Environmental Assessment of the Alaskan Continental Shelf

Final Reports of Principal Investigators
Volume 11. Biological Studies

U.S. DEPARTMENT OF COMMERCE
National Oceanic & Atmospheric Administration
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TOXICITY OF OIL-WELL DRILLING MUDS
TO ALASKAN LARVAL SHRIMP AND CRABS

by

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Research Unit 72

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INTRODUCTION

Environmental concerns about oil-industry activities in the marine environment have focused primarily on the effects and clean up of spilled oil. There have been less concern and less research on the potential effects of discharged drilling muds. Drilling muds are used during the well-drilling process and are utilized to bring up rock cuttings, control subsurface pressures, support the walls of the well hole, deliver hydraulic energy on the formation being drilled, aid in the suspension of the drill string and casing, prevent corrosion, and cool and lubricate the bit (IMCO 1980).

There are several common types of muds and hundreds of additives that may be used. The specific constituents and proportions vary considerably, depending on drilling conditions (depth, rock formation, etc. [Tagatiz et al. 1979]). Most drilling muds are water-based. They are complex chemically and may include bactericides, sealants, corrosion inhibitors, emulsifiers, flocculants, lubricants, foaming agents, filtrate reducers, weighing agents, and substances to control the pH. Barite (barium sulfate) is added to increase the density of the mud; bentonite (Montmorillinite clay) is commonly added to increase the viscosity. Lignosulfonates, which are derived from the treatment of wood lignin with bisulphite, are widely used viscosity reducers (IMCO 1980; Hrudey 1979). Ferrochrome lignosulfonate (FCL) has trivalent chromium ions chelated with the lignosulfonate complex (McAtee and Smith 1968).

The discharge of drilling muds might not be considered a problem for several reasons: (1) relatively small amounts of drilling muds enter the water during the drilling process (although a large volume may be discharged after drilling at a site has been completed); (2) although drilling muds may contain toxic additives, they are usually in low concentrations, and the bulk of the mud components is relatively inert; (3) mud is dense and rapidly settles out of the water column; (4) any toxic components are quickly dispersed and diluted; (5) bioassays have documented that the toxicity of most muds is low. Nevertheless, there is insufficient information to categorically conclude that drilling muds have no significant effects on marine life.

In 1978, the English Bay Native Corporation brought suit against the U.S. Department of Interior to stop discharging drilling muds into lower Cook Inlet. Many of the members of the corporation are fishermen with concerns about the local fishery resources, particularly shrimp and crab. Although an earlier study in Cook Inlet by Dames and Moore (1978) showed that drilling muds were not very toxic to salmon fry and adult shrimp, there was no information about the effects on larvae of crab and shrimp. Crustacean larvae are sensitive to oil water-soluble fractions (WSF's), particularly when molting (Brodersen et al. 1977; Mecklenburg et al. 1977). Because larvae are small, they equilibrate with toxicants rapidly and may be more sensitive than adults to the physical effects of suspended mud particles.

The purpose of this study was to measure the toxicity of drilling muds to crab and shrimp larvae, to provide a better basis for assessing potential environmental effects of drilling muds.

The study had four major objectives:

(1) To examine the toxicity of drilling muds to crustacean larvae. What proportion of the effect is due to physical stress caused by suspended solids, and what proportion is due to dissolved chemicals? Is the toxicity stable over time? Do toxic effects occur rapidly as they do with oil?

(2) To compare the toxicities of several muds using stage-I larvae of one shrimp and one crab species. Muds vary widely in constituent composition and probably have different toxicities.

(3) To compare the sensitivities of stage-I larvae of several species of shrimp and crab to one relatively toxic mud. Observations included survival and inability to swim after different lengths of exposure.

(4) To determine the effects of several pure mud additives--ferrochrome lignosulfonate, barite, and bentonite. Barite and bentonite make up the bulk of many drilling muds, and ferrochrome lignosulfonate is a common additive for reducing viscosity.

METHODS AND MATERIALS

Several types of tests were conducted to reach the objectives stated. Mud toxicities were compared by exposing larval king crab and coonstripe shrimp to all six muds and water-soluble fractions (WSF's) of muds. (A description of the muds tested during this study is given in table 1.) All six species were compared by exposing them to used Cook Inlet mud (mud B) suspensions (SM) and WSF's. Additionally, the persistence of toxicity of the mud B WSF was tested with king crab and coonstripe shrimp larvae by repeatedly testing progressively older WSF preparations. The effect of salinity on toxicity was investigated by exposing coonstripe shrimp larvae at various salinities in mud B WSF. The toxicities of three mud components (ferrochrome lignosulfonate [FCL], barite, and bentonite) to Dungeness crab and dock shrimp were also determined.

Six species of crab and shrimp larvae were tested: king crab (Paralithodes camtschatica), Tanner crab (Chionoecetes bairdi), Dungeness crab (Cancer magister), coonstripe shrimp (Pandalus hypsinotus), dock shrimp (Pandalus danae), and kelp shrimp (Eualus suckleyi). Gravid king, Tanner, and Dungeness crabs were collected by divers in Auke Bay and maintained in large flow-through seawater aquaria. The coonstripe and dock shrimp were collected in Auke Bay and Big Port Walter, but the kelp shrimp were collected only in Auke Bay.

Larvae for the bioassays were collected daily from the water column as they were released by the adults. All tests were static and were conducted with stage I larvae 3-days old or younger. Larvae were not fed during the 6-day experimental periods, which limited the length of testing and also resulted in some cannibalism. Salinities ranged from 28.4 to 30.9°/₀₀ with a mean of 30.0 ± 0.8°/₀₀ through the course of study. Temperatures gradually increased throughout, at approximately 0.04°C/day, and ranged from 4.5 to 7.5°C with a mean of 5.6 ± 0.8°C.

The muds were stored in 5-gallon buckets with snap-top lids placed in a bath of cold water to keep them as cool as possible. Muds were mixed in the storage buckets with a barrel mixer at 3,450 rpm for a minimum of one-half hour before use to ensure sample homogeneity. All the muds contained ferrochrome lignosulfonate (FCL) except mud A' (Table 1).

In order to measure the mud WSF, salinity, pH, and absorbance, samples were centrifuged until all, or most of, the particulate matter was removed. The supernatant was then passed through a #5 filter. Salinities were measured with an osmometer, and pH was measured with a combination glass electrode. Samples were diluted with distilled water as necessary for spectrophotometric measurements and scanned from 400 to 190 nm in a Beckman[1] model 25 spectrophotometer.

The chemical stability of FCL was determined by maintaining six replicate samples with an initial concentration of 0.160 g/l of FCL at four different temperatures (-0.2° ± 0.5°C, 5.8° ± 0.6°C, 11.9° ± 1.5°C, and 18.7° ± 1.7°C) for 24 days. The absorbance peaks at 277 nm were measured six times over this period, at 1, 4, 8, 17, and 24 days. Identical tests were completed with the mud B WSF starting at 0.98% by volume.

Drilling Mud Tests

Suspended Mud Tests

Tests began with the solid fraction of the muds distributed homogeneously through the water. Drilling mud (1-10% by volume) was added by syringe to seawater in 25 mm x 200 mm glass test tubes (final volumes were 50 ml). The tubes were then capped and shaken vigorously 10-20 seconds and the larvae were added immediately by pipette. Death was a difficult parameter to quantify accurately in the SM tests because some of the larvae were buried. Behavioral observations were more accurate: larvae were classified as swimming if they maintained their positions in the water column or were observed swimming up off the surface of the mud.

Except for mud B, the majority of the suspended mud settled out very rapidly (within 1-2 h). Because the suspended particles in mud B prevented direct observation even after 6 days, the testing procedure for this mud was different. Mud B was added by syringe to 400 ml beakers. Concentrations ranged from 0.05% to 10% by volume in 200 ml seawater. The mud was agitated, and larvae confined in glass tubes with screen bottoms (2 cm dia X 15 cm with 210μm plankton net). Observations were made by briefly placing the larvae in clean seawater. Death was determined from such visual clues as body posture, color, and opacity. Larvae that swam horizontally or upward after the tubes were mildly agitated with an up-and-down motion were classified as swimmers.

WSF Tests

To prepare mud WSF's, equal volumes of mud and seawater were added to an Erlenmeyer flask and agitated vigorously for 2 min. This mixture was then centrifuged in 30 ml tubes at 10,000 rpm for 10 min, then aspirated through GF/C or #5 filters. Mud B (only) was centrifuged a second time at 21,500 rpm for 10 min to remove remaining particles. The supernatant salinity was measured, then adjusted to match the daily salinity of Auke Bay seawater by adding a brine solution. The WSF's were then diluted to the desired test concentrations.

Larvae were placed by pipette into glass tubes with screen bottoms in clean seawater. These tubes were then transferred to glass beakers containing 200 ml of the WSF to begin testing. Fresh WSF's were prepared at the beginning of each experiment. If the highest concentrations of WSF were too opaque for observation, larvae in all concentrations (including controls) were placed briefly in clean seawater for observation. Observational criteria were the same as for mud B suspended-mud experiments.

Coonstripe shrimp larval assays were conducted at different salinities with mud B WSF to determine whether the additional stress would increase the toxicity of the WSF. Salinities ranged from 30.58 $^{o}/_{oo}$ to 12.01 $^{o}/_{oo}$.

Tests designed to determine the stability of the toxic effect required repeated assays with the same WSF preparation. Beakers containing the concentration series remained in the water bath between tests. The WSF preparation ranged from fresh to that aged for 4 weeks.

Component Tests

Ferrochrome lignosulfonate powder was dissolved in seawater with the aid of a magnetic stirrer. Testing procedures were analogous to the WSF testing techniques. Test concentrations ranged from 0.07 to 16.67 g/l of FCL.

Barite (barium sulfate) and bentonite samples were weighed and added to 25 X 200-mm glass test tubes containing 50 ml of seawater. Experimentation proceeded as with the suspended-mud tests. Barite concentrations ranged from 0.004 to 0.200 g/ml, and bentonite concentrations ranged from 0.004 to 0.100 g/ml.

Analytical Methods

The LC50's and EC50's were determined from the bioassay data by logit analysis (Finney 1971). (EC50's are those concentrations that caused 50% of the larvae to cease swimming.) Abbott's correction was applied as necessary (Finney 1971). However, replicates with a control mortality greater than 20% were disregarded. The LC50's and EC50's were further analyzed with analysis-of-variance techniques (ANOVA) followed by the Scheffe' a posteriori multiple comparison test. All Scheffé comparisons were made at the 95% confidence level. If all comparisons were significant, a ">" was used; if some of the comparisons were significant, "≥" was used to define the relationship, and nonsignificant differences were represented with a "~."

Average mud LC50's and EC50's were converted to equivalent FCL concentrations with the use of a standard curve and correlated with mud LC50's by computing the product-moment correlation coefficient (Sokal and Rohlf 1969). Negative correlations were expected since LC50's and EC50's and chemical toxicity are inversely proportional--that is, the greater the FCL concentration, the smaller the LC- or EC50 should be.

RESULTS

The Nature of Drilling-Mud Toxicity

The rates of response (changes in swimming behavior and mortality) to mud B suspensions (SM) and water-soluble fractions (WSF's) were slow.

Measurable mortality (LC50's) began at 48-72 h, decreased at variable rates, and stabilized between 96 and 144 h. Measurable changes in swimming ability (EC50's) began between 4 and 24 h, and approached stability between 72 and 120 h (Figure 1). Comparisons between mud toxicities or species sensitivity at 144 h were, therefore, independent of the larval response rate because EC50 and LC50 curves became asymptotic before 144 h.

Although mud B was the most toxic mud tested, depressed swimming was not noted until approximately 24 h, and no recovery was observed. In some cases, particularly with the Dungeness crab larvae, mud accumulated in the gut of the larvae. This did not result in immediate death but inhibited swimming activity.

The sensitivity variation between species was measured by exposing each species to mud B SM's and WSF's. Species sensitivity to mud B suspensions (LC50's) ranged from 0.05% (dock shrimp) to 0.94% (Tanner crab), and the EC50's ranged from 0.05% (dock shrimp) to 0.28% (king crab) (Figure 2). Mud B WSF LC50's ranged from 0.30% (dock shrimp) to 3.34% (king crab), and the EC50's ranged from 0.21% (dock shrimp) to 2.58% (king crab) (Figure 2, Table 2).

Coonstripe and dock shrimp larvae were relatively sensitive in both the mud suspensions and WSF's. In contrast, larval tanner crab and kelp shrimp appeared to be relatively more sensitive than the other larvae in the WSF but more tolerant in the suspensions. The species sensitivities were as follows:

Decreasing Tolerance →

(1) Suspended mud B: Tanner > kelp ≧ king > Dungeness ~ coonstripe ~ dock.

(2) Mud B WSF: king ≧ Dungeness ≧ tanner ~ coonstripe ~ kelp ~ dock.

In tests involving the remaining muds, king crab larvae were generally more tolerant than larval coonstripe shrimp.

The variation in mud toxicities, which was considerable, was measured by exposing king crab and coonstripe shrimp larvae to each of the six muds. In the suspended-mud tests, EC50's varied from 0.28% (mud B) to 1.53% (mud D) for king crab larvae, and from ≦0.2% (mud B) to 2.98% (mud D) for larval coonstripe shrimp. (Only EC50's were computed for the SM's because some larvae were buried in the settlings, which made it difficult to assess mortality accurately.) In the WSF tests, the EC50's for king crab larvae varied from 2.58% (mud B) to 18.05% (mud D), and from 0.65% (mud B) to 26.79% (mud D) for larval coonstripe shrimp. The WSF LC50's for king crab larvae ranged from 2.33% (mud A') to 30.08% (mud D), and from 0.90% (mud B) to 37.62% (mud D) for coonstripe shrimp larvae. Larval coonstripe shrimp were generally more sensitive than king crab larvae (Figure 3, Table 3).

Mud B was generally the most toxic mud, whereas mud D was generally the least toxic. The comparative toxicities were as follows:

Decreasing Toxicity →

(3) Suspended-mud tests: $B > A \sim C \sim C'$.

(4) Mud WSF tests: $A' \sim B \geqq C' \sim C \geqq A \geqq D$, where

A ≡ used Prudhoe Bay mud (2926 m)

A' ≡ unused Prudhoe Bay mud

B ≡ used Cook Inlet mud (3382 m)

C ≡ Homer 'spud' mud

C' ≡ unused Homer "spud" mud

D ≡ used Homer mud (442 m)

The toxicity of the suspended mud was much greater than the WSF toxicity. Comparison of mud WSF's and the suspended muds $1 - \frac{\text{WSF LC50}}{\text{SM LC50}}$ indicates that the particulate matter in the whole muds accounted for 81% ±

16% of the toxicity. Cessation of swimming indicated that the particulate matter contributed 80% ± 10% of the observed response.

The stability of the mud B WSF toxicity was tested with king crab and coonstripe shrimp larvae. The toxicity in mud B WSF EC- and LC50's increased gradually over time (Table 4). These increases were not significant for king crab larvae in 21 days but were significant for coonstripe crab larvae in 28 days. The decrease in toxicity (indicated by increased sensitivity) was due to dilutions of the toxicant caused primarily by water condensation.

Coonstripe shrimp larvae were also tested in mud B WSF at several different salinities. Their sensitivity to mud B WSF was unaffected by salinities ranging from 30.58°/oo to 15.07°/oo. A salinity of 12°/oo without toxicant was lethal within 96 h. The median lethal salinity, without acclimation, was 15.51°/oo (13.09-17.93°/oo) at 96 h. Evidently, coonstripe shrimp larvae are euryhaline because salinities in controls as low as 18.14°/oo caused no death or behavioral changes. Salinity differences apparently did not alter the chemical configuration of the toxicant sufficiently to change its toxicity.

Mud-Component Toxicities

Dock shrimp and Dungeness crab larvae were tested in ferrochrome lignosulfonate (FCL) solutions. The LC50's were 0.12 g/l (dock shrimp) and 0.21 g/l (Dungeness crab), and the EC50's were 0.05 g/l (dock shrimp) and 0.15 g/l (Dungeness crab) (Table 5). Dock shrimp larvae were also more sensitive than Dungeness crab larvae in the suspended-mud and WSF tests.

The FCL concentrations in a given mud could be calculated from the mud absorbance data (Table 1) and a FCL standard curve. Mud B, for example, contained 28.5 g/l FCL according to data supplied by IMCO (Table 6), and

66% of this was detected in the WSF. The actual FCL concentrations (FCL 'equivalents') at the LC50 (or EC50) were then calculated for each mud, and compared with the observed mud LC- and EC50's. Negative correlations were anticipated because greater FCL concentrations should yield smaller mud LC- and EC50's. FCL LC50 equivalents ranged from 0.04 to 0.63 g/l (king crab) and from 0.04 to 0.17 g/l (coonstripe shrimp). Equivalent FCL EC50's ranged from 0.04 to 0.48 g/l (king crab) and from 0.02 to 0.12 g/l in the coonstripe tests. Moderate-to-strong negative correlations (-0.31 and -0.95) between FCL and mud WSF LC50's and between FCL and mud WSF EC50's (-0.49 and -0.89) were obtained in the king crab experiments. However, FCL and mud WSF LC50's correlations from the coonstripe shrimp experiments were negligible to moderate (-0.09 and -0.64), and no correlation between FCL and EC50's (0.06 and 0.03) was found. Further analysis revealed the regression coefficients (slopes) were not significantly different from zero and implied that other factors also contributed significantly to the mud WSF toxicity.

The rate of response to FCL was very similar to the mud B WSF rate. Measurable LC50's began at 48 h and approached stability by 120 h. Measurable EC50's began at 4 h and were stable by 72 h (Figure 4).

Barite and bentonite were not particularly toxic. The EC50's were first measurable after 24 h and did not decrease with time, thereafter. The EC50's for Dungeness crab larvae ranged from 3.88 g/l to 4.28 g/l with bentonite and was 3.57 g/l (2.22-5.75 g/l) with barite. Dock shrimp larvae were more sensitive: the bentonite EC50's ranged from 0.69 to 1.73 g/l, and the barite EC50's 0.27 to 2.52 g/l (Table 4).

In toxic mud B suspensions, bentonite was present at 1% to 3% of its toxic level, and barite was present in more significant quantities (12% to 63% of its toxic level). The quantities of barite and bentonite in mud B were calculated from the data in table 2. The bentonite concentrations were 0.02 g/l (dock shrimp) and 0.1 g/l (Dungeness crab); barite concentrations were 0.3 g/l (dock shrimp) and 1.4 g/l for Dungeness crab.

DISCUSSION

The toxicities of the drilling muds we tested are similar to the toxicities to crustacean larvae reported in other drilling-mud studies. Gilfillan et al. (1980) observed a 96-h WSF LC50 of 1.7% for Stage I pink shrimp (Pandalus borealis) larvae, and 0.5% for stage V American lobster (Homarus americanus) larvae. Carr et al. (1980) observed a 96-h WSF LC50 of 2.7% in 1-day-old Mysidopsis almyra juveniles. Neff et al. (1980) observed a 96-h WSF range of 1.17-2.75% for stage I grass shrimp (Palaemonetes pugio) larvae. All of these values fall within the 96-h range observed in this study.

Dames and Moore (1978) reported that coonstripe shrimp adults had a 96-h LC50 range between approximately 3.2% and 15%. Comparison with coonstripe shrimp larvae findings in this study suggest the larvae may be approximately an order of magnitude more sensitive than the adults. Neff et al. (1980) observed adult and larval grass shrimp sensitivities varied by a factor of approximately 3-4.

Cessation of swimming responses were more sensitive indicators of the larval response to the toxicants than mortality responses. Compared to mortality, swimming stopped relatively early in the exposures and at lower exposure levels. The EC50's for cessation of swimming and LC50's eventually did approach convergence, however; since dead animals cannot swim, the number of nonswimming larvae is dependent on mortality. At the extreme, 100% mortality and 100% nonswimming must occur together. The mean EC50:LC50 ratio at 96 h, 0.51 (0.45-0.58), was significantly less than at 144 h, 0.66 (0.60-0.71).

Chemical compositions and toxicities between drilling muds vary widely, as is evident from this study. Hrudey (1979) found that surface muds were the most toxic, and midhole muds were the least toxic. Data in our study tend to follow this pattern. Other studies have demonstrated increasing mud toxicity with drilling depth (Tornberg et al. 1979). With multiple mud and formation combinations possible, it is probable that consistent trends do not occur. Mud B was comparatively toxic for two reasons: (1) it stayed in suspension; therefore, the larvae were subjected to continual physical stress; and (2) mud B contained a much higher concentration of FCL than the other muds.

The effect of the suspended muds on larval swimming ability was not very rapid. The rate at which swimming ceased was the same as the rate of cessation in the controls but occurred earlier with increasing mud concentrations (Figure 5). This suggests the toxicity mechanism is physical, rather than chemical, by requiring extra energy expenditure to cope with suspended particles. Because none of the larvae were fed during the testing periods, experimental larvae, which probably expended more energy, would run out of energy and stop swimming before the controls, but this rate of decline would be the same (Figure 1). In contrast, acute chemical toxicity would be expected to cause a more rapid decline, because the larvae probably take up chemical toxicants quickly.

The particulate matter in the drilling muds, which was composed primarily of barite and bentonite, caused roughly 80% ± 16% of the observed toxicity. This agrees reasonably well with work by Logan et al. (1973) who determined barite and bentonite accounted for approximately 45-60% of the total theoretical mud toxicity (Land 1974). Logan et al. (1973) point out that the contribution of solids is strongly dependent on the actual mud composition. Several authors (Beckett et al. 1975; Dames and Moore 1978; Sprague and Logan 1979; Gilfillan et al. 1980) have suggested that suspended solids may cause mortalities through abrasion, erosion, or the clogging of respiratory surfaces. Robison (1957) suggested the toxic effect of Montmorillonite (bentonite) may be related to its absorptive capacity as suspended solids are passed through the gut. All these effects, including swimming in a more viscous mud, would consume more of the larva's energy.

The fact that barite and bentonite had an initial effect, followed by no change in the component tests, suggests that the detrimental effects were caused by particles in suspension and that after these had settled out of the water column, no further interaction took place. Others (Daugherty 1951; Logan et al. 1973; Sprague and Logan 1979) have found very low bentonite and barite toxicities. Sprague and Logan (1979) found 96-h LC50's for rainbow trout (Salmo Gairdneri) were 76 g/l for barite and 19 g/l for bentonite. Our experiments indicate that crustacean larvae are approximately an order of magnitude more sensitive than trout, and perhaps more, because no attempt was made to keep these materials in suspension in our larval tests.

Water-soluble fractions accounted for about 20% of the toxicity of drilling muds. Apparently, the chemical compounds in the WSF also increased the rates of larval energy expenditure. Carr et al. (1980) found Mysidopsis almyra juveniles increased food consumption and initial respiration rates but their growth was retarded when exposed to sublethal mud WSF's. Respiration rates eventually returned to normal, but dose-dependent growth retardation became more pronounced. He concluded that the shunting of energy into homeostatic mechanisms reduced the amount of energy available for growth.

The FCL content of the muds (see the WSF absorbance data, Table 1) suggested that B >> C' > C > D > A. This hypothesis was largely substantiated (Comparison 4) and implies that FCL is a major factor in the WSF toxicity. The FCL concentration correlated well with the observed toxicity in the king crab experiments.

Absorbance data indicated that FCL did not volatilize or degrade in seawater but changes in concentration were caused by water evaporation and condensation. The bioassays also indicated that FCL was essentially stable under the given test conditions. The concentration of the mud WSF slowly decreased over time due to two factors: (1) the principal concentration decrease was due to dilution caused by water condensation, and (2) water introduced with each new batch of larvae caused slight progressive dilutions. This dilution explains the observed drift in toxicities over the course of a month.

The chromium associated with the lignosulfonates may be one of the toxic factors in mud toxicity. The toxicity of chrome varies widely for different aquatic organisms and also depends on its valence (Hrudey 1979). Chromium exhibits its greatest bioavailability in pure solution, is less available in FCL solutions, and is least available in mud WSF's (Page et al. 1980). This decreasing bioavailability is due to (1) chelation of Cr with the lignosulfonate molecule, and (2) the ion-exchange capacity of bentonite. FCL is absorbed along the edge of the clay platelets and may also be absorbed on barite (Monaghan et al. 1976; Sprague and Logan 1979; Ray and Meek 1980).

Other heavy metals also occur in drilling muds and may contribute to its toxicity. Only a small fraction of these metals appear in the aqueous phase. Natural-formation drill solids may be the major source of most trace elements. Lead may originate from drill-string lubricant (Ayers et al. 1980; Page et al. 1980; Ray and Meek 1980).

Although petroleum hydrocarbons and drilling muds are the two main pollutants from well-drilling activities, they are very different chemically and toxicologically. In oil WSF's, crustacean larvae are unable to swim within minutes of exposure although it may take several days before they die. Low concentrations of aromatic hydrocarbons in the oil WSF are toxic and are taken up quickly. In contrast, the effects of relatively high drilling-mud concentrations are slow, and the principal toxic factor is physical. EC50 hydrocarbon WSF concentrations for king crab, coonstripe shrimp, Dungeness crab, and kelp shrimp larvae range from 0.8 ppm to 2.1 ppm (Rice et al. 1981). This range is roughly 3-5 orders of magnitude below the mud WSF EC50 range. A difference of two orders of magnitude occurs between FCL toxicity and hydrocarbon WSF toxicity.

The fate of drilling muds in the natural environment is more complex than in the laboratory. The same currents that bring larvae into contact with a plume of discharged drilling muds also dilute the plume and carry larvae downstream. After a relatively brief exposure, the mud WSF probably will virtually "disappear" through water dilution. Ray and Meek (1980) observed dilutions of 500:1 to nearly 1,000:1 within 3 m of a platform discharge pipe; within 200 m of the discharge, total suspended solids were approaching background levels.

Our toxicity studies indicate that larvae are not damaged quickly because both the chemical and physical toxicity of drilling muds is low. Because the length of time they are exposed to significant drilling-mud concentrations is very short, discharges of drilling muds are not particularly harmful to crustacean larvae even though they are probably an order of magnitude more sensitive than salmon fry and adult shrimp.

SUMMARY

Drilling muds were toxic to crustacean larvae, with the level of toxicity dependent on the mud composition, species, and the type of test (suspended mud or WSF). All comparisons between toxicities or sensititivities were made at 144 h because the larval response had stabilized by that time.

1. The suspended muds were more toxic to crustacean larvae than mud water-soluble fractions were. For used Cook Inlet mud (mud B), the 144 h LC50 range for several species was 0.05-0.94% by volume for suspended mud, and 0.30-3.34% for the water-soluble fraction.
2. The particulate fraction of the muds caused approximately 80% of the observed toxicity, and the water-soluble fraction accounted for the remaining 20%.
3. Variation between mud toxicities was greater than variations between species sensitivity. The 144-h mud WSF LC50 range was 0.90-37.62 for king crab and coonstripe shrimp larvae. The WSF toxicity from the most toxic to least toxic mud was: $A' \sim B \geq C' \sim C \geq A \geq D$,

   where A ≡ used Prudhoe Bay mud (2926 m)

   A' ≡ unused Prudhoe Bay mud

   B ≡ used Cook Inlet mud (3382 m)

   C ≡ Homer 'spud' mud

   C' ≡ unused Homer mud

   D ≡ used Homer mud (442 m).
4. Mud-component tests with dock shrimp and Dungeness crab larvae indicated that barite and bentonite EC50's ranged from 0.3 to 4.3 g/l. At 144 h, average ferrochrome lignosulfonate LC50's were 0.2±0.1 g/l.

5. Ferrochrome lignosulfonate concentrations in the mud B WSF correlated well with the toxicity and swimming cessation in the king crab larval tests. Chromium may be a significant factor in FCL toxicity.

6. Some variation in relative species sensitivity occurred between the suspended mud and the water-soluble-fraction (WSF) tests. Larval tanner crab and kelp shrimp were relatively tolerant in the suspended muds, but were more sensitive in the WSF. However, coonstripe and dock shrimp larvae were sensitive in both test types, and larval king and Dungeness crab were generally tolerant.

7. The cessation of larval swimming was a more sensitive indicator of the mud toxicity than mortality was. EC50's, measured by nonswimming, were measurable earlier (4-24 h) than LC50's, measured by death, (48-72 h) and occurred at lower exposure concentrations (66% of the LC50 at 144 h).

8. Variations in salinity over the range 30.58-15.07°/₀₀ did not affect the water-soluble fraction toxicity of the used Cook Inlet mud (mud B).

CONCLUSIONS

1. The toxic nature of drilling muds is very different from the toxic nature of crude oil. Drilling muds affect larval crustacean swimming ability and survival slowly, whereas the effects of oil are very rapid. The water-soluble fractions of drilling muds are stable in solution, but oil WSF's are not. However, the particulate fraction of the mud generally settles out of the water quickly.

2. The slow nature of the drilling-mud toxicity suggests the toxic components are not very active as chemical poisons, but cause extra larval energy expenditure to maintain homeostasis. Accelerated energy depletion results in early death.

3. Crustacean larvae are more sensitive to drilling muds than adult crustaceans and fish by approximately an order of magnitude. However, drilling muds are not particularly toxic, for toxic concentrations ranged from approximately 4 to 40 parts per thousand.

4. Water-column concentrations of drilling muds capable of causing toxicity are probably brief and limited to distances less than 3 m from the point of platform discharge. Under most conditions, drilling mud discharge probably has no measurable impact on planktonic and nectonic communities in the natural marine environment.

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FOOTNOTE

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

TABLE 1

Description of Drilling Muds Used in Bioassays

Mud identity	Location	Condition	Depth (m)	Density ($kg \cdot l^{-1}$)	100% WSF pH	100% WSF Salinity (‰)	100% WSF Color	100% WSF Absorbance[a]
A	Prudhoe Bay	used	2,926	1.122	8.9±0.0	1.8±0.1	yellow	2.68
A'	Prudhoe Bay	new	0	1.183	13.2±0.0	3.1±0.0	clear	b
B	Cook Inlet	used	3,382	1.655	8.6±0.0	17.5±0.1	red/orange	173.77
C	Homer	used "spud"	--	1.168	9.9±0.0	5.2±0.1	yellow	5.26
C'	Homer	new	0	1.174	9.9±0.0	5.2±0.1	yellow	5.46
D	Homer	used	442	1.067	12.2±0.0	4.0±0.1	yellow	4.19

[a]--Calculated 100% values at 277 nm.

[b]--No absorbance peak at 277 nm.

Table 2. Sensitivity of shrimp and crab larvae to used Cook Inlet mud (mud B). Sensitivities were measured by mortality (LC50's) and the cessation of swimming (EC50's). Tests were conducted with whole mud suspensions and with mud water-soluble fractions. The 144-h means and the 95% confidence intervals are listed as percent mud by volume.

	LC50		EC50	
Species	SM	WSF	SM	WSF
King crab	0.48 0.35-0.61	3.34 1.12-5.56	0.28 0.00-0.57	2.58 1.62-3.54
Coonstripe shrimp	*	0.90 0.54-1.27	≦0.20	0.65 0.46-0.83
Tanner crab	0.94 0.00-6.25	1.65 0.40-2.90	NC	0.56 0.35-0.77
Kelp shrimp	0.44 0.36-0.53	0.47 0.24-0.69	<0.50	NC
Dungeness crab	0.20 0.16-0.23	1.41 0.00-3.85	NC	NC
Dock shrimp	0.05 0.05-0.05	0.30 0.00-1.53	0.05 0.02-0.08	0.21 0.16-0.29

NC. Not calculable.
* Not tested.

Table 3. Comparative mud toxicities, using larval king crab and coonstripe shrimp as indicator species. See table 2 for the mud B data. Tests measured mortality (LC50's) and the inability to swim (EC50's). The 144-h means and 95% confidence intervals are in percent mud by volume. See table 1 for description of mud types.

Species	A	A'	C	C'	D
		A--WSF LC50			
King crab	*	2.33 0.00-9.96	9.45 7.67-11.22	7.17 7.09-7.24	30.08 17.68-42.48
Coonstripe shrimp	15.31 4.29-26.34	3.23 0.46-5.99	*	<5	37.62 27.72-47.53
		B--WSF EC50			
King crab	*	NC	6.60 4.61-8.58	6.18 4.13-8.24	18.05 11.87-24.24
Coonstripe shrimp	9.07 6.17-11.97	2.42 (0.00-5.38)	*	<5	26.79 16.47-37.11
		C-SM EC50			
King crab	*	<1	NC	<1	1.53 0.86-2.71
Coonstripe shrimp	*	<1	*	NC	2.98 1.18-7.51

NC. Not calculable.

* Not tested.

Table 4. Toxicity of aged Cook Inlet mud (mud B) water-soluble fractions with king crab and coonstripe shrimp larvae as indicator species. The tests measured mortality (LC50's) and the swimming cessation (EC50's). The 144-h means and 95% confidence intervals are listed as percent mud by volume.

	AGED WSF LC50			
Species	7	14	21	28
King crab	3.91 2.60-5.21	6.03 1.16-10.89	5.63 4.22-7.51	*
Coonstripe shrimp	1.47 0.88-2.06	4.08 1.44-6.72	5.83 1.47-10.19	4.19 2.90-5.49

	Aged WSF EC50			
Species	7	14	21	28
King crab	2.41 1.37-4.23	3.63 0.00-10.89	NC	*
Coonstripe shrimp	0.92 0.79-1.05	2.49 0.00-5.82	2.87 0.00-19.31	3.82 1.51-6.13

NC. Not calculable.
* Not tested.

Table 5. Mud-component toxicities. Sensitivities of larval Dungeness crab and dock shrimp to ferrochrome lignosulfonate (FCL), bentonite, and barite were measured by mortality (LC50's) and the loss of swimming ability (EC50's). Means and 95% confidence intervals are in grams per liter.

FERROCHROME LIGNOSULFONATE

Species	LC50	EC50
Dungeness crab	0.21 0.18-0.24	0.15 0.09-0.24
Dock shrimp	0.12 0.00-0.48	0.05 0.02-0.16

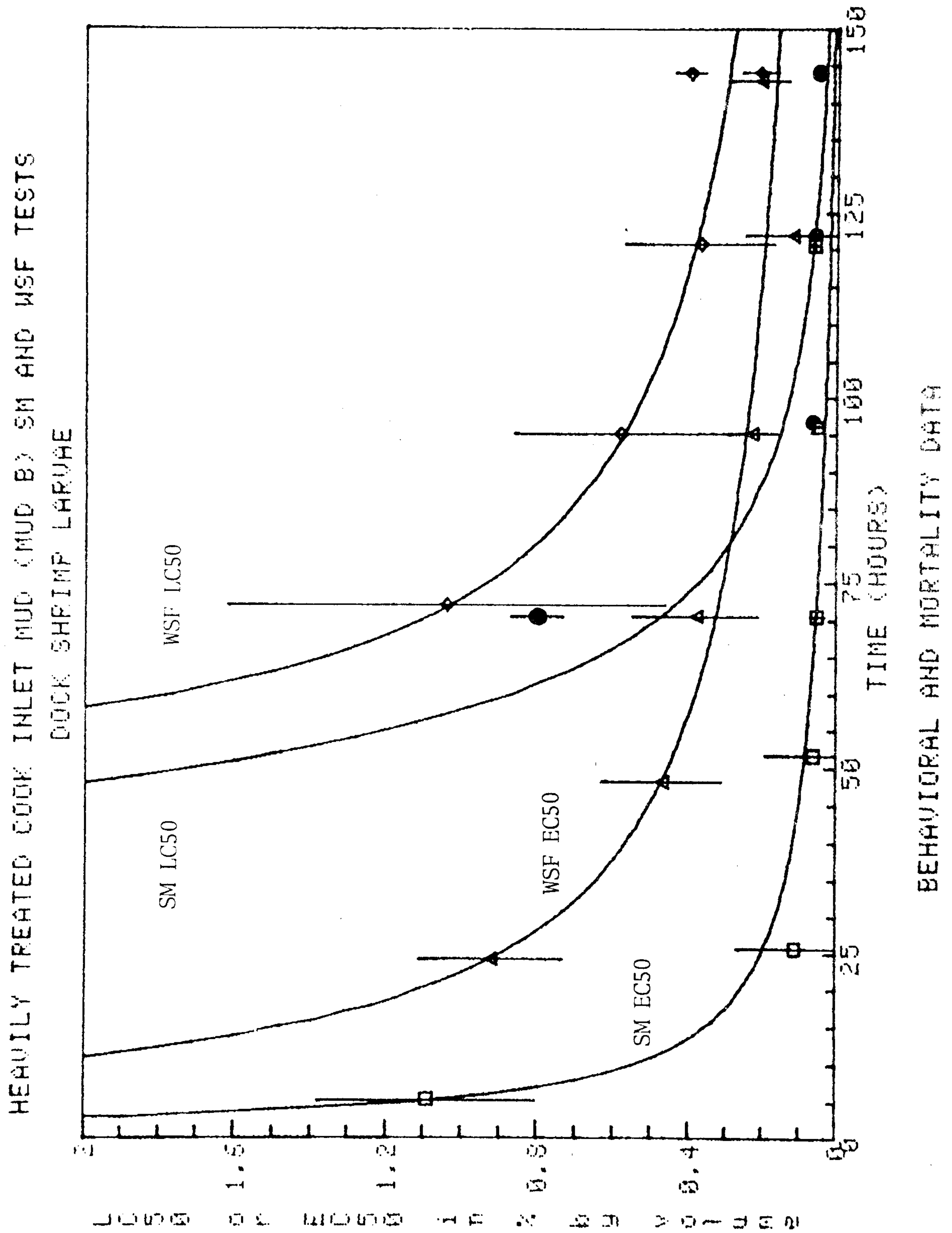
Species	24.1 h	42.8 h	71.1 h	119.0 h
		BENTONITE		
Dungeness crab	NC	3.88 2.06-7.31	4.28 3.05-6.02	NC
Dock shrimp	0.99 0.45-2.17	NC	0.97 0.00-4.48	1.53 0.28-8.29
		BARITE		
Dungeness crab	NC	NC	3.57 2.21-5.75	NC
Dock shrimp	0.40 0.00-2.72	NC	NC	2.52 0.41-15.64

NC. Not calculable.

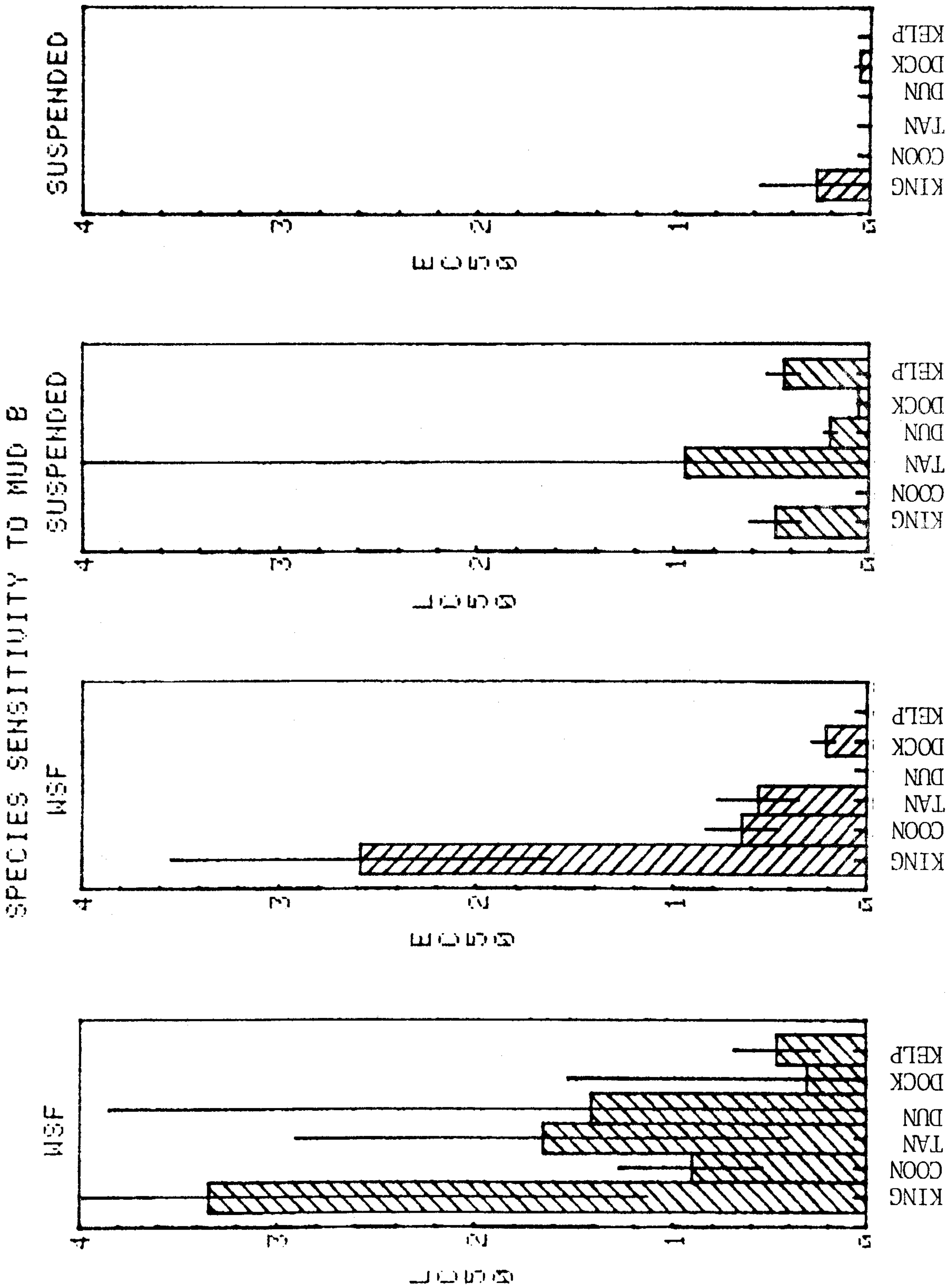
Table 6. Composition of mud B*

Component name	Composition	Quantity (g/l)
IMCO Bar	Barite ($BaSO_4$)	570.0
IMCO Gel	Bentonite (Montmorillinite clay)	42.8
IMCO VC-10	Ferrochrome lignosulfonate	28.5
Soltex	Sulfonated asphaltene	17.1
Drispac Super Lo	Polyanionic cellulosic polymer	5.7
IMCO Poly Rx	Ferrochrome lignosulfonate, lignite, sodium carbonate, sodium nitrilotriacetic acid	2.9
Desco	Sulfonated quebracho containing tannins of the condensed type	2.9
IMCO caustic soda	Sodium hydroxide (NaOH)	2.9
Water	(% by volume)	75%
Solids	(% by volume)	25%

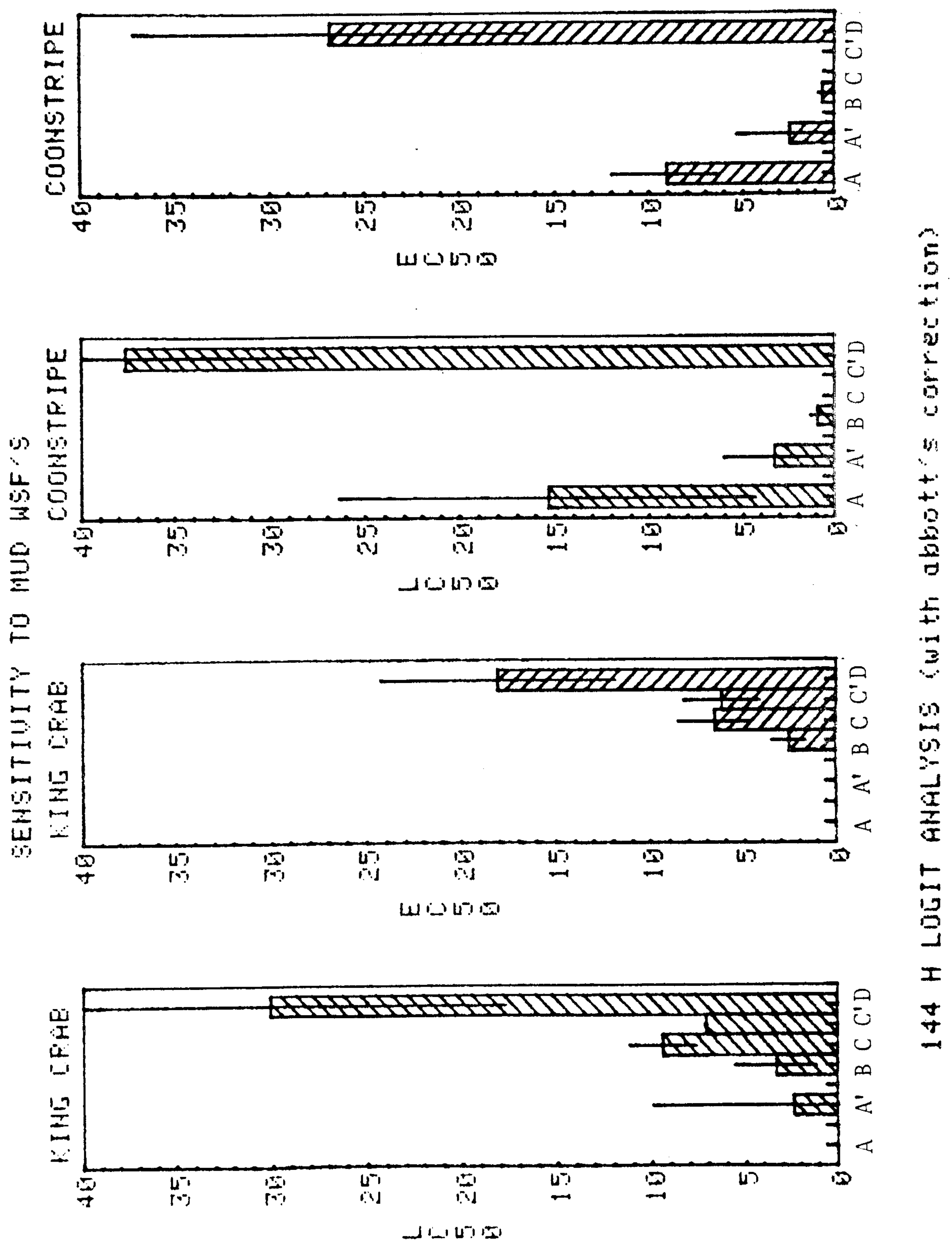
* Data supplied by IMCO Services, the supplier of mud B.



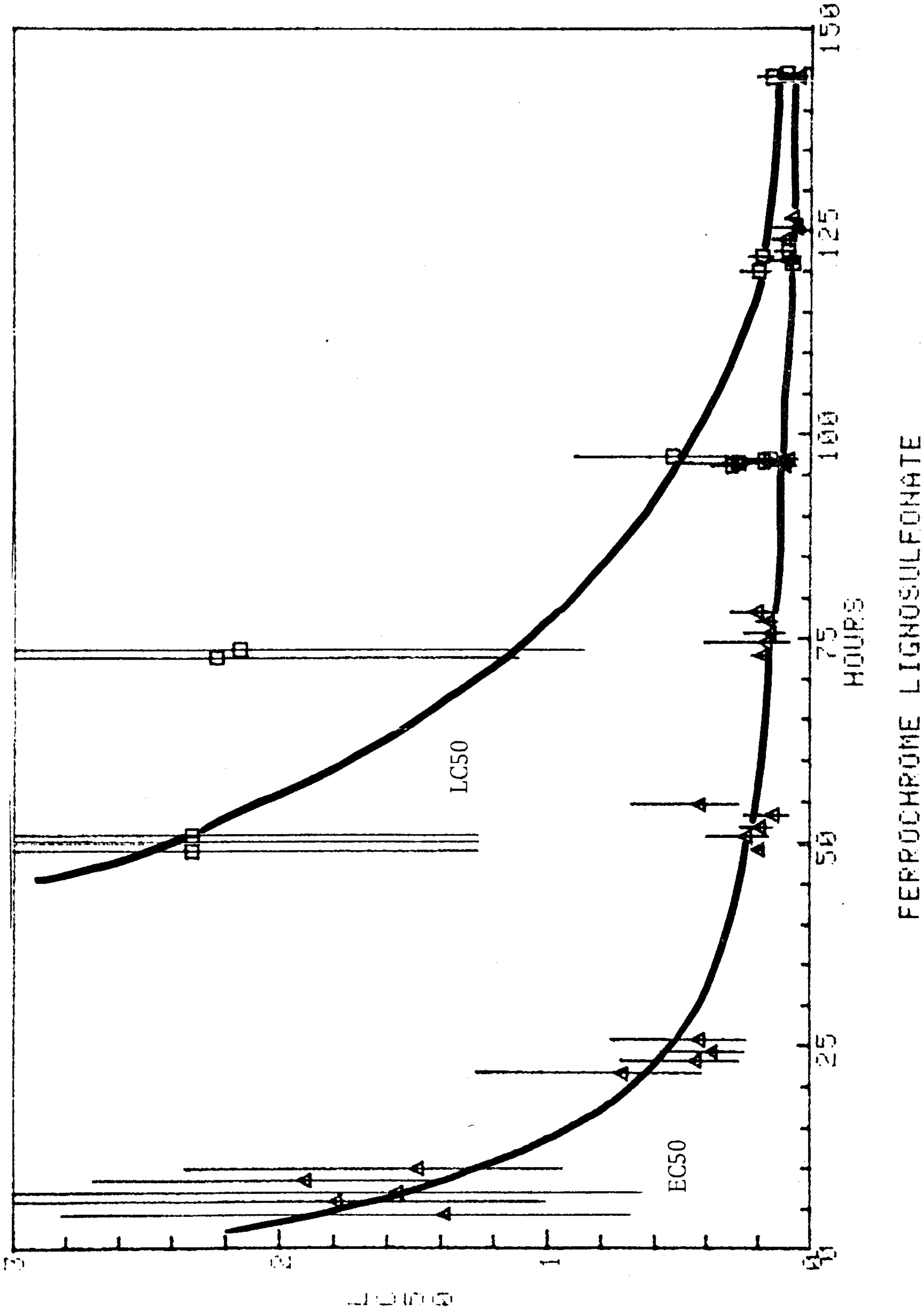
1. Comparison of average mud B suspension and WSF rates of effect on dock shrimp larvae. The effect in the suspensions occurred prior to the WSF effect, and resultant EC- and LC50's were smaller. Cessation of swimming (EC50's) occurred well before mortality (LC50's) began. Vertical bars indicate the 95% confidence interval.



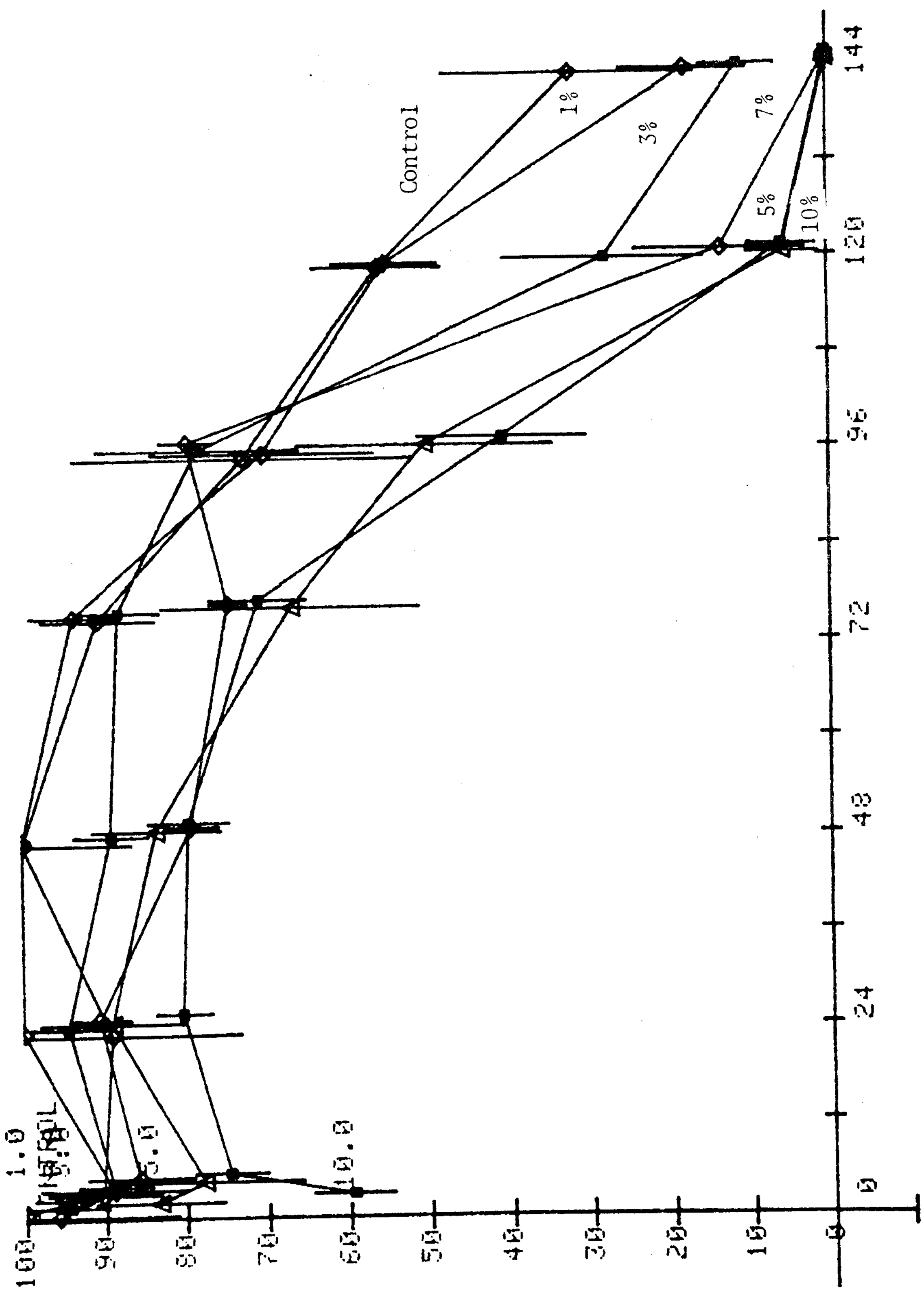
2. Comparison of sensitivity of six species of larval shrimp and crabs to both the water-soluble fraction (WSF) and suspension (SM) of a heavily treated Cook Inlet drilling mud (mud B). The responses measured were mortality (LC50) and the inability to swim (EC50). Vertical bars indicate the 95% confidence interval.



3. Comparison of mud WSF toxicities (LC50's) and concentrations causing swimming cessation (EC50's) with king crab and coonstripe shrimp larvae as indicator as species. See table 1 for description of mud types.



4. Rate of effect of ferrochrome lignosulfonate (FCL) on dock shrimp larvae. Changes in swimming (EC50) occurred before mortality (LC50) began. Rate patterns for FCL and mud B WSF (Figure 1) were quite similar.



5. Effect of used Homer mud (mud D) suspension on swimming ability of larval king crab. After the initial effect, some recovery was observed. Note that swimming declines tended to mirror the control pattern.

FINAL REPORT OF CHUKCHI SEA ACTIVITIES

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Trophic Relationships Among Ice-Inhabiting Phocid Seals and Functionally Related Marine Mammals in the Chukchi Sea

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DISCLAIMER

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I. Summary

A total of 41 spotted seal, 581 ringed seal, and 243 bearded seal stomachs containing food and collected in the Chukchi Sea were analyzed. In addition, we examined 83 belukha whale and 4 walrus stomachs containing food. Most of the specimens were obtained from Eskimo subsistence hunters at three coastal villages: Shishmaref, Point Hope, and Wainwright. Most of the belukhas were collected in Eschscholtz Bay (inner Kotzebue Sound). Samples were collected at several times of year in order to assess seasonal changes in feeding patterns. The best sample coverage was near the coast in spring and summer when native hunting activity is greatest. Poorest sample coverage was in winter, and in offshore areas that are not accessible to coastal based hunters.

The diet of ringed seals in the Chukchi Sea shows pronounced seasonal variation. In most seals collected in fall, winter, and early spring, arctic cod were the main food. Near Shishmaref saffron cod were important in the fall and spring periods, with arctic cod most important in midwinter. During spring and summer crustaceans, mostly shrimps, amphipods and mysids, were the major prey. Age-related differences in diet were found in seals from Shishmaref. Almost one-third of the diet of pups was comprised of small crustaceans such as mysids, amphipods, and euphausiids, and the fish they ate were entirely cod. Older seals ate proportionately less crustacean material and a much greater variety of fishes.

Bearded seals are primarily benthic feeders, eating mostly crabs, shrimps, and clams. The vast Chukchi Platform provides extensive shallow water feeding habitat for them. Clams are found in the diet only during summer months. Pup bearded seals eat more shrimps and isopods than do older seals which eat more clams, crabs, and echuiroid worms.

Based on very limited samples, spotted seals and belukhas forage primarily on several species of coastal and anadramous fishes including herring, saffron cod, capelin, and rainbow smelt.

Clams comprised most of the contents of the four walrus stomachs exmained.

During much of the year the distribution of marine mammals is determined by the distribution and abundance of their prey. In order to assess the probable effects of OCS development on marine mammals, data must be available on the distribution, abundance, and hydrocarbon sensitivity of their principal prey species. Available data are reviewed in this report and found to be inadequate. Recommendations for further studies of the foods and feeding habits of marine mammals as well as the biology and hydrocarbon sensitivity of prey species are given.

II. Introduction

During the last 5 years there has been a continually changing series of oil and gas leasing schedules proposed for areas of "promising" oil and gas potential on the continental shelf off Alaska. Among these areas are the nearshore waters of the Chukchi Sea. The present leasing schedule calls for sale #85 (Chukchi Sea) in February 1985 and sale #86 (Hope Basin) in May 1985. Final Environmental Impact Statements for those areas are due in July and October 1984, respectively.

Since 1975, as a part of the Alaskan Outer Continental Shelf Environmental Assessment Program (OCSEAP), this research unit has been investigating trophic relationships of ice-associated marine mammals, primarily phocid seals, of western and northern Alaska. This final report presents the information collected in the Chukchi Sea during a 4-year field program in order to make it available to resource managers for consideration during tract selection, EIS preparation, and policy formulation.

The waters off the coast of Alaska support a tremendous abundance and diversity of marine mammals. Some species occur only during ice-free months while others are more or less dependent on sea ice as a habitat in which to whelp, breed, molt, and feed. The relationship between northern marine mammals and sea ice has been well summarized by Burns (1970) and Fay (1974).

Several species of marine mammals regularly occur in the Chukchi Sea. From April to June bowhead whales pass through leads in the nearshore ice of the Chukchi Sea on their way from wintering areas in the Bering Sea to their summer feeding grounds in the eastern Beaufort Sea. These whales leave the Beaufort Sea when ice reforms in September and October and once again pass through the Chukchi on their way to overwintering areas. Belukha or white whales accompany the bowheads north in spring. Some of these small whales may bear their young in coastal lagoons and estuarine systems of the Chukchi. They, too, usually leave in autumn as the ice forms. Belukhas winter primarily in areas of moving ice. Occasionally they are trapped in polynyi where they overwinter or perish as the ice cover becomes complete.

As the pack ice disintegrates and recedes north in the spring, most of the Pacific walrus population leaves its wintering grounds in the Bering Sea and moves north. The majority of these animals summer in the northern Chukchi Sea and off the coast of northeast Siberia. Some walruses penetrate the western and central Beaufort Sea. They move south in the early autumn, passing through the Bering Strait mainly in the months of October, November, and December.

Spotted seals utilize the ice front of the Bering Sea for whelping and molting in late winter and spring. They move north and toward the coast as the ice recedes in May and June. Many are found along the Chukchi coast during summer and early fall. They are not adapted to wintering in this area, and so move south in early fall with the onset of freezeup.

Only three species of marine mammals can be considered year-round residents of the Chukchi Sea. These are ringed seals, bearded seals, and polar bears. Although arctic foxes range widely over all types of sea ice, it is debatable whether they can be considered truly marine.

Polar bears are distributed throughout ice-covered arctic waters. In summer they are found on the pack ice, with greatest densities along the edge. They are primarily found in areas of high abundance and availability of ringed and bearded seals which are their main prey.

Bearded seals are year-round residents of the Chukchi Sea. They are able to maintain breathing holes in ice, but appear to do so only rarely, and are thus largely excluded from the fast ice zone. Rather, they are most common in the transition zone and offshore pack ice (Burns 1967, Burns and Harbo 1972, Stirling et al. 1975). The Chukchi Sea is underlain by the Chukchi Platform, a vast area of continental shelf with water depths less than 100 m. As bearded seals can feed at depths up to 100 m, the Chukchi Sea offers an extensive foraging area. During the summer there is an influx of bearded seals from the Bering Sea as the ice there melts and recedes north. Although some seals move into the Beaufort Sea in summer, the majority appear to remain over the shallow Chukchi Platform.

Ringed seals are found almost throughout ice-covered seas of the northern hemisphere, and they are overall the most common species of seal in the Chukchi Sea. Their density in any given area and at any given time is closely related to ice conditions. In late March and early April ringed seal pups are born in lairs excavated in snow-covered ice (McLaren 1958, Burns 1970, Smith and Stirling 1975). Although stable landfast ice is the preferred area for pupping, and the greatest density of seals occurs there, some pups are born on drifting ice. There are some indications that older, more experienced females may occupy the preferred breeding habitat (McLaren 1958, Burns 1970). Subadult animals are often found congregated along transient lead systems (Stirling et al. 1975; Burns, unpubl.).

Subsequent to pupping and breeding, ringed seals undergo a period of molting during which they spend a large amount of time hauled out on the ice. During this period feeding intensity is quite low (McLaren 1958, Johnson et al. 1966). As the ice melts in the Bering Sea in May and June, seals move into the Chukchi and Beaufort Seas where they spend the summer dispersed throughout ice-covered areas. With the onset of winter and the increase in ice cover, the area occupied by ringed seals expands accordingly. Specific details of these movements are largely unknown.

Ringed, spotted, and bearded seals, as well as the other species of marine mammals, are of cultural and economic importance to residents of the Chukchi coast. Seal hunting occurs regularly at the villages of Shishmaref, Point Hope, and Wainwright where seals are hunted for human and dog food, and for the skins which have traditionally been used for clothing, equipment, and crafts. National interest in these animals and the habitats they utilize is high. This interest is perhaps best exemplified by the Marine Mammal Protection Act of 1972 (Public Law 92-522) passed by the Congress of the United States which states that "marine mammals have proven themselves to be resources of great international significance, esthetic and recreational as well as economic, and it is the sense of the Congress that they should be protected and encouraged to develop to the greatest extent feasible commensurate with sound policies of resource management."

These factors and others make it imperative that the potential effects of oil and gas exploration and development in the Chukchi Sea on ice-inhabiting marine mammals be anticipated and minimized to whatever degree possible. Such an evaluation requires an understanding of the biology of the species involved, as well as how they affect and are affected by their environment. This study of the trophic relationships of ice-inhabiting phocid seals of the Chukchi Sea will contribute to such an understanding. We have dealt in greatest detail with the two resident and most abundant species, ringed seals and bearded seals. In addition, preliminary data are presented for three summer residents, spotted seals, walruses, and belukha whales.

The intricacy of biological systems is such that even gross simplifications are difficult to render verbally and/or graphically. However, through this study of trophic relationships of marine mammals we have attempted to identify key species, those organisms which are the most tightly woven into the web of trophic interdependencies. It is our hope that identification of these key species and important interdependencies will provide a focus of attention and contribute to the assessment of anticipated ecological effects. When integrated with other OCSEAP research it should be possible to identify potential differential sensitivity of parts of the system and to evaluate which times, places, or species appear to be most or least vulnerable.

In the discussions that follow it will be necessary to give the names of many species of marine animals. The authors realize that there are advantages to the use of either common or scientific names. In this report we will use common names whenever such are available and appropriate. For purposes of clarity and ease of reference, the accepted scientific names of most species for which we will use common names are given in Table 1. For species mentioned seldom in this report, both common and scientific names are given at the first mention of that species.

Table 1. Common and scientific names of species commonly mentioned in this report.

Common Name	Scientific Name
Pollock	Theragra chalcogramma
Arctic cod	Boreogadus saida
Saffron cod	Eleginus gracilis
Herring	Clupea harengus
Rainbow smelt	Osmerus mordax
Sand lance	Ammodytes hexapterus
Capelin	Mallotus villosus
Sculpin	Family Cottidae
Flatfish	Family Pleuronectidae
Tanner crab	Chionoecetes opilio
Spider crab	Hyas coarctatus

III. Current State of Knowledge

We know of only two accounts of the food habits of marine mammals in the Chukchi Sea published prior to this OCSEAP study. An extensive study was conducted as a part of Project Chariot by Johnson et al. (1966) at Point Hope and Kivalina from November 1960 through June 1961. They examined 1,923 stomachs from ringed seals. During the months of November, December, January, and February, fishes (mostly sculpins, arctic cod, and saffron cod) made up 90 percent or more of the contents. During March, April, May, and June, invertebrates, mostly shrimp and amphipods, were the predominant food, making up more than half and occasionally more than 80 percent of total stomach contents.

The stomach contents of 164 bearded seals were examined in that study. The only month in which a large sample (129) was obtained was June. Shrimp, crabs, and clams were the most common food items with other benthic invertebrates found in small quantities and fishes (sculpins and arctic cod) usually comprising less than 10 percent of the total volume.

Burns (1967), in his summary of the biology of the bearded seal, reported on his examination of stomachs from seals collected at Nome, Gambell, and Wainwright. In May he found that brachyuran and anomuran crabs (Hyas coarctatus alutaceus and Pagurus sp.) accounted for 57 percent of the contents with shrimp, fishes (saffron cod, arctic cod, and sculpins), and sponges comprising most of the remainder. In July and August clams (Serripes groenlandicus, Spisula sp. and Clinocardium sp.) were the most abundant food item, with shrimp, crabs, and isopods also quite commonly found.

Results of our OCSEAP studies of the food habits of bearded seals in the Bering and Chukchi Seas have been compiled and are currently in press (Lowry et al. 1980).

There are no published accounts of the foods of spotted seals, walruses, or belukha whales in the Chukchi Sea.

Published accounts of the food habits of ringed, bearded, and spotted seals, as well as belukha whales, in other parts of the world have been reviewed in 1978 and 1979 annual reports for this research unit (Lowry et al. 1978a, Lowry et al. 1979a).

IV. Study Area

The study area encompasses the Alaskan sector of the Chukchi Sea from Bering Strait to Point Barrow (Figure 1). Data we have collected from the Bering Strait (Wales and Diomede) will be presented in a future report dealing with the Bering Sea. In the Chukchi Sea we collected specimens from the villages of Shishmaref, Point Hope, and Wainwright. The region between Bering Strait and Point Hope is referred to as Hope Basin. The region between Cape Lisburne and Wainwright is referred to simply as "the Chukchi," or Sale #85.

V. Sources, Methods, and Rationale of Data Collection

Field Collections

OCSEAP sponsored collection efforts began in 1975 and intensified in 1976-1979. Collectors were sent to the coastal hunting villages during predictably good hunting periods. Specimen material, including jaws and claws for age determination, reproductive tracts, and stomachs were purchased from hunters. Sampling was done by the principal investigators and other ADF&G employees. A schedule of field activities and summary of specimens obtained is presented in Table 2.

Whenever possible seals from which specimen material was taken were weighed, sex was determined, and a series of standard measurements was made for use in this and other ongoing studies of ice-inhabiting seals. Tissue and blood samples were collected in some cases and made available to other investigators for heavy metal, hydrocarbon, PCB, and pathogen analysis. (See methods section in RU #230, Annual Report, for detailed description of standard measurements and collection of additional specimen material.)

Only stomachs containing food were collected. Stomachs were tied at the cardiac and pyloric sphincters and severed from the remainder of the alimentary canal near these ties. They were then either injected with 10 percent formalin, labeled and placed intact in plastic bags

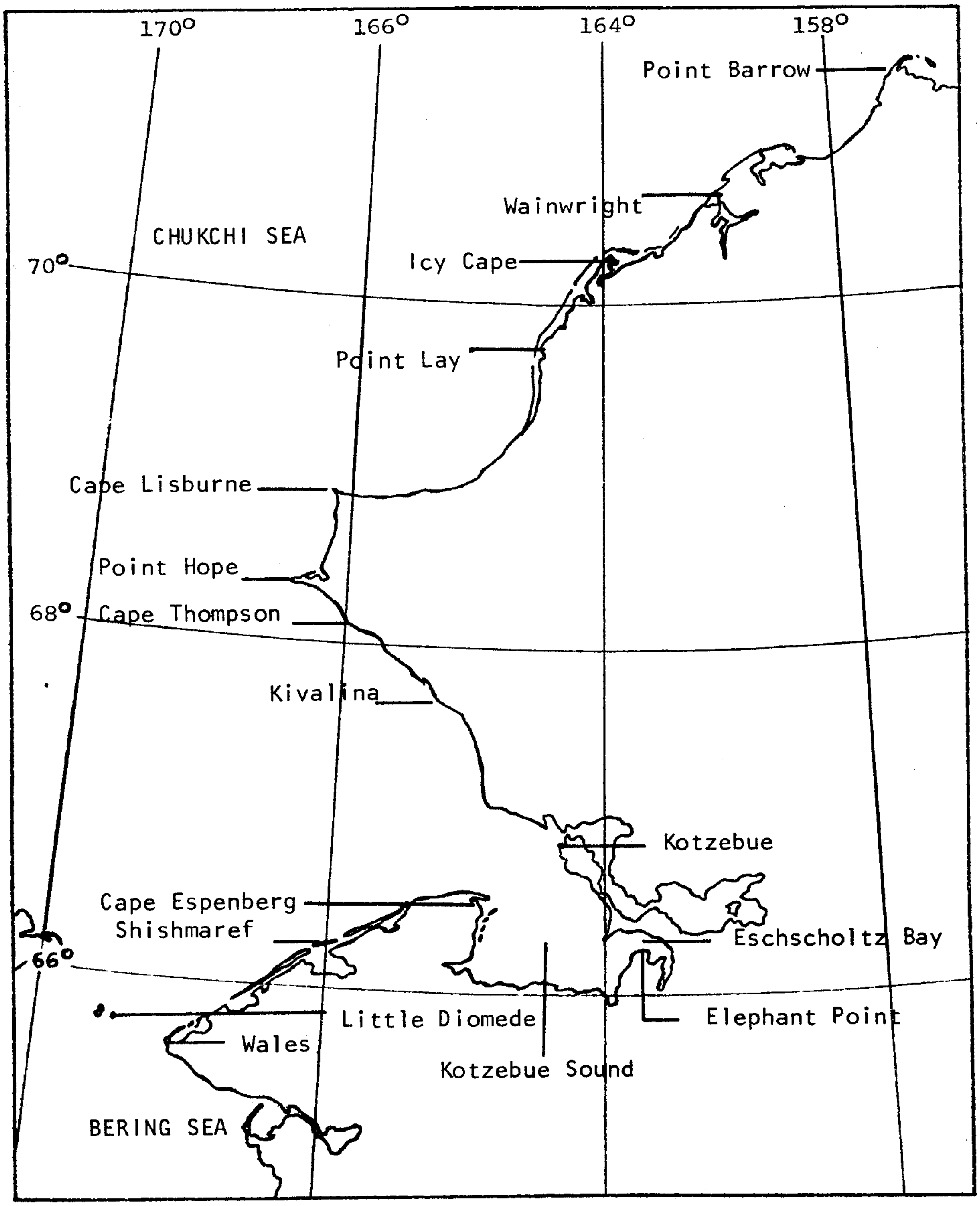
170°
166°
164°
158°
Point Barrow
Wainwright
CHUKCHI SEA
Icy Cape
70°
Point Lay
Cape Lisburne
Point Hope
68°
Cape Thompson
Kivalina
Kotzebue
Cape Espenberg
Shishmaref
Eschscholtz Bay
66°
Little Diomede
Elephant Point
Wales
Kotzebue Sound
BERING SEA

Table 2. Schedule of field activities in the Chukchi Sea and summary of specimens obtained. Only stomachs with food are included.

Location/Platform	Dates	Specimens Obtained				
		Spotted Seals	Ringed Seals	Bearded Seals	Belukha Whales	Walrus
Wainwright	24 July-11 Aug 1975	3	17	22		
Cape Lisburne	10 Mar-20 Apr 1976		3			
Point Hope	19 Apr-1 June 1976		33			
Shishmaref	22 June-15 July 1976	3	106	40		
Wainwright	22 July-1 Aug 1976			7		
DISCOVERER	17 Aug-3 Sept 1976		2	1		
Point Hope	15 Apr-2 June 1977		26		5	
Shishmaref	24 June-21 July 1977	10	235	112		3
Wainwright	22 July-24 July 1977			3		
GLACIER	1 Aug-5 Aug 1977			2		
Shishmaref	15-31 October 1977	14	6	13		
Shishmaref	4-11 November 1977	1	7			
Shishmaref	6 Jan-10 Feb 1978		24			
Kotzebue	February 1978		3			
Point Hope	10-28 Apr 1978		15	1	9	
Wainwright	25 Apr-22 May 1978		4	1		
Shishmaref	20 May-21 June 1978	10	56	17		
Elephant Point	13-18 June 1978		3		62	
Wainwright	1-12 July 1978		24	4		
Point Hope	6-8 May 1979				2	
Shishmaref	24 May-8 June 1979		12	4		
Wainwright	25 June-13 July 1979		5	16	2	1
Elephant Point	16-23 June 1979				3	
Totals		41	581	243	83	4

containing 10 percent formalin, or placed in bags and frozen. All stomachs were shipped to the ADF&G lab in Fairbanks. Upon arrival in the lab those stomachs containing large numbers of small otoliths, which degrade rapidly in formalin, underwent a preliminary sort in which the otoliths were removed and stored in 95 percent ethanol.

Laboratory Procedures and Identification

The preserved contents of stomachs were washed onto a 1.0-mm mesh screen. Contents were sorted and identified to the lowest taxonomic level permitted by their condition, using appropriate taxonomic keys and reference specimens. In the majority of cases identifications entailed the sorting and recognition of small bits and pieces of organisms. Crustaceans were frequently identified by claws, carapaces, or abdomens. Fishes were identified on the basis of otoliths and bone fragments. The volume and number of each type of prey item were determined by water displacement and counts of individuals or otoliths. Size ranges of various prey items were determined when possible.

Virtually all identifications were made by project personnel. Necessary taxonomic keys and references, both published and unpublished, were accumulated. Much use was made of the University of Alaska Marine Museum/Sorting Center reference collection and of the expertise of Sorting Center personnel. A reference and voucher collection of invertebrates and fishes was established at ADF&G. In addition, an otolith collection was compiled. Considerable interchange of specimen material and ideas occurred among personnel of this project, Dr. James Morrow, OCSEAP RU# 285, and John Fitch, California Department of Fish and Game (retired).

VI. Results

Spotted Seals

Most of the spotted seal specimens we have examined were from seals taken at Shishmaref. Foods found in specimens collected in the spring-summer varied widely among the 3 years sampled (Table 3). Largest volumes of food were found in seals taken 8-19 July 1977 which had eaten mostly herring. Our results are obviously influenced by the timing of seal collections in relation to the appearance of schools of spawning herring. Barton (1979) reported schools of herring off Shishmaref on 25 July 1976. Herring were obviously abundant in the vicinity from 8-19 July 1977 when our spotted seal samples were collected, but apparently had not yet arrived when seals were taken in early July 1976 and June 1978. Spotted seals taken at Shishmaref in October 1977 had also eaten mostly herring (Table 4). A seal taken there in early November had eaten only arctic cod. Three spotted seals taken at Wainwright in summer 1975 had eaten small amounts of sculpins and cod (arctic or saffron) and traces of shrimp and isopods.

Ringed Seals

Most of the ringed seal specimens we examined were collected at Shishmaref, Point Hope, and Wainwright. Foods eaten by ringed seals during the late spring-early summer period at Shishmaref were similar in 1976, 1977, and 1978 (Table 5). Fishes (mostly saffron cod) and shrimps (mostly *Crangon septemspinosa*) were the major foods in all 3 years with amphipods, mysids, euphausiids, and isopods also eaten. Seals taken at Shishmaref in spring 1979, slightly earlier than previous years, had eaten almost entirely fishes: saffron and arctic cods, and rainbow smelt. Seals collected at Shishmaref in October had eaten mostly hyperiid amphipods while arctic cod were the primary food item in November, January, and February (Table 6).

Four ringed seal stomachs containing food were collected at Point Hope during January-March. Foods eaten included arctic cod, sand lance, gammarid amphipods (mostly *Ampelisca* spp.), and hyperiid amphipods (Table 7). Stomach contents of seals collected in April varied widely among the 3 years sampled. Overall during April, fishes (several species), *Ampelisca* spp., and shrimps (primarily *Pandalus goniurus*) were the main foods (Table 8). Foods eaten by seals collected in May 1976 and 1977 were similar (Table 9). Several types of prey were identified from the stomachs including shrimps (mostly *Argis lar*), gammarid amphipods (mostly *Ampelisca* spp., some *Anonyx nugax*), mysids (*Mysis litoralis* and *Neomysis rayi*), euphausiids (*Thysanoessa* spp.), and several species of fishes, mainly saffron cod and sand lance.

Four seals collected at Wainwright during winter and spring 1978 had eaten small amounts of primarily gammarid amphipods (mostly *Anonyx nugax*, some *Ampelisca* spp.) and shrimps (*Argis lar*, *Sclerocrangon boreas*, and *Pandalus goniurus*). Seals taken in winter had eaten arctic cod also. Stomach contents varied greatly in seals collected during summer 1975, 1978, and 1979 (Table 10). Overall the stomach contents consisted mostly of fishes (primarily arctic cod), gammarid amphipods (*Gammarus* sp. and *Onisimus* sp.), and shrimps (*Eualus gaimardii* and *Sclerocrangon boreas*).

Stomach contents of 11 ringed seals collected at miscellaneous locations in the Chukchi Sea were examined (Table 11). The presence of herring in seals taken near Kotzebue in February was of interest since overwintering of herring in that area was not previously documented. The two seals collected on the DISCOVERER cruise provided the only data collected on summer foods of ringed seals in offshore waters of the northern Chukchi Sea. Those seals had eaten mostly shrimps (*Eualus gaimardii*, *E. macilenta*, and *Pandalus goniurus*) and arctic cod.

The large samples of ringed seals collected at Shishmaref during June-July 1976-1978 were examined for age- and sex-related differences in foods (Table 12). Foods of male and female seals were very similar. Small crustaceans (amphipods, mysids, and euphausiids) make up 28 percent of the stomach contents of pups but only 4-9 percent of the contents of older seals. The proportion of fish in the stomach contents increased

Table 3. Spotted seal stomach contents data from Shishmaref. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Shishmaref	Shishmaref	Shishmaref		
Dates:		4-6 July 1976	8-19 July 1977	6-21 June 1978	All years combined 1976-1978	
Sample Size:		3	10	10	23	
Mean Volume (ml)		402.9	632.0	49.7	359.7	
Food Items	1	Shrimp 87	Fish 99 Herring 96 Saffron cod 4	Fish 80 Sand Lance 94 Saffron cod 3 Sculpins 2	Fish 85 Sand Lance 48 Herring 36 Saffron cod 8 Flatfish 7	
	2	Fish 13 Flatfish 62 Saffron cod 38	Shrimp 1	Shrimp 8	Shrimp 14	
	3			Hyperiid amphipod 7		
	4			Mysid 3		
	5			Gammarid amphipod 1		

Table 4. Spotted seal stomach contents data from Shishmaref. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Shishmaref	Shishmaref			
Dates:		10-24 Oct 1977	4 Nov 1977			
Sample Size:		14	1			
Mean Volume (ml)		432.9	751.0			
Food Items	1	Fish 99 Herring 83 Saffron cod 17	Fish 100 Arctic cod 100			
	2					
	3					
	4					
	5					

Table 5. Ringed seal stomach contents data from Shishmaref. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Shishmaref	Shishmaref	Shishmaref	Shishmaref	Shishmaref
Dates:		4 June-12 July 1976	10 June-19 July 1977	9-21 June 1978	24 May-8 June 1979	All years combined 20 May-19 July
Sample Size:		106	235	56	12	409
Mean Volume (ml)		96.1	97.6	104.2	102.4	98.3
Food Items	1	Shrimp 47	Fish 57 Saffron cod 83 Arctic cod 8 Sand lance 4 Flatfish 3	Fish 44 Saffron cod 89 Sand lance 8 Arctic cod 1	Fish 95 Saffron cod 77 Rainbow smelt 13 Arctic cod 8	Fish 52 Saffron cod 86 Arctic cod 5 Sand lance 4 Flatfish 3
	2	Fish 41 Saffron cod 91 Flatfish 6 Herring 1	Shrimp 31	Shrimp 27	Shrimp 2	Shrimp 29
	3	Mysid 4	Euphausiid 3	Hyperiid amphipod 16	Echiuroid worm 2	Mysid 4
	4	Isopod 4	Mysid 3	Mysid 6	Mysid 1	Hyperiid amphipod 2
	5	Gammarid amphipod 2	Gammarid amphipod 2	Gammarid amphipod 3		Gammarid amphipod 2

Table 6. Ringed seal stomach contents data from Shishmaref. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Shishmaref	Shishmaref	Shishmaref		
Dates:		23-28 Oct 1977	4-5 Nov 1977	6 Jan-2 Feb 1978		
Sample Size:		6	7	24		
Mean Volume (ml)		122.0	272.7	314.9		
Food Items	1	Hyperiid amphipod 88	Fish 100 Arctic cod 86 Saffron cod 14	Fish 99 Arctic cod 83 Saffron cod 10 Sculpins 3		
	2	Fish 7 Saffron cod 100				
	3	Shrimp 5				
	4					
	5					

Table 7. Ringed seal stomach contents data from Point Hope. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Point Hope	Point Hope	Point Hope		
Dates:		January 1977	February 1978	March 1976		
Sample Size:		2	1	1		
Mean Volume (ml)		149.5	140.0	15.6		
Food Items	1	Fish 84 Arctic cod 96 Sand lance 4	Gammarid amphipod 100	Gammarid amphipod 59		
	2	Hyperiid amphipod 16		Fish 32 Sand lance 100		
	3			Shrimp 5		
	4					
	5					

Table 8. Ringed seal stomach contents data from Point Hope. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area: Dates: Sample Size:		Point Hope April 1976 12	Point Hope April 1977 17	Point Hope April 1978 15	Point Hope Combined April 1976-78 44	
Mean Volume (ml)		118.9	42.3	59.9	67.3	
Food Items	1	Fish 75 Arctic cod 78 Sculpins 9 Sand lance 6 Saffron cod 5	Hyperiid Amphipod 52	Gammarid Amphipod 32	Fish 46 Arctic cod 49 Sand lance 29 Sculpins 16 Saffron cod 3	
	2	Hyperiid amphipod 16	Shrimp 36	Fish 33 Sand lance 64 Sculpins 26 Arctic cod 6 Saffron cod 2	Gammarid amphipod 29	
	3	Shrimp 4	Fish 7 Arctic cod 64 Sand lance 16 Sculpins 12 Pricklebacks 8	Shrimp 27	Shrimp 19	
	4	Echiuroid worm 3	Euphausiid 4	Hyperiid amphipod 8	Hyperiid amphipod 2	
	5				Echiuroid worm 1	

Table 9. Ringed seal stomach contents data from Point Hope. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:	Point Hope		Point Hope		Point Hope			
Dates:	May 1976		May 1977		Combined May 1976-77			
Sample Size:	20		7		27			
Mean Volume (ml)	27.9		55.8		35.1			
Food Items 1	Shrimp	36	Shrimp	42	Shrimp	38		
Food Items 2	Gammarid amphipod	30	Gammarid amphipod	22	Gammarid amphipod	27		
Food Items 3	Euphausiid	11	Mysid	22	Mysid	11		
Food Items 4	Fish Sand lance Arctic cod	8 69 19	Fish Saffron cod Sand lance Arctic cod Sculpins	13 65 17 14 4	Fish Saffron cod Sand lance Arctic cod Sculpins	10 42 37 16 5		
Food Items 5					Euphausiid	7		

Table 10. Ringed seal stomach contents data from Wainwright. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Wainwright	Wainwright	Wainwright	Wainwright	
Dates:		8 July-7 August 1975	1-2 July 1978	25 June-13 July 1979	All years combined 25 June-7 August 1975-1979	
Sample Size:		17	24	5	46	
Mean Volume (ml)		26.3	117.7	63.8	78.1	
Food Items	1	Shrimp 42	Fish 71 Arctic cod 99 Sand lance 1	Gammarid amphipod 75	Fish 61 Arctic cod 96 Sculpin 2 Sand lance 1	
	2	Fish 22 Sculpins 50 Cod 25 Capelin 17	Gammarid amphipod 27	Fish 21 Arctic cod 93 Sculpin 7	Gammarid amphipod 29	
	3	Gammarid amphipod 8	Shrimp 1	Mysid 1	Shrimp 6	
	4	Isopod 5			Isopod 1	
	5	Hyperiid amphipod 2			Mysid 1	

Table 11. Ringed seal stomach contents data from misc. areas in the Chukchi Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:	Kotzebue	Elephant Point	Cape Lisburne	DISCOVERER	
Dates:	February 1978	June 1978	March-April 1976	27-28 August 1976	
Sample Size:	3	3	3	2	
Mean Volume (ml)	212.3	21.9	36.6	75.9	
Food Items 1	Fish 100 Herring 51 Saffron cod 37 Smelt 6 Arctic cod 3	Fish 62 Saffron cod 71 Sculpins 29	Fish 31 Arctic cod 96 Sculpins 4	Shrimp 84	
Food Items 2		Mysid 17	Shrimp 29	Fish 13 Arctic cod 100	
Food Items 3		Shrimp 15	Gammarid amphipod 20	Gammarid amphipod 2	
Food Items 4		Isopod 2	Mysid 1		
Food Items 5		Gammarid amphipod 1			

Table 12. Major food items of ringed seals collected at Shishmaref in June-July 1976-1978. Results are presented by age and sex categories. Numbers indicate percent of total volume for invertebrates and total fish, and percent of total number for species of fishes.

	Sexes Combined				Seals ≥5 yrs old	
Food Item	Pups N=99	Yrlgs N=24	2-4 yrs old N=36	≥5 yrs N=212	Males N=100	Females N=126
Shrimp	19	37	38	30	31	33
Hyperiid Amphipod	9	*	*	2	1	*
Gammarid Amphipod	8	*	1	2	2	2
Mysid	7	6	3	3	4	3
Euphausiid	4	-	*	2	3	1
Total Fish	45	42	48	52	49	53
Saffron Cod	92	60	75	90	85	93
Arctic Cod	7	38	11	3	2	3
Sand Lance	1	-	-	2	*	-
Sculpin	*	*	1	*	1	*
Flatfish	-	1	1	4	11	3
Mean Volume of Contents (ml)	39.3	98.9	111.6	121.9	120.7	111.1

* Indicates values less than 1 percent.

slightly with age. Pups ate almost exclusively cod while other fishes occurred more frequently in stomachs of older seals. The mean volume of stomach contents showed a steady increase with age.

Bearded Seals

Most of the bearded seal specimens we examined were collected at Shishmaref and Wainwright. At Shishmaref during June and July shrimps (mostly Crangon septemspinosa and some Argis lar) were the main food in all 4 years sampled (Table 13). Brachyuran crabs (mostly Telmessus cheiragonus), clams (mostly Spisula polynyma and Serripes groenlandicus), isopods (Saduria entomon), and fishes were also major foods. In 13 bearded seals taken at Shishmaref 16-30 October 1977, the stomach contents averaged 631.8 ml and was comprised of 87 percent shrimps and 13 percent fishes (flatfish, sculpins, and saffron cod).

Stomachs of bearded seals were collected at Wainwright during five summers (Table 14a). Clams (Spisula and Serripes) were the primary prey during 1975-1977. Shrimp (Sclerocrangon boreas and Eualus gaimardii) were the major food in 1978 and 1979. Overall for the 5 years sampled, clams were the major food followed by shrimp, crabs (Chionoecetes opilio and Hyas coarctatus), fishes, and Saduria (Table 14b). The stomach of one bearded seal collected at Wainwright on 18 May 1978 contained 1171.7 ml of food consisting of 52 percent shrimp, 34 percent fishes (98% sculpins, 2% arctic cod), 9 percent gammarid amphipods, and 2 percent clams (Musculus sp.).

Only four bearded seal stomachs containing food were obtained from other locations in the Chukchi Sea (Table 15). Little can be said about those small, scattered samples. It is interesting and perhaps significant that three types of prey which were not important foods at Shishmaref and Wainwright (eelpout, priapulids, and snails) were major foods of seals collected in the northern Chukchi Sea ice edge in August.

Age- and sex-related differences in the bearded seal diet were examined using data from seals collected at Shishmaref in June-July 1976-1978 (Table 16). Foods of males and females were generally similar although shrimp and isopods were proportionately more important in the diet of females while males ate more echiuroid worms. The importance of clams, brachyuran crabs, and echiuroid worms in the diet increased with age while shrimp and isopods were of lesser importance in the diet of older seals.

Walruses

We obtained and examined stomach contents of only four walruses taken in the Chukchi Sea. Small amounts of food (mean volume 48.5 ml) were found in three walruses taken at Shishmaref on 25 October 1977. The contents consisted of 75.7 percent clams (Siliqua sp. and Tellina sp.), 11.7 percent priapulid, 6.5 percent shrimp (Crangon septemspinosa), and 4.2 percent snail (Natica sp. and Polinices sp.). One walrus taken

Table 13. Bearded seal stomach contents data from Shishmaref. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Shishmaref		Shishmaref		Shishmaref		Shishmaref		Shishmaref	
Dates:		4 June-11 July 1976		24 June-20 July 1977		9-21 June 1978		3-8 June 1979		3 June-20 July 1976-1979	
Sample Size:		40		112		17		4		173	
Mean Volume (ml)		415.2		460.4		407.9		433.8		444.5	
Food Items	1	Shrimp	51	Shrimp	35	Shrimp	41	Shrimp	65	Shrimp	40
	2	Brachyuran Crab	19	Brachyuran Crab	21	Clam	17	Isopod	17	Brachyuran Crab	20
	3	Clam	16	Clam	14	Echiuroid	16	Echiuroid	4	Clam	14
	4	Isopod	4	Isopod	13	Brachyuran Crab	13	Snail	3	Isopod	10
	5	Fish Flatfish Saffron cod Sculpins Sand lance	3 54 15 14 7	Echiuroid worm	6	Fish Sculpins Flatfish Sand lance Saffron cod	4 45 34 14 6	Clam	3	Fish Sculpins Saffron cod Flatfish	6 34 32 30

Table 14a Bearded seal stomach contents data from Wainwright. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Wainwright		Wainwright		Wainwright		Wainwright		Wainwright	
Dates:		24 July- 7Aug 1975		28-29 July 1976		23 July 1977		8 July 1978		27 June-1 July 1979	
Sample Size:		22		7		3		4		16	
Mean Volume (ml)		530.7		848.3		367.6		761.0		593.4	
Food Items	1	Clam	55	Clam	66	Clam	75	Shrimp	81	Shrimp	39
	2	Shrimp	12	Shrimp	25	Shrimp	13	Isopod	9	Clam	32
	3	Fish Sculpin Cod	10 96 4	Brachyuran Crab	5	Brachyuran Crab	7	Brachyuran Crab	5	Brachyuran Crab	12
	4	Brachyuran Crab	4	Isopod	2	Snail	2	Clam	4	Gammarid amphipod	3
	5	Snail	4	Fish Sculpin Sand lance Arctic cod	1 60 26 14					Fish Sculpin Arctic cod Saffron cod	1 77 21 1

Table 14b. Bearded seal stomach contents data from Wainwright. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area: Dates: Sample Size:		Wainwright All years combined 27 June-7 August 1975-1979 52				
Mean Volume (ml)		601.1				
Food Items	1	Clam 46				
	2	Shrimp 29				
	3	Brachyuran Crab 7				
	4	Fish 4 Sculpin 74 Arctic cod 15 Sand lance 10				
	5	Isopod 2				

Table 15. Bearded seal stomach contents data from misc. areas in the Chukchi Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Point Hope	DISCOVERER	GLACIER		
Dates:		16 April 1978	27 August 1976	1-5 August 1977		
Sample Size:		1	1	2		
Mean Volume (ml)		1172.4	655.5	454.5		
Food Items	1	Shrimp 88	Fish 29 Eelpout 91 Sculpins 9	Snails 48		
	2	Fish 6 Sculpins 100	Brachyuran Crabs 26	Shrimp 9		
	3	Brachyuran Crab 5	Shrimp 6	Priapulids 6		
	4		Priapulids 3	Amphipods 4		
	5			Brachyuran Crabs 3		

Table 16. Major food items of bearded seals collected at Shishmaref in June-July 1976-1978. Results are presented by age and sex categories. Numbers indicate percent of total volume for invertebrates and total fish, and percent of total number for species of fishes.

Food Item	Sexes Combined			Seals ≥3 yrs old	
	Pups N=38	1&2 yrs old N=21	≥3 yrs old N=91	Males N=27	Females N=64
Shrimp	59	30	30	26	32
Isopod	18	18	8	2	11
Clam	4	11	19	20	18
Brachyuran Crab	6	20	24	23	25
Echiuroid Worm	*	*	9	19	4
Total Fish	7	11	6	6	5
Saffron Cod	51	18	30	28	31
Sculpin	28	55	25	24	25
Flatfish	20	25	37	46	38
Mean Volume of Contents (ml)	324.8	462.4	492.4	539.7	472.5

* Indicates values less than 1 percent.

at Wainwright on 28 June 1979 contained 2039 ml of food comprised of 99.7 percent clam and trace amounts of priapulids and polychaete worms. Of the identifiable clams in that walrus, 50.3 percent (by volume) were *Mya truncata*, 48.6 percent were *Spisula polynyma*, and 1.1 percent were *Serripes groenlandicus*.

Belukha Whales

Stomach contents of 62 belukhas collected at Elephant Point (eastern Kotzebue Sound) in June 1978 were examined (Table 17). Small amounts of shrimp (*Crangon septemspinosa*), isopods (*Saduria entomon*), snails (*Polinices* sp.), polychaetes, and octopus were found in the stomachs. Most of the stomach contents consisted of bones and otoliths of fishes, primarily saffron cod and sculpins. Stomachs of three whales taken in Kotzebue Sound in June 1979 contained food. Two were taken in Eschscholtz Bay and contained numerous saffron cod otoliths and traces of shrimp and snails. The third was taken near the village of Buckland and contained 5810 ml of partially digested fish, most of which was remains of 11 arctic char up to 50 cm long. Otoliths and bones representing 7 whitefish, 5 suckers, 50 sculpins, 22 smelt, and 1 arctic cod were also present in that stomach.

At Point Hope we found food remains in stomachs of five belukhas taken in May 1977 and 9 taken in April 1978 (Table 18). Most of the stomach contents in April was fragments of crangonid shrimps and arctic cod otoliths. Octopus beaks were very common in stomachs collected in May 1977, occurring in all five stomachs containing food. Stomachs of two belukhas taken on 6 and 8 May 1979 at Point Hope contained food. One stomach contained otoliths from 3 arctic cod; the other contained 1 octopus beak, 1 saffron cod otolith, and 2 small unidentifiable fishes.

One belukha taken at Wainwright on 22 July 1976 contained beaks from three octopus and four gonatid squids. Two belukhas taken at Wainwright on 18 July 1979 contained 12 partially digested rainbow smelt, otoliths from 2 saffron cod, and trace amounts of snails and isopods.

Possible age- and sex-related differences in belukha foods were examined using data from whales collected at Elephant Point in June 1978. The composition of the stomach contents in young and older belukhas was quite similar (Table 19). The composition of the stomach contents of male and female whales was slightly different (Table 20). Shrimp accounted for a greater proportion of the contents and occurred more frequently in females while the converse was true for isopods. The most obvious difference occurred in the consumption of sculpins which were eaten by 4 of 28 females and 21 of 29 males.

VII. Discussion

A. Foods of Marine Mammals

We investigated the foods utilized by marine mammals in the Chukchi Sea based on stomachs collected during 1975-1979. During 1975-1977,

Table 17. Stomach contents of belukha whales collected at Eschscholtz Bay, 13-18 June 1978 (N=62).

Prey Item	% of total volume	% of total number	% frequency of occurrence
Shrimp	4	--	76
Isopod	6	--	34
Octopus	<1	--	52
Other Invertebrate	<1	--	41
Total Invertebrate	11	--	90
Rocks and Pebbles	1	--	66
Total Fishes	87	--	94
Saffron Cod	--	88	94
Sculpins	--	11	42
Rainbow Smelt	--	<1	29
Pacific Herring	--	<1	3
Eelpout	--	<1	2
Mean Volume of Contents (ml)		47.2	
Total # Identified Fishes		4346	

Table 18. Stomach contents of belukha whales collected at Point Hope.

Prey Item	22-27 May 1977, N = 5 % of total volume	% of total number	% frequency of occurrence	25-26 April 1978, N = 9 % of total volume	% of total number	% frequency of occurrence
Shrimp	<1	--	20	99	--	67
Squid	0	--	0	<1	--	11
Octopus	75	--	100	<1	--	78
Other Invertebrate	<1	--	60	<1	--	11
Total Invertebrate	75	--	100	100	--	100
Rocks and Pebbles	25	--	40	<1	--	22
Total Fishes	0	--	0	<1	--	11
Arctic Cod	--	0	0	--	100	11
Mean Volume of Contents (ml)		53.3			48.4	
Total # Identified Fishes		0			43	

Table 19. Stomach contents of belukha whales collected at Eschscholtz Bay, June 1978, separated by age categories.

Prey Item	Less than 6 years old, N = 9			6 or more years old, N = 47		
	% of total volume	% of total number	% frequency of occurrence	% of total volume	% of total number	% frequency of occurrence
Shrimp	15	--	78	5	--	77
Isopod	7	--	22	7	--	38
Octopus	3	--	56	<1	--	47
Other Invertebrate	<1	--	44	<1	--	30
Total Invertebrate	25	--	100	12	--	89
Rocks and Pebbles	2	--	67	1	--	68
Total Fishes	72	--	100	86	--	94
Saffron Cod	--	92	100	--	89	94
Sculpins	--	7	44	--	10	40
Rainbow Smelt	--	<1	33	--	<1	32
Pacific Herring	--	0	0	--	<1	4
Eelpout	--	0	0	--	<1	2
Mean Volume of Contents (ml)		9.9			44.3	
Total # Identified Fishes		571			3562	

Table 20. Stomach contents of belukha whales collected at Eschscholtz Bay, June 1978, separated by sex.

	Females, N = 28			Males, N = 29		
Prey Item	% of total volume	% of total number	% frequency of occurrence	% of total volume	% of total number	% frequency of occurrence
Shrimp	11	--	82	2	--	72
Isopod	2	--	25	8	--	48
Octopus	<1	--	64	<1	--	34
Other Invertebrate	<1	--	21	<1	--	38
Total Invertebrate	14	--	93	10	--	86
Rocks and Pebbles	<1	--	64	1	--	69
Total Fishes	85	--	89	88	--	97
Saffron Cod	--	98	89	--	82	97
Sculpins	--	<1	14	--	17	72
Rainbow Smelt	--	2	39	--	<1	24
Eelpout	--	<1	4	--	0	0
Mean Volume of Contents (ml)		24.8			73.0	
Total # Identified FIshes		1648			2588	

collection efforts concentrated only on seals. In 1978 and 1979 we systematically attempted to collect stomachs from belukha whales also. Stomach contents of belukhas and walruses were obtained on an opportunistic basis throughout the collection period.

Virtually all marine mammal stomachs were obtained from animals killed by Eskimo subsistence hunters. The distribution of our sample collections reflects locations and times where active subsistence marine mammal hunting occurs. Most of the seal specimens were collected at Shishmaref and Wainwright in the late spring-summer period. Most of the belukha specimens were collected at Point Hope in spring and Elephant Point in June. Therefore, our results cannot be extrapolated to and should not be considered representative of the entire Chukchi Sea. Rather, they represent the feeding patterns of marine mammals in localized areas of the nearshore zone. This is unfortunate since marine mammals occur and feed throughout the vast area of the Chukchi Sea. In order to allow a broader interpretation of our findings and a description of overall feeding patterns in the Chukchi Sea, many more animals (ringed and bearded seals and walruses) must be collected from offshore areas and systematic collections of spotted seals must be made in certain coastal areas. Offshore collections can be made from ice-strengthened vessels and shore-based helicopters. Adequate ship and helicopter support have not yet been provided by OCSEAP in the Chukchi Sea, although in the Bering and Beaufort Seas we have had great success in using such logistics. With the background data presented in this report, an adequate understanding of feeding of marine mammals in the Chukchi Sea can be developed when appropriate support and logistics are made available.

Spotted Seals

Spotted seals forage in coastal waters of the Chukchi Sea primarily during June-October. Major concentrations of spotted seals occur in Kotzebue Sound and the coastal lagoons and barrier islands between Point Lay and Point Barrow. Based on our samples from Shishmaref, herring are a major food of spotted seals at least in July and October. Other fishes and shrimps may be the main foods earlier and later in the year. Concentrations of herring have not been documented north of Kotzebue Sound and the few seal specimens we obtained at Wainwright do little to identify major prey in the northern Chukchi. Based on results from other areas (Bukhtiyarov et al. in press), capelin, smelt, arctic cod, saffron cod, and sculpins, in addition to herring, are probably all significant prey of spotted seals in the Chukchi Sea. Identification of specific seasonal and geographical prey utilization patterns will require systematic sampling.

Ringed Seals

Ringed seals are abundant throughout the Chukchi Sea, particularly in coastal waters, from late October through July. During August through mid-October when much of the Chukchi Sea is ice-free, many ringed seals are thought to be associated with the pack ice in the northern Chukchi.

At Shishmaref, arctic cod and some saffron cod were the main foods of ringed seals in November-February. Saffron cod and several types of crustaceans were the primary foods in late spring and early summer as were hyperiid amphipods in October. A similar pattern was documented at Point Hope by Johnson et al. (1966) based on 1,432 stomachs containing food. Fishes were the main food there in November-February. Arctic cod were eaten throughout that period but were proportionately most important in December-February. Saffron cod were most commonly eaten in November, December, April, and June. Crustaceans (amphipods, shrimp, and mysids) were the primary food in March-June. The results of our limited collections from Point Hope generally agree with those of Johnson et al. The foods eaten at Wainwright in summer were slightly different from those found further south. Arctic cod were overall the dominant food. This is probably due to the fact that the pack ice edge usually remains close to Wainwright during the summer. Our data from Wainwright at other times of year are inadequate. However, it seems likely that the seasonal pattern of food utilization would be similar to other areas, i.e. primarily arctic cod in winter and mostly crustaceans in spring.

The feeding pattern of ringed seals near coastal villages in the Chukchi Sea is similar to what we observed in the Beaufort Sea (Lowry et al. 1979b) with the following exceptions: 1) more species of fishes are regularly eaten, and saffron cod are of considerable importance in the diet especially at Point Hope and Shishmaref; 2) shrimp (*Crangon septemspinosa*, *Eualus gamardii*, *Pandalus goniurus*, and *Sclerocrangon boreas*) are proportionately more important in the spring-early summer diet in the Chukchi Sea. In general, more species are of importance in the diet in the Chukchi Sea than in the Beaufort Sea. In August-October in the Beaufort Sea, ringed seals forage intensively on nektonic crustaceans (euphausiids and hyperiid amphipods) associated with pack ice. The only two seals we examined from the summer pack ice of the northern Chukchi had eaten mostly shrimp. That is not surprising since nektonic crustaceans appear to occur in patches, perhaps related to oceanographic conditions. Relatively large amounts of hyperiids in ringed seal stomachs collected in October at Shishmaref indicate that patches of nekton do occur in the Chukchi. The distribution and causes of such concentrations of nekton are of great interest since they appear to be of major importance in the annual feeding cycle of ringed seals (Lowry et al. in prep.).

Bearded Seals

Bearded seals forage throughout the Chukchi Sea. During winter months they are most common in areas of regular ice movement. They are generally absent from open water areas in summer.

The foods of bearded seals in the late spring-summer period at Shishmaref and Wainwright were generally similar to those found at other locations (Lowry et al. 1980). Shrimp, brachyuran crabs, and clams made up the majority of the stomach contents. The composition of the diet was relatively stable over the several years sampled; however, clams made up a smaller proportion of the diet at Wainwright in 1978 and 1979 than in previous years.

There are very few data available on foods of bearded seals nearshore during fall, winter, and early spring or offshore at any time of year. Distinct seasonality was observed in foods of bearded seals collected at Point Hope; clams were important in the diet only in June (Johnson et al. 1966). A similar seasonal pattern occurs in the Bering Sea (Lowry et al. 1980).

Walruses

A large portion of the Pacific walrus population summers and feeds along the pack ice edge in the northern Chukchi Sea (Estes and Gilbert 1978). Walruses are not common in the Chukchi Sea during winter months.

Foods of walruses in the Chukchi Sea are poorly documented. The stomach contents of the four walruses we examined was mostly clams. Clams appear to make up most of the walrus diet in all areas of the Bering and Chukchi Seas (Fay et al. in press).

Belukha Whales

Belukha whales migrate through the Chukchi Sea in spring and fall. Some belukhas spend summer months in and near coastal lagoons and estuaries in Kotzebue Sound and between Point Lay and Wainwright and along the edge of pack ice in the northern Chukchi Sea.

The intensity with which belukhas feed during migration is not known. Our results from Point Hope indicate that some feeding does occur during the spring migration: octopus, shrimps, and arctic cod are eaten.

Belukhas taken at Elephant Point (which had probably fed in the Eschscholtz Bay portion of Kotzebue Sound) had eaten saffron cod, sculpins, shrimps, isopods, snails, polychaetes, and octopus. Based on food remains in stomachs, saffron cod were the major prey. Belukhas we examined were taken in mid-June. Interviews with local residents indicated that later in the summer (July and August) belukhas in the area feed extensively on herring and occasionally on salmonids. Less is known about the foods of belukhas summering in the Point Lay-Wainwright areas. The few stomachs we have examined contained mostly rainbow smelt, saffron cod, octopus, and squids. Belukhas observed near Point Lay in summer appeared to be feeding on capelin (Seaman and Lowry, in prep.).

There are no data available on foods of belukhas in the summer Chukchi Sea pack ice. Based on other studies (Kleinenberg et al. 1964), arctic cod may be a major food in that region.

B. Biology of Major Prey Species

The probable effects of OCS exploration and development on marine mammals in the Chukchi Sea will depend to a large degree on the effects such activities may have on populations of prey species. In this section we review the available information on the biology of major marine mammal prey with particular respect to distribution and abundance, reproductive strategy, and food habits. Since little data for most species have been collected in the Chukchi Sea, we have had to draw on data collected in other areas in many instances.

Arctic Cod

Arctic cod is the single most important forage fish in far northern waters (Klumov 1937, Tomilin 1957, Tuck 1960, Lowry et al. 1979a&b). In the southeastern Chukchi Sea in September-October, Wolotira et al. (1977) found them to be the most widely distributed of all species of fishes, with the greatest abundance in the Hope Basin area, excluding Kotzebue Sound. Alverson and Wilimovsky (1966) noted that arctic cod were the most common species near Point Hope in August 1959. Over a thousand individuals were caught at a single station approximately 80 km northeast of Cape Lisburne. Lowry et al. (1978a) found arctic cod to be the most numerous fish in 10 trawls conducted in the northeastern Chukchi Sea in August. Quast (1974) sampled surface and mid-depth waters between Cape Lisburne and Icy Cape at night during September and October 1970 and found juvenile arctic cod to be ubiquitous and at least 10 times more numerous than sand lance, the only other species caught. Quast estimated an average density of 28 juvenile cod/1000 m^3.

The distribution of adult arctic cod is closely related to low temperatures and/or the presence of sea ice, with much of the population believed to stay under or near the edge of compact ice for most of the year (Svetovidov 1948, Andriyashev 1954, Ponomarenko 1968). Andriyashev (1954) indicated that in autumn large schools may be found nearshore, especially in warm, relatively fresh water near river mouths. Recent OCSEAP research in the Beaufort Sea has also documented large concentrations of arctic cod in nearshore areas in late summer and autumn (Bendock 1979, Craig and Haldorson 1979). The precise time and location of spawning for arctic cod in Alaska is unknown. In the Beaufort Sea individuals caught nearshore during November were gravid, and by the next sampling period in February all individuals had spawned. This coincides closely with spawning periods in the Barents and Kara Seas and eastern Siberia (Moskalenko 1964, Rass 1968, Ponomarenko 1968). Spawning probably occurs in coastal areas.

Arctic cod have the largest and fewest eggs of all cods (Svetovidov 1948, Andriyashev 1954). The eggs develop in surface waters under the ice and probably hatch in May or June. Larvae live in surface waters until August or September when transition to the juvenile stage takes place and the fry descend to the bottom (Rass 1968, Baranenkova et al. 1966). Association with the ice is thought to begin after the first year. Individuals mature at 3 to 4 years and probably do not live much longer than 6 years (Gjosaeter 1973).

Arctic cod eat a variety of euphausiids, copepods, benthic amphipods, shrimps, mysids, hyperiid amphipods, and small fish (Lowry and Frost unpubl., Klumov 1937, Craig and Haldorson 1979). Planktonic forms--

copepods (mostly _Calanus hyperboreas_, _C. glacialis_, and _Euchaeta glacialis_) and gammarid amphipods (_Apherusa glacialis_)--were the major prey of arctic cod from the northeastern Chukchi Sea (Lowry et al. 1978a).

Saffron Cod

Saffron cod are important prey of seals, belukha whales, and seabirds (Lowry et al. 1978a, 1979a; Tomilin 1957; Springer and Roseneau 1978). Alverson and Wilimovsky (1966) and Wolotira et al. (1977) found them to be much less abundant in central and southeastern Chukchi Sea and Kotzebue Sound than in the northern Bering Sea and Norton Sound. Greatest densities were in relatively shallow water near the mouth of Kotzebue Sound, offshore from the northern Seward Peninsula, and in waters less than 25 m deep between Cape Lisburne to Point Hope. Most saffron cod caught north of Bering Strait were small (less than 10 cm in length).

Saffron cod are thought to reside in the coastal zone coming close to shore in the fall to spawn in river mouths, bays, and inlets, and moving into deeper water (30-50 m) in summer to feed (Svetovidov 1948, Andriyashev 1954). Such movements may not occur in the Chukchi Sea. Saffron cod are present and abundant in nearshore shallow waters in June and July, as indicated by their importance in the diets of seals and belukhas at Shishmaref and Eschscholtz Bay at that time. No trawl surveys have been conducted in offshore waters in June and July, but by August-October saffron cod are not numerous there. It is probable that they remain nearshore throughout the year. Spawning probably takes place between December and February (February in Norton Sound) at subzero temperatures (-1.0 to -1.8°C). The eggs are demersal and are spawned on clean sandy or pebbly bottoms (Andriyashev 1954). Most larvae hatch in April. Normal embryonic development occurs at temperatures of -3.8° to 8°C and salinities of 28-30 ppt. Development is suspended below -3.8°C; however, eggs will resume growth even after freezing in ice once temperatures are greater than -3.8°. Larvae perish en masse in water warmer than 8°C (Mukhacheva 1959). Larvae stay near the surface after hatching and are often associated with the jellyfish _Cyanea_ sp. (they live inside the protection of the mantle and tentacles). Growth is probably very slow until August when larvae are fully transformed into fry and descend to the bottom to assume a demersal life similar to the adults. Maximal growth occurs in the first 3 years of life, and almost all of each year's growth occurs in September-October. Sexual maturity occurs at 2-3 years and individuals probably live at least 12 years (Svetovidov 1948). Saffron cod eat a variety of benthic organisms including polychaetes, shrimps, crabs, mysids, and amphipods.

Herring

Herring are present and locally abundant in nearshore areas of the southern Chukchi Sea. Barton (1979) reported peak herring abundance along the northern coast of the Seward Peninsula and southern Kotzebue Sound (Eschscholtz Bay) in late July and August. Both pre- and post-spawning segments of the population remain nearshore during spring and summer. Barton also noted that herring were present in autumn and winter near Shishmaref (October, March, April) and in Kotzebue Sound (November). We have found herring in the stomachs of spotted and ringed seals from Shishmaref in October, January, and February. Wolotira et al. (1977) reported that herring made up 22 percent of the total catch of fish in the southeastern Chukchi and Kotzebue Sound. Catch rates were highest in outer Kotzebue Sound and lowest in inner Kotzebue Sound. Relatively few herring were caught by Alverson and Wilimovsky (1966) in their 1959 trawl survey. Highest relative abundance was near Cape Thompson. In all of the Chukchi trawl surveys very few young fish (less than 2 years) were caught. In the Bering Sea herring make large scale onshore-offshore movements in summer and winter. Major wintering concentrations occur northwest of the Pribilofs and at the seasonal ice edge. Herring move to the coast in summer to spawn and feed (Barton 1979). It is unknown whether Chukchi and Bering Sea herring are part of the same stocks. Barton suggests that there may be an overwintering population in Kotzebue Sound. Percy (1975) working in the MacKenzie Delta found herring to congregate nearshore during winter and spawn in spring and summer in coastal bays and river mouths.

Herring spawn in late July or August in the Chukchi Sea (spawning occurs earlier farther south). Most spawning occurs subtidally in relatively shallow bays, lagoons, or inlets such as Shishmaref Inlet and Kugruk and Kiwalik lagoons in Kotzebue Sound (Barton 1979). Spawning is also known to occur along rocky headlands of eastern Eschscholtz Bay. Eggs develop in about 23 days at 6-8°C (Andriyashev 1954). Barton found Chukchi Sea herring to be euryhaline and believed they are also eurythermal if they in fact overwinter north of Bering Strait. Sexual maturity probably occurs between 3 and 6 years of age. Herring feed on euphausiids, copepods, hyperiids, mysids, amphipods, and fish fry (Andriyashev 1954, Percy 1975, Rumyantsev and Darda 1970). Feeding is probably most intensive during the period following spawning.

Sand Lance

The distribution and abundance of sand lance in the Chukchi Sea are poorly known. Alverson and Wilimovsky (1966), Wolotira et al. (1977), and Barton (1979) make no mention of them in any of their Chukchi Sea fish surveys. They were one of two species caught by Quast (1974) in a midwater survey of the eastern Chukchi Sea in 1970. In that survey sand lance were taken mostly near the surface and were about one-tenth as abundant as arctic cod. Swartz (1966) reported sand lance as a major food of murres, kittiwakes, and gulls in the Cape Thompson region. They did not appear in the diets, however, until mid-June or early July. According to Andriyashev (1954) sand lance form schools near the bottom in sandy areas, sometimes burrowing into the sand. They inhabit deep water in winter and move close to the coast in June. Spawning occurs from November-February at 50-75 m on sandy bottoms. Sand lance mature in their third year of life. Their main foods include copepods, barnacle larvae, euphausiids, and amphipods.

Sculpins

Many species of sculpins are present in the Chukchi Sea. Five species were among the 20 most abundant fishes caught in the southeastern Chukchi and Kotzebue Sound (Wolotira et al. 1977). They were, in relative order of abundance, Myoxocephalus scorpius, Gymnocanthus tricuspus, Enophrys diceraus, Triglops pingeli, and Megalocottus platycephalus. Myoxocephalus (averaging 25 g in weight) were most abundant slightly north of Bering Strait in water deeper than 25 m, and farther north near Kivalina and Point Hope. Alverson and Wilimovsky (1966) listed the genera Gymnocanthus, Artediellus, Triglops, and Myoxocephalus among the 10 most common fishes near Cape Lisburne and Point Hope. Together they comprised almost 20 percent of the total catch.

Sculpins are demersal and most prefer water temperatures around 0°C. Most species spawn in fall or winter (Andriyashev 1954). In general they feed on benthic or epibenthic organisms such as shrimps, amphipods, polychaete worms, isopods, mysids, and molluscs.

Flatfishes

Flatfishes (F. Pleuronectidae) were the most abundant group of fishes in southeastern Chukchi Sea and Kotzebue Sound, comprising 30 percent of the total fish biomass (Wolotira et al. 1977). They were less abundant in Kotzebue Sound (10%) than in offshore waters (42%). Starry flounder (Platichthys stellatus), mostly large, older fish, was the most abundant species in this group in the southern portion of the Chukchi Sea. Alaska plaice (Pleuronectes quadrituberculatus) were locally abundant along the north coast of the Seward Peninsula, with small individuals closest to shore and larger fish offshore. Yellowfin sole (Limanda aspera) were most abundant in inner Kotzebue Sound (mostly small fish) and along the north coast of the Seward Peninsula. They were absent farther north. Bering flounder (Hippoglossoides robustus) were found mostly north of Kotzebue Sound. None were caught in inner Kotzebue Sound. Arctic flounder (Liopsetta glacialis) were restricted to very shallow waters in Kotzebue Sound, and near Kivalina. Mean size of individuals was quite small (less than 14 cm). Flatfishes feed on a variety of benthic organisms including polychaetes, molluscs, and small crustaceans, and on small fishes.

Hyperiid Amphipods

Parathemisto libellula is very common in arctic waters. According to Dunbar (1942) "P. libellula is without doubt one of the most important organisms in the Arctic, in any habitat, terrestrial or aquatic." He later stated (Dunbar 1957) that "it forms the most important link in the food chain between the copepods and other smaller planktonic forms on the one hand, and the vertebrates on the other, and in fact it takes the place, in cold water, of the euphausiids in this respect." Although Parathemisto is probably somewhat less "important" in more southern waters, it is nonetheless a major food of ringed seals at some locations and during certain times. It may be relatively more important in far northern Chukchi waters than in more southern areas with warmer water. Information on the distribution and relative abundance of Parathemisto in the Chukchi Sea is virtually nonexistent, except by inference from stomach contents of predators.

Parathemisto is a pelagic species which spends its life in the water column. It is often considered to be an indicator of cold arctic waters. Individuals are found closer to the surface during the day due to a positive phototropic response (Tencati and Leung 1970). The young develop directly in brood pouches in the female rather than as free swimming larvae. Individuals probably breed only once in their 18-month to 2-year lifetime (Dunbar 1957). Breeding takes place over an extended period lasting from September until April. There may be two breeding periods during this time: September-October and March-April. Foods include small crustaceans such as copepods and barnacle, crab, and shrimp larvae.

Gammarid Amphipods

Gammarid amphipods are a diverse element of the Chukchi Sea fauna. They are the predominant food of many demersal fishes, and regular prey of seabirds, arctic cod, ringed and bearded seals, and bowhead and gray whales. Although primarily benthic, several species make use of the inverted substrate provided by the undersides of ice floes (Barnard 1959, George and Paul 1970, Tencati and Leung 1970). Ampelisca, Anonyx, and Gammarus are all important genera to seals and whales. Based on scattered samples collected in the Chukchi Sea, Anonyx is widespread though apparently not present in large numbers. We found Ampelisca to be much less abundant, but because they are tube dwellers, trawls probably do not provide a true reflection of their abundance. Stoker (pers. comm.) found Anonyx, Rhacotropis, and Stegocephalus to be the most ubiquitous genera in the Chukchi Sea. Sparks and Pereyra (1966) also found Stegocephalus to be very abundant in the Point Hope region. This species is large and heavily armored and is probably poorly suited as food.

Ampelisca is probably the single most important species to marine mammals. Ampelisca macrocephala lives 1-1/2 to 2 years, with some females living to age 3 and reproducing a second time (Kanneworff 1965). Maximum growth occurs in spring and early summer and breeding takes place in the fall (October). Females carry eggs in a brood pouch until the young are released in about April when feeding conditions are good. Ampelisca is both an active predator and a detritus feeder. Prey includes copepods, other small crustaceans, and various detrital plant and animal material. Feeding (as well as growth and gonad development) is most intense during spring and summer when phyto- and zooplankton are abundant.

Mysids

Mysids (Mysis litoralis and Neomysis rayii) occurred as major prey in samples from May and June near Shishmaref, Point Hope, and Elephant Point. Redburn (1974) encountered mysids only rarely in his collections from the Chukchi Sea near Point Barrow. Geiger (1969) did not catch mysids in 13 tows from the southwestern Chukchi, but cautioned that this should not be interpreted as complete absence of the group from the Chukchi Sea. Broad (1978) listed Mysis as one of the principal genera at 4 of 18 nearshore stations between Point Hope and Point Barrow and at 2 of 23 between Bering Strait and Point Hope. Neomysis was one of the principal genera at 13 of 23 more southern stations. In general Mysis and Neomysis are found throughout shallow waters of the Alaskan continental shelf. Mysis is tolerant of low salinities and is often found nearshore (Geiger 1969). They live on or near the bottom and are probably detritus feeders.

Isopods

The isopod Saduria entomon is locally abundant in shallow nearshore waters of the continental shelf (McCrimmon and Bray 1962, Mohr and Geiger 1968). This species is extremely euryhaline (0-31.6 ppt) and eurythermal (-1.4-11.0°C) (Bray 1962). Sparks and Pereyra (1966) reported cosmopolitan distribution of Saduria in the eastern Chukchi. The life cycle probably requires 2-3 years; individuals spawn once and then die. Spawning activity takes place throughout the summer in the western Canadian Arctic, with females moving inshore to release the young. Young are borne in a brood pouch and released when 3-4 mm long. Saduria is an omnivorous scavenger, eating a variety of plant and animal material and occasionally preying on small crustaceans (Green 1957).

Shrimps

Three families of shrimps are present and important as marine mammal prey in the Chukchi Sea: F. Hippolytidae, F. Crangonidae, and F. Pandalidae. The pandalids are of commercial importance in the Gulf of Alaska and Bering Sea, but no species are commercially harvested in the Chukchi. Information on the distribution and abundance of shrimps in the Chukchi Sea is scarce.

Eualus gaimardii is the most widespread and abundant of the hippolytids. MacGinitie (1955) found it to be the most numerous shrimp near Point Barrow. We caught this species throughout the Chukchi, both nearshore and offshore, in depths of 5-55 m on muddy and rocky bottoms. It was usually the most numerous shrimp species in our trawls. In the Canadian arctic individuals probably spawn biennially (Squires 1969). Spawning frequency in the Chukchi is unknown. Many ovigerous females were found in spring-summer when most of our trawls were made. Eualus eat ostracods, euphausiids, copepods, and phytobenthos.

Pandalus goniurus is the most abundant pandalid shrimp in the Chukchi Sea. We caught them in trawls from Bering Strait to Barrow.

Most individuals we caught were small, and none were ovigerous. Pandalid shrimps are protandrous hermaphrodites, that is they reproduce first as males (probably during the first year), then become females and produce eggs when large (1-1/2 to 2-1/2 years) (Butler 1964). Breeding takes place in the fall and the eggs are carried until they hatch in spring. Larvae are planktonic during summer and settle to the bottom in late summer or early fall (Charnov 1979). Adult shrimps eat small crustaceans, polychaete worms, and detritus.

Crangonid shrimps which are major prey of seals include Crangon septemspinosa, Argis lar, and Sclerocrangon boreas. Crangon septemspinosa is euryhaline and eurythermal, and is especially common in very shallow waters (Price 1962). Broad (1978) found them to be abundant between Wales and Point Hope in water 0-5 m deep. Argis lar is one of the most abundant and widespread shrimps throughout the Chukchi Sea (Feder and Jewett 1978, Lowry et al. 1978a, Stoker unpublished). Sclerocrangon boreas is apparently less abundant there, being found at only a few stations, mostly in the northeastern Chukchi near Wainwright (Lowry and Frost unpublished, Stoker unpublished). It is a relatively large, heavily armored shrimp which occurs at temperatures of -1.5 to -5°C (Squires 1967). Spawning in the three species may occur over a broad time span, although all probably carry eggs through the winter and hatch them in spring-summer. Sclerocrangon and Argis females carrying eggs were caught in October (Feder and Jewett 1978). During June-July very few Crangon females had eggs, whereas many Argis and Sclerocrangon either had large eggs ready to hatch, recently hatched eggs, or recently extruded eggs (Squires 1968, Lowry and Frost unpublished). Crangonid shrimps eat a variety of organisms including phytobenthos and detritus, polychaete worms, small crustaceans, crustacean eggs and larvae, and to a lesser degree foraminiferans, gastropods, and ophiuroids (Squires 1967).

Crabs

Brachyuran crabs are widely distributed in the Chukchi Sea. Three species are important to bearded seals--Hyas coarctatus, Telmessus cheiragonus, and Chionoecetes opilio. Feder and Jewett (1978) and Wolotira et al. (1977) found Chionoecetes and Hyas to be nearly ubiquitous in southeastern Chukchi Sea and outer Kotzebue Sound. Telmessus was found mostly nearshore and in Kotzebue Sound. Chionoecetes was over 4 times more abundant than either of the other two species. Sparks and Pereyra (1966) listed Chionoecetes as one of the dominant organisms in trawls near Point Hope/Cape Lisburne. Lowry et al. (1978a) found both Hyas and Chionoecetes in the northeastern Chukchi. Hyas was the most abundant of the two.

Watson (1970) found that Chionoecetes males mature at about 5.7 cm and females at about 5.0 cm. Since most individuals caught in the Chukchi Sea were smaller than 5 cm, the number of reproductively mature specimens there is probably very low (Feder and Jewett 1978, Lowry and Frost unpublished). In contrast, reproductively mature Hyas are common in the Chukchi. Many females with eggs were found in July-August and

October. In Canada Squires (1957) found eggs only in July and August. *Telmessus* were ovigerous in June-July but not in October (Feder and Jewett 1978, Frost and Lowry unpublished).

Brachyuran crabs are scavengers or predators. They eat a variety of detritus, phytobenthos, crustaceans such as amphipods, euphausiids, copepods, and shrimps, molluscs, ophiuroids, polychaetes, hydroids, and in some cases, fishes (Feder and Paul 1979, Squires 1967).

Clams

Two genera of clams, *Serripes* and *Spisula*, are especially important as food for bearded seals and walruses in the Chukchi Sea. Virtually nothing is known about the distribution or abundance of either species there. Filatova (1957) lists *Serripes* as one of the abundant bivalves in the southwestern Chukchi and *Spisula* as common along the Alaska shore from Bering Strait to the MacKenzie River. Neither of these clams was mentioned in his biomass calculations, perhaps because of sampling difficulties and patchy distribution.

Serripes is hermaphroditic and probably spawns in spring after the phytoplankton bloom has begun (Petersen 1978). Settling of larvae probably occurs in late summer-autumn. In Greenland waters some examples of size at age are as follows: 1 yr, 3-10 mm; 11 yrs, 53.4 mm; 14 yrs, 58.3 mm. They probably grow as large as 10 cm (Clench and Smith 1944).

Little is known about the life history of *Spisula*. They seem to prefer medium grade sediments of sand and gravel mixture. In southeastern Bering Sea they are found primarily in coastal waters 24-33 meters deep. *Spisula* is probably patchy in distribution, with given patches consisting of clams of a single year class (due to favorable larval settlement and survival in specific areas in a particular year). They are active burrowers, sometimes living as deep as 22 cm. Individuals reach about 13.5 cm, or 16 years of age, with growth until age 8 occurring at a rate of 10-12 mm/year (North Pacific Fishery Management Council, in preparation). There is no information on reproduction of *Spisula* in Alaska. *Spisula* in the North Atlantic are dioecious (sexes separate), unlike *Serripes*, and spawning probably occurs in summer. Larvae are planktonic for some unknown period of time, then settle to the bottom as miniature adults.

Spisula and *Serripes* are both filter feeders, removing small particles from seawater.

C. Food Webs and Trophic Relationships

The food webs which support marine mammal populations in the Chukchi Sea are considerably more complex than in the Beaufort Sea. More species of marine mammals regularly feed in the Chukchi Sea and they utilize a greater number of prey species. Major prey dependencies of the marine mammals we have studied are summarized in Table 21.

Table 21. Major prey of marine mammals in nearshore waters of the Chukchi Sea. Items which are probably major prey but have not occurred in samples examined during this project are followed by a question mark.

SEASON	SPOTTED SEALS	RINGED SEALS	BEARDED SEALS	WALRUSES	BELUKHA WHALES
SPRING	Not present	Gammarid Amphipods Shrimps Mysids Arctic Cod Saffron Cod	Shrimps Brachyuran Crabs? Sculpins	Not present	Octopus Shrimps Arctic Cod
SUMMER	Herring Saffron Cod Sand Lance Shrimps Rainbow Smelt? Capelin?	Hyperiid Amphipods? Euphausiids? Shrimps Gammarid Amphipods Arctic Cod	Clams Shrimps Brachyuran Crabs Isopods Sculpins	Clams Snails Priapulids Polychaetes	Saffron Cod Herring Rainbow Smelt Sculpins Salmonids Arctic Cod? Shrimps
AUTUMN	Herring Saffron Cod Arctic Cod Rainbow Smelt?	Hyperiid Amphipods Saffron Cod Arctic Cod	Shrimps Brachyuran Crabs? Sculpins Flatfish	Clams Priapulids Shrimps Snails	Saffron Cod? Arctic Cod? Rainbow Smelt? Shrimps?
WINTER	Not present	Arctic Cod Saffron Cod Sculpins Gammarid Amphipods Shrimps	Shrimps? Brachyuran Crabs? Sculpins?	Not present	Not present

Bearded seals and walruses feed primarily on benthic organisms. Much of the bearded seal diet is comprised of epifauna (shrimp and crabs) while infaunal species, particularly clams, are the most important foods of walruses. In some areas clams are a major component of the bearded seal diet, and in such instances seals compete with walruses for food since the species of clams eaten by the two are the same (Serripes groenlandicus, Clinocardium ciliatum, Spisula polynyma). Available information is not adequate to address the magnitude and effects of such competition in detail. However, it presently appears that competition may have a greater effect on walruses than on more euryphagous bearded seals (Lowry et al. 1980). The prey utilized by walruses and bearded seals are generally benthic omnivores (crabs and shrimps), detritus feeders (some clams and polychaetes), or filter feeders (priapulids and some clams). A relatively small portion of the diet is made up of predators of other benthic organisms (snails, sculpins, and some polychaetes).

Based on our samples belukhas and spotted seals in coastal waters utilize very similar prey, the majority of which are small to medium sized forage fishes. It appears that aggregations of the forage fishes which occur in coastal waters in summer and fall are of major importance in the diet of spotted seals and belukhas and influence their summer distributions. The distribution, abundance, and phenology of forage fishes in the Chukchi, and their importance in marine mammal diets, warrants considerable further study. The food habits of forage fishes in the Chukchi Sea have not been studied.

Ringed seals also eat considerable quantities of the same fish species consumed by spotted seals and belukhas. However, they also feed to a large extent on crustaceans and therefore have a more diverse food resource base, and utilize organisms from more points in the trophic structure. Nektonic crustaceans eaten by ringed seals feed on other, smaller crustaceans and phytoplankton, while benthic crustaceans consumed are detritivores, predators, and omnivores.

Bowhead whales migrate through the Chukchi Sea in spring and autumn. While it is known that they seldom feed during the spring migration, the extent of their summer and autumn foraging in the Chukchi is not known. In some areas of the Beaufort Sea, ringed seals and bowhead whales feed on the same prey (Lowry et al. 1978b, Lowry and Burns 1980).

In summer grey whales forage throughout the Chukchi Sea. Foods of grey whales in the Chukchi are poorly documented. In the Bering Sea they feed primarily on benthic crustaceans, mostly gammarid amphipods (Zimushko and Lenskaya 1970). They may be significant trophic competitors with ringed seals which also feed considerably on gammarid amphipods in some areas.

Seabirds compete to some extent with marine mammals for food. In particular, murres (Uria spp.) which are very abundant near Cape Lisburne feed on many of the fish species which are consumed by marine mammals (Swartz 1966).

In some areas such as the Bering Sea, commercial fisheries harvest considerable quantities of the same species eaten by marine mammals (Lowry et al. 1979c). In the Chukchi Sea, few species of marine mammal prey are of potential commercial value. The primary exception is herring which in the Bering Sea have been harvested at increased levels in recent years. Considering the importance of herring to marine mammals, any commercial fishing of stocks occurring in the Chukchi Sea should be approached very cautiously.

D. Potential Effects of Petroleum Development

This study was designed to develop an understanding of the feeding and trophic interactions of marine mammals, particularly ringed, bearded, and spotted seals, in the Chukchi Sea and to assess the possible and/or probable effects of petroleum exploration and development on the ability of those animals to meet their nutritional requirements. Possible effects fall into two categories: 1) those directly affecting the seals and their access to feeding habitat and 2) those affecting the availability of prey. The potential for and severity of any effects will vary by season and geographic area. For that reason we have organized the following discussion of effects by time period and, when appropriate, by area.

Winter exploration and development activities are likely to include such things as seismic profiling, construction and operation of drilling facilities, and maintenance activities such as supply and service of facilities. In the immediate future most activity will probably occur nearshore using landfast ice as a stable platform from which to operate. During this time period ringed and bearded seals and polar bears are the only resident marine mammals. Bearded seals and polar bears are found mostly offshore in areas of moving broken ice. Ringed seals are also present in the offshore area; however, preferred breeding habitat is the shorefast ice. It is this nearshore area where direct effects on feeding seals are most likely to occur and be of significance.

Prime ringed seal habitat coincides with and may be determined by the availability of arctic cod which are abundant nearshore under the fast ice during winter. Spilled oil or high noise levels which may displace ringed seals from this area would in fact be excluding them from their major food source at a time of year when energetic requirements are high and alternate prey are least available.

The nearshore area is important in winter, not only to ringed seals but to several major prey species. Arctic cod aggregate in autumn-winter and move onshore to spawn during January-February. The schooling of adult arctic cod at spawning time, particularly near narrow cracks in the ice and in slushy "frazil" ice, places them in areas most likely to be contaminated by winter oil spills. It also suggests that in the event of a catastrophic spill or blowout a large proportion of the breeding segment of the population might be affected. Preliminary toxicity studies have shown adult arctic cod to be very sensitive to crude oil at less than 2 ppm (NAFC 1979).

Both the eggs and larvae of arctic cod are pelagic, developing near the undersurface of the ice. The egg stage lasts 1.5-3.0 months, and the larval stage lasts about 2 months. Because the eggs and larvae are in the upper portion of the water column, they are likely to be exposed to surface and under ice spills, emulsions, and dispersions. Studies of other members of the cod family have shown eggs and larvae to be highly sensitive to even short-term exposure (5-30 hrs) to crude oil and crude oil extracts (Mironov 1967, Kuhnhold 1970).

Saffron cod also spawn nearshore under the ice in winter. Spawning aggregations form in autumn-early winter near river mouths, bays, and inlets in such places as Shishmaref, Kotzebue Sound, and the area near Point Hope. Unlike arctic cod the eggs are demersal and are laid on clean, sandy gravel bottoms. The presence of sinking oil in areas where saffron cod spawn could kill or cause abnormal development of eggs and larvae. Adult mortality occurs within 24 hours when individuals are exposed to the soluble fractions of crude oil at less than 2ppm at 3°C (Devries 1976).

Other major prey species reproduce in deeper offshore waters during autumn-winter. Sand lance spawn then as do many species of sculpins. Percy and Mullin (1975) found fry of the sculpin *Myoxocephalus quadricornis* to be the most sensitive organisms they tested, with 100 percent mortality occurring after 24 hours in a heavy dispersion of oil. *Parathemisto* breeds in autumn-winter and broods its eggs until spring. A similar pattern occurs in many gammarid amphipods, including *Ampelisca* and *Gammarus*, and some shrimps such as *Pandalus*, *Argis*, and *Sclerocrangon*. The crabs *Hyas* and *Chionocetes* carry eggs in autumn and perhaps winter. Time of hatching in the Chukchi is unknown. Water soluble fractions of crude oil can cause loss of eggs by gravid female amphipods (Busdosh and Atlas 1977) and may cause similar effects in shrimps and crabs.

The spring-summer period is a time of increased biological activity. Ringed and bearded seals bear their pups in April. As the ice melts in the Bering Sea there is an influx of ringed, bearded, and spotted seals, as well as walruses and belukhas, into the Chukchi. Walruses remain associated with pack ice in the northern Chukchi while belukhas move inshore to calve and feed in nearshore lagoons, bays, or inlets. Some prey species also undergo major movements at this time, moving into or out of nearshore areas to feed and/or reproduce.

The two major forage fishes of ringed seals, arctic and saffron cod, have already spawned. Larvae of both species develop in surface waters where exposure to toxic pollutants is most likely, then descend to the bottom in late summer and assume a demersal life similar to adults. Adult arctic cod disperse offshore during spring/summer and are probably least sensitive to oil spills and pollutants at this time. Most saffron cod apparently remain nearshore in areas where exploration and development are likely to occur.

Herring form pre-spawning concentrations in spring and move en masse into lagoons, bays, and inlets (for example the north coast of the Seward Peninsula, Shishmaref Inlet, Eschscholtz Bay, and outer Kotzebue Sound) to spawn at about the time the ice breaks up. After spawning they remain aggregated and feed intensively throughout the remainder of the summer.

Spawning takes place in two very different habitats: on kelp growing near exposed rocky headlands (such as Cape Espenberg in Kotzebue Sound) and on eelgrass (Zostera sp.) growing in shallow, brackish bays, lagoons, or inlets (such as the inlets near Shishmaref). The latter of these types is probably the most important spawning habitat in the Chukchi and the most vulnerable to either large or small scale discharges of pollutants. Rocky headlands are quite rapidly cleansed of oil as a result of wind and wave action. Such cleansing action occurs more slowly in lagoons, bays, or inlets where wind and wave action are more moderate and hydrocarbons can become entrained in sediments.

In herring, hydrocarbons cause reduced survival of ovarian eggs prior to spawning, of embryos from the time of fertilization to hatching, and of larvae through the yolk absorption stage (Struhsaker 1977; Kuhnhold 1970; Mironov 1970; Eldridge et al. 1978; Smith and Cameron 1977). In addition, hatching may be delayed and a significant proportion of the larvae may develop abnormally. In the natural environment only 5-10 percent of the herring are estimated to survive beyond the larval stage. The presence of hydrocarbons may aggravate a natural tendency toward embryonic mortality, and it is possible that an entire year class could be eliminated in localized areas. In addition to effects on eggs and larvae, benzene has been shown to cause aberrant swimming and disequilibrium in adults (Struhsaker 1977).

Many invertebrates release their young during spring and summer. Among the major species are the amphipods Ampelisca and Gammarus, the isopod Saduria, the shrimps Eualus, Pandalus, Crangon, Argis, and Sclerocrangon, and the clams Serripes and Spisula. The eggs of Hyas and Chionocoetes crabs may also hatch then. Growth and molting of crab larvae are impaired by hydrocarbons even in species in which adults are highly resistant (Mironov 1970; Parker and Menzel 1974; Rice et al. 1976). Pandalid and hippolytid shrimp larvae are sensitive to hydrocarbons. Low concentrations (1-5ppm) of water soluble fractions cause mortality and cessation of swimming activity (Malins et al. 1977; Brodersen et al. 1977; Craddock 1977).

Water soluble fractions of crude oil cause reduced fertilization of eggs, decreased survival of eggs, sperm, and larvae, and abnormal development of embryos in bivalve molluscs (Scarratt and Zitko 1972; Renzoni 1975). Growth, survival, and recruitment rates in local clam populations remained depressed for 3-6 years after the occurrence of oil spills in Nova Scotia and Maine (Gilfillan and Vandermeulen 1978).

Young amphipods may not colonize oiled sediments. Atlas et al. (1978) found that arctic amphipods occurred less frequently in oiled sediments than in unoiled (control) sediments. Although contaminated sediments were later recolonized, species composition was quite different. If colonization of a species such as Ampelisca, which is a major food not only of ringed seals but also of grey whales and numerous fishes, were discouraged it could have major implications for predators.

In general the literature indicates that many of the fishes, crustaceans, and bivalves (especially their eggs and larvae) which are important prey species in the Chukchi are sensitive to the presence of hydrocarbon in water. Summer is probably the period when reproductive products are most abundant; however, it is also the time of open water and warmer temperatures, which may facilitate dispersal, dilution, and degradation of contaminants. Consequently, the occurrence of an oil spill in summer may be less critical from the standpoint of prey species than a similar spill in winter. The probable exception is a summer spill in areas such as bays, inlets, and lagoons, where water circulation is sluggish, flushing time slow, and abundance of spawning and/or juvenile organisms is very high. Such spawning/nursery areas are very important to maintenance of prey species populations.

Fewer species reproduce during winter but many of the ones that do are major prey of marine mammals. The winter ice cover and accompanying colder water act to reduce dispersion rates, evaporative loss of toxic fractions, and biodegradation rates, and may concentrate pollutants in places of high biological activity such as leads and slush ice.

Pollutant levels high enough to cause large-scale die-offs of individuals will probably occur only on a very localized basis (except where oil or pollutants are trapped under the ice and transported long distances in a relatively unweathered state). The greatest concern may not be with local catastrophic events but with long-term sublethal effects of pollutants. Individuals may not be killed directly, but instead very low concentrations of pollutants may affect locomotion, metabolism, or reproduction and lead to substantial reduction of populations over several generations (Percy and Mullin 1975). These long-term reductions are of special concern in considering food availability to consumers.

VIII. Conclusions

Spotted seals are summer residents in the Chukchi Sea. They feed mostly on fishes, although at certain times and places shrimps are a major food. Among the fishes eaten are herring, arctic and saffron cods, sculpins and sand lance, and probably capelin and rainbow smelt.

Belukha whales are also summer residents in the Chukchi Sea. Based on our samples from coastal waters they utilize much the same prey as spotted seals; small to medium-sized forage fishes make up most of the diet. Aggregations of those fishes which occur in coastal waters during summer and fall probably influence the distribution of both spotted seals and belukhas.

Bearded seals are abundant year round residents in the Chukchi. They eat mostly shrimps, brachyuran crabs, and clams. The diet appears to vary on a seasonal basis with clams important only during summer. Young seals eat more shrimps and isopods while older seals eat more clams, crabs, and echiuroid worms.

A large proportion of the Pacific walrus population summers and feeds in the Chukchi Sea but they are not common there during winter. Foods of walruses in the Chukchi are poorly documented. They probably eat mostly clams, as they do elsewhere in their range. Walruses may compete for food with bearded seals in areas such as Wainwright where clams are a major component of the bearded seal diet.

Ringed seals are the most abundant marine mammal in the Chukchi Sea and they compete with and provide food for other marine species. Arctic cod and some saffron cod (at Shishmaref) are their main foods in winter. Crustaceans (amphipods, shrimps, and mysids) are the main food in March through June. Ringed seal pups eat more small crustaceans (amphipods, mysids, and euphausiids) than older seals, while older seals eat slightly more fish. Ringed seals eat many of the same fish species consumed by spotted seals and belukhas. However, they also utilize crustaceans in significant quantities and therefore have a more diverse food resource base.

Available information on the distribution, abundance, and natural history of most major prey species is inadequate. Information on hydrocarbon sensitivity of all but a few species is totally lacking. Without such information the potential effects of OCS development in the Chukchi Sea on marine mammals cannot be quantified. However, based on what information is available, a real potential for detrimental effects on prey populations exists. Changes in the abundance of prey can be expected to influence populations of marine mammals.

IX. Needs for Further Study

The data summarized in this report pertain almost exclusively to the nearshore waters of the Chukchi Sea in spring and summer. Virtually nothing is known about foods of marine mammals in offshore waters in either summer or winter, or about winter food habits in coastal areas. With adequate logistic support the necessary data could be obtained.

The Chukchi Sea is the major summering and feeding area for much of the Pacific walrus population yet virtually nothing is known of either food habits or distribution of potential prey in that region. Of particular interest are areas where bearded seals and walruses are found together and appear to compete for the same major prey (clams). Very little is known about utilization of the Chukchi coast by belukha whales. Although many belukhas migrate through the Chukchi to other areas, some spend summer months in and near coastal lagoons and estuaries in Kotzebue

Sound and between Point Lay and Wainwright. Future studies should address the distribution of whales in relation to available food resources such as herring, saffron cod, capelin, and anadromous fishes.

Distribution and abundance of arctic cod are virtually unknown in the Chukchi Sea. Spawning time and locations are unknown. Very limited data are available on arctic cod foods. Prey specificity, seasonal variation in prey, availability of alternate prey items and sensitivity of prey to hydrocarbons should be studied. Arctic cod are one of the most important forage species in the Chukchi Sea. Research should be undertaken immediately to fill these data gaps.

Data are needed on a seasonal basis on the distribution and abundance of other important prey species, the factors determining their presence or absence and the timing of important life history events. Some information on these species is available in the literature. It should be compiled and analyzed in light of questions pertaining to petroleum development. Critical feeding areas for marine mammals in the Chukchi Sea will be determined in part by the distribution of these organisms. The species include:

Fishes - Herring, saffron cod, sand lance
Gammarid amphipods - *Ampelisca* spp.
Mysids - *Mysis litoralis*, *Neomysis rayii*
Shrimps - *Crangon septemspinosa*, *Argis lar*, *Sclerocrangon boreas*, *Pandalus goniurus*, *Eualus gaimardii*
Brachyuran crabs - *Hyas coarctatus*, *Chionoecetes opilio*, *Telmessus cheiragonus*
Clams - *Serripes groenlandicus*, *Spisula polynyma*
Hyperiid amphipods - *Parathemisto libellula*

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FINAL REPORT OF BERING SEA ACTIVITIES

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Trophic Relationships Among Ice-Inhabiting Phocid Seals and Functionally Related Marine Mammals in the Bering Sea

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I. Summary

A total of 62 spotted seal, 28 ribbon seal, 199 ringed seal, 218 bearded seal, 3 belukha, and 53 walrus stomachs containing food and collected in the Bering Sea were analyzed between October 1975 and August 1980. Most of the specimens were obtained from Eskimo subsistence hunters at five coastal villages: Nome, Gambell, Savoonga, Diomede, and Wales. Samples were collected at several times of year in order to assess seasonal changes in feeding patterns. The most complete sample coverage was near the coast in spring and summer when hunting activity is greatest. Poorest sample coverage was in winter and in the vast offshore areas of southern and central Bering Sea that are not accessible to coastal based hunters.

The diet of spotted seals consists mostly of pelagic and semi-demersal fishes. In southeastern Bering Sea in spring capelin are the major prey, in the southcentral and central regions the major prey are pollock and also eelpout, and in northern Bering Sea arctic cod, saffron cod, and capelin are most commonly eaten. During late summer and autumn, when spotted seals are present in coastal areas, they feed on saffron cod, herring, capelin, smelt, and sand lance. Foods during winter months are poorly known, but it is likely that arctic cod are important at that time. Belukha whales eat many of the same species of fishes as do spotted seals, in addition to cephalopods and crustaceans, especially shrimps. It is probable that the distribution of belukhas and spotted seals is at least partially determined by the distribution and abundance of the aggregating fishes upon which they feed.

Ribbon seals have not been sampled during times of year when they feed intensively. During spring, when feeding occurs at very low levels, they prey on pollock, eelpout, Greenland halibut, and capelin in southern and central Bering Sea, and on arctic cod and occasionally saffron cod, sculpins, octopus, and pollock in northern Bering Sea.

Bearded seals and walruses are primarily benthic feeders. Bearded seals forage mostly on epifaunal invertebrates such as crabs, shrimps, and, during summer, clams, whereas walruses eat mainly infaunal clams. Bearded seals and walruses compete for the cockle Serripes, and there are indications that their combined predation is in excess of the sustainable yield of that species.

The feeding of ringed seals in the Bering Sea shows pronounced seasonal variation. Saffron cod are most important in the diet during autumn and spring along the mainland coast. Arctic cod are the primary species eaten during winter months. Shrimps are eaten in small amounts in all seasons and at all areas, but are of greatest importance during spring and summer in northern Bering Sea and Norton Sound. Mysids are eaten in largest quantities in southeastern Bering Sea and near St. Lawrence Island. Gammarid amphipods and sculpins are eaten most commonly near St. Lawrence and Little Diomede Islands. Age-related dietary differences are pronounced. Crustaceans make up most of the diet of recently weaned pups and of yearlings, whereas adults eat mostly fish.

Two other species of pinnipeds, the northern fur seal and the Steller sea lion, are also abundant in the Bering Sea and compete for food with phocid seals. In total more than 2 million pinnipeds are being supported primarily by the pelagic and semidemersal fish resource of Bering Sea. The same species of fishes (pollock, capelin, arctic and saffron cods, herring, and smelt) are consumed in large numbers by some species of whales, porpoises, and seabirds. In addition, humans compete directly with pinnipeds for food. Commercial fisheries currently remove in excess of 1 million metric tons of fish per year from Bering Sea.

If the trophic subsystems such as the pelagic and benthic food webs described for Bering Sea marine mammals are in equilibrium, changes in population size of either consumer or prey species as a result of commercial fisheries or petroleum exploration and development can be expected to have direct effects on other consumer populations. The mechanisms and magnitude of the response of pinniped populations to such changes are presently impossible to predict.

II. Introduction

In 1975 the Alaskan Outer Continental Shelf Environmental Assessment Program (OCSEAP) was initiated to conduct environmental research prior to oil and gas exploration and development in Alaskan waters. Six proposed lease areas have been identified, four of which are in the Bering Sea. Those areas and proposed sale dates are: Norton Basin, September 1982; St. George Basin, December 1982; North Aleutian Shelf, October 1983; and Navarin Basin, December 1984. In preparation for those sales this research unit has been investigating trophic relationships of ice-associated marine mammals, primarily phocid seals, of western and northern Alaska. This final report presents information collected in the Bering Sea during a 4-year field program and makes it available to other scientists and resource managers for consideration during tract selection, EIS preparation, and policy formulation.

The waters off the coast of Alaska support a tremendous abundance and diversity of marine mammals. Some species occur only during ice-free months while others are more or less dependent on sea ice as a habitat in which to whelp, breed, molt, and feed. The relationship between northern marine mammals and sea ice has been well summarized by Burns (1970) and Fay (1974). Seven ice-associated species are seasonal or year-round residents of the Bering Sea. They are: ringed seals (Phoca hispida), bearded seals (Erignathus barbatus), spotted seals (Phoca largha), ribbon seals (Phoca fasciata), walruses (Odobenus rosmarus), belukha whales (Delphinapterus leucas), and bowhead whales (Balaena mysticetus). The four species of seals were the main focus of this project. Preliminary data were collected on an opportunistic basis for walruses and belukhas. Bowhead whales were outside the scope of this project and will not be included in this final report.

Sea ice begins to form in the northern Bering Sea in early November, particularly in Norton Sound and along the coast. As winter progresses the ice advances southward, reaching south of St. Lawrence Island by January and usually south of St. Matthew Island by February. Maximum extent of the ice which usually occurs in March may reach as far as the continental shelf break south of the Pribilof Islands. In April the ice begins to melt and recede north and by May the southern and central Bering Sea is ice free. Ice remnants persist in northern Bering Sea into June and sometimes early July. Open water persists from July through October.

Several zones or ice types are found in seasonal sea ice. The front region occurs at the leading edge of the ice and consists of a band of relatively thin, dispersed moving floes. The size of the floes and the width of the band are largely determined by prevailing wind and weather conditions. The exact geographical position of the ice front varies widely depending on meteorological conditions in a particular year. North of the front lies the pack ice which consists of thicker, more closely packed and larger floes. Pack ice coverage may be close to 100 percent. Along the coast land-fast ice is present. It is most extensive in sheltered areas of convoluted coastline and in the lee of coastal promontories. Fast ice forms a large, continuous sheet of ice and is the most stable of the ice zones. Between the fast ice and pack ice one finds a transition region where the two zones interact. Considerable ice movement and ridged and deformed floes are characteristic of this zone, as well as leads and other openings.

Ribbon seals are associated with the winter-early spring ice front and late spring ice remnants in the Bering Sea during which time they give birth, support young, mate, and molt. When the last of the sea ice disappears the ribbon seals become pelagic; their distribution during the open water season, when they probably feed intensively, is largely unknown (Burns 1970). Population size in the Bering Sea is estimated at 90,000 to 100,000 (Burns, in press). Of the four Bering Sea lease areas, ribbon seals probably are most common in Navarin and St. George Basins. They sometimes occur in Norton Basin during late spring in association with receding ice remnants.

The entire Bering Sea population of 200,000-250,000 spotted or larga seals is found in the ice front region of the Bering Sea during February to May when they bear and nurse their young and breed. As the ice begins to disappear in May and early June, largas are concentrated in the remaining ice remnants where they spend much of their time molting and basking on the ice. In months when ice is absent in the Bering Sea they are found feeding near shore and hauled out on the coast, frequently near estuaries. Spotted seals occur in all four of the Bering Sea lease areas but are least common on the North Aleutian Shelf.

Bearded seals are widely, though not uniformly, distributed throughout the drifting pack ice of the Bering Sea during winter. Highest densities occur in the northern part of the ice-covered Bering Sea shelf. Like spotted and ribbon seals, they bear and nurse their young in April on the drifting ice. Bearded seals migrate north from mid-April through June following the receding ice through Bering Strait to the Chukchi Sea where they spend the summer near the fragmented margin of the multi-year ice. Some bearded seal pups occur in the open sea during summer. The fall migration back to the Bering Sea occurs in late fall through winter. Population size is estimated at 300,000 (Burns and Frost 1979). Few bearded seals occur in the North Aleutian shelf and in Navarin Basin, as the two areas are infrequently covered by ice. St. George Basin is on the southern boundary of bearded seal range, with its importance being directly related to annual ice conditions. Norton Basin is important bearded seal habitat from November through June. Large numbers migrate through the area in spring and fall, and they are abundant residents whenever ice is present.

Ringed seals are the most widely distributed and abundant pinniped in Alaskan waters, probably numbering in excess of one million seals. They are high trophic level consumers, constitute the basic diet of polar bears, and are utilized in large numbers by coastal Eskimos. They occur seasonally in the Bering Sea, appearing with the formation of seasonal sea ice in November. In late March and early April ringed seal pups are born in lairs excavated in snow-covered ice. Stable landfast ice is the preferred area for pupping and the greatest density of ringed seals occurs there, although some pups are born on drifting ice. Subadult animals are often found congregated along transient lead systems. Subsequent to pupping and breeding ringed seals undergo a period of molting during which they spend a large amount of time hauled out on the ice. As the ice melts in the Bering Sea in May and June, ringed seals move into the Chukchi and Beaufort Seas where they spend the summer dispersed throughout ice-covered areas. With the onset of winter and the increase in ice cover the area occupied by ringed seals expands accordingly and again includes the Bering Sea. Of the four lease areas, Norton Basin is by far the most important to ringed seals.

The Pacific walrus population ranges seasonally throughout the waters covering the Bering and Chukchi Sea platform. Since they are benthic feeders they do not regularly occur in deep waters off the continental shelf. During winter and spring walruses are found throughout areas of moving pack ice in the Bering Sea and Bristol Bay. Most calves are born on the ice in May. Much of the population moves north through Bering Strait as seasonal ice disappears. Several thousand walruses summer on coastal haulouts in Bristol Bay and the northern Bering Sea. Recent estimates indicate a population in excess of 209,000 (Krogman et al. 1978). Walruses are present in all four proposed lease areas. They occupy Navarin and St. George Basins in winter-spring and North Aleutian Shelf and Norton Basin in spring through autumn.

The distribution and abundance of belukha whales in the Bering Sea are not well known. The whales winter primarily in areas of moving ice in the Bering Sea. They move north in spring through leads in the ice to the Chukchi and Beaufort Seas where they spend the summer. Some of them remain in Bering Sea where they may bear their young in coastal lagoons and estuarine systems. Belukhas move away from the coast and south in autumn as the ice forms. The size of the present population is estimated at about 9,000 (U.S. Dept. Commerce 1979). These whales are seasonally present in St. George, Navarin (winter), and Norton Basins (year-round), and are largely absent from the North Aleutian Shelf.

Ringed, bearded, and spotted seals, walruses, and belukhas are of cultural and economic importance to the residents of the Bering Sea coast. Seal hunting regularly occurs at, among others, the villages of Hooper Bay, Mekoryuk, Nome, Wales, Gambell, Savoonga, and Diomede. Walruses are important to residents of Nome, Wales, Gambell, Savoonga, and Diomede and belukha whales are sometimes taken by villages of inner Norton Sound. Marine mammals are not only important to humans as food but they compete directly with humans for food. Pelagic and semidemersal fishes such as pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), herring (*Clupea harengus*), arctic cod (*Boreogadus saida*), and saffron cod (*Eleginus gracilis*) comprise a major portion of the diet of spotted, ribbon, and ringed seals, and belukhas, while clams and brachyuran crabs are major foods of walruses and bearded seals. Commercial or subsistence fisheries exist or are developing for most of those species. Extant models which deal with consumption of finfish by pinnipeds indicate that more fish are consumed by pinnipeds than are caught by commercial fisheries in the Bering Sea (McAlister and Perez 1976). Since consumption of marine organisms by marine mammals and removal by human fisheries have grossly similar effects, i.e. a reduction in the standing stock of prey or target species, it is desirable and necessary to implement multi-species management in the formulation of fishery management plans and management policies for marine mammals. In addition, because marine mammals, and fisheries, are of such import to people, it is imperative that the potential effects of oil and gas exploration and development in the Bering Sea on marine mammals be anticipated and minimized to whatever degree possible. Such an evaluation requires an understanding of the biology of the species involved, as well as how they affect and are affected by their environment. The study of trophic relationships of the marine mammals included in this report will contribute to such an understanding.

In the discussions that follow it will be necessary to give the names of many species of marine animals. The authors realize that there are advantages to the use of either common or scientific names. In this report we will use common names whenever such are available and appropriate. For purposes of clarity and ease of reference, the accepted scientific names of most species for which we will use common names are given in Table 1. For species mentioned seldom in this report, both common and scientific names are given at the first mention of that species.

Table 1. Common and scientific names of species commonly mentioned in this report.

Common Name	Scientific Name
Pollock	Theragra chalcogramma
Arctic cod	Boreogadus saida
Saffron cod	Eleginus gracilis
Herring	Clupea harengus
Rainbow smelt	Osmerus esperlanus
Sand lance	Ammodytes hexapterus
Capelin	Mallotus villosus
Greenling	Hexagrammos sp.
Eelpout	Lycodes sp.
Stickleback	Pungitius pungitius
Prickleback	Lumpenus sp.
Sculpin	Family Cottidae
Flatfish	Family Pleuronectidae
Poacher	Family Agonidae
Tanner crab	Chionoecetes opilio
Spider crab	Hyas spp.

III. Current State of Knowledge

We know of only seven accounts of the food habits of ice-inhabiting phocid seals published prior to this OCSEAP study which began in 1975. The food habits of those seals in the Bering Sea had not been given systematic attention despite the fact that several species are known to feed extensively on commercially important fishes or invertebrates (Lowry et al. 1979a). A summary of the results of earlier studies follows as well as short summaries of studies on food habits of belukha whales and walruses in the Bering Sea. Published accounts of the food habits of those species in other parts of the world have been reviewed in 1978 and 1979 annual reports for this research unit (Lowry et al. 1978a; Lowry et al. 1979b).

Ringed seal

Kenyon (1962) reported on the stomach contents of 14 ringed seals taken at Little Diomede Island, 11 May-14 June 1958. Shrimp of the genus Pandalus accounted for 96 percent of the food items encountered with mysids, amphipods, and fishes present in small amounts.

Results of our OCSEAP studies of the food habits of ringed seals in Bering Sea waters have been compiled and presented in several publications (Lowry et al. 1977; Lowry et al. 1978b; Lowry et al. 1979a; Lowry et al. 1980a; Frost and Lowry, in press a; Lowry and Frost, in press).

Bearded seal

Kosygin (1966, 1971) reported on the foods of the bearded seal in the Bering Sea in spring and early summer (March to June) 1963 to 1965. Stomachs from 565 animals were examined, 152 of which contained food. The tanner crab was the species most commonly eaten, making up from 53 to 76 percent of the food. Shrimp (particularly Argis (=Nectocrangon) lar) were the second most important food. Snails were also important. Octopus, priapulids, and fishes (particularly pricklebacks and flatfishes) were eaten quite regularly. Kosygin noted considerable constancy in the diet from year to year which he explained by the fact that the animals tend to be found in the same areas each year. Some annular changes were noted (e.g. polychaetes were commonly eaten in 1963 but not in 1964 or 1965) which Kosygin thought were mostly due to heavy ice fields excluding animals from certain feeding areas. No age- or sex-related feeding differences were noted with the exception that it appeared that young bearded seals foraged mostly in the morning while mature animals ate more in the afternoon. The average amount of food in the stomachs decreased from April to June.

Kenyon (1962) reported on the stomach contents of 17 specimens taken at Little Diomede Island, 11 May-6 June 1958. Shrimps (Pandalus sp. and Sclerocrangon sp.), crabs (Hyas coarctatus alutaceus and Pagurus sp.), and clams (Serripes groenlandicus) comprised the bulk of the contents. Other benthic invertebrates (sponges, annelids, and snails) and several species of fish were present in small amounts.

In his summary of the biology of the bearded seal, Burns (1967) reported on his examination of stomachs from seals collected at Nome, Gambell, and Wainwright. In May he found that crabs (Hyas coarctatus alutaceus and Pagurus sp.) accounted for 57 percent of the contents with shrimp, fishes (saffron cod, arctic cod, and sculpins), and sponges comprising most of the remainder. In July and August clams (Serripes groenlandicus, Spisula sp., and Clinocardium sp.) were the most abundant food item, with shrimp, crabs, and isopods also quite commonly found.

Frost et al. (1977), Burns and Frost (1979), Lowry et al. (1979a), Lowry et al. (1979c), Lowry et al. (1980b), and Lowry and Frost (in press) report the results of our OCSEAP studies of bearded seals.

Spotted seal

Many studies have been done on the food of *Phoca vitulina*; however, most of these have been done on the land-breeding subspecies (*P. v. richardsi*). A single report has been found dealing with the feeding habits of the ice-breeding form (*P. v. largha*) in the Bering Sea.

Gol'tsev (1971) examined 319 stomachs from seals collected primarily in the northwest Bering Sea during the 1966-1968 hunting seasons (April-June). From his collections he concluded that spotted seals feed in the morning and in the evening and digest their food quite rapidly. The food of newly weaned young (5 weeks old) was entirely amphipods (*Nototropis* sp. and *Anonyx nugax*) and some algae. At 7 to 8 weeks old they begin to feed on shrimps (*Spirontocaris macarovi*, *Eualus fabricii*, and *E. gaimardii*) and sand lance. When 12 weeks old, larger fish (flatfish and saffron cod) begin to be eaten. Juveniles (age 1 to 4 years) fed mostly on fish (arctic cod, sand lance, saffron cod) and shrimps (*Pandalus* sp.). Adults appear to feed more on benthic forms with octopus, crabs, flatfishes, sculpins, and other bottom fishes prevalent.

Recent data on foods of spotted seals collected in the Bering Sea by Soviet and American investigators have been summarized and presented in Frost et al. (1977), Lowry et al. (1979a), Bukhtiyarov et al. (in press), and Lowry and Frost (in press).

Ribbon seal

Shustov (1965) examined 1,207 stomachs from seals taken at the ice front of the Bering Sea from March through July. Only 32 of these stomachs contained recognizable food. Shrimps (*Pandalopsis* sp., *Argis lar*, *Pandalus borealis*, *Eualus gaimardii*, and others), amphipods (*Parathemisto* sp.), mysids, and cephalopods were frequently found. Many types of fishes, especially arctic cod, saffron cod, and herring, were encountered but were not very common. In interesting contrast to the findings in the Sea of Okhotsk (Arseniev 1941; Wilke 1954; Fedoseev and Bukhtiyarov 1972), no pollock were found in the Bering Sea sample. This can perhaps be explained by the fact that the seals examined by Shustov were taken in the northern Bering Sea, somewhat north of the main concentrations of pollock.

Burns (in press) reports on the food remains found in the stomachs of six specimens collected in the Bering Sea. Four animals were taken in April and May; one contained fish (*Pholis* sp.), two contained shrimps (*Pandalus* and *Sclerocrangon* sp.), and one contained only milk. The stomachs of two specimens collected in February contained large volumes of pollock and arctic cod.

Frost et al. (1977), Lowry et al. (1979a), Frost and Lowry (1980), and Lowry and Frost (in press) report results of our OCSEAP studies.

Belukha whale

The only published information on foods of belukhas in Alaska comes from the work of Brooks in Bristol Bay (Brooks 1954a, 1955 and reported in Klinkhart 1966). Five species of salmon (Oncorhynchus spp.), smelt, flatfishes, sculpins, blennies, lamprey (Lampetra japonica), shrimps, and mussels were found in the stomachs examined. Smelt were the main food in early May. In late May downstream migrating fingerling salmon were the most important food. From the first of July through the end of August upstream migrating adult salmon were the main prey. Preliminary data on food habits of belukhas collected on an opportunistic basis during our OCSEAP studies is presented in Frost and Lowry (in press b) and Seaman and Lowry (in prep.).

Walrus

Although there are quite a number of published reports dealing with the foods of walruses in different parts of the world, few pertain to the Bering Sea.

Brooks (1954b) examined stomachs of walruses collected during May and June in the Bering Strait region. He found molluscs to be the predominant food, with echinoderms, polychaete worms, and priapulids also eaten. The clam genera Mya and Clinocardium were most frequently eaten by bulls whereas Astarte and Macoma and the polychaete Nephtys were most common in cows. Brooks also noted that local hunters sometimes killed walruses that had eaten ringed and bearded seals and whale carrion.

Tikhomirov (1964), during an investigation of the distribution and biology of Bering Sea pinnipeds, examined the stomachs of 50 walruses collected about 160 km east of the Pribilof Islands in March. They had eaten shrimp, crabs (including several king crabs, Paralithodes sp.), and some mollusks, although the latter were not a main food item.

Fay et al. (1977) examined the stomachs of 107 walruses collected in northern Bering Sea near Gambell, Savoonga, Diomede, Nome, and King Island in spring (April to June). Identifiable prey items included representatives of 10 phyla and at least 45 genera, among which were polychaetes, sipunculids, echiurids, priapulids, crustaceans, mollusks, holothuroids, ascidians, and a bearded seal. The clams Mya, Hiatella, Spisula, and Serripes comprised more than 80 percent of the total wet weight of identifiable items, with Mya most abundant at all areas except Nome where Serripes was dominant. Other common food items were Echiurus, Priapulus, Tellina/Macoma, Neptunea/Beringius, Polinices, and Thyonidium. Females tended to select smaller items than males, regardless of age. Fay et al. reported on the stomach contents of only two walruses collected in winter in northern Bering Sea, both near St. Lawrence Island. One had eaten mostly Spisula with a few other clam and gastropod feet, while the other contained the tunicate Pelonaia, clam feet, and small quantities of amphipods and shrimps. From southeastern Bering Sea Fay et al. reported unpublished data of Stoker and Muktoyuk (2 stomachs) and Yu. Bukhtiyarov (21 stomachs). In both instances bivalves (mostly Clinocardium) and gastropods were the main foods. Recently molted brachyuran crabs had also been eaten. In summary the authors suggested that walruses in the Bering Sea removed at least 25 percent of the bivalve standing stock per year, a rate close to the estimated net annual production of bivalves, and that it was highly probable that the walrus population was at or near the carrying capacity of its winter range in terms of food supply.

The dietary overlap and potential competition between walruses and bearded seals has been discussed in Lowry et al. (1979c), Lowry et al. (1980b), and Lowry and Frost (in press).

IV. Study Area

The study area encompasses seasonally ice-covered regions of the Bering Sea which lie east of the US-USSR Convention Line. Collections were centered around prospective OCS lease areas including Bristol Bay Basin, St. George Basin, Navarin Basin, and Norton Basin. Most work was shipbased in the first three of these areas whereas in Norton Basin most collections were made at coastal hunting villages. Specimens were obtained from the villages of Gambell, Savoonga, Nome, Diomede, and Wales with smaller samples from Hooper Bay, Mekoryuk, and Stebbins. Collection locations and OCS lease areas are shown in Figure 1.

V. Sources, methods, and rationale of data collection

Literature

Compilation of existing literature and unpublished data on the food habits and trophic interactions of ice-inhabiting seals is essentially complete. Available information on the distribution, abundance, and natural history of potentially important prey species has also been compiled. Pertinent literature was obtained through an OASIS literature search for information about food habits of seals, discussion and consultation with personnel from the University of Alaska Marine Museum/Sorting Center, use of various translation services (Israel Program for Scientific Translations and Fisheries Research Board of Canada) for access to Russian literature, search of Alaska Department of Fish and Game reprint files, library and other literature collections, use of University of Alaska library facilities, and inter-library loan services.

Field collection of specimen material

OCSEAP-sponsored collection efforts began in 1975 and intensified in 1976-1979. Collectors were sent to coastal hunting villages during predictably good hunting periods. Specimen material, including jaws and claws for age determination, reproductive tracts, and stomachs, was purchased directly from hunters. Sampling was done by the principal investigators and other ADF&G employees. A schedule of field activities and summary of specimens obtained is presented in Table 2.

Shipboard collections of seals were made by project personnel in areas inaccessible to coastal hunters. Collection in the Bering Sea ice front, where the ice was often impenetrable by small boats, was aided by a Bell 206 helicopter. Other shipboard collection efforts were conducted from small boats. Animals were shot either on the ice or in the water, taken to the ship, and processed as described below. Two early spring collections were made in Norton Sound from helicopters.

Whenever possible, seals from which specimen material was taken were weighed, sex was determined, and a series of standard measurements was made for use in this and other ongoing studies of ice-inhabiting

Table 2. Schedule of field activities in the Bering Sea and summary of specimens obtained. Only stomachs containing food are included.

Location/ Platform	Dates	Ribbon Seals	Spotted Seals	Ringed Seals	Bearded Seals	Walrus	Belukha Whales
Mekoryuk	22 Apr-12 June 1975		8	6	12		
Savoonga	7 May-13 June 1975		5	1	6		
Gambell	7 May-13 June 1975			1	2		
Nome	May 1975			4	1		
Diomede	28 May-10 June 1975			12	6		
Nome	22-25 Jan 1976			1			
SURVEYOR	14 Mar-1 May 1976	5	7				
Savoonga	1 May-30 June 1976			4	2		
Gambell	1 May-30 June 1976			1	4		
Diomede	1 May-30 June 1976			1	4		
Nome	11-21 June 1976			4	5		
MILLER-FREEMAN	27 Sept.-13 Oct. 1976				1		
Nome	18-24 Nov 1976		1	5			
Stebbins	19-21 Nov 1976			2			
Nome	25-29 Jan 1977			4			
Nome	8-20 Mar 1977			21	4		
SURVEYOR	15 Mar-3 May 1977	4					
DISCOVERER	18 May-13 June 1977		3				
Savoonga	20 May-24 June 1977			1	1		
Gambell	20 May-24 June 1977		2	30	15		
Diomede	20 May-24 June 1977			7	4		
Wales	28 May-2 July 1977		2	10	6		
Elim	12 June 1977						3
Nome	28 May-4 July 1977			13	8		
Hooper Bay	Jan-Nov 1978		2	3	1		
Gambell	1-24 Mar 1978			12	4		
Nome	Jan-Apr 1978			8	3		
Gambell	28 Apr-29 May 1978		3	1	33		
SURVEYOR	1 May-15 June 1978	18	11	5	10		
Savoonga	27 May-11 June 1978		2	3	14		
Wales	31 May-17 June 1978		6	20	12		
Diomede	19 May-15 June 1978			3	2		
SURVEYOR	9 Apr-4 May 1979	1	1		4		
Savoonga	May-June 1979		5	4	21	15	
Diomede	May-June 1979				8	21	
Gambell	May-June 1979		4	2	19	15	
Nome	May-June 1979			1	6		
Wales	May-June 1979					2	
Hooper Bay	Jan-June 1979			9			
TOTAL		28	62	199	218	53	3

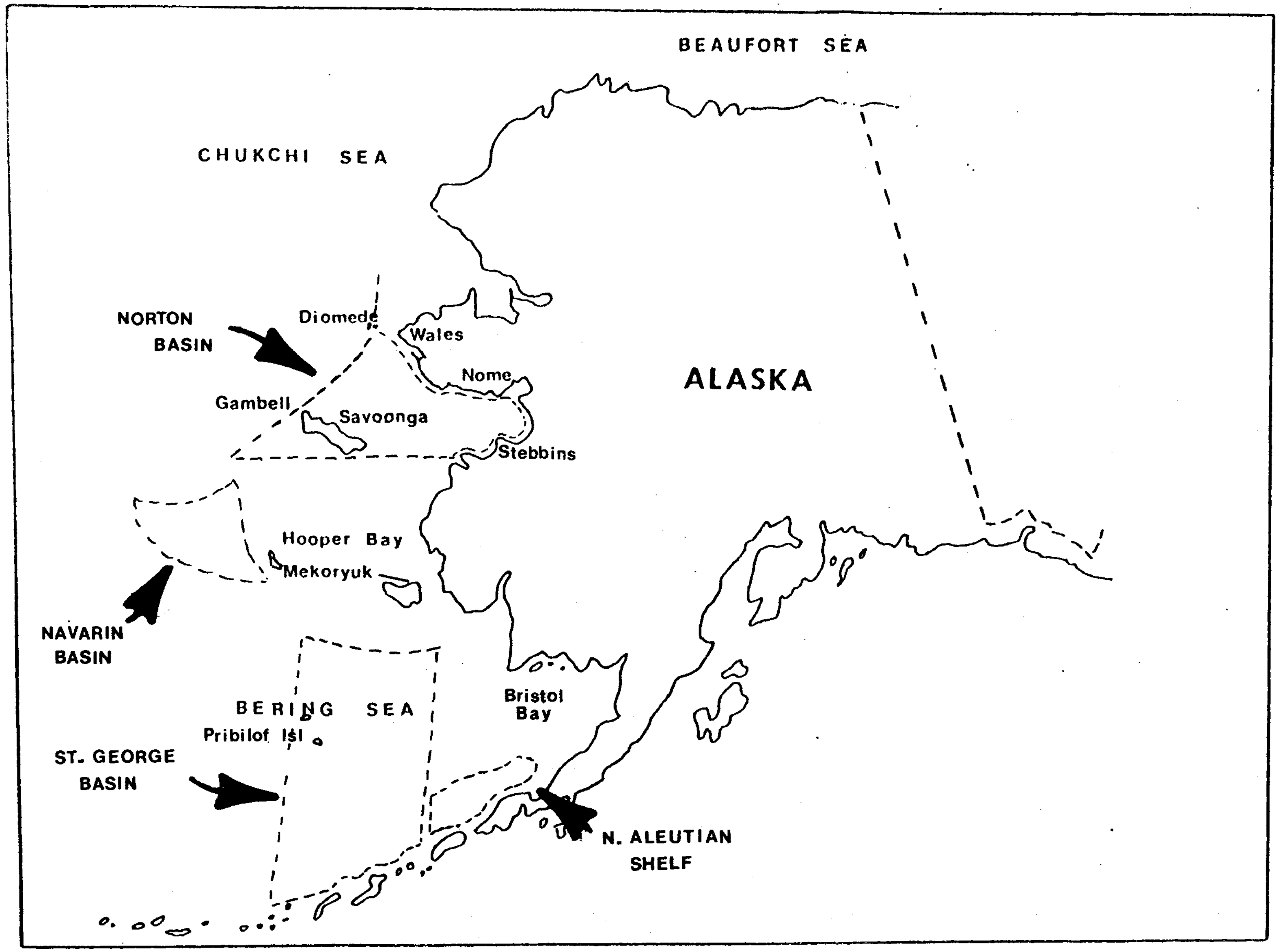

Figure 1. Locations where the major collections of specimen material and data were obtained during this investigation.

seals. Tissue and blood samples were collected in some cases and made available to other investigators for heavy metal, hydrocarbon, PCB, and pathogen analysis. (See methods section in RU #230, Annual Report, for detailed description of standard measurements and collection of additional specimen material.)

Only stomachs containing food were collected. Stomachs were tied at the cardiac and pyloric sphincters and severed from the remainder of the alimentary canal near these ties. They were then either injected with 10 percent formalin, labeled, and placed intact in plastic bags containing 10 percent formalin, or placed in bags and frozen. All stomachs were shipped to the ADF&G lab in Fairbanks. For some of the animals collected by project personnel, the contents of the small intestine were also retained and examined for food remains. In cases where the stomach was empty this often provided some information on recent diet. Upon arrival in the lab, stomachs containing large numbers of otoliths, which degrade rapidly in formalin, underwent a preliminary sort in which the otoliths were removed and stored in 95 percent ethanol.

When possible, bottom sampling for fishes and invertebrates with a 19-foot Marinovich otter trawl (1-3/8-inch stretch mesh body, 1/4-inch mesh cod end liner) was done in conjunction with the collection of seals. Trawls were of 10-20 minutes duration at a ship speed of 2-4 knots. Contents of each trawl were identified, enumerated, and representative specimens of organisms retained. Fishes were measured and weighed, and the otoliths removed and measured to determine the correlation of otolith size to fish size (see Frost and Lowry 1980; Frost and Lowry 1981). Stomach contents of some fishes were examined. Examples of selected invertebrate species were measured and weighed to provide an index of length/weight ratios that could be applied to partially digested food items found in seal stomachs.

Laboratory procedures and identification

The preserved contents of stomachs were washed onto a 1.0-mm mesh screen. Contents were sorted and identified to the lowest taxonomic level permitted by their condition, using appropriate taxonomic keys and reference specimens. In the majority of cases identifications entailed the sorting and recognition of small bits and pieces of organisms. Crustaceans were frequently identified by claws, carapaces, or abdomens. Fishes were identified on the basis of otoliths and bone fragments. The volume and number of each type of prey item were determined by water displacement and counts of individuals or otoliths. Size ranges of various prey items were determined when possible.

Virtually all identifications were made by project personnel. Necessary taxonomic keys and references, both published and unpublished, were accumulated. Much use was made of the University of Alaska Marine Museum/Sorting Center reference collection and of the expertise of Sorting Center personnel. A reference and voucher collection of invertebrates and fishes was established at ADF&G. In addition, an otolith collection was compiled. Considerable interchange of specimen material and ideas occurred among personnel of this project, Dr. James Morrow, OCSEAP RU #285, and John Fitch, California Department of Fish and Game (retired).

VI. Results

Spotted seals

We have examined the stomachs of spotted seals collected during research cruises in the Bering Sea ice front and ice remnants and of seals taken at coastal hunting sites. Seals associated with the Bering Sea ice front in March and April 1976 and 1977 had eaten capelin and pollock (Table 3). In outer Bristol Bay capelin were by far the major prey while one seal northwest of the Pribilof Islands had eaten only pollock. In April 1978 a seal taken in the ice front southwest of St. Lawrence Island contained remains of pollock, arctic cod, and sculpins. Seals associated with Bering Sea ice remnants in late May and early June had eaten fishes and octopus (Table 4). Capelin and herring were the only species eaten by seals near Nunivak Island in 1977. In 1978 seals taken at several locations west and east of St. Lawrence Island had eaten arctic and saffron cods in addition to capelin and herring. In addition to material in stomachs, otoliths recovered from intestines indicated that eelpout, sculpins, flatfish, and pricklebacks are occasionally eaten.

At coastal locations in May-June spotted seals we examined had eaten mostly fishes and shrimps (Table 5). Fishes eaten were mostly arctic and saffron cods, sand lance, and sculpins. Shrimps eaten were mostly *Crangon dalli* at Mekoryuk, *Pandalus goniurus* at Savoonga, and *Eualus gaimardii* at Gambell and Wales.

We have examined only 10 spotted seal stomachs with food from coastal areas in summer and autumn, 9 of which were collected prior to the commencement of OCSEAP. Fishes, primarily saffron cod, sand lance, smelt, and herring, comprised most of the stomach contents of those seals (Table 6).

Ribbon seals

Stomachs and intestines of 61 ribbon seals collected during research cruises in the ice front and ice remnants were examined. Very little fresh food was found in the stomachs; however, hard parts of prey, particularly fish otoliths, were found in digestive tracts of 28 seals. Weights of fishes of each species consumed were estimated from sizes of otoliths in seals or from average size of fishes of that species caught in trawls (Frost and Lowry 1980). The principal species of fish eaten varied with the area of collection (Table 7). Pollock and eelpout were major foods in the southcentral and central Bering Sea, while arctic and saffron cods were the main prey of ribbon seals in the northern Bering Sea. Invertebrates appeared to be only minor and perhaps incidental components of the diet. However, the dietary importance of invertebrates is difficult to evaluate since the seals we examined were not feeding at the time of collection.

Ringed seals

We have examined stomach contents of ringed seals taken during spring and early summer at seven locations on the Bering Sea coast

Table 3. Spotted Seal stomach contents data from Bering Sea ice front. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		outer Bristol Bay	NW of Pribilof Islands	outer Bristol Bay	SW of St. Lawrence Island	
Dates:		25-27 March 1976	22 March 1977	20 April 1977	28 April 1979	
Sample Size:		7	1	4	1	
Mean Volume (ml)		506.3	336.8	144.5	16.0	
Food Items	1	Fish 100 Capelin 100	Fish 100 Pollock 100	Fish 100 Capelin 96 Pollock 4	Fish 100 Pollock 60 Arctic Cod 20 Sculpins 20	
	2					
	3					
	4					
	5					

Table 4. Spotted Seal stomach contents data from Bering Sea ice remnants. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		W of St. Matthew Island	W of Nunivak Island	around St. Lawrence Island		
Dates:		26 May 1977	30 May 1977	May - June 1978		
Sample Size:		1	2	11		
Mean Volume (ml)		6.0	1134.0	270.5		
Food Items	1	Octopus 100	Fish 100 Capelin 51 Herring 49	Fish 96 Arctic Cod 43 Capelin 26 Saffron Cod 20 Herring 4 Octopus 3		
	2					
	3					
	4					
	5					

Table 5. Spotted Seal stomach contents data from Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Mekoryuk	Gambell	Savoonga	Wales	
Dates:		17-30 May 1975	May - June 1977-79	May 1975-79	June 1977-78	
Sample Size:		8	9	12	8	
Mean Volume (ml)		97.7	253.3	178.2	76.9	
Food Items	1	Fish* 87	Fish 96 Arctic Cod 34 Sand Lance 33 Sculpins 32	Fish 75 Arctic Cod 57 Sculpins 39	Fish 70 Saffron Cod 62 Smelt 12 Herring 10 Sand lance 6	
	2	Shrimp 13	Shrimp 3	Shrimp 23	Shrimp 29	
	3			Euphausiids 1		
	4			Hyperiid Amphipods 1		
	5					

* Accurate specific identification of fishes was not possible due to otoliths degraded by formalin. Several fishes

Table 6. Spotted Seal stomach contents data from Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Cape Woolley	Teller	Teller	Nome	
Dates:		14 Aug.-20 Sept. 1971 & 1972	12 Sept.-15 Oct. 1970 & 1972	8-21 November 1972	21 November 1976	
Sample Size:		2	5	2	1	
Mean Volume (ml)		50.1	1480.0	965.0	867.0	
Food Items	1	Fish 97 Saffron Cod 97 Sand lance 2	Fish 100 Herring 70 Smelt 20 Capelin 10	Fish 100 Smelt 76 Saffron cod 24	Fish 100 Sand lance 99 Saffron cod 1	
	2	Gammarid amphipods 2				
	3					
	4					
	5					

Table 7. Food items in stomachs and intestines of ribbon seals collected in the Bering Sea during March-June, 1976-79

	Southcentral Bering March-April 1976, 1977 N = 9			Central Bering April-May 1978, 1979 N = 12			Northern Bering May-June 1978 N = 7		
Food Item	Percent of Total # of Fishes	Percent Total Wt. of Fishes	No. of Occurrences	Percent of Total # of Fishes	Percent Total Wt. of Fishes	No. of Occurrences	Percent of Total # of Fishes	Percent Total Wt. of Fishes	No. of Occurrences
Invertebrates									
Clam	--	--	5	--	--	--	--	--	--
Snail	--	--	1	--	--	--	--	--	--
Octopus	--	--	3	--	--	--	--	--	2
Mysid	--	--	--	--	--	1	--	--	--
Shrimp	--	--	3	--	--	--	--	--	1
Tanner crab	--	--	--	--	--	--	--	--	1
Fishes									
Pollock	89.4	47.9	9	54.9	27.8	11	1.1	0.6	1
Arctic cod	--	--	--	3.7	6.8	2	86.0	95.0	7
Saffron cod	--	--	--	--	--	--	9.7	2.6	1
Eelpout	6.0	45.1	7	8.8	31.3	6	--	--	--
Capelin	2.7	2.3	5	8.5	3.3	5	--	--	--
Prickleback	0.4	0.4	3	11.2	7.6	4	--	--	--
Sculpin	0.1	0.2	1	--	--	--	3.2	1.8	2
Flatfish	0.7	1.8	2	12.9	18.5	9	--	--	--
Poacher	0.3	0.1	1	--	--	--	--	--	--
Snailfish	0.4	0.4	2	--	--	--	--	--	--

(Tables 8 and 9). At all locations fishes (mostly saffron and arctic cods and sculpins) and crustaceans made up most of the food. Shrimps (mostly Eualus gaimardii and Pandalus goniurus) were eaten at all localities. The dietary importance of other small crustaceans (amphipods, mysids, and euphausiids) varied considerably among the locations. The stomach contents of ringed seals collected in June in the ice remnant near St. Lawrence Island were similar to those of seals taken at nearby coastal villages (Table 10).

Data are available on the spring foods of ringed seals at Diomede for 7 years since 1958 (Table 11). Although shrimps, arctic cod, and gammarid amphipods were major prey in all years, the relative importance of those three kinds of prey varied from year to year. The highest volumes of stomach contents were generally found in years when arctic cod were the primary food.

Most of the ringed seal stomachs we examined from times other than spring and early summer were collected near Nome. Marked seasonality in foods was observed (Table 12). Saffron cod were the main food in November and May-June, arctic cod were the primary food in January-March, and shrimp were particularly important in the diet in March and April. Similar seasonality was seen in seals collected at Savoonga and Gambell (Table 13). Mysids and amphipods made up a greater portion of the diet in February and March than in May-June. More fishes, particularly arctic and saffron cods, were eaten in the latter period and quantities of food consumed were larger.

We combined all the data on stomach contents of ringed seals collected in the Bering Sea in April-June 1975-1979 and separated the results by age and sex categories (Table 14). Foods of male and female seals were similar. The proportion of fish in the diet increased dramatically with age from 1 percent in pups to 80 percent in seals 5 or more years old. The proportion of the food which was comprised of shrimps, hyperiid amphipods, and mysids showed a corresponding decrease with age.

Bearded seals

Stomachs of bearded seals collected in the eastern Bering Sea ice front and at coastal locations in the southeastern Bering contained mostly shrimps (Argis lar, Crangon spp.) and brachyuran crabs (Chionoecetes opilio and Hyas spp.) (Table 15). Particularly large quantities of Chionoecetes were found in three seals collected north of the Pribilof Islands in spring 1977.

In the northern Bering Sea in spring foods eaten by bearded seals at Diomede, Savoonga, and Gambell were very similar, with brachyuran crabs, sculpins, and shrimps the major foods (Table 16). Shrimp were a major component of the diet at both Nome and Wales. Brachyuran crabs at Wales and clams (Serripes groenlandicus) at Nome were other major foods. Bearded seals collected in the ice remnant near St. Lawrence Island in May-June 1978 had eaten mostly shrimp, clams (Serripes), and brachyuran crabs (Table 17).

Table 8. Ringed Seal stomach contents data from Southeastern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Mekoryuk	Hooper Bay			
Dates:		22 April-12 June 1975	March-May 1978-79			
Sample Size:		6	11			
Mean Volume (ml)		67.0	18.0			
Food Items	1	Fish 58 Saffron Cod 65 Sculpins 32	Mysid 87			
Food Items	2	Mysids 18	Fish 10 Saffron cod 87 Stickleback 6			
Food Items	3	Hyperiid Amphipods 13	Shrimp 2			
Food Items	4	Shrimp 4				
Food Items	5	Gammarid Amphipods 1				

Table 9. Ringed seal stomach contents data from northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Diomede	Savoonga	Gambell	Nome	Wales
Dates:		May-June 1975-78	May-June 1975-79	May-June 1979	May-June 1975-79	May-July 1977-78
Sample Size:		23	13	35	19	30
Mean Volume (ml)		63.5	110.4	85.5	312.4	122.5
Food Items	1	Shrimp 38	Fishes 62 Arctic cod 95 Sculpin 3	Shrimp 41	Fish 96 Saffron cod 96 Sticklebacks 3	Fish 67 Saffron cod 100
	2	Gammarid amphipods 34	Shrimp 20	Fish 35 Arctic cod 40 Saffron cod 33 Sculpins 17 Sand lance 2	Shrimp 3	Shrimp 27
	3	Fish 18 Arctic cod 81 Saffron cod 11 Sculpins 5	Mysids 13	Mysids 13		Mysids 5
	4		Euphausiids 2	Hyperiid amphipods 6		
	5		Gammarid amphipods 1	Gammarid amphipods 4		

Table 10. Ringed seal stomach contents data from Bering Sea ice remnants. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		around St. Lawrence Island				
Dates:		June 1978				
Sample Size:		5				
Mean Volume (ml)		125.9				
Food Items	1	Shrimp 78				
	2	Fish 20 Arctic cod 72 Saffron cod 17 Herring 6 Sculpins 6				
	3	Gammarid amphipods 2				
	4					
	5					

Table 11a Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Diomede	Diomede	Diomede	Diomede	Diomede
Dates:		17 May-14 June 1958	20 May-3 June 1970	23 May-11 June 1971	15 May-1 June 1974	28 May-1 June 1975
Sample Size:		14 Kenyon (1962)	12	14	15	12
Mean Volume (ml)		86.0	118.3	255.7	138.1	54.9
Food Items	1	Shrimp	Fish 99 Arctic cod 81	Fish 99 Arctic cod 100	Fish 88 Arctic cod 69 Saffron cod 23 Sculpins 8	Gammarid amphipods 58
	2	Gammarid amphipods		Shrimp 1	Gammarid amphipods 10	Shrimp 18
	3	Fish			Shrimp 2	Fish 14 Sculpin 54 Arctic cod 43
	4	Mysids				
	5					

Table 11b Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Diomede	Diomede			
Dates:		27 May-3 June 1977	21-28 May 1978			
Sample Size:		7	3			
Mean Volume (ml)		50.8	136.1			
Food Items	1	Shrimp 44	Shrimp 83			
	2	Fish 40 Arctic cod 86 Saffron cod 12	Gammarid amphipods 17			
	3	Gammarid amphipods 15				
	4					
	5					

Table 12 Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area: / Dates: / Sample Size:		Nome and Stebbins November 1976 7	Nome January-February 1976-78 8	Nome March 1977-78 26	Nome April 1978 3	Nome May-June 1975-79 17
Mean Volume (ml)		246.3	64.1	228.2	182.1	312.4
Food Items	1	Fish 96 Saffron cod 78 Boreal smelt 13 Arctic cod 4 Sand lance 3	Fish 100 Arctic cod 85 Saffron cod 15	Fish 63 Arctic cod 83 Saffron cod 12 Sculpins 3 Sticklebacks 1	Shrimp 99	Fish 96 Saffron cod 96 Sticklebacks 3
	2	Shrimp 3		Shrimp 36	Fish 1 Sculpins 50 Sticklebacks 38 Saffron cod 12	Shrimp 3
	3					
	4					
	5					

Table 13. Ringed seal stomach contents data from the northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		Savoonga	Savoonga		Gambell	Gambell
Dates:		February-March 1976	May-June 1975-79		March 1978	May-June 1977-79
Sample Size:		4	13		9 ≥2 Years Old	7 ≥2 Years Old
Mean Volume (ml)		71.8	110.4		58.0	267.3
Food Items	1	Mysids 79	Fishes 62 Arctic cod 95 Sculpin 3		Gammarid amphipods 54	Fish 55 Saffron cod 54 Sculpins 29 Arctic cod 17
	2	Hyperiid amphipods 11	Shrimp 20		Fish 32 Sculpins 81 Saffron cod 12 Sand lance 6	Shrimp 37
	3	Shrimp 8	Mysids 13		Shrimp 12	Mysids 6
	4	Gammarid amphipods 2	Euphausiids 2		Mysids 1	
	5		Gammarid amphipods 1			

Table 14. Major food items of ringed seals collected in the Bering Sea, April-June 1975-1979. Results are presented by age and sex categories. Numbers indicate percent of total volume for invertebrates and total fish, and percent of total number for species of fishes.

Food Item	Sexes Combined				Seals ≧5 yrs old	
	Pups N=46	Yrlgs N=24	2-4yrs old N=17	≧5yrs N=32	Males N=14	Females N=18
Shrimp	59	46	28	14	20	10
Hyperiid Amphipod	8	2	*	*	*	*
Gammarid Amphipod	4	4	6	4	7	2
Mysid	23	24	6	*	*	*
Euphausiid	2	-	-	-	-	-
Total Fish	1	23	60	80	70	85
Saffron Cod	33	92	99	97	97	97
Arctic Cod	43	*	*	2	2	3
Sand lance	5	2	-	*	-	*
Sculpin	5	-	*	*	1	*
Mean Volume of Contents (ml)	39.4	65.8	155.0	288.3	221.9	340.0

Table 15. Bearded seal stomach contents data from Southeastern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area: Dates: Sample Size:		100 nm north of Pribilof Islands 22 March - 23 April 1977 3		outer Kuskokwim Bay 29 March 1977 1		Mekoryuk 6-30 May 1975 12		Hooper Bay 29 April 1978 1		
Mean Volume (ml)		1011.5		342.0		137.9		3.0		
Food Items	1	Brachyuran Crabs	92	Shrimp	64	Shrimp	39	Shrimp	100	
	2	Polychaetes	4	Brachyuran Crabs	22	Fish Sculpins Pollock Saffron Cod	19 85 7 5			
	3	Snails	2	Anomuran Crabs	5	Brachyuran Crabs	18			
	4	Fish Eelpout Flatfish Pollock	2 84 10 5			Isopods	10			
	5					Gammarid Amphipods	1			

Table 16. Bearded seal stomach contents data from northern Bering Sea. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

	Area:	Diomede	Savoonga	Gambell	Nome	Wales
	Dates:	May-June 1975-79	May-June 1975-79	April-June 1975-79	May-June 1975-79	June-July 1977-78
	Sample Size:	24	42	58	21	18
	Mean Volume (ml)	555.6	429.9	452.4	436.1	307.0
Food Items	1	Brachyuran Crab 35	Brachyuran Crab 34	Brachyuran Crab 43	Clam 56	Shrimp 46
	2	Fish 29 Sculpins 87 Arctic cod 10 Eelpout 2	Fish 29 Sculpins 95 Poachers 1	Fish 16 Sculpins 94 Arctic cod 3 Pricklebacks 1 Poachers 1	Shrimp 32	Brachyuran Crab 45
	3	Shrimp 17	Shrimp 22	Shrimp 15	Brachyuran Crab 3	Fish 4 Saffron cod 79 Sculpins 17 Arctic cod 2 Flatfishes 1
	4	Sponge 4	Clam 5	Clam 11	Anemone 2	Clam 2
	5	Clam 3	Gammarid Amphipods 2	Sponge 3	Fish 2 Sculpins 63 Saffron cod 27 Flatfishes 3	

Table 17. Bearded seal stomach contents data from Bering Sea ice remnants. Numbers in parentheses indicate percent of the total stomach contents volume made up by that taxon, except for fish taxa which are percent of the total number of fishes identified which belonged to that taxon.

Area:		around St. Lawrence Island				
Dates:		May-June 1978				
Sample Size:		10				
Mean Volume (ml)		595.3				
Food Items	1	Shrimp 41				
	2	Clam 22				
	3	Brachyuran Crab 13				
	4	Snails 5				
	5	Fish 3 Sculpins 56 Arctic cod 27 Saffron cod 17				

Samples of bearded seal stomach contents have been collected during spring at Nome and Diomede for several years since 1958. The most obvious difference among those samples was a marked decrease in the amount of clams consumed, particularly at Diomede (Table 18). Prior to 1975 at Diomede clams were a major component of the diet. After 1975 only small amounts of clams were found in bearded seals taken there. At Nome clams were a large component of the diet from 1970-1977. Very few clams were found in seals collected at Nome in 1979.

We have collected very few specimens from bearded seals which were taken at times of the year other than during spring and summer. Therefore, we have combined our data from all locations in the Bering Sea and separated the results into two time periods (Table 19). In May-September, clams, shrimps, crabs, and fishes are all major foods. In October-April stomach contents consisted mostly of shrimp and crabs. Clams (mostly *Serripes*) occurred in 30 of 46 seals in the former period but only 1 of 11 from the latter period.

Data from all seals collected in spring and summer in the Bering Sea were separated by age and sex categories (Table 20). Males consumed more clams and slightly less fish than did females. The diet of bearded seal pups was composed of a larger proportion of shrimp and a smaller proportion of clams than was found in seals 3 or more years old. In addition, the fishes eaten by pups included a large proportion of saffron cod while older seals ate almost entirely sculpins.

Walrus

We obtained and examined stomach contents from 53 walruses taken in the northern Bering Sea in May-June 1979. One walrus stomach from each location sampled (Savoonga, Gambell, Wales, and Diomede) contained primarily meat, blubber, and organs from seals. All other walruses examined had eaten mostly clams (Table 21). The quantities of the various clam species consumed varied among the localities. Overall, most of the clams eaten were *Mya* sp. which were the primary prey species at all localities except Wales where *Tellina* (or *Macoma* which cannot be distinguished from *Tellina* in stomach contents) made up most of the contents. Species other than clams were of minor importance in the diet except at Gambell where polychaetes (*Abarenicola* sp.) occurred in large quantities in two walrus stomachs.

Belukha whales

The only belukha whale stomachs we examined from the Bering Sea were from three animals taken at Elim on 12 June 1977. The stomach contents of the three animals were similar and consisted of a combined total of 887 ml of partially digested fish and 381 ml of pebbles, mostly 2 cm or less in diameter. Fishes eaten by the three whales included at least 3,900 saffron cod, 55 sculpins, and 5 herring. Saffron cod eaten averaged 16.5 cm long (range 6.5-29.1 cm) and 40.0 gms in weight (range 1.6-168.4 gms). Sculpins eaten averaged 35.6 cm (range 22.9-51.0 cm) and 524.6 gms (range 119.6-1,362.2 gms).

Table 18. Percent of total stomach contents volume which consisted of clams in bearded seals collected at Nome, Diomede, and Wainwright between 1958 and 1979. Frequency of occurrence (no. of stomachs containing clams/total no. of stomachs in sample) is given in parentheses. Only stomachs from seals collected between May and August are included.

Year	Nome	Diomede
1958	-	one of two primary foods[1] (9/17)
1967	-	59% (5/6)
1970	40% (1/2)	-
1975	48% (1/1)	9% (5/6)
1976	87% (4/5)	2% (2/4)
1977	44% (5/8)	0% (0/4)
1978	-	0% (0/2)
1979	* (1/6)	2% (3/8)

[1] Kenyon 1962

* Indicates values less than 1%

Table 19. Major foods of bearded seals collected in the Bering Sea sorted by time period. Results are presented as in Table 17. Percent frequency of occurrence (no. stomachs containing item/ total no. stomachs in sample X 100) is also given. Only specimens from seals 3 or more years old are included.

	1 May - 30 September N=46		1 October - 30 April N=11	
	Percent Volume/No.	Percent Frequency of Occurrence	Percent Volume/No.	Percent Frequency of Occurrence
Clam	28	63	*	9
Snail	2	48	1	27
Shrimp	20	94	53	73
Brachyuran crab	23	80	37	91
Total Fish	16	78	5	82
Saffron cod	3	4	4	36
Arctic cod	9	17	5	27
Sculpins	82	46	76	54
Flatfish	-	-	3	46
Mean Volume of Contents (ml)	662	-	743	-

* Indicates values less than 1%

Table 20. Major food items of bearded seals collected in the Bering Sea in spring and summer 1975-1978. Results are presented by age and sex categories. Numbers indicate percent of total volume for invertebrates and total fish and percent of total number for species of fishes.

	Sexes Combined			Seals ≧3yrs old	
	Pups N=52	1&2yrs old N=31	≧3yrs old N=50	Males N=25	Females N=17
Clam	2	3	25	36	18
Snail	*	*	2	*	6
Shrimp	45	26	27	20	20
Brachyuran crab	28	38	27	23	22
Total Fish	13	26	10	14	19
Saffron cod	41	5	4	-	4
Arctic cod	5	2	6	7	13
Sculpins	47	89	77	82	80
Mean volume (ml)	213	578	670	668	712

* Indicates values less than 1%

Table 21. Food items identified from stomachs of walruses taken in the northern Bering Sea in May and June 1979.

Food Item	Savoonga N=14		Gambell N=14		Wales N=1		Diomede N=20	
	% of Total Weight	Number of Occurrences	% of Total Weight	Number of Occurrences	% of Total Weight	Number of Occurrences	% of Total Weight	Number of Occurrences
Clam Total	79.9	13	56.0	13	96.4	1	92.9	20
Hiatella sp.	-	-	2.2	1	-	-	3.9	1
Mya sp.	54.0	12	34.7	11	-	-	78.2	20
Serripes sp.	16.3	8	7.1	10	-	-	*	2
Spisula sp.	2.0	7	8.1	10	3.3	1	4.9	17
Tellina/*Yoldia* sp.	3.0	3	1.5	4	92.6	1	5.0	2
Other	4.6	3	2.3	6	*	1	-	-
Snail	1.2	13	4.1	11	*	1	*	4
Sea Cucumber	1.3	6	*	5	-	-	2.1	13
Priapulid	1.4	7	*	5	-	-	*	3
Echiuroid	4.3	2	2.5	3	-	-	*	2
Polychaete	*	4	17.6	2	-	-	*	2
Crustaceans	*	4	1.2	10	-	-	-	-
Rocks/Pebbles	10.8	9	16.6	12	3.6	1	2.8	19
Mean Weight of Contents (kg)	1.52		2.17		1.17		3.09	

* Indicates values less than 1%

VII. Discussion

A. Foods of Marine Mammals

Our investigations of the foods utilized by marine mammals in the Bering Sea were based on stomachs collected during 1975-1979. In 1977 we were able to obtain stomachs from three belukha whales. In 1979 we systematically collected stomach contents of walrus taken in the northern Bering Sea.

All belukha and walrus stomachs and most of the seal stomachs we examined were obtained from animals killed by Eskimo subsistence hunters. Therefore, the majority of our samples came from the spring and early summer from locations in the northern Bering Sea. In order to extend our geographical coverage, we made collections of seals (primarily ribbon and spotted) from ice-strengthened NOAA vessels in the Bering Sea ice front and ice remnants during spring. Also, in order to obtain information on seasonal aspects of feeding, we collected ringed seals in Norton Sound from NOAA helicopters in March and April. Although our efforts have greatly increased our understanding of foods of Bering Sea marine mammals, substantial data gaps still exist. These data gaps relate primarily to summer and autumn foods of seals and belukhas in the coastal zone and winter foods of seals and walruses in the Bering Sea ice. Needs for further study are discussed in more detail in section IX.

For purposes of discussion we have divided the Bering Sea into four major areas (Figure 2).

Spotted seal

The entire Bering Sea population of 200,000-250,000 spotted seals is associated with the ice front zone during the months of February, March, and April. During May and June adults and pups are found concentrated in remnants of seasonal ice while subadults appear to have moved to coastal waters. During summer and autumn spotted seals haul out in coastal areas from northern Bristol Bay to the western Beaufort Sea.

The results of recent Soviet studies and of our OCSEAP research on foods of spotted seals in the Bering Sea have been summarized by Bukhtiyarov et al. (in press). Thirty-one spotted seals with food remains in stomachs or intestines collected in the American sector of the Bering Sea were examined. All of those animals were collected in the ice front and ice remnants during spring months. Fishes were the major food in all areas. In the southeastern Bering Sea capelin were by far the major food, followed by herring and pollock. In the southcentral and central Bering Sea pollock were the major food and eelpout were also commonly eaten. In the northern Bering Sea, arctic cod, saffron cod, and capelin were all major foods. Pollock, herring, sand lance, and sculpins were minor food items in this area. Spotted seals collected in Soviet waters in the western Bering Sea in spring were found to have eaten similar species of fishes (Gol'tsev 1971; Bukhtiyarov et al., in press). In Soviet waters, crustaceans (amphipods, shrimps, and

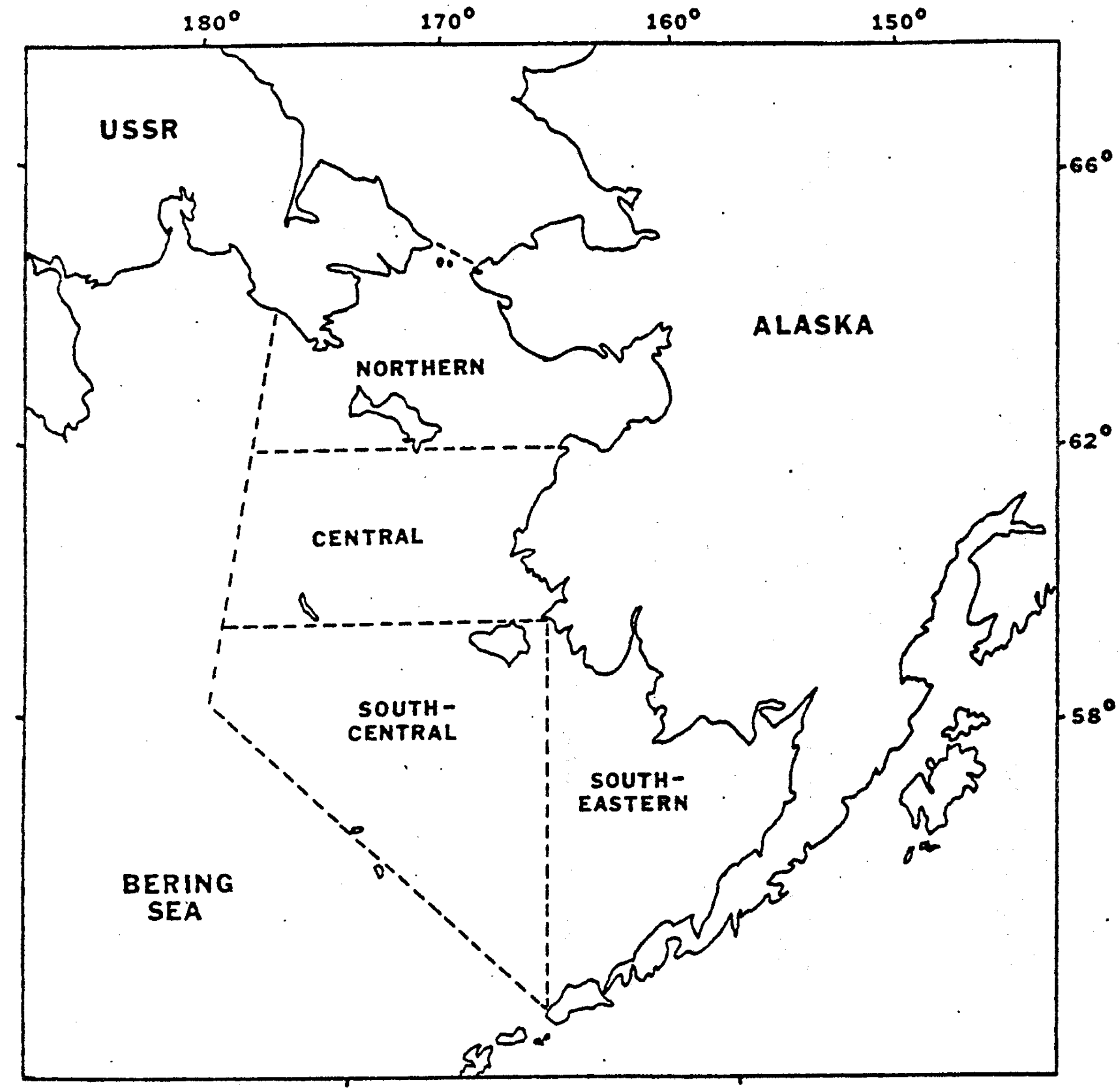

FIGURE **2.** MAP OF THE BERING SEA SHOWING REGIONS DISCUSSED IN THE TEXT.

euphausiids) and octopus were eaten more commonly than in the eastern Bering Sea. Crustaceans appeared to be most important to young seals while octopus were most frequently eaten by adults (Bukhtiyarov et al., in press).

Other than during spring, there are few data available on foods of spotted seals in the Bering Sea. Saffron cod, sand lance, herring, smelt, and capelin were the primary prey of 10 spotted seals collected along the southern Seward Peninsula in late summer and autumn. These species of fishes are probably the main foods of spotted seals in the eastern Bering throughout summer and autumn. Based on observations of ringed seal foods, it is likely that during winter months arctic cod is also a major food of spotted seals. In the Chukchi Sea in June-October herring are a major food of spotted seals (Lowry et al. 1980c). Saffron cod, sculpins, shrimps, and isopods were also found in stomachs of spotted seals collected in the Chukchi Sea.

Ribbon seal

The Bering Sea population of ribbon seals, numbering about 100,000 animals, is found in the Bering Sea ice front and ice remnants during spring. During these months the animals pup, breed, molt, and spend little time feeding. Although there is little direct evidence, ribbon seals are thought to spend the remainder of the year feeding pelagically in the vicinity of the Bering Sea shelf break (Burns, in press).

All major studies of foods of ribbon seals have been based on animals collected during the spring period of reduced feeding. Shustov (1965) examined the stomachs of 1,207 seals taken in the ice front of the Bering Sea (between St. Matthew and St. Lawrence Islands and the Gulf of Anadyr) in the months of March to July. Only 32 stomachs contained recognizable food, most of which was shrimps, amphipods, mysids, and cephalopods. Several species of fishes, particularly arctic cod, saffron cod, and herring, were eaten, but not frequently.

Results of recent OCSEAP studies on foods of ribbon seals in the Bering Sea are summarized in this report and Frost and Lowry (1980). Animals were collected in the months of March to June. Food remains were found in the stomachs of seven of 61 animals examined. By collecting otoliths from small intestines, data on the species of fish consumed were obtained for a total of 28 animals. Trace amounts of invertebrates (octopus beaks, fragments of shrimps, and small clams) were found in 11 of the 28 specimens examined. In the southcentral Bering, pollock were the most numerous prey, and capelin and eelpout were also eaten in substantial numbers. In the central Bering, pollock were again the numerically dominant prey followed by eelpout, Greenland halibut (Reinhardtius hippoglossoides), pricklebacks, and capelin. North and east of St. Lawrence Island arctic cod were the major food with saffron cod, sculpins, octopus, and pollock occasionally eaten. Based on the size of otoliths recovered and the relationship between fish weight and otolith length, eelpout eaten were about nine times as heavy as pollock. Therefore, eelpout may be a more important food in the southcentral and central Bering Sea than is indicated by the number consumed.

Burns (in press) reported the stomach contents of two ribbon seals collected in the Bering Sea in February. One of the seals had eaten exclusively pollock, the other had eaten arctic cod. Each of these specimens contained over a liter of food in the stomach. Unfortunately, these are the only data available on the foods of ribbon seals during the period of active feeding.

Ringed seal

Ringed seals are the most widely distributed and abundant of northern hemisphere pinnipeds. They occur seasonally in the Bering Sea, appearing with the formation of sea ice in November and leaving during ice disintegration in May and June. They are found primarily in coastal areas where shorefast ice provides a stable substrate for care and weaning of pups. Ringed seals of the Bering, Chukchi, and Beaufort Seas appear to constitute a single population estimated to number 1 to 1.5 million individuals.

Although there have been numerous studies of foods of ringed seals in various parts of their range, until recently there was only one published report on foods of ringed seals in the Bering Sea. That study (Kenyon 1962) reported the stomach contents of 14 seals collected at Diomede in spring 1958. Recent OCSEAP studies have considerably expanded our understanding of foods of ringed seals in the Bering Sea. Most of the specimens have been collected at the northern Bering Sea villages of Nome, Gambell, Savoonga, Diomede, and Wales. At all locations, over 80 percent of the stomach contents in our samples of ringed seals was made up of three or four of the following prey: arctic cod, saffron cod, sculpins, shrimps, mysids, and gammarid amphipods. The major prey utilized vary both seasonally and geographically. Saffron cod are most important in the diet during autumn and spring months along the mainland coast. Arctic cod are the primary species eaten during winter months in northern Bering Sea. Shrimps are eaten in small amounts at all areas and in all seasons but are of greatest importance during spring and summer in northern Bering Sea and Norton Sound. Mysids are eaten in largest quantities in the southeastern Bering and near St. Lawrence Island. Gammarid amphipods and sculpins are eaten most commonly near St. Lawrence and Little Diomede Islands.

Sufficiently large samples have been collected to allow testing for age- and sex-related dietary differences. Foods of male and female ringed seals collected in the Bering Sea were similar. However, major differences were found in the relative importance of the various prey types to different age classes of seals collected during spring. Crustaceans (primarily shrimps, mysids, and amphipods) made up 98 percent of the food of recently weaned pups, 77 percent of the food of yearlings, 40 percent of the food of 2- to 4-year-old seals, and 20 percent of the food of seals 5 or more years old. The importance of fish in the diet showed a corresponding increase with age.

Year-to-year variations in the primary prey at a single locality and season have also been documented at Diomede. Shrimps and arctic cod were each the primary food in 3 years, and gammarid amphipods were the primary food in 1 year. These differences showed no systematic pattern and are therefore probably related to annual differences in relative abundance of the various prey species. Foods of ringed seals in the Bering Sea are generally similar to those reported in the Chukchi Sea (Lowry et al. 1980c). Arctic cod and small crustaceans appear to be of greater importance in the diet in the Chukchi while saffron cod and shrimps are eaten in larger quantities in the Bering. In comparison with the Beaufort Sea (Lowry et al. 1979d), foods of ringed seals in the Bering Sea are more variable and include a wider array of prey species. Aspects of variability in the diet of ringed seals throughout Alaskan waters are dealt with in detail in Lowry et al. (1980a).

Bearded seal

Bearded seals are circumpolar in distribution and common throughout areas of moving ice in the Bering Sea. Like ringed seals they occur only seasonally in the Bering Sea, being generally absent during ice-free months. Bearded seals in the Bering and Chukchi Seas are considered a single population numbering about 300,000 animals.

Results of Soviet investigations on foods of bearded seals in the Bering Sea have been reported by Kosygin (1966, 1971). Kenyon (1962) reported on the stomach contents of 17 bearded seals taken at Diomede in spring 1958. Burns (1967) reported the results of his examinations of 23 bearded seal stomachs collected in the northern Bering and Chukchi Seas. Results of recent OCSEAP studies based primarily on specimens collected at coastal villages have been summarized in Burns and Frost 1979 and Lowry et al. 1980b. Most specimens reported on in both Soviet and American studies were collected during spring.

Throughout the Bering Sea, crabs (Chionoecetes opilio and Hyas spp.), shrimps (Argis spp., Crangon spp., Eualus spp., and Pandalus spp.), and clams (mostly Serripes groenlandicus) make up the bulk of the bearded seal diet, while fishes are generally of little importance. The fishes most commonly eaten are sculpins and saffron cod. Kosygin (1971) reported snails, octopus, and flatfishes as important foods and did not find Serripes in his samples.

Geographical variations in the relative importance of the major prey species are evident (Lowry et al. 1980b). Shrimps comprise a relatively constant proportion of the food, ranging from 16 to 33 percent. The species of shrimps eaten change in relation to patterns of shrimp distribution. Similarly, Chionoecetes is the major species of crab eaten in offshore waters of the southeastern and southcentral Bering while Hyas is more commonly eaten nearshore and in the northern Bering. The proportion of clams in the diet is highly variable, ranging from 4 to 69 percent depending on locality. Consumption of clams and crabs appears to be inversely related. In areas where large amounts of clams are consumed, crabs are not eaten in quantity. Sculpins were found in particularly large quantities in bearded seals taken at Diomede. Similar foods have been reported from bearded seals collected in the Chukchi and Beaufort Seas (Lowry et al. 1979d, 1980c).

Differences in foods of male and female bearded seals are slight and probably not significant. Age-related changes in foods are marked.

The importance of clams in the diet increases with age while the relative amount of shrimps consumed decreases. In recently weaned pups saffron cod are eaten almost as frequently as sculpins, while over 75 percent of the fishes eaten by older seals are sculpins.

Seasonal changes in major food items are also marked. Clams are eaten in significant amounts only during spring and summer months. The relative proportion of shrimps and crabs in the diet is greatest during fall and winter.

Data on foods of bearded seals taken during spring at Diomede during the period 1958-1979 suggest long-term changes in food availability. Clams were the primary food found in 1958 and 1967. Since 1975 clams have been a minor component of the food, accounting for less than 10 percent of the stomach contents. It has been suggested (Lowry et al. 1980b) that this is due to a reduction in clam populations caused by increased numbers of walruses foraging in the area. Similar changes may presently be occurring near Nome. However, further data are required from that area.

Walrus

The Pacific walrus population ranges seasonally throughout the waters covering the Bering-Chukchi platform. Since they are benthic feeders they do not regularly occur in deep waters off the continental shelf. During winter and spring months walruses are found throughout areas of moving ice in the Bering Sea and Bristol Bay. Much of the population moves north through Bering Strait as seasonal ice disappears. Several thousand walruses summer on coastal haulouts in Bristol Bay and the northern Bering Sea. Recent estimates indicate a population in excess of 200,000 (Krogman et al. 1978).

The only significant published accounts of foods of walruses in the Bering Sea are those of Fay et al. (1977 and in press). The following summary is taken directly from those reports.

The contents of the stomachs of 21 walruses collected in March and April 1976 in the southeastern Bering Sea were examined. The major foods were clams (mostly *Serripes groenlandicus* and some *Mya truncata*), tanner crabs, and snails (*Neptunea* sp. and *Buccinum* sp.).

Fay et al. (in press) reported on the stomach contents of 107 walruses taken near five locations in the northern Bering Sea (Gambell, Savoonga, Nome, King Island, and Diomede) during April to June 1974-1976. Five genera of clams (*Mya*, *Serripes*, *Hiatella*, *Spisula*, and *Clinocardium*) made up from 85 to 99 percent of the identifiable food at all areas. Other prey items such as crustaceans, worms, tunicates, and echinoderms were of only minor importance in the diet. *Mya* was the primary prey at all locations except south of Nome where *Serripes* made up 98 percent of the identifiable stomach contents.

Although the same array of species is eaten by both male and female walruses, in the northern Bering Sea females tend to eat smaller clams than do males. Females tended to eat the smaller species such as

Hiatella and small individuals of the large species such as Mya and Serripes. Males fed primarily on large individuals of large species, particularly Mya.

Age-related differences in diet have not been rigorously examined. Fay et al. (in press) suggest that young animals may feed on smaller items than do adults.

Our results agree very closely with those reported by Fay et al.

Belukha whales

Belukha whales are widespread in arctic and subarctic waters. Many belukhas spend the summer months in the coastal zone, frequenting shallow bays and estuaries. Their distribution is amphiboreal; Atlantic and Pacific populations apparently do not mix (Tomilin 1957). The Bering Sea stock winters in the central Bering Sea and moves in spring to the Yukon-Kuskokwim Delta, Norton Sound, Kotzebue Sound, and north through the Chukchi Sea to the Beaufort Sea. There is a resident population in Bristol Bay (Tomilin 1957; Harrison and Hall 1978) estimated at 1,000-1,500 individuals (Lensink 1961). The rest of the Bering Sea belukha population is estimated to number at least 8,000 whales.

Belukhas eat primarily pelagic and semidemersal fishes. In addition, they eat cephalopods and crustaceans, especially shrimps. Among the fishes eaten are herring, salmon, saffron cod, arctic cod, capelin, flatfishes, Pacific cod (Gadus macrocephalus), and whitefish (Coregonus spp.) (Vladykov 1946; Tomilin 1957; Kleinenberg et al. 1964; Sergeant 1973).

There is little published information on foods of belukhas in Alaska. Brooks (1954a, 1955) found five species of salmon, smelt, flatfishes, sculpins, blennies, lamprey, shrimps, and mussels in the stomachs he examined from Bristol Bay belukhas. Smelt were the main food in early May. In late May downstream migrating fingerling salmon were the most important food. From the first of July through the end of August upstream migrating adult salmon were the main prey. Saffron cod and sculpins were the major prey eaten by the three whales we examined from Norton Sound. Lowry et al. (1980c) reported on the foods of belukhas in the Chukchi Sea. Whales from Kotzebue Sound had also eaten mainly saffron cod. In addition, sculpins, herring, octopus, smelt, and eelpout were eaten at one or both locations.

It is probable that belukha distribution is partially determined by the distribution and abundance of aggregating fishs such as herring, salmon, and arctic cod. Kleinenberg et al. (1964) and Klumov (1937) have suggested that the distribution and movements of belukhas in northern waters are correlated primarily with those of arctic cod. In the Bering Sea saffron cod and herring may play a similar role in determination of belukha distribution and movements.

A detailed treatment of the foods of belukhas in Alaskan waters is currently being prepared (Seaman and Lowry, in prep.).

B. Biology of Major Prey Species

Walleye pollock

Walleye pollock are found throughout the north Pacific and in greatest abundance along the continental shelf break of the Bering Sea. They comprise over 40 percent of the total apparent biomass of fishes and invertebrates in southeastern Bering Sea (Pereyra et al. 1976). Abundance decreases rapidly north of St. Matthew Island, and they are caught only rarely north of Bering Strait (Pereyra et al. 1976). They are not common in Norton Basin. The species supports a commercial fishery of almost 1 million metric tons per year, one of the largest in the world. Pollock form a major portion of the diet of all pinnipeds of the southern Bering Sea, except bearded seals and walruses, and are eaten by at least 4 species of cetaceans, 13 species of seabirds, and 10 species of fishes in that area. The distribution, abundance, and biology of pollock in the Bering Sea have been summarized in considerable detail by Pereyra et al. (1976), Berg (1977), Bakkala and Smith (1978), and Svetovidov (1948) and for that reason we will present only a general discussion of pertinent life history events taken from those reports.

Pollock undergo seasonal migrations from deeper parts of the shelf and the upper slope in winter (160-300m) to, at least in warm water years, shallow shelf waters in summer. Large winter concentrations occur between the Pribilof and Unimak Islands and southwest of St. Matthew Island where almost 80 percent of the total pollock biomass is located. A spawning concentration forms northwest of Unimak Island in spring in the shallower waters of the outer shelf (90-140 m), and spawning begins in March, peaks in May, and ends in the middle of July (Berg 1977).

The eggs, which are pelagic, occur at depths of 13-300 m, mainly in the upper 100 m layer where they develop. Hatching takes 10-30 days depending on water temperature, with the most rapid development occurring in warmer (6-10°C) water (Pereyra et al. 1976). Newly hatched eggs float at the surface until the yolk sac is absorbed (10-22 days depending on water temperature). Larval pollock feed near the surface on diatoms, copepod eggs, and nauplii, and as they grow larger on copepods, euphausiids, and other zooplankton. They become demersal at a length of 35-50 mm, and reach 90-110 mm by the end of their first year of life. One and 2-year-old pollock (the size classes most important as food of marine mammals, birds, and fishes) appear to be widely distributed with no discernible seasonal patterns. They are generally found closer to the surface than older fish. Overall, age groups 1-3 make up over 90 percent of the estimated total number of pollock. Pollock grow rapidly during the first 4 years of life, maturing at age 3 or 4, after which time growth slows down. The oldest pollock caught in the Bering Sea in resource assessment test fishing was a 17-year-old female (Pereyra et al. 1976).

Predominant food items of pollock include semi-pelagic crustaceans such as euphausiids, copepods, and amphipods. Large pollock (over 50 cm) eat as much as 50 percent 0- to 1-year-old pollock.

Arctic cod

Arctic cod is the single most important forage fish in far northern waters (Klumov 1937; Tomilin 1957; Tuck 1960; Frost and Lowry 1981). It is one of the major prey species of marine mammals and seabirds in Norton Basin. In September-October 1976, Wolotira et al. (1979) found them to occur in 83-93 percent of the trawls in each sample area in Norton Sound and northern Bering Sea, being most common south of Golovnin Bay, south of Nome, and west of Nome at about 167°W. Arctic cod caught during that survey ranged in size from 4 to 26 cm, with an average of about 13 cm. Fish smaller than 8 cm (first year class) were found almost exclusively in deeper water northeast of St. Lawrence Island, whereas larger fish were more widely distributed. Arctic cod were virtually absent from inner Norton Sound during that survey. Winter distribution and abundance in the Bering Sea is unknown except by inference from the catches of coastal subsistence fishermen or the winter diets of marine mammals, which suggest they are locally very abundant at that time.

The distribution of adult arctic cod is closely related to low temperatures and/or the presence of sea ice, with much of the population believed to stay under or near the edge of compact ice for most of the year (Svetovidov 1948; Andriyashev 1954; Ponomarenko 1968). Andriyashev (1954) indicated that in autumn large schools may be found nearshore, especially in warm, relatively fresh water near river mouths. Recent OCSEAP research in the Beaufort Sea has also documented large concentrations of arctic cod in nearshore areas in late summer and autumn (Bendock 1979; Craig and Haldorson 1979). The precise time and location of spawning for arctic cod in Alaska is unknown. In the Beaufort Sea individuals caught nearshore during November were gravid, and by the next sampling period in February all individuals had spawned. This coincides closely with spawning periods in the Barents and Kara Seas and eastern Siberia (Moskalenko 1964; Rass 1968; Ponomarenko 1968). Spawning probably occurs in coastal areas.

Arctic cod have the largest and fewest eggs of all cods (Svetovidov 1948; Andriyashev 1954). The eggs develop in surface waters under the ice and probably hatch in May or June. Larvae live in surface waters until August or September when transition to the juvenile stage takes place and the fry descend to the bottom (Rass 1968; Baranenkova et al. 1966). Association with the ice is thought to begin after the first year. Individuals mature at 3 to 4 years and probably do not live much longer than 6 years (Gjosaeter 1973).

Arctic cod eat a variety of euphausiids, copepods, benthic amphipods, shrimps, mysids, hyperiid amphipods, and small fish (Klumov 1937; Craig and Haldorson 1979; Lowry and Frost in prep.).

Saffron cod

Saffron cod occur in the eastern Bering and Chukchi Seas and throughout the western Arctic Ocean (Andriyashev 1954). They are also present, but less abundant, in the Beaufort Sea. They are important prey of seals, belukhas, and seabirds, and are a major subsistence food item to local residents (Tomilin 1957; Lowry et al. 1978a, 1979b; Barton 1979; Frost and Lowry 1981).

Saffron cod are very abundant in Norton Basin. Barton (1979) found them to be the most frequently encountered species in gillnet catches and the second most frequent in beach seines in Norton Sound during summer. Wolotira et al. (1979) found saffron cod to be the most abundant fish species encountered, with large concentrations in outer Norton Sound and the eastern portion of the northern Bering Sea. Fish ranged from 5-35 cm and averaged 11.5 cm. Most large fish occurred in outer Norton Sound. Age groups 0-2 predominated by number, comprising over 96 percent of the total fish, with age group 0 alone comprising 67 percent. Most 0-2 age fish were found in outer Norton Sound and northeastern Bering Sea.

In southern Bering Sea saffron cod occur only on the inner shelf region, generally in the area between St. Matthew, Nunivak, and the Pribilof Islands. Pereyra et al. (1976) found catch per unit effort (CPUE) to be only 25 percent of what Wolotira et al. (1979) reported for the northern Bering Sea.

Saffron cod are thought to reside in the coastal zone, coming close to shore in the fall to spawn in river mouths, bays, and inlets, and moving into deeper water (30-50 m) in summer to feed (Svetovidov 1948, Andriyashev 1954). Spawning probably takes place between December and February (February in Norton Sound) at subzero temperatures (-1.0 to -1.8°C). The eggs are demersal and are spawned on clean, sandy or pebbly bottoms (Andriyashev 1954). Most larvae hatch in April. Normal embryonic development occurs at temperatures of -3.8° to 8°C and salinities of 28-30 ppt. Development is suspended below -3.8°C; however, eggs will resume growth even after freezing in ice once temperatures are greater than -3.8°. Larvae perish en masse in water warmer than 8°C (Mukhacheva 1959). Larvae stay near the surface after hatching and are often associated with the jellyfish Cyanea sp. (they live inside the protection of the mantle and tentacles). Growth is probably very slow until August when larvae are fully transformed into fry and descend to the bottom to assume a demersal life similar to the adults. Maximal growth occurs in the first 3 years of life, and almost all of each year's growth occurs in September-October. Sexual maturity occurs at 2-3 years and individuals probably live at least 12 years (Svetovidov 1948). Saffron cod eat a variety of benthic organisms including polychaetes, shrimps, crabs, mysids, and amphipods.

Herring

Herring are locally and seasonally abundant throughout the Bering Sea. They are important prey of a large number of marine birds, mammals, and other fishes, and support substantial commercial and subsistence fisheries in Alaska. They were fished in Norton Sound as early as 1909, on their wintering range northwest of the Pribilofs since the 1960's by the Japanese and Soviets, and in Bristol Bay near Togiak also since the 1960's (Macy et al. 1978). They are most abundant south of the Yukon delta, especially in the Togiak district of Bristol Bay. North of the Yukon River they are most abundant in southern and eastern Norton Sound.

The biology of herring has been well summarized by Macy et al. (1978) as well as Barton (1979), Andriyashev (1954), and Rumyantsev and Darda (1970). The following will be an abbreviated discussion of those reports. Herring exhibit strong schooling behavior and are highly migratory. They winter in deep water (>100 m) over the continental shelf, mainly northwest of the Pribilofs, and along the southern edge of the ice pack, with some found near Unimak Island. During winter they are found 5-10 m off the bottom, moving to mid- or surface waters at night to feed. In March and April they begin to move towards the coast and by April or early May are found southwest of Nunivak Island in water 10-70 m deep. Spawning occurs shortly after the ice breaks up--during May in Bristol Bay and progressively later farther north (early June in Norton Sound). During July and August they live in the warmed surface waters of the coastal zone from Unimak to Nunivak, and extending in a narrow strip to Norton Sound, usually within 20 miles from the shore in less than 30 m of water and temperatures of 4-6°C. In August-September they begin to leave the coast, and by October the first large offshore concentrations are again found northwest of the Pribilofs.

Most spawning occurs nearshore in shallow water (from <1 m to 12-15 m) usually on vegetation such as kelp or surf grass in sheltered bays, along steep, rocky shores, or on open, sandy beaches. South of the Yukon most spawning is intertidal, whereas in Norton Sound where tidal amplitude is low, spawning is subtidal.

The eggs are adhesive and are deposited on solid surfaces where they are fertilized by the males. Egg development requires 12-50 days (usually around 20-25) depending on water temperature and salinity, with normal development occurring at 0.5-9.2°C and 6.7-25.8 o/oo. The planktonic larvae hatch at 4-8 m, grow to 35-40 mm after 40-70 days, at which time they metamorphose to actively swimming, schooling juveniles. By 1 year the juveniles attain lengths of 90-100 mm. One- and 2-year-olds are found in schools off shore. They mature at 3-4 years, at which time they show up at nearshore spawning areas.

Mortality is extremely high in herring. Mortality may be as high as 80 percent in eggs, greater than 99 percent in larvae, and 30-40 percent by age 4. As few as 0.1 percent of the eggs produced may survive to spawn.

Herring are mostly zooplankton feeders. The larvae eat microscopic eggs, diatoms, and nauplii of small copepods. Fry 20-100 mm prey on copepods, barnacle and mollusk larvae, and a variety of other small plankton. The adults eat almost entirely crustaceans, including euphausiids, copepods, gammarid and hyperiid amphipods, and mysids, and some fish fry (pollock, smelt, capelin, and sand lance). Feeding is most intensive after spawning and during summer, and least so during spawning. Herring probably compete for food with capelin, sand lance, pink salmon, and pollock.

Capelin

Capelin are widely distributed over much of the arctic. They are present along the entire Alaskan coast but are most abundant in the southern Bering Sea, where they are found in large schools near the bottom (benthopelagic). In spring and summer they move toward the shore to spawn. Barton et al. (1977) found them to be the most geographically widespread forage fish in southeastern Bering Sea and second in abundance of fishes captured inshore. He found capelin to be present but not abundant in Norton Sound during the late 1970's. Abundance may vary considerably from year to year, as early explorers to Alaska remarked about their extreme abundance in Norton Sound.

Spawning takes place in May and June in Bristol Bay, and somewhat later farther north. Primary spawning habitat in Alaska includes relatively smooth sand and gravel beaches in 1-4 m of relatively high salinity water (Andriyashev 1954, Barton et al. 1977). The eggs are adhesive. Known spawning grounds in Bristol Bay include the area from just north of Cape Newenham south and around to Togiak Bay (Macy et al. 1978). The actual spawning occurs mostly at night just after high tide. Once released and fertilized, the eggs become buried in the sand by waves where they remain until they hatch (about 15 days at 10°C) and are washed out of the sand and carried out to sea where they spend most of their early life in deep water (Musienko 1970; Macy et al. 1978). Research cruises in the Bering Sea have located relatively large concentrations of larvae west of Cape Newenham, south and east of the Pribilofs, and northwest of Unimak Island. Most growth occurs in the first 2 years of life. Capelin become reproductively mature at the end of the second or third year at a size of about 11.0-14.6 cm. Post-spawning mortality is about 90 percent and especially heavy if the surf is high.

Capelin feed mainly on small crustaceans such as euphausiids, copepods, hyperiid amphipods, decapod larvae, and other microzooplankton (Andriyashev 1954). Atlantic capelin, and presumably Pacific capelin, have a highly seasonal feeding cycle. Feeding is intensive prior to spawning, does not occur during spawning, and takes place at a low level over winter. Capelin are important prey of fishes such as salmon, cod, pollock, and flatfishes, of seabirds, especially alcids, and of many marine mammals.

Rainbow smelt

Rainbow smelt are found from Bristol Bay all along the Alaska coast to Point Barrow. During the nonspawning period they are found in brackish estuaries and bays, and during spawning they enter rivers. Barton (1979) found them to be the most abundant of the smelts in Norton Sound, with greatest concentrations in the southern and eastern regions. Wolotira et al. (1979) found them to be widely distributed in northern Bering Sea, occurring in greater than 70 percent of all trawls and comprising about 5 percent of the total fish biomass. They were found nearshore and offshore from breakup to freezeup. Larvae were also widespread. Greatest concentrations were present in a swath from Cape Rodney and south across the entrance to Norton Sound in 20-30 m of water. The greatest number of large fish (>20 cm) was also present in this area. The body length and relative abundance of rainbow smelt decreases from north to south (Macy et al. 1978).

Spawning usually occurs between April and June, although in some areas (Okhotsk Sea) a second spawning run in the fall has been reported (Macy et al. 1978). Large schools enter rivers or low salinity bays just before or soon after the ice breaks up. Spawning occurs at night, when adhesive eggs are deposited on rocks or vegetation. Hatching is dependent on water temperature and requires 8-27 days, after which the larvae drift downriver and grow to 20-40 mm within several months. Smelt in Bristol Bay grow to an average length of about 13-18 cm. In other areas they may grow as long as 36 cm (Macy et al. 1978). Individuals mature at the age of 2 or 3 years and may live as long as 8-12 years.

Food of young capelin includes copepods, amphipods, ostracods, and aquatic insects while in fresh water, and mysids, cumaceans, and amphipods in the marine environment. Adult smelt also eat zooplankton, but in addition prey upon squid and small fishes (Macy et al. 1978). They appear to feed throughout the year, including during migration and spawning.

Sand lance

The Pacific sand lance is found from southern California north to Alaska along the entire Alaskan coast and across Canada to Hudson Bay. Specific details of their distribution in the Bering Sea are poorly known. They have been reported from Bristol Bay and the north side of the Alaska Peninsula (Macy et al. 1978). Barton (1979) found them to be the overall most numerous species in nearshore waters of Norton Sound and northern Bering Sea with greatest abundance near Port Clarence and Grantly Harbor and also near Golovnin Bay and Bluff. They were infrequent and much less abundant in southern and eastern Norton Sound. Mean fish size was 80-84 mm during spring and 60-64 mm in fall. In some parts of their range sand lance live close to the coast in summer and move offshore in winter. Barton caught none in early June or October, indicating this might be the case in northern Bering Sea.

Sand lance are present in a variety of habitats including offshore waters, tidal channels, and along beaches, but they are usually found in shallow water close to land. They form schools near the bottom and frequently burrow in coarse beach sand and fine gravel (Andriyashev 1954). They appear to be euryhaline and eurythermal (Macy et al. 1978). Little is know about life history events in Alaskan populations. Barton found small larvae in Norton Sound in June-July and proposed that spawning occurs in May-early June.

Eggs are adhesive and are deposited on sandy substrate. Development may take 13-33 days, depending on water temperature. The nonfeeding pre-larvae are demersal, remaining buried in sand until they attain a length of 4-5 mm, at which time they become planktonic. Metamorphosis to the juvenile stage occurs at 30-40 mm. Age at sexual maturity is not known for Alaskan sand lance but could be as early as 1 year or as late as 3 years of age. Maximum length attained is about 26 cm, although most are considerably smaller (Macy et al. 1978).

Sand lance larvae feed on small phytoplankton changing to copepod eggs and nauplii as they grow. Adults eat copepods, chaetagnaths, and a variety of other small creatures. Sand lance are important food of sockeye and silver salmon in Bristol Bay, and also of cod and halibut. In addition, they are eaten by a variety of marine birds and mammals.

Sculpins

Many species of sculpins are present in the Bering Sea. There is very little specific information on distribution and abundance as they are not fished commercially and have not been included in fishery resource surveys. Wolotira et al. (1979) listed six species of sculpins among the 20 most abundant fish taxa in Norton Sound, although in total sculpins made up less than 7 percent of the catch of fishes. In northern Bering Sea, north of St. Lawrence Island, five species of sculpins, comprising about 27 percent of the catch, were among the 20 most abundant. A single species, *Myoxocephalus scorpius* made up 20.5 percent of the catch in northern Bering Sea. Among the most abundant species were *Myoxocephalus scorpius*, *M. jaok*, *M. quadricornis*, *Gymnocanthus tricuspis*, and *Enophrys diceraus*. Sculpins in general were least abundant in inner Norton Sound and most abundant throughout northern Bering Sea.

In southeastern Bering Sea sculpins as a group usually made up less than 1 percent of the total catch. In the area south and west of Nunivak Island they comprised almost 6 percent of the total catch (Pereyra et al. 1976).

Sculpins are demersal. Most species spawn in fall or winter (Andriyashev 1954). In general they feed on benthic or epibenthic organisms such as shrimps, amphipods, polychaete worms, isopods, mysids, and mollusks.

Eelpout

Eelpout, like sculpins, are considered "trash fish" in fishery resource surveys and as a result little information is available on distribution and abundance of this group in Bering Sea. In northern Bering Sea the genus *Lycodes* made up 2 percent of the catch, and in Norton Sound about 1 percent. Distribution was patchy with several areas of relatively high abundance north of St. Lawrence Island, off Nome, and in central Norton Sound (Wolotira et al. 1979). In southeastern Bering Sea eelpouts were virtually absent from Bristol Bay and inside about the 50 m contour north to Nunivak. They were most abundant along but inside the shelf break from Unimak Island to northwest of St. Matthew Island, especially northwest of Unimak and west of St. Matthew, where they sometimes made up 4-7 percent of the catch (Pereyra et al. 1976). Some of the commonly encountered species are *Lycodes palearis*, *L. brevipes*, *L. raridens*, *L. mucosus*, and *L. polaris*.

Eelpouts are bottom fishes, preferring muddy bottoms and often burrowing into the bottom tail first. They usually prefer water below or near 0°C with salinity greater than 30 o/oo. Spawning is thought to occur in late fall or winter. Eggs are demersal, as apparently are the larvae (Andriyashev 1954). Little else is known about their life history.

Eelpouts feed on a variety of benthic organisms including polychaetes, bivalve mollusks, crustaceans (especially amphipods), and echinoderms.

Crabs

Brachyuran crabs are widely distributed in the Bering Sea. Two species are important to bearded seals--Chionoecetes opilio and Hyas coarctatus.

In southeastern Bering Sea C. opilio is the most widely distributed and one of the two most abundant invertebrates (20-30% of the total invertebrate biomass). It occurs in a wide band approximately parallel to the edge of the shelf break and is found north into the Chukchi Sea (Pereyra et al. 1976; Feder and Jewett 1978; Wolotira et al. 1979). Wolotira et al. (1979) caught few in Norton Sound and no mature females. Greatest abundance was in a strip from St. Lawrence Island to Bering Strait.

Although published information regarding the life history of C. opilio in the Bering Sea is sparse, there are several accounts for other geographical areas. The reader should refer to Pereyra et al. (1976) or Adams (1979) for detailed accounts.

Female C. opilio mature at 50-60 mm and males at 65-75 mm. Spawning probably occurs in March-April with the eggs being carried about a year. The eggs hatch into zoeae, the first larval form, and rise to surface waters. Eventually (within about 2 months) they metamorphose to the megalop stage, which lasts 1-10 months, and settle to the bottom at the end of that period, at which time they metamorphose to a first instar which resembles the adult (Adams 1979). Molting continues at a frequency inversely proportional to age until maturity is reached (7 to 10 or 12 instar molts) at 6-8 years of age. Individuals may live as long as 12-16 years. C. opilio larvae eat phytoplankton and small zooplankton. Once they metamorphose and settle to the bottom they utilize detritus and benthic organisms. Adults are omnivorous, eating a variety of detritus, polychaetes, brittle stars, bivalve mollusks, fish, and amphipods (Feder and Jewett 1978).

Spider crabs, Hyas coarctatus, are much less abundant than Tanner crabs in Bering Sea and, because they are a small, noncommercial species, data on their distribution and abundance are scarce to nonexistent. Feder and Jewett (1978) found them to make up less than 1 percent of the invertebrate biomass in northern Bering Sea/Norton Sound. They were absent from inner Norton Sound and were most abundant from St. Lawrence Island north and east to outer Norton Sound. Biomass was less than $0.02 g/m^2$ at all but a few stations where it reached $0.16\ g/m^2$.

There is little information on the life history of spider crabs. Ovigerous females are commonly caught throughout Bering Sea.

Spider crabs, like tanner crabs, are omnivorous, eating a variety of detritus, phytobenthos, crustaceans such as amphipods, euphausiids, and shrimps, mollusks, ophiuroids, polychaetes, and in some cases fishes (Feder and Paul 1979; Squires 1967).

Clams

Two genera of clams, Serripes and Spisula, are especially important as food for bearded seals and walruses in the Bering Sea. Little is known about the distribution or abundance of either species there.

Serripes is hermaphroditic and probably spawns in spring after the phytoplankton bloom has begun (Petersen 1978). Settling of larvae probably occurs in late summer-autumn. In Greenland waters some examples of size at age are as follows: 1 year, 3-10 mm; 11 years, 53.4 mm; 14 years, 58.3 mm. They probably grow as large as 10 cm (Clench and Smith 1944).

Little is known about the life history of Spisula. They seem to prefer medium grade sediments of sand and gravel mixture. In southeastern Bering Sea they are found primarily in coastal waters 24-33 m deep. Spisula is probably patchy in distribution, with given patches consisting of clams of a single year class (due to favorable larval settlement and survival in specific areas in a particular year). They are active burrowers, sometimes living as deep as 22 cm. Individuals reach about 13.5 cm, or 16 years of age, with growth until age 8 occurring at a rate of 10-12 mm/year (North Pacific Fishery Management Council, in preparation). There is no information on the reproduction of Spisula in Alaska. Spisula in the North Atlantic are dioecious (sexes separate), unlike Serripes, and spawning probably occurs in summer. Larvae are planktonic for some unknown period of time, then settle to the bottom as miniature adults.

Spisula and Serripes are both filter feeders, removing small particles from seawater.

Shrimps

Three families of shrimps are present and important as marine mammal prey in the Bering Sea: F. Hippolytidae, F. Crangonidae, and F. Pandalidae. The pandalids are of commercial importance in the southern Bering Sea, but no species are commercially harvested in northern Bering Sea. Published information on the noncommercial species is scarce.

Eualus gaimardii is the most widespread and abundant of the hippolytids. In the Canadian arctic individuals probably spawn biennially (Squires 1969). Spawning frequency in the Bering Sea is unknown. Many ovigerous females were found in spring-summer when most of our trawls were made (Frost and Lowry, unpubl.). Eualus eat ostracods, euphausiids, copepods, and phytobenthos.

Pandalus gonuirus and P. borealis are both caught in Bering Sea with the former most abundant in water less than 100 m and the latter in water deeper than 100 m (Frost and Lowry, unpubl.). Pandalus borealis is not common in northern Bering Sea where P. goniurus is the predominant species. Pandalus hypsinotus is also seasonally and locally common in Norton Sound.

Pandalid shrimps are protandrous hermaphrodites, that is they reproduce first as males (probably during the first year), then become females and produce eggs when large (1-1/2 to 2-1/2 years) (Butler 1964). Breeding takes place in the fall and the eggs are carried until they hatch in spring. Ovigerous P. goniurus were common in early spring trawls but scarce or not present in June-August trawls. Larvae are planktonic during summer and settle to the bottom in late summer or early fall (Charnov 1979). Adult shrimps eat small crustaceans, polychaete worms, and detritus.

Crangonid shrimps which are prey of seals in Bering Sea include three genera: Crangon, Argis, and Sclerocrangon. Two species of Argis, A. lar and A. dentata, are present. Argis dentata is usually found in deeper water (>70 m), and A. lar in shallower areas (Frost and Lowry unpubl.). Two Crangons are also found--C. communis and C. dalli. As with Argis, one is found in deep water (C. communis) and one in shallow water (C. dalli). Sclerocrangon boreas was not numerous and was caught only in northern Bering Sea. Females of all species were ovigerous in spring. Ovigerous Crangon communis females were caught in March-April, but not May-August, whereas eggbearing C. dalli were caught through July. We caught Argis lar which had recently hatched eggs in May and June. Spawning probably occurs over a broad time span, although all probably carry eggs through the winter and hatch them in spring-summer. Crangonid shrimps eat a variety of organisms including phytobenthos and detritus, polychaete worms, small crustaceans, crustacean eggs and larvae, and to a lesser degree foraminiferans, gastropods, and ophiuroids (Squires 1967).

Gammarid amphipods

Gammarid amphipods are a diverse element of the Bering Sea fauna. They are the predominant food of many demersal fishes and regular prey of seabirds, fishes, ringed and bearded seals, and gray whales. Although primarily benthic, several species make use of the inverted substrate provided by the undersides of ice floes (Barnard 1959; George and Paul 1970; Tencati and Leung 1970). Ampelisca, Anonyx, and Gammarus are all important genera to seals and whales.

Ampelisca is probably the single most important species to marine mammals. Ampelisca macrocephala lives 1-1/2 to 2 years, with some females living to age 3 and reproducing a second time (Kanneworff 1965). Maximum growth occurs in spring and early summer and breeding takes place in the fall (October). Females carry eggs in a brood pouch until the young are released in about April when feeding conditions are good. Ampelisca is both an active predator and a detritus feeder. Prey includes copepods, other small crustaceans, and various detrital plant and animal material. Feeding (as well as growth and gonad development) is most intense during spring and summer when phyto- and zooplankton are abundant.

C. Food Webs and Trophic Relationships

Since the actual species of prey consumed by seals vary greatly, both geographically and seasonally, a single diagrammatic food web dealing with the specific prey species would be extremely difficult to construct or understand. Consequently, we will deal with major types of prey involved in seal, walrus, and belukha food webs. The various types of prey directly consumed by seals and walruses can be divided into six major categories. The prey types and major species included in each are shown in Table 22.

Figure 3 shows a generalized food web for harbor, spotted, ribbon, and ringed seals. Although very few specimens have been examined it appears that belukha whales can be appropriately included in this food web. Only major trophic connections among the various types of organisms are shown. Four prey types are significant sources of food for these species. However, most of the food of each is derived from the pelagic portions of the food web. Energy transfers in the pelagic subsystem are generally very direct. For example, a ringed seal may eat euphausiids which have been feeding on diatoms. This involves only two energy transfers between producer and top consumer. As many as four energy transfers may be involved, as in the following: dinoflagellate → small copepod → hyperiid amphipod → pollock → ribbon seal.

A generalized food web for bearded seals and walruses is shown in Figure 4. Both of these species derive most of their food from benthic organisms. Walruses feed almost exclusively on clams which feed mostly on detritus and phytoplankton. Although bearded seals also derive some of their nutrition from such short energetic pathways, their trophic resource base is more diverse. Bearded seals may feed as many as four energetic steps from producers, as in the following: phytoplankton → clam → tanner crab → sculpin → bearded seal.

From the preceding discussion of food habits and food webs it is obvious that there is considerable overlap in the types and particular species of prey consumed by seals, belukhas, and walruses. Two other species of pinnipeds, the northern fur seal (Callorhinus ursinus) and the Steller sea lion (Eumetopias jubatus), are also abundant in the Bering Sea and compete for food with phocid seals. The relative importance of the various prey types to belukhas and Bering Sea pinnipeds is shown in Table 23.

Bearded seals and walruses are the only pinnipeds in this area that feed predominantly on benthic organisms. Major features of distribution and movements of these two species are also similar. However, competition for food is minimized by the fact that much of the walrus diet is made up of burrowing infaunal clams which are generally not eaten by bearded seals. The two species do compete for Serripes and there are indications that the combined predation on this species is in excess of the sustainable yield. As mentioned previously, the amount of Serripes found in bearded seals taken at Diomede has decreased in recent years. This decrease is closely correlated with an increase in the numbers of walruses summering in Bering Strait (Lowry et al. 1980b).

Gray whales (Eschrichtius robustus) forage in the Bering Sea during summer months. They consume mostly benthic epifauna and nektobenthos (Zimushko and Lenskaya 1970) and compete for food with bearded seals and, to a lesser extent, with ringed seals. In the northern Bering Sea much of the diet of both gray whales and ringed seals consists of gammarid

Table 22. List of major species included within six types of prey directly consumed by seals, walruses, and belukha whales in the Bering Sea.

Prey Type	Major Species
Pelagic and Semidemersal Fishes	Walleye pollock - *Theragra chalcogramma* Saffron cod - *Eleginus gracilis* Arctic cod - *Boreogadus saida* Pacific cod - *Gadus macrocephalus* Capelin - *Mallotus villosus* Rainbow smelt - *Osmerus mordax* Herring - *Clupea harengus*
Demersal Fishes	Eelpout - *Lycodes* spp. Sculpins - *Myoxocephalus* spp., *Gymnocanthus* spp., *Icelus* spp. Flatfish - *Reinhardtius hippoglossoides*, *Limanda aspera*, *Lepidopsetta bilineata*, *Hippoglossoides* spp. Sand lance - *Ammodytes hexapterus*
Pelagic Nektonic Invertebrates	Euphausiids - *Thysanoessa* spp. Hyperiid amphipods - *Parathemisto* spp.
Nektobenthonic Invertebrates	Mysids - *Neomysis rayi*, *Mysis* spp. Shrimps - *Pandalus* spp., *Eualus* spp., *Crangon* spp., *Argis* spp. Gammarid amphipods - *Ampelisca* spp., *Anonyx nugax*, *Gammarus* spp. Octopus - *Octopus* spp.
Epifaunal Invertebrates	Crabs - *Chionoecetes opilio*, *Hyas* spp. Snails - *Buccinum* spp., *Natica* spp., *Polinices* spp., *Neptunea* spp.
Infaunal Invertebrates	Clams - *Serripes groenlandicus*, *Mya truncata*, *Spisula polynyma*, *Hiatella arctica*, *Clinocardium ciliatum* Polychaete worms - *Nephthys* sp., *Lumbrinereis* sp. Echiuroid worms - *Echiurus echiurus* Priapulids - *Priapulus caudatus*

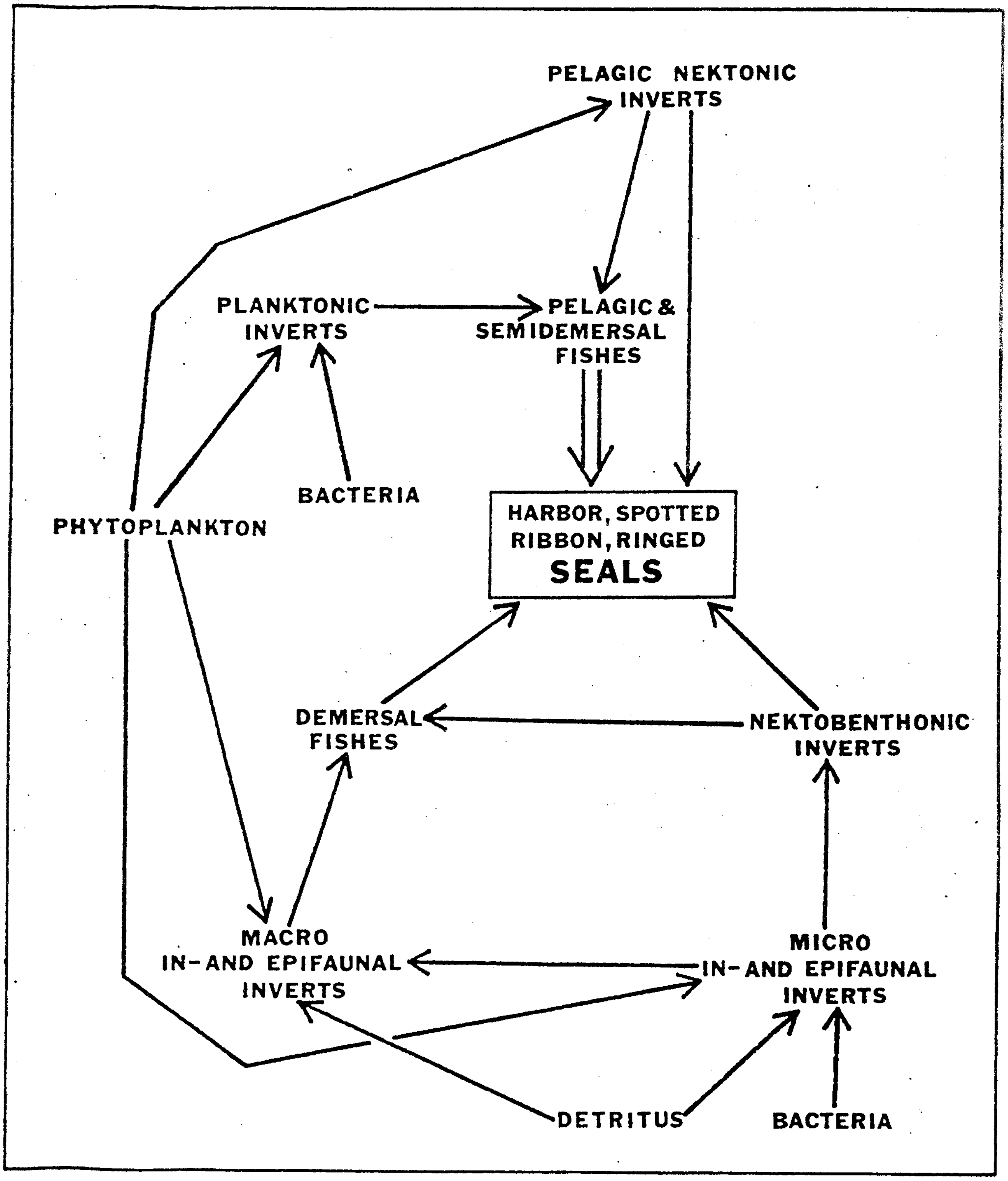

Figure 3. Generalized food web for harbor, spotted, ribbon and ringed seals in the Bering Sea.

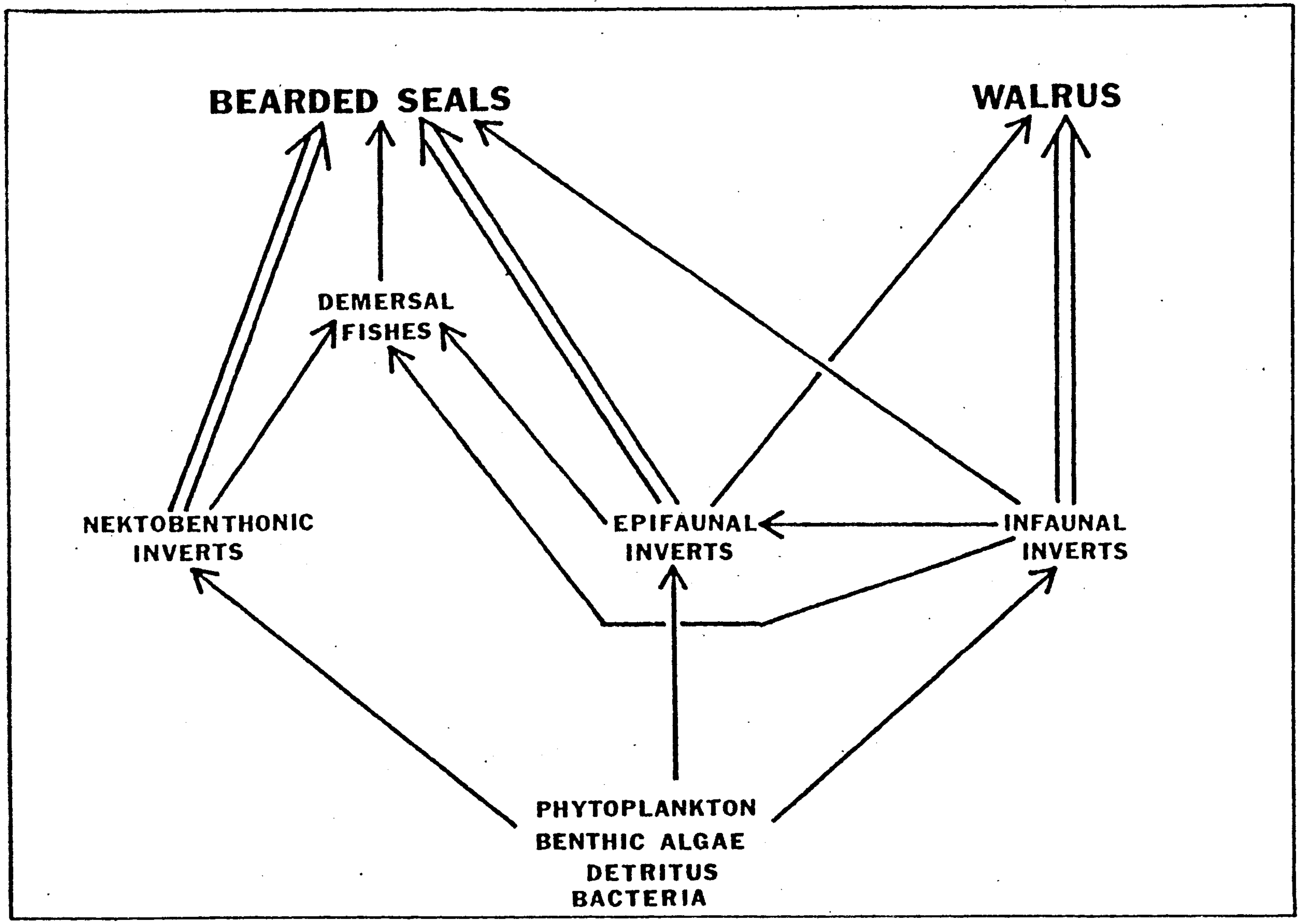

Figure 4. Generalized food web for bearded seals and walruses in the Bering Sea.

Table 23. Relative importance of major prey types in the diet of pinnipeds and belukha whales in the eastern Bering Sea.

Predator Species	Pelagic and Semidemersal Fishes	Demersal Fishes	Pelagic Nektonic Invertebrates	Nektobenthonic Invertebrates	Epifaunal Benthic Invertebrates	Infaunal Benthic Invertebrates
Harbor Seal	Major	Minor		Minor		
Spotted Seal	Major	Minor	Major-Juveniles	Minor-Adults Major-Juveniles		
Ribbon Seal	Major	Major		Minor		
Ringed Seal	Major	Minor	Major	Major		
Bearded Seal		Minor		Major	Major	Major in some areas
Walrus				Minor	Minor	Major
Fur Seal	Major		Major (squids)			
Sea Lion	Major	Minor		Minor		
Belukha Whale	Major	Minor	Minor	Minor	Minor	

amphipods. The combined foraging activities of bearded seals, walruses, and gray whales undoubtedly influence the structure of benthic communities and food webs.

Pelagic and semidemersal fishes comprise a major portion of the diet of all other species of pinnipeds and belukha whales in the Bering Sea. Pollock and capelin are the primary species eaten in the southern Bering, arctic and saffron cod are the major species in the northern Bering, and herring and smelt are important throughout coastal waters. Although foraging activities of many species are geographically or temporally offset, more than 2 million pinnipeds are being supported primarily by this fish resource. In addition, the same species of fishes are consumed in large numbers by some species of whales and dolphins (Frost and Lowry, in press b) and seabirds (Divoky 1977; Hunt 1978). The importance of whales in this system is magnified by the fact that they also consume planktonic and pelagic nektonic invertebrates which are the main foods of pelagic and semidemersal fishes. If the pelagic trophic subsystem is in equilibrium, changes in population size of one consumer species would have direct effects on other consumer populations.

Humans also compete directly with pinnipeds for food. Commercial fisheries can alter not only the total standing stock of fishes (or shellfishes) in a given area but also the proportion of the biomass which is made up by individual fish species. Changes in composition of the fish fauna apparently induced by fishing have been documented for the North Sea (May et al. 1979) and have probably also occurred in the Bering Sea (Pruter 1973). Such changes undoubtedly affect the competitive balance among pinniped populations. It is presently impossible to predict what the effects on pinnipeds might be due to lack of data on the suitability of various prey species and the mechanisms and magnitude of responses to changes in overall availability.

D. Potential Effects of Petroleum Development

This study was designed to develop an understanding of the feeding and trophic interactions of marine mammals, particularly ringed, bearded, ribbon, and spotted seals, in the Bering Sea and to assess the possible and/or probable effects of petroleum exploration and development on the ability of those animals to meet their nutritional requirements. Possible effects fall into two categories: 1) those directly affecting the seals and their access to feeding habitat and 2) those affecting the availability of prey. The potential for and severity of any effects will vary by season and geographic area. Petroleum exploration and development in the Bering Sea will differ substantially from that in more northern waters of the Chukchi and Beaufort Seas. Duration and extent of seasonal sea ice cover are variable, and the ice itself is thinner and less suitable as a platform from which to operate. Unlike the Beaufort Sea where ice provides a stable platform on which to work, the moving pack ice and the thinner fast ice of the Bering may serve to hinder and/or disrupt operations and in some instances may preclude winter exploration.

Winter exploration and development activities, where they occur, are likely to include such things as seismic profiling, construction and operation of drilling facilities, and maintenance activities such as supply and service of facilities. Activity may occur nearshore using landfast ice as a platform from which to operate, or in more southern areas in the moving floes of the ice front.

In Norton Basin during winter ringed and bearded seals and occasionally polar bears are the only resident marine mammals. Bearded seals and polar bears are found mostly offshore in areas of moving broken ice. Ringed seals are also present in the offshore area; however, preferred breeding habitat is the shorefast ice. It is this nearshore area where direct effects on feeding ringed seals are most likely to occur and be of significance. Prime ringed seal habitat coincides with and may be determined by the availability of arctic cod which are abundant nearshore under the fast ice during winter. Spilled oil or high noise levels which may displace ringed seals from this area would in fact be excluding them from their major food source at a time of year when energetic requirements are high and alternate prey are least available.

The nearshore area in Norton Basin is important in winter, not only to ringed seals but to several major prey species. Arctic cod aggregate in autumn-winter and move onshore to spawn during January-February. The schooling of adult arctic cod at spawning time, particularly near narrow cracks in the ice and in slushy "frazil" ice, places them in areas most likely to be contaminated by winter oil spills. It also suggests that in the event of a catastrophic spill or blowout a large proportion of the breeding segment of the population might be affected. Preliminary toxicity studies have shown adult arctic cod to be very sensitive to crude oil at less than 2 ppm (NAFC 1979).

Both the eggs and larvae of arctic cod are pelagic, developing near the undersurface of the ice. The egg stage lasts 1.5-3.0 months, and the larval stage lasts about 2 months. Because the eggs and larvae are in the upper portion of the water column, they are likely to be exposed to surface and underice spills, emulsions, and dispersions. Studies of other members of the cod family have shown eggs and larvae to be highly sensitive to even short-term exposure (5-30 hrs) to crude oil and crude oil extracts (Mironov 1967; Kuhnhold 1970).

Saffron cod also spawn nearshore under the ice in winter. Spawning aggregations form in autumn-early winter near river mouths, bays, and inlets. Unlike those of arctic cod the eggs are demersal and are laid on clean, sandy gravel bottoms. The presence of sinking oil in areas where saffron cod spawn could kill or cause abnormal development of eggs and larvae. Adult mortality occurs within 24 hours when individuals are exposed to the soluble fractions of crude oil at less than 2 ppm at 3°C (Devries 1976).

Other major prey species reproduce in deeper offshore waters during autumn-winter. Sand lance spawn then as do many species of sculpins. Percy and Mullin (1975) found fry of the sculpin *Myoxocephalus quadricornis* to be the most sensitive organisms they tested, with 100 percent mortality occurring after 24 hours in a heavy dispersion of oil. *Parathemisto* breeds in autumn-winter and broods its eggs until spring. A similar pattern occurs in many gammarid amphipods, including *Ampelisca* and

Gammarus, and some shrimps such as *Pandalus*, *Argis*, and *Sclerocrangon*. The crabs *Hyas* and *Chionoecetes* carry eggs in autumn and winter and larvae hatch in spring. Water soluble fractions of crude oil can cause loss of eggs by gravid female amphipods (Busdosh and Atlas 1977) and may cause similar effects in shrimps and crabs.

The spring-summer period is a time of increased biological activity. Ringed and bearded seals bear their pups in April. As the ice melts in the southern Bering Sea, seals, walruses, and belukhas move north into Norton Basin with the ice remnants. Most ringed and bearded seals and walruses pass through Bering Strait into the Chukchi Sea where they summer. Spotted seals move to the coast, as do belukhas, and ribbon seals return to southern Bering Sea where they are pelagic during summer. Gray whales move up from Mexico and California to spend the summer feeding around St. Lawrence Island. Some prey species also undergo major movements at this time, moving into or out of nearshore areas to feed and/or reproduce.

By the open water period the two major forage fishes of ringed seals, arctic and saffron cod, have already spawned. Larvae of both species develop in surface waters where exposure to toxic pollutants is most likely, then descend to the bottom in late summer and assume a demersal life similar to adults. Adult arctic cod disperse offshore during spring-summer and are probably least sensitive to oil spills and pollutants at this time. Most saffron cod apparently remain nearshore in areas where exploration and development are likely to occur.

Herring form pre-spawning concentrations in spring and move en masse into lagoons, bays, and inlets to spawn at about the time the ice breaks up. After spawning they remain aggregated and feed intensively throughout the remainder of the summer.

Spawning takes place in two very different habitats: on kelp growing near exposed rocky headlands and on eelgrass (*Zostera* sp.) growing in shallow, brackish bays, lagoons, or inlets. The latter of these types is probably the most vulnerable to either large- or small-scale discharges of pollutants. Rocky headlands are quite rapidly cleansed of oil as a result of wind and wave action. Such cleansing action occurs more slowly in lagoons, bays, or inlets where wind and wave action are more moderate and hydrocarbons can become entrained in sediments.

In herring, hydrocarbons cause reduced survival of ovarian eggs prior to spawning, of embryos from the time of fertilization to hatching, and of larvae through the yolk absorption stage (Struhsaker 1977; Kuhnhold 1970; Mironov 1970; Eldridge et al. 1978; Smith and Cameron 1977). In addition, hatching may be delayed and a significant porportion of the larvae may develop abnormally. In the natural environment only 5-10 percent of the herring are estimated to survive beyond the larval stage. The presence of hydrocarbons may aggravate a natural tendency toward embryonic mortality, and it is possible that an entire year class could be eliminated in localized areas. In addition to effects on eggs and larvae, benzene has been shown to cause aberrant swimming and disequilibrium in adults (Struhsaker 1977).

Many invertebrates release their young during spring and summer. Among the major species are the amphipods Ampelisca and Gammarus, the isopod Saduria, the shrimps Eualus, Pandalus, Crangon, Argis, and Sclerocrangon, and the clams Serripes and Spisula. The eggs of Hyas and Chionoecetes crabs also hatch then. Growth and molting of crab larvae are impaired by hydrocarbons even in species in which adults are highly resistant (Mironov 1970; Parker and Menzel 1974; Rice et al. 1976). Pandalid and hippolytid shrimp larvae are sensitive to hydrocarbons. Low concentrations (1-5 ppm) of water soluble fractions cause mortality and cessation of swimming activity (Malins et al. 1977; Brodersen et al. 1977; Craddock 1977).

Water soluble fractions of crude oil cause reduced fertilization of eggs, decreased survival of eggs, sperm, and larvae, and abnormal development of embryos in bivalve mollusks (Scarratt and Zitko 1972; Renzoni 1975). Growth, survival, and recruitment rates in local clam populations remained depressed for 3-6 years after the occurrence of oil spills in Nova Scotia and Maine (Gilfillan and Vandermeulen 1978).

Young amphipods may not colonize oiled sediments. Atlas et al. (1978) found that arctic amphipods occurred less frequently in oiled sediments than in unoiled (control) sediments. Although contaminated sediments were later recolonized, species composition was quite different. If colonization of a species such as Ampelisca, which is a major food not only of ringed seals but also of gray whales and numerous fishes, were discouraged it could have major implications for predators.

In general the literature indicates that many of the fishes, crustaceans, and bivalves (especially their eggs and larvae) which are important prey species in Norton Basin are sensitive to the presence of hydrocarbons in water. Summer is probably the period when reproductive products are most abundant; however, it is also the time of open water and warmer temperatures, which may facilitate dispersal, dilution, and degradation of contaminants. Consequently, the occurrence of an oil spill in summer may be less critical from the standpoint of prey species than a similar spill in winter. The probable exception would be summer spills in areas such as bays, inlets, and lagoons, where water circulation is sluggish, flushing time slow, and abundance of spawning and/or juvenile organisms is very high. Such spawning/nursery areas are very important to maintenance of prey species populations.

Fewer species reproduce during winter but many of the ones that do are major prey of marine mammals. The winter ice cover and accompanying colder water act to reduce dispersion rates, evaporative loss of toxic fractions, and biodegradation rates, and may concentrate pollutants in places of high biological activity such as leads and slush ice.

In the St. George and Navarin Basins spotted, ribbon, and bearded seals and walruses are the resident pinnipeds during ice-covered months. Belukhas and bowhead whales also winter in the pack ice of the Bering. Exact locations are poorly defined but they are probably present in the Navarin Basin. Winter is a time of active feeding for all species except perhaps bowhead whales. With the melting of ice in spring most of the winter marine mammal residents leave the St. George and Navarin

Basins. The exceptions are ribbon seals, which are probably pelagic in the vicinity of the Pribilofs during summer. Spotted seals are present along the coast of Bristol Bay and areas north. Some walruses, perhaps 15,000-20,000 bulls, remain in Bristol Bay, as do an undetermined number of belukhas. From the south there is a great influx of marine mammals including fur seals, sea lions, and several species of whales. Although outside the scope of this report, those species must be considered in any evaluation of potential impacts of petroleum activity. Many swim thousands of miles to summer in the rich feeding grounds of southern Bering Sea.

Most trophic impacts on seals (except bearded seals) in southern to central Bering Sea will be measured in terms of the availability of forage fishes. Those species most important from a trophic standpoint are pollock, capelin, and herring. The sensitivity of herring to hydrocarbons was discussed in the previous pages. Almost nothing is known about the sensitivity of pollock, although DeVries (1977) found in preliminary tests that naphthaline at 4 ppm (+1°C) was lethal to adults after 13 hours. Eggs and larvae of other cods, for example Atlantic pollock (Pollachius virens) and Atlantic cod (Gadus morhua), are extremely sensitive to crude oil extracts and it is reasonable to assume that walleye pollock are similarly sensitive (Grose, cited in Clark and Finley 1977; Kuhnhold 1970; Mironov 1967).

The effects of hydrocarbons on capelin are largely unknown. We do know, however, that spawning takes place on sandy beaches, where the eggs are buried by wave action until hatching. On such beaches oil may penetrate several centimeters, and the same wave action that buries the capelin eggs will bury oil. Assuming capelin larvae are as sensitive to oil fractions as most fish larvae, a major portion of a year's recruitment on a particular beach or beaches might be destroyed. In addition, coarse sand and gravel beaches are virtually impossible to clean up mechanically, and oil buried months prior to spawning may persist for many years, affecting not just one, but many year classes. See Barton (1979) for further discussion of the susceptibility of different coastal spawning habitats to oil spills.

The previous discussion on the susceptibility of invertebrates in Norton Basin applies also to southern Bering Sea.

Pollutant levels high enough to cause large-scale die-offs of individuals will probably occur only on a very localized basis (except where oil or pollutants are trapped under the ice and transported long distances in a relatively unweathered state). The greatest concern may not be with local catastrophic events but with long-term sublethal effects of pollutants. Individuals may not be killed directly, but instead very low concentrations of pollutants may affect locomotion, metabolism, or reproduction and lead to substantial reduction of populations over several generations (Percy and Mullin 1975). These long-term reductions are of special concern in considering food availability to consumers.

VIII. Conclusions

Spotted seals are winter residents of southern Bering Sea (including St. George Basin and sometimes the Navarin Basin and North Aleutian Shelf), during which time they feed mostly on pollock (southcentral) and capelin (southeastern). In spring they move north with the receding ice, and then to the coast where they spend the summer feeding and hauling out on the shore. In northern Bering Sea arctic cod are the major food, in addition to saffron cod, capelin, herring, and sculpins. During summer and fall spotted seals feed on coastal runs of spawning fishes such as herring, smelt, and capelin and perhaps on anadromous species.

Belukhas are found in the pack ice of the Bering Sea during winter during which time their diet is unknown. Since they are largely fish eaters it is presumed that they eat a variety of forage fishes including pollock and arctic cod. During summer when they inhabit coastal regions they utilize much the same prey as spotted seals; small to medium-sized forage fishes make up most of the diet. In Norton Sound they are known to eat saffron cod and herring. Aggregations of those fishes which occur in coastal waters during summer and fall probably influence the distribution of both spotted seals and belukhas.

Bearded seals are abundant residents of the Bering Sea during months when sea ice is present. They eat mostly shrimps, brachyuran crabs, and clams. Tanner crabs are especially important in southern Bering Sea. The diet varies on a seasonal basis with clams important only during summer and only in some locations. Young seals eat more shrimps while older seals eat more clams, crabs, and echiuroid worms.

Ribbon seals spend the entire year in the Bering Sea. They are associated with sea ice during winter-spring and become pelagic during open water months. Our data, which are from the period March-June, indicate that pollock and eelpout are the major foods of ribbon seals in southcentral and central Bering Sea and arctic cod are important in northern Bering Sea. Food habits during the open water period and in early winter are unknown.

The Pacific walrus population winters in southern and central Bering Sea. They migrate through Norton Basin on their way to and from summer feeding grounds in the Chukchi Sea, and at least part of the population remains in Norton Basin throughout the summer. Foods of walruses consist mostly of clams with lesser amounts of snails, priapulids, polychaete worms, echiuroid worms, other miscellaneous invertebrates, and occasionally seals. Walruses may compete for food with bearded seals in areas such as Nome and Diomede where clams are, or used to be, a major component of the bearded seal diet.

Ringed seals are very abundant in Bering Sea in ice-covered months and they compete with and provide food for other marine species. Arctic cod and some saffron cod are their main foods in winter. Shrimps and other crustaceans, as well as arctic and saffron cods, are major foods in March through June. Ringed seal pups eat more small crustaceans (amphipods, mysids, and euphausiids) than do older seals, while older seals eat slightly more fish. Ringed seals eat many of the same fish species consumed by spotted and ribbon seals and belukhas. However, they also utilize crustaceans in significant quantities and therefore have a more diverse food resource base.

Available information on the distribution, abundance, and natural history of most invertebrate prey species and some of the fishes, particularly arctic cod and capelin, is inadequate. Information on hydrocarbon sensitivity of all but a few species is totally lacking. However, based on what information is available, a real potential for detrimental effects on prey populations exists, especially in species such as herring, capelin, and arctic cod which aggregate to spawn in habitats susceptible to contamination by oil. Changes in abundance of prey can be expected to influence populations of marine mammals.

IX. Needs for Further Study

The data included in this report on spotted seals cover only part of the year (spring) and limited geographic range. Needs for additional data are as follows: 1) information on food habits in summer and autumn, when spotted seals utilize coastal regions and presumably feed on anadromous fishes and/or aggregations of spawning fishes such as herring, smelt, and capelin which are also utilized by humans; and 2) additional samples from St. George Basin. Pollock are presumed to be the major prey but at present that presumption is based on a single seal.

Our data on ribbon seals, as well as the limited other data available from Soviet studies, were collected from a single time period (spring) when the seals are pupping, breeding, and molting, are hauled out on the ice for long periods of time, and when feeding activity is minimal. We have no information on times of year when major feeding activity takes place. This data gap may be difficult or impractical to fill in the near future given the pelagic nature of the seals during open water months, and the complete lack of precise information on distribution and abundance during all but the spring months.

With the exception of winter months and offshore areas, data on ringed seals and bearded seals should be adequate for OCSEAP purposes.

Foods of walruses are poorly documented. Some data are available from northern Bering Sea during spring. Winter food habits are unknown. In light of an increasing walrus population and upcoming petroleum exploration and development in walrus feeding habitat, it is important that base-line data be gathered to facilitate reevaluation at a future date of competitive interactions and/or the effects of human disturbance on what may already be a stressed population.

An area/season matrix of major data gaps for the above species is given in Table 24.

Few data are available on food habits of belukhas in Alaska, although they apparently utilize many of the same species eaten by spotted seals. A combined study of the two, with localized collection and examination of spotted seal stomachs, and analysis of the timing of movements and

Table 24. Major gaps in the data base on foods of phocid seals and walruses in the Bering Sea. For each area-season combination, species listed are those for which data are inadequate at the descriptive level.

Season	Area: Southeastern	Southcentral	Central	Northern
Autumn Sept.-Nov.	Harbor Walrus	Ribbon	Ribbon	Walrus
Winter Dec.-Feb.	Harbor Spotted Bearded Walrus	Spotted Ribbon Bearded Walrus	Bearded Ringed Spotted Ribbon Walrus	Walrus
Spring Mar.-May	Harbor Ringed Bearded Walrus	Bearded Walrus	Ringed Bearded Walrus	
Summer June-Aug.	Harbor Spotted Walrus	Ribbon	Ribbon	

distribution of both species, as well as analysis of coastal fisheries information, should provide preliminary data on prey utilization.

In areas (such as Nome or Diomede) where walruses and bearded seals coexist and utilize the same foods, additional specimen collections are desirable in order to further evaluate interspecific competition. There is evidence, based on limited historical collections from Diomede, that the diet of bearded seals has changed over the last 20 years as the walrus population has increased.

We strongly urge a systematic study of arctic cod, the single most important forage fish in northern Alaskan waters.

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FINAL REPORT

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ECOLOGICAL STUDIES IN THE BERING STRAIT REGION

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ECOLOGICAL STUDIES IN THE BERING STRAIT

I. Introductory Remarks and Context (This material appeared as an article in Natural History, February 1978.)

For the edges of the high arctic, the Bering Sea Region, Beringia, is surprisingly rich in species. At the same time, the numbers of fish, marine mammals and birds boggle the mind. Much of this has survived because it was protected by remoteness, despite the intensity of exploitation of this area for its natural resources.

The theme of the history of western Alaska and the Bering Sea has been exploitation, beginning with the discovery of Sea Otters and the breeding grounds of the fur seals in the 18th century and of Bowhead whales in the 19th century. In the 20th century, mining of gold, tin, platinum, and mercury followed; then industrialization of river run salmon and the ground fish on the edges of the Continental Shelf.

Now that oil is added to the list, the passage of large ships through the Bering Strait is forecast, and establishment of transhipment ports at Nome, Port Clarence, and/or Cape York has been suggested. Port Clarence is the first deep-water port north of Dutch Harbor in the Aleutians on the way to the oilfields of the Beaufort Sea.

Northwest Alaska is now more than a remote "colony" whence resources are taken to fuel the affluence of the lower forty-eight. Many people see its land and wildlife as valuable for themselves.

It is necessary 1) to take account of the physical and biological components of the region, 2) to understand what makes the biological systems work, and 3) to take steps to assure peaceful coexistence of wildlands, wildlife with some degree of development.

This report focuses on seabirds as the central element of a study of ecological processes in the northern Bering Sea. We study birds because they are evident, numerous, and therefore convenient for deriving biological generalizations which can be applied to other animals whose lives are more obscure. Intensive and extensive biological study of birds in developed parts of the world makes their biology well known; they are useful as indicators of the conditions in the environments of which they are a part. We will use a brief discussion of the reasons for the diversity and abundance of marine birds in the Bering Sea and Bering Strait Region to set the stage for our report.

Biogeography of Beringia

The exceptional richness of Beringia seems to contradict the familiar geographical rule that a) tropical regions produce many species, while the populations of each species are small, and b) fewer species inhabit the higher latitudes, but their populations tend to be large. A bird watcher in the inland tundra of Alaska would be lucky to spot twenty bird species in a day, but in the forests, fields and swamps of Central America, the sighting of two-hundred species in a day is not unusual.

With a few conspicuous exceptions, such as the Sooty Tern of tropical seas or the Quelea weaver finch of the East African plains, large bird populations are rare in the tropics.

The difference in species diversity and population size between low and high latitudes reflects differences in climate and biological productivity; uniformly warm and moist climates support more species than do climates in which temperature or rainfall vary widely.

Although most species of land animals conform to these geographic rules, exceptions occur among marine species. One of the most pronounced exceptions are the seabirds, waterfowl, and shorebirds of the Bering Sea. The number of seabird species in equatorial oceanic systems is actually lower than in the Bering Sea; about twenty species inhabit the Hawaiian Islands, the Galapagos Archipelago or the coast of southern California. Large populations of more than thirty-four species nest on the islands and along the varied coastline of the Bering Sea. On the Pribilof Islands in the southern Bering Sea, some 225,000 Red-legged Kittiwakes -- nearly the entire world population -- nest along with roughly 100,000 Black-legged Kittiwakes, 1.5 million Thick-billed Murres, and enormous numbers of Crested and Least Auklets. Six hundred miles to the north, 750,000 auklets crowd the cliffs and rock-strewn shores of Little Diomede Island in the Bering Strait.

Birds are not the only animals that show great species diversity in the Bering Sea. Forty-five species of sculpin occur in the southern Bering Sea and along the edge of the Continental Shelf, and five species of river run salmon spawn in Alaska's rivers.

The terrestrial flora of the region is more diverse than that of the higher latitudes of interior North America. The flora of the Canadian Arctic archipelago consists of 340 species (Polunin, 1959; Porsild, 1957); the flora of the Seward Peninsula includes 475 species of vascular plants (Hulten 1969).

The highly mobile seabirds, waterfowl and shorebirds use the arctic regions only during the productive summer season. Marine birds of Beringia (Figure 1) spend the winter at sea around the Aleutian Islands/or along coasts of

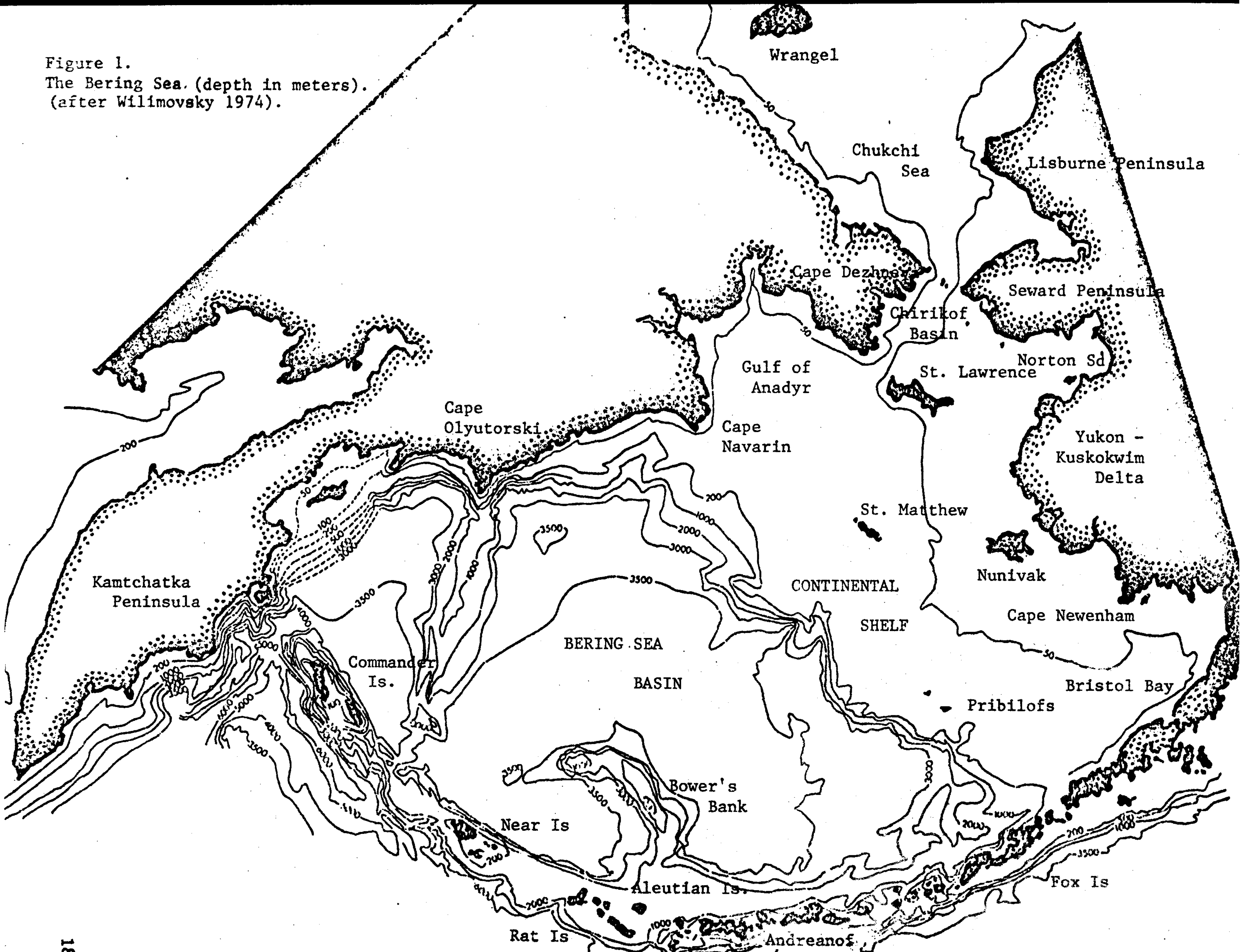


Figure 1.
The Bering Sea (depth in meters).
(after Wilimovsky 1974).

the Pacific Ocean in both North and South America. During April, murres, kittiwakes and puffins appear north of the ice front in the leads in the winter ice. In May, flocks of eiders, Old Squaws and scoters hurry north along the windrows of drift ice to nest on coastal tundra. By late May, auklets swarm around the rubble slopes that are their nesting areas.

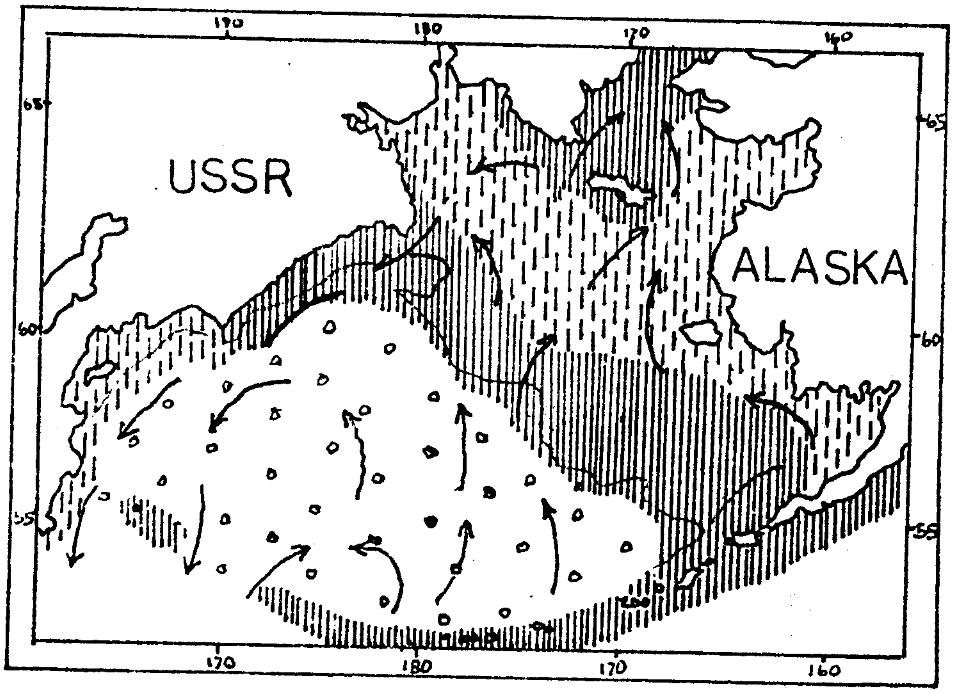
Later in the summer, Short-tailed Shearwaters from the Southern Hemisphere arrive through the passes of the Aleutian Islands and cross over the waters of the Continental Shelf near Saint Lawrence Island on their way to the Bering Strait and the Chukchi Sea. During the last century, the now endangered species of Short-tailed Albatross was common in the northwest Bering Sea at this time of year.

The numbers and diversity of marine bird species has a patchy distribution over the Bering Sea (Figure 2). One area of abundance and diversity -- seabird megalopoloi as Eppley et al. (1980) calls them, is at the western end of the Aleutians and the Commander Islands. We will refer to elements of these seabird megalopoloi as "cities" or "bazaars". The endemic species, Whiskered Auklet, Red-legged Kittiwake and the extinct flightless cormorant of the Commander Islands, are restricted to this archipelago and the Pribilof Islands (Figure 1).

The area of the outer tip of the Alaska Peninsula and the inner Aleutians, together with the Pribilof Islands and Cape Newenham on the north shore of Bristol Bay, make up another major population center. The northernmost center is in the Bering Strait and the Chirikov Basin.

Widely different climatic conditions within Beringia -- the area that includes Alaska's interior mountains, the coastal ranges of southeastern Alaska, the Aleutian-Commander Islands chain, the Kamchatka Peninsula, and the Bering Strait islands -- account, in part, for the region's intriguing

Figure 2.
Seabird concentrations in summer.



- low concentration
- medium concentration
- high concentration
- currents

and complex faunal and floral diversity. This climatic variety is, in turn, related to latitudinal spread and pronounced topographic relief, which together create varied habitats. The climate of the Aleutian Islands and southeastern Alaska, for example, is mild and moist, whereas that of the Seward Peninsula is cold and surprisingly dry. In interior Alaska, the temperature on winter days might be -50°F, while in the summer, the heat is greater than Miami's.

Geologic forces have created diverse habitats. Much of the topography is the result of the energy released by the meeting of three tectonic plates -- the Pacific Ocean plate, the Siberian, and the North American. The resulting energy is released in volcanic activity throughout Beringia, especially in Alaska's major mountain ranges and along the Aleutian-Commander Islands chain. Extruded lava cooled rapidly to form fine-grained rocks and this friable material has been broken into rubble by frost action. In other places rocks have been metamorphosed and uplifted, then eroded by waves into vertical cliffs.

Scattered along the coasts are spectacular sheer cliffs that rise in some places hundreds of feet. The tops and feet of these cliffs are buried in rubble, which together with the ledges and crevices on the cliffs, supply abundant nesting sites for seabirds (see Figures 3a, 3b, and 4). Pelagic Cormorants and Black-legged Kittiwakes occupy the smaller ledges, and Common Murres the wider ones. Least Auklets and Crested Auklets nest in the passages under boulders and cobbles produced by frost riving of the lava and basalt outcrops at the tops of the hills. Pigeon Guillemots nest in the crevices and holes among boulders at the base of the cliffs. Horned Puffins and Parakeet Auklets nest in crevices.

Figures 3a and 3b.
Bird Cities of the Bering Strait Region.

These drawings serve two purposes:

1. To illustrate the forms of the cliffs
   3a) those of the volcanic outcrops at Southwest Capes on Saint Lawrence Island, at King Island and at Little Diomede Island,
   3b) those of the cliffs at Bluff or west of Savoonga
2. To illustrate how nesting birds are distributed on the cliffs: murres tend to nest higher than kittiwakes, guillemots nest at the foot of the cliffs; puffing nest at the foot and tops of the cliffs.

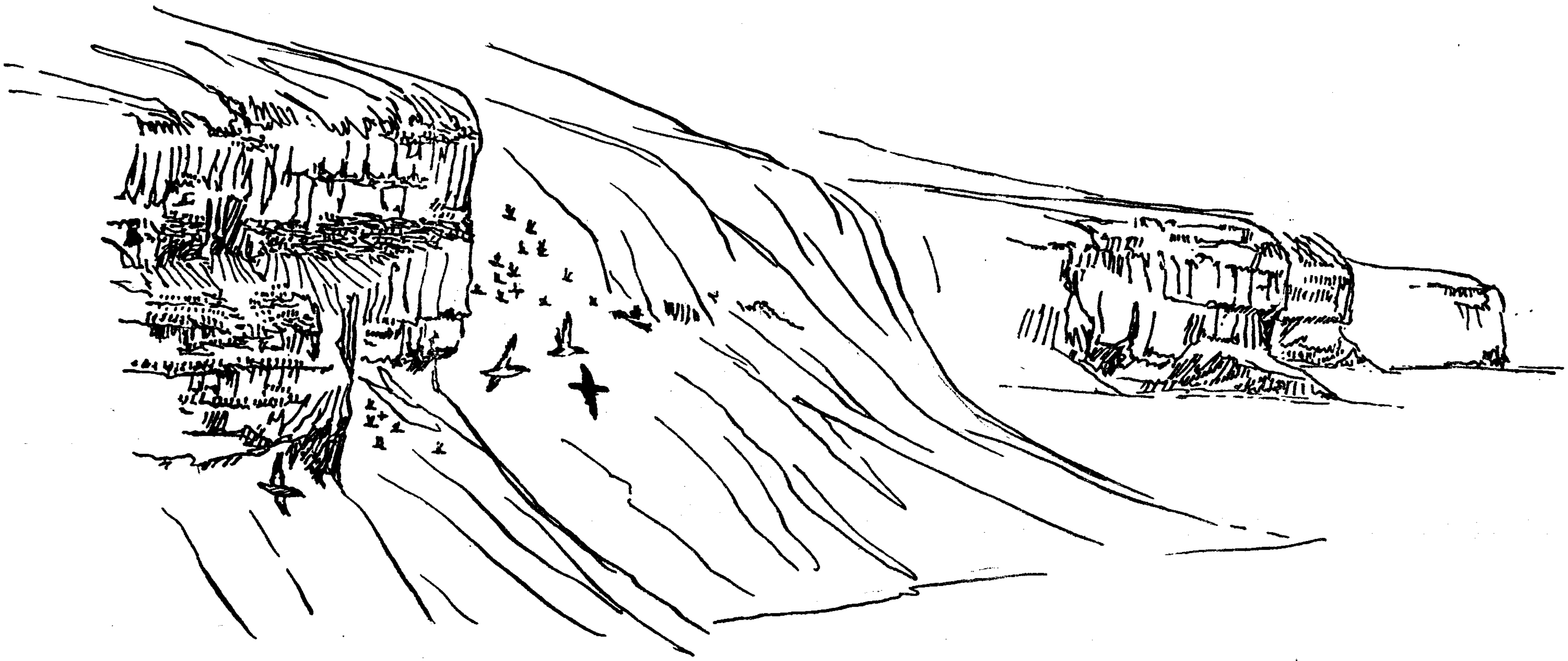
Figure 4.
Bird Cities of the Bering Strait Region

This drawing illustrates the form of the cliffs east of Savoonga and at Egg Island.

Figure 3a. Bird Cities of the Bering Strait Region.

Figure 3b. Bird Cities of the Bering Strait Region.

Figure 4. Bird Cities of the Bering Strait Region.



For the diversity and large numbers of seabirds to exist in the Bering Strait Region, an abundant food supply is as necessary as the varied climatic variation and habitats resulting from climatic variations in the area and the supply of nesting sites. The Bering Sea is an area of exceptionally high biological productivity. The proliferation of plankton is an indispensable key to the biological system. Many of the mineral nutrients necessary for production of plankton come from the Pacific Ocean via the deep trenches between the Aleutian Islands. The currents that carry the nutrients form the Bering Sea gyre, and strong winds of the southern Bering Sea cause turbulence which brings the nutrients to the surface. These winds are associated with storms that cross the northern Pacific and southern Bering Sea (Figure 1).

The area which we call the Bering Strait Region and which we treat in this report (i.e. the Saint Lawrence Island waters, Norton Sound, the Bering Strait and the southern Chukchi Sea south of Cape Lisburne, Figures 5 &6) are north of the main storm paths. The region lies in the influence of polar high pressures. The northerly winds which accompany a high pressure system over northeast Siberia bring clear skies for days on end over Norton Sound. Often under these conditions fresh breezes blow in the Chirikov Basin and fog covers the waters west of King Island. The northerly winds slow the northward flow of water through the Bering Strait. When storms move into the area from the southwest, winds blow out of the southeast in Norton Sound and the Saint Lawrence Island waters and the rate of northward flow increases. Consequently, it has been suggested that the general northward flow of water up from the southern Bering Sea over the shelf and north through the strait is determined primarily by gradients in barometric pressure.

Figure 5.
Bodies of water and settlements in the Bering Strait Region.

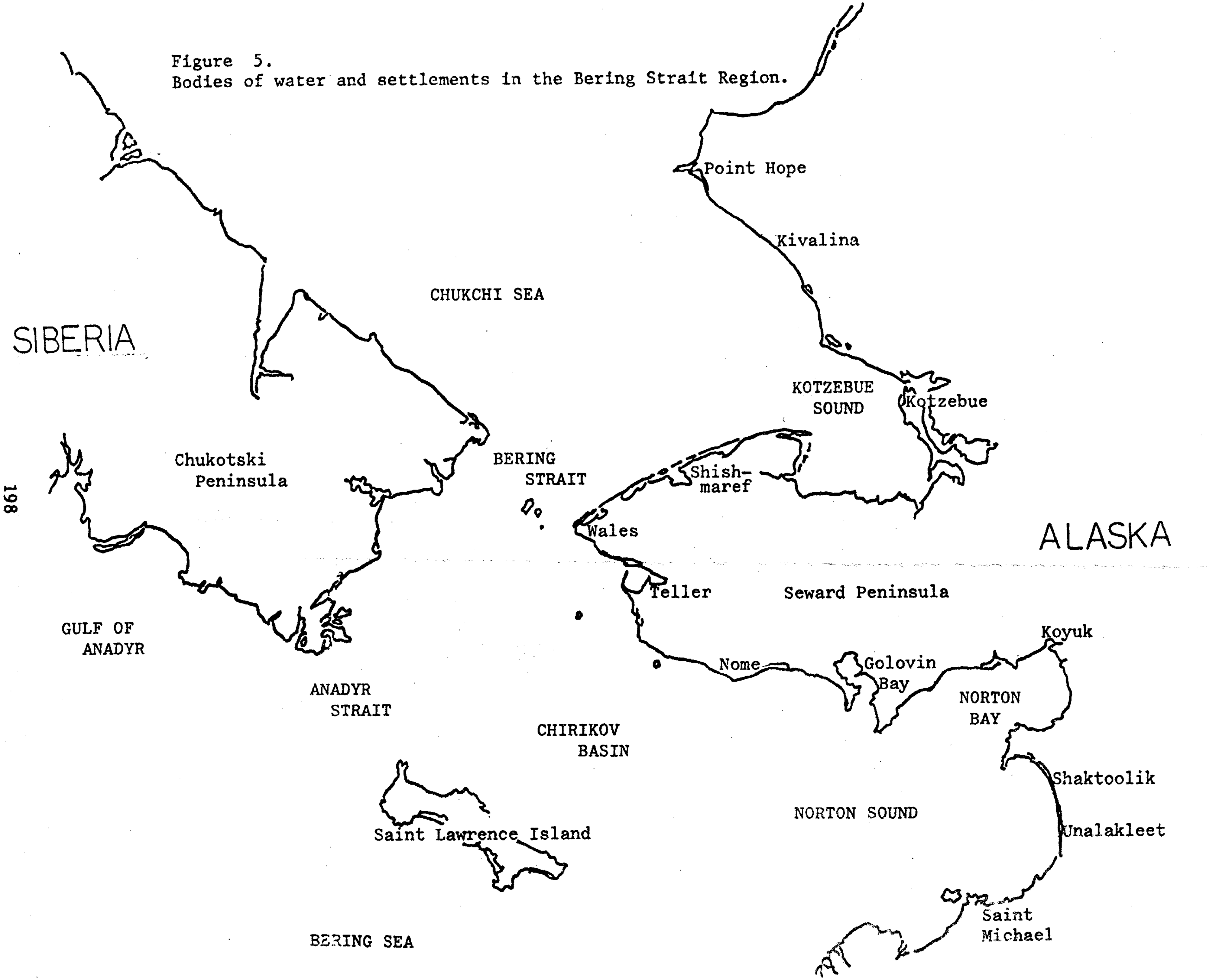


Figure 6 .
Islands and capes in the Bering Strait Region.

Water out of the deep basin north of the Aleutians and south of the Continental Shelf enters the northward flow over the shelf edge and continues north around Saint Lawrence Island, through the Bering Strait, and into the Chukchi Sea (Figure 7). Water dominated by heavy spring runoff from the Yukon and Kuskokwim Rivers also flows northward along the shallow Alaska coast. Lenses of this water are found as far north as Herald Shoal and Point Barrow.

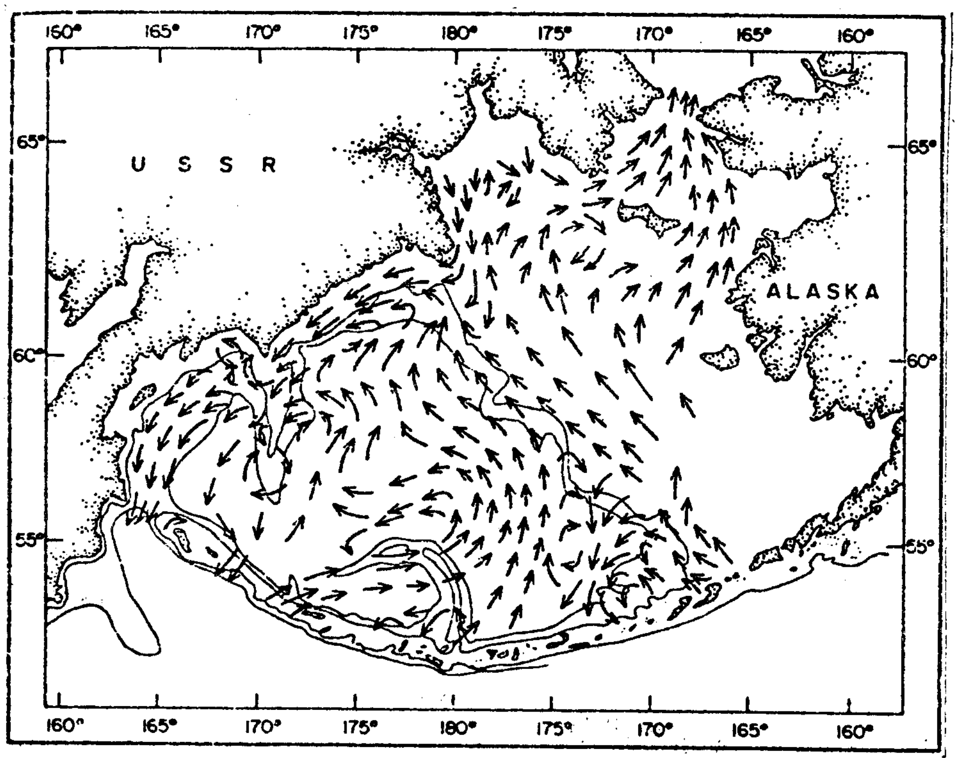
Researchers have found that primary productivity north of the Aleutian Islands creates 250 milligrams of carbon per square meter of water surface per day (mg C/m^2 H_2O/day). In the central Bering Sea area, they have measured the productivity at 350 milligrams. For comparison's sake, 70 milligrams of carbon are fixed per square meter of water surface per day in the open water of the high seas.

The amount of productivity on the western side of the Bering Strait is even higher. Here, Husby and Hufford (1971) determined that plant plankton fixes 1,000 mg C/m^2 H_2O/day, i.e., the low end of the productivity of the world's best-known upwelling systems, such as the one off the coast of Peru. Off Peru, plankton in the cold waters that flow north from Antarctica fix 11,200 mg C/m^2 H_2O/day.

Another important source of productivity important for the breeding of seabirds is the phytoplankton bloom as the ice breaks up in the spring. This bloom nourishes crustaceans and small fish, which, in turn, attract seabirds and mammals.

One group of organisms that takes advantage of the local productivity in the northernmost Bering Sea and Bering Strait is the benthos (worms,

Figure 7.
Bering Sea Circulation according to
Dobrovol'skii and Arsen'ev (1959);
from Hughes, Coachman and Aagaard, 1974.



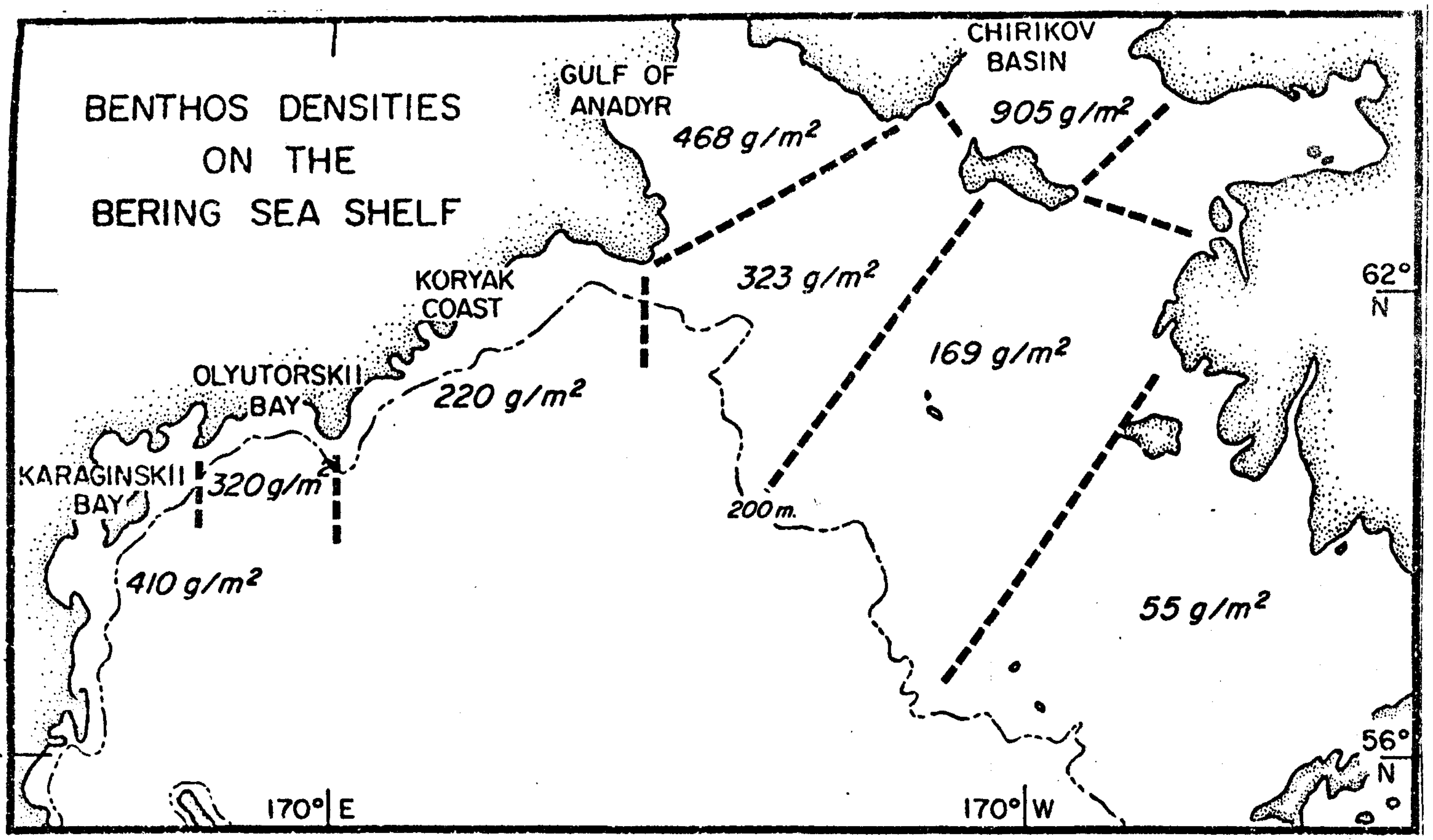
clams, snails, barnacles, starfish and shrimplike crustaceans) feeding on the remains of plant or animal plankton that sink from the sunlit zone above or washed into shallow water. In turn, many seabirds and mammals consume the benthos. Other benthos in the many coastal lagoons along the shore are important food for waterfowl and shorebirds. Sea ducks dive for bivalves and crustaceans, and shorebirds probe for worms and clams on the mud and sand flats of lagoons, inlets, and estuaries.

The distribution of benthic animals is (like so many things) patchy in the Bering Sea, but their abundance in the Chirikov Basin and southern Chukchi Sea is spectacular. The Chirikov Basin bottom produces 900 grams of benthos per square meter in bottom samples (Alton, 1974), whereas bottom samples from Anadyr Gulf and Bristol Bay produce 470 and 55 grams of benthos per square meter, respectively (Figure 8).

Fish, of commercial value, feed on the benthos along the edge of the Continental Shelf. Their numbers support major fisheries for Japan and Russia, the two nations whose fishing fleets harvest the area intensively. About 4 1/2 million tons of fish are taken annually in the area. This compares with some 500,000 tons hauled each year from the waters off New England. Although some 270 fish species inhabit the Bering Sea, the principal one caught is Walleye Pollock, which, since the demise of the Peruvian Anchovy, has the dubious distinction of being the most heavily utilized fish species in the world. Other abundant species are flounder, halibut, and hake, all bottom fish inhabiting the edge of the Continental Shelf; salmon in Bristol Bay; and herring in the mid-Bering Sea surface waters,

The Saint Lawrence Island waters and Bering Strait do not support a commercial fishery, although exploratory settings for crabs have been

Figure 8.
Benthos Density in Various Sectors of the Bering Sea Shelf and Slope; from Alton, 1974.



made recently. Instead, the benthos supports large populations of Bearded Seals, Walrus, and Gray Whales.

One of the major zoogeographic features of the Bering Strait region is the segregation of species by water masses. The benthic feeding sea mammals are concentrated in the cold waters to the west of the Seward Peninsula where plankton-eating Bowhead Whales and the three species of auklet also congregate. In the shallow more brackish Alaska Coastal waters, there are fewer sea mammals and the seabirds are both fewer and also include virtually no endemic species.

Availability of nesting sites and food resources are necessary but by themselves are not sufficient reasons for the diversity of bird species in the Bering Sea. Other, pervasive though subtle, influences have allowed the persistence of more than thirty-four seabird species. Each year, some species -- Bartailed Godwits, Wheatears, Arctic Warblers, and Curlew Sandpipers -- migrate to Alaska from Siberia. The ranges of Dovekies and Black Guillemots extend from the eastern Arctic Ocean. Some species occur in the Bering Sea because individuals have straggled outside of their usual migratory routes while in most cases, the majority of a particular population follows the same habits year after year. A few individuals will be colonizers. One example is the case of the Herring Gull population in the mouth of the Saint Lawrence River in eastern Canada. The majority of these gulls nest within 15 miles of where they hatched. Occasionally, however, we find a few birds from this region nesting in Massachusetts. In a comparable manner, a few birds of various species wander into the Bering Sea from other areas. Such wanderers, together with species endemic to the Bering Sea, may contribute to the wide diversity of seabird life here. The status of some of these species seems to be insecure; others have persisted a long time -- apparently through the Pleistocene period 50,000-80,000 years ago.

The location of the Bering Sea region where North America and Siberia come together sets the stage on which birds of both faunal areas mix. This was noticed by the earliest visitors here and was documented by Bailey (1948) in the spring of 1922:

> The Wales region is interesting, for three distinct migration routes cross there. Birds typical of the North American continent move along the coast of Wales, and some species cross the Strait and fly _up_ and _down_ the Siberian coasts -- and their lines of migration are cut by Old World birds which make the northern flight along the sterile Siberian shores, and then pass over the ice-filled Bering Strait to the Wales area. Here then, is the meeting place of Old World and New World forms, where two distinct groups are met by a third -- great hosts of water birds, which have wintered in the Bering Sea.

Radar studies of birds migrating past Cape Mountain at Cape Prince of Wales by Warren Flock (in Drury _et al._, 1979), show Snow Geese migrating northwest to nest on Wrangell Island in Siberia and Sandhill Cranes crossing the Bering Strait into Siberia. While the movements of songbirds are harder to follow than those of the large birds on the radars in use, observers along the shore find Bluethroats, White and Yellow Wagtails, Arctic Warblers, and Wheatears nesting on the coastal tundra of Seward Peninsula. The major populations of these species are in Eurasia. Dotterels, Wood Sandpipers, Rufous-necked Sandpipers, and Mongolian Plovers appear, some regularly and some irregularly. Sharp-tailed Sandpipers from Siberia occur at Wales beside their American equivalents, Pectoral Sandpipers; Bar-tailed Godwits appear beside their American equivalents, Hudsonian Godwits, on the salt marshes at the head of Norton Sound.

Thus, the faunas of the new world and the old exchange here and the bird populations of the tundra on both sides of the Bering Strait are made up of a mixture of species from very different backgrounds.

What allows a variety of species to coexist is more complex than what allows birds to get there. When the Pleistocene ice sheets moved south some 50,000 years ago, parts of present-day Alaska and the Bering Sea escaped glaciation, even though most of Canada and much of the northern half of the United States did not. Botanists have concluded that this ice-free zone was at least partially responsible for Alaska's diverse present-day flora. This reasoning could well be extended to include the Bering Sea's high number of endemic species of seabirds.

That such diversity of seabirds, as well as other animals and plants, occurs in such high latitudes as the Bering Sea is remarkable considering the paucity of species in many other high-latitude regions. From a comprehensive ecological viewpoint, however, the diversity of species is consistent with the generalization that species abundance is greatest where regional topography and local climates are varied, where biological productivity is high, and where historical accidents have allowed the perpetuation and enrichment of flora and fauna.

The rest of this report is designed to focus attention on the marine ecology of the Bering Strait region as we define it (see above). In the second section we describe the effects of local topography, water masses and movements on productivity in the entire Bering Sea on the biological basis of the seabird communities in our region. In the third section we describe productivity and changes in resources which accompany the changes in the waters and seasons from winter through spring and on into the summer breeding season. We emphasize the major effects of the sea ice. In the fourth section we describe the distribution of birds according to the data we collected during our extensive surveys of the waters of the Bering Strait region. We want to emphasize in this section that the birds are primarily birds of the sea and the water masses are the major ecological features which determine their numbers and distribution. Seabirds come to shore only when driven to do so by the necessities of breeding, and do so then with hesitation. In the fifth section we formulate our model, or paradigm, of the operation of the marine biological systems of which the seabirds are part. This section reviews in part the theoretical basis for our studies and the conclusions which we have drawn. In the sixth section we review the detailed studies which we and others have made at several of the important seabird cities in the region. In this section we emphasize the breeding biology of the species upon which we concentrated our attention and the differences in their reproductive performance between areas and between seasons. This section justifies the use of observations made of seabirds as a basis for monitoring changes in the biological oceanography of the Bering Strait Region which may accompany industrial development of the region. In the seventh section we review coastal habitats, primarily on the south shore of the Seward Peninsula, and describe the distribution of waterfowl along those shores. The eighth section presents our conclusions and thoughts about the general and specific impacts which development promises to have on the communities which we studied.

II. The Bering Sea and the Bering Strait Land Bridge

A. Geology and Geography

The Siberian and North American continental land masses meet in the Bering Sea; Cape Dezhneva and Cape Prince of Wales are less than 60 nautical miles apart. When sea level was lower during the Pleistocene ice advances a land bridge connected the two and the Yukon River flowed south of Saint Lawrence Island.

Two continental plates and an oceanic plate have come together in the course of movements of large sections of the earth's surface, driven by the circulation of molten material in the interior of the earth. The Olympian forces involved create the ring of volcanic fire which circles the North Pacific. Where the Pacific Ocean Plate is being forced under the Asian Plate a line of volcanoes marks the Aleutian Islands, surrounded as they are on both north and south sides by deep ocean basins (see Figure 1). The edge of the Continental Shelf is further north, between the Pribilof Islands and Cape Navarin. Shallow water of the Continental Shelf extends north from there through the Bering Strait and beyond the edge of our area to Point Barrow and Wrangel Island.

Effects of the collisions have moved through the area of eastern Siberia and northwestern North America. Transcurrent faults which releive the stresses set up by the shearing of the plates run across the Bering Strait on the north and south. The tilted and modified sediments of the Lisburne Peninsula mark one set of faults. The valleys of the Noatak and Kobuk Rivers run between these mountains and those of the backbone of the Seward Peninsula which were created by another set of faults extending across the Bering Strait into Eastern Siberia. Where igneous and sedimentary deposits have been thrust up and eroded into cliffs by the sea they provide nesting cliffs for seabirds in the central and northern part of our region. This tectonic activity produced the Kuskokwim Mountains, east of Unalakleet, rounded and reduced by intense frost action. The sharp mountain ridges of the western Seward Peninsula, such as the Kigluaiks, reflect continuing uplift in the recent past.

Vulcanism associated with this crustal activity has produced the cores of the Diomede Islands, King Island, Sledge Island, the basalt along the shore from Tolstoi Point to Stuart Island and Cape Romanzof, as well as the complex of volcanic cones and lavas that form Saint Lawrence Island. Friable and rapidly eroding volcanic rocks provide nesting ledges for seabirds across the southern half of our region.

Metamorphosis of sedimentary rocks exposed to high temperatures and pressures in these earth movements allowed molten segregation of heavy metals hence the tin, gold, and mercury mines of the Kuskokwim Mountains and the gold bonanzas along the south shore and inland valleys of the Seward Peninsula. Metamorphic rocks make up the bird cliffs at Cape Denbigh and Bluff Cliffs.

Interior and western Alaska was apparently too dry during the Pleistocene to support large continental ice masses. Consequently, the land surface was exposed to exceptionally intensive frost action. Heavy frost-riving has made the extensive and deep rubble fields on the volcanic stocks in the region which provides nesting sites for auklets. Heavy frost-riving, combined with soil movement driven by frost action, has brought massive amounts of debris off the hilltops onto the depositional slopes of the valley sides. From there, spring freshets have carried sands and gravels toward the coast, creating on the one hand gold placers, and on the other hand deep deposits of sand and gravel at the river mouths.

Coastal currents have moved these river born deposits to form mile upon mile of barrier beaches which contain the large number of biologically productive lagoons that occur along the shore. The same geological processes are responsible for the lack of harbors suitable for ship use.

B. Water Masses, Currents and Productivity

Ocean water from the northern North Pacific and from the deep basin of the southern Bering Sea flows northward across the Continental Shelf. The water coming through the Aleutian Passes and flowing up over the Continental Shelf forms upwelling systems. Productivity is high in a band along the north shores of the Aleutian Islands, where there is a large commercial fishery for crabs. Productivity is high all along the edge of the Continental Shelf extending northwest from the Pribilof Islands toward Cape Navarin. All along this shelf-edge there are major international ground fisheries. Productivity is also high at the mouth of Bristol Bay where low saline water from Alaskan rivers meets water coming north through Unimak Pass and up over the Continental Shelf around the Pribilof Islands. There are major fisheries for salmon, crabs, herring, and Walleye Pollock in this area. Productivity is high west of the Aleutians where water coming through the deep passes rises over the edge of the Siberian continent east of Kamchatka from Cape Olyutorski, past Cape Navarin and into the Gulf of Anadyr. Shuntov (1972) reported a band of productivity running northwest-southeast from Nunivak Island towards Cape Navarin on the shelf.

Winter ice is another significant factor in the marine environment of the Bering Strait region. The edge of the winter ice usually lies approximately along the edge of the shelf. Swells from winter storm waves surge through the ice front so that the southern limit is marked by a zone of long bands of ice pans drifting into the open or blown into dense packs with the wind. Special adaptations of phytoplankton to living in the underside of ice pans have made the opportunity for spring blooms of benthic phytoplankton in the zone of the ice front. The separation of cold surface water from warmer saltier water at depths, also found at the ice front, is associated with a rich fish and crustacean fauna which supports wintering seabirds in early spring.

We have not found floristic studies of regional differences in the phytoplankton or studies of relations between species, standing crop and productivity. The phytoplankton flora of the shallower, less saline (neritic) Alaskan Coastal Water from Bristol Bay northward past Nunivak Island resembles the flora found in the Gulf of Anadyr, according to Japanese workers Motoda and Minoda (1974). This neritic flora is separable from the oceanic flora of the Bering Sea Basin which is carried up over the mid-shelf. The general picture is clear, however; the upwelling waters and the primary productivity are carried northward from the southern Bering Sea and form the basis of much of the marine resources in the northern Bering Sea and the Bering Strait.

"Bering Shelf Water" (Fleming and Heggarty 1966; Coachman, Aagaard & Tripp 1975 flows north from the Bering Sea Basin around both ends of Saint Lawrence Island, through the Bering Strait and past the Point Hope Headlands as far as Wrangel Island and Point Barrow, where it meets cold water from the Arctic Basin (see Figures 9 and 10). Elements of Shelf Water together with elements that

Figure 9.
Bathymetry of the Bering Strait Region; measurements are in meters.

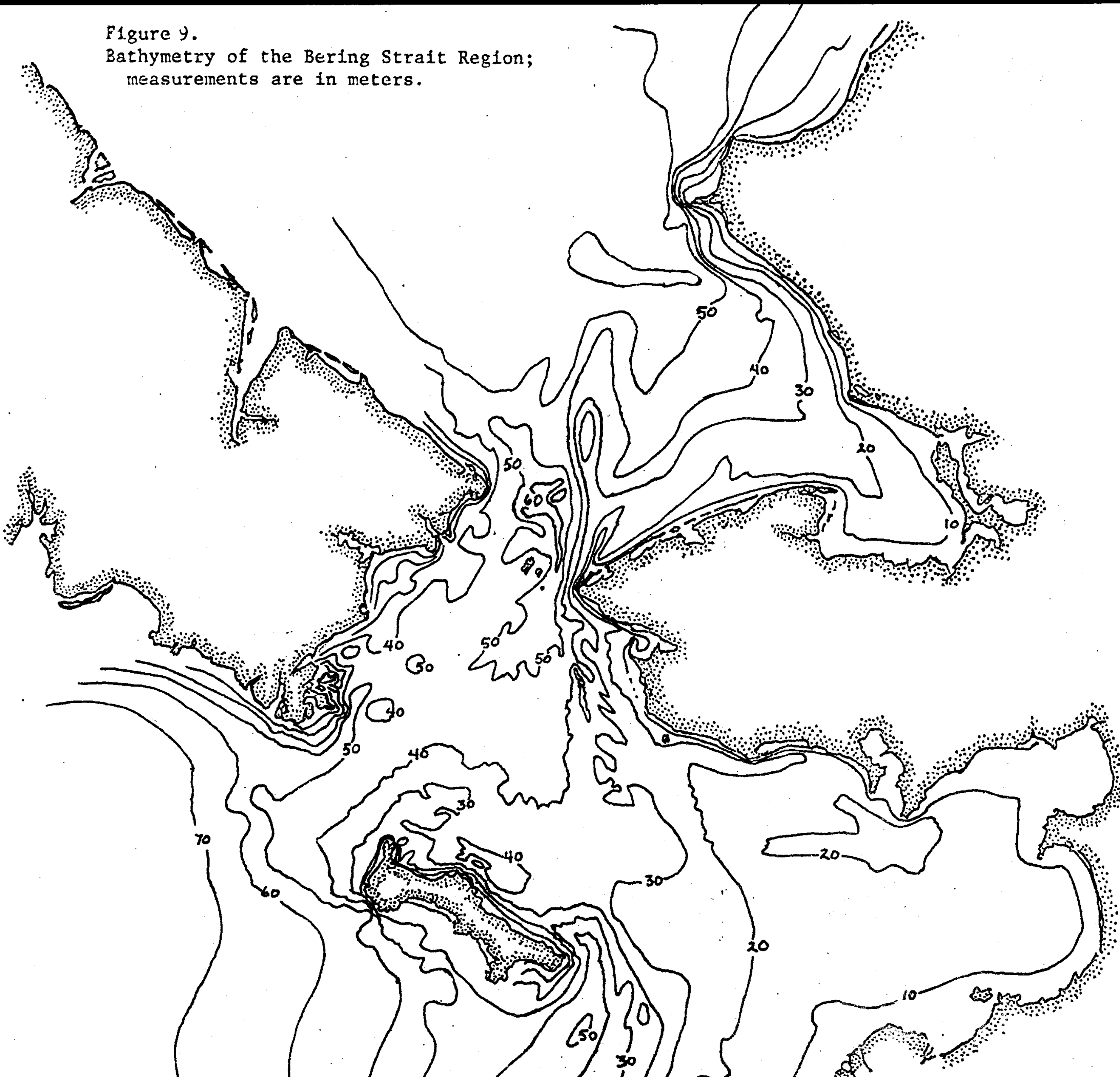
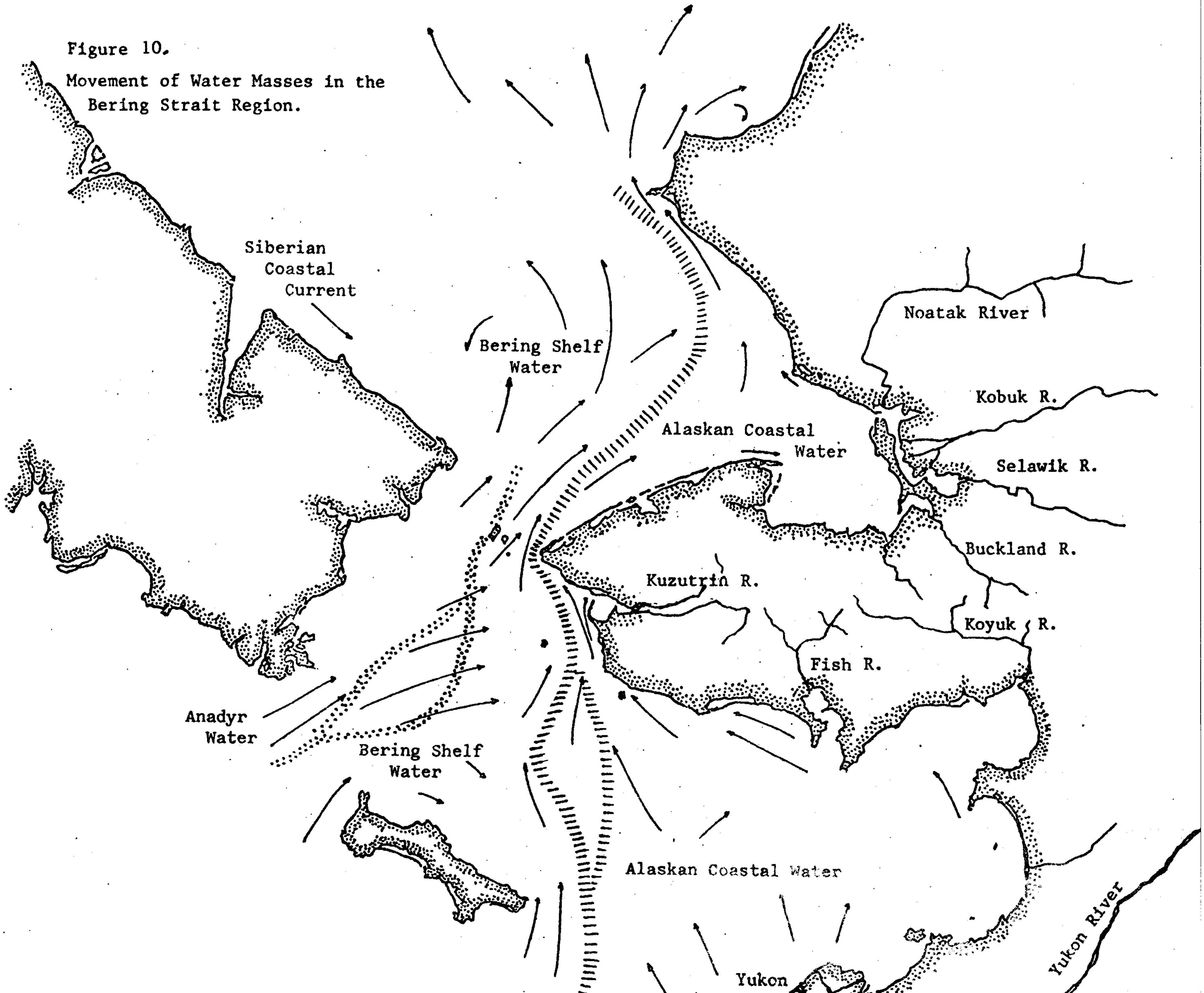


Figure 10.

Movement of Water Masses in the Bering Strait Region.



persisted near the bottom during the previous winter, where conditions are consequently relatively cold and saline, underlie the surface waters of most of the region to the north.

The water moving north accelerates and cuts deeper channels east and west of Saint Lawrence Island; the turbulence carries cold bottom water to the surface northwest of Gambel. This phenomenon apparently has major effects on the marine life of the Chirikov Basin. Apparently these waters are rich in crustacean plankton because crustacean feeders (auklets and Thick-billed Murres) are numerous in them, while they are virtually absent from Norton Sound and Shpanberg Strait. As the water slows in the Chirikov Basin, productivity settles out, supporting a magnificent benthic fauna.

The shallows along the eastern shore are occupied by warmer water of low salinity, the Alaskan Coastal Water. This water is dominated by the outflow of the major Alaskan rivers. It reaches its warmest and least saline conditions in inner Norton Sound and inner Kotzebue Sound. Alaskan Coastal Water moves northwest around the end of the Seward Peninsula sheering against the Bering Shelf Water and confined by it to a narrow coastal band (Fleming and Heggarty 1966; Coachman, Aagaard and Tripp, 1975). The northwest flow past western Seward Peninsula has carved the long gravel spit of Point Spencer that shelters Port Clarence. The Alaskan Coastal Water continues north through the Bering Strait, retaining its identity along the eastern shore.

The turbulence associated with passage through the Bering Strait produces unusually high productivity that supports a large number of auklets there. Organic debris again settles out as the water fans out and slows north of the Bering Strait, and thus there is more rich benthos in the southern Chukchi Sea. Bering Shelf Water turns northeastward beyond the strait, confining the Alaskan Coastal Waters against the Lisburne Peninsula; the birds from Cape Thompson take advantage of the feeding conditions where the masses shear past one another.

Bering Shelf and Alaskan Coastal Waters continue northward. Some of the Coastal Water moves northwest toward Herald Shoal; some moves northeast past Point Barrow where it overrides deep saline water from the Arctic Basin that intrudes up Barrow Canyon and Herald Canyon.

C. Marine Zoology

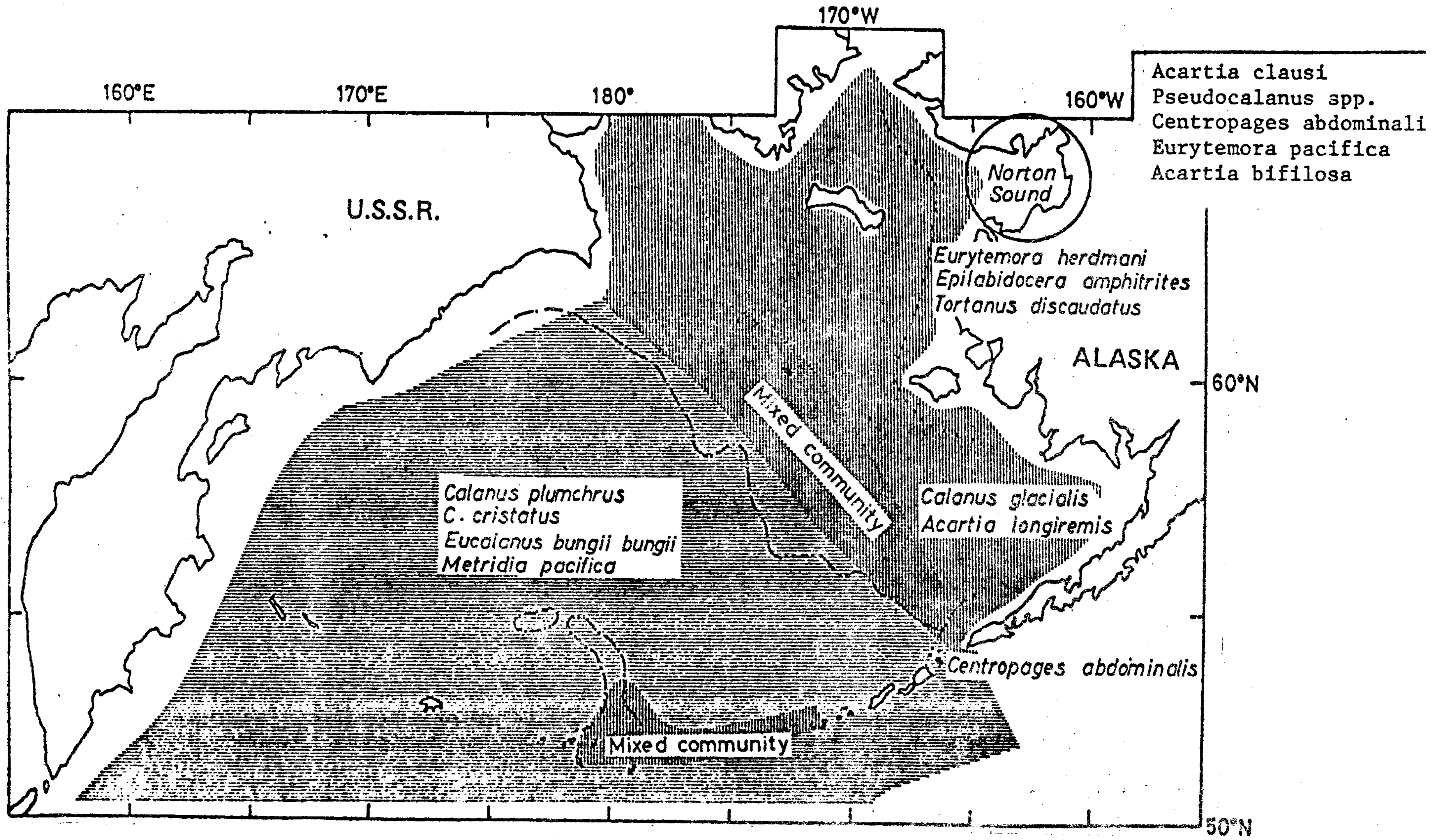
Herbivorous Copepods are probably the key group of energy transformers. They graze phytoplankton and are fed upon by the larger carnivorous crustacea and smaller fish which form the food base of the seabirds. The copepods characteristic of the northern Pacific and Bering Sea Basin are carried north over the shelf edge with everything else. These southern organisms are replaced progressively by northern species as the water moves on (Figure 11). Circumboreal species replace the Bering Sea forms by the time the water reaches the southern Chukchi Sea.

A copepod fauna characteristic of neritic waters is found in the Alaskan Coastal Waters. This fauna reaches clearest expression in inner Kotzebue Sound and Norton Sound, and elements can be traced through the southeastern Chukchi Sea and past Point Hope. Detritus from shallow, fresh water systems, such as lagoons, are important contributions to the productivity of these areas.

Southern species of pelagic Amphipods and Euphausiids also start the journey north in the deeper waters of the southern Bering Sea basin. These, too, are replaced by cold-hardy elements as the water passes through the Chirikov Basin into the southern Chukchi Sea.

Most of the species referred to in the text are illustrated in Plates 1 through 8 (pages 291-298) at the end of this report.

Figure 11.
Regional Distribution of Bering Sea Copepod Communities in the Upper Water in early to mid-summer, based on Motoda and Minoda, 1972, from Neimark 1979.
The circle surrounds Norton Sound.



The pelagic invertebrates and the larval stages of many fish make these productive waters turbid. Benthic organisms disperse to new habitat by releasing their eggs or free floating young into the water. The larvae of molluscs (bivalves and snails), starfish, sand dollars, sea urchins, and barnacles and the predators on them form a floating community. Small fish feed on these organisms; either young fish, or in many cases, fish small enough to prey on small forms throughout their lives. The shallow-water and bottom-feeding fish feed on detritus-feeding crustacea (Mysids), Oligochaete and Polychaete worms, and benthic molluscs. Thus, the transition is made to the active vertebrates.

The auklets, primary endemic seabirds of the Bering Sea, feed on pelagic crustacea, including herbivorous copepods and the Amphipods, Euphausiids, and Mysids which feed upon them. By feeding on lower trophic levels, auklets make use of an exceptionally abundant food supply. Their numbers are so large as to form clouds of auklets around the rubble fields of the islands in the Bering Strait, the western Aleutians and the Pribilof Islands.

Although there is a high density of fish and of benthic invertebrates in the Bering Strait region, the fish are not large enough to support a commercial fishery. Recently, exploratory hauls have been made to see whether a crab fishery is viable. The best-known fish of the region are the river-run salmon; the seabirds of inner Norton Sound make some use of the smolt as they leave the rivers in June.

As there are few fish species whose numbers and availability make them a resource for people, so there are a few "workhorse" species which support seabirds. Wherever seabirds have been studied in the north, the

Arctic Cod, which feeds on the bottom as well as on pelagic crustacea on the under surface of the ice, is the mainstay. In our region these, together with copepods and amphipods which have overwintered under the ice, provide the food in spring which allows female seabirds to lay eggs. Faunal diversity in this region is illustrated by two species of cod. Arctic Cod (*Boreogadus saida*), which is widespread all around the north, is abundant in the colder water and southern Chukchi Sea. In the warmer waters of Kotzebue Sound and especially Norton Sound it is replaced by Saffron Cod (*Eleginus gracilis*), a species limited to the Bering Sea region.

The relation between predators and their prey is generally a subject of special interest to ecologists. To some degree, seabirds catch the first fish they happen upon, but it is clear that murres prefer fish of definite shapes and sizes: not too small, not too large, not too fat, not too prickley. The murres of the region seldom use the abundant flounder. Similarly, sculpins with their sharp fins and spines are seldom used. One presumes this is because they are too hard to swallow. This interplay between selectivity and relative abundance of prey is shown also in the feeding of Saffron Cod and Rainbow Smelt in Norton Sound (Neimark, 1979). The two fish prey on the most abundant copepods, *Acartia*, but prefer *Eurytemora* as shown by comparisons of abundance in stomach contents and abundance in plankton hauls. Neimark found further that Saffron Cod fed preferentially on an abundant Cladoceran, *Evadne*, while Rainbow Smelt fed preferentially on the equally abundant Cladoceran *Podon*. In this way similar species will tend to segregate to avoid competition.

In the same way that the small fish prefer the copepod *Eurytemora*, the seabirds prefer Sand Lance. Nearly all species feed heavily on Sand Lance in July as soon as the fish moves into the region. Kittiwakes feed on Sand Lance less than two inches long; murres swallow the Lance of this size and carry larger ones, 4-8 inches long, "home" to the cliffs.

Early breakup of the ice is associated with early laying of clutches by seabirds, and larger clutches in some species. Crustacea and cod are the staples during egg-laying. As this food supply is diminished, birds turn to other prey until the Sand Lance come. The number of fish species used increases, and this effect is greatly emphasized in "poor" years when the staple species are scarce. The increase in diversity of prey during "hard" times reflects the principle that only a few species occur in large numbers. Most are relatively rare, so if the major food items (whether fish or crustacea) are reduced, seabirds will catch more diverse prey simply by catching the first fish they happen upon; lists of prey species tend to have a long "tail" of species found in less than five percent of the stomachs.

The food supply of seabirds in the Bering Strait is less diminished by intense cropping by feeding seabirds than one might suspect, because the ocean constantly moves past the breeding cliffs on its northward journey. Some regions of the Bering Sea are better endowed with renewing resources than others, and the Bering Strait region seems to be one of those.

III. Seasonality of Productivity and Timing of the Breeding Season

A. Over-Wintering, Productivity and the Ice Edge, and Spring Migration

Marine birds spend most of the year, from October through April, and most of their lives at sea away from their breeding sites. Waterfowl begin to gather in coastal marshes and lagoons for their southward migration in July; shorebirds move off the tundra to the tidal flats about the same time; murres begin to leave the cliffs as soon as their young fledge by jumping off the ledges in August. Young auklets move from their crevices to the sea in August. By mid-September most shorebirds have left and Pintails and Whistling Swans are moving out. Only kittiwakes and Pelagic Cormorants are lingering at their nesting sites. All move south to spend their winters feeding in areas where productivity is high and their habitat is relatively free of ice. Some, like waterfowl, may be relatively sedentary once they have arrived on their wintering grounds, but the seabirds appear to spend their winters in constant movement which allows them to exploit widely dispersed resources. Some, like Black-legged Kittiwakes, winter off the California coast. Most of the auklets and murres winter in the Gulf of Alaska or the southern Bering Sea. Some murres apparently winter in patches of open water north of the "ice front," the broad zone of drifting ice which marks the southern edge of the winter sea ice.

This wide dispersal relieves them of much of the competition which they experience at the breeding cliffs and which landbirds experience throughout the year.

While some species, like Tufted Puffins and Black-legged Kittiwakes, appear to winter over deep water, it appears that most of the seabirds

Table 1.
Primary Productivity in the Bering Sea in Winter, measured in milligrams of carbon produced per cubic meter and square meter of water, per hour; from McRoy and Goering, 1974.

	Surface (0-m) ($mg/m^3/hr$)	Water Column ($mg/m^2/hr$)
Open water south of ice	0.07	–
Water at ice front	1.98	7.44
Water under ice cover	0.23	2.35
Sea ice	6.75	0.34

nesting in our area winter over the Continental Shelf. Springer and Roseneau's report on murres (1980) provides a good illustration of winter behavior:

> During the late fall, northern murres tend to disperse over the Continental Shelf from the Anadyr Gulf to Bristol Bay. As winter progresses and an ice front zone in the Bering Sea becomes established, murres begin to concentrate along the front, moving with it as it advances. Smaller numbers of murres remain in open leads within the consolidated pack ice and some remain in polynyas and leads well north of the Bering Strait. ...Thus, the most important wintering zone for murres inhabiting the Chukchi and Bering Seas appears to include the annually variable Bering Sea ice-front zone, the Continental Shelf waters over the shelf-break zone and in southern Bristol Bay...
>
> In regions of the southern Bering Sea and Gulf of Alaska unaffected by ice cover, murres tend to disperse over Continental Shelf areas in the fall. Numbers appear to increase in the eastern Aleutian Islands including the Unimak Pass area, and farther to the east into the Gulf of Alaska. There is evidence that many murres move out of the Bering Sea through Unimak Pass and into the western Gulf of Alaska. ...

Sea ice and associated patches of open water play a major part in the lives of seabirds wintering in the Bering Sea. Although ice covers the northern Bering Sea in the winter south to the edge of the Continental Shelf, there are several important patches of open water. Polynyi and the leads which open in spring where stresses appear, e.g., Anadyr Strait, Bering Strait and off the Lisburne Peninsula are probably important for the survival over-winter of local populations of Beluga Whales and murres, and are of great importance to migrating sea mammals and early-returning seabirds, such as murres. Hood and Reeburgh (1974) suggest that polynyi are important in CO_2 exchange between the air and water; thus, they may play an important role in the high primary productivity which occurs under and at the edge of the ice (Table 1).

The following is from "The distribution, abundance and feeding ecology of birds associated with pack ice," Divoky et al., 1978:

Bering Sea

Ice begins to cover the northern Bering Sea in late November. Ice coverage is at a maximum in February and March when the southern edge of the ice is usually found near the edge of the Continental Shelf. Decomposition of the pack ice begins in April and continues until mid-June. This period (approximately six months) of ice cover is quite short compared to the Chukchi and Beaufort Seas where some ice is present throughout the year. Because almost all of the ice in the Bering Sea is first year ice it lacks extensive keels and pressure ridges found on ice in the Arctic. While the Bering Sea ice supports an in-ice phytoplankton bloom (McRoy and Goering, 1974), it is not known to have an under-ice fauna associated with its underside.

The Bering Sea ice "front" refers to the area of loose ice south of the more consolidated pack. It is composed primarily of bands of ice pans. Large floes are prevented from forming by swells on the open water to the south. When the wind is from the south the front is compacted against the main pack ice in a narrow band. When the wind is from the north the front becomes wider and more diffuse. In spring primary productivity is high in the water column under the ice front. At the same time productivity in the water column under the consolidated pack and south of the ice front is low (McRoy and Goering, 1974). For this reason the ice front is an important biological area supporting large numbers of birds and mammals (Fay, 1974).

Another feature of the Bering Sea pack ice of importance to birds is the open water associated with the islands found in the pack ice. These areas of open water (polynyi) are formed by the northerly winds which concentrate ice on the north side of islands and move ice away from the southern sides. These polynyi act as refugia deep in the pack ice.

Chukchi Sea

Ice covers the Chukchi Sea from November to May and coverage is almost complete during this period. Exceptions are the area of broken ice in the Bering Strait, a polynya associated with the shoreline in the Point Hope area (Shapiro and Burns, 1975) and a lead system northwest of Point Barrow. In late May the ice in the southern Chukchi Sea begins to decompose and most of the area south of Cape Lisburne is ice free by July. The edge of the Arctic pack ice is present in the northern Chukchi throughout the summer occurring anywhere between 70° and 72°N.

The ice in the Chukchi Sea apparently supports an in-ice algae bloom similar to those found in the Bering and Beaufort Seas. The multi-year ice in the Chukchi is known to support an under-ice fauna of zooplankton and arctic cod. The underside of multi-year ice has numerous keels and pockets which create a large surface area. Amphipods are known to concentrate on the ice underside presumably obtaining food from the plankton blooms occurring in and on the underside of ice (Mohr and Geiger, 1968; MacGinitie, 1955). Arctic cod prey on the amphipods and other zooplankton found next to the ice. The underside of multi-year ice is thus similar to a reef in that it has fish and invertebrate populations associated with a substrate. Little is known about this community. It is present in the spring and summer but nothing is known about the winter situation.

The water flowing north through the Bering Strait is a major influence on the Chukchi Sea. This water is warmer than Arctic waters and is the main reason for the rapid decomposition of ice in the southern Chukchi Sea. This water also supports high levels of primary productivity in summer (McRoy, et al., 1972) and makes the southern portion of the Chukchi Sea the most biologically productive waters in the Arctic Ocean off Alaska.

......

Pelagic bird distribution in the Bering Sea is determined by a complex set of parameters including distance from land, distance from shelfbreak, ice conditions, sea surface temperature and nature of the water column. As all of these factors have varying degrees of importance, the analysis of the Bering Sea data will be complex but extremely interesting. In last year's annual report an attempt was made to analyze the correlation of bird densities with distance from the northern and southern edge of the ice front. The analysis showed that certain species had affinities for specific parts of the ice front. Such an analysis is useful for predicting bird densities based on satellite photos. Cruises in 1977 showed, however, that the primary factor in determining the abundance of birds in and near the ice front is the presence of a two layered system: a cold water layer above a warmer layer. Studies by R.T. Cooney and other personnel from R.U. 246 found the bottom layer contained pollock (*Theragra chalcogramma*), capelins (*Mallotus villosus*), *Parathemisto libellula* and *Neomysis rayi*. Analysis of murre stomachs showed that the species mentioned above made up the bulk of the prey (Tables 5 and 6). A series of zooplankton tows taken during a 24-hour period by R.U. 246 showed that the fish and zooplankton migrate up into the water column at night. Because the layer of fish and zooplankton occurred at depths of 30 fathoms and more, murres may be feeding primarily in the early morning hours when prey are still present close to the surface with enough light to be visible. In order to test this assumption we collected bird specimens at three periods of the day: 800-1200, 1200-1600, 1800-2000 ADT. Common Murres (*Uria aalge*) fed most in the mid-afternoon (Table 5). Murres are visual feeders and can probably locate a maximum quantity of prey during maximum light penetration of the water column in early afternoon.

Note: Tables 5 and 6 of Divoky et al. are not included here.

Springer and Roseneau (1980) continue:

The spring murre migration occurs at a more rapid pace than does the fall migration and it consists of many large flocks of birds. Although few murres have been seen moving south, large numbers have been observed flying northward along the eastern coast of Kamchatka and in the western Bering Sea. Large flights are also common in the eastern Aleutian Islands, especially through Unimak Pass, and in Bristol Bay and the eastern Bering Sea. Murres are also known to pass St. Lawrence Island, the Diomede Islands, Point Hope and Wainwright in large numbers.

The spring migration of murres in the southern Bering Sea generally begins in early April when the ice-cover first starts to dissipate and to retreat northward. By that time many murres have attained their breeding plumage and densities of murres in the ice-front zone are lower than those commonly found there in March. Murres begin to arrive at St. Lawrence Island and at the southeastern Chukchi Sea colonies by mid-April, and numbers increase steadily through the next several weeks. In years when ice-cover in the Bering Sea does not reach its usual southern extent, murres may begin to arrive at Cape Lisburne during the latter half of March and early April.

Murres that enter the northern Bering Sea and Chukchi Sea in the spring fly over large areas of receding ice. By April a major lead system develops in the flaw zone between the shore-fast ice and the floating pack-ice and extends northward through Bering Strait to Cape Lisburne, thence northeastward to Point Barrow. This extensive system of leads and the large polynyas that persist south of the Lisburne Peninsula, the Seward Peninsula and Saint Lawrence Island provide abundant open water for resting and feeding murres long before the last ice cover is gone from the northern Bering Sea and the southern Chukchi Sea.

As indicated by this description, the northward movement of birds starts before the sea ice has broken up with the appearance of murres and King Eiders flying over largely frozen sea. The intensity of the movement and the progressive arrival of new species has been a source of great interest to a number of naturalists over the years. Traditionally, the Eskimos eagerly waited for the arrival of the first ducks to break what was often a late-winter fast.

Spring movement starts in April and continues into mid-June, by which time the ice has largely left the Bering Strait region. We will present the excitement of this movement by quoting from the report of A. Bailey, written after his experiences at Wales in the spring of 1922. Then we will summarize the report of the migration as seen by Prof. W. Flock using radar between 1969 and 1978. We believe that these reports emphasize how important the movements are as natural phenomena which deserve our respect and consideration during the breathless pursuit of industrial development. These quotations make a third point; the barrage of gunfire which meets the seabirds and waterfowl as the birds approach their breeding grounds has not diminished between 1922 and 1978.

Selections from Bailey's report of spring migration at Wales in 1922:

> April was a disagreeable month for a collector. There was no sign of spring and the winds blew with great violence...The first whale of the season was sighted on April 13; on the 24th I saw a flock of King Eider and three days later collected a Mandt's (=Black) Guillemot and a Kittlitz's Murrelet.
>
> It was not until May that the northwest winds calmed down and we were able to launch an oomiak. My notes for May 5th read:
>
> "The northwest winds which have been blowing for the past two weeks calmed down today...Was up at six and along the beach, or rather along the wall of the shore ice, and saw a good many eiders in flight, but all were out over the open lead...Time and again it seemed that there was a "mile of ducks" in sight. A few Glaucous Gulls and cormorants were seen during the day, and hundreds of Pallas's Murres,(Thick-billed the latter migrating north, following along the edge of the pack-ice. The breeze died until we had a "slick ca'm," and the shore ice was mirrored in the quiet waters...The eiders increased in numbers, and we shot until we were out of ammunition, our boat taking one hundred twenty..."
>
> Bird life gradually increased as the month wore along so that each day brought new forms. Spring seemed just around the corner one moment, and old man winter was much in evidence a short time later. The notes of May 20 give some indication of variable weather conditions and difficulties of collecting at Wales...
>
> "The wind switched to the south on the seventeenth, and we had quite a migration of birds, many eider going through. It blew and snowed so that collecting was very difficult. The natives were out until 2:00 a.m., and got a few ducks, including a pair of Steller's and a Spectacled. They said they saw a great many Ivory Gulls but not close enough to shoot them. Yesterday it still blew from the south all morning, but there were few birds migrating...We paddled back along the shore ice, as the wind was unfavorable for sailing, passed the Cape, and stopped on the floe opposite Tin City, where we made tea. There were a few Pacific Eider flying, but the channel was too wide for us to do much shooting. Old-squaws were plentiful along the shore-ice, where they seem to prefer to dive for their snails. We collected a fine male Spectacled Eider. He looked remarkably small, a case of camouflage, I presume, for his fantastic markings surely helped to make him blend into his surroundings. Also secured an American (=Black) Scoter of which there were a number among the Old-squaws, and an immature King Eider with his small sexual adornment on forehead and faint V-tracing on throat...

"I took a plover yesterday, a female with very large ovaries. She was very thin, doubtless due to her long trip, and was very tame. Saw a pair of Emperor Geese yesterday."

The majority of tundra nesting birds appeared the last few days of May. I collected an Asiatic Knot, the only one from this continent so far, and a Bristle-thighed Curlew. Experiences for the last few days of May and the first week of June were summed up as follows:

"May 31...A few Stellers and Pacific Eiders were seen, and numerous kittiwakes, Glaucous and Vega Gulls, and a single Bonaparte. Small birds, sandpipers and passerine were occasionally seen out over the ice, but none taken; also a few straggling flocks of Pomarine Jaegers.

"We camped all night on an ice cake...I collected a Vega (=Herring)/Gull, or at least a Herring with red eye-ring, three kittiwakes, two fulmars, a Pomarine Jaeger, some Old-Squaws, and a young King Eider...We had drifted far out by that time, being much nearer to the Diomedes than to Wales...Little life was seen out there, a Mandt's Guillemot or two, and the seals...We got in late and saw quite a few birds inroute, Old-squaws, a few Spectacled Eider and Pacifics/ (=Common) and several flocks of Emperor Geese at rest on the ice cakes...

"Many birds were migrating, shore birds being especially abundant, the Red-backs having come in in great numbers just overnight, and longspurs appearing everywhere in the last two days. Saw Pectoral and Baird's, and some species of little fellows which I did not identify, Golden Plover, and Aleutian Sandpipers, the latter fairly abundant, which was a surprise to me. I saw a couple of these on the 29th, and one the day before. A great many Snow Geese were in flight, and several were killed by the natives. I have secured one as a specimen, and also one male crane. Long-tailed Jaegers and Short-eared Owls are now working over the bare spots on the tundra, passerine and sandpiper calls fill the air; spring seems to be here for fair now, and the barren tundra is beginning to take on a different look...

"The brown of the dried grass here and there appeared, and flocks of sandpipers lined the pools, wavies (snow geese) circled over the village calling loudly, and cranes were seen continually passing.

"June 4. Left for walrus hunting in our big skin boat the afternoon of June 1st and headed for the Diomedes..."

Radar Studies of Bird Migration at Wales in 1978

Professor Flock and Joel Hubbard, his assistant, spent about a month at Wales and Tin City Radar beginning in mid-May 1978. Dr. Flock had made observations of bird movements on the radars at this site in 1969, 1970, and 1975.

They report the movements of seabirds and waterfowl as seen along the edges of the sea ice by Hubbard or as recorded on radar/ (in Drury *et al.* 1979). Movements of seabirds and waterfowl apparently coincided to some extent with atmospheric conditions which increased clutter caused by echos from sea ice; so the record of movements is somewhat confused. The two authors found that visual and radar observations confirmed each other as to when major movements occurred. The absence of equipment to make a continuous record and the difficulties with sea-ice-clutter led to the radar record's missing the start and other details of the movements.

Evidently the surges of migration coincide with south winds, but as the natives know, early flights (19-24 April and 5-15 May, 1978) may occur during periods of strong north winds. When the birds arrive flying against northerly winds, the barometric pressure has already started to rise and the winds will shift to the south. Apparently the birds "overfly" their favorable winds in their rush to get to their breeding grounds. The first flocks to arrive are huge. As the movements continue, the birds arrive in flocks that are smaller though more numerous.

A large migration of King Eiders had already passed in 19-24 April, 1978, before the observers arrived. The most numerous of the birds observed by Hubbard during May were murres. Murres numbers reached a peak in the period May20-5 June. The second most numerous species was Black-legged Kittiwakes whose movements reached a peak in late May.

The third most numerous was Black Brant in late May and early June. Common Eiders were fourth most numerous in this period and Oldsquaws fifth.

Spring movement of Sandhill Cranes and Snow Geese to Siberia occurred between May 5 and May 15, earlier than the movement reported by Bailey.

Additional waterfowl: Red-throated Loons, Yellow-billed Loons, Red-breasted Mergansers and Pintail passed steadily but in small numbers during the late peak 25 May-5 June. Some species which nest in small numbers along the northwest shore of the Seward Peninsula were not reported. These include Whistling Swans, Canada Geese, Emperor Geese, White-fronted Geese, Mallards, Wigeons, and Great Scaups.

Large numbers of shorebirds -- Dunlin, Semipalmated Sandpipers, Western Sandpipers, Long-billed Dowitchers and Red Phalaropes -- nest at Wales, but their arrival was not recorded by the radar or watches along the ice edge. Bailey's report reflected their sudden arrival as if out of nowhere. Shorebirds migrate at considerable heights. The movements of song birds were not recorded, either.

Many movements of seabirds were recorded from the observation spot at the edge of the shore-fast ice at Wales. Kittiwakes, murres, Least and Crested Auklets were seen flying in flocks both north and south from nesting areas on Fairway Rock and the Diomede Islands. Although many birds were seen flying close to the edge of the ice, many unidentifiable birds moving northward could be seen through a telescope at the limit of visibility.

B. Spring Breakup and the Start of the Breeding Season

In some years break-up in Norton Sound may take place as early as the first week of May, while in others it may occur as late as the third week of June. The timing of break-up is very important in the lives and reproductive success of the seabirds.

In many years melting of snow brings freshets of water down to the coast. Before break-up ponds form where this water is dammed at the mouths of rivers, providing resting places for migrants: loons, grebes, cormorants, Oldsquaws and Black Scoters.

When heavy sea ice is massed offshore, murres and kittiwakes come to the nesting cliffs for short periods. They hang around on the cliffs or below on the ice but spend as many days away at sea as at the cliffs during this pre-breeding period.

Once the main break-up of the ice in eastern and southern Norton Sound has begun, large patches of open water alternating with windrows of drifting sea ice pans persist for about a month. Sea ice drifts around in the main part of Norton Sound and the Chirikov Basin, while shore-fast ice persists along the south shore of the Seward Peninsula and inside Point Spencer. After the shore-fast ice moves, a large area of ice pans persists south of Nome and Sledge Island, extending past the east side of King Island, through the Bering Strait and northeastward past Shishmaref toward Kivalina. Windrows of ice sometimes drift south before the wind, but primarily to the north carried on the main currents. Common Seals, Ringed Seals and Bearded Seals haul out on the pans and the Walrus herds ride northward on the seaward edges of the ice-fields.

Shorly after the main ice in Norton Sound and the Chirikov Basin starts to break up, the ice moves out of the Bering Strait and the southern Chukchi Sea. Ice persists north of Saint Lawrence Island and in inner Kotzebue Sound some weeks after most of the sea ice has broken up and started moving north.

The timing of egg-laying is affected by the time of break-up and by the availability of nesting sites. Each year's schedule is different because these vary from year to year, with the spring's weather.

Snow drifts may persist into late June or early July on lee (south) slopes, covering rubble slopes, crevices, and in some cases, the faces of low cliffs where seabirds nest. We have seen puffins and auklets standing around on the snow waiting for their nesting sites to clear of snow. Snows blanketed the faces of the lower seabird cliffs near Southeast Capes on Saint Lawrence Island into mid-June 1977.

It appears that food supply is at a peak as the seabirds and waterfowl arrive. The birds move into an area where food has not been depleted during the previous six months and is, in fact, beginning its own period of dramatic increase associated with reproduction. Yet several aspects of early spring breeding behavior suggest that finding enough food is tremendously important: a) many birds delay their laying of eggs until a few weeks after break-up; b) during this period many are periodically absent from their breeding territories for several days; c) courtship feeding is almost universal. The food available under the ice as it disintegrates may supply the energy required to establish and defend territories and to lay eggs. In addition there seems to be a built in or programmed annual rhythm. Kittiwake clutches have been larger in years when laying began earlier and clutch sizes in kittiwakes and cormorants have been progressively smaller as laying is delayed by a late season. This trend is manifested by regional differences in clutch size and date of laying as referred to in Section IV (Tables 2 & 3). Reproductive potential for the whole season is lower when break-up is late and the season starts late.

In early spring when the ice front is not far from the cliffs, the food items brought to the cliffs at Bluff include a wide variety of fish, including Pricklebacks, Saffron Cod, and occasionally salmon, herring and small flounder. Kittiwakes are seen pecking at the surface of the water next to the ice pans or under the cliffs as if catching small crustacea.

Table 2.
Clutch Sizes of Black-legged Kittiwakes in Alaska, 1975-1977.

Place	Date Clutches Began	Date of Laying Peak	Clutch Size
Cape Lisburne	July 1	July 10-16	1.02
Cape Thompson	July 2	July 5-13	1.10
Cape Thompson (Schwartz '59-'61)	(June 21-25)		(1.88-1.92)
Sledge Island	June 20		1.53
Bluff Cliffs	June 19-25	July 4-12	1.16-1.20
Cape Pierce	June 18	June 20	
Saint Paul Island	June 29-July 5		1.37-1.46
Saint George Island	June 30-July 1		1.36-1.46
SW Gulf of Alaska Kodiak Island	June 5-10	June 12-17	1.56-1.96
NE Gulf of Alaska	June 1-10	June 17-23	1.76

Table 3. Comparison of Kittiwake Clutch Sizes in England, Russia and Alaska.*

	May				June				July	
	1st wk	2nd wk	3rd wk	4th wk	1st wk	2nd wk	3rd wk	4th wk	1st wk	2nd wk
England	2.3-2.8	2.0-2.4	1.9-2.3	1.8-2.0	1.8-2.0					
	(2.4)'	(2.3)'	(2.1)'	(1.9)'	(1.8)'	(1.5)'				
Russia	2.3		2.0	1.5						
Alaska					1.8	1.6-2.0	1.5-1.9	1.4-1.5	1.4-1.5	1.0

* Coulson and White (1961), Belopol'skii (1957), Uspenski (1956).

' Average clutch size.

Each year has periods of stormy, rainy weather and periods of fine weather during spring thaw and break-up. The timing of these has an important effect on breeding success. If long periods of stormy weather occur before nesting has begun, the birds stay at sea, thus delaying the beginning of clutches; this reduces their potential success. Some years when kittiwakes are building nests the weather is rainy. Rain softens the soil and stimulates plant growth. Our observations indicate that each time it rains, kittiwakes flock to grassy slopes and carry mud and plant materials to their ledges where they display ("choke") with their mate and incorporate the material into the nest platform. A dry year is reflected in small nests, many of which fail. Years that are wet in late June, and fair in July are reflected in large, well-built nests.

C. The Availability of Food and the Events of the Breeding Season

If long periods of stormy weather occur during the early days of incubation (July) parents leave the cliffs to look for food and may not be able to return because of storms at sea. Their absence leaves their eggs vulnerable to destruction by their own neighbors as well as Glaucous Gulls and ravens. Their absence also allows murres to take over sites on the ledges where previously kittiwakes had built.

Following the early spring peak of food associated with the ice front, there appears to be, during July, a period of decrease in the amount of food available. Unlike the picture for primary productivity, this part of the marine ecological scene is hazy. Springer and Roseneau (1977, 1978), working at Cape Thompson, have suggested that an initial food supply is gradually depleted and food becomes progressively harder to find. The situation becomes critical in years when food was already scarce early in the season. If the resources which the birds depend on for the next phase of their breeding cycle have not arrived when the eggs hatch, the year's efforts may end in disaster as they did throughout the Bering Strait region in 1976.

There appears to be a broad, high peak of food available when young of the year of crustacea, Copepods (Calanus), Amphipods (Parathemisto), and Euphausiids (Thysanoessa), and small fish (Ammodytes) either reach adequate size to be useful as food, or migrate into the area.

The arrival of Sand Lance (Ammodytes) in late July and early August, moving east along the south shore of the Seward Peninsula, northwestward between Kivalina and Point Hope or southward past Point Lay, is an event of major importance in the lives of all the fish-eating seabirds. When the fish fail to come, seabirds fail in their reproductive efforts. When the Sand Lance do come, nearly all the seabird young which hatch survive to leave the cliffs.

Sometime in late August, storms again lash the coast. A bad storm may eliminate all the nests and young below 50-75 feet on the cliffs. Small young may be exposed when, after several stormy days, their parents finally go to sea in search of food. The high probability that storms will occur in August selects those individuals who begin their reproductive activity as soon as possible after the ice clears.

The murres and auklets feed at the greatest distances from their cliffs, and their young leave the ledges first, in mid-August. The young kittiwakes leave next. The young puffins and cormorants, which feed at relatively short distances, stay longest in their nests. Springer and Roseneau (1980) said: "Many fall movements of murres...are accomplished by swimming rather than flying, as the adults continue to care for the growing young. As a consequence, the fall migration southward occurs at a somewhat slower rate than does the spring migration, and occurs in a somewhat more diffuse manner..."

This fall migration of hundreds of thousands of flightless murres, together with the late summer molt of scoters and eiders is a significant part of the annual cucle of marine birds. Oil on the waters of the Bering Strait Region during this time of year can contaminate astronomical numbers of birds.

In summary, the timing of breeding seems to be set early in the season by a combination of disappearance of ice and presence of a good temporary food supply. There seems to be a "thin" period during incubation of most birds, and the timing of young in the nest is set or influenced by the appearance of the annual crop of reproduction of that season. The end of the period, when seabirds are leaving the cliffs, is influenced by deterioration of the weather, the effects that has on the food supply, and the need for some to swim the long distance to the southern Bering Sea before the sea freezes over in November.

IV. Distribution and Abundance of Seabirds During the Breeding Season

A. Distribution at Sea

1. General introduction

The seabird cliffs and the associated waters of the Bering Strait region offer unusually favorable circumstances for studying relationships of predators to their prey and the effects on reproductive success. At the start of our project we planned to see whether we could contribute to clarifying that most intractable of all ecological problems, the relation between the availability of prey as perceived by the predator and the absolute numbers of the prey. The key to the study of this is transportation, but Nome is an exceptionally unfavorable place to arrange transportation.

The managers of OCSEAP have given first priority to intensive work in the Beaufort Sea and to the southeastern Bering Sea/Bristol Bay region. Partially as a consequence of this the priorities set for use of NOAA vessels meant rejection of our requests for logistic support for work at sea. The Arctic Project Office arranged for money to pay for chartering a fishing vessel, but the owners decided at the last moment they could make more money fishing. Further attempts to arrange for a boat through NARL convinced us that the boats available at Barrow were not safe to operate more than a few days away from a repair base. Nome has no repair facilities and no vessels available.

Nome is, furthermore, a difficult place to have as a logistical base. We had many difficulties not only with price gouging but with failure to live up to agreements. We found local arrangements for work at King Island and at Little Diomede Island to be very expensive, awkward to arrange, undependable, and the work was ineffective. We found it most effective to extemporize with the opportunities that arose, and to work with those people with whom we could deal pleasantly and upon whom we could depend. We did not learn fast enough what we could depend on and what we could not. Therefore, we gravitated to one season of work at King Island and Little Diomede, short visits to Sledge Island in several years, surveys of eastern Norton Sound and, especially, the detailed studies at Bluff Cliffs, an ideal location, where we could depend upon the support of the Olson Air Taxi Service from Golovin (see Section V).

We made every available use of aircraft to survey the distribution of birds over the waters of Norton Sound and the Saint Lawrence Island waters, from the island north through the Bering Strait. We believe that these air surveys are the major contribution of our work; again, they would not have been possible without the generous cooperation and personal involvement of the Olsons. In this section we make some general remarks about how and why birds are distributed at sea and present specific observations about several bird cities made in the course of our studies.

2. Behavior of seabirds

A major characteristic of seabirds is their mobility. Mobility allows an organism freedom to crop several resources and habitats, and hence, to become relatively emancipated from the direct coupling to simple physical and chemical systems which characterizes organisms at the base of food chains. The increased expenditure of energy involved allows greater control over their lives.

Birds do not think and form hypotheses; certain members of the population survive and reproduce because they have done the right thing, not because they understood what they were doing. Those that succeed have responded correctly to a few features of their habitat which reflect the distribution, abundance and behavior of their major food sources. Those that do not cannot try something new; they can only do the same things over again until they succeed or die. A new adaptation emerges when some offspring are programmed in a new way, not by an individual changing its behavior. Therefore, to understand how seabirds use their environment we need to find simple clues to which the birds may respond with the behaviors for which they are programmed.

Clues can come from experience that certain flights have produced results; e.g. flights in certain directions for certain distances or flights toward loose ice pans, or toward streaks of calm water, or to the muddy outflow from river-mouths. Programmed behavior includes such things as techniques of feeding by skimming, or plunge diving (Ashmole, 1971; Nelson 1978), how deep they dive and what sorts of search image they have for their prey.

3. Correlation of the distribution of birds at sea with features of the marine habitat

One of the most widely observed correlations of feeding seabirds with water character is their association with upwelling systems. Murphy (1936), Ashmole and Ashmole (1967), Shuntov (1972), and Brown (in press) have discussed the association of major seabird aggregations with regional upwelling systems. Ashmole and Ashmole pointed out association with upwelling cells in equatorial currents and countercurrents. Brown described an association of Red

Phalaropes, Sooty and Great Shearwaters, Herring Gulls, Great Black-backed Gulls, Bonaparte's Gulls and Northern Phalaropes with cells of circulation where strong tidal currents meet steep underwater ledges at the mouth of the Bay of Fundy in southeastern Maritime Canada. He refers to the streaks of calm water along which the birds gather. Other signs exist in our area: contrast of smooth and ruffled water, floating debris, and most conspicuously drifting pan ice. We have found Crested Auklets and Aleutian Terns associating with "streaks" in Norton Sound and murres associating with similar "streaks" or "fronts" in the Bering Strait.

Divoky and Watson (1976) and Nettleship and Gaston (1978) report concentrations along windrows of ice. In our experience the ice front is of major importance. The auklets, which, later in the year, are largely restricted to the western waters, occur among the windrows of ice in spring time along the edge of Alaskan Coastal Waters.

Hartley and Fisher (1936) and Uspenski (1958) report seabirds feeding at places where food is concentrated at the edges of water masses. Hartley and Fisher in Spitzenbergen found Fulmars, Thick-billed Murres, Black-legged Kittiwakes, Atlantic Puffins and Arctic Terns feeding on Euphausiids and Amphipods where meltwater flows from the face of a glacier displacing surface water so that subsurface water upwells to replace it. Uspenski reported Thick-billed Murres feeding at fronts between fresh water streams and salt water in narrow fjords at Novaya Zemlya.

Powers (pers. comm.) has found concentrations of Phalaropes and Wilson's Petrels along the edge of the Continental Shelf in the New York Bite and in an area of cold water upwelling in the Great South Channel between Nantucket Shoals and Georges Bank. He also has shown that the concentrations of Fulmars lie along the northern edge of Georges Bank even though these birds are notorious followers of fishing boats which crisscross the whole bank.

Bedard (1969b)reported auklets feeding northwest of Saint Lawrence Island where cold water upwells upon passing through the Strait of Anadyr.

4. The general pattern of distribution of birds in the Bering Strait Region

The most conspicuous feature of the distribution of seabirds in the Bering Strait region is that there is a lack of birds in Norton Sound and a concentration of birds in the Chirikov Basin (Shuntov 1972; and Figures 12.1a-12.5h) This pattern is evident in all our samples of distribution of birds at sea. West of a line drawn from the east end of Saint Lawrence Island to Cape Spencer, we often saw as many as 200 birds in a five-minute period during air transects, and flew few periods when we saw no birds at all. In Norton Sound, east of this line, one must be within 10 km of the cliffs at Sledge Island or 20 km of the cliffs at Bluff to find birds at all, let alone concentrations as high as one finds 100 km offshore to the west.

The numbers of seabirds seen is highest in the deeper water on the west end of Saint Lawrence Island, west of King Island and in the Bering Strait. The differences reflect primarily abundance of zooplankton feeders (Thick-billed Murres, Parakeet Auklets, Crested Auklets and Least Auklets). Fish-eating species (Pelagic Cormorant, Glaucous Gull, Black-legged Kittiwake, Horned Puffin, Tufted Puffin) are relatively evenly distributed. The changes in distribution of birds at sea during the season and the characteristic distribution of the major species is shown on maps and discussed in Appendix V.

Figure 12. Maps of the Distribution of Birds at Sea based on aerial transects conducted in 1976, 1977 & 1978.

Maps of all seabird species seen during each transect are presented in full detail in Appendix V, "The Distribution of Birds at Sea". We have chosen significant, representative maps for inclusion here in the main body of the text.

Figure 12.1 ICE MAPS: Representations of the distribution of sea ice.

12.1a Chirikov Basin - northeastern Bering Sea; early June.

12.1b Chirikov Basin - northeastern Bering Sea; mid-June.

12.1c Chirikov Basin - northeastern Bering Sea; late June.

12.1d Chirikov Basin, along transect route flown on June 8, 9 & 12, 1978.

12.1e southern Chukchi Sea, along transect route flown on June 9, 1978.

12.1f southern Chukchi Sea, along transect route flown on June 24, 1977.

12.2 MURRES - Distribution at Sea

12.2a Chirikov Basin, sea ice present (see Fig. 12.1a, 12.1b & 12.1d), June 8, 9 & 12, 1978.

12.2b Chirikov Basin, July 6, 7 & 8, 1978.

12.2c Chirikov Basin, July 31 & August 16, 17 & 18, 1978.

12.2d southern Chukchi Sea, sea ice present (see Fig. 12.1e), June 9, 1978.

12.2e southern Chukchi Sea, sea ice present (see Fig. 12.1f), June 24, 1977.

12.2f southern Chukchi Sea, July 7, 1978.

12.2g Chukchi Sea, July 25, 27 & 29, 1978.

12.2h Chukchi Sea, August 18 & 19, 1978.

12.2i Norton Sound, July 6, 1978.

12.2j Norton Sound, August 16, 1978.

12.2k Norton Sound, Surface Transects, August 5-13, 1976.

12.3 ALL AUKLETS - Distribution at Sea of Unidentified + Least + Crested + Parakeet Auklets

12.3a Chirikov Basin, sea ice present (see Fig. 12.1a, 12.1b & 12.1d), June 8, 9 & 12, 1978.

12.3b Chirikov Basin, July 6, 7 & 8, 1978.

12.3c Chirikov Basin, July 31 & August 16, 17 & 18, 1978.

12.3d southern Chukchi Sea, sea ice present (see Fig. 12.1e), June 9, 1978.

12.3e southern Chukchi Sea, sea ice present (see Fig. 12.1f), June 24, 1977.

12.3f southern Chukchi Sea, July 7, 1978.

12.3g Chukchi Sea, July 25, 27 & 29, 1978.

12.3h Chukchi Sea, August 18 & 19, 1978.

12.4 HORNED PUFFINS - Distribution at Sea

12.4a Chirikov Basin, sea ice present (see Fig. 12.1a-12.1d & 12.1f), May 20, 1977; June 4, 1976; June 8, 9 & 12, 1978; and June 22, 23 & 24, 1977.

12.4b Chirikov Basin, July 6, 7 & 8, 1978.

12.4c Chirikov Basin, July 31 & August 16, 17 & 18, 1978; and August 21 & 21, 1977.

12.5 BLACK-LEGGED KITTIWAKES - Distribution at Sea

12.5a Chirikov Basin, sea ice present (see Fig. 12.1a-12.1d & 12.1f), May 20, 1977; June 2, 1977; June 4, 1977; June 8, 9 &12, 1978; and June 22, 23 & 24, 1977.

12.5b Chirikov Basin, July 6, 7 & 8, 1978.

12.5c Chirikov Basin, July 31 & August 16, 17 & 18, 1978; and August 21 & 22, 1977.

12.5d southern Chukchi Sea, sea ice present (see Fig. 12.1e), June 9, 1978.

12.5e southern Chukchi Sea, sea ice present (see Fig. 12.1f), June 24, 1977.

12.5f southern Chukchi Sea, July 7, 1978.

12.5g Chukchi Sea, July 25, 27 & 29, 1978.

12.5h Chukchi Sea, August 16, 17 & 18, 1978.

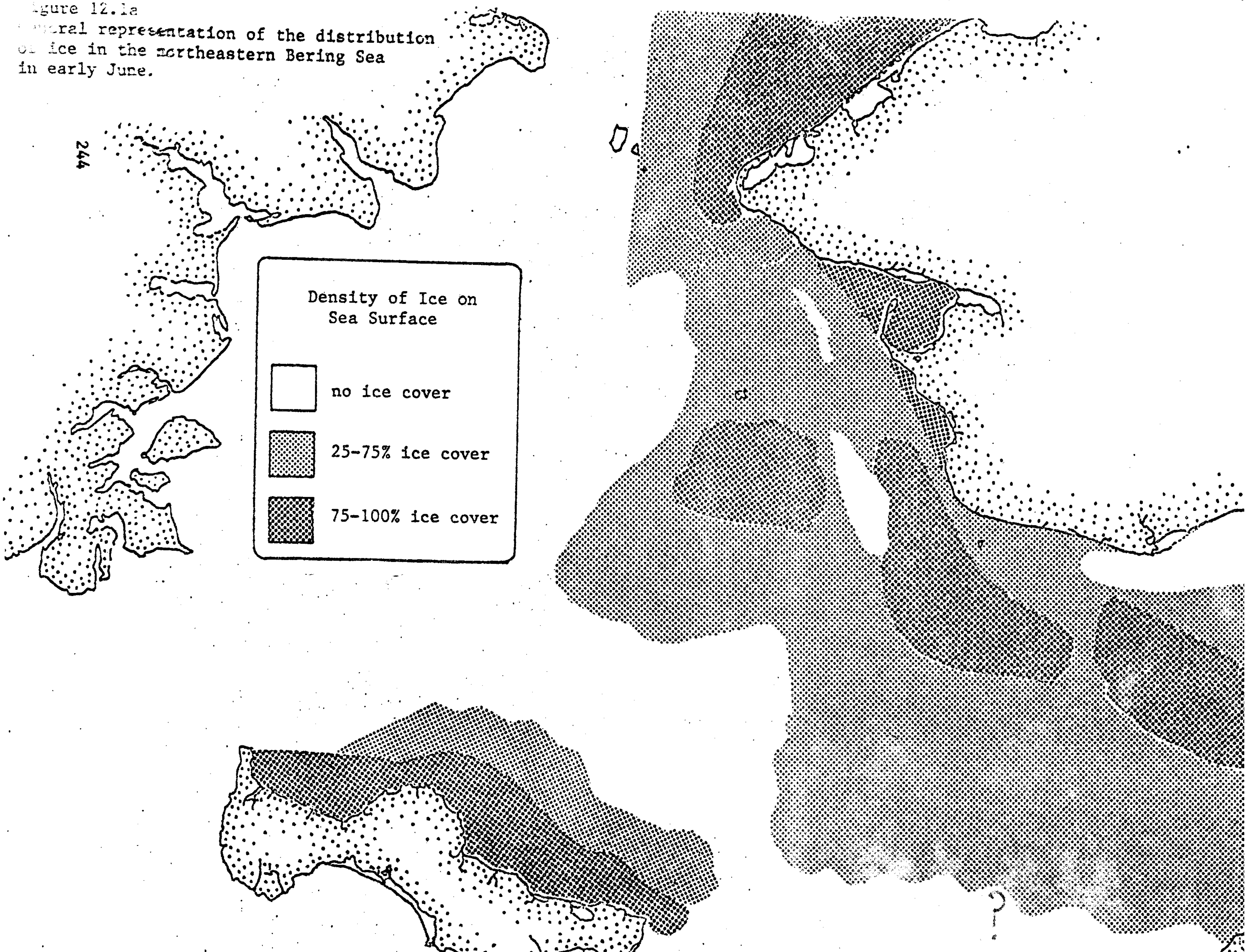


Figure 12.1a
General representation of the distribution of ice in the northeastern Bering Sea in early June.

gure 12.1b
neral representation of the distribution of ice in the northeastern Bering Sea in mid-June.

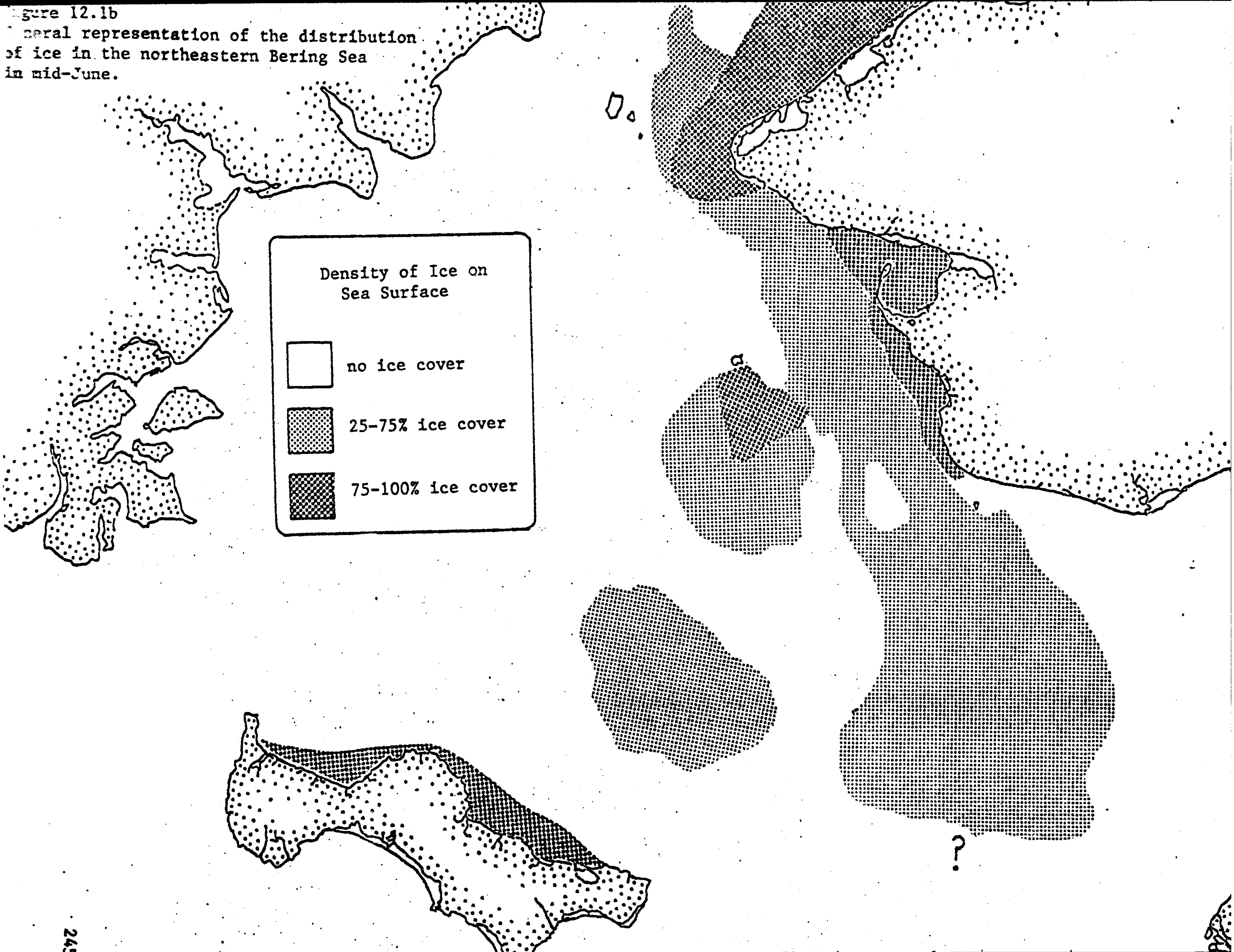


Figure 12.1c
General representation of the distribtution of ice in the northeastern Bering Sea in late June.

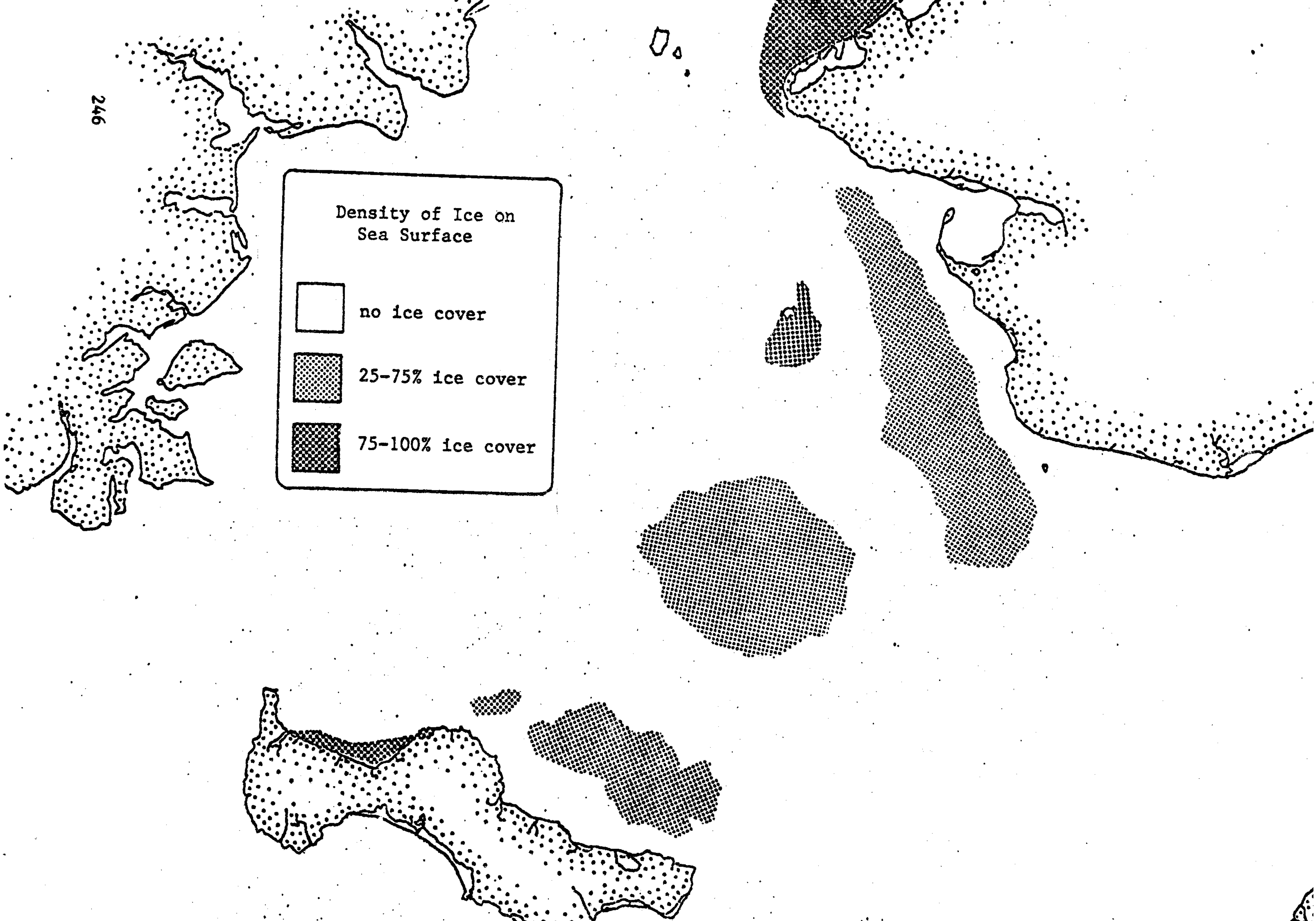


Figure 12.1d
Representation of ice coverage along route of surveys run on June 8, 9, 12, 1978 (Drury et al.).

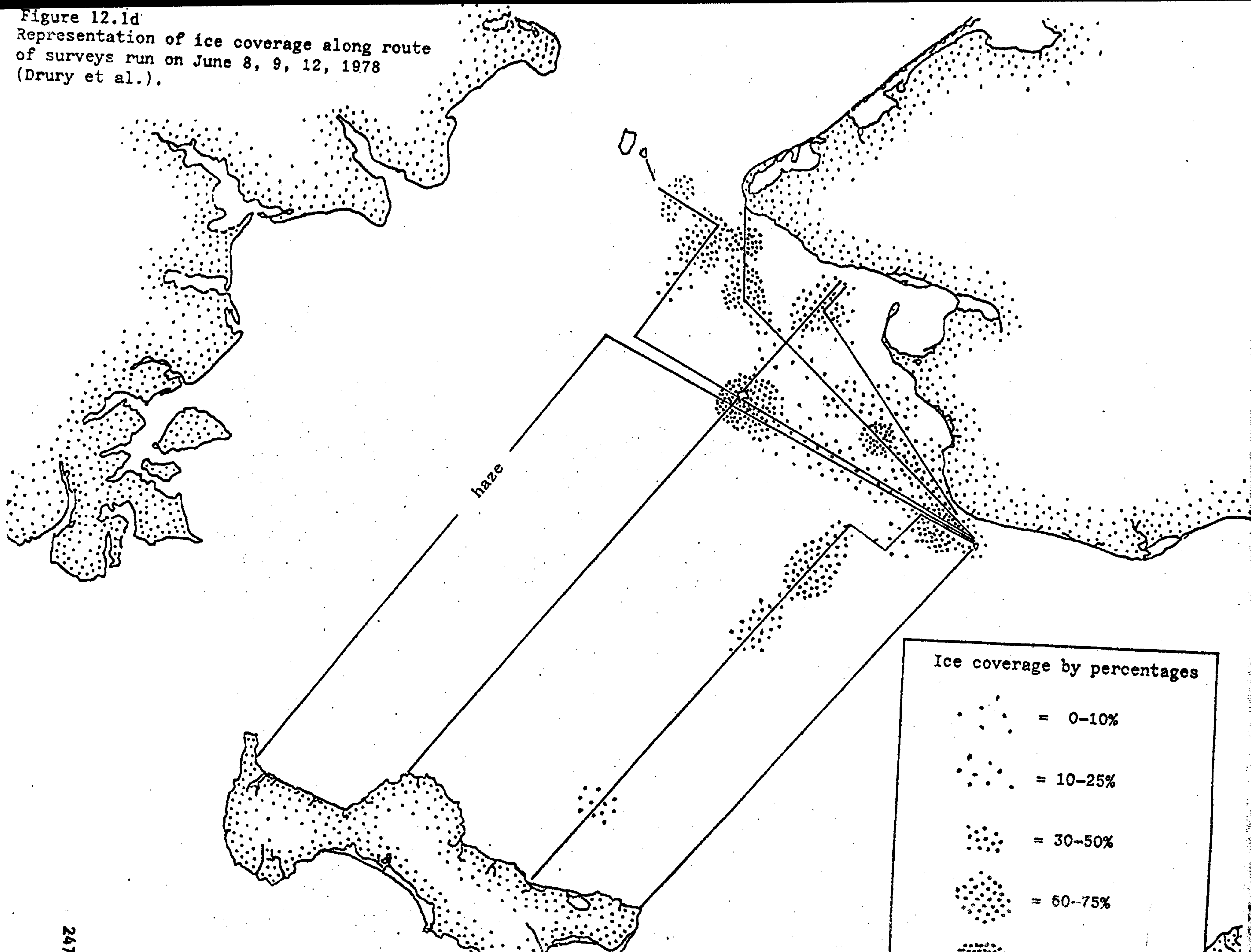


Figure 12.1e
Representation of ice coverage along route of surveys run on June 9, 1978 (Drury et al.).

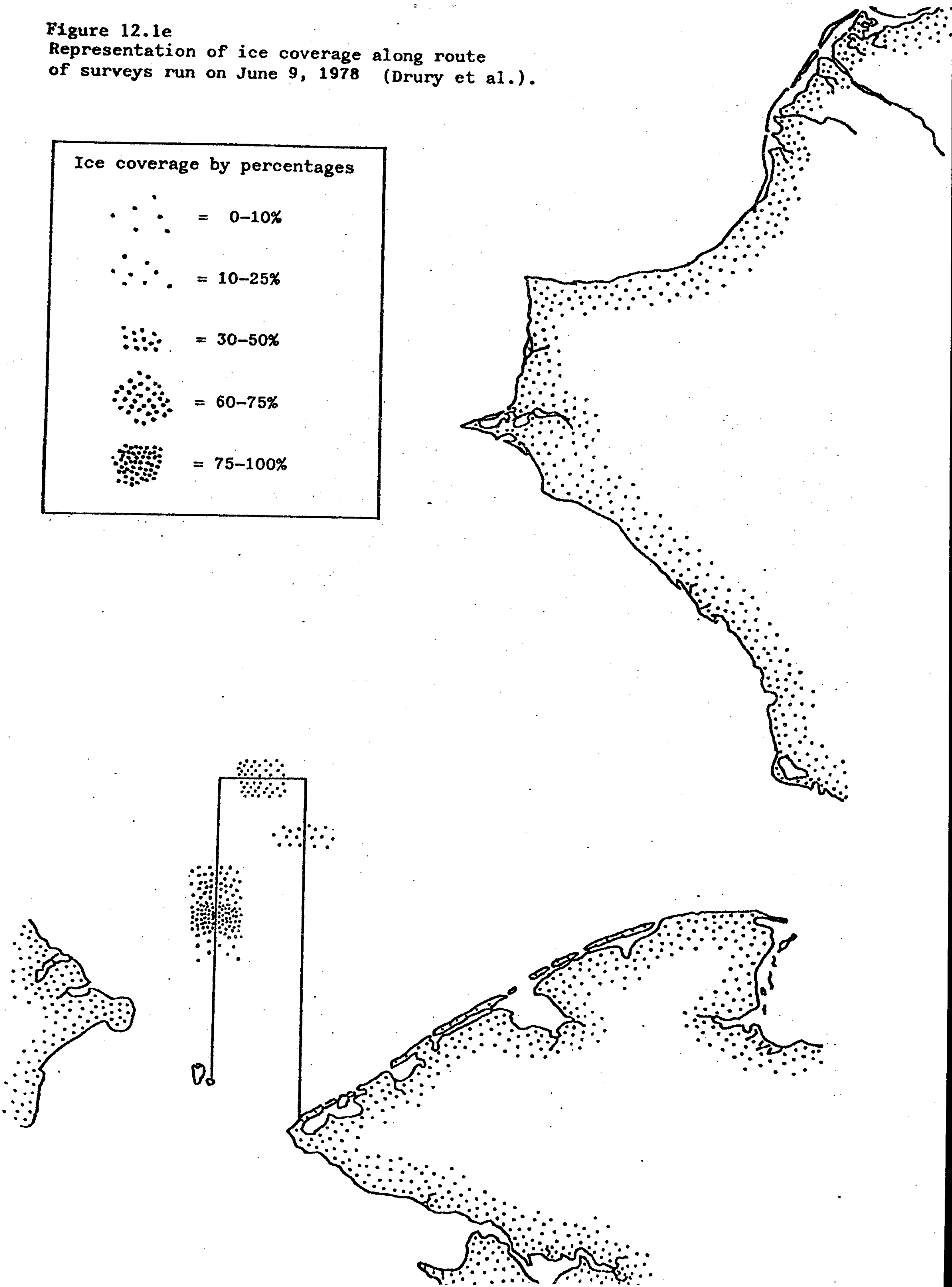


Figure 12.1f
Representation of ice coverage along route of surveys run on June 24, 1977 (Drury et al.).

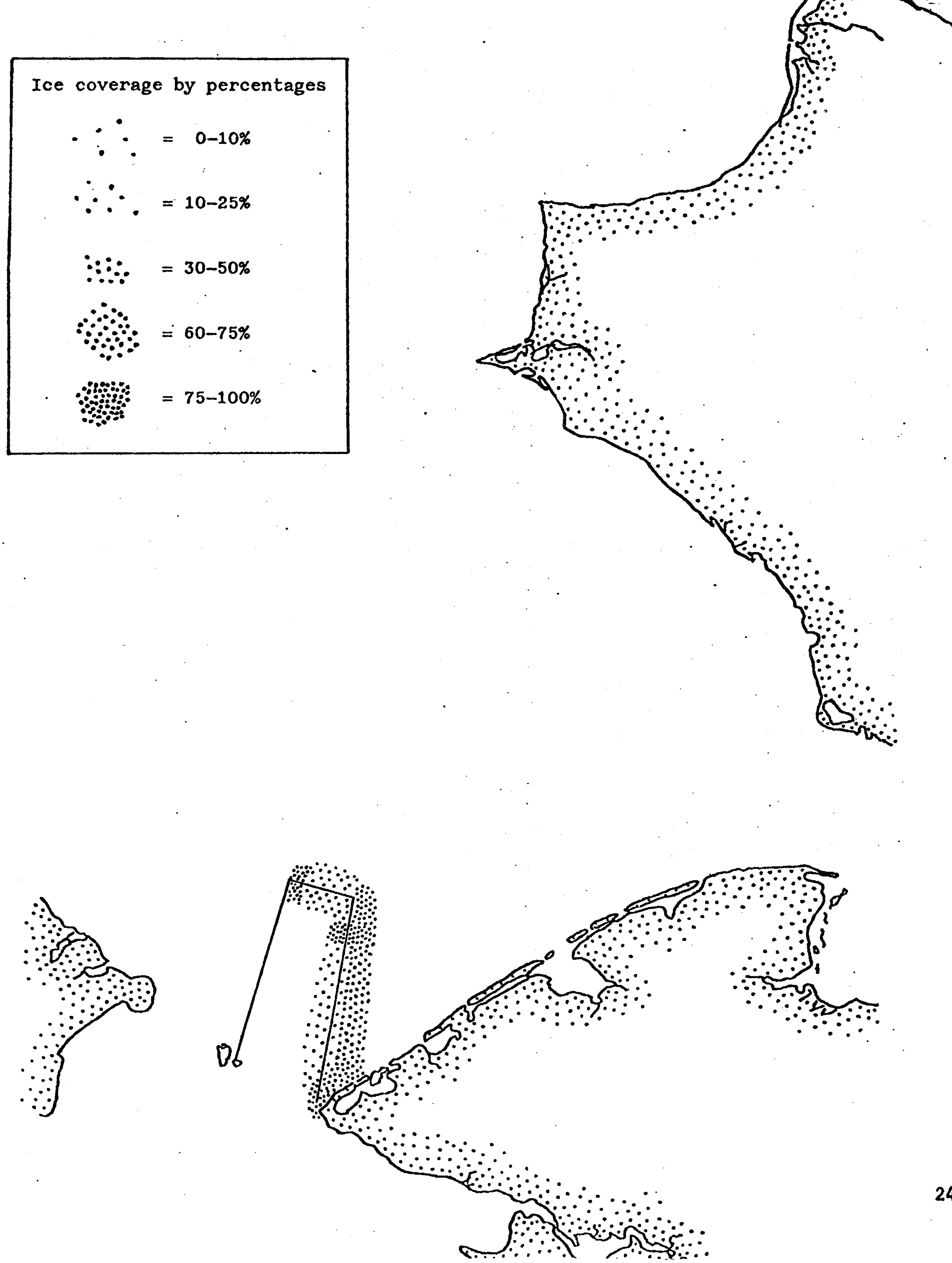


Figure 12.2a
Murres seen during aerial transects in the presence of sea ice on June 8, 9, 12, 1978 (Drury et al.).

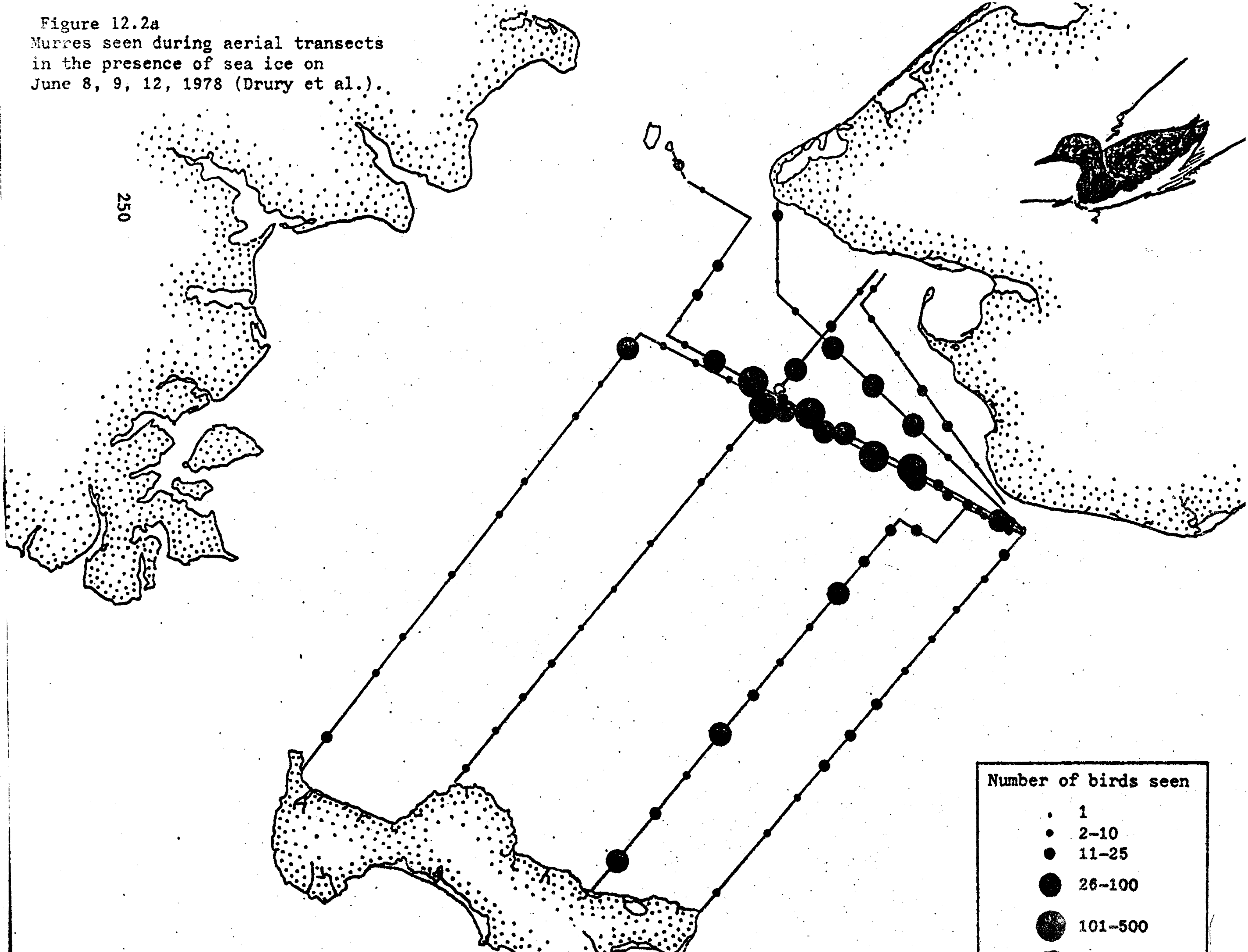


Figure 12.2b
Murres seen during aerial transects on
July 6, 7, 8, 1978
(Drury et al.).

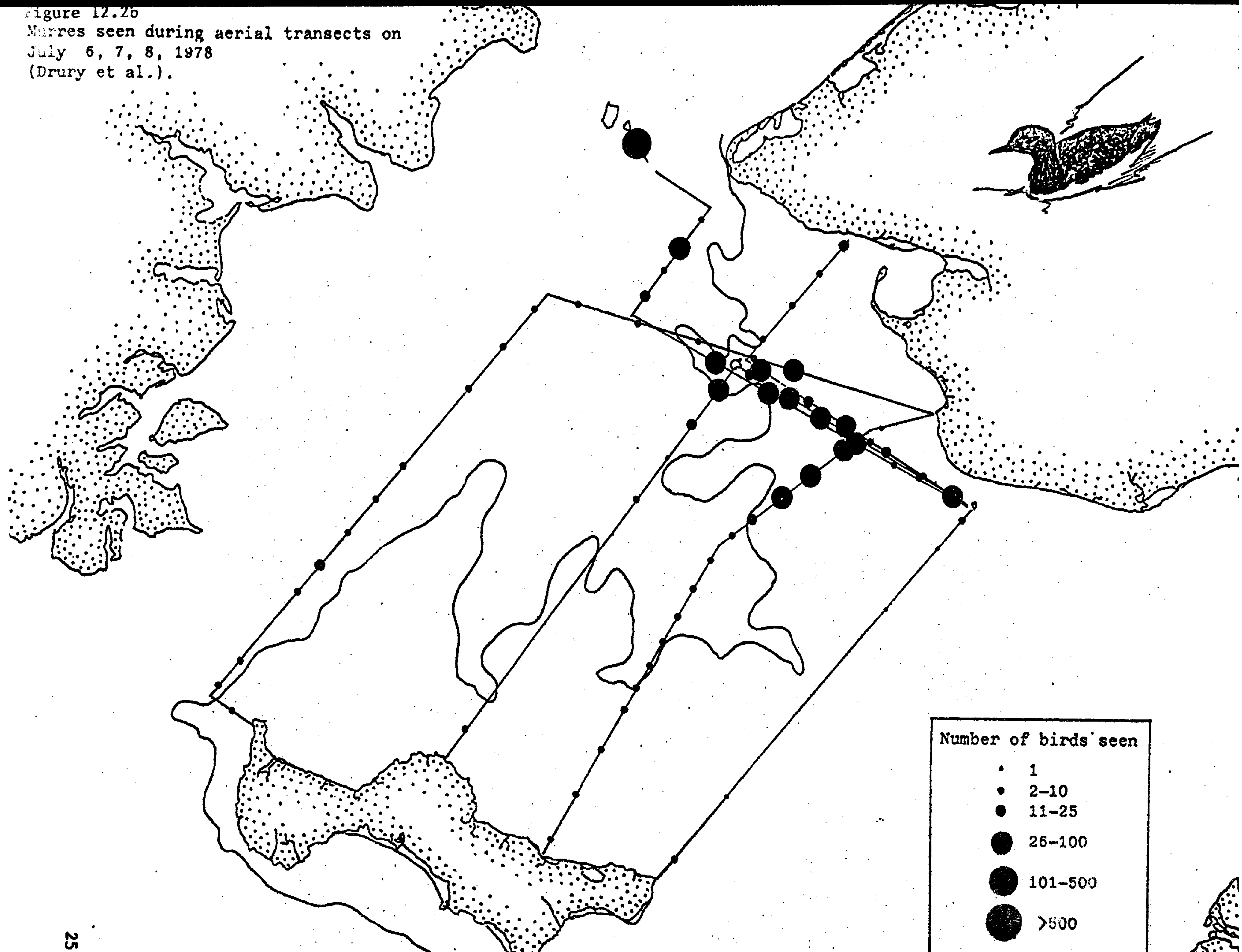


Figure 12.2c
Murres seen during aerial transects on July 31 and August 16, 17, 18, 1978 (Drury et al.).

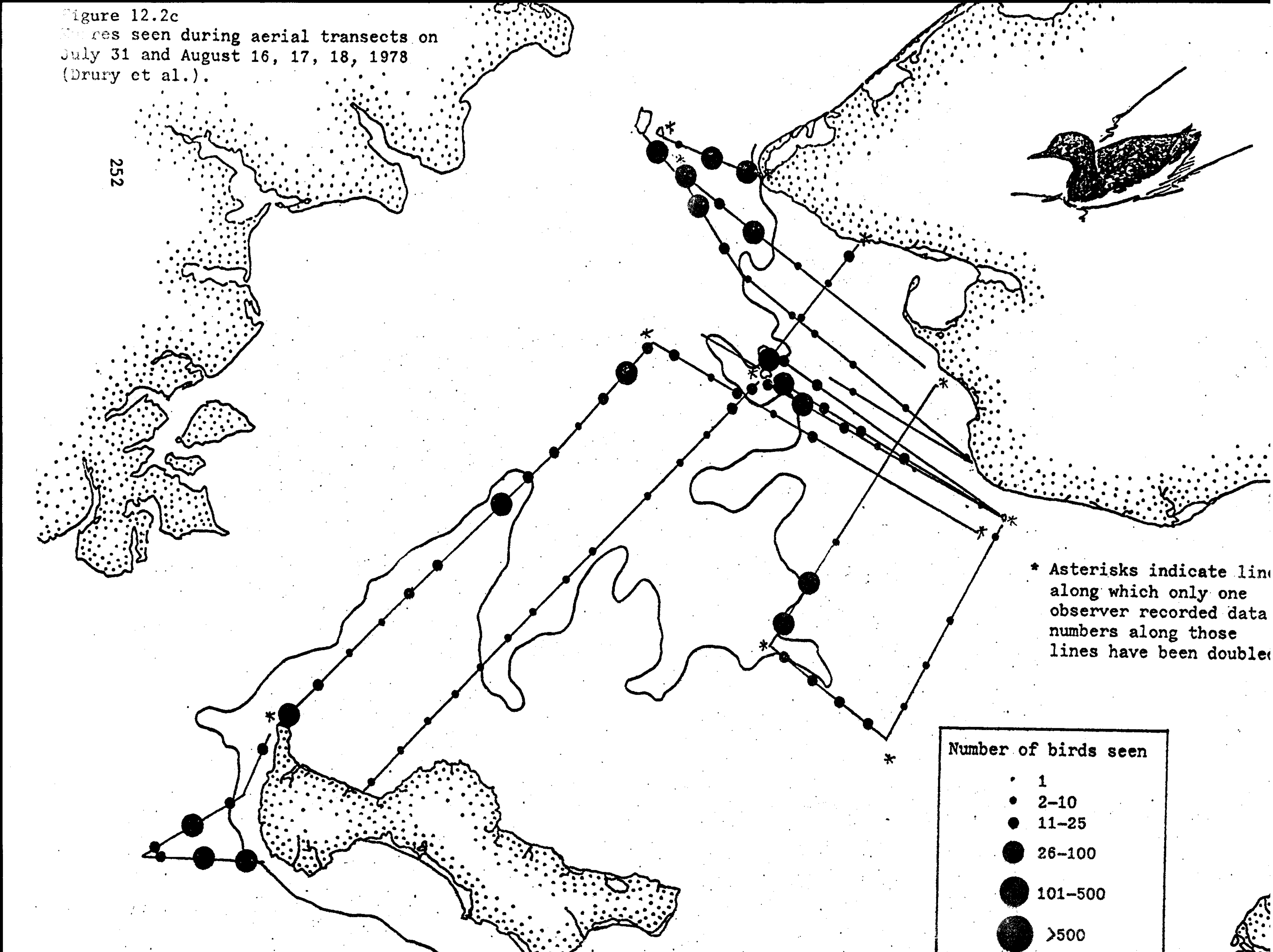


Figure 12.2d
Murres seen during aerial transects in the Chukchi Sea in the presence of sea ice on June 9, 1978 (Drury et al.).

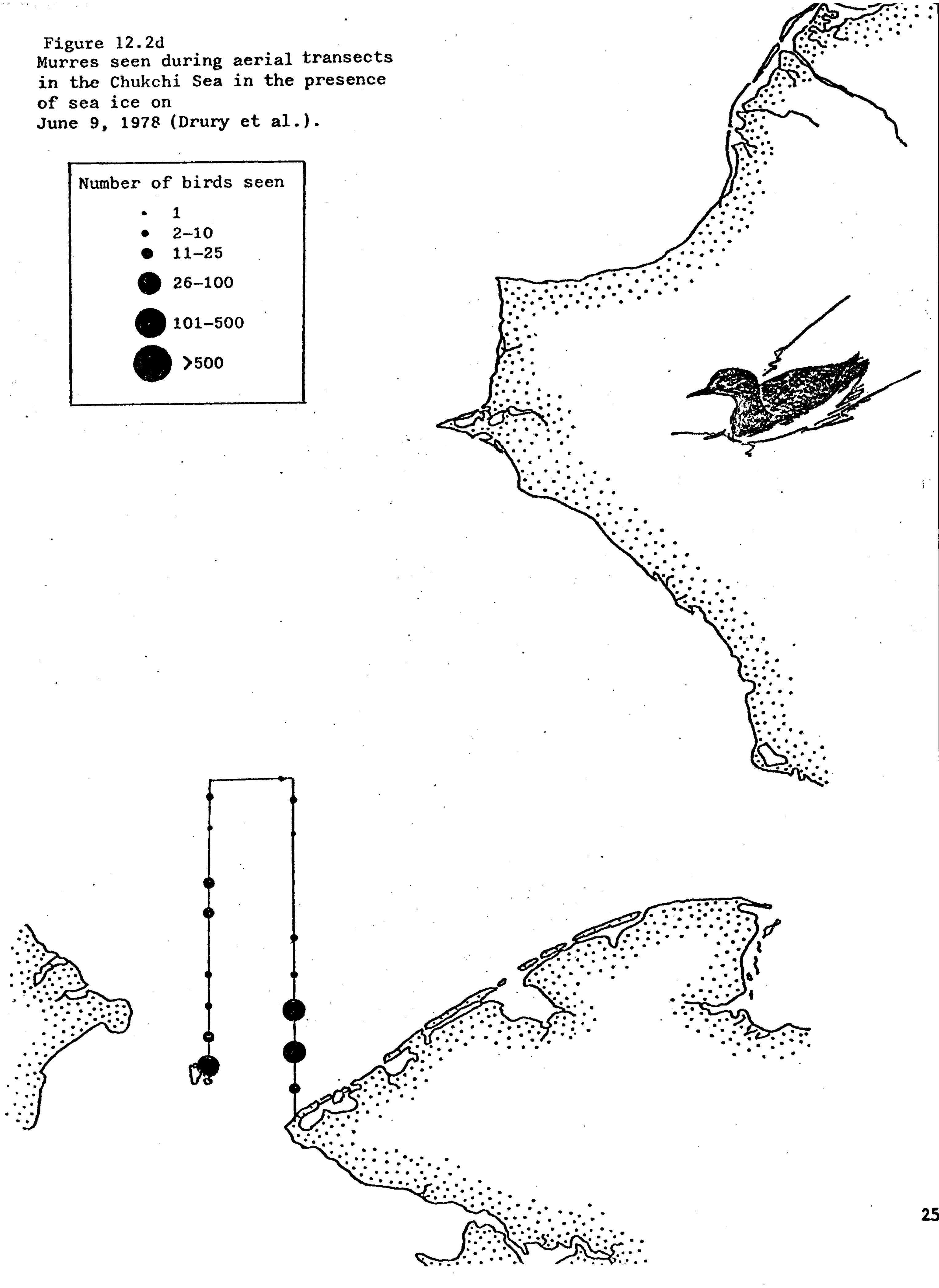


Figure 12.2e
Murres seen during aerial transects in the Chukchi Sea in the presence of sea ice June 24, 1977 (Drury et al.).

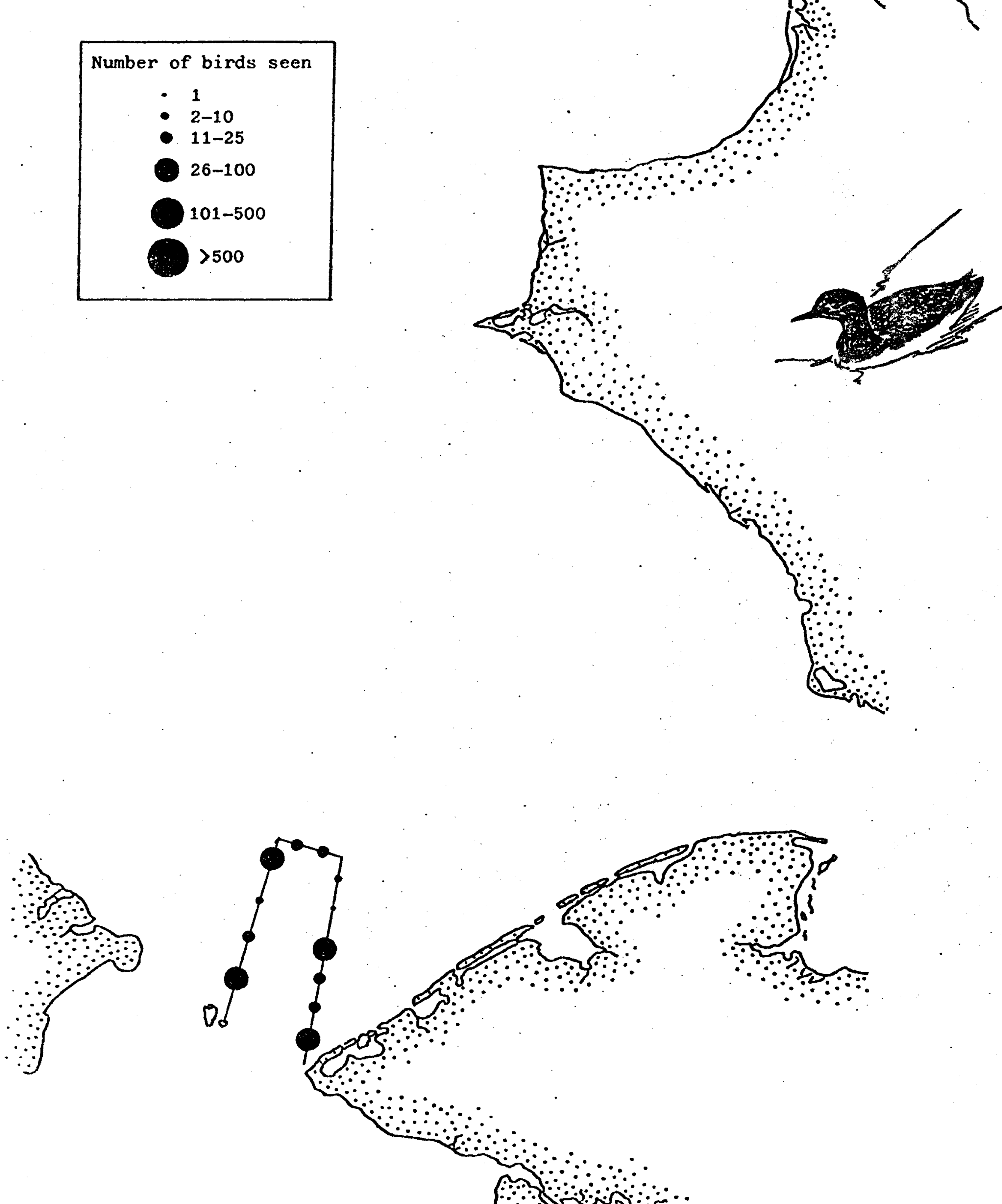
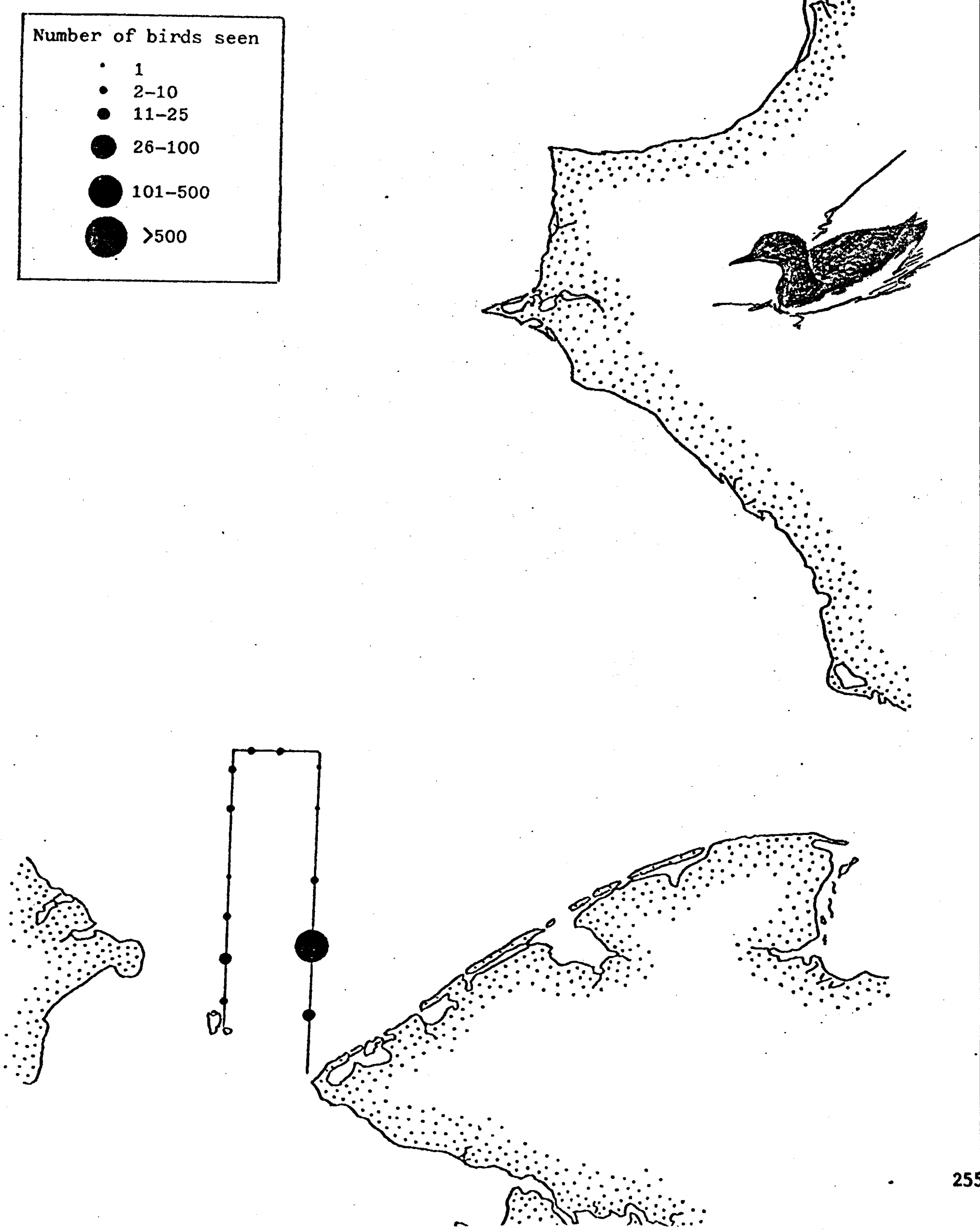


Figure 12.2f
Murres seen during aerial transects
in the Chukchi Sea
July 7, 1978 (Drury et al.).



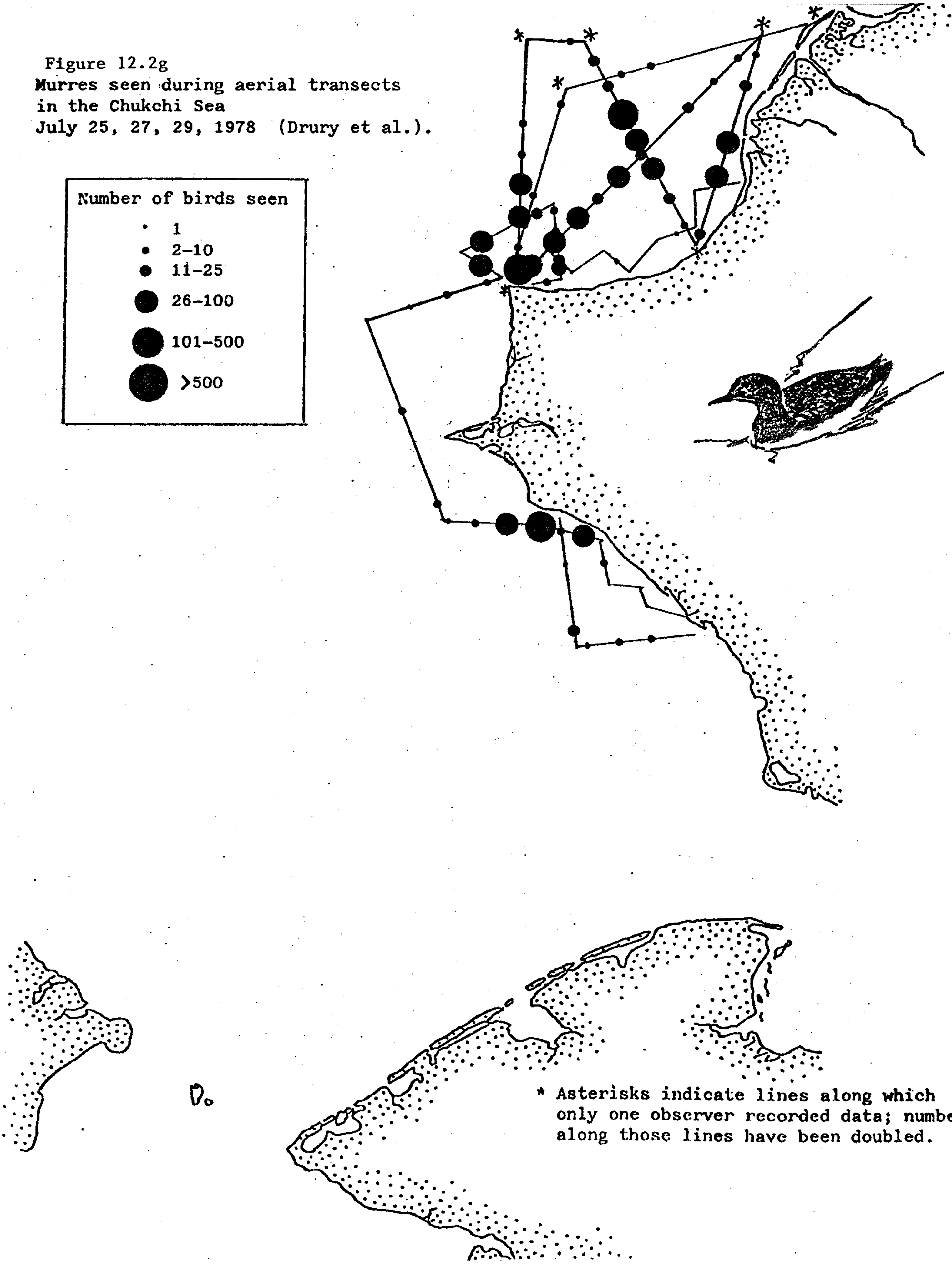
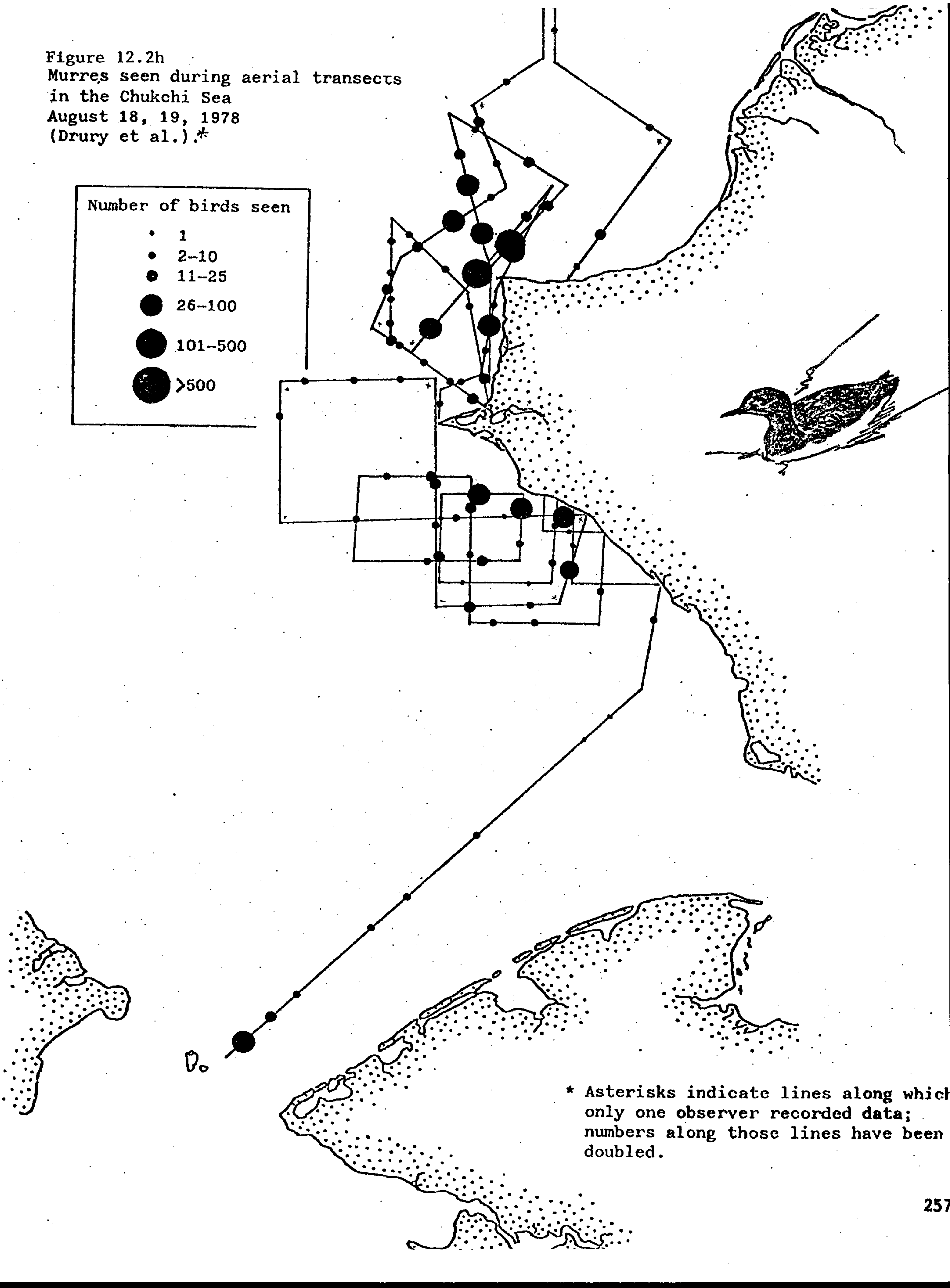


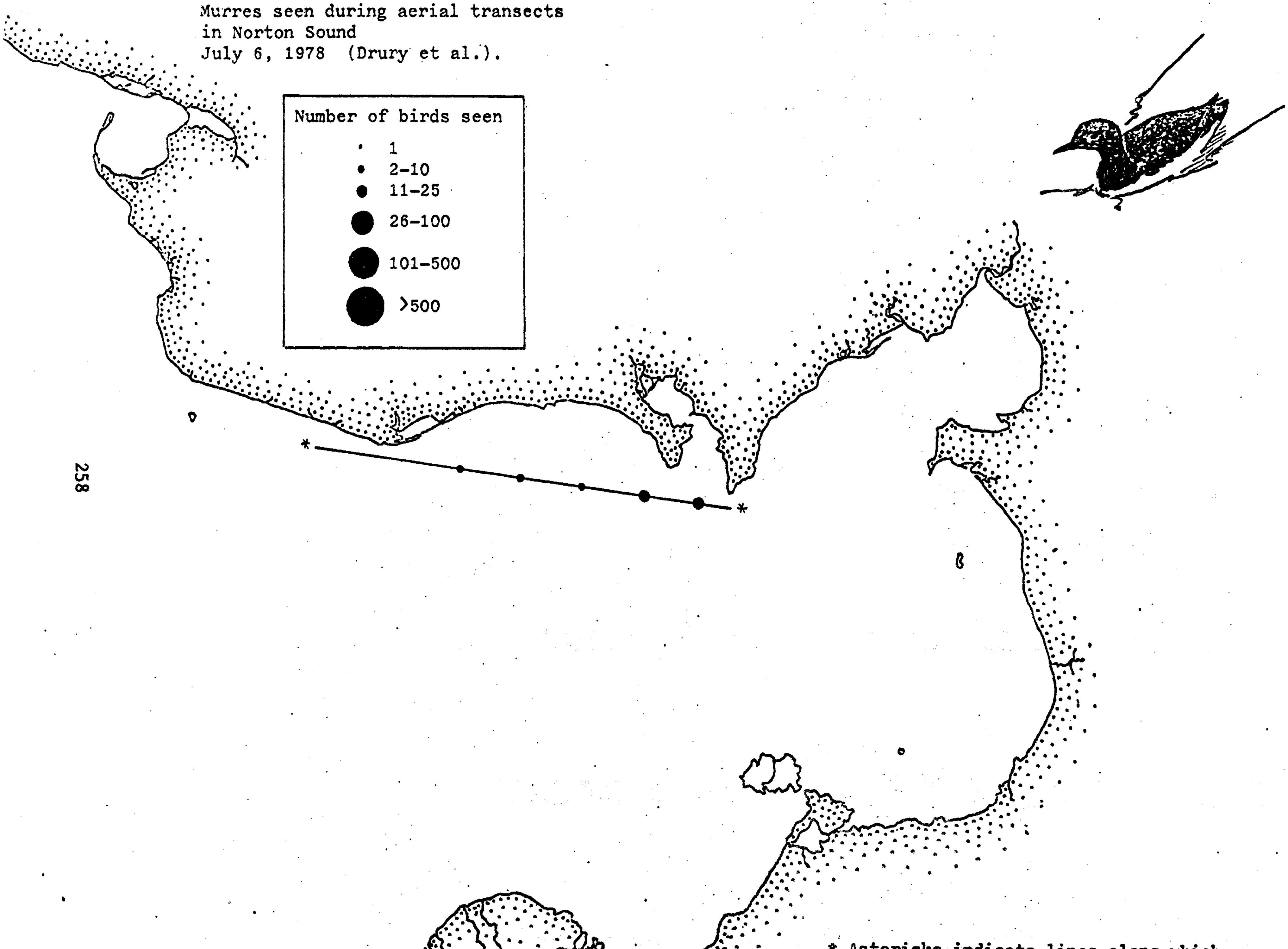
Figure 12.2g
Murres seen during aerial transects in the Chukchi Sea
July 25, 27, 29, 1978 (Drury et al.).

Figure 12.2h
Murres seen during aerial transects
in the Chukchi Sea
August 18, 19, 1978
(Drury et al.).*



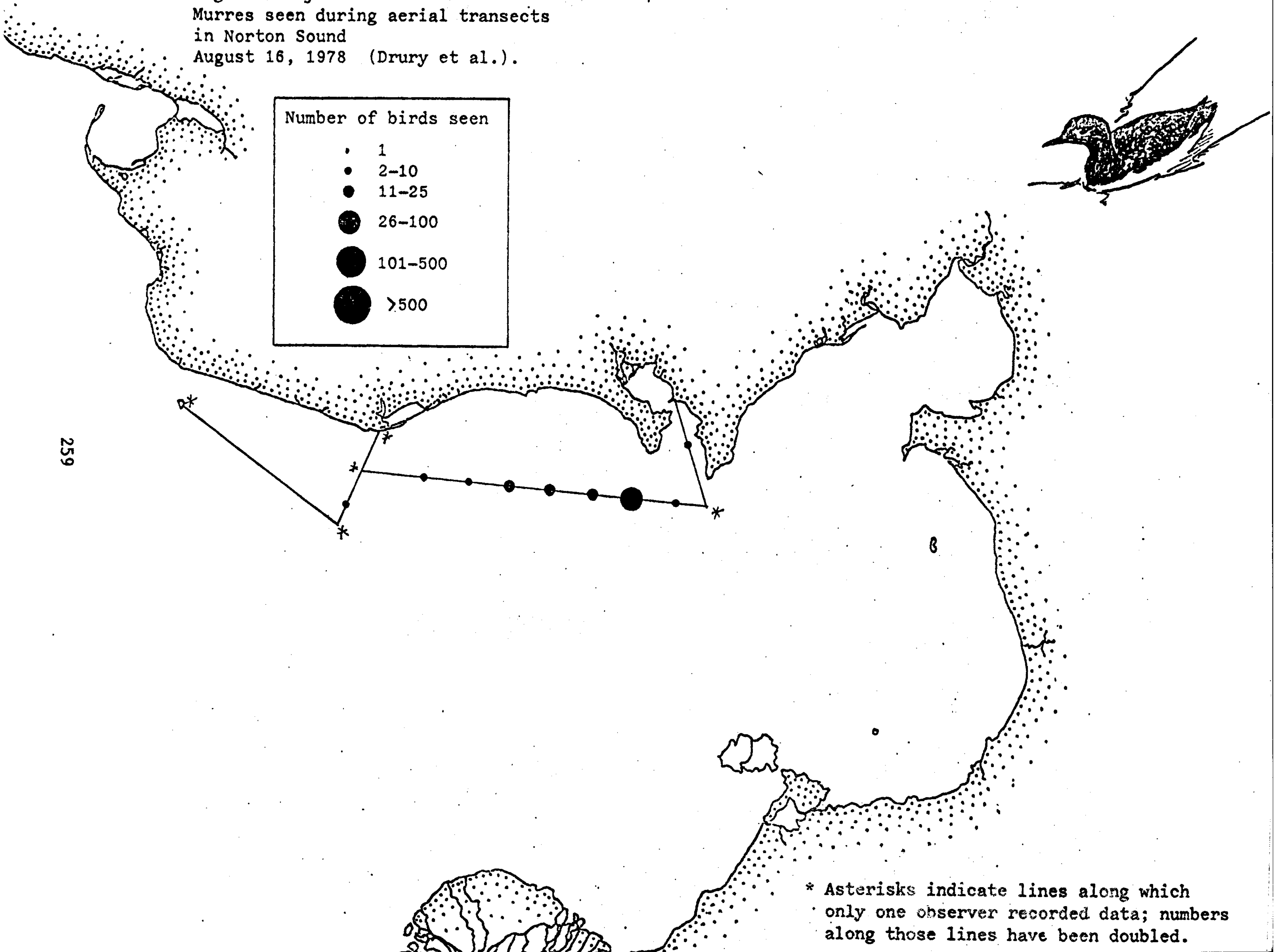
* Asterisks indicate lines along which only one observer recorded data; numbers along those lines have been doubled.

Figure 12.2i
Murres seen during aerial transects
in Norton Sound
July 6, 1978 (Drury et al.).



* Asterisks indicate lines along which

Figure 12.2j
Murres seen during aerial transects
in Norton Sound
August 16, 1978 (Drury et al.).



* Asterisks indicate lines along which only one observer recorded data; numbers along those lines have been doubled.

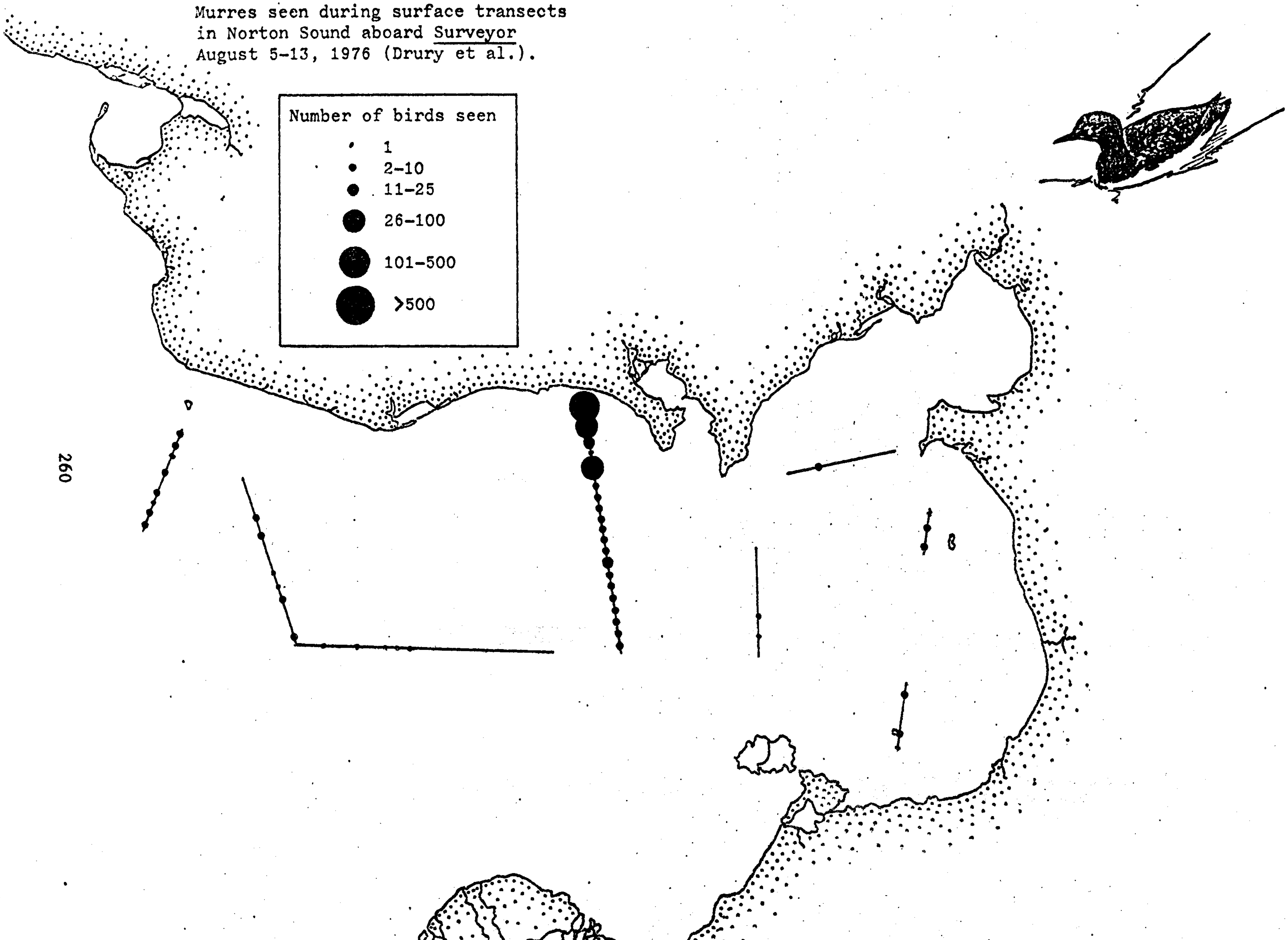
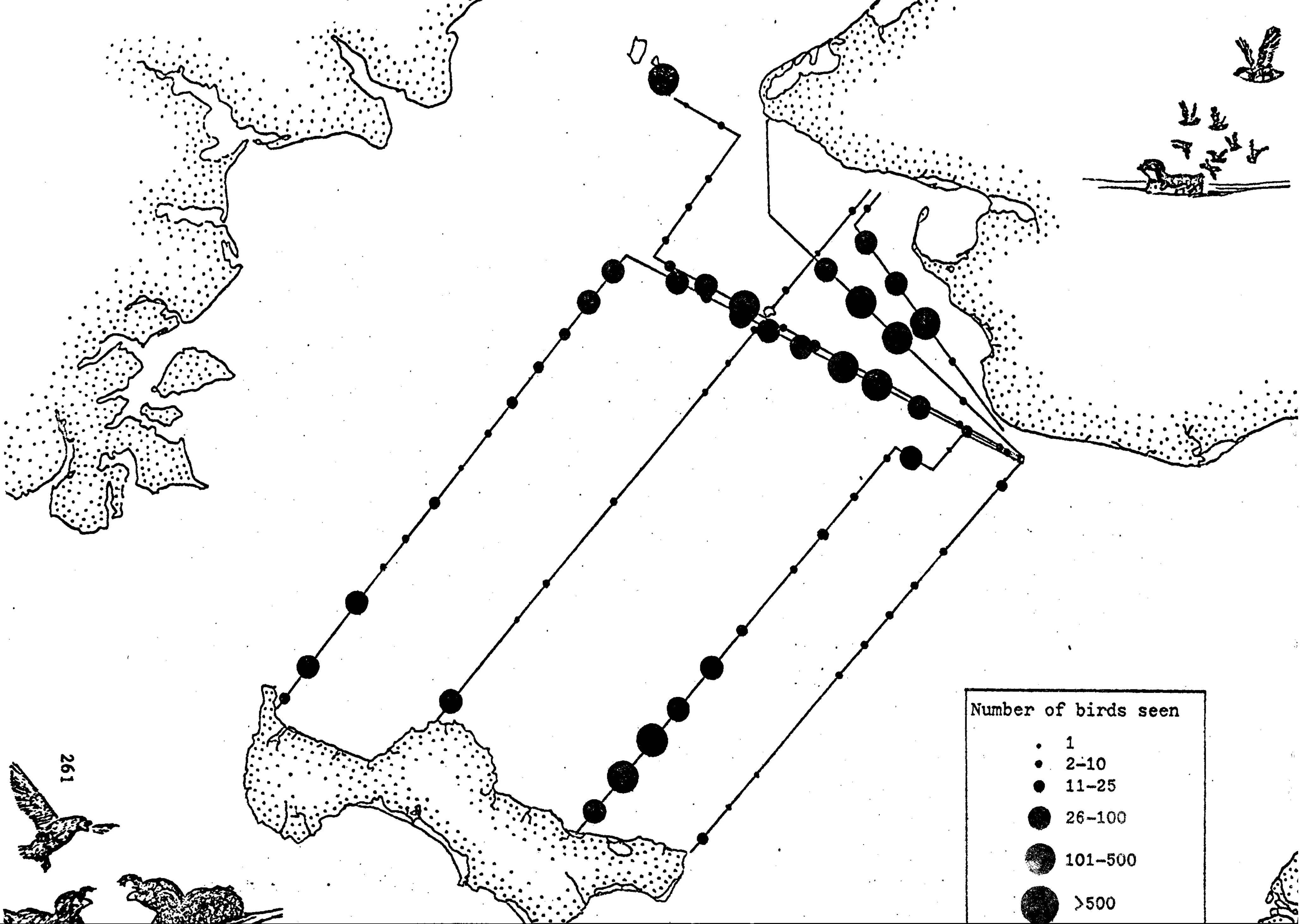


Figure 12.2k
Murres seen during surface transects in Norton Sound aboard Surveyor August 5-13, 1976 (Drury et al.).

Figure 12.3a
All Auklets (Least + Crested + Parakeet + unidentified) seen in the presence of sea ice on June 8, 9, 12, 1978 (Drury et al.)



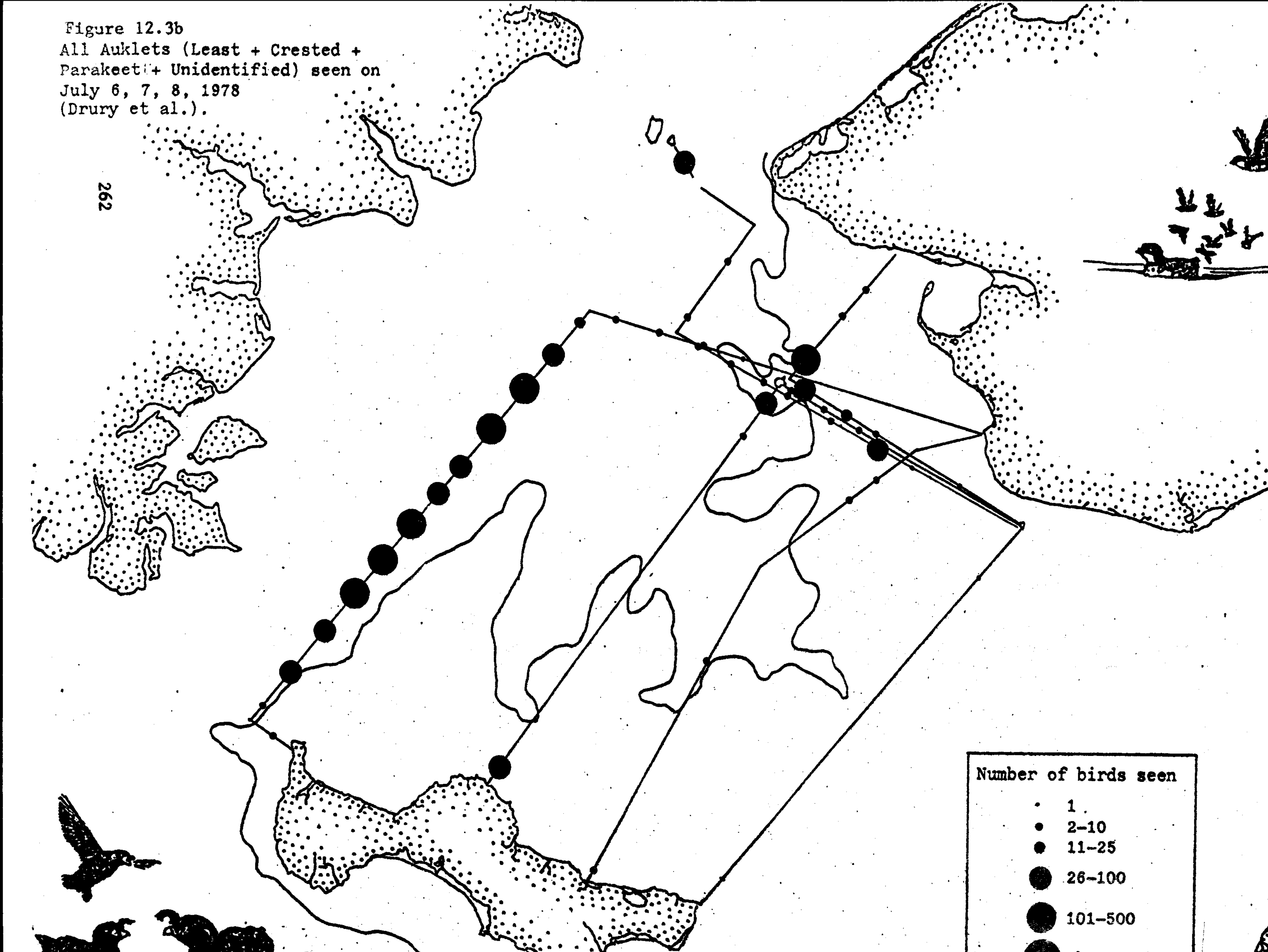


Figure 12.3b
All Auklets (Least + Crested + Parakeet + Unidentified) seen on July 6, 7, 8, 1978 (Drury et al.).

Figure 12.3c
All Auklets (Least + Crested + Parakeet + Unidentified) seen during aerial transects on July 31 and August 16, 17, 18, 1978 (Drury et al.)

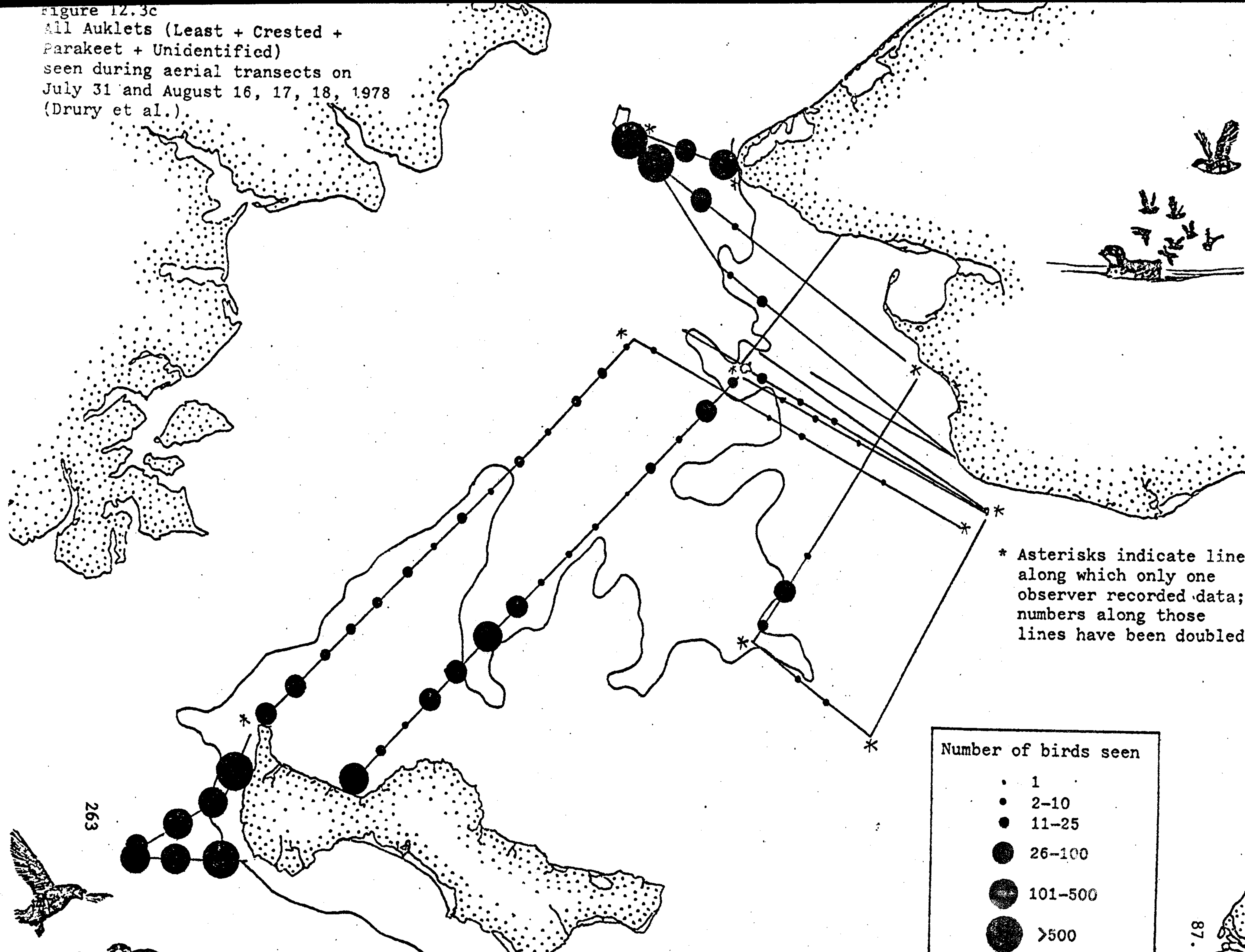


Figure 12.3d
All Auklets (Least + Crested + Parakeet + Unidentified) seen during aerial transects in the Chukchi Sea in the presence of sea ice on June 9, 1978 (Drury et al.).

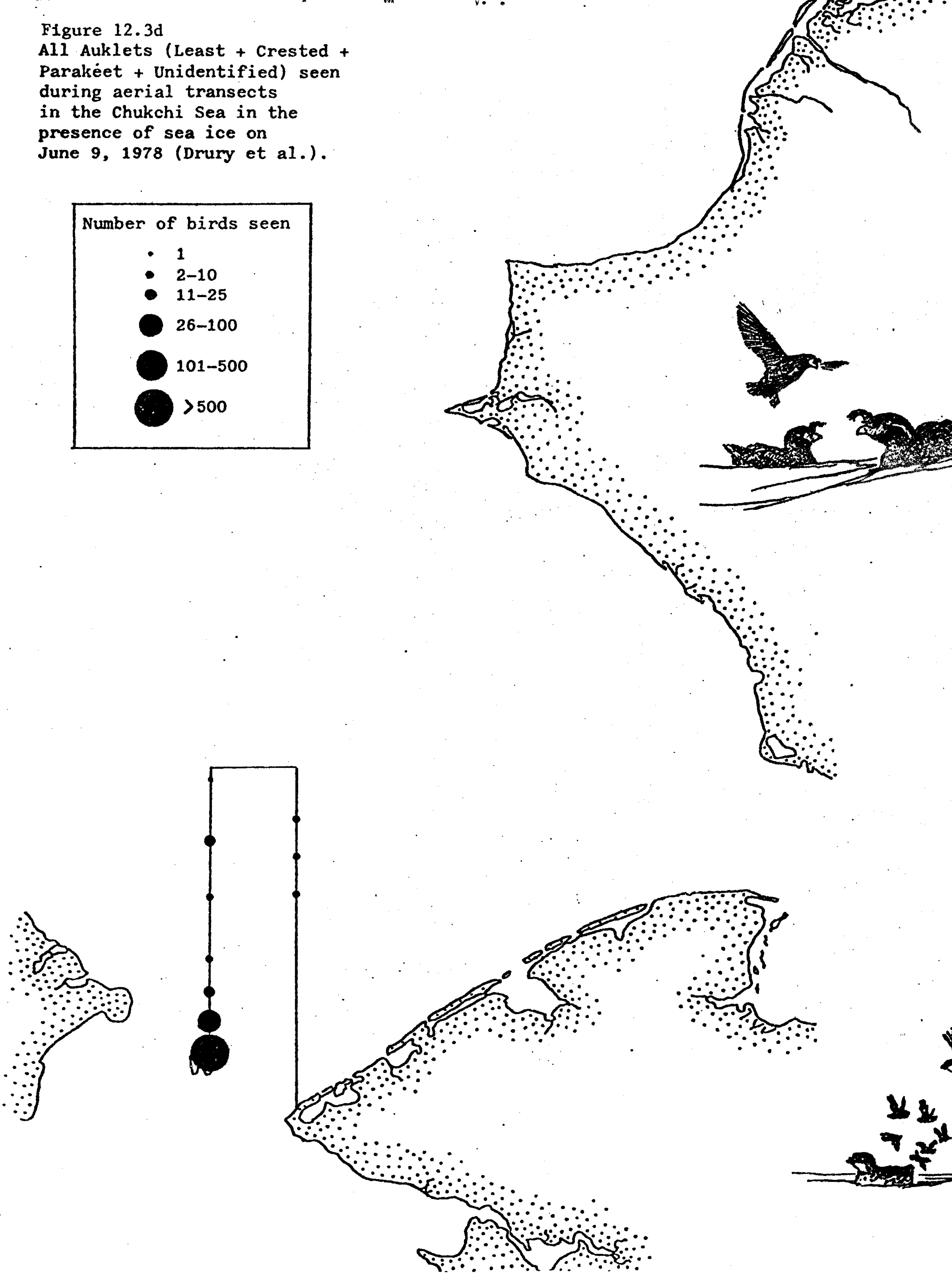


Figure 12.3e
All Auklets (Least + Crested + Parakeet + Unidentified) seen during aerial transects in the Chukchi Sea in the presence of sea ice June 24, 1977 (Drury et al.).

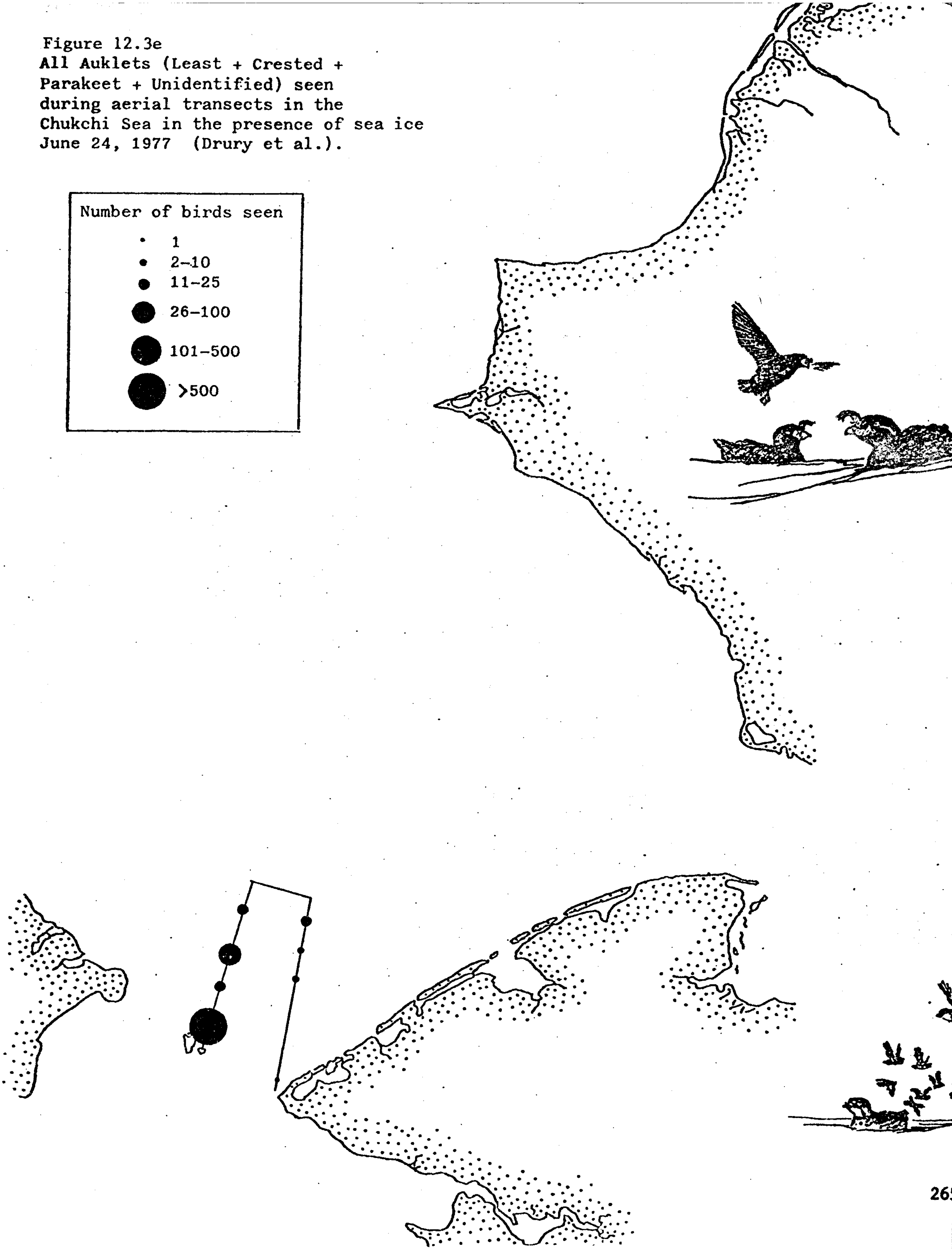


Figure 12.3f
All Auklets (Least + Crested + Parakeet + Unidentified) seen during aerial transects in the Chukchi Sea
July 7, 1978 (Drury et al.).

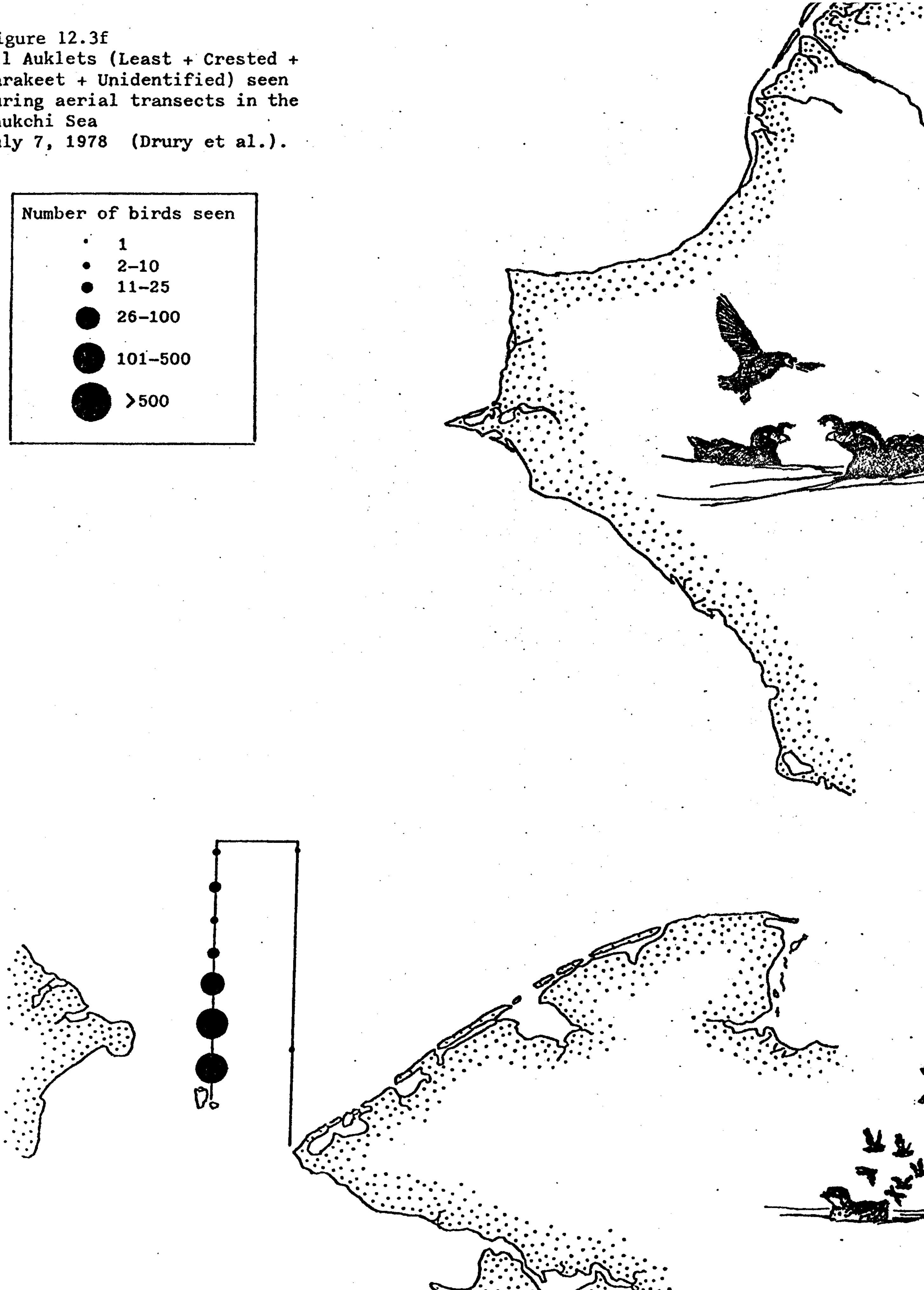
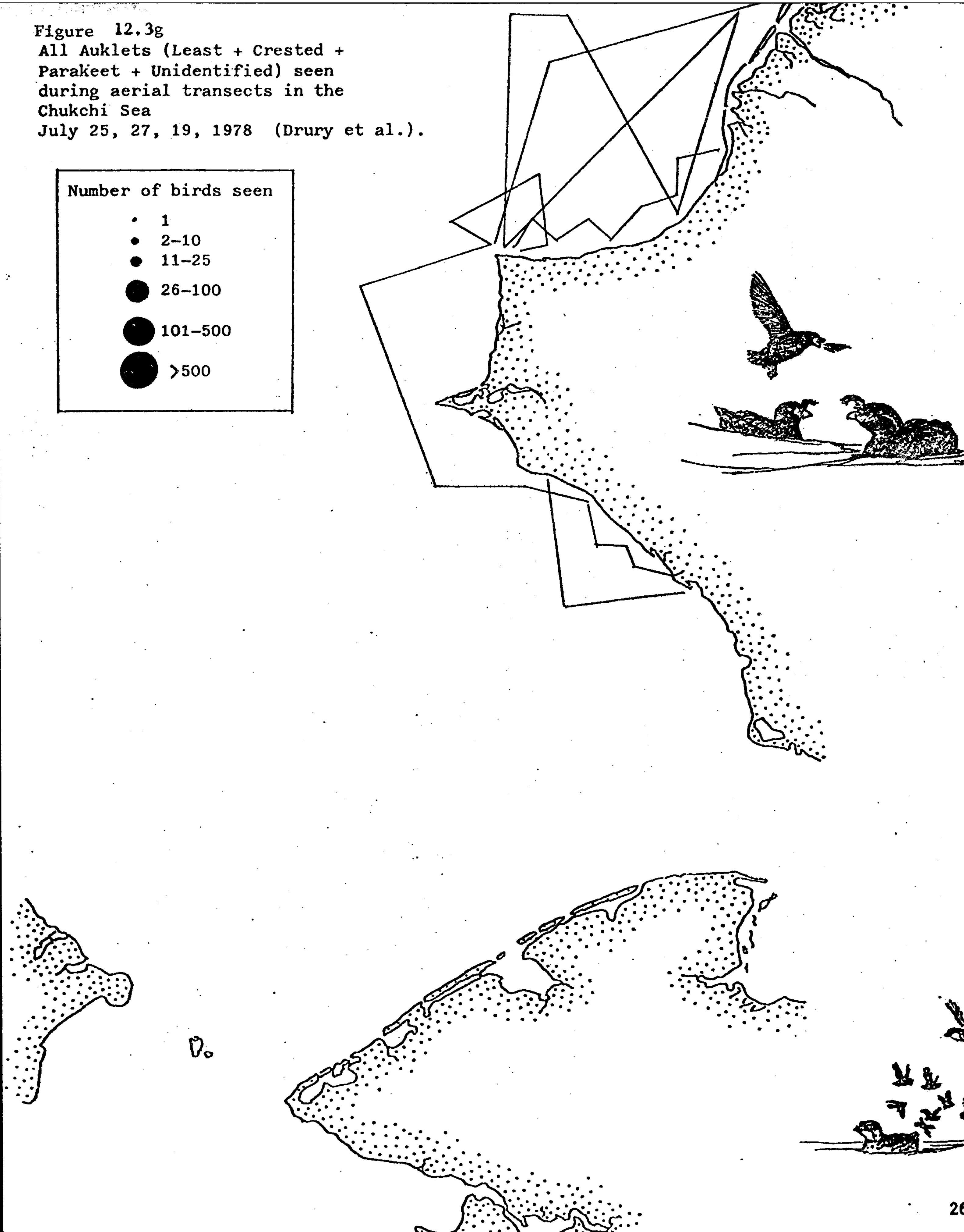
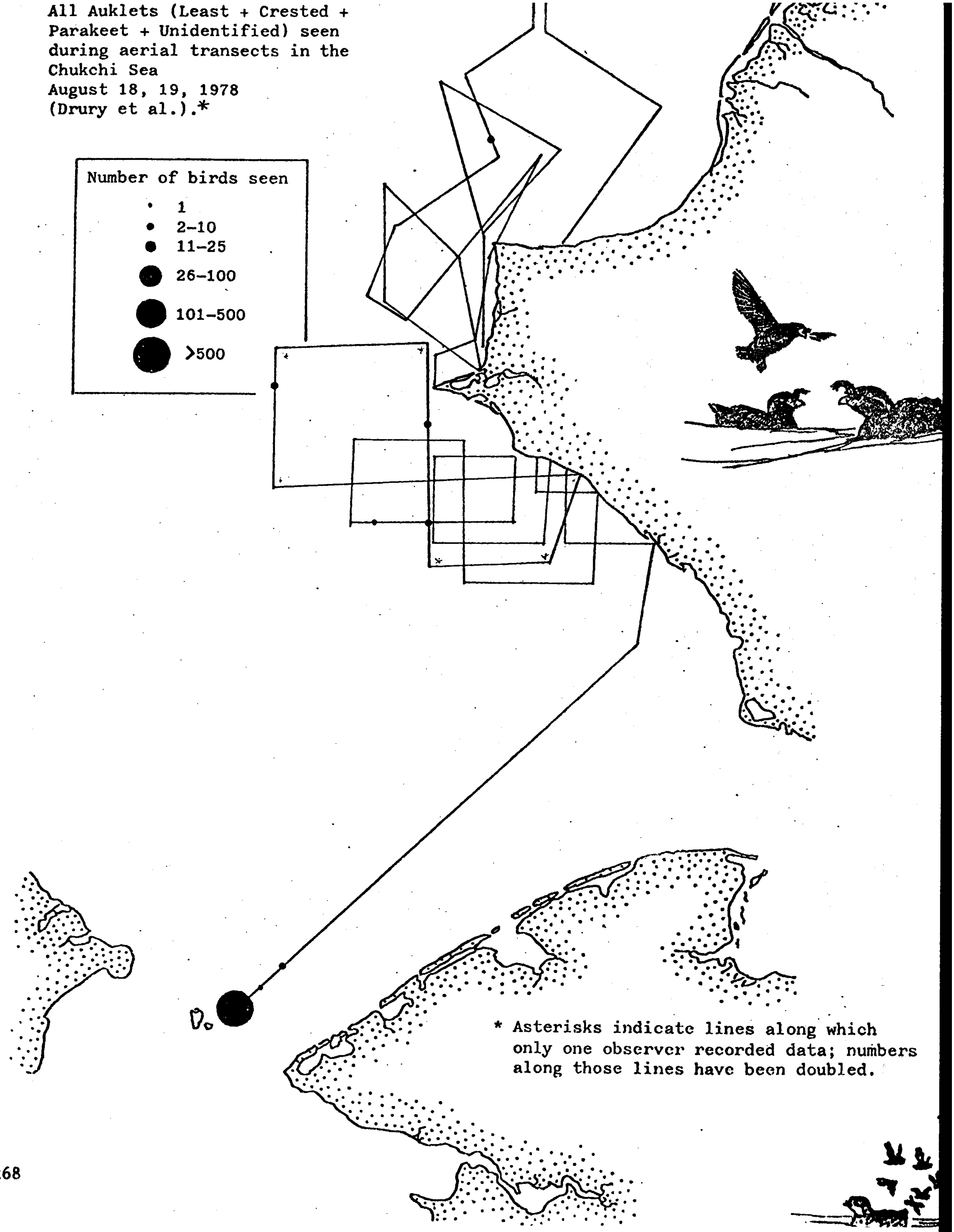


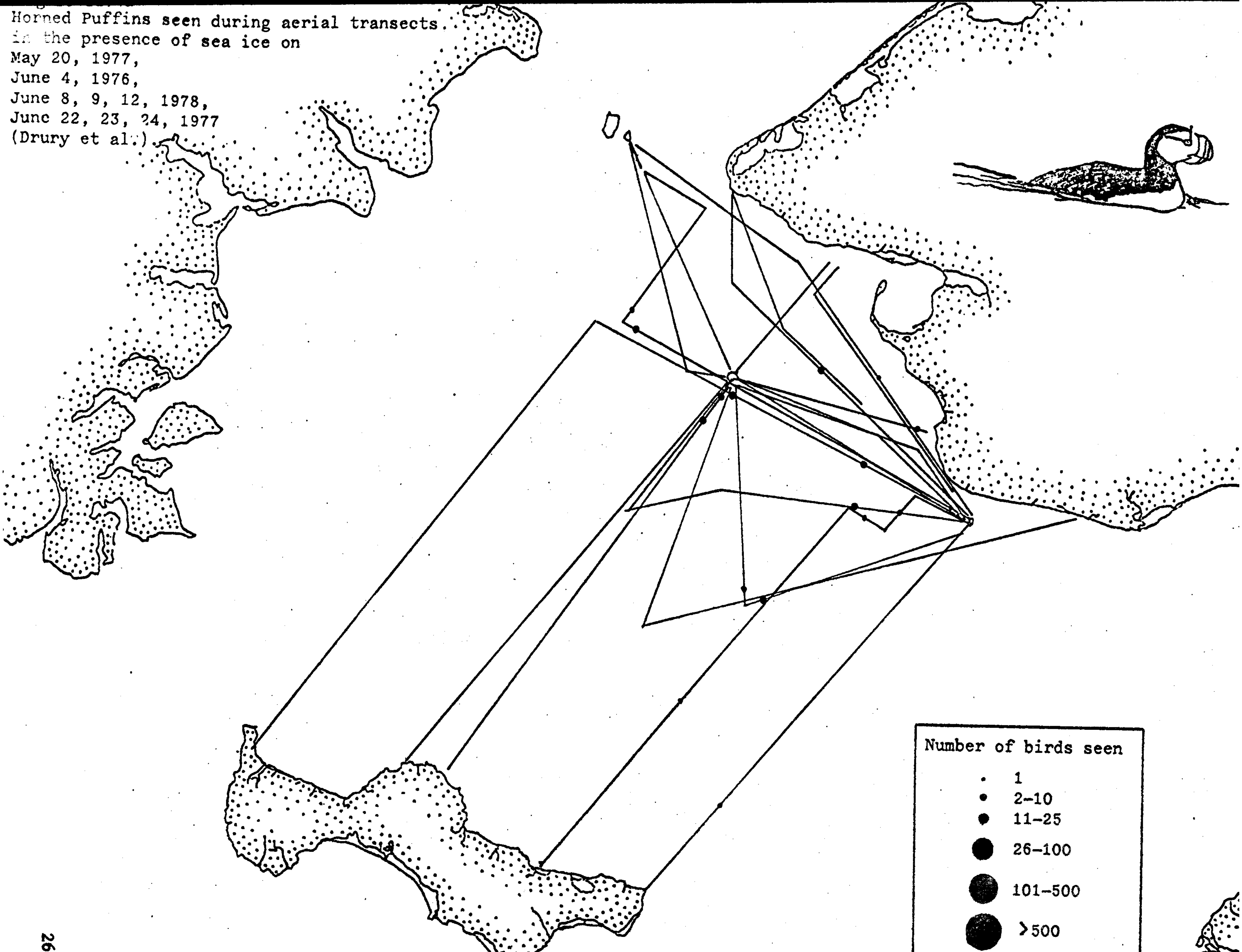
Figure 12.3g
All Auklets (Least + Crested + Parakeet + Unidentified) seen during aerial transects in the Chukchi Sea
July 25, 27, 19, 1978 (Drury et al.).



All Auklets (Least + Crested + Parakeet + Unidentified) seen during aerial transects in the Chukchi Sea
August 18, 19, 1978
(Drury et al.).*

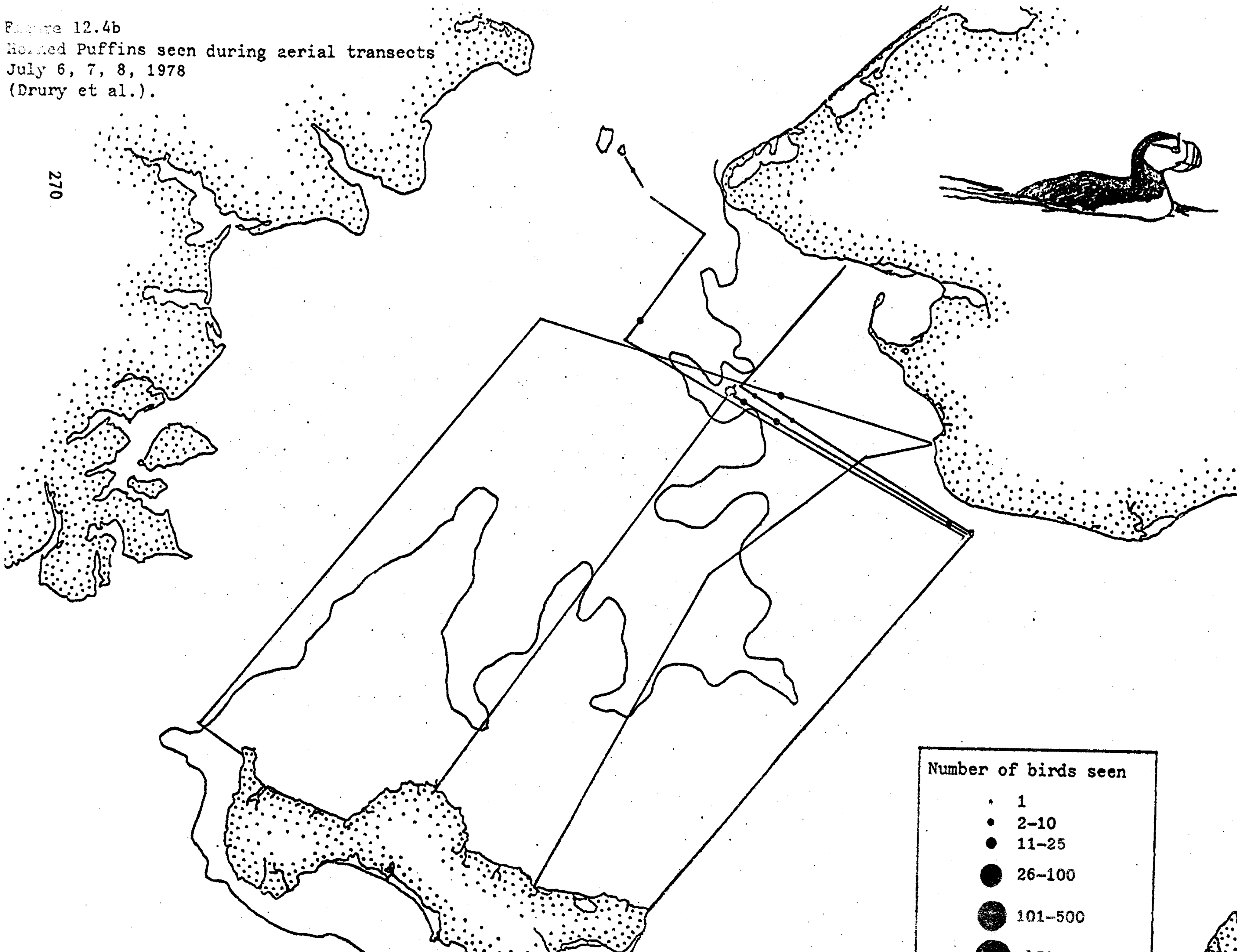


* Asterisks indicate lines along which only one observer recorded data; numbers along those lines have been doubled.



Horned Puffins seen during aerial transects in the presence of sea ice on May 20, 1977, June 4, 1976, June 8, 9, 12, 1978, June 22, 23, 24, 1977 (Drury et al.)

Figure 12.4b
Horned Puffins seen during aerial transects
July 6, 7, 8, 1978
(Drury et al.).



...gure 12.4c
...rne Puffins seen during aerial transects
...ly 31 and August 16, 17, 18, 1978,
...gust 21, 22, 1977
...rury et al.).

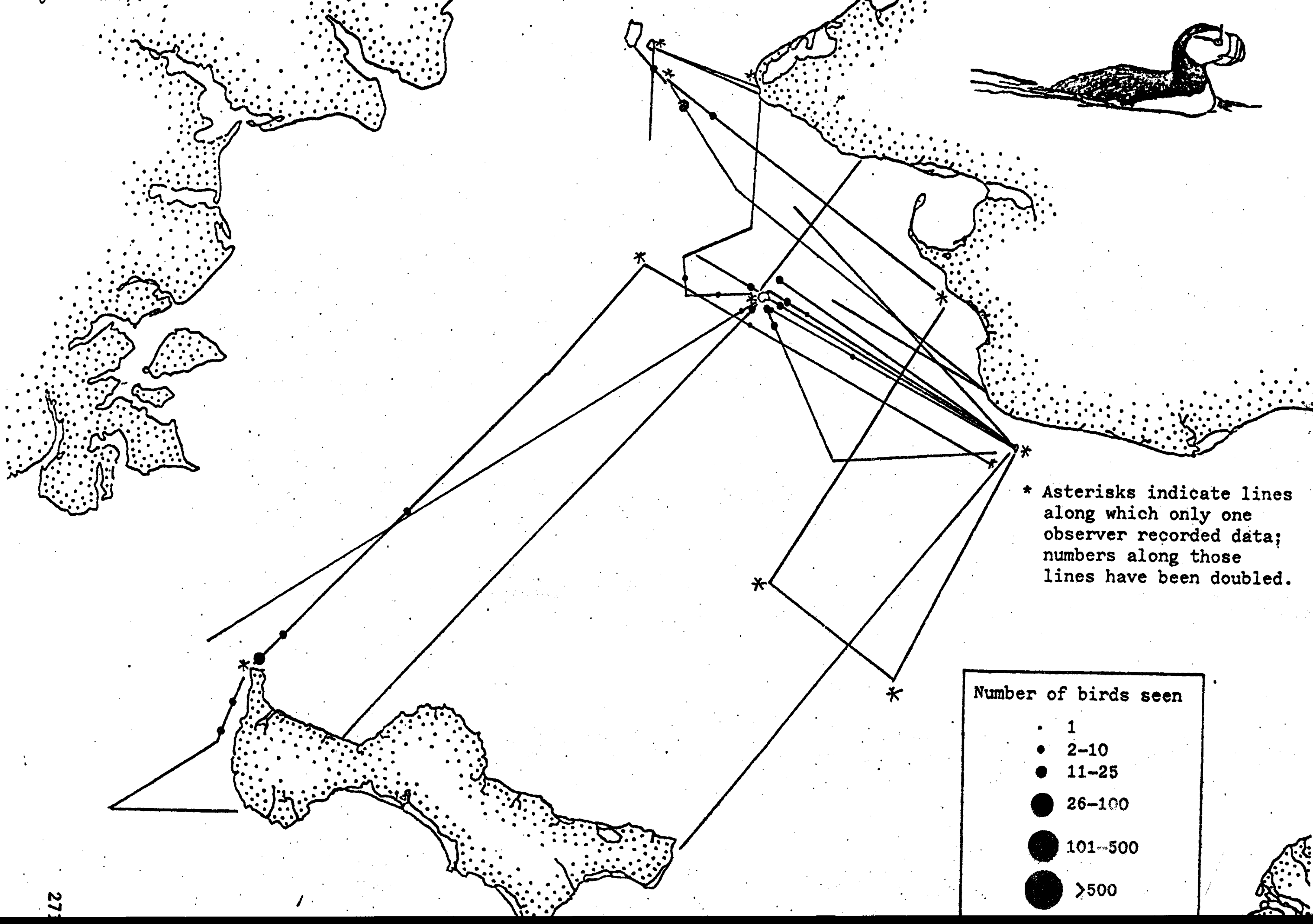
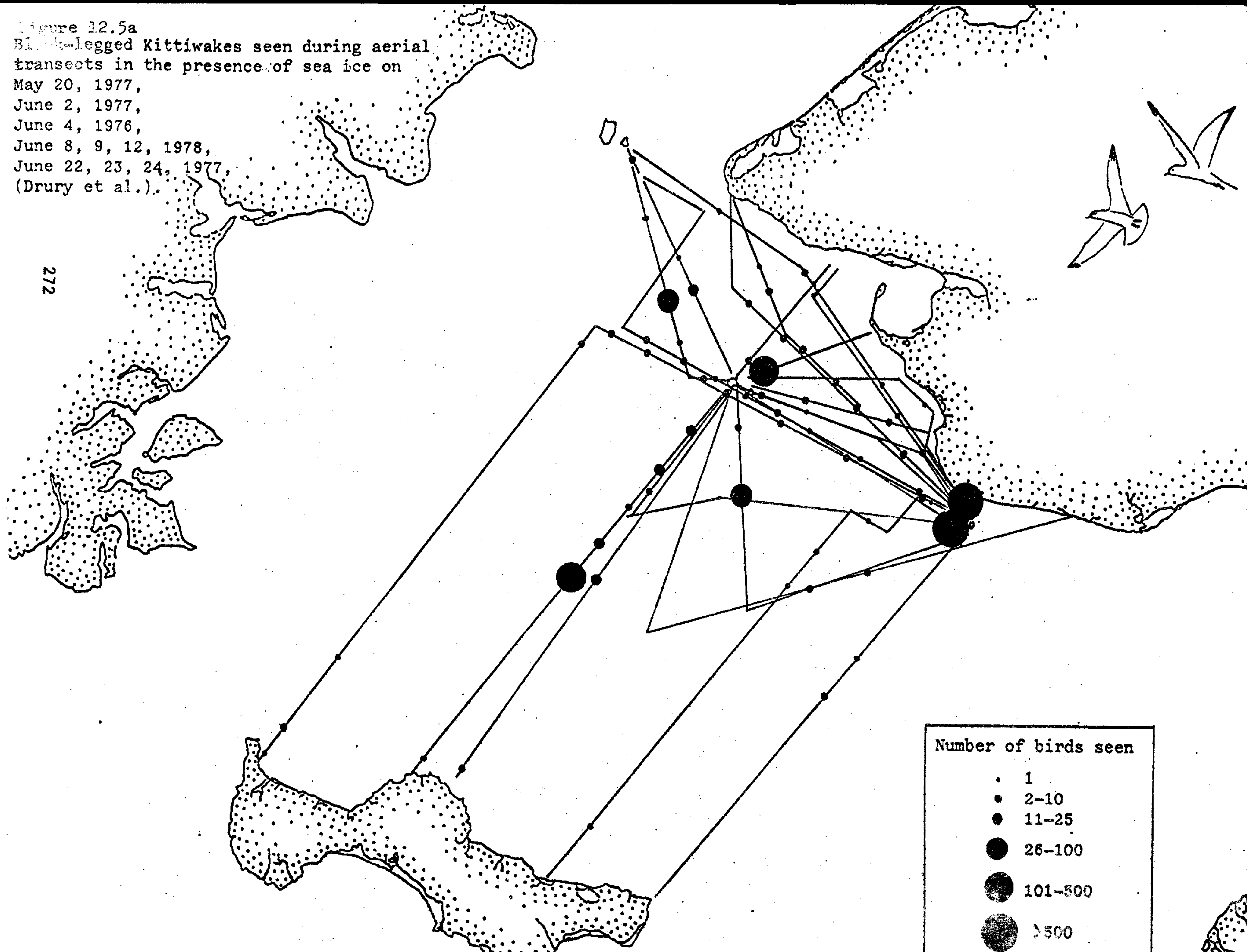


Figure 12.5a
Black-legged Kittiwakes seen during aerial transects in the presence of sea ice on
May 20, 1977,
June 2, 1977,
June 4, 1976,
June 8, 9, 12, 1978,
June 22, 23, 24, 1977,
(Drury et al.).



lack-legged Kittiwakes seen during
rial transects on
July 6, 7, 8, 1978
(Drury et al.).

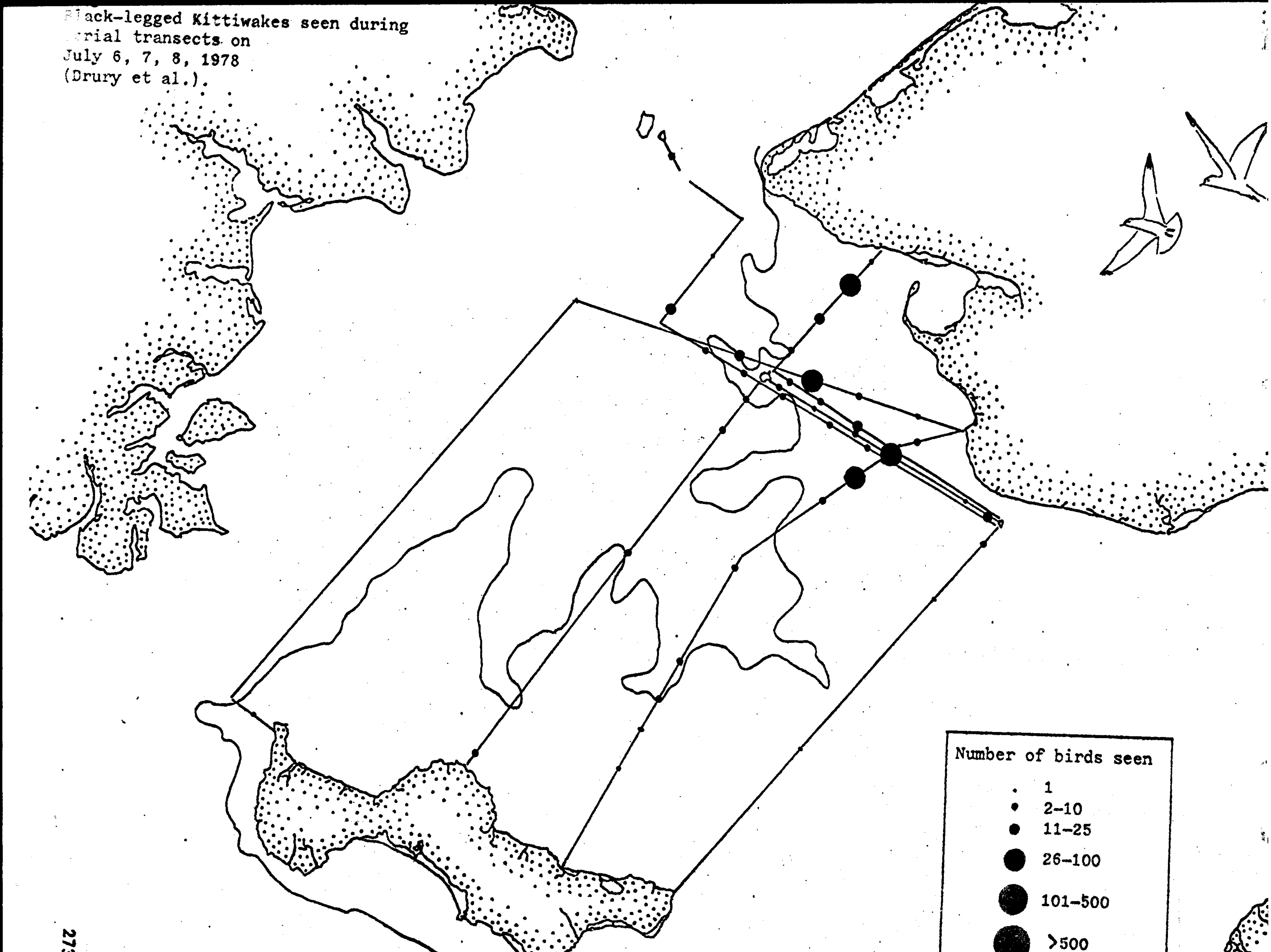


Figure 12.5c
Black-legged Kittiwakes seen during aerial transects on July 31 and August 16, 17, 18, 1978, August 21, 22, 1977, (Drury et al.).

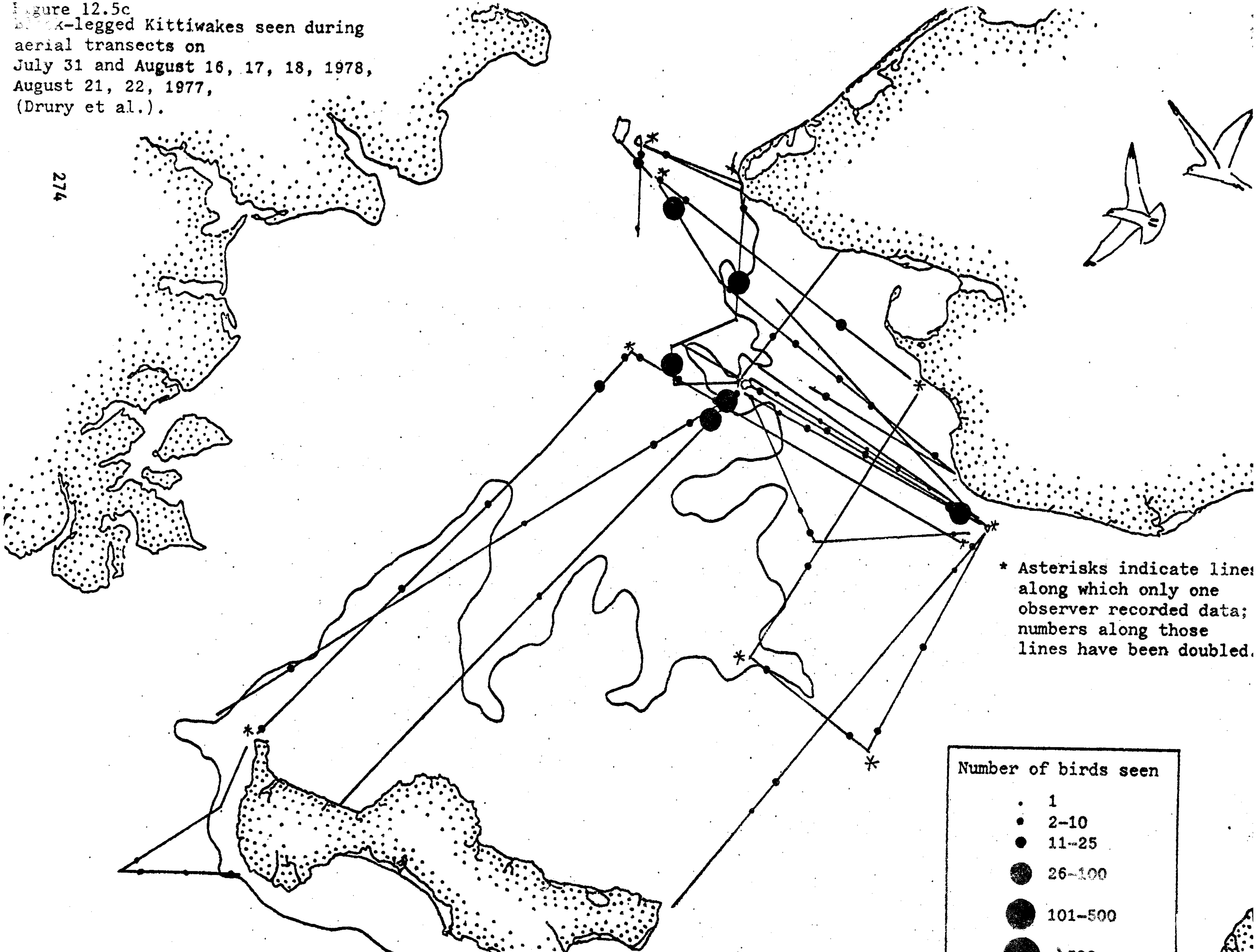


Figure 12.5d
Black-legged Kittiwakes seen during aerial transects in the Chukchi Sea in the presence of sea ice June 9, 1978 (Drury et al.).

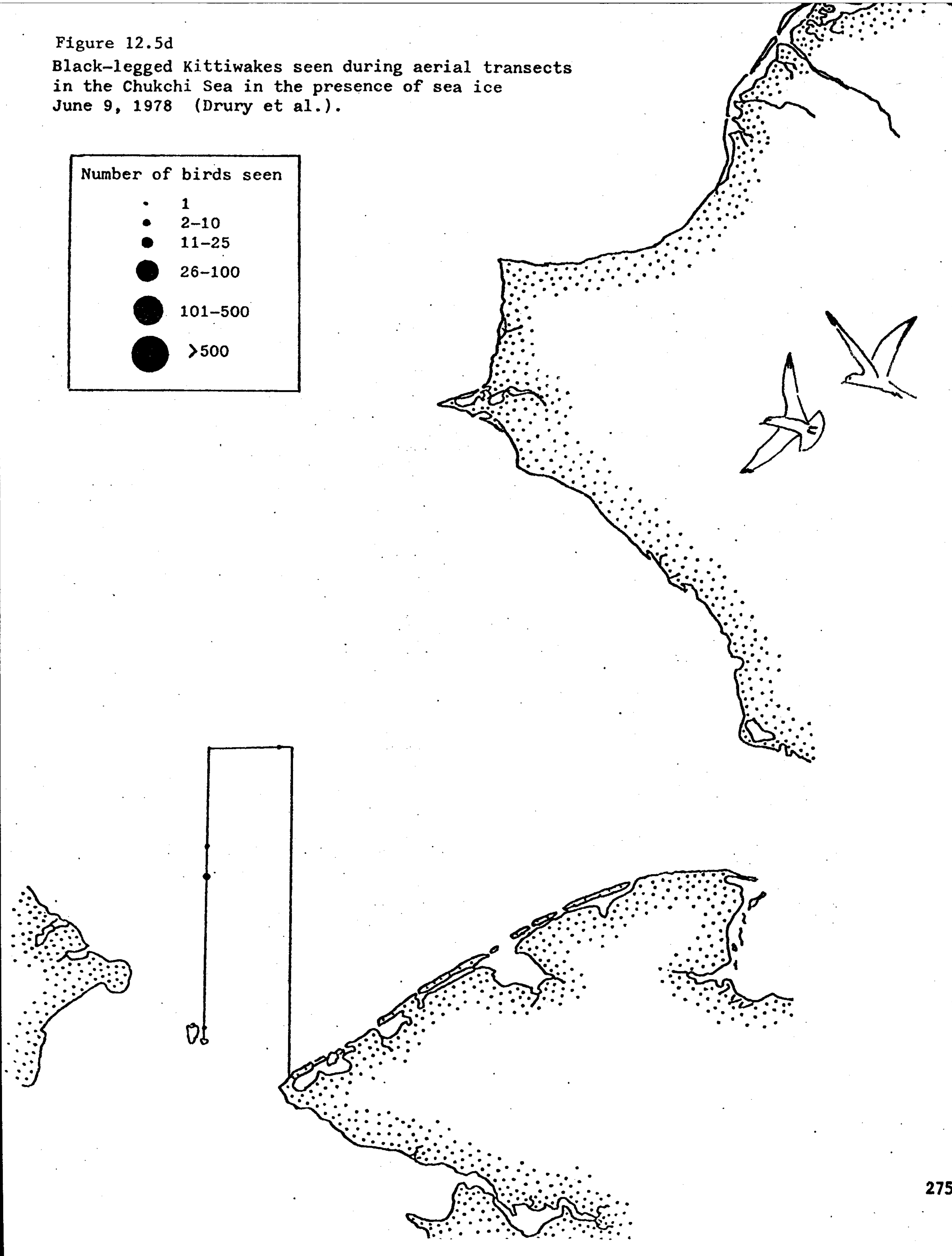


Figure 12.5e
Black-legged Kittiwakes seen during aerial transects in the Chukchi Sea in the presence of sea ice June 24, 1977 (Drury et al.).

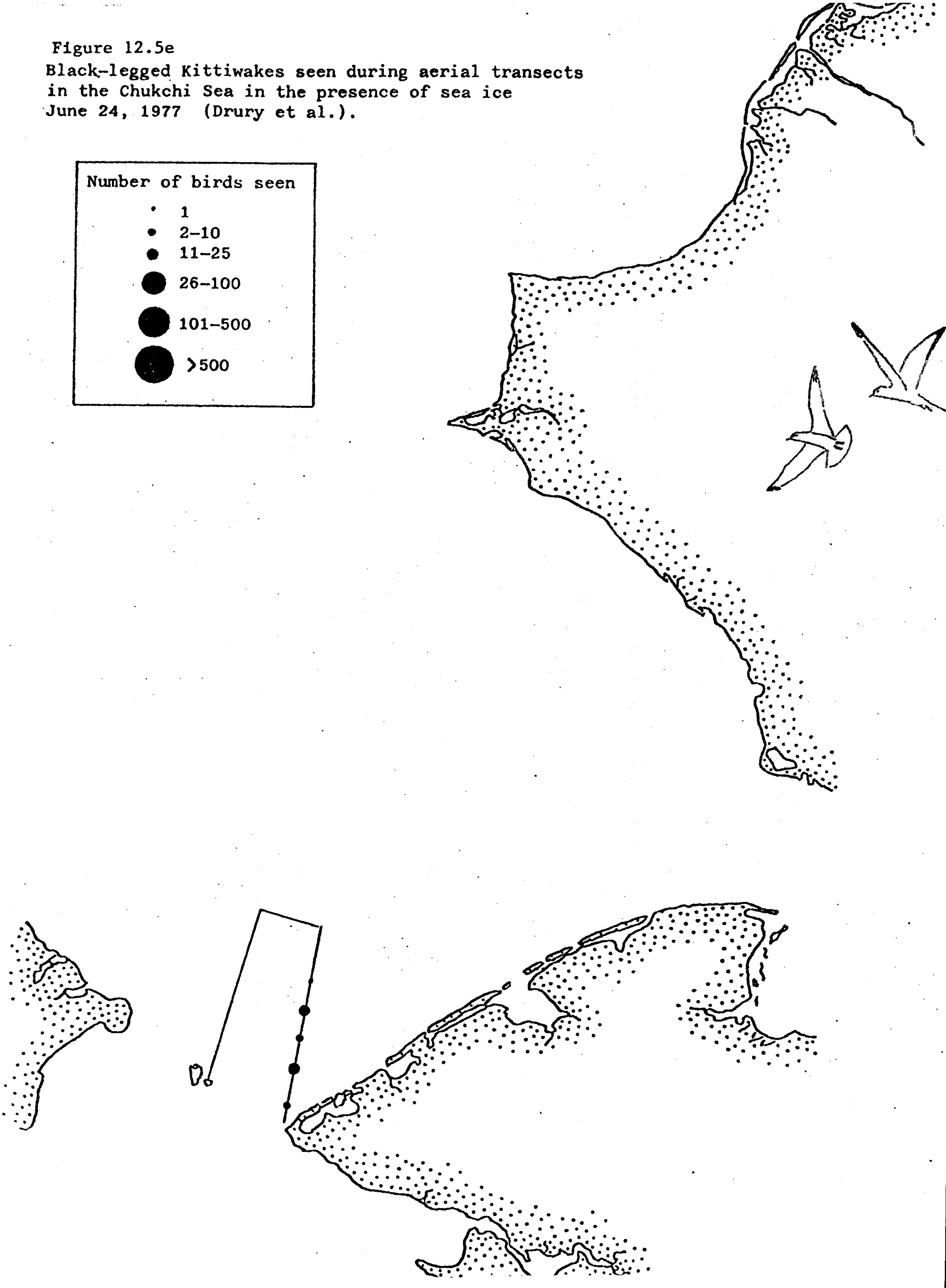


Figure 12.5f
Black-legged Kittiwakes seen during aerial transects in the Chukchi Sea July 7, 1978 (Drury et al.).

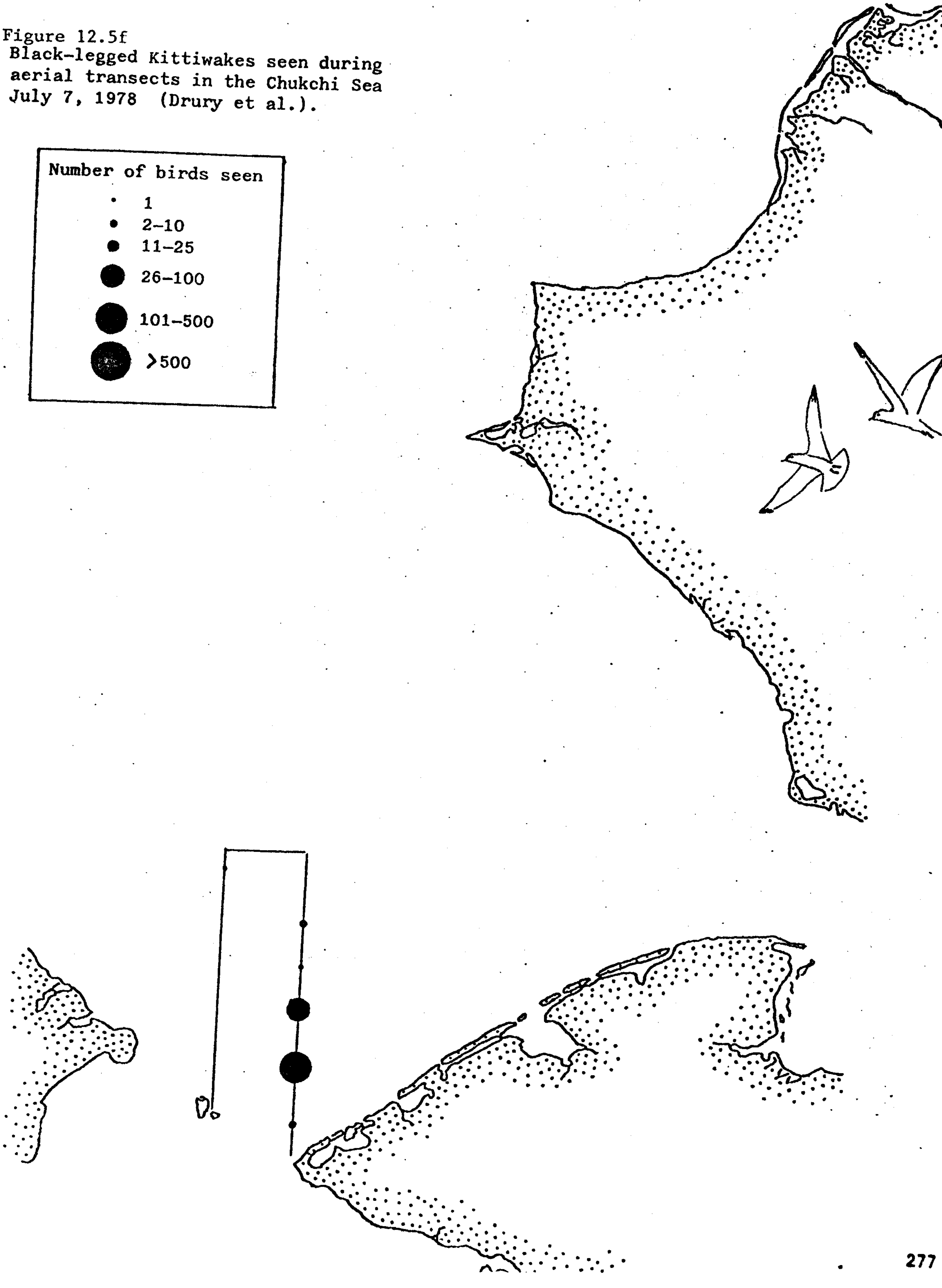


Figure 12.5g
Black-legged Kittiwakes seen during aerial transects in the Chukchi Sea July 25, 27, 29, 1978 (Drury et al.).

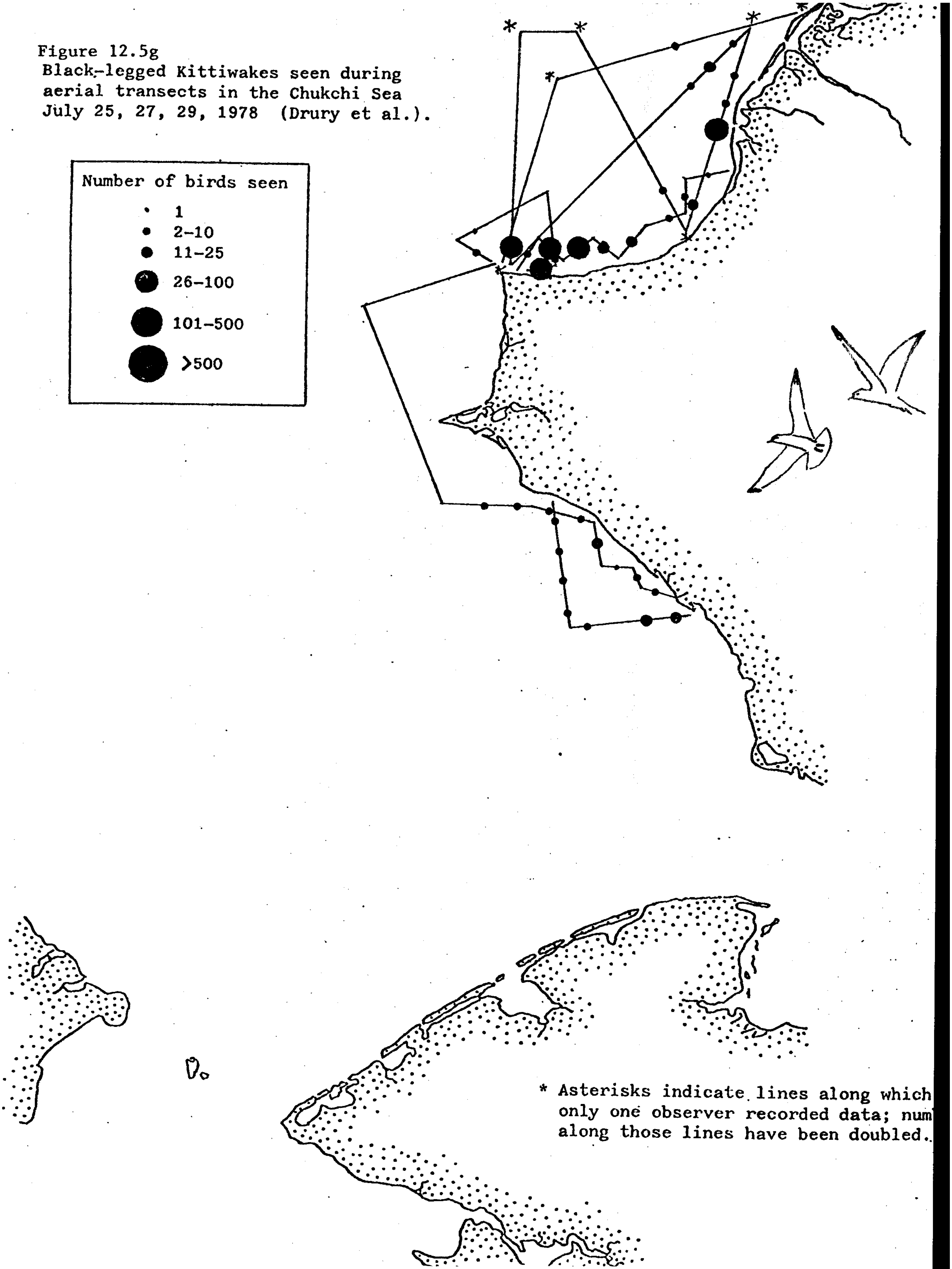
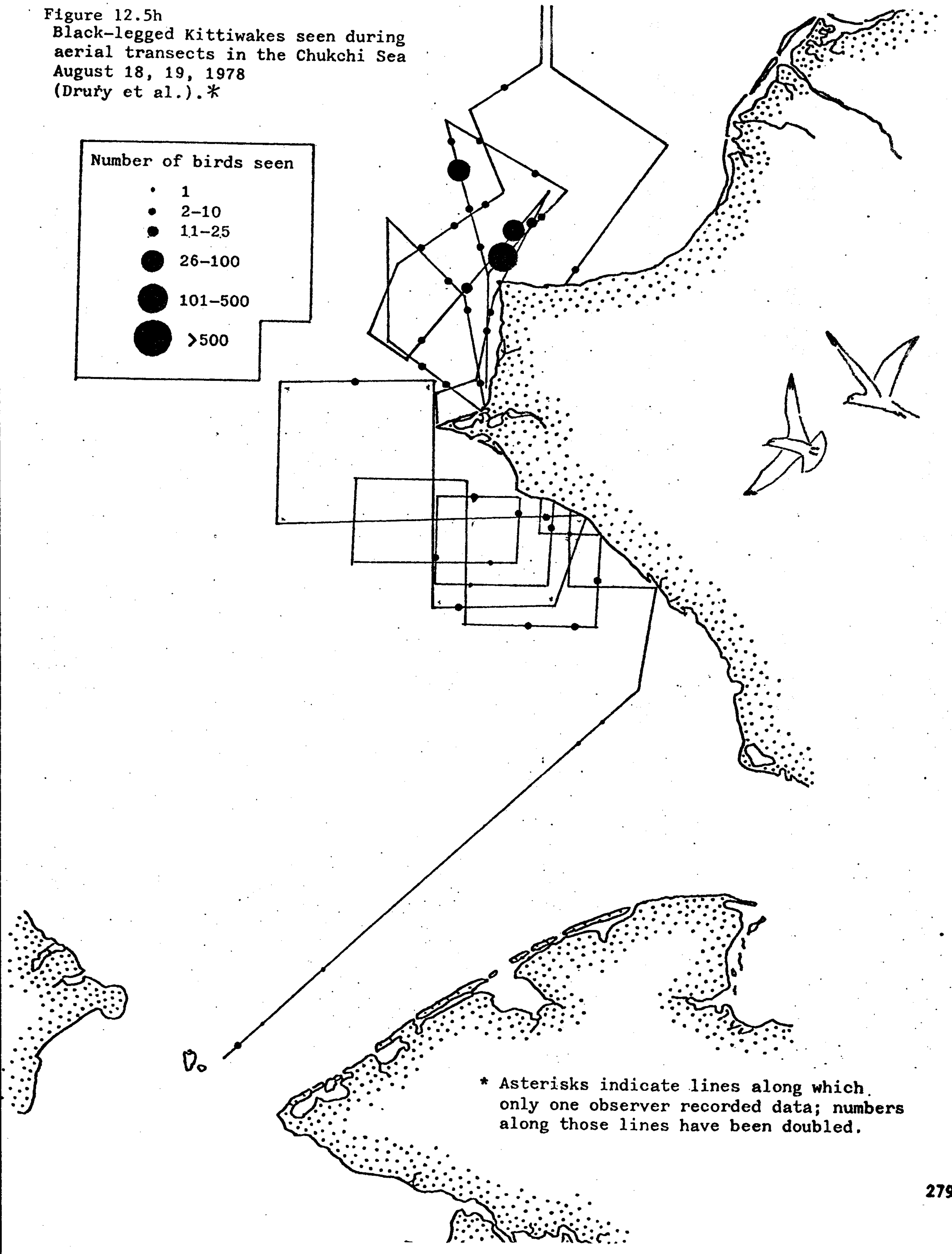


Figure 12.5h
Black-legged Kittiwakes seen during aerial transects in the Chukchi Sea August 18, 19, 1978 (Drury et al.).*



* Asterisks indicate lines along which only one observer recorded data; numbers along those lines have been doubled.

5. The relation between breeding sites and feeding grounds

Feeding areas are crucial to nesting success. To illustrate this, there are no auklets in Norton Sound although there are many suitable nesting sites.

Our observations indicate that birds from several seabird cities feed together, especially the auklets and murres of western Saint Lawrence Island. This raises questions about the trophic significance of each separate colony and its relation to each feeding area. Do the locations of colonies reflect merely the distribution of good nesting sites within a certain radius of a feeding site? Can this interaction between nesting and feeding areas be regarded as "nesting radii" related to underwater topography and water masses?

Our surveys indicate that some of the feeding grounds change with the season. Birds were found feeding at sea at especially great distances during June. It is reasonable to think that birds will be freer to commute long distances to preferred feeding areas before they have laid eggs and consequently, are relatively free to leave their nesting ledges. There are some important constraints: 1) the birds must protect their ledge against usurpation; 2) just before and during egg laying, the male must remain close to his mate to prevent cuckolding. During incubation one of the pair can travel long distances, but not go so far that its absence brings stress on the incubating partner. When their young are being fed, the parents have to compensate for two additional difficulties: first, they must return relatively frequently with food for the young one, and second, the food must be large enough to make the commuting trip energetically efficient.

So far we have described the marine habitat of the seabirds which we have studied and the biological processes which make those habitats productive. In the next sections we describe the numbers, distribution and reproductive activities of the birds at their nesting sites. Acknowledging that the birds spend less than a quarter of each of their mature years at the cliffs and spend the rest at sea, we realize that the activities and their success at the cliffs are critical for the survival of the birds.

B. Distribution of Seabird Cities

Our estimates, together with those of Bedard (1969a) and Searing (1977), indicate that about four and one-half million seabirds (4.5×10^6) live in the area between Saint Lawrence Island and the Lisburne Peninsula. The Bering Strait region is about twice the size of the Gulf of Maine (between Cape Cod and Nova Scotia) on the northeast coast of North America; yet the number of seabirds breeding in this area may be twice as large as the number of seabirds nesting between central Labrador and Cape Hatteras. While millions of murres and Dovekies from the Canadian Arctic winter on the Continental Shelf off the Canadian Maritimes, and millions of Great Shearwaters, Sooty Shearwaters, Wilson's Petrels and Northern Fulmars summer there, even larger numbers of Southern Hemisphere-breeding Short-tailed Shearwaters enter the northern Bering Sea in late summer. The presence of 15,000 Gray Whales, 150,000 Pacific Walrus and large numbers of Ringed Seals, Common Seals, Largha Seals and Bearded Seals emphasize that the Bering Strait region provides habitat for a fauna of major world-wide importance.

The Bering Strait Islands form the northernmost cluster of nesting sites for more than a million Least, Crested and Parakeet Auklets, Beringian endemics which occur only in the western Gulf of Alaska, the Bering Sea and the Sea of Okhotsk. In addition, murres, kittiwakes and the two Pacific puffins, widely distributed in northern seas, reach their northernmost breeding limit at Cape Lisburne. In this section we will discuss the birds present at the many imposing seabird cities: bazaars, as they are called by the Russians Belopol'skii and Uspenski, or megalopoli as Hunt et al. called them.

1. The colony and the sea

The size and aerial extent of the seabird colonies in the Bering Strait Region are truly impressive. The birds cover cliffs that often extend for several miles, and vary in height from 50 to more than 1,000 feet. The largest colonies contain on the order of three quarters of a million birds (Biderman et al., 1978), and breed at densities of greater than ten birds per square meter (Birkhead 1978a). The impressive spectacles are enhanced by the chorus of tens of thousands of murres and kittiwakes and the stench of a season's worth of guano.

The colony life of these birds is so compelling that it is easy to overlook their primary adaptations to life at sea. The high density aggregations of birds at the colony occur only during the four summer months. The birds spend eight or more months of the year at sea. Further, banding studies have shown that immature murres usually stay away from the colony until their third or fourth year (Birkhead and Hudson 1977).

A similar pelagic juvenile stage is seen in the kittiwake (Coulson and White, 1959). Thus, only part of the population follows the temporal pattern of eight months at sea and four associated with the breeding cliff.

First, we will briefly review the geographic subdivisions of the Bering Strait Region; then we will discuss numbers of seabirds and the variations in numbers which are a consequence of the comings and goings between the sea and the breeding cliffs. Then, we will review briefly the characteristics of the major cliffs according to our present knowledge. In Section V, we will review the schedule of attendance at the cliff through the year and detailed studies we carried out at the cliffs at Bluff.

2. Geographic subdivisions of the Bering Strait Region and the distribution of seabird species

The southeastern Chukchi Sea is surrounded by U.S. mainland; the Seward Peninsula on the south, the delta of the Noatak and Kobuk Rivers on the east, and the Lisburne Peninsula on the northeast. It is occupied in the west by Bering Shelf Water, cold and saline, in the middle by northward flowing Alaska Coastal Water, and in the east by warm and low saline water in inner Kotzebue Sound.

The seabird cities of inner Kotzebue Sound consist of several small cliffs of murres, kittiwakes and Pelagic Cormorants on the south shore, several large cities of Horned Puffins on the coastal islands in the east, at the northwest end of the Lisburne Peninsula. No auklets nest in this area, yet at the northern cities Thick-billed Murres are equal in numbers to Common Murres. A large population of the eastern arctic Black Guillemot breeds at Cape Lisburne.

The Bering Sea north of Saint Lawrence Island can be divided into two large bodies of water. The first, Norton Sound, is surrounded by U.S. mainland and contains relatively warm, low-saline coastal waters dominated by the outflow of the Yukon River. The second, the Chirikov Basin, is bordered by the Bering Strait to the north, Saint Lawrence Island south, and the Chukotsk Peninsula of Siberia to the west. It contains colder, more saline water, nutrient rich, and poor in CO_2. Primary productivity (phytoplankton) is high in the Chirikov Basin, and low in Norton Sound.

The Chirikov Basin supports two orders of magnitude more seabirds than Norton Sound. The majority of these birds are Crested, Parakeet and Least Auklets, zoo-plankton-eaters, nesting in immense cities on islands. The predominant murre is the Thick-billed Murre, which eats zooplankton as well as fish. Thus, the fish-eating seabirds, Black-legged Kittiwakes, Common Murres, Tufted and Horned Puffins, and Pelagic Cormorants, are a minority.

In Norton Sound, fish-eating seabirds predominate at the relatively small colonies dispersed along the mainland coast. Common Murres are much more numerous than Thick-billed, and there are virtually no auklets. Black-legged Kittiwakes, Glaucous Gulls, Horned Puffins and Pelagic Cormorants comprise the rest of the seabird fauna.

Most of Saint Lawrence Island which forms the southern border of the Bering Strait region is ringed with barrier beaches and lagoons. Seabirds nest in three major concentrations on the sea cliffs and rubble fields associated with volcanic mountains, around Savoonga, near Gambel and along the Southwest Capes. A Siberian element is evident at Saint Lawrence Island; the Siberian Herring Gull and the Slaty-backed Gull. The apron of sea cliffs along the north shore provide nesting sites for murres, kittiwakes and major numbers of puffins and Pigeon Guillemots. The rubble fields above the cliffs provide nesting areas for major numbers of auklets.

C. Number of Birds Breeding at the Cities

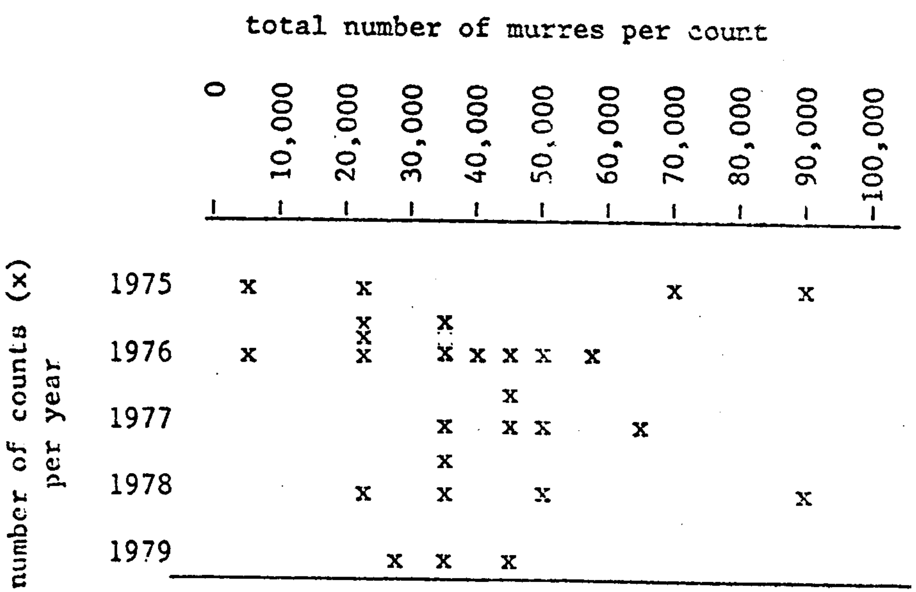
1. Variation in numbers of birds at their breeding sites

When seabirds first come to the cliffs in spring, they spend only a few hours at the ledges, then leave for several days. Their numbers become more consistent when incubation starts, but at any time during the breeding season unfavorable weather or lack of food drives them back to sea. Numbers vary from day to day by 30% without obvious reason. During years when the ice breaks up late there may be only 60% as many birds at the cliffs as there are during a favorable year. Furthermore, British students of murres (or guillemots as they are called in Britain) (Southern 19), have recorded indications of what may be decade-long "surges" of numbers which lead to large increases or decreases in the numbers of birds at any set of cliffs. Despite these temporary oscillations there is good evidence of a major decline of murres which can be detected as shown by the careful counts at Cape Thompson between 1960 (Swartz, 1966), and the late 1970's (Springer and Roseneau 1977, 1978, and Murphy, pers. comm.). These declines in numbers of breeding birds may be a consequence of the deahts of hundreds of thousands of murres on their wintering grounds in gill nets set for salmon. Similar deaths in salmon nets and decreases in numbers of murres in Greenland have been reported.

Observed variations in numbers. Tables 4 , 5 , and 6 record the numbers of murres counted at Bluff Cliffs by epople counting by "twos" or "tens" in a small boat moving slowly past the cliffs. Birkhead and Nettleship (1980)review methods of censusing murres. Virtually all students have converged independently on very similar techniques. Air figures show wide daily and seasonal variation, and emphasize that it is necessary to understand the reasons for these variations before one can establish a single number or range of variation to apply to the murre population at Bluff. Figures 13, 20 & 22 show how the daily or weekly variation decreases after incubation has started. Variation and totals increase again later in the season. Those observing migration of murres past Cape Wales have recorded steady northward movement of murres continuing well into the summer. Figures 13 and 20 show how total numbers increase steadily during the summer as, we presume, immature birds arrive to prospect for future nest sites.

The phenomena of short-term oscillations in numbers and of influx of large numbers of birds later in the season are especially obvious among

Table 4.
Distribution of counts of Murres at Bluff Cliffs throughout the Breeding Season, all counts included. From data of Drury 1975, 1976, 1977, 1978, and Murphy 1979.



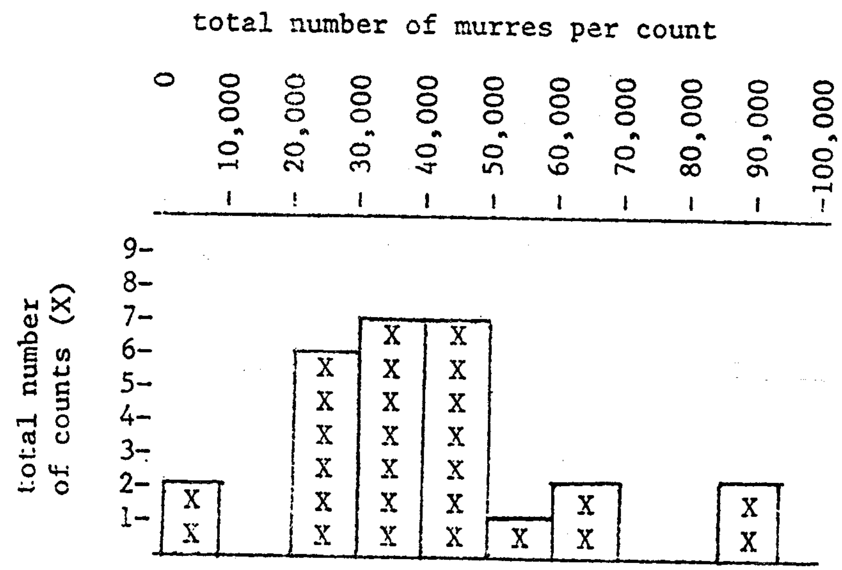
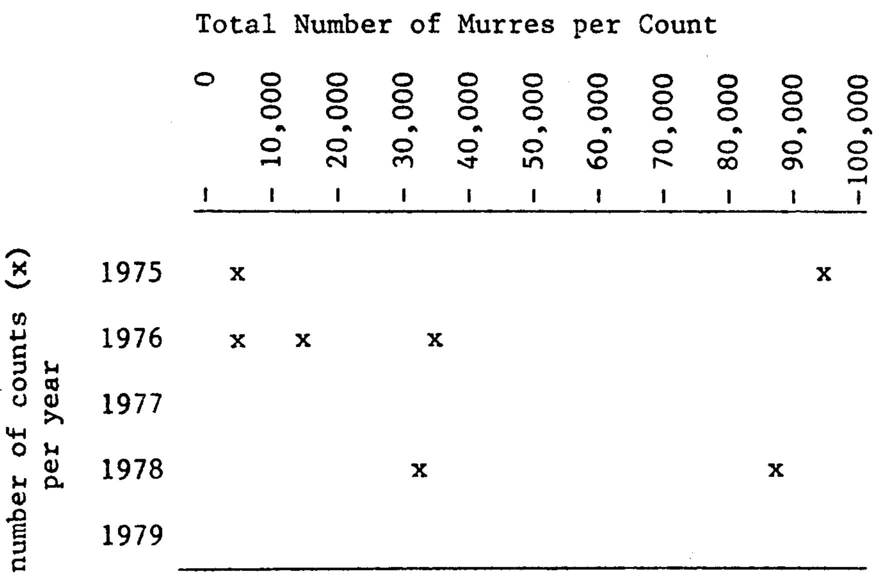


Table 5.
Distribution of counts of Murres at Bluff Cliffs before June 25 and after August 20, 1975-1979, showing more variation before and after the presence of eggs and chicks. From data of Drury 1975, 1976, 1977, 1978, and Murphy 1979.



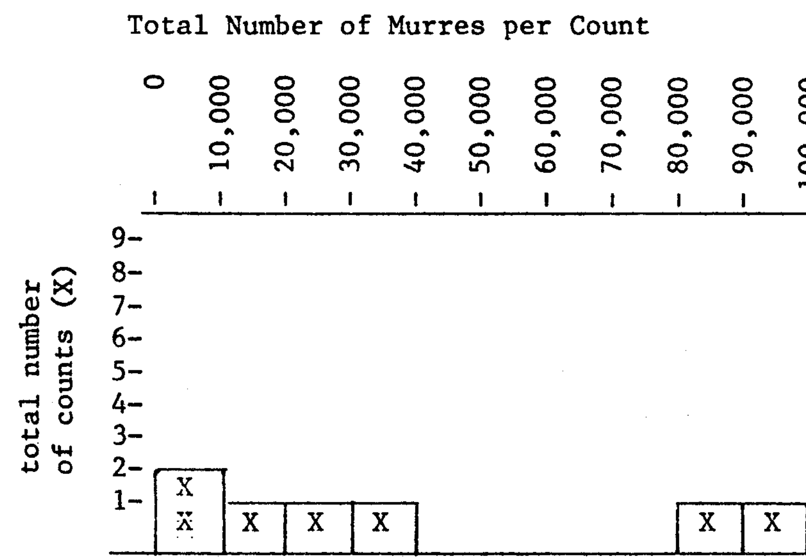
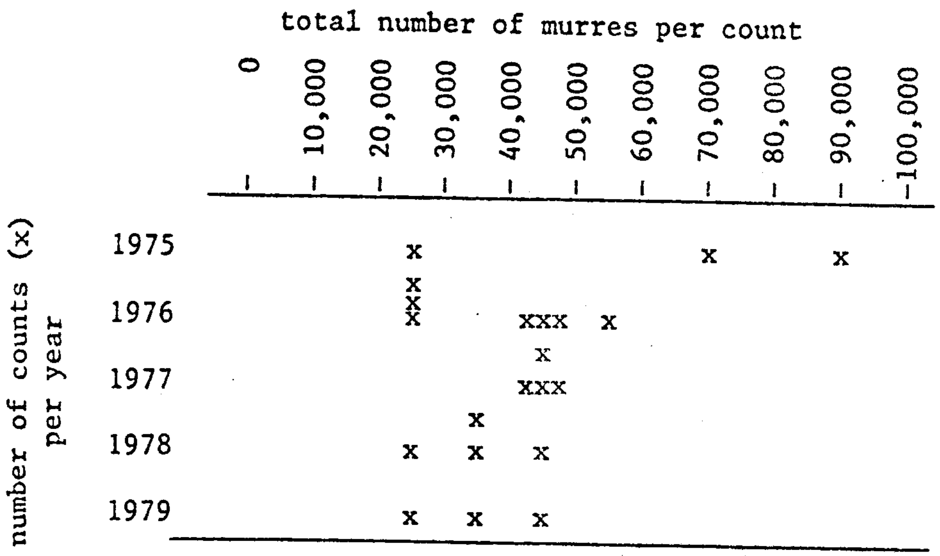
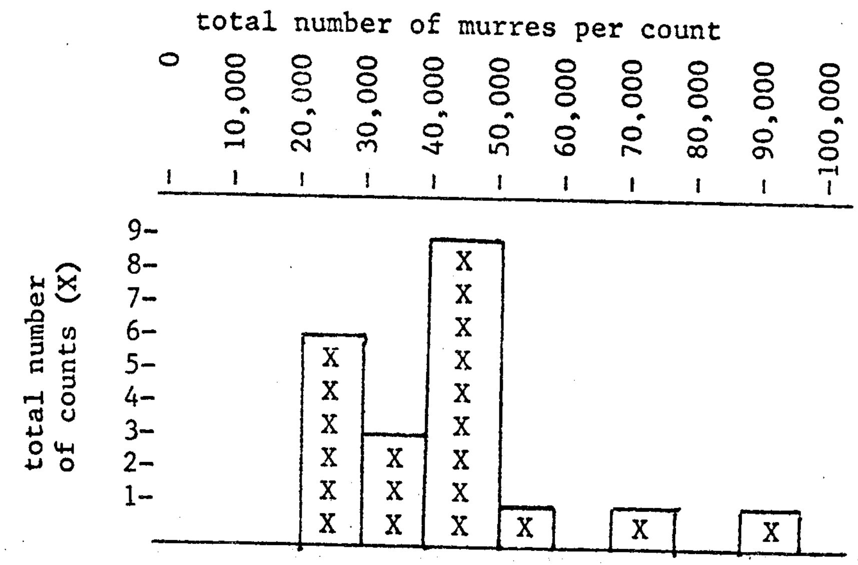


Table 6.

Distribution of Counts of Murres at Bluff Cliffs between June 25 and August 20, 1975–1979, showing less variation during the period when eggs or chicks are on the cliffs. From data of Drury 1975, 1976, 1977, 1978, and Murphy 1979.





Number of counts in five thousand increments

16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-65	66-70	71-75	76-80	81-85	86-90
0	5	1	3	2	6	1	0	1	0	1	0	0	0	1

Table 7. Maximum total numbers of murres, both flyers and non-flyers, counted during colony censuses at Bluff, 1975-1978.

1975		1976		1977		1978	
Date	Total	Date	Total	Date	Total	Date	Total
		26 June	41,780	28 June	42,000	26 June	23,595
[a]4 July	90,000	11 July	20,779	7 July	42,600	[b]18 July	33,520
1 Aug	69,900	26 July	45,175	29 July	45,250	9 Aug	48,460
8 Sept	6,545	12 Aug	55,390	19 Aug	36,100	14 Aug	32,080

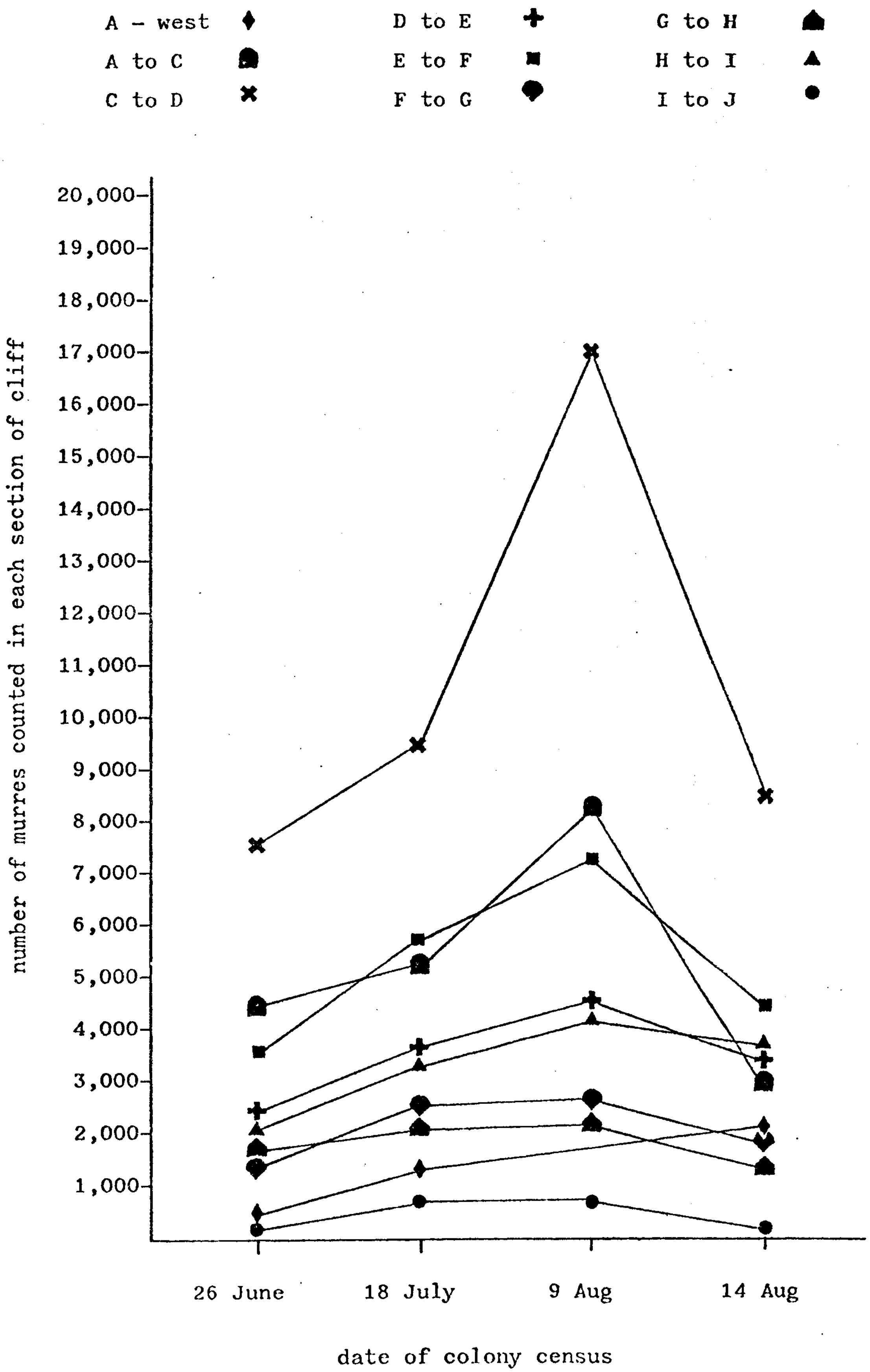
[a]Number includes birds on the water as well as on the cliff.

[b]Flyers not included in this census; number is only non-flyers (i.e., birds on the cliff).

Table 8. Number of murre flyers as percentage of total number of murres counted during colony censuses of Bluff Cliffs, 1976-1978. In 1975, flyers were counted with non-flyers for a lumped total, so percentages are not available.

1976		1977		1978	
Date	% Flyers	Date	% Flyers	Date	% Flyers
26 June	55%	28 June	34%	26 June	5%
11 July	49%	7 July	7%		
26 July	41%	29 July	4%	9 Aug	7%
12 Aug	32%	19 Aug	14%	14 Aug	7%

Figure 13. Variation in the maximum number of murres counted in each section of cliff (A to J) during colony censuses at Bluff, 1978.



Horned Puffins, as Figure 14 indicates. On favorable wind conditions late in the summer, five or six times as many birds may fly along the crest of the cliffs as are recorded regularly during July. This effect was recorded at both King and Little Diomede Islands, as well as at Bluff Cliffs, so it appears to be general and to reflect the existence of a population of puffins much larger than the number of nest sites available.

The relation of numbers of birds present to the numbers of pairs or the number of females which lay eggs. Our counts of total adults in the breeding season and the numbers of visible nests compared to the number of incubating birds for Glaucous Gulls and Pelagic Cormorants illustrate the indirect relation between numbers of birds at nesting cliffs and the actual numbers of nests. We do not know whether these differences reflect growing populations (i.e., the presence of subadults in adult plumage), shortage of nest sites or other reasons, but they indicate that there is no simple relation between the numbers of birds counted at a cliff and the number of birds actually breeding. We discuss this problem for murres and kittiwakes further in Appendix VI. Nelson (1979) made some cogent comments on this subject as it applies to Gannets, and these are quoted in that appendix. As he observed, one really is counting occupied sites by counting birds at cliffs. Frequently the number of birds is about 40% higher than the number of nests or nesting sites (Table 9).

Estimates of numbers of birds at cliffs surveyed only from the air. We estimated the numbers of birds at most cliffs in the Bering Sea region in the course of our aerial surveys of the distribution of birds at sea. These estimates are not as reliable as counts made from a boat moving slowly past the foot of the cliffs; but we do have the air estimates and for many cliffs we do not have estimates from the water.

Figure 14 .

Variation in numbers of Horned Puffins at Bluff Cliffs, 1977.

Mean number of Horned Puffins at five study sites, shown as a percent of the season's high counts.

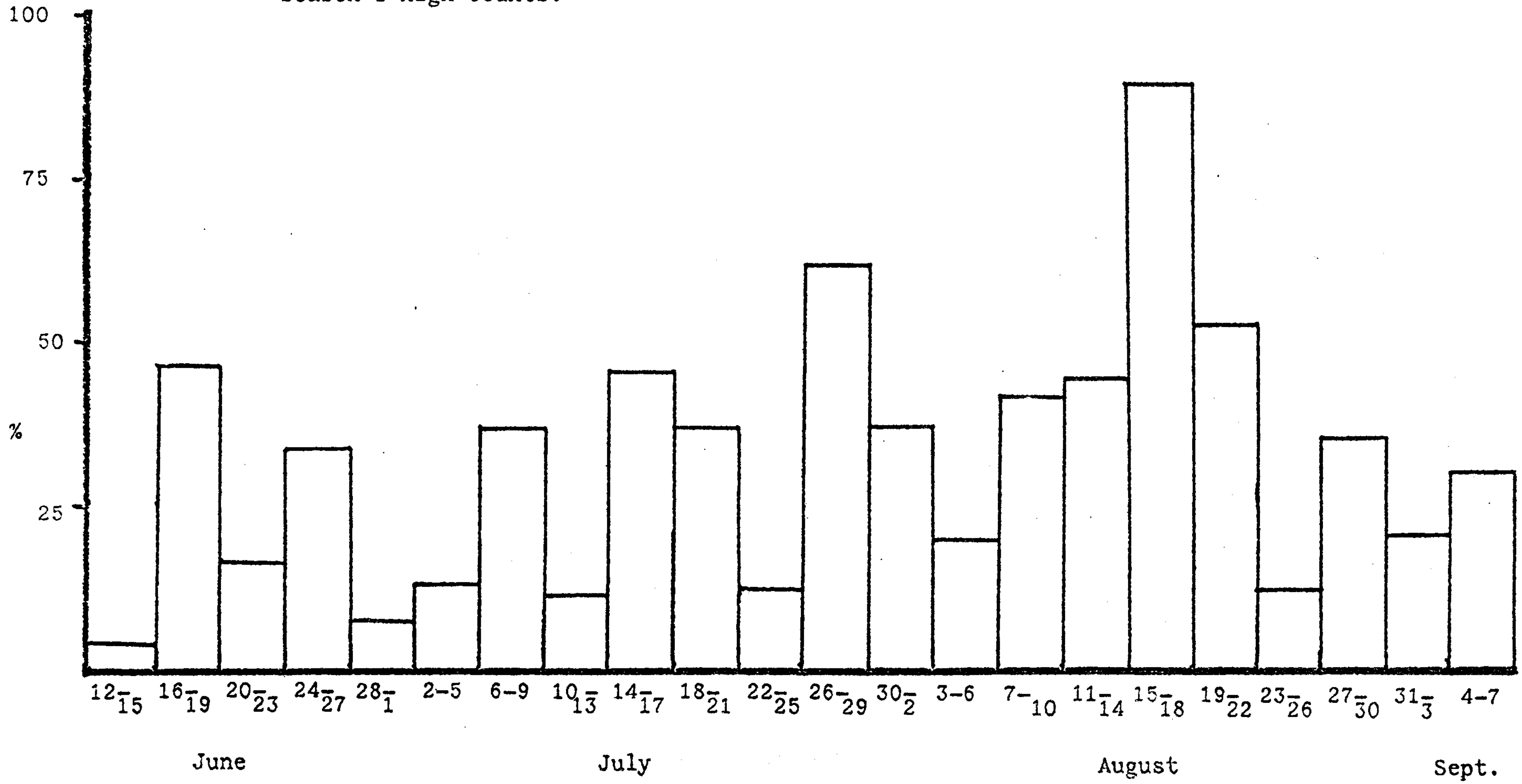


Table 9. Variations in numbers of murres at Bluff Cliffs, Square Rock, and Sledge Island, 1975–1978. (Date of count is in parentheses.)

	1975	1976	1977	1978
BLUFF				
[a]pre-breeding season count	—	40,000 (5/30)	61,000 (5/21)	89,000 (5/29)
breeding season high count	[b]90,000 (7/4)	55,390 (8/12)	[c]45,250 (7/29)	48,460 (8/9)
estimated number of breeding pairs	25,000	20,000	20,000	23,500
SQUARE ROCK	6,100 (7/3)	4,000 (7/11)	7,600 (8/19)	4,070 (7/15)
SLEDGE ISLAND	2,200–3,000 (7/23)	2,900 (8/7)	2,800 (8/23)	4,300 (7/13)

[a]These pre-breeding season counts are of murres on the water in front of the cliffs.

[b]This is the total number of murres on the water in front of the cliffs as well as on the cliffs.

[c]In the Annual Report for 1977 (March 1978), this count was "corrected" to the nearest twenty-four hour count; the number appearing here is the original number counted.

How reliable are these air estimates? Table 10 shows a number of estimates made from the air and numbers counted from a boat at the same cliffs. We have referred to the high variability we found in counts made from a boat (Table 11) and observe that the numbers estimated from the air fall well within the limits of variation shown in surface counts. We are convinced that differences between air and surface counts, therefore, do not necessarily indicate inaccuracy in the air estimates. The air estimates may reflect there being more or fewer than average seabirds at the cliffs at the time the aerial estimate was made as well as the counts made from a boat.

Dependability of our counts in establishing significant changes in numbers. At Little Diomede we can compare counts made by Kenyon and Brooks (1960) with counts made by the Steeles and Watson in 1977 (Drury and Biderman 1978). The two sets of counts are very close. For both sets the smaller numbers report actual counts. The upper limits offered by Steele and Watson are estimates extrapolated from sample counts of habitat-types using a simple calculation of area of the islands sides. The upper limits of the counts published by Kenyon and Brooks were the high numbers which they "thought might possibly be there" (Kenyon pers. comm.) (see Figures 15 and 16). When we compare the lower estimates between the two samples the results indicate that little real change has occurred. The Diomeders themselves reported that they believed the murres have increased and the Crested Auklets have decreased, which would be consistent with the data.

At Cape Thompson, Springer, Roseneau and Murphy have made counts of the cliffs from a small boat in 1976, 1977 and 1979, using the same methods as did Swartz in 1960. Their counts indicate a 60% decrease in

Table 10 .
Comparison of Counts Made from the Water with Estimates Made from the Air.

BLACK-LEGGED KITTIWAKE

bird cliffs at:	counts from the water	estimates from the air
Egg Island	525	650, 900
Cape Denbigh	1850	1820, 2300
Bluff Cliffs	4000, 6000	3000, 5000
Sledge Island	750, 1300	620
King Island	3000, 4000	3000, 6000
Little Diomede Island	17500, 20000	12000, 17500

MURRE

bird cliffs at:	counts from the water	estimates from the air
Egg Island	1250, 2000	1250, 2500
Cape Denbigh	10500 (1976)	10300 (1976), 17650 (1
Bluff Cliffs	25000, 35000, 45000, 55000	17000, 35000
Sledge Island	2300, 2900, 4300, 6300	1350, 4250, 7000
King Island	4000, 100000	85000
Little Diomede Island	46000, 60000	42000
Cape Thompson	120000, 145000, 155000 (Springer & Roseneau, 1976, 1977, 1978)	210000-250000 (Drury 1978)
Cape Lisburne	185000-@200000 (Springer & Roseneau, 1976, 1977)	190000-210000 (Drury 1978)

The figures represent particular counts or estimates, except for those at Cape Lisburne and Cape Thompson, which represent the spread of estimates made during one pass along the cliffs at each place.

The counts made from the water which are used in this table were made in mid-July to mid-August, so as to coincide with the season at which the estimates were made from the air.

Variation in the actual numbers as reflected in the counts seems to be large enough to mask any consistent bias in the estimates made from the air.

Table 11.
Variations in Counts of Murres made from the Water

	1975	1976	1977	1978
Bluff early July	21600, 90000	20800, 22000	42600	33500
Bluff August	70000	55000	42000	48500
Sledge Island mid-July	2200-3000	2900	6300	4300
Square Rock early August	6200	4000	7600	4000

These tables show that variation in conspicuous within each season with a progressive increase from early July until mid-August. They also show that there are important differences in the usual "high" counts in early July or August between years, i.e., 1977 was a high year at Sledge Island and at Square Rock, but not at Bluff Cliffs.

There is also variation within the day as shown by "24-hour counts". These counts show a minimum number of birds at the cliffs around the middle of the day and around midnight, although some sections of the cliffs may be out of phase. Our counts suggest that the daily variations in June usually amount to about 30%; those in July amount to 15% up to 25%; those in August average 25%.

In compensating for the natural variations in numbers, it would be possible though expensive, to run a 24-hour count at the same time that a count from the water and another estimate from the air were being made. One could calculate correcting factors in this way and measure the reliability of observers and of the air versus water methods. When one came to apply these corrections to another set of cliffs, one would have to start over again, because one would not know the cycles of that other cliff, nor the degree to which any given day is not typical of the ordinary cycles.

We have presented our data without corrections, because we have concluded that treating the data on a logarithmic scale will eliminate the minor variations and that we might exaggerate our error as much as we might reduce it by applying "corrections" until we understand the patterns of activities at each cliff. When we do understand each cliff, we will not need to use corrections.

To summarize, we show counts and estimates of birds at the cliffs and conclude that for reconnaissance purposes, estimates made from the air are useful. We believe that such estimates are useful in making comparisons among different cliffs and will be useful if there are substantial changes in numbers at any cliff over a series of years.

Figure 15.
Number of seabirds at Little Diomede Island (Ignalook) in 1954 & 1958, and in 1977.

The numbers represented by the lines with perpendicular ends are from Kenyon and Brooks (1960). The lines with circles at the ends are our data. Keyon reported that the lower estimates are the results of this tallies; the higher are possible expansions of the estimates. The differences within the 1977 estimates reflect differences between two ways of estimating the area of the sides of the island. Note that Kenyon and Brooks were not on the island in July and August when the subadült Horned Puffins prospect the cliffs.

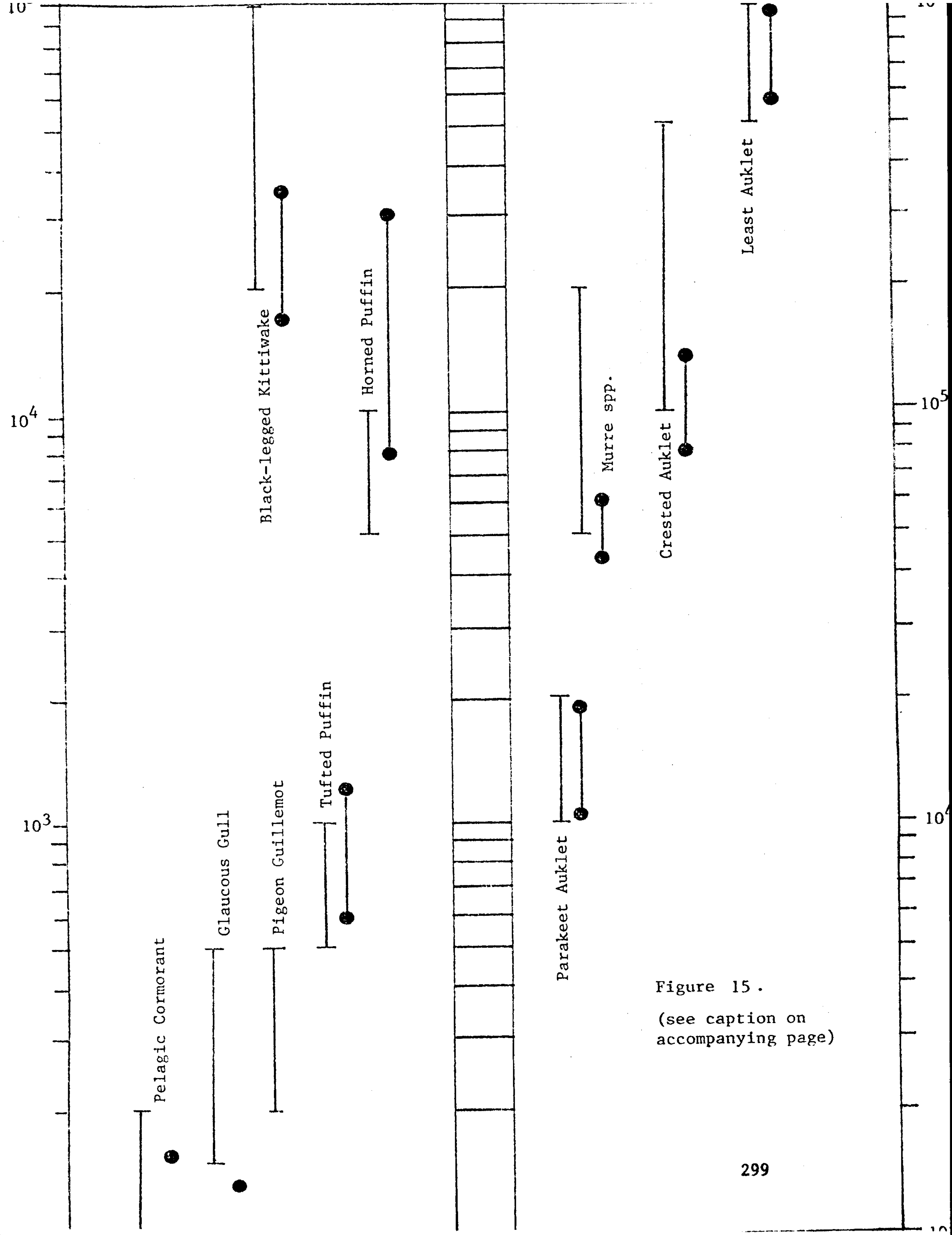
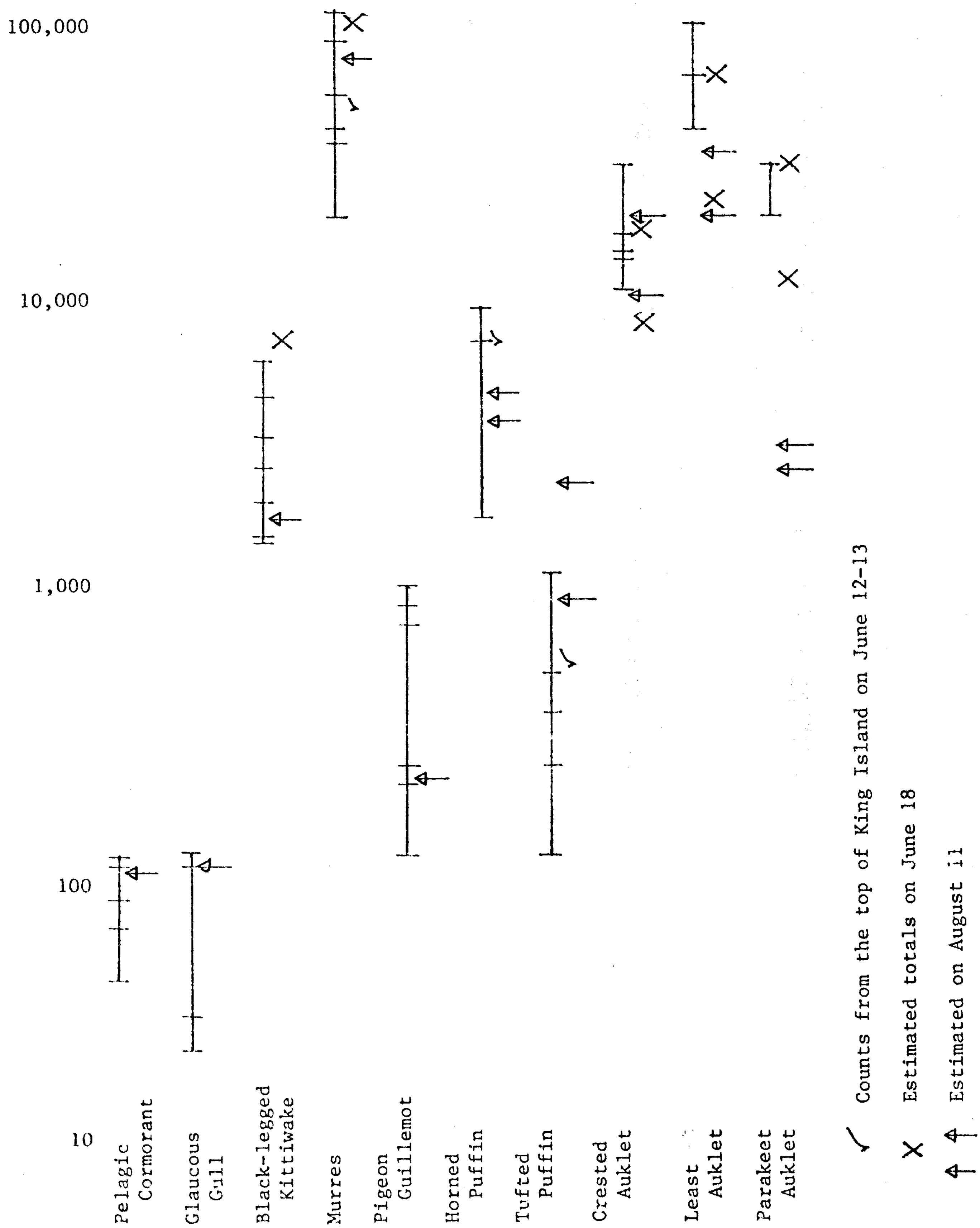


Figure 15.

(see caption on accompanying page)

Figure 16 . Numbers of seabirds at King Island in 1976.



the numbers of birds when compensating for daily cycles (391,400-155,000). Our estimates from the air (210,000-250,000) suggest a smaller decrease, 40-45%. Of course, the air estimates are less precise, but our experiences at Bluff Cliffs suggest that differences of 30% between 150,000 and 225,000 are to be expected within or between seasons. All the data available suggest an important decline.

While our estimates at Cape Thompson differ from those of Springer and Roseneau, our estimates are in good agreement at Cape Lisburne. We estimated 200,000-220,000 from the air; Springer and Roseneau (1978) said the numbers may be well in excess of 200,000.

We review the techniques and reliability of counts of breeding populations in Appendices VI and X, and conclude that one should not draw precise conclusions based on data gathered in surveys made over one or two years, no matter how precise and thorough the counting techniques are. One can draw informative conclusions from counts or estimates though, in spite of differences in sampling techniques and levels of precision, provided: 1) estimates have been made in a systematic way that is described and is repeatable; 2) overall changes in numbers have been considerable; and 3) ordinary changes, which occur daily, weekly, seasonally and between years are understood. We do not think that numbers which show a large degree of variability are *a priori* unreliable.

We have become convinced that although it may be convenient it is misleading to use a single number to represent the size of a seabird city. Our experience censusing Herring Gulls and Great Black-backed Gulls, or Black-crowned Night Herons, Great Blur Herons, and Egrets in coastal New England convinced us of this, but we did not have the data to confirm the impression. Our work on Common Murres at the seabird cliffs in northwestern Alaska does document the conclusion.

Thus, we are convinced that /numbers should be regarded as a series of approximations. One should consider percentage differences, not absolute differences, and one should use logarithmic series until shown that it is preferable to do otherwise. For example, we have found that the numbers of murres which we estimate at cliffs fall into "sets": 2,000-5,000; 10,000-20,000; 25,000-50,000; 60,000-90,000; and 150,000-200,000/ (see Figures 15 and 16). We have no difficulty distinguishing among these "sets." Note, the percentage variation decreases as the numbers increase. We believe that the limits to these "sets" are fixed by the areas of cliff and that the techniques which we use are adequate to establish real differences.

2. The Eastern Chukchi Sea

The seabird bazaars on the cliffs of the Lisburne Peninsula consist of two huge gatherings and one smaller only by comparison. The cliffs at Cape Lisburne consist of uptilted sedimentary rocks, showing alternately dark and light. The birds occupy the northwest corner of the bold headland. Most of the birds nest on the west-facing cliffs. An Eskimo village, Wevok, was located on the north shore, but it has been buried under an airstrip serving a radar station. Above the cliffs are steep, vegetated slopes of rubble, but no auklets breed there. The west cliffs are deeply cut by river valleys and Grizzly Bears come down these valleys. Springer and Roseneau report that at least one bear has learned to crawl along the ledges gathering eggs, despite the fact that the tops of the cliffs are 500-700 feet above the sea.

Currents flowing north move on past Cape Lisburne leaving an eddy to the east, between the Cape and Point Lay. The edge of the lighter north flowing water and the dark eddy was clearly visible when we visited the area. Springer and Roseneau report that the Sand Lance are abundant in the eddy and we saw flocks of kittiwakes and murres milling within 1/4 mile of the low bluffs on the shore running eastward toward Corwin Creek.

A bird city of several tens of thousands exists at Cape Lewis, part of the way south to the gravel spit at Point Hope, and there are other smaller rocky outcrops where Pelagic Cormorants and Glaucous Gulls nest.

The steep slopes retreat diagonally southeast across the base of the Point Hope gravel spit to the precipitous headlands at Cape Thompson. The first and highest of these cliffs offers nesting space for what is probably the largest single concentration of murres on any cliffs in the region; Springer and Roseneau have counted 60,000-80,000 birds on this single face (Table 12). Our estimate of 120,000-130,000 from the air was hurried, yet differs little from the counts made by Swartz in 1960. There are four other lower sets of cliffs at Cape Thompson with steep, vegetated slopes at their tops. Behind them rolling upland extends to the north.

The seabirds at Cape Thompson were studied by Swartz in 1958, 1959, and 1960. The results of those studies, together with recent ones, indicate that in the early period kittiwakes nested earlier, laid larger clutches and reproduced much better than they did in 1976 and 1977, when Springer and Roseneau studied the cliffs. The kittiwakes at these northern nesting sites nest later and have smaller clutches than do birds nesting further south in the Bering Sea and Gulf of Alaska (Table 2). This is consistent with a similar trend in the Atlantic (Table 3). The phenomenon suggests

Table 12 . Seabird Populations along the Lisburne Peninsula. From estimates made by Springer and Roseneau, except where indicated.

Species	Cape Lisburne	Cape Lewis	Cape Thompson: Imnakpak	Agate	Artigotrat	Crobill	Total
Pelagic Cormorant	80	60	5		30	16	50
Glaucous Gull	50	50	35	100	40	120	300
Black-legged Kittiwake	25,000	3,000	10,000	6,000	10,500		26,500
Murres (50% Common; 50% Thick-billed) Roseneau & Springer	200,000+	25,000-45,000	70,000	22,000	60,000	2,500	155,000
Drury	200,000-220,000	45,000	130,000-150,000	18,000	75,000-90,000	800	224,000-260,000
Black Guillemot	170	30	2		2		4
Pigeon Guillemot	2	-	10		4		14
Horned Puffin	1,450	300	680	250	345	325	1,600
Tufted Puffin	20	4	4	4	10	13	30

a fixed genetic relation of clutch size with date; either local selection has not modified the relation because of gene flow, or smaller clutches contribute better fitness in these regions of perennial reproductive failure.

The reproductive success of murres and kittiwakes at these cliffs have varied parallel with the success measured at other cliffs in the Bering Strait region between 1976 and 1979. Kittiwake reproduction in 1976, appears to have been a total failure here as it was at King Island and on Saint Lawrence Island that year (Searing 1977). Reproduction was better in 1977, but still not comparable to the earlier success. All colonies studied did well in 1978. The kittiwakes in this region appear to be tied to a cycle of boom or bust. The murres, however, have had moderate success each year without extreme annual variations (Table 19).

Rolling hills extend east and southeast from Cape Thompson, but there are no bird cliffs because the shore follows a long barrier beach extending from Cape Thompson to Cape Kruzenstern and beyond. Behind the beach are a series of lagoons which support large flocks of waterfowl past Kivalina and Cape Kruzenstern all the way to the point at Sheshalik, north of Kotzebue.

Kotzebue is located on morainic material which must have been brought there by glaciers from the valley of the Noatak and Kobuk Rivers. At the southern end of the Choris Peninsula are low, rounded islands: Puffin and Chammiso Islands. There large nesting cities of Horned Puffins are a National Wildlife Refuge. Along the southern shore of Kotzebue Sound there are three small bird cliffs (Table 13), at Cape Deceit, Toawlevic Point and Sullivan Bluffs. The bedrock cliffs at each of these places are

Table 13 .
Seabird Populations in southern Kotzebue Sound, west of Deering.

	Cape Deceit	Toawlevic Point	Sullivan Bluffs	no name	no name
Pelagic Cormorant	-	-	-	20	20
Glaucous Gull	10	-	35	-	-
Black-legged Kittiwake	600	280	550	-	-
Murre	1300	1300	700	-	-

75-100 feet high, and a few hundred meters long, and are fully occupied. Lack of suitable rocky faces in inner Kotzebue Sound probably limits the numbers of seabirds breeding. We presume that the murres at these cliffs are largely Common Murres because the waters of Kotzebue Sound resemble those of Norton Sound and Bristol Bay where Common Murres predominate.

3. The Bering Strait

We counted birds at Little Diomede Island and King island; we have little information on seabirds on Big Diomede Island. Our brief observations in passing (sic) indicated the presence of perhaps 200 Glaucous Gulls, 300 Pelagic Cormorants and 20,000 Crested Auklets on the southern end. We saw no murres or kittiwakes there. We counted a total of about one million birds on Little Diomede and King Islands. Roughly 85% of the total are auklets, an indication of the productivity of planktonic invertebrates. We have no information on the east coast of Siberia.

Little Diomede Island is located in the narrowest part of the Bering Strait between Cape Prince of Wales and Cape Dezhneva, Siberia (Figure 6). Big Diomede Island, USSR, lies about 2 miles west of Little Diomede. There is a small Eskimo village, Ignaluk, located on the northwest corner at the base of Little Diomede's steep slopes. The topography of the island resembles King Island, but Little Diomede is larger, higher (400m above sea level), and its sides are steeper. Extensive rubble fields on the top and sides of the island provide nesting habitat for auklets.

The numbers of birds nesting at Diomede are phenomenal. The auklets comprise 750,000 out of a total of 1.0 million birds here, and the Least Auklets account for 600,000 (see Table 14). This number of birds is obviously difficult to measure.

Table 14. Composition of the Seabird Colonies of the Bering Strait.

Species	King Island	Fairway Rock	Little Diomede Isla
Pelagic Cormorant	100	25	140
Glaucous Gull	100	125	160
Black-legged Kittiwake	6,000	650	20,000
Thick-billed Murre	38,000 (50%)	4,000	35,000 (60%
Common Murre	38,000		25,000
Pigeon Guillemot	940	100	275
Parakeet Auklet	35,000	500	15,000
Crested Auklet	35,000	10,000	100,000
Least Auklet	85,000	15,000	600,000
Horned Puffin	10,000	75	10,000
Tufted Puffin	1,000	1,000	1,000
Total	250,000	32,000	807,000

The breeding biology of the auklets is difficult to study. All three species nest underground; the Least and Crested Auklets nest under boulders on talus covered slopes, while Parakeets dig burrows in the vegetated slopes or nest in rock crevices. The auklets first appear on the island in late May. Massive flocks of Parakeet and Least Auklets settled onto the cliffs about ten days earlier than the Crested Auklets in 1977. The snow remained longer on the grassy slopes than on other nesting habitat, and this appeared to delay egg-laying in the Crested Auklets. These birds must wait to breed until the snow has melted and water has drained out of the burrows. The timing of breeding events is difficult to monitor in the underground nests. From behavioral observation and information provided by Eskimo children, we figured egg-laying to be in early July. We were not able to measure reproductive success in the auklets.

Eskimo tradition says that the murres come to the island at the first break-up of the sea ice. Kenyon reported murres flying past Little Diomede in April. Early in the season leads in the ice are important for all species here as at Bluff. The information we have on murres at Diomede suggests a breeding season slightly later than that of Bluff. Murres at Diomede took longer to settle than at Bluff in 1977, and egg-laying began around July 1, two weeks later than Bluff. The number of murres at Diomede increased through the season as did the Bluff population. Thick-billed Murres make up 60% of Little Diomede's murre population, as compared to less than 1% at Bluff. We have no data on productivity of the murres at Diomede.

Little Diomede Island is the site of the largest kittiwake colony in the Northern Bering Sea with a population of 20,000 to 35,000. Kittiwakes here, like murres, have a schedule of breeding slightly later than the Bluff population. The kittiwakes settled onto the cliffs and began building nests on June 15th, two weeks later that year than at Bluff. To estimate reproductive success we have to compare the numbers of eggs and chicks per nest found in early August at Little Diomede with a similar period at Bluff (Table 15). In 1977, Diomede may have had better kittiwake productivity than did Bluff, but not much better. The proportion of nests with eggs was higher but the numbers of eggs and chicks per nest indicates similar productivity at the two places.

Our observers reported an exceptionally large population of non-breeding Horned Puffins (25,000 birds) at Little Diomede late in the season.

King Island. Traditionally Eskimos use colonial seabirds for food and often villages are located near a seabird colony. Vast numbers of seabirds nest on King Island, which had an active village, Ukivok, up until twenty years ago. King Island rises abruptly out of the ocean to a flat top about 370m high; the steep sides have a slope of about 40°. The island lies about 45 miles west of Cape Spencer.

More than two-thirds of the birds at the colony are the plankton-eaters, including the auklets and Thick-billed Murres. Thick-billed comprise about 50% of the murre population, as compared to less than 1% at Bluff and the other Norton Sound colonies. The auklets are as difficult to study here as they are at Little Diomede Island. The general picture of breeding biology is similar to that at Little Diomede. Parakeet Auklets nest in crevices and burrows in the sod on the middle and lower third of the slopes. Least and Crested Auklets use the rubble-covered upper slopes and the boulder fields on the top of the island. We have little data on

Table 15. Comparison of Chick Counts at Study Areas at Little Diomede Island (1977), and Bluff Cliffs (1977 and 1978). The counts at Bluff were chosen from a date corresponding to the 1977 count at Little Diomede, and froma 1978 count corresponding to the nearly-equal ratio of chicks hatched to eggs unhatched seen in the nests on Little Diomede in August of 1977.

location	year	date	no. of chicks counted	no. of eggs counted	no. of nests	chicks per nest on a single day
Little Diomede Island, west side, site 16, 16B, 17, 18	1977	Aug 11	19	20	116	0.16
Bluff Cliffs, stakes 8, 10, 13, 14, 17, 4B	1977	Aug 5	14	10	110	0.13
Bluff Cliffs, stakes 8, 10, 13, 14	1978	July 20-22	71	75	113	0.63

reproductive success for the auklets but our rough calculations of egg-laying dates together with information reported by King Islanders (Ed Muktoyuk, John Pullock, Mike Saclamanna) are similar to those for Little Diomede.

Like the seabirds at other cities, it is appearance of open water around the colony that determines the date of arrival in the spring. Murres were seen around the colony in leads in the ice as soon as we arrived in early June 1976, but they did not begin laying eggs until the end of June. It appeared that Thick-billed Murres laid about one week ahead of the Common Murres, something we have not noticed at other colonies. Black-legged kittiwakes and Horned Puffins are the next most numerous species. The breeding season of 1976 was evidently a total disaster for the kittiwakes at King Island. Tufted Puffins, Pelagic Cormorants, Pigeon Guillemots, and Glaucous Gulls are all present in relatively small numbers. We saw one individual Dovekie (Plantus alle), an Atlantic species of plankton-eater.

King Island is a difficult place to study the cliff nesting birds too, because of the steepness of the sides of the island and the lack of places from which to get a clear view of the cliffs.

4. Norton Sound

The species composition and approximate maximum numbers of the birds in Norton Sound are shown in Table 17a & 17b, and Figure 17/ (see also Appendix VII). Bluff Cliffs is the major colony in this area, both in numbers and diversity of species. We concentrated our studies at this place from 1975-1978. The dynamics of the seabird colony at Bluff are presented in Section V. Sledge Island, Topkok, Square Rock, Rocky Point, and Cape Denbigh are the group of next largest colonies. We studied the seabird cities at Sledge Island and Square Rock and censussed the others.

Sledge Island is a small island approximately one square mile in area, 25 miles west of Nome and 7 miles offshore. It is the site of a former village, Ayak, whose people were killed off in the influenza epidemic of 1917. The fish-eating birds are the major component of the seabirds at Sledge (see Table 17). There are no Least or Crested Auklets; however, 20 to 150 Parakeet Auklets have been seen and may breed there. Thick-billed Murres are about one-fifth as numerous as Common, in contrast to Bluff where they are less than 1% of the population of murres. Thus, it appears that Sledge Island is at the edge of the breeding area of plankton-eating alcids, characteristic of the Saint Lawrence Island waters and Bering Strait. The water around Sledge is Alaskan Coastal Water. A steady, strong coastal current flows past the island from the southeast.

Sledge is a major breeding area for Pelagic Cormorants and supports 120 nests (see Table 16 for reproductive success). Productivity of kittiwakes at Sledge varied in parallel with that at Bluff over three years: very low productivity in 1976 and 1977, followed by a sharp increase in 1978.

Square Rock is a stack of rock standing 75 feet high, roughly 100 feet long and 40 feet across. It stands 75 feet off a bold shore with cliffs on which murres and kittiwakes nest. We have included birds from both the rock and the cliffs in the count of this colony.

Square Rock is less than 1/2 mile from the eastern end of Bluff Cliffs but appears to be a distinct colony in terms of daily schedule and reproductive success. In 1977, we conducted 24-hour watches at Square Rock along with those at Bluff. Early in the season murres and kittiwakes at Bluff were on a different daily schedule than those at Square Rock. The murres were

Table 16. Population size and reproductive success of Pelagic Cormorants in the Norton Sound Region.

location	no. of adults	no. of nests	chicks per nest	(year)
Sledge Island	280	150	1.91	(1975)
			0.75	(1976)
			2.65	(1978)
Bluff Cliffs	125	60	1.45	(1975)
			1.28	(1976)
			2.77*	(1977)
			2.41*	(1977)
			1.22*	(1978)
			1.50*	(1978)
Topkok Head	300-400	140	1.58	(1975)
			1.60-2.40	(1977)
			0.78	(1978)
Rocky Point	400	165	0.81-1.2	(1978)
Cape Darby	450	74	1.54	(1976)

* It is important to realise that the figure for chicks per nest shown above are based on counts of chicks in the nest on the one day a count was made, and therefore, do not reflect actual reproductive success based on the number of chicks fledged. There is only one value above (*Bluff 1977) representing the number of chicks that actually fledged from 22 nests studied at Bluff in 1977.

Ed Muktoyuk (pers. comm.) of King Island told us the usual clutch size of Pelagic Cormorants is 4 eggs; we calculated clutch size at Bluff at 2.3 eggs/nest in 1976, and 3.4 eggs/clutch in 1977.

strikingly opposed; peak attendance occurred early in the morning at Bluff, corresponding to the low point of attendance at Square Rock at that time. The schedules of both species became similar in mid-July when peak attendance occurred in the early afternoon. In 1977 kittiwakes at Square Rock were much more faithful nest attendants than those at Bluff, especially from mid-July on. This correlates with a particularly high reproductive success at Square Rock, roughly five times that of Bluff. Evidently, the kittiwakes at Square Rock were not adversely affected by the causes of the low productivity seen at Bluff in 1977. Curiously, the kittiwake sites on the mainland cliffs of the Square Rock colony showed the Bluff pattern of poor attendance and suffered poor reproductive success.

Other colonies in Norton Sound. Other colonies of murres in Norton Sound were censussed from the air in 1975, 1976, and 1977, and photographic estimates of reproductive success were made in 1975 and 1976 (Drury and Steele, 1977). This technique showed that Bluff had the lowest productivity those years, and that both Egg Island and Cape Denbigh were substantially more productive.

The other colonies in Norton Sound are very small and have not been studied intensively. Table 17 shows that murres and kittiwakes occur in only five colonies in Norton Sound, but cormorants, Horned Puffins and Glaucous Gulls occur in ten to fifteen, usually in small numbers. The reasons for the dispersal of breeding sites are peculiar to each species; Glaucous Gulls are inshore and coastal scavengers and disperse to find food. Puffins and Cormorants do not fly long distances between nesting sites and feeding grounds so they are among the seabirds which tend to nest in many relatively small, dispersed places.

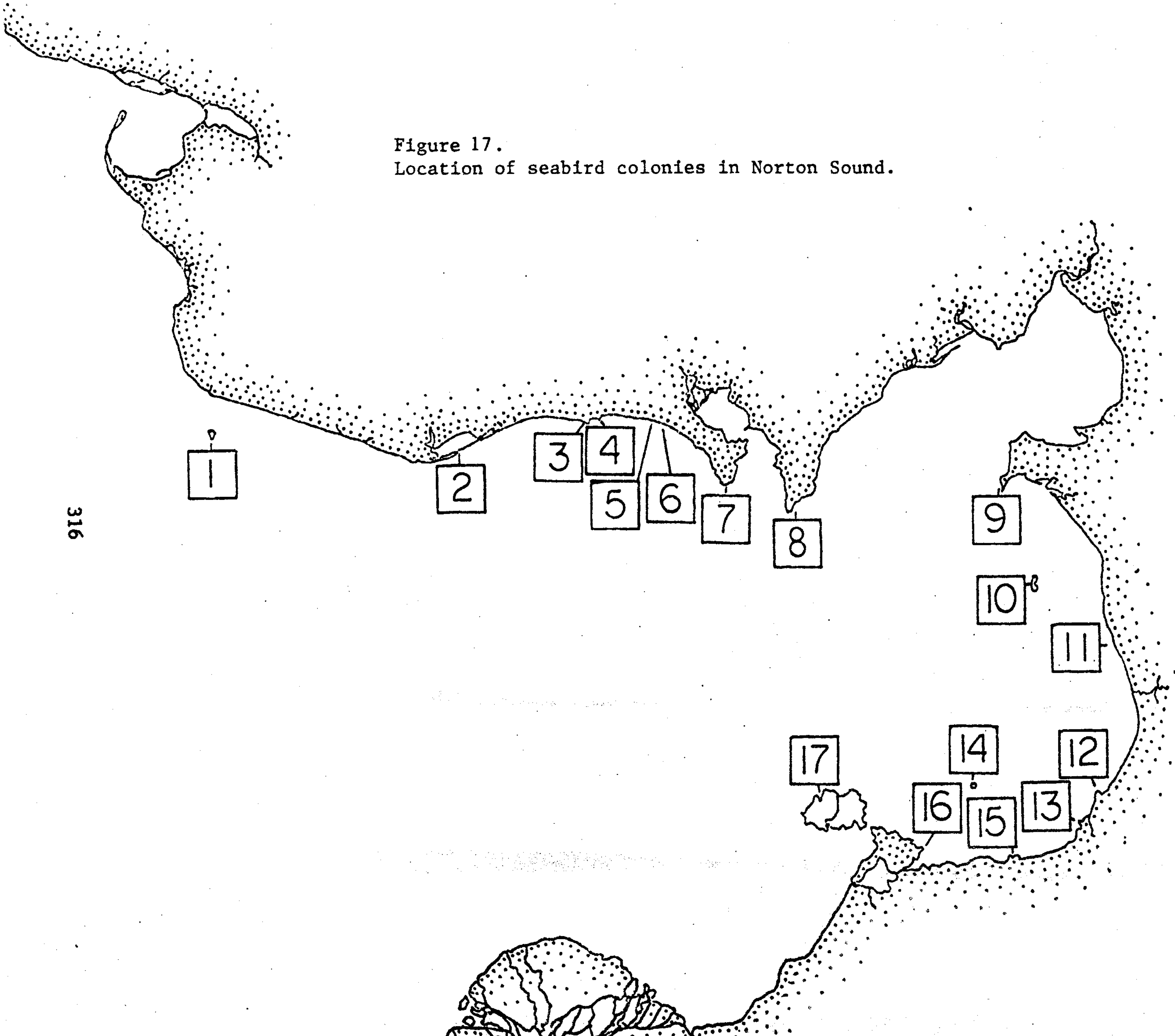


Figure 17.
Location of seabird colonies in Norton Sound.

Table 17a.
Composition of the seabird colonies of the south shore of the Seward Peninsula. Numbers of locations correspond with numbers on the map of Norton Sound in Figure 17.

	Pelagic Cormorant adults (nests)	Glaucous Gulls adults (nests) *pairs	Black-legged Kittiwakes	Common Murre	Thick-billed Murre	Pigeon Guillemot	Parakeet Auklet	Horned Puffin	Tufted Puffin	Total
1. Sledge Island	300-500 (125-150)	45 *6 (2-4)	1000- 2500	2000- 2500	400- 700	8-10	85-165	160	15	4000-6600
2. Safety		*90 (30)								90-180
3. Topkok	320-385 (135-165)	304 *30 (30-36)				13-15		50-180	30-35	700-900
4. Tonok	1-50	2 *10 (2)								3-70
5. Bluff Cliffs	100-170 (70-125)	75-200 (12-30) *15-35	4000- 7500	50,000	500	2-4	50-75	600-3000	10	55,350-61,500
6. Square Rock	15-18 (4-8)	24-26 (9) *13	800- 1500	4000- 6000	50			70-400	1-6	5000-8000
7. Rocky Point	415-900 (165-250)	380 *55-75				3		190-210	6	1000-1500
8. Cape Darby	325-450 (74-100)	*50 (145)						575	51	1000-1200
number of colonies	7	8	3	3	3	4	2	6	6	8
birds per colony	1476- 2473	970- 1255	5800- 11,500	56,000- 58,500	950- 1250	26- 32	135- 240	1645- 4525	113- 123	67,150- 80,000

Table 17b.
Composition of the seabird colonies of inner and southern Norton Sound. Numbers of location correspond with numbers of the map of Norton Sound in Figure 17.

	Pelagic Cormorant adults (nests)	Glaucous Gull adults (nests) *pairs	Black-legged Kittiwake	Common Murre	Thick-billed Murre	Pigeon Guillemot	Parakeet Auklet	Horned Puffin	Tufted Puffin	Total
9. Cape Denbigh (north + south)	30–150	25	700–1850	13,000–18,000	200			40–90	3	14,000–20,300
10. Besboro Island	50–90	15 *15–25								65–105
11. Egavik	5–10	12 *5						8–15		25–37
12. Tolstoi Point	60	*10						15–20		85–100
13. Black Point and islands	20–25	*10						100	2	132–147
14. Egg Island	1	4 *5	300–500	1200–2000	50		5	150	25	1750–2750
15. Klikitarik		4 *5						15		19–25
16. St. Michael								10–150	5–10	15–160
17. Stuart Island (northwest)	1	*100						185	15	300–400
number of colonies	7	8	2	2	2	0	1	8	5	9
birds per colony	167–337	180–347	1000–2350	14,200–20,000	250	0	5	523–725	50–55	16,400–24,000

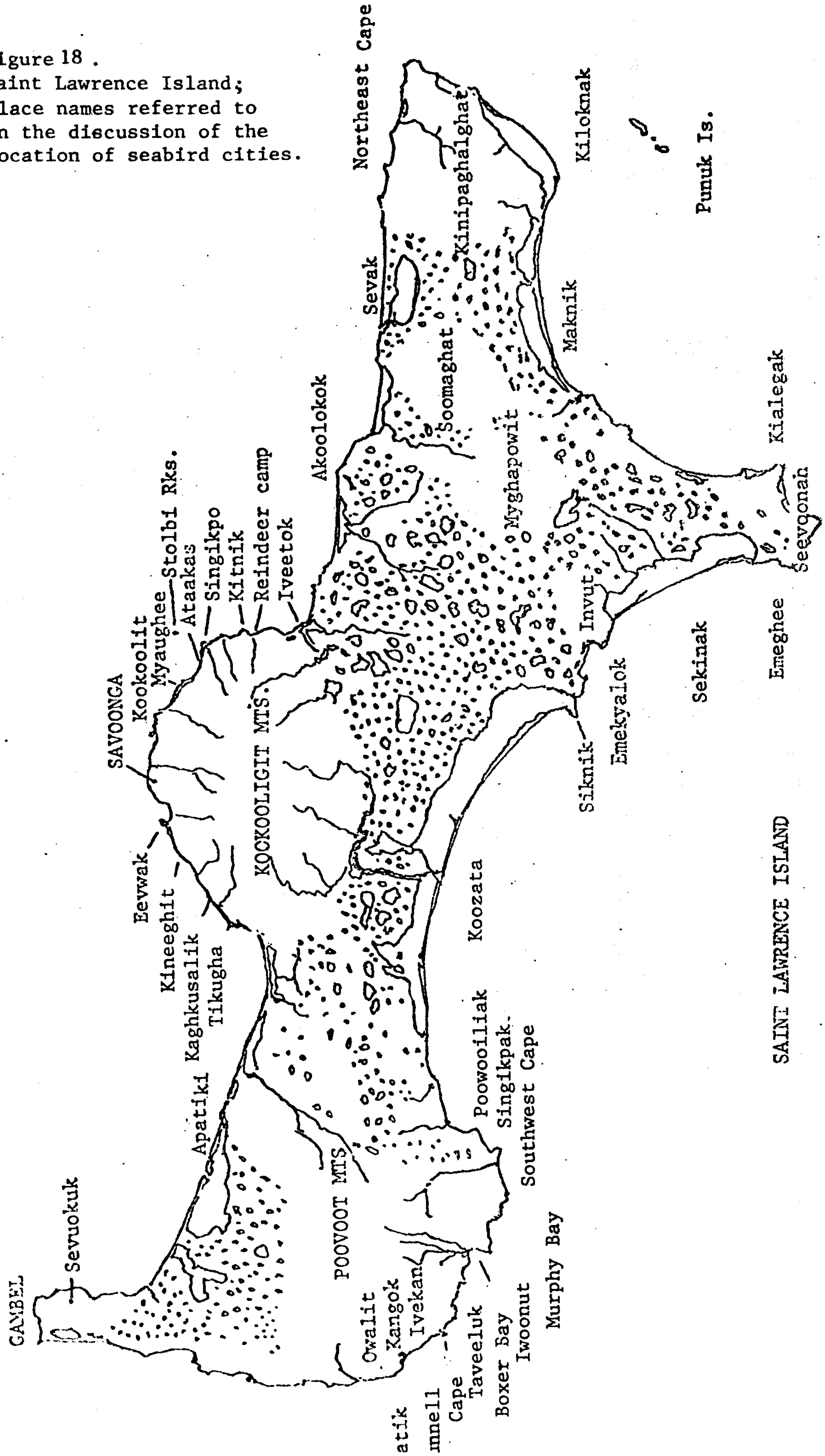
5. Saint Lawrence Island

Seabirds nest at three main areas on Saint Lawrence Island. One is near Savoonga on the north coast along the margin of a fan of volcanic material from the Kookoologit Mountains (Figure 18). East of Savoonga the cliffs are 100 feet high, and made primarily of columnar basalt. In one large section recent lava flows cover the surface with tortuous ribbons and ridges. The basalt outcrops are topped by shallow, rounded slopes; in many places the cliffs are interrupted by steep, vegetated slopes. West of Savoonga lower slopes border the sea for several miles. Then sheer cliffs rise to 150-500 feet on the western rim of the fan. This rock is more massive than that to the east. Here murres are numerous and kittiwakes are relatively few.

A second nesting area is at Sevuokuk Mountain, on the northwest corner of the island next to Gambel. The mountain resembles a turned-over boat and is covered with rubble almost down to the beaches.

The third main bird cliffs are on the southwest rim of Saint Lawrence Island, a fan of volcanic material from Owalit Mountain to Singikpak. The cliffs to the west, Owalit Mountain and Ivekan Mountain, like those of King Island, are made of triangular faces cut into the ends of sharp ridges. Steep, rubble-lined vegetated valleys separate small sections of cliff. The major portion of auklets nest in the rubble fields along these mountain ridges and around a broad basin (Kangok Basin) between Owalit Mountain and Ivekan Mountain. The major bird cliffs are west of Taveeluk Point and terminate at a broad valley at the head of Boxer Bay. East of Iwoonut Point, around Murphy Bay and the Southwest Cape proper, the cliffs are lower, 150-250 feet, and the points are extended into rows of rock stacks. The rock faces are massive in contrast to the friable material further west. These moderate cliffs

Figure 18 .
Saint Lawrence Island;
place names referred to
in the discussion of the
location of seabird cities.



continue as far as Singikpak, beyond which rounded, but steep earthern vegetated slopes are found. The cliffs end in low rock stacks and boulders at Singikpak. From there on steep vegetated slopes extend to the western end of the gravel beach which forms the south shore of the island as far as the low rock outcrops at Siknik Cape.

Pelagic Cormorants nest in scattered places on the low cliffs east of Savoonga and on the Stolbi Rock Stacks offshore. They are found in flocks roosting on the edges of the late snow banks south of Gambel near Owalit Mountain. The major concentration of cormorants is on the rock stacks and cliffs east of Iwoonut Point and especially on the rocky stacks near Singikpak. Glaucous Gulls are widely scattered in small numbers along the gravelly beaches of the eastern two-thirds of Saint Lawrence. Although flocks loaf at the town dump at Savoonga, Glaucous Gulls are numerous only on the rock stacks around Iwoonut Point and Murphy Bay.

Black-legged Kittiwakes nest nearly continuously along the basaltic cliffs from Reindeer Camp to Savoonga but are sparce on the taller cliffs west of Savoonga. None breed at Sevuokuk Mountain. We found the kittiwakes between Owalit Lake and Southwest Cape hard to estimate because in the years we flew along these cliffs there were very large flocks (10,000 birds) on the lakes at Boxer Bay and Owalit Lake. We suspect that the birds had failed and were not occupying their territories regularly even in July.

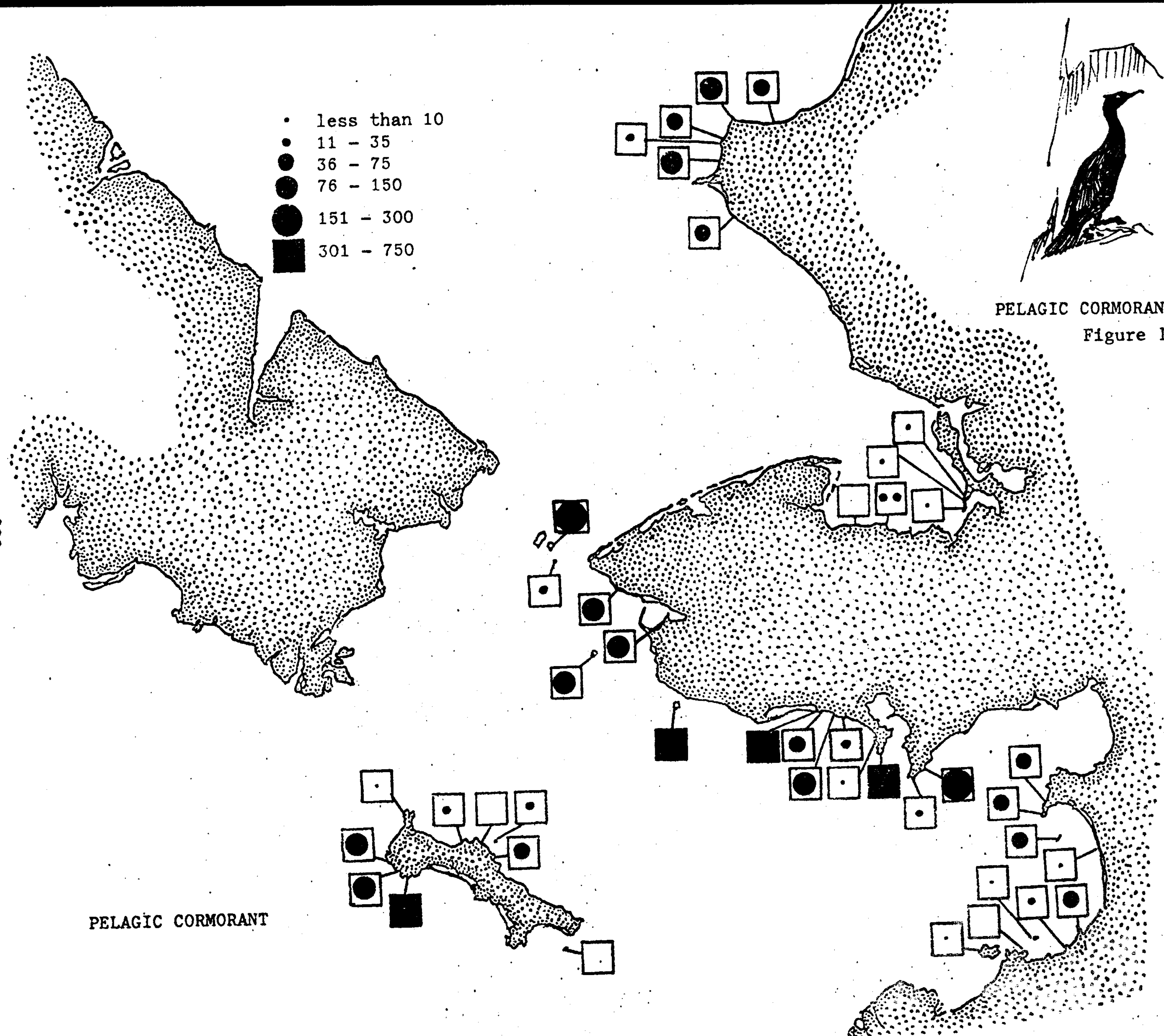
We have no estimates of the proportion of Thick-billed Murres to Common Murres on Saint Lawrence except those discussed by Searing (1977). His notes suggest proportions either equal or three Thick-billed Murres to one Common Murre. Murres nest densely east and west of Savoonga around the basalt apron. The major numbers are on the cliffs on Owalit Mountain and

Ivekan Mountain. A separate nesting area east of Southwest Cape (Murphy Bay) is comparable to those on the north shore.

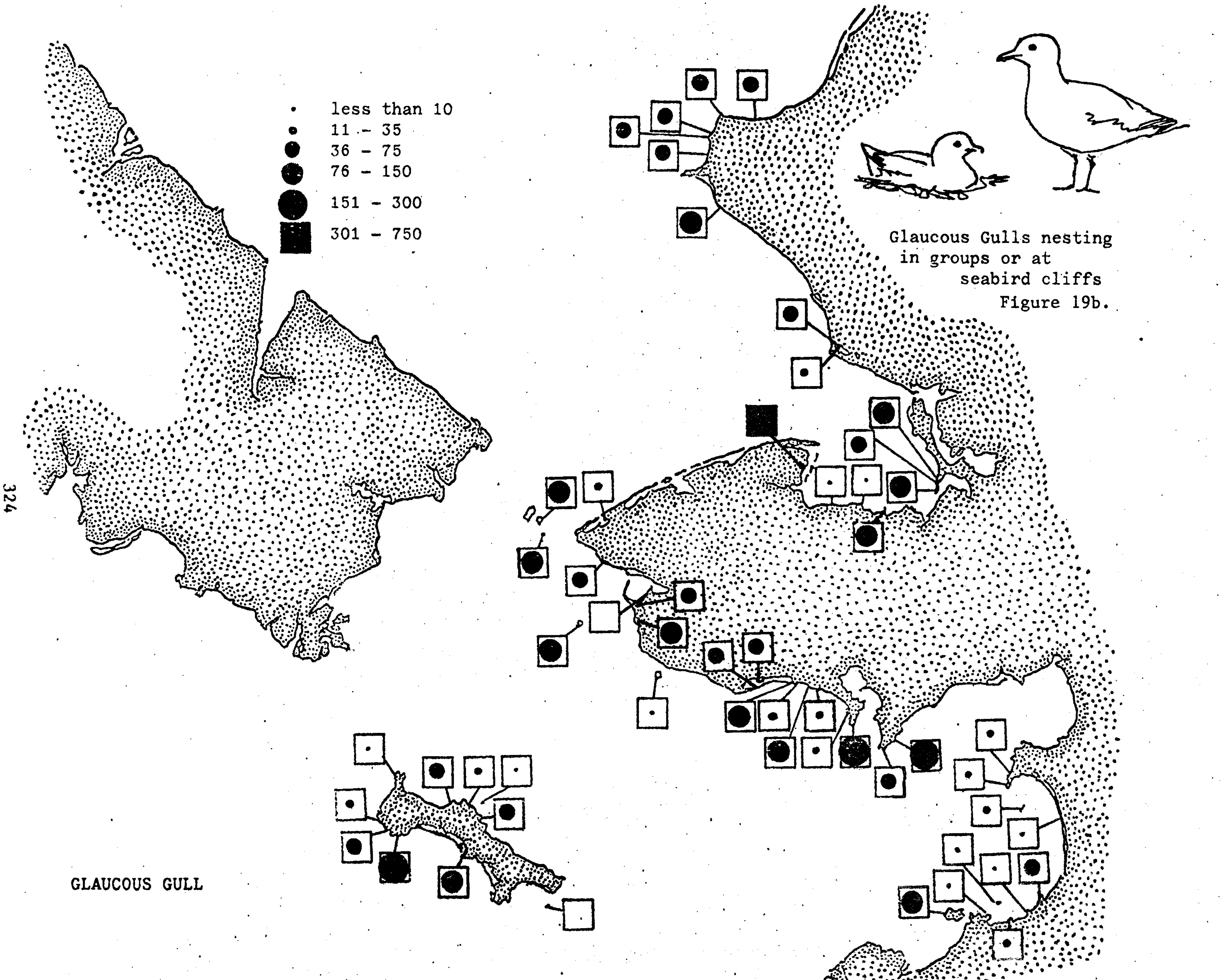
The distribution of Parakeet Auklets is poorly understood because they nest in crevices in bedrock outcrops (Sealy and Bedard, 1973). The nesting of Crested and Least Auklets is concentrated in an area of lava rubble east of Savoonga, at Sevuokuk Mountain and especially in a great rubble amphitheater between Owalit Mountain and Ivekan Mountain. Bedard (1969a)visited the auklet nesting sites east of Savoonga, at Sevuokuk Mountain and at Owalit Basin between 1964 and 1966. His study provides the only substantial information on the food of these plankton-eating seabirds and the first studies of their nesting. Searing (1977) found a major increase in the number of Least Auklets in the Kungok Basin east of Owalit Mountain between the 1960's and 1976, but estimates based on acreages of habitat and numbers of birds counted on sample plots are subject to wide variations. Further studies are needed.

Horned Puffins and Pigeon Guillemots are especially numerous along the perimeter of the volcanic apron around Savoonga and at Sevuokuk Mountain. Horned Puffins are moderately numerous east of Boxer Bay but Pigeon Guillemots are relatively few.

Puffins and Pelagic Cormorants are reported to nest on the Punuk Islands on the east end of Saint Lawrence Island, but we did not survey these islands due to poor weather and low fuel reserves when we passed along that stretch of coast.

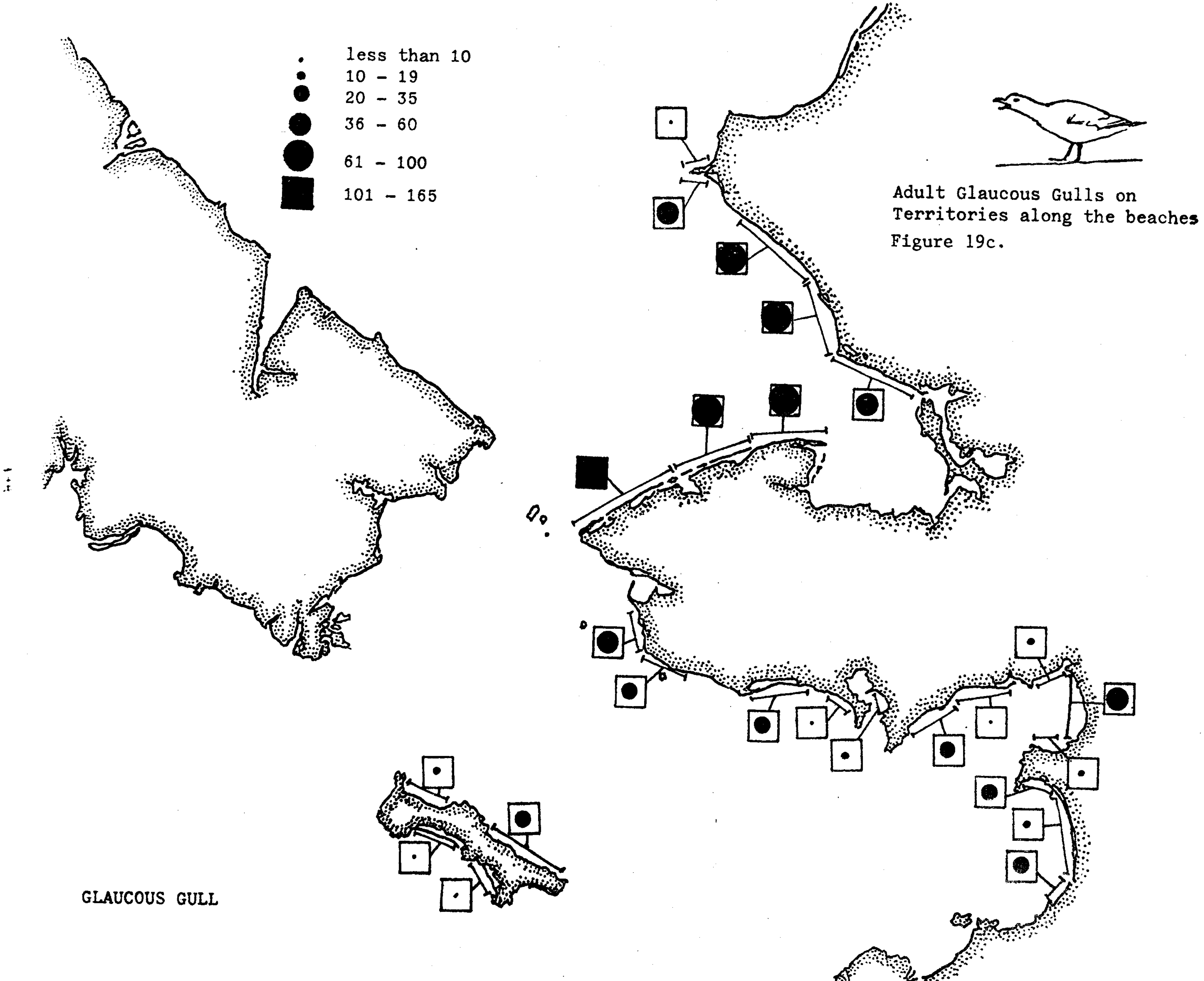


PELAGIC CORMORANT
Figure 19a.

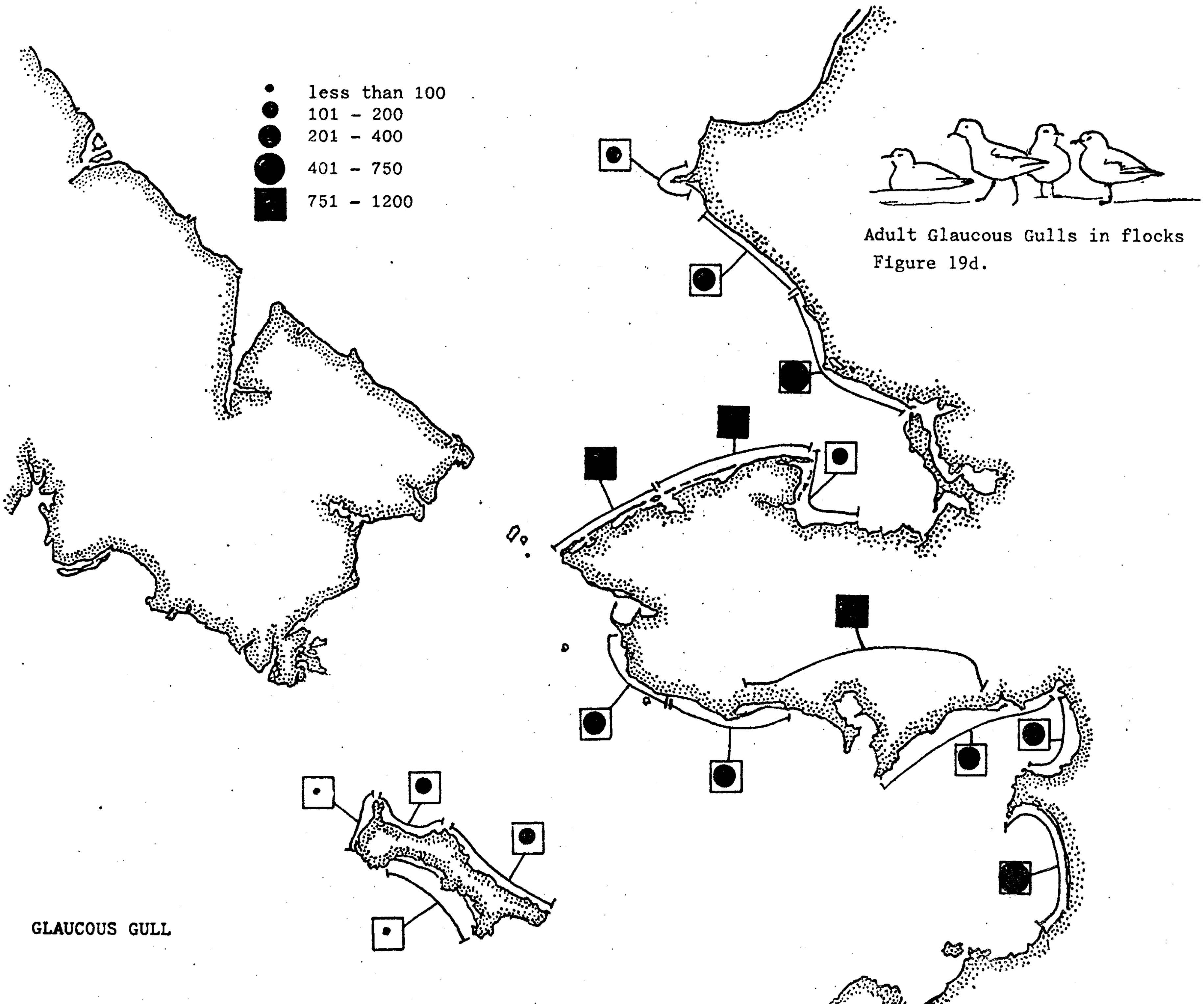


Glaucous Gulls nesting in groups or at seabird cliffs
Figure 19b.

GLAUCOUS GULL



Adult Glaucous Gulls on Territories along the beaches
Figure 19c.



Adult Glaucous Gulls in flocks
Figure 19d.

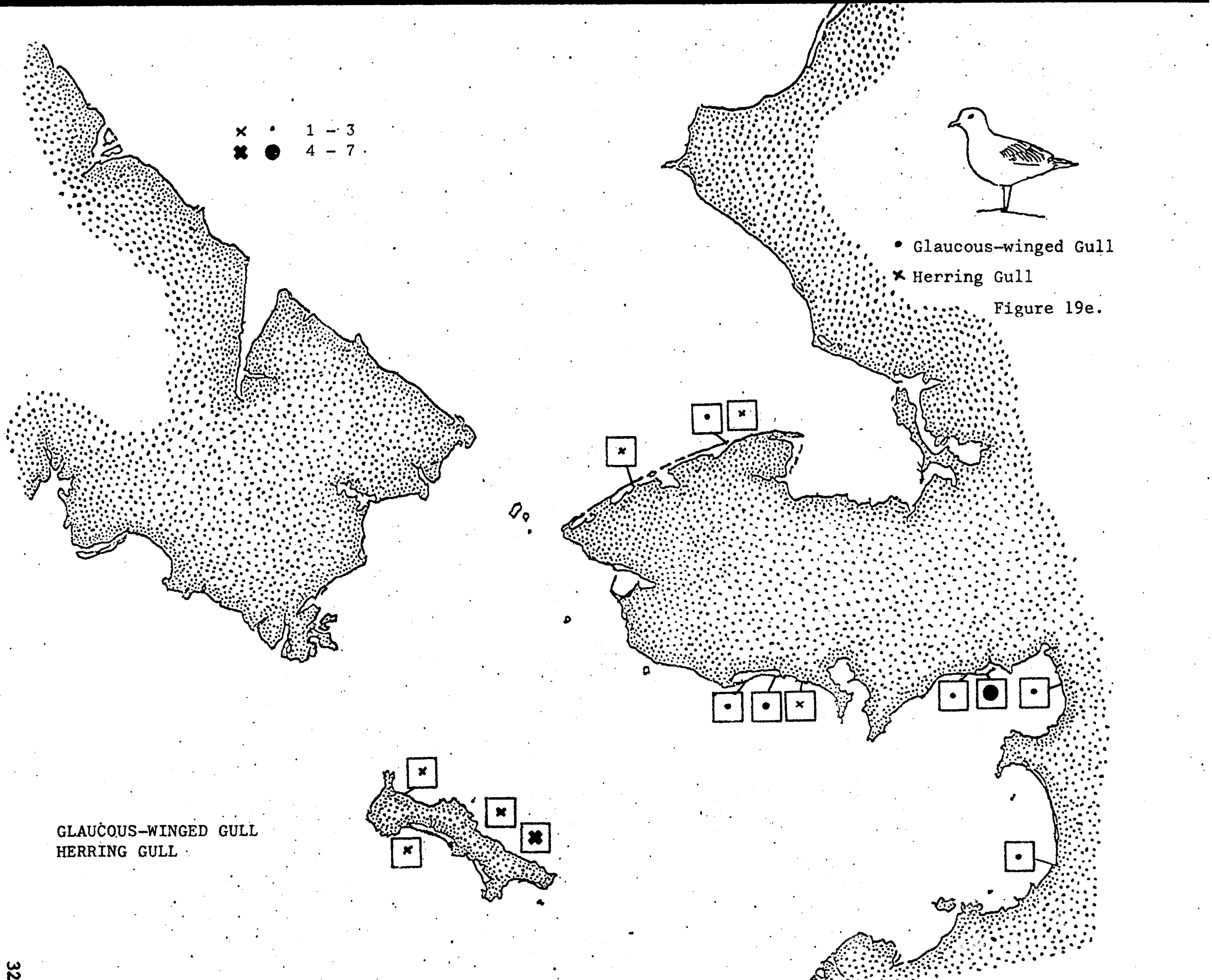
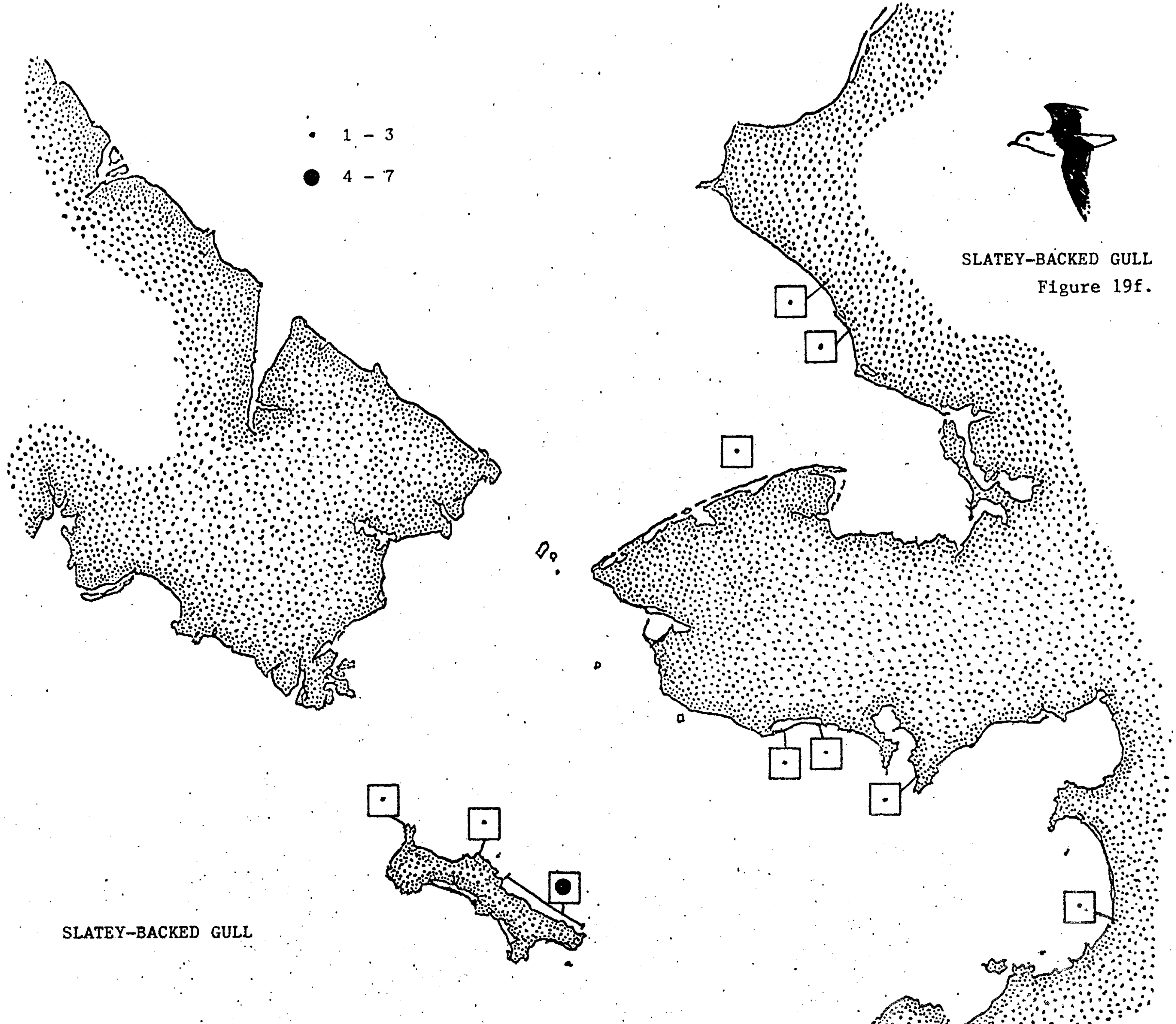
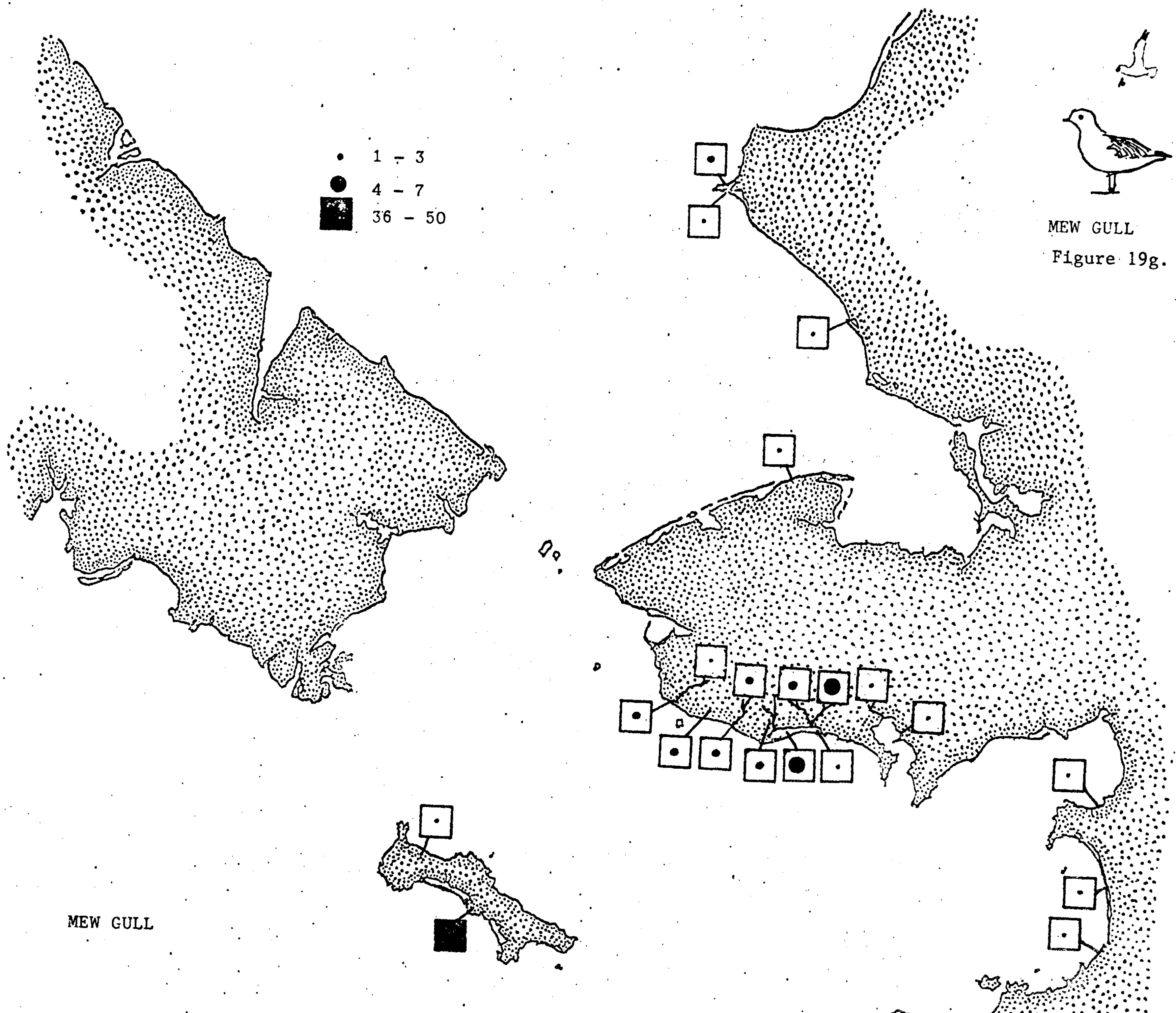

× • 1 – 3
✖ ● 4 – 7
• Glaucous-winged Gull
✖ Herring Gull
GLAUCOUS-WINGED GULL
HERRING GULL

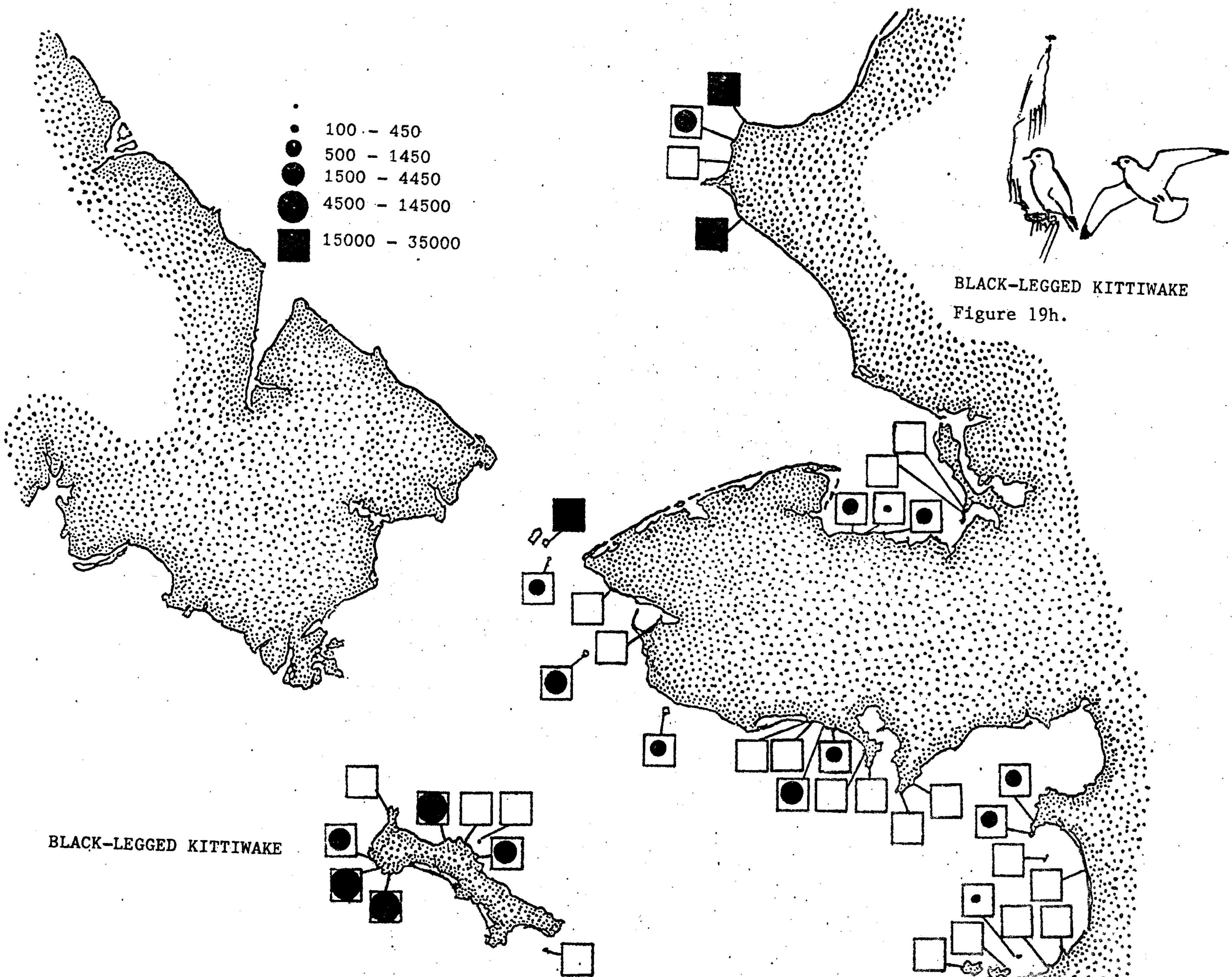
Figure 19e.



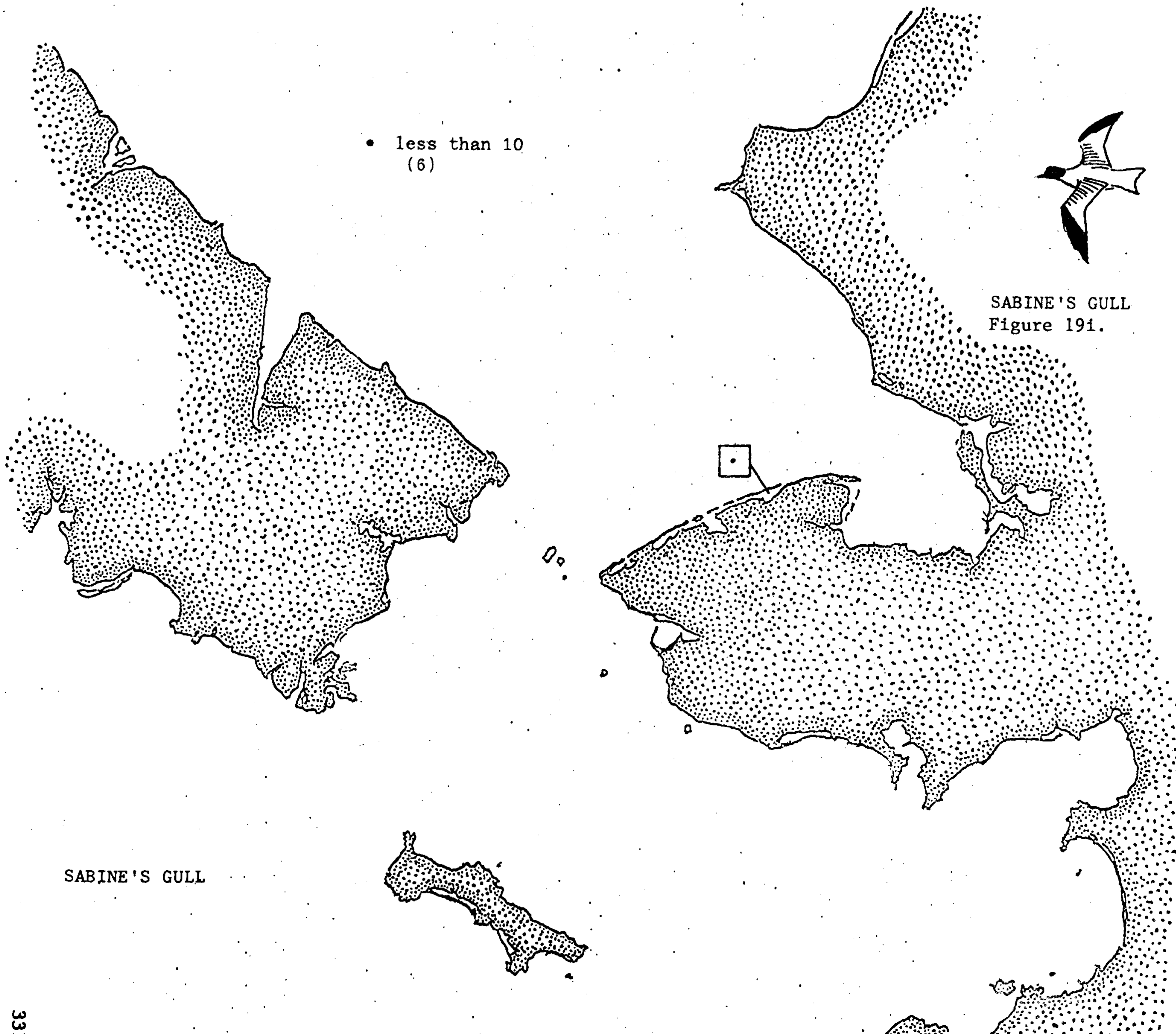
SLATEY-BACKED GULL
Figure 19f.



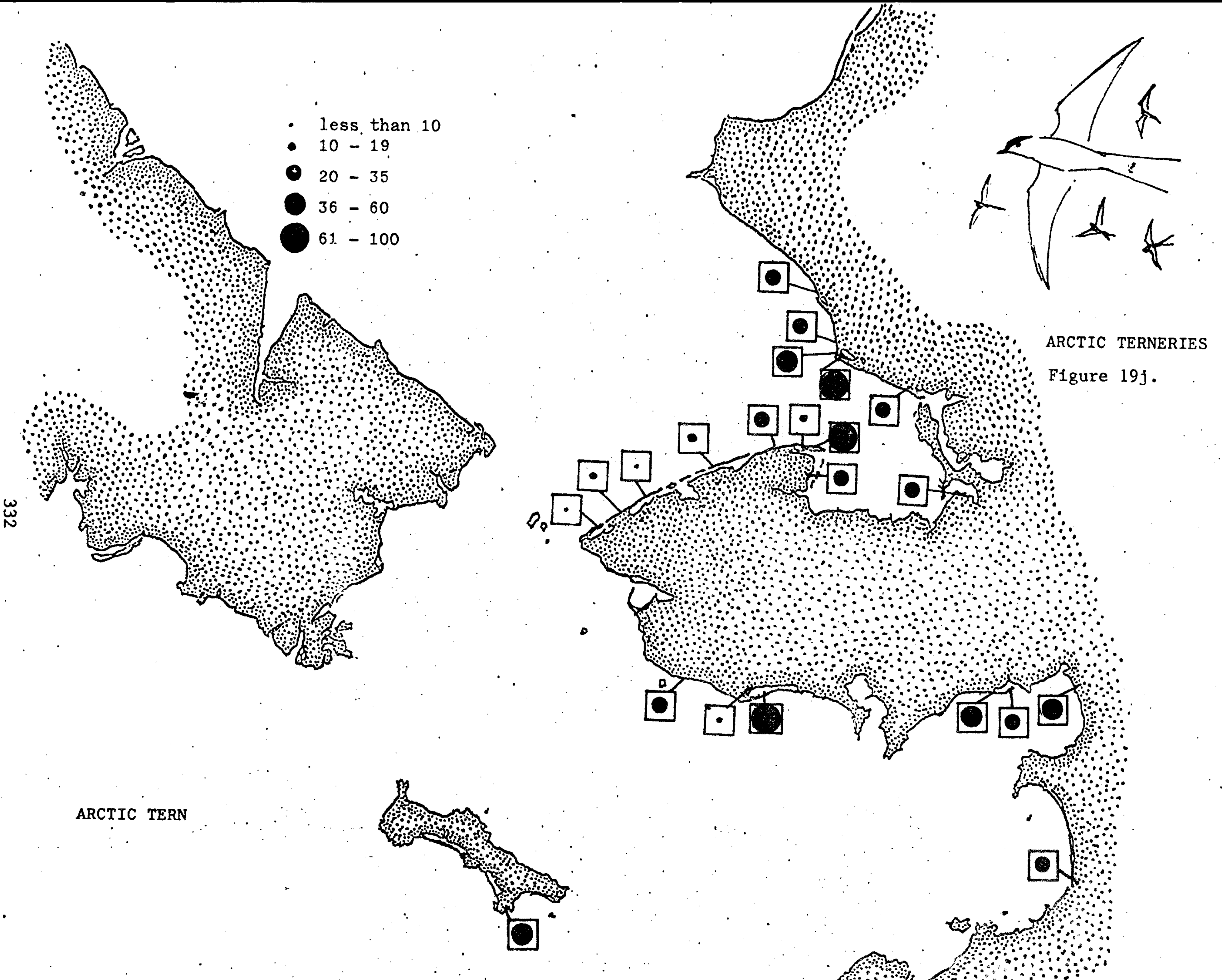
MEW GULL
Figure 19g.



BLACK-LEGGED KITTIWAKE
Figure 19h.



SABINE'S GULL
Figure 19i.



ARCTIC TERNERIES

Figure 19j.

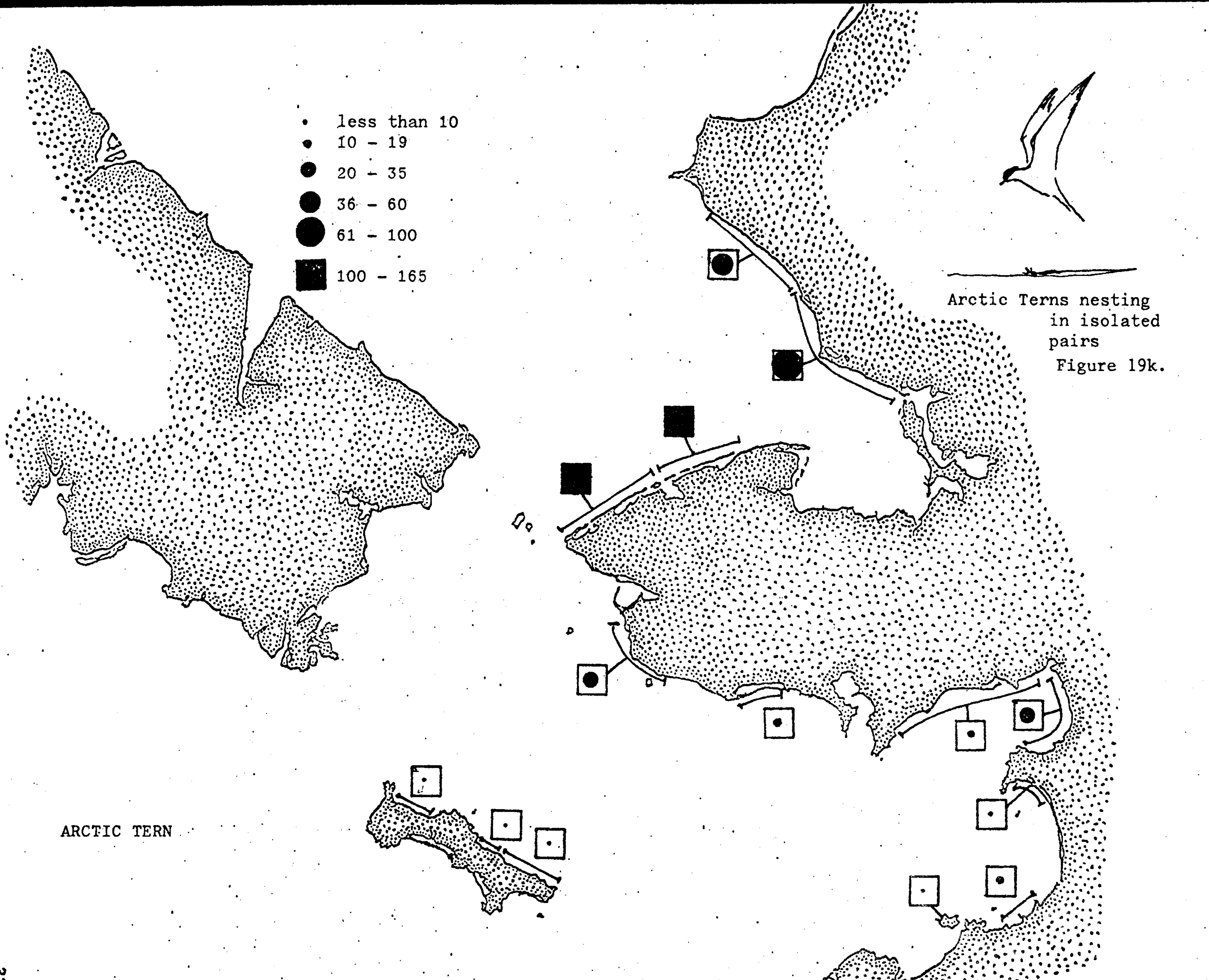
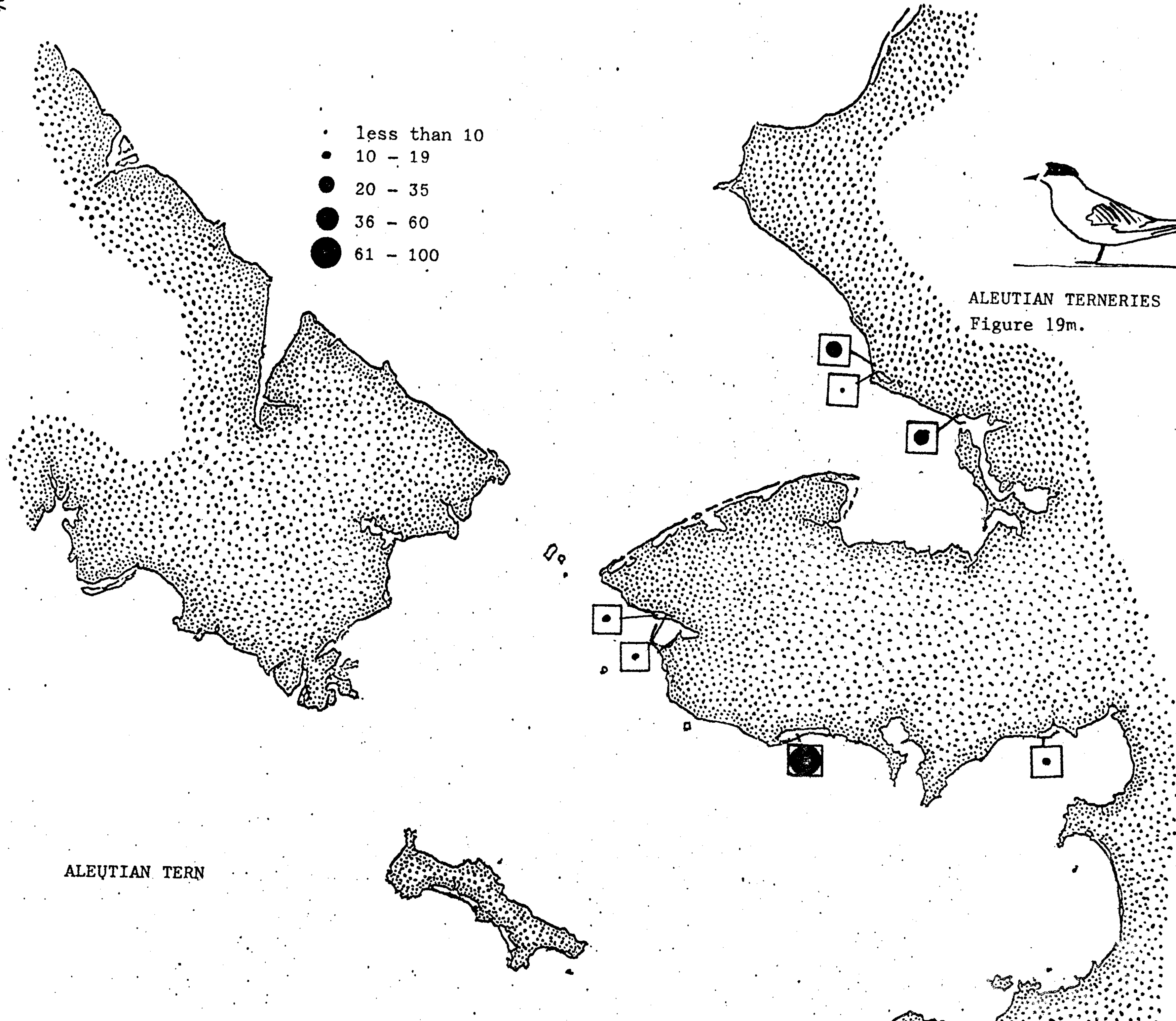

less than 10
10 - 19
20 - 35
36 - 60
61 - 100
100 - 165
Arctic Terns nesting in isolated pairs
ARCTIC TERN

Figure 19k.



ALEUTIAN TERNERIES
Figure 19m.

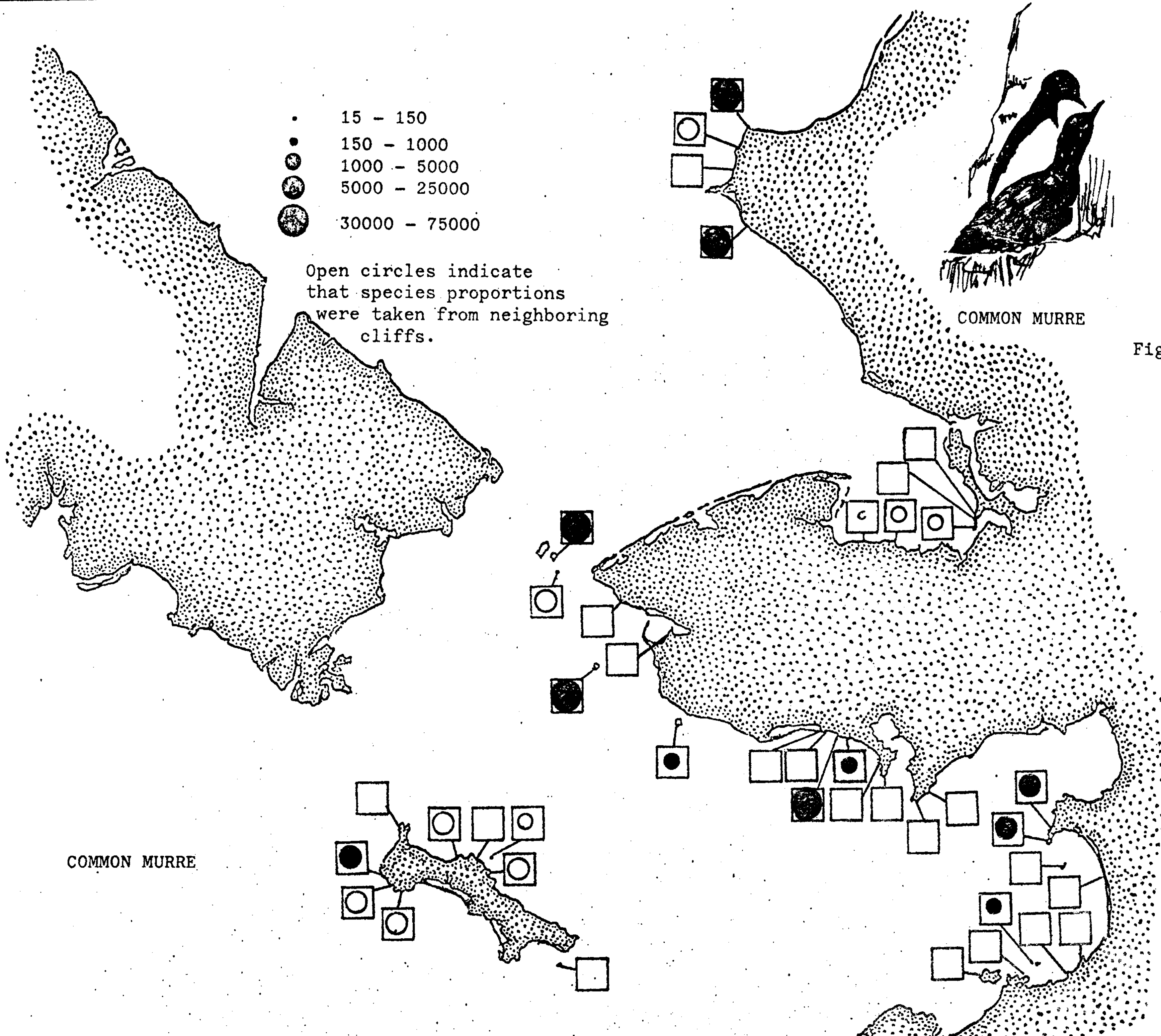
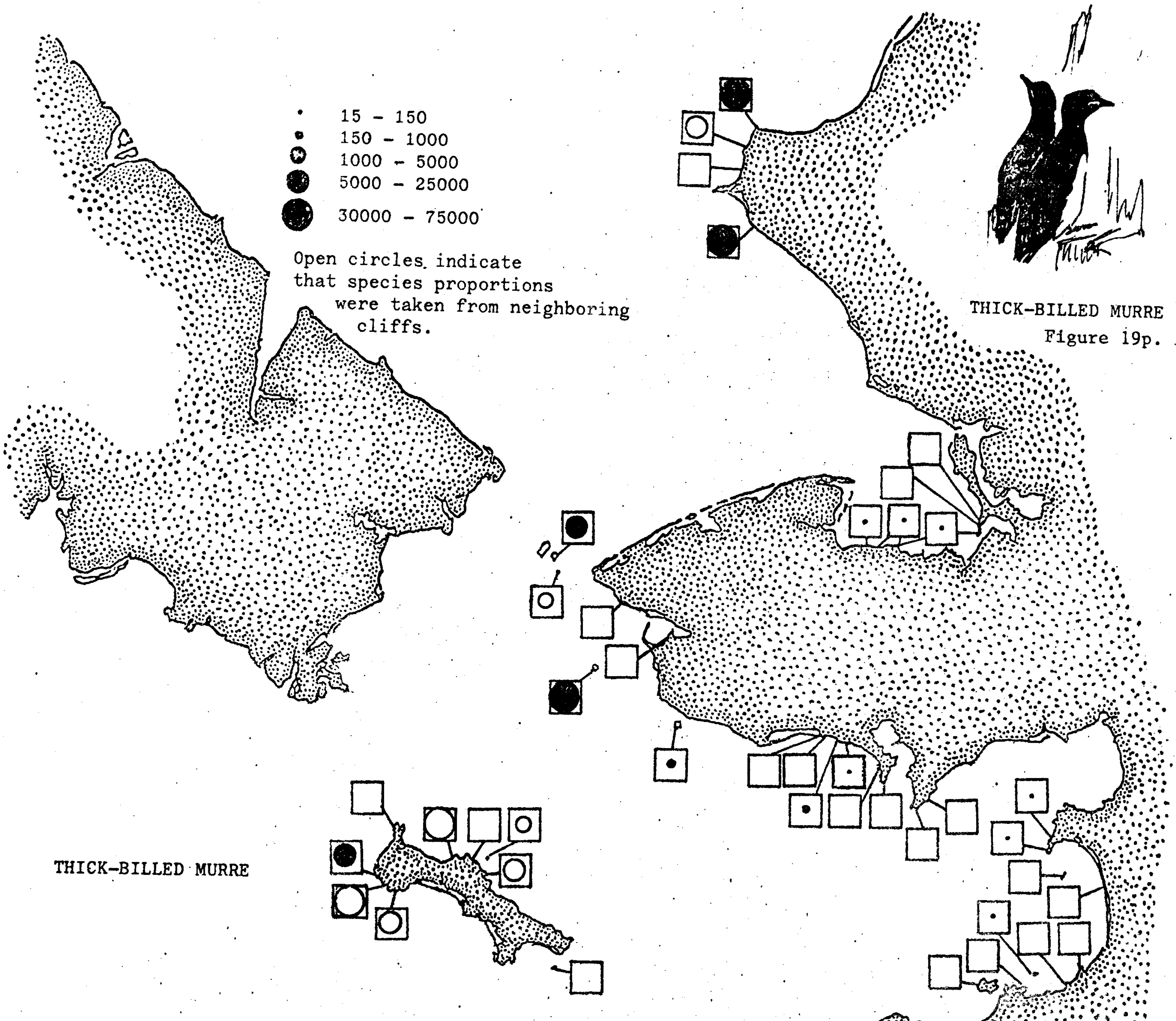
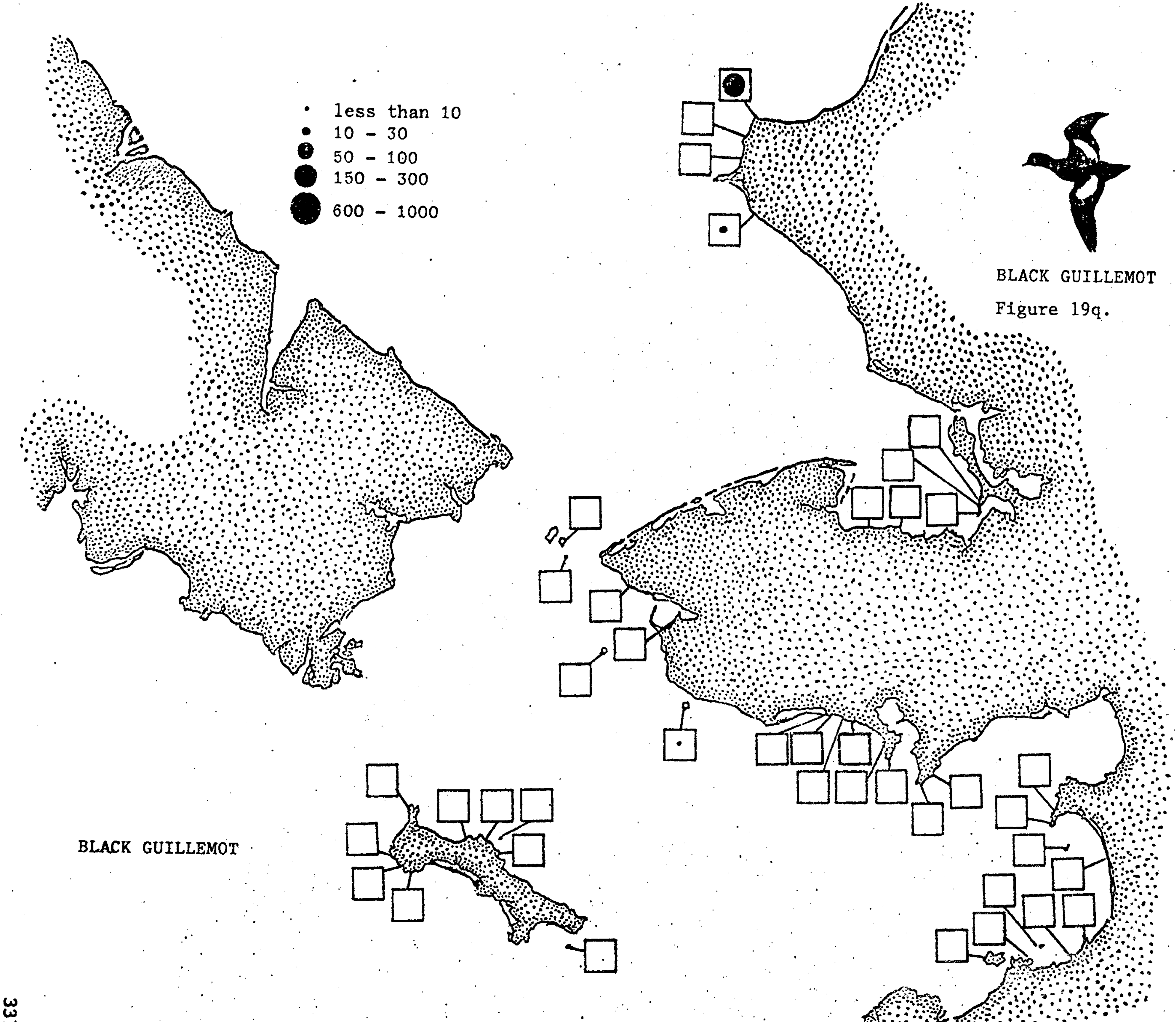

15 - 150
150 - 1000
1000 - 5000
5000 - 25000
30000 - 75000
Open circles indicate that species proportions were taken from neighboring cliffs.
COMMON MURRE
COMMON MURRE

Figure 19n.

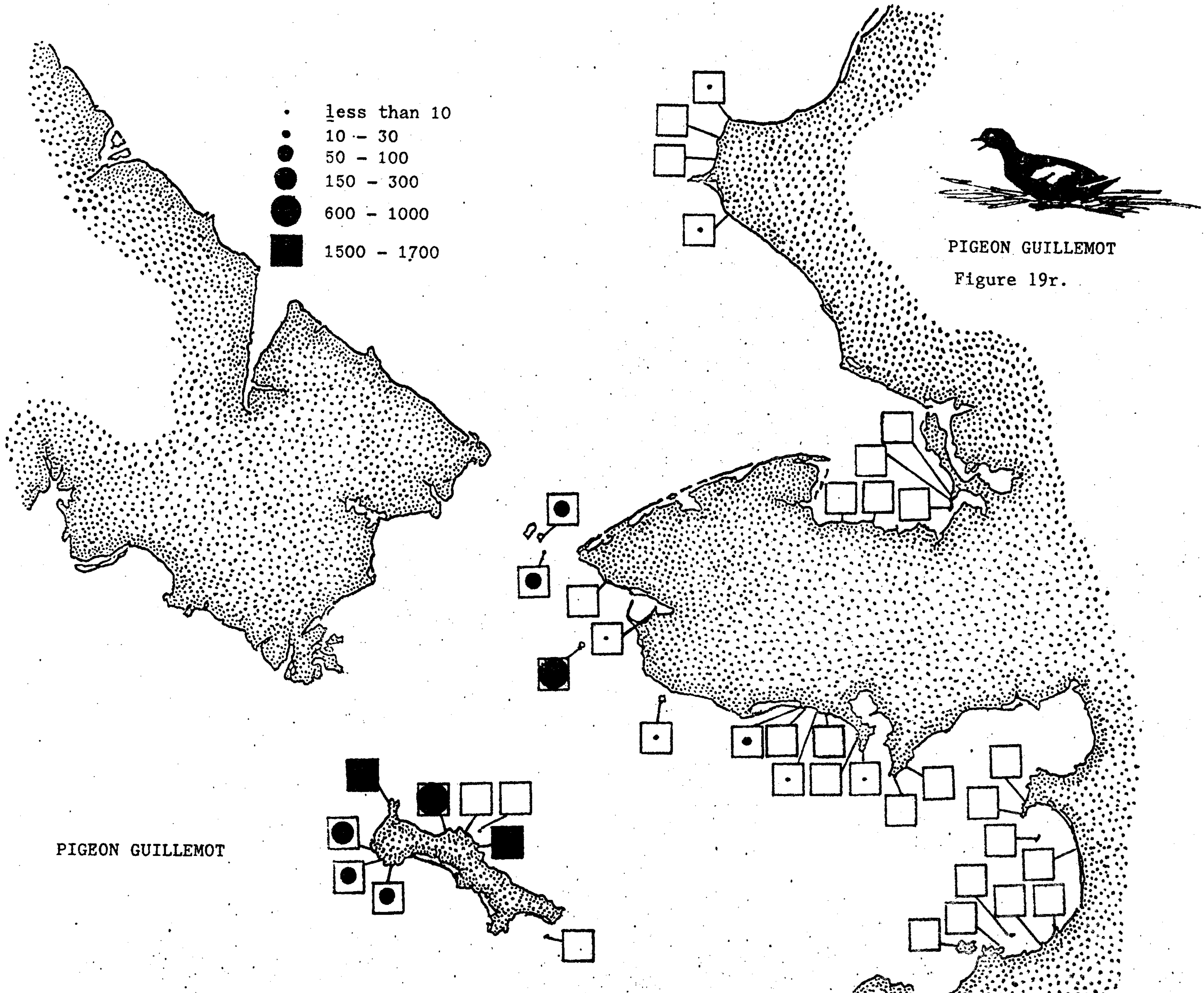


THICK-BILLED MURRE
Figure 19p.



BLACK GUILLEMOT

Figure 19q.



PIGEON GUILLEMOT

Figure 19r.

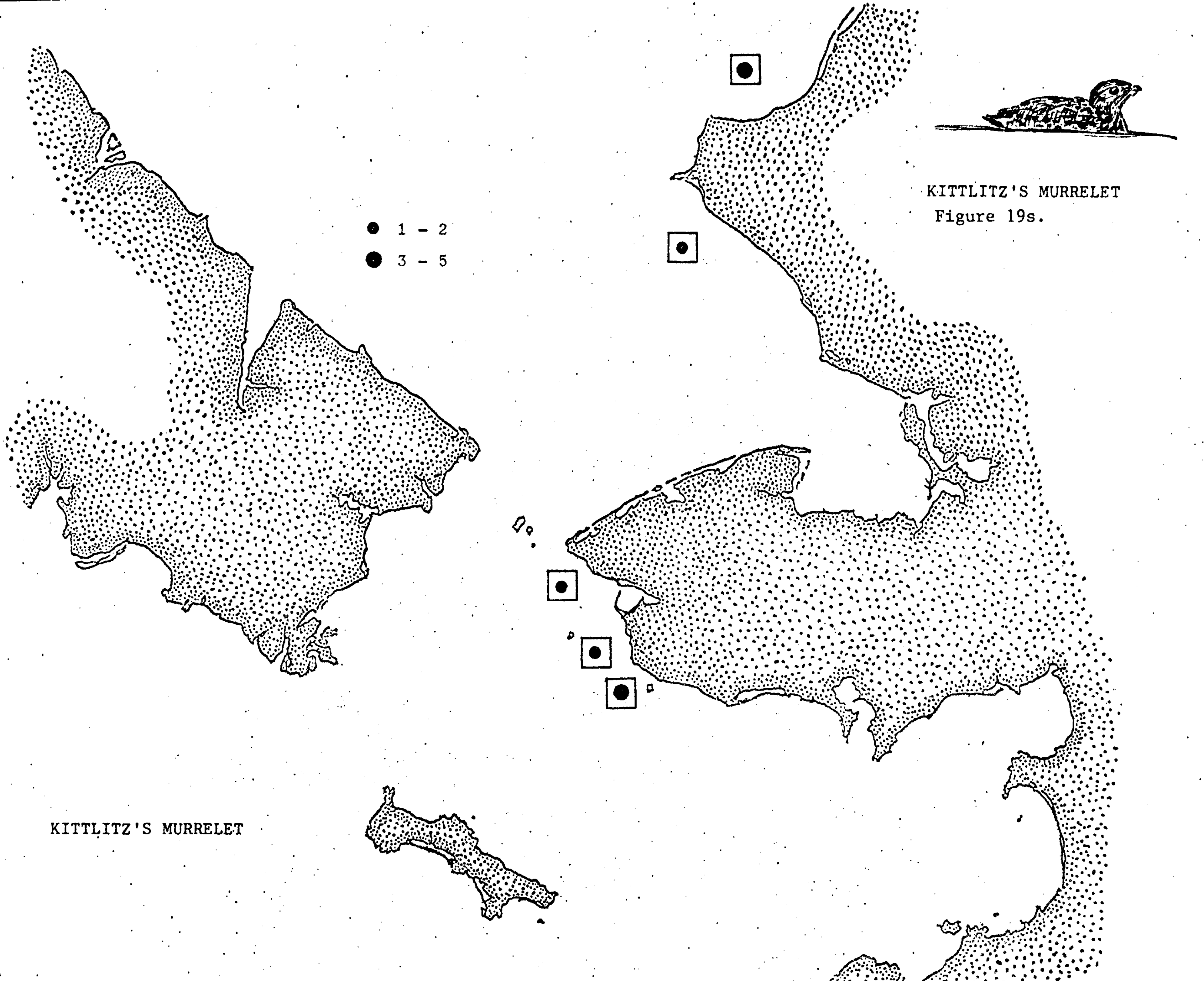
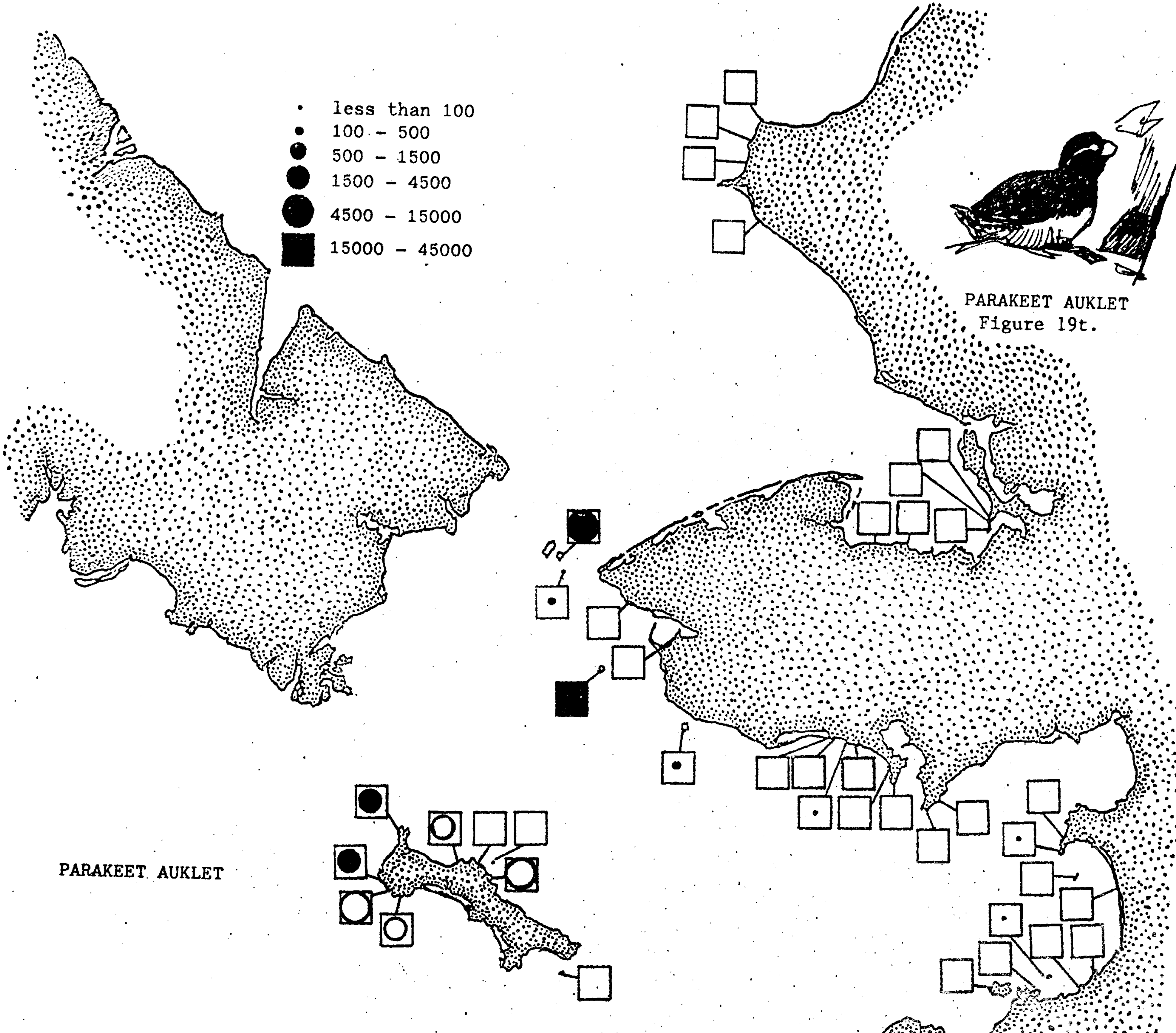


Figure 19s.



PARAKEET AUKLET
Figure 19t.

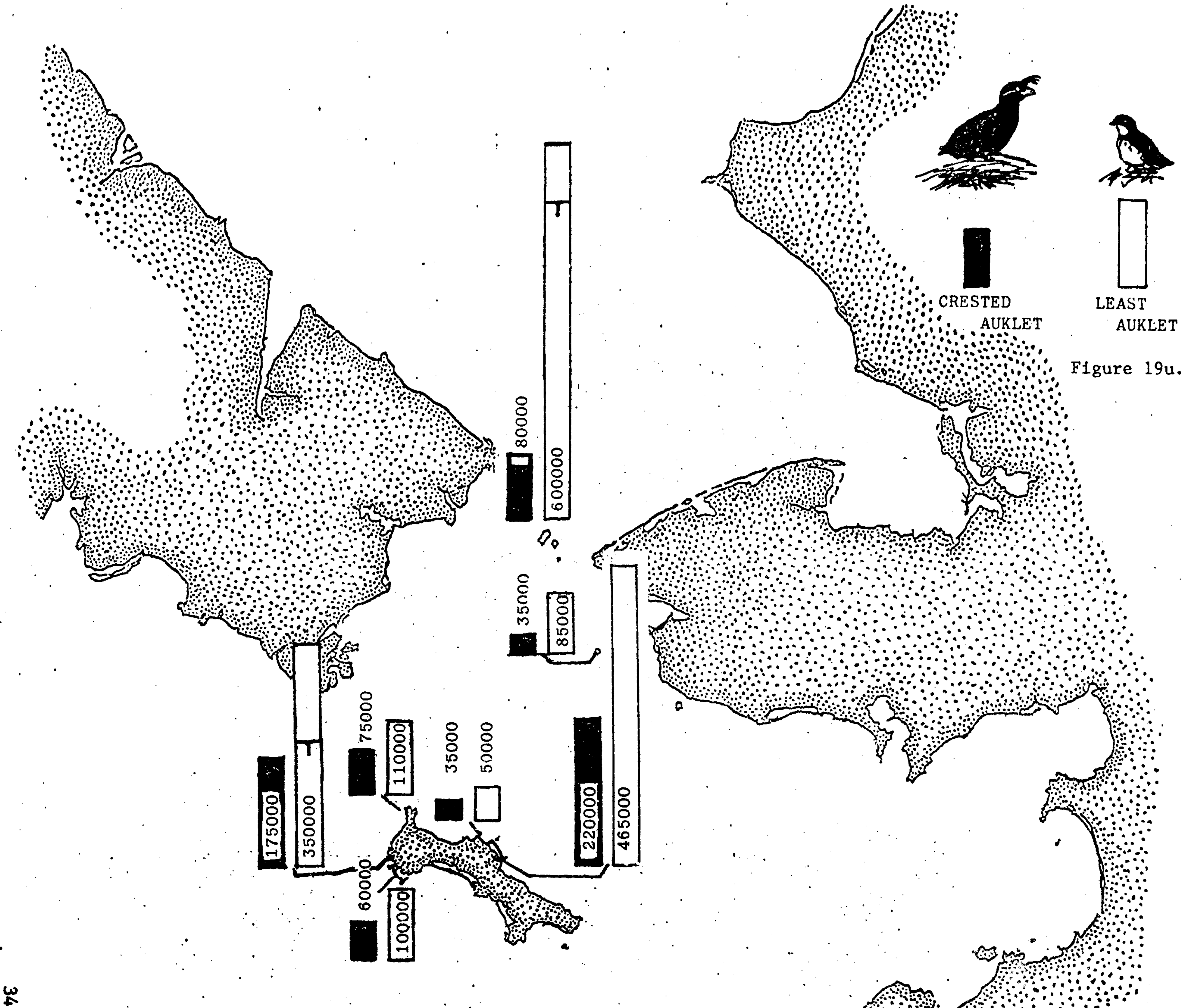
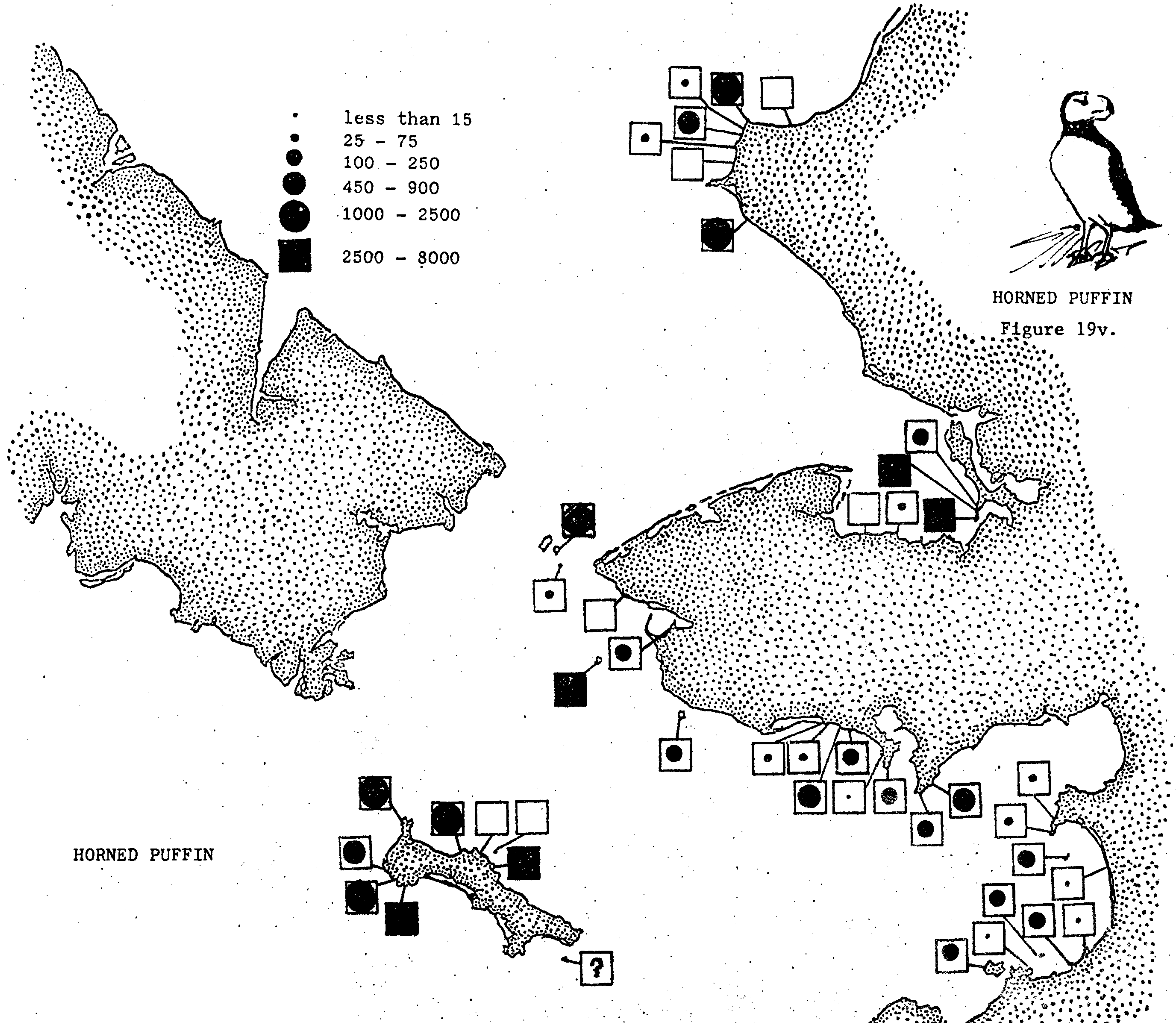
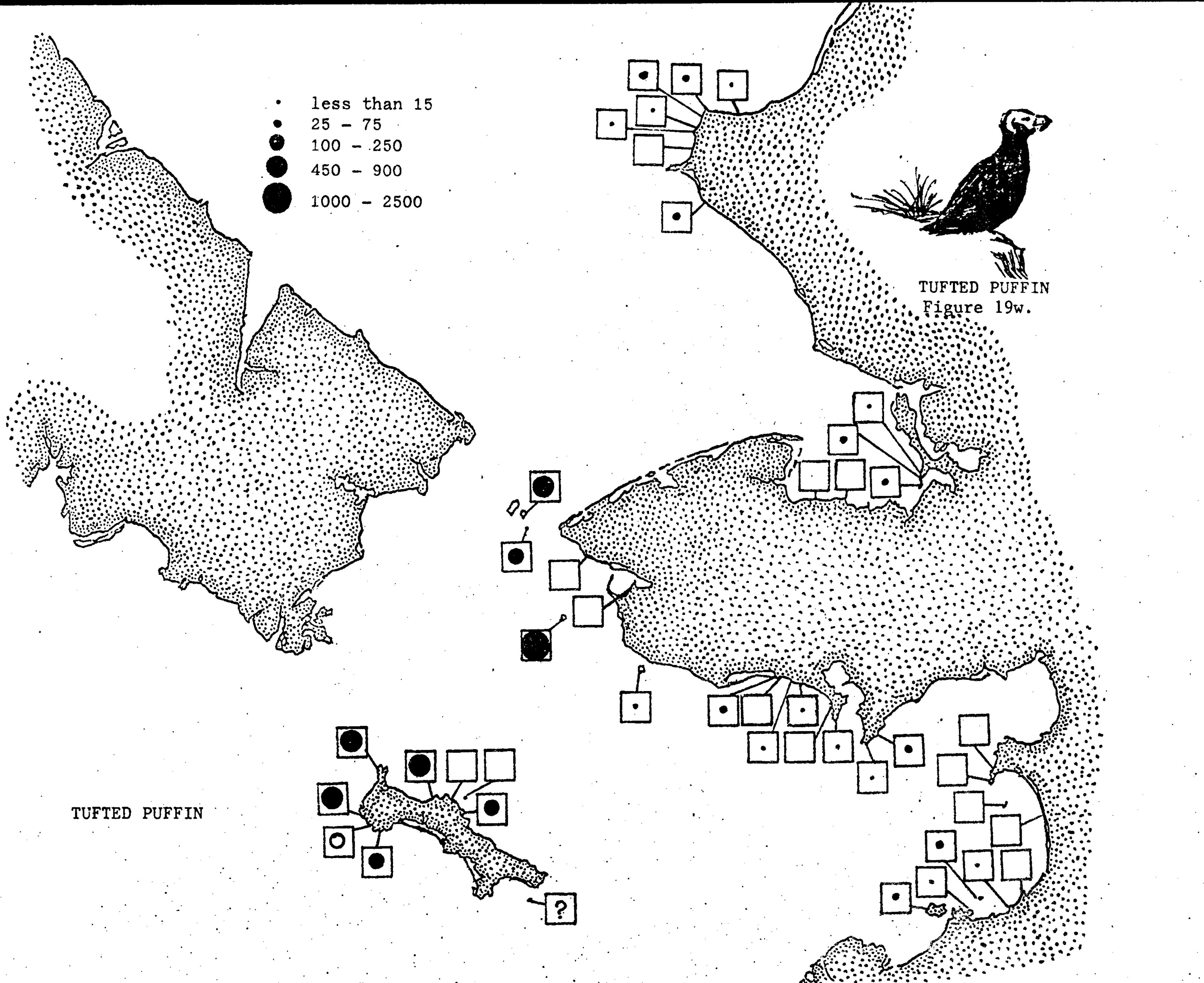

CRESTED AUKLET
LEAST AUKLET
80000
600000
35000
85000
75000
110000
35000
50000
220000
465000
175000
350000
60000
100000

Figure 19u.



HORNED PUFFIN

Figure 19v.



TUFTED PUFFIN
Figure 19w.

V. The Colony of Bluff

Data from our studies of the seabird cliffs at Bluff (see Figure 6) allow us to put together a rather complete picture of the breeding biology of one seabird colony, to which we can relate data from other colonies in the northern Bering Sea. In order to put Bluff in perspective of the Bering Strait region, it is important to note the virtual absence there of the plankton-eating birds (Parakeet, Crested, and Least Auklets, and Thick-billed Murres), which comprise the majority of the bird fauna of the northern Bering Sea. However, the ease of access and the amount of information gatherable make Bluff a very worthwhile study site. At Bluff, Common Murres and Black-legged Kittiwakes, both fish-eating species, make up the majority of the population. Glaucous Gulls, Horned and Tufted Puffins, Thick-billed Murres, Pigeon Guillemots and Pelagic Cormorants are present in tens or hundreds. The colony is also used by several predators.

In the section which follows we review details of what we have learned about the interactions between seabirds and their marine environment as expressed in the reproductive performance of Common Murres and Black-legged Kittiwakes. The convenience of study at Bluff and the wide variation in breeding success among the years from 1975 to 1979, suggest that these birds are very sensitive to changes in the sea and that their responses can be put into quantitative terms easily. This chapter is an argument a) for the kinds of observations which we believe will be useful in a program monitoring environmental quality and b) for the suitability of the cliffs at Bluff and the Black-legged Kittiwakes nesting there for this program of monitoring.

A. Colony Numbers

The seabirds at a cliff are constantly coming and going. Consequently, a colony is characterized by changes and trends which are both daily and seasonal, and which vary from year to year. We have gone to some length to clarify these patterns of change in the previous section and in Appendix VI. Figures 20 & 21 show changes through the season in the number of murres and kittiwakes at Bluff Cliffs. Murres show a distinctive attendance pattern, with the highest number of birds seen early in the season. A precipitous decline in numbers is followed by a season-long increase, and finally by the departure of all birds for open water. This broad pattern varies little among the years 1975-1979, although 1977 shows the presence of a slightly larger population than other years. It is clear that using one number to describe "the population" of Bluff is an oversimplification.

We cannot be certain of the identity of the early group of murres without banding. However, we can make a reasonable guess using some related information. Work done by Southern et al. (1965), and Southern (1966) has shown high year-to-year fidelity to a colony among adults, as well as very little gene flow among colonies. The birds using a certain cliff are, therefore, a partially isolated breeding population. From this we suggest that the early peak in murre numbers represents most of this population, including juveniles and breeding adults. The majority of these birds depart. The few that remain are probably the older and more experienced birds, and the slow increase is due to the gradual return of younger, less experienced birds who have not yet bred. First year birds, and most of the second year birds, do not come to land at all (Birkhead and Hudson, 1977).

Figure 20.
Variation in numbers of Murres counted during colony censuses at Bluff Cliffs, 1975-1979. Counts were made from a small boat passing in front of the cliffs.
These counts include all murres; that is, murres flying and on the water as well as those on the cliff.

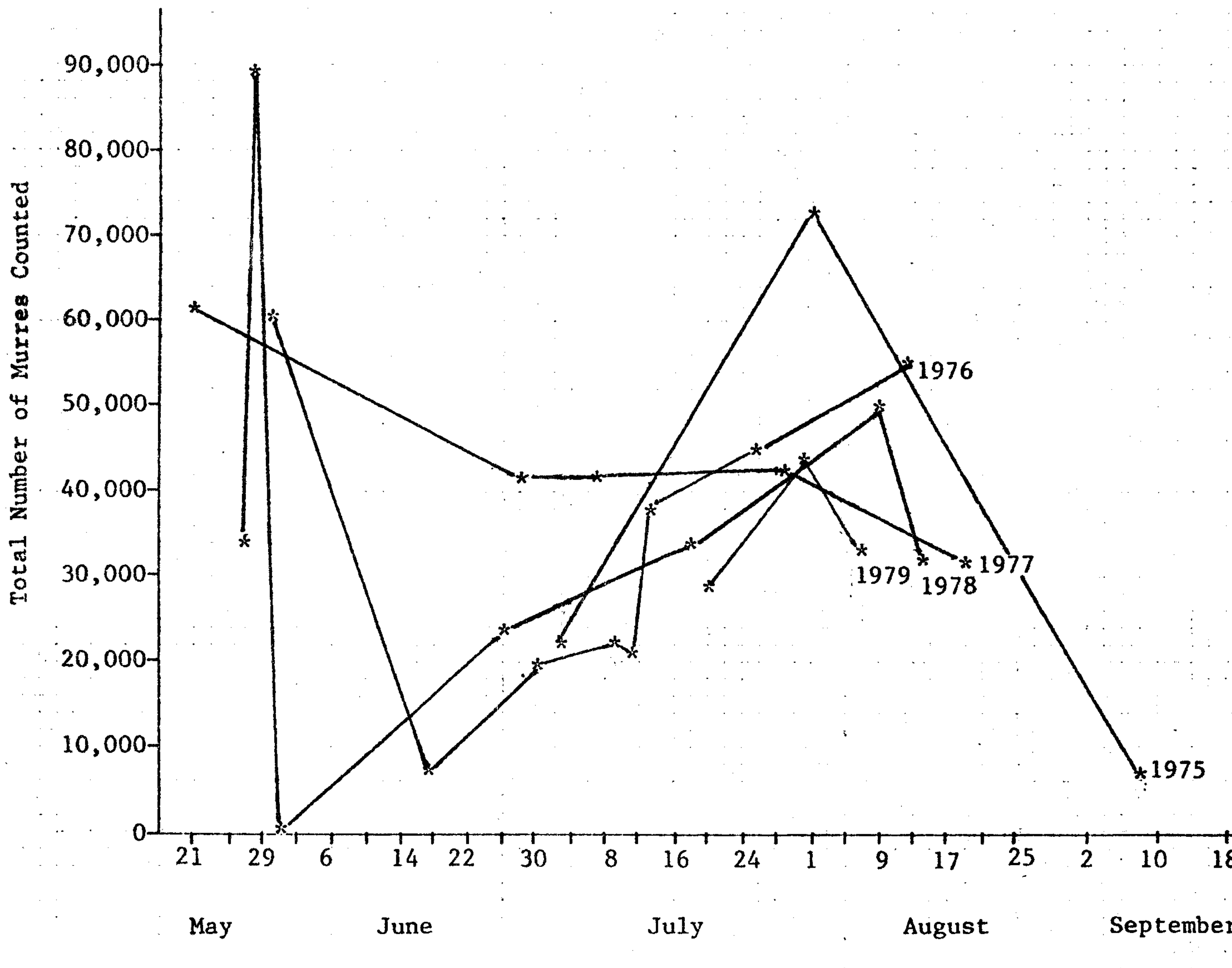
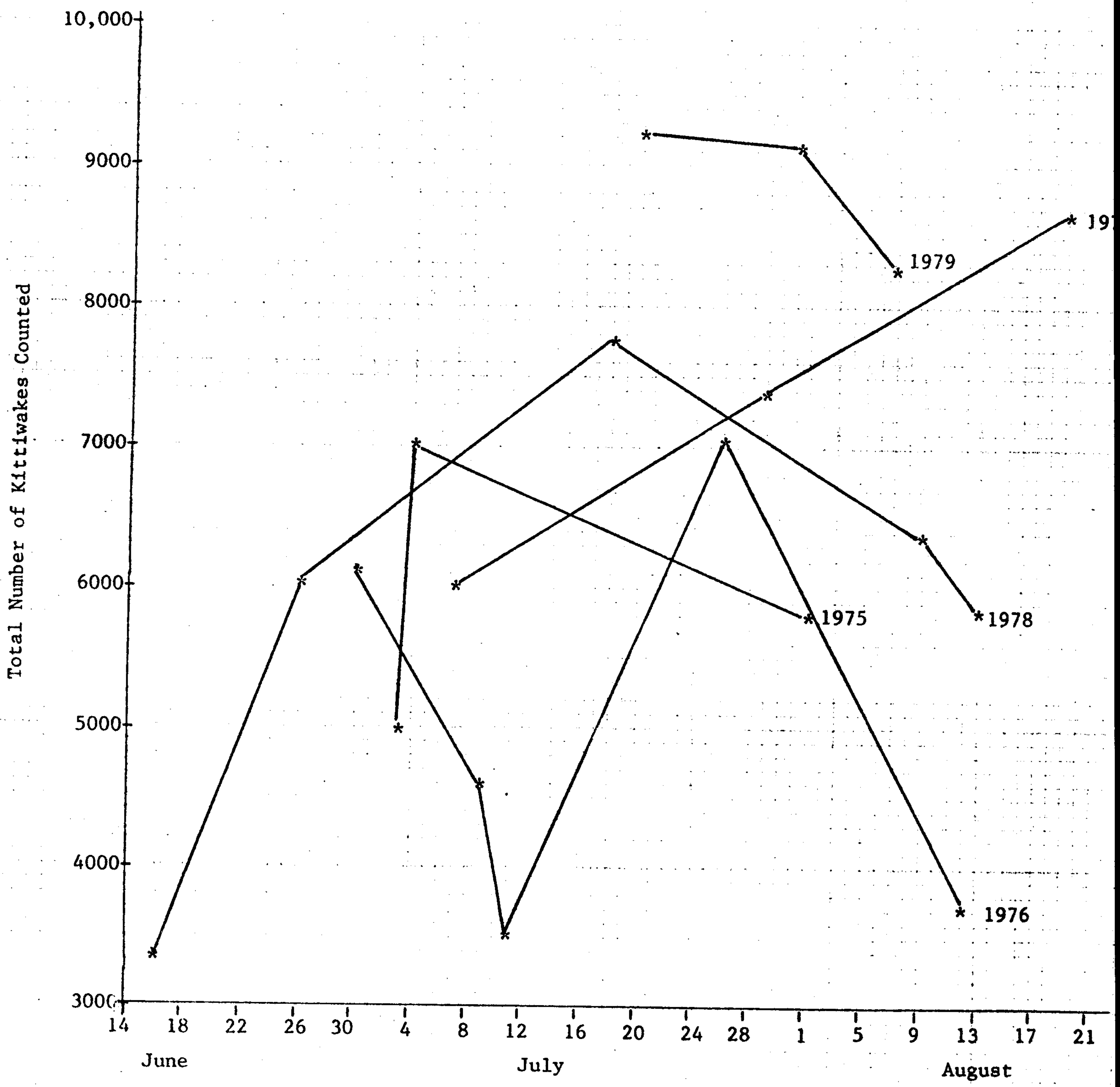


Figure 21 .
Variation in numbers of Black-legged Kittiwakes counted during colony censuses at Bluff Cliffs, 1975-1979. Counts were made from a small boat passing in front of the cliffs.



The seasonal changes in numbers of murres on the cliff can be related to the activity of certain segments of the population. The increase in number continues right through the period of egg-laying. This continued increase is not simply due to breeding birds, and the literature contains references to "prospecting" (Tuck, 1960) or "loafing" (Birkhead and Hudson, 1977) birds increasing in numbers later in the season. Birkhead and Hudson (op. cit.) have shown with a banded population in Wales that older immatures arrive at the colony earlier than younger ones, and that they spend more time on cliff ledges than do younger birds. It is unclear what benefits accrue to these nonbreeders by coming to the breeding colony, but it presumably increases the chance for successful breeding in subsequent years -- an important circumstance for birds with only one egg and a short breeding season. It may be advantageous for inexperienced murres to establish dominance, to learn the social skills needed for breeding, and perhaps to acquire a nest site, before attempting to breed. High levels of aggression early in the year and late in the summer indicate strong competition for nest sites (Birkhead, 1978).

We believe the non-breeders, being loosely attached to the cliff, comprise the "flyers" counted during colony censuses. "Flyers" are birds that readily fly off the cliff when a boat approaches. Data from censuses of murres at Bluff during the breeding seasons of 1975-1978 are presented in Table 7. The number of flyers (murres flying off the cliff during the counts) is given in Table 8 as percentages of the total number counted during the census. The percentage of flyers varies markedly through the season and among years. The censuses of 26 June 1976 and 28 June 1977 were made before laying had begun, and the percentage of flyers was high. Laying was well underway by this time in 1978 and the murres' attachment to the cliff was higher as indicated by the lower percentage of flyers. The percentage of flyers was consistently low in 1978, in contrast to the consistently high percentages of flyers in 1976; this suggests that the birds present in 1978 highly motivated to remain on the cliff.

The dramatic peak of murre numbers early in the season is not seen in kittiwakes. Kittiwakes show a similar pattern of seasonal increase in numbers, though with less extreme changes (approximately 25% variation over the time of data collection versus 50% variation over the same time period for murres). This difference may be due to the slightly younger age at first breeding in the kittiwake (Coulsen 1966). Consequently, the seasonal increase in numbers due to non-breeding birds is not as extreme since they are a smaller fraction of the population. At Bluff, we see an increase in the number of cliff sites occupied by kittiwakes late in the season. These cannot be serious attempts to breed so late in the season, and must be non-breeding birds. Coulson (op. cit.) has shown that birds breeding for the first time have improved breeding performance (earlier date of first egg), if they have spent the previous year at the colony.

Murre parents leave the colony as soon as the chicks can jump to the water. Some down still remains. The chick is led by the parent, usually the male (Birkhead 1976) and develops complete plumage as they swim toward the open ocean and the wintering grounds. Some murres remain into September, but as the fall progresses proportional mortality of chicks still on the cliff undoubtedly rises. We have watched Ravens patrol the faces of the cliffs and repeatedly flying at clusters of murres who linger about the late-fledging young. Repeated harassment has sometimes driven many adults from the ledges and allowed a Raven to make off with a chick. Kittiwake chicks feather out fully and are able to fly before leaving the cliff. A few fledglings and adults are still present into October. Thus, the kittiwakes linger a little longer than the murres. The early fledging (jumping) period is a critical one for the survival of chicks of both species, and is presumably a period of high mortality.

B. Breeding Season Phenology

1. Arrival

At this latitude (60° 30' N), winter weather constrains the length of the breeding season in both spring and fall. The date on which the birds arrive at the cliff in the spring thus becomes an important factor in breeding.

The arrival of the seabirds at Bluff is dependent on the break-up of the sea ice and its movement away from shore. The ice broke up extremely early in 1979, quite early in 1978 and 1975, and at a "relatively average" date in 1976 and 1977 (Table 18). For murres, open water has some practical meaning, since as they take off from the cliff they occasionally hit the water below. Kittiwakes do not have this problem, but appear at the cliffs at the time of ice break-up nonetheless. The date of ice break-up also has been shown to be important to the schedule of seabird breeding to the north of Bluff at Cape Thompson. Over the last three years, the rank order of the date of ice break-up has correlated perfectly with the date of onset of the reproductive schedule in those years (Springer et al., Annual Report, 1979).

Table 18.
Phenology of Black-legged Kittiwakes at Bluff Cliffs, 1975-1979.

Event	1975	1976	1977	1978	1979
sea ice out (approx. date)	15-18 June	12-20 June	20-22 June	7-15 June	15 May
first egg	21 June	21 June	20 June	18 June	
peak of laying	6 July*	5 July	7 July	24 June	14 June
first hatching	18 July*	19 July	18 July	10 July	
peak of hatching	28-30 July*	30 July	2 Aug	21 July	11 July*
first fledging seen at colony	31 Aug	27 Aug	7 Sept	21 Aug	20 Aug*

* These are conservative estimates calculated from plumage characteristics of chicks seen in the nest, and based on the average length of incubation (27 days) and brooding (44 days) periods.

During the period before the murres take to the cliff they often swim together and fly together in group displays that Tuck (1960) calls "water-dances" and "joy-flights." There is evidence from data collected at Cape Thompson (Springer and Roseneau, 1978) and Novaya Zemlya in the Barents Sea (Uspenski 1956), that murres arrive at the colony with gonads less than fully developed. An hypothesis for the physiological function of these mass displays is that they have endocrinal effects that bring the birds into breeding condition.

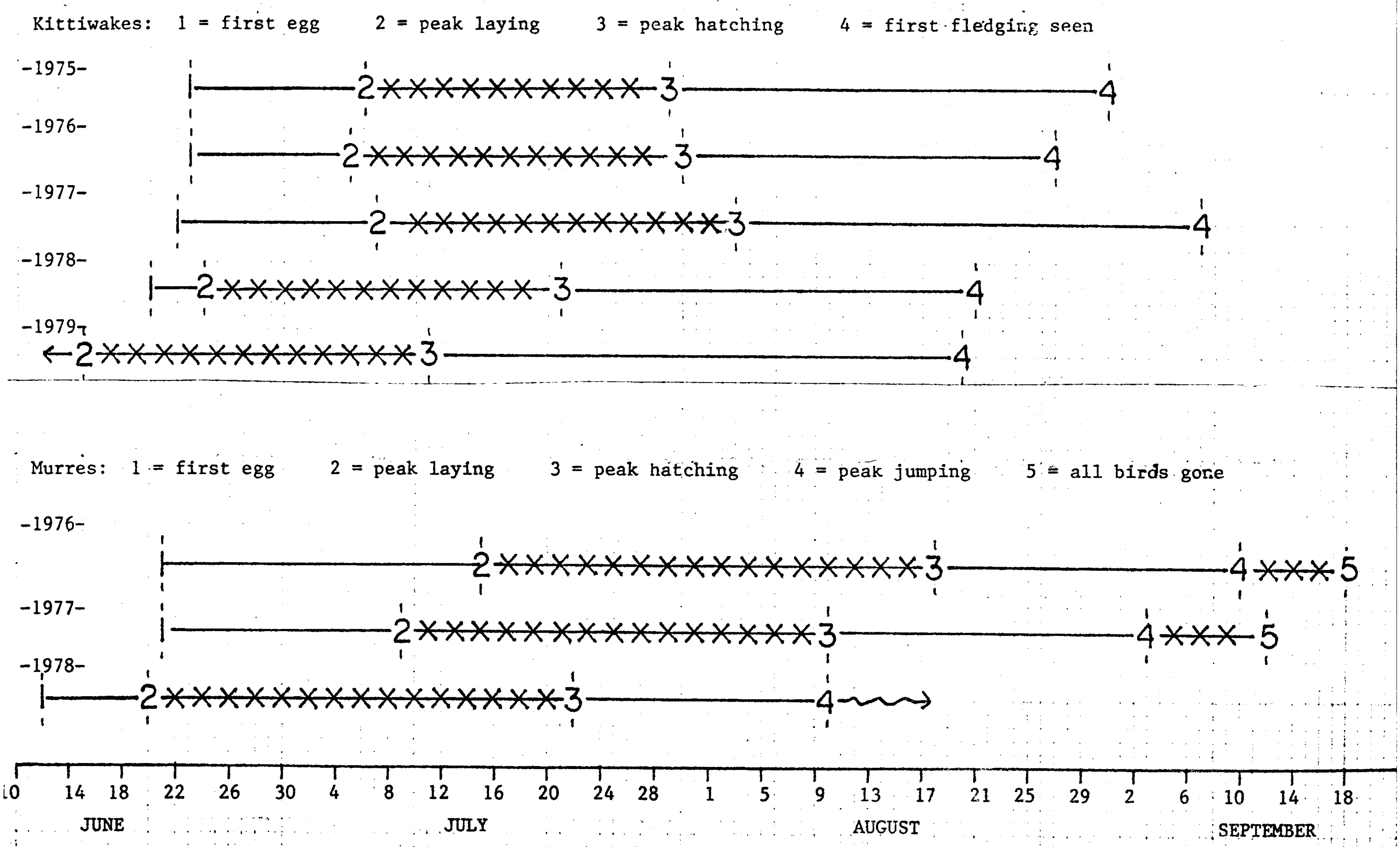
Murres and kittiwakes approach the cliff tentatively at first, gathering in the leads of open water in the ice off the cliffs. The birds begin to alight on the cliff after a period of display on the water. In 1976 and 1977, the birds were just beginning to alight on the cliff around the first of June, but arrival was much earlier in 1978; when we arrived at Bluff on May 27th, about 90% of the sites on the cliff were occupied. Both the kittiwake and murre populations had settled.

The other birds that use the cliffs at Bluff arrive earlier than the murres or kittiwakes. By the first of June, Glaucous Gulls and Pelagic Cormorants already have nests with eggs. Similarly, the raptors (Golden Eagle, Rough-legged Hawk, Harrier, Peregrine and Gyrfalcons) around the cliff have eggs by the time the seabirds arrive.

2. Laying, hatching and fledging

Figure 22 compares the schedule of breeding over five years (1975-1979) for both kittiwakes and murres, and Table 18 shows the dates of the occurrence of the major breeding events of kittiwakes. There are two important features to note. First, there is substantial variation in the schedule of breeding events among the years. Notice especially that for murres the

Figure 22. Phenology of Black-legged Kittiwakes at Bluff Cliffs, 1975-1979, and of Murres at Bluff Cliffs, 1976-1978.



peak laying date (2) in 1978 was earlier than the first egg laid (1) in 1977. The 1979 and 1978 seasons for both species was considerably earlier than in either 1977 or 1976. Second, the variation among the years is a result of the date of first egg and, more significantly, the length of time between the laying of the first egg and peak laying for the population (interval 1-2). The time between other important breeding events is relatively constant for both species. Thus, in some years the populations breed both earlier and more synchronously than in others. The extent to which synchrony and early breeding are independent of each other is hard to determine from these data.

During the early stages of breeding kittiwakes often engage in concpicuous social frenzies of gathering nest material. This seems to be socially facilitated; as it gathers momentum, each frenzy attracts more birds to it until it stops of its own accord. This activity could reinforce the synchronization.

Murres are also synchronized in their breeding, although murre ledges appear to be chaotic. The loud, piercing, "pa-daah" call given by the female while copulating may have this effect although its function is probably prevention of rape/cuckolding. The greatest percentage of eggs lost due to predation occurs very early in the season, and the greatest percentage of chicks are taken very late in the season. Predation pressure thus trims off the reproductive effort at either end and makes each season more synchronous. To the extent that the timing of breeding is heritable, predation is a pressure that will increase breeding synchrony over the years.

3. Effects of weather

Weather can have both direct and indirect effects on breeding phenology. As was noted above, this latitude allows only a short breeding season, and each year the onset of breeding is constrained by the presence of sea-ice. For kittiwakes, nest building is correlated with stormy weather. Rain loosens the sod at the top of the cliff allowing them to pull out grass and beak-fulls of mud. Melting patches of snow produce the same effect, and in years with little rain, slopes below snow patches are the prime sources of nesting material. Grass, seaweed and straw are collected into windrows on the water by storms, and these are a major source of nest material. It was exceptionally dry in 1977, and kittiwake nests were small and poorly made. The lack of stormy weather early in the year may have accounted partially for the fact that only 25% of the nests were built early enough to fledge a chick at normal incubation and rearing times.

Weather affects phenology indirectly by influencing feeding rates and hunting success. High winds can hamper the attempts of murres to land on the cliffs, and Tuck and Squires (1955) report that murres often stay on the ledges in high winds. Birkhead (1977) shows that the rate at which murres feed their chicks decreases with increasing roughness of the sea surface; he attributes this to increased difficulty in finding fish. These weather conditions can delay both egg-laying, and the growth of chicks if the females are short of calories. The feeding rate of plunge-divers like kittiwakes has been shown to vary with wind and water conditions, but not in a direct way (e.g., Dunn, 1973). The capture success of terns increases with wind speed to a maximum at some optimal speed, and then declines as the wind continues to increase (Salt and Willard, 1971). Poor weather may affect foraging of kittiwakes in a similar manner. The detrimental effects of poor foraging conditions will be similar to an actual decrease in the populations of food species.

C. Productivity

Reproductive success is affected by many variables and is sensitive to a variety of environmental differences. Reproductive output below a replacement level means that a population will decline and eventually die off. The life history of seabirds is characterized by long lives, low yearly reproductive output and delayed maturity. It is therefore essential to monitor reproductive success directly, and not to rely on population numbers for assessing the health of the population. This is because several years of poor productivity will not show up in the breeding population until the old birds begin to die off. Thus, an environmental condition that affects the population by reducing productivity will not be detected for at least the time of one generation (3-4 years in kittiwakes and murres), by which time marked changes in the population may already have been made.

Murres and kittiwakes are very different in both their breeding biology and the ease with which data on productivity are gathered. Consequently, we consider the productivity of the species separately.

1. Murres

Gathering reproductive data on murres is difficult. There are no nests, eggs are laid on bare rock, and even after an egg is laid the adults may move it around the ledge as far as three feet from its original position. Thus, specific breeding pairs cannot be counted directly. Eggs are very hard to see, and we found incubation postures to be an unreliable indication of the presence of an egg. We did not have areas which we could visit to count eggs regularly without serious disturbance to the birds. Thus, we do not have good data on egg production and hatching success.

Young chicks are also difficult to see, and it is not until they are at least a week old that the chicks can be seen standing apart from their parents. Consequently, chick production and mortality were difficult for us to measure, especially since a chick is most vulnerable during the first days of its life.

Our methods for collection of data changed from year-to-year as we learned to give what we considered to be less biased and more reliable results. Nevertheless, there are data that are comparable from year-to-year that show trends in productivity. Table 19 shows two measures of murre productivity for the years 1976-1979. It is obvious that productivity increased markedly through these years.

The measure of chicks per average number of adults in Column A is the easiest to interpret. Chicks counted were those seen standing apart from an adult, and were therefore a week or more old. The number of adults was averaged from several site visits. This measure does not distinguish between adults that attempted to breed and those that did not, but the counts were made in July when a minimum number of non-breeders are at the cliffs.

We would like to be able to give a number for chicks produced per breeding pair, but clearly determining the number of breeding pairs is difficult. In an attempt to discern the breeding segment of the population, we counted the number of birds on the ledges in a sitting position that looks as though the bird is incubating. Murres with eggs are not always in a sitting position, and sometimes birds "incubate" when there is no egg beneath, so we cannot use birds in a sitting posture to count eggs. With our present methods we must consider the population as a whole, and assume that the

Table 19. Productivity of Common Murres at Bluff, 1975-1979.

Year	A. chicks per ave. no. of adults present in study area	B. chicks per ave. no. sitters	C. sitters per adults (A/B)
1975	0.18	-	0.143
1976	0.04	0.26	0.154
1977	0.34	0.56	0.607
1978	0.44	0.78	0.564
1979	0.50	1.17	0.427

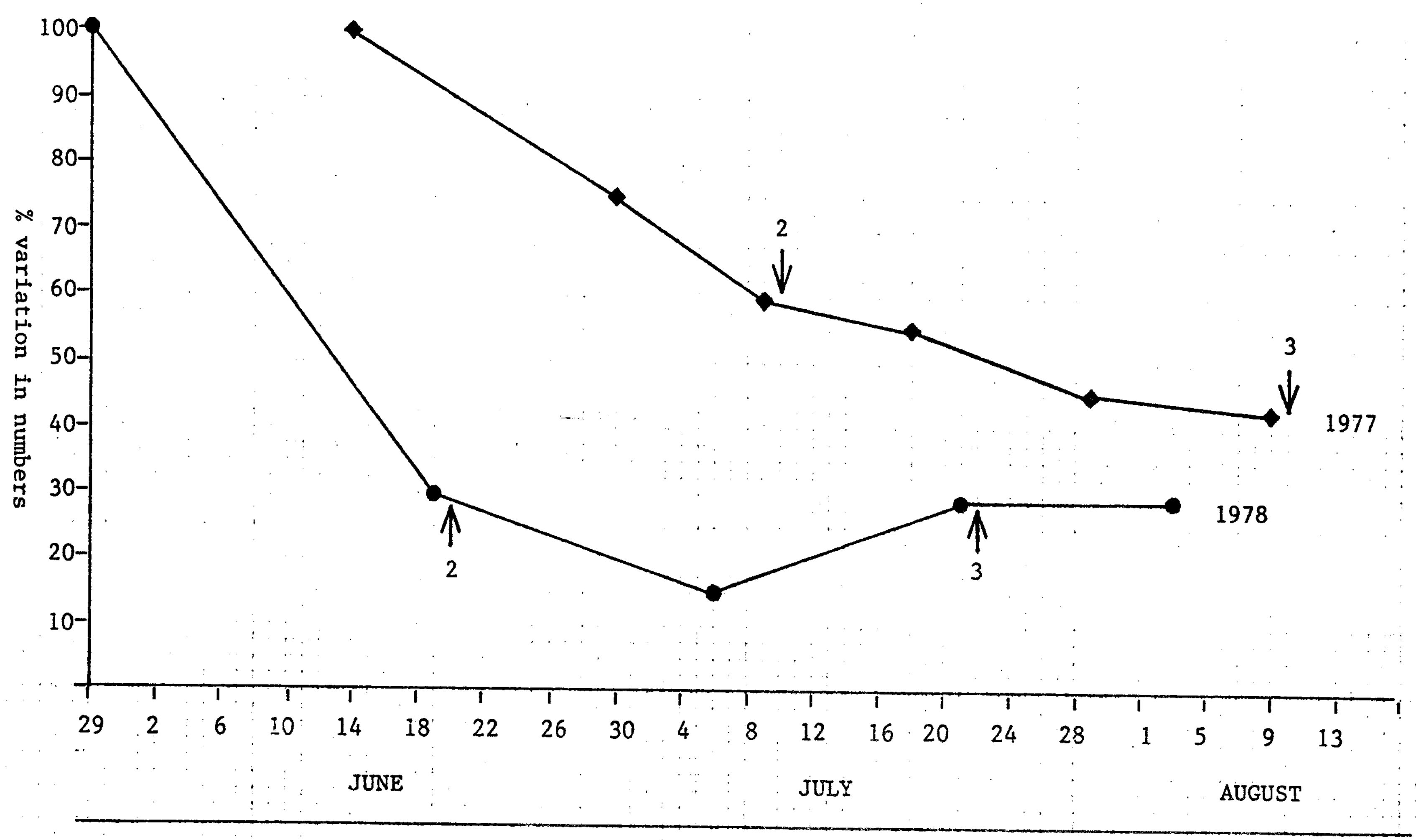
class of birds in the sitting posture measures that part of the population that is motivated enough to show reproductive behavior. The figure for chicks per sitters in Column B of Table 19 is an estimate of the productivity of the breeding population.

Both measures of productivity of murres show a substantial increase each year over the previous one. There is a strong correlation between the phenology of the murres and productivity. The dates of peak egg-laying (see Figure 23) show a striking change, becoming earlier each year. Murre productivity appears to be correlated with early egg laying. Also, the intervals between the date the first egg was laid and the date of peak laying become shorter each year, suggesting that the synchrony of breeding is correlated with reproductive success. This is the Fraser-Darling effect, first suggested by him for gulls in 1938, and investigated for many colonial species since then. It is virtually impossible to separate cause from effect in this phenomenon which is still controversial.

Differences in the daily schedule of murres may reflect the differences in productivity, at least for 1977 and 1978. In those years we counted an area of the cliff once an hour on several days throughout the season. The variation in numbers through the 24-hour period is a measure of how closely the murres stuck to the cliff, and this is shown in Figure 23. In both 1977 and 1978, variability is high early in the season, and declines later. In 1977, however, the variability never decreased to the level seen in 1978; this means more murres spent more time away from the cliff in 1977 than in 1978, especially during egg-laying. Reasons for this are not clear but may be related to shortages of food, requiring the birds to spend more time searching. Regardless of the cause, eggs

Figure 23. Variation in numbers of Murres over 24-hour counts at Bluff, 1977 ◆ and 1978 ●.

2 = peak laying
3 = peak hatching



and chicks left untended on the cliff suffer high mortality from predation as well as exposure.

2. Kittiwakes

Kittiwakes at Bluff are almost ideal animals to study. Data on all aspects of reproduction (number of nests built, number of eggs laid, number of chicks hatched and fledged) can be gathered easily, in contrast to data on murre reproduction. We mapped nests on the cliff and checked the contents of the nests regularly. Being easy to study, kittiwakes make a good species with which OCSEAP could monitor the health of the marine ecosystem. They are less prone to the immediate ill-effects of spilled oil than are the auks, and being secondary consumers, will reflect the productivity of the organisms in lower trophic levels. They are more sensitive than murres to changes in environmental conditions, as indicated by our data. We presume that this is because they feed only at the water's surface. Thus, we would expect the long-term impact of an oil spill, or of chronic low-level environmental insult, to be reflected in kittiwake populations.

The productivity of kittiwakes at Bluff for 1975-1979 is shown in Table 20. The most important measure of productivity in a population is the number of chicks fledged per nest. We can see that productivity varies over the five years, from the extremely low levels of 1976 (1 chick produced in 33 nests) and 1977 (1 chick produced in 10 nests) to high levels in 1978 (at twenty times the 1976 level) and 1979. It should be recognized that not all birds that fledge survive to breeding age. Coulson (1966) calculated an annual mortality rate of 12.1% among adults, and the mortality rate of first year birds at 21%. Thus, recruitment into the breeding population is much lower than the figure for reproductive success.

The remainder of Table 20 breaks down the productivity of each season so that we can see what accounted for the differences among the years. Both

Table 20. Productivity of Black-legged Kittiwakes at Bluff, 1975-1979.

year	Reproductive Success (chicks fledged per nest built)	Clutch Size: eggs per clutch	eggs per nest	Brood Size: chicks hatched per brood: excluding empty nests	including empty nests	Hatching Success: eggs hatched as percentage of eggs laid	Fledging Success chicks fledged as percentage of chicks hatched
1975	0.43	1.22	-	1.05	0.57	85%	78%
1976	0.04	1.11	0.34	1.00	0.03	15%	71%
1977	0.11	1.08	0.41	1.00	0.11	34%	73%
1978	0.82	1.56	1.55	1.16	1.20	75%	70%
1979	1.03	-	-	1.32*	1.10*	-	-

* These estimates are based on a minimum number of hatchings; observers arrived at the cliffs after hatching had begun and so may have missed chicks hatched early and lost.

the production of eggs (eggs per nest), and the proportion of those eggs that hatched (hatching success), increase with the level of productivity over these years. Hatching success is roughly doubled each year, and this, along with a huge increase in egg production in 1978 and 1979 over 1977, accounts for the increase in the levels of reproductive success.

Table in Appendix VI presents productivity measured at four geographically comparable study areas from 1976 to 1979. In years of low success (1976 and 1977), the sample size of chicks hatched and fledged is too small to yield meaningful estimates. For example, fledging success within the comparable areas was 100% in 1976, but this is deceiving; though all chicks that hatched survived in 1976, the number was only 3, as compared to 116 chicks fledged from the exact same area in 1979. When a larger sample size of chicks is used to estimate fledging success, the estimates among the years do not differ significantly (Table in Apndx. VI.) and so chick loss after hatching accounts for none of the variability in reproductive success among the years.

The factors underlying greater egg production are not clear, though one presumes that the supply of food is of primary importance. There is evidence detailed below that food was scarce in 1976 and 1977 and abundant in 1978. The yearly breeding schedules in Figure 22 , do not show a significantly earlier date of the onset of laying for 1978. But, like the schedule of murres in 1978, the interval between the onset of egg-laying and the peak of laying is very short, indicating a population with adequate food, breeding synchronously. The earlier kittiwakes breed, the larger the clutches they lay (Tables 18 & 20), and further, the experienced, well-fed female may produce larger and more eggs.

We can point to two factors that presumably increased hatching success in 1978. First, the kittiwake nests were conspicuously more sturdy and better made in 1978 than previous years. This was due to the early and continued availability of good nesting material. We mentioned above that wet (and stormy) weather softens the sod at the cliff edge and allows the kittiwakes to pull out grass and mud for nests. Around Nome the summer of 1978 started earlier than 1976 or 1977, and was particularly wet. Second, the birds were more attentive to their nests and chicks in 1978 than in 1976 or 1977. Figure 24 shows the percent variation of kittiwake numbers during the several 24-hour watches made in 1977 and 1978. In both years the attendance of the birds became more and more regular in the early part of the breeding season until a plateau was reached around the time of peak laying. In 1977, variation in attendance was greater during laying than in 1978, and "absenteeism" increased again shortly after peak laying. Just before peak hatching (at [3]) the maximum variation in numbers was seen. This inattention during the incubation period resulted in the deterioration of nests and egg loss. In 1978, nests were kept in good repair throughout incubation.

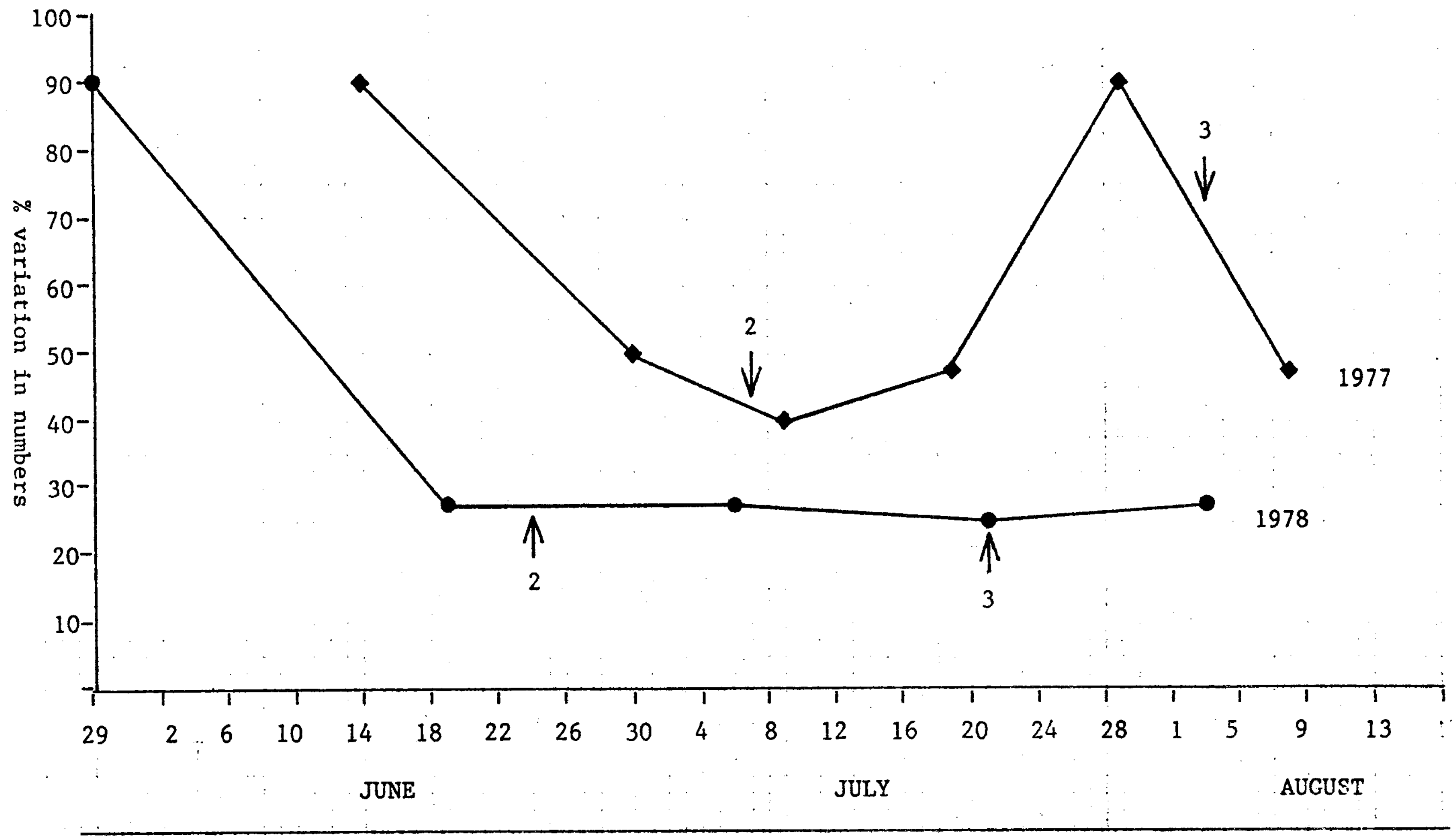
We have postulated that there was a general food shortage during both 1976 and 1977, with the shortage in 1976 being the more severe. This may explain in part the depressed productivity in those years for both murres and kittiwakes relative to 1979 (see next section).

D. Variation in Reproductive Success and Causes of Mortality of Black-Legged Kittiwakes

The annual variation in reproductive performance of the Black-legged Kittiwakes at Bluff suggests the problems the birds face and that birds at Bluff are in a sensitive area. Reproduction was highly successful in 1979 (1.05 chicks produced per nest studied); it was successful in 1978

Figure 24. Variation in numbers of Kittiwakes over 24-hour counts at Bluff, 1977 ◆ and 1978 ●.

2 = peak laying
3 = peak hatching



(0.83 chicks produced per nest studied); it was moderate (.43 chicks per nest) in 1975; it was poor in 1977 (0.06-0.14 chicks per nest); and a disaster in 1976 (0.03 chicks per nest) (Table 20).

Predation by Ravens on murre and kittiwake eggs is conspicuous; eggshells are found along the length of the cliff edge. However, even the resident two or three pairs of Ravens take only a small fraction (< 5%) of the total egg production.

Figures 25 and 26 show the record of appearance and disappearance of eggs for the two disaster years, 1976 and 1977. Both years, the beginning of laying was late (Figure 22 and Table 18). Each year the birds began to be absent from their nest sites in mid-July when they should have been incubating closely.

In 1976, the absence started suddenly after an intense storm on July 9, and the birds did not return until after 12 July. Leaving early in July meant that the birds left even before the peak of egg laying; so the number of eggs laid was small. In addition there was high mortality of eggs while the adults were absent. It is interesting that in the few nests whose incubation period we could measure incubation extended 6-10 days longer than the usual.

In 1977, the peak of attendance of birds at the cliffs came in early July at the peak of egg-laying and many more eggs were laid that year as compared to 1976. The disaster became obvious when about two in three eggs failed to hatch. Birds were reported absent from their nest sites beginning in mid-July and many birds were absent 16-26 July. The parents at those nests at which we recorded loss of eggs were absent; a few were absent before, many were absent during, and many after the date on which the eggs disappeared. It is interesting, but may be a coincidence that

Figure 25. Number of kittiwake eggs present and amount of mortality at Bluff Cliffs, 1976.

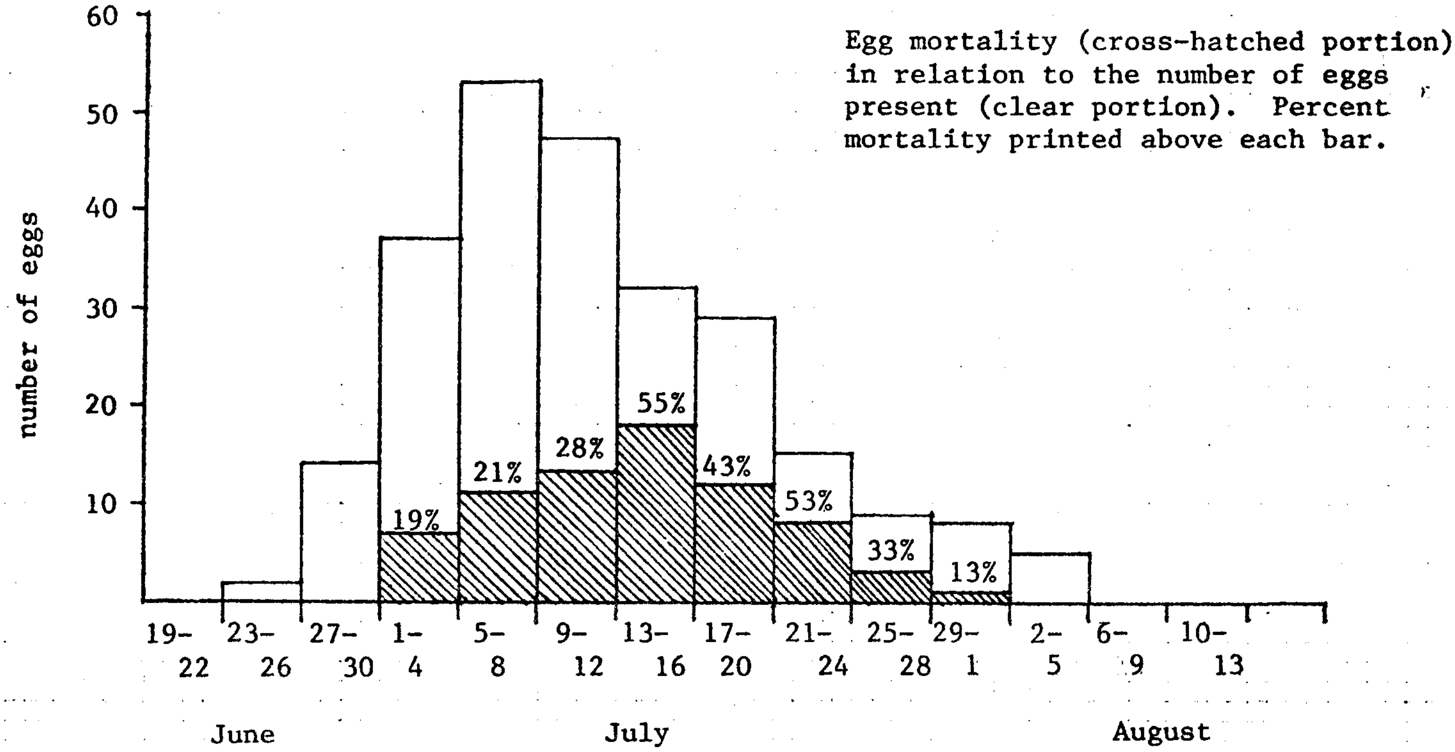
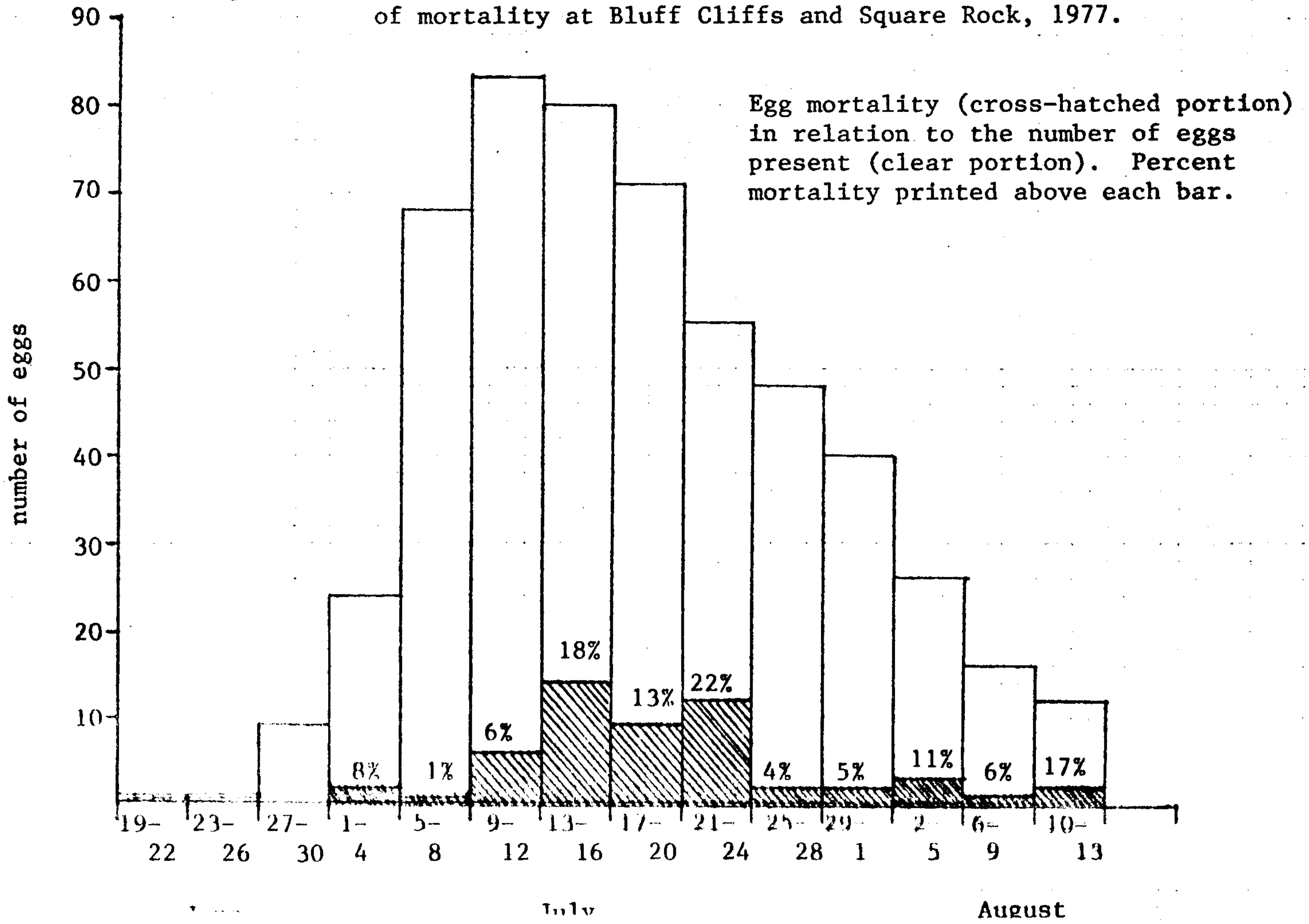


Figure 26. Number of kittiwake eggs present and amount of mortality at Bluff Cliffs and Square Rock, 1977.



the adult birds began to return to the cliffs in late July when the numbers at the cliffs generally increase every year as, presumably, subadult birds come in.

We cannot define precisely the beginning of egg-laying or its peak in 1975, but our observations indicate that attendance at nests was good, clutch size larger than in 1976 or 1977, and that the kittiwakes at Bluff produced about .43 chicks per nest. The first young had hatched by July 18, and the peak of hatching was around July 28-30, indicating that that year was earlier than 1976 or 1977. Survival of chicks was especially good except for the effects of a late August storm (Table 21).

In 1978, the number of eggs laid was high (Tbl. in Apndx. VI.); for the first time we recorded several nests with three eggs, the normal clutch size of kittiwakes in northern Europe. We recorded little absence of birds from the cliffs during incubation and a high percentage of the eggs (75%) hatched (Table 20). In some nests the eggs hatched on the same day and in these cases both young usually survived. In a number of nests the eggs were laid over a period of several days (Figures 21, 27, and 28) and in a number of cases we recorded the harrassment of the younger nestling by the older. This harrassment apparently was associated with the younger's getting less food and in all cases a) the smaller chick grew more slowly, and b) the smaller chick died, often after leaving or being driven away from its nest. It appears that there is a mechanism by which the older chick survives, if a) the female cannot get enough food to lay both eggs on the same day and b) there is restricted food during the first week after hatching.

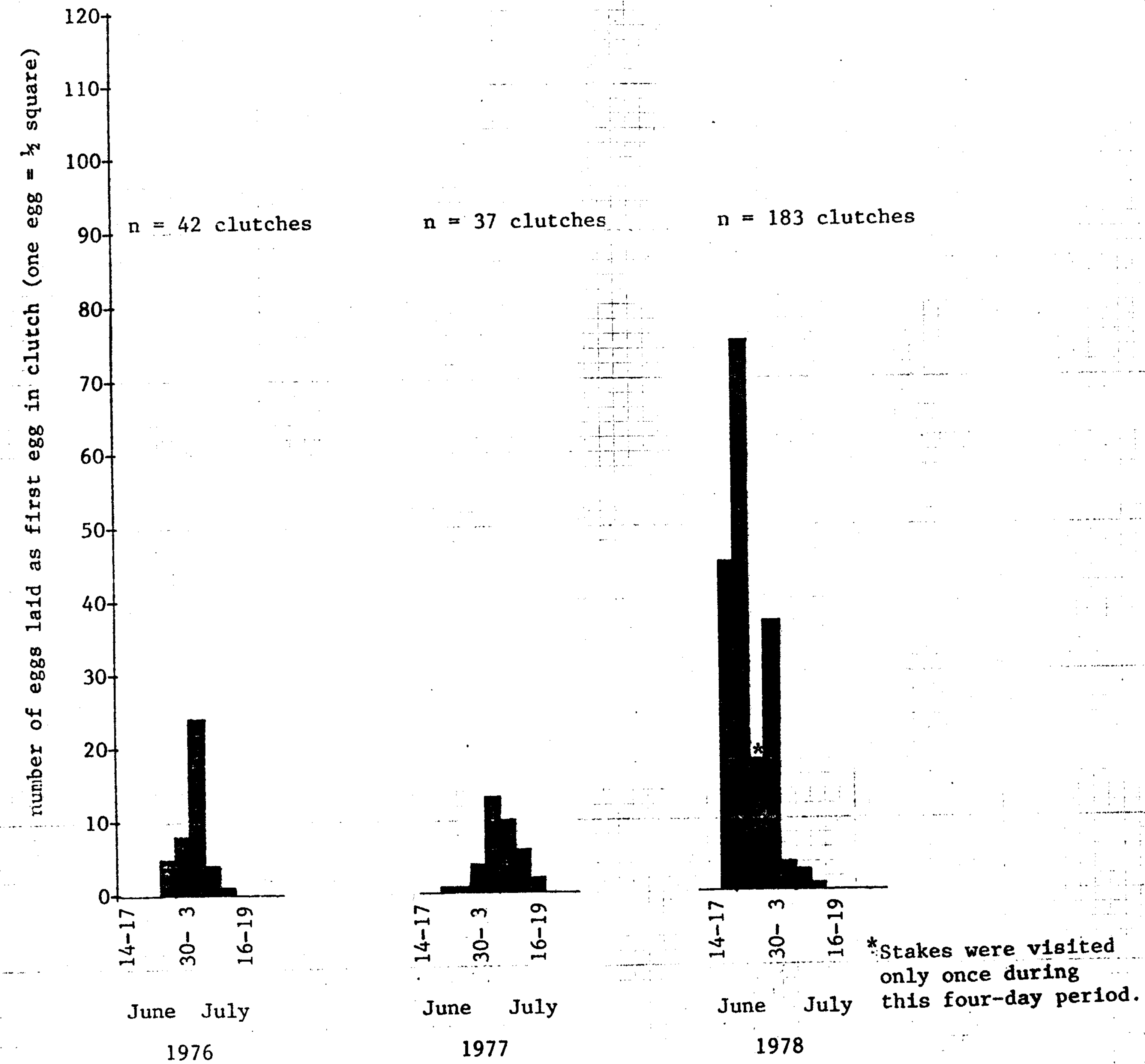
We noticed an additional interesting facet: in several cases, the younger chick, being driven from its own nest, moved along a relatively

Table 21. The effects of a storm in late August 1975, on the survival of kittiwake chicks at Stake 1, Bluff.

location at Stake 1	before storm on August 19		effect of the storm		
	no. of nests	no. of chicks	chicks present	chicks lost	% loss
top section	31	19	14	5	26%
middle cliff	20	8	7	1	12.5%
lower cliff	25	12	1	11	92%

Figure 27.

Date of first appearance of first eggs in all clutches at five kittiwakes stakes at Bluff Cliffs in 1976, 1977, and 1978.



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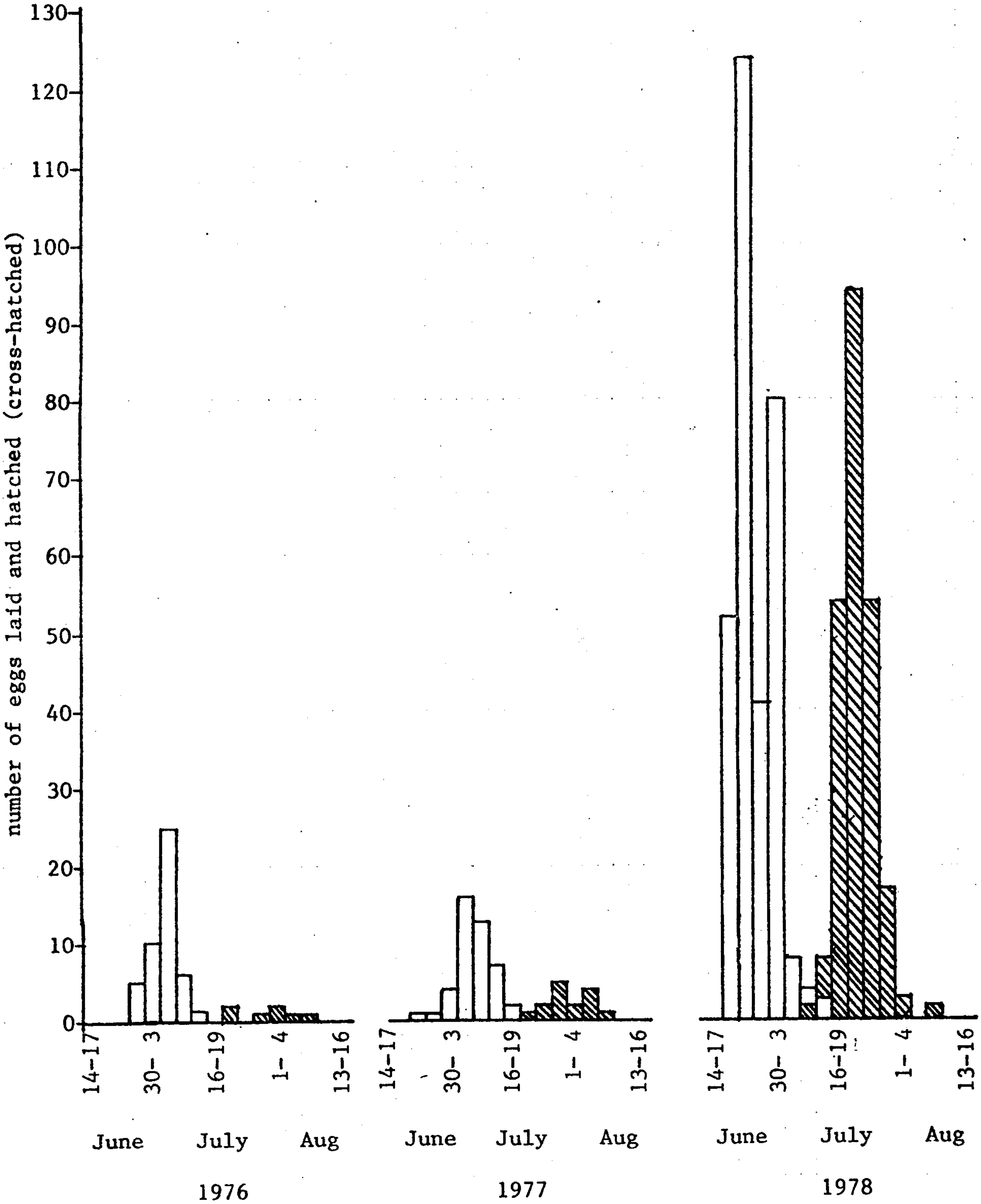
	1976	1977	1978
date first eggs seen at colony	21 June	20 June	18 June
peak of laying of first eggs	4-7 July	4-7 July	22-25 June

Figure 28.

Laying and hatching of Black-legged Kittiwake eggs at five stakes at Bluff Cliffs in 1976, 1977 and 1978. Laying period is represented by clear bars; the hatching period is cross-hatched.



	1976	1977	1978
peak of laying	5 July	7 July	24 June
peak of hatching	30 July - 4 August	28 July- 2 August	21 July

broad ledge and into the nest of a neighbor if the eggs in that nest had not hatched or the young were very small. These emmigrant young were accepted and pre-empted the attention of the adults. It offers an interesting problem for natural selection, and will be the subject of a special paper.

In 1979, the year of greatest reproductive success, the birds began to lay at the earliest date we recorded and laid over a narrower period of the calendar: more nests were occupied, more nests contained eggs, the average clutch size was larger, and there was high rate of survival of eggs in the nests. Detailed studies were not made because we had a smaller party of observers at the cliffs. In all of these years mortality among the chicks after the first week was very low. All years, even the disaster years, 75% of the chicks that hatched survived to fledge. The exception, a special case, was recorded in 1975 (Table 21). On August 19, 1975, there was an intense southeasterly storm which drove waves high onto the cliffs. Our records indicate that all of the nests on the lower third of our study sites on exposed faces were washed away. A small number of nests in the middle levels disappeared and none on the upper parts of the cliff were harmed. The number of birds nesting on the lower parts of the cliff are few and the occasional August storm may be the reason why.

* * * * * * * * * * * * *

The unusually favorable opportunities for studying individual nests and birds at Bluff make it possible to document the differences in behavior among individuals and between years. The observations show that certain birds perform well each year and that certain parts of the cliffs may do well even though other areas have failed (e.g. Square Rock 1977). Our studies suggest that sections of the cliff act as if "in concert," which suggests social facilitation in some cases. These studies give a picture of the problems faced by the birds as familiar individuals. Sometime it may be possible to integrate detailed studies such as these on marked birds in conjunction with observations made following the birds to their feeding grounds at sea. Such studies will allow investigators the opportunity to observe the behavior of successful and unsuccessful individuals and to relate the birds' behavior to the distribution and abundance of the species used as food. Such an exercise would be very instructive; in the meantime we can be sensitive to the reality that kittiwakes respond to conditions in the ocean in such ways that they are sensitive indicators of marine conditions, even though their adaptations tend to insulate them from the direct impact of the changes. In the next section we will discuss the relation of organisms at several trophic levels of the ecosystem of which they are a part, and present a picture of the way in which seabirds interact with their food at sea.

VI. Structure and Process in the Marine Communities of the Bering Strait Region

A. Introduction

One can consider communities as 1) a set of constituent species according to their relative abundance or 2) a series of trophic levels through which energy flows, or 3) as players in a series of processes. All three are necessary to understand the marine ecology of a region. In order to avoid lists we will design this discussion on a framework of theoretical mechanisms -- the processes which guide the action of natural selection.

We will make a few major points that are not as much theory as they are ways of thinking about systems. First, we conceive of communities as extemporizations among temporary members, not interactions within a consistent organization tuned over a period of time so as to improve efficiency of energy flow.

As Harper (1977) cogently put it:

> A theory of natural selection that is based on the fitness of individuals leaves little room for the evolution of populations or species toward some optimum, such as better use of environmental resources, higher productivity per acre of land, more stable ecosystems, or even for the view that plants in some way become more efficient than their ancestors. Instead, both the study of evolutionary processes and of the natural behavior of populations suggest that the principles of "beggar my neighbor" and "I'm all right Jack" dominate all and every aspect of evolution...Natural selection is about individuals and it would be surprising if the behaviour that favoured one individual against another was also the behaviour that maximized the performance of the population as a whole.

Second, we assume that natural selection is acting to favor mobility in organisms; that the benefit of increased mobility is emancipation or insulation of the individual from capricious fluctuations in its organic and physical environment. Third, we see that orfanisms cannot do everything equally well and their world is constantly changing. So, in some years one set of behavior patterns is favored; other years a different set. As a result, the spectrum of adaptations of a species consists of constellations of adaptations which balance out to an effective way of life called a strategy in ecological jargon. The word strategy implies a plan. Inherited structures and programmed behavior, not "thought", are the survival tools of birds and virtually all other organisms. Fourth, we accept Lack's (1954) contention that natural selection favors those individuals who produce a maximum number of young to the age of independence. This great surplus of progeny contributes the "proletariat", the prey or food upon which other trophic levels feed. Fifth, we believe that orhanisms survive by maintaining an interaction or balance, however tenuous, between their physical and biological environment and their programmed structures and responses. Birds use these programmed "fixed patterns" of behavior, the sense organs with which the individuals perceive their habitats and their anatomical structures to search for, find, cathc, dismember and eat what they can. The individual can change the circumstances under which it uses its inherited or programmed activities; it cannot try some new pattern. If its efforts do not produce results, the individual can only reprat the same activity. If the programmed activities continue to fail, the individual will die. New combinations appear because an individual has a new genetic combination programmed to a different activity, not because an individual adapts. Sixth, the programmed structures, sense organs and behaviors are tuned to the entire spectrum of habitats with which the interbreeding population must interact. Species which live in a region where conditions vary widely must be able to tolerate changes in temperature, salinity, humidity, and and also the form or typr of foods available. Thus, the food of wide-ranging, opportunistic feeders may differ considerable as to species over the whole range, although usually the prey type or form falls into rather narrow limits as do the habitats in which the prey is sought. Seventh, in a community generally there are a few abundant species. If the predator notices, and can catch them, these become food staples. If in some places or some years these species fail, the predator suffers privation and must seek alternate prey. When the staples fail, the diversity of prey used can be expected to rise sharply. The diversity of species available to become food when the mainstays fail is shown by the presence of 100 additional species listed as occurring in amounts less than 2%, in the original papers from which we selected our tables of food used by seabirds (see Tables 23-27.). Most of these are uncommon bottom fish or crustacea. This marked increase in diversity reflects the principle identified by Gleason (1920), Raunkaier (1918), and Preston (1948) that species abundance follows an experiential decay curve and most species are uncommon or rare. Thus, eighth, species persistence depends upon region-wide systems which contain enough redundancy of habitat to supply refuges in which individuals can build up their numbers or find refuge to survive hard times.

B. Productivity and Food Webs -- Open Systems

We described the conditions in the Bering Strait region as a series of systems in flux. The phytoplankton of the Bering Sea region evidently "pumps" energy into the local biological system via photosynthesis. Although the energy is inevitably and soon dissipated, perhaps as directly as from producers to decomposers, some species are able to intercept and use the energy "on its way." The communities of consumers take on certain forms and functions which allow them to use that energy for their own purposes. What species, how many species and how many individuals of each species are present depends on the responses of those species that happen to be around.

As for the species of marine organism which appear in the Bering Strait region, some are boreal Pacific and some range over the Arctic Ocean and occur in the North Atlantic; some are found in low salinity shallow (neritic) waters, others in highly saline; some are benthic, others pelagic or epipelagic. The communities reported for this region have seldom, if ever, been made up of species of uniform origins.

As for the birds of the region, some have their major distributions in North America; others have their distributions primarily in Siberia; some are widespread over the circumboreal region; some have limited distributions in the Beringian Region; some species occur sporadically in this area.

We picture the aggregation of individuals and species into associations as open systems (von Bertalanffy, 1950). Over time and space the constituent members of the communities are steadily changing; new ones are being added by immigration and others are disappearing by local failure. In this context, it is necessary for individuals to move around and for there to be places to move to in order for populations and species to persist. Food resources are dispersed and clumped, and furthermore, in many places where marine food might support large populations of breeding seabirds, breeding sites may be missing.

C. Trophic Levels and Emancipation from Changes in the Physical Environment

Species at lowest trophic levels are directly affected by changes in their surroundings while those at higher levels are progressively emancipated by mobility. Mobility allows them to crop alternative habitats or alternative resources. We believe that this progressive emancipation, which is a trend from "lower" to "higher" organisms, is a consequence of natural selection's favoring those individuals which can shift to different places or different foods and thus escape the effects of decline in resources in one "habitat." In the following pages we will describe the ways in which this emancipation works. Discussion of the species concerned is found in Appendices III, IV, and VI.

At the level of producers, the growth of phytoplankton depends upon presence of chemicals contained in water of suitable temperature in the euphotic zone. Some of these independent variables are controlled by eddies, turbulence, and unique events in weather patterns, including shifts in wind. Variations of light, temperature and the amount of minerals in the euphotic zone have sporadic and dramatic effects on phytoplankton, creating peaks of productivity and valleys of failure month to month, season to season, year to year.

Plants can vary their "tactics" to take advantage of favorable conditions by investing in asexual reproduction so as to build up their numbers rapidly, or, by storing oils and reverting to sexual reproduction and resistant spores so as to survive periods of shortage. Plants can, however, do little to mitigate the effects of changes in their immediate surroundings and that is what we mean by saying they are closely coupled to the physical and chemical vagaries of their environment.

Only scattered areas of intense activity have been identified in the studies of primary productivity in the Bering Sea. It appears that energy captured in the areas of intense primary productivity is deflected into different sorts of conspicuous communities in different parts of the Bering

Sea, according to the effects on species composition, of local temperatures, salinities and water depths. While there is a large commercial ground fishery on the edge of the Continental Shelf northwest of the Pribilof Islands, there is an impressive biomass of Gray Whales, Walrus and Bearded Seals in the Chirikov Basin and Chukchi Sea. Another manifestation of productive waters is the abundance of seabirds which feed on herbivorous copepods.

The presence of dense copepod populations depends on the relation between rates of copepod reproduction and rates of grazing as compared to the rates at which phytoplankton reproduce. The growth and reproduction of copepods reflect factors in their physical environment, such as currents, salinity, and temperature; these affect survival of their eggs, their larvae, and the ability of copepodites to store oil reserves. The rates of these activities, like those of the phytoplankton, are at the mercy of capricious events reflecting coincidences of favorable and unfavorable combinations of physical conditions. But copepods move. They have diurnal migrations to seek concentrations of food, to avoid predation and settling into the depths, and to mitigate the direct impact of capricious changes in their world.

Larger crustacea -- the Amphipods, Decapods, Mysids and Euphausiids -- are more mobile still. They often make extensive daily movements and may migrate at breeding times to occupy a part of the water column especially favorable for reproduction. These animals also feed on a wider spectrum of food items and apparently can choose food items which they can feed on efficiently rather than filtering whatever is available. These options tend to damp fluctuations in the resources available to the crustacea.

These crustacea are, nevertheless, still vulnerable to the effects of major turbulence and temperature, as compared to the greater mobility and responsiveness of small fish.

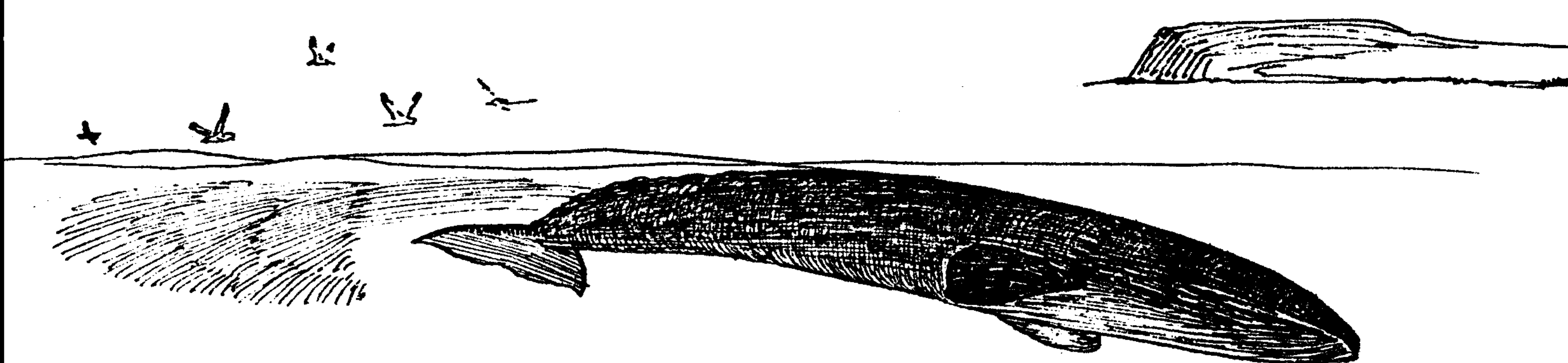
The eggs and larval stages of fish are as vulnerable at critical times to the vagaries of turbulence, temperature and predation as are the other less mobile occupants of the water column. Adult fish can, however, migrate seasonally even more widely than the invertebrates. This helps them to choose favorable places to spawn to improve the odds of success. Nevertheless, as Hardy (1956) discussed, spawning of herring in the North Sea is dependent upon a complex set of conditions which affect wide fluctuations in fish stocks. Independently varying conditions (in the North Sea) interact and become favorable or unfavorable to the set of spawn; the coincidences determine outstanding year classes or near total failure. Once the fish have survived the egg and larval stages, the growing fish can move relatively freely through the water column. They achieve some emancipation by choices among alternative sizes and species of prey (Copepods, Amphipods, Euphausiids, Mysids, Pteropods, Annelids, Chaetognaths). Most prefer larger items, but they can resort to smaller, more numerous prey when the items they prefer are hard to find.

In many cases small fish have long movements from deep waters where they winter, to shallow water where they feed and perhaps breed, taking advantage of locally favorable conditions. Some breed in lagoons or their young use these especially productive areas as nursery grounds. Fish can stay in places where they find the feeding is good or move on out of poor areas.

Yet changes in the sea, reflected in changes in numbers of herbivorous crustaceans, may reverberate through the fish fauna. During the 1950's, changes in plankton in the North Sea from small bodied, neritic copepods similar to those Neimark, Cooney and Geist (1979) found in Norton Sound, to more oceanic, larger bodied Calanus, were associated with an increase in Herring (Cushing 1975); similar changes may be associated with the large changes in Herring stocks in Norton Sound in the last three decades.

Fish are still relatively closely coupled to their habitat, 1) because of their vulnerability during spawning, 2) because they are strongly affected by temperature, and 3) because they are restricted in their opportunities to move and crop alternative resources. For example, Wolotira et al. (1977) suggests that there are not fish of sufficient size for a commercial fishery in the Chirikov Basin because the water is too cold for the commercially valuable fish to colonize there, despite the abundant benthic food supply. Moreover, species of mid-water fish, such as Capelin and Smelt, are not as numerous in these waters as they are in neighboring regions of the Bering Sea.

The combined oscillations of the species described form the background or stage upon which seabirds play their parts. Oscillations in their numbers exist but are progressively damped because, being larger, they can move between areas and compensate for seasonal or annual shortages. Among active vertebrates, seabirds are maximally mobile. They can move long distances from their breeding sites to feeding grounds and they can leave productive summering grounds for distant wintering grounds, thereby cropping resources in several different regions. By taking advantage of temporary abundance seabirds can escape the oscillations of single food sources. For example, some seabirds, like terns, feed primarily in the shallow waters of the lagoons and yet fish offshore at convergences, at



the edge of drifting ice, or at the mouths of rivers where food may be concentrated. While some, like kittiwakes, feed primarily at the surface, others, like murres, feed throughout the water column. Some species, like kittiwakes and Glaucous Gulls, will fly to sea to follow whales which are bringing benthic invertebrates to the surface. Murres and auklets fly as much as 100 miles from their nesting islands to patches of food. The auklets from the rubble slopes behind Savoonga may fly as far as the Strait of Anadyr. All of these birds converge on windrows of ice in the spring to take advantage of the special productivity there (McRoy and Goering 1974; Divoky 1976 and 1978).

The arctic environment has selected individuals which can survive years of failure even though that ability to persist may be at the cost of being less effective at reproduction when conditions are favorable. This emancipation exists in both animals and plants. As an illustration, plant species have the "problem" that many summer seasons in the arctic do not produce suitable conditions for reproduction by flowers. Because they cannot "count on" having seeds germinate in any given year, most plants are perennials and can survive many years without reproducing. Similarly, many insects remain in "immature" stages for several years, a most unusual life history for insects at lower latitudes. Seabirds are long-lived, and our observations at Bluff show that murres and kittiwakes may go several years without producing enough young to replace "average annual" mortality.

If the individual's characteristics are congruent with the resources of the region, it is possible for the organism to occupy that place. If the resources used are abundant and widespread, the species will probably be numerous, too. If resources are spotty, so will be the species. But as selection acts on individuals it is of little consequence how numerous the population is. Rare species, if they persist, should be considered as successful as the abundant ones.

D. Water Masses as Habitat Types

Movement of water is the central force in the lives of marine birds. One movement, that of sea water north from the Bering Sea Basin over the Continental Shelf and through the Bering Strait, dominates the marine ecology of the area we are studying. Another movement, that of fresh water from the interior, dominates the lagoon systems where rivers meet the sea and upon slowing, deposit sediments. The sediments are molded by ocean currents to form bay-mouth and barrier beaches which hold in fresh and brackish lagoons. The movement of water in both of these systems provides a constantly renewed food supply.

The marine birds of the Bering Strait are separable into three major categories according to the water masses which they occupy: 1) those of shallow, relatively low salinity Alaskan Coastal Water; 2) those of deeper more saline Bering Shelf Water; and 3) those of the lagoons behind barrier beaches. We concentrate on the seabirds and neglect several numerous species which feed primarily in the lagoon systems. In Section VII we report on coastal habitats, evaluating their importance to waterfowl.

The Alaskan Coastal Water reaches minimum salinity and maximum temperature in inner Norton Sound (Figures 29 and 30), inner Kotzebue Sound, and especially in places like Golovin Bay, Grantly Harbor, Imuruk Basin, Hotham Inlet and Selawick Lake, which are transitional to lagoon systems. This has variable salinity and temperatures, hence the species tend to be few

Figure 29 . Sea surface salinity contours during the June to July, 1977, _Surveyor_ cruise in Norton Sound (Neimark 1979).

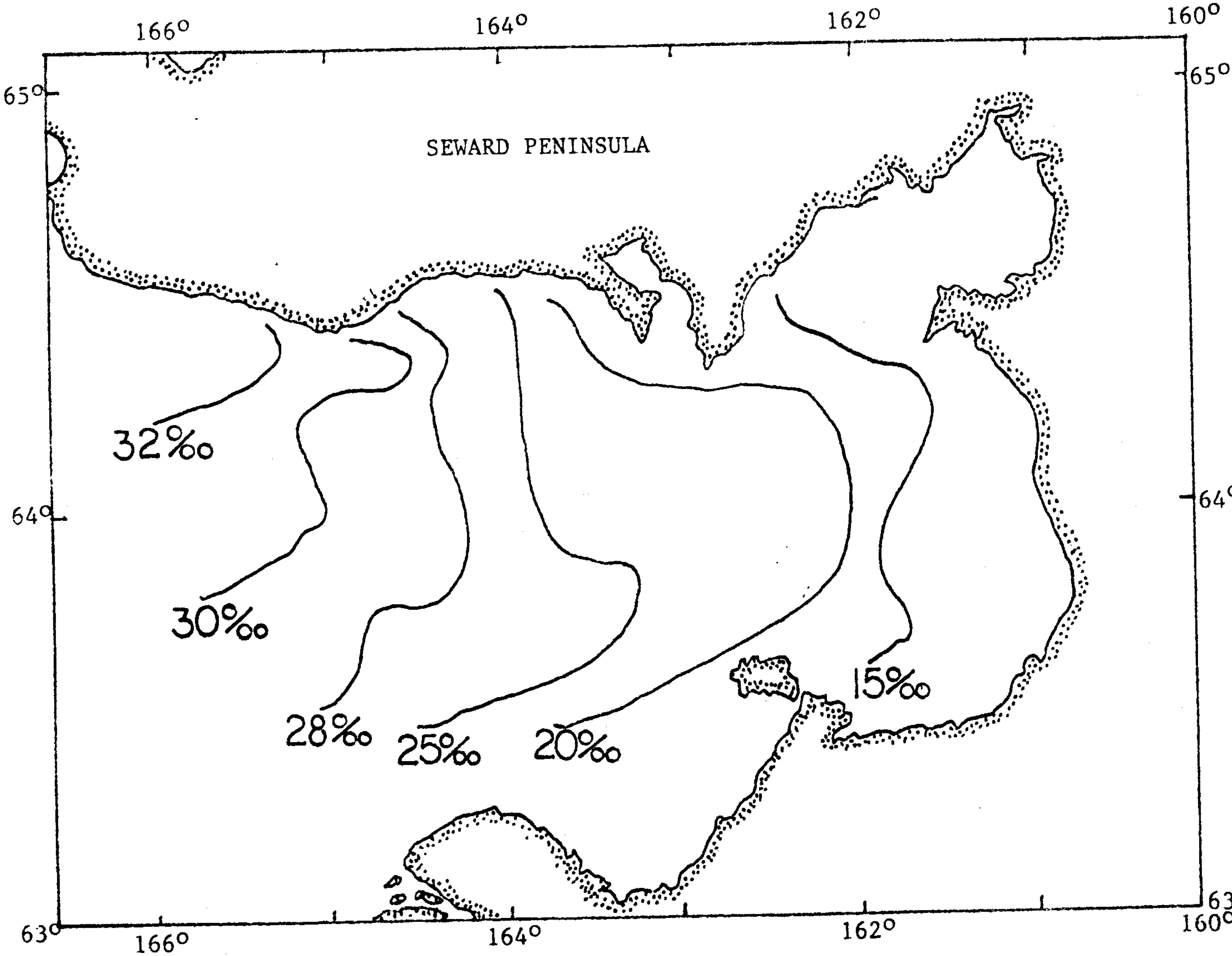
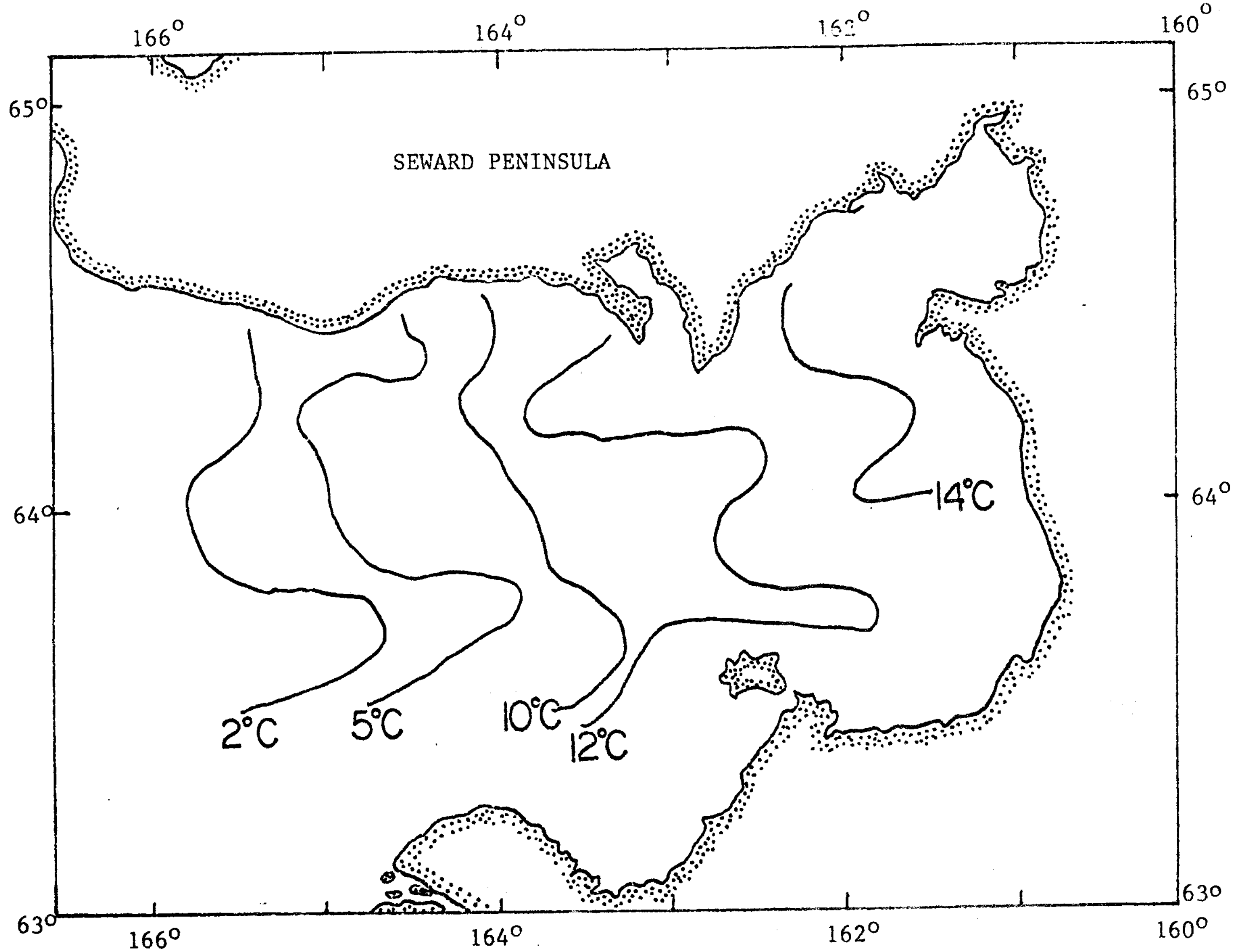


Figure 30 . Sea surface temperature contours during the June to July, 1977, Surveyor cruise in Norton Sound (Neimark 1979).



and to be generalists, i.e., species of wide geographic ranges. Widespread species of seabirds are numerous in the Alaska Coastal Waters, while the specialized species of seabirds for which the Bering Sea is known occur primarily in the high saline, cold waters of the Bering Shelf.

The northward flowing shelf waters pass through several topographic conditions which affect the biological activities. South of Saint Lawrence Island, movement of water out of the deep basin up over the edge of the Continental Shelf brings nutrients to the surface. High productivity is reported in a zone north of Saint Matthew Island and in the Gülf of Anadyr. Acceleration of the flow as the water is confined seems to have a positive effect on seabird numbers in the Strait of Anadyr but not in Shpanberg Strait. The water slows in the Chirikov Basin, moves to the northeast and produces some eddies (Figures 7 and 10).

Fronts between water masses seem to influence where the birds from King Island feed. These convergences are important as collecting sites for drifting ice in spring. Yet it is not clear from our observations in this region that the fronts, in themselves, are of direct importance to biological activity.

The Bering Shelf Water accelerates again as it is confined to flow through the Bering Strait, and again turbulence and productivity have a marked effect that is an increase in plankton-feeding seabirds. Beyond the Bering Strait the water fans out into the southern Chukchi Sea. Part swings northeast and accelerates again as it moves past the Lisburne Peninsula, confining the Alaskan Coastal Water mass and causing it to accelerate there, too. Seabirds occur along the front between these masses, and nest in large numbers on cliffs along the Lisburne Peninsula.

An eddy between Cape Lisburne and Point Lay in another major feeding area; it is a place where Sand Lance collect.

E. Adaptations to Lifestyle

A series of social, behavioral, and anatomical adaptations exist among seabirds to allow them to crop their mobile resources. No species can do everything equally well. Therefore, each species tend to be selected to do a particular thing and to acquire characteristics that facilitate the key adaptations. Thus, subsets of adaptations emerge which define a way of life (Lack 1966). They include habitat preferences, feeding techniques, distances the birds go to feed, timing of movements, and responses to reproductive failure. At one extreme, some seabirds feed on resources available and close to their nest. At the other extreme, some species feed at sea at great distances from their nesting areas.

Species of waterfowl and shorebirds which feed close have dispersed nests, cryptically colored plumages, eggs and young. The young usually are precocial, i.e., can leave the nest soon after hatching, and usually are largely self-sufficient. Such species often lay larger clutches of eggs than do the other seabirds, as illustrated primarily by waterfowl. When their reproductive efforts fail they may replace the clutch of eggs several times and if disturbed move readily to nest at a different site.

Species, such as auklets and petrels, which feed at long distances at sea congregate in large numbers to breed at a few especially favorable sites. Because these species are adapted to long-distant flights they are awkward on land. Consequently, they are vulnerable to predation and must seek well-protected nesting sites; but they can fly additional distances to reach preferable sites. They lay small clutches, usually one egg; the young are altricial, grow slowly and are dependent upon their parents for many weeks. These adaptations allow them to tolerate periods when the far-flying parents may be prevented by storms from bringing food. These birds seldom replace a lost clutch and only reluctantly form new colonies.

In the Bering Strait region shorebirds and waterfowl, and to some extent terns and gulls, belong to the category of birds that feed close to or within their dispersed breeding territories. Other gulls and terns, together with cormorants and puffins, have intermediate characteristics. They may nest singly or in groups as the protected sites are available. They may be dispersed along the shore in small nesting groups and may move their nesting from one site to another. These qualities allow these species to take advantage of small rocky bluffs or to accomodate to changes in long-shore currents. Currents along these shores are constantly eroding and depositing sand beaches, hence changing the sandy islands where they nest or shoals where they feed.

While many of the cliff nesting birds feed close to their nesting cliffs (for example, Tuck and Squires, 1955, reported that most Thick-billed Murres at Akpatok Island fed within 16 km.), Brown found large numbers of murres feeding 80 km from Digges Island in Hudson's Bay, and a moderate number out to 160 km. Nettleship and Gaston (1978) determined 110 km to be maximum range for murres from Prince Leopold Island in Lancaster Sound, in the Canadian Eastern Arctic.

Nettleship and Gaston reported kittiwakes feeding within 50 km of Prince Leopold Island; Pearson (1968) judged from elapsed time between feedings that kittiwakes probably foraged within 55 km of the Farne Islands in northeastern England. Swartz (1966) reported kittiwakes dispersed out to 130 km and murres out to 60 km from Cape Thompson.

F. Foraging of Seabirds

We believe that seabirds do not use the major portion of the food actually present, though many individuals have difficulty finding food. The birds have certain anatomical and behavioral tools which they use to find, catch, handle, and eat the species that are vulnerable to those techniques. Some species of prey are "suited" to the adaptations (L. Tinbergen 1943) held by seabirds, and these are preyed upon in preference to others which the seabirds do not notice or whose living space the seabirds do not visit.

Storer (1952) and Bedard (1969b)discussed the anatomical adaptations of auk species a) which specialize in feeding on fish -- longer, thinner bills with sharp margins, and b) which specialize on crustacea -- broad flat bills with rough edges and special pads. Such modifications are expressed in the subtle differences between fish-eating Common Murres and fish/crustacea-eating Thick-billed Murres (Spring, 1971).

The work of Belopol'skii (1961) and Uspenski (1956) in the Kara Sea and Barent's Sea point out the marked variation of food species within form-types, used by Thick-billed Murres, Atlantic Puffins and Black-legged Kittiwakes. In some cases the total list of species is the same but a species that is a major food item in one place is virtually unused in another (Table 22 compares the Murmansk Coast with Novaya Zemlaya). Foods used by murres and kittiwakes on the Alaskan Outer Continental Shelf between Cape Lisburne and Middleton Island show similar variations of species "chosen" from a number of species of similar form (Tables 23, 25 & 27).

It is evident that there are major differences between the food species used 1) in different parts of the same species' range, and 2) even within

Table 22 .
Food of Murres, Puffins and Kittiwakes on the north Siberian coast showing variation in species of fish used among regions (percent occurrence). Data from Belopol'skii (1957) and Uspenski (1956).

Thick-billed Murre	Kharlov Island to East Murman Coast[1]	Bezymyannaya Inlet, Novaya Zemlya[2]
Fish Species		
Ammodytes tobyanus (Sand Lance)	23.1	0.9
Mallotus villosus (Capelin)	17.9	1.7
Clupea harengus (Common Herring)	38.5	0.6
Gadus morrhus (Common Cod)	20.5	44.3
Boreogadus saida (Arctic Cod)	--	51.3
Gymnelis viridis (Ocean Pout)	--	0.9
Myoxcephalus scorpius (Sculpin)	--	0.3

Atlantic Puffin	Seven Islands East Murman Coast[3]	Ainovy Islands West Murman Coast[4]
Ammodytes tobyanus	56.8	6.3
Mallotus villosus	21.0	43.7
Clupea harengus	19.7	50.0
Gadus morrhua	2.5	--
Black-legged Kittiwake		
Fish	70.9	59.0
Molluscs	12.1	9.8
Crustacea	7.8	31.2

Data from: [1] 111 stomachs
[2] 314 stomachs
[3] 100 stomachs
[4] 39 stomachs

a relatively homogeneous geographic unit such as the Bering Strait, from Cape Lisburne to Saint Lawrence Island. This effect of food supply is reflected in differences in proportions among the species of seabirds (Tables 23, 25 & 27) in different parts of our region. First, the proportion of Thick-billed Murres to Common Murres changes from 75% Thick-billed at Cape Lisburne to 60% at Little Diomede, to 50% at King Island, to 15% at Sledge Island, and less than 1% at Bluff Cliffs and Cape Denbigh. Second, the number of kittiwakes as a percentage of the number of murres remains about the same, about 10-20%, over most of the region, except for a sharp contrast between Little Diomede Island (60%) and Sledge Island (40%), as compared to King Island (6%), Capes Lisburne and Thompson (10%), Bluff Cliffs (13%), Square Rock (16%), Cape Denbigh (15%), and Egg Island (25%). Third, approximately the same number of Least and Crested Auklets occur on Saint Lawrence Island, but Least Auklets become many times more numerous at King Island and at Little Diomede.

1. Feeding techniques in the Bering Strait

Ashmole (1971) described categories of foraging among seabirds: skimming, dipping, plunge diving, diving below the surface. In our region some species feed on only what is available at or near the surface (kittiwakes, Glaucous Gulls, jaegers). Others dive as far as midwater, but feed primarily on surface fish (puffins or shearwaters). Others feed throughout the water column (murres and cormorants).

If the behavior is keyed specifically to details of a limited set of species, the organism tends to be closely linked to those species and a limited range of preferred habitat, and the species is called a specialist. If the behavior is suitable to cropping a broad spectrum of food items in habitat with broad characteristics, then it is loosely linked, a generalist. The species of seabirds in the Bering Strait are generalists according to this definition. Some of them are extreme generalists.

Yet as Grinnel (1917) and Gausse (1932 and 1934) showed, individuals of closely related species are selected to avoid using the same food resource because the individuals of one species will have techniques which allow them to use the resource better, and individuals of the other species will benefit by developing talents to use other resources. This trend is "character displacement" (Brown and Wilson, 1956).

Neimark (1979) and Neimark et al (1979), studying the food of shallow water fishes in inner Norton Sound, commented on the generalist adaptations of the fish and pointed to the complementary adaptation of avoiding competition. Thus, while Saffron Cod (*Eleginus gracilis*) and Rainbow Smelt (*Osmerus mordax*) used whatever available of many similar prey items, (the very numerous detritus feeding *Neomysis* and the locally abundant copepods *Acartia clausi* and *Eurytemora pacifica*, benthic Oligochaetes and polychaetes); the cod used differentially more of the abundant Cladoderan *Evadne* and the smelt fed more on the equally abundant Cladoceran *Podon*, as would be expected in accordance with Grinnel (1917) and Gausse(1932 & 1934). Illustrations of these crustacea are offered in Figure .

Tables 22, 24 & 26 list the species of fish taken by Common and Thick-billed Murres in northern Russia, Great Britain, and northern Labrador. Tables 23, 25 & 27show the fish and invertebrates taken by seabirds in several parts of western Alaska. These tables show the wide diversity of species which the birds use in different parts of their ranges, and yet, they show that the size and form of the fishes remain similar; small, slender, "bait" fish. Swennen and Duiven (1977) studied the dimensions

Tables 23 through 27 show the percent occurrence, i.e., the percent of the total stomachs containing the item represented of (a) contents of stomachs of shot birds;

(b) items in regurgitated stomach contents (kittiwake chicks);

(c) items brought to the cliffs by murres and dropped onto the the nesting ledges.

Table 23.

BLACK-LEGGED KITTIWAKE
ALASKA

	Beaufort Sea	E. Chukchi Sea	C. Lisburne	C. Thompson '60	C. Thompson '60	C. Thompson '76	C. Thompson '77	Bluff '78	Bering Sea ice	Pribilofs '75-77	Chiniak Is. '77	Sitkalidak '76	Sitkalidak '76	Kodiak Is. '77
Number of samples	15	25	37	92	43	15	49	12	29	401	35	22	108	82
				Ad	Chx							Ad	Chx	
CLUPEIDAE Herring														
Clupea harengus														
SALMONIDAE Salmon, Trout														
Oncorhynchus													5	
OSMERIDAE Smelt, Capelin											15			60
Osmerus mordax														
Mallotus villosus							10		45	13	50	65	60	45
MYCTOPHIDAE Lanternfish										14				
GADIDAE Cod, Pollock								5		30				6
Boreogadus saida	85	75	50	55	25	35	60		80					
Eleginus gracilis			10			35	45	20						
Theragra chalcogramma											10	15	5	3
ZOARCIDAE Eelpout														
Bothrocara														
Lycodes					3									
HEXAGRAMMIDAE Greenling														
COTTIDAE Sculpin														
Gymnocanthus														
Myoxocephalus quadricornis				2										
" scorpius														
Triglops														
Artedius														
CYCLOPTERIDAE Snailfish														
Liparis														
STICHAEIDAE Prickelback														
Chirolophis														
Lumpenus fabricii														
Stichaeus														
AMMODYTIDAE Sand Lance														
Ammodytes hexapterus			45	30	65		20	77		3	10			9
PLEURONECTIDAE Flounder					3									
POLYCHAETES			5							3		5		
Nereis			10	5										
MOLLUSCS			5							2				
CEPHALOPODS Squid										9				
GASTROPODS Snail						15								
Naticidae Moon Shell														
CRUSTACEA														
AMPHIPODS	20	20								16				
GAMMARIDAE Skud				4						7				
Koroga														
HYPERIIDAE										13				
Hyperia														
Parathemisto	7								7	10				
EUPHAUSIACEA										10				
Thysanoessa									7	3	3			2
DECAPODA										4		5		
PANDALIDAE												20	5	
HIPPOLYTIDAE														
Lebbius														
'shrimp parts'	7			7						2				
MYSIDACEA		8							7					

Table 24.
COMMON MURRE
NORTH ATLANTIC

	EAST MURMANSK COAST 1935	1942	1948	1949	Farne Is.	Pembrokeshire	Skomer			
Number of samples/items	46	24	47	41		15	1140			
CLUPEIDAE Herring					30		99			
Clupea harengus	14	42	30	32	*	80				
Clupea sprattus					*		*			
OSMERIDAE capelin										
Mallotus villosus	14	42	28	21						
MYCTOPHIDAE Lanternfish										
GADIDAE Cod, Haddock, Hake					20					
Boreogadus saida					*					
Gadus merlangus					*					
Gadus morrhua	52	13	10	36						
Melanogrammus aeglefinus										
ZOARCIDAE Eelpout										
Gymnelis viridis										
Lycodes										
COTTIDAE										
Gymnocanthus tricuspis										
Icelus bicornis										
Myoxocephalus scorpius										
" scorpioides										
BLENNIDAE Blenny										
Blennius pholis										
PHOLIDAE Rock Eel					10					
Pholis gunnelius					*					
STICHAEIDAE										
Eumesogrammus										
Lumpenus										
CYCLOPTERIDAE Snailfish										
Liparis										
AMMODYTIDAE Sand Launce					40					
Ammodytes americanus										
" tobyanus	21	4	33	11	*	20				
GASTEROSTEIDAE Stickleback										
Gasterosteus aculeatus										
PLEURONECTIDAE										
Reinhardtius hippoglossoides										
POLYCHAETES										
Nereis										
MOLLUSCA										
CRUSTACEA										
COPEPODA										
AMPHIPODA										
GAMMARIDAE										
DECAPODA										
PANDALIDAE										
HYPOLYTIDAE										
INSECTA										

Table 25.
COMMON MURRE
ALASKA

	C. Lisburne	C. Thompson '60	C. Thompson '76	C. Thompson '77	Sledge Is. items	Bluff	Bluff items	Bering Ice '76	Bering Ice '77	Pribilofs '75	Pribilofs '76	Pribilofs '77	Kodiak Is.
Number of samples/items	28	84	20	20	48	25	317	55	83	24	36	19	27
CLUPEIDAE Herring													
Clupea harengus					2		1		1				
SALMONIDAE Salmon, Trout													
Oncorhynchus					2		8						
OSMERIDAE Smelt, Capelin													56
Osmerus mordax						1	2						
Mallotus villosus				27	13		2	16	25		8	5	
MYCTOPHIDAE Lanternfish												5	
GADIDAE Cod, Pollock	43	3	8	13		14	3			29	42	63	7
Boreogadus saida	29	78	42	20		1							
Eleginus gracilis	24		33	13		40	1	36	4				
Theragra chalcogramma											25	26	4
ZOARCIDAE Eelpout													
Bothrocara													
Lycodes			8										
HEXAGRAMMIDAE Greenling													
COTTIDAE Sculpin											6		
Gymnocanthus													
Myoxocephalus quadricornis													
" sp.		2		7									
Triglops		2											
Artedius													
CYCLOPTERIDAE Snailfish													
Liparis	5					1							
STICHAEIDAE Prickelback						1							
Chirolophis		2											
Lumpenus fabricii					2	10	31						
Stichaeus						1	1						
AMMODYTIDAE Sand Lance		3											
Ammodytes hexapterus	57	28	17	80	81	32	52						11
PLEURONECTIDAE Flounder	10	6											
POLYCHAETES	5	6											
Nereis	5												
MOLLUSCS													
CEPHALOPODS Squid												11	
GASTROPODS Snail													
Naticidae Moon Shell													
CRUSTACEA													
AMPHIPODS		2				3						5	
GAMMARIDAE Skud			17										
Koroga													
HYPERIIDAE												5	
Hyperia													
Parathemisto								16	27		6	5	
EUPHAUSIACEA								16	16			5	
Thysanoessa													
DECAPODA			15							8			
PANDALIDAE													
HIPPOLYTIDAE													
'Shrimp parts'		2											
MYSIDACEA													
Neomysis									17				

Table 26.

THICK-BILLED MURRE
NORTH ATLANTIC-WHITE SEA

	NOVAYA ZEMLYA Bezymyannaya Inlet 1934	1942	1947	1948	1949	1950	Akpatok Is. items
Number of samples/items	62	46	292	44	521	312	2700
CLUPEIDAE Herring							
Clupea harengus			3	15			
Clupea sprattus							
OSMERIDAE capelin							
Mallotus villosus	11	4	1		0.5	2	1
NYCTOPHIDAE Lanternfish							1
GADIDAE Cod, Haddock, Hake							
Boreogadus saida	16	43	54	18	66	35	35
Gadus merlangus							
Gadus morrhua	58	51	40	47	12	8	
Melanogrammus aeglefinus					7	5	
ZOARCIDAE Eelpout							
Gymnelis viridis		2	0.5	2			20*
Lycodes						2	
COTTIDAE							
Gymnocanthus					1	2	0.1
Icelus bicornis					3	10	0.2
Myoxocephalus scorpius			0.5				
" sp.					3.5	8	0.1
Triglops pingeli							27
PHOLIDAE Rock Eel							
Pholis gunnelius							
STICHAEIDAE							
Eumesogrammus							
Lumpenus					3	8	20*
CYCLOPTERIDAE Snailfish							
Liparis							
AMMODYTIDAE Sand Launce							
Ammodytes americanus							1
" tobyanus	10		1	18	1	8	
GASTEROSTEIDAE Stickleback							
Gasterosteus aculeatus							
PLEURONECTIDAE					5	13	
Reinhardtius hippoglossoides							7
POLYCHAETES							1
Nereis							
MOLLUSCA							4
CRUSTACEA							
COPEPODA							
AMPHIPODA							
GAMMARIDAE							1
DECAPODA							
PANDALIDAE							0.3
HYPOLYTIDAE							3
INSECTA							

* Tuck included Gymnelis, Lumpenus and Eumesogrammus in one category.

Table 27 .
THICK-BILLED MURRE
ALASKA

	C. Lisburne	C. Thompson '60	C. Thompson '76	C. Thompson '77	Ice Front '76	Ice Front '77	Pribilofs '75	Pribilofs '76	St. Paul '77	St. George '77
Number of samples	84	176	52	108	11	44	20	31	35	33
CLUPEIDAE Herring										
Clupea harengus										
SALMONIDAE Salmon, Trout										
Oncorhynchus										
OSMERIDAE Smelt, Capelin										
Osmerus mordax										
Mallotus villosus			2	6		16		7		6
MYCTOPHIDAE Lanternfish									3	
GADIDAE Cod, Pollock	24			20			25	42	77	58
Boreogadus saida	20	45	25	6						
Eleginus gracilis	6		8	22						
Theragra chalcogramma					73	20		16	17	
ZOARCIDAE Eelpout										
Bothrocara			12							
Lycodes										
HEXAGRAMMIDAE Greenling										
COTTIDAE Sculpin	24		10	7				13		
Gymnocanthus				7						
Myoxocephalus quadricornis		5	2	4						
" sp.	10	3	16	30						
Triglops										
Artediellus	11		2	15						
CYCLOPTERIDAE Snailfish										
Liparis										
STICHAEIDAE Prickelback, Eelblenny								7		3
Chirolophis										
Lumpenus fabricii										
Stichaeus										3
AMMODYTIDAE Sand Lance										
Ammodytes hexapterus	23	9	4	29				3	3	6
PLEURONECTIDAE Flounder, Halibut										3
POLYCHAETES	1	9		3					3	3
Nereis	8		18	4						
MOLLUSCS										
CEPHALOPODS Squid			14	10	9	7		3	9	27
GASTROPODS Snail	8	5								
Naticidae Moon Shell										
CRUSTACEA										
AMPHIPODS										
GAMMARIDAE Skud	7		8	4						
Koroga	8			15						
HYPERIIDAE								10		
Hyperia	10									
Parathemisto					27	80	5	7	31	28
EUPHAUSIACEA	7			1		25		7	9	6
Thysanoessa										
DECAPODA								3	3	
PANDALIDAE	18		25							
HIPPOLYTIDAE			25							
Lebbius										
'shrimp parts'	13	5	29	13						

of dead fish which murres selected and found that they prefer individuals below a certain size and prefer slender fish. Some fish, like flounders, which are numerous and widely distributed (Wolotira et al., 1977; Barton, 1978), are absent from the food items found in stomachs and brought to the cliffs. Another species, Prickleback (*Lumpenus fabricii*), though widespread, is nowhere abundant, yet is conspicuously "over-represented" in the food items brought to the cliffs.

In other words, the fishes brought by the birds are often different from those recorded in samples of fish taken by fishermen. For example, in Norton Sound, Barton (1978) reported the most numerous fish taken in gill nets and beach seines to be Sand Lance; Lance is a major food item of kittiwakes and puffins. Other abundant fishes in the gill net and beach seine hauls, however, (Bering Cisco *Coregonus laurettae*, Least Cisco *Coregonus sardinella*, and Rainbow Smelt) were rarely included in the samples of fish which we have from the bird cliffs. The fishes that were most numerous in the bottom trawls, Arctic Char *Salvelinus alpinus*, six other species of salmon, whitefish, and Starry Flounder *Platichthyes stellatus*, were also seldom represented. Tables of the distribution and relative abundance of the common species of fish (after Barton, 1978; Wolotira, 1977) are included in Appendix IV .

2. Efficiency of feeding and commuting

Efficiency has been selected into the actions of seabirds, within the constraints set by the irregularities of their habitats and other community members. As Gibb (1956) pointed out, for Coal Tits (*Parus ater*), birds distribute their efforts so as to get a maximum of food for the energy expended; thus they will move on if food dispersion is too great and will dally where food is concentrated. Yet as L. Tinbergen (1960) and Gibb (1956) observed, their "expectations" may be swamped by extraordinary abundance of prey, and they may move along at rates predicated by "probable" prey densities because areas of exceptionally high density tend to be small and sparse. The birds select larger, more easily caught prey if it is available. In order to increase efficiency further when they are feeding young, they may eat smaller items they find at sea and carry the bigger items "home" so as to reduce the number of trips. This optimizing of cost/benefit has been examined in detail: by Royama (1966) as to the prey brought to nest boxes by Great Tits (*Parus major*), by Wolf *et al.* (1971) for territory defense and feeding among hummingbirds and sunbirds, by Davies (in press) for winter territories and feeding in Pied Wagtails (*Motacilla alba*) and by Pullian (1974 and 1975) for wintering Juncos (*Junco hiemalis*) and Chipping Sparrows (*Spizella passerina*).

Murres disperse widely at sea and are reported to fish at all depths, from the surface down to the bottom. We presume that their food is scattered and that one individual does not profit by fishing close to another. Murres fly toward their feeding grounds singly or in small groups, but when they return to the cliffs they usually form into large skeins of birds flying high and conspicuously. Often they follow behind a Horned Puffin. This behavior would be consistent with the idea that the birds distribute themselves "capriciously" to feed, but profit by taking advantage of the combined experience of several others in finding the shortest route back to the cliffs. They can profit especially by the actions of puffins which do not disperse very far and therefore should have a clear "idea" of the direct route to the cliffs.

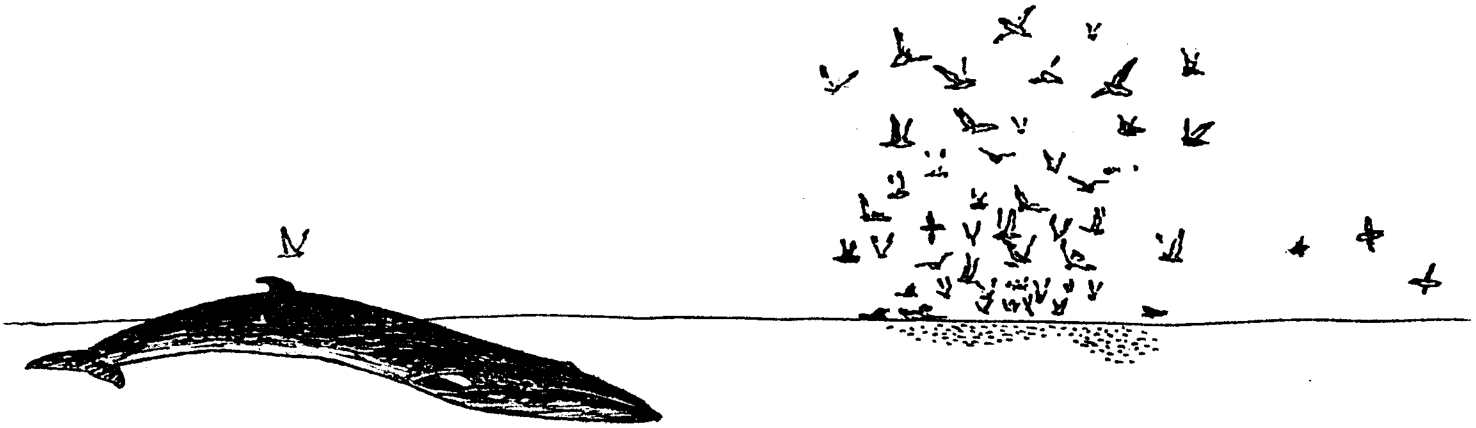
Kittiwakes, and in our area Puffins, and Least and Crested Auklets, use clumped resources: Sand Lance, Copepods, Amphipods, Euphausiids, and

Mysids. These birds feed in flocks and follow each other for long distances to the good feeding places. For example, we believe that the flights of large numbers of auklets seen flying both northeast and southwest past Gambel on Saint Lawrence Island reflect major movements of birds coming from both the Southwest Capes and around Savoonga and flying to and from the dense shoals of crustacea in the waters of the Anadyr Strait.

Under these circumstances the individuals and flocks of kittiwakes, puffins and auklets commuting between the cliffs and the feeding melees were obvious; as Ward and Zahavi (1973) and Emlen and Demong (1975) have described birds can observe the actions of others and follow their lead. This may be a mechanism by which individual birds profit by others' success in locating abundant food.

3. Seabirds feeding in the Bering Strait Region

In the spring the birds are attracted to concentrations of food along the ice front. If the seabirds can find a rich food supply in spring as the ice breaks up they can establish breeding territories and gather enough energy to lay eggs. Melting ice exposes water carrying the late/winter bloom of plankton and the successful birds are able to get their eggs laid on the energy in the crustacea and carnivorous cod lurking at the edge of the icepans. The more experienced and efficient individuals are able to start as soon as the ice goes. Apparently this food resource is gradually depleted during incubation. In poor years, late years, and stormy years birds have trouble getting enough food even during the period of the relative quiet inactivity of incubation, when either partner can spend many hours at sea feeding. If the stress is too great the eggs and nests are neglected and the number of failures increases (see Section V).



For most birds, apparently, hatching of eggs coincides with the appearance of the current year's young of a major food item: Calanoid Copepods, Euphausiids, Pricklebacks or Sand Lance. Kittiwakes feed on small Sand Lance swarming at the surface; because they swallow the food they bring to the cliffs, they can cram many small prey items in. Murres eat Saffron Cod as well as Sand Lance, and carry home the much larger, though more dispersed, Pricklebacks. If the year's crop is poor or late the chicks starve as they hatch, only the older young survive among kittiwakes or virtually none do (1976 and 1977). Under these circumstances murres, which feed throughout the water column, are able to raise a fair proportion of their single young. Thus their conservative clutch of one and broad zone of feeding pays off in hard times. The cost is that they do not increase their productivity above one chick per year during the good times. Kittiwakes, in some parts of their range, regularly produce two young, not much by the standards of waterfowl or titmice, but a lot better than one.

We found at Bluff that kittiwakes and Horned Puffins concentrated on Sand Lance when they arrived, but murres were not conspicuous members of the aggregations over shoals of fish. We found feeding melees of kittiwakes off Cape Woolley 50 km from King Island and Sledge Island. When Sand Lance moved east into Norton Sound in 1975, we saw kittiwakes from Sledge fly as far as Cape Nome where they met kittiwakes from Bluff.

We observed Common Murres and kittiwakes dispersing from Bluff Cliffs 40 km southeast toward the mouth of Golovin Bay; many fly off to the south and many disperse southwest and can be found feeding off the mouth of Safety Lagoon and Cape Nome, beyond 50 km. At the mouths of Golovin and

Safety Lagoons the birds are feeding where fresh and salt water masses meet; we have found Sticklebacks in the stomachs of murres flying from that direction.

Along the Cape Lisburne Peninsula, Swartz (1966) observed large numbers of murres feeding at the edge of the deeper water southwest of Cape Thompson and toward the southeast from the cliffs. Wilimovski (1966 and 1974) and Quast (1974) reported Arctic Cod to be relatively abundant in these places. Springer and Roseneau (1977, 1978, 1979) recorded murres and kittiwakes flying from Cape Lisburne to the southwest, to the northwest, north and to the northeast. From Cape Thompson they observed birds flying to the west-southwest (as if to the edge of deeper water) and to the southeast. They emphasized the importance of the arrival of Sand Lance from the north, which was associated with an abrupt shift in the directions of flight so that the birds commuted directly to the shoals of Sand Lance as soon as they arrived. In the course of survey flights around Cape Thompson and Cape Lisburne in July and August 1978, we observed murres flying west and southwest from Cape Thompson and resting on the water over deeper water (40 meters). Most conspicuous however, were the flights of murres and kittiwakes commuting to shoals of Sand Lance southeast from Cape Thompson along the beaches almost 70 km and northeast from Cape Lisburne, almost 100 km.

4. Diets of some common species

Glaucous Gulls. Glaucous Gulls, like the closely related Glaucous-winged and Herring Gulls, are extreme generalists. The species used for food by Herring Gulls, Glaucous-winged Gulls, and Glaucous Gulls have been studied in great detail in many parts of the Northern Hemisphere. These studies emphasize the diversity of the foods the gulls are able to crop using a limited set of behavioral and anatomical "tools."

The gulls of the Larus group hunt by patrolling shallow water or recently exposed intertidal areas with their neck stretched and head peering down. They fly hesitantly, reconnoitering potential feeding sites. They keep an eye on the behavior of other gulls to get clues as to the location of food. They pick up prey and dismember it by seizing small parts and shaking. They swallow objects of large size and awkward shapes. Their competent digestive system extracts the good out of a wide variety of vertebrate and invertebrate foods; crabs, sea urchins, mussels, dead fish on the coast of Maine; spider crabs, cockles, quahogs, bay scallops, whelks on the coast of Massachusetts; dead salmon, Walrus carrion, young seabirds and waterfowl, salmon and herring eggs, and berries on the coast of northwest Alaska. They can apply their set of behavioral and anatomical tools to whatever elements of their habitat are "suitable" to those tools. Learning must play an important part in mastering the resources of their world; this is reflected in the fact that they require a half a dozen years of growing up before they are sufficiently competent to undertake raising a brood. Differences among the success of individual pairs is high too, a small percentage of adults evidently raising a majority of the young produced any year. This same effect has been found among kittiwakes in England (Coulson 1966) and among Red-billed Gulls (Larus novachollandiae) in New Zealand (Mills 1973) indicating that the importance of experience and individual competence is larger in many gulls.

Kittiwakes. Kittiwakes feed on small fish and crustacea caught at or near the surface. Swartz (1966) reported kittiwakes at Cape Thompson eating 91% fish and 25% invertebrates in a year of high reproductive success.

Roseneau and Springer (1978 etc.) reported their eating 67% fish (*Boreogadus* and *Ammodytes*) and 53% invertebrates in a year (1976) which was a reproductive disaster. (Percent is the percent of stomachs in which the species was found). In Norton Sound (1975-1978), virtually all stomachs and food regurgitated by young kittiwakes contained Sand Lance. Reproductive success varied widely between years; some years one nest in forty produced young; other years almost every nest produced some and many "twins" were raised. Frequently we watched kittiwakes feeding on crustacea early in the season around ice pans, and we commonly found kittiwakes feeding in the mud which feeding Gray Whales carried to the surface over their feeding grounds southwest of King Island. Hunt *et al*. report from the Pribilof Islands that a wide variety of food is used, primarily cod (gadids) and capelin (*Mallotus*), and that reproductive success is consistent and moderate. Almost no twins are ever raised. At Cape Pierce, Baird *et al.* (1979), and Peterson and Sigman (1977) reported that the kittiwakes fed their young on Euphausiids. From the Kodiak area south of the Alaska Peninsula, Baird and Moe (1978) reported that Capelin is the staple food, and Sand Lance is important in making the difference between ordinary reproductive performance and real success. The abundant mid- and bottom-living fish Walleye Pollock (*Theragra chalcogramma*) occurs only sporadically in stomachs.

Sand Lance deserves special consideration because it becomes a major component of the food supply for all three types whenever and wherever it is available. Roseneau and Springer (1977, 1978, 1979) have emphasized the movement of kittiwakes and murres along shore to areas where Sand Lance are caught. They report that Sand Lance move into the area northeast of Cape Lisburne from the north, then appear off Cape Thompson. When they arrive all species turn to feed on these, and their presence makes a major difference in the success or failure of the reproduction of all the species at Cape Lisburne and Cape Thompson. In our experience kittiwakes, puffins, and to a less extent murres, gather in melees over schools of Sand Lance as the fish move into Norton Sound during the summer. We have not seen feeding melees in the Bering Shelf Waters; this may be due to absence of Sand Lance which forces the seabirds at Saint Lawrence Island (Searing 1977), Pribilof Islands (Hunt et al. 1976, 1977, 1978) and Bristol Bay (Searing 1977) to increase their use of crustacea and other, more dispersed fish.

Murres. The murres take small slender fish. The tables of species taken show that they feed throughout the water column and upon many species and genera. In some places the birds are feeding near the surface or in mid-water on Capelin, Sprats, and Sand Lance; in others, they must be fishing close to the bottom on cod, Prickleback, Sculpins, and Blennies.

Differences in the food species used are evident even within our region. The murres at Cape Thompson are feeding both on Arctic Cod (*Boreogadus saida*) and Saffron Cod (*Eleginus gracilis*) and bring these fish back to the cliffs. Roseneau and Springer reported that Thick-billed Murres took 25% *Boreogadus* and 8% *Eleginus*, while Common Murres took 42% *Boreogadus* and 33% *Eleginus*. At Bluff the cod being fed on is primarily Saffron Cod (*Eleginus gracilis*) and most of these are eaten at sea; few are brought back to the cliffs. These observations are consistent with the idea that in the warmer, less saline Alaskan Coastal Waters of Norton Sound and near-shore waters off Cape Thompson, *Eleginus* replaces *Boreogadus*. Observations of where seabirds feed made by Swartz (1966), Springer and Roseneau (1978) and by us, indicate that the murres feed at the edge of

Table 28.
Species of fish fed on by murres, primarily Common Murres, in the Norton Sound-Chirikov Basin, 1975-1978. All numbers refer to individual fish recovered from ledges where they were dropped or taken from stomachs (Bluff Cliffs, 1978).

	Bluff 1975 dropped	Bluff 1976 dropped	Bluff 1977 dropped	Bluff 1976 stomachs	Sledge Island 1975 dropped	Sledge Island 1976 dropped	King Island 1976 dropped
CLUPEIDAE - Herrings							
Clupea harengus pallasi	1				1		
SALMONIDAE - Salmon, Char							
Oncorhynchus sp., incl. *keta*	12	13			1		
OSMERIDAE - Smelt, Capelin							
Osmerus mordax dentex	2	3		2			
Mallotus villosus	2	2	2		6		
GADIDAE - Cods							
Boreogadus saida				1			2
Eleginus gracilis		4		57			
unidentified	8	2		20			3
COTTIDAE unidentified					25		6
STICHAEIDAE - Pricklebacks							
Lumpenus fabricii	39	36	22	14			20
Lumpenus unidentified						1	
Stichaeus punctatus	2	1		2		1	
AMMODYTIDAE - Sand Lance							
Ammodytes hexapterus	114	37	15	46	17	22	6

Table 29.
Relative proportions of fish and crustacea in the diet of murres in several years and in several parts of their circumboreal ranges.

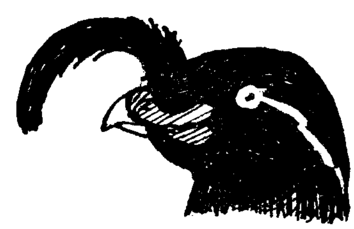
		BARENT' SEA	AKPATOK ISLAND	CAPE LISBURNE	CAPE THOMPSON 1960	CAPE THOMPSON 1976	CAPE THOMPSON 1977	BLUFF CLIFFS 1978	ST. LAWRENCE IS. 1976	PRIBILOF IS. (Preble & McAtee)	PRIBILOF IS. (Hunt *et al.*)	BRISTOL BAY
COMMON MURRE	Fish	95		100	96	93	100	97			95	
	Crustacea	3		19	6	33	13	12			3	
COMMON and THICK-BILLED	Fish								33	49		44
	Crustacea								72	51		40
THICK-BILLED MURRE	Fish	96	94	90	64	76	84				78	
	Crustacea	3	6	61	34	78	65				30	

the deep water southwest of Cape Thompson where Alaskan Coastal Water is replaced by colder more saline Bering Shelf Water. This feeding distribution coincides with areas where fish, primarily cod, were reported to be most abundant by Wilimovsky and Wolfe (1966) and Quast (1974). Our small sample of aerial observations of "black" vs. "brown" murres at sea suggest that Thick-billed (black) feed further offshore that Common Murres.

Furthermore, although the samples are small, samples of figh picked off nesting ledges at King Island, Sledge Island and Bluff Cliffs suggest that salmon smolt may not be available at Sledge Island and King Island (Tables 28 and 29). The data suggest that Capelin are more abundant or that other species are less abundant at Sledge Island and King Island than they are in inner Norton Sound. Unfortunately, our party on Little Diomede Island did not collect any fish.

Parakeet Auklet

Least Auklet



Crested Auklet

Auklets. Though zooplankton occurs at the surface throughout the summer in arctic waters, food density of both crustacea and fish tends to increase with depth (Bedard 1969b; Quast 1974). As larger, heavier forms of planktonic crustacea are present in the colder, more saline waters of Anadyr Strait the auklets which feed on them gather there. They are found in smaller numbers in the Bering Shelf Waters, and are virually absent from the Alaskan Coastal Waters.

Bedard (1969b) studied the feeding habits of the three plankton-feeding auklets on Saint Lawrence Island. The Anadyr waters supply buoyance for larger, heavier crustacea than those living in Alaskan Coastal Waters; this effect is increased by the vertical movement of turbulent water flowing through the Strait of Anadyr. Cold water, at about 0°C, comes to the surface just north of Gambel, carrying zooplankton to the surface. Bedard reports that auklets disperse singly toward their feeding grounds and return in skeins and clouds, flying both southwest and northeast past the gravel spit at Gambel. These streaming flocks can be used by outgoing birds to find feeding grounds by "working upstream". The birds select the large Calanus copepods and bypass the numerous other planktonic forms (Chaetognaths, Pteropods, crustacean larvae, smaller medusae, Ctenophores, Oikopleura), and smaller copepods like Metridia and Pseudocalanus.

Crested and Least Auklets exhibit similar patterns of feeding: during early summer, both have a diversified diet (mysids, hyperiids, gammarids, decaplds, etc.) but restrict themselves largely to one principle prey during the chick-rearing period. Then the Least Auklets fed mostly on Calanus finmarchicus (marshallae) and Calanus crustatus, while the Crested Auklets fed mostly on Thysanoessa. In all years, 1964-1966, hatching coincided with the appearance of these prey items (copepods and Euphausiids).

The Parakeet Auklet maintained a diversified diet throughout the summer. Early in the season, before preferred foods arrived, Parakeet Auklets fed on epibenthic gammarids and Calanus cristatus. Parathemisto libellula, the pelagic amphipod, was the dominant prey with lesser quantities of gammarids, Cephalopods and Pteropods (Bedard 1969).

Searing (1977), working at Kongkok Bay south of Gambel on Saint Lawrence Island, found about the same results in 1976 as Bedard found between 1964 and 1966. In his smaller samples he found the Least Auklets depended primarily on Neocalanus plumchrus rather than Calanus finmarchicus (also known as C. marshallae). This difference may be only a difference in taxonomic opinion or it may reflect a difference in fauna resulting from a bloom of one species and absence of another. While Crested Auklets fed their young on Euphausiids (56%) and copepods (36%) from 1964 to 1966, Searing found in 1976, that they fed their young mostly copepods (97%), again Neocalanus plumchrus. The shift from Euphausiids of a size of 15 mm, to copepods of 7 mm, may, as Searing suggests, reflect a great abundance of the copepod and/or a decrease in availability of Euphausiids, requiring the Crested Auklets to work harder to feed their young. The fact that Searing found that the other species at the Southwest Capes, e.g., Black-legged Kittiwakes, had a disastrous reproductive season in 1976, suggests that 1976 was a year of failure of Euphausiids.

VII. The Coastal Habitats of the Bering Strait Region

In an earlier section we pointed out the segregation of seabirds according to the major offshore water masses of the region. In this section we will discuss the marine birds which use the onshore or coastal waters and the largely fresh waters at the mouths of rivers, behind barrier beaches and the lakes thawed into the frozen tundra. We indicated the contribution to the biological richness of the region's offshore waters of the movement of sea water from the deep part of the Bering Sea over the Continental Shelf and through the Bering Strait. Movement of water is also central to the richness of the lagoon systems and coastal waters.

During the short spring and summer rivers flow from the uplands across the narrow lowlands and into the sea, carrying all the water which collected as snow on the uplands from October until May. These streams carry a heavy load of sediments and organic material which is made available to lagoons and coastal systems during the short growing season. Consequently, plant growth is prolific in the shallow waters along the coast. The detritus supports large populations of invertebrates and hence small fish feeding upon them. Many fish use the lagoons during their younger stages of life, some coming downstream to the sea from spawning grounds, others coming into shallow water from the sea. The plants, invertebrates and fish form the food base for waterfowl and shorebirds which use the coastal areas in large numbers. The waterfowl are today an important element in the subsistence part of the economy of the Eskimos.

The entire coastal system is enriched by the annual renewal of minerals and organic material carried from the uplands to the coast. So, as with the offshore waters, these coastal biological systems depend upon resources from a large area concentrated into relatively small areas and renewed continually. The fact that these systems require renewal of the resources by flowing water and depend on large "hinterland" for resources must be considered in plans for industrial development.

A. Geological Setting

The Bering Strait Region is one of relatively little rainfall, about twenty inches a year, comparable to the rainfall of the eastern prairies. The landscape of the Seward Peninsula resembles that of grasslands. In most areas of low rainfall riverflow is characterized by floods alternating with long periods of low flow. Such conditions of periodic heavy runoff create characteristic topography with rolling, broad uplands and narrow, terraced river valleys. Northern regions have an additional characteristic in that the uplands are subjected to intense frost action, and thus the topographic zone of creep or solifluction is large while the zone of river erosion is rather narrow. As a consequence, the uplands are broad and convex and the river valleys are filled mostly with debris. Soil creep and water percolating through the soil in spring contribute fine-grained material to the rivers which carry an abundant load during the spring freshets. The mouths of the rivers in this area deposit extensive deltas of sand and mud, usually richly mixed with organic detritus. The longshore tidal currents and the general northerly flow of the sea picks up and carries these materials, depositing bay-mouth bars and extensive barrier beaches which hold in lagoons. A major portion of the mainland coast from Unalakleet to Cape Thompson and virtually all of the coast of Saint Lawrence Island is lined with barrier beaches, and behind the beaches lie highly productive lagoons.

It seems worthwhile to point out again that the coastal geomorphic and biological systems are not static, but are very much open systems. River water flows through the systems from inland; coastwise currents resculpt the beaches. Waterfowl and shorebirds use these habitats during short periods when productivity is high. Then the active vertebrates move to other estuaries, often thousands of miles away.

In this section we make some general observations of the use of coastal habitats by marine birds along the southern Seward Peninsula according to our experience. We also describe briefly the topography and distribution of lowlands, lagoons, beaches and cliffs from the Lisburne Peninsula to Saint Lawrence Island.

B. Use of Coastal Habitats by Marine Birds

The marine birds which use coastal habitats can be subdivided into categories according to their habitats. Some feed in the shallow water of the sea within a few miles of shore; some gather along low rocky shores; some feed along the beaches on food concentrated by waves, currents or storms; many feed in the body of the lagoons; many feed on mudflats at river deltas. Many of the birds which feed in these coastal areas nest in ponds, small lakes and wetlands on the gentle depositional slopes extending from the coastal hills to the shoreline. We will discuss the use of coastal habitats under these categories.

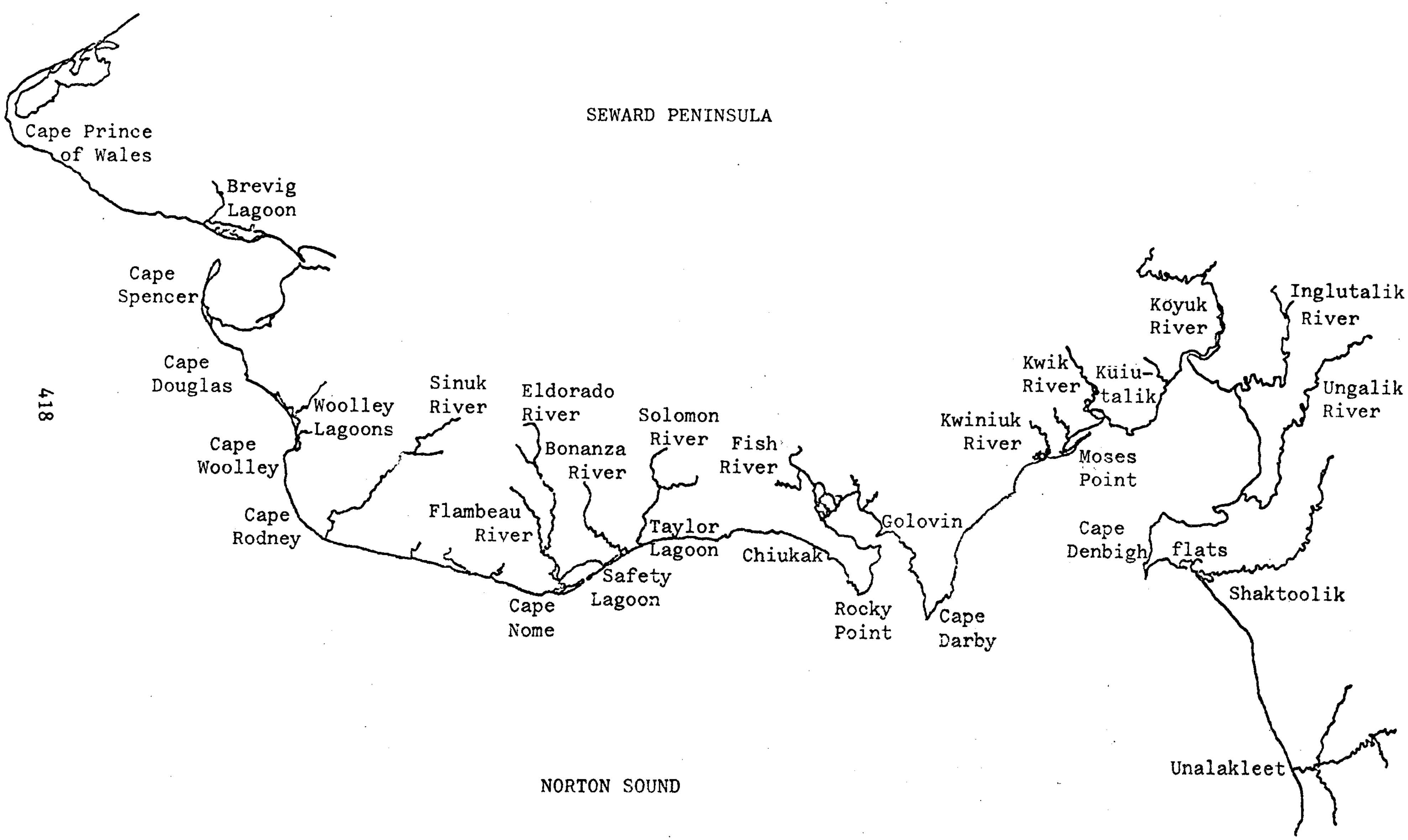
Although we flew over the lagoons around Cape Thompson, Kotzebue and Wales and around Saint Lawrence Island, we concentrate our report on our experience with the habitat on the south shore of the Seward Peninsula. Our remarks refer primarily to the area between Cape Spencer and Unalakleet. Figure 31 shows the names of places we will refer to in this section.

1. Shallow waters onshore

Rivers begin to flow in early spring before the sea ice breaks up and freshwater collects against the sides of roads, above ice jams and at rivermouths at the edge of the sea ice. Later in spring the sea ice has moved intact away from the shore a few tens or hundreds of yards. Debris from rivers collects in these first bodies of water. After the appearance of the King Eiders in April, later arriving waterfowl gather in coastal leads and at the mouths of the rivers. Migrating loons, Old Squaws, Harlequin Ducks, Black Scoters, the four species of Eiders and Red-breasted Mergansers appear in these leads. Kittiwakes, Arctic and Aleutian Terns, Glaucous Gulls, Sabine's Gulls and puffins feed there before break up. These coastal areas are critical to migrant waterfowl in the early spring, and are also vulnerable to disturbance by traffic of people and contamination with chemicals (see Section VIII).

Later in the summer, the shallow waters are used, though less conspicuously, by marine waterfowl and are also feeding grounds of gulls, terns and loons. Sand Lance move into the shallow water in July, and surface-feeding seabirds follow the Sand Lance. The feeding melees made up of kittiwakes, puffins and Glaucous Gulls which occur in July and August are confined to the shallow nearshore waters, according to our observations.

Figure 31.
Geography of the south shore of the Seward Peninsula.



2. Rocky and bouldery shores

For a few weeks after the females of several species of seabirds start to incubate, the males gather in flocks of up to 150 along rocky shores. Male Old Squaws, Steller's Eiders, Harlequin Ducks, Black Scoters and Common Eiders gather on the southeast and southwest shores of Saint Lawrence Island and on the Seward Peninsula from Cape Nome to Cape Spencer.

It is important to locate the molting grounds of the marine waterfowl of this region. Molting grounds, where the birds lose all their flight feathers and are very vulnerable, are critical to the survival of the local population. In the course of surveys for other species we have seen flocks of molting Surf Scoters in the shallow water north of the Yukon Delta, and of molting Spectacled Eiders in the relatively shallow water west of Point Lay.

3. Barrier beaches and the mouths of lagoons

In our region, the shores between rocky headlands are lined with the sweeping curves of coarse sandy barrier beaches. The primary bird species using these beaches are the Glaucous Gulls gleaning scraps of flotsam. Ravens visit the beaches, especially the walrus carcasses which wash up in mid and late summer. Along the shore of the Beaufort Sea phalaropes feed on crustacea that wash up along barrier beaches (Divoky et al. 1978, Connors 1978 and Schamel 1976) but we have not seen sandpipers or phalaropes feeding along the surf line. We have seen flocks of plovers and Whimbrels resting on the beaches.

Inlets interrupt the barrier beaches where rivers come to the coast. Gulls and terns gather on the points and islands formed at these openings. Gulls gather there in large numbers when the Salmon are running. Large nesting colonies of terns are usually found on islands close to an inlet.

Flocks of ducks also tend to congregate near lagoon outlets. Flocks of kittiwakes gather at fresh water ponds right behind the beach or at the mouths of rivers near their nesting cliffs.

4. Large lagoons

The main bodies of the lagoons along the coast of our region are shallow. Many lagoons consistently are empty of waterfowl and shorebirds; others consistently support large populations. We have not investigated the reasons why and do not have an explanation, but this marked difference in productivity or attractiveness among wetlands is familiar to ecologists.

Lagoons along the coast are the major habitats for ducks and geese, and in this region a high diversity of ducks occurs in the lagoons: Old Squaws, Black Scoters, Red-throated Loons, Black-throated Loons, Greater Scaup, Lesser Scaup (rarely), Redhead (rarely), Canvasback (rarely), Pintail, Wigeon, Shoveller, Green-winged Teal, Mallard. Many of these species spend the entire summer at the same lagoon.

Whistling Swans appear in the lagoons early in the season and later, in July and August.

Along the shores of the lagoons are extensive meadows of grasses and sedges. Geese, primarily Canada Geese and Black Brant on the Seward Peninsula (and formerly, Snow Geese and White-frosted Geese), and Black Brant and Emperor Geese on Saint Lawrence Island, occur in these grassy meadows and retreat to the open water at the center of the lagoons for protection.

Some areas of salt marshes lining the lagoons, especially those with pannes or small ponds, are visited by large numbers of shorebirds in July and August. Pintail often occur in the same salt marshes. We saw Dowitchers, Golden Plovers, Western Sandpipers, Dunlin, Whimbrels, Bar-tailed Godwits and Tatlers. Shorebirds are hard to identify from a small airplane.

We observed that those areas of meadow and saltmarsh through which a drainage runs are especially attractive to gatherings of ducks and shorebirds, e.g. the channel between Safety Lagoon and the mouth of the Bonanza River, and the channel which crosses Stewart Island.

5. Mud flats

Fine-grained sand and silt are deposited at the mouths of rivers and streams where they empty into lagoons. The tidal range is small and largely capricious along the south shore of the Seward Peninsula, but in the later part of the summer occasional north winds blow the waters of Norton Sound offshore exposing large areas of fine material. The flats are inaccessible to people and large gatherings of ducks, especially Pintails and Wigeon, and geese, swans and shorebirds can be found on them. These places, we presume, supply good feeding areas and thus they are some of the most important coastal habitats for shorebirds and waterfowl in our region.

We found extensive mudflats in Safety Lagoon, at the mouth of the Fish River in Golovin Lagoon, at the mouth of the Kwik River north of Moses Point and at the mouth of the Koyuk River, Inglutalik River and along the shore from there to Shaktoolik (Figure 31). Although the flats on the north shore were occupied by large numbers of birds, we found almost no birds on the flats behind Cape Denbigh, both north and south. There are extensive mud flats at the mouth of the Shaktoolik River but few birds are there or on the salt marshes and meadows behind the village of Shaktoolik. In contrast, there were many birds at the mouth of the Unalakleet River, another native settlement. We doubt, therefore, that the absence of waterfowl near Shaktoolik is simply a consequence of hunting pressure.

6. Tundra lakes - thaw sinks

The lowlands along the coast of Norton Sound are underlain with frozen ground. Scattered on the surface of these frozen sediments are shallow ponds and lakes a few feet to several hundred meters across. These have formed where, for a variety of reasons, the protective vegetation insulation has been broken and thawing of frozen sediments has resulted in removal of ice, hence a reduction in volume of sediments and a depression. These lakes often grow as winds blow warm water against the exposed banks of frozen ground. These lakes and the wet tundra around them provide nesting grounds for many ducks, geese, swans and shorebirds. Many depressions which were produced by thawing are now vegetated with grasses and sedges and provide feeding grounds for geese and shorebirds.

Pintail, Canada Geese, Whistling Swans and Red-throated Loons and Northern Phalaropes nest around the smaller ponds. Black-throated Loons and Old Squaw, Red-necked Grebes and Greater Scaup have been seen on larger lakes.

The wet tundra and the marshy or boggy low places are breeding habitat for local shorebirds: Bar-tailed Godwits, Whimbrel, Dunlin, Western Sandpiper, Long-billed Dowitchers, and occasionally other sandpipers.

7. Other habitats

Modification of habitats by mining activities has had some interesting effects in the area around Nome. It is hard to identify specific cases of birds which have disappeared because we do not what was in the area before 1900. Mine tailings however, have provided many small, deep ponds, and tall shrubby vegetation has grown around some of these ponds. Tall shrubs are rare in this area, usually being confined to sheltered places along rivers. Ponds in mine tailings at Nome provide nesting places for Northern Phalaropes, Green-winged Teal, and Pintails and the tall shrubs seem to have attracted nesting Lesser Yellow-legs, a species otherwise rare in this area.

C. Distribution of Waterfowl Habitats Along the Coasts of the Bering Strait Region

Our data on the concentrations of waterfowl along the south shore of the Seward Peninsula in late summer and early fall are shown in Figures 32a through 32f ; species composition at the concentrations is indicated in bar graphs on the maps and in the corresponding tables, Tables 30a through 30f.

These figures present a composite of the information we have gathered and indicate those parts of the coast which are used most heavily by waterfowl.

D. Seasonal Use of Coastal Habitats by Waterfowl

1. Seasonal use

We ascribe special importance to those areas of water that open up the earliest. Access to leads appearing early allows birds to begin breeding early. The older, experienced birds which tend to migrate earlier and to take up territories earlier are usually responsible for the majority of reproductive success. If open water is available when these birds arrive the breeding cycle may be upset.

River mouths and associated lagoons deserve special consideration. These areas are used as staging habitat during spring and fall migrations and attract aggregations of waterfowl throughout the breeding season.

Waterfowl occupy suitable tundra, pond and coastal habitat in a patchy (rather than even) distribution. Many forces and processes combine to make an area of habitat attractive. Seasonal or yearly variations in these forces affect the suitability of certain locations as habitats. The fact that wildlife tend to gather in those places where a maximum number of factors are favorable is reflected in the movement of aggregations of waterfowl from place to place from season to season and from year to year. Though only a portion of habitat may be used in any one year, redundancy of habitat is crucial. The repetition of similar habitat increases the odds of the survival of populations that use it. Loss of habitat redundancy also makes it less likely that once a population is reduced it will regain previous abundance.

Spring

Feeding and gathering habitat:

1. leads in the ice at sea, that open up the earliest
2. leads along the shore at river mouths and freshwater lagoons behind sea beaches, which open up when most of the sea is still frozen
3. temporary ponds created by the overflow of rivers and creeks in spring freshet
4. coastal lakes created during the process of beach deposition

Important areas in the spring include:

i) Woolley Lagoons

ii) leads between Nome and Cape Nome

iii) lower reaches and mouths of the Flambeau and Eldorado Rivers at Safety Lagoon

iv) lagoons between the Bonanza River and Taylor Lagoon where Pine Creek empties (mouth of Bananza River to the mouth of Solomon River)

We have not surveyed the coast of eastern Norton Sound during the spring.

Summer

Breeding areas:

1. wet lowland mossy tundra along the coast and associated small ponds
2. lagoons and ponds on the coastal tundra
3. marshes and sloughs along inland rivers
4. coastal wetlands created by the draining of lakes and lagoons as a result of overflow and subsequent stream erosion during spring meltwater runoffs

Fall

Migratory gatherings are focused around river mouths:

1. salt marshes at the lower reaches of rivers (Bonanza River at the east end of Safety Lagoon); the gatherings of waterfowl in such areas in late August and September indicate the beginning of fall migration
2. mudflats at the mouths of rivers (Fish River, Kwik River, Koyuk-Inglutalik River)
3. shallow water in lagoons and at river mouths during low water periods in September

Specific places used in late Summer and Fall:

Areas used extensively (flocks of hundreds or thousands):

1. mudflats at Safety Lagoon and lower Bonanza River
2. lower Flambeau River
3. Golovin Lagoon and the mudflats of the Fish River
4. distributory fan of the Koyuk and Inglutalik Rivers in Norton Bay
5. lowlands and marshes north of Moses Point along lower reaches and mouth of the Kwik River

Areas of moderate use (several ponds with flocks of tens, most ponds empty):

1. at the base of Cape Spencer
2. the Woolley Lagoons to the Kuzitrin River in the lower flats east of the Imuruk Basin
3. the tundra ponds along the coast from Cape Woolley to Sinuk and along Safety and Taylor Lagoon areas
4. the canal crossing Stuart Island in southeastern Norton Sound

Areas of sparse concentration (most ponds empty, few birds on ponds and small lakes):

1. on the coastal tundra west and northwest of Nome
2. over most of the flats east of the Imuruk Basin in the tundra ponds
3. in the tundra ponds in back of the coast along the Kwik River, Koyuk River, and between the Inglutalik River and Cape Denbigh
4. Brevig Lagoon (not as attractive because of sandy substrate and little vegetation)
5. Grantly Harbor (not as attractive due to steep banks)

2. The most conspicuous species of songbirds, waterfowl and shorebirds breeding on the south shore of the Seward Peninsula.

The following is a list of the more conspicuous species breeding in each of the habitat types labelled below. The most conspicuous or abundant have been marked with an asterisk (*).

Flats: sedgy areas with areas of wet tundra and ponds

Arctic Loon *Gavia arctica*

Red-throated Loon *Gavia stellata*

Whistling Swan *Olor columbianus*

*Canada Goose *Branta canadensis*

*Pintail *Anas acuta*

*Green-winged Teal *Anas crecca*

*Greater Scaup *Aythya marila*

*Oldsquaw *Clangula hyemalis*

*Black Scoter *Melanitta nigra*

*Northern Phalarope *Phalaropus lobatus*

*Semipalmated Sandpiper *Calidris pusilla*

*Dunlin (Red-backed Sandpiper) *Calidris alpina*

Wet Tundra: mossy-heath shrubs with small areas of sedges

Northern Harrier (Marsh Hawk) *Circus cyaneus*

*Lesser Golden Plover (American Golden Plover) *Pluvialis dominica*

Bar-tailed Godwit *Limosa lapponica*

*Whimbrel (Hudsonian Curlew) *Numenius phaeopus*

*Common Snipe *Gallinago gallinago*

*Western Sandpiper *Calidris mauri*

Long-tailed Jaeger *Stercorarius longicaudus*

*Lapland Longspur *Calcarius lapponicus*

Low shrubs in wet tundra

Yellow Wagtail <u>Motacilla</u> <u>flava</u>

*Savannah Sparrow <u>Passerculus</u> <u>sandwichensis</u>

<u>Alder-Willow Thickets</u>

*Gray-cheeked Thrush <u>Catharus</u> <u>minimus</u>

Orange-crowned Warbler <u>Vermivora</u> <u>celata</u>

Yellow Warbler <u>Dendroica</u> <u>petechia</u>

Wilson's Warbler <u>Wilsonia</u> <u>pusilla</u>

*Redpoll: birds appear to be intermediates of Common Redpoll (<u>Carduelis</u> <u>flammea</u>) and Hoary Redpoll (<u>Carduelis</u> <u>hornemanni</u>)

Tree Sparrow <u>Spizella</u> <u>arborea</u>

*White-crowned Sparrow <u>Zonotrichia</u> <u>leucophrys</u>

*Fox Sparrow <u>Passerella</u> <u>iliaca</u>

<u>Rivers</u>: gravel beds of rivers

Harlequin Duck <u>Histionicus</u> <u>histrionicus</u>

Red-breasted Merganser <u>Mergus</u> <u>serrator</u>

Semipalmated Plover <u>Charadrius</u> <u>semipalmatus</u>

Spotted Sandpiper <u>Actitis</u> <u>macularia</u>

Wandering Tattler <u>Heteroscelus</u> <u>incanus</u>

*Glaucous Gull <u>Larus</u> <u>hyperboreus</u>

Mew Gull <u>Larus</u> <u>canus</u>

Tall alder and willow shanks along rivers, in addition to species of alder-willow thickets

American Robin <u>Turdus</u> <u>migratorius</u>

Varied Thrush <u>Ixoreus</u> <u>naevius</u>

Northern Waterthrush <u>Seiurus</u> <u>noveboracensis</u>

Northern Shrike <u>Lanius</u> <u>excubitor</u>

E. Distribution of Coastal Habitats in the Bering Strait Region

1. The Mainland Coast

At the northern limit of our region, steep bluffs mark the shore east of Cape Lisburne. The arctic system of lagoons begins where barrier beaches enclose the mouth of the Kukpowruk River at Point Lay. Point Hope, extending west from the Lisburne Peninsula is a gravel spit lined on the north and south by barrier beaches. The enclosed lagoons were not occupied by waterfowl when we visited the area, but were occupied by large numbers of gulls.

The hills which are cut off to make the cliffs at Cape Thompson extend about fifteen miles southeast of the bird cliffs. From there, productive coastal lagoons lie inside barrier beaches along nearly all of the northeast shore of the southeastern Chukchi Sea and Kotzebue Sound. Kivalina is at the mouth of one large lagoon; Cape Kruzenstern contains a large lake and the fishing village at Shesualik marks the entrance to Hotham Inlet, the large body of brackish water east of Kotzebue. We observed many waterfowl, gulls and terns in the lagoons along this coast.

The broad deltas of the Noatak and Kobuk Rivers, which form the north shore of Hotham Inlet and Selawik Lake appear to provide large areas of good waterfowl and shorebird habitat, but we did not survey the area. The south and west shore of this lowland is made up of the Baldwin Peninsula off which Choris Peninsula extends to the south. The city of Kotzebue is at the northern tip. This peninsula seems to be remnants of frozen upland and resembles a glacial moraine. Large gulleries occur on the Choris Peninsula and there are large Horned Puffin cities on the islands off the peninsula at the entrance to Eschscholtz Bay. There appeared to be little waterfowl habitat along this peninsula.

The south shore of Kotzebue Sound, from Motherwood Point around Goodhope Bay to the mouth of the Nugnugalurtuk (Goose) River, is made of steep bluffs which are cut into small seabirds cliffs at three places.

The east side of Cape Espenberg is made up of low sandy islands and very shallow water. Gulls and terns nest on the small islands. Seals haul out on the tip of the cape. From Cape Espenberg to Kividlo, at the eastern end of the lagoons, the northwest shore of the Seward Peninsula is made up of relatively high sand dunes (20-30 feet) and/or frozen ground. Meadows and sedge swales in the low places between the dunes supply breeding habitat for ducks, geese and shorebirds (Mickelson, Schamel, Tracy, et al., 1977 and 1978).

Large, productive lagoons line the coast inside the beaches from Kividlo past Shishmaref to the tip of Cape Prince of Wales. These and the wet tundra behind them provide good nesting habitat for many waterfowl, geese and shorebirds.

The coast is made of high, dry rocky faces from Wales to the Lost River and Brevig Lagoon. These faces support a few Pelagic Cormorants. A long barrier beach contains Brevig Lagoon and extends beyond the lagoon to form the spit north of Teller Spit. The shores of Grantly Harbor are steep and there is little waterfowl habitat until one goes through the Tuksuk Channel to Imuruk Basin where there are waterfowl flats on the north shore. Southwest of Teller a circular arm of Point Spencer surrounds Port Clarence. The base of this point is made of frozen ground upon which are many thaw ponds and meadows. Gulls, ducks and cranes seemed to be nesting there. The tip is a long gravel and sand spit which is a stopping place for geese and shorebirds and resting place for Glaucous Gulls and Kittiwakes.

A barrier beach extends from Cape Douglas to Cape Woolley blocking the mouths of the Tisuk River and Feather River and containing productive lagoons. From Cape Woolley to Cape Nome the beach is narrow and steep; the lowland behind is frozen ground vegetated with wet tundra and pock-marked with thaw lakes. Wet tundra and thaw lakes provide nesting habitat for Pintails, Red-throated Loons, swans and geese. A few large thaw lakes were found to be empty of waterfowl while some old thaw lakes along the shore drained by advance of erosion were used heavily by ducks and shorebirds.

The rivers along this coast between Cape Rodney and Cape Nome, such as the Sinruk, Cripple and Nome Rivers, create open water at their mouths in spring and are gathering places for early arriving waterfowl. East of the Nome River there are several lagoons behind the sand beach. The one at Hastings is good for seaducks and shorebirds.

East of Cape Nome the barrier beach which contains Safety Lagoon extends many miles to the mouth of the Bonanza River and on to the rocky cliffs at Topkok. The lower parts of the Flambeau and Eldorado Rivers which empty into Safety Lagoon are summering grounds for many fresh water ducks. The thaw lakes on the lowlands around these rivers and between these and the Bonanza River are nesting places for geese, swans, ducks and cranes. A channel extends from Safety Lagoon behind the beach to the mouth of the Bonanza River and this area and the marshes and lagoons beyond, including Taylor Lagoon, are good habitat for summering ducks, migrant geese and shorebirds. Pintail and other ducks gather along the channel in late July as soon as they leave their nesting grounds. The shallow water at the west end of Safety Lagoon near Cape Nome is attractive to shorebirds in spring. Geese gather in the middle of the lagoon in August. Arctic and Aleutian Terns nest on the islands at the entrance. Large flocks of shorebirds gather on the mudflats at the entrance in August.

Most of the shore between Topkok and Isaac's Point is steep and rocky, except for the inner part of Golovin Lagoon and the area behind the barrier beach at Moses Point. These two large deltas with the associated shallows and mudflats are some of the most heavily used waterfowl and shorebird habitat in the region. The upper part of Golovin Lagoon in the shallow water at the mouth of the Fish River is very productive, especially in the fall. Pintail, Wigeon, Canada Geese and swans gather there in the very shallow water.

At the mouths of the Kwiniuk, Tubutulik and Kwik Rivers, behind Moses Point, there is a large boggy wetland. Many ducks and geese use this; most of the birds come out onto the mudflats in the afternoon when the tide is low. All along the northeast shore of Norton Bay there are broad mudflats in the afternoon in the fall. Many Pintail gather on these flats, especially in the shore between Koyuk and the Inglutalik River.

The shore from just below Shaktoolik to above Unalakleet is steep, poorly consolidated sediments. Marshes behind Unalakleet are productive for waterfowl and gulls. Beyond Unalakleet the beach is narrow. Behind the beach are 30-foot bluffs of silt or muck. The bluffs retreat inland beyond Tolstoi Point where columnar outcrops of basalt support a small seabird city. Columnar basalt makes up the points from there to Stuart Island. The gentle slopes in between are covered with wet tundra.

Trees line the rivers and drainage lines along the coast between Koyuk and Tolstoi Point. Trees are absent again west of Tolstoi Point. Trees occur along the north shore of Norton Bay as far as Elim, east of Golovin. Large alder shrubs extend as far west as Topkok on the slopes facing south. From there vegetation gets lower and lower as one goes northwest towards Wales. The vegetation of the uplands at Wales is low and sparce, but the wet tundra in low areas behind sand dunes is thick enough to provide good habitat for feeding shorebirds and geese.

Shallow muddy water extends several miles north of the shore at the northern edge of the Yukon Delta. Mudflats are exposed in the afternoon. Wet tundra and sedgy soughs come down to the shore which is a three-foot frozen mudbank with waves washing against it.

2. Saint Lawrence Island

Saint Lawrence Island (Figure 33) is constructed of two major and perhaps six minor volcanic mountains and ridges. The rugged uplands are connected by broad, gentle lowlands covered with wet tundra and marked with hundreds if not thousands of ponds. One major volcanic system centers behind Savoonga in the Kookooligit Mountains. The second forms a triangular ridge, narrow at the north at Apatiki Camp, and broadest and highest in the southwest at Owalit Mountain, Ivekan and Poovookpuk Mountain and Oongayuk Hill. Other small volcanic hills are scattered over the broad lowlands to the east. They suggest drumlins or overturned boats. Kinipaghuilghat Mountains at the Northeast Capes are tall and steep-sided and resemble the "young mountains" of the western Seward Peninsula.

Table 30a.
Waterfowl Censuses: 1975.

Date	Area	All Species	Canada Goose	Whistling Swan	Pintail	Other	Un-I.D. Duck
18 Aug	Fish River mouth	337		2	335		
	Shaktoolik to north corner of hill on Cape Denbigh	16		2	14		
19 Aug	Bonanza - Safety Lagoon	486	100	15	225	146[a]	
	Taylor Lagoon	123		3	90	30[b]	
29 Aug	Cape Spencer to Cape Douglas	840	440	35	40	325[c]	
	Cape Douglas to Cape Woolley	229		13	115	101[d]	
	Cape Woolley to Sinuk	781	405	54	66	256[e]	
	Totals	2812	945	124	885	858	

[a]
1 Black Brant
50 Green-winged Teal
40 Scaup
35 Red-breasted Merganser
20 Baldpate

[b] 30 Black Brant

[c] 325 Black Brant

[d]
15 Green-winged Teal
29 Old Squaw
15 Eider
42 Red-breasted Merganser

[e]
2 Black Brant
144 Old-Squaw
110 Eider

Figure 32a.
Numbers of waterfowl in major coastal habitats.
August 18, 19, and 29, 1975.

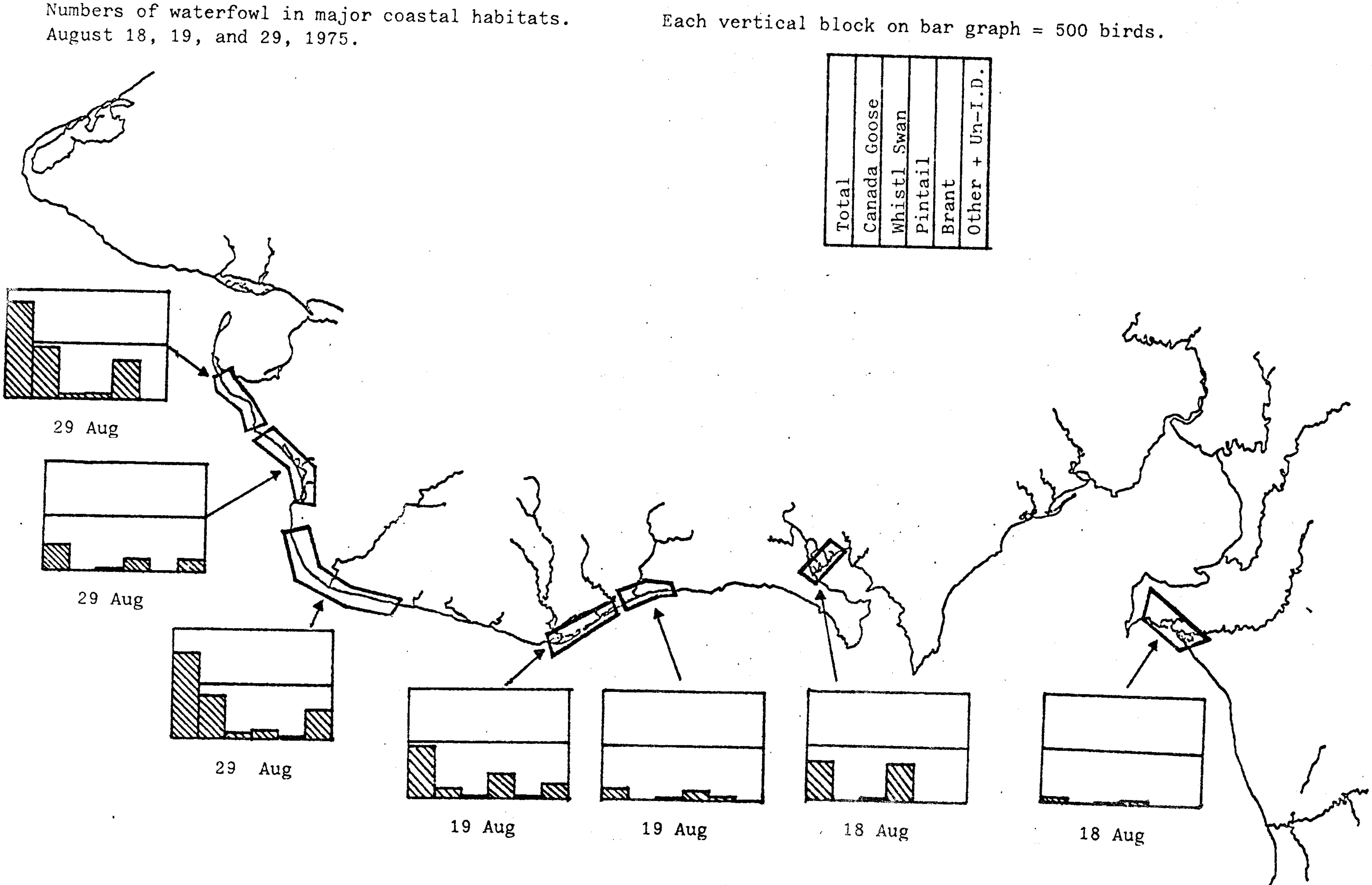


Table 30b.
Waterfowl Censuses: 1976. August 11, 13, 14, and 20.

Area	All Species	Canada Goose	Whistling Swan	Pintail	Other	Un-I.D. Duck
Cape Douglas and base of Cape Spencer	139	25	37	31	45[a]	1
Woolley Lagoon	259	62	17	117	63[b]	
Cape Nome to Flambeau River to Bonanza River	152	6	14	80	47[c]	5
Safety Lagoon	783	120	2	572	40[d]	49
Fish River Flats	318		2	185		131
North shore of Golovin Lagoon	161		6	155		
Moses Point to Kwik River	1412	870	3	313	201[e]	25
Totals	3224	1083	81	1453	396	211

a
2 Black Brant
13 Old Squaw
30 Red-breasted Merganser

b
2 Black Brant
43 Emperor Goose
8 Widgeon
10 Old Squaw

c
9 Green-winged Teal
1 Widgeon
36 Greater Scaup
1 Old Squaw

d
30 Widgeon
5 Greater Scaup
5 Old Squaw

e
15 White-fronted Goose
185 Widgeon
1 Eider

Figure 32b.
Numbers of waterfowl in major coastal habitats.
August 11, 13, 14, and 20, 1976.

Each vertical block on bar graphs = 500 birds.

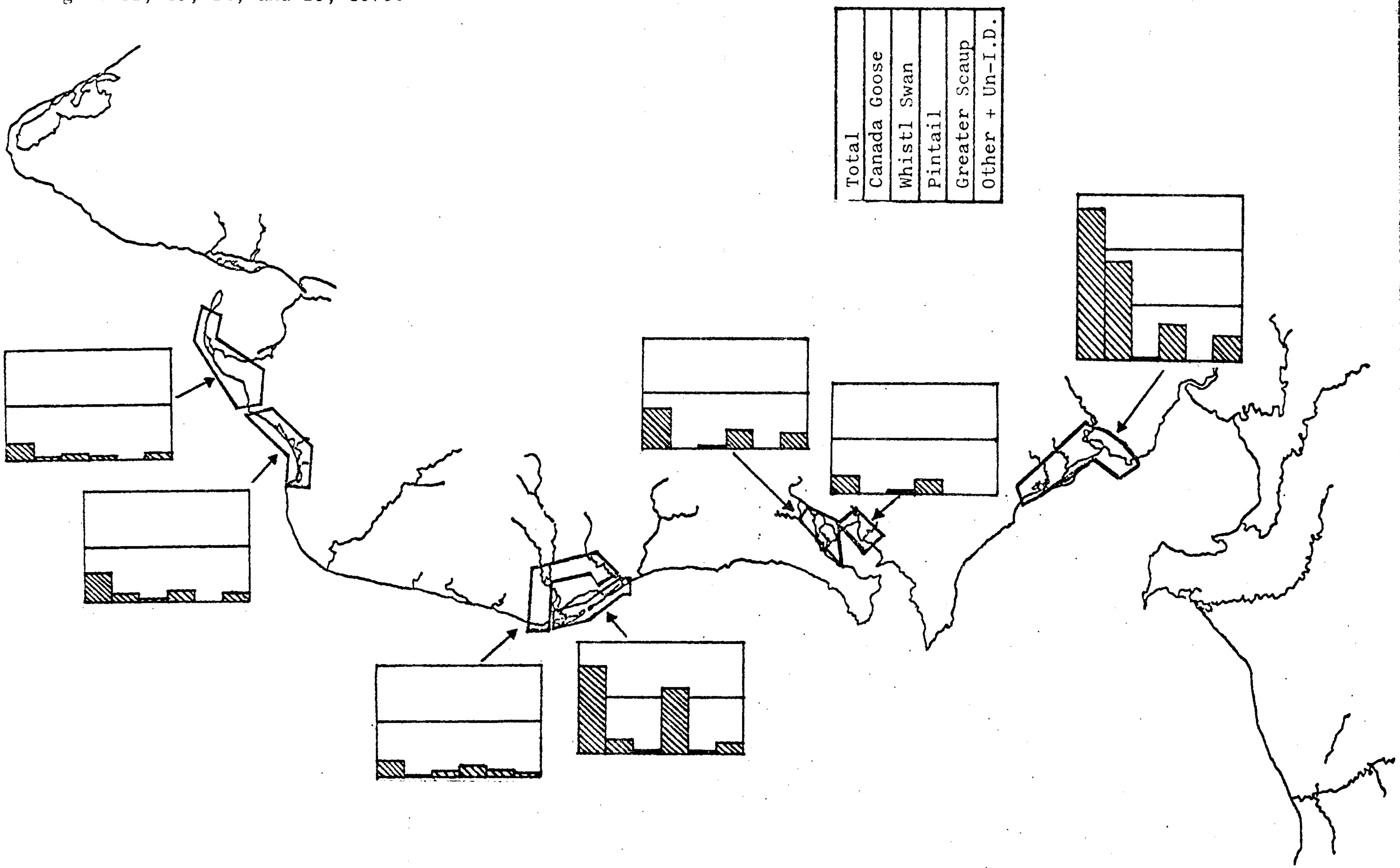


Table 30c.

Waterfowl Censuses: 1976. September 9.

Area	All Species	Canada Goose	Whistling Swan	Pintail	Other	Un-I.D. Duck
Cape Woolley to Sinuk	61	50	11			
Safety Lagoon	1227	124	10	217	34[a]	842
Taylor Lagoon	226	13	34		150[b]	29
Edge of Fish River Flats at Golovin Lagoon	9816	3860	500	10		5446
East shore of Golovin Lagoon	0					
Moses Point to Kwik River	902	50	8	7		837
Totals	12,232	4097	563	234	184	7154

[a] 8 Black Brant
1 Widgeon
25 Red-breasted Merganser

[b] 100 Black Brant
50 Red-breasted Merganser

Figure 32c.
Numbers of waterfowl in major coastal habitats.
September 9, 1976.

Each vertical block on bar graph = 500 birds.

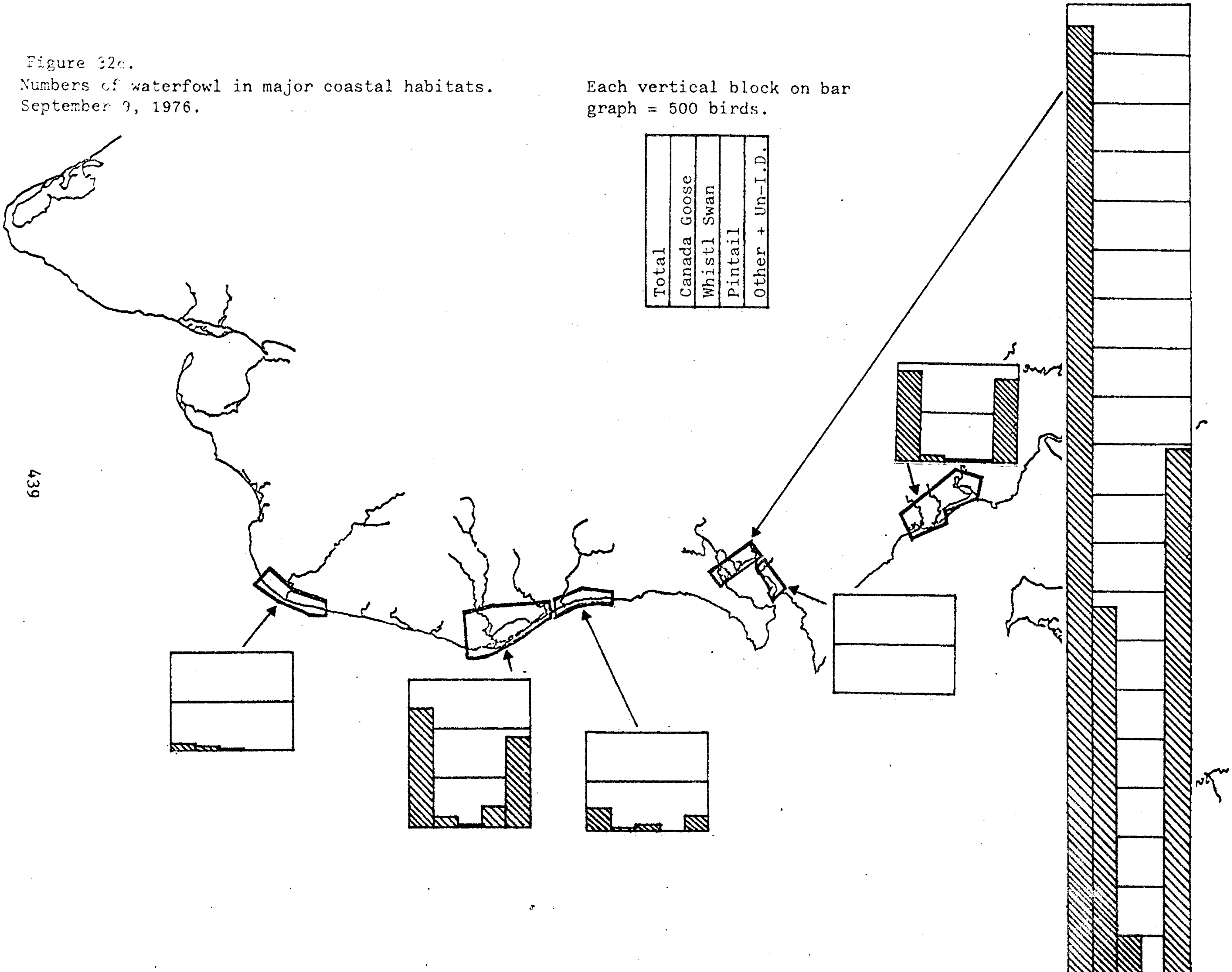


Table 30d.
Waterfowl Censuses: 1976. September 24.

Area	All Species	Canada Goose	Whistling Swan	Pintail	Other	Un-I.D. Duck
Brevig Lagoon	45	45				
Point Spencer to Cape Douglas	209	141	1		12[a]	55
Cape Douglas to Cape Woolley	102	86	8		4[b]	4
Cape Woolley to Sinuk	239	216			6[c]	17
Safety Lagoon northeast	349	191	2	150		6
Taylor Lagoon	59	45	4		10[d]	
Totals	1003	724	15	150	32	82

[a] 1 Red-necked Grebe
1 Greater Scaup
10 Eider

[b] 4 Widgeon

[c] 6 Eider

[d] 10 Widgeon

Figure 32d.
Numbers of waterfowl in major coastal habitats.
September 24, 1976.

Each vertical block on bar graph = 500 birds.

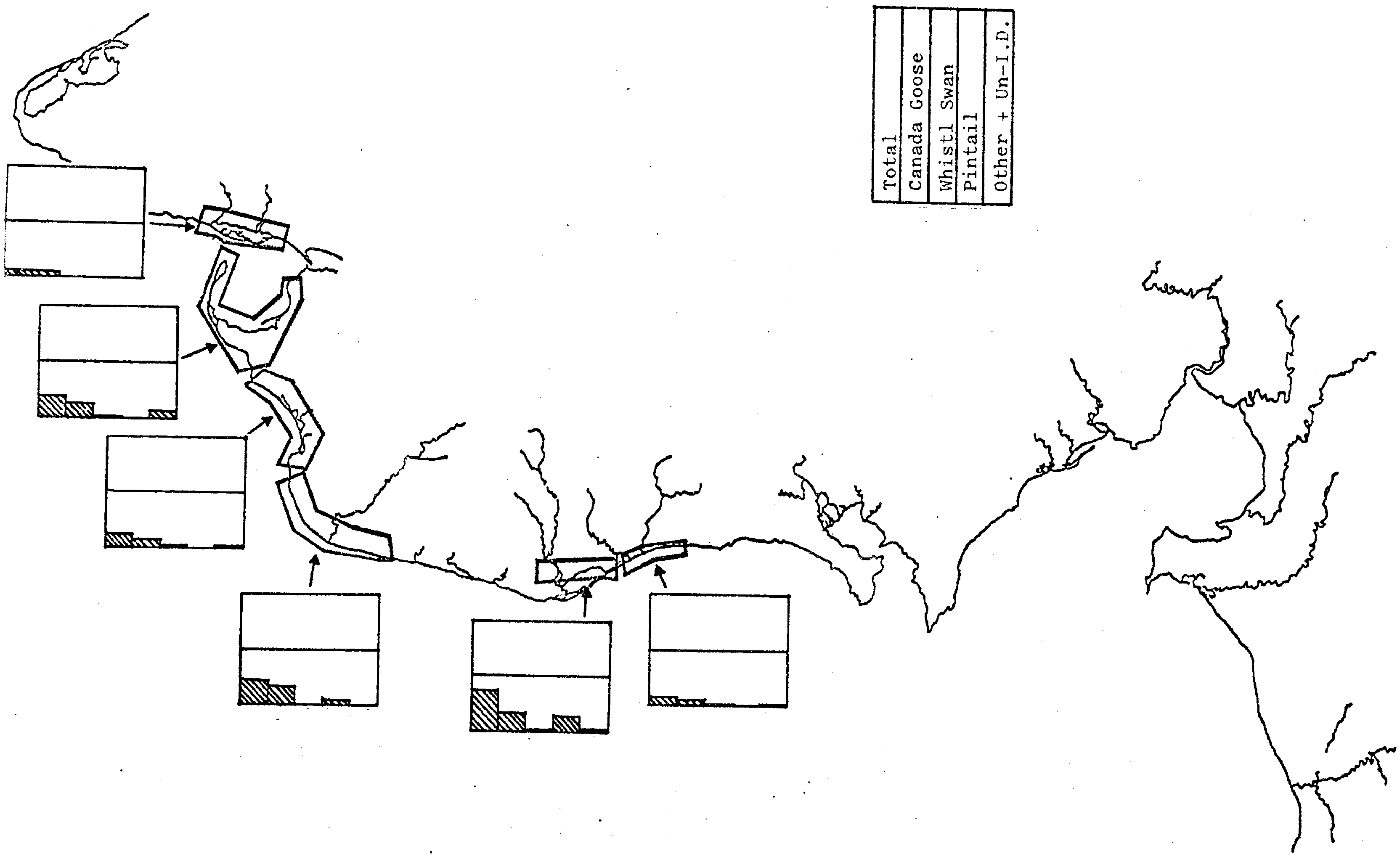


Table 30e.

Waterfowl Censuses: 1976. October 1.

Area	All Species	Canada Goose	Whistling Swan	Pintail	Other	Un-I.D. Duck
Fish River Flats	66	8	9		5[a]	44
Edge of Fish River Flats - north shore of Golovin Lagoon	6792	3720	509		750[b]	1813
Southwest corner of Golovin Lagoon to east of Chiukak	558	493				65
East shore of Golovin Lagoon	126	85	6	10	25[c]	
Moses Point to Kwik River	1148	405	20	260	283[d]	180
Mouth of Kuiutulik River to and up Koyuk River	3169	570	49	504	575[e]	1471
Inglutolik River to Ungalik River	1408	200	393	146	283[f]	386
Cape Denbigh, Ungalik, and Shaktoolik	275	185		4	50[g]	36
Totals	13,542	5666	986	924	1971	3995

[a] 5 Red-breasted Merganser

[b] 750 Widgeon

[c] 25 Widgeon

[d] 117 Widgeon
103 Greater Scaup
63 Red-breasted Merganser

[e] 30 Green-winged Teal
60 Widgeon
485 Red-breasted Merganser

[f] 150 Widgeon
8 Greater Scaup
25 Eider
100 Red-breasted Merganser

[g] 45 Black Brant
5 Widgeon

Figure 32e.
Numbers of waterfowl in major coastal habitat.
October 1, 1976.

Each vertical block on bar graphs = 500 birds.

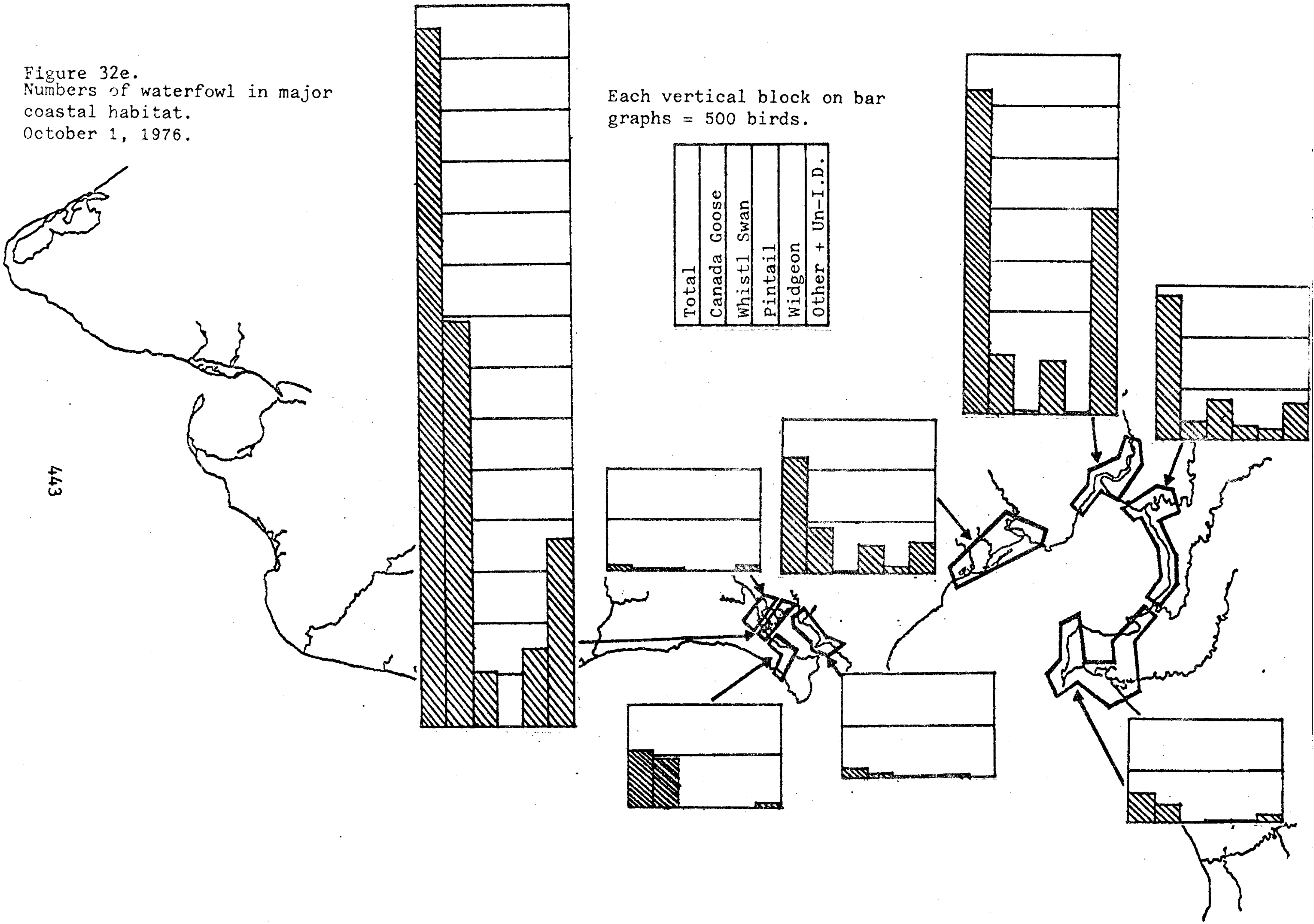


Table 30f.

Waterfowl Censuses: 1977. August 26-31.

Area	All Species	Canada Goose	Whistling Swan	Pintail	Other	Un-I.D. Duck
Base of Cape Spencer	650	200	6			444
Woolley Lagoons	132	106				26
Cape Woolley to Sinuk	570	347	16	56		151
Flambeau River to Bonanza River	2351	2		1808	354[a]	187
Bonanza River to Taylor Lagoon	1962	375	57	905	625[b]	
Fish River Flats	2753	87	35	1430	1020[c]	181
Golovin Lagoon	14288	5620	1050	6940	678[d]	
Moses Point	10266	1630	25	7516	1095[e]	
Koyuk to Inglutalik River	5475	719	149	3415	558[f]	634
Cape Denbigh and Shaktoolik River Flats	1758	854	118	343	133[g]	310
Totals	40,205	9940	1456	22,413	4463	1933

[a] 40 Greater Scaup
314 Baldpate

[b] 245 Greater Scaup
380 Baldpate

[c] 880 Greater Scaup
140 Baldpate

[d] 105 Greater Scaup
573 Baldpate

[e] 2 Greater Scaup
1093 Baldpate

[f] 256 Greater Scaup
302 Baldpate

[g] 73 Greater Scaup
60 Baldpate

Table 32f.
Numbers of waterfowl in major coastal habitats.
August 26-31, 1977.

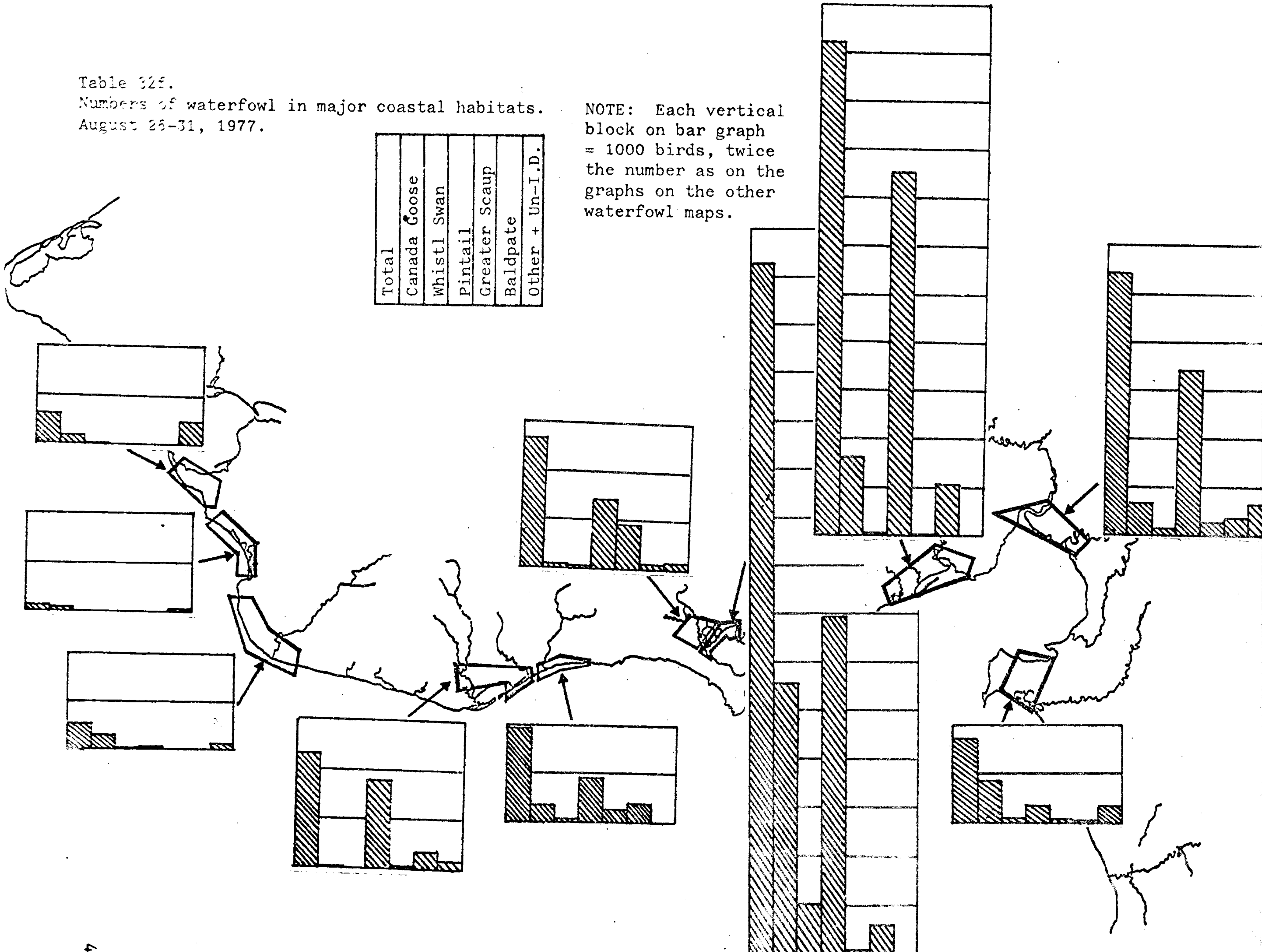
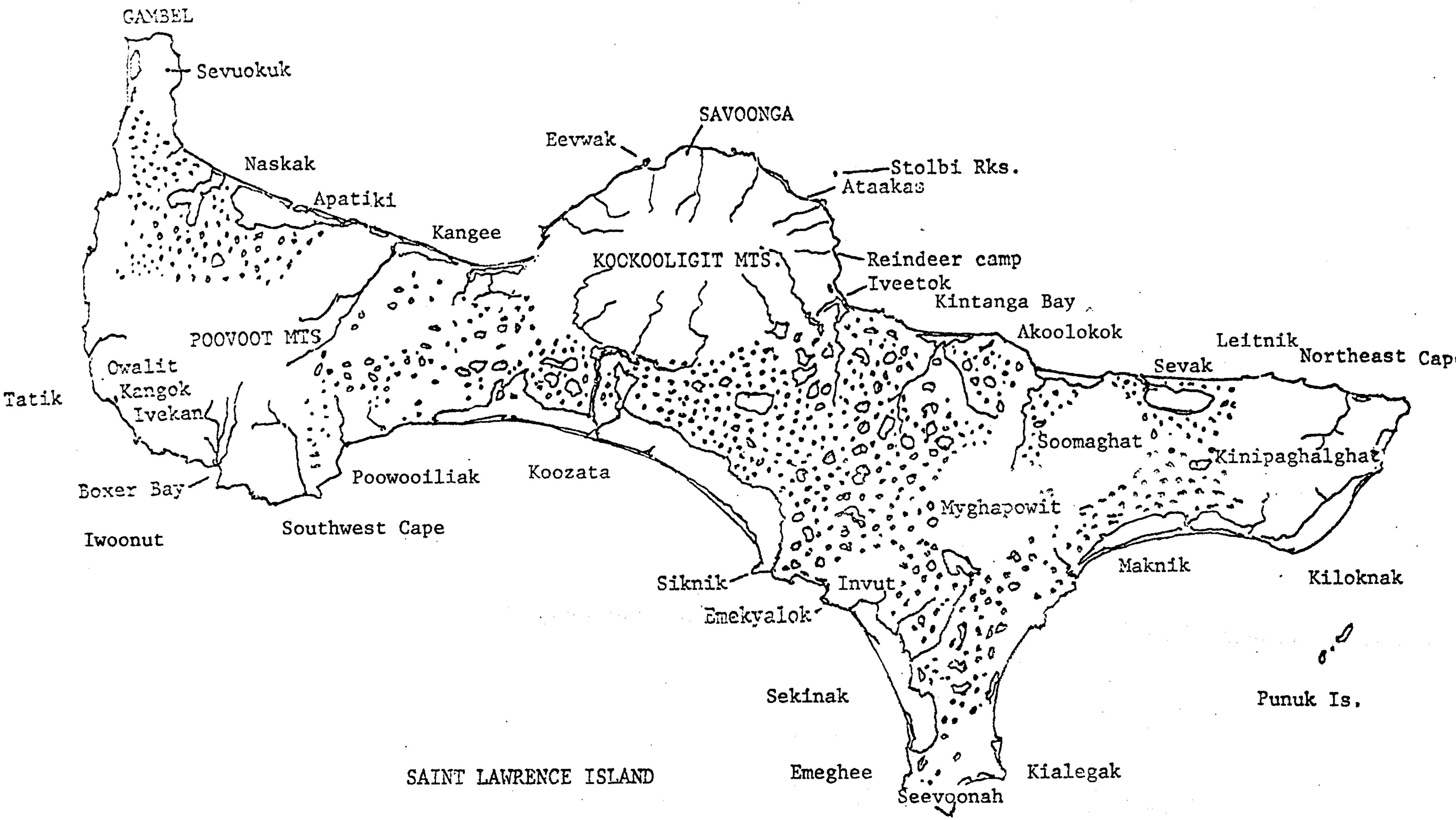


Figure 33.
Saint Lawrence Island; place names referred to in the discussion of waterfowl habitat.



A broad low apron of recent, unvegetated, broken and contorted lava extends from the Kookooligit Mountains in a fan from Reindeer Camp in the east to near Savoonga on the north and beyond to end in massive cliffs next to Kangee Camp.

From Kangee Camp on the western end of the fan of volcanic material to Sevuokok Mountain behind Gambel, the north shore is made of a barrier beach and broad lagoons, except for the rounded low ridge at Apatiki Camp. The western stretch of barrier beach and lagoons appears to have been the site of a major pre-contact community indicated by the mounds marking old houses. There are several inlets along these beaches. Shorefast ice persists along this shore late into June.

Sevuokok Mountain is high and boat shaped, and covered with rubble. On its west flank is the broad gravel shoulder on which a traditional community now called Gambel is located. This spit contains a large lagoon; then south of Gambel low rolling hills come down to the west shore from the rolling uplands, resembling the low slopes along the coastline east of Saint Michael. Twenty to thirty foot earthern cliffs and scattered boulders form headlands between scalloped bays. In June, these shores have been blanketed with snow. Cormorants, Glaucous Gulls and kittiwakes roost on the snowbanks. Auklets feed in flocks in the shallow water, and flocks of Steller's Eiders, Oldsquaws, and Harlequin Ducks gather in the bays. The mountain ridges reach the sea at Owalit Mountain and the bird cliffs start there. They extend past Iwoonut, Southwest Capes and Singikpak. The bird cliffs end at Poowooiliak Camp where, on a boulder field, many cormorants are usually found. Vegetated steep slopes mark the shore from there to the west end of the long lagoon, Koozata, which marks the south shore as far as Siknik Cape. Low depositional slopes mark the inland shore of this lagoon. Flocks of Common Eiders, Oldsquaws, and Spectacled Eiders appear on the shallow bay and lagoons. Flocks of Emperor Geese and Brant fly up from the beaches and marshes. We found a gullery behind Siknik Cape, and a ternery in the bight west of Kialegak. We also note the name of Emekyalok Point, a name that resembles the Inuit name for Arctic Tern as used in the eastern Arctic, Emeketailok. Low flat land, blocks of rock outcrops, and boulders form the shore as far as the start of Sekinak Lagoon, and a long barrier beach connects to ridges less than 1000 feet at Seevoonah Mountain at Southeast Capes. Similar low shores with scattered outcrops of boulders and blocky basalt form the shore extending northeast to Maknik Lagoon and the Kinipaghulghat Mountain System forming the Northeast Capes. Shallow water with boulders visible within a mile or so of shore extends along this southeastern shore. Black Scoters, Oldsquaws, and Common Eiders were associated with ice pans in this area when we flew over in 1977.

Kiloknak Lagoon borders the shore of the eastern mountains to the Northeast Capes.

Small lagoons and meadowy, low slopes form the shore west from the Northeast Capes to the community of Leitnik and the former radar installation. A long beach extends west to meet 20-foot bluffs west of Sevak Camp. West of there the coast alternates lagoons and low bluffs beyond Akoolokok Point, and Kintanga Bay to the beginning of columnar basalt outcrops at Reindeer Camp at the eastern base of the volcanic fan behind Savoonga. All of the inland lowlands along the north shore are low, flat, vegetated with meadowy tundra, and spotted with innumerable lakes. Out of the plain rise the two mountains, like great boats turned over.

Scattered along the north shore we found Glaucous Gulls, Siberian Herring Gulls and Slaty-backed Gulls around Walrus and Gray Whale carcasses. Common Eiders, cranes, Emperor Geese and Brant flew up from the lagoons or marshes along the shores of the lagoons.

VIII. Special Problems Associated with the Secondary Effects of OCS Development

In this section we will not be presenting a general review of the effects of oil and development, as others have already done so (Vermeer and Vermeer, 1974; Curry and Lindhal, 1960; Bourne, 1968; Hartung, 1965, 1967, etc.). Instead we discuss what we conclude is directly implied from our studies and observations. We discuss how studies of marine birds are useful in monitoring the "health" of ecosystems; then we discuss activities associated with development that will have major impacts on populations in the Bering Strait Region. We address the concept of "insults" or "damage" and "recovery" and make concluding remarks on critical coastal habitats and protection or the guarantee of public access.

A. Seabird Populations and Monitoring of Habitat

Because seabirds are a conspicuous component of the marine ecosystem and because they are responsive to changes in habitats of several kinds, they are more useful as indicators of ecosystem health than are other marine organisms. Their accessibility has allowed bird biologists to examine in detail the actual behavior of species and thus to test whether the ecological functions suggested for active predators by general theorists are helpful.

Different species feeding in different parts of the water column and in different parts of the sea will reflect different qualities of the marine system and the trophic structures at different places and levels.

Because birds are at the top of the food chain some species will be useful as indicators of the productivity and transfer of energy among the organisms lower in the food chain. We can categorize species according to the tactics they use for obtaining resources and then make detailed studies of representative species. Some species concentrate on feeding grounds along the coast (e.g., migrating shorebirds and waterfowl), while others (murres, kittiwakes, auklets) are widely dispersed across the sea.

Certain species and certain colonies are well-qualified by their characteristics to be used for continued monitoring or continued study to clarify the meaning of general phenomena at less hospitable sites. Some seabird species are useful in monitoring conditions in the sea as their populations and reproductive success can be measured easily. The degree to which individuals of a species are successful in finding preferred foods will be reflected in their breeding schedules and reproductive success each season and will reflect conditions in the part of the water column in which they feed. We have been making detailed studies of promising species of seabirds at a few breeding cliffs, gathering data and formulating our interpretations which should apply to other places. Murres and kittiwakes are both relatively easy and inexpensive to monitor, especially at a colony such as Bluff. Like all predators, they are sensitive to the availability of preferred prey items and because murres feed throughout the water column and kittiwakes feed close to the surface, they will reflect different conditions in different parts of the water column. Both species respond quickly to local circumstances, and these responses are expressed in changes in the size of breeding colonies, mortality rates, breeding phenology, clutch size and fledging success each season.

Waterfowl are useful in monitoring coastal habitats as their populations can be measured and locations noted (see part B.3., in this section, on importance of coastal habitats and habitat redundancy).

Waterfowl are a resource which is used directly not only by local people but also hunters in "the lower 48." Variation in their numbers is of direct concern to a vocal segment of society; thus monitoring of numbers of waterfowl is a task already recognized as important and has been undertaken by U.S. Fish and Wildlife Service and the Alaska State Department of Fish and Game. To this degree monitoring of populations and distribution of waterfowl is not concerned with the condition of a habitat but directly serves its own ends. Shifts or changes in waterfowl numbers indicate that steps need to be taken to see whether satisfactory habitat is available. In this way the study of waterfowl serves a different purpose than does the study of distribution and abundance of seabirds in the context of OCSEAP studies.

The structure and processes of marine ecosystems are multi-dimensional, open, non-linear and complex; identification of a single species as an indicator of the effects of development on the health of an entire ecosystem is unrealistic. Changes in the numbers of different types of species due to different causes will be echoed at different levels of the system and will result in differing effects on different species. Specific biological characteristics of each species studied can be useful in monitoring specific problems such as will result from activities described in the next section; the characteristics of each species are reviewed in Appendix VI on Major Players.

B. Major Predicted Impacts

1. The effects of "social" vs. "ecological" (or "chronic" vs. "acute") disturbances

The species of birds that participate in the marine system of the Bering Strait Region are not elements of a long-established natural configuration exhibiting homeostasis. Rather, the species vary in numbers and many move in from outside the region (see Sections I and III A., on the assemblage of three faunas); any single species is not a critical element. We believe that in northern areas and in areas where seabirds are long-lived, catastrophic events resulting in high mortality may be less serious than chronic damage lowering reproduction over several decades. Chronic disturbances are those which occur either continuously or sufficiently often that the biota affected does not have time to recover between doses (Trasky et al., 1977); the effect on reproduction is subtle, and yet over time may be more devastating to populations than single, short-term incidents (as for example, a major oil spill).

Regardless of whether or not oil deposits are found in Norton Sound, the Seward Peninsula will experience industrial development and secondary growth associated with petroleum extraction on the North Slope. Discovery of a commercial field in Norton Basin will only accelerate the development of airports, shipping ports, and other support facilities. The greatest effect of this development will be not the increasing numbers of people per se, but the effects of their movements and activities on wildlife and the inevitable disregard for the effects of human actions on critical habitats.

We are more concerned that the effects of social disturbances will be more widespread and pervasive than local acute ecological disturbances.

Social disturbances promise to be varied and chronic in nature, and over time will threaten to lower reproductive rates. Social disturbances will result from the increase in the numbers of people, their mobility and the effects of their actions on wildlife and on segments of the native human populations who rely on subsistence living.

Disturbance of wildlife populations and habitat will be caused by intrusion into breeding and resting areas by visitors in helicopters, airplanes, boats and all-terrain vehicles. The effects of the visits will be made worse by hunting because in a hunted population the reaction to all people of panic is reinforced.

It is a truism that predators reduce their prey populations to a level at which it is awkward for individual predators to get the next prey animal. This happens even though hunting territories mitigate the impact for those able to exclude competitors from their territory. While human predators walk and kill with arrows, game is conspicuous and populations maintained at higher levels in areas of habitat over which it is not economical for humans to hunt on foot. If, however, predators use snowmachines, aircraft, and rifles the game will be reduced to levels at which it is perceived as scarce by all people. Additional emmigrants using new technologies will reduce wildlife resource further, either actually or as perceived, making the lives of bush natives harder and the visits of naturalists less satisfying.

One must ask, do the economic conveniences of industrial development preclude consideration of the concerns of other parts of society, for example the natives living in a subsistence economy? Hunting by non-subsistence people will be detrimental to those living by subsistence.

Furthermore, do the direct concerns of hunting according to the Native Land Claims and customs preclude considerations of a significant and growing segment of society where non-consumptive uses are reduced or spoiled by the effects of industrial activities and the increase in hunting that accompanies industrial development in such a region? The problems stem from multiple demands and competition for limited resource and restricted area by various segments of society (consumptive, industrial and non-consumptive; wildlife and habitat). Certain activities interfere with others, and so the question needs to be raised concerning what priorities of activity should be assigned to what areas; which minority has the right to exclude other minorities from a resource whether the resource is meat, land or the opportunity to watch big game in the wilderness?

2. Disturbance

The effects of increased mobility on wildlife in the Bering Strait Region

Presently the human population on the Seward Peninsula is sparse and though the population of hunters is adequate to effect wild populations, there is plenty of relatively undisturbed habitat for wildlife. But as development advances more people will be moving into and around in the region, and as a consequence we can expect a flood of recreational bush-whacking and exploring with all-terrain vehicles, boats, planes and helicopters. Habitats and populations, such as waterfowl, seabirds, walrus, and Grizzly Bear, will be more accessible and consequently vulnerable to increased hunting pressure. A variety of populations will be affected by intrusion into breeding colonies and close-range observing of seal and walrus haul-outs by curious visitors, tourists, photographers, natural historians, fishermen, eggers, idle harassers and hunters.

The concentration of seabirds into breeding cities makes them exceedingly vulnerable to disturbance at those small spots of intensely concentrated activity. The important seabird cities in the Bering Strait where traffic will be concentrated are likely to be subjected disproportionately to greater amounts of human activity and exploitation. The proximity of the North American and Asian continents at the Bering Strait and the fact that the region escaped glaciation 3,000-8,000 years ago, make the region biologically unique. Dozens of tourist excursions are attracted to the Nome area and to Saint Lawrence Island every year to see the large number of endemic and Eurasian species. We can expect that this will increase as the region becomes more popular and accessible.

Few roads now exist in northwest Alaska; they are expensive to build and maintain on permafrost and so may not be feasible as transport routes to temporary exploratory settlements (oil under Seward Peninsula is not yet suggested as a possibility). In time, parts of the Seward Peninsula will be made more accessible by road; in the meantime, reliance on air traffic will be even more extensive than at present.

Areas not served by road or plane will be served by helicopter. Helicopters have disastrous effects at seabird colonies; the noise, air pressure and turbulence created by the blades serve to drive 30-40% of the birds (and along with them, many eggs) off a cliff. It is imperative that during the breeding season from mid-May to late September helicopter traffic be eliminated from the vicinity of seabird breeding locations. If authorities have the will to do so, air traffic can be routed around areas of land critical to wildlife populations during critical times of the years so that disturbance is minimized.

Hunting

Until recently almost all who settled in Alaska assumed hunting to be a major part of their lives. The hunting mystique has played a major and traditional role in the social milieu of Alaska. But this cannot continue long uncontrolled. Productivity of tundra and forest systems will not support the game necessary to satisfy the growing needs of consumptive and non-consumptive users. Although the human population on the Seward Peninsula is still sparse, already too many hunters are driving waterfowl from habitats critical for their survival. Increasing numbers of increasingly mobile people, primarily hunters, will have serious impact on the numbers and behavior of wildlife and threaten to disturb all kinds of habitat.

At present many people, caucasian and native, hunt extensively in winter, spring, summer and fall. Much of this hunting is called "subsistence" in that the hunters eat the meat themselves; but much is illegal in that meat of native wildlife is on sale consistently at grocery stores in Nome.

Subsistence hunting by natives is at a period of transition. Up until recently most natives lived in a subsistence economy. Now the lives of the people who are still living subsistence economies are being made more difficult by competition for game from affluent fellow natives. Today, people with good-paying jobs which are part of the White Man's state and federal economy, do much of the effective hunting in the Bering Strait Region. These people's "subsistence" hunting is, to a large degree, recreational. They have new technology of manufactured boats, high-speed outboard motors, four-wheel drive vehicles, snow machines and high-powered rifles, so they now have the opportunity to sweep the entire habitat. These changes in technology have not been forced on unwilling Eskimos. Individuals we have talked with agree that the old way of life was very hard work and uncomfortable. They do not want to go back to it because of the advantages of the technology, comforts and conveniences brought in by the White Man.

Hunting plays an important social role as well as economic. A number of small communities still depend to a large degree on hunting and fishing for their living and it is a matter of national concern whether these small native villages can survive. On the one hand, it is very hard for a man who has fed his family by hunting for a number of years to be told that he will have to reduce the amount of game he kills. On the other hand, for many natives who are successful in the White Man's world or who are "kept" by welfare payments, successful hunting is of major importance in establishing themselves among their peers and maintaining their self-esteem.

A dilemma exists in the context of the present Native Land Claims Settlement. The natives are calling upon other U.S. citizens and the state and local governments to guarantee them political rights, economic resources and social benefits. At the same time they are claiming special exemption from the laws and institutions which apply to the relations between other U.S. citizens and wildlife. For example, do the native rights, which seem to allow them to hunt waterfowl in spring, allow them to damage the waterfowl hunting of people in the Lower Forty-eight? -if so, why cannot hunters in the Lower Forty-eight increase their duck and goose bag, thereby damaging the hunting of Alaskan natives? Should native claims to private property rights allow them to preempt public access to, and government protection of seabirds on nesting cliffs or waterfowl on breeding and resting areas on coastal tundra and wetlands?

Generally stated, because native groups in Alaska have extensive state and federal subsidies (a source of powerful new technology) which interfere with the natural interactions between them and their prey, it seems necessary to require the natives to conform to biologically designed programs to perpetuate the affected species of wildlife. In the old days when a group killed off local game they had to move and compete with some other hunters or starve. Many stories are still told of entire villages starving. Such effective though unattractive feedback mechanisms kept the native predators and their prey in natural balance.

Native Americans with their new technology and affluence cannot claim special exemption from "the laws of nature" which, as biological knowledge and common sense suggest, set constraints on the size of the kill, and establish the consequences of hunting on the behavior of the hunted population.

Hunting tends to drive organisms away from habitat. The mortality that results may be greater than that caused directly by shooting. The intense fear stimulated in hunted populations from the discharge of firearms makes then flee in panic from all humans and makes them leave the restricted areas of habitat in which they could survive, to exist in marginal habit where they will starve slowly. Thus, social enjoyment of the population as a recreational resource by non-consumptive users is denied. This problem will exist wherever natives, white residents and wildlife congregate. To mitigate this problem, to have a population pool and to serve the interests of the non-consumptive users, large areas of land should be closed to hunting so that wildlife can lose its terror of humans in the absence of disturbance and so that the non-consumptive uses (study, watching, photography) are not in competition with and lessened by the consumptive uses.

It seems reasonable for natives, because they should have a continuing attachment to the lands and the husbandry of the resources, to take a major part in the political control of how a season's kill is distributed among several interests: natives, non-natives, local residents, fee-paying hunters from out-of-state, bird watchers, and so forth. However, because the institutions and the governments which benefit the native community and guarantee native rights are supported by the whole U.S. community, it would not seem unreasonable to expect that these political decisions should include consideration of the interests of all U.S. citizens.

3. Effects of contaminants

Oil spills and leaks illustrate the difference in the effect of acute and chronic disturbances.

A catastrophe such as an oil spill often receives a great deal of attention. Public outcry is usually great and the oil industry responds quickly with clean-up efforts. But the continual phenomenon of leaks acting as chronic disturbance, poses more of a serious threat to marine organisms and their habitat than the occurrence of a large spill. The continuous exposure from unchecked, unattended leaks does not allow an affected population time to "recover" between exposures as has been demonstrated in the case of the populations of murres and puffins in northwestern Europe during the last four decades (Birkhead and Ashcroft, 1975; Hedgren, 1975; Nettleship, 1977). If recovery is possible, a population's chances for doing so will be greater when the threat of an oil spill of any size or frequency is removed. Without leaks, the primary impact of oil development might be tolerable. The Beringian ecosystem, which is in a constant state of flux, probably stands a greater chance of recovery from rare catastrophic spills than from the continual chronic exposure that will be provided by many small leaks. Detection of leaks and contingency plans are needed to minimize the amount of oil spilled and to contain, recover, or disperse the oil as quickly as possible.

The places where birds and other active marine invertebrates congregate are places where oil and other contaminants are likely to concentrate. The places most critical include the Bering Strait, the edge of the Alaskan Coastal Water and the Anadyr Strait, and leads in the ice across the northern Bering Sea and in front of the seabird cliffs.

Seabird habitat

We know that water masses from the Bering Sea move north through the Bering Strait and into the southern Chukchi Sea. This guarantees that any materials introduced into the marine system to the south will be swept north and funnelled through the Strait, past the major seabird cities at Saint Lawrence Island, King Island and the Diomede Islands. Any contaminants moving north through the region have the potential of affecting the astronomically large populations of marine birds and mammals and the food webs.

The convergence of the Bering Shelf Waters with the Alaskan Coastal Waters along a line from the eastern edge of Saint Lawrence Island to Cape Prince of Wales ensures that spilled oil or contaminants will gather along this line as does drifting ice in spring. The seabirds migrating along this line in spring and feeding along the convergence later in the season will be maximally vulnerable to the contamination.

Of paramount significance is the fact that from mid-August to early November a major migration of flightless murres with their chicks moves through the Bering Strait and the straits east and west of Saint Lawrence Island, to the edge of the Continental Shelf. These birds will be extremely vulnerable to the presence of contaminants on the surface of the sea and in the water column, so contaminants in the northern Bering Sea at this time of year could have far-reaching effects on the murre populations from Saint Lawrence Island to Cape Lisburne.

Port Clarence is the only deep water harbor north of the Aleutian Islands. Because of the protection Port Clarence affords, one can presume that staging and refueling facilities will be developed for large ships waiting for the ice to clear at Point Barrow. Serious implications of development in the Port Clarence area are the dangers of contamination of the major seabird cities on King Island and the two Diomede Islands. According to Barton (1978), Port Clarence supports a locally abundant and diverse finfish population. Waterfowl breed on Point Spencer's thaw ponds and salt marsh pans and moderate numbers of geese migrate through the area. Thousands of Snow Geese and Sandhill Cranes migrate across this area in spring to breed in Siberia and return in the fall.

The seabird populations in Norton Sound are small relative to those in the Bering Strait at Saint Lawrence Island, King Island and the Diomedes, so direct exposure to contaminants would not have as "important" an effect in reducing the region's population as a whole as would exposure of seabirds in the Strait. Because Norton Sound water is not as heavily influenced by the main northward movement of water in the Bering Sea it is unlikely that pollutants moving toward and through the Strait will have much of an effect on the populations in Norton Sound.

Onshore winds in Norton Sound in the summer will threaten coastal habitats with surface-borne contaminants. Oil (or other material) in front of Bluff Cliffs would get to all the birds on the water in front of the cliffs; at times many tens of thousands of birds gather there.

Waterfowl habitat

The shores of the Seward Peninsula provide important or critical habitat for shorebirds and waterfowl migrating, resting, feeding, and breeding, from May through October (see Section VII D.). Especially important are the shallow bays, tidal flats, salt marshes, river mouths and lagoon and estuarine systems; these areas may be subjected to dredging operations associated with mineral explorations and secondary developments. In these places contaminants (oil, for instance) cannot be blown or washed away easily; they must be chemically degraded if they are to be removed. Contamination of these areas could have catastrophic effects on shorebirds and waterfowl using these areas as breeding and feeding habitat before undertaking long distance migrations to their wintering grounds. Fish populations using them as spawning grounds or "nursery" grounds (as used by Arctic Cod), and fishery resources on which the fish-eating seabirds (cormorants, kittiwakes, Common Murres, puffins) depend will similarly be seriously affected.

Waterfowl and shorebirds habitually congregate at certain kinds of preferred habitat; these habitats are not evenly dispersed over a wide area. Aggregations of waterfowl usually move from place to place from season to season from year to year. A number of independently varying forces and processes combine to make their habitat attractive; they gather in those places where a maximum number of forces are favorable. At any one time waterfowl and shorebirds can survive in some, not in most of their habitat. Consequently, redundancy of habitat is critical to increase the odds of survival of the populations that use it.

Developmental activities, which threaten to disturb waterfowl or degrade essential habitat include the filling of wetlands, draining, polluting or simply disturbing birds on their breeding sites, contamination of river mouths, in addition to increased hunting and disturbance discussed previously.

Reductions in the total area of tundra and coastal lakes as a result of development reduce the odds that suitable habitat will be available, even though only a portion of the tundra and a few lakes are used in any year or season. Developers may argue that when only a portion of available habitat is used occasionally by wildlife, any one portion of the region is not critical; but, loss of key areas and of habitat redundancy increases the odds of population reduction and makes it less likely that a population, once reduced, will readily regain its previous abundance.

In this situation, the effects of the depletion of habitat can be mitigated by the control of some of the varying forces that make habitat attractive or unattractive; such as control of water levels in the remaining lakes and ponds. To the degree that a population might come to depend on such management, it is partially domesticated. Such partial domestication of wildlife may be a cost of mineral development, but should be acknowledged and undertaken nevertheless.

4. Population changes, decreases and recovery

In their "normal" state of nature, populations may vary dramatically through time and space without interference by man. We know this to be true of the seabirds, shorebirds and waterfowl inhabiting the Bering Strait Region. Some populations, most notably Black-legged Kittiwakes, may experience years of reproductive failure alternating with years of exceedingly high reproductive success. Seabirds are long-lived, and as a consequence their populations have large components of older, experienced birds. A population may experience years of reproductive failure without the evident decline that would be manifested in populations of short-lived species (Ashmole, 1971). Effects on the population may not be evident for a number of years, and the structure of the population may be seriously affected before any numerical shifts are detectable.

We are uncomfortable with the concept of "recovery" of a population that has experienced a decrease in size. Although the growth of populations may be slowed as their density increases, there is no necessary corollary that their growth is stimulated by low densities. Local populations are in flux, and some may dwindle; the "population" may be maintained by immigration of individuals from other areas where there is a population surplus and hence emigration.

We also feel uneasy about blanket statements about "negative impact on ecosystems" or "damage from which ecosystems recover." As mentioned earlier, no single species is a critical element of the system. Often, negative effects on one species in the system will be associated with positive effects on another. For instance, scavenger species such as Glaucous Gulls, Glaucous-winged Gulls, Ravens, Red and Arctic Foxes will enjoy expansion in habitat provided by the subsidy of human settlements (especially open dumps and solid waste disposal). We can predict population increases in these species, as well as in introduced species such as dogs, cats and rats. These species (along with the already-present population of small boys with rifles) potentially pose a greater threat to other wildlife surrounding human settlements than at present. The increase in gulls and Ravens will be accompanied by important biological problems; first in the cases where these predators displace other less aggressive species such as raptors (Peregrines and Gyrfalcons) from their nest sites; second in cases where their predation on seabird and waterfowl young will be intensified; third in cases where Glaucous-winged Gulls meet and hybridize with Glaucous Gulls in the Yukon-Kuskokwim Delta.

C. Concluding Remarks: Common Property Resources, Wildlife and Private Property Rights

Waterfowl, seabirds and other wildlife are the property of all Americans, and the habitats critical to their survival should not be subject to the whims of private owners to use or misuse. Habitats where wildlife breed, gather on migration and over-winter should be given special status within the broad concept of private property rights claimed by all Americans.

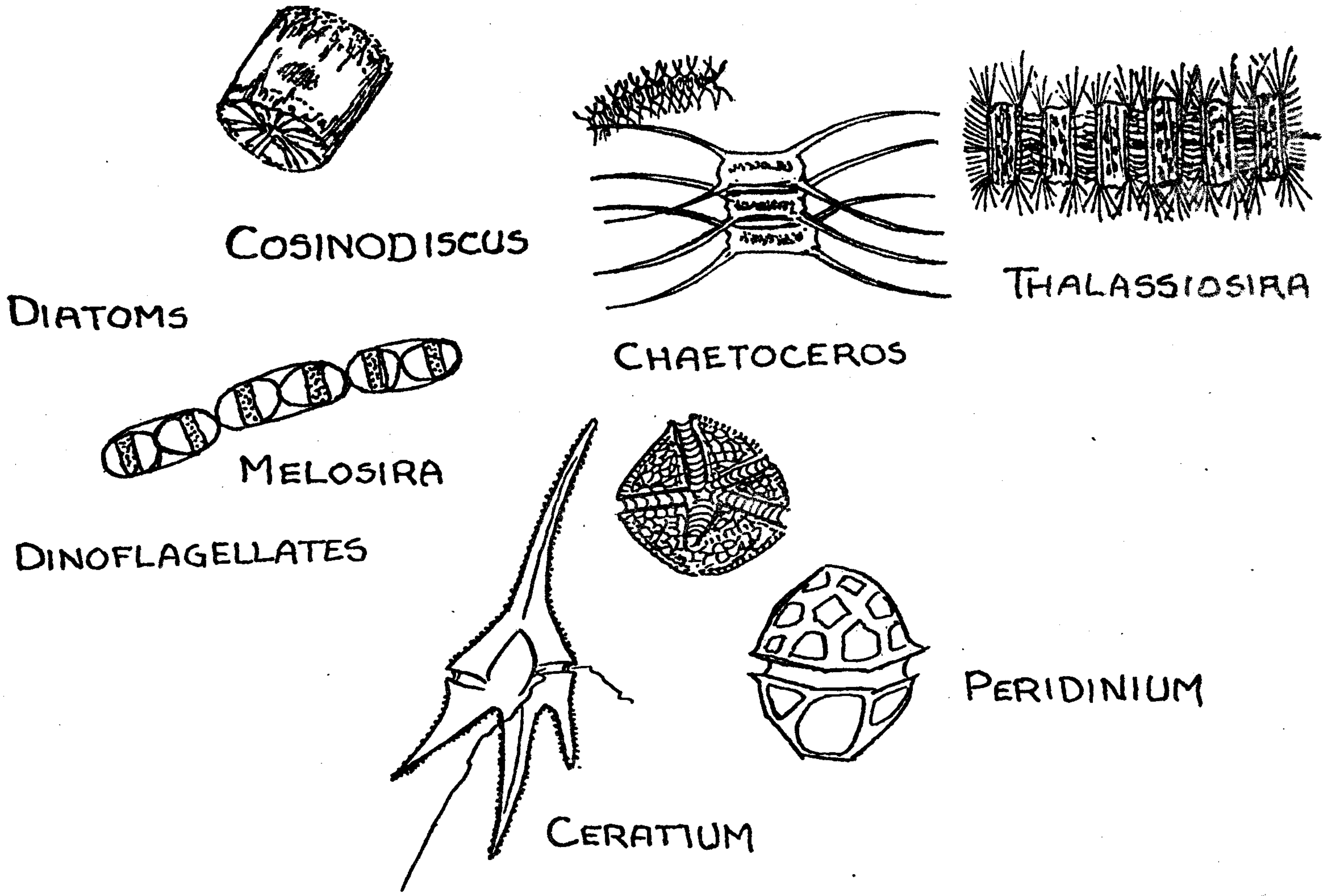
As the human population on the Seward Peninsula grows it will be necessary to establish large areas that support reservoirs of breeding wildlife populations which can export croppable surplus. Equitable resolutions will be needed for the conflicts which develop between non-consumptive uses, including the long-term needs of population and habitat maintenance, the consumptive needs of hunting for recreation or for subsistence, the non-consumptive uses of another segment of the American population, and the land claims of natives.

One of the major problems we anticipate is the conflict between "private" property rights and the requirements of "common property" resources such as wildlife. Because Eskimos were originally hunters and food gatherers, traditional village sites were at seabird cliffs, waterfowl habitats, or at sites convenient for hunting marine mammals; that is, they were at the best wildlife concentrations where obtaining food was easiest. As a consequence there exists a general and direct conflict between Native Land Claims and the needs of wildlife.

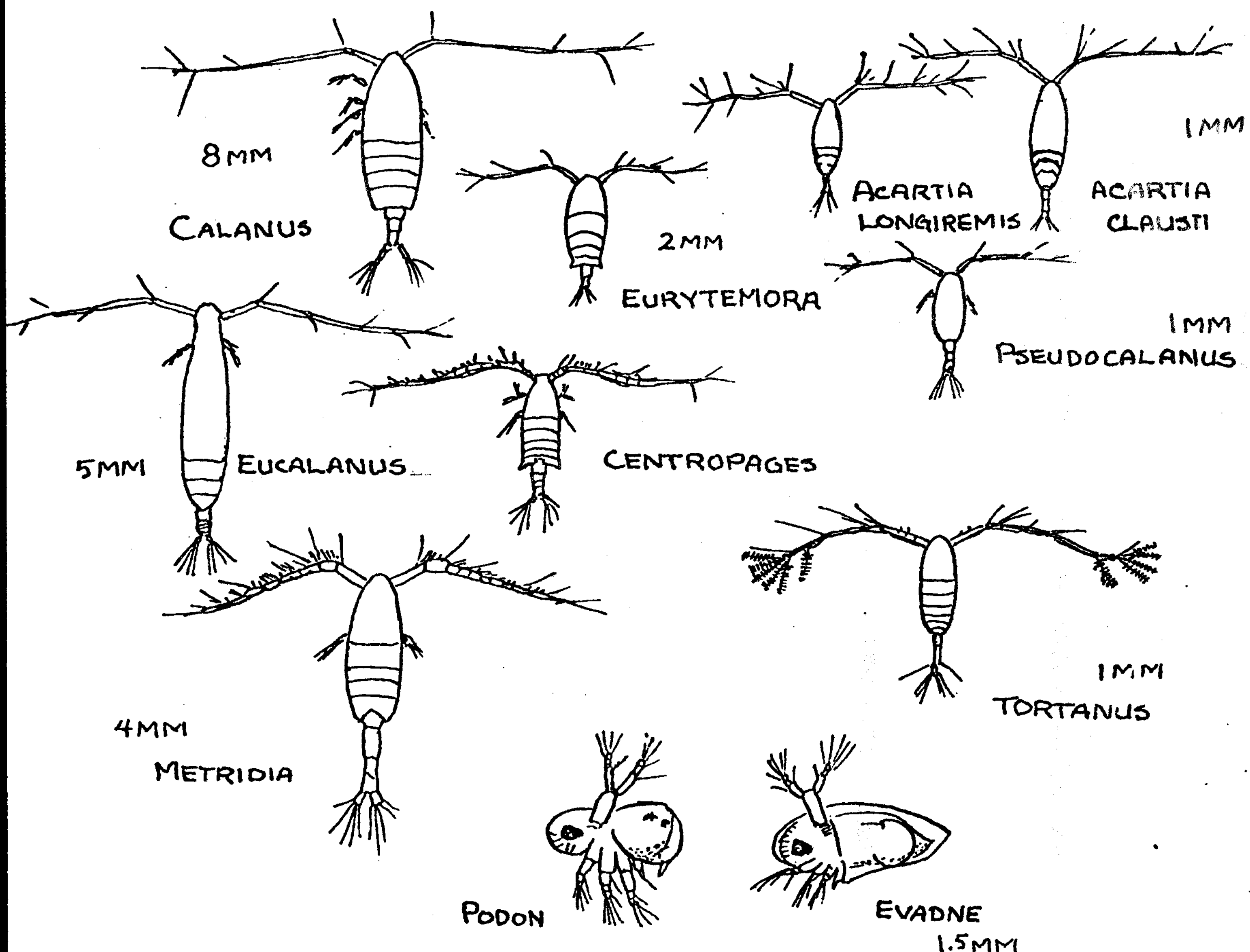
Our research has led us to conclude that a) the major seabird cliffs in our study area, such as those at Saint Lawrence Island (east and west of Savoonga, on Sevuokok Mountain and between Owalit Mountain and Singikpak), as well as King Island, Little Diomede Island and the cliffs at Bluff and Cape Denbigh, deserve special recognition as a public resource. (We omit the cliffs at Cape Thompson and Cape Lisburne which already have some protection). b) The wetlands of major importance as waterfowl and shorebird habitat include the Woolley Lagoons, the lower reaches and mouths of the Flambeau, Eldorado and Bonanza Rivers including Safety and Taylor Lagoons, the mudflats of the Fish River and Golovin Lagoon, the distributory fans of the Koyuk and Inglutalik Rivers, and the lowlands and marshes north of Moses Point along the lower reaches and mouth of the Kwik River. These areas also deserve public recognition so that access is not in the hands of an elite segment of the American public and so that they cannot be destroyed at private whim or as the result of a single corporate decision. Easements or other formal arrangements are needed so that the fate of these areas, which are small geographically but which are indispensible to the waterfowl, shorebirds and seabirds of major international significance are not given over into private ownership in "fee simple."

- PLATES 1-8 -

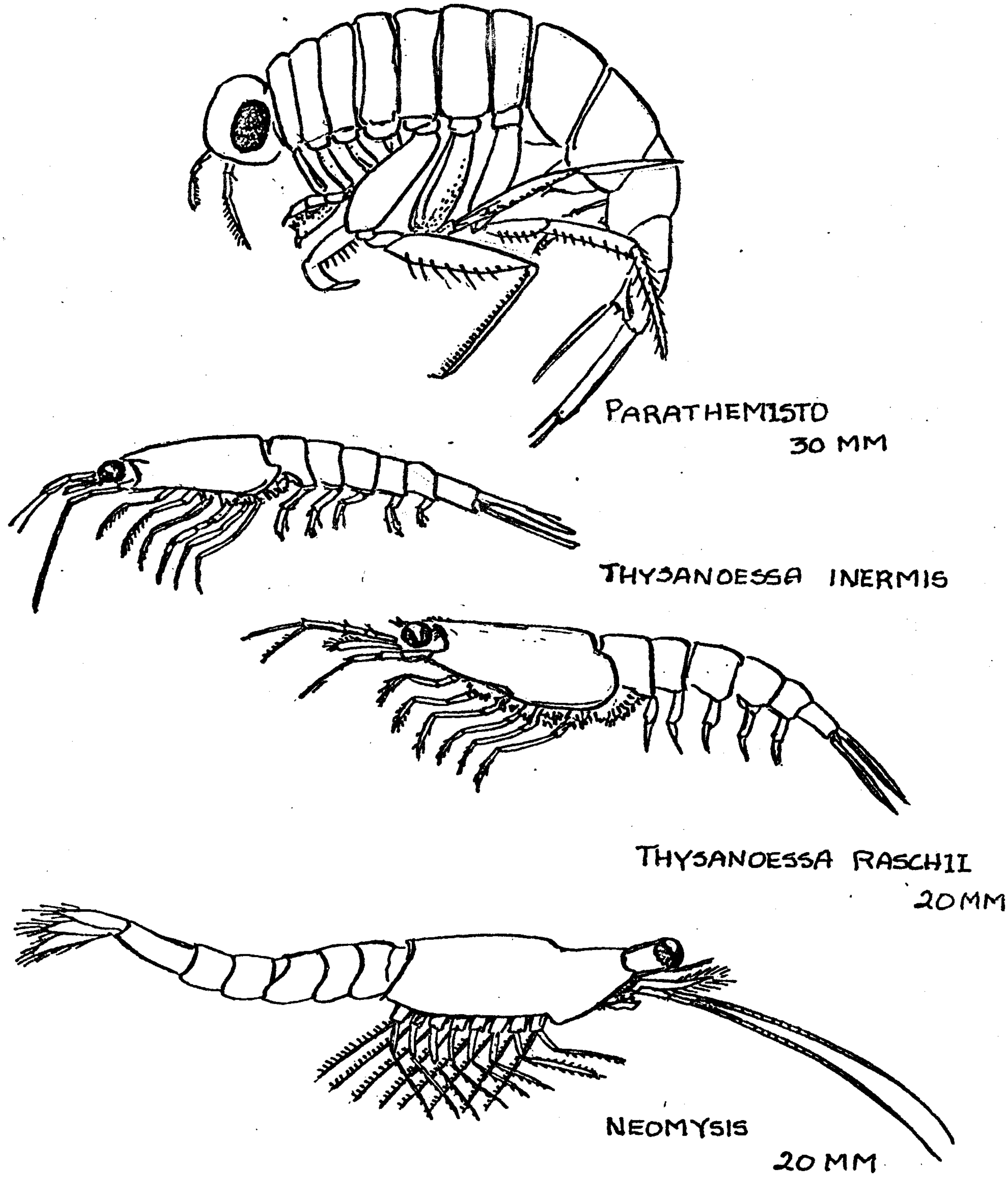
The following illustrations are pictures of species that have received special notice as important members of the marine communitiy of the Bering Strait Region.


COSINODISCUS
CHAETOCEROS
THALASSIOSIRA
DIATOMS
MELOSIRA
DINOFLAGELLATES
PERIDINIUM
CERATIUM

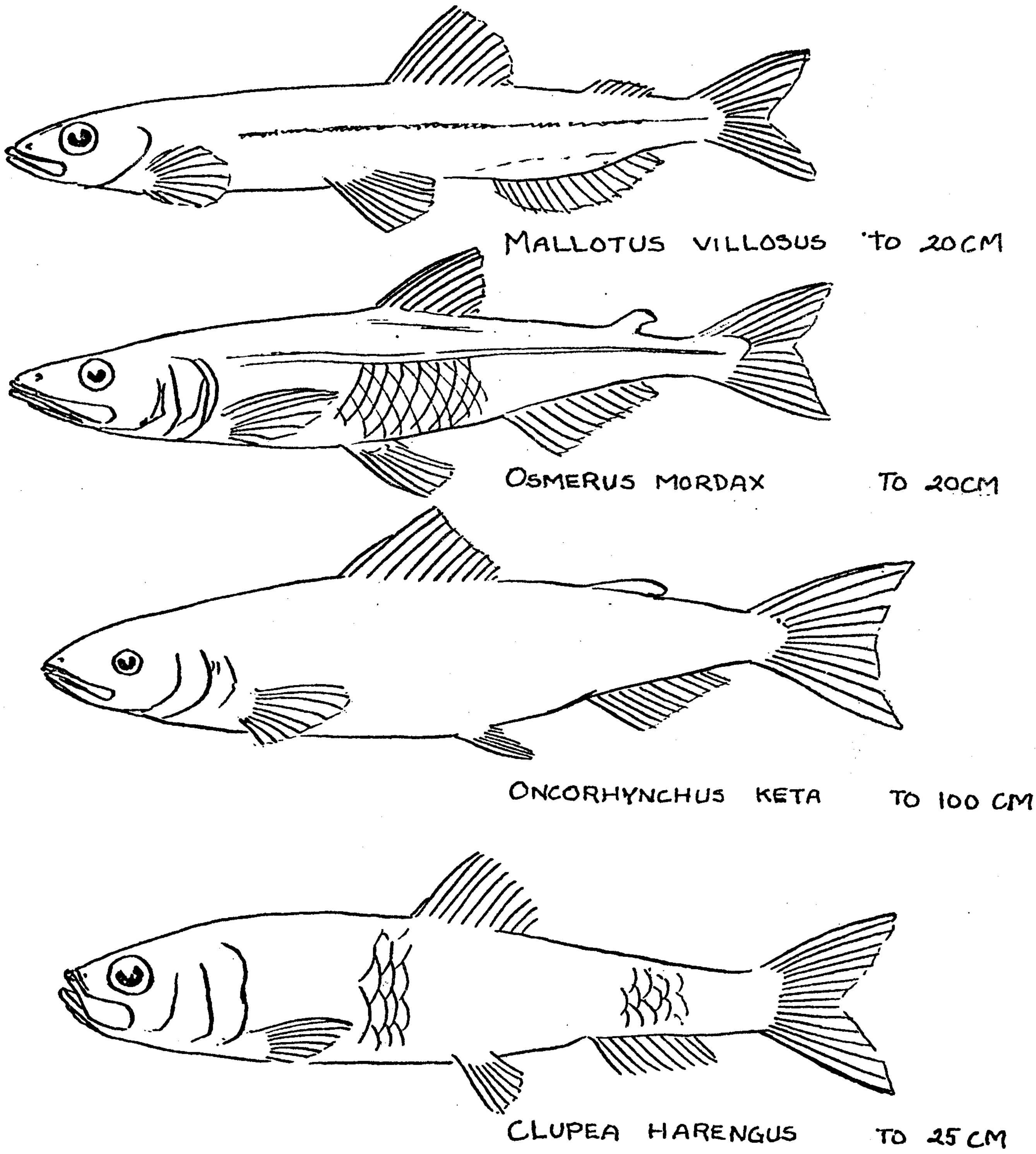
– PLATE 1 –


8 MM
CALANUS
2 MM
EURYTEMORA
ACARTIA
LONGIREMIS
ACARTIA
CLAUSII
1 MM
1 MM
PSEUDOCALANUS
5 MM
EUCALANUS
CENTROPAGES
1 MM
TORTANUS
4 MM
METRIDIA
PODON
EVADNE
1.5 MM

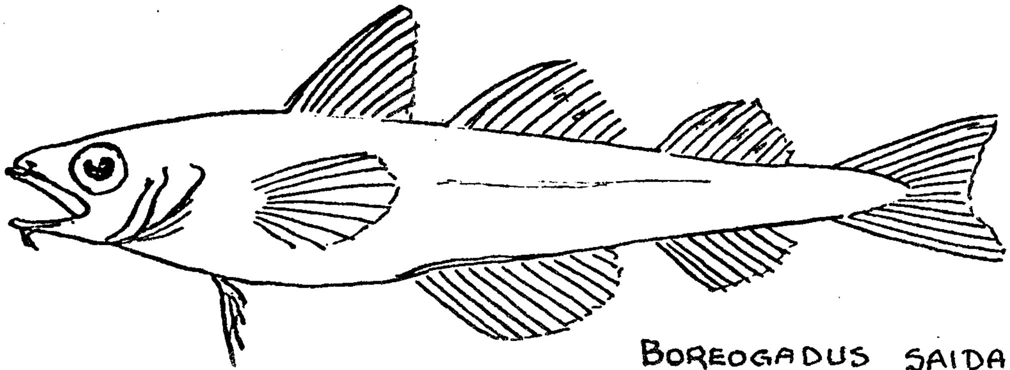
– PLATE 2 –


PARATHEMISTO
30 MM
THYSANOESSA INERMIS
THYSANOESSA RASCHII
20MM
NEOMYSIS
20 MM

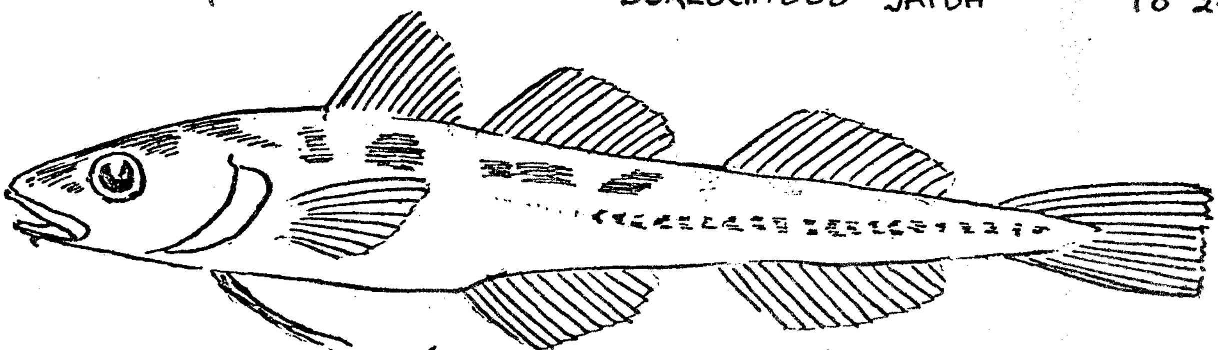
- PLATE 3 -


MALLOTUS VILLOSUS TO 20CM
OSMERUS MORDAX TO 20CM
ONCORHYNCHUS KETA TO 100 CM
CLUPEA HARENGUS TO 25 CM

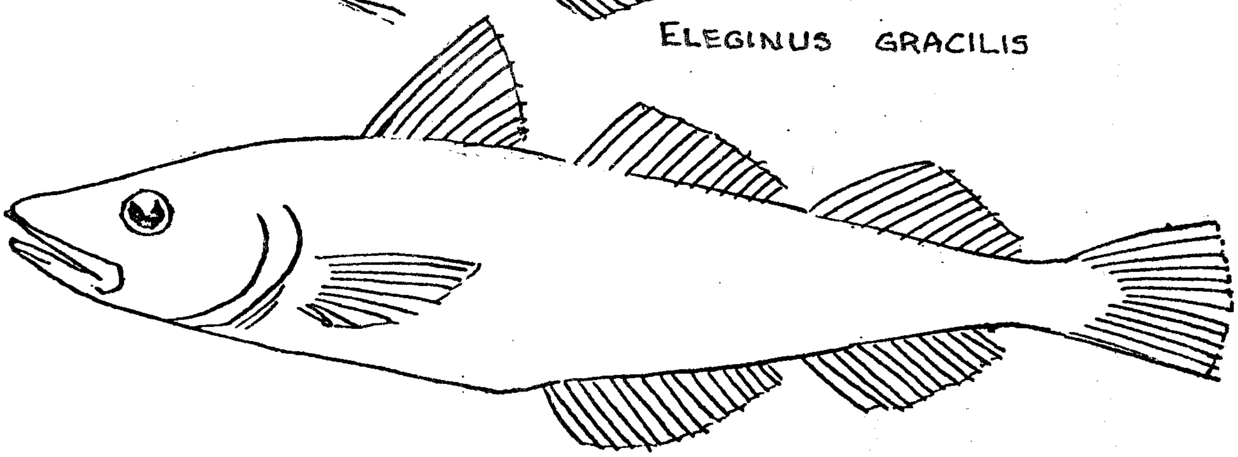
– PLATE 4 –



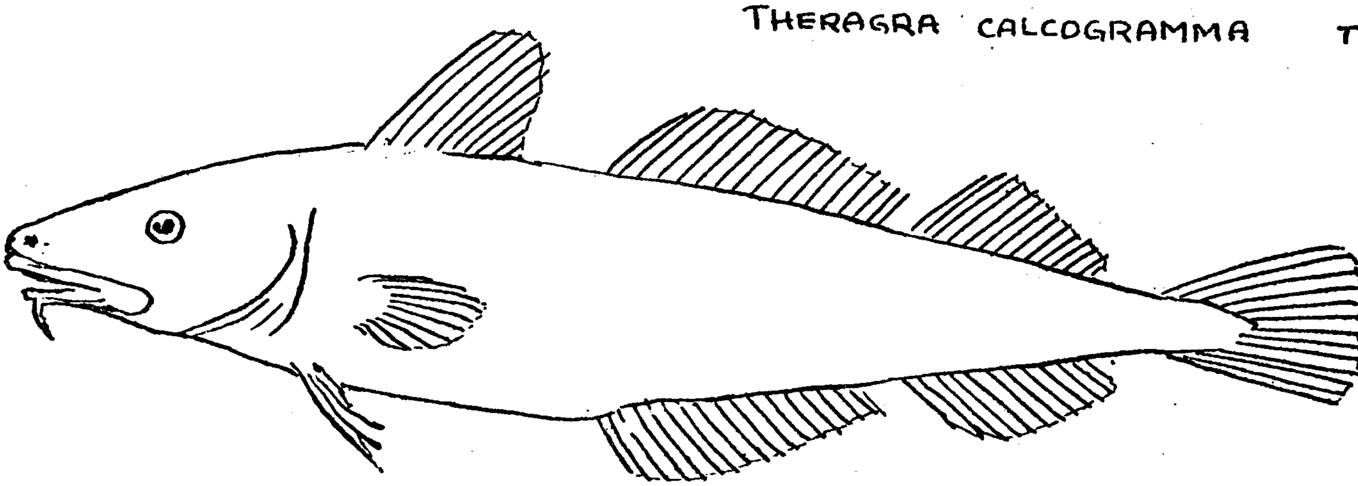
BOREOGADUS SAIDA TO 25 CM



ELEGINUS GRACILIS

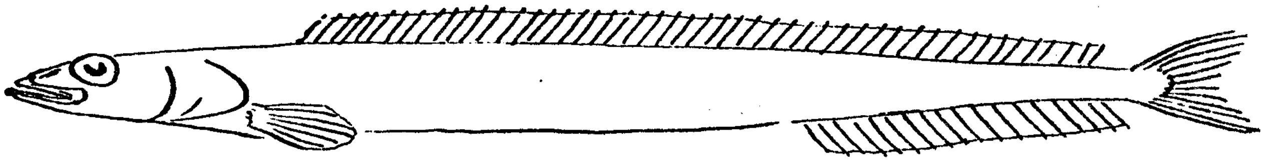


THERAGRA CALCOGRAMMA TO 90 C

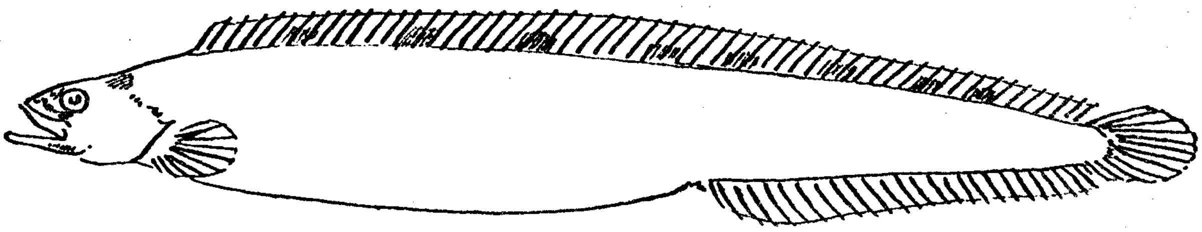


GADUS MACROCEPHALUS TO 100 CM

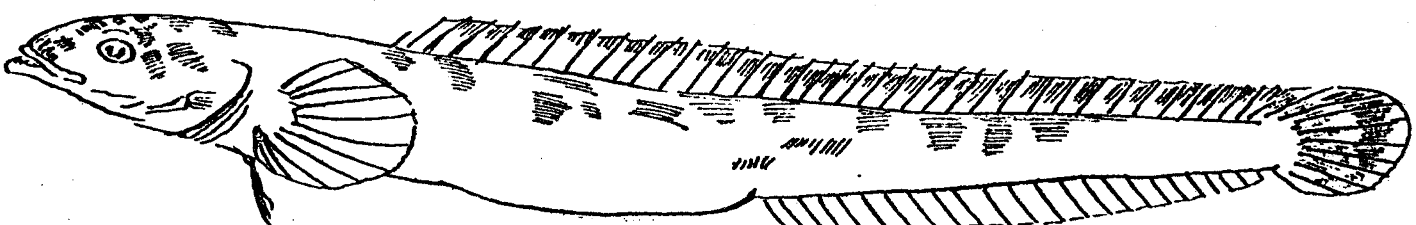
- PLATE 5 -



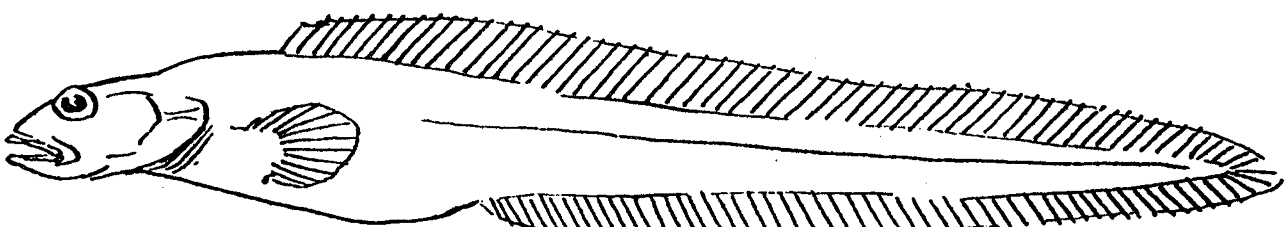
AMMODYTES HEXAPTERUS TO 20 CM



PHOLIS GUNNELLUS TO 20 CM

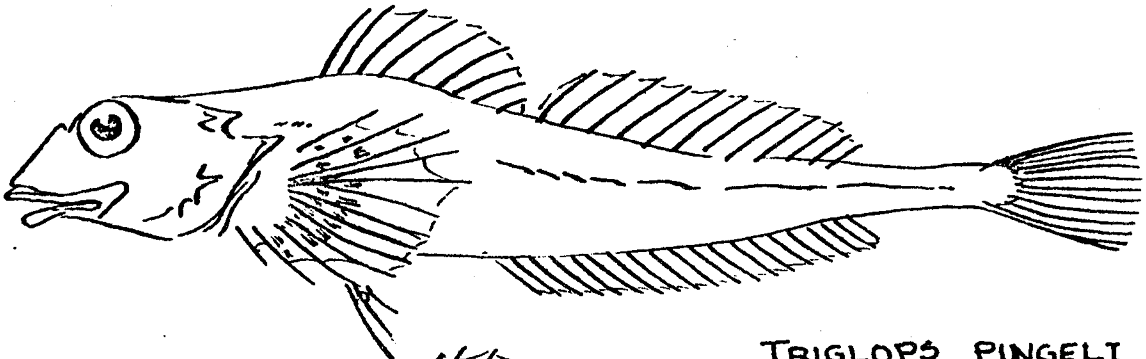


LUMPENUS FABRICII TO 25 CM

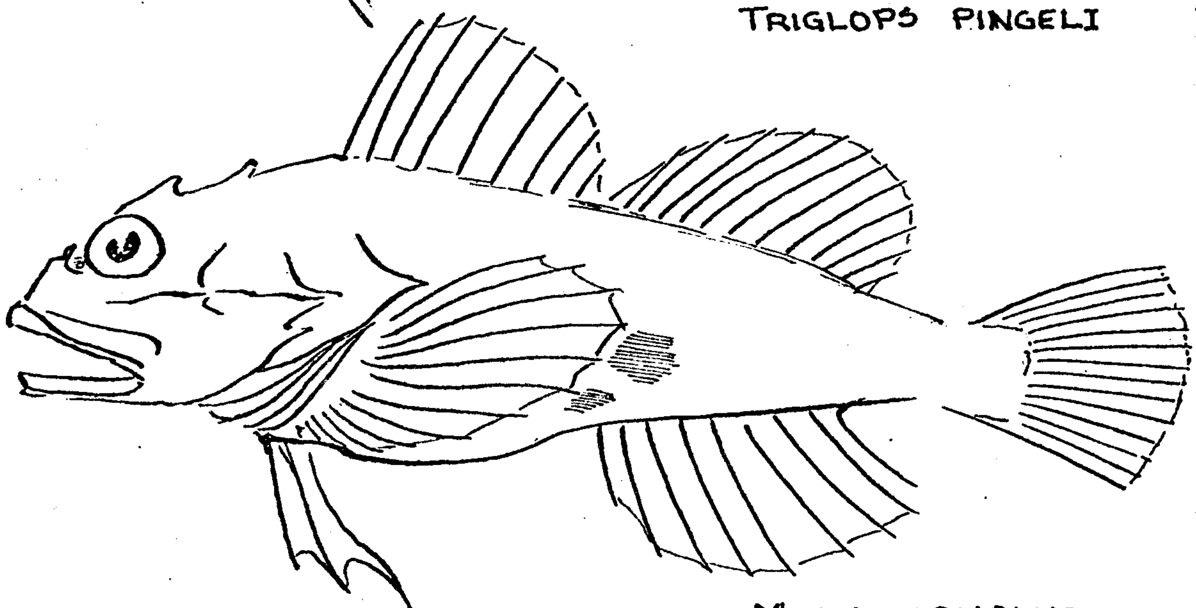


GYMNELIS VIRIDIS TO 20 CM

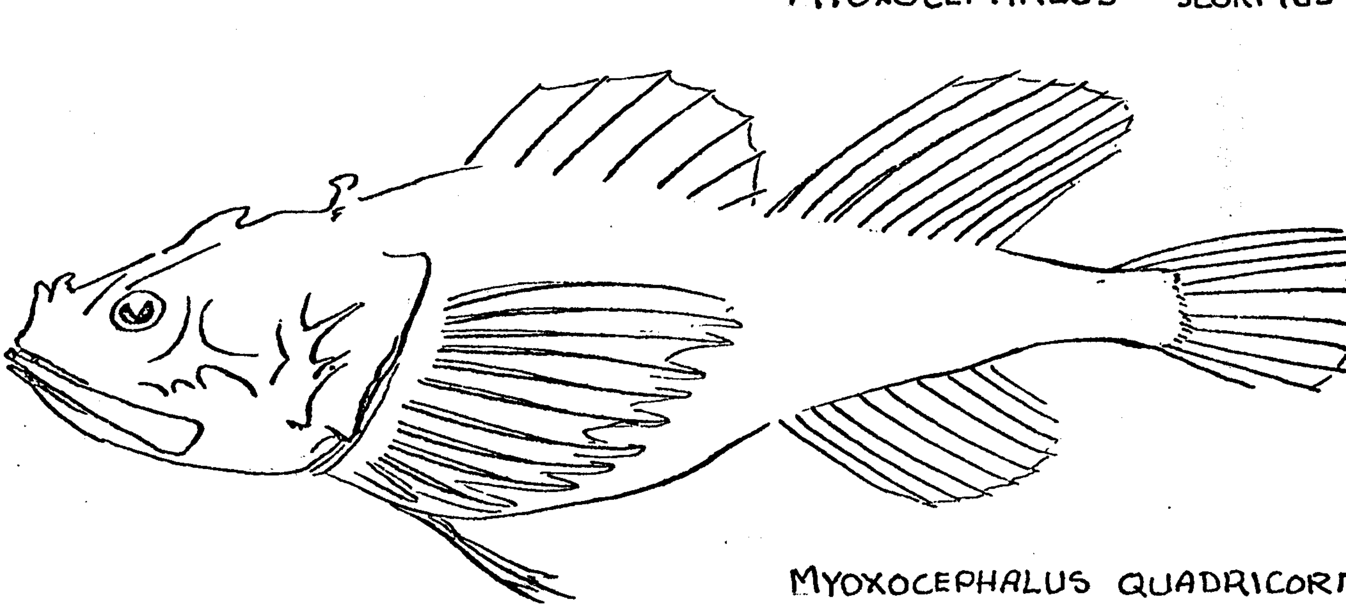
– PLATE 6 –



TRIGLOPS PINGELI TO 15 CM

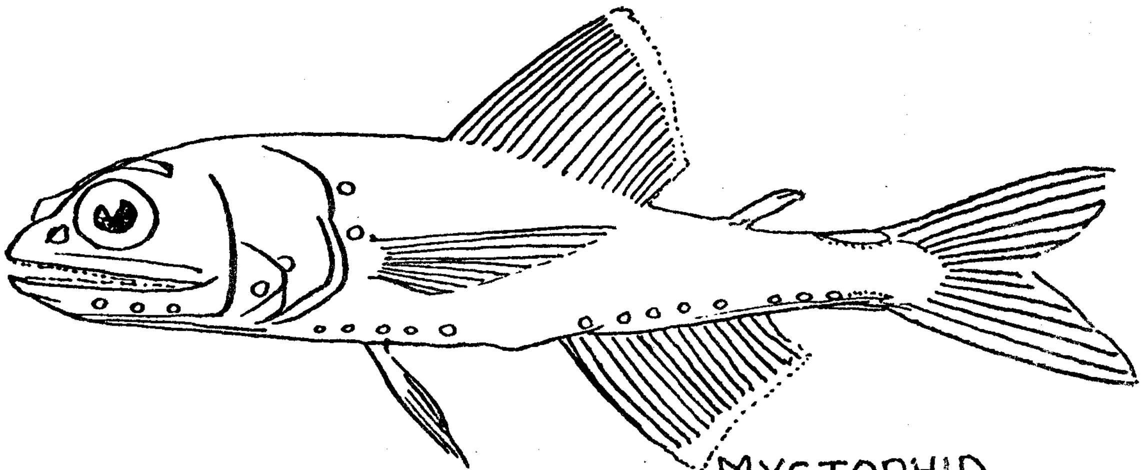


MYOXOCEPHALUS SCORPIUS TO 50

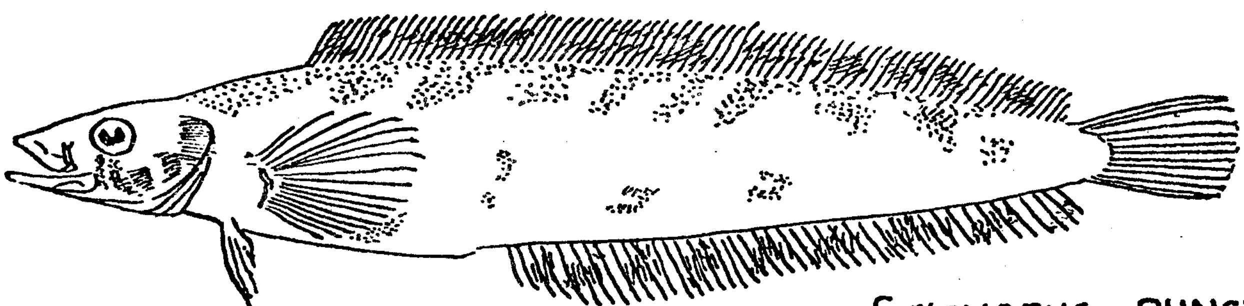


MYOXOCEPHALUS QUADRICORNIS TO 25 CM

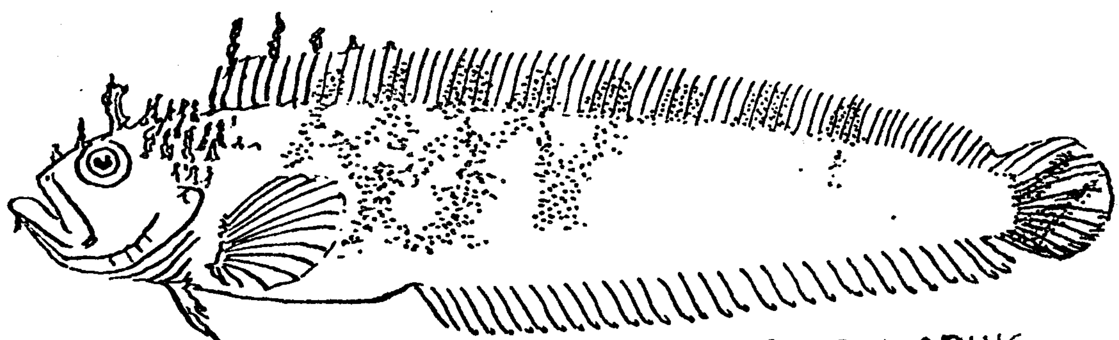
- PLATE 7 -



MYCTOPHID
TO 15CM



STICHAEUS PUNCTATUS
TO 15CM



CHIROLOPHIS
TO 40 CM

- PLATE 8 -

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FINAL REPORT

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THE RELATIONSHIPS OF MARINE MAMMAL DISTRIBUTIONS, DENSITIES AND ACTIVITIES TO SEA ICE CONDITIONS

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The Relationships of Marine Mammal Distributions, Densities and Activities to Sea Ice Conditions

I. INTRODUCTION

This study began with the knowledge that some relationship exists between the annual cycle of movements and activities of marine mammals that inhabit the seasonal ice zone of the Bering, Beaufort and Chukchi Seas and the characteristics in space and time of the ice cover itself. The observation that these mammals are adapted to the various configurations of the pack ice as it changes through the year further implies some degree of regularity and repeatability in the distribution and features of the ice. It is logical to expect such repeatability because the environmental factors which form the ice and cause it to move and deform are generally cyclic or recurrent. The seasonal temperature cycle is the most obvious of these. Prevailing winds are repetitive by definition, and ocean currents tend to be consistent on the average. Finally, the ice in motion intersects immovable coastlines and islands which have constant shapes. These factors interact to form the features of the ice cover. To the extent that the contributing factors are repetitive and predictable, the same should be true of the marine mammals as well.

That each species of marine mammal residing in the ice-covered zone has a distinctive and predictable annual cycle of movements and activities, timed to coincide with specific characteristics and events of the ice itself, is a very old concept. The Eskimos of western and northern Alaska have been acutely aware of it for thousands of years. Every male resident of every Eskimo community on the coast was schooled in understanding the perpetually changing ice conditions of local areas and the ways in which these were related to the presence and absence of the different species of seals and whales. For it was of vital importance to know the ice, the effects of weather on it, and the influences of both ice and weather on the marine mammals that they hunted for food, clothing, and other raw materials essential to their existence.

The perception by these coastal people of the relationships of marine mammal distributions, densities, and activities to sea ice conditions was (and still is) understandably more local than regional, by reason of the limited mobility of the hunters. But it was more extensive than one might expect, for these people did travel out into the ice by boat within about 30 miles of their villages and ranged widely along the coasts by dog sledge. They climbed the local mountains, promontories, and ice ridges for a better overview, and they learned to interprete the reflections ("ice blink") on the clouds, as well.

Much of the lore and art of judging local ice conditions and relating them to availability of marine mammals still is utilized by modern Eskimos in coastal Alaska, for they continue to be dependent to a considerable degree on that mammalian resource for food and income. Utilizing some of their lore, together with personal experience, data from aerial surveys, and reports from Soviet sealers, Burns (1970) compiled the first broad overview of the associations of Bering-Chukchi pinnipeds with the seasonal pack ice, pointing out the general, regional pattern of their distribution in relation to specific ice zones. Drawing on similar sources, Fay (1974) summarized the "state of art" up to the winter of 1971-72 as regards the dynamics of this seasonal ice sheet and the ways in which the northern seals and whales are adapted to and make use of it. These were pioneering efforts, based more on intuition and logic than on objectively gathered data, for we did not have at that time the marvelous synoptic views from earth-orbiting satellites or the benefit of extensive, repetitive aerial and shipboard surveys, the data from which are now available in profusion.

Data on the extent and characteristics of the seasonal sea ice, relative to marine mammals, were first obtained in the 1950's and 60's during aerial surveys, small boat operations from shore, and multidisciplinary oceanographic cruises. Broad-scale, synoptic views became available from ERTS imagery, starting in 1972, from DAPP in 1973 and from NOAA/VHRR in 1974. Thus our analyses of characteristics of the ice habitats were based on data from several scales of observation: high and very high altitude satellite imagery, low altitude aircraft surveys, observations from ships, and surface observations from small boats and afoot on the ice.

Distributions of marine mammals were determined through a series of aerial surveys conducted intermittently from 1958 to 1979 and from shipboard expeditions in 1968, 1970-1973 and 1975-1979.

Data from aircraft and surface observations of ice were qualitative and included general descriptions of extent, relative thickness and size of floes, amount of snow cover, extent of rafting and deformation, and proximity of open water. These surface and near-surface observations were compared with characteristics apparent in satellite imagery obtained during the same time periods.

The first detailed overall views of the seasonal pack ice of western and northern Alaska from satellite imagery became available in the winter of 1972-73 from the U.S. Air Forces' DAPP system. About the same time, more restricted views but with finer resolution became available from the National Aeronautics and Space Administration's ERTS systems. The imagery from these and from subsequent systems tended to confirm the speculations by Fay (1974) of a general north-south movement of the seasonal pack in the Bering-Chukchi region (Shapiro and Burns, 1975a, 1975b; Muench, 1974) and related that movement to prevailing northerly winds (Muench and Ahlnas, 1976). The imagery from these systems also disclosed patterns of lead and flaw formation, convergence, and divergence that showed promise of helping to explain some of the distributional problems faced by marine mammals and to answer some of the questions concerning the reasons for their concentration in certain parts of the pack.

The work reported here was conceived in 1975 as an extension of our earlier investigations. Its goal was to determine more definitely which marine mammals of the pack ice zone might be affected by proposed exploration and development of petroleum resources of the outer continental shelf of the Bering, Chukchi, and Beaufort seas. Insofar as possible, we would try to determine how and to what extent they might be impacted. Our specific objectives were to determine (a) the characteristics, distribution, and extent of the sea ice habitats utilized by marine mammals, (b) the distribution and relative densities of mammals in those habitats, and (c) the major biological events in the lives of those mammals that are linked to their use of the ice. Recognizing that both the seasonal and the "permanent" packs vary in extent and quality from year to year, we sought to develop predictive ability for identifying the areas of critical importance to these mammals at any time, through interpretation of high altitude satellite imagery.

The opening section of this report is a general overview of the subject. Its purpose is to provide a synoptic view of the basic seasonal variations in ice conditions and marine mammal distributions, before describing specific aspects of them in greater detail. The system of ice and associated mammals is never static. During winter and early spring, when the ice cover is at or near its maximum, the marine mammals are dispersed throughout it in specific habitats from the southern edge in the Bering Sea to the consolidated pack of the Arctic. As the spring retreat of the ice begins, so do the migrations of the mammals. The previous associations of each species with specific winter ice habitats change or break down entirely. During the retreat of the pack, discrete masses of ice referred to as "remnants" occur regularly in the Bering Sea and sporadically in the Beaufort and Chukchi Seas. These provide important habitats at times when the pack per se is absent. In the summer months when the pack ice is at its minimum the populations either become pelagic in the open sea, move inshore, or are concentrated along the edge of the ice. As the ice advances southward in autumn, the populations either precede it or remain associated with its fringes. Finally, they disperse once again into their wintering areas.

The general plan of the report follows the cycle outlined above. After the overview, the distribution of potential habitats in the winter pack ice is analyzed in detail. This is followed by a description of the fast ice, and then the fringe and front zones. The origin and distribution of the remnants is then described to complete the discussion of ice habitats. Throughout these sections, the utilization of each habitat by marine mammals is described. Finally, all of the above are discussed in relation to the locations of recognized sedimentary basins on the continental shelf which constitute potential OCS lease areas. The potential effects of development in those areas on the ice-associated marine mammal populations is included.

Ice terminology used in this report, insofar as possible, follows the WMO Sea-ice Nomenclature: Terminology, Codes and Illustrated Glossary, WMO/OMM/BMO No. 259, 147 pp., published in 1970 by the World Meteorological Organization.

II. GENERAL OVERVIEW

A. Introduction

The ice that covers the polar seas differs substantially from that of most fresh water bodies in that it generally is not smooth and continuous but rough, highly variable in quality, and usually interspersed with cracks and other openings (e.g. see Armstrong and Roberts, 1956). Also it generally is weaker and more flexible than freshwater ice, largely because of the brine trapped within it (Weeks and Assur, 1967). The mammals that inhabit the ice-covered areas also are not uniformly distributed there, for each species has its own distinctive habitat requirements. For the most part, their distribution is determined by the juxtaposition of ice of the "right" type over their feeding grounds and by their ability to make and maintain holes through that ice (Burns, 1970; Fay, 1974). The ice itself is a major barrier between the two parts of their environment: the water in which they obtain their food, and the air that they must breath for oxygen to metabolize that food. Those mammalian species that are incapable of making holes through the barrier, or have limited ability to do so, are obliged to reside in the open sea or in parts of the ice sheet where natural openings are dependably present.

For the mammals that have adapted to this barrier, the ice serves many functions, such as a substrate on which to rest, molt, and bear young. As such, it may offer several advantages over the use of shorelines for these functions, because it is closer to the food supply, more remote from predators, more sanitary, and more spacious (in terms of available "shoreline") (Fay, 1974). It also may provide them with shelter from the weather and, incidentally, transportation to new feeding grounds. It is an integral part of their environment and one which is in large part responsible for their great abundance and diversity.

The relationships of these mammals to ice and their level of dependence on it vary seasonally as the ice itself changes in extent and quality. In the following sections of this report, those relationships and dependencies will be described in some detail. By way of introduction, a brief overview of the annual cycle of events on a regional basis is essential, to set the stage for the more detailed considerations to follow.

B. Winter

The winter pack ice is a highly dynamic ice sheet, which interacts to a significant degree with the adjacent continents and islands. Driven principally by northerly and northeasterly winds, it tends to move southward, pushing against the northern coasts of Alaska and Chukotka, forming extensive masses of jumbled, grounded ice inshore. A portion of the Chukchi pack extrudes southward through Bering Strait, into the northern Bering Sea (Shapiro and Burns, 1975a). There, its further southward progress is impeded by St. Lawrence Island, which lies directly across its path. Part of that ice piles up in a deep, dense, more or less triangular mass against the northern side of that island, while the remainder makes its way along the courses of least resistance, around the eastern and western ends, (Shapiro and Burns, 1975b). Once past this barrier, the way is mainly clear for it to continue southward into the central Bering Sea (Muench and Ahlnas, 1976).

Of course, not all of the ice in the Bering Sea is derived from the Chukchi; most of it originates in the Bering itself, especially in the Gulf of Anadyr, in Norton Sound, south of St. Lawrence Island, and in the Nunivak Island to Bristol Bay region. The generation of new ice in these areas takes place throughout the winter, also a consequence of the prevailing northerly winds. For, while the winds drive the pack against the northern coasts of the continents and islands, the same winds move it away from the southern coasts of those features. Thus, there tends to be persistent southward retreat of the Bering Sea ice from the southern coasts of Chukotka, St. Lawrence Island, the Seward Peninsula, St. Matthew and Nunivak Islands, and the Alaskan mainland from the Kuskokwim estuary to inner Bristol Bay (Figure 1). This creates large open water areas immediately to the south of these land masses, in which new ice continually is generated (Shapiro and Burns, 1975b; Muench and Ahlnas, 1976).

Where the moving pack is driven toward a strait between two land masses, it tends to be compressed. In these areas of convergence, such as Bering Strait, close packing and pressure ridging are dominant processes within the moving ice, while shearing occurs at its edges (Shapiro and Burns, 1975a, 1975b). To the south of such straits are zones of divergence, where leads and polynyas develop in profusion as the pack expands into areas of low or no compression. New ice quickly forms on the openings, adding further mass to the pack as it advances.

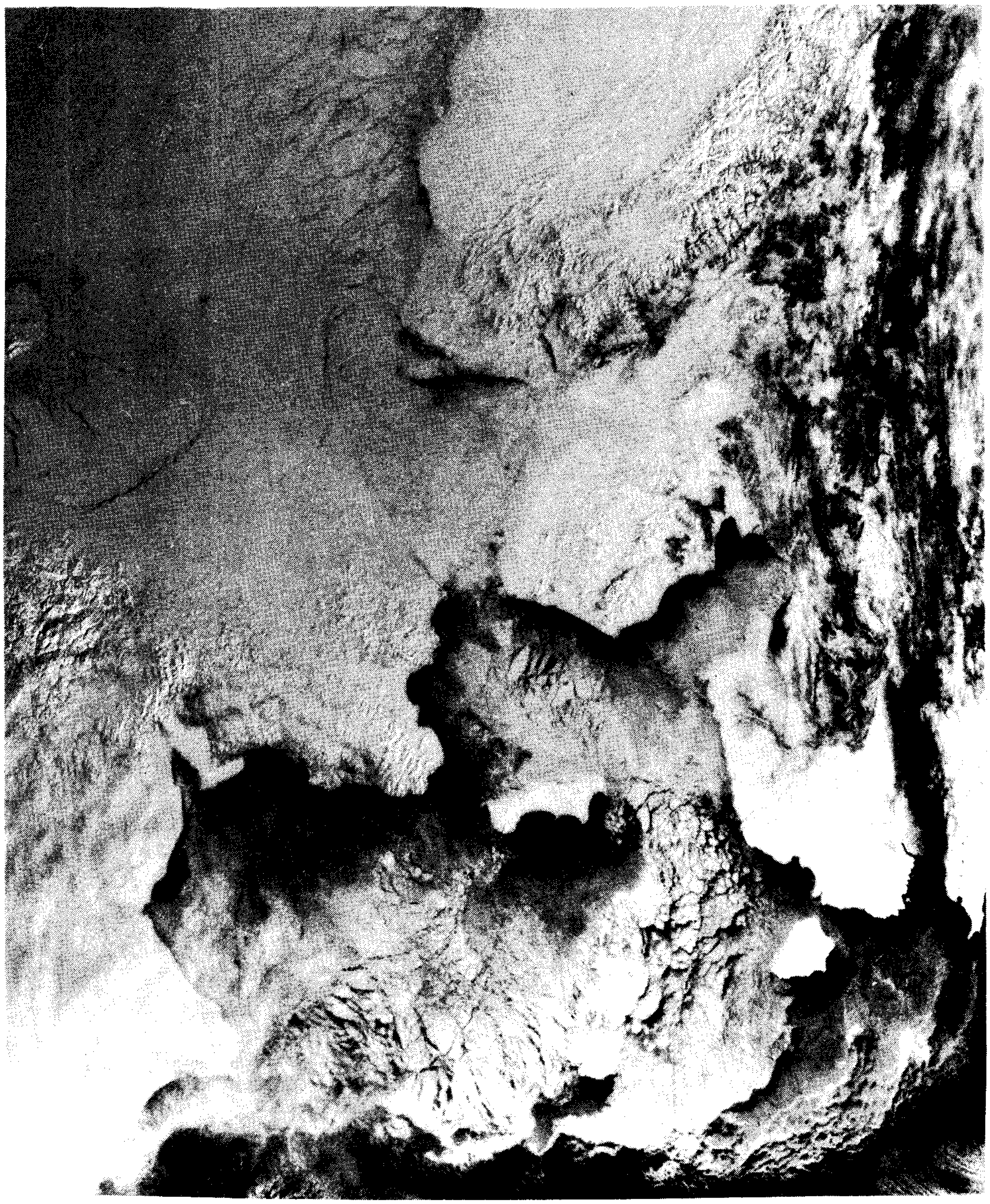


Figure 1. NOAA/VHRR visible band imagery of the eastern Bering and southern Chukchi Sea; acquired on 20 March 1978.

Nearer to shore, particularly in sheltered bays and to a lesser extent on the rest of the coast, locally formed ice freezes fast to the shore and, in shallow waters, to the bottom as well. This sheet of landfast ice extends out over the neritic waters, and at its outer edge interacts with the moving pack which may add to it or subtract from it, depending on the nature of the interaction. Between the stationary fast ice and the moving pack is a strip known as the "flaw", which, as the term implies, usually contains some open water. Depending on the rate and direction of movement of the pack, the flaw may be a lead as narrow as a few millimeters or a zone tens of kilometers wide in which case it may include a large amount of broken white ice and newly formed gray ice.

At its southern periphery, the pack tends to be open and made up of smaller floes than are found farther north. Tongues of broken and melting ice extend out into the open sea for several kilometers, beyond the edge of the consolidated pack. For several kilometers back into the pack from this southern "fringe" is a zone in which the floes are repeatedly subjected to vertical motion by ground swells from the open sea. This motion tends to break up the large ice fields into smaller floes and to create large amounts of brash in the interstices. We refer to this zone as the "front", a term borrowed from the North Atlantic sealers who have recognized for a long time that it is an important habitat for certain marine mammals.

Movement of the ice in the Bering Sea towards the north does occur during periods of cloudy weather, which are generally associated with winds from the south. However, the distance and rate of movement to the north are limited by lack of space, i.e. by the presence of immovable barriers (land masses) in the northern Bering Sea and by the increased mass of the pack through addition of new ice in the leads and polynyas. The result is a net transport of ice toward the south through the winter and early spring months. The average rate of north-south movement in March-April 1974, as determined by Muench and Ahlnas (1976) from satellite imagery, was about 15.5 km/day, which corresponds well to our own observations from icebreakers in March-April 1971 and 1972 in that area. If this is typical (as it seems to be), it means that ice in the vicinity of St. Lawrence Island would tend to reach the southern ice front after about one month of drifting during that period.

In the Bering Sea area, surface winds tend to be strongest and air temperatures lowest during February (Brower at al., 1977), and we presume that the rates of north-south movement, consolidation, and new ice formation are highest at that time in most years. Similar but slightly milder conditions prevail in March, but by late April and May, surface air and water temperatures and wind velocities over the Bering Sea usually ameleorate to the extent that production of new ice ceases.

The effect of all of these processes working on the winter pack in concert, is creation of a wide variety of pack ice habitats which occur with such regularity, year after year, that certain marine mammals have become adapted to them and can reliably be found in them. The principal general categories of these are: (1) fast ice, (2) persistent flaw, (3) polynyas which are centers of new ice formation, (4) divergence zones, and (5) the front. For in nearly every case, these mammals require movement and dispersion of the ice sufficient to create new leads and polynyas. In such situations, access to the air is virtually assured, either through natural openings or temporary holes made by the animals themselves in thin ice. Thus, the bearded seal (Erignathus barbatus) resides in habitats (2) through (5); and the spotted and ribbon seals

(Phoca largha and P. fasciata) reside almost entirely in (5). Only one species, the ringed seal (Phoca hispida), is sufficiently adapted to unbroken ice to be able to reside by choice in (1), the shorefast ice, and in other areas of vast, unbroken floes. Being most adaptable, it also resides to some extent in each of the other habitats. The walrus (Odobenus rosmarus) winters mainly in Bering Sea, primarily in habitats (3) and (4). Small numbers winter in the Chukchi Sea and occasionally in the Beaufort Sea (Stirling, 1974), as the annual severity of ice conditions allow.

C. Spring

The winter pack generally reaches its southernmost limit for the year in late March or April (Wittman and MacDowell, 1964; Brower at al., 1977). At that time, the processes of deterioration also begin to be evident in the Bering Sea (Muench and Ahlnas, 1976; Burns and Fay, unpublished). The position of the maximum southern border of the pack varies by as much as 6° of latitude (about 665 km) from year to year, in southeastern Bering Sea (Brower et al., 1977), but it tends to be not far from the southern edge of the continental shelf in most years. Its rate of degradation also varies appreciably, generally being most rapid in years of minimal extent and least rapid after maximal advance. Nevertheless, the recognized habitat types enumerated above tend to occur in the same relative locations in the pack, though not necessarily in precisely the same geographical positions.

While the general southerly and southwesterly movement of the Bering Sea pack continues to take place through April, leads and polynyas become larger. This appears to be due to diminution in rate of new ice formation, while the rates of fracture and deformation remain largely unchanged. This appears to be ultimately the result of a 3-fold increase in incident solar radiation (Johnson and Hartman, 1969), which upsets the previous balance between heat gain and heat loss. By late April there is abundant evidence of loosening of the winter pack, especially in the southern and eastern parts of the Bering Sea. This continues at an increasing rate thereafter (e.g. see Muench and Ahlnas, 1976) as melting of the ice takes place with increasing warmth of the surface environment. At the same time, winds become more variable and weaker, leading to cessation of the general north-south trend of ice movement.

By mid- to late-May, even in the northern Bering Sea, rising surface water temperatures result in melting of the floes, as evidenced by extreme undercutting and development of numerous holes (the "Swiss cheese" effect) in the submerged parts. Under those conditions, the thinner ice disintegrates rapidly and only the most massive floes persist into June. By the end of May, the ice sheet that has covered nearly the entire shelf of the Bering Sea is reduced to a few rafted remnants of heavy, broken ice that cover less than one-fourth of that area, and these too disappear in June or early July (Muench and Ahlnas, 1976).

Meanwhile, the Chukchi pack, which has remained largely intact throughout April, begins to show signs of impending breakup (Figure 2). In March and April the flaw along the Alaskan coast becomes more persistent and ice-free, whereupon the bowhead and belukha whales (_Balaena mysticetus_ and _Delphinapterus leucas_) begin their annual northward migration along it. Slightly later, an increasingly evident east-west fracture pattern develops in the southern Beaufort Sea (Figure 2), and the whales apparently make use of it to pass eastward, toward Banks Island. By late May or early June, in most years, there is significant loosening of the southern

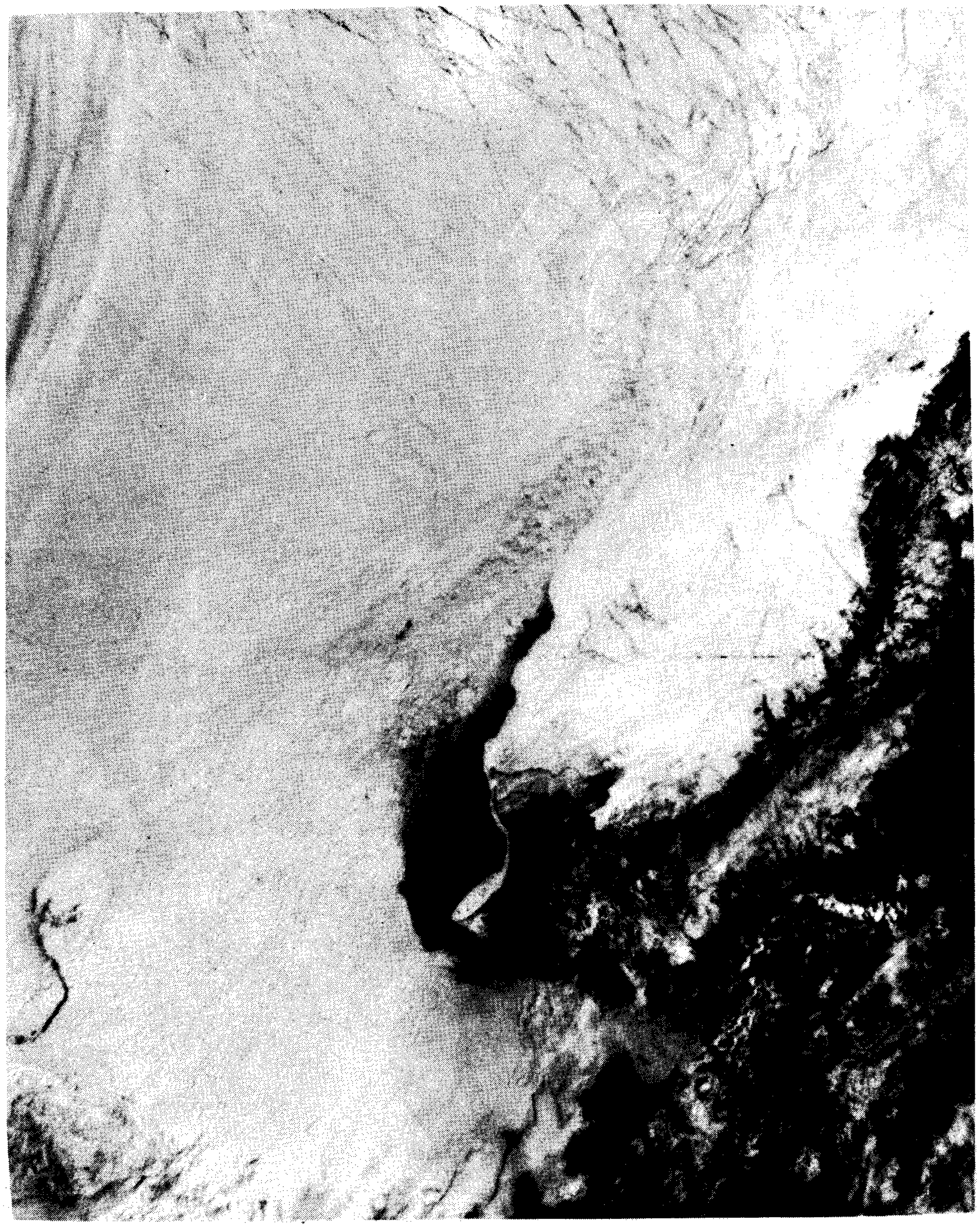


Figure 2. NOAA/VHRR visible band imagery of the northeastern Chukchi and southwestern Beaufort Seas; acquired on 23 May 1978.

part of the Chukchi pack, probably due mainly to influx of warmer water from the now nearly ice-free Bering. By the end of July, the Chukchi pack usually is reduced to one-third or less of its former extent, and by August, the western Beaufort shows extensive opening.

Not far behind the bowheads and belukhas (which begin their northward migration in late-March) are the walruses, whose vanguard advances through Bering Strait in April. By late May, most of their numbers have passed that point, as have the bearded and ringed seals that wintered in the Bering Sea. The spotted and ribbon seals do not migrate extensively until the last remnants of the Bering Sea pack have melted, at which time the spotted seals mainly move up along the coast, while the ribbon seals apparently become pelagic in the open sea.

D. Summer

When the ice sheet is at its annual minimum in late summer, most of the ice-associated marine mammals of the Bering-Chukchi-Beaufort region inhabit either the open sea to the south of the ice or the fringe of the "permanent" polar pack. Those associated at least partially with the fringe are the polar bear (Ursus maritimus), walrus, bearded seal, ringed seal, belukha, and bowhead. This polar ice cap exists mainly over the abyssal part of the Arctic Ocean, but extends southward also over the continental shelves of the northernmost continents and islands. It is relatively thick and old, being made up mostly of multi-year accumulations of sea ice and bits of glacial ice principally from the Greenland and Ellesmere ice caps. Its movement relative to the continents is generally clockwise around the polar basin, which translates into east-to-west movement in the western Beaufort and northeastern Chukchi seas, off northern Alaska. The average rate of movement of ice in the offshore polar gyre in summer is about 2 to 2.5 km/day (Webster, 1954). Nearshore, in the Beaufort Sea, it is more like 10 km/day (Marko, 1975). The mammals residing in the perimeter of this ice utilize it as a resting and feeding area. Some, such as the ringed and bearded seals and the polar bear, penetrate well into it in some circumstances.

E. Autumn

The formation of new ice in the Beaufort Sea begins inshore in September or early October, starting earlier in the western than in the eastern part of that area (Markham, 1975; Marko, 1975). New ice begins to form extensively in the Chukchi Sea by mid-October in most years but usually is delayed until late November or December in the northern Bering Sea. Apparently, the bowhead and belukha whales leave the Beaufort for the Chukchi in August and September (Fraker et al, 1978), and they and most of the other marine mammals leave the Chukchi for the Bering during October and November. Left behind are the polar bears, many ringed seals, and a few bearded seals, which inhabit the northern ice throughout the winter. Most of the migrating pinnipeds tend to stay in the water at this time; however, the walruses come out on shore in traditional hauling grounds (e.g. see Gol'tsev, 1968).

Up to a month before the formation of new ice in the Bering Sea, a few large chunks of multi-year ice from the polar pack drift southward through Bering Strait, frequently stranding on the northern coast of St. Lawrence Island (Fay, unpublished). This is a stormy season, with frequent, strong, northerly winds and high seas. Surface waters may become supercooled, leading to formation of a substantial amount of anchor ice (on the bottom) along the exposed coasts, while at sea broad strips of "grease" and slush ice form up parallel to the wind. During periods of calm, vast areas at sea become covered with new, gray ice, which becomes "finger-rafted" when set in motion. As might be expected, the protected embayments, such as Kotzebue Sound, Port Clarence, and Norton Bay, are the first to be iced over entirely.

III. ANALYSIS OF PREDICTABLE FEATURES OF THE WINTER PACK ICE OF THE BERING, CHUKCHI AND BEAUFORT SEAS

A. Method of Approach

1. Selection of Data

One problem addressed in this study was identification and description of the major, repetitive features of the moving pack ice in winter (excluding the ice fringe and front zones) and evaluation of their importance as habitats for mammals. Because the ice cover is almost continuous from the ice fringe in southern Bering Sea northward, it is logical to inquire as to the extent with which it moves and deforms as a unit. While data from any area within this region are of interest, synoptic coverage of the entire area is required if the regional relationships are to be recognized and understood. Also, it is desirable to know if ice conditions change in a systematic manner throughout the study area, or within definable sub-units. Is there some identifiable pattern to the distribution of ice conditions? This is relevant to the study because it describes the distribution of various possible ice habitats and the relationships in time between them. Information acquired over large areas within a specified time range obviously is required to answer this question.

The first step in the approach to this study was selection of scales, both temporal and spatial, on which data were required. The temporal scale is dictated by the rates at which major changes in the configuration of the ice cover can occur. Since these are closely tied to changes in weather patterns, the scale will be up to a few days (but generally less than a week). Major changes in the character of the ice cover in any area can occur faster than the mammals in that area can respond by moving to a more favorable location. Therefore, the presence of mammals in an area implies recurrence of favorable conditions. To define such persistence or recurrence, data must be acquired on a time scale which is shorter than that required for major changes to occur; that is, on a daily basis.

In a preliminary study prior to the start of this project,(Shapiro and Burns, 1975b) as well as in the early stages of the project, LANDSAT imagery was used extensively to identify and describe the features which tend to recur repeatedly. LANDSAT imagery of the study area is only obtained for 3 or 4 consecutive days (depending upon latitude) of each 18 day cycle of the satellite so that the spacing in time between LANDSAT images is greater than the time scale required for this project. In addition, LANDSAT data generally are not supplied for scenes with greater than 50% cloud cover, which further decreases the number of available images, and can lead to misleading results.

The temporal requirement in scale dictated that the bulk of the study be done using satellite imagery from the NOAA/VHRR weather satellites. These provide daily coverage of most of the Bering, Beaufort and Chukchi Seas, (satisfying the requirements of spatial scale) with IR imagery during the winter and with visible and IR during the rest of the year. With this imagery it is possible to examine ice conditions on a small scale, over the entire area of interest every day.

2. Organization and Data Extraction

Several attempts were made to develop a quantitative description of sea ice conditions which defines the state of the ice as habitat for marine mammals. In order for such a description to be useful, it must be based upon quantifiable measurements from satellite images, in order to take advantage of the repetitive and synoptic aspects of these data.

Two basic elements are required for the development of such a description. First is the determination of the parameters of the ice habitats of each species, and the second is to learn how to identify and measure those from the satellite data. Data for the first requirement would need to be developed through aerial surveys and surface ecological studies, preferably coinciding with satellite passes. The second requires experimentation with procedures for extracting information from the satellite data. The methods by which the discrimination of ice conditions was attempted are described here.

The major problem to be solved in developing a quantitative description of ice conditions is that some method for determining ice thickness from the satellite is required. No method for rigorously accomplishing this is known, and our attempts to do so for this project have been unsuccessful, despite the fact that the only requirement is that the thickness greater or less than about 20 cm can be discriminated. The problem was approached using LANDSAT imagery for consecutive days in which a lead or polynya was observed to be in the initial stages of formation on the first image and continued to expand on subsequent days. New ice forming in a lead or polynya will grade in thickness from zero at the edge of open water to some greater thickness at the boundary with older ice. This thickness will depend upon the ambient weather (see, for example Stehle, 1965). Since there is a gradation of tone changes from black for open water to light gray for thick pack ice, a series of measurements of film density on a photographic product of the data (or of reflectance from the digital data) forming a profile across such an area might provide a means of associating reflectance with ice thickness up to the limit of light penetration into the ice.

This possibility was investigated by examining the distribution of reflectance levels of newly formed ice in leads as shown on a printout from digital tapes of LANDSAT image 1228-22273-7 (Figure 3) acquired on March 8, 1973. The results were negative because the reflectance from the surface of the newly formed ice in the lead became almost constant a short distance from the open water. Estimates based upon the assumption of a constant rate of lead opening (for the 24 hours since the previous image was acquired) and on knowledge of the temperature at the nearest weather stations, indicated that the thickness of the ice probably was less than 10 cm when the reflectance became constant. It is not possible to determine whether this was due to a lack of light penetration into the ice, the growth of ice flowers, or the addition of blowing snow to the surface. Whatever the cause the result is the same and negates the method.

In the absence of a method for estimating ice thickness from the imagery, a classification was adopted for the purpose of determining floe size and spacing between floes from LANDSAT imagery. The ice was divided into two categories: 'thick' ice, which has high reflectivity and appears in tones of light gray on band 7 of the LANDSAT imagery, and open water or 'thin' ice, which ranges from black through the darker gray tones. Using these, it was possible, statistically, to define the parameters of floe size and open water.

In order to make the measurements, a scanning microdensitometer was used to establish the film density along a number of lines on a

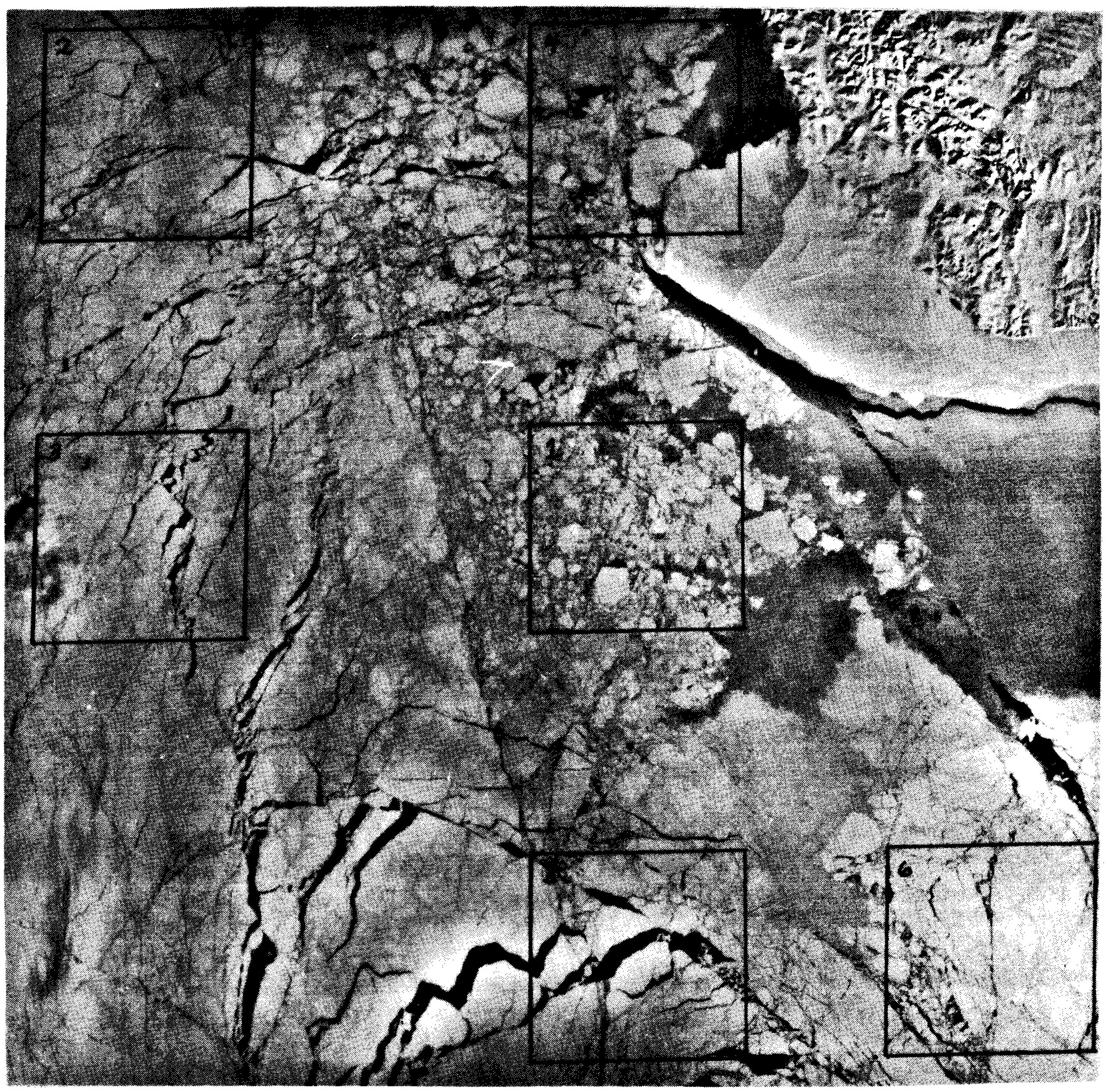


Figure 3. LANDSAT image #1228-22273-7 of the southeastern Chukchi Sea, acquired on 8 March 1973.

70 mm positive transparency of band 7 of LANDSAT Image 1228-22273-7, shown in Figure 3. The scene covers the southeastern Chukchi Sea, with Point Hope in the upper right quadrant. Note that this scene is part of the sequence studied by Shapiro and Burns (1975a) so that the ice motion at the time the image was acquired is known. Outlined on the picture are six areas with dimensions of 35 x 35 km which were used in the study. Each area was scanned twelve times by the microdensitometer; six scans each in north-south and east-west directions. The density variation was recorded as a continuous curve on a strip chart recorder where the scanning and recording speeds were known so that distances along the curve could be scaled as distances on the image. From these charts, sharp changes in film density between thick ice floes and thin ice or open water were readily identified. The exact value of film density at which the changes occurred was determined by comparison of observed densities of thick and thin ice on the image with the density scale on the transparency. Having established a "decision level", the path distances over thick ice, and over thin ice or open water, were measured along the curve. The results (Table 1) define numerically the differences in ice conditions in the six areas.

The range of values in Table 1 does serve to indicate that differences in ice characteristics can be detected and expressed quantitatively.

TABLE 1

SUMMARY OF STATISTICAL DATA FROM MICRODENSITOMETER TRACES

	THICK ICE PATH LENGTHS					THIN ICE - OPEN WATER PATH LENGTHS				
Area	% Path	Mean(1)	Standard Deviation	Median	Mode	% Path	Mean	Standard Deviation	Mediun	Mode
1	75.1	1.18	2.26	0.46	0.23-0.46	24.9	0.33	0.54	0.17	0.23-0.46
2	90.2	3.15	4.07	2.05	1.82-3.65	9.8	0.40	0.88	0.26	0.23-0.46
3	90.1	3.47	5.18	1.37	1.82-3.65	9.9	0.43	0.48	0.23	0.11-0.23
4	70.1	1.33	2.75	0.23	0.23-0.46	27.9	0.53	1.12	0.11	0.23-0.46
5	83.1	2.76	3.54	1.48	0.46-0.91	16.9	0.63	1.00	0.40	0.11-0.23
6	91.3	3.10	5.81	1.03	1.82-3.65	8.7	0.33	0.32	0.23	0.23-0.46

(1) All path lengths in kilometers

As an example, most of areas 1 and 4 include ice which is typical of that deformed in the flaw zone along the coast. These areas have lower values of percent of ice cover, mean, standard deviation, and mode of thick ice path length and median open water - thin ice path length, than do the remaining areas. Thus, the ice cover in these areas consists of relatively small flows separated by narrow leads, which implies that the ice is in the process of being broken into small floes, and that there has not been sufficient time for the leads to freeze over.

Areas 2, 3 and 6 are all dominated by thick ice. However, at the time the image was acquired, long, narrow tension fractures were developing in areas 2 and 3 and the pack ice was therefore probably diverging. At the same time, the ice in area 6 was drifting at a relatively uniform rate to the south-southeast, at a velocity of about 9 - 10 km/day. The data for these areas are generally similar except that the parameters for the thin ice - open water path lengths suggests that these are of more uniform size in area 6 than in areas 2 and 3. The differences would probably be enhanced if the data were taken from the LANDSAT image of the area acquired on the following day when the tension cracks in areas 2 and 3 had opened to widths of several kilometers.

Finally, ice within area 5 is in the process of being deformed by the development of tension fractures as well as by shear along the line trending NW-SE across the area. The statistical parameters for this area are correspondingly different from those of the remaining areas.

This method demonstrated that it is possible to derive statistical descriptions of the ice cover which can reveal distinctions not readily apparent by visual inspection. However, the time required to accomplish the work described here was simply too great to permit routine coverage for the entire area of interest. An attempt was made to duplicate these results using digital tapes of LANDSAT images. This too proved feasible, but the expense of acquiring the tapes was more than the project could bear for the entire area. As a result no further study of this type was done. In the future, when distribution and habitats of the various marine mammals are better defined, such work could be done for the relevant areas.

An attempt was made also to obtain data required for classification of ice types using the Fourier transforming properties of spherical lenses. In theory, the technique is straightforward. A point source of monochromatic light from a laser is passed through a spherical lens to form a plane wave. The beam then passes through a small area of a photographic image which is placed at the back focal plane of a second spherical lens. The light collected by the second lens forms a diffraction pattern in the front focal plane. This diffraction pattern, which is the Fourier transform of the illuminated photographic image, provides information about the spatial frequency distribution of the photograph. The geometry and intensity of the light distribution in the diffraction pattern relates directly to the size distribution and spacing of objects in the photograph. Thus, in theory it would be quickly and conveniently possible to obtain detailed information about sea ice states by applying the technique to photographic products of either the LANDSAT or NOAA satellite data.

In practice, however, the accuracy and utility of the method is limited by the "noise" in the system. For this project, the necessary apparatus was set up using available equipment which was known to be too crude for detailed work, but was adequate for judging if the method was sufficiently promising to justify further effort. Light from a laser source was passed through a small part of a 70 mm transparency of a LANDSAT image and of a NOAA satellite image, generating diffraction patterns which changed as the images were moved through the beam. In both cases the changing pattern reflected changes in the image which the beam was sampling. However, the noise level of the resulting pattern was too great for usable data to be obtained. It was determined that the bulk of the noise was due to the film grain on the images. Noise from this source could not be overcome and would render any results unsatisfactory so that this approach was not pursued further.

Thus, the total effort devoted to finding automated methods of rapid classification of ice relative to the habitats of marine mammals did not prove feasible within the constraints of the project. Hence, the decision was made to use visual inspection of the daily coverage available from NOAA/VHRR satellites to obtain the necessary data.

3. Description of Data from NOAA Satellite Imagery

Ideally, imagery from at least one satellite pass per day should have been available for the time period over which the study was conducted.

However, occasional difficulties in transmission or absence of data from a suitable pass (see below) reduced the number of available images. The totals by month for the period from March, 1974, when data was first received, to June 1977, when data acquisition for the project ended, are shown in Table 2. This constitutes the basic data set used in the study.

The imagery used included both visible and infrared bands for the months when sufficient light was available for the visible band to be useful. In winter, only the infrared band was available. Comparative data from the IR and visible imagery in spring and summer shows little difference.

Of the large number of images available each day, the one centered on Bering Strait was chosen for study when available, since it provided the best possible view of the area.

The scale of the NOAA imagery is about 1 mm = 9 km, and the resolution is about 0.6 km. The ice classification adopted was intended to describe features and conditions visible at that scale and resolution. As discussed below (Section III.A.5.), the descriptive terms used appear to be applicable to scales at least as large as that of the LANDSAT imagery (1 mm = 1 km) in some cases.

The NOAA satellite imagery used was all in the form of positive transparencies; these were studied on a light table. In this form, on the visible band, the ice ranged in color from almost black for thin, new ice, to light gray or white for snow-covered, thicker ice. The imagery from the infrared band of the NOAA satellite provides, in effect,

TABLE 2

NUMBER OF NOAA/VHRR IMAGES AVAILABLE

Month	Year 1974	1975	1976	1977	Total
December	-	29	17	31	77
January	-	23	10	31	64
February	-	28	29	28	85
March	24	31	31	31	117
April	17	29	30	30	106
May	28	31	31	31	[illegible]
June	27	30	26	30	113

a map of surface temperatures. On positive transparencies, the density scale ranges from light gray to black with increasing temperatures, so that open water appears dark and the colder ice surface appears in a lighter tone. The identification of open water presents no problem, but there is some loss of detail in ice-covered areas because the surface of both thick and thin ice tends to be at a uniform temperature. In the visible band, ice bordering a new polyna can be identified by its dark gray tone when not snow covered, but when its surface temperature reaches that of the adjacent older ice, it cannot be discriminated in the infrared imagery. Some difficulty was encountered also in discriminating between clouds and ice in the IR band, but texural differences usually were sufficient to resolve that problem. In general, visible band imagery was used when available.

4. Definition of Sub-Areas

In a preliminary study, Shapiro and Burns (1975b) utilized imagery acquired during March and April of 1973 and 1974 from the DAPP and the NOAA/VHRR systems to identify the major features of the ice cover in the Bering and Chukchi Seas. The results were verified with available LANDSAT data. The procedures used in the present project were based upon the experience gained in that study.

Daily ice conditions throughout the study area were described by classifying the ice in each of 23 sub-areas (Table 3, Fig. 4) selected on the basis of experience gained in the preliminary study. The ice conditions within each sub-area had been recognized as sufficiently uniform for any particular satellite image to permit description by a single term.

TABLE 3

BERING, CHUKCHI AND BEAUFORT SEA SUB-AREAS

Sub-area #	Area
1	East of Prudhoe Bay
2	West of Prudhoe Bay
3	West Coast of Alaska, Barrow to Point Hope
4	Coastline East of Pt. Hope
5	Kotzebue Sound
6	Open Sea North of Bering Strait
7	Wrangell Island
8	North Coast of Chukchi Peninsula
9	Bering Strait - Diomede Island
10	South Side of Seward Peninsula
11	Norton Sound
12	Siberian Coast South of Bering Strait
13	Open Sea South of Bering Strait
14	North Side of St. Lawrence Island
15	South Side of St. Lawrence Island
16	Strait Between St. Lawrence Island and Siberia
17	Sea Between St. Lawrence Is. and Mouth of Yukon River
18	Gulf of Anadyr
19	Bering Sea Between St. Lawrence and St. Matthew Islands
20	Nunivak Island
21	St. Matthew Island
22	Pribilof Islands
23	Bristol Bay

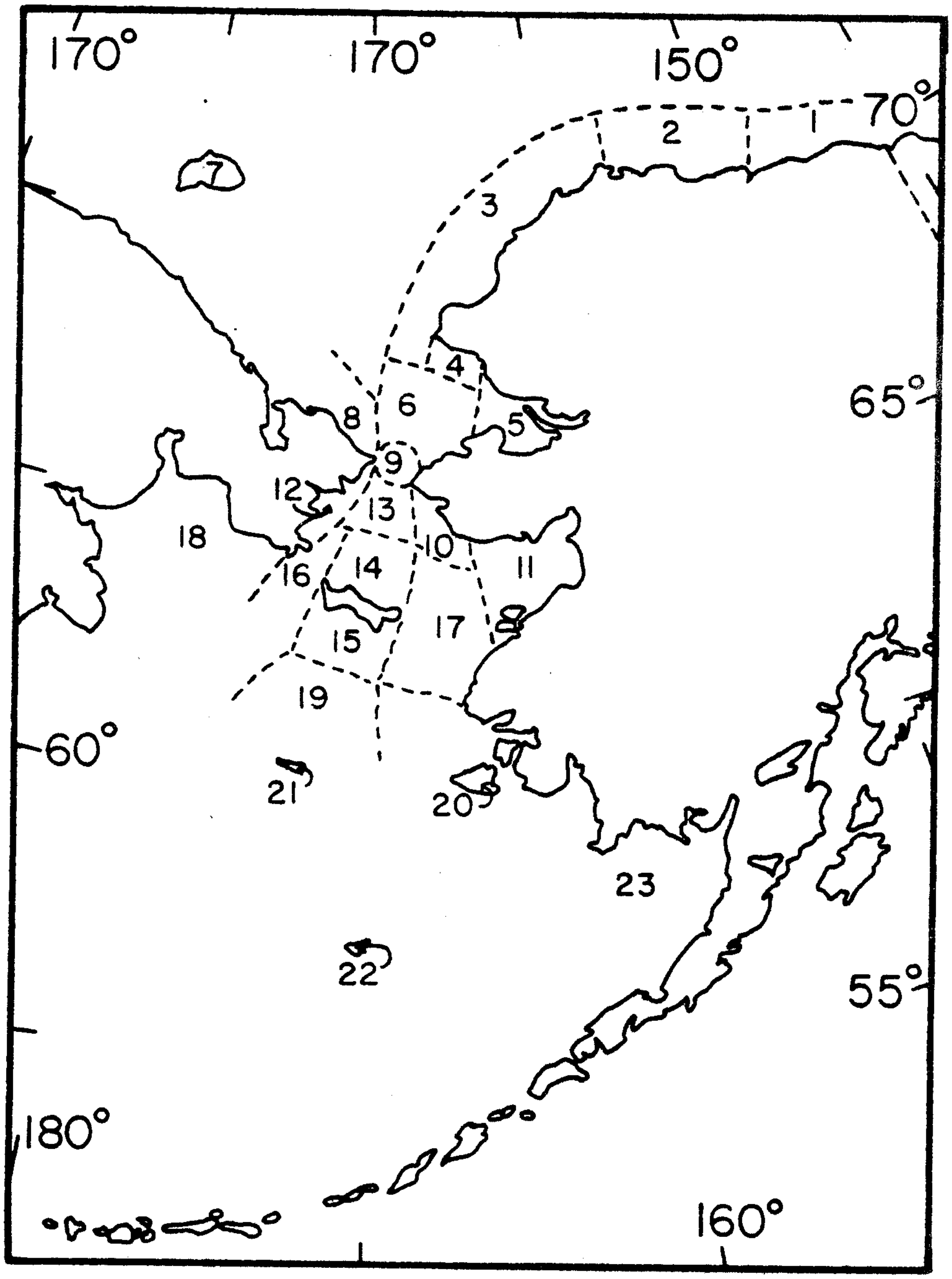


Figure 4. Locations of sub-areas.

5. Classification of Ice Conditions

The standard method of describing sea ice distribution is based on oktas (or eighths) of ice cover. This was not applicable in the present study, since areas with the same okta rating may contain a few large floes or many small floes, and be very different from the aspect of marine mammals. Most of the Bering Sea is classified as 7 or 8 oktas throughout the winter months, but much of that ice is thin and presents no barrier to most of the mammals; for them thin ice is of equal value to open water. Classification by oktas was therefore simply too coarse for the purpose of this project.

Details of the manner in which the various species of marine mammals utilize the pack ice are discussed elsewhere in this report. In general, the critical factor in areas north of the front zone appear to be persistence of open water or thin ice, either as polynyas or recurring leads, through which the animals can pass to and from the water. The amount of "shoreline," in the sense of linear interface between open water (thin ice) and heavy ice also appears to be important for some species. In addition, the persistence of leads along migration routes is clearly important at certain times of year. The occurrence of these features is a function of the dynamics of the ice, as well as of air and sea temperatures, which determine the rate of freezing. The dynamics are clearly more important because ice in motion at differential velocities (such as movement around a point or through a constriction) is continuously breaking and forming new leads.

The ice classification adopted was based upon features visible on NOAA imagery to which the terminology of the WMO classification generally could not be applied. Although the resolution of the NOAA satellite imagery is only 0.6 km, leads smaller than that can be detected, since the energy reflected or radiated is averaged. An area which includes a mixture of ice and open water will have a gray tone intermediate between areas of continuous ice and continuous open water or thin ice. The tone will indicate the relative proportions of each. It is not possible to assign percentages of cover to areas of intermediate gray tones by visual inspection of an image, but the presence of open leads within an area generally can be inferred, if the area is relatively large compared to the size of a resolution element.

The categories of ice conditions identified were:

1. Continuous Heavy Ice Cover: This category was applied where the ice cover appeared as a relatively continuous field of white to light gray tones with no recognizable leads. Gradients in tone sometimes implied separate floes, but distinct leads were absent.

2. Flaw Zone: This category was applicable only in coastal areas. Two sub-categories were recognized: (a) narrow flaw lead separating the landfast ice and pack ice, indicating the early stage of offshore ice motion, and (b) flaw zone, in which the ice is broken by numerous leads or occurs as discrete floes in a relatively narrow zone. The flaw zone which frequently develops along the Alaskan coast between Point Hope and Point Barrow sometimes reaches widths of more than 50 km. Examples of flaw lead and flaw zone are given in Figures 16 and 20 of Section III.B.3.

3. Pack Ice with Leads: This is pack ice crossed by leads which generally are sub-parallel and may intersect. This category represents the first stage of breaking of continuous ice cover. An example in the southern Beaufort Sea is shown in the NOAA/VHRR image in Figure 5. A LANDSAT image of the same area acquired on the same day is shown in Figure 6. The increase in scale shows the presence of more leads and

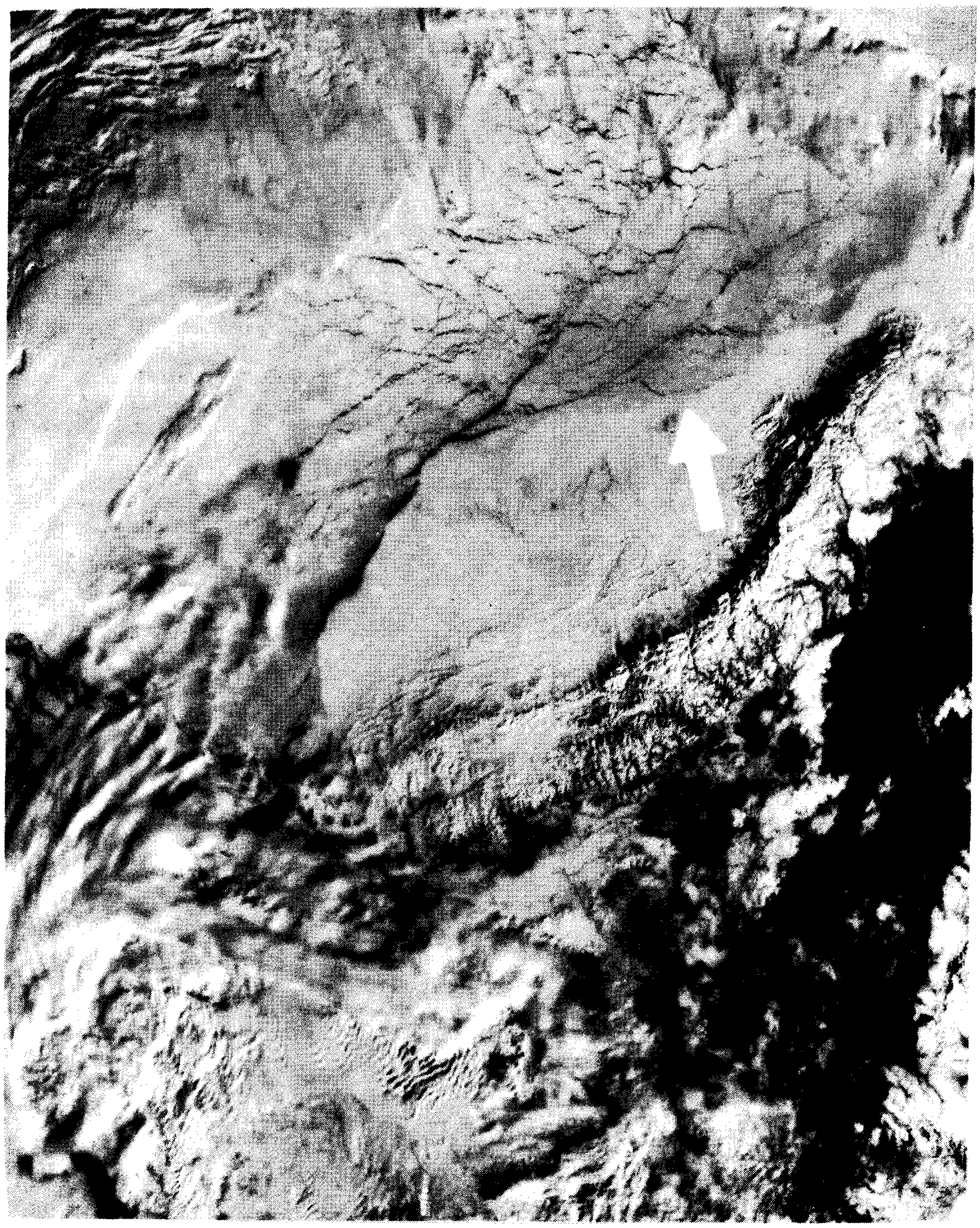


Figure 5. NOAA/VHRR visible band imagery acquired on 19 April 1975.

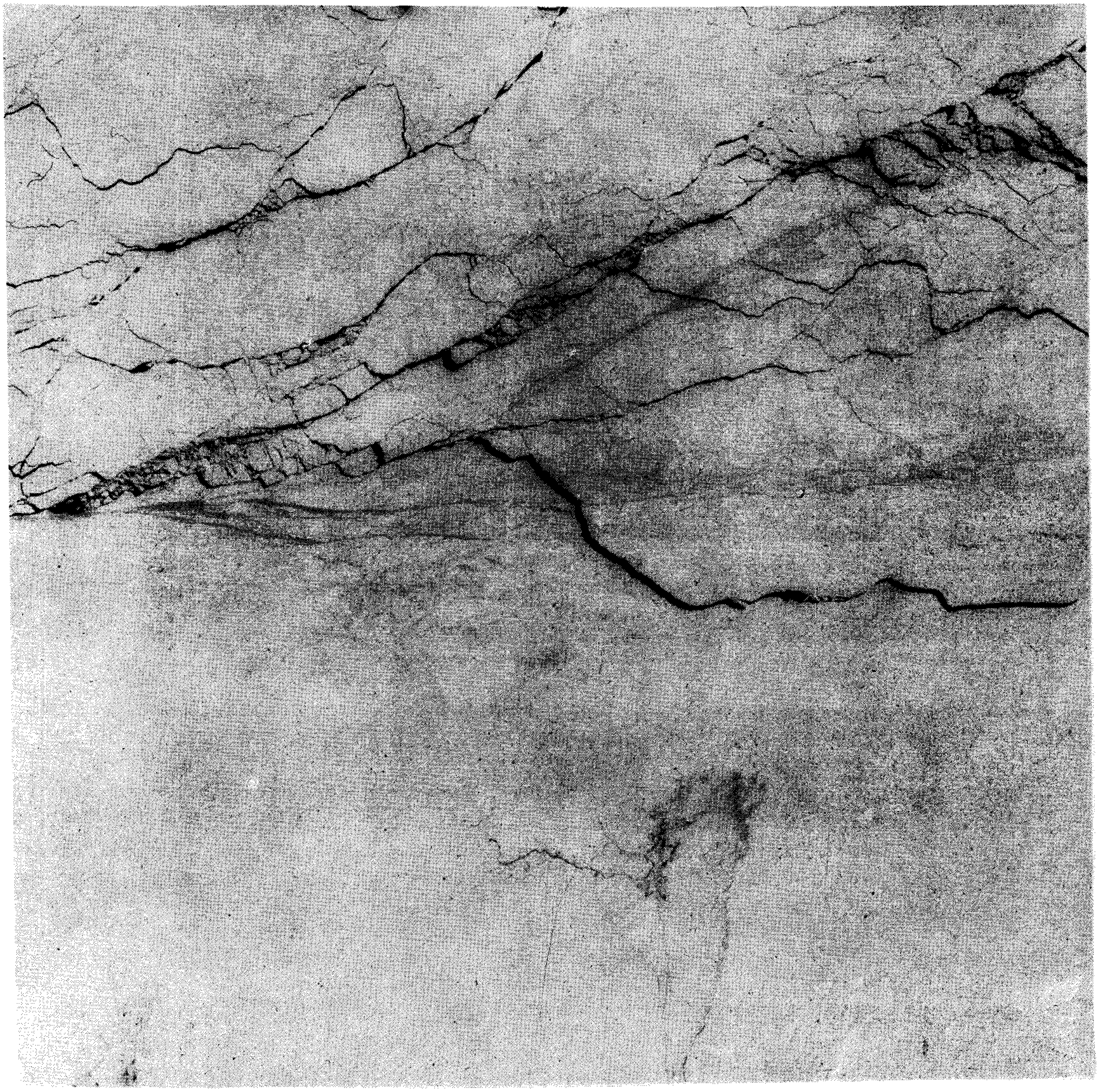


Figure 6. LANDSAT image #2087-21112-7 acquired on 19 April 1975.

illustrates the comparative resolution of the NOAA/VHRR and LANDSAT imagery.

4. Broken Pack Ice: Broken pack ice was identified by the presence of two or more intersecting sets of leads forming floes of variable sizes but generally with an angular form. This configuration represents an additional step beyond category 3 in breaking of the ice cover. In areas classified as broken pack, heavy ice occupies more than 85% of the surface. The NOAA/VHRR image for March 30, 1977 (Figure 7) shows an example of this ice category over most of the Bering Sea south of St. Lawrence Island. A more detailed view acquired on the same day by LANDSAT is shown in Figure 8. As in Figures 5 and 6, the greater detail of the LANDSAT image is obvious, but the classification is the same.

5. Rounded Pack Ice: This refers to areas of at least 50% heavy ice cover in which the floes are predominantly rounded, rather than angular. An example is shown in the area between St. Lawrence and Nunivak Islands in Figure 9. A LANDSAT image of the area just west of Nunivak Island on the same day (Figure 10) indicates that the classification is applicable on that scale as well. This category was applied even when heavy ice was almost continuous, provided that discrete, rounded floes separated by thin ice or open water were identified.

6. Loose Pack Ice: This category was used for areas with less than 50% heavy ice cover consisting of scattered floes. The space between the floes was either open water or thin, new ice. Comparative NOAA/VHRR and LANDSAT views of the area east of St. Lawrence Island are shown in Figures 11 and 12.

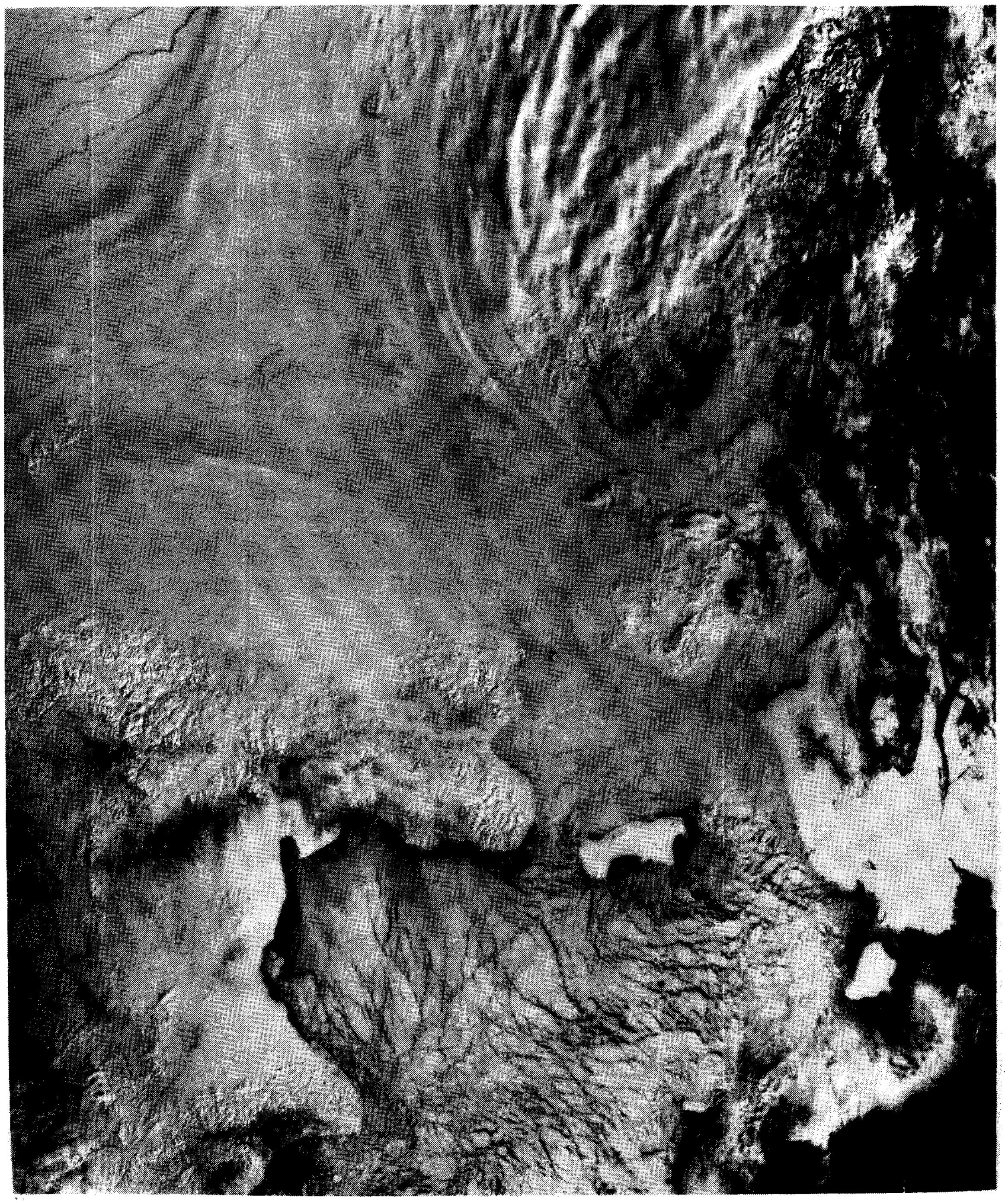


Figure 7. NOAA/VHRR visible band image acquired on 30 March 1977.

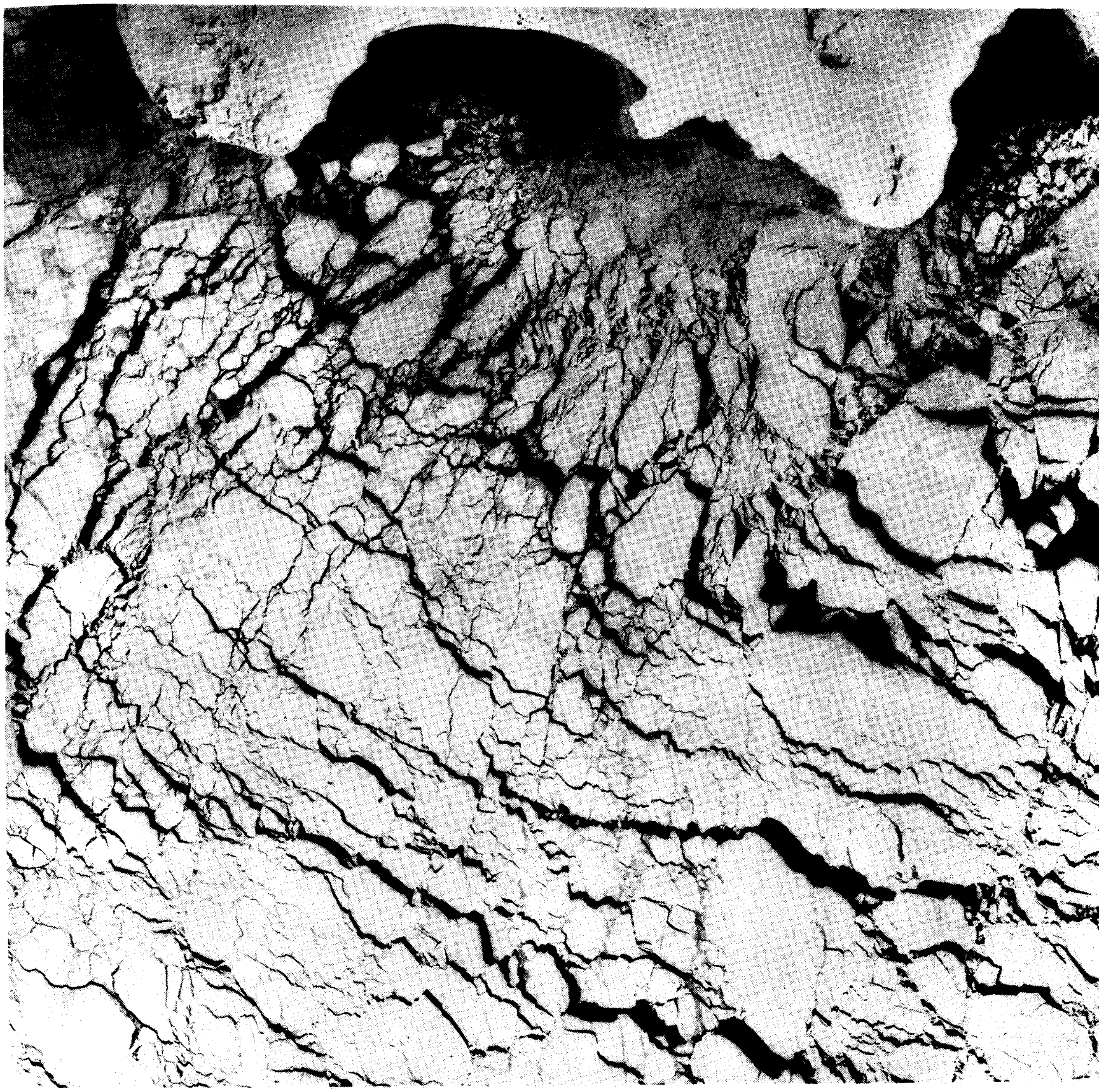


Figure 8. LANDSAT image #2798-21484-5 acquired on 30 March 1977.

Figure 9. NOAA/VHRR visible band image acquired on 19 April 1976.

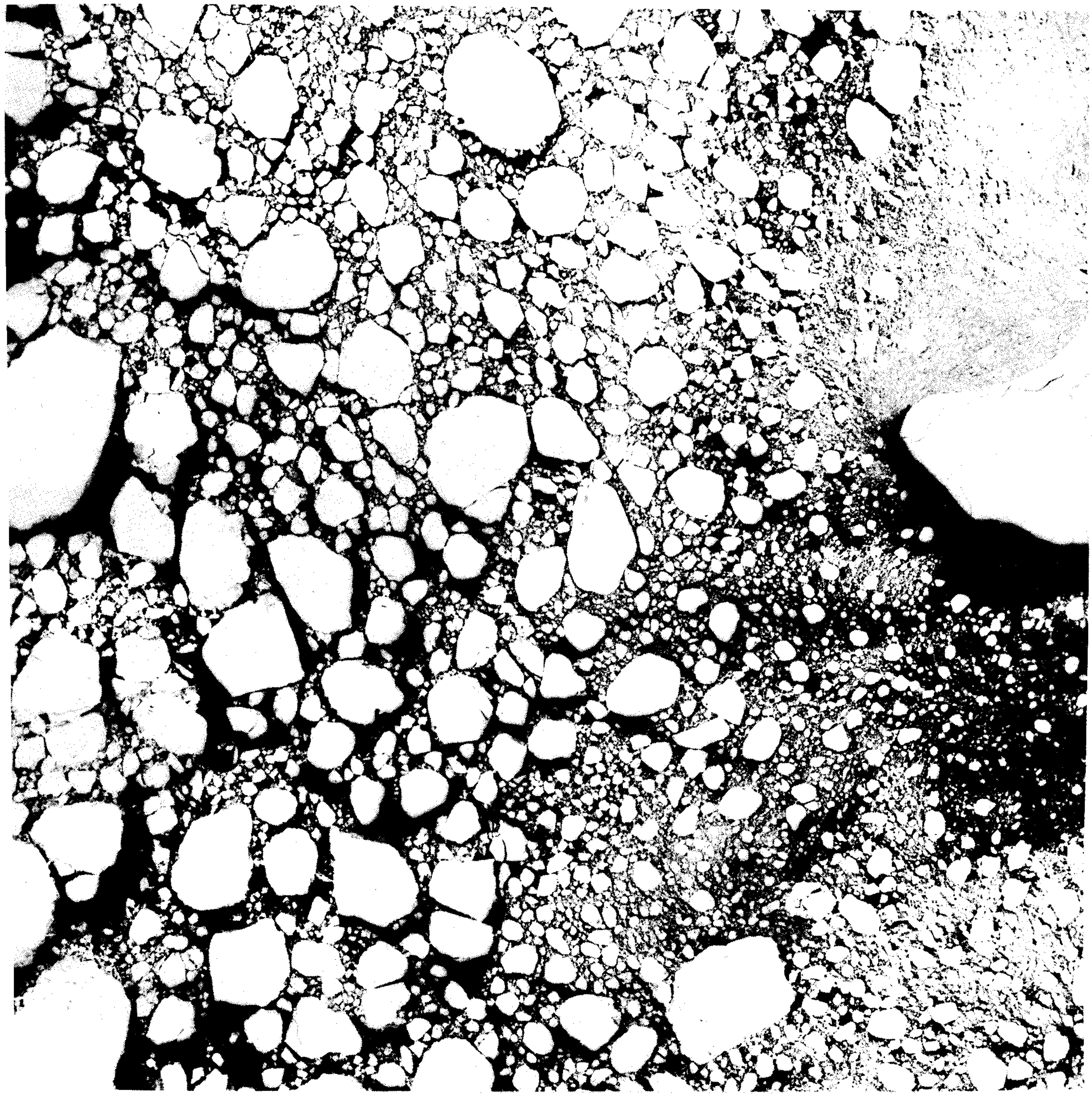


Figure 10. LANDSAT image #2453-21440-7 acquired on 19 April 1976.

Figure 11. NOAA/VHRR visible band image acquired on 21 May 1977.

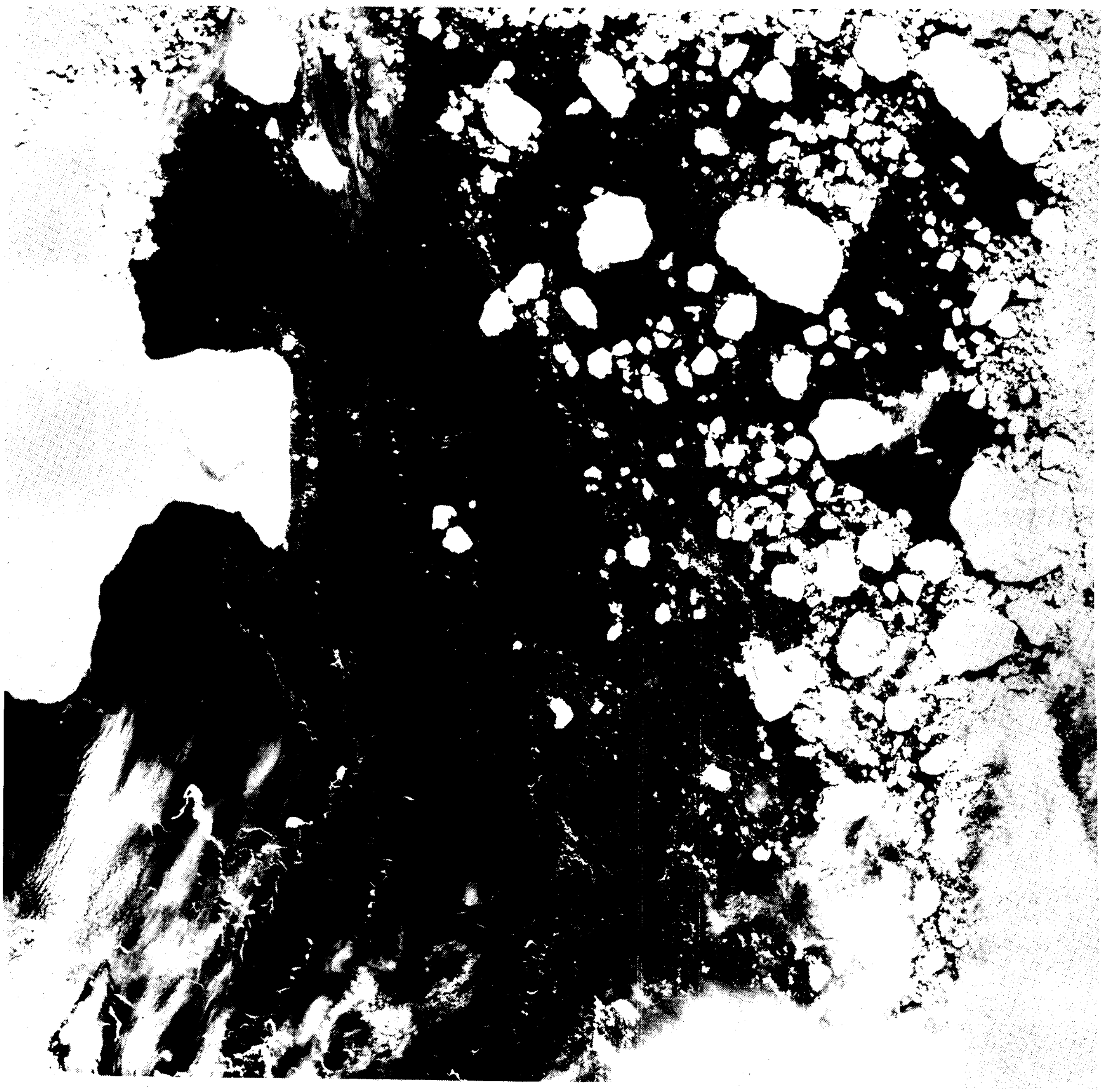


Figure 12. LANDSAT image #2050-21343-5 acquired on 21 May 1977.

7, 8, 9, 10, 11. Open: Areas in which no heavy ice was present (although new, thin ice may be) were classified as 'open'. Category 7 was open sea. Categories 8, 9, 10 and 11 were applied in coastal areas or near islands to indicate that portion of the coast along which a polynya had formed:

8 - polynya or open to the north

9 - polynya or open to the south

10 - polynya or open to the east

11 - polynya or open to the west.

This classification represents a gradation from continuous, heavy pack ice to open water or thin ice, but it is not meant to imply that conditions in any one area must pass through all the intervening stages in changing from a low to a high numbered category. Ice along a coastline can change from category 1 to category 2, and then to category 7 (or 8 - 11), without passing through the intervening stages, if the pack moves offshore as a unit. This is a common sequence along the coast east of Point Hope (Sub-area 2), where the ice tends to drift rapidly away from shore with little or no internal fracturing.

6. Method of Data Acquisition

All of the data for ice classification were obtained by visual inspection of NOAA satellite imagery. The available imagery for each day was examined, and the ice in each of the sub-areas listed in Table 3 was categorized. The extent of ice cover in each sub-area also was estimated, and the image was compared with those from the previous one or two days to determine whether the ice had moved perceptibly in that time and the direction of movement. Presence of clouds obscuring a sub-area also was recorded. Finally, the quality of the data for each sub-area was noted as an indicator of the level of confidence with which the ice was classified.

C. RESULTS

1. Introduction

Data on ice conditions could only be obtained from satellite imagery when cloud cover was very thin or absent, hence the data are obviously biased toward clear weather days. In general, those were associated with periods when the winds were from the north, driving the ice toward the south. Cloudy periods, in the Bering and southern Chukchi Seas, usually occurred when winds were from the south, tending to move the ice toward the north. The ice conditions resulting from southerly winds therefore were less often observed than those resulting from northerly winds. Observation of the pattern resulting from southerly winds generally was possible only when the weather was changing from cloudy to clear and the ice was beginning to respond to the new weather system. On the first day of clear weather following a cloudy period, the ice in any sub-area was usually in the state that could be associated with southerly winds. Subsequently, it changed to a condition (or series of conditions) typical of clear weather periods in that sub-area. The length of time required for the transition depended upon meteorological variables, but it was obvious that the initial and transition states of the ice were not typical of clear weather conditions. A similar lag must also occur following the transition to cloudy weather, but usually cannot be observed. Ice conditions in any sub-area sometimes could be observed even during cloudy periods, when the overcast was thin or there were gaps between clouds. The 'typical' cloudy weather ice conditions for any sub-area, can therefore be determined, given sufficient observations during and just after cloudy periods, but there is little possibility of obtaining data during the transition from clear to cloudy weather. As a result, we were unable to assemble the data set required for a complete statistical treatment of ice conditions.

The data available provided 3-year coverage for the months of December, January, February and June, and 4 years for March, April and May. For any particular sub-area and month, the number of clear weather days varied, so that the data set available was not necessarily typical of long-term trends. One unusual month could strongly bias statistics on the frequency of occurrence of conditions. For example, the number of clear days for some sub-areas during February 1976 was almost 4 times as great as the number in 1975 and 1977, so that statistics for February are dominated by conditions in 1976. There will be no method for judging the representativeness of the February data set until observations from more years are available. While it is representative of the clear weather ice distribution, it probably is not representative of the overall conditions in that month.

Our analysis of the data has been directed toward defining 'typical' patterns associated with clear and cloudy weather. These are the most common conditions and can be used to define the consistency of the ice conditions as habitat for marine mammals. Clearly, if major changes can occur in the ice cover with each change of weather and if these severely affect the ice as habitat for a species, then the species cannot reside there.

No attempt has been made to correlate the occurrence of cloudy weather with particular storm tracks. We recognized that all storm systems do not follow the same path, so that the local winds which affect the ice in any area may not be the same for each occurrence of cloud cover. However, the general association of clear weather with northerly winds and cloudy weather with southerly winds does seem valid as recently demonstrated for the Beaufort Sea by K. Jayaweera (in preparation). Therefore, we assume that anomalous ice conditions or lack of consistency in the association of observed ice and weather conditions reflects some unusual deviation from the normal relationships.

2. Descriptions of Ice Conditions by Sub-Area

Sub-Areas 1 and 2-Beaufort Sea Coast East and West of Prudhoe Bay

These two sub-areas were treated separately in order to determine whether there were recognizeable differences in ice conditions between them. The results did not indicate this, hence they were combined for this description.

From December to May, the ice in both sub-areas was consistently classified as continuous ice cover, pack ice with leads, or flaw lead (categories 1, 2, or 3). The frequency of occurrence of each category in any month was virtually identical for the two areas. Continuous ice cover occurred with a frequency of 57% to 74% on clear weather days from January to May, and 40% to 50% in December and June. In most instances, periods of cloud cover longer than 4 days were associated with a shift of conditions to more open ice, that is, from category 1 to 2, or category 2 to 3. Shorter cloudy intervals led to reversals in conditions, such that if the ice was classified in category 2 or 3 prior to the area becoming cloud covered, then it was in category 1 on the next clear day.

Ice of category 1 changed to category 2 or 3 under similar conditions. The month with the highest percentage of continuous ice and the most stable conditions was April, in which category 3 never occurred. Broken pack ice (category 4) was recognized in June, but only on 5% of the days for which data were available.

Conditions throughout December to June in these sub-areas were generally stable with no areas of persistent small floes, open water, or thin ice. Leads tended to form at the pack ice - landfast ice boundary or, if farther offshore, parallel or sub-parallel to that boundary. Secondary sets of leads perpendicular to the shore seldom formed.

These sub-areas are utilized during winter mainly by ringed seals and by the polar bears which prey on them. Apparently bowhead whales and belukhas use the offshore leads during the spring migration.

Sub-Area 3-Point Hope to Point Barrow

Ice conditions in this sub-area were less variable than were those of any sub-area other than Kotzebue Sound (where the landfast ice is stable all winter). For the period from December to June, the ice was classified as category 2 (flaw zone or flaw lead) for 86% of the observations. On the first day following cloudy periods, the ice was usually in this category, so that the frequency of occurrence probably was higher than that for clear days alone.

The occurrence of a narrow flaw lead tended to be associated with closing of the polynya southeast of Point Hope (sub-area 4) when the wind was predominantly from the south or southeast. At such times, a nearly continuous flaw lead tended to open along the coast from Point Hope to Point Barrow, as a result of movement of the ice to the north or northeast. When the wind was from the northeast or north, the pack ice moved along the coast in a southwesterly direction. At such times, small polynyas formed along the coast, leads radiated from promontaries, and other leads formed across the width of the flaw zone. These sometimes extended up to 50 km offshore, and were often concave to the south, indicating movement in that direction. Repeated occurrences of such southwesterly movement were responsible for formation of the wide flaw zone (Figure 13).

The flaw lead and flaw zone generally were more common in March, April and May than earlier in the winter. From December through February, their frequency of occurrence during clear weather was in the range of 65% to 72% with continuous ice present about 27% of the time in January and February. In March, however, the frequency of occurrence of continuous ice droped to near zero, and the flaw lead or flaw zone was present from 92% to 99% of visible days until break-up.

The pattern described above virtually assures the continued formation of a relatively dense network of new leads in this sub-area through most of the winter. Because of this, the sub-area normally provides winter and spring habitat for bearded seals as well as ringed seals and polar bears. The former apparently require the presence of open water in areas of relatively shallow water where they can feed. As a result, their winter distribution north of Point Hope is mainly restricted to the width of the flaw zone.

The flaw zone also provides the migration path for belukhas and bowhead whales in spring, and in this context, it may be of interest that the frequency of occurrence of continuous ice cover in the area

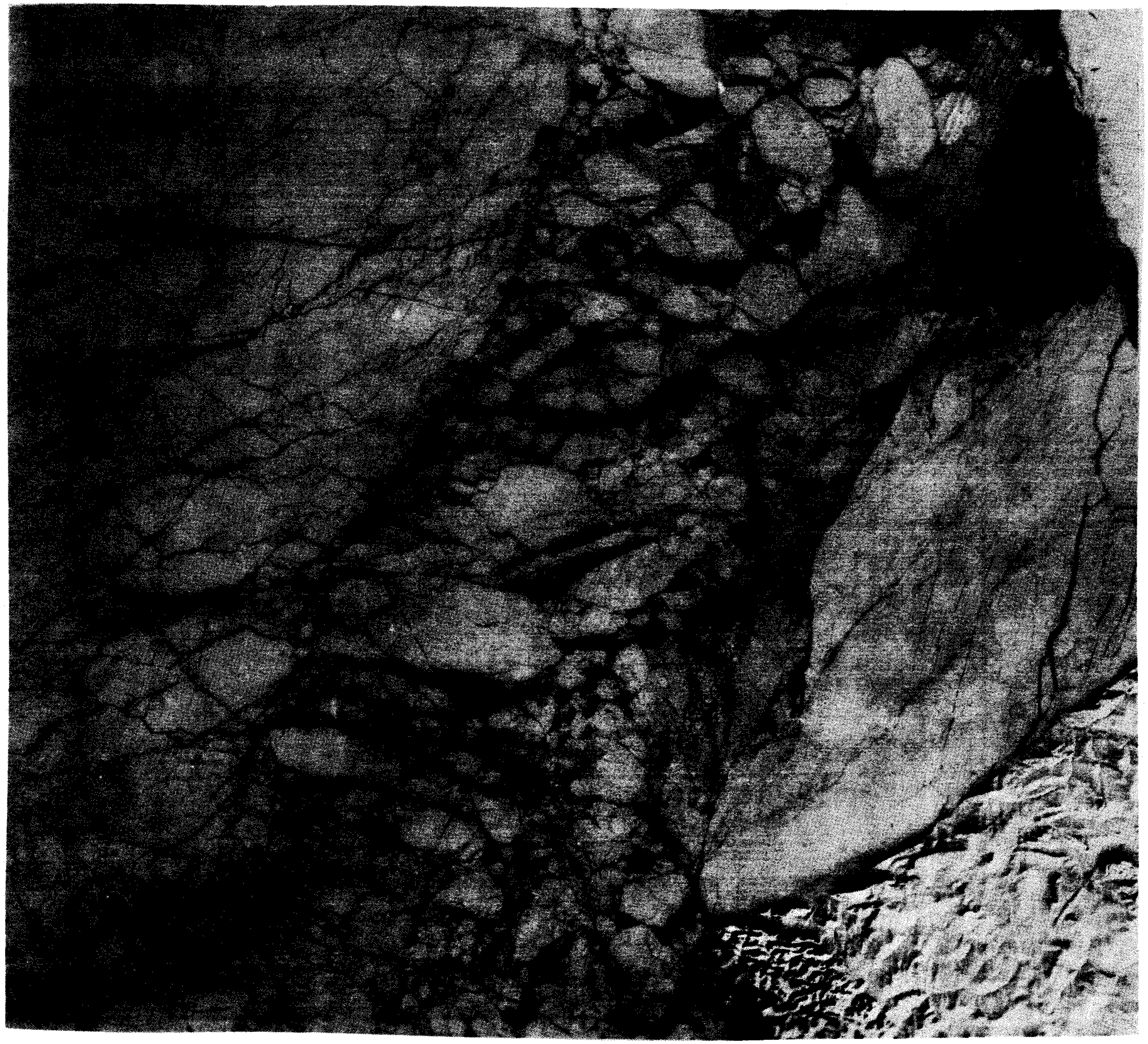


Figure 13. LANDSAT image #1228-22270-7 acquired on 8 March 1973.

drops to nearly zero in March when the migration normally starts. In addition, some birds appear to follow the flaw zone during spring migrations, and walruses also pass through it on their annual transit northward. Thus, the flaw zone is a habitat of outstanding importance in the life cycle of many species. It also is likely to be the path followed in any attempt to extend the shipping season to the North Slope. Any OCS development along the Chukchi Sea coast of Alaska must also occur within this zone, so that the potential for environmental damage in this sub-area could be high.

Sub-Area 4-Coast Southeast of Point Hope

This sub-area extends from Point Hope to the edge of the landfast ice in Kotzebue Sound. The coast is oriented in a northwest-southeast direction, almost perpendicular to the prevailing northeasterly winds. Those winds, which are associated mainly with clear weather, tend to push the ice offshore producing a polynya along the coast. Previous work in this area, based on LANDSAT imagery, has suggested that this polynya is persistent. However, the data presented here, based on NOAA imagery, indicate that the ice cover is continuous along that coast more often than the polynya is present. LANDSAT images generally are supplied only for days of minimal cloud cover, hence the data available from them are strongly biased to clear weather when the polynya is present. Daily images from the NOAA satellites show that the polynya closes during cloudy periods. When data were available for the first day following a cloudy period, or when the sub-area was visible through the clouds, the ice cover was observed to be continuous with the shore. If the days when the area was classified as continuous ice cover (category 1) are combined with the number of days of cloud cover (when ice conditions probably also were in this category) the polynya was open in less than 40% of days in January, March and April, 52% in February and 45% in May. Movement of ice in this sub-area tended to be onshore and offshore, with little evidence of motion along the coast. Movement along shore would be expected to cause formation of leads and breaking of the ice, but categories 3, 4 and 5, which would indicate this, occurred only 12 times during all of the period of observation.

This sub-area is utilized in winter by ringed seals, bearded seals and polar bears. Bowhead and belukha whales migrate through the western part of it, around Pt. Hope and northward into the flaw zone in April-June. Persistent leads radiating northward from the east side of Bering Strait (see below) probably provide the route of access to this sub-area from the south.

The fair weather ice conditions affecting marine mammal distribution are illustrated by Figure 14. The pattern is dominated by the polynya, which is bounded on the west by a stream of small floes. The latter probably were formed by fracture of the ice as the pack drifted southward around Point Hope. This pattern is similar to that commonly present to the west and southwest of St. Lawrence Island, an area that is heavily utilized by walruses. The question arises as to why the Point Hope area is not also used by this species, and the answer seems to be that the pattern simply is not persistent enough to accommodate them. Frequent reversal destroys the potential habitat by closing the ice against the shore, whereas, in the St. Lawrence Island area, reversals of wind, while compressing the pack ice, seldom produce continuous ice cover. In addition, the lower air temperatures at the latitude of Point Hope probably

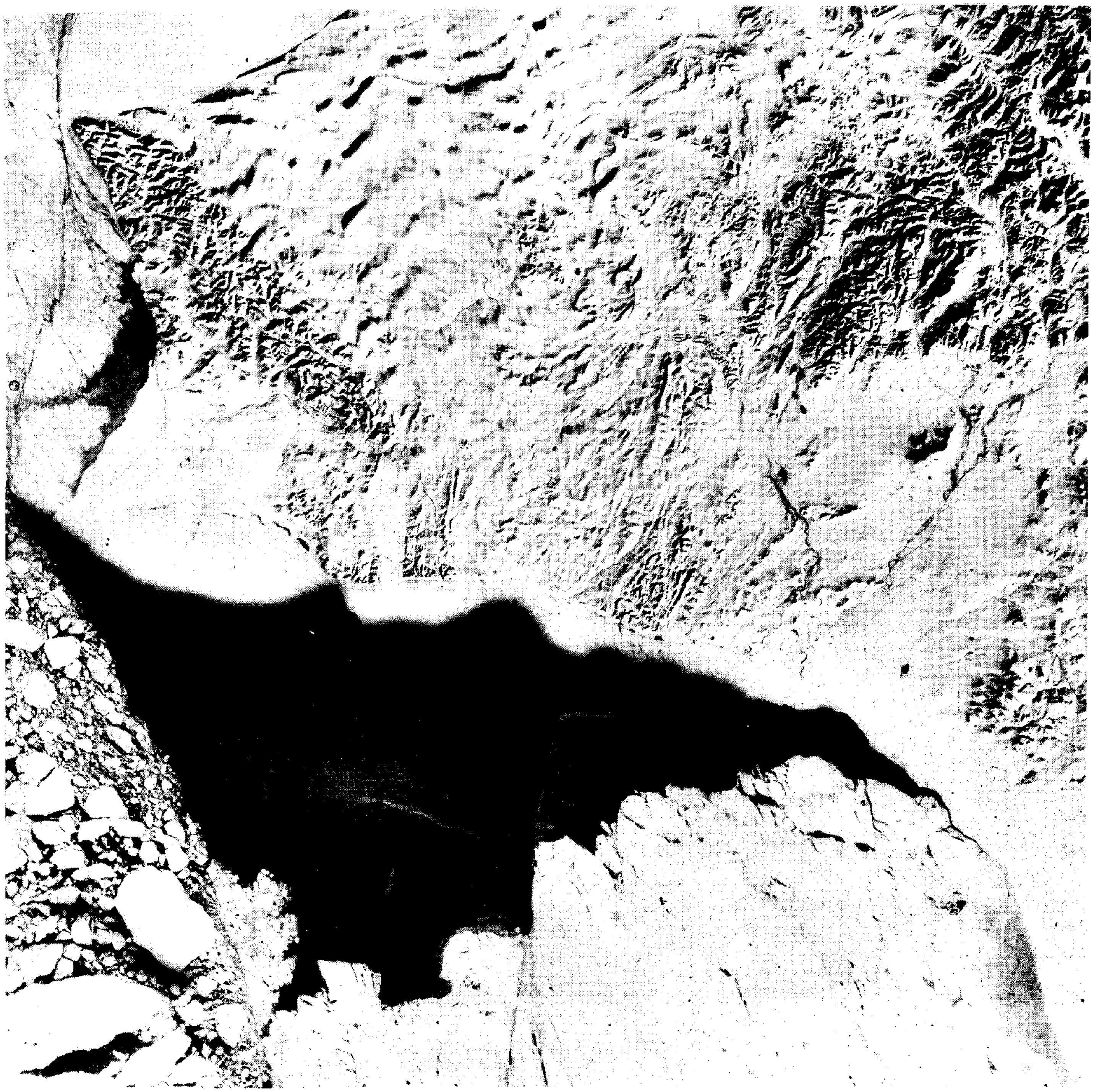


Figure 14. LANDSAT image #2420-21595 acquired on 17 March 1976.

result in more rapid refreezing of new leads and more rapid attainment of ice thickness too great for walruses to break through.

Sub-Area 5-Kotzebue Sound

The ice in Kotzebue Sound is essentially stable from freeze-up to break up, with little or no evidence of movement on the scale of the NOAA imagery from December to June. Ringed seals are the only mammals which regularly inhabit the area during the winter. Belukhas and spotted and bearded seals enter it after breakup.

Sub-Area 6-Sea North of Bering Strait

The ice in this sub-area is mainly a southern extension of the flaw zone north of Point Hope which is often present as a recognizable 'stream' of broken floes (Figure 3). The eastern boundary of the sub-area is defined by a series of leads that extends northward from the massive ridge of grounded ice which annually forms on Prince of Wales shoal.

The ice within the sub-area tends to be continually in motion. As noted earlier, the ice along the coast southeast of Point Hope is very sensitive to local winds, which open and close the polynya there with each change in weather. When the polynya opens, the pack ice south of it is forced toward Bering Strait where it converges to continuous ice cover until southward breakout occurs through the Strait. When the polynya closes, the ice converges to the north against the coast. New ice formed in the sub-area must therefore be absorbed in ridging or rafting. Because there is no exit for the ice to the north, the net ice transport is to the south.

Ice conditions in this sub-area ranged from continuous to broken pack through most of the winter. Continuous motion of the ice, combined with the differential motion between the ice east and west of the stream (as described under Sub-Area 8, the north coast of the Chukchi Peninsula), results in frequent formation of new leads. As a result, bearded seals as well as ringed seals are widely dispersed in this sub-area. In spring it is used intensively by migrating bowheads, belukhas, and walruses.

Sub-Area 7-Wrangell Island

The Wrangell Island area was included in this study because preliminary work showed that a polynya usually is present somewhere along its coast. This suggested that some information regarding large scale circulation of the Chukchi Sea pack ice might be obtained from a correlation between the location of the Wrangell Island polynya and ice conditions along the Alaskan coast. Unfortunately, the data were not adequate to test this possibility. Because this is the westernmost sub-area it was observable only on imagery from the satellite pass over Bering Strait (see above). Images obtained from passes farther east generally were too distorted along the western margins to provide useful information on the Wrangell Island area. This limitation, combined with the normal cloud cover, greatly restricted the number of days in which the sub-area could be observed.

The most common clear weather pattern showed the polynya on the east side of the island during December, January and February. In March, it occurred on the east side 32% of the time, the same frequency with which continuous ice surrounded the island. In April, continuous ice occurred 86% of the time, and the only polynas were on the west side of the island. During May, continuous ice occurred 62% of the time and the polynyas were on the north and west sides of the island with almost equal frequency. There was no apparent consistency to the ice configuration following cloudy periods. Polynyas on all sides of the island, as well as continuous ice cover, were observed on the first clear weather days.

Sub-Area 8-North Coast of the Chukchi Peninsula

The coastline in this sub-area is oriented approximately northwest-southeast, perpendicular to the prevailing northerly winds. North and northeast winds associated with clear weather kept the ice tightly packed against the coast. The lowest frequency of occurrence of continuous ice (category 1) was 75% in December; the highest was 98% in February. We anticipated that the ice would be moved off the coast during cloudy periods (i.e. with southerly winds) but this was not consistent. On the first clear day after a cloudy period, a lead or small polynya usually was present, but these leads and polynyas closed rapidly, returning the ice to category 1 within one or two days. When Point Hope was cloudy, or when ice was closed against the coast in that area, there usually was continuous ice cover in Sub-Area 8. This implies a degree of differential motion of the ice across Sub-Area 6 (sea north of Bering Strait) which may explain the persistence of leads in that area. The fact that the pack ice can be held tightly against both the coast southeast of Point Hope and that on the north side of the Chukchi Peninsula at the same time suggests that the internal inertia of the pack ice of the western Chukchi Sea is sufficient to overcome the force of local southerly winds.

Sub-Area 9-Bering Strait - Diomede Islands

During most clear weather periods, the ice in Bering Strait was in categories 3, 4, and 5 with leads actively forming. This indicated motion and general instability. However, in March, April and May, the frequency of occurrence of continuous ice was up to 35%, about 5 times greater than during January and February, indicating a tendency toward greater stability in those months. During cloudy periods, the ice tended to converge into the Strait from the south. When the clouds cleared, the ice condition on the first day always was continuous cover with few or no large leads.

A prominant shoal (Prince of Wales Shoal) projects northward from the east side of Bering Strait. A large grounded ice mass forms annually on this shoal (Kovacs, 1971) and anchors the landfast ice along the northwestern coast of the Seward Peninsula. As a stationary feature in a moving ice field, it also acts as the stress concentrator that initiates north-trending leads on the east side of Sub-Area 6. In spring, those leads provide the routes for migrating bowhead and belukha whales as well as walruses. In addition, there is evidence that some birds also follow this lead system during spring migration, rather than the more circuitous route around Kotzebue Sound.

A small concentration of walruses usually is present just south of the Diomede Islands in winter. During periods of southerly ice motion a small polynya forms there in the lee of the islands and the landfast ice which joins them. When the direction of movement reverses, it seems likely that leads are still present between the small floes where the pack ice breaks around the islands, thus maintaining access between air and water.

Sub-Area 10-Seward Peninsula between Bering Strait and Nome.

The orientation of the coast in this sub-area is similar to that of the coast southeast of Point Hope and ice conditions usually were sensitive to local winds. During clear weather periods, a polynya formed all along the coast. However, its southeastern boundary often was distorted by the presence of one or two important shear zones which extended to the southeast. These zones separated the ice in Norton Sound from that in Bering Sea to the west (see below) and tended to form rapidly when the ice moved in a southerly direction. During cloudy periods, pack ice moved against the coast, so that the ice on the first day after even a short cloudy interval always was classified as continuous ice cover. Usually within one day the ice moved offshore and the polynya was reestablished.

The ice in this sub-area moves rapidly and continually and can generally be characterized as 'active'. Because of the continual ice movement, formation of new ice between floes does not appear to be enough to exclude walruses from the area in winter but they occur in small numbers only in the vicinity of Sledge Island in that season. Bearded seals are present throughout this sub-area in winter.

Sub-Area 11-Norton Sound

As noted above, the ice in Kotzebue Sound was stable over most of the winter. In contrast, the ice in Norton Sound tended to be in motion most of the time. The dominant clear weather pattern in this sub-area included a polynya along the northern shore of the Sound with a second polynya in Norton Bay at the head of the Sound. Occasionally, the pattern reversed and the ice closed against the northern shore, leaving a polynya along the southern shore. This occurred even when the polynyas to the southeast of Point Hope and in Sub-Area 10 were well developed under north to northeasterly winds. This suggests that the ice in Norton Sound can move independently of these, which is consistent with the appearance of the shear zones noted in the discussion of Sub-Area 10. There is no barrier to southwesterly movement of ice out of the Sound.

The position of the polynyas tended to reverse following cloudy periods. That is, when the polynya was on the south side of the Sound at the start of a cloudy period, then it usually was on the north side when the clouds moved off.

Ringed and bearded seals are abundant in Norton Sound during winter. Highest densities of the former occur in the shore fast ice and the adjacent flaw zone. Bearded seals are present throughout the drifting ice. Walruses are absent in Norton Sound in winter except at Sledge Island. During the spring migration, walruses occur in large numbers throughout the western part of the Sound and in small numbers in the eastern part.

Sub-Area 12-Coast of Chukchi Peninsula from Bering Strait to Cape Chaplin

This area was separated from Sub-Area 13 (the sea south of Bering Strait) for the purpose of obtaining a record of the frequency with which pack ice is in contact with the coast. Based upon previous work, we knew that heavy ice often is absent in winter from Anadyr Strait, between Cape Chaplin and western St. Lawrence Island. Therefore, the question arose as to whether this was due to a drift trend around the eastern side of the island, or to convergence of ice north of Anadyr Strait which impeded ice movement through it. If the former was the case, the ice should have tended to remain away from the Siberian coast north of the strait. The clear weather imagery did not indicate any such tendency; instead, the ice was packed against the coast at least 70% of the time and was classified in categories 1, 3, 4 and 5. This also occurred after cloudy periods, indicating that both north and south winds tended to converge the ice against the coast. These observations suggest that the generally lighter ice between Cape Chaplin and western St. Lawrence Island is mainly the result of restricted flow between the Island and the Siberian mainland, rather than to drift away from the latter. The blockage appears to develop between the Siberian coast and the wedge of heavy ice north of the Island (see below). The southern, more open water part of this sub-area is occupied by large numbers of walrus and bearded and ringed seals throughout the winter. Anadyr Strait is a major migration route for whales, walruses and seals in spring and fall.

Sub-Area 13-Sea South of Bering Strait

The extent of ice cover in this sub-area during clear weather increased through December and January, reaching a maximum in February when the area was covered by continuous pack ice 72% of the time. March and April were similar to January (40%-45% continuous ice); in May, the onset of melting and movement of ice out of the area was apparent. Following cloudy periods, the ice was invariably in category 1, apparently as the result of southerly winds forcing the ice northward toward Bering Strait and the adjacent coastlines, where further movement was impeded.

Open water periods in clear weather increased from 1% during May to 80% in June, illustrating that break-up and disappearance of the ice in this sub-area occurs rapidly.

There was little correlation between the extent of ice in this sub-area and that south of Point Hope. Sub-Area 13 is effectively a channel for ice moving northward or southward. Changes in wind direction affect the direction of ice movement, but do not appreciably affect the extent of ice cover. In effect the ice surges back and forth with changes in the wind, probably with a net southerly transport during the period of ice growth (December to April).

During winter, this area is occupied mainly by ringed seals; the peripheral parts are utilized by bearded seals and walruses. Walruses, bowheads, belukhas, and seals migrate through the area during March to June.

Sub-Areas 14 and 15-North and south sides of St. Lawrence Island

These two sub-areas are described together because the ice conditions in them tended to be complimentary. Generally, there was continuous ice on the north side of the island when the polynya south of the island was well-developed. During clear weather, this configuration was present more than 80% of the time. The first day after cloudy periods however, invariably showed the pattern reversed, with the pack ice north of the island more open and the polynya to the south closed. A polynya seldom developed in the northern area; instead, the ice was more often in category 4 or 5. At such times, the ice on the south side seldom compacted to category 1; rather, it usually was in category 4 or 5.

During periods of sustained northerly winds, the ice was driven tightly against the northern side of St. Lawrence Island. At such times, it tended to form a compact wedge-shaped mass of heavy, pressure ridged ice extending northward for more than 100 km (Figure 15). This

Figure 15. Mosaic of LANDSAT images #1226-22165, 22171, and 22174 acquired on 6 March 1973.

was described and analyzed previously by Shapiro and Burns (1975a,b) and by Sohdi (1977).

Under the influence of winds with a strong component parallel to the long axis of the island, the ice on both the north and the south sides tended to disperse as broken or rounded pack ice.

The discussion of the distribution of marine mammals around St. Lawrence Island is deferred to the next section.

Sub-Areas 16 and 17-St. Lawrence Island to the Yukon River Delta and St. Lawrence Island to Gulf of Anadyr

During the period December to April, the ice was most commonly in categories 3 and 4 east of St. Lawrence Island; west of the island, it tended to be in categories 4, 5 and 6. Continuous ice cover occurred significantly more often east of St. Lawrence Island than to the west. Close to the eastern end of the island, the ice tended to break into small fragments in a narrow zone close to shore. To the west of the island, conversely, the ice was looser, and the broken ice along the coast dispersed over a wider area. Heavy ice was absent from the western sub-area following periods of prolonged winds from the north, resulting in a significant number of days in which open water or thin ice predominated. This occurred in all months of ice cover other than January and February for the area west of the island. It never occurred in the eastern sub-area from December to April.

In both sub-areas, periods of cloudy weather were associated with a general convergence of the ice.

The ice conditions in the four sub-areas surrounding St. Lawrence Island can be summarized as follows: with the exception of the wedge of heavy ice which forms on the north side, the ice around the island generally is heaviest to the east, lightest to the west, and classifiable as broken to rounded pack throughout the winter and spring. This implies that the ice to the east, south, and west usually is active, with new leads forming almost constantly. Ice movement around the eastern and western ends of the island produces areas of small highly deformed floes, in which the length of edge between heavy ice and open water is large. Along the eastern side of the island, the small floes are restricted to a narrow zone near shore, while the corresponding zone to the west usually is much wider.

Some of the heaviest concentrations of walruses in the Bering Sea occur to the west and south of St. Lawrence Island in winter. Bearded and ringed seals are abundant in the same areas and some bowheads and belukhas apparently winter there.

Sub-Area 18-Gulf of Anadyr

During clear weather the Gulf of Anadyr was dominated by continuous heavy ice in its southwestern sector and a large polynya just south of the Chukchi Peninsula. The polynya was present on 39% of the clear weather images for December. This increased to 81% in January, then dropped to 50% in February, and was 79% and 73% for March and April, respectively. For most of the remaining clear weather days, the ice was classified as continuous cover (category 1). Following prolonged periods of cloudy weather, the pack ice on the first clear day usually was continuous with the shore, indicating closure of the polynya. During a visit to the area in March, 1979, the ice along the northern part of the polynya was observed to be only about 10-25 cm thick; farther south, the thickness increased to about 1m. Over the distance in which this occurred there was little or no evidence of ridging or rafting (B. P. Kelly, oral comm, 1979). If this is typical, it implies that the opening and closing of the polynya are rather 'gentle' processes, essentially closing the open water areas without appreciable internal deformation of the ice cover. The gradual thickening of the ice to the south also implies a general drift in that direction, the ice in the south being older than that in the north.

Sub-Area 19-Bering Sea Between St. Lawrence and St. Matthew Islands.

The ice in this sub-area during clear weather was consistently classified as broken pack (category 4) from January through March. For December and April, the frequency of occurrence of this condition dropped to 63% and 76% respectively, with the ice on the remaining days classified as rounded pack (category 5). Category 5 also was the most common classification in May, occurring 44% of the time. The ice usually was gone from this sub-area in late May, and was present only on 7 occasions in June.

This is part of the principal wintering concentration areas of walruses and bearded seals. It also is used as a wintering area by some bowheads and belukhas.

Sub-Area 20-Nunivak Island

Imagery for a total of 18 days of clear weather were available in December for the Nunivak Island area. All of the images showed pack ice around the island; a polynya was present to the south on 12 of the 18 days. Only 2 clear days occurred during January. The polynya was present in one of these; for the other, the island was surrounded by continuous pack ice. In the remaining months of ice cover the limited data indicated the polynya to the south to be the most common feature of the ice cover, with occasional periods of continuous ice or polynyas to the north. The latter apparently is the usual condition during cloudy periods, as it was generally present on the first day after even short periods of cloud cover.

Walruses and bearded seals are common west and south of Nunivak Island in winter.

Sub-Area 21-St. Matthew Island.

There are few observations available for the St. Matthew Island sub-area because of frequent cloud cover. The data for clear weather in December, January and February indicated loose pack ice surrounding the island, with a polynya usually off the southern coast. The latter was the most common ice condition also during clear weather in March, April and May. The first image acquired after the end of a cloudy period invariably showed a polynya off the northern side of the island, and this probably is the prevailing condition during periods of southerly winds.

Aircraft observations of the area in March 1979, when the polynya to the south was present, showed the ice packed tightly against the north side of the island and extensively ridged. A ribbon seal and a sea lion were trapped by the tightly packed ice, suggesting that movement of the ice against the northern shore had been rapid. Bowhead whales were observed off the western end of the island in an area of heavy broken ice (B. P. Kelly, oral comm., 1979).

Sub-Area 22-Pribilof Islands.

The Pribilof Islands, which are close to the southern limit of the pack, usually were obscured by clouds. Only two observations were obtained for December and January, both of which showed no ice in the area. Images in February showed open water on four occasions and continuous ice on 3. In March and April (32 and 35 observations, respectively) there was continuous ice cover on only 6 days. During four days in April, the ice edge was south of the islands, with a polynya close to them. All observations in May were of open water. When clouds covered this sub-area, the ice apparently withdrew to the north, leaving open water around the islands.

This is an area utilized mainly by spotted and ribbon seals and some walruses and steller sea lions in the fringe and front zones.

Sub-Area 23-Bristol Bay

Clouds obscured the Bristol Bay sub-area most of the time during this study. Of the few observations available for the months of December, January and February, most showed either continuous ice, open water, or thin ice. The totals for March were 11 days of continuous ice, 8 days of open water or thin ice, and 7 days in which the ice was classified as category 3 and 5. April totals were 5 days of continuous ice, 17 days of open water or thin ice, and 17 days of ice in category 5. Of the 32 days in May for which observations were possible, 31 showed open water.

Harbor seals are present in the coastal zone of this sub-area throughout the year. Spotted and ribbon seals are associated with the ice fringe and front zones whenever these habitats are present. Walruses and bearded seals are most abundant in the sub-area during January to April.

3. Illustration of the Ice "Cycle".

A series of NOAA/VHRR images in the visible band acquired during 9 to 30 April 1975 illustrate the sequence of events in an ice 'cycle', beginning with the pattern prevailing under northerly winds to that resulting from southerly winds, then back to northerly. This particular series of images was chosen because it provides the maximal number of sequential views over a single complete 'cycle' of southward-northward-southward movement.

In the first image of the sequence (Figure 16), the lead extending northeast from Point Barrow along which a set of northward-trending leads terminates, separating the more stable ice of the Beaufort Sea from the diverging pack to the north and west. The single dark spot approximately due west of Point Barrow and the two smaller spots northwest of Cape Lisburne are open water or thin ice surrounding grounded ice masses (Stringer and Barrett, 1975; Kovacs et al., 1975); the small polynyas are on the leeward sides of these grounded floes. These ice masses act as stress concentrators because of their resistence to the movement of the pack ice. Their role as loci of lead formation will be apparent in the succeeding images of the sequence.

The flaw zone along the coast between Point Hope and Point Barrow is unusually wide. The bight just northeast of Cape Lisburne contains a large landfast ice mass. This is a persistent feature on that coast during winter and spring. For example, it is present also in Figure 13, a Landsat image acquired in March, 1973. The lead within this ice mass in both images is a common feature.

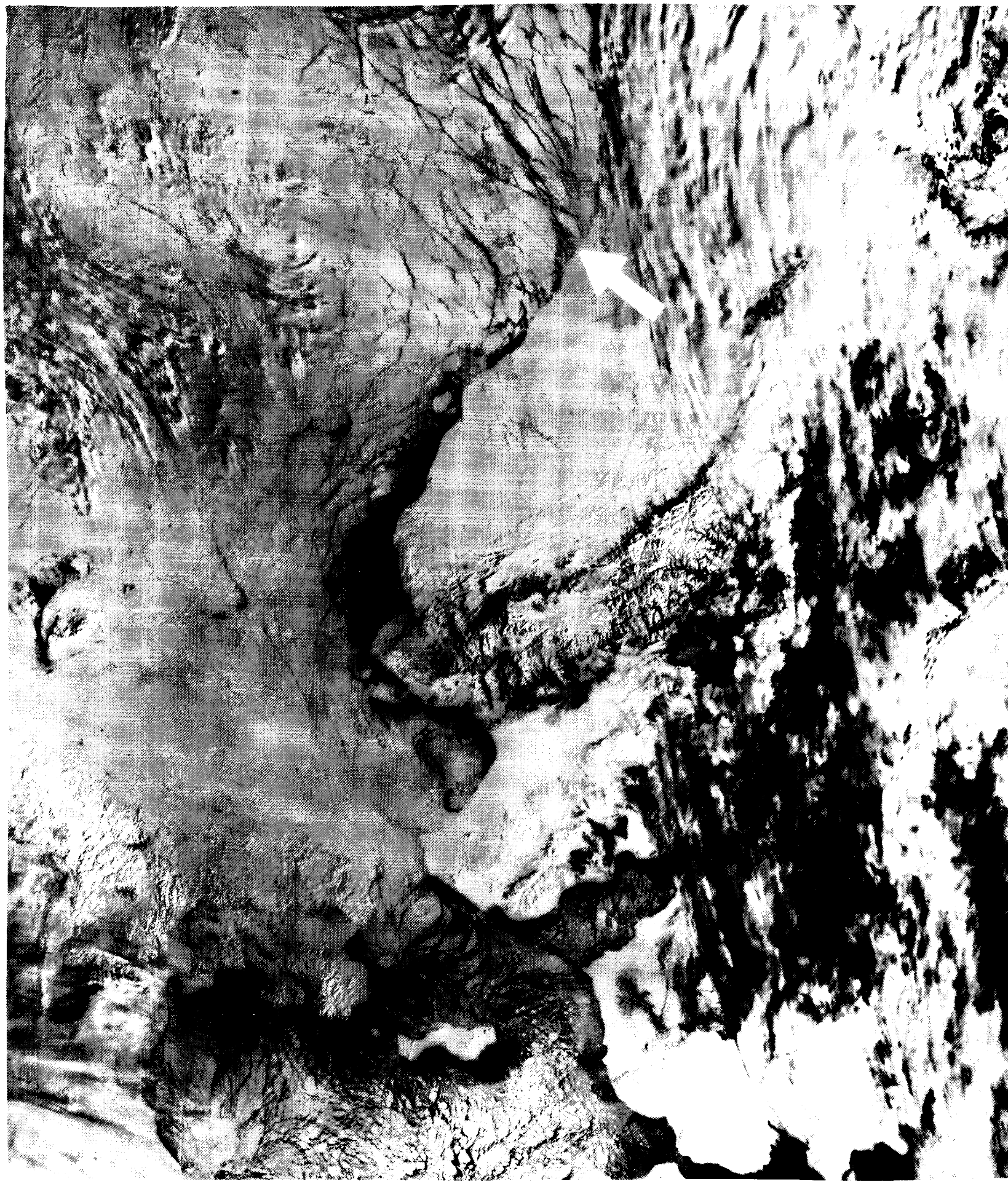


Figure 16. NOAA/VHRR visible band image acquired on 9 April 1975.

A polynya extends southeastward along the coast from Point Hope, then curves around the edge of the landfast ice in Kotzebue Sound. This is unusual; the more normal extent of this polynya is indicated in Figure 14.

The ice cover immediately north of Bering Strait appears to be continuous, although a few long north-south leads traverse the area, indicating some movement. South of Bering Strait, the pack is more open, and there are several indicators of recent southward movement. These include (a) the narrow lead along the Siberian coast, just south of Bering Strait, (b) the concave NE-SW leads between the Chukchi and Seward Peninsulas, (c) a small polynya south of the Diomede Islands, (d) a polynya along the western coast of the Seward Peninsula, (e) a shear zone extending north-south across the mouth of Norton Sound, and (f) the polynyas south of St. Lawrence Island and the Chukchi Peninsula. Note that the only extensive area of open water in Norton Sound is in Norton Bay, at its head. The change in extent of ice cover in the Sound will be apparent in the later images of the sequence.

The tendency for ice moving south from Bering Strait to pass east of St. Lawrence Island is evident. Clearly, the ice east of St. Lawrence Island is significantly heavier than that to the west, and our aerial and shipboard observations have shown that the eastern ice is extremely ridged and deformed. The ice on the north side of the island is very compact and ridged and is virtually continuous, while the polynya to the south of the island is large and slightly east of its usual position.

In the northern Gulf of Anadyr, the ice is close to shore in the west, and farther offshore and open toward the east. South of the open polynya, the ice is broken into angular floes which contrast with the more rounded floes in the area south of St. Lawrence Island.

To the southeast in Kuskokwim and Bristol Bays, a polynya along the south-facing shore is apparent, and ice is rather tightly packed against part of the northern shore of Nunivak Island.

Several changes are apparent in the clear areas of the image acquired two days later on April 11 (Figure 17). The small polynya south of the Diomede Islands has disappeared and a larger polynya has opened to the north. Closure of the polynya southeast of Point Hope also is evident, as is the formation or widening of leads north of Bering Strait. There is a new lead trending northeastward from Prince of Wales Shoal indicative of northerly movement. The ice in the eastern Gulf of Anadyr has closed against the shore, and there may be more ice in the area between St. Lawrence Island and the Siberian coast than in the previous image. The presence of cloud cover makes interpretation of the image difficult for that area. Finally, more open water is present along the south side of the Seward Peninsula and the linear aspect of the shear zone has been destroyed.

By April 15 (Figure 18), the pattern of the ice has changed markedly. The polynya south of St. Lawrence Island is nearly closed, heavy ice almost fills Anadyr Strait, and the ice appears to be farther offshore in the northwestern part of the Gulf of Anadyr. A polynya is visible along the southern shore of Norton Sound as a dark area in the clouds. The changes north of Bering Strait are more striking. The flaw has closed along the coast from Point Hope to Point Barrow, and short new leads are scattered through the area. The component of movement perpendicular

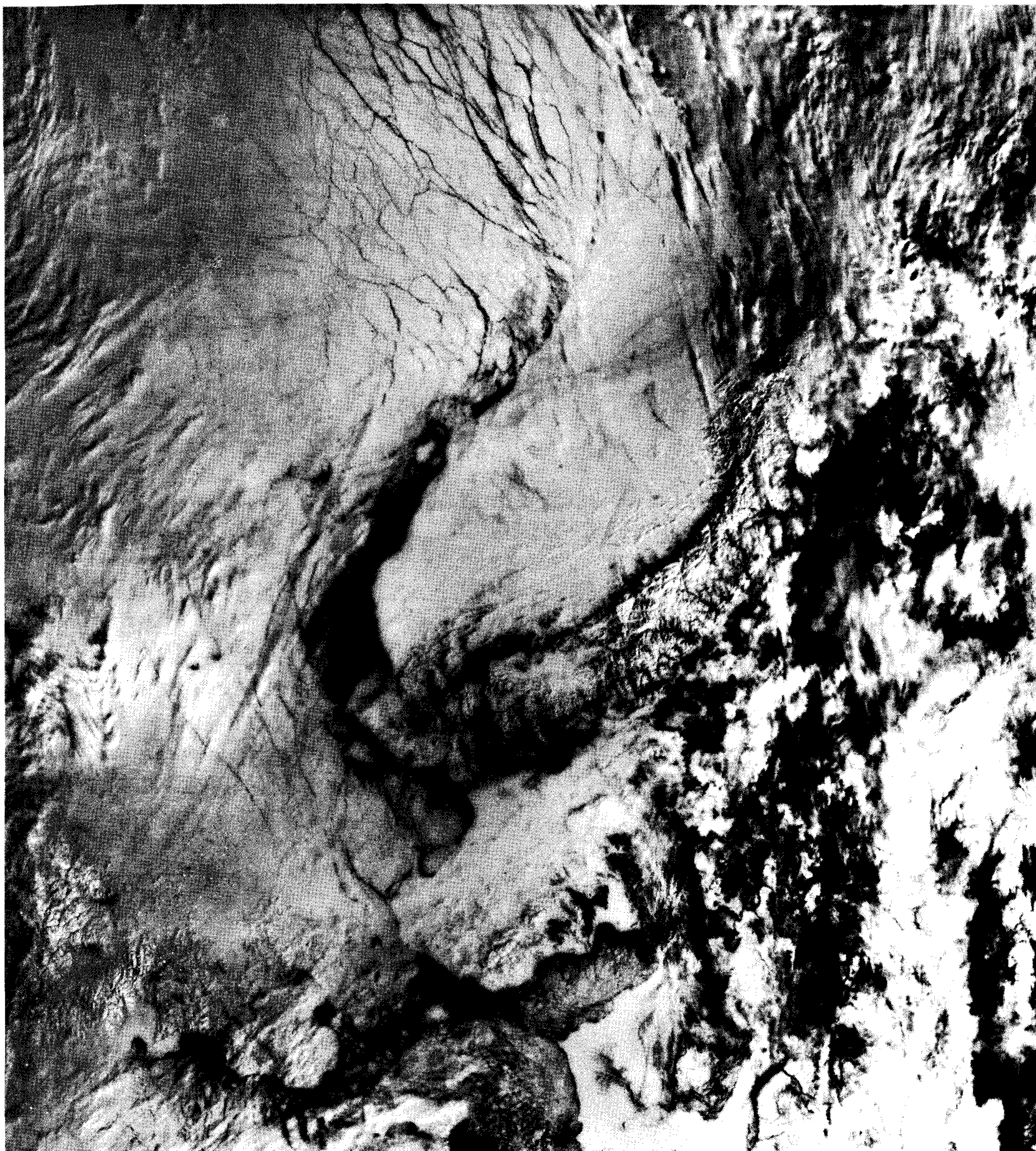


Figure 17. NOAA/VHRR visible band image acquired on 11 April 1975.

Figure 18. NOAA/VHRR visible band image acquired on 15 April 1975.

to the coast was estimated at about 15 km from "marker floes" visible in a few locations on the NOAA/VHRR infra-red images. The lead in the fast ice in the bight north of Cape Lisbourne is closed. A narrow lead is visible along the northern coast of the Chukchi Peninsula. The long, concave southward set of leads across the Arctic Ocean, shown in the earlier figures, is closing, and a new lead is visible along the edge of the landfast ice east of Barrow.

On April 17 (Figure 19), there is a new set of leads in the Arctic Ocean, and these are concave to the north, indicating movement of the ice in that direction. A few new leads are present along the Beaufort Sea Coast and in the area of Point Hope and Cape Lisburne. The polynya east of Point Hope is now almost closed, with heavy ice close to shore. The lead along the north side of the Chukchi Peninsula has extended northwestward. In the Bering Sea, the ice has closed northward toward Bering Strait, and leads are present in the heavy ice north of St. Lawrence Island. The polynya along the southern shore of Norton Sound is clearly visible, as is one along the northern shore of Nunivak Island. Etolin Strait appears to be free of ice. The ice in the Gulf of Anadyr, however, shows little or no evidence of northward motion between Figures 18 and 19 though it is less open in the east and more open in the west than in earlier images.

The Bering Sea was cloud covered when the image of April 19 was acquired (Figure 20). However, the flaw along the Chukchi Sea coast of Alaska can be seen to have opened as a result of northerly movement of the pack ice. The flaw along the edge of the landfast ice in the western Beaufort Sea also has opened wider, and the large mass in the bight

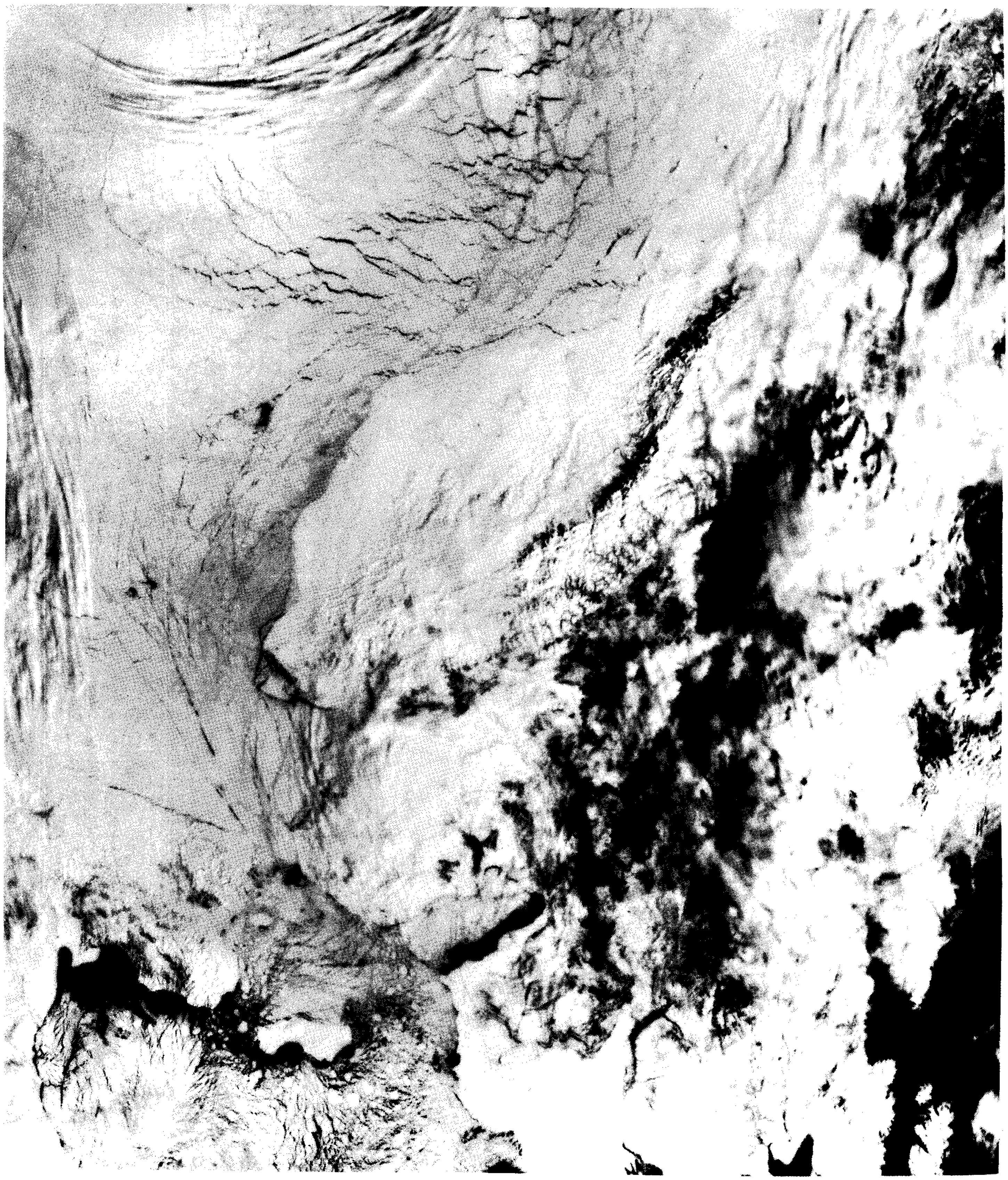


Figure 19. NOAA/VHRR visible band image acquired on 17 April 1975.

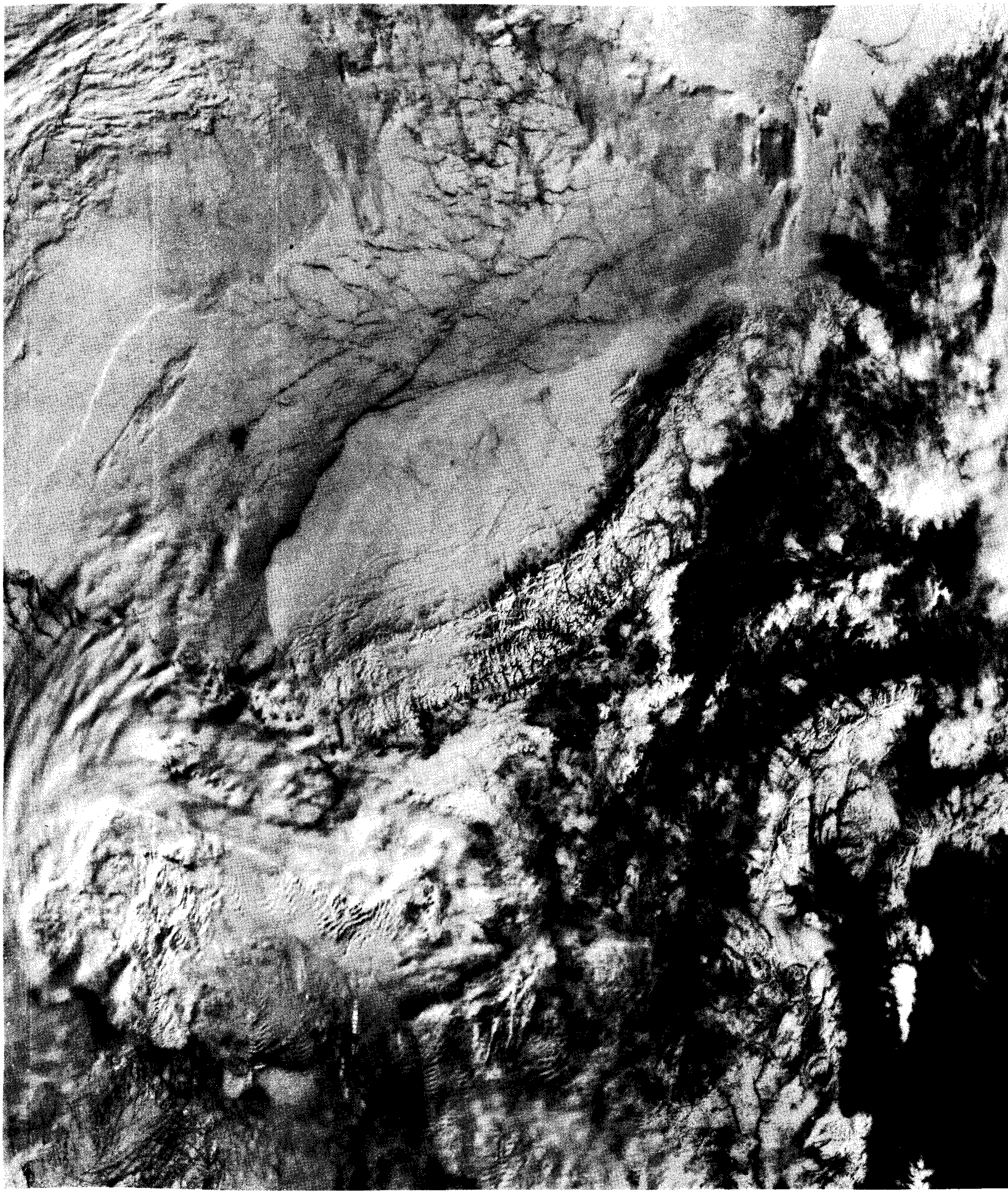


Figure 20. NOAA/VHRR visible band image acquired on 19 April 1975.

north of Cape Lisburne is again defined by a lead on its shoreward side, as it was in Figures 13 and 16. The coast between Point Hope and Cape Lisburne is open, while the ice is tight against the coast southeast of Point Hope.

The image from April 22 (Figure 21) shows continuation of the northerly movement in most areas. The ice has closed completely against the coast southeast of Point Hope, and an unusual pattern of broken ice has developed in the mouth of Kotzebue Sound. However, along the northern side of the Chukchi Peninsula, just west of Bering Strait, the ice again has closed against the coast, and a set of leads trends northwestward from the western side of the Strait. The ice off the northern side of the Seward Peninsula, the polynya on the northern side of the Diomede Islands, the curving leads, concave to the north in Bering Strait, and the ice against the coast in northern Gulf of Anadyr and Norton Sound all indicate that the ice is moving northward everywhere in the region, except along the northern coast of the Chukchi Peninsula.

The remaining images in the series for April 23, 26 and 30 (Figures 22, 23 and 24) show the transition back to the pattern dominated by southward movement under northerly winds. The first indications of this are the formation of a narrow lead along the coast southeast of Point Hope and movement of the ice off the southwestern coast of the Seward Peninsula, the southern sides of St. Lawrence and Nunivak Islands, and the south-facing coast of Kuskokwim Bay (Figure 22). On the image for April 26 (Figure 23), the ice in each of those areas has moved farther south; in Norton Sound, it has been driven against the southern shore. Southerly motion of the ice in the Gulf of Anadyr also is evident, and

Figure 21. NOAA/VHRR visible band image acquired on 22 April 1975.

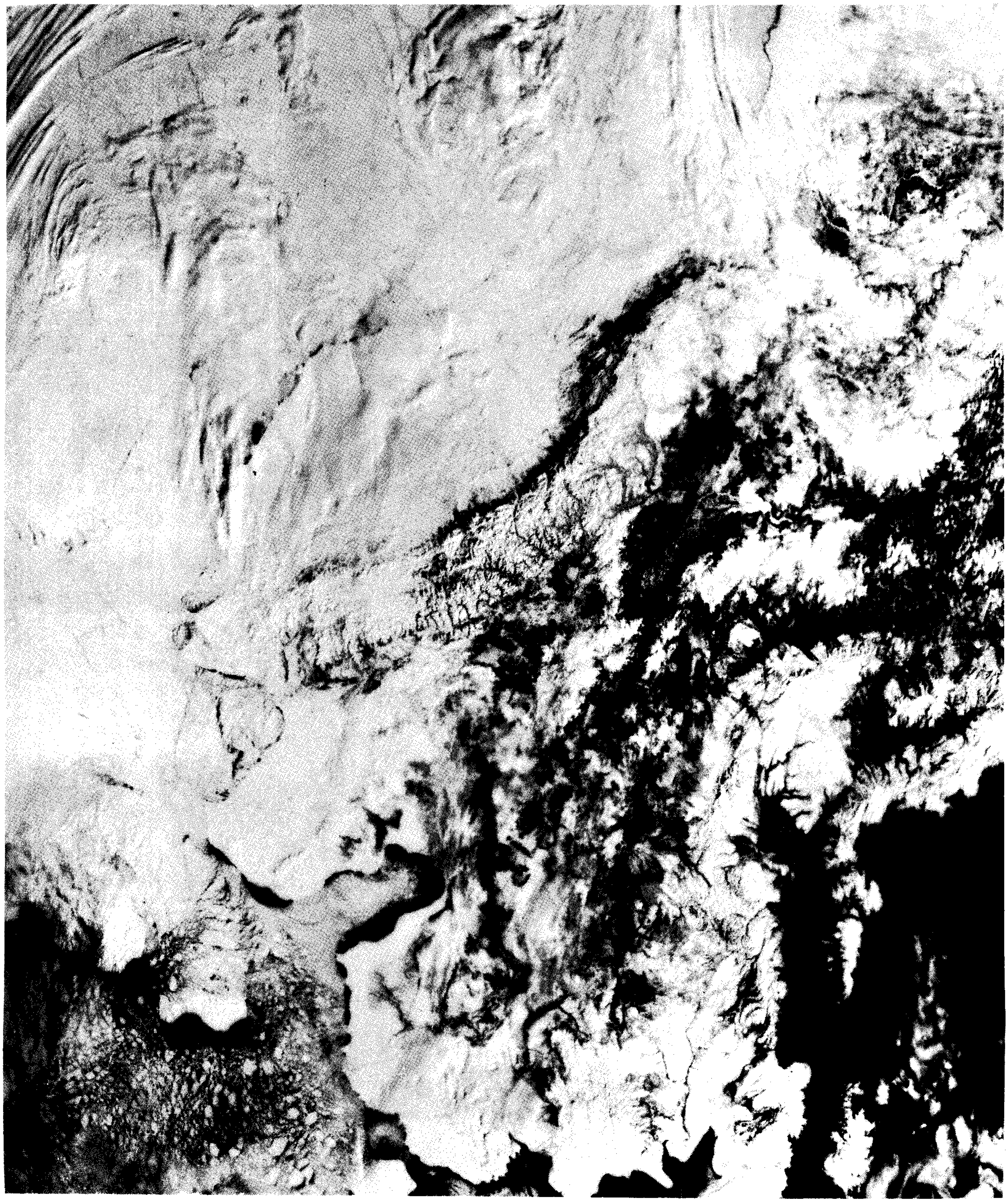


Figure 22. NOAA/VHRR visible band image acquired on 23 April 1975.

Figure 23. NOAA/VHRR visible band image acquired on 26 April 1975.

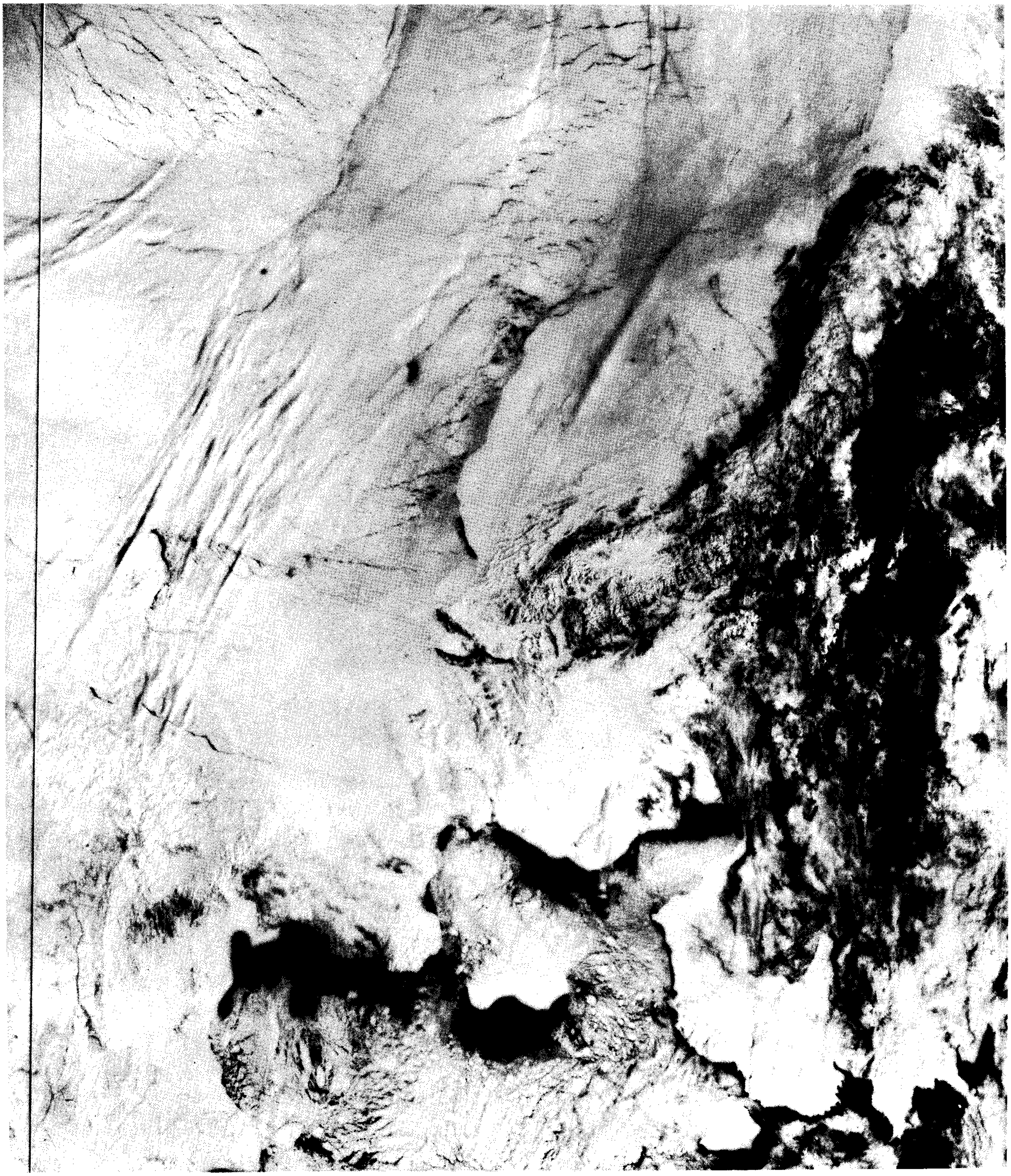


Figure 24. NOAA/VHRR visible band image acquired on 30 April 1975.

the ice again has converged against the northern side of St. Lawrence Island and diverged in the area west of the island. The polynya southeast of Point Hope is noticeably wider than in the last image. The inshore lead in the large ice mass in the bight northeast of Cape Lisburne is again closed and the polynya north of it has been reestablished. The ice along the remainder of the coast to Point Barrow is broken and clearly drifting southward, establishing a broad flaw zone.

Finally, in Figure 24, continued southerly movement is especially apparent in the enlargement of the polynyas south of the islands and peninsulas. The pattern of curving leads just north of Bering Strait also indicates initiation of a breakout of ice southward through the strait.

4. Discussion

The foregoing descriptions of each of the sub-areas indicate that there is consistent recurrence of specific ice conditions in relation to general weather conditions. The data also indicate monthly variations in the ice cover which seem consistent with monthly changes in weather. However, our monthly data sets are not yet large enough to permit saying with certainty the extent of similarity or consistency of ice patterns in different years, though a high degree is implied.

While the extent of ice cover is apparent from the NOAA imagery, many of the details of changes in the quality of ice with the seasons or between years may be indeterminate on the scale used in this study. For example, "continuous ice cover" may be a relatively smooth, continuous ice sheet or may represent floes driven together by the wind to form a compact ice mass within which leads or openings are abundant but too narrow to be detected by the imagery. With additional experience, it may be possible to identify these differences on the basis of gray tones and textures of the images, but we did not succeed in solving that problem in the present study. Hence, the patterns described probably include both.

The clear weather ice conditions for any sub-area can be identified without difficulty. Those for cloudy conditions have been determined with reasonable confidence, principally from the data obtained during transitions from cloudy to clear weather. Ice states during transitions from clear to cloudy weather usually were obscured and, in most cases, did not permit determination of the duration of the transitional state. This created some problems in interpretation of the ice cover in terms of its suitability as habitat for marine mammals. The known presence or absence of the mammals themselves, however, provided some guidance. That is, where the ice conditions in clear weather seemed suitable, but the animals were known to be absent, we assumed that some unsuitable conditions prevailed during the unobserved cloudy weather and/or clear-cloudy transitions. A larger number of observations of the transitional states would be needed to permit more objective evaluations.

In the 'typical' pattern for clear weather (in Figure 25), prominent lead systems are indicated and ice conditions are designated according to the classification system described earlier. Boundaries between areas of different ice conditions have been omitted, except where usually represented by leads.

The pattern indicates a shear lead extending northeastward into the Arctic Ocean from the vicinity of Point Barrow, with the ice tight along the Beaufort Sea coast and few leads in the nearshore zone. The flaw

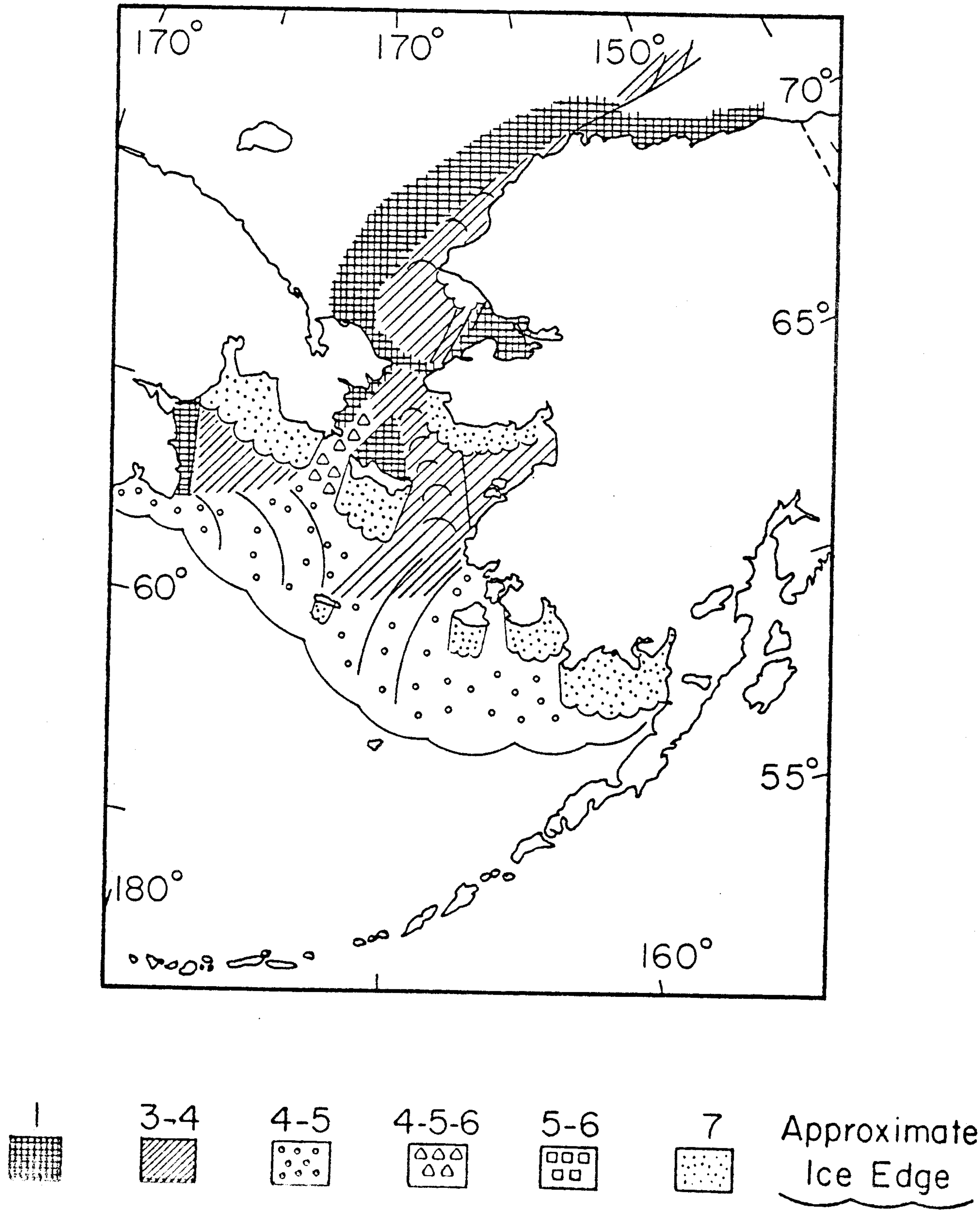


Figure 25. Ice conditions for a 'typical' clear weather pattern.

zone along the Chukchi Sea coast between Point Hope and Point Barrow is well-developed, as is the polynya along the coast southeast of Point Hope. Within the flaw zone the ice is classified as pack with leads or broken pack ice, and this condition extends almost to Bering Strait, where the ice converges to continuous ice cover. During a breakout of ice through the Strait, this would change to a higher numbered category as the ice moves out of the area. South of Bering Strait, the ice is again indicated as category 3 or 4 but could also be in a higher numbered category under sustained northerly winds. Polynyas are indicated along the south facing coasts throughout the Bering Sea, and the wedge of heavy ice north of St. Lawrence Island also is shown. Note the gradient in extent of the ice cover shown between St. Lawrence Island and Siberia.

The 'typical' pattern for cloudy weather (Figure 26) shows a flaw lead along both the Beaufort and Chukchi Sea coasts and generally heavy ice over most of the area north of Bering Strait. The ice cover has converged into the northern Bering Sea, and is generally continuous in the areas just south of Bering Strait. The wedge of ice north of St. Lawrence Island is shown as broken by generally east-west leads with the ice cover reduced, while east and west of the island there is little change in conditions. The polynya to the south of the island is closed, but the ice cover remains relatively dispersed. The only anomaly in this pattern occurred in the Gulf of Anadyr, where convergence of the ice against the coast may or may not be complete.

Comparison of Figures 25 and 26 shows areas of consistency in ice conditions. The ice generally remains dispersed or relatively open in the areas west and south of St. Lawrence Island, and probably elsewhere

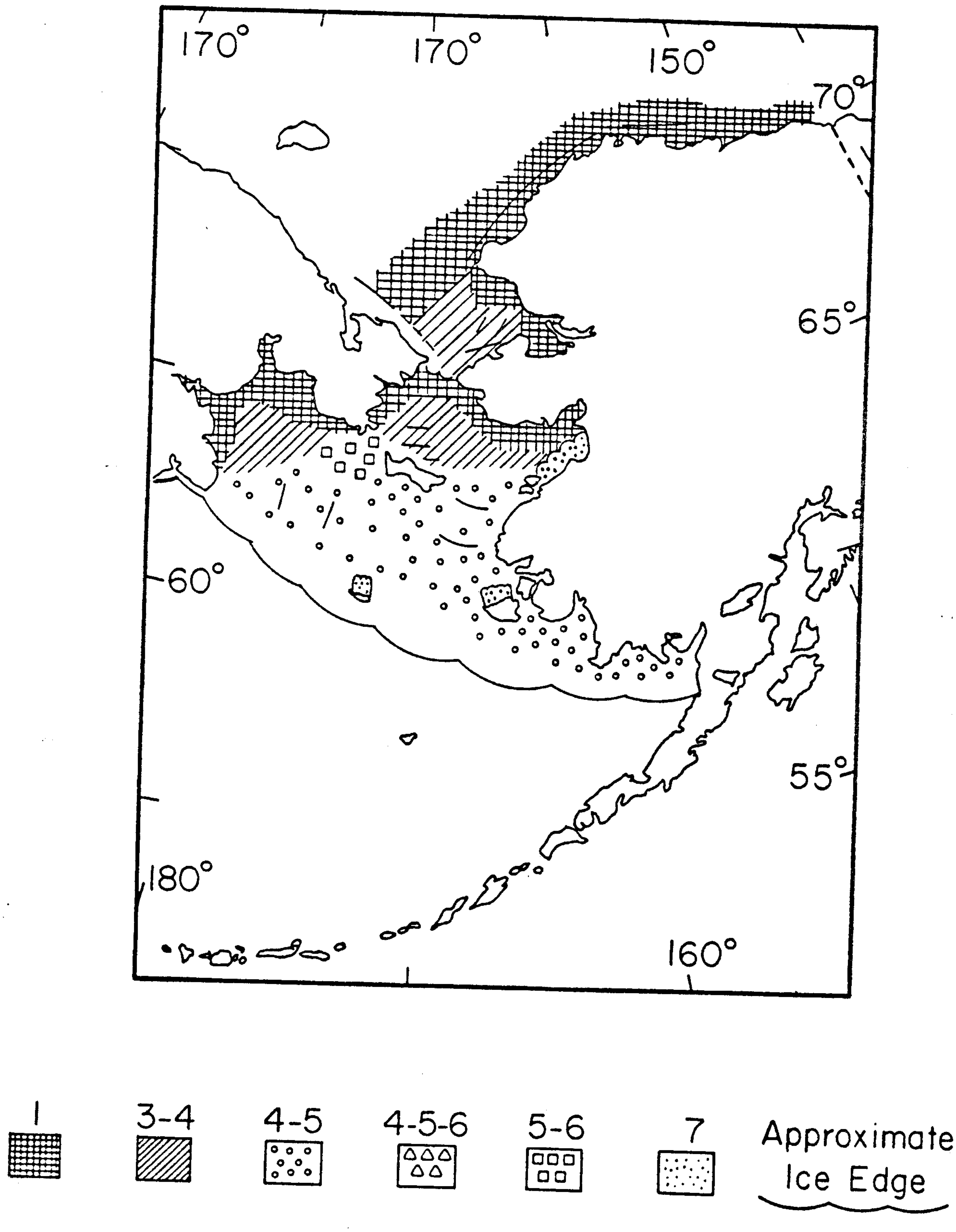


Figure 26. Ice conditions for a 'typical' cloudy weather pattern.

in the southern Bering Sea as well. Presumably, this is the reason why these areas are persistently occupied by walruses in winter, while other areas farther north are not, though they seem suitable in clear weather. To the north, the shifting of the ice maintains some lead systems which are used by bearded seals, but the ice cover is more extensive overall than in the Bering Sea. For that reason, these northern areas are mainly ringed seal and polar bear habitats.

IV. Fast Ice

A. Description and Distribution

Fast ice is sea ice which remains attached to the shore. In Alaska, the local vernacular for it is "shore ice". It begins to develop in autumn, increases in extent throughout the winter, and persists for some time into the spring-summer melting season.

Fast ice develops around all of the larger islands of central and northern Bering Sea, as well as along the mainland coast from Bristol Bay to the Beaufort Sea. In the warmer southern areas, it can be short-lived, occurring only during periods of extreme cold. In the Beaufort Sea it is a normal, persistent feature of the autumn to mid-summer ice cover. It varies in width from a few meters to tens of kilometers, depending on both latitude (temperature) and configuration of the coastline (Stringer 1978).

The most extensive fast ice occurs where the developing ice cover is protected by some physiographic feature from strong winds, currents, and the moving pack. These same forces drive thick ice into shallow water, where it becomes grounded and serves to protect and stabilize the thinner, floating fast ice inshore. Protected embayments such as Norton Bay, Port Clarence, Grantly Harbor and Kotzebue Sound are examples of areas in which a continuous, flat cover of fast ice develops and persists throughout the winter. Much of the northern coastline, facing the Beaufort Sea, has extensive fast ice, often bounded by and interspersed with grounded ridges or floes (Figure 27).

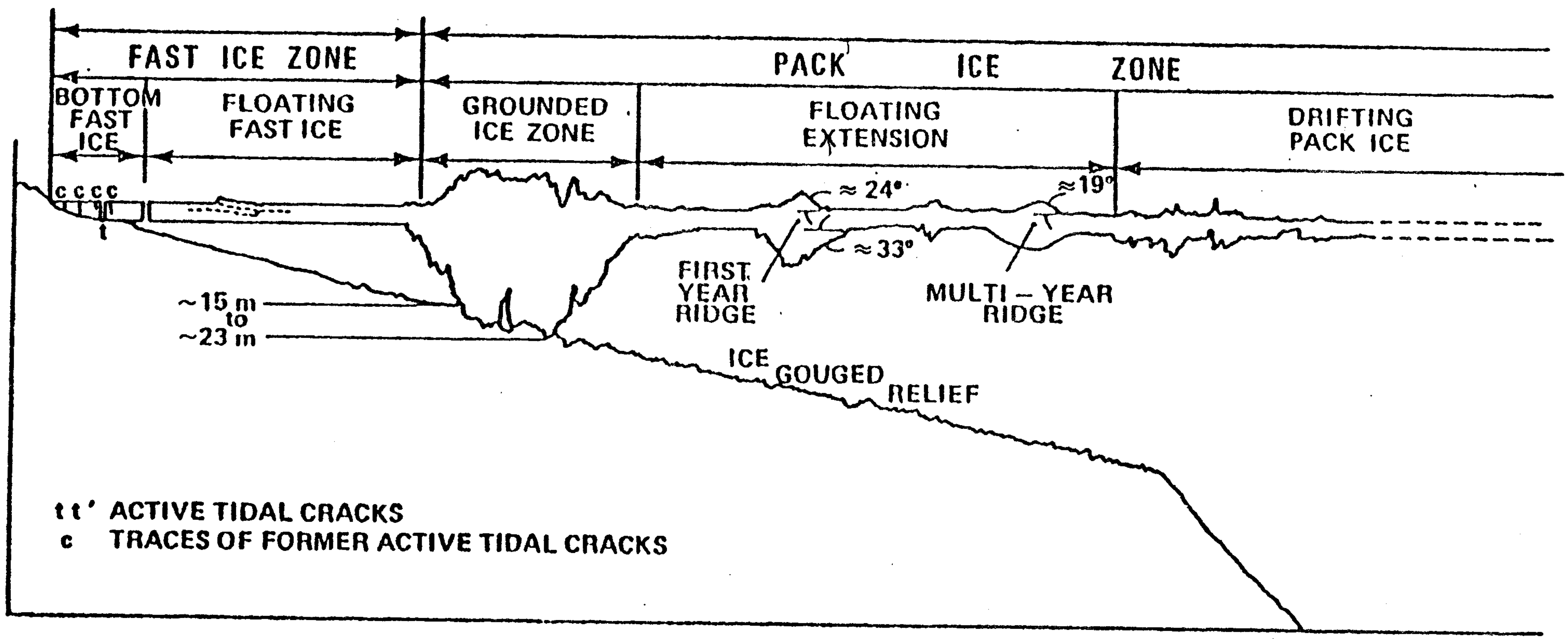


Figure 27. Schematic illustration of fast ice features (modified from Kovacs, unpublished)

Although the extent and structure of fast ice varies annually, this variability is within rather narrow limits for each region. The configuration of embayments is fixed, the direction of seasonally prevailing winds is, by definition, repetitive, and heavy ice floes tend to become grounded in specific locations and water depths. Thus, the extent of fast ice, as well as the configuration of its seaward boundary, tend to be similar from year to year (Figures 28 and 29). The appearance of the seaward margin of fast ice in the Chukchi Sea in June is shown in Figure 30.

B. Use of Fast Ice by Mammals

Since fast ice is a feature of the nearshore zone, it is utilized mainly by those marine mammals which usually occur near shore. These include harbor seals in Bristol Bay, spotted seals in the Bering and Chukchi Seas, and ringed seals in all areas where they occur. The use of fast ice by harbor seals is opportunistic; that is, they are not dependent on its presence but utilize it when it occurs in their area. Fast ice develops irregularly in Bristol Bay and around the Pribilof Islands where these seals haul out. They utilize it when they are prevented by its presence from hauling out on land. Since they do not ordinarily make holes in ice, they inhabit its margin or the irregular openings in its thinner parts. Since, it is inconsistently present within the range of these seals in winter, and since basking is minimal in that season, fast ice is not heavily utilized by harbor seals as a haul-out habitat.

Spotted seals in the Bering and Chukchi Seas utilize fast ice when it first forms in autumn and during late spring-early summer, when it is deteriorating. In winter and early spring they inhabit the moving pack,

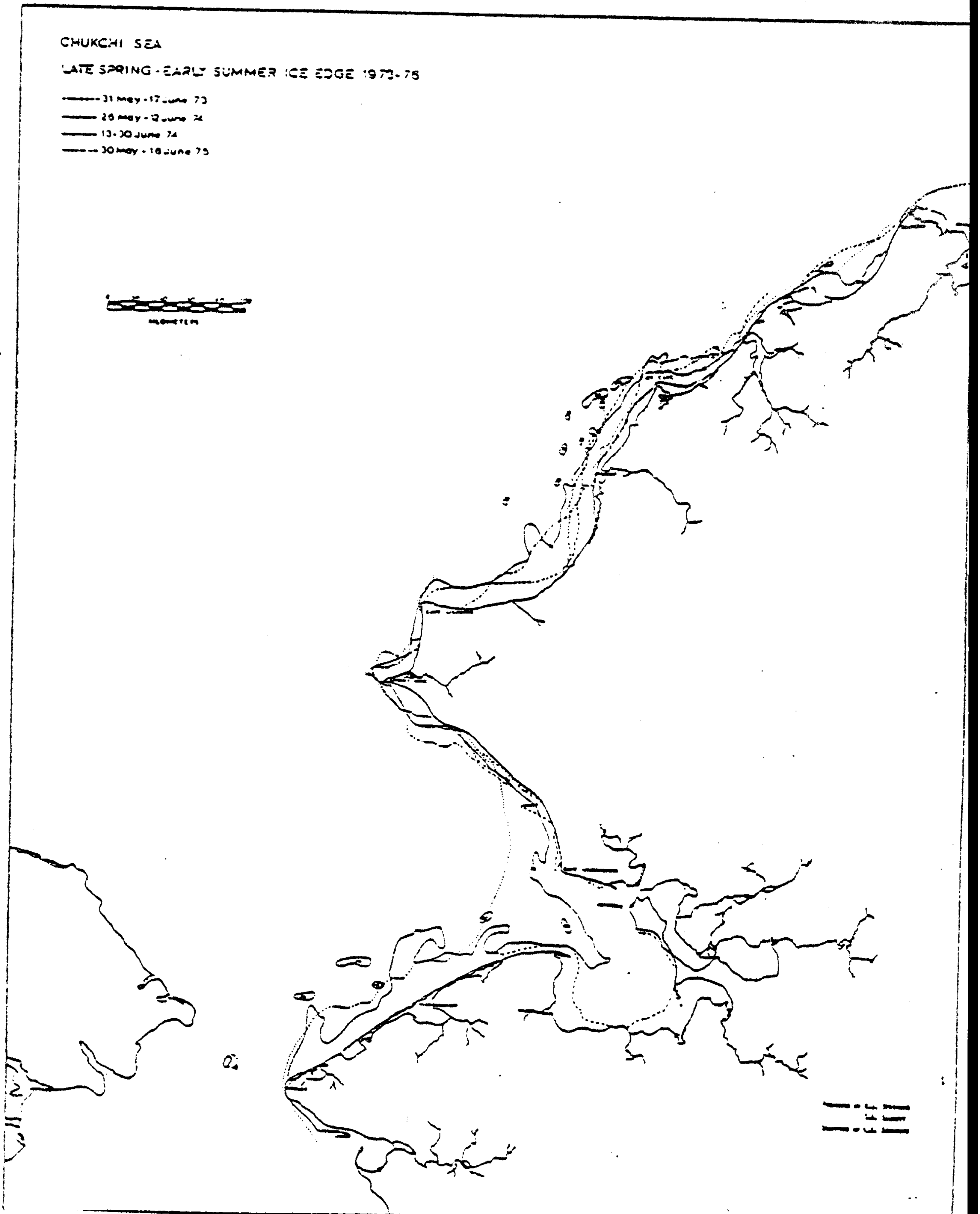


Figure 28. Seaward extent of fast ice along the Chukchi Sea coast (from Stringer, 1978).

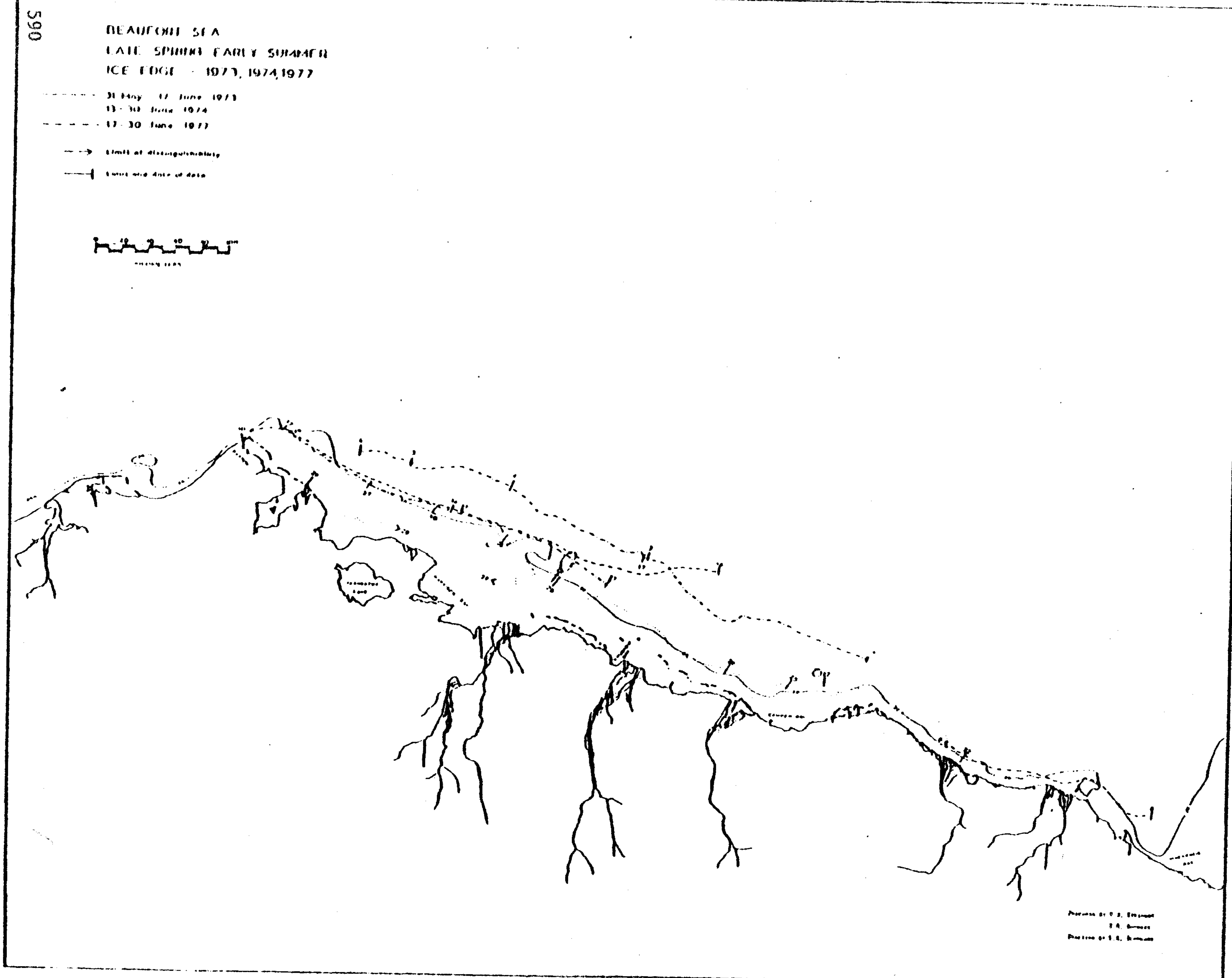


Figure 29. Seaward extent of fast ice along the Beaufort Sea coast (from Stringer, 1978).

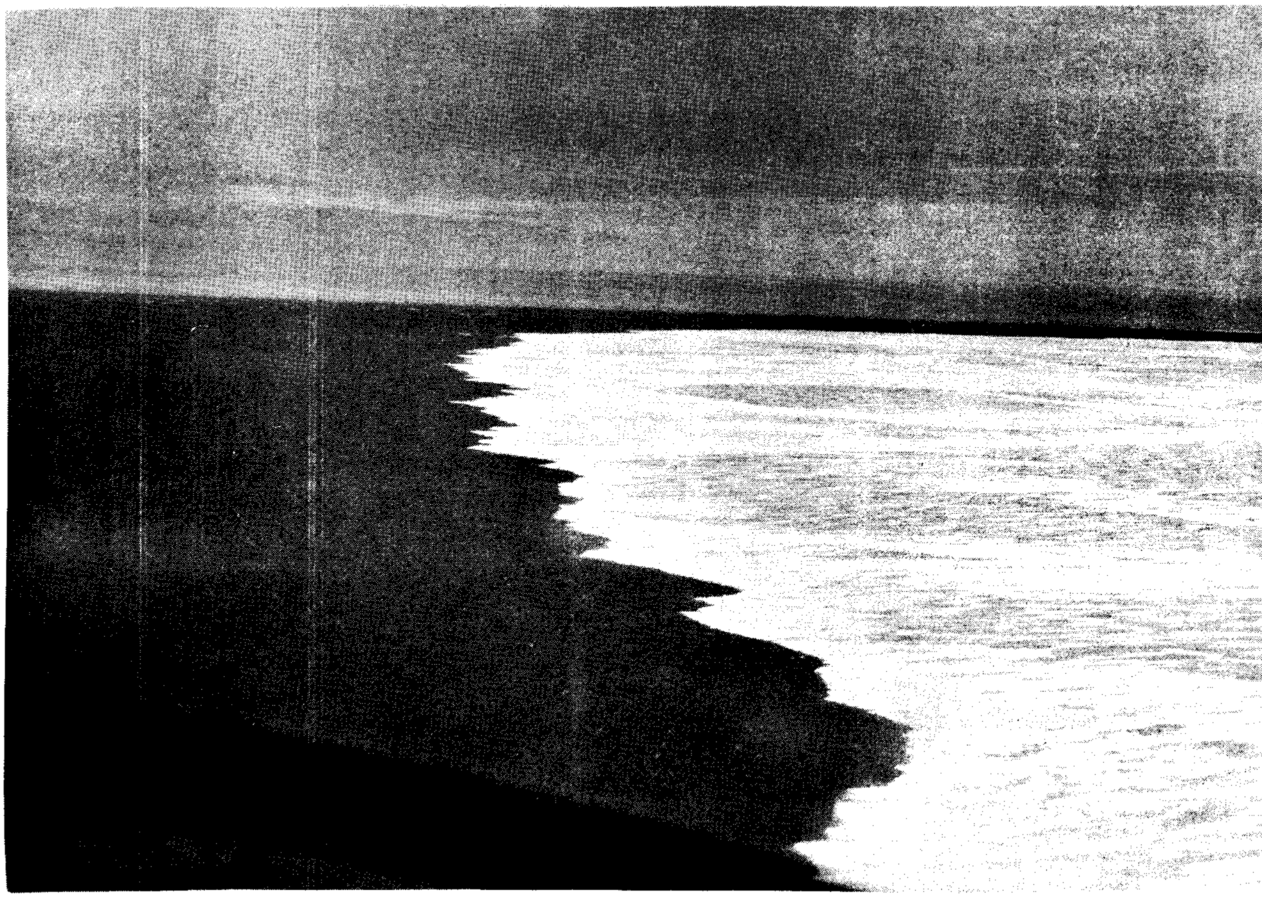


Figure 30. Low-altitude aerial view of the seaward margin of fast ice near Icy Cape, Alaska, 6 June 1978.

mainly the ice front (Burns, 1970, Fay, 1974, Braham et al. in prep.); in summer they use the ice-free coastal zone (Burns 1970). Their use of newly developing fast ice in autumn is during their southward migration. They haul out on it then in small numbers, apparently to rest, and only in periods of relative calm. The decaying fast ice in late spring-early summer is used much more intensively. In parts of the Yukon-Kuskokwim Delta region and in Norton Sound, hundreds of these seals can be seen in rather dense concentrations along that ice, (Regnart, personal communication, Burns, personal observation). It is of special importance there because of its juxtaposition with herring and capelin schools, which approach the coast prior to and during spawning. The seals feed intensively on those fishes and use the ice for basking during the final stages of their molt. Their incursions into the fast ice at that time are facilitated by its disintegration, which creates numerous openings and passages. As the fast ice disappears, spotted seals move inshore to traditional haul-out areas.

Ringed seals show the greatest dependency on, and the most prolonged use of fast ice (McLaren 1958). They are the most abundant and widely distributed seals associated with sea ice and are the best adapted for occupying regions of extensive, thick, stable ice. Their breathing and exit holes have been found in ice exceeding 2.3 m thick in the Beaufort Sea (Burns, personal observation). These seals occur in association with fast ice of the Bering, Chukchi and Beaufort Seas for as long as it persists. They make and maintain breathing holes in it throughout the winter and excavate subnivian lairs, in which they rest, give birth and nurse their pups (McLaren 1978, Smith 1976, Smith and Stirling 1975). During the molt in May through July, they bask on the fast ice.

Although ringed seals occur throughout the sea ice zone they usually occur in highest densities in the fast ice itself. This is especially true of mature adult seals and newborn pups. The ringed seal is the only seal in the northern hemisphere which regularly inhabits fast ice during the period when it is most extensive and thick. The pups are born there from late March through April (mainly early April) in prepared snow lairs or cavities and in pressure ridges (McLaren, 1958; Burns, 1970; Smith and Stirling, 1975). Stability of the ice in which these birth chambers are made is considered to be a prerequisite for survival of pups to the age of independence at 4 to 6 weeks (McLaren 1958).

Ringed seals comprised more than 99 percent of the marine mammals seen during aerial surveys over the fast ice of the Beaufort and Chukchi Seas in June 1970, 1975, 1976 and 1977 (Burns and Eley 1978). The density of these seals ranged from a low of 0.4 seals/nm^2 between Flaxman and Barter Islands in 1976 to a high of 6.2 seals/nm^2 between Wainwright and Barrow in 1975 (Table 4). Conversely the density of basking ringed seals in the pack ice in 1976 was 0.2 and 0.1 per nm^2 in the Chukchi and Beaufort Seas, respectively (Burns and Eley 1978). The area of the pack is huge, and although the density of seals there is very low, their numbers there are many times greater than in the fast ice. However, because the fast ice is important as a habitat for breeding, its use by ringed seals probably is essential for maintenance of the population.

The fast ice is utilized also by polar bears, arctic foxes, and man mainly as a relatively stable extension of land. Polar bears use the ice in transit between the pack and the shore. They cross it when they come ashore for denning or scavenging; females leaving shore with very

Table 4. Densities of ringed seals seen on the fast ice of the eastern Chukchi and western Beaufort Seas, based on aerial surveys in June 1970, 1975, 1976 and 1977. The values are the average number of seals per nm^2 in each sector (Barnes and Eley, 1978).

Sector of Coastline	1970	1975	1976	1977
Kotzebue Sound	-	-	0.7	-
Cape Krusenstern-Point Hope	-	-	2.3	-
Point Hope-Cape Lisburne	-	-	0.9	-
Cape Lisburne-Point Lay	-	-	4.9	-
Point Lay-Wainwright	5.4	2.9	1.9	3.3
Wainwright-Barrow	3.7	6.2	3.8	2.6
Barrow-Lonely	2.3	2.8	1.4	1.0
Lonely-Oliktok	1.0	1.4	1.1	0.5
Oliktok-Flaxman Island	1.4	1.0	1.4	0.7
Flaxman Island-Barter Island	2.4	1.8	0.4	1.2

young cubs frequently spend several days on the fast ice, on which they may excavate one or more temporary shelters (Lentfer, 1972; Burns, personal observation). On the extensive fast ice of the Beaufort Sea, some bears may den and give birth to their cubs (J. Lentfer, pers.comm.). In winter, polar bears are most numerous at the flaw between the moving pack and the fast ice (Lentfer 1972). This is where their main prey (ringed and bearded seals) are most accessible in the Chukchi and Beaufort Seas.

The arctic fox is the most abundant quadruped in the fast ice zone. These foxes prey on newborn ringed seals during the period when the latter are confined to their subnivian lairs in the fast ice (Smith 1976). The fast ice zone is an important part of the total habitat of Arctic foxes in northern regions, although the extent of dependence of this zone is presently unknown.

Human activity on the fast ice probably has always had an effect on certain marine mammals and fishes, if only because it made them more accessible to harvesters. Formerly, Eskimos netted ringed seals under this ice and hunted them at the flaw between the fast ice and the moving pack. Recent findings (Burns and Eley 1978) indicate that the presence of men and machinery on the fast ice has resulted in displacement of ringed seals. Aerial surveys of ringed seals in June 1976 showed that the density of seals basking on the fast ice was significantly lower in the vicinity of Eskimo villages than it was farther away (Figure 31). Similarly, in fast ice of the Beaufort Sea, the densities of basking ringed seals and of observed ringed seal holes in the ice differed between areas in which seismic exploration was conducted (disturbed areas) and those in which it was not conducted (control areas), as shown

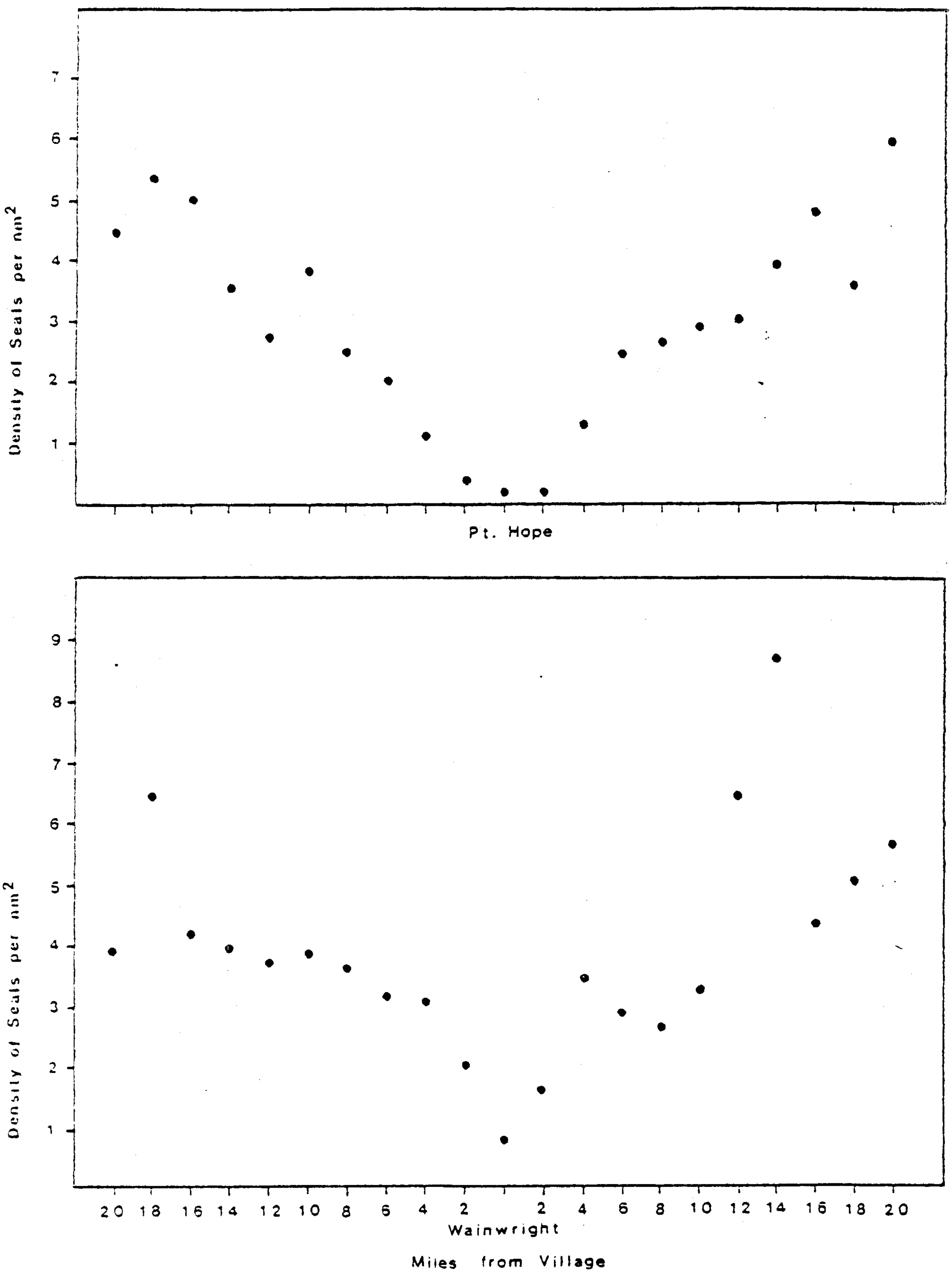


Figure 31. Densities of ringed seals on fast ice in relation to distance from two Alaskan villages as determined by aerial surveys (Burns and Eley, 1978).

in Table 5. Application of the Kruskal-Wallis H Test (Zar 1974) to these data indicates that the differences were highly significant (P > 0.025). Since in these cases removal of seals did not occur, the differences in density are presumed to be the result of displacement by disturbance alone. Disturbance from seismic exploration activities occurred between January and 2 March. Aerial surveys were conducted between June 10 and 18.

C. Characterization of Ringed Seal Habitat in Fast Ice by Side-Looking Airborne Radar (SLAR)

1. Objectives and Methods

The objective of this phase of the study was to test the hypothesis that the distribution of ringed seals on the fast ice is correlated with the surface topography of the ice. We felt that SLAR imagery would provide a more objective representation of the relative roughness of the ice than could be obtained by visual judgement. To test this, we overlaid maps of ringed seal distribution, as determined by aerial survey, on the appropriate SLAR images and compared seal numbers with SLAR film density. In the SLAR negatives, areas of high film density corresponded to rough ice and areas of low film density to smooth ice. All of the images and seal distributional data were acquired during May-June, 1976.

The flight paths of ringed seal surveys were plotted on mylar overlays, at a scale of 1:500,000. Flight paths were divided into minutes of flight time and the numbers of ringed seals observed per minute were registered on the overlay. The survey observers' estimate of percent deformity (roughness) of the ice were added to the overlay for the appropriate minutes.

Table 5. Comparative densities of basking ringed seals within and outside of seismic exploration areas on fast ice of the Beaufort Sea[1].

	Survey Sectors					
	Lonely-Oliktok		Oliktok-Flaxman Is.		Total	
	Exploration Area	Control Area	Exploration Area	Control Area	Exploration Area	Control Area
1975						
No. aerial survey miles	51	119	115	162	166	287
No. seals sighted	18	117	61	189	79	306
Seal density/nm^2	0.35	0.98	0.44	1.13	0.48	1.07
1976						
No. observed survey miles	96	43	30	60	126	103
No. seals sighted	81	89	31	77	112	166
Seal density/nm^2	0.84	2.07	1.15	1.30	0.89	1.61
1977						
No. aerial survey miles	17	27	37	15	54	42
No. seals sighted	7	17	18	34	25	51
Seal density/nm^2	0.41	0.60	0.50	2.30	0.46	1.21
1975-1977						
No. aerial survey miles	164	189	182	237	346	432
No. seals sighted	106	223	110	300	216	523
Seal density/nm^2	0.64	1.18	0.60	1.27	0.62	1.21

[1] From summary of survey data analyzed by K. Frost, Alaska Department of Fish and Game.

The mylar overlays were placed over the corresponding SLAR negatives at the same scale and visually examined for relationships between seal numbers, estimates of ice deformity and image density. Actual image densities were measured for each minute of the survey flight path with a MacBeth "Quanta Log" Densitometer having an aperature setting of 1.0 mm. Densitometer readings were taken through approximately 2.0 mm circles drawn on the mylar overlay and corresponding to each minute of observation during the seal surveys.

Tests for correlation between image densities and ringed seal survey data were as follows:

a. SLAR images acquired 11-13 May 1976 and covering the landfast ice from Point Barrow to Kokruagarok (70°55'N, 153°05'W), Alaska;

(1) Image density for each minute of flight path, by number of ringed seals observed during survey flight on 6/15/76.

(2) Image densities for each minute in which one or more seals were observed, by number of ringed seals (6/15/76).

(3) Image densities for each minute in which less than 5 seals were observed, by number of ringed seals (6/15/76).

(4) Image densities for each of 38 minutes randomly chosen from the 56 original observations of one or more seals, by number of ringed seals (6/15/76).

b. SLAR images acquired 11-13 May 1976 and covering the landfast ice from Kokruagarok to Flaxman Island, Alaska;

(1) Image densities for each observation of one or more seals, by number of ringed seals (6/15/76).

(2) Image densities for each observation of less than 5 seals, by number of ringed seals (6/15/76).

(3) Image densities, by 27 observations of estimates of percent deformity of the ice.

The results of the analysis are presented in Table 6.

With one exception the correlations were weak for dispersed seals (< 5/min) and non-dispersed seals (>5/min) as these categories were defined by Burns and Harbo (1972). In the Point Barrow to Kokruagarok section (SLAR #4, Table 6), dispersed seal numbers showed a moderately strong correlation with image density (correlation coefficient = 0.98469). A larger sample of dispersed seals in the Kokruagarok to Flaxman Island section (SLAR #3, Table) showed essentially no correlation with image density (correlation coefficient = 0.01909).

Figure 32 and 33 show the number of observation points within the specified SLAR image density range when no seals, 1 to 4 seals, or 5 or more seals were seen.

The correlation coefficient for SLAR image density and the seal observers' estimates of percent deformity of the ice was 0.02390 with 95 percent confidence limits of -0.3595 and +0.4004 (i.e. a poor correlation).

2. Evaluation

The single strong correlation observed between dispersed seals and SLAR image density (Point Barrow to Kokruagarok) may be a function of the relatively small sample size (38 microdensity readings of points where seals were present). A similar random sample of 38 dispersed and non-dispersed seals showed a weak correlation with image density. Data from the Kokruagarok to Flaxman Island section, on the other hand, gave

Table 6. Results of correlation between the density of ringed seals and surface relief of fast ice as determined from side-looking airborne radar (SLAR). These data are from May-June 1976.

Identification No. of SLAR Image	Image Density in relation to	Number of Micro-Density determinations	Image Density		Number of Seals		Product Moment correlation coeff.	95 percent confidence limits	
			Mean	Std. Dev.	Mean	Std. Dev.		L1	L2
3	each observation of one or more seals	105	1.24	4.06	4.06	5.28	0.22145	0.0311	0.3963
3	each observation of less than 5 seals	78	1.22	2.06	2.06	1.32	0.01909	-0.2044	0.2406
4	each minute of survey flight	114	1.12	0.96	2.31	4.23	0.41598	0.2626	0.5656
4	each observation of one or more seals	56	1.30	1.30	4.70	5.03	0.40857	0.1631	0.6064
4	each observation of less than 5 seals	38	1.44	1.55	2.71	3.08	0.89469	0.8053	0.9443
4	38 mins. randomly chosen from 56 in which 1 or more seals were seen	38	1.45	1.55	4.82	5.59	0.44598	0.1472	0.6702

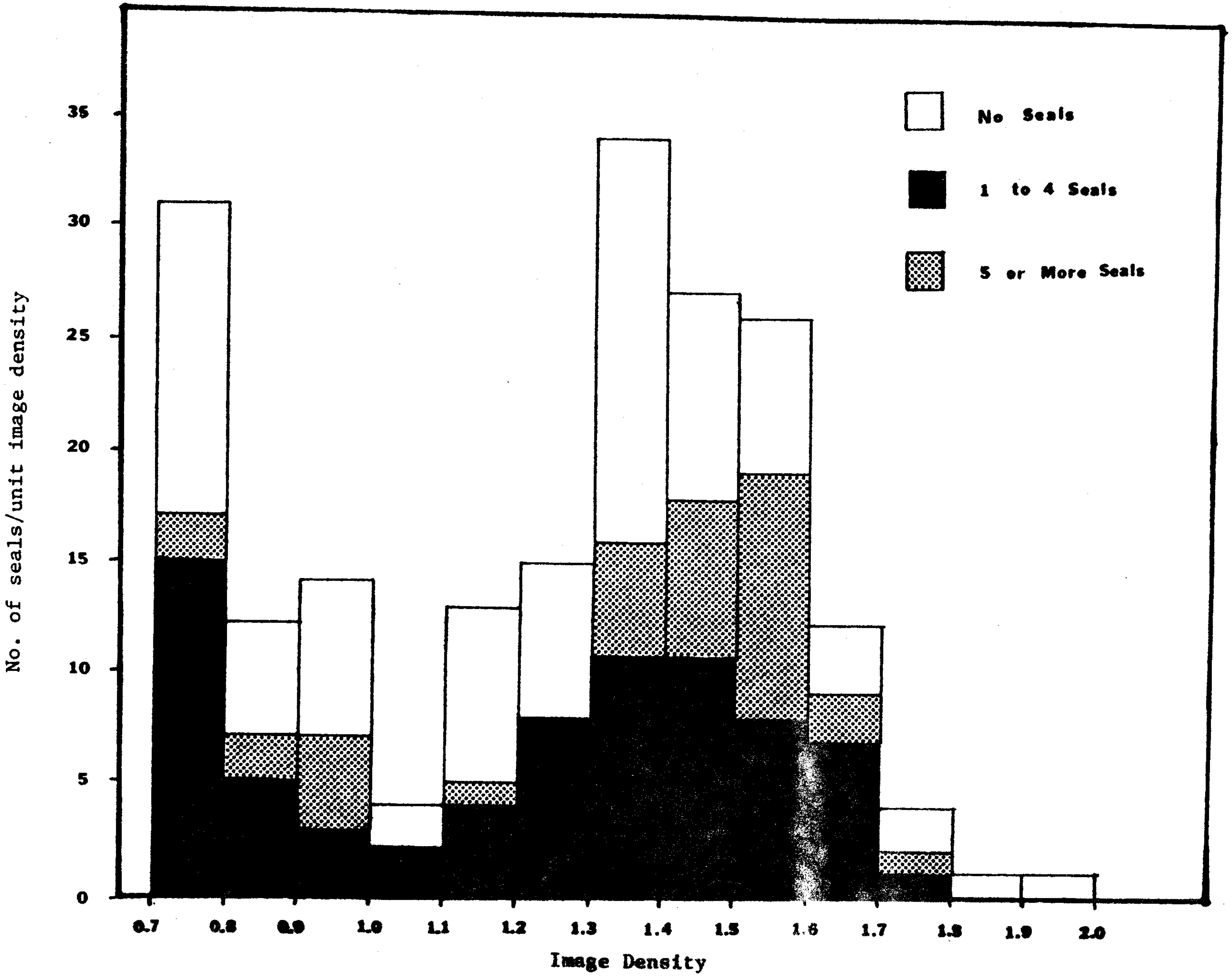


Figure 32. Number of sightings of ringed seals in relation to the film density of images obtained by SLAR. Data from the fast ice in the area between Point Barrow and Kokruagarok, obtained May-June 1976.

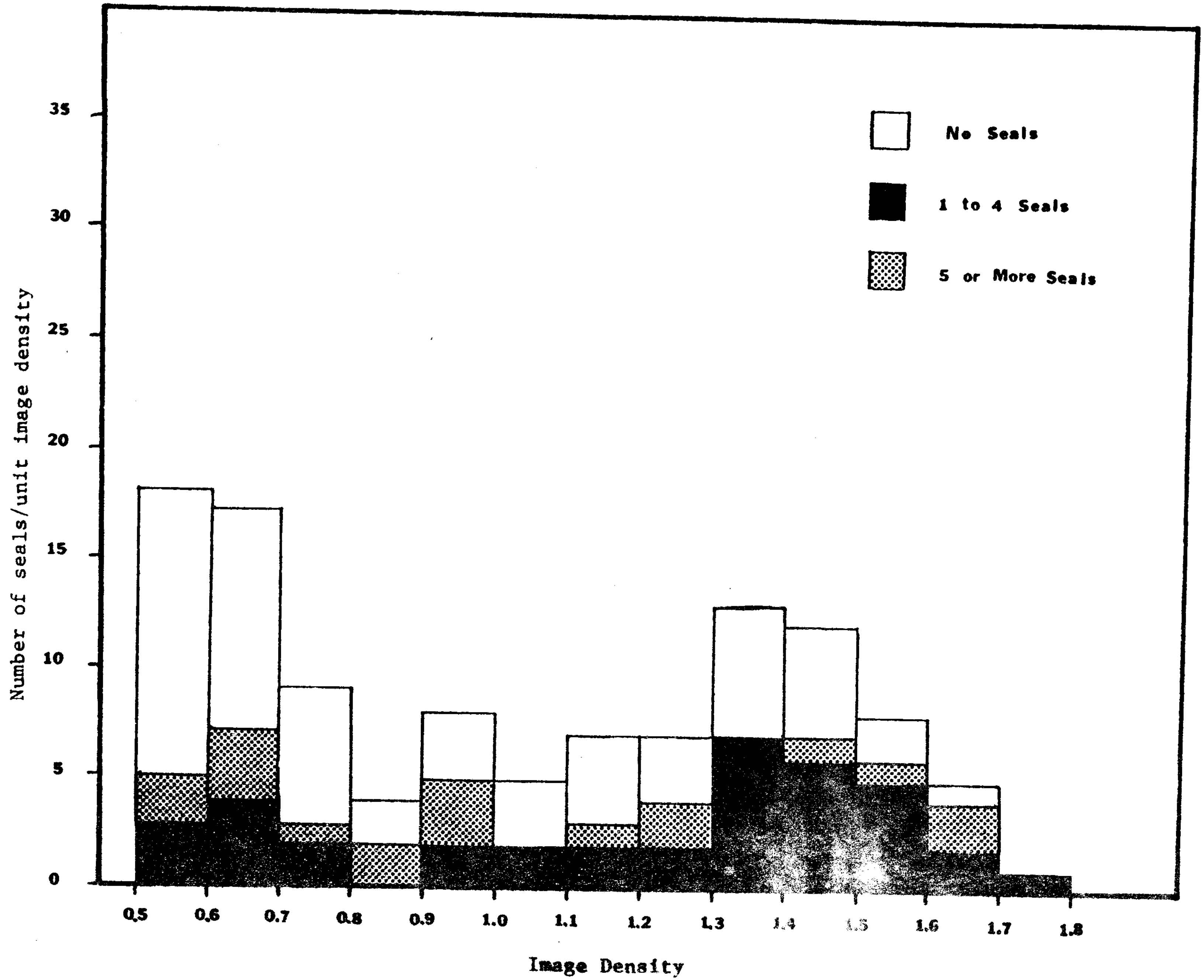


Figure 33. Number of sightings if ringed seals in relation to the film density of images obtained by SLAR. Data from the fast ice in the area between Kokruagarok and Flaxman Island obtained May-June, 1976.

a correlation coefficient of only 0.01909 (n=78). All of the coefficients were positive suggesting that seal sightings increased with increasing ice roughness, which was contrary to field observations. Whether the difference between the correlation coefficients for the Point Barrow to Kokruagarok section and the Kokruagarok to Flaxman Island section represents an actual difference in ice types utilized in the two areas, or is merely a function of small sample size, remains in question.

We have low confidence in the findings because of several problems which, in retrospect, should have been addressed before SLAR imagery was used for characterizing ringed seal habitat. First, only two of the SLAR images had adequate temporal and spatial overlap with the seal surveys. Second, the SLAR images did not show enough of the shoreline features to allow accurate matching and scaling with the seal surveys. Third the quality of SLAR film itself was found to be variable in density. Density of the film base of images used was found to vary by up to 0.06 density units, introducing a possible 4.9 percent error rate into the measure of ice roughness. Hence, each film had to be analyzed separately, even when one was a continuation of another. Fourth, there was some distortion in the SLAR images. Fifth, there were errors inherent in the navigational system utilized during seal survey flights. Although SLAR internally adjusts for distance distortion created by its oblique angle to the terrain, some distortion was still detected. This introduced a small error with respect to locating seal positions on SLAR images. This was further compounded by aircraft navigational errors in the seal surveys. Because a relatively small shift in position can result in large differences in image density, SLAR image distortion and survey navigational errors could have obscured any actual relationships between seal numbers and image density.

The survey observers' estimates of percent deformity of the ice did not match well with the SLAR method of measuring deformity. This may have been due to the positional errors discussed above or to different levels of discrimination by the observers and the radar. Since SLAR utilizes wave lengths of approximately 3.5 cm, it "sees" texture on a finer scale than is apparent visually from the moving aircraft. A large but rounded piece of ice could return considerably less energy to the SLAR receiver than a field of small pieces having sharp angles. As a result, the larger piece would register as a lower density on the film, whereas an observer probably would register quite the opposite. Extensive snow cover, which appears flat to an observer, often overlies fields of ice with low profile roughness. Based on the capability of SLAR to discern refrozen tide cracks beneath the snow cover, we assume that it also would detect such fields and show them as rough rather than smooth surfaces. In that case, records of the survey observer and data from the SLAR would not be in agreement.

Unfortunately, little is known about the comparability of visual and SLAR registers of topography of ice or other terrain. Our results suggest that man and SLAR do not "see" ice in the same way. A similar experiment should be repeated with better controls to overcome the five problems we encountered. Such an experiment should include surface level verification of SLAR imagery and survey observer records as well as greater use of low altitude photographs.

V. Fringe and Front Zones

A. Fringe

1. Description

The ice fringe is defined here as the irregular southern margin of the main pack ice. Terms such as ice "edge" or "terminus" are less appropriate, as they imply a discrete, regular boundary, instead of the numerous wind-rafted tongues of broken, melting ice. When viewed from high altitude, these resemble a fringe (Figure 34).

In winter to early spring, the fringe of the Bering Sea pack ice usually extends from Bristol Bay to the vicinity of Cape Navarin, thence southwestward along the Siberian shore to Karaginski Bay. Since general movement of the pack is from north to south, as a result mainly of prevailing winds (Muench and Ahlnas 1976), the open ocean south of the fringe allows unimpeded drift and divergence of ice. The ice tongues of the fringe extend southward away from the main pack during periods of northerly winds (Figure 35). The area occupied by the fringe varies depending on the velocity and duration of northerly winds.

The fast-moving fringe is compacted against the slower moving pack during episodes of southerly winds. At that time, the fringe more closely approximates a definite ice "edge." Satellite images of the compacted fringe were not available because of the extensive cloud cover associated with southerly winds in the study area. Ice of the fringe probably is melting continuously, because of its contact with the warmer waters of the southern Bering Sea. Swells and chop tend to break it up into small pieces.

The general southerly drift of the pack maintains a continuous supply of ice to the winter fringe. In "average" years, the fringe west

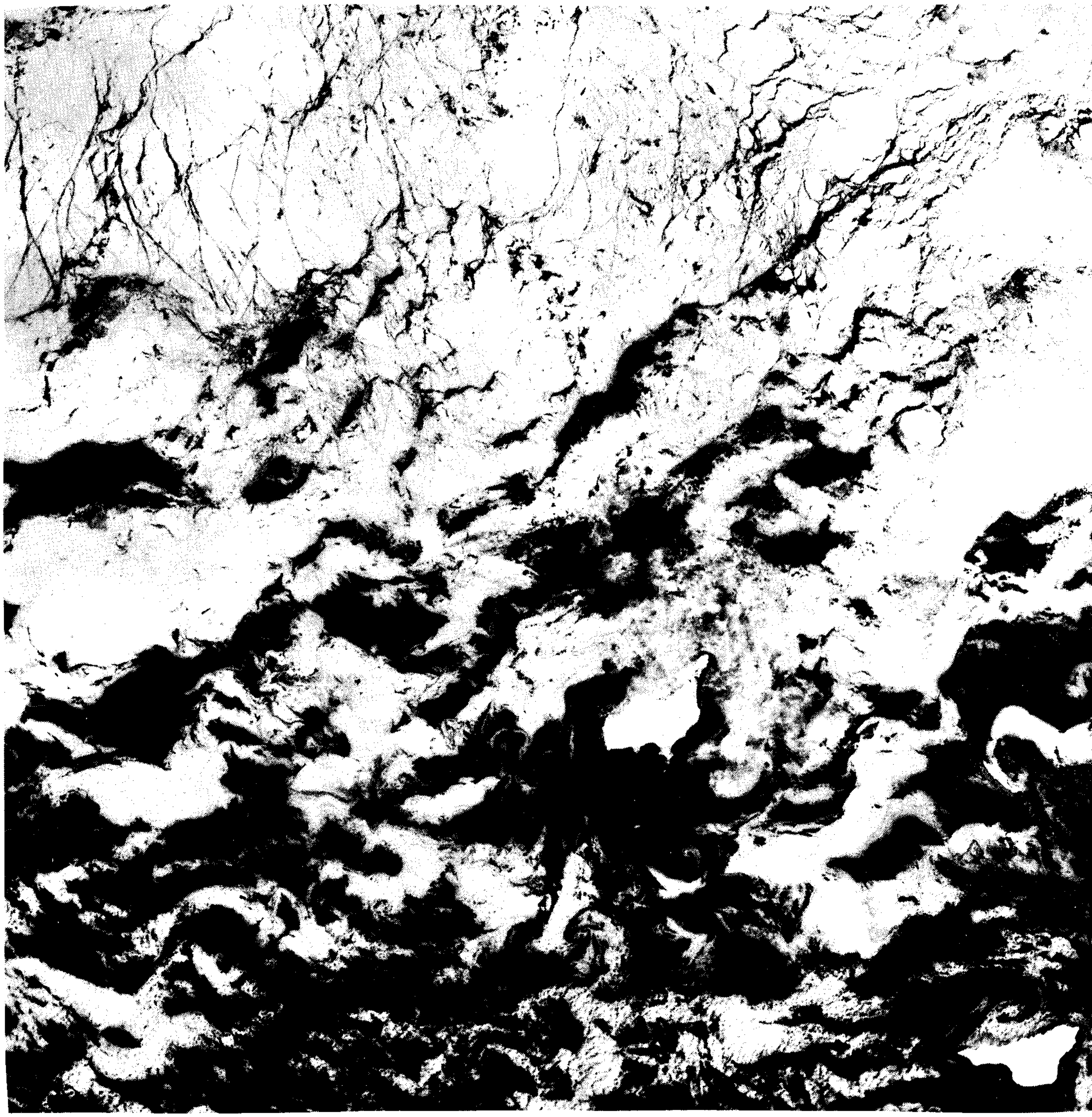


Figure 34. LANDSAT image #2453-21445, (19 April 1976) showing the ice fringe and front zone near the Pribilof Islands.

Figure 35. Low-altitude aerial view of an ice tongue of the fringe.

of St. Matthew Island occurs at or near the edge of the continental shelf, but in the eastern Bering Sea it is somewhat north of the edge. During periods of extreme cold, always associated with prolonged, northerly winds, surface water and air temperatures are lowered, new ice forms in the fringe, and the pack temporarily advances southward. On such occasions it may extend beyond the shelf break west of St. Matthew Island; in the eastern Bering Sea, it may reach the edge of the shelf. We presume that the more northern location of the eastern fringe, relative to the shelf break, is due to significant incursion of warm water into the southeastern Bering Sea, in part from the Alaska Stream (c.f. Takenouti and Ohtani 1974, fig. 2.10).

After April, in most years, the continuity of the Bering Sea pack is lost through breakup and melting. The pack as a whole no longer has any continuous fringe, for the different wind and water current regimes result in fragmentation of the main pack, rather than orderly withdrawal. Most of the large deformed floes and segments of the fast ice from the Alaskan and the Siberian coasts become entrained in rafted remnants; others drift northward through Bering Strait. Each disjunct remnant of the pack has its own "fringe" at that time.

By early June, the pack is mainly north of Bering Strait. Its withdrawal northward in the Chukchi Sea is more orderly than in the Bering, with the result that there is again a more regular fringe. This fringe, like that of the Bering Sea pack in winter, is a discrete ice zone. It is composed of thick, rafted floes, which have withstood the destructive processes of melting and wave action. By July, the fringe begins to approximate a definite edge, probably because of more southerly winds, and the persistence of deep-keeled floes which tend to drift at the same rate and in the same direction as the pack.

The period of minimal ice cover, on the average, is in late September (Brower, et al., 1977b). At that time, the fringe is most like an abrupt "edge" in the Chukchi and Beaufort Seas. Only the thickest pieces of seasonal and multi-year ice persist. Average and maximal northern retreat of the pack during the open water season in the Beaufort and eastern Chukchi Seas are shown in Figure 36. The characteristic appearance of the thick, weathered floes of the summer fringe is shown in Figure 37.

In fall and early winter (October to early January) the advancing and forming ice, like the retreating ice in late spring, has numerous indefinite fringes. These include the fringe of the irregularly developing main pack and those of the numerous separate loci of new ice formation, south of the advancing pack. Ice forms wherever air and water temperatures permit. In the coastal zone, this occurs first where there is outflow of fresh water into the sea. Major rivers such as the Noatak, Kobuk, Yukon and Kuskokwim produce plumes of ice. Ice also develops in shallow waters along the coast and drifts about in accordance with winds, remaining near shore or being blown seaward. As the processes of ice formation and southward movement continue, temporary fringes ultimately become incorporated into the advancing pack. By late January the fringe of the main pack becomes identifiable at its southern terminus.

2. Use of the fringe by mammals

The associations of marine mammals with the fringe are most apparent during periods when the pack is most stable, i.e. in late winter to spring

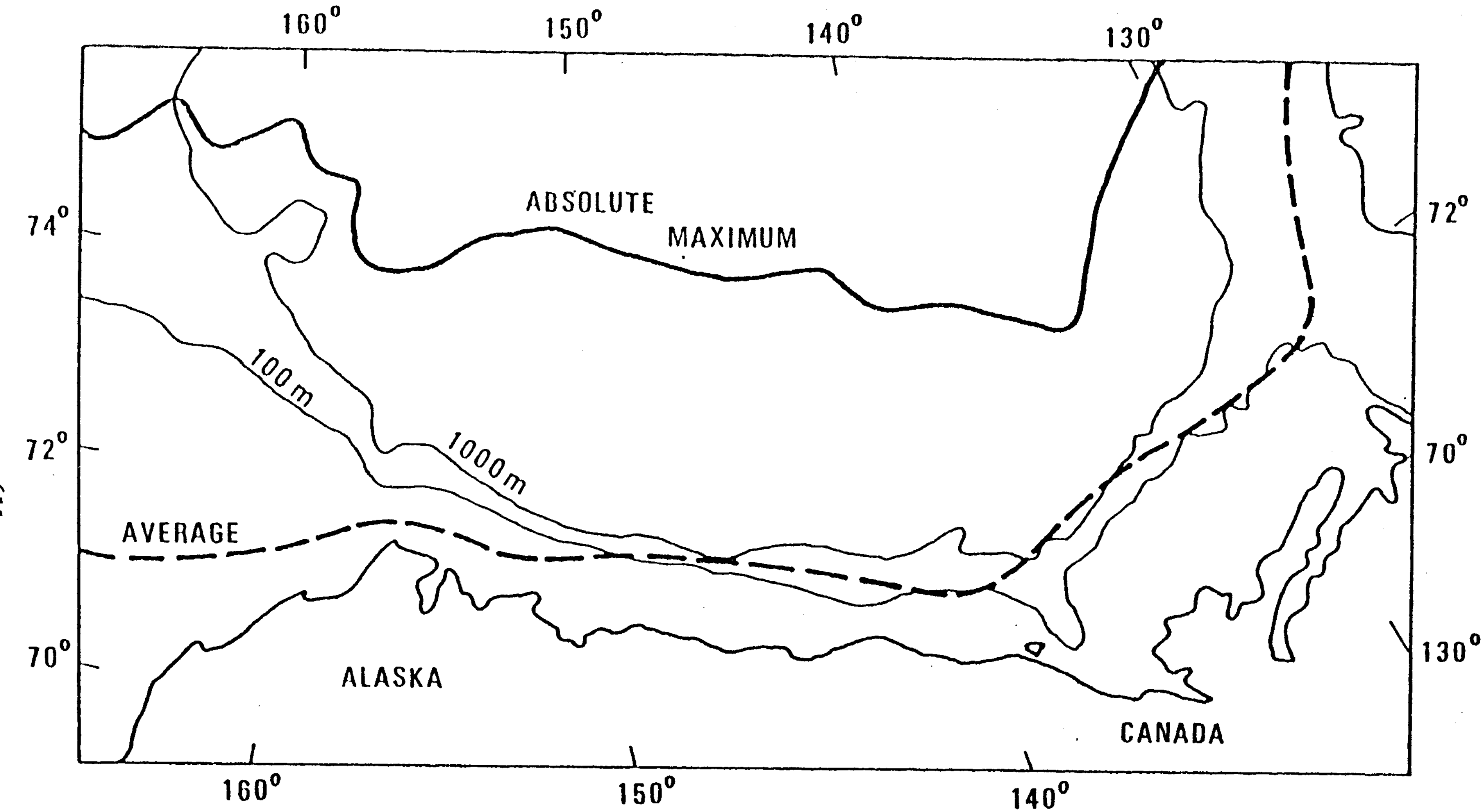


Figure 36. Average and maximum northern retreat of pack ice in the Beaufort Sea.

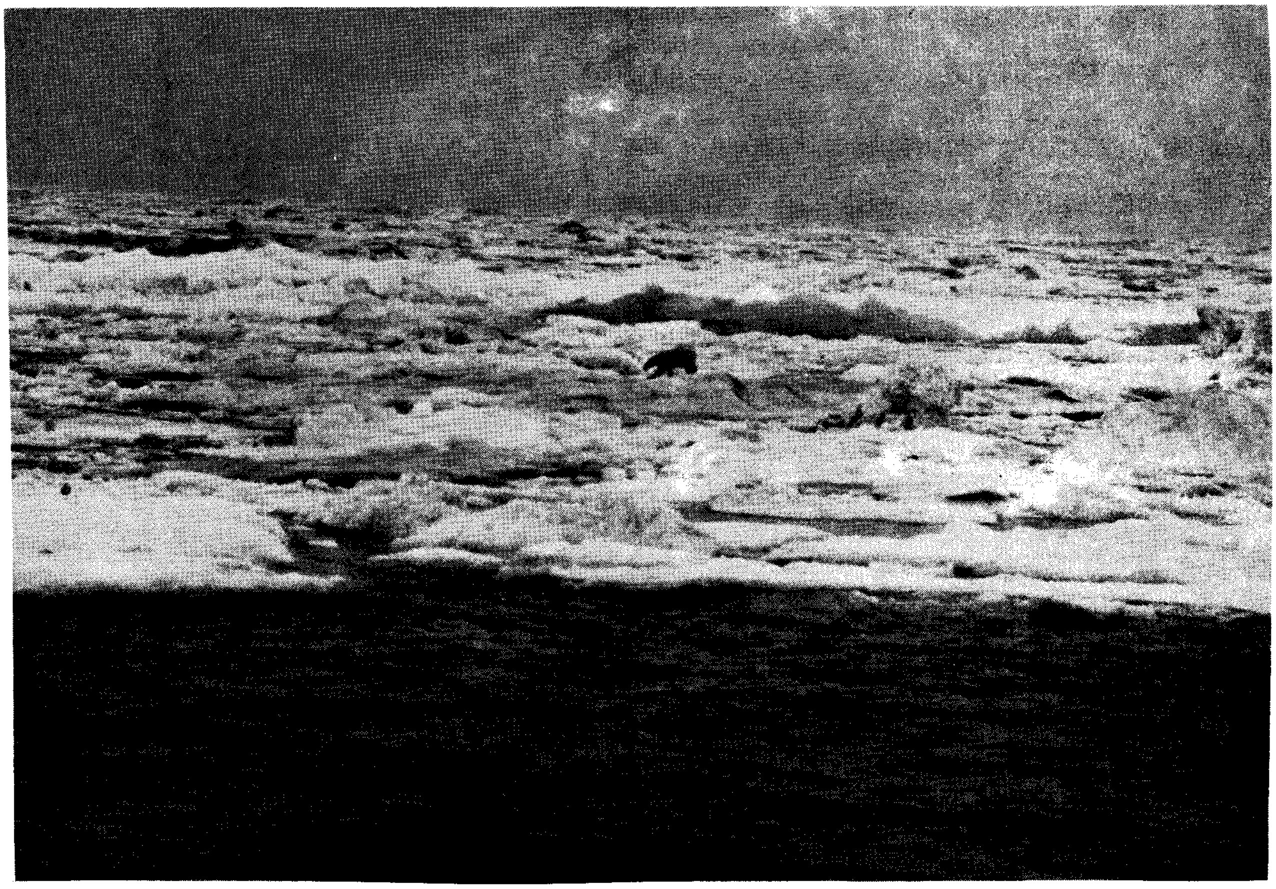


Figure 37. Thick, weathered floes of the summer fringe in the north central Chukchi Sea, 28 August 1973.

in the Bering Sea and in late summer to early fall in the Chukchi and Beaufort Seas. Seven species of pinnipeds occur in the late winter-spring fringe of the Bering Sea. Steller sea lions (Eumetopias jubatus) occur only there and in the open water south of the pack. They rarely penetrate farther into the pack than the fringe. Spotted seals and ribbon seals, on the other hand, are abundant not only in the fringe but well back into the pack as well; they are not known to range into the open water south of the fringe at that time. During April 1971, 1972, 1976 and 1977, these seals and sea lions were sighted on large tongues of ice extending as far as 21 km south of the loose pack. Walruses and bearded seals are uncommon in the fringe of the winter pack and ringed seals are rare. Harbor seals utilize the fringe during years when it is present in southern Bristol Bay (Burns and Harbo, 1977; Braham et al., in preparation; Fay and Burns, unpublished).

In late spring to early summer, during breakup and retreat of the pack, each of the above-mentioned species, except harbor seals, occurs in association with the fringes of the rafted remnants of the pack in the Bering Sea (see section on Remnants). The discontinuous and irregular northward retreat of the ice, and the generally northward migration of these animals, result in all species temporarily occupying fringe-type habitats. Spotted seals are the most abundant species in nearshore fringes, while ribbon seals occur more often in the offshore fringes. Walruses and bearded seals are common in the northern fringes. Weaned pups of bearded, spotted and ringed seals also occur in fringes close to shore.

The summer-autumn ice fringe in the northern Chukchi Sea usually is over the continental shelf, while that in the Beaufort Sea usually overlies deep water. Pacific walruses dominate the marine mammal fauna of the Chukchi Sea fringe at this time; ringed seals are dominant in the Beaufort fringe. During August-October 1973-1975, 1977 and 1978, few walruses were found in consolidated ice immediately north of the fringe, but they were more common in the open water to the south of it (Gol'tsev 1975; Estes and Gilbert 1978; Burns, unpubl.). Apparently these animals utilize ice of the fringe for resting between feeding forays in the vicinity of the pack and in the open water to the south of it. Bearded seals also are common in the Chukchi fringe, though numerous only within 50 miles of the Alaskan coast. Ringed seals are less numerous than bearded seals in the Chukchi fringe, and we presume that they are more abundant farther north, in the consolidated pack.

During aerial surveys in September 1974 and 1975, belukha whales were found in widely spaced groups along the entire fringe of the eastern Chukchi and western Beaufort Sea.

Polar bears are present in the fringe only during the summer-autumn period. As indicated by our sightings during August-September 1973, and September 1974 and 1975, they occur most often near (and among) walrus herds and in areas where bearded seals are numerous. The most intensive predation by bears on walruses and bearded seals probably takes place in this period when these three species are relatively abundant in the same areas. C. Ray (pers. comm.) reported sightings of polar bears hunting walrus calves in the Chukchi fringe during July 1977, and we observed similar situations there in August 1978.

Ringed seals and belukha whales were the most common mammals seen in the fringe of the western Beaufort Sea during aerial surveys in September 1974. In August 1977, during a traverse of the fringe by ship, marine mammals were not abundant. Bearded seals and an occasional walrus were seen northeast of Point Barrow and ringed seals were present at all locations to our easternmost station north of Demarcation Point. Apparently ringed seals were more numerous in the ice north of the fringe, as breathing holes were abundant there in newly formed ice.

Spotted and ribbon seals generally are not associated with ice in late summer and early fall. During this period, spotted seals occur mainly in the coastal zone of the Bering and Chukchi Seas in ice-free waters. The distribution of ribbon seals during this season is not known but is presumed to be mainly in the open waters of the Bering Sea (Burns 1970, Fay 1974).

In autumn and early winter, the southward migration of ice-associated marine mammals precedes the advance of the pack ice. At that time, there seem to be no strong associations of marine mammals with specific ice conditions; rather, the various species are intermixed. During October and November, the majority of walruses utilize coastal hauling grounds south of the pack, especially along the northern and eastern coasts of the Chukchi Peninsula, on islands in Bering Strait, and on the Punuk Islands, just east of St. Lawrence Island (Gol'tsev 1968, 1975; Fay and Kelly, in press). Spotted, ringed and bearded seals also are numerous nearshore, south of the advancing pack. The nearshore abundance of ringed and bearded seals increases as new ice forms. Their presence in areas of grease and slush ice appears to anticipate the development of ice types which they will occupy during the winter months when they mostly inhabit fast ice and flaw zone, respectively.

Spotted and ribbon seals also move southward, mainly ahead of the advancing seasonal pack. These seals continue their southward movement into the Bering Sea, remaining mostly close to the fringe. In autumn, at St.

Lawrence Island, an influx of spotted and ribbon seals occurs with the first ice. In Norton Sound this influx is of spotted seals alone, followed closely by ringed and bearded seals.

B. The Ice Front

1. Description

The "front" is a zone of transition between the fringe and the heavier, consolidated pack. It is one of the most labile segments of the winter pack of the Bering Sea. It is strongly affected by both surface weather and sea state, and for that reason its character can change rapidly.

The existence of the front is dependent on a balance between factors which contribute ice to southern parts of the pack and those acting to destroy it. The former include low temperatures and prevailing northerly winds. The latter are warmer water and frequent North Pacific storms. The front is a zone of dynamic equilibrium between regions of cold, windy and warmer, stormy conditions.

Since there is great annual variation in extent of ice cover in the Bering Sea, there are major annual differences also in location of the fringe and front zones. Figure 38 illustrates the location of the fringe and front zones in March-April 1960-1979. Late winter-spring 1976 was a period of prolonged northerly winds, lower than normal temperatures (especially in April) and extensive ice coverage, with a front zone in excess of 130 km wide in the vicinity of the Pribilof Islands. In the same period in 1979, the pack was much less extensive, and the front zone was unusually narrow, being less than 30 km wide. The ice coverages in 1976 and 1979 were not maximum and minimum extremes, although they did approach the extremes.

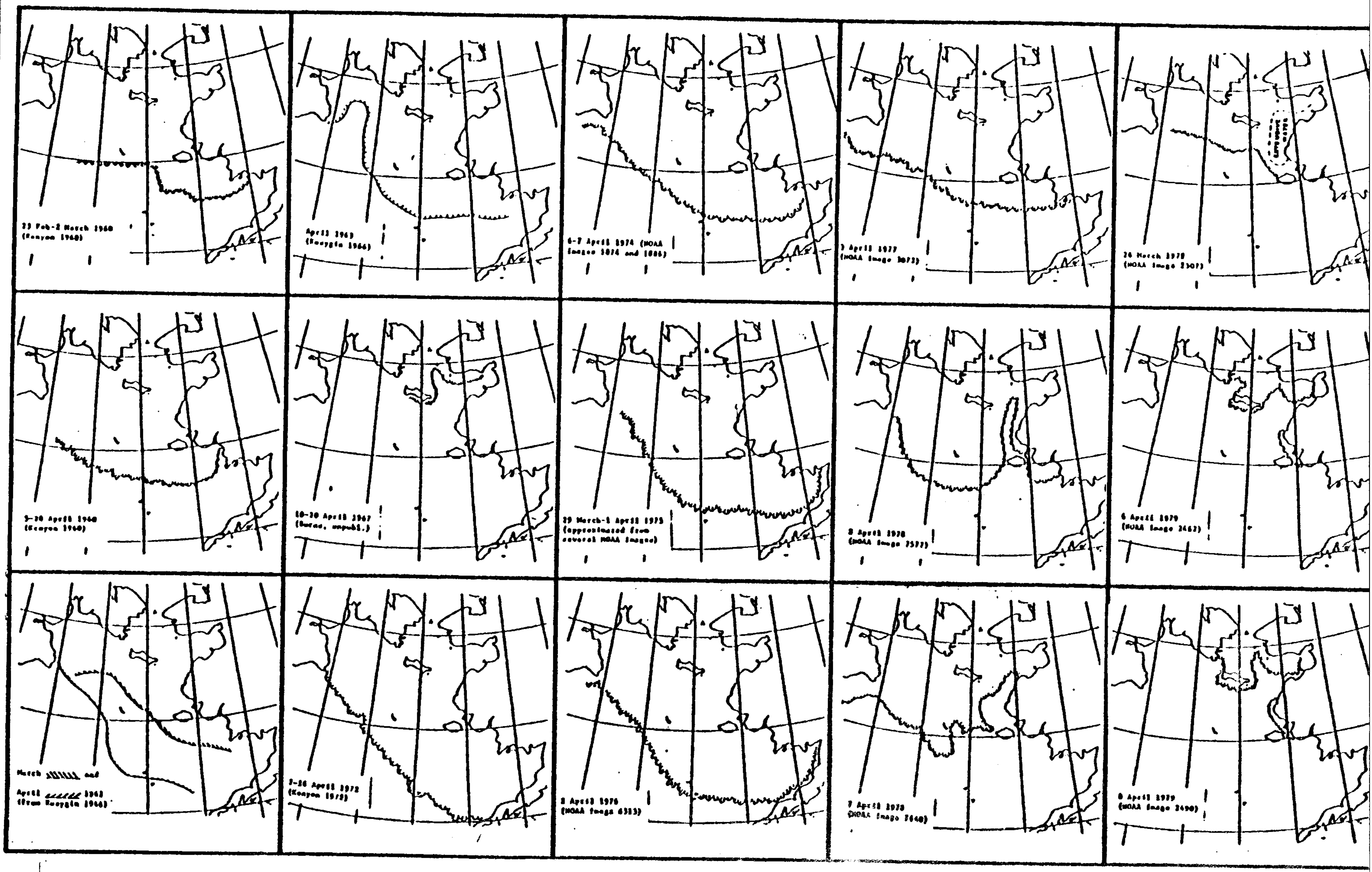


Figure 38. Annual differences in location of the fringe and front zone in the Bering Sea, March-April, 1960-1979.

In our experience, the maximal extent of the pack ice occurred in 1972. In March and April of that year, the southern margin reached Unimak Island (55°N) and exceeded the maximum reported by Wittmann and MacDowell (1964). Conditions were almost as extreme during the previous year. In both years, ice resulted in significant mortality of sea otters, (Enhydra lutris) in Bristol Bay; these animals are little adapted to ice (Schneider and Faro 1975). The minimal extent of ice occurred 1967. In mid-April, that year it was just south of St. Lawrence Island and central Norton Sound (63°N) and the ice-associated marine mammals were distributed much farther north than usual. Walruses were abundant around St. Lawrence Island in March of that year. In normal winters the majority of the walrus population is well south of that location, at that time.

The difference between maximal and minimal limits of the eastern Bering Sea pack in April of those extreme years was approximately 870 km.

We have made shipboard excursions into the front on seven occasions in March and April since 1968. Our most extensive study and repetitive coverage of it was in March-April 1976, when shipboard (NS SURVEYOR, ZRS ZAGORIANY) and aerial surveys were conducted throughout this zone from eastern Bristol Bay to about 179°E. As in other years, the front was composed mainly of small floes, less than 20 m in diameter, separated by water, slush ice and brash for most of that period. Occasionally, during brief periods of calm, it refroze into a consolidated unit. In stormy periods, it converged or dispersed depending on wind direction and velocity. During or just following each storm, the refrozen units were broken up by swells moving in from the open sea (Figure 39). Indeed, it appeared that the depth of the front was a function of the depth of penetration into the pack by those swells, and the size of the floes

Figure 39. Surface level view of floes in the front after an episode of penetration by ground swells.

was a result of the wavelength and amplitude of the swells. Under the influence of the swells, ice of all thicknesses was broken into units of about 20 m or less.

East of 160°W longitude, in inner Bristol Bay, the ice cover in March-April 1976 was made up predominantly of rafted new ice in floes mostly larger than 100 m in diameter and with rough surfaces. Ice ridges were of very low profile, apparently resulting from refreezing of rafted pancake ice rather than from pressure of convergence. All visible surfaces were covered with silt, which also appeared to be incorporated into the ice. The latter probably was derived from the turbid waters of this part of the bay and from windblown sediments off the land.

The ice of the front from 160°W to approximately 169°W was quite uniform. A south-north gradation in coverage from open water to nearly 8 oktas occurred there over an average distance of 25 km in the eastern part of the area, 40 km in the central part and 60 km in the western part. Maximal width of the front was 84 km in the vicinity of 166°W. There was a clear trend of increasing thicknesses and deformity of floes from east to west, although floe diameter was similar in all areas. In the east, the floes were mainly of thin, gray ice, while those in the west were thicker (about 0.7 m) and had more accumulated snow. The degree of deformation (pressure ridging) also increased from east to west.

West of 169°W, ice conditions in the front in March-April 1976 were markedly different from those described above. Although, the majority of floes were about the same size ($\sim$ 20 m in diameter), they were made up of thicker (0.7 to 1.0 m) ice, even to the southern limit of the zone. Snow cover appeared to be much thicker, the degree of deformation was between 15 and 50 percent, and there was a strikingly higher proportion of clear, blue ice in the pressure ridges than was seen farther to the east. The ice edge extended south of the shelf margin in this region, from 174°W at least to 179°E, which was the western limit of our aerial surveys.

The motion of ice in the front, particularly vertical motion produced by the penetrating swells, appears to be the most important factor in periodically shaping the characteristics of this zone. Swells break up the ice cover and, in turn, are damped as they pass north into the pack. While surface chop acts on the fringe to reduce floes to a very small size, its energy is rapidly dissipated; only the ground swells penetrate far into the front. During periods of ice formation, surface chop, because of the characteristically short amplitudes and frequencies, results in slush and small pancake floes often less than 1 m in diameter. A gradient from slush and small cakes of the fringe to the larger floes of the front usually occurs over less than 10 km. The ground swells penetrate the pack up to 80 to 90 km beyond that, however, producing floes of relatively uniform size that make up the front. The point where the swells are no longer of an amplitude sufficient to fracture the ice marks the inner edge of the front and the beginning of the consolidated pack. In the latter, floe size tends to be much larger and more variable.

During a 6 week shipboard penetration of the pack in southeastern Bering Sea during March and April 1976, refreezing of the front into broad, unbroken ice fields occurred repeatedly. Breakup of this refrozen ice cover due to swells coming from the southwest, was noted on 25 March at 56°48'N, 165°58'W, on 30 March at 57°02'N, 166°15'W, and on 7 April at 57°21'N, 165°16'W. Based on the known position of the ice fringe on those dates, penetration of the pack by swells was approximately 74 km, 96 km and 133 km, respectively.

Waves and swells also affect the form of floes making up the fringe and front. The horizontal and vertical motion of floes grinding against each other results in rounding of their edges and in the production of brash between them. On thicker floes, undercutting (melting) takes place at the water surface, and the submerged rams (feet) tend to pump and dip brash and water onto the floes as they rise and fall. During periods of strong southerly winds or swells from a distant storm, sea water may wash over the floes, intensifying melting when weather is warm or adding further ice to the exposed parts, when weather is cold. In the latter case, refrozen water or slush forms a raised rim at the perimeter of low, flat floes (Figure 39).

The action of waves and swells in the front apparently does not result in the kinds of deformation produced by overriding and pressure ridging farther inside the pack. The deformation and massiveness of heavy ice in the front are mainly expressions of forces operating much farther north, during the formation and movement toward the front. Formation and drift of ice in the north usually are not accompanied by significant vertical motion. New ice formed in the pack usually is rather flat. It is broken and deformed, mainly through stress from surface winds and interaction with adjacent land masses or major ice massifs. The thick, pressure-ridged floes that occur in the front are brought there by southerly drift of the pack. Their location in the front is a function of their place of origin in, and their route of drift from, more northerly regions. The heaviest ice is derived from areas of repeated convergence in the central and northern Bering Sea. The much lighter ice in the front of the southeastern Bering Sea and Bristol Bay is derived mainly from centers of formation in Bristol and Kuskokwim Bays and south of Nunivak Island. This lighter ice is less deformed than that in the central Bering Sea because of its origin relatively close to the front in areas mainly of ice divergence.

2. Use of the front by mammals

Regular mammalian occupants of the front of the eastern Bering Sea include most of the spotted and ribbon seal populations and, during February, March, and early April many walruses, bearded seals and belukha whales (Kenyon 1960, 1962; Kosygin 1966; Gol'tsev 1976; Braham et al., 1977). Some ringed seals also are present, as are bowhead whales. Minke, gray and killer whales, and sea lions penetrate the front in spring as it disintegrates and recedes. Harbor seals utilize the front occasionally when it extends into their late winter-spring range, mainly around the Pribilof Islands and in Bristol Bay.

Spotted and ribbon seals show the strongest association with the front and are found there during February to late April (or to mid-May in years of late disintegration of the pack). In February and March, they mainly appear to be feeding; at the same time, they are distributing themselves into habitats suitable for events which follow in April to June. They give birth to pups on the ice of the front, mainly during the first half of April. Pups of both species, born as lanugo-clad "whitecoats," are weaned after 3 to 4 weeks. Although these pups "paddle" through water or brash between floes, they do not normally swim or dive until they are weaned and have shed most of the lanugo. They seek protection from the wind by utilizing cavities and depressions in ridged ice. On floes of the eastern part of the front, such protection often is not available, and pups are protected by their mothers.

Adult spotted and ribbon seals mate in the front during April and early May. Individuals of all ages begin their annual molt there in April and spend an increasing proportion of time basking on the ice.

The molt continues into June and July, with the subadults completing the molt before the adults. In May and June when the front no longer exists, both species are concentrated in the wind-rafted "remnants" of the pack. After disintegration of the eastern remnants, spotted seals complete their molt on land, while ribbon seals continue to occupy the western remnants.

Bearded seals and walruses in the front occur most often during February to early April. However, the centers of abundance for both are farther north. Both species begin to migrate out of the front in April although some male walruses remain in Bristol Bay all summer utilizing ice as long as it is present. Bearded seals give birth from late March through early May with the peak occurring about 20 April. Thus, some bearded seal pups are born in the front. These pups swim almost from birth and move with their mothers, mainly vacating the front by late April. Walrus calves are born mainly in May, well north of the front.

Our most intensive and quantifiable surveys of marine mammals in the front were conducted in March and April of 1976 to 1979. These surveys were made from a Bell 206 helicopter based aboard the NOAA ship Surveyor. The comparative densities of walruses and seals in the front during the 1976-79 surveys are indicated in Table 7. The comparative densities of the seals, by species, are presented in Table 8. Locations where surveys were conducted are shown in Figure 40. These data indicate that spotted seals had the broadest general distribution in the front with highest concentrations near Bristol Bay (up to 6.78 per nm^2 in 1976 and 6.72 per nm^2 in 1967). Ribbon seals also occurred throughout the front, mostly in low numbers. Ribbon seals were found to be highly clumped, mainly west of the Pribilof Islands. Bearded seals were more uniformly distributed in low numbers throughout the front (except in 1979 , when this zone

Table 7. Relative abundance of seals and walrus sighted during aerial surveys in the front, 1976 to 1979.

Year	Station No.[1]	Date	Area Surveyed (nm^2)	Total No. of seals and walrus counted	Density of seals & walrus ($/nm^2$)	Density of Walrus	Density Seals
1976	1	27 March	82.7	560	6.77	0	6.77
	2	20 April	40.0	1	0.03	0	0.03
	3	23 April	27.5	87	3.16	0	3.16
	4	24 April	26.0	151	5.81	0	5.81
	5	24 April	13.0	11	0.93	0.10	0.85
	6	25 April	24.5	81	3.31	0	3.31
	7	25 April	24.5	186	7.59	0	7.59
1977	8	28 March	103.3	253	2.45	0.65	1.80
	9	30 March	81.2	249	3.07	2.82	0.25
	10	21 April	40.5	287	7.09	0.15	6.94
	11	23 April	85.0	14	0.16	0	0.16
	12	23 April	85.3	18	0.21	0.01	0.20
	13	24 April	15.0	8	0.53	0.06	0.47
	14	24 April	30.6	28	0.92	0	0.92
	15	25 April	43.9	20	0.46	0.03	0.43
	16	27 April	31.2	35	1.12	0	1.12
	17	27 April	24.7	31	1.26	0	1.26
1978	18	5-6 April	94.5	136	1.44	0	1.43
	19	7-9 April	211.0	668	3.17	2.46	0.71
	20	10-13 April	177.0	652	3.68	2.79	0.89
1979	21	15 April	67.0	150	2.24	1.79	0.45
	22	18 April	51.0	132	2.59	0	2.59
	23	20 April	60.0	113	1.88	0.43	1.45
	24	21 April	59.0	923	15.64	12.95	2.69
	25	22 April	44.0	129	2.93	0.18	2.75
	26	24 April	49.0	266	5.43	2.12	3.31
	27	25 April	49.0	374	7.63	4.16	3.47
	28	27 April	48.0	166	3.46	0.52	2.92

[1] See Figure 40

Table 8. Species composition and relative densities of seals seen during aerial surveys in the ice front, 1976 to 1979.

			Species Composition and Density (/nm²) for seals							
			Ribbon		Spotted		Ringed		Bearded	
Year	Station No.[1]	Date	Percent	Density	Percent	Density	Percent	Density	Percent	Density
1976	1	23 March	0	0	99.9[2]	6.77	0	0	0	0
	2	20 April	100	0.03	0	0	0	0	0	0
	3	23 April	0	0	100.0	3.16	0	0	0	0
	4	24 April	0	0	100.0	5.81	0	0	0	0
	5	24 April	0	0	27.0	0.23	0	0	45.0	0.38
	6	25 April	0	0	94.0	3.10	0	0	0	0
	7	25 April	0	0	89.0	6.78	0	0	1.0	0.04
1977	8	28 March	1.0	0.01	62.0	1.13	0	0	37.0	0.66
	9	30 March	0	0	20.0	0.05	0	0	80.0	0.20
	10	21 April	0	0	97.0	6.72	0	0	3.0	0.22
	11	23 April	7.0	0.01	79.0	0.13	0	0	7.0	0.01
	12	23 April	41.0	0.08	24.0	0.05	0	0	35.0	0.07
	13	24 April	0	0	86.0	0.40	0	0	14.0	0.07
	14	24 April	4.0	0.03	96.0	0.88	0	0	0	0
	15	25 April	0	0	84.0	0.36	0	0	16.0	0.07
	16	27 April	26.0	0.29	74.0	0.83	0	0	0	0
	17	27 April	6.0	0.09	94.0	1.17	0	0	0	0
1978	18	5-6 April	54.0	0.77	45.0	0.65	0	0	1.0	0.01
	19	7-9 April	9.0	0.07	75.0	0.53	1.0	0.01	15.0	0.11
	20	10-13 April	1.0	0.01	44.0	0.39	10.0	0.09	45.0	0.40
1979	21	15 April	0	0	50.0	0.22	0	0.	50.0	0.22
	22	18 April	0	0	78.0	2.02	16.0	0.41	6.0	0.16
	23	20 April	9.0	0.13	22.0	0.32	0	0	69.0	1.00
	24	21 April	10.0	0.27	58.0	1.56	0	0	32.0	0.86
	25	22 April	29.0	0.80	55.0	1.50	1.0	0.02	14.0	0.39
	26	24 April	8.0	0.27	42.0	1.39	1.0	0.04	49.0	1.61
	27	25 April	15.0	0.53	19.0	0.65	1.0	0.02	64.0	2.20
	28	27 April	29.0	0.83	25.0	0.73	0	0	46.0	1.35

[1]See Figure 40.

[2]The other animals seen were sea lions.

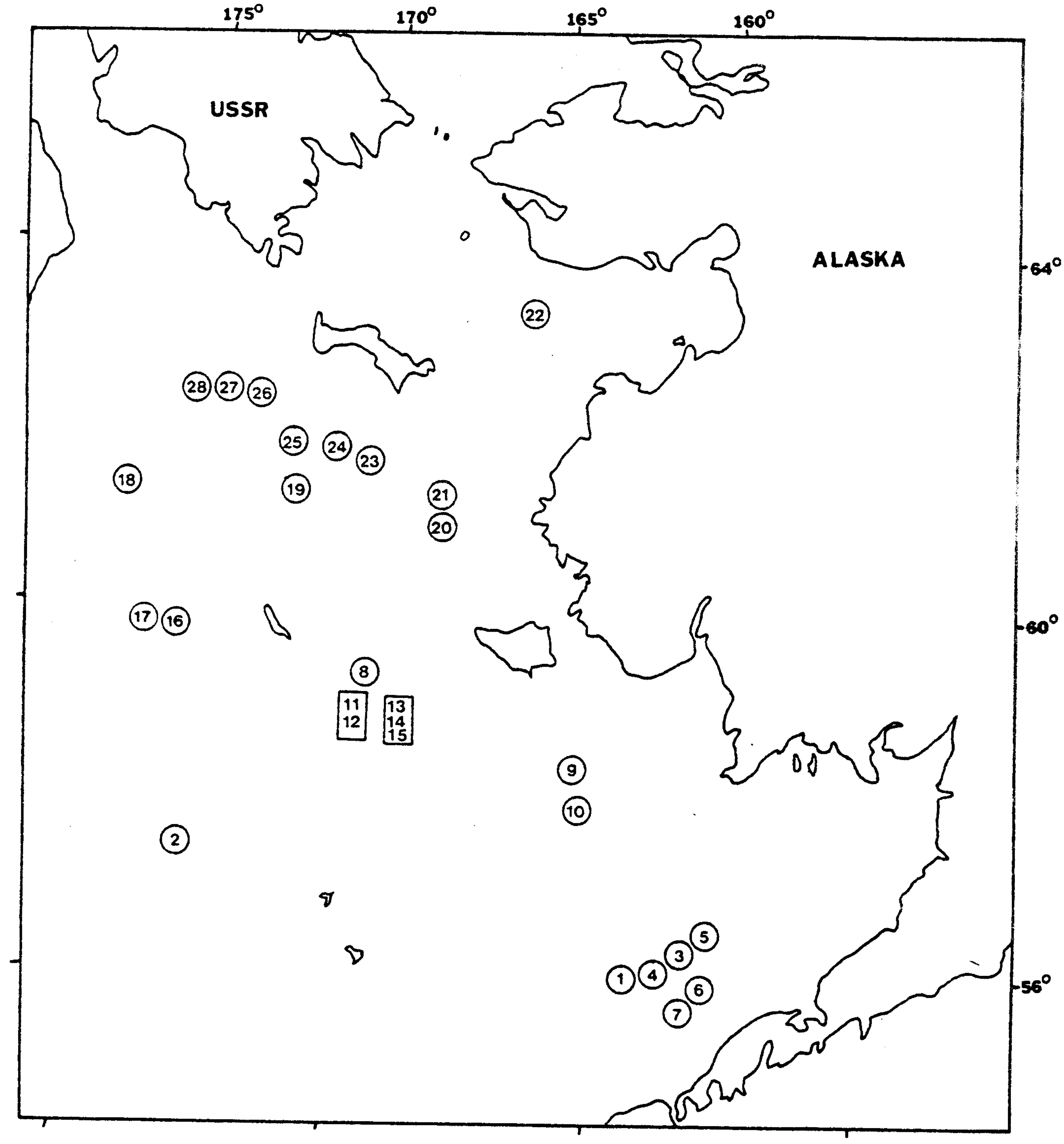


Figure 40. Locations of aerial surveys in the ice front.

was further north than in the previous 3 years). Ringed seals seldom were seen in our surveys south of Norton Sound except relatively near shore (Braham et al., in preparation). Walruses showed a highly clumped distribution but they usually were the most abundant animals seen during each survey. Highest densities were 2.8 per nm^2 in 1977, 2.79 per nm^2 in 1978 and 12.95 per nm^2 in 1979. Our data suggest that, in many instances the density of seals (except for bearded seals) tended to be inversely related to the density of walruses.

As the retreat and disintegration of the front proceed, the ice-associated marine mammals migrate northward (walruses, bearded and ringed seals) or become temporarily redistributed in the rafted remnants of the pack (ribbon and spotted seals); many spotted seals move into the ice-free coastal zone.

VI. SPRING REMNANT-ICE

A. Introduction

Our observations prior to 1968 of the breakup and disintegration of the pack, as seen from shore stations at St. Lawrence Island, Nome, and in Bering Strait, led us to believe that by late May and early June the only ice remaining in the Bering Sea usually was situated between eastern St. Lawrence Island and Bering Strait. During a multidisciplinary cruise of the R/V Alpha Helix in early June 1968, Burns (1969) observed "the occurrence of a disjunct band or remnant of seasonal ice, far south of the normally receding ice edge". Associated with that remnant were numerous ribbon seals, which were utilizing it as a place to rest while undergoing their annual molt. Burns speculated that the presence of such rafted remnants of ice might be an annual feature of the spring pack that is of critical importance to those seals as molting habitat. However, it was not until high resolution satellite imagery became available to us some years later (1974) that the possibility for further investigation of that point became feasible. Our findings since then have confirmed the presence annually of several large masses of wind-rafted ice in the Bering Sea that persist well into June and July and that these are heavily utilized by the seals.

B. Characteristics of the Remnant Ice- Bering Sea

Using principally the NOAA/VHRR visible band imagery, we have followed the development of the rafted remnants each spring since 1974, with the objectives of (a) tracing their origin and duration and (b) determining whether there is any predictable pattern to their size, form, and location. Further, we have examined some of them in closer view from ships, aircraft, and small boats, in order to assess their mammalian fauna and the quality of their constituent ice.

A series of comparative views of the development, extent, and distribution of the major rafted remnants of seasonal pack ice in the northern Bering Sea, each year from 1974 to 1978, is shown in Figure 41. These cover the period from 21 May to 20 June. Prior to that period, the ice was much more extensive; after 20 June in most years, clouds obscured the view of the remaining ice. From these comparative views, it is apparent that:

1. In four of the five years, there was remarkable uniformity in timing of development and disintegration of the remnants.

2. The basic pattern of development was set in most years by late May and was remarkably similar from year to year.

3. While there was considerable variation in shape and size of the remnants, the major deviations in location usually took place in mid- to late-June.

The remnant ice originated each year as two major massifs. One of these (Alaskan Massif) extended from Bering Strait to eastern St. Lawrence Island and southern Norton Sound, thence southward toward St. Matthew and Nunivak islands. The other (Anadyr massif) extended in most years from southwestern Gulf of Anadyr generally southeastward, toward St. Matthew Island. In 1974, the identity of the southern parts of these two massifs was lost in early May, when the southern end of the Alaskan massif moved westward and combined with the southeastern part of the Anadyr massif (Muench and Ahlnas, 1976: figs. 2, 3). In 1975-78, they remained clearly distinguishable well into early June. Parts of both

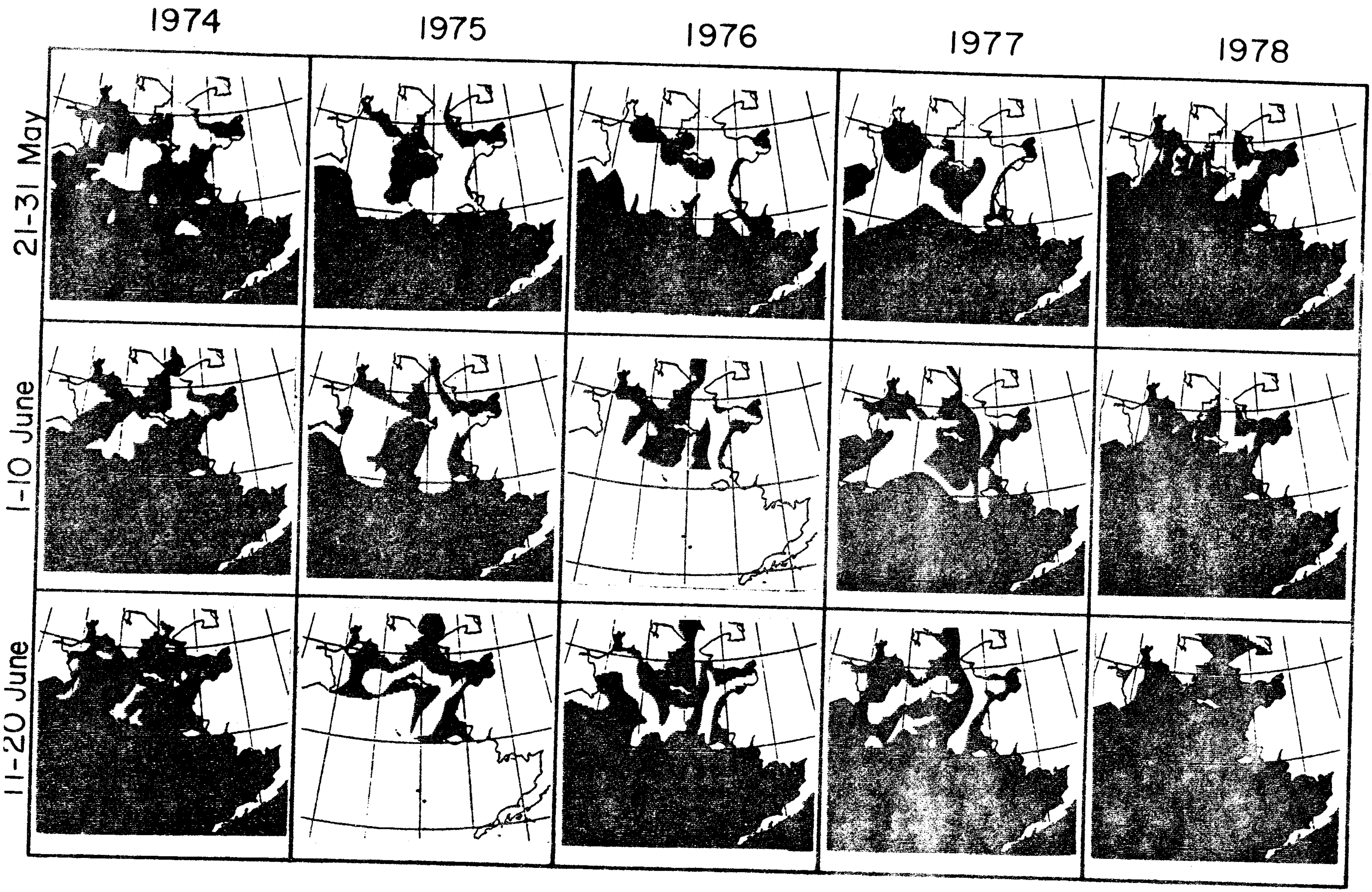


Figure 41. Shape, location, movement and degeneration of rafted remnants of the Bering Sea pack ice, 1974-1978.

persisted until late June in 1974-1977; in 1978, only a portion of the Anadyr massif persisted that long. In 1979 (not shown), the Alaskan and Anadyr massifs were clearly separate, the former being less extensive than in 1978 and the latter more extensive.

During our probes into the Alaskan massif and some of the small remnants between it and the Anadyr massif in late May to early June 1968, 1977, and 1978, we observed that many floes were larger (up to 30 m in diameter), rougher (50 to >80% deformation), and stood higher out of the water (hence also deeper underwater) than the flat, small floes usually found in the southeastern ice front (cf. Figures 42 and 43). Frequently, the pressure ridges also contained numerous chunks of clear, blue ice, not seen in the southeastern front. This ice closely resembled that formed in the northern Bering and Chukchi seas in winter when there is little particulate matter in the surface water and epontic algae are absent. These massive floes were deeply undercut as a result of melting; where lighter, thinner floes were present, they were very fragile and were rapidly disintegrating.

The persistence of the Alaskan massif well into June and the Anadyr massif into July, long after the locally formed ice had disintegrated, appeared to be mainly a function of the enormous mass of these heavy, deformed floes. Simply because of their greater mass, they are more resistant to melting than the thinner, less deformed floes that are generated, for example, in the broad areas of divergence south of St. Lawrence Island and in Bristol Bay. Even by early June in the southern edge of the remnants, many of the floes were 20 x 30 m in diameter and at least 10 m deep. Their occurrence as rafts seems to be mainly a

Figure 42. Typical floe in the Bering Sea spring remnants. front.

Figure 43. Typical floes in the southeastern Bering Sea ice front.

result of their comparatively uniform quality. That is, because of their great mass and deep keels, they tend to move slowly and as a group.

Considering the quality of this ice and its distribution, we hypothesized that the two massifs must be derived from the parts of the winter pack that are made up of the thickest, most deformed ice, i.e. that they do not develop at random but in specific loci from specific parts of the pack. We presumed that those parts would be in the areas of greatest convergence and downstream from them. To test this hypothesis, we selected the clearest NOAA/VHRR satellite views of the winter pack at its annual maximum in late March, and using standard base maps, sketched an outline of the whitest (presumably thickest) ice (Figure 44). We compared these with sketched outlines of the limits of remnant ice in late May, also derived from NOAA visual imagery. The results, while crude, tend to support the hypothesis.

Each year, the distribution of remnant ice in late-May was sufficiently similar to the pattern of white ice in late-March to indicate a distinct positive relationship (Figure 45). The correlation was closest in 1975, 76, and 77, which were the years with the heaviest winter ice and most persistent spring remnants; it was least satisfactory in 1974, 1978 and 1979. In each of the latter years, the pack was lighter and broke up a little earlier than in 1975-77 and, by late-May, was more advanced in its degradation. In all years, the area occupied by the late-May remnant ice was mainly within the same area that had been occupied by the late-March white ice (Table 9).

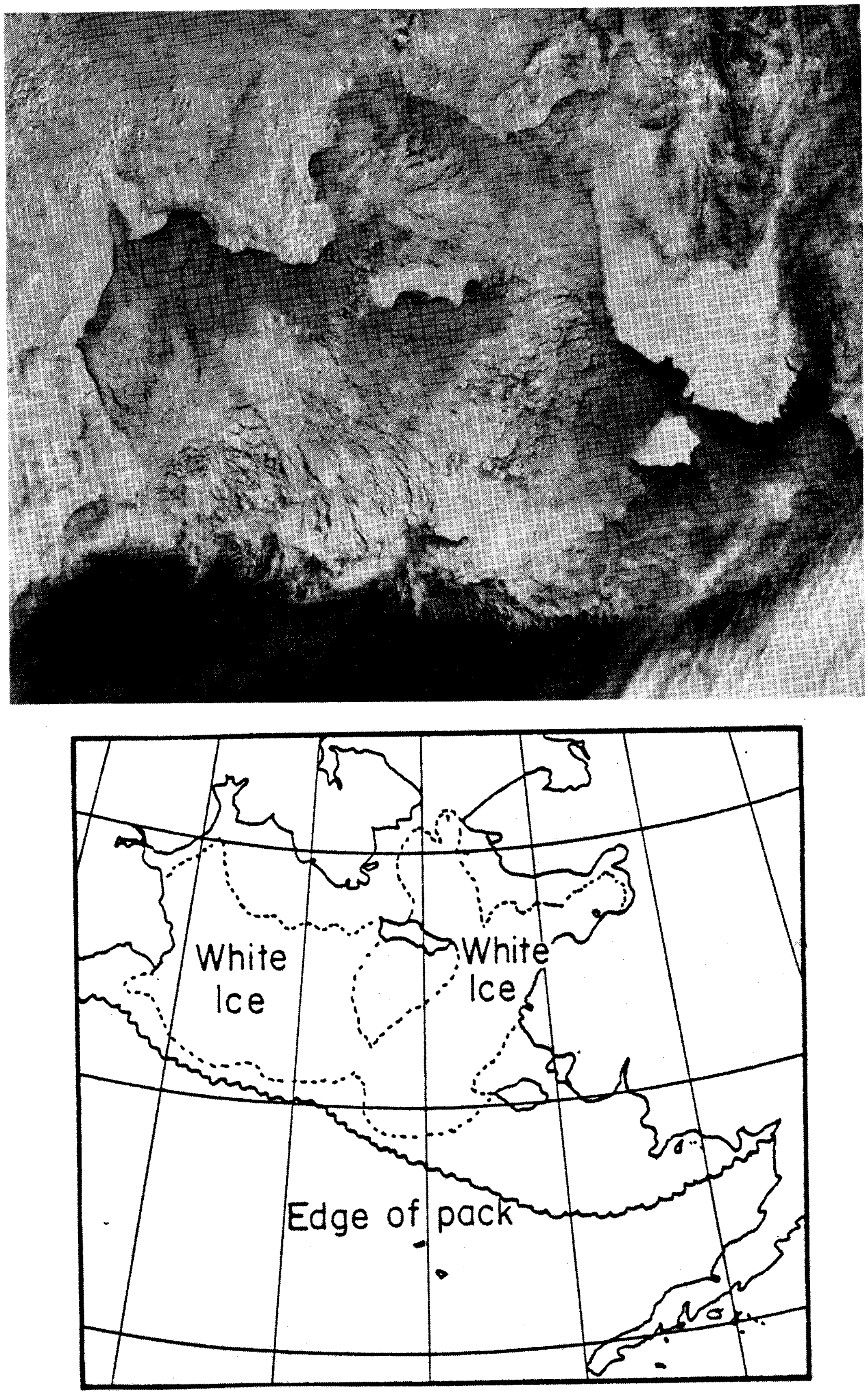


Figure 44. Example of satellite view and sketch of the extent of white ice, Bering Sea, 18 March 1978.

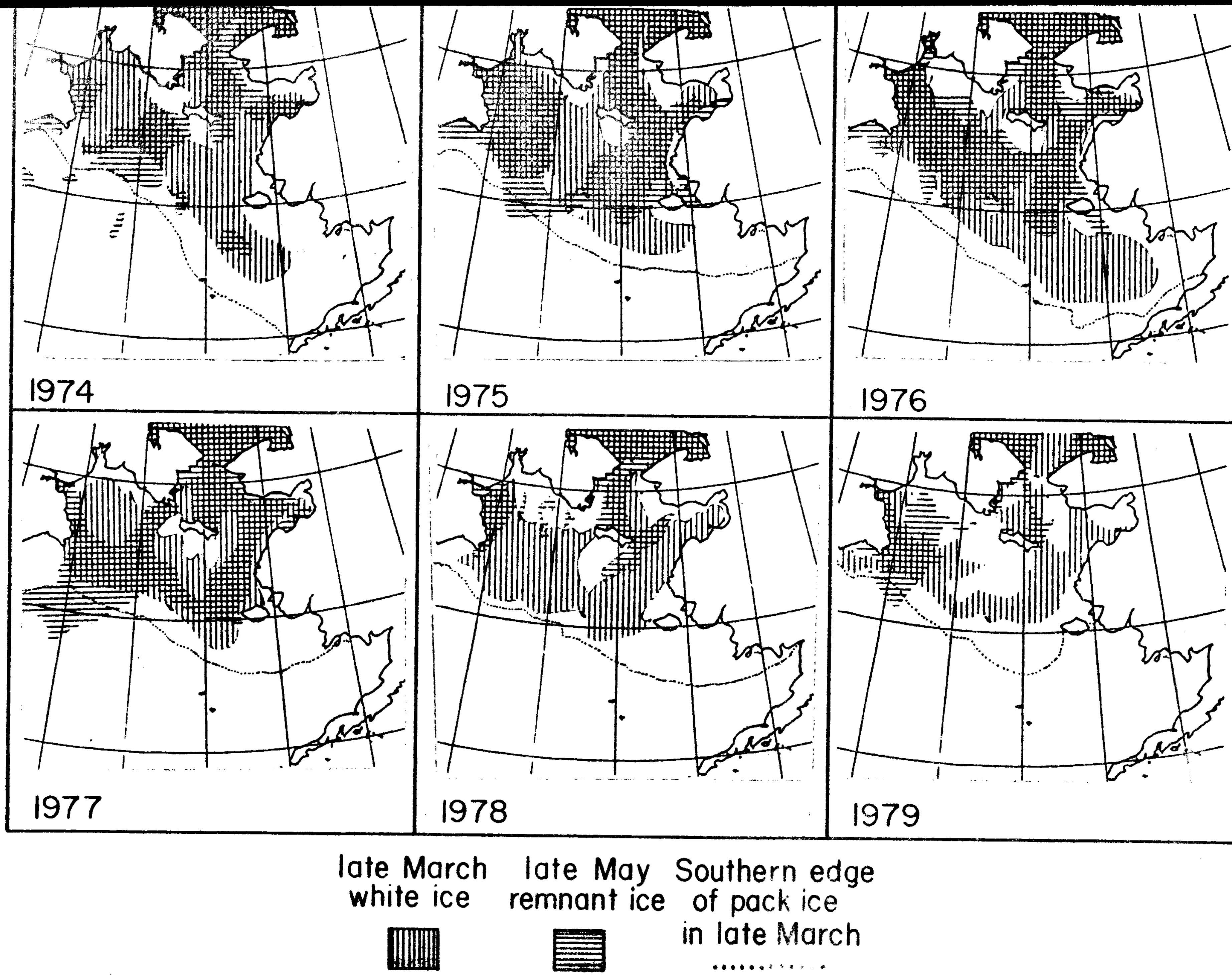


Figure 45. Overlay of remnant ice of 21-31 May on white ice of 17-29 March in Bering Sea, 1974-1979.

Table 9. Proportion of area of late-May remnant ice situated within same area as late-March white ice, Bering Sea 1974-1978

Year	Area of white ice in March ($km^2 x 10^3$)	Area of late-May remnant ice in location of March white ice ($km^2 x 10^3$)	Percentage
1974	194	155	80
1975	348	276	79
1976	358	281	78
1977	319	225	70
1978	83	60	72
1979	89	51	57

The relationship between the extent of white ice in late-March (km^2 of coverage) and that of total remnant ice in late-May was remarkably close (Figure 46). That is, as the area of white ice in late March increased, so did the area of remnant ice in late-May. This relationship lends further support to our hypothesis and indicates that even with wide variation in extent and quality of the pack and of the attendant weather, it may be feasible to predict the size and location, and to some extent, the shape of the spring ice remnants at least two months in advance, by extrapolation from the distribution of white ice in late winter. In general, it seems that the white ice south of 60° N lat and immediately to the west and southwest of St. Lawrence Island is the least likely to persist beyond mid-May; the western part of the Anadyr massif and the northern part of the Alaskan massif are the most likely to persist beyond 1 June (Figure 45).

C. Use of the Remnants by Mammals - Bering Sea

Our aerial surveys of the distribution of seals in the ice front of the Bering Sea in March and April consistently showed a high proportion of ribbon seals in the west and of spotted seals in the east. Furthermore, Kosygin (1966) indicated that in the Gulf of Anadyr, ribbon seals comprised 90 percent of the seals available to Soviet sealers, whereas in the eastern Bering Sea, spotted seals comprised 50 percent of the catch. On this basis, we hypothesized that the distribution of ribbon and spotted seals in the remnants in May and June as molting areas would be comparable, i.e. that ribbon seals would tend to be most numerous in the Anadyr and spotted seals most numerous in the Alaskan massif. Unfortunately, we were not able to sample the Anadyr massif adequately, but we did acquire

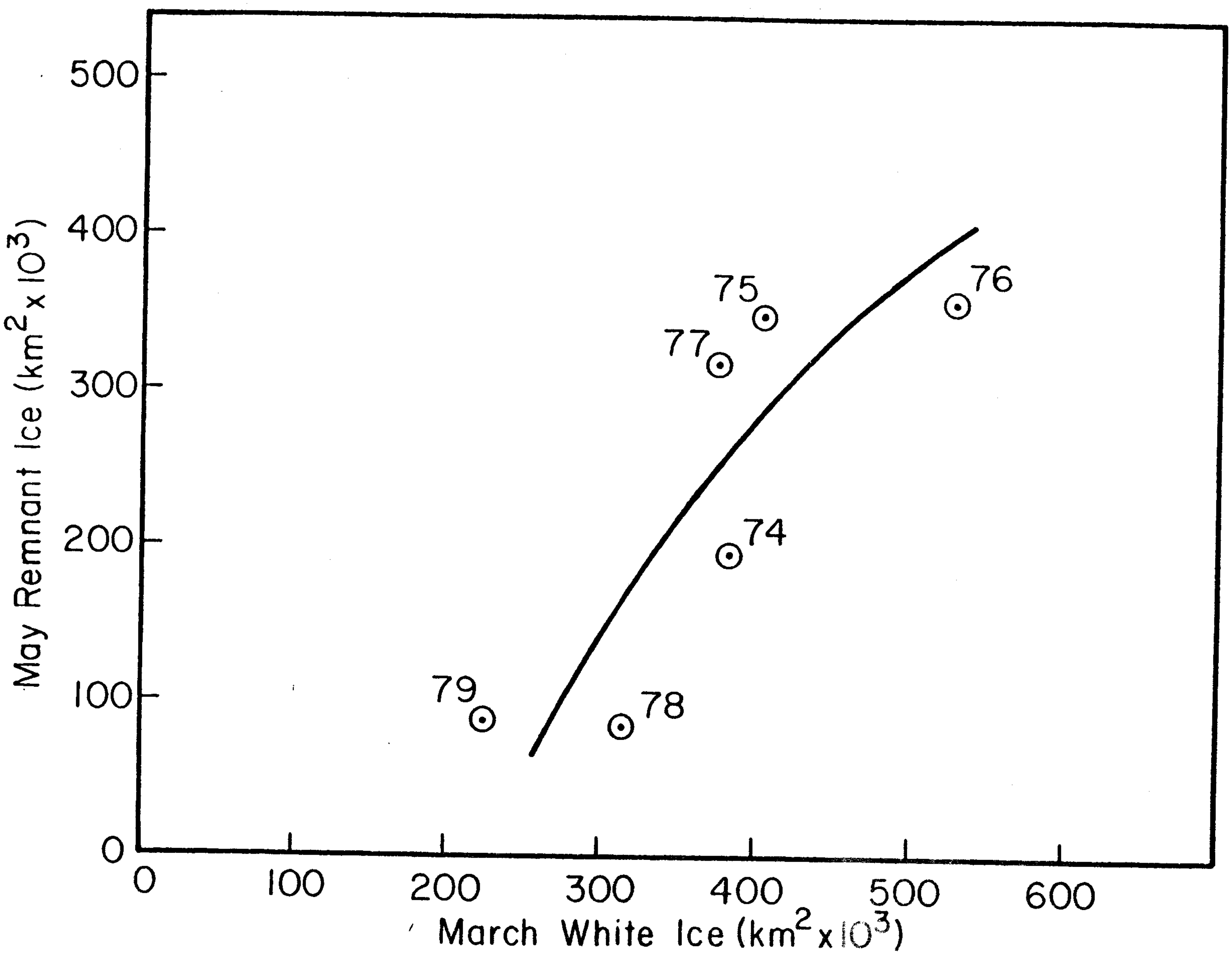


Figure 46. Approximate relationship between total areal coverage of white ice in late-March and total areal coverage of remnant ice in late-May in the Bering Sea, 1974-1979

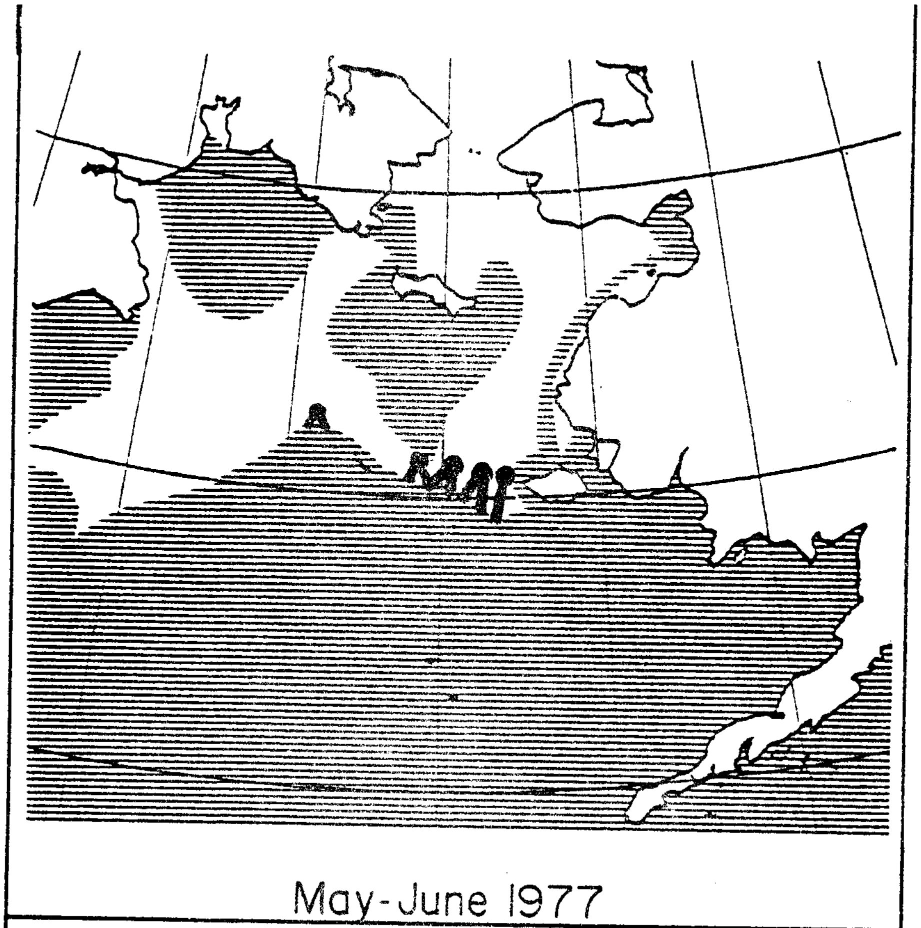
some data from the Alaskan massif and from a few areas between with which to test that hypothesis. We conducted two probes into the Bering Sea remnants by ship. These were limited for political reasons to the Alaskan massif and some portions between it and the Anadyr massif, east of the International Convection Line. On each occasion, surveys were conducted in an effort to assess the kinds and abundance of mammals utilizing the remnants.

In the first instance (24 May-6 June 1977), surveys were conducted from the NS Discoverer while in transit between oceanographic stations, as well as from small boats in the vicinity of each station (i.e. within a radius of about 5 km of the ship). In the shipboard surveys, the observers stood on the flying bridge (approx. 18 m above the water) and counted all mammals by species sighted within about .5 km of the ship using 7 x 35 binoculars for visual aid. At the same time, the ship's command determined the location of the cruise track and distance covered. In the small boat surveys, the approximate area covered was estimated by the observers, who also recorded the number of mammals of each species sighted within it.

In the second instance (28 May-9 June 1978) the surveys were conducted via ship-based (NS Surveyor) Bell 206 helicopter, flown at an altitude of approximately 500 ft (152 m) at speeds ranging from about 35 to 85 kt (approx. 65-160 km/hr). The observers (one forward, next to the pilot; one behind the pilot) recorded the number and species of all mammals sighted within 1/4 nm (.46 km) to each side of the flight track (i.e. the total width of the survey track was approximately .93 km). The flight tracks for each survey were pre-determined, based on the distribution of ice in the area and the wind direction and velocity. The surveys were designed to sample as much of the remnant ice area as possible within 30 nm (55km) of the ship (including several replicates) at each oceanographic station. The position of each station had been selected for the purpose of sampling different portions of the remnant, without prior knowledge of ice conditions or mammal distributions there.

The approximate areal coverage by the surveys, relative to the total area of the remnants,and their location is shown in Figure 47. In 1977, one station was in the eastern edge of the Anadyr massif, just west of St. Matthew Island; one was in the link between the Anadyr and the Alaskan massifs; and three were in the southern end of the Alaskan massif. The numbers of seals in the two stations west of 170°W were low (approximately 0.5 seals/km^2); the numbers in the three stations east of 170°W were significantly higher (approximately 2 to 6 km^2). At all stations, spotted seals predominated (80 to 94%); ribbon seals made up about 5% overall and bearded and ringed seals about 1% each.

The surveys in 1978 were of the various parts of the main Alaskan massif and of one small, linear remnant directly west of St. Lawrence Island. The densities of seals utilizing these remnants, as indicated by the survey data, ranged from about 1 to 5/km^2. Densities were lowest in the western part of the Alaskan massif (1 to 2/km^2) and were highest (2.75 to 5/km^2) along the eastern margin. Bearded seals predominated in the west (74%) and spotted seals in the east (69%); ribbon seals made up about 12% overall and ringed seals about 4%. Walruses and gray whales also were abundant in and near the eastern and southern margins, respectively, of the massif.



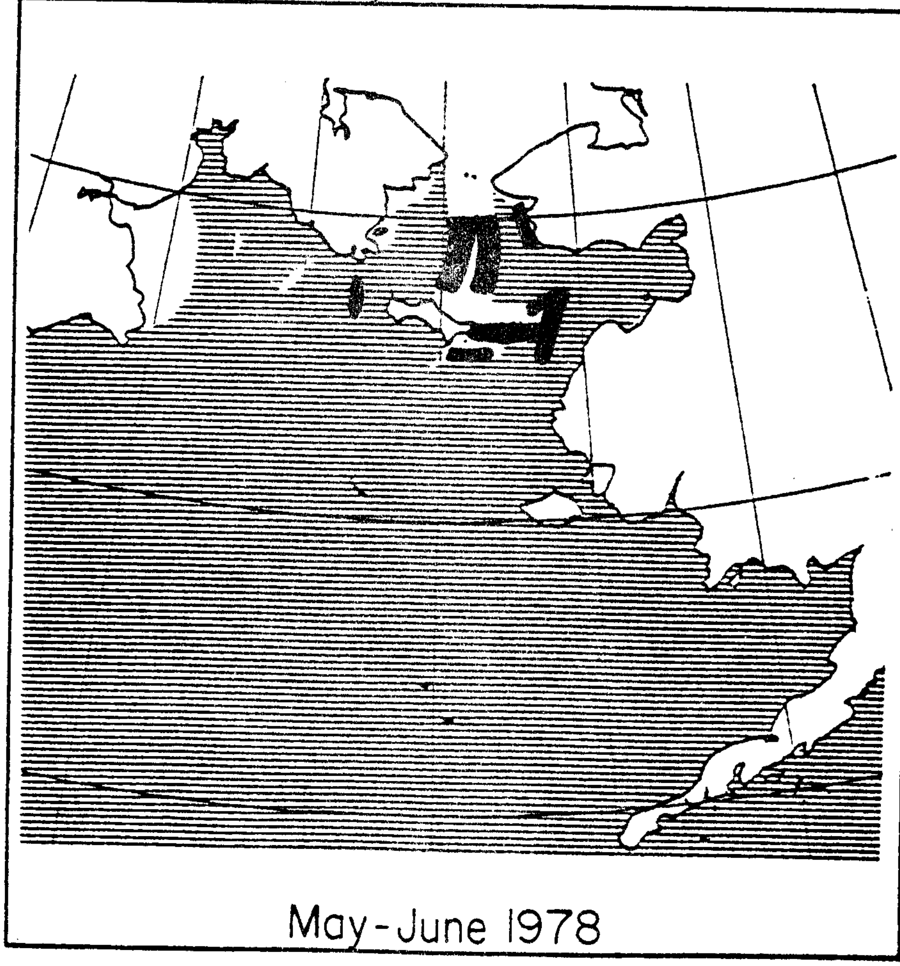


Figure 47. Survey coverage of the Spring remnant ice of the Bering Sea in May-June, 1977-1978.

While the probes were not adequate comparisons of the distribution of seals in the Anadyr versus Alaskan massifs, the findings do indicate that ribbon seals tended to be more abundant in the western than in the eastern parts of the remnants examined:

1. In the southern edge of the remnant ice on 24 May-6 June 1977, a total of 363 seals were sighted from the ship and small boats. The ratio of spotted to ribbon seals sighted in and near the two stations west of 170°W was 30:4 (7.5:1), whereas in those east of 170°W, it was 293:14 (21:1). This difference is significant (X^2=3.18) at the 90% confidence level.

2. In the remnant about St. Lawrence Island and northward toward Bering Strait on 28 May-6 June 1978, the aerial survey results showed a ratio of spotted to ribbon seals on the western side of 39:35 (1:1), whereas on the eastern side it was 376:75 (5:1). This difference is highly significant (X^2=36.1).

D. Chukchi-Beaufort Remnant Ice

The seasonal pack ice of the Chukchi Sea usually retreats northwestward in a regular fashion, without any recurrent pattern of remnants to the south other than persistence of ice for some time in the larger bays, such as Kotzebue Sound. Occasionally, slender remnants of former shorefast ice occur along the coasts, or a tongue from the main pack may be detached and rafted. The remnant ice in the bays is not ordinarily utilized by seals, though any offshore remnants that develop may be used opportunistically by walruses and by spotted, bearded, and ringed seals for completing their molt. Most of the Chukchi pinnipeds at this time are found in association with the main pack.

Conditions in the Beaufort Sea are similar, in that there is generally an orderly retreat of the pack from the shore during July to September, without any regular occurrence of remnants in particular areas. Frequently, in late August and September, a broad tongue of ice extends southward toward the shore in the area between Harrison and Camden Bays (as it did in 1976, 77, and 78), and it is conceivable that small parts of that tongue might occasionally become separated as "remnants". Diffuse nearshore remnants occurred in August 1976 between Thetis and Barter islands; a similar remnant occurred in the vicinity of Barter Island in August 1978. The most outstanding coastal remnants developed in August 1974 between Cape Halkett and Flaxman Island and from Camden Bay to Herschel Island, and in July 1977 between Harrison and Camden Bays. In both of the latter years, these remnants persisted at least through early September, in and just north of the proposed Beaufort Sea oil lease area (Figures 48, 49). These apparently formed by entrainment of drifting ice around persistent, grounded ice masses of the stamukhi zone, as described by Reimnitz, et al., (1977).

The nearshore remnant in August 1977 contained higher numbers of seals than did the offshore pack. The highest densities were in the vicinity of Harrison Bay, where surveys via small boats yielded sightings of from 5 to 15 seals per hour. Comparable surveys in the offshore pack showed counts of from less than one to about 3.5 seals per hour in 1977 and from 0.3 to 3.4/hr in 1978. Both ringed and bearded seals occurred in the nearshore ice, whereas only ringed seals were present offshore, over deeper water. Since this was well after the molting season, seals were seldom out on the ice; they were mainly sighted in the water where

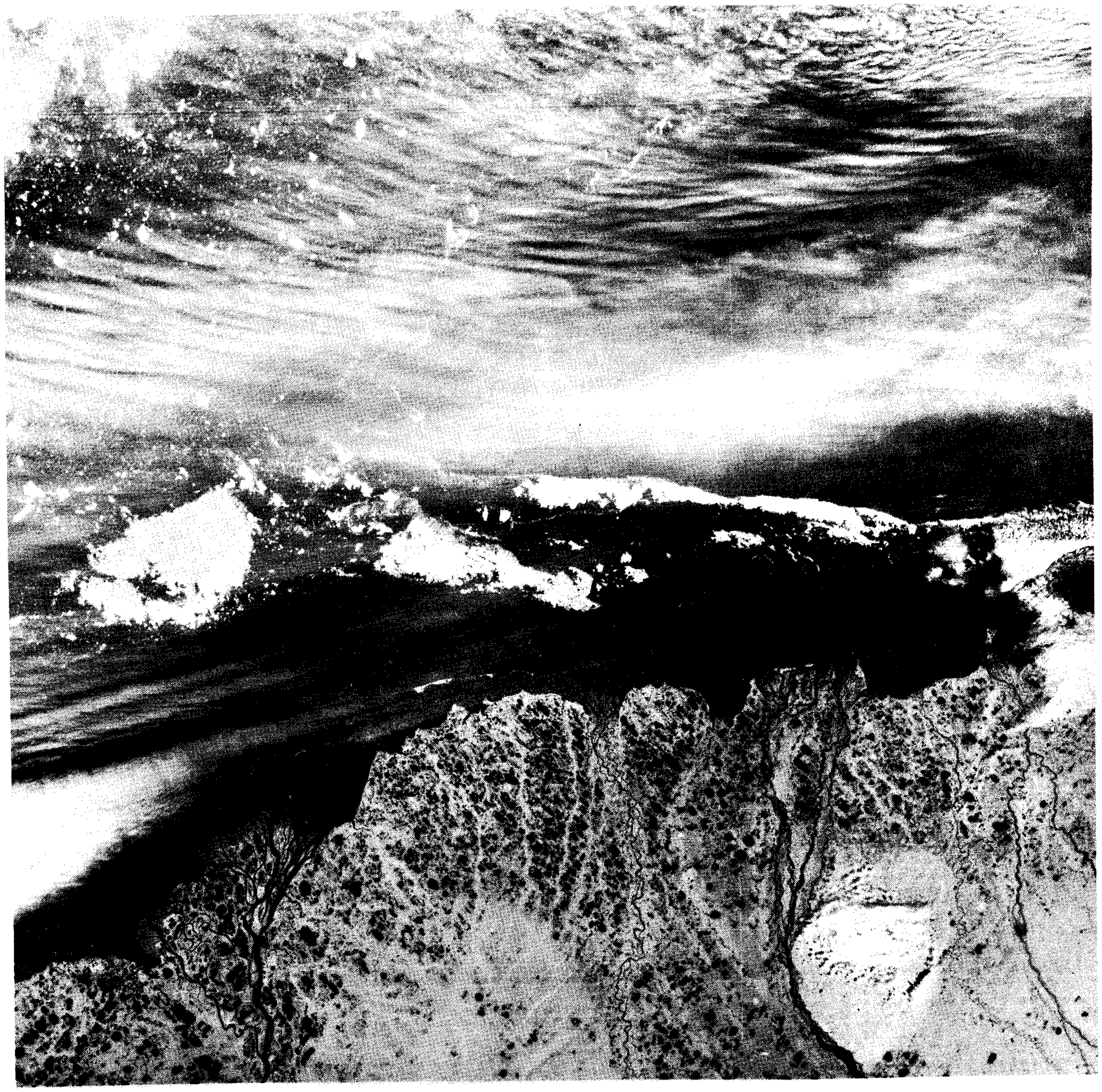


Figure 48. LANDSAT image #2933-20473 showing nearshore remnants in the area between Harrison Bay and Flaxman Island, 12 August 1977.

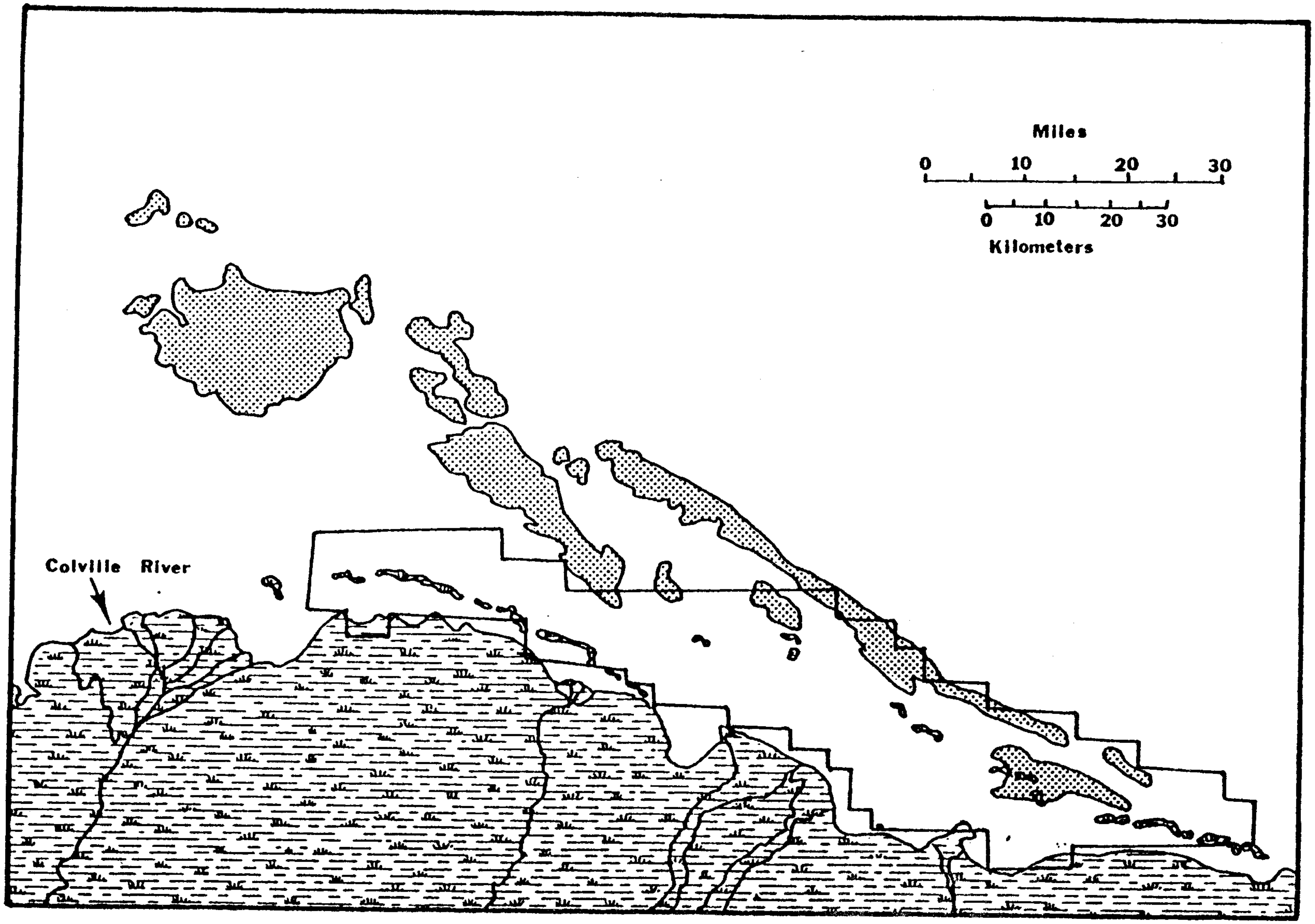


Figure 49. Schematic of the ice remnants of Figure 48 in relation to the Beaufort Sea lease area.

they were feeding. No seals were sighted in the open sea between the remnant and the offshore pack.

E. Discussion

The presence in the Bering Sea in late spring and early summer of two or more extensive, rafted remnants of the winter pack ice is now known to be a feature that occurs annually with a high degree of reliability. These remnants are situated in approximately the same locations each year, and the ice of which they are composed is some of the heaviest, most deformed ice that develops in the entire region. This massiveness certainly is one of the major reasons for their persistence; another is the seasonal change in climate, in which surface winds diminish greatly in velocity and become more variable in direction, tending to allow the remaining ice to disintegrate more or less in situ during May to July.

This extra-heavy ice apparently is a product of the net southward movement of the winter pack. Ice from the Chukchi Sea moving southward through Bering Strait and that formed locally in the northern Bering Sea is greatly deformed where it impinges on the northern coasts of the islands and mainlands of Alaska and eastern Siberia. The product is two major massifs of heavy, pressure-ridged ice, one extending southeastward from the Gulf of Anadyr, and the other essentially from Bering Strait to Nunivak and St. Matthew Islands. The western part of the Anadyr massif and the northern part of the Alaskan massif are the most reliably persistent. The Anadyr massif persists the longest; usually into July.

Each of these major remnants, as well as a number of smaller, more irregularly situated ones, is utilized intensively by pinnipeds of the Bering Sea, which rely on them as haulout areas on which to rest and, especially, to complete their annual shedding and replacement of hair. On that account, these remnants in late May and June contain some of the greatest concentrations of seals ever formed during the year (Shustov, 1965, 1969; Tikhomirov and Kosygin, 1966). Our observations, and those of Soviet biologists, indicate that the western ice (i.e. west of about 172°W) is utilized mainly by ribbon seals and the eastern ice (east of 172°W) mainly by spotted seals. Bearded and ringed seals inhabit the western and northern remnants, walruses occur principally in northern parts. There is not perfect geographical segregation of any of these species, only a tendency for the majority of individuals of each to be situated in those areas.

The observed tendency toward geographical clumping probably does not occur by chance alone. The predictability of location and persistence of the various remnants probably has played a selective role in the evolutionary adaptation of each of these pinnipeds to the Bering Sea pack ice. The ribbon seal's closer association with the western than with the eastern ice appears to be related to the more regular occurrence and duration of the Anadyr than of the Alaska massif. Since these seals do not ordinarily haul out on land (Tikhomirov, 1964; Shustov, 1965) and since they probably must come out of the water in order to complete their molt (Feltz and Fay, 1966; Ling, 1970, 1974), they appear to be dependent on the persistence of remnant ice well into July. Spotted seals, on the other hand, appear to be more adaptable in that they utilize the remnants as available but often complete their molt on shore (Tikhomirov, 1961, 1964; Burns and Fay, unpublished). Because the spotted seals are not wholly dependent on remnant ice for molting sites, and because the eastern remnants often are nicely juxtaposed beside the spring migration route of an important food supply (spawning herring), most of the adult spotted seals tend to concentrate in the eastern Bering Sea.

We suspect that the distribution of ribbon and spotted seals in the ice front during the breeding season (which just precedes the molt) and their apparent selection there of different qualities of ice as haulouts are linked to their differential dependence on the remnants as molting sites. Ribbon seals in the front tend to utilize larger, thicker floes than do the spotted seals (Shustov, 1965; Burns and Fay, unpublished). That is, they appear to selectively occupy those floes that, because of their greater mass, will be most likely to persist as a component of the remnants. While such floes are abundant near the southern edges of both the Alaskan and Anadyr massifs in April-May, the ribbon seals concentrate in the western ice, as if in anticipation of having access to the most extensive and persistant remnant.

In years of minimal extent of ice such as 1979, the Alaskan massif is absent south of 64°N by late May. In that case, spotted seals probably dispersed early, mostly moving inshore while the ribbon seals travelled northward to the Anadyr massif, which persisted through June. In the spring of 1967, however, ribbon seals occurred in enormous numbers on remnant ice between St. Lawrence Island and Bering Strait (Burns, 1968). That instance was unique in our experience (1952 to present) as well as in that of the Eskimos of St. Lawrence, King, and Little Diomede islands. We suspect that the Anadyr massif did not persist in that year alone, and that the ribbon seals were obliged to seek ice elsewhere, farther north, on which to complete their molt.

The ice cover in the eastern Bering Sea was extremely light also in the springs of 1955, 1959, and 1979, but ribbon seals were not unusually abundant in the St. Lawrence-Bering Strait region in those years. At least for 1979, the Anadyr massif still was very extensive in early June and persisted for some weeks longer.

For bearded and ringed seals and walruses of the Bering Sea, the presence of remnant ice after late May appears to be a convenience but not a necessity for their existence. Usually, by that time, most have already migrated into Bering Strait or on northward into the Chukchi Sea, where the presence of ice always is reliable. When remnants of the Anadyr and Alaskan massifs persit to that time or longer, they are heavily utilized by these animals in prodigious numbers. Neither bearded nor ringed seals of the Bering-Chukchi region haul out on land ordinarily, and walruses seem always to use ice in preference to land as a haulout. In June, each of these species is well along in its molt, and the walruses are in the final stages of their calving season.

The Beaufort Sea remnants, appear to be utilized intensively by bearded and ringed seals during the summer, but this is more a relationship with feeding than with breeding or molting. The juxtaposition of floating ice over shallow water probably is particularly advantageous for bearded seals, which are bottom-feeders not known to dive to great depths. The importance of the relationship for ringed seals is less certain but may be connected with the nearshore migration of Arctic cod, a major forage fish utilized by those seals. At any rate, it seems that the presence of such remnants near shore does lead to concentration of both of these species of seals in and near the Beaufort lease area, well after their molt has been completed.

VII RELATIONSHIP TO OCS DEVELOPMENT

A. Introduction

There are nine species of mammals which are strongly and positively linked with the occurrence of sea ice in western and northern Alaska. These are the arctic fox, polar bear, belukha and bowhead whales, the walrus, and the bearded, ringed, spotted, and ribbon seals. Our interpretations of their relative abundance and activities in each of the potential oil-producing basins of the Bering, Chukchi, and Beaufort seas (Figure 50) are summarized in Table 10. Major parts of the populations of each species are found in one or more of those basins in all or a significant part of each year.

Within the ice, there is unequal distribution of these species, as the table indicates. Where two or more occur together in a given basin at the same time, there is partitioning of the available habitats and other resources, as exemplifed by their different feeding habits, birth times, choice of birth sites, and the relative precocity of their young (Table 11). At the same time, each is constrained to a considerable extent by the ice itself, which prevents most of them from advancing far northward in winter and restricts some of them to certain narrow corridors for migration in spring.

The risks of impact on these mammals by OCS oil development in the seasons when pack ice covers the Bering, Chukchi, and Beaufort seas will differ with each phase of that development. Seismic surveys probably will be conducted mainly on fast ice in winter and spring and from vessels at sea in the ice-free summer. In that case, the most important considerations of mammal-ice relationships will be in the fast ice itself and in the adjacent flaw zone. Probably, exploratory drilling

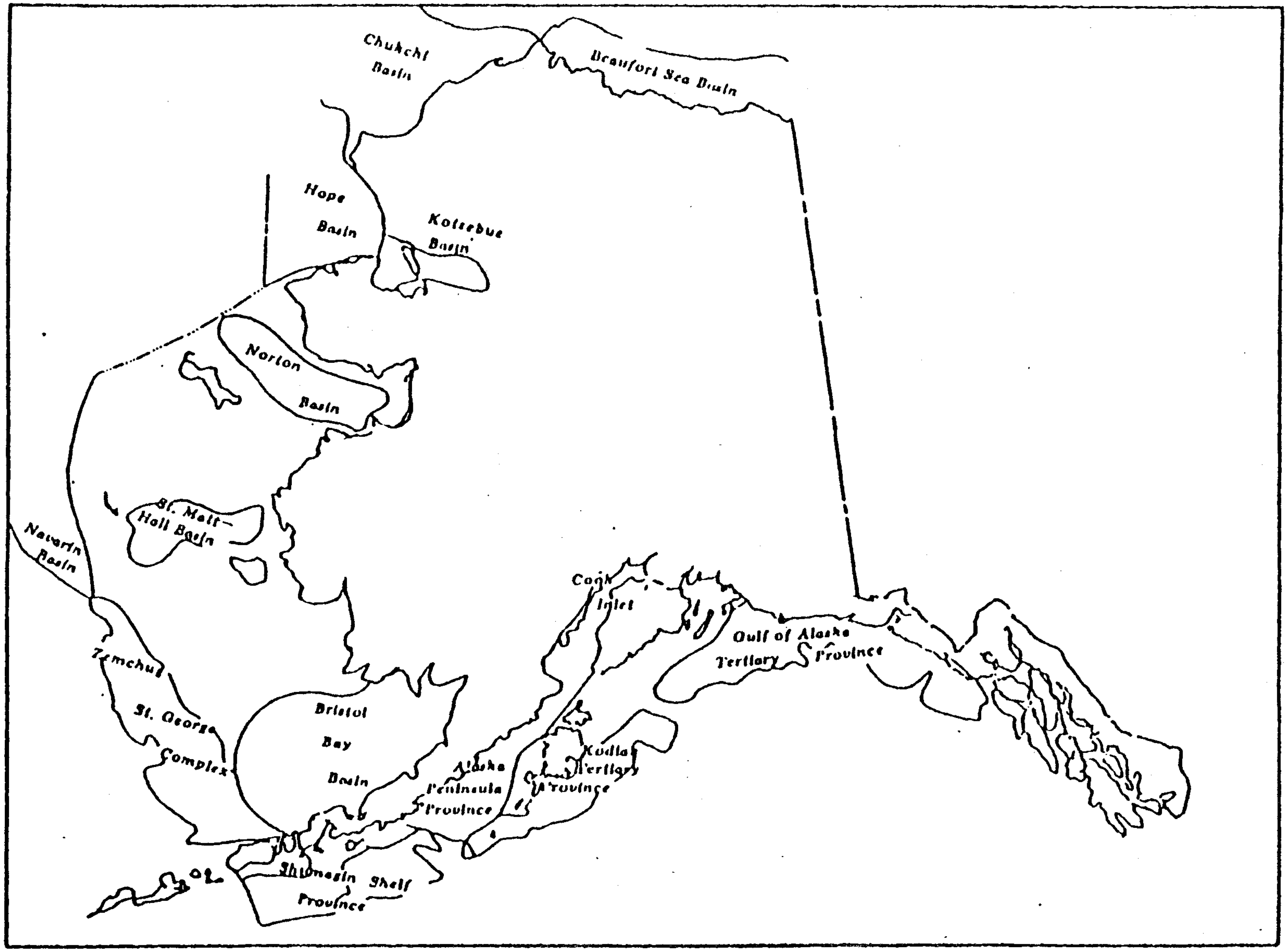


Figure 50. Geologic basins of the Alaskan Continental Shelf.

Table 10. Relative Abundance and Activities of Ice-Associated Marine Mammals in the Geological Basins of the Alaskan Outer Continental Shelf.

Species	Ice type	BRISTOL	ST. GEORGE	NAVARIN	ST. MATTHEW	NORTON	HOPE	CHUKCHI	BEAUFORT
ARCTIC FOX	Consol. pack & fast	Rare-winter, spring	Uncommon-winter, spring	Rare-winter, spring	Few-winter, spring	Abundant-winter, spring Feeding Travelling	Abundant-winter, spring Feeding Travelling Mating	Abundant-winter, spring Feeding Travelling Mating	Abundant-winter, spring Feeding Travelling Mating
POLAR BEAR	Consol. pack & fast	Rare-late winter, spring	Rare-late winter, spring	Rare-late winter, spring	Rare-late winter, spring	Few-late winter, spring Feeding Travelling	Abundant-fall, winter, spring Feeding Nurture Mating Travelling	Abundant-all yr Mating Birth Nurture Feeding Molt	Abundant-all yr Mating Birth Nurture Feeding Molt
BELUKHA	Open pack, flaw, & fringe	Abundant-all yr Feeding Mating Birth Nurture	Uncommon-winter Feeding Travelling	Common-winter Feeding Travelling	Uncommon-winter Common-spring Migrating Mating Feeding	Rare-winter Abundant-spring Migrating Mating Feeding Common-summer Birth Nurture Feeding Abundant-fall Migrating Feeding	Absent-winter Abundant-spring Migrating Mating Feeding Common-summer Birth Nurture Feeding Abundant-fall Migrating Feeding	Absent-winter Abundant-spring, summer, fall Migrating Mating Birth Nurture Feeding	Absent-winter Abundant-spring, summer, fall Migrating Mating Birth Nurture Feeding
BOWHEAD	Open pack, flaw & fringe	Rare-winter	Uncommon-winter	Abundant-winter, spring Migrating Birth Nurture Feeding(?)	Uncommon-winter, spring	Absent-winter Abundant-spring Migrating Birth Nurture Feeding(?) Rare-summer Abundant-fall Migrating Feeding(?)	Absent-winter Abundant-spring Migrating Birth Nurture Feeding(?) Rare-summer Abundant-fall Migrating Feeding	Absent-winter Abundant-spring Migrating Birth Nurture Feeding Rare-summer Abundant-fall Migrating Feeding	Absent-winter Abundant-spring, summer, fall Migrating Nurture Mating Feeding

Table 10. continued

Species	Ice type	BRISTOL	ST. GEORGE	NAVARIN	ST. MATTHEW	NORTON	HOPE	CHUKCHI	BEAUFORT
WALRUS	Open pack & front (winter); Flaw & remnants (spring); Fringe (summer-fall)	Abundant-all yr Feeding Mating Molt Nurture	Common-winter Feeding	Uncommon-winter	Common-winter Feeding Abundant-spring Migrating Feeding Birth Nurture	Uncommon-winter Abundant-spring, summer, fall Migrating Birth Nurture Feeding Molt	Rare-winter Abundant-spring, summer, fall Migrating Birth Nurture Feeding Molt	Rare-winter Abundant-spring, summer, fall Migrating Nurture Feeding Molt	Uncommon-spring, summer, fall
BEARDED SEAL	Open pack, flaw & front (winter,spring) & remnants (spring); Fringe (summer - fall)	Common-winter, spring Feeding Mating Molt Birth Nurture	Common-winter, spring Migrating Feeding Mating Molt Birth Nurture	Rare-winter	Common-winter Feeding Abundant-spring Migrating Feeding Birth Nurture Mating Molting	Common-winter Feeding Abundant-spring Migrating Feeding Birth Nurture Mating Molting Few-summer Feeding Abundant-fall Migrating Feeding	Common-winter Feeding Abundant-spring Migrating Feeding Birth Nurture Mating Molting Few-summer Feeding Abundant-fall Migrating Feeding	Common-winter Feeding Abundant-spring, summer, fall Migrating Feeding Birth Nurture Mating Molting	Rare-winter Common-spring, summer, fall Feeding Birth Nurture Mating Molting
RINGED SEAL	Consol. pack & fast (all yr); open pack, fringe, & remnants (spring, summer)	Few-winter, spring	Few-winter, spring	Few-winter, spring	Common-winter, spring Migrating Feeding Birth Nurture Mating	Abundant-fall, winter,spring Migrating Feeding Birth Nurture Mating Molting Uncommon-summer	Abundant-fall, winter,spring Migrating Feeding Birth Nurture Mating Molting Uncommon-summer	Abundant-all yr Feeding Birth Nurture Mating Molting	Abundant-all yr Feeding Birth Nurture Mating Molting
SPOTTED SEAL	Front, fringe, & remnants (winter, spring)	Abundant-winter, spring Feeding Birth Nurture Mating Molting	Abundant-winter, spring Feeding Birth Nurture Mating Molting	Few-winter, spring	Abundant-winter, spring Migrating Feeding Birth Nurture Mating Molting	Abundant-spring, summer, fall Migrating Feeding Molting	Abundant-spring, summer, fall Migrating Feeding Molting	Abundant-spring, summer, fall Migrating Feeding Molting	Uncommon-summer

Table 10. continued

Species	Ice type	BRISTOL	ST. GEORGE	NAVARIN	ST. MATTHEW	NORTON	HOPE	CHUKCHI	BEAUFORT
RIBBON SEAL	Front & remnants (winter, spring)	Common-winter, spring Feeding Birth Nurture Mating Molting	Abundant-winter, spring Feeding Birth Nurture Mating Molting	Few-winter, spring	Abundant-winter, spring Feeding Birth Nurture Mating Molting	Common-spring, fall Feeding Molting Migrating	Common-spring Feeding Molting Uncommon-summer, fall	Uncommon-spring, summer, fall	Rare-summer

Table 11. The birth period, characteristics of birth sites, duration of dependency and mobility of the young of nine species of ice-associated mammals.

Species	Birth Period	Characteristics of Birth Site	Duration of Dependency	Mobility of Dependent Young
Arctic Fox	May-June	Subsurface Den on land	3-5 mos.	Restricted to densite until independent.
Polar Bear	Nov-Dec	Subnivian den mainly on land	24-28 mos.	2-3 mos. restricted to densite; then travel with mother
Belukha	June-Aug	Near shore-open water	24 mos.	Mobile - travel with mother
Bowhead	March-May	Leads in pack	24 mos.?	Mobile - travel with mother
Walrus	April-June	On pack	18-24 mos.	Mobile - travel with mother
Bearded Seal	March-May	On pack	2-3 weeks	Mobile - travel with mother
Ringed Seal	March-April	Subnivian lair on fast ice and heavy pack	4-6 weeks	Restricted to lair until weaned
Spotted Seal	March-April	On ice of front zone	3-4 weeks	Passive drift on ice
Ribbon Seal	March-April	On ice of front zone	3-4 weeks	Passive drift on ice

will be conducted mainly during the ice-free period, except in the western Beaufort Sea, in which case mammal-ice relationships only in the latter locality will require some consideration. For the production phase, in which permanent offshore platforms, shore camps, shipping, air traffic, and potential spills are among the factors to be considered, a much broader variety of mammal-ice relationships must be reckoned with, since this phase will affect greater areas and persist for a much longer period of time.

It is perhaps most useful to consider each of the major ice-habitats of these mammals that exist within the geological basins and to point out some of the known and potential impacts that could occur with the different phases of oil development.

B. Fast Ice

Fast ice of sufficient extent and stability for exploratory operations occurs in or adjacent to the Norton, Hope, Kotzebue, Chukchi and Beaufort basins. As an annual, relatively stable extension of land, it is a convenient platform for conducting many operations connected with nearshore petroleum development. Its stability and thickness are generally related to latitude. Thus, it is of greatest utility to man in the most northerly latitudes.

To date, fast ice has provided a useful platform on which to construct temporary roads and to conduct exploratory seismic and drilling operations. For local residents of coastal areas, fast ice provides an excellent route of travel and a platform important in fishing and hunting. It is anticipated that human activity in the fast ice zone, especially from Norton Sound northward, will intensify as development progresses from the exploratory stage.

The principal mammalian inhabitants of the fast ice are ringed seals, for whom it is the primary habitat for birth and nurture of their young. Its degree of stability seems to be the principal factor affecting the success (or lack thereof) in the annual production of young by this species (McLaren, 1958). That is, the best production of ringed seals takes place in the most stable ice, which also will tend to be the most useful ice for seismic surveys and exploratory drilling. Polar bears and arctic foxes also occur on this ice, probably in numbers proportional to the density of ringed seals, since the latter are their main reason for being there. The bears and foxes feed on ringed seal pups, and the bears also take older seals, the remains of which are fed on by the foxes after the bears are sated.

As we have demonstrated earlier in this report, seismic surveys conducted on the fast ice do have a displacing effect on ringed seals, hence, presumably on polar bears and foxes, as well. While we assume that this effect is temporary, i.e. that they are displaced only in the year when the disturbance occurs, it is conceivable that repetitive disturbance over several years, or disturbance causing activities covering great expanses of the available ringed seal habitat, could have very significant effects on the production of young by this species and, in turn, on the availability of food for the bears and foxes. Probably the establishment of permanent camps, platforms, shipping centers, etc. will have long-term displacing effects, but these will be local. Unless such facilities are numerous along a large part of the coast, the impact on the ringed seal population as a whole probably will not be significant.

We suspect that, in the production phase, the probability of petroleum spills will be greater under the fast ice than farther from shore. Under-ice releases probably will be contained in the immediate area, as long as the ice remains stable, for it will be temporarily trapped in pockets in the irregular undersurface of the ice. We think that there is low probability of recovery of such entrapped oil from the fast ice zone, because of that irregularity. At any rate, it is likely to have an adverse impact on the resident ringed seals, before it can be recovered. Since the oil will tend to rise and accumulate in the breathing holes of the seals, and since most of those holes do not penetrate completely through the snow to the air above, there will be a tendency for the volatile fractions to be released and accumulate in the air pockets and subnivian lairs used by the seals. We expect that most of the adult seals in the area so affected would depart at once. Some females might remain, but on emerging into their lairs to nurse their pups, they would become coated with oil and, ultimately transfer it to the inside of the lair and the pups themselves. This would cause reduction in insulative value of the pup's woolly lanugo coat, on which it relies for warmth. Probably, some oil from the mothers body surface would be ingested during suckling. We anticipate that, in the area of a spill under fast ice, all of the ringed seal pups would be lost, either from desertion, excessive heat loss, oil ingestion, or any combination of these. The extent of this impact would be dependent on the extent of the spill.

C. Flaw Zone

Flaw zones of major importance to mammals occur in the St. Matthew, Norton, Hope, Chukchi, and Beaufort basins. Of these, we regard as most important the persistent flaw along the northwestern coast, between

Point Hope and Barrow. This flaw is frequented throughout the winter by ringed and bearded seals and because of the latter's abundance, by polar bears and arctic foxes. A large proportion of the bear population of the Chukchi Sea resides in this area in spring. At that time also, the flaw becomes the migration corridor for practically all of the bowheads, belukhas, walruses, and bearded and ringed seals moving northward from their wintering grounds in the Bering Sea to their summer feeding areas in the Chukchi or Beaufort seas. En route to the flaw, these animals come around the eastern and western ends of St. Lawrence Island, then through Bering Strait, and northward through the broken pack to the vicinity of Point Hope. The period of greatest mammal numbers along that route and in the flaw between Point Hope and Barrow is from March to July. It is probable that any seismic activity, drilling, shipping, or heavy aircraft traffic it, especially its narrower parts, will discourage if not prevent those mammals from completing their normal migrations in timely fashion, for they seem to have no alternative routes.

D. Fringe and Front

The fringes and front may occur annually in most of the proposed lease areas north of the Alaska Peninsula and Aleutian Islands. Exceptions are the southwestern part of the Navarin Basin, over which sea ice usually does not occur, and the St. George Basin, where ice is present only during years of maximal extent of the pack. The front is a feature of the pack during February through April. It occurs almost annually in Bristol Bay and less regularly over the St. George Basin. In occasional winters of minimal ice cover, it may occur in the Norton Basin.

The front is of critical importance to virtually the entire populations of spotted and ribbon seals from March to late April. This zone also is

This zone also is utilized by some bearded and ringed seals, walruses and, depending on its location, harbor seals. Almost the entire annual production of spotted and ribbon seal pups is born in the front and fringe. Pups of both species remain on the ice until weaned and are dependent on their woolly hair (lanugo) for insulation. The importance of the lanugo for thermoregulation decreases as thickness of the blubber layer increases (e.g. see Davydov and Makarova 1965). The young of bearded seals and walruses are born mainly north of the front. Unlike those of spotted and ribbon seals, the young of these two species are swimmers (though they swim poorly and for short periods of time), and they move with their mothers soon after birth.

Vessel traffic in the front probably would result in direct mortality of some young seals in areas of high seal density. The number of cases of pups being forced into the water for prolonged periods of time also will be increased, thus contributing to increased mortality through thermal stress.

The motion and structure of ice comprising the front are such that oil in the water will become concentrated in the openings between floes. Through the dipping and pumping action of floes rising and falling with waves and swells, this oil would be deposited on the ice. Lanugo-clad pups, may become coated by this oil, largely destroying the insulative qualitities of their hair. Adults surfacing through a slick or moving on the oil-covered floes likewise would become coated. Contact of oil-covered females with their pups may lead to the pups being coated, as well as to ingestion of oil by the pups while nursing. Oiling of molting seals might increase skin irritation, possibly increasing the probability of infection by other agents.

E. Remnants

The presence of the spring remnant ice in the Bering Sea is of critical importance for the seals that do not haul out on land and must haul out on ice in order to complete their molt. Judging from the reactions of seals held in captivity, the molt itself causes considerable metabolic and psychological stress to the animals, who show this through their irritability, general lethargy, and disinterest in food (Ronald et al., 1970). At the time of hair loss and shedding of the outer protective layer of cornified epidermis, there is loss of serum and electrolytes, and the skin is particularly vulnerable to infection by microbiological agents (Greenwood et al., 1974). Probably, the affected skin is equally vulnerable to irritation by toxicants. This, then, is a period when further stresses, by disturbance or introduction of chemical irritants may have especially deleterious, direct effects on the seals. For the majority of seals in this region, the period of greatest vulnerability is during May and June, though some individuals are molting as early as April or as late as July. Molt in the walrus is more prolonged, extending mainly from April to August.

Use of the remnant ice by walruses in May and June is connected also with their annual calving season, which lasts from about mid-April to mid-June (Burns, 1965; Krylov, 1969). At that time, the females haul out on ice, especially in the northern remnants (i.e. north of 62°N), where they give birth to their calves and suckle them. Although the calves quickly become capable of sustained immersion in the cold water, they are ill-prepared for this at birth and apparently rely on spending a large amount of time on the ice, where they can be warmed by the sun and by contact with the mother (Fay and Ray, 1968; Ray and Fay, 1968). Disturbances resulting in prolonged immersion at this early age may take a considerable metabolic toll. While that is not necessarily lethal in itself, it may contribute to calf mortality in combination other stresses and pathogens.

G. General

Some polar bears will be attracted to sites of human activity, requiring removal. However, most (particularly pregnant sows or sows with cubs) will be displaced. Because of displacement, petroleum development probably will reduce the extent of available habitat for polar bears, in direct proportion to the extensiveness of development activities.

Arctic foxes are attracted by and can be expected to congregate near sites of human activity. This will result in an increasing incidence of their predation on ringed seal pups in those areas and an increase in the public health hazard to humans through diseases transmitted by foxes (i.e. rabies and alveolar hydatid disease).

Impacts on the more aquatic mammals of the ice zone probably will be mainly effects of sight, sound, and odors, plus some direct and indirect effects of oil spills per se. The acoustical and olfactory senses of marine mammals appear to be especially keen, and it is probable that the main effects will be through those receptors. Our experience indicates that continuous, low frequency sounds such as those made by heavy machinery seem to be least deterring; irregular or intermittent sounds and high frequencies seem to be more deterring. Fumes from combustion and other strong odors clearly elicit fright reactions in most species, as do sight and sound of low-flying aircraft and outboard-powered small boats. Large vessels seem to be less frightening than small boats, though recent studies in Japan and in southeastern Alaska have suggested that large whales respond more adversely to large than small vessels (Nishiwaki and Sase, 1977; Jurasc and Jurasc, unpublished).

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