

Densities of isopods collected in this study were within the ranges reported from other studies along the Beaufort Sea coast (Table 2).

Crane (1974) speculated that isopods in Simpson Lagoon emigrate as freeze-up progresses, because of the associated increases in salinity below the ice, and reoccupy the lagoon each spring from offshore areas. In light of this postulation, the high isopod biomass encountered at Station 1 in July (Table 7) was surprising, since this station is the farthest one from marine water. However, the Harrison Bay area is ice-free in the spring well before the lagoon, and it is possible that the isopods came from this area.

Isopods were found in the diets of fish and birds during this study, but not in significant numbers. Detailed life history information about the major isopod species (*Saduria* [*Mesidotea*] *entomon*) in Simpson Lagoon is discussed by Crane (1974).

Tunicates

Tunicates were collected throughout the season at all stations except Station 5 (Table 7). The presence of numerous tunicates, a sessil species, at all lagoon stations indicates that they probably overwintered in the lagoon. The large tunicate biomass at Station 1 early in the season and at Station 3 late in the season suggests that these animals may be able to withstand freezing. Many of these tunicates were large, and had apparently been present for a considerable period. It is unlikely they could have moved either out of the deep central portion earlier in the year or back into deeper waters late in the season. However, some redistribution of tunicates from the central lagoon may occur as a result of storm-generated turbulence.

Tunicates were not found in any of the fish stomachs and in only one bird stomach (see RU 467, FISH and AVIAN ECOLOGY sections).

Bivalves

Bivalves were present in low densities at all stations throughout the season, even in the shallow waters (<2 m) at Station 1. It appears that bivalves, like tunicates, are either able to withstand freezing or are able to essentially migrate between the shallow and deep central portions of the lagoon. Certain molluscs are known to survive freezing into ice (Scholander *et al.* 1953, cited in Holmquist 1963), and other molluscs have been found living in shallow water just under the ice (Crane 1974). Molluscs were also found in anoxic condition in Safety Lagoon near Nome (McRoy 1969). Thus, it is not unreasonable to assume that bivalves could survive freezing and ice stress associated with shallow nearshore areas.

Bivalves did not appear in the diets of any of the fish species. However, they represented 16.3% and 6% of the stomach contents of oldsquaw ducks during the early and mid-season sampling periods, respectively (RU 467, AVIAN ECOLOGY section).

Other Taxa

Several other taxonomic groups were collected in the trawls, including cnidarians, priapulids, bryozoans, chaetognaths, copepods, cumaceans, polychaetes, decapods and pteropods (Table 8, Fig. 3). Generally, these groups were present in small numbers and except for copepods were not important as food items for either birds or fish (see RU 467, FISH and AVIAN ECOLOGY sections).

Early Season Movement of Epibenthic Invertebrates

Prior to breakup epibenthic trawl samples were collected in open leads around Pingok Island (Fig. 9) to determine whether mysids and amphipods recolonized shallow nearshore areas by way of the ocean. Although the results were highly variable (Table 13), there was an indication that recolonization of the lagoon was probably from the ocean, since early in the season amphipods and mysids were more numerous at ocean sites and in the channel between islands than at lagoon sites. Most mysids and amphipods collected at this time were small (length $\leq$ 5 mm) and had apparently been recently released from adult brood pouches. No adults of either group were collected in any of the samples.

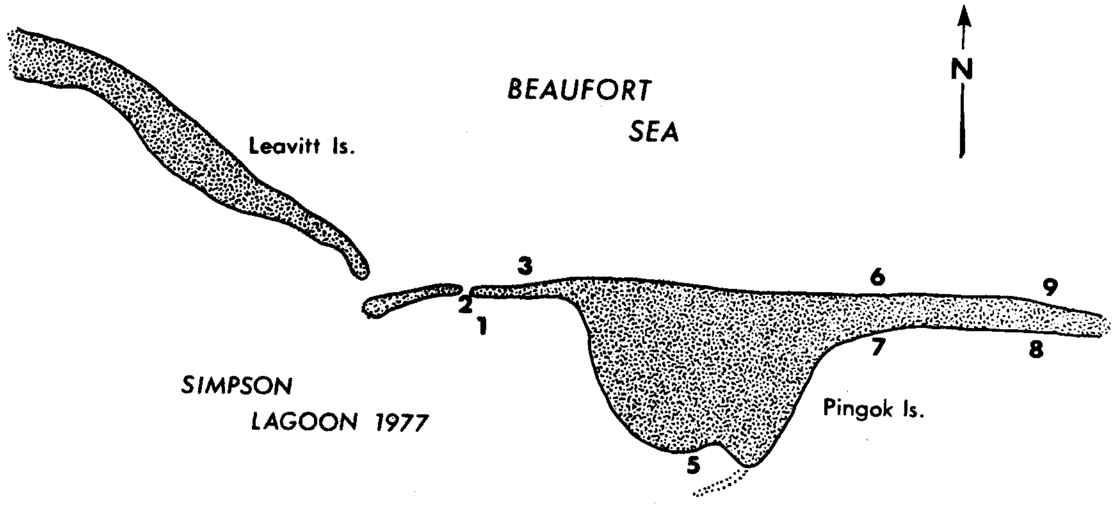

Fig. 9. Sites of Early Season (Pre-breakup) Epibenthic Trawls, 17 June - 3 July 1977. All tows conducted with 10 x 14 cm trawl with 0.333 mm mesh; all tows 10 m in length.

Table 13. Numbers of Mysids and Amphipods Collected in Epibenthic Trawl Samples in Nearshore Leads Around Pingok Island 17 June - 3 July, 1977.

Date	*Site 1, 2 No/m^2		Site 3 No/m^2		Site 5 No/m^2		Site 6 No/m^2		Site 7 No/m^2		Site 8 No/m^2		Site 9 No/m^2	
	Amph.	Mysid	Amph.	Mysid	Amph.	Mysid	Amph.	Mysid	Amph.	Mysid	Amph.	Mysid	Amph.	Mysid
17/06/77	400	0	NA	NA	NA	NA	5.0	0.0	NA	NA	0	0	NA	NA
19/06/77	171	0	26	214	19	0.7	21	70	0	0	0	7	13	9
21/06/77	321	1.0	2	2	0.0	17	50	143	43	0.0	1.0	0	9	10
24/06/77	59	153	ice over	ice over	50	1414	ice over	ice over	9	68	NA	NA	ice over	ice over
26/06/77	221	1150	ice over	ice over	14	1571	ice over	ice over	100	7243	NA	NA	ice over	ice over
03/07/77	250	2985	50	6	129	1407	ice over	ice over	NA	NA	NA	NA	ice over	ice over

*See figure 9 for location of sampling sites.

NA Data not available.

Zooplankton Biomass

The zooplankton biomass (wet weight in g/m^3) for Stations 1-7 during each sampling period is shown in Table 14. There was wide variability among time periods and stations (Table 14, Fig. 10). No significant difference was found among lagoon Stations 1, 2 and 3 (Friedman χ^2=2.00, P=0.486, n=7, k=3), or among lagoon stations and Station 5 (Friedman χ^2=5.00, P=0.194, n=6, k=4). Consequently the data from the four stations have been grouped. Results show a rapid increase in biomass early in the season, a mid-season leveling-off period, and a rapid decline to a relatively constant level late in the season.

Generally, the zooplankton biomass estimates from Simpson Lagoon are similar to estimates of zooplankton in surface waters of other productive areas in Arctic regions (Table 15). Some tentative speculations concerning relationships of zooplankton and phytoplankton standing crop can be drawn from Fig. 10. Chlorophyll-a concentrations are used as a measure of phytoplankton (see Appendix IV). Zooplankton biomass increased early in the season and leveled off toward the end of the open-water season, but chlorophyll-a levels followed an opposite pattern. The development of high zooplankton biomass thus followed shortly after the occurrence of high phytoplankton standing crop, suggesting synchronization of the reproduction of some zooplankton species with periods of phytoplankton abundance.

Microcalanus pygmaeus, a deep cold-water marine copepod, was present in all zooplankton hauls at Station 5 and absent from all hauls at Station 2. This suggests the potential presence of two distinct water masses:

1. Cold marine water lying offshore of the barrier island.
2. Warmer, less saline water lying along the mainland shore.

Oceanographers have postulated that under normal summer circulation regimes these two waterbodies retain their identity throughout the coastal zone from Point Barrow to Demarcation Point (J.B. Matthews, pers. comm.). Temperature and salinity measurements made during summer also support this concept (Appendix IV). Water at Station 2 is warmer (mean=4.9°C, range 1.5-6.5°C) and less saline (mean=21 ppt, range=14-28 ppt) than water at Station 5.(temperature mean=2.0°C, range 0.4-4.5°C; salinity mean=26 ppt; range 22-30 ppt).

Table 14. Zooplankton Biomass (Wet Weight g/m^3) From Each Sampling Period, Simpson Lagoon 1977.

		STATION						
Date	Sampling Period	1 g/m^3	2 g/m^3	3 g/m^3	4 g/m^3	5 g/m^3	6 g/m^3	7* g/m^3
11/7	I	.036	.016	.008	.008	-	-	.021[+]
22/7	II	.126[+]	.049[+]	.016	.004	.014	.162	.014
31/7	III	.299	.053	.151	.982	.004	.277	.056
15/8	IV	.348	.153	.094	.434	.045	.472	.308
25/8	V	.174	.248	.195	-	.186	.386	.223
5/9	VI	0.008	.040	.096	.030	.032	.047	
16/9	VII	.065	.054	.056	.012	.015	.456	.250
Mean		.151	.088	.088	.245	.049	.300	.145

*Station 7 not included in calculations as it was not sampled on the same day as the other stations.

[+] These values are estimates (% of total sample) due to large amount of organic matter in sample.

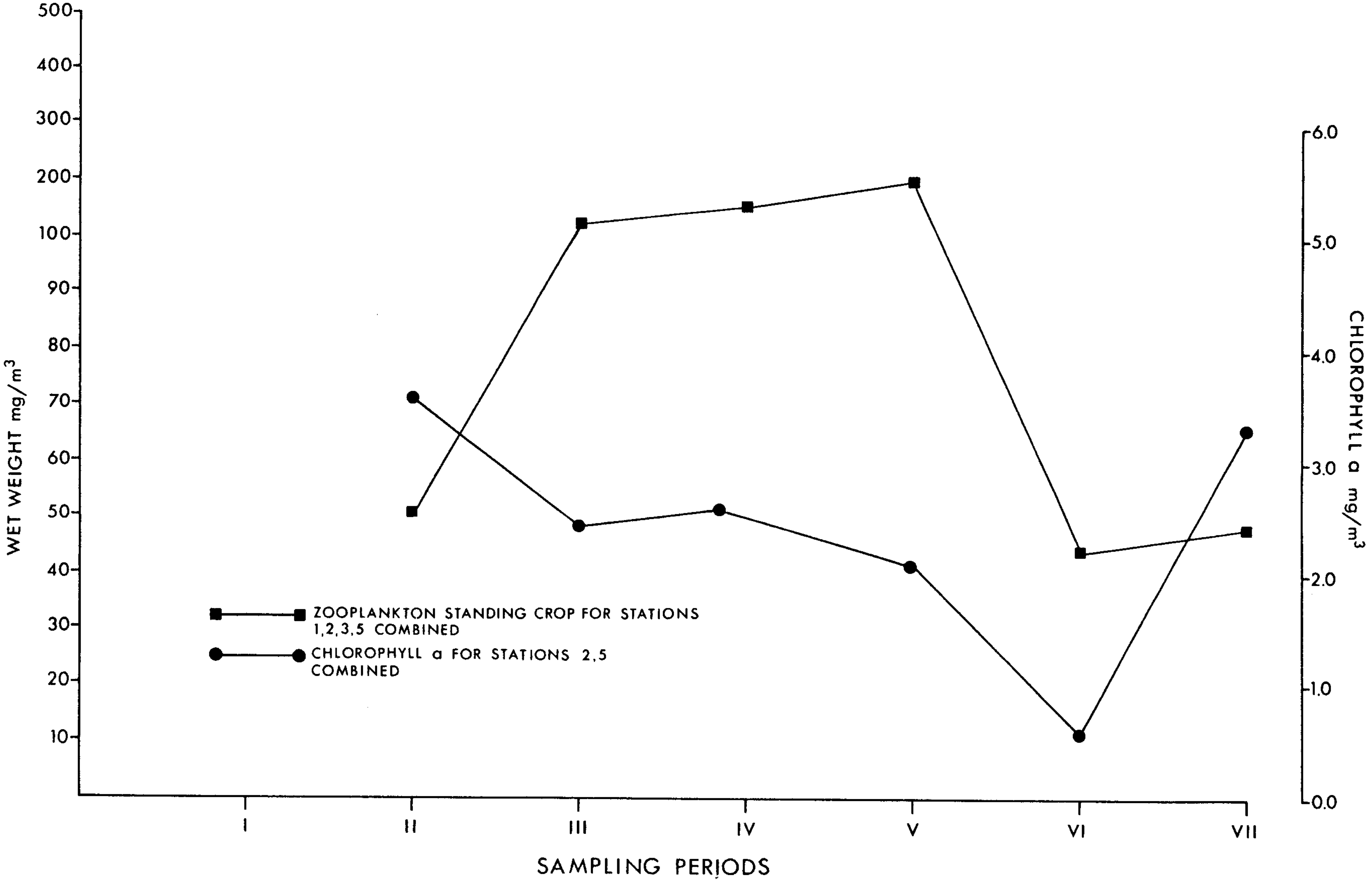

Fig. 10. Seasonal Variation in Zooplanktoh Standing Crop and Chlorophyll-a Concentration, Simpson Lagoon, 1977.

Table 15. A Comparison of Zooplankton Biomass From Several Northern Regions.

Location	Depth (m)	Season	Biomass (mg/m^3)	Reference
Bering Sea, Alaska	0-800	Summer over 15 years	180-840	Motoda and Minoda 1974
Frobisher Bay, N.W.T. (Baffin Is.)	0-50	Summer	160-330	Grainger 1971
Foxe Basin, N.W.T.	0-50	Summer	26-51	Grainger 1962
S.W. Foxe Basin	0-100	Summer	55	Grainger 1962
Assistance Bay (Cornwallis Is.), N.W.T.	0-50	July-August	80	Mohammed and Grainger 1974
Slidre Fjord (Ellesmere Is.), N.W.T.	0-50	July-August	84	Mohammed and Grainger 1974
Creswell Bay, (Somerset Is.), N.W.T.	0-40	July-August	192	Mohammed and Grainger 1974
Lancaster Sound, N.W.T.	0-150	July-September		LGL unpublished data 1976
Cape Warrender			240 (121-696)	
Cape Sherard			246 (164-406)	
East Mid-Sound			181 (79-306)	
Middle East-Sound			284 (84-446	
Navy Board Inlet			263 (92-612)	
West Mid-Sound			171 (59-293)	
Simpson Lagoon				
Station 1	Surf	July-September	151 (8-299)	
Station 2			88 (15-248)	
Station 3			88 (8-151)	
Station 4			245 (4-982)	
Station 5			49 (4-186)	
Station 6			300 (47-456)	
Station 7			145 (14-308)	

CONCLUSIONS

1. Invertebrate Use of Simpson Lagoon

Invertebrates representing 15 major taxonomic groups were collected in the Simpson Lagoon study area during the open-water season, but four groups--amphipods, mysids, isopods and tunicates--accounted for most of the biomass (86.9-99.9%) in trawl samples. However SCUBA diver estimates of the density of the epibenthic invertebrates (organisms living on or near the bottom) were 10^2 to 10^3 times greater than the estimates obtained by traditional trawl methods.

The abundance of epibenthos in shallow water environments, compared to abundance of the more infaunal species, can be attributed to the mobile lifestyle of epibenthos, which allows them to annually recolonize nearshore areas that freeze solid each winter. In 1977, mysids and amphipods were the most abundant components of the Simpson Lagoon epibenthos. Mysid densities of 12-1100/m^2 and amphipod densities of 0-450/m^2 were estimated by divers. Principal mysid species were *Mysis litoralis* and *M. relicta*; the principal amphipods were *Gammaracanthus loricatus, Onisimus glacialis, Gammarus setosus* and *Apherusa glacialis*.

Densities of epibenthos varied spatially and temporally, suggesting a patchy distribution. Data taken at intervals in summer indicated that large-scale movements of mysids and amphipods occur in Simpson Lagoon during the open-water season. Some indication of springtime reinvasion of nearshore habitat from the ocean was noted as the lagoon ice melted.

2. Trophic Relations

Epibenthic invertebrates are the major source of food for the more abundant species of fish and birds in the lagoon ecosystem. The estimated biomass of mysids and amphipods was at least one or two orders of magnitude greater than the daily consumptive capacity of predators in 1977, and invertebrate biomass tended to increase through the summer. Detritus, which covers much of the lagoon bottom, may directly or indirectly furnish food for some epibenthic invertebrates.

RECOMMENDED FURTHER RESEARCH

Needs for further study are addressed in RU 467, OVERVIEW AND SYNTHESIS section: RECOMMENDED FURTHER RESEARCH.

SUMMARY OF 4th QUARTER OPERATIONS

Fourth quarter operations are summarized in RU 467, OVERVIEW AND SYNTHESIS section: SUMMARY OF 4th QUARTER OPERATIONS.

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Appendix I. Numbers and Wet Weights (Biomass) of Organisms Collected per Trawl Sample During the Sample During the Seven Sampling Periods in Simpson Lagoon, 1977. P = organism was present but in such small quantities it could not be counted or weighed.

TAXON OR SPECIES	STATION 1															
	PERIOD I		PERIOD II		PERIOD III		PERIOD IV		PERIOD V		PERIOD VI		PERIOD VII		MEAN	
	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)
Cnidarians	1	.015	5	2.75	9	.761	10	.210	1	.145	1	.190	-	-	4	.582
Priapulids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bryozoans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetognaths	1	.009	3	.025	2	.020	1	.010	-	-	1	.010	-	-	1	.011
Mysids																
Mysis oculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mysis litoralis	11	.171	6	.796	6	.077	1	.020	284	17.359	54	1.676	5	.174	52	2.897
Mysis relicta	103	1.645	60	1.943	30	.772	28	.511	26	1.381	141	8.136	7	.183	56	2.086
Mysis sp.	86	1.124	125	1.100	3	.105	3	.429	49	3.892	67	1.908	6	.227	49	1.256
Neomysis rayii	-	-	-	-	-	-	-	-	-	-	-	-	1	.001	P	P
TOTAL	200	2.941	190	3.840	38	.958	32	.960	359	22.657	263	11.720	18	.584	157	6.237
Euphausiids	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Amphipods																
Paroediceros lycaneus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parathemisto libellula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyperia medusarum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyperiid spp.	-	-	-	-	-	-	1	.015	-	-	-	-	-	-	P	.002
Onisimus glacialis	11	.093	2	.008	3	.018	1	.014	8	.096	2	.016	-	-	4	.005
Onisimus littoralis	-	-	-	-	-	-	-	-	-	-	1	.002	-	-	P	.001
Onisimus spp.	13	.051	2	.009	2	.004	-	-	1	.005	7	.036	1	.003	4	.015
Boeckosimus affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apherusa glacialis	-	-	-	-	-	-	-	-	-	-	1	.001	-	-	P	P
Gammarus setosus	2	.119	4	.231	19	1.613	2	.412	4	.281	5	.542	1	.019	5	.460
Gammarus wilkitzkii	-	-	-	-	-	-	-	-	-	-	-	-				
Gammaracanthus loricatus	5	.352	2	.167	18	2.336	-	-	24	4.579	2	.892	-	-	7	1.189
Acanthostepheia behringiensis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weyprechtia pinguis	-	-	-	-	-	-	-	-	1	.017	1	.048	-	-	P	.009
Weyprechtia heuglini	-	-	-	-	-	-	-	-	-	-	2	2.047	-	-	P	.292
Pontoporeia affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculopsis longicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculodes packardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atylus carinatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	31	.612	9	.416	41	3.970	4	.441	38	4.977	20	3.583	2	.022	21	2.003
Isopods	36	70.300	2	2.260	1	3.930	-	-	3	1.750	5	2.215	2	8.731	7	12.741
Copepods	-	-	5	.001	-	-	-	-	-	-	1	.010	-	-	1	.002
Cumaceans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polychaetes	2	.010	3	.025	1	.005	-	-	-	-	1	.010	-	-	1	.007
Bivalves	37	4,430	8	.665	1	.125	-	-	2	.240	2	.115	-	-	7	.796
Decapods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pteropods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tunicates	5	3.950	25	19.750	2	2.505	-	-	8	3.735	2	1.265	-	-	6	4.458
Unknown	P	.009	P	.025	P	.001	-	-	-	-	-	-	-	-	P	.005
TOTAL	313	82.276	250	29.757	95	12.275	47	1.621	411	33.504	296	19.118	22	9.337	205	26.841
*No. of Trawl Samples	n=2		n=2		n=2		n=2		n=2		n=2		n=1			

*Number of trawl samples per period varies as ice and weather conditions prevented the collection of some samples.

Appendix I. (cont'd)

TAXON OR SPECIES	STATION 2															
	PERIOD I		PERIOD II		PERIOD III		PERIOD IV		PERIOD V		PERIOD VI		PERIOD VII		MEAN	
	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)
Cnidarians	P	.330	12	1.600	3	0.120	8	.214	24	.670	13	.577	P	.010	9	.503
Priapulids	-	-	-	-	-	-	3	.027	-	-	-	-	-	-	P	.004
Bryozoans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetognaths	-	-	1	.010	1	.010	3	.004	4	.050	-	-	-	-	1	.011
Mysids																
Mysis oculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mysis litoralis	166	4.923	6	.074	17	.479	498	30.066	12	.506	41	.529	1729	35.156	353	10.247
Mysis relicta	83	1.656	33	.473	33	1.403	313	27.184	48	1.368	33	.869	108	3.032	93	5.140
Mysis sp.	41	3.306	36	.199	21	.587	137	12.302	-	-	45	.934	418	27.812	99	6.449
Neomysis rayii	-	-	-	-	-	-	-	-	-	-	-	-	1	.001	P	P
TOTAL	290	9.885	74	.745	70	2.469	948	69.552	60	1.873	119	2.332	2255	66.002	545	21.837
Euphausiids	1	.01	-	-	-	-	-	.04	-	-	-	-	3	.16	1	.03
Amphipods																
Paroediceros lycaneus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parathemisto libellula	-	-	-	-	-	-	-	-	-	-	1	.148	11	1.328	2	.211
Hyperia medusarum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyperiid spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Onisimus glacialis	-	-	3	.060	11	.065	2	.012	-	-	2	.001	2	.012	3	.022
Onisimus littoralis	-	-	-	-	-	-	-	-	-	-	-	-	2	.009	P	.001
Onisimus spp.	-	-	-	-	-	-	16	.047	1	.017	2	.059	75	.050	13	.024
Boeckosimus affinis	-	-	-	-	-	-	1	.007	-	-	-	-	-	-	-	-
Apherusa glacialis	-	-	-	-	-	-	-	-	-	-	1	.001	-	-	P	P
Gammarus setosus	-	-	-	-	-	-	-	-	1	.044	2	.077	-	-	P	.017
Gammarus wilkitzkii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammaracanthus loricatus	-	-	1	.083	2	.219	4	1.585	14	.297	369	.279	1	.388	56	.407
Acanthostepheia behringiensis	-	-	-	-	6	.396	-	-	-	-	1	.132	2	.480	1	.144
Weyprechtia pinguis	-	-	-	-	-	-	-	-	-	-	-	-	2	.155	P	.022
Weyprechtia heuglini	-	-	-	-	-	-	-	-	-	-	1	.142	-	-	P	.021
Pontoporeia affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculopsis longicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculodes packardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atylus carinatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	-	-	4	.143	19	.681	22	1.643	16	.358	378	.839	95	2.423	76	.870
Isopods	1	2.565	1	.040	P	.210	2	10.447	4	9.999	2	18.100	8	44.050	3	12.202
Copepods	-	-	1	.010	-	-	3	.004	1	.020	-	-	-	-	1	.005
Cumaceans	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Polychaetes	-	-	-	-	-	-	-	-	1	.020	-	-	-	-	P	.003
Bivalves	17	2.895	10	.980	4	.650	1	.107	7	1.570	3	.370	1	.080	6	.950
Decapods	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pteropods	-	-	-	-	-	-	3	.007	-	-	-	-	-	-	P	.001
Tunicates	37	40.535	84	73.498	47	79.800	69	62.573	77	74.600	64	52.900	67	20.800	64	57.815
Unknown	-	-	-	-	-	-	P	.008	-	-	-	-	-	-	P	.001
TOTAL	346	56.20	187	77.026	144	83.94	1063	144.06	194	89.16	579	75.12	2429	133.525	706	94.231
*No. of Trawl Samples	n=2		n=1		n=2		n=2		n=1		n=1		n=2			

*Number of trawl samples per period varies as ice and weather conditions prevented the collection of some samples.

Appendix I. (cont'd)

TAXON OR SPECIES	STATION 3													
	PERIOD I		PERIOD II		PERIOD III		PERIOD IV		PERIOD V		PERIOD VII		MEAN	
	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)
Cnidarians	-	-	-	-	19	.370	P	P	-	-	-	P	3	.062
Priapulids	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bryozoans	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetognaths	8	.095	8	.060	9	.120	2	.008	-	-	-	-	5	0.047
Mysids														
Mysis oculata	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mysis litoralis	102	2.675	14	.226	48	1.145	268	6.880	312	7.636	14,720	379.137	2577	66.284
Mysis relicta	16	.160	90	1.876	79	1.002	148	4.540	348	1.719	4,352	162.688	839	28.661
Mysis sp.	41	1.208	11	.333	21	.614	28	1.032	44	2.164	2,689	110.592	472	19.324
Neomysis rayii	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	159	4.043	115	2.435	147	2.762	444	12.453	704	11.520	21,760	652.418	3888	114.272
Euphausiids	2	.105	-	-	-	-	-	-	-	-	-	-	P	.018
Amphipods				-										
Paroediceros lycaneus	-	-	-	-	-		2	.004	-	-	-	-	P	.001
Parathemisto libellula	-	-	-	-	-	-	-	-	-	-	4	.624	1	.104
Hyperia medusarum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyperiid spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Onisimus glacialis	-	-	-	-	-	-	-	-	68	.868	276	3.227	57	.604
Onisimus littoralis	-	-	-	-	-	-	-	-	3	.015	1	.014	1	.005
Onisimus spp.	-	-	1	.012	2	.002	-	-	6	.012	-	-	2	.005
Boeckosimus affinis	-	-	-	-	-	-	-	-	-	-	24	.131	-	.027
Apherusa glacialis	-	-	-	-	-	-	3	.030	2	.001	24	.131	5	.027
Gammarus setosus	1	.031	1	.069	-	-	40	1.962	16	1.389	-	-	9	.575
Gammarus wilkitzkii	-	-	-	-	-	-	-	-	1	.215	-	-	P	.036
Gammaracanthus loricatus	2	.418	-	-	3	1.803	12	.167	19	.819	176	36.190	36	6.566
Acanthostepheia behringiensis	-	-	-	-	-	-	-	-	55	1.188	39	1.577	16	.461
Weyprechtia pinguis	-	-	-	-	-	-	1	.002	-	-	-	-	P	P
Weyprechtia heuglini	-	-	-	-	2	4.121	-	-	-	-	-	-	P	.686
Pontoporeia affinis	-	-	-	-	-	-	1	.004	-	-	-	-	P	.001
Monoculopsis longicornis	1	.004	-	-	-	-	2	.002	-	-	34	.075	7	.013
Monoculodes packardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atylus carinatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified	-	-	-	-	28	.033	-	-	1	.007	28	.212	9	.042
TOTAL	4	.452	2	.081	35	5.958	61	2.170	170	4.047	583	42.050	142	9.126
Isopods	-	-	-	-	2	8.630	12	.160	21	7.100	54	120.000	15	22.648
Copepods	1	.008	-	-	-	-	-	-	-	-	-	-	P	.001
Cumaceans	-	-	-	-	-	-	2	.008	-	-	7	.040	2	.008
Polychaetes	P	P	P	P	P	P	P	P	3	.490	1	.830	1	.220
Bivalves	3	1.010	2	.160	3	.620	P	P	7	1.510	P	P	3	.550
Decapods	-	--	-	-	1	.008	-	-	-	-	-	-	P	.001
Pteropods	-	-	-	-	-	-	-	-	1	.060	-	-	P	.009
Tunicates	7	4.724	46	34.100	-	-	22	16.600	15	17.109	39	38.900	22	18.573
Unknown	-	-	-	-	-	-	-	-	-	-	3	.008	P	.002
TOTAL	184	10.437	178	36.836	216	18.468	543	31.399	921	41.836	22,447	854.246	4081	165.537
*No. of Trawl Samples	n=2		n=1		n=2		n=2		n=1		n=1			

*Number of trawl samples per period varies as ice and weather conditions prevented the collections of some samples.

Appendix I. (cont'd)

	STATION 5													
TAXON OR SPECIES	PERIOD II		PERIOD III		PERIOD IV		PERIOD V		PERIOD VI		PERIOD VII		MEAN	
	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)	No.	Biomass (g)
Cnidarians	P	.276	-	-	7	.170	5	.114	6	.701	2	.005	2	.211
Priapulids	-	-	-	-	1	.265	-	-	-	-	-	-	P	.044
Bryozoans	2	.005	-	-	-	-	1	.070	-	-	-	-	1	.012
Chaetognaths	2	.025	-	-	3	.020	6	.105	6	.190	-	-	3	.057
Mysids														
Mysis oculata	-	-	-	-	-	-	-	-	-	-	1	.098	P	.017
Mysis litoralis	7	.096	7	.278	32	1.084	68	1.608	230	2.250	159	6.866	84	2.030
Mysis relicta	-	-	-	-	12	.447	33	1.278	58	1.169	-	-	17	.482
Mysis sp.	3	.050	2	.065	18	.227	45	1.309	28	1.521	46	8.806	23	1.997
Neomysis rayii	-	-	-	-	-	-	1	.001	-	-	-	-	P	P
TOTAL	9	.146	8	.343	62	1.758	147	4.196	317	4.940	206	15.771	125	4.526
Euphausiids	-	-	-	-	1	.025	-	-	-	-	-	-	P	.005
Amphipods														
Paroediceros lycaneus	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Parathemisto libellula	-	-	-	-	-	-	-	-	1	.144	135	35.079	22	5.871
Hyperia medusarum	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hyperiid spp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Onisimus glacialis	-	-	-	-	-	-	-	-	-	-	3	.250	P	.042
Onisimus littoralis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Onisimus spp.	2	.174	-	-	1	.034	-	-	-	-	1	.003	1	.036
Boeckosimus affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Apherusa glacialis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gammarus setosus	-	-	1	.341	-	-	-	-	-	-	1	.068	P	.068
Gammarus wilkitzkii	-	-	1	.978	-	-	-	-	-	-	1	.061	P	.173
Gammaracanthus loricatus	-	-	1	1.799	2	.933	3	1.031	1	.280	1	.314	1	.726
Acanthostepheia behringiensis	1	.215	7	1.859	14	4.166	45	11.053	4	1.487	10	1.748	13	3.422
Weyprechtia pinguis	1	.092	1	.184	1	.039	-	-	-	-	-	-	1	.052
Weyprechtia heuglini	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pontoporeia affinis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculopsis longicornis	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Monoculodes packardi	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Atylus carinatus	-	-	-	-	1	.099	-	-	-	-	-	-	p	.017
Unidentified	-	-	-	-	-	-	1	.004	-	-	1	.027	P	.006
TOTAL	4	.481	10	5.161	18	5.272	48	12.084	6	1.911	154	37.524	39	10.405
Isopods	1	1.680	4	19.600	292	610.455	13	52.500	6	22.100	81	136.755	66	140.515
Copepods	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cumaceans	-	-	-	-	-	-	1	.005	1	.020	3	.090	1	.019
Polychaetes	-	-	-	-	5	.065	68	.345	-	-	1	.166	12	.096
Bivalves	1	.040	1	.210	-	-	17	6.295	6	.679	7	.925	6	1.358
Decapods	-	-	-	-	-	-	1	.560	-	-	1	.001	P	.094
Pteropods	-	-	-	-	-	-	-	-	1	.300	1	.274	P	.096
Tunicates	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unknown	-	-	-	-	-	-	P	2.555	-	-	P	1.200	P	.626
TOTAL	19	2.653	23	25.314	389	618.03	307	78.829	349	30.841	456	192.711	257.1	158.063
*No. of Trawl Samples	n=2		n=1		n=2		n=2		n=1		n=2			

*Number of trawl samples per period varies as ice and weather conditions prevented the collections of some samples.

Appendix II. Reference Literature Used In Identification of Invertebrates.

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Appendix III. Mysid and Amphipod Species Collected in Simpson Lagoon, 1977. List includes species collected by all sampling techniques plus fish and bird stomachs.

- Phylum Arthropoda
  - Class Crustacea
    - Order Mysidacea
      - Subfamily Mysinae
        - Tribe Mysini
          - *Mysis oculata* (O. Fabricius)
          - *Mysis relicta* (Lové N)
          - *Mysis litoralis* (Banner)
          - *Neomysis rayii* (Murdock)
    - Order Amphipoda
      - Suborder Hyperiidea
        - Superfamily Phronimoidea
          - Family Hyperiidae
            - *Hyperia medusarum* (O. F. Müller)
            - *Parathemisto libellula* (Lichtenstein)
      - Suborder Gammaridea
        - Family Atylidae
          - *Atylus carinatus* (J. C. Fabricius)
        - Family Calliopiidae
          - *Apherusa glacialis* (H. J. Hansen)
        - Family Gammaridae
          - *Gammaracanthus loricatus* (Sabine)
          - *Gammarus setosus* (Dementieva)
          - *Gammarus wilkitzkii* (Birula)
          - *Gammarus* sp.
          - *Weyprechtia heuglini* (Stebbing)
          - *Weyprechtia pinguis* (Buchholz)
        - Family Haustoriidae
          - *Pontoporeia affinis* (Lindström)
        - Family Lysianassidae
          - *Boeckosimus affinis* (Hoek)
          - *Onisimus littoralis* (Kröyer)
          - *Onisimus glacialis* (G. O. Sars)
          - *Onisimus nanseni* (G. O. Sars)
          - *Onisimus* sp.
        - Family Oedicerotidae
          - *Acanthostepheia behringiensis* (Lockington)
          - *Acanthostepheia incarinata* (Gurjanova)
          - *Monoculopsis longicornis* (Boeck)
          - *Monoculodes packardi* (Boeck)
          - *Monoculodes* sp.
          - *Paroediceros lycaneus* (M. Sars)
          - Oedicerotid

Appendix IV. Water Quality and Aquatic Productivity.

Since the overall research design of the Barrier Island-Lagoon Process Studies has been to examine the ecosystem "from the top down", upper trophic levels (birds, fish, invertebrates) have received emphasis during the first field season. As key biological processes are being identified, research emphasis is correspondingly shifting to include an examination of energy sources that drive the system (primary production, terrestrial detritus).

In this section, a brief account is given of water quality, nutrient and primary productivity data gathered in 1977. Specific objectives of the 1977 effort in this area were (1) to describe seasonal changes in water quality (temperature, salinity, dissolved oxygen and turbidity) in the study area, and (2) to provide preliminary nutrient and primary productivity data for use in simulations of system processes.

Methods

Seven sampling stations were established in Simpson Lagoon and adjacent areas (Fig. 1, Table 1). Water temperature, salinity, dissolved oxygen and turbidity were measured at approximately 10-day intervals from 12 July to 25 September 1977 at Stations 1 through 6. These parameters were also measured daily at Station 1 from 31 July-22 September. Chlorophyll-a and nutrient concentrations (ammonia, nitrate) in marine waters (Station 5) were compared with concentrations at two sites inside Simpson Lagoon (Stations 2 and 7). Sampling instruments and methods are summarized in Table 2.

Results

The initial stages of spring breakup in Simpson Lagoon consisted of the formation of open water leads along mainland and island shorelines while the rest of the lagoon and ocean remained ice-covered. At Station 3 on the lagoon side of Pingok and Leavitt islands, shoreline waters first began melting about 16 June and by 1 July the shorelead was 10-100 m wide Water temperatures in the lead during this period ranged from 0-4.5°C and

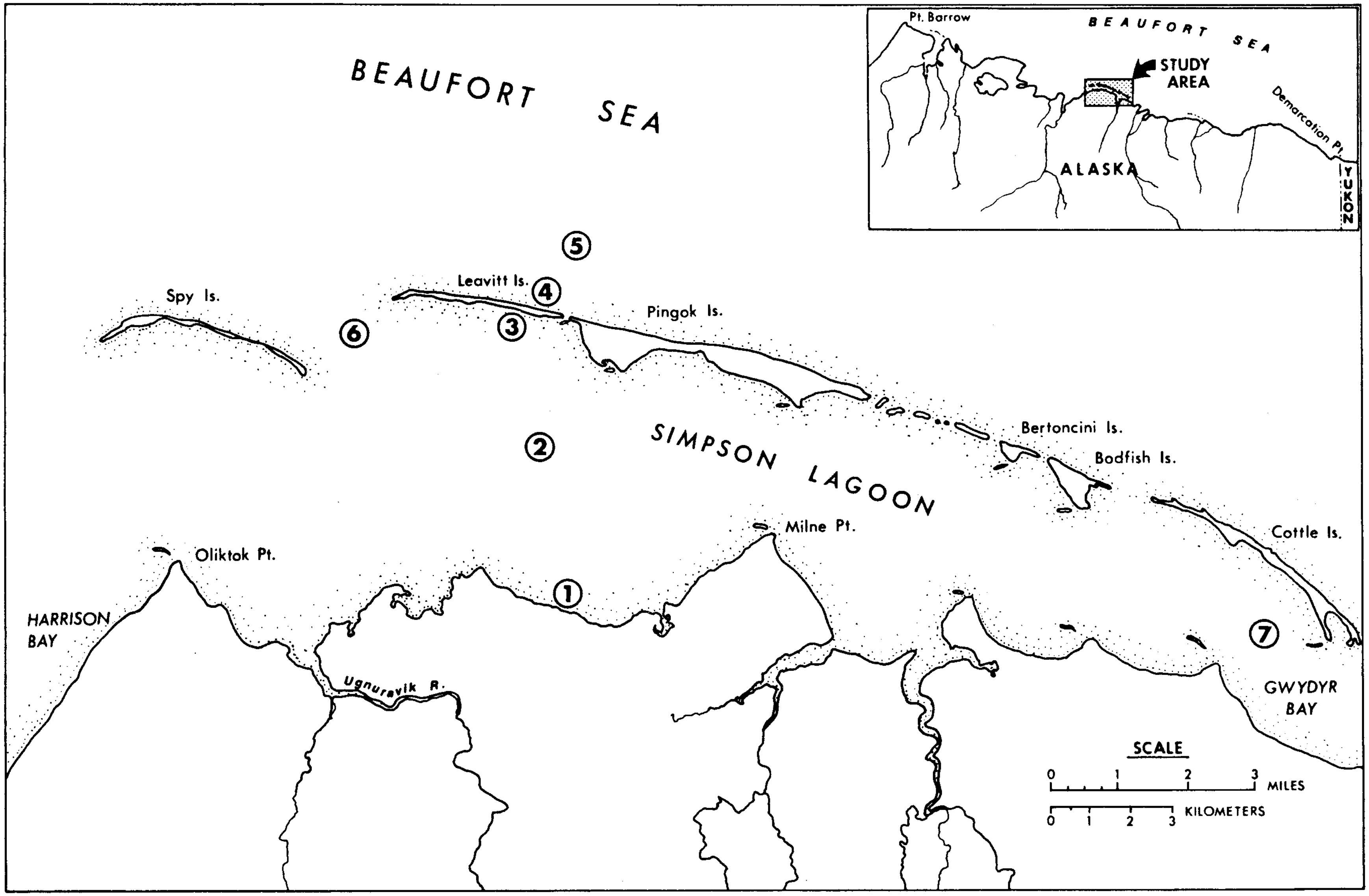

Fig. 1. Principal Sampling Stations for Water Quality, Nutrients and Chlorophyll-a in Simpson Lagoon, 1977.

Table 1. Principal Sampling Stations in Simpson Lagoon and Adjacent Areas.

Station Number	Location	Water Depth (m)	Substrate
1	near mainland shore	0-1	mud and sand
2	mid-lagoon	2-2.5	mud and sand
3	lagoon side Leavitt Island	0-1	sand and gravel
4	ocean side Leavitt Island	0-2	gravel and sand
5	1.6 km north of Pingok Island camp	10	mud and sand
6	between Leavitt and Spy islands	2	mud and sand
7	between Beechey Point and Cottle Island	2.5	mud and sand

Table 2. Summary of Sampling Gear, Analysis Techniques, Accuracy and Units for Measurements of Water Quality, Nutrients and Chlorophyll-a in Simpson Lagoon, 13 July to 20 September 1977.

Parameter	Method	Analysis	Maximum Accuracy	Units
Salinity*	YSI-33 Salinity/Conductivity Meter	Field Measurement	± 0.9 ‰ above 4°C ± 1.0 ‰ below 4°C	‰
Temperature*	(1) YSI-33 Salinity/Conductivity Meter	Field Measurement	± 0.1° at -2°, ± 0.6° at 45°	°C
	(2) Mercury Pocket Thermometer	Field Measurement	± 0.5°	°C
Dissolved Oxygen	Hach Portable Oxygen Determination Kit	Field Measurement	± 0.5 mg/l	mg/l
Turbidity	Hach Model 2100A Turbiditimeter	Field Laboratory Measurement	± 0.5 % of full scale	Nepelometric Turbidity Units (N.T.U.)
Ammonia NH_3 as N	1 Liter Plastic Bottles filtered and preserved with 5 ml H_2SO_4	Dames and Moore Lab., Fairbanks	± 2 %	mg/l
Nitrate NO_3 as N	1 Liter Plastic Bottles filtered and preserved with 5 ml H_2SO_4	Dames and Moore Lab., Fairbanks	± 0.05 mg/l	mg/l
Chlorophyll-a	1 Liter Dark Plastic Bottles filtered, preserved with Mg CO_3 and frozen	Dames and Moore Lab., Fairbanks (Parsons/Strickland method)	0.05 mg/l	mg/l^3

*Measured using 15 m lead.

salinities from 2.1-6.0 ppt. Within two weeks, most nearshore ice had melted or been blown away by winds. All sampling stations could then be reached by boat and the sampling schedule at each station was begun. Resulting data are presented below.

Temperature and Salinity

Salinities and temperature varied greatly during the open water season (Fig. 2). Summer salinity variations of 10 ppt and temperature variations of 5°C were characterisitic of most study areas, and it is likely that these ranges would have been even greater had more frequent measurements been made. The lagoon environment was generally warmer and less saline than non-lagoon waters seaward of Pingok Island. Mid-summer values inside Simpson Lagoon were typically 5-8°C and 20-27 ppt, while outside the lagoon values were 0-4°C and 25-30 ppt. This difference is also reflected in the seasonal averages of temperature and salinity at all six stations:

	Salinity (ppt)		Temperature (°C)	
Station	Mean	(Range)	Mean	(Range)
1	17.5	(2-24)	6.3	(2.5-8.5)
2	21.4	(14-28)	4.9	(1.5-6.5)
3	24.1	(20-29)	4.3	(1-6)
4	25.9	(20-30)	1.3	(-0.5-4.5)
5	26.0	(22-30)	2.0	(0.4-4.5
6	25.5	(19-30)	2.0	(0-4.5)

Temperatures and salinities at Station 6, located in a channel between Spy and Leavitt islands, were more similar to Stations 4 and 5 (non-lagoon) than Stations 1 through 3 (lagoon).

A noticeable trend was that the shallow waters along the mainland shoreline (Station 1) were consistently warmer and less saline than all other sites. The differences in temperature among stations were statistically significant (Friedman $\chi^2=23.08$, $P<0.001$, $N=6$, $k=6$), as were the

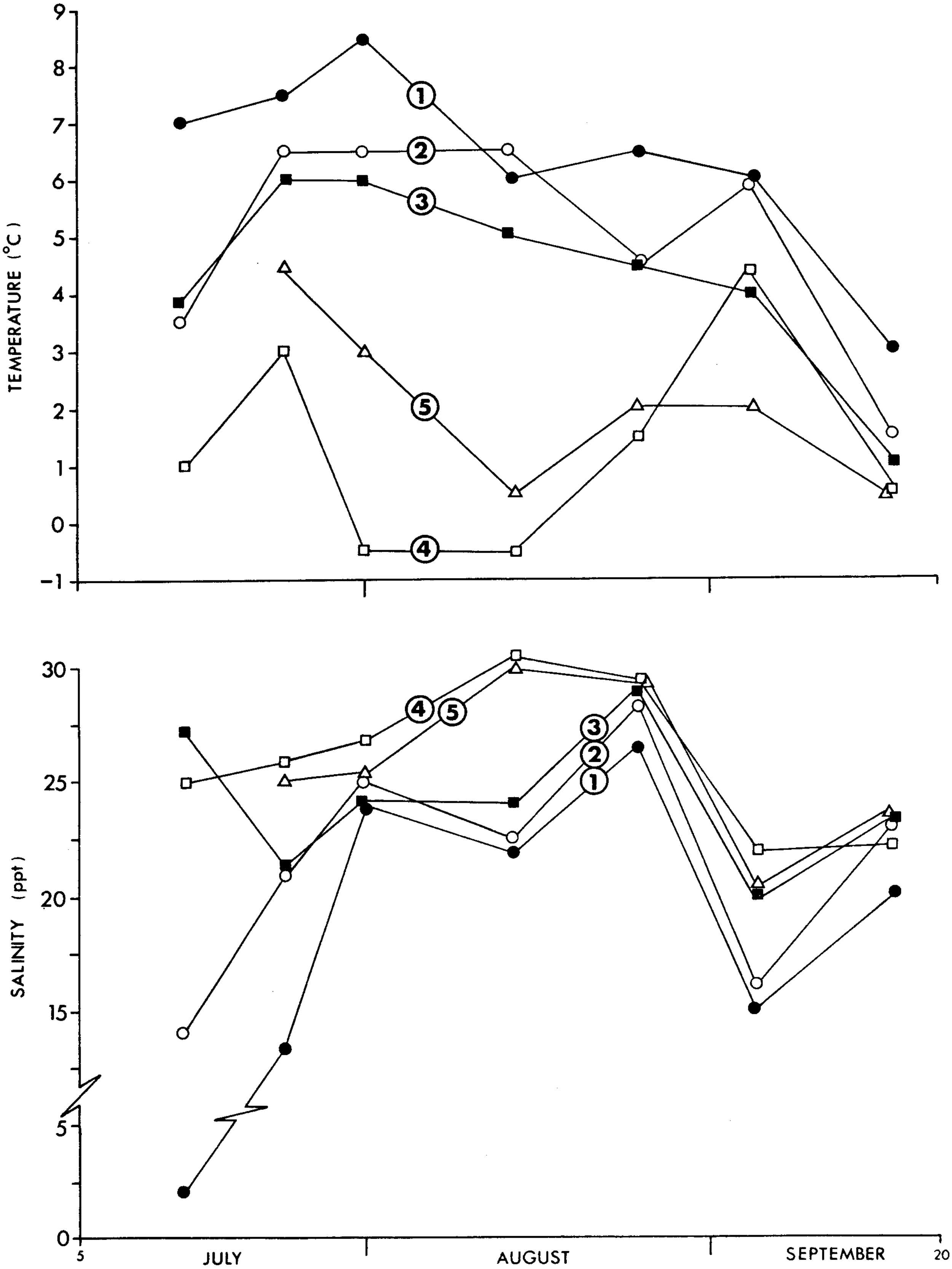

Fig. 2. Variation in Temperature and Salinity at Stations 1-5, 1977.

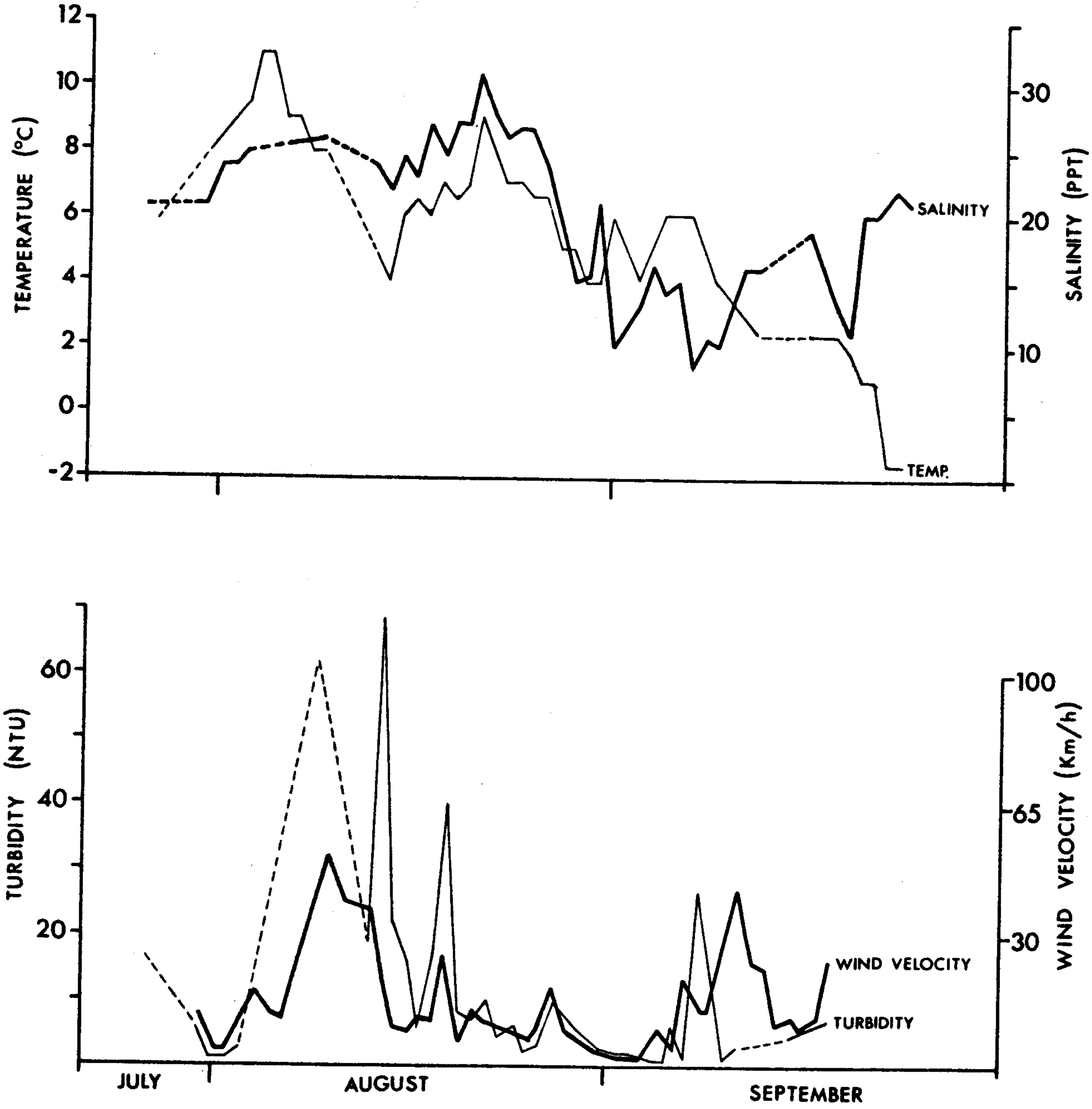

Fig. 3. Daily Records of Water Temperature, Salinity, Turbidity and Wind Speed at Station 1 from 25 July to 23 September 1977. Dotted lines span days when weather conditions prevented data collection.

differences in salinity (Friedman $X^2=20.44$, $P<0.005$, $N=6$, $k=6$).* This habitat difference presumably reflects the influence of freshwater discharge from tundra streams and nearby rivers, which is transported along the shore by prevailing westerly currents.

A more detailed record of temperatures and salinities at Station 1 is shown in Fig. 3. Water temperatures reached a maximum (11°C) in early August and declined thereafter. Slush ice formed in areas of the lagoon when water temperatures dropped to -2°C after 23 September. Salinities ranged from 2 ppt (14 July) to 31 ppt (20 August).

Dissolved Oxygen

Dissolved oxygen concentrations remained high at all stations during the open water period. The average summer value was 9.8 ml/l (range 7.0-12.0 ml/l).

Turbidity

Turbidity readings fluctuated widely (0.7-68 NTU) at all stations, but there was no significant difference among stations on a seasonal basis (Friedman $\chi^2=8.77$, $P>0.1$, $N=5$, $k=6$).

	Turbidity (NTU)					
	Station No.					
Date	1	2	3	4	5	6
14 July	-	3.1	-	0.7	-	-
23 July	-	1.0	0.8	1.2	-	-
31 July	1.4	0.7	0.7	3.4	0.7	1.4
13 August	68.5	7.4	12.5	5.0	3.8	6.8
24 August	1.4	2.2	2.4	4.4	1.4	1.1
4 September	0.6	0.7	0.9	2.1	0.8	0.8
16 September	6.4	15.0	14.0	15.0	11.0	26.0

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*See Siegel, S. 1956. Nonparametric statistics for the behavioral sciences. McGraw-Hill, New York. 312 p.

Maximum turbidities occurred after periods of high winds (Fig. 3): the correlation between turbidity and wind speed was highly significant (correlation coefficient r=0.527, P≃0.001, n=35). After the winds slacken, turbidity readings fall rapidly as the sediments quickly settle out.

Chlorophyll-a

Chlorophyll-a concentrations were measured to provide a preliminary estimate of primary production inside and outside Simpson Lagoon. Seasonal changes in concentration were monitored at Stations 2, 5 and 7; other stations were sampled occasionally. Chlorophyll-a concentrations (in mg/m^3) were determined by the Parsons/Strickland method:

Dates	Stations				
	2	3	4	5	7
July 13-14	6.3	1.2	2.0	-	-
25	5.4	-	-	1.7	2.4
August 1-2	2.5	-	18.5	2.3	3.0
14	2.0	-	-	2.9	5.9
24	1.5	-	-	2.7	2.4
September 4	0.9	-	-	0.3	2.7
16-17	3.2	-	-	3.5	-

Chlorophyll-a concentrations at Stations 2, 5 and 7 were similar, averaging 2.9 mg/m^3). The values obtained at these three stations were not significantly different.

If there was a phytoplankton bloom early in the season, it was not measured. The springtime ice algal bloom occurs in May and early June (D. Schell, pers. comm.), prior to the time sampling was initiated. A plankton bloom (chlorophyll-a 18.5 mg/m^3) was recorded at Station 4, however, during an apparent upwelling of cold water against the seaward shoreline of Pingok Island on 1-2 August. For two days, surface water temperatures at Station 4 were cooler (-1°C) than farther offshore at

Station 5 (0°C). The bloom resulted in a noticeable band (approx. 50-200 m wide) of brown-red water against the shoreline; this band vanished on 3 August when the wind direction changed from east to west.

Nutrients (NH_3, NO_3)

Nutrient concentrations were low throughout the season (maximum NH_3 and NO_3 concentrations were 9.27 and 0.11 mg/l, respectively). Values obtained (in mg/l) are listed below for ammonia and nitrate:

	Station							
	2		3		5		7	
	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3	NH_3	NO_3
June 17	-		1.61	<.05	-		-	
19	-		0.76	.11	-		-	
24	-		0.65	.07	-		-	
26	-		1.42	.07	-		-	
July 3	-		0.33	.11	-		-	
13	1.14	.06	-		-		1.86	.06
25	3.56	<.05	-		0.85	.05	9.27	<.05
August 1-2	5.81	<.05	-		0.71	<.05	6.56	<.05
14	2.27	.08	-		9.27	.07	2.57	<.05
24	0.94	.07	-		1.95	.08	-	
September 4	2.88	<.05	-		0.71	<.05	-	
16-17	1.21	.06	-		1.78	<.05	2.04	<.05

High nutrient concentrations were expected early in the season in association with freshwater runoff; however, this was not observed just south of Leavitt Island (Station 3), the one station sampled during June. The reason for this is not known but it may be attributed to one or more of the following:

1. Nitrogen input is in organic form.
2. Nitrogen input is consumed as soon as it enters the system.
3. The analytical methods for NH_3 and NO_3 were inadequate; i.e. too much time delay occurred between collection and analysis.

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