Environmental Assessment of the Alaskan Continental Shelf

Annual Reports of Principal Investigators for the year ending March 1981

Volume I: Receptors - Birds, Fish, Marine Mammals, Plankton, Littoral

U.S. DEPARTMENT OF COMMERCE
National Oceanic & Atmospheric Administration
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The facts, conclusions and issues appearing in these reports are based on interim results of an Alaskan environmental studies program managed by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, and primarily funded by the Bureau of Land Management (BLM), U.S. Department of Interior, through interagency agreement.

DISCLAIMER

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Shorebird Dependence on Arctic Littoral Habitats

Annual Report, R.U. 172

August 1, 1981

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Preface

The final report for all Beaufort studies of R.U. #172 is now in preparation. This Annual Report only summarizes progress toward that product, and provides examples of some of the most recent analyses and conclusions.

I. Summary

The principal objective of R.U. #172 has been the assessment of the degree and nature of dependence of shorebird species on arctic habitats which are potentially susceptible to damage resulting from offshore oil development. During the past year we have studied shorebird use along the shores of Harrison Bay, where extensive arctic saltmarshes are important for post-breeding concentrations of geese and shorebirds. Larger patches of this critical and sensitive habitat occur in southern Harrison Bay than are present in previously studied areas near Barrow and Prudhoe Bay. The most extensive and heavily used of these, in the deltas of the Colville river and Fish Creek, should be avoided as sites of development activity.

Analyses of a large multi-year data set of shorebird densities lead us to conclude that annual variation in numbers of birds using the littoral zone in late summer reflects more than just local breeding density fluctuations, and is not closely related to local weather during the breeding season. It is related to late summer weather, possibly mediated through changes in turnover rates of migrant birds. Some groups of species exhibit similar patterns of annual variation in numbers, responding similarly to variation in undetermined environmental factors. These groups share common littoral zone habitats during late summer but not during the breeding season. Environmental perturbations in these littoral habitats, such as might accompany oil development, would be expected to produce density fluctuations in groups of species preparing to migrate southward.

Extensive analyses of habitat descriptions for all transects, done on a finer scale than previously, allow us to place all our transects in a habitat space which emphasizes differences in habitats. The procedure is quantitative, relatively insensitive to observer differences, and does not require extensive training of field observers. It therefore allows field workers to survey new areas, collecting descriptive data which can be compared directly and quantitatively to known habitats in other areas for which we have extensive shorebird data.

The analyses of our 6 measured variables separate Barrow littoral transects into 3 groups corresponding approximately to gravel ocean beaches, slough edges, and littoral flats. These agree in general with our intuitive classifications of these transects based on several seasons' experience. Bird species respond to the same habitat differences, showing a similar pattern, but with less distinction between slough edges and littoral flats. Our bird data show that groups of shorebird species show similar habitat preferences each year, in spite of variation in annual patterns of use in habitat space. This quantitative analysis of shorebird habitat use patterns supports our earlier classification of species relative vulnerability to oil development (Connors, Myers and Pitelka, 1979).

II. Results and Discussion

A. Harrison Bay Studies

Results of our transect work in this area, principally in Fish Creek Delta, have been summarized in the Lease Sale 71 Synthesis and will be detailed in the Final Report of R.U. #172. A brief listing of principal conclusions follows:

(1). Habitat analyses.

Compared with Barrow and Prudhoe Bay, littoral habitats in the Fish Creek Delta area are characterized by wider flood zones, lower slopes, more vegetation and muddier substrates. Figure 1 presents a principal components analysis of habitat characterization (Connors and Risebrough, 1976, 1977) for transects at the 3 coastal sites. In general, gravel beaches score negatively in both first and second components, with littoral flats and slough edges scoring more positively. Barrow and Prudhoe transects occupy the same range of habitat space, but Harrison Bay transects are all in one class (saltmarsh and mudflat) with positions more extreme than any recorded from the other 2 sites. Saltmarsh occurs farther from the shore in more extensive patches in Harrison Bay than in the other two areas studied previously.

(2). Bird use.

Very briefly, Harrison Bay in 1980 lacked the heavy use by red phalaropes, sanderlings, ruddy turnstones, arctic terns and Sabine's gulls which occur in areas with gravel spits and barrier islands. For species which utilize saltmarsh habitats (dunlin, semipalmated sandpiper, lapland longspur) densities were comparable to, or greater than, those measured in similar habitats at other Beaufort sites. However, the much greater area of these habitats in Harrison Bay implies greater total numbers of these species in littoral areas of Harrison Bay.

The saltmarshes also support heavy use by geese (Canada, white-fronted, and brant) and other waterfowl during nesting and post-breeding season. These species are more sensitive to disturbance than are shorebirds. Development activities should avoid the major saltmarsh areas identified in the Lease Sale #71 Synthesis Report.

B. Annual Variation in Shorebird Densities

Arctic ecosystems are commonly characterized as subject to extremely high variation in environmental and biological components, but the data to examine annual variation are scarce. Time, funding and other limitations have held most arctic bird studies to 1 or 2 years at a single site. R.U. #172 has maintained a schedule of censuses on fixed littoral zone transects at Barrow for at least the post-breeding season in 4 consecutive

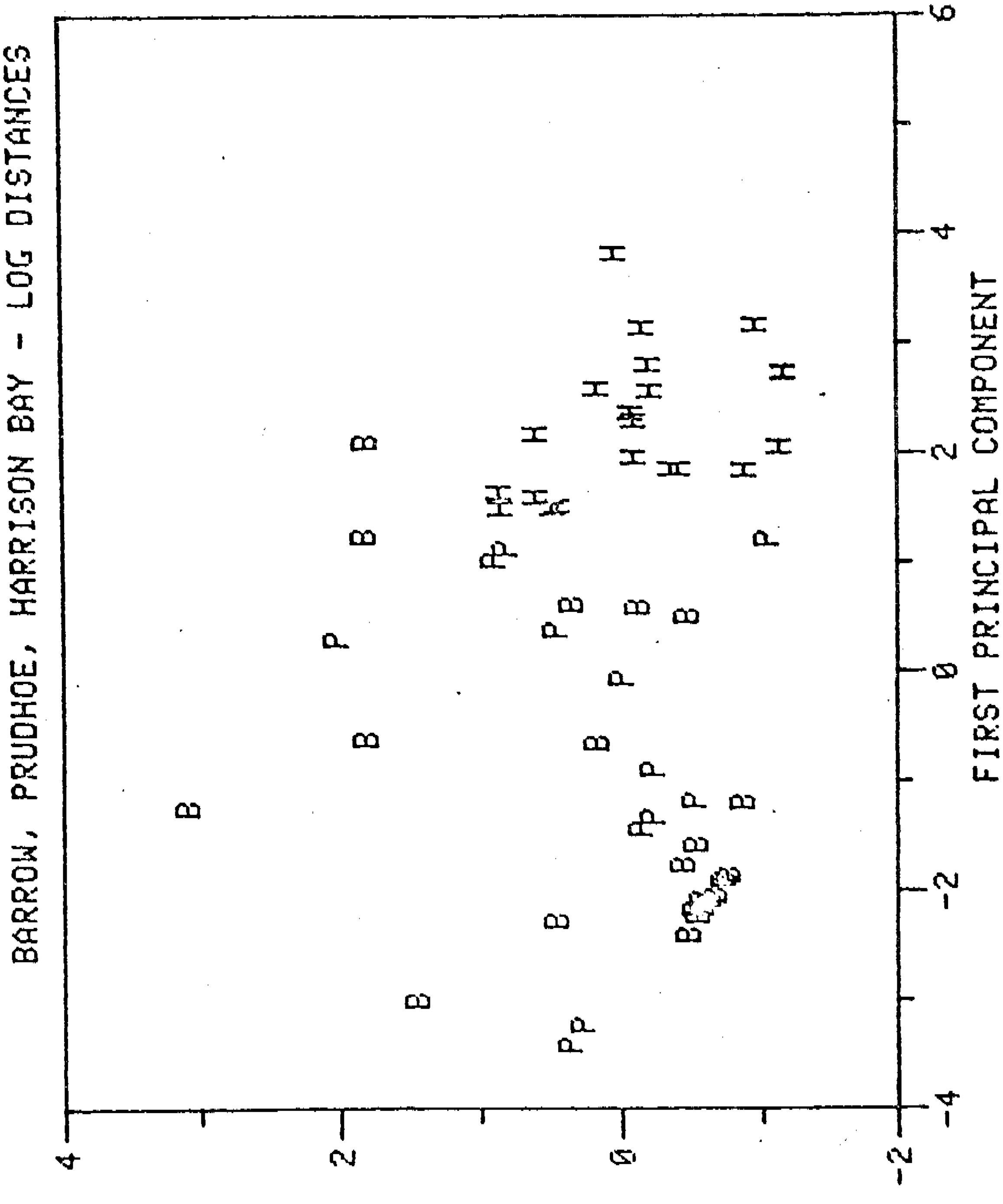

Figure 1. Locations of littoral transects in habitat space defined by first and second principal components derived from 6 habitat variables. P, Prudhoe Bay; B, Barrow; H, Harrison Bay.

years, 1975-1978. Shorebird densities recorded by the same methodology on similar tundra transects are available from Myers and Pitelka (1980) for 5 years (1975-1979) at Barrow and 3 years (1977-1979) inland at Atkasook. These data, together with daily meteorological records from Barrow, provide a unique opportunity to examine patterns of annual variation in numbers of shorebirds using the littoral zone at one site on the arctic coast.

Briefly, the data consist of repeated censuses every 5 days on marked, fixed transects - a total of about 3000 individual censuses over 5 years. Weather temperature data are treated as cumulative temperature deviations from the Barrow mean temperature for each date, summed over different periods of ornithological relevancy. Data sets were compared by Pearson correlation analysis.

The general pattern of shorebird habitat use has been documented previously by R.U. #172. Most species nest on tundra in June and July, with a shoreward movement as the season progresses, first by post-breeding adults and then by large numbers of juveniles in August and early September. Does this shoreline movement represent just the local birds shifting habitats, or is it a widespread phenomenon, drawing birds from farther away? Briefly, our analyses show no correlations between post-breeding littoral densities and breeding densities at either site. We conclude that annual variation in post-breeding migrant densities at Barrow reflects more than just local breeding fluctuations.

Considering annual variation in temperatures during 3 periods of summer (Table 1), we find no general correlation between early summer temperatures and shorebird densities during any period, but magnitude and timing of post-breeding shoreline movements are correlated with post-breeding temperatures. In years of warmer late summer temperatures, littoral zone densities are higher, and migration peaks are earlier. It is surprising that post-breeding migrant densities are influenced more by late summer temperatures than by local breeding season temperatures, and this suggests that birds respond to conditions within the littoral zone during late summer. Changes in turnover rates of migrating birds might be involved in this effect. This would imply the need for a reappraisal of all population estimates based on censuses of migrating birds, since a slower turnover rate could sharply increase recorded densities even with a constant total population passing through a census site.

Table 1. Shorebird Densities and Temperature Trends at Barrow: Patterns Across Species

Higher Temperatures	Tundra Breeding Densities	Littoral Post-Breeding Densities	Post-Breeding Movement Median Date
Pre-breeding	--	--	--
Breeding	--	--	--
Post-breeding	--	Higher	Earlier

Figure 2 shows annual variation in littoral post-breeding densities for two ecologically similar species, semipalmated and western sandpipers. The correspondence of these two sets of data is remarkable in magnitude, shape and timing, in spite of huge annual fluctuations. It also suggests that these fluctuations are not random; there must be some environmental variation affecting both species similarly. We can compare variation in the two species graphically by expressing each year's cumulative density as a percent of the 4-year total (Figure 3). Similarly, Figure 4 displays a high correspondence of variation in densities of pectoral sandpiper and dunlin with semipalmated sandpiper. These 3 sandpipers, with western sandpiper, form a group of species whose numbers fluctuate similarly from year to year. Red phalaropes and ruddy turnstones comprise another group, with numbers displaying a different pattern of annual variation. We conclude that these groups of species respond similarly to annual variation in some undetermined environmental factors. If we classify all common Barrow shorebirds by breeding habitat and again by post-breeding habitat (Table 2), and consider all pairs of species which show correlations in annual variation in post-breeding numbers (Table 3), we find that species which fluctuate similarly do not in general share the same breeding habitat ($\underline{p} = .14$). They do, however, occur together in the same post-breeding habitats ($\underline{p} < .005$). This implies a connnection of some sort through conditions in the littoral zone during the post-breeding period. We have also shown a relationship between post-breeding density and temperature during the post-breeding period which bolsters this conclusion.

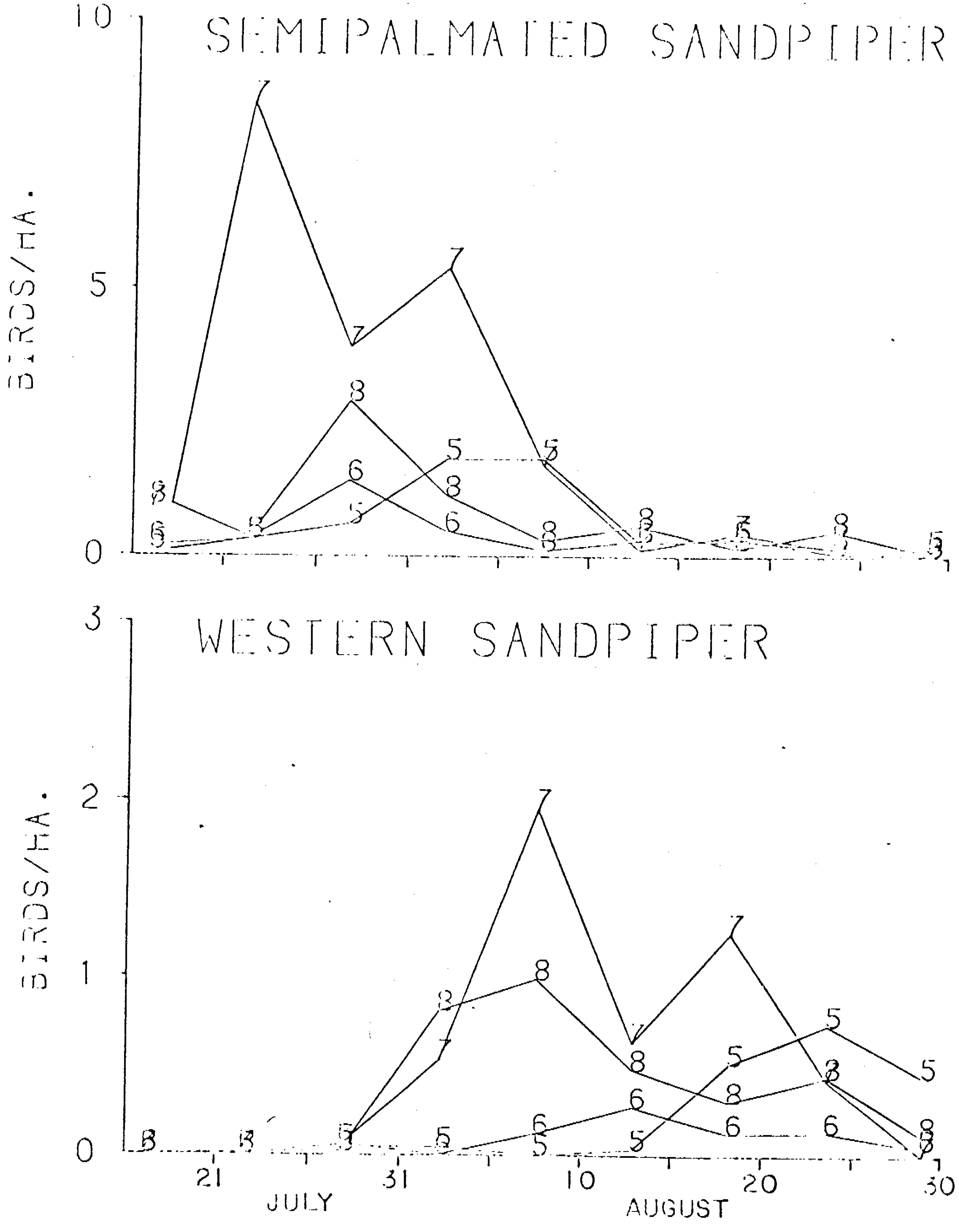

Figure 2. Annual variation in sandpiper post-breeding densities on littoral zone transects, 1975-1978.

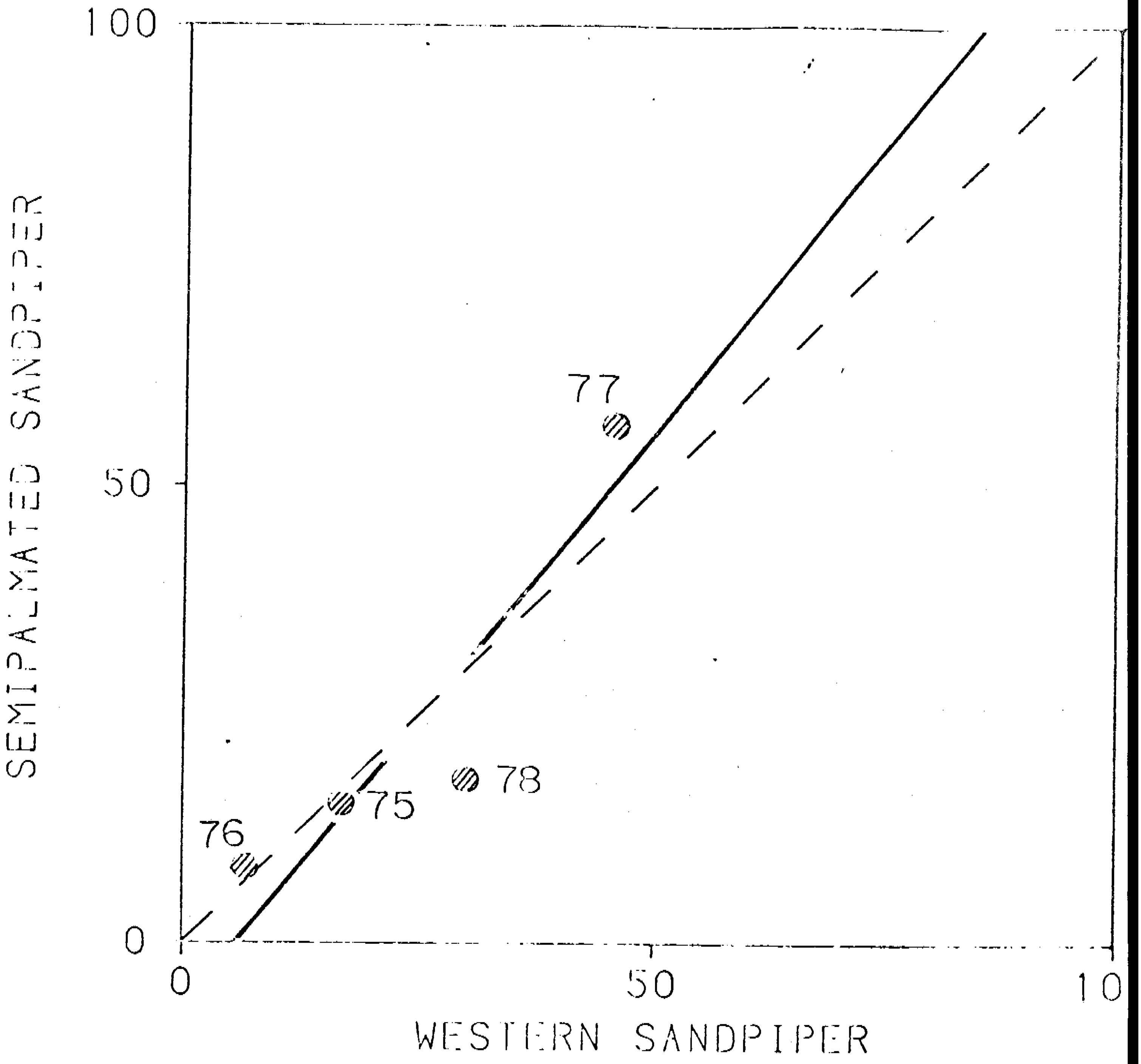

Figure 3. Per cent of 4-year cumulative density during post-breeding period on littoral zone transects, 1975-1978.

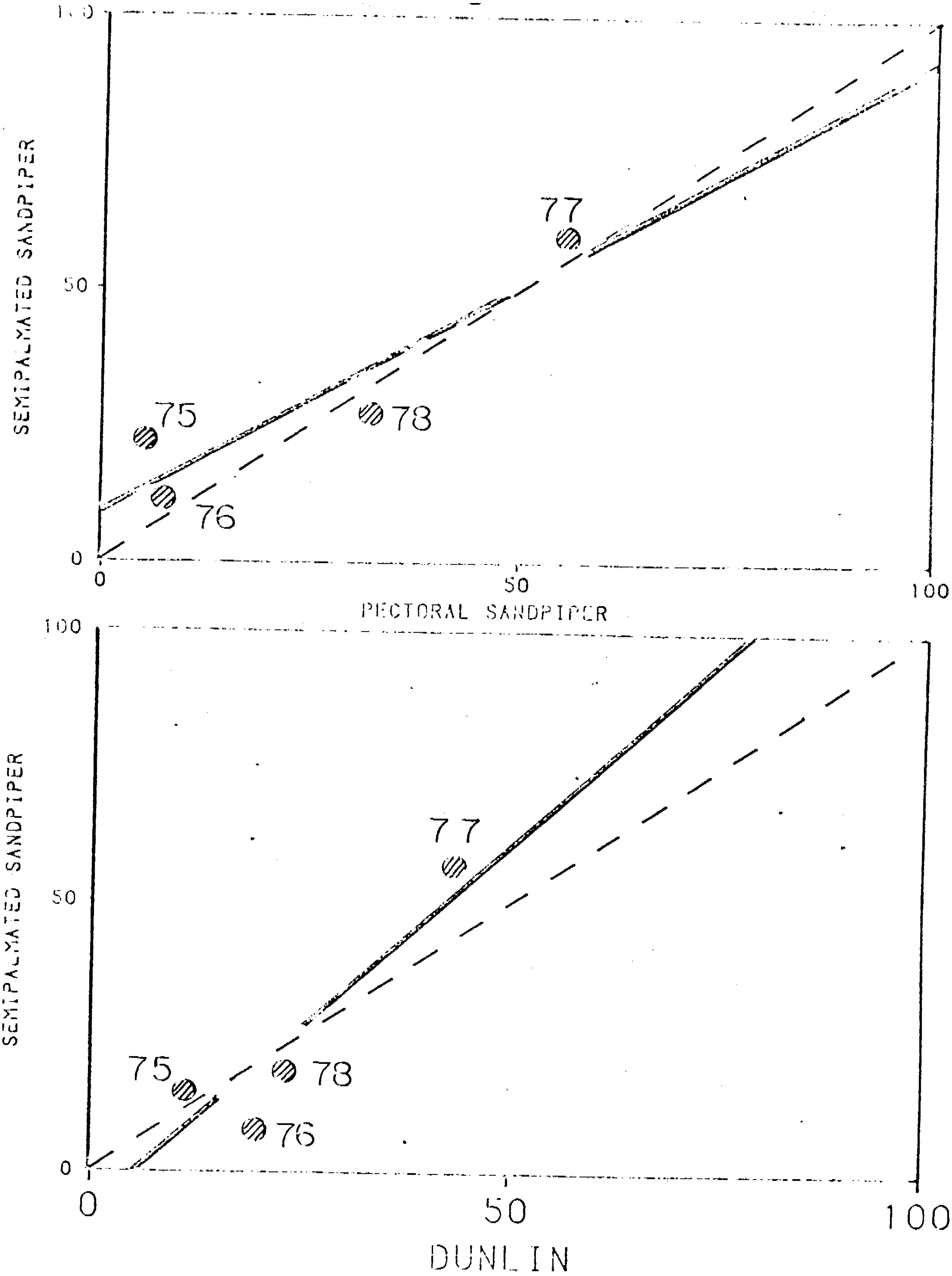

Figure 4. Per cent of 4-year cumulative density during post-breeding period on littoral zone transects, 1975-1978.

Table 2. Seasonal Habitat Groups of Common Barrow Shorebirds

Breeding Habitat Groups

Lowland Tundra

Pectoral Sandpiper
Red Phalarope
Northern Phalarope

Upland Tundra

Golden Plover
Ruddy Turnstone
Semipalmated Sandpiper
Western Sandpiper
Baird's Sandpiper
Dunlin

Post-Breeding Habitat Groups

Gravel Beaches

Ruddy Turnstone
Sanderling
Red Phalarope

Littoral Flats, Lagoon Edges

Golden Plover
Semipalmated Sandpiper
Western Sandpiper
Baird's Sandpiper
Pectoral Sandpiper
Dunlin
Long-Billed Dowitcher
Northern Phalarope

Table 3. Species - Pair Correlations of Annual Variation in Post-Breeding Densities

	Breeding	Post-Breeding
Within Habitat Groups	6	18
Between Habitat Groups	12	2
X^2 - Test	$P = .14$	$P < .005$

What sort of effect can this be? Since it occurs after the birds have left the tundra, it is unlikely to be mediated through changes in breeding productivity, but post-fledging survival, once birds reach the littoral zone, may be involved. Differences in weather stress or in foraging profitability through variable prey conditions, storm water levels, or other habitat changes during or before this period may be responsible. These might affect the survival of individuals, the geographic movements of birds over local or large areas, or the length of time individuals remain in one area during migration. Environmental perturbations in these littoral habitats, such as might accompany oil development, will be expected to produce density fluctuations in species groups of migrant shorebirds, not just individual species.

C. Habitat Analyses

Previous reports by R.U. #172 have discussed patterns of seasonal habitat use by shorebirds, emphasizing shifts from tundra to littoral habitats. We are now focusing on finer details of littoral zone use by multivariate statistical techniques. We measured 6 habitat variables on each 50m x 50m plot on 22 transects: distance to water's edge, width of normal flood zone, width of maximum flood zone, percent water cover, type of exposed substrate, and percent vegetation cover. Principal component analysis of these data confirmed our subjective conclusion that our transects represented 3 distinct habitat types: ocean gravel beaches, slough edges, and littoral flats (mudflats and saltmarsh). Plotting the densities of the 11 most common shorebird species in the habitat space defined by PC analysis demonstrated that different species respond differently to these three habitat types. Ordinating the transects based on presence or absence of the 31 common species confirmed that the 3 habitat types attract different suites of birds. The strongest distinctions in bird use occur between gravel beaches and slough edge - littoral flat habitats.

Groups of species which share regions of PC habitat space can be delineated. These groups are generally consistent from year to year. However, single species habitat use patterns do change between years, possibly in response to changes in prey abundance in different habitats. Our analyses show the importance of these three different habitat types to post-breeding birds along the arctic coastline, and support our earlier conclusions regarding differential susceptibility of shorebird species to oil development impacts based on habitat use patterns (Connors *et al.*, 1979).

Our habitat classification methods can be easily applied by field workers at other arctic sites. Assigning variables does not require extensive training. Multivariate techniques can then place newly described transects in habitat space with known transects for which bird density data are available (see Figure 1). This permits comparison of areas studied by different researchers, and may allow prediction of expected bird densities based only on habitat descriptions and geographic locality.

XII. Auxiliary Material

A. References

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Connors, P.G. and R.W. Risebrough. 1976. Shorebird dependence on arctic littoral habitats. In Environmental Assessment of the Alaskan Continental Shelf (Annual Reports from Principal Investigators), Volume 2:401-456.

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B. Papers in Preparation or in print

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Connors, P.G. 1981. Distribution and ecology of shorebirds in Alaska's coastal zone: a review of studies in the Outer Continental Shelf Environmental Assessment Program. Wader Study Group Bulletin 31:48-51.

C. Oral presentations

Connors, P.G., J.P. Myers, and F.A. Pitelka. Seasonality in a shorebird fauna of a high arctic Alaska locality. Presented at pacific Seabird Group Meeting, 6 January 1977.

Connors, P.G., K. Hirsch, and C. Hohenberger. Effects of coastal oil development on shorebirds in arctic Alaska. Presented at Pacific Seabird Group Meeting, 15 December 1978.

Connors, P.G. Alaskan coastal oil development: impacts on arctic shorebird populations. Presented at Northern Chapter, Cooper Ornithological Society Meeting, 11 January 1979.

Connors, P.G. and S. Gellman. Red Phalarope responses to thin oil films in foraging experiments. Presented at Pacific Seabird Group Meeting, 25 January 1980.

Smith, K.G., P.G. Connors, and C.S. Connors. Post-breeding habitat selection of birds at Barrow, Alaska. Presented at Cooper Ornithological Society Annual Meeting, 10 May 1981.

Connors, P.G., K.G. Smith, and J.P. Myers. Annual variation in breeding and post-breeding shorebird numbers in arctic Alaska. Presented at Cooper Ornithological Society Annual Meeting, 10 May 1981.

D. Summary of OCSEAP Shorebird studies published in Wader Study Group Bulletin 31:48-51.

of daylight with the level below 3 m, representing a marked increase in the availability of daylight feeding time. The subsequent increase in weight that began in March was accompanied by a body moult to breeding plumage and it preceded the eventual migration to Alaska in April.

Conclusions

Observations from the lower mainland of British Columbia did not support the hypothesis that the winter weight fluctuations of Dunlin at this locality are a response to stresses such as a depletion of food items, a decrease in food availability and a dependence on night feeding. The observations that weight decreases at a time when food appears to be more available, when the weather is milder and when there is more opportunity for daylight feeding, support a second hypothesis that weight reserves represent a response to the probability of poor weather during the winter.

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G.W. Kaiser and M. Gillingham, Canadian Wildlife Service - Pacific and Yukon Region, P.O. Box 340, Delta, British Columbia, Canada. V4K 3Y3.

DISTRIBUTION AND ECOLOGY OF SHOREBIRDS IN ALASKA'S COASTAL ZONE: A REVIEW OF STUDIES IN THE OUTER CONTINENTAL SHELF ENVIRONMENTAL ASSESSMENT PROGRAM

by Peter G. Connors

With the impetus of proposed oil exploration on the Alaska continental shelf, the U.S. Department of the Interior began in 1975 the Outer Continental Shelf Environmental Assessment Program (OCSEAP) to guide decisions concerning Alaskan oil development. OCSEAP, administered by the National Oceanic and Atmospheric Administration (NOAA) and the Bureau of Land Management (BLM), has since provided financial and logistic support for hundreds of researchers from universities, state and federal agencies, and independent research organizations. Recognizing that shorebirds figure among the most prominent animal groups potentially affected by coastal oil development, OCSEAP has encouraged studies of the distribution and ecology of shorebirds at a variety of sites in coastal Alaska. To alert workers unfamiliar with OCSEAP to the kinds of information being developed within the program, I shall review below the projects most involved with the coastal shorebird research.

Before 1975, much shorebird work had been completed near Barrow by Pitelka and his coworkers and several studies added information at other coastal sites, but emphasis was on nesting periods and habitats, rather than on shoreline activities. Non-OCSEAP research has continued at several sites in recent years (e.g. Myers, J.P. and F.A. Pitelka, 1980. Seasonal abundance and habitat use patterns of shorebirds at two sites in northern Alaska. Wader Study Group Bulletin 29: 28-30).

The net result of these five years of OCSEAP-sponsored shorebird research has been a dramatic expansion in our understanding of migration routes, breeding distributions, habitat dependences, and susceptibilities to development of shorebirds along the coast of Alaska. We now know the breeding shorebird communities at a series of coastal sites from the Canadian border west and south to Nelson Lagoon (Figure 1), the timing of movements by migrants through these areas, and the seasonal patterns in habitat use by common species at particular sites. Several areas - among them the Copper River Delta, Nelson Lagoon and Point Barrow - support large concentrations of migrating shorebirds. We have accumulated information on the trophic relationships of many of the common species. And we now have a fairly complete picture of the dependence of many species on shoreline areas, particularly during post-breeding periods, to balance the more extensive information available from the breeding season. These data should allow us to predict the timing and intensity of bird use for other sites, to integrate these predictions with OCSEAP research on other trophic levels and on physical processes important to causing or dispersing oil pollution in arctic coastal areas, and, ultimately, to synthesize these diverse sets of information into predictions on how developing Alaska's petroleum resources may affect shorebird populations.

Still, Alaska's coastline is extensive and the ecological processes involved are complex. Basic distributional data continue to be needed because many areas of the Alaskan coast have been visited briefly, if at all. More information about trophic relationships is needed. And most critically, we need to examine how well patterns in use predict patterns in dependence. This will hinge upon a number of factors specific to shorebirds and oil - especially the behavioural responses of birds to oil slicks - and on issues arising in shorebird population biology as a whole, particularly the timing and mechanisms of population regulation. We lack critical understanding of the causes and effects of resource variability, both on breeding grounds, where productivity is determined, and in littoral habitats, where survival and migration success may be set. We have only the most general notions about how flexible birds are in responding to patterns in resource or environmental variability. Faced with locally depressed resources, or food made unavailable by an oil slick, will individuals respond by breeding elsewhere? Can they migrate successfully using alternate staging areas?

As we move from site-specific questions to a larger area view, our understanding decreases. What are the relationships on a community level over wide areas of the Alaskan arctic and points east and west? How are regional differences in shorebird communities related to available habitats or to migration routes? How far inland can shorebird populations be affected by coastal disturbances? How much may the success of birds nesting in Canada, Siberia or Alaska depend upon conditions in these other areas? Our knowledge of migration routes and winter areas of local arctic breeding populations of most species is very limited and generally inadequate to predict the effects of disturbances on populations elsewhere.

Have these applied studies - with practical goals in environmental management - stimulated interest in basic issues? Of course they have! Basic questions of shorebird biology have been raised or answered in all of the principal studies

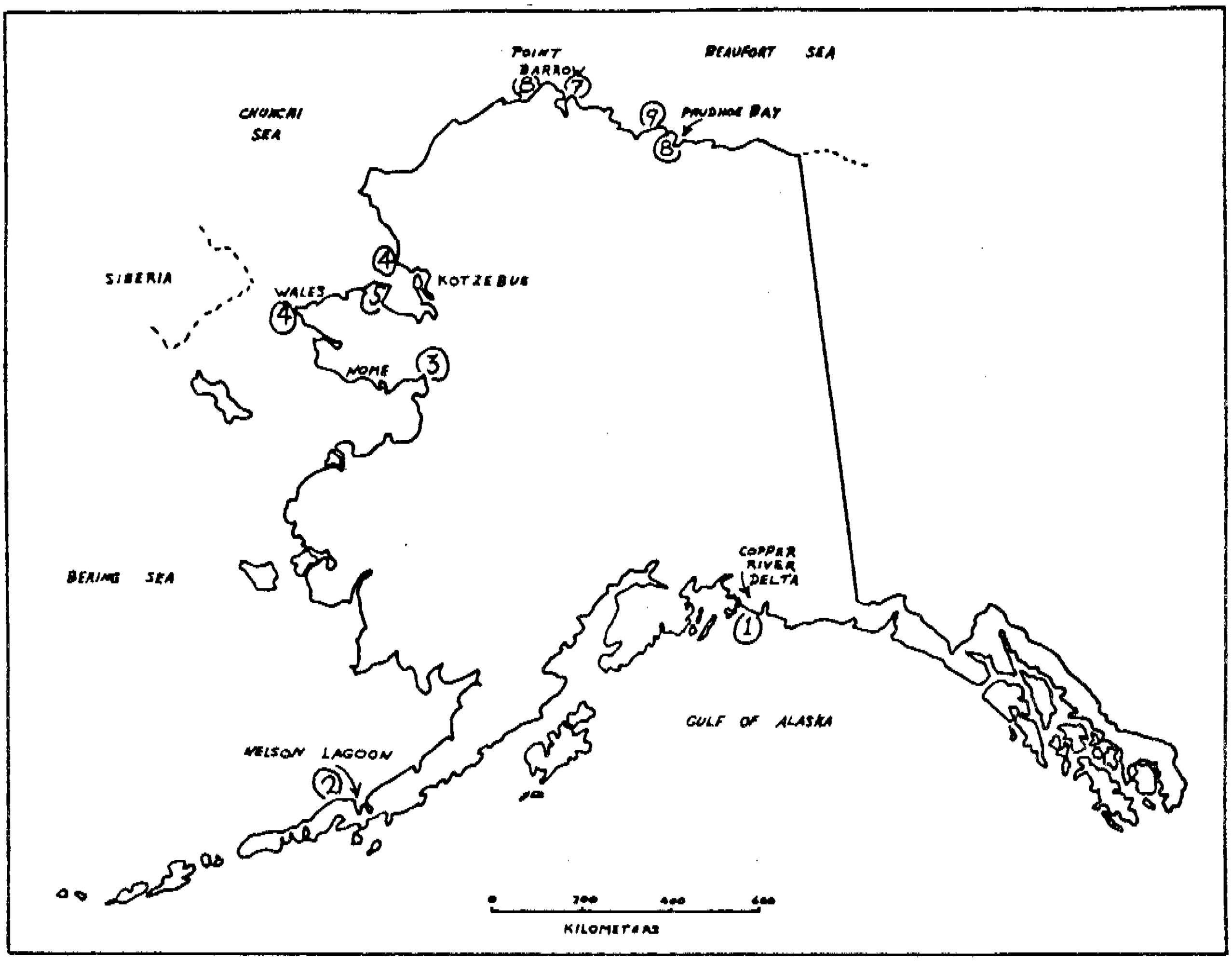

Figure 1. Map of Alaska, showing locations of OCSEAP shorebird study sites. Numbers refer to text.

listed below, in areas of energetics, migration dynamics, resource use strategies, and in topics less central to the study objectives. I am most familiar with the peripheral questions emerging from my own work. What is the relationship between breeding populations of the two races of American Golden Plover, Pluvialis dominica dominica and P. d. fulva, in the extensive Alaskan coastal area where they are sympatric? Is an observed correlation between shoreline foraging distribution of phalaropes and wind direction in relation to the shoreline mediated through effects on plankton distribution, heat loss energetics, or prey visibility and capture dynamics? At a site where Western Sandpipers Calidris mauri and Semipalmated Sandpipers C. pusilla both nest in high densities, do their use of resources overlap? Apparently they do, and as competition theory would predict, interspecific aggression is much more common than among other sympatric Calidris species which overlap less in resource use.

OCSEAP, primarily through the efforts of a few key scientist-administrators within the program, has repeatedly shown an appreciation of the practical importance of shorebird research in evaluating impacts of coastal oil development in arctic and subarctic areas as well as the fundamental interest to shorebird biologists and other scientists of questions raised here. It falls on the hopeful investigator to propose studies which will provide answers or clear guidelines for administrators who must make environmental-economic decisions, while at the same time contributing to our general understanding of shorebirds and their environment.

List of OCSEAP shorebird studies

The accompanying map of Alaska (Figure 1) shows the major shorebird study sites described below. Some studies have been single season projects; others are continuing. The location and sequence of projects has been governed partly by the schedule of leasing proposed for different coastal sections. I list projects here by region, moving clockwise around the Alaskan coast. Government reports to the contracting agency are listed in abbreviated form, as follows: the series entitled Environmental Assessment of the Alaskan Continental Shelf (Outer Continental Shelf Environmental Assessment Program, National Oceanic and Atmospheric Administration, Boulder, Colorado 80303, U.S.A.) is referred to as E.A.A.C.S.

I. Gulf of Alaska

1. Nutritional significance of the Copper River-Bering River intertidal system to spring migrating shorebirds breeding in Western Alaska. Principal Investigators: Stanley E. Senner, George C. West, David W. Norton, University of Alaska, Fairbanks, Alaska.

During a brief period in spring migration the delta system of these two rivers supports virtually the entire western Alaska breeding populations of Western Sandpiper Calidris mauri and Dunlin C. alpina. Few other sites are available for northward migrating sandpipers in southern Alaska. Senner et al. established the critical importance of this stopover in replenishing fat reserves in migrating Dunlins with censuses, marking and collection of birds for analysis of stomach contents, lipid and calcium levels. Western Sandpipers showed less weight gain on the delta system, and apparently stop at another site soon after their departure from this system. The researchers also examined migration dynamics of these species along the entire west coast of North America, based partly on comparative analysis of collected birds from other regions during migration.

Publications:

Senner, S.E. 1977. E.A.A.C.S. Annual Reports, vol. 4: 576-592.

Senner, S.E. 1977. The ecology of Western Sandpipers and Dunlins during spring migration through the Copper-Bering River delta system, Alaska. Thesis, University of Alaska, Fairbanks. 108pp.

Senner, S.E. and Norton, D.W. 1977. Shorebirds and oil development in the Copper River Delta area, Alaska. In D.W. Norton, ed., Science in Alaska, Proc. 27th Alaska Sci. Conf., Fairbanks.

Senner, S.E. and West, G.C. 1978. E.A.A.C.S. Annual Reports, vol. 3: 877-908.

Senner, S.E. 1979. An evaluation of the Copper River Delta as a critical habitat for migrating shorebirds. Studies in Avian Biology 2: 131-146.

II. Bering Sea

2. Avifaunal assessment of Nelson Lagoon, Port Moller and Herendeen Bay, Alaska. Robert E. Gill, U.S. Fish and Wildlife Service, Anchorage, Alaska.

Using aerial and ground transect censusing, Gill and several coworkers documented heavy seasonal use of this lagoon system on the Alaska Peninsula by several species of shorebirds. Few birds visit the site in spring, but total populations on Nelson Lagoon reached an average of 60,000 shorebirds during fall migration in the two years of study. Peak numbers of 50,000 Dunlins, 15,000 Western Sandpipers and 8,000 Bar-tailed Godwits Limosa lapponica were recorded, suggesting Nelson Lagoon is a major fall staging area for these species. Gill et al. compared shorebird use of different habitat areas within Nelson Lagoon, conducted food resource measurements and trophic studies, and contrasted this estuary with others in the area. Extensive banding and marking (2,400 shorebirds in 1977) provided data to discuss local movements, turnover rates and dispersal and migration strategies of the most common species.

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Gill, R.E., Jorgensen, P.D., De Gange, A.R. and Kust, P. 1977. E.A.A.C.S. Annual Reports, vol. 4: 594-632.

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Gill, R.E. and Jorgensen, P.D. 1979. A preliminary assessment of timing and migration of shorebirds along the North Central Alaska Peninsula. Studies in Avian Biology 2: 113-124.

3. Avian community ecology of the Akulik-Inglutalik River delta, Norton Bay, Alaska. Gerald F. Shields, Leaonard J. Peyton, Univ. of Alaska, Fairbanks, Alaska.

During two breeding seasons, Shields and Peyton studied avian nesting productivity on the delta and migratory use of mudflats and other delta habitats by all bird species. They banded about 800 shorebirds. Their work records the seasonal movements of shorebirds and supplies information on habitat use for an estuary from a little-known section of Alaska's coast.

Publication:

Shields, G.F. and Peyton, L.J. 1979. E.A.A.C.S. Final Reports, vol. 5: 608-710.

III. Chukchi Sea

4. Shorebird dependence on arctic littoral habitats. Peter G. Connors, Bodega Marine Laboratory, University of California, Bodega Bay, California.

This study examined littoral zone use by all shorebird species along the arctic coasts of the Chukchi and Beaufort seas. Regular censusing throughout the summer season of fixed transects in tundra and shoreline habitats provided seasonal habitat use patterns, principally at two sites in the southern Chukchi area: Wales, at Bering Strait, and near Cape Krusenstern. Supplemented by trophic studies and by wider area censuses, Connors and coworkers used these data to assess the relative importance of different coastal habitats and sites and the relative susceptibility of species to oil development impacts.

Mudflats and saltmarshes of northern Seward Peninsula and Kotzebue Sound supported much higher densities of migrant shorebirds than did nearby tundra nesting areas. Habitat use, and therefore oil susceptibility, differed for some species between this area and the Beaufort coast, where similar data were gathered (see below). Evidence suggests that juveniles of two species born in Siberia (Sharp-tailed Sandpiper Calidris acuminata and Pacific Golden Plover Pluvialis dominica fulva) regularly cross Bering Strait in late summer to feed in North American saltmarshes before migrating southwestward to wintering areas in Asia and the Pacific.

Publications:

Connors, P.G. and Risebrough, R.W. 1978. E.A.A.C.S. Annual Reports, vol. 2: 84-166, and 1979, vol. 1: 271-329.

Connors, P.G. and Connors, C.S. 1978. Wet coastal tundra I (breeding birds census, Cape Krusenstern, Alaska). American Birds 32: 118.

Hirsch, K. and Woodby, D. 1978. Wet coastal tundra II (breeding bird census, Wales, Alaska). American Birds 32: 118-119.

Connors, P.G., Woodby, D., and Connors, C.S. 1979. Wet coastal tundra I (breeding bird census, Cape Krusenstern, Alaska). American Birds 33: 102.

5. Avian community ecology at two sites on Espenberg Peninsula in Kotzebue Sound, Alaska. Peter G. Mickelson, University of Alaska, Fairbanks, Alaska.

Cape Espenberg contains a large area of coastal wet tundra supporting high densities of nesting waterfowl and shorebirds, and is bordered by sandy beach and protected mudflat. Mickelson and his coworkers spent two complete summers and part of a third at the site, measuring nest densities, clutch sizes, habitat use, phenology, and predation rates. They recorded 85 species; two waterfowl (Pintail Anas acuta and Common Eider Somateria mollissima) and four shorebirds (Dunlin, Western Sandpiper, Semipalmated Sandpiper and Northern Phalarope Phalaropus lobatus) occurred in peak numbers in the thousands.

The study also recorded aerial surveys of southern Kotzebue Sound and measured use of shoreline habitats at Cape Espenberg. Of 34 nesting species, 13 were dependent on marine food sources during part or all of the nesting and brood rearing season.

Publication:

Schamel, D., Tracy, D., Mickelson, P.G. and Seguin, A. 1979. E.A.A.C.S. Final Reports, vol. 5: 289-607.

6. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. George J. Divoky, Point Reyes Bird Observatory, Stinson Beach, California.

With a team of field workers, Divoky used ships, airplanes and an army of foot soldiers to survey extensive areas of the Beaufort and Chukchi coasts during summer 1976. Results include average densities by month of bird species or species groups in different coastal habitats. Data are most complete for seabird breeding densities of loons, waterfowl and larids along the coast. For some coastal areas, the observations made during visits by these hardy biologists remain the only information we have of shorebird densities and habitat associations.

Publications:

Divoky, G.J. 1978. E.A.A.C.S. Annual Reports, vol. 1: 482-569, and 1979, vol. 1: 330-599.

7. The distribution, abundance and feeding ecology of birds associated with pack ice. George J. Divoky, Point Reyes Bird Observatory, Stinson Beach, California.

This project has had two foci. Firstly, seabird numbers have been sampled in a series of ship cruises in the Bering, Chukchi and Beaufort seas. Most of the work has applied to seabirds, but Divoky and his team present densities of phalaropes at sea in several areas and have gathered shoreline transect data through several seasons for phalaropes and other shorebirds at Cooper Island. Secondly, this project uses a regular program of nearshore plankton sampling to provide information on annual variation of this important parameter for comparison with shorebird densities.

Publications:

Divoky, G.J. 1976. E.A.A.C.S. Annual Reports, vol. 3: 53-106; 1977, vol. 2: 525-573; 1978, vol. 2: 167-509; and 1979, vol. 1: 330-599.

8. Shorebird dependence on arctic littoral habitats. Peter G. Connors, Bodega Marine Laboratory, University of California, Bodega Bay, California.

This study of shorebird habitat paritioning and seasonality, migratory movements and trophic dependences in littoral areas of the arctic coast measured bird densities on shoreline transects at Point Barrow for four summers and at several other sites during brief visits. Contrasted with tundra transect densities collected by J.P. Myers and F.A. Pitelka, the data defined a marked post-breeding shift of most shorebird species from tundra to littoral habitats; compared with similar data from southern Chukchi sites (see 4 above) they showed regional and species differences in seasonal habitat use patterns. These led to ratings of relative susceptibility of each species to oil development effects. For example, concentrations of juvenile phalaropes forage in shallow water on nearshore zooplankton, accumulating fat prior to southward migration and are therefore sensitive to nearshore changes arising from oil development. Dunlin and Long-billed Dowitchers Limnodromus scolopaceus, feeding primarily on dipteran larvae, also shift to littoral habitats in late summer, but to a lesser extent. Foraging experiments with captive Red Phalaropes Phalaropus fulicarius suggested rapid learning by naive birds after brief contact with thin oil films, and a subsequent avoidance of oil (Connors and Gelman, in prep.).

A single season of transect data comparing shorebird use of disturbed and undisturbed habitats in the Prudhoe Bay oilfield led to predictions of the effects of oil development on breeding and post-breeding shorebird populations. Some disturbances (dust effects, habitat destruction) may reduce densities, while others (artificial gravel pits, drainage changes) may increase local bird use.

Publications:

Connors, P.G. and Risebrough, R.W. 1976. E.A.A.C.S. Annual Reports, vol. 2: 401-456; 1977, vol. 3: 402-524; 1978, vol. 2: 84-166; 1979, vol 1: 271-329; and 1980, in press.

Connors, P.G., Myers, J.P. and Pitelka, F.A. 1979. Seasonal habitat use by arctic Alaskan shorebirds. Studies in Avian Biology 2: 101-111.

9. Beaufort Sea barrier island-lagoon ecological process studies. Avian ecology in Simpson Lagoon, 1977. S.R. Johnson, LGL Limited, 10110-124, Edmonton, Alberta, Canada.

Red and Northern phalaropes were the most common shorebirds encountered on transects monitored as part of a multidisciplinary study of a coastal lagoon ecosystem. Shorebird densities averaged higher on the oceanside island beach than on the lagoonside beach or mainland beach, with most phalaropes foraging in very shallow water. In a sample of 46 phalarope stomachs, principal prey items were copepods, amphipods and mysids. In spite of high densities of migrating phalaropes along the lagoon shorelines in August, Johnson estimated the energy available in mysids and amphipods was more than an order of magnitude in excess of phalarope energy requirements.

Publication:

Johnson, S.R. 1978. Beaufort Sea Barrier Island-Lagoon Ecological Process Studies. E.A.A.C.S. Section 2: 1-112.

Four other studies have contributed primarily distributional data for phalaropes at sea or for these and other shorebirds on barrier islands and mainland shores.

10. Seasonal distribution and abundance of marine birds. Calvin J. Lensink, James C. Bartonek, Craig S. Harrison, U.S. Fish and Wildlife Service, Anchorage, Alaska.

11. Identification, documentation and delineation of coastal migratory bird habitat in Alaska. Paul D. Arneson, Alaska Department of Fish and Game, Anchorage, Alaska.

12. Birds of coastal habitats on the south shore of the Seward Peninsula, Alaska. William H. Drury, College of the Atlantic, Bar Harbor, Maine.

13. Avifaunal utilization of the offshore island area near Prudhoe Bay, Alaska. Douglas Schamel, George Mueller, Institute of Marine Science, University of Alaska, Fairbanks, Alaska.

Peter G. Connors, Bodega Marine Laboratory, University of California, Bodega Bay, California 94923, U.S.A.

Annual Report

Contract #: 02-7-022-35410
Research Unit: 196
Number of pages: 17

The Distribution, Abundance, and Feeding Ecology of Birds Associated with Pack Ice

George J. Divoky
Principal Investigator

Report prepared by:
George J. Divoky
Douglas A. Woodby - Norton Sound Project Leader

Point Reyes Bird Observatory
1 April 1981

R.U. 196 is currently completing analysis of all Beaufort Sea data obtained by it and R.U. 3/4 since 1975. The analyses are being done in three sections that are based on three principal marine zones of the Beaufort. These are:

Palagic - 10-fathom curve to shelfbreak. Observations made from icebreakers.

Inshore - Inside 10-fathom curve but not including beaches. Observations made from ALUMIAK and NATCHIK.

Littoral - Beaches including water and land habitats adjacent to beaches. Observations made by persons walking on shore.

In addition, the Beaufort has been divided into five sections between Point Barrow and Demarcation Point based on oceanography, coastal land forms, and other considerations. The arrangement of three marine zones and five geographic sections stratifies our data into 15 areas. Data is being analyzed to determine what factors are most important in causing the differences in distribution and abundance of birds between and within these fifteen areas. It appears that three systems are the principal food sources for birds in the Beaufort, and the importance of these systems in any one area has much to do with determining abundance. These systems are listed in Table A.

Computer print-outs from the Data Projects Group at the University of Rhode Island have been received and are currently being analyzed. A final report will be completed later this year.

Table A. The characteristics of the three systems thought to play the primary roles in determining seabird distribution and abundance in the Beaufort Sea

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I. System: Bering Sea Intrusion

Location: Offshore. Most pronounced northeast of Pt. Barrow, decreasing in importance to the east but still discernible in areas north of Harrison Bay.

Description: Bering Sea water (as warm as 10°C) that has moved north through Chukchi and advected into Beaufort contains zooplankton from the Bering Sea which can provide food for Beaufort seabirds directly, as well as possibly providing phytoplankton and zooplankton for Beaufort sea zooplankton that are then consumed by birds.

Evidence for effect on birds: Offshore areas north of Pt. Barrow to Cape Halkett have the highest pelagic bird densities in the Alaskan Beaufort and a strong west-to-east gradient. The effect is strongest on surface feeding zooplankton consumers. There appears to be no evidence of fish densities being higher in the Intrusion either through sub-arctic fish species associated with the Intrusion or arctic species feeding on the zooplankton in the Intrusion.

Prey species associated with system: *Thysannoessa* spp., copepods.

II. System: Under-Ice (or Ice Associated)

Location: Most highly developed on underside of multi-year ice. Location depends on locality of ice.

Description: Fish and zooplankton closely associated with underside of ice and deriving most of their energy from the in-ice phytoplankton bloom that occurs in spring.

Evidence for effect on birds: Primarily small-scale effects in both pelagic and nearshore areas that can concentrate birds near decomposing multi-year ice. No large-scale effects evident in Beaufort since no species are more abundant in or next to ice than they are in open water, pelagic, or nearshore areas. Apparently important food source in inshore areas for fall migrants.

Prey species associated with the system: Arctic Cod (*Boreogadus saida*), *Apherusa glacialis*, *Gammaracanthus loricatus*, copepods.

III. System: Inshore Epibenthic

Location: Inshore areas being most pronounced in lagoonal systems associated with river mouths.

Description: Detrital system that derives its energy from productivity occurring in nearshore ice and water as well as tundra produced peat.

Evidence for effect on seabirds: Diving species such as Oldsquaw, Loons, Eiders are most abundant nearshore and most concentrated in lagoonal areas associated with river mouths.

Prey species associated with system: *Gammarus*, *Beokisimus*, *Idotea*, *Mysis* spp., *Gammarus setosus*, *Onisimus glacialis*.

Report of Activities for RU 196 - Norton Sound Coastal Habitat Surveys, 1980

I. Introduction

A. General Nature and Scope:

Surveys of birds in coastal habitats of Norton Sound, not including the major seabird colonies studied previously by William Drury (RU 237).[1]

B. Objective:

To assess the seasonal dependency of birds on coastal habitats.

II. Study Area:

The coastal strip from Cape Prince of Wales to Pastol Bay, including the northeast part of the Yukon delta.

III. Methods

A. Field work

1. Land Surveys

Fifteen sites were chosen for land-based surveys to sample a well distributed and representative array of habitats around Norton Sound (Figure 1). Most of these have wetland qualities such as lagoon systems, river mouths and deltas, or low-lying, marshy tundra. Eight observers walked a total of 1600 kilometers in these 15 areas in 1980 (Table 1) censusing birds along transects averaging 1 to 2 kilometers long. These transects were 50 meters wide on beaches, including 500 meters of nearshore waters, and were 100 meters wide on the tundra.

Thirteen habitats were recognized on land (Table 2). Sampling effort in these was based on access and on an estimated variability of bird numbers in each. Variability increases with the magnitude of bird use, so the more productive habitats, such as wet tundra, received greater effort relative to how much was available. Data gathered provide information on bird species per kilometer of each habitat in each area.

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[1] Drury, W.H., C. Ramsdell, J.B. French, Jr. 1980. Ecological studies in the Bering Strait region. Final report to Nat'l. Ocn. Atmos. Admin., OCSEAP. 308 p.

2. Aerial surveys

Coastal surveys were flown at least once each month to census the shoreline from Wales to the Yukon delta (Table 3). This shoreline is over 1000 km long and was divided into 15 physiographic sections to aid data analysis and interpretation (Figure 2). In addition, a single flight was made to St. Lawrence Is. on 18 September. Eleven categories of coastal habitats were censused from the air (Table 4).

Most of the aeial surveys were flown from Nome to Koyuk on the north shore of the Sound. The least effort was spent from Unalakleet to the Yukon delta due to logistical problems of censusing long distances from Nome.

Census altitudes averaged 30m and transect width was roughly 600m. Tracklines were usually 100m seaward of the shoreline, except along spits where the plane often flew directly over the center of the spit. Air speed was variable but averaged 200 km per hour.

Only the larger, more conspicuous birds, such as ducks, geese, gulls, terns, and cranes were identified adequately from the air. Many shorebirds were counted but not identified to species, while the smallest sandpipers were often not seen. Passerines other than Ravens were ignored. Thus, the aerial survey data is best used to describe the seasonal habitat use by the more visible bird species. These censuses provide information on birds per linear kilometer of each habitat in each coastal section.

3. Aerial transects over wetlands

Productive wetlands were censused from the air in 1980 with a method used previously by W. Drury.[1] This employed census techniques almost identical to those for other habitats, yet the air speed was slower (160 km per hour) and the density of birds is computed as a number of birds per minute of flight. A slower speed was necessary because birds were more concentrated in wetlands, and densites were based on time because tracklines over wetlands rarely followed shorelines and overland distances were difficult to measure.

Ninety-two of these wetland transects were flown in 1980 (Table 5) at sites shown in Figure 3. Elapsed time for these transects ranged from 2 to 14 minutes. A synopsis of bird densities in wetlands for the entire 1980 field season for all bird species is given in Table 6. These data are indices of abundance, expressed as birds per minute, and are ranked to show which areas have the greatest bird concentrations.

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[1] Drury, W.H., and B.B. Steele. 1977. Birds of coastal habitats on the south shore of the Seward Penisula, Alaska. In: Environmental Asses. of the Alaskan Cont. Shelf. Annual Repts. of Principal Investigators. Nat'l. Ocn. Atmos. Admin., OCSEAP, Vol. III:1-178.

B. Office work

1. Data processing

All numerical information gathered during the 1980 field season has been entered on magnetic tape and is now being processed. The initial analyses to be made are of:

a) Average densities for aerial and land surveys. This will be by species and species groups for each habitat in each area on a monthly basis.

b) Average number of birds per minute for aerial surveys of wetlands, by species and species groups for each area on a monthly basis.

2. Data products

A final report on bird use of coastal habitats in Norton Sound will be completed in December, 1981.

Figure 1. Land survey sites in Norton Sound, 1980.

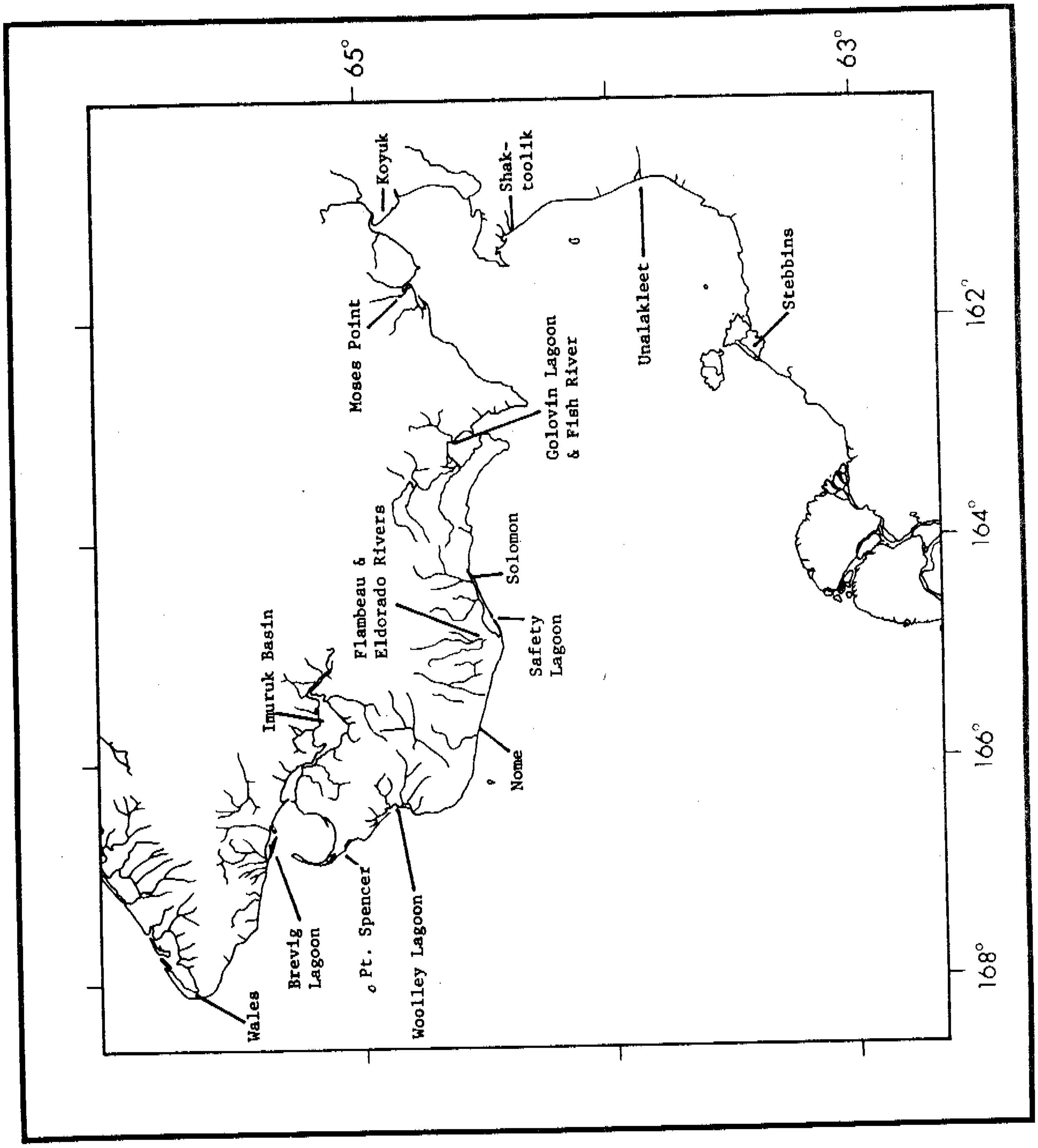


Table 1. Norton Sound land surveys, 1980.

Area	Dates	km of transects	Observers
Wales	May 17-20	0	Woodby (migrant watch)
	June 21-23	5.9	Hausler, Woodby
	July 25-28	2.9	Woodby
Brevig Lagoon	July 1-7	62.4	Blick, Drury
	August 2-8	68.9	Drury, Warheit
Imuruk Basin	June 26- July 1	52.5	Hausler, Warheit, Woodby
Pt. Spencer	May 29- June 3	49.2	Blackham, Weisel
	July 3-9	48.4	Blackham, Chance
	August 2-9	50.8	Blick, Chance
Woolley Lagoon	May 29-30	8.5	Chance, Woodby
	June 8	9.8	Blackham, Blick, Chance
	July 9	10.5	Drury, Woodby
	August 2	10.8	Warheit
	September 9	9.5	Blackham, Warheit, Weisel
Nome	weekly from May 12- Sept. 25	124.7	all personnel
Safety Lagoon	weekly from May 14- Sept. 27	273.2	all personnel
Solomon	June 15	3.0	Blackham, Blick
	July 2	3.0	Hausler, Woodby
	July 19	3.0	Blick, Drury
	August 20	3.0	Drury. Warheit
	August 30	3.0	Chance, Warheit
	September 21	3.0	Hausler, Woodby
Flambeau and Eldorado Rivers	June 15	9.3	Drury, Weisel
	July 11	11.3	Weisel, Woodby
	August 12	11.3	Blick, Woodby
	September 4	11.3	Blackham, Blick, Warheit
Fish River and Golovin Lagoon	June 7-11	42.5	Drury, Hausler, Woodby
	July 11-16	67.1	Blick, Drury
	August 13-18	45.5	Chance, Drury
	September 6-10	38.4	Hausler, Woodby

Table 1 continued.

Area	Dates	km of transects	Observers
Moses Point	June 24-30	35.9	Blick, Chance
	July 23-28	45.3	Blick, Drury
	August 22-26	33.3	Chance, Weisel
	September 10-16	35.8	Blackham, Blick, Weisel
Koyuk	June 14-17	37.3	Hausler, Woodby
	July 16-19	32.0	Chance, Woodby
	August 26-29	19.3	Chance, Weisel
Shaktoolik	June 9-13	52.7	Blackham, Blick, Chance
	July 15-16	20.4	Chance, Woodby
Unalakleet	May 15-22	25.9	Chance, Weisel
	July 3-9	31.9	Warheit, Weisel
	August 6-11	35.4	Weisel, Woodby
Stebbins	June 18-23	45.6	Blackham, Drury, Weisel
	July 15-21	61.6	Blackham, Warheit, Weisel
	August 26-29	44.9	Blackham, Warheit, Woodby

Table 2. Coastal habitats censused on land, Norton Sound, 1980.

Habitat type	Kilometers walked
1. Disturbed beach	59.4
2. Lagoon beach with moist tundra	25.1
3. Lagoon beach on a spit	174.4
4. Lagoon beach with wet tundra	20.6
5. Moist tundra	208.9
6. Moist and wet tundra (mixture)	33.9
7. River mouth	19.0
8. Sea beach with cliffs	24.3
9. Sea beach with moist tundra	82.3
10. Sea beach on a spit	220.0
11. Spit	104.0
12. Sea beach with wet tundra	52.1
13. Wet tundra	575.6
Total =	1600.0

Table 3. Norton Sound aerial surveys, 1980.

Date	Areas															Observers
	A_1	A_2	A_3	A_4	B_1	B_2	C	D_1	D_2	E_1	E_2	F_1	F_2	G_1	G_2	
May 8						X	X	X		X		X	X		X	Woodby
May 15										X		X				Chance, Weisel
May 22						X	X	X		X	X	X				Chance, Weisel
May 26	X	X	X	X	X											Blackham, Weisel, Woodby
May 31						X	X	X	X	X	X	X	X	X		Chance, Woodby
June 13							X			X	X	X				Blackham, Blick, Chance
June 18												X	X	X	X	Blick, Chance
June 30	X	X	X	X	X											Blackham, Drury, Weisel
July 24						X	X	X	X	X	X	X				Warheit, Weisel, Woodby
July 25	X	X			X											Blackham, Chance, Woodby
August 15						X	X	X	X	X	X	X	X	X		Warheit, Woodby
August 16	X	X	X	X	X											Blackham, Weisel
August 23	X						X									Blackham, Warheit, Woodby

Table 3 continued.

Date	Areas															Observers
	A_1	A_2	A_3	A_4	B_1	B_2	C	D_1	D_2	E_1	E_2	F_1	F_2	G_1	G_2	
Sept. 2	X	X	X	X	X											Chance, Warheit, Woodby
Sept. 6						X	X	X	X	X	X	X	X	X		Blackham, Blick, Weisel
Sept. 10							X									Hausler, Woodby
Sept. 17	X	X			X											Hausler, Woodby
Sept. 23							X	X	X	X	X	X	X	X		Blackham, Hausler, Weisel
October 27						X	X	X		X						Woodby

Figure 2. Coastal sections in Norton Sound.

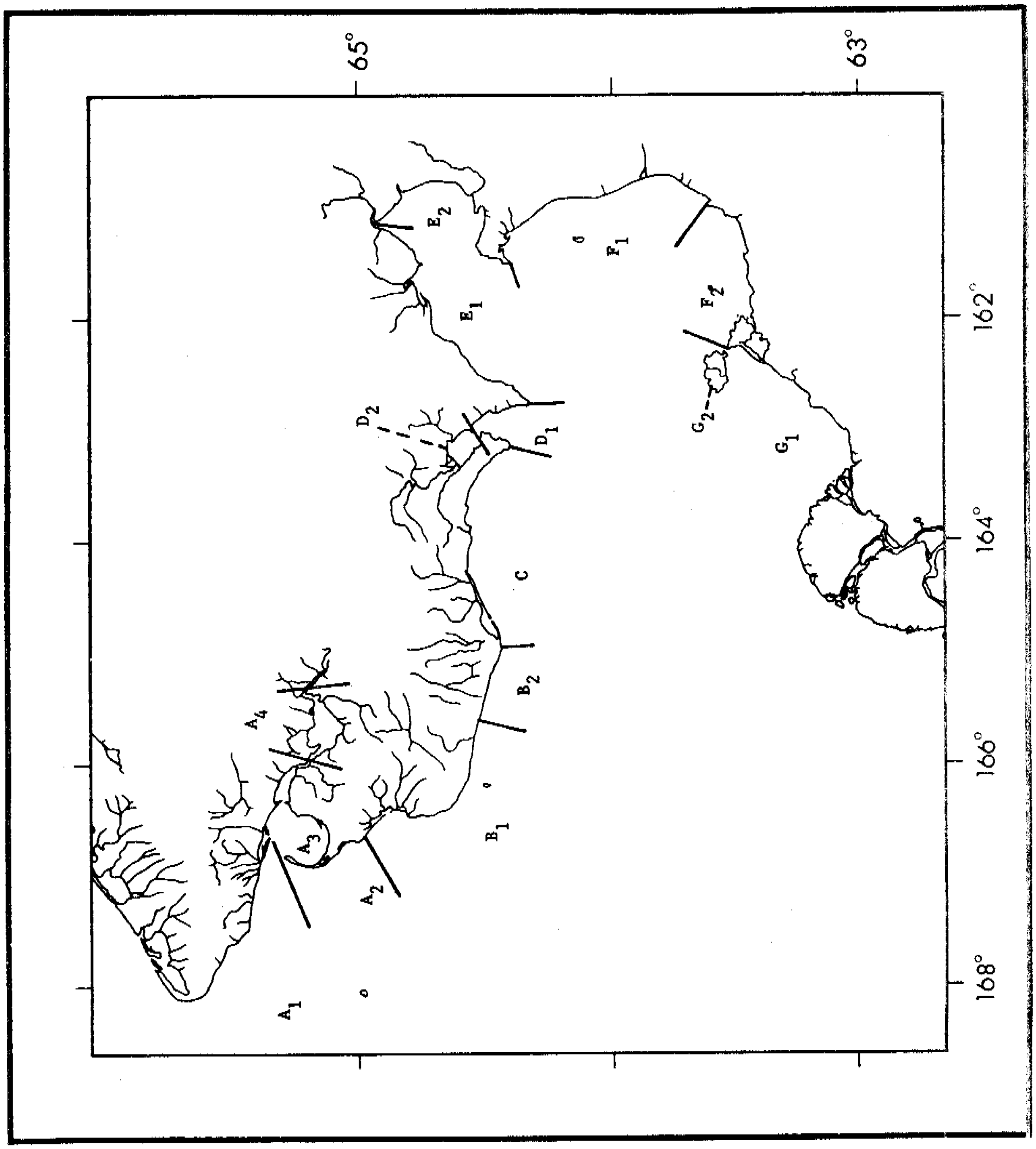


Table 4. Coastal habitats surveyed by air in Norton Sound, 1980.

Habitat type	Kilometers flown
1. Lagoon beach with cliffs	21.8
2. Lagoon beach with moist tundra	905.7
3. Lagoon beach on a spit	679.2
4. Lagoon beach with wet tundra	298.3
5. River delta	364.2
6. River mouth	60.4
7. Sea beach with cliffs	828.1
8. Ice edge	366.9
9. Sea beach with moist tundra	2666.2
10. Sea beach on a spit	883.5
11. Sea beach with wet tundra	574.9
Total=	7649.2

Table 5. Wetland aerial survey sites, Norton Sound, 1980

Date	Imuruk Basin	Port Clarence	Cape Woolley	Flambeau River	Safety Lagoon	Fish River	Moses Point	Koyuk River	Shaktoolik	Unalakleet	Stebbins	Stuart Island	Yukon Delta	Shishmaref Coast	Observers
May 31					X	X		X	X		X				Chance, Woodby
June 7						X									Drury, Woodby
June 9					X	X	X	X	X						Blackham, Chance
June 11					X	X									Drury, Woodby
June 13					X		X	X							Blick, Chance
June 18									X		X	X	X		Blick, Chance
June 30	X	X													Drury, Weisel
July 19					X	X	X	X							Chance, Woodby
July 24			X	X	X	X	X	X							Warheit, Weisel
July 25				X											Blackham, Chance
July 28					X	X	X								Blick, Drury
August 15				X	X	X	X	X	X		X		X		Warheit, Woodby
August 16	X	X													Blackham, Weisel
August 23		X		X	X	X	X	X						X	Blackham, Woodby
Sept. 2	X	X													Warheit, Woodby
Sept. 3				X	X	X									Blackham, Weisel
Sept. 6						X	X	X	X	X	X	X	X		Blackham, Blick
Sept. 10				X	X	X									Hausler, Woodby
Sept. 16							X								Blick, Weisel
Sept. 17		X	X												Hausler, Woodby
Sept. 23				X	X	X	X	X	X		X	X	X		Blackham, Weisel
Sept. 29				X	X	X	X	X	X						Hausler, Woodby
October 27				X	X			X							Woodby

Figure 3. Wetland aerial survey sites, Norton Sound, 1980.

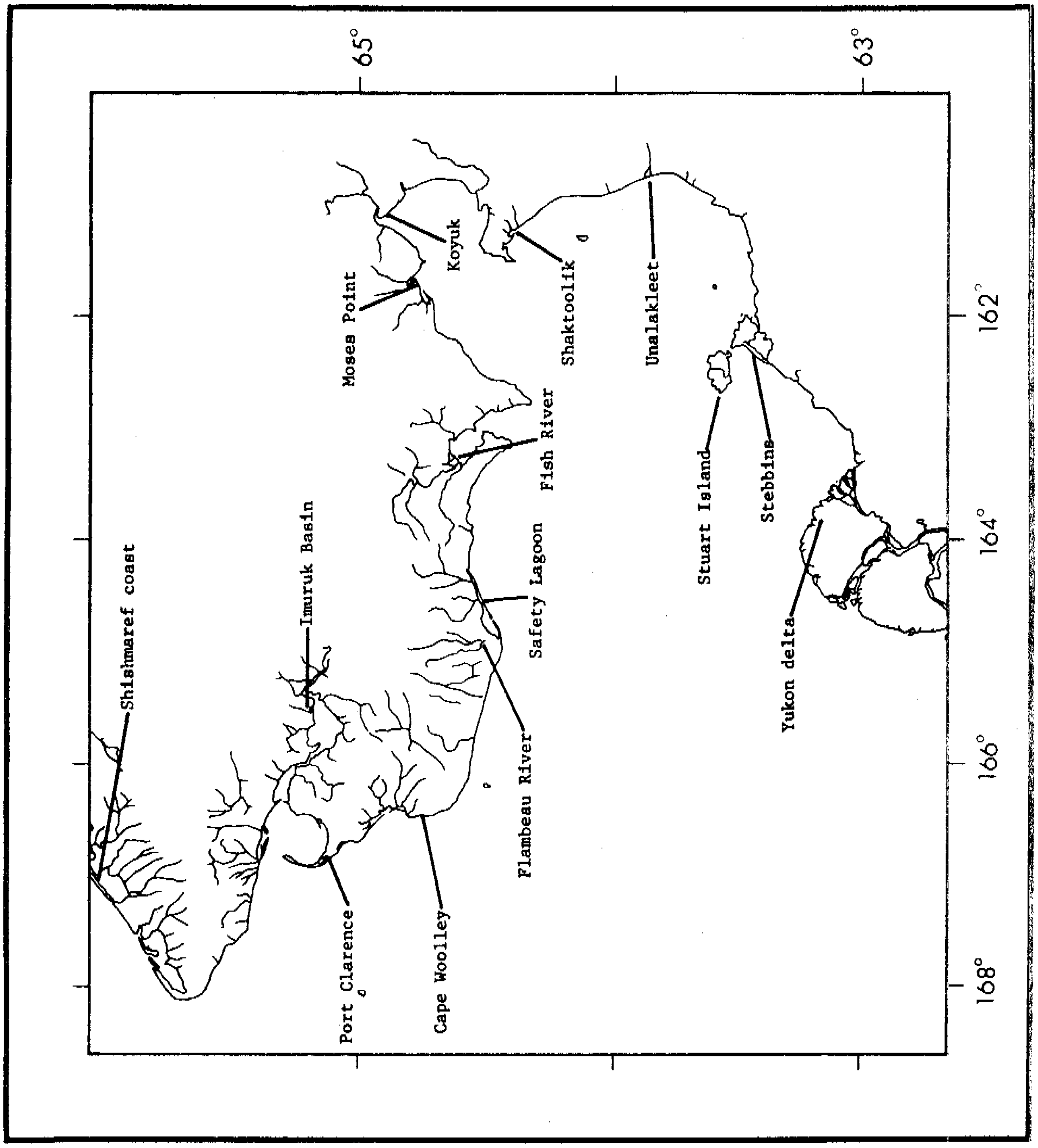


Table 6. Average densities of all birds on Norton Sound wetlands, May through October, 1980. Values are numbers of birds per minute of aerial survey.

Area	Birds per minute
Moses Point	108.1
Fish River/Golovin Lagoon	101.2
Koyuk River delta	65.4
Woolley Lagoon	55.1
Stebbins	48.3
Safety Lagoon	47.5
Flambeau and Eldorado Rivers	47.4
Port Clarence	36.7
Shishmaref coast	35.9
Stuart Island	34.8
Yukon delta (NE part)	29.1
Shaktoolik	25.8
Imuruk Basin	23.9
Unalakleet	17.3

UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON 98195

ANNUAL REPORT

STORM-PETRELS AS INDICATORS OF ENVIRONMENTAL CONDITIONS

Principal Investigator: P. Dee Boersma
Associate Professor

Research Unit Number: RU 598

Reporting Period: June 1, 1980 - June 1, 1981

Date: August 14, 1981

Institute for Environmental Studies, FM-12
University of Washington
Seattle, Washington 98195
(206) 543-1812

I. Abstract:

We are developing an early warning system using storm-petrels to reflect marine environmental quality. Storm-petrels and other Procellariiformes feed within a few centimeters of the ocean's surface where many pollutants, including oil, become concentrated. By determining the level of petroleum products in different water masses and in different regions, management can quantify the impact on ocean water quality of policy changes affecting oil transport or development. This approach is applicable to monitoring other pollutants as well. Knowledge of the normal variability of an ecosystem, and the potential impact of increases of fossil fuel hydrocarbons, is a necessary prerequisite for management to assess whether a perceived change is likely to be due to (a) human activity and (b) such activity will or will not be detrimental.

In the first year of funding, we found that storm-petrels and other Procellariiformes ingest fossil fuel hydrocarbons and that, as predicted, the more offshore feeders consume fewer petroleum products. The number of birds that ingest fossil fuel hydrocarbons increases significantly after a spill. Furthermore, the Cook Inlet and Northern Gulf of Alaska storm-petrels regularly consume petroleum products. As a result of continuing this study we expect to develop an inexpensive and reliable technique which could be used to monitor regional or global changes in petroleum products in the ocean due to energy development, transport, or human use.

II. Task objectives:

1. To determine if Fork-tailed Storm-Petrels are ingesting any human-produced hydrocarbons.
2. To determine the normal range and variability of stomach oils of Fork-tailed Storm-Petrels.
3. To determine the prey/food items of Fork-tailed Storm-Petrels.
4. To determine whether the food and reproductive parameters of Fork-tailed Storm-Petrels living within a few kilometers are similar.

Summary of Progress

Although our information is limited because we have been gathering these data for only one field season and do not know how variable these parameters may be, we have shown (1) that Fork-tailed Storm-Petrels do ingest fossil fuel hydrocarbons and that Fulmars and Leach's Storm-Petrels do as well; (2) we know that stomach oil varies considerably in color and composition, but that they remain stable as evidenced by thin-layer chromotography; (3) Fork-tailed Storm-Petrels have a varied diet, including five different types of crustaceans and at least one type of fish; and (4) food samples and growth rates of storm-petrels on different islands appear similar, suggesting they are foraging over a wide area.

> "Birds are a good ecological litmus paper. They sample so much of our habitat and environment; they have a high rate of metabolism; they cover wide areas; they drink the water and breathe the air; they truly sample life all over the planet. When something goes wrong with them--just as the canary's death told the miners to get the hell out of a mine --the birds are saying to us: Beware." (Russell Peterson 1980)

Introduction

Reproductive patterns of seabirds are known to reflect changes in the environment (Hutchinson 1950, Boersma 1978). Seabirds sample the ocean constantly, and consequently are useful indicators of pollutants such as DDT, trace metals and PCB's (Riseborough et al 1967, 1968; Vermeer and Peakall 1979). One group of seabirds, the Procellariiformes, have natural history traits that should make them regional monitors of offshore oceanic conditions. Procellariiformes feed in the top few centimeters of the ocean where they are likely to encounter marine pollutants. They have well-developed olfactory lobes (Barg 1971) and feed on fish, crustaceans and squid (Palmer 1962). Many species are attracted to natural slicks of fish and animal oils upon which they feed (Gill 1977, Wahl and Heinemann 1979, Hutchison and Wenzel 1980). They are also attracted to areas with unnatural slicks. For example, approximately 200 Wilson's Storm-Petrels (Oceanites oceanicus) were attracted to and fed in a slick of sulfuric acid-iron sulfate waste dumped from a barge off the coast of Delaware (Rowlett 1980).

Although the reproductive traits of seabirds are rather similar, selection has favored some unusual reproductive adaptations in Procellariiformes and in storm-petrels in particular, because they forage far from their breeding sites. For example, Fork-tailed Storm-Petrels (Oceanodroma furcata), which incubate their eggs more irregularly than any other seabirds, may abandon the eggs for seven consecutive days without the embryo dying (Boersma and Wheelwright 1979).

The growth of chicks is variable between years and reflects the availability of food (Boersma et al 1980). These types of reproductive behaviors are easily monitored and may be useful reflectors of environmental change. Furthermore, storm-petrels have long incubation and chick-rearing periods so they are tied to a breeding colony/area for almost four months--longer than most other seabirds. Thus, they can be used as a reflector of environmental conditions for a relatively long period.

Many seabirds are inshore foragers and are good mirrors of local conditions. However, only wide-ranging seabirds such as storm-petrels have the potential for becoming inexpensive and sensitive regional indicators.

Although Procellariiformes are offshore foragers, some are relatively more open ocean foragers than others. For example, Harris (1974) reports that fishermen do not encounter Leach's Storm-Petrels (Oceanodroma leucorhoa) closer than approximately 100 kilometers from shore. Data from Crossin (1974) show spatial differences in foraging: Leach's Storm-Petrels forage off the continental slope and Fork-tailed Storm-Petrels within 60 km offshore. By comparing food samples from species of Procellariiformes that forage in different water masses, off continental slope waters can be compared to relatively closer waters for fossil fuel hydrocarbons or other pollutants.

Five characteristics make Procellariiformes potentially more useful than other organisms or direct sampling techniques in monitoring ocean water quality. (1) They forage over a wide area and presumably act as integrators of the fish, crustaceans and pollutants in the region's surface waters. Homing experiments confirm flights of at least 600 km in three days for one species of storm-petrel (Billings 1968). Fossil fuel hydrocarbons were found in food samples from Procellariiformes collected near New Zealand (Lewis 1969) but not in ones collected in the Antarctic (Clarke and Prince 1976). (2) Oil from their food tends to accumulate, is digested slowly (Imber 1976) and regurgitated readily so it can be easily collected (Boersma 1980). The concentration and type of hydrocarbons, lipids and other compounds can be monitored directly by gathering regurgitated food samples. (3) Procellariiformes are one of the most abundant groups and breed near all tanker lanes and offshore oil and gas lease areas. (4) Their breeding biology has many parameters that appear to change in response to variations in oceanic conditions and can be easily measured. These include time of breeding, egg size, egg neglect, food, visitation frequency, growth rate, reproductive success and fledging weight. Eventually, by understanding the coupling of reproductive biology with human-induced environmental alterations, we may be able to detect changes long before their negative impacts become apparent. Such early warning systems are vital to allow management to mitigate potential damage to an area due to subtle environmental degradation.

The concentration of oil in the Pacific Ocean will rapidly increase because of increased transport of oil and oil and gas development on the offshore continental shelf. Approximately 35% of petroleum hydrocarbons entering the oceans in 1973 came from marine transportation (M'Gonigle and Zacher 1979). We know little about the current levels of oil pollution in the Pacific Ocean and its effect(s) on marine communities. Furthermore, crude oils contain trace metals such as nickel, vanadium and iron (Speers and Whitehead 1969) that may have adverse impacts on organisms. Aromatics are preferentially degraded from crude oils followed by branched-chain paraffins and straight-chain paraffins (Hansen 1975). Generally under natural conditions these reactions are estimated to be slow and tar balls may have residence time of one year (Myers and Gunnerson 1976). Thus, organisms near the water's surface are exposed to oil for long periods.

Near-surface measurements of hydrocarbons range from about 1 to 10 ppb with slightly higher levels in coastal waters and tanker traffic lanes (Myers and Gunnerson 1976). Wong found consistently higher concentrations of tar in the western Pacific; the eastern Pacific was an order of magnitude lower on average but has more plastic (Wong et al 1974, Shaw and Mapes 1979). Wong et al (1976) summarized the distribution of tar based on cruise dates from 1967 to 1972. The Kuroshio area (near Japan) had the highest concentration, followed by the northwest Pacific, and then the south Pacific. Food samples collected from storm-petrels in these areas should follow the same relative ranking for fossil fuel hydrocarbons.

The subtle and less dramatic effects caused by small amounts of oil may be of more critical importance to the survival of seabird populations than large oil spills. Oil in small amounts may alter oceanic productivity or become concentrated in crustaceans and change the amount or quality of the food available to other organisms. Once seabirds reach adulthood, they are long lived and have low reproductive rates, so that major reductions in reproductive success because of changes in the quality or quantity of food available (due to human impacts) would not be reflected in drastic population decreases for some years. Once discovered, the consequences might already be irreversible. Where oil development results in lower reproductive success and occasional oil spills kill adults, probably population recovery would be unlikely. These are reasonable concerns, as indicated by the recent front-page story of petrels washing ashore in Scandinavia (MacLeod 1981).

Not only may seabirds be good integrators of conditions, but there is strong public concern focused on protecting seabird populations. Oiled seabirds washed up on beaches over the world have fostered public awareness and concern about the impact of oil development and transportation. Oil spills are generally apparent, and their effect in killing birds is well documented (Holmes and Cronshaw 1977, Barrett 1979). In Europe the decline of the puffin may be due to oil (Bourne 1979).

In part, as a response to public concern, much effort has been devoted to population counts and island surveys of seabirds. The number of birds counted depends on the day, weather, observer, stage of the breeding cycle of the birds, and numerous other variables. Small changes in populations cannot be reliably or meaningfully determined. Most of the data presently available on seabirds will be useless in assessing subtle damage due to marine pollution. A new approach is needed to determine the impact of fossil fuel hydrocarbons on seabirds and marine systems.

In 1976 the Office of Biological Services and the National Wildlife Refuge System funded a study of the seabirds of the Barren Islands, Alaska. We are documenting the natural variability in many natural history features of the Fork-tailed Storm-Petrel's breeding biology (Boersma and Wheelwright 1979; Wheelwright and Boersma 1979; Boersma et al 1980.

Table 1.

ITINERARY, 1980 BARREN ISLANDS

Date	Personnel	Location
6/26	Dr. P. Baird, USFWS Dr. P. Boersma, A. Power, D.McDonald and USFWS/YACC personnel	Anchorage to Homer by truck
6/27	P. Baird, P. Boersma, D. McDonald, A. Power	Homer to E. Amatuli by LCM "Naomi"
7/7	P. Baird, P. Boersma, D. McDonald, A. Power	E. Amatuli to Sugarloaf and return by Zodiac raft.
7/9	P. Boersma, A. Power, D. McDonald	E. Amatuli to W. Amatuli, Sud and return by Zodiac.
7/13	P. Boersma, P. Baird	E. Amatuli to Homer by Maritime Helicopter
7/16	A. Power, D. McDonald	E. Amatuli to Sugarloaf, Sud, Ushagat and return by Zodiac raft.
7/25	A. Power, D. McDonald	E. Amatuli to Sugarloaf, Sud, by Zodiac. Camped at Sud.
7/26	A. Power, D. McDonald	Sud to Ushagat and E. Amatuli by Zodiac.
8/4	A. Power, D. McDonald	E. Amatuli to Sugarloaf and return by Zodiac.
8/9	G. Sanger, USFWS P. Boersma	Homer to E. Amatuli by Maritime Helicopter.
8/12	G. Sanger, D. McDonald	To Ushagat and Sud by Zodiac. Camped at Sud.
8/13	G. Sanger, D. McDonald	To E. Amatuli by Zodiac.
8/14	G. Sanger, P. Boersma D. McDonald	E. Amatuli to Sugarloaf and return by Zodiac.
8/20	G. Sanger, P. Boersma	E. Amatuli to Homer by helicopter.
8/23	A. Power, D. McDonald	E. Amatuli to Sud and return by Zodiac.
8/24	A. Power, D. McDonald	E. Amatuli to Sugarloaf and return by Zodiac.
8/28	A. Power, D. McDonald	E. to W. Amatuli and return by Zodiac.
9/6	A. Power, D. McDonald	E. Amatuli to Homer by LCM "Nanook"
9/18	A. Power, D. McDonald	Anchorage to Sitka by air
9/19	A. Power, D. McDonald	Sitka to St. Lazaria National Wildlife Refuge by fishing vessel.
9/21	A. Power, D. McDonald	St. Lazaria to Sitka by helicopter.

III. Field and Laboratory Activities

A. Field trip schedule

We were in the field between June 1980 and September 1980. USFWS provided personnel (Pat Baird and Jerry Sanger) and equipment (outboard motors, zodiacs, transportation to Homer and some field equipment) for portions of this study. Logistical support was chartered out of Homer, Alaska. Flynn's Barge Service transported personnel and equipment to and from the island (E. Amatuli) on June 26 and September 6, 1980. Maritime Helicopter reprovisioned the camp and transported personnel in July and August 1980. Table 1 shows the itinerary and personnel present during the field season in Alaska.

B. Scientific party

1. Dr. P. Dee Boersma
   Associate Professor
   University of Washington
   Institute for Environmental Studies and Department of Zoology

2. Ms. Alison Power
   Graduate Student
   University of Washington
   Department of Zoology
   Field assistant, the Barren Islands and St. Lazaria Island, Alaska

3. Mr. David McDonald
   Fifth year student
   University of Washington
   Department of Zoology
   Field assistant the Barren Islands and St. Lazaria Island, Alaska
   and Laboratory Assistant

4. Dr. Pat Baird
   Research Scientist (ornithologist)
   U.S. Fish and Wildlife Service, Anchorage Office
   Field assistant, Barren Islands, Alaska

5. Mr. Jerry Sanger
   Research Scientist (biological oceanographer)
   U.S. Fish and Wildlife Service, Anchorage Office
   Field assistant, Barren Islands, Alaska
   Laboratory visitor to help identify prey, November 27-30, 1980

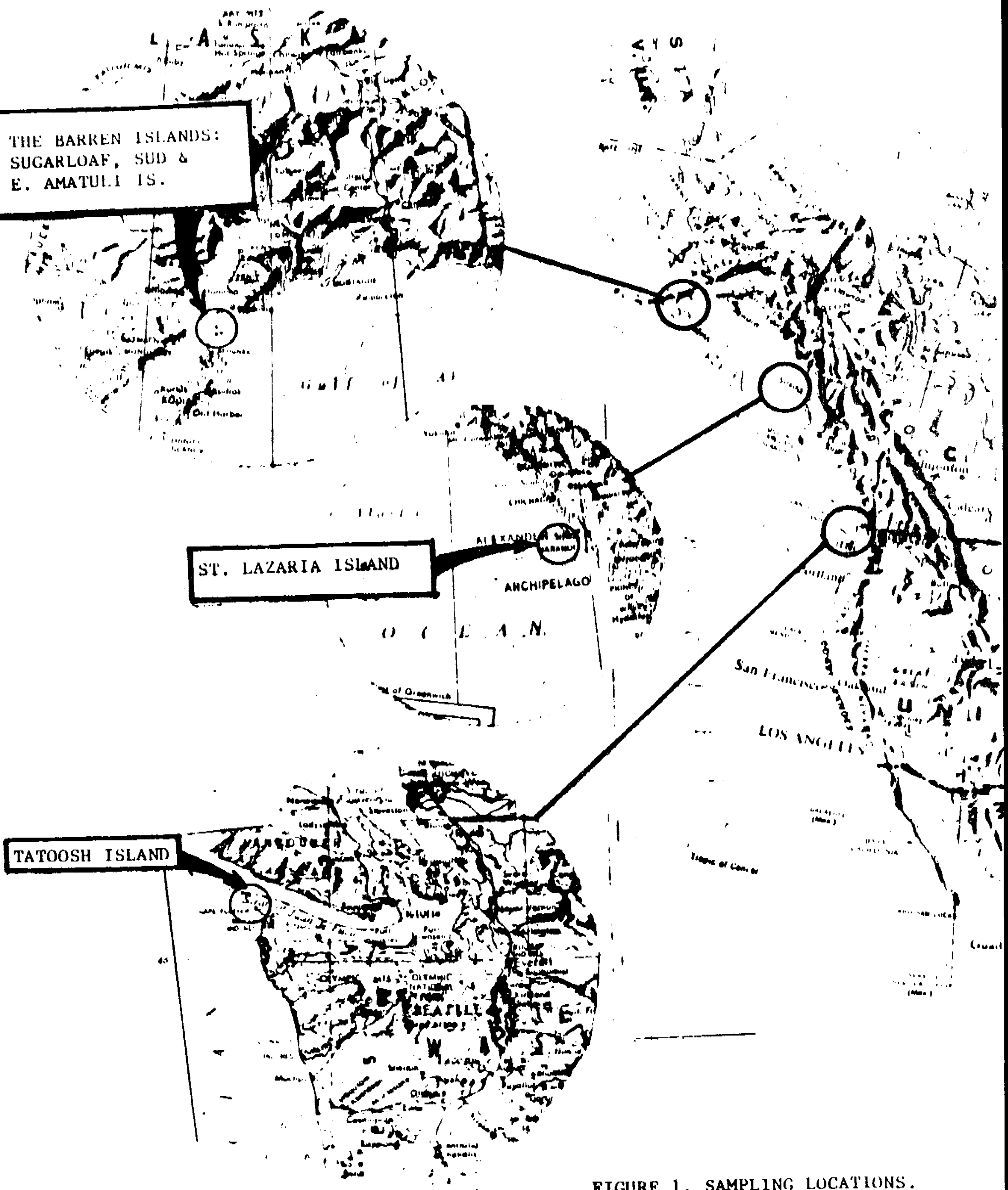


FIGURE 1. SAMPLING LOCATIONS.

6. Dr. David Kalman
Research Assistant Professor and Director, Trace Organic Laboratory
University of Washington
Department of Environmental Health
Gas chromatography and mass spectophry analysis

7. Mr. Paul Schroeder
Fifth year student
University of Washington
Laboratory assistant and field assistant on Tatoosh Island, Wa.

8. Ms. Terry Friedmann
Third year studnet
University of Washington
Laboratory assistant and field assistant on Tatoosh Island, Wa.

C. Methods:

Collection of samples

Food samples were collected from Fork-tailed Storm-Petrels (Oceanodroma furcata) that were either mist netted or captured at their nest site. Sample locations are shown in Figure 1. To collect the samples a Nalgene funnel rinsed with dichloromethane was held in front of the bird. When the bird regurgitated, the food sample was rinsed down into a scintillation vial with nanograde dichloromethane. We banded birds with stainless steel bands, weighed (± 1 gram) and measured them. Vials were labeled with the band number and date and stored at approximately 10°C.

Thin-layer chromatography

The purpose of thin-layer chromatography is to determine whether samples change with time. Between one hour and two days after the sample was collected we removed a small sample of food oil from the vial, using a micropipette cleaned in dichloromethane. The oil was spotted onto a strip of silica

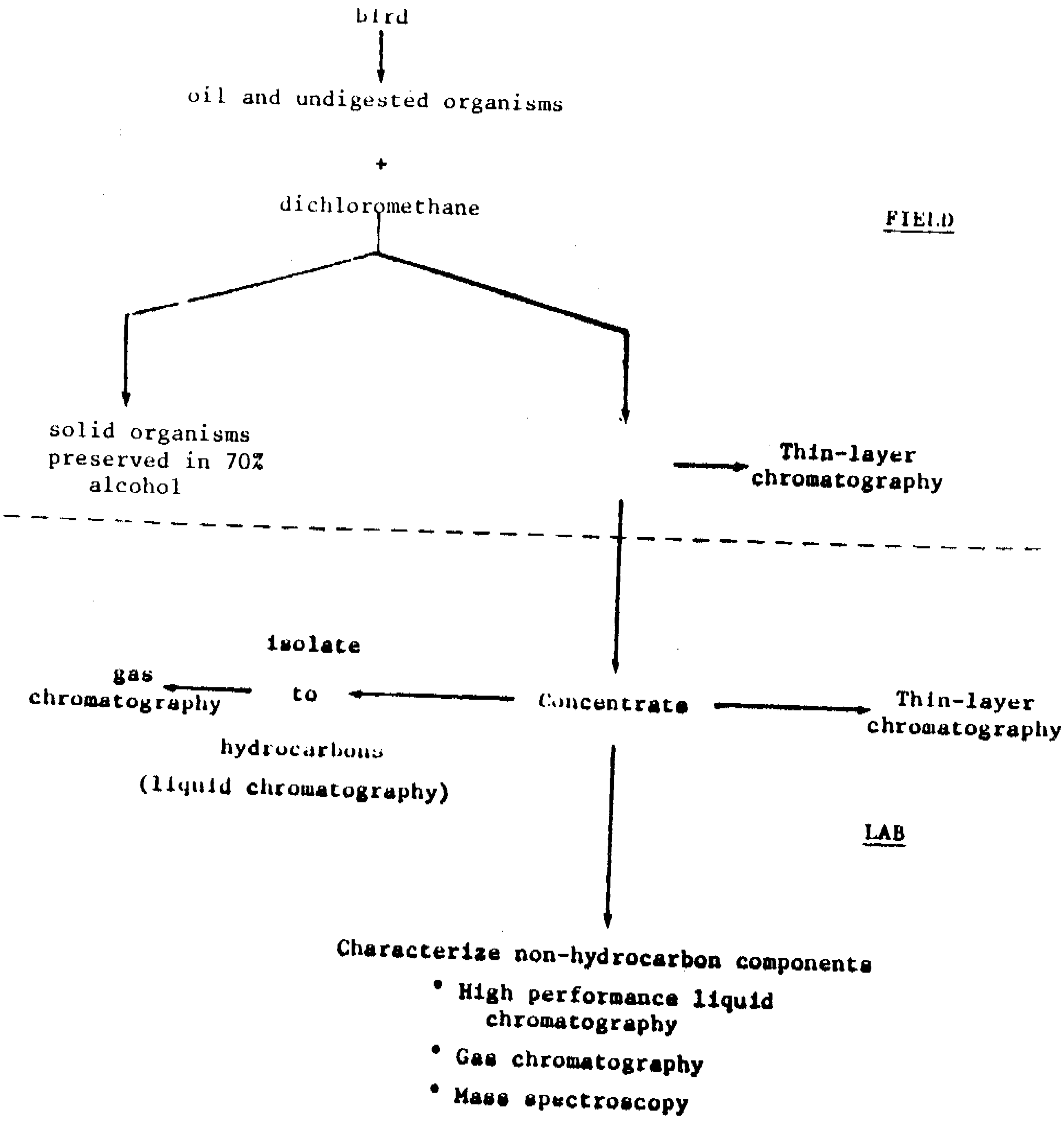


Figure 2. Procedure for Food Sample Analysis.

gel and allowed to migrate in dichloromethane solvent. After development with iodine crystals, the patterns could be recorded for analysis and later comparison. All samples were re-analyzed in the laboratory using the same methods and the patterns were compared with those developed in the field, so as to determine whether the samples had changed during storage.

Gas/liquid chromatography

The purpose of gas/liquid chromatography is to test for the presence of fossil fuel hydrocarbons, Figure 2 shows the general procedure for food sample analysis. An aliquot (2-35% of the sample by volume) of the oil component of the samples was extracted, using either nanograde hexane or trimethylpentane (SpectAR) and reduced with dry nitrogen. First, the sample was rinsed through a 5-3/4" transfer pipette packed with silica gel and plugged with glass wool. Three hexane rinses flushed the sample from the pipette into a collection vial. The sample was then reduced to 1 ml. with dry nigrogen. The silica gel was stored in methanol and is available for potential analysis of dietary components.

David Kalman analyzed the prepared sample by gas chromatography which yields measurable peaks in a printout in response to any impurities. Gas chromatography was done on a Hewlett/Packard 5840A and a Hewlett/Packard 5880 gas chromatograph equipped with FID, Ec, and N/P detectors and splitless injection and fused silica SE-54 columns (J and W Scientific). Conformation of hydrocarbon components in one sample was carried out by GCMS. The Finnigan 4023 equipped with a directed Nova/3 computer and Incos software with a 30,000 entry library of mass spectra, together with reference libraries generated within the laboratory itself was used for identity searching.

Each sample batch (30 samples) was run against a standard of Prudhoe Bay crude oil. A distinctive regular pattern of hydrocarbon peaks on the printout is diagnostic of fossil fuel hydrocarbons. Spiked samples and a reference sample were analyzed with each batch to confirm the reliability and precision of the analysis. After each sample a blank was analyzed as a further control. We also did extractions of three simulated samples, following the field and laboratory sampling procedures, so as to check for any possible contamination in the sampling process itself. All analyses were run on an SE-54 fused silica capillary column (J & W Scientific) with splitless injection and helium carrier gas (30 cm/sec linear velocity).

Samples were scored as positive when the hexane extracted oil sample matched 10 of the 27 potential peaks of the Prudhoe Bay standard sample and when the trimethylpentane extracted samples matched 3 of 18 potential peaks. Peaks were considered matches when they where consistently within ± .05 seconds of the standard's peaks and greater than twice the magnitude of the control sample's peaks.

D. Study Sites

Food samples were collected on three of the Barren Islands, Alaska; at St. Lazaria Island, Alaska; and at Tatoosh Island, Washington (see Figure 1).

E. Data Collected or Analyzed

Number and types of samples:

Oil samples were collected from approximately 50% of the birds mist netted. In 1980 we handled over 1,000 Fork-tailed Storm-Petrels and banded 685 new adults and 164 chicks. On St. Lazaria Island, Ak., we banded 17 Fork-tailed Storm-Petrels and 55 Leach's Storm-Petrels (*Oceanodroma leucorhoa*). We collected 242 oil samples from the Barren Islands, 19 from St. Lazaria Island and one from Tatoosh Island during June to September 1980. Samples were collected from three species: Fork-tailed Storm-Petrels (242), Northern Fulmars (10) (*Fulmarus glacialis*), and Leach's Storm-Petrel (10). Any solid

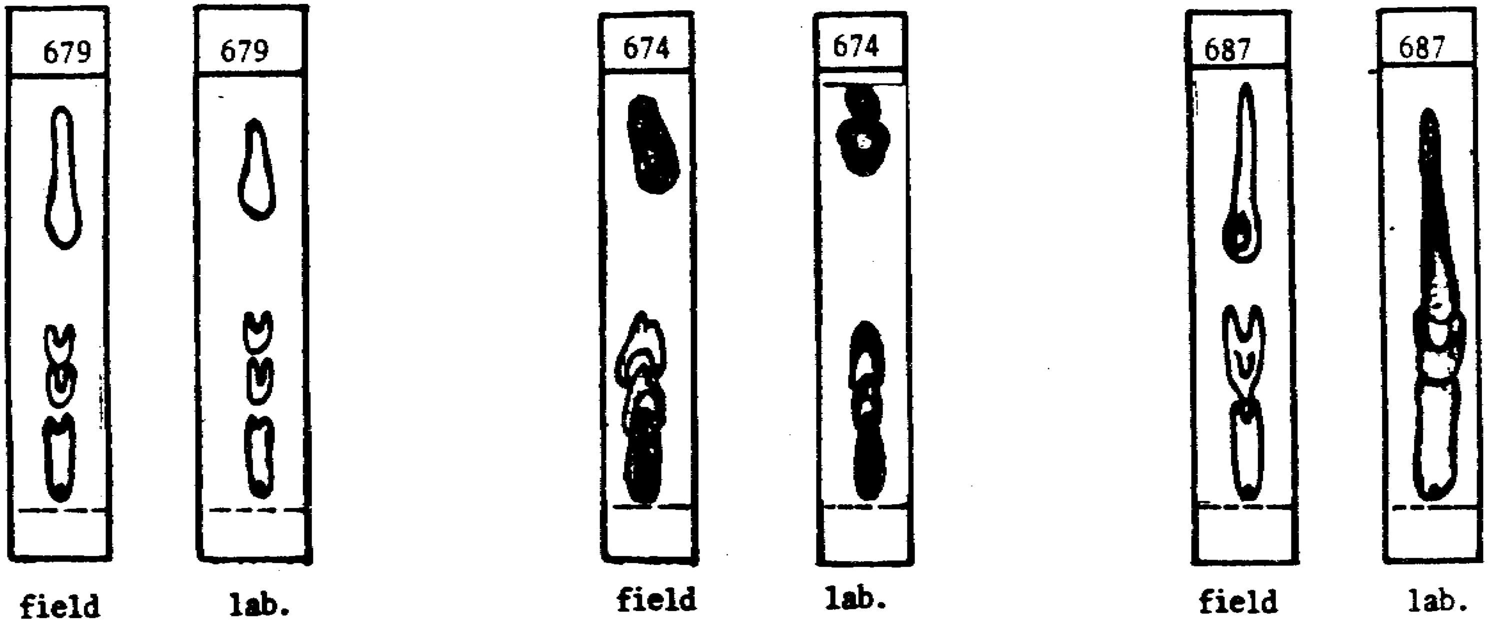


Figure 3. Thin-layer chromatography done in the field and laboratory on three food samples from Fork-tailed Storm-Petrels. The first thin-layer chromatography was done in the field and the other in the laboratory. The similarity in the migration of spots indicates the samples have remained stable.

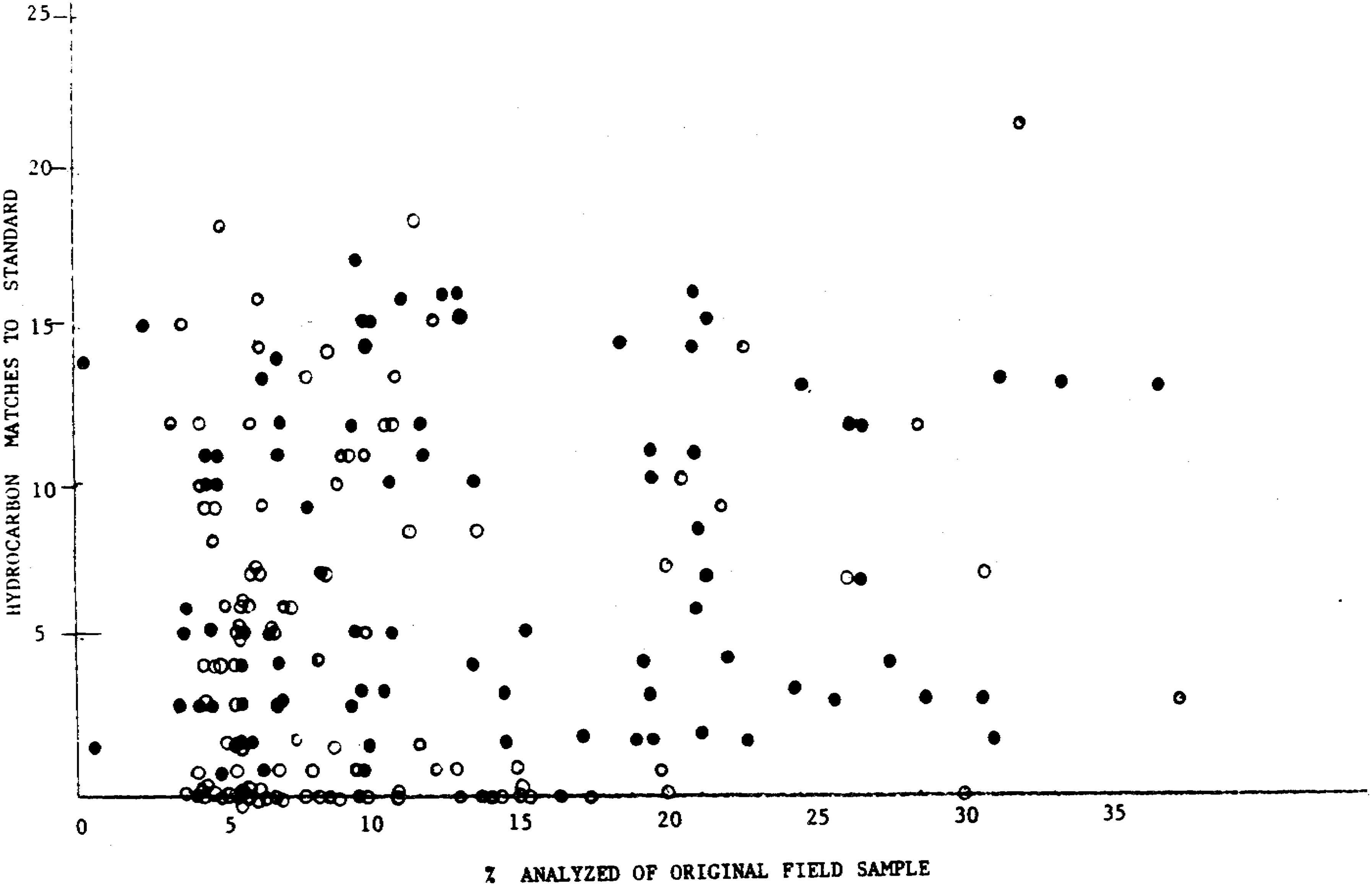


FIGURE 4.

HYDROCARBON MATCHES WITH RESPECT TO THE % OF THE ORIGINAL SAMPLE USED FOR ANALYSIS. THE SPREAD OF POINTS INDICATES THAT THE RELATIVE AMOUNT OF THE ORIGINAL SAMPLE USED DOES NOT AFFECT THE RESULTS OF THE MATCHES.

food items were also collected and preserved in 70% ETOH. During the field season we installed 120 artificial nesting boxes for Fork-tailed Storm-Petrels. We plan to use these boxes for an experiment on the effects of controlled addition of fossil fuel hydrocarbons to the diet of petrel chicks.

Prey items in the food samples have been identified by reference keys and by reference samples provided by Jerry Sanger, U.S. Fish and Wildlife Service, Anchorage. We recorded numbers and size of the prey items identified. We continued studies begun in 1976 on growth rates, nesting success and mate and burrow fidelity of Fork-tailed Storm-Petrels, with less extensive monitoring of a Tufted Puffin (Lunda cirrhata) colony. We have also monitored the general reproductive success of four other species of seabirds in the Barren Islands.

IV. Results:

Reliability and precision of analysis

Besides running standards, blanks and spiked samples to verify our ability to detect fossil fuel hydrocarbons, we have also re-run 23 samples (20% of the sample tests). All showed the same patterns of peaks upon re-analysis. The patterns of thin-layer chromatography performed in the field and repeated for each sample in the laboratory are not quantitatively different (Figure 3) and show that samples have not changed with time. The proportion of the samples used for analysis does not affect our ability to detect fossil fuel hydrocarbons (Figure 4).

Results of analysis

Comparison of samples using different solvents indicates that trimethylpentane allows more sensitive discrimination of fossil fuel contaminants. Furthermore, trimethylpentane volitalizes at a low temperature so sample

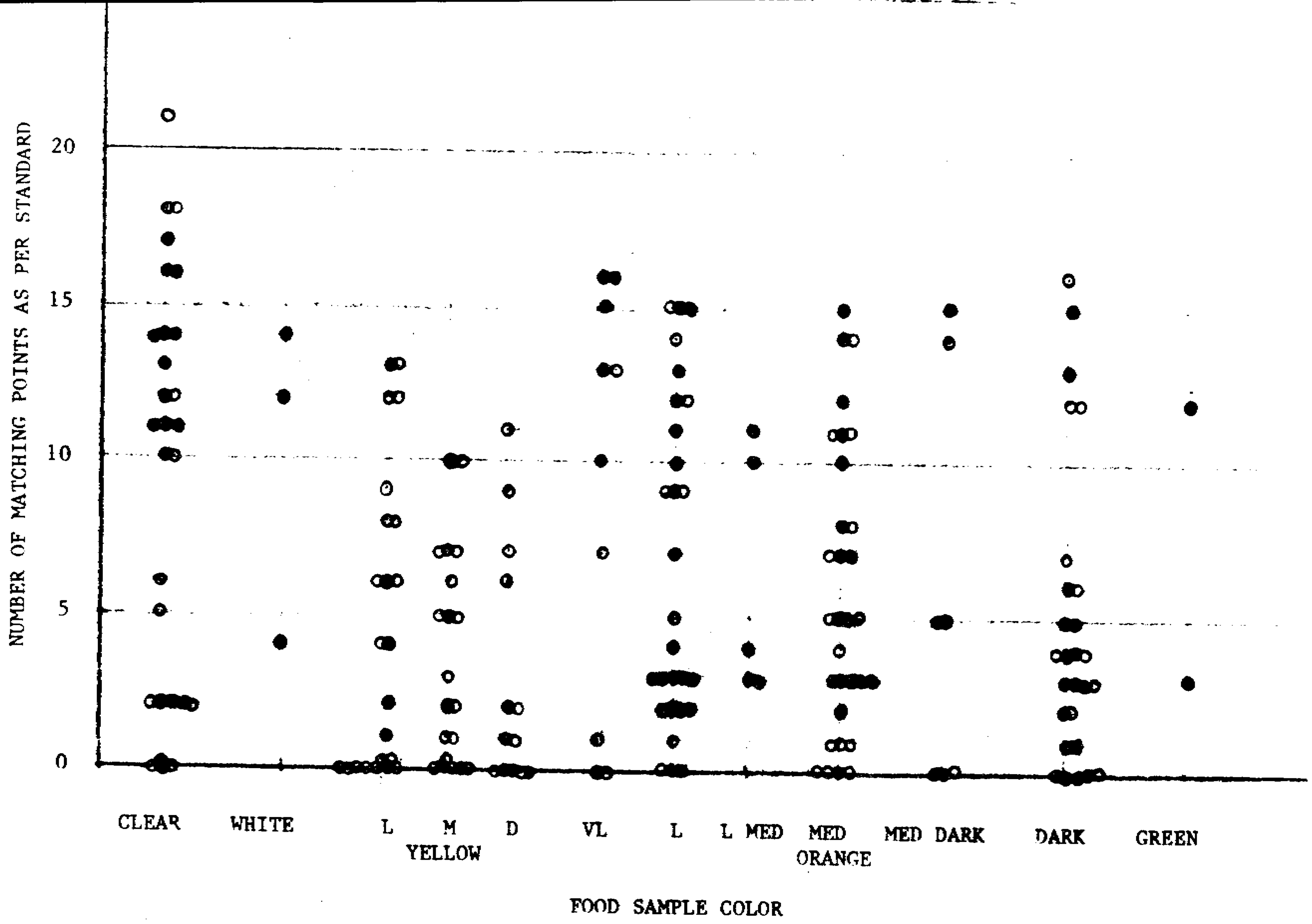
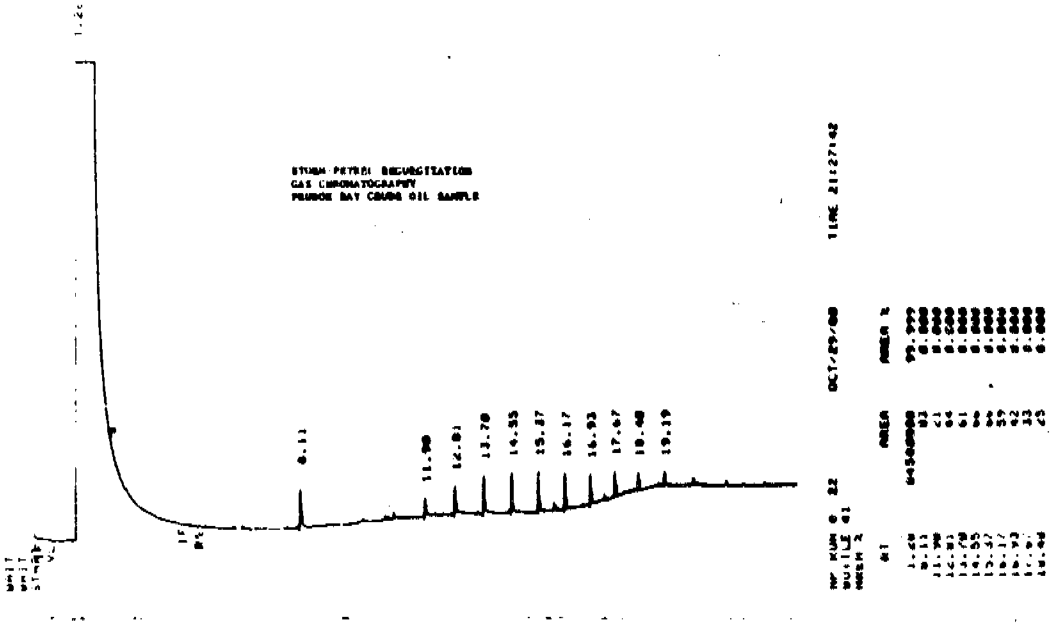


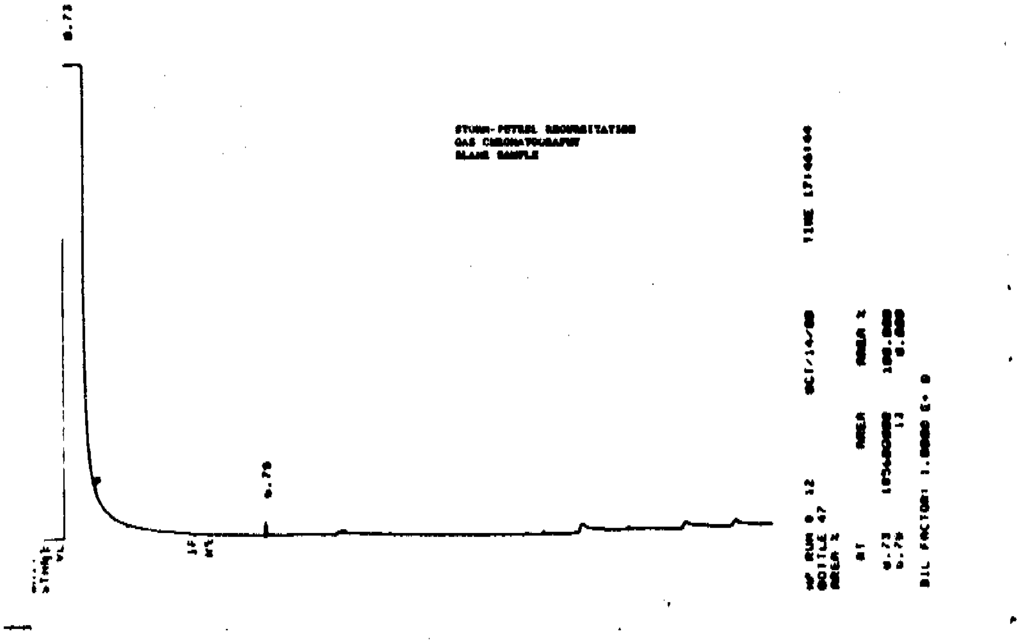
Figure 5: Fork-tailed Strom-Petrel food samples containing fossil fuel hydrocarbons. Food sample color reflects what the bird has been eating. Regardless of diet, birds ingest fossil fuel hydrocarbons.

SOLVENT USED•

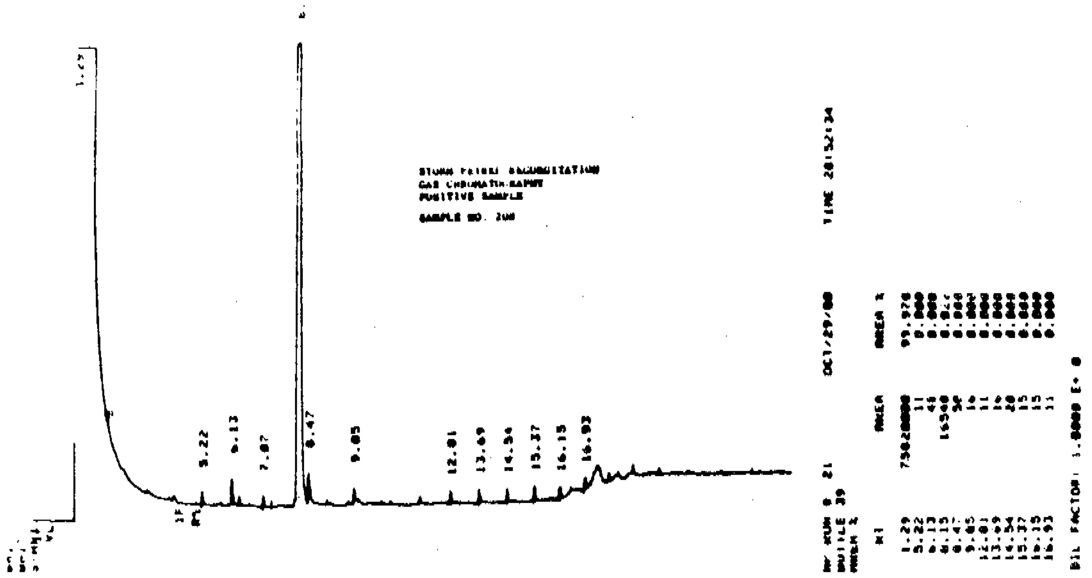
● = HEXANE ○ = TRIMETHYLPENTANE



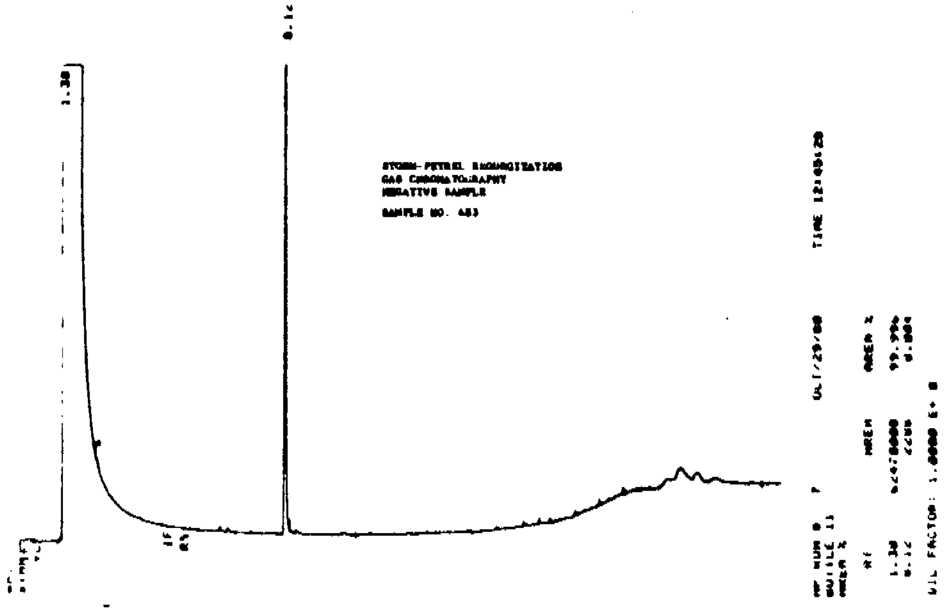
6.a. PROFILE OF KNOWN HYDROCARBON USED AS STANDARD. NOTE SERIES OF DISTINCT PEAKS FROM 11.98 MINUTES TO 19.19 MINUTES.



6.b. PROFILE OF SOLVENT BLANK



6.c. EXAMPLE OF SAMPLE PROFILE SHOWING DISTINCT PEAKS COMPARABLE TO THAT OF STANDARD (FIG. 6a)



6.d. EXAMPLE OF SAMPLE PROFILE SHOWING NEGLIGIBLE REACTION IN COMPARISON TO STANDARD (FIG. 6a)

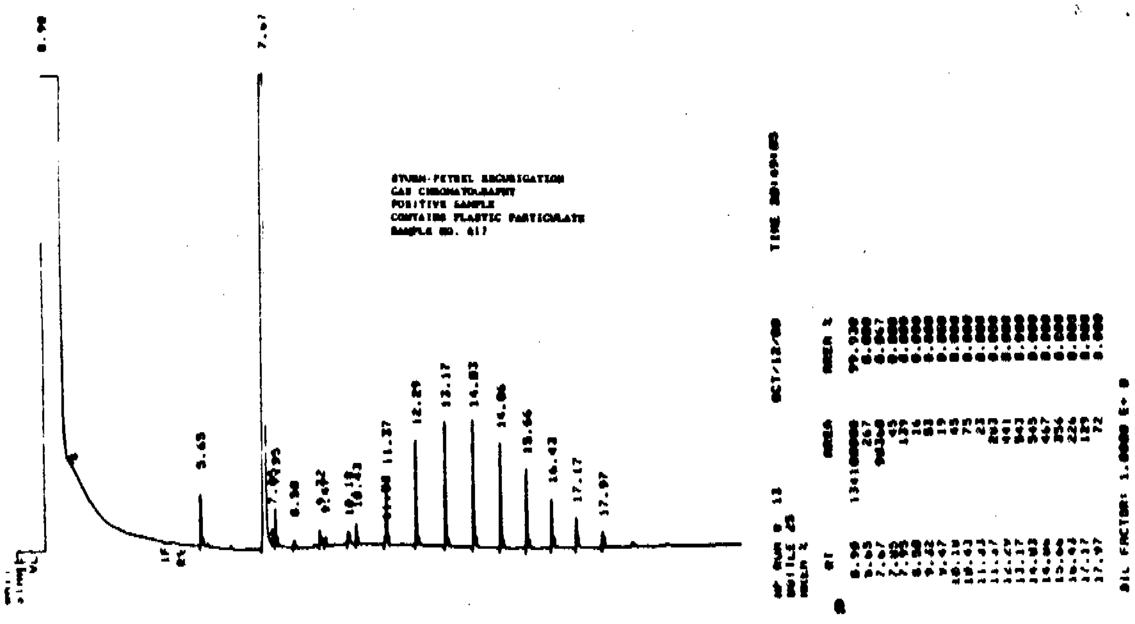


FIGURE 6.e.

PROFILE OF SAMPLE CONTAINING PLASTIC PARTICLE SHOWING SERIES OF DISTINCT PEAKS COMPARABLE TO STANDARD (FIG. 6a)

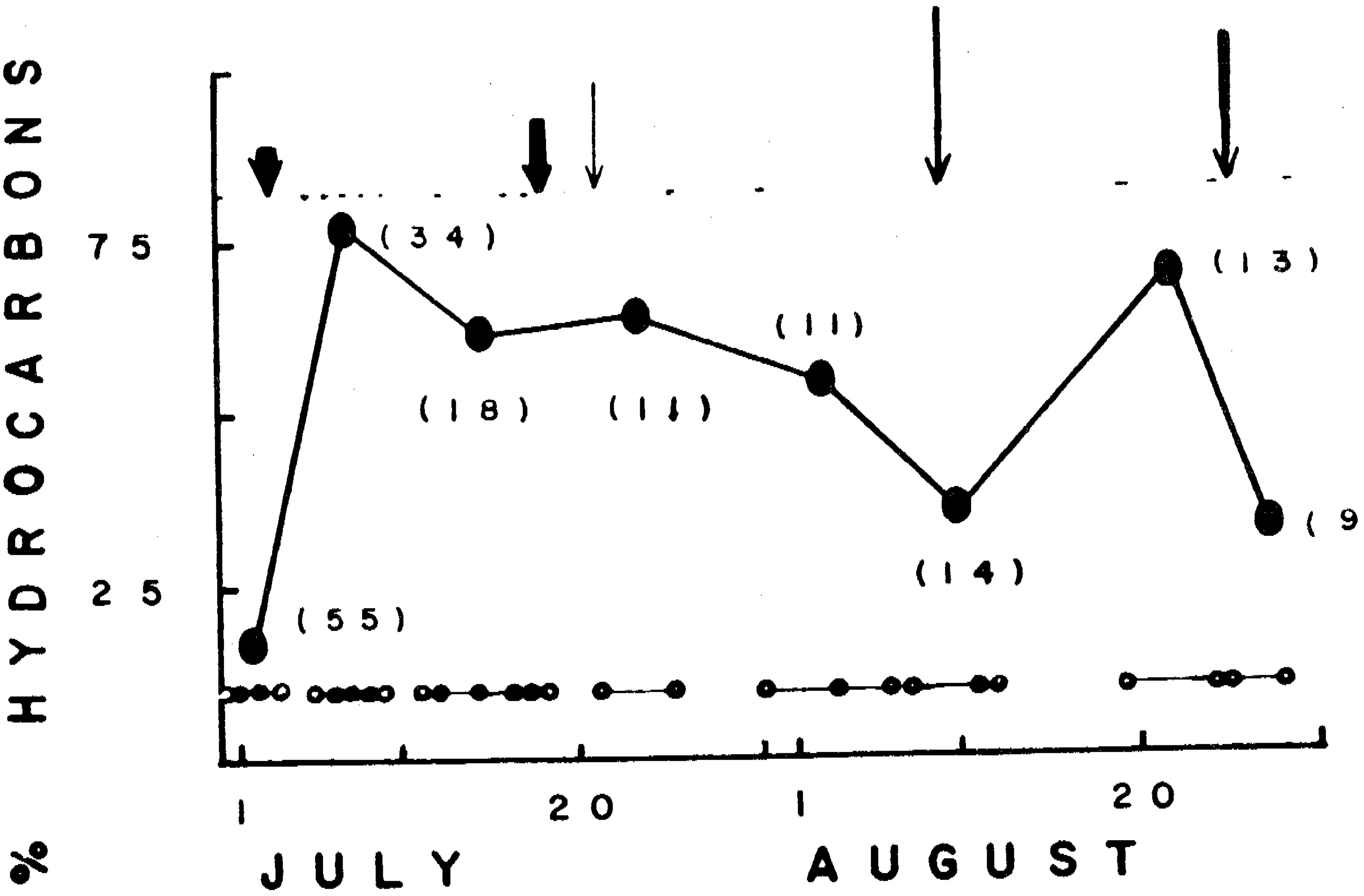


Figure 7: The percentage of Barren Island Fork-tailed Storm-Petrel food samples containing fossil fuel hydrocarbons are indicated by large black dots for 8 sampling periods. The number of samples in each period is enclosed by parentheses.

● = days samples were collected.

o = the first or last sample in the sampling period.

Arrows show all large oil spills or slicks within 200 km of the Barren Islands that were reported to the Coast Guard. The thickness of the arrow represents the relative magnitude of the spill and the length the distance of the spill from the islands.

All days where 60% or more of the food samples had fossil fuel hydrocarbons are shown below the arrows by a dash.

analysis is less expensive. The scoring criteria are empirically based and represent a balance between conservatism and precision. The color of the sample is not a useful predictor of fossil fuel content (Figure 5), but may be useful in determining dietary components. Figure 6 shows profiles of representative printouts from the chromatography analysis. To test whether Procellariiformes could monitor regional oil pollution, we collected 261 food and oil samples from three species of Procellariiformes: Fork-tailed Storm-Petrels, Northern Fulmar (Fulmarus glacialis), and Leach's Storm-Petrel on the Barren Islands. The Barren Islands, located at the opening of Cook Inlet in the Gulf of Alaska, have tanker, fishing and freighter traffic as well as oil development and transport near them. Any hydrocarbons spilled in Cook Inlet should eventually flow by the Barren Islands and into the Gulf of Alaska. Because oil products seem to be mainly spilled in nearshore areas, and because human use in nearshore areas is higher per unit area than in offshore areas, seabirds that feed further offshore should encounter fewer fossil fuel hydrocarbons than those that feed closer to the continental shelf. To test this hypothesis, we sampled Northern Fulmars which feed frequently off the continental shelf and Fork-tailed Storm-Petrels which feed close to shelf break. As predicted, food samples from Northern Fulmars had fewer hydrocarbons (30%) than those from Fork-tailed Storm-Petrels (47%).

The occurrence of hydrocarbons should not be uniform but should reflect pollution events. We collected food samples from Fork-tailed Storm-Petrels frequently to determine the range of fossil fuel hydrocarbons in the environment and whether the birds detected a pollution event. During July and August of 1980, the Coast Guard recorded five pollution events within 200 km of the Barren Islands. All of these events appear to be reflected as an increase in the percent of samples with fossil fuel hydrocarbons (Fig. 7).

The coupling of known pollution events with increases in fossil fuel hydrocarbons for as long as two weeks suggests that Fork-tailed Storm-Petrels are sensitive indicators of oil in the marine environment. The largest pollution event the Coast Guard reported during the study was a 200 gal. diesel spill at Jakalof Bay which is approximately 50 km from the Barren Islands. This event was reflected as a clustering of contaminated samples between 5 July and 9 July. This was the longest period when daily over 60% of the food samples contained fossil fuel hydrocarbons. This period also had the most contaminated samples (Fig. 7). The second largest known event occurred on 18 July when a 2 mile by 11 mile slick from the O.H. Dai Son moved up Cook Inlet. On 21 July, 2 of 5 samples and on 25 July, the next sampling period, 5 of 6 samples contained fossil fuel hydrocarbons. The time between a spill and ingestion by Fork-tailed Storm-Petrels seems to increase with the distance of the spill from the island. Such a lag period could account for the increase in food samples with fossil fuel hydrocarbons on 19 August because a 1.2 square mile slick was reported near the head of Cook Inlet on 9 August. It may have entered the storm-petrel's foraging area on or near August 19. An alternate explanation, based on the dramatic increase in polluted food samples, is that a larger unreported spill occurred on approximately 16 August within 100 km of the islands.

In another test of the ability of storm-petrels to detect fossil fuel hydrocarbons we sampled storm-petrels on St. Lazaria Island 12 and 13 days after 30,000 gallons of diesel were spilled 50 km from the island. Much of the diesel was burned but still 60% of the Fork-tailed Storm-Petrels had fossil fuel hydrocarbons. We expected that, like Northern Fulmars, Leach's Storm-Petrels would be less contaminated because they forage in waters off the continental shelf. They were. Only 44% of their food samples had fossil fuel hydrocarbons. The Leach's Storm-Petrels, however, were more contaminated than the Northern Fulmar's samples from the Barren Islands where there was not such a large event.

V. Discussion:

We have refined the techniques for detecting fossil fuel hydrocarbons with rigorous testing and are confident that we can analyze samples accurately and conservatively without sacrificing precision. The system is conservative in that only samples which unquestionably contain hydrocarbons are scored as positive. Since we can still detect hydrocarbons, the technique is not over-conservative and reflects a level of precision within the range of biologically meaningful contamination.

The technique can be used in two ways. The first is an inexpensive monitoring scheme whereby the samples reflect the oceanic conditions with regard to hydrocarbon pollution. The second use would be in conjunction with controlled studies of the physiological effects of hydrocarbons on seabird chicks. If the long and short-term effects of hydrocarbons in chick diets were determined then the monitoring would allow assessment of the effects of trends in oceanic pollution on seabirds as a key component of the marine food web. Studies are in progress to determine the effects on Fork-tailed Storm-Petrel chicks of ingesting weathered crude oil.

As a monitoring technique our results demonstrate that pollution events can be detected and pinpointed in time. During the 5 July - 9 July clustering, many different birds on three islands were affected. The fact that four of the seven samples containing plastic particles were collected during this time period is independent evidence for a pollution event. Since storm-petrels are widely scattered while foraging (Crossin 1974; Harris 1974), the pollution event was probably widespread in area but restricted in time. Besides its usefulness in detecting particular regional pollution events, the technique could serve as a long-term monitor of marine pollution levels.

Hydrocarbon concentrations after many oil spill incidents, returned to base-line levels within days or weeks after the event (Westerheim and Wilhelm sen 1979). The continued high numbers of Fork-tailed Storm-Petrel food samples with hydrocarbons suggests a continued input of oil in Cook Inlet or parts of the Gulf of Alaska. As Laughlin et al (1981) note, long-term low-level inputs of hydrocarbons are probably the most environmentally damaging. Storm-petrel food sample analysis could allow assessment of regional levels of chronic oil pollution and comparison between different parts of the ocean. Using these data, managers can activate controls to avoid damage from low-level contamination.

The continuance of studies begun in 1976 on the patterns of reproductive success in Barren Islands seabirds is an important component in integrating the monitoring technique with biological knowledge. Quality natural history data are easily procured but essential for understanding the mechanisms and resilience of ecosystems. With this data base (Boersma and Wheelwright 1979; Wheelwright and Boersma 1979; Boersma et al 1980), we can gauge the effects of major environmental changes or chronic pollution as it is revealed by the food sample analysis technique.

In conclusion these data show that we are able to detect known pollution events, that bigger and closer events are indicated by more contaminated samples, and that more distant foragers like Northern Fulmars and Leach's Storm-Petrels that forage in areas with presumably fewer fossil fuel hydrocarbons ingest fewer hydrocarbons. Our preliminary information supports the hypothesis that Procellariiformes are good regional integrators of marine oil pollution. We with to continue to develop a system to use Procellariiformes to monitor marine pollution and to assess the relative increase of oil and oil-based products in the Pacific Ocean.

VI. Auxiliary Material:

References.

VII. Problems Encountered - Recommended Changes

Receiving funds in a timely manner so that the field season could start in May has been more than difficult.

VIII. Estimate of funds expended.

$39,966

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RECEPTORS-FISH
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ANNUAL REPORT

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Studies of fish and epibenthic invertebrates in coastal waters of the Alaskan Beaufort Sea

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INTRODUCTION

This report describes studies of fish and epibenthic invertebrates in coastal waters of the Beaufort Sea. The report is, in large part, a continuation of the barrier island-lagoon ecological process studies (RU-467) reported earlier by Craig and Haldorson (1981) and Griffiths and Dillinger (1981).

Objectives of the 1980 studies were to:

1. Examine distributions of fish and epibenthic invertebrates in Harrison Bay.
2. Continue studies of distribution patterns and life-history characteristics of fish and epibenthos that overwinter in Beaufort Sea coastal waters.
3. Continue studies of movements and distributions of fish and epibenthic invertebrates in nearshore waters, with special reference to the Prudhoe Bay causeway.
4. Monitor changes in the populations of least and arctic cisco.
5. Locate the spawning grounds of arctic cisco in the Colville River drainage.

Each of these objectives is considered separately in Parts 1-5 of the text. Part 6 provides a record of mark and recapture data from fish tagging programs.

PART 1

Survey of fish and epibenthic invertebrates in Harrison Bay, August 1980.*

SUMMARY

The waters of Harrison Bay in August 1980 were a complex mixture of (1) offshore marine waters and (2) the freshwater discharge from the Colville River. A well-developed discontinuity layer was often present 3-4 m below the surface out to 15-30 km from shore. Average temperatures and salinities were 7°C and 24 ppt in the upper layer, and 1.8-4.5°C and 27-30 ppt in various bottom areas. Hydroacoustic surveys indicated that fish densities were highly variable. Fish were present throughout the water column and, in one instance, an accumulation of fish was found at an interfacial zone between distinct water masses. Catches of fish and epibenthic invertebrates are discussed.

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*Portions of hydroacoustic studies in this report were conducted by Walt Campbell.

INTRODUCTION

The next petroleum lease sale in coastal waters of the Alaskan Beaufort Sea is planned for a relatively unstudied but biologically interesting area -- Harrison Bay. This bay lies directly off the mouth of the Colville River, Alaska's largest North Slope drainage. The Colville River supports large stocks of anadromous ciscoes, whitefish and char. These stocks play an important role in nearby subsistence and commercial fisheries. These fish may range offshore in Harrison Bay, utilizing the plume of brackish water extending from the Colville River. Recent studies also indicate that Harrison Bay is an important overwintering area for several fish species, particularly boreal smelt and fourhorn sculpin (Craig and Haldorson 1981).

The present study consisted of limited sampling to examine the distribution of fishes and their prey (epibenthic invertebrates) in Harrison Bay. This information is supplemented by trawl data collected in the bay during other OCSEAP investigations (C. Broad, RU356).

STUDY AREA

Harrison Bay is one of the larger embayments along the Alaskan Beaufort Sea coastline. A general description of this waterbody follows (abstracted from Naidu and Mowatt 1975):

> "This bay has an E-W length of about 100 km and a maximum N-S width of about 30 km. It is comprised of the embayed continental margin extending roughly east-west from Oliktok Point to Cape Halkett, and out to the 10-m isobath seaward. The entire shallow bay (1 to 10 m depth range) is susceptible to gouging by grounded ice (Reimnitz et al. 1973; and Reimnitz and Barnes 1974). As a result of this ice action several characteristic microrelief features are developed on the bay floor, and there are pronounced effects on the nature of sediment deposits. It is also observed that large scale devastation may occur to the bottom fauna as a result of this ice gouging. Details of these unique ice gouging features have been graphically displayed by Reimnitz et al. (1973) and Reimnitz and Barnes (1974).
>
> Walker (1972, 1974) and Alexander (1974) have documented the seasonal hydrologic regime and nutrient chemistry, respectively, of Harrison Bay. The bay has an ice cover for at least eight months in a year, and during this time the sea water moving toward the Colville River flushes Harrison Bay as well. The salinity of water under the ice during the winter may vary

from 30 to 40°/₀₀, higher salinities being observed in water pools entrapped between fast ice. At spring -- the most dynamic period -- the ice in the Colville River breaks up earlier than that offshore. Following the river break-up, the bulk of the sediment-laden fluvial discharge initially fans out seaward over fast sea-ice of Harrison Bay for distances as far as 10 to 14 km from the Colville distributary mouths (Reimnitz and Bruder, 1972; and Walker, 1974).

Finally, the sediment incorporated in the overflow may either settle on the shore fast ice or drain to the bay bottom -- generally beyond the 2 m isobath where no seasonal fast ice is present -- through holes and cracks (strudels) on the ice.

Some of the Colville River discharge during spring flows seaward as a wedge under the sea ice, and along open channels, as far as 40 km from the river mouth. At this time definite salinity and thermal stratifications appear in the water column, because of the presence of less dense fresh and warm fluvial water as well as more dense saline and cold seawater. The total weight of suspensates transported by this fluvial discharge during any one of the days in spring is quite significant (3×10^5 metric tons) (Walker, 1974).

The continental permafrost of the North Slope presumably extends under Harrison Bay, as the mean annual sea bottom temperature in the bay is approximately -1.3°C (Lewellen, 1974). The mean primary biological productivity rate for surface water in Harrison Bay is relatively very low, on the order of 0.6 mg C m^{-3} hr^{-1}."

METHODS

Fish and invertebrates in Harrison Bay were sampled by a two-man crew aboard the "D.W. Hood", a 10 m research vessel. The crew participated in three short cruises (3-5 August, 7-9 August and 13-14 August 1980) for a total sampling opportunity of approximately 70 h. During this time, fish distributions were documented by hydroacoustic equipment, and a limited number of fish and invertebrate samples were collected. Brief accounts of each cruise track are given below to serve as reference to Figure 1 (note: bathymetry is shown in Figure 5).

Cruise Track No. 1. The first trip (16:30 on 3 August to 2:00 on 5 August) was arranged to examine fish densities in eastern Harrison Bay from Pingok Island to the Colville River Delta and from the 2 m depth contour to the navigational limits of the *D.W. Hood* (less than 10 km from prominent shore based markers). Several north-south transects were traversed, and then we proceeded southward to examine watermass mixing. This was followed by one 27 km transect to the northwest during which two surface gillnets with radio buoys were deployed. Two otter trawl samples were taken and two additional gillnets were attached to a free floating iceberg (marked with a radio buoy) and allowed to drift with the ice for 6.5 km (5.5 h) before recovery.

Cruise Track No. 2. On the second cruise track (14:10 on 7 August to 23:30 on 9 August) depth contours and running time were used to estimate position within central to western Harrison Bay beyond the 3 m isobath (no shipboard instruments were available to allow even a crude estimate of vessel, wind or current velocity). One of the radio buoy gillnets from the previous cruise near Thetis Island was serviced; the cruise then proceeded offshore and west along the 15.2 m contour.

This depth contour was followed to 6 km west of Pitt Point (which was the next geographical feature from which location could be calculated). The vessel then returned south to the 7 m isobath west of Cape Halkett and proceeded east along this contour. Severe weather forced abandonment of this transect 15 km east of Atigaru Point. After waiting at the mouth of the Kogru River (Eskimo Islands) for 12 h, the vessel then proceeded north of Atigaru Point to the 13 m contour, and then east along this until just north of Thetis Island.

Cruise Track No. 3. The third cruise (15:30 on 13 August to 20:12 on 14 August) was used to complete the 6.1 m isobath terminated 20:30 on 14 August due to rough seas. Drop net samples for epibenthic invertebrates were taken at four intervals along the 6.1 m contour. The radio buoy gillnet

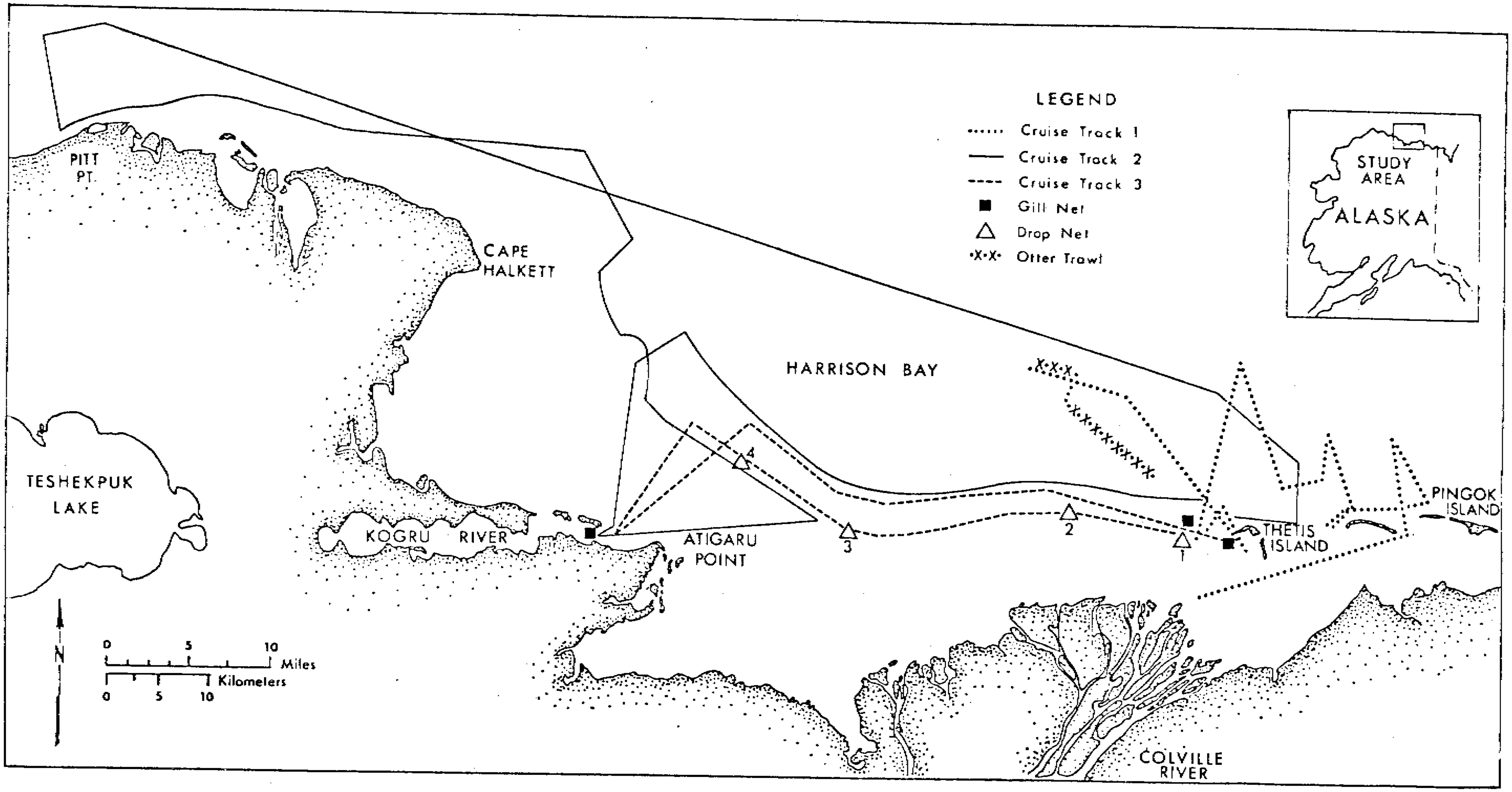

Figure 1. Cruise tracks for hydroacoustic surveys and sampling stations, August 1980.

set on 8 August was recovered 4.5 km ESE of its starting point after 6.3 days of drift. Inclement weather and an exhausted crew forced a return to shelter of the Eskimo Islands at the mouth of the Kogru River for 12 h. The vessel then proceeded offshore to the 12.2 m isobath to continue sampling in areas missed on the second cruise due to heavy ice cover on 9 August.

Hydroacoustic Surveys

A Simrad EY-M echo sounder was used to gather data on fish distributions. This instrument transmits a 600 ns, 75 watt pulse at 70 KHz. The acoustic beam (3.2 pulses/s) was projected into a 27° arc by a wide angle transducer (Simrad Model 74AA). The received signal (echo returns from the bottom, thermocline, plankton and fish) was printed on chart paper and recorded on magnetic tape. The transducer was mounted in front of the bow on the center line of the vessel in order to minimize effects of boat passage over fish before counting as well as to limit turbulence, noise and vessel roll effects on perceived echo returns.

Application and Limitations

Since the first published application of acoustic methods applied to surveys of cod populations (Sund 1935), interpretation of the records from echo sounders has seldom been as precise as might be expected considering the extremes of engineering precision incorporated into the equipment. The transmitted acoustic pulse can be characterized precisely up to the point it enters the water. Unfortunately the "targets" represented by sonar records vary in size of individuals, size of groups, density of groups, acoustic density of individuals and groups, and proximity to other features of similar acoustic density (e.g., thermoclines). Position errors are common when objects are not directly centered within the projected conical beam (the most frequent situation). This cosine error causes objects off-center to appear to be farther away than they really are. For this reason, single large fish close to the transmitting transducer characteristically produce a hyperbolic or "fingernail" shaped echo pattern as the beam moves past (Cushing 1963). Smaller fish located near the transducer produce single vertical bar records because they are detected only when near the center of the beam. Small and juvenile fish, phytoplankton and zooplankton generally provide distinct echo returns only when they are present in high densities. The diffuse echo pattern that they return is less sharp than the echo from a single fish, but usually is more expansive due to the presence of many individuals (Cushing 1963). Thermoclines usually produce an even less distinct echo return, often of larger areal extent than the return from an accumulation of planktonic organisms or a school of fish (Cushing et al. 1955). Surface reverberation from rough water or reverberation between the bottom and a "target" can cause distortion and obliteration of sonar records (Cushing 1963). Since planktonic organisms frequently accumulate at thermoclines (Anderson 1969; Baker and Brook 1971; Harris 1972; Karl 1978; Chester 1978) and are often the prey of arctic cod (OCSEAP 1978), it should not be surprising to find thermoclines, plankton and nekton together. In this case analysis is especially difficult.

After discarding hydroacoustic records that were obliterated by surface reverberation from rough water (two of the three cruises were interrupted by severe weather), indices of fish densities were calculated using the number of fish "targets" recorded on chart paper per volume of water sampled. Water volumes were calculated as the transect length times the area of the lengthwise-section of the cone, under the 27° arc of the transducer (the height of this triangle area was the average of water depths at the beginning and end of a transect). Water volumes were expressed as 10^4 m^3 to facilitate comparisons with data collected in Prudhoe Bay (Moulton et al. 1980).

The fish densities calculated using this method should be considered as indices rather than actual densities since no corrections were made for a number of recognized errors. For example, use of the average water depth at beginning and end of transects will contribute a different degree of error to each volume estimate. No correction was made for the cosine error. However, interpretation of fish "targets" on the chart records was facilitated since fish "targets" usually appeared individually (rather than in schools) and were of a similar size (thereby reducing interpretive errors in distinguishing between one large fish versus several small fish together).

Fish Samples

Gillnets measured 45.7 x 2 m and consisted of five equal-length panels with mesh sizes (stretched) of 2.5, 3.8, 5.1, 6.4 and 8.9 cm. Gillnetting was marginally successful -- only 3 of the 7 sets were unaffected by ice flows, currents or seals (Table 1).

A 4.9 m otter trawl was used on only two occasions (Table 1) since an extensive trawling effort was conducted in the same region by C. Broad (RU356) and his results are summarized in this report.

Invertebrate Samples

Epibenthic invertebrates were collected at four offshore stations on 13 August 1981 (Fig. 1). Five replicate samples were taken at each station with the deep-water version of the central-pursing drop net described by Griffiths and Dillinger (1981).

Physical and Chemical Measurements

Surface and bottom temperatures and salinities were recorded at 32 stations using a YSI-33 salinity/conductivity meter. The meter has an accuracy of ± 0.6°C and ± 1.1 ppt.

Table 1. Gillnet and trawl sampling stations in Harrison Bay, August 1980.

Sample location	Lat.	Long.	Date (8/80)	Method Gear*	Method Time (h)	Set*	Water depth (m)	Temp(°C) Surf./Bottom	Salinity(ppt) Surf./Bottom	Comment
near Thetis Is.	70°34'	150°16'	4-7	GN	77	W	3-4	5.9/5.5	30/27	-
near Thetis Is.	70°34'	150°10'	4	GN	-	S	3	-	-	ice loss
near Thetis Is.	70°33'	150°11'	7-13	GN	150	W	3-4	6/4	27/31	-
Kogru	70°34'	152°3'	9	GN	11	W	1-2	8.5/8.5	17/17	2 km from shore
offshore - 1a	70°38'	150°44'	4	GN	-	S	15	-	-	ice loss
offshore - 1b	70°38'	150°44'	4	GN	-	S	15	-	-	ice loss
offshore	70°40'	151°39'	13	GN	-	S	7	-	-	seal loss
offshore	70°42'	150°40'	4	OT**	1	M	12	3.5/2.5	28/32	5 km tow
offshore	70°38'	150°30'	4	OT**	2	M	11	4/2.5	27/33	12 km tow

* S(surface), M(mid-water), W(most of water column); GN (gillnet), OT (otter trawl).

** towed at about 3 knots.

RESULTS AND DISCUSSION

Temperature and Salinity Patterns

In early August, waters in Harrison Bay were a brackish mixture of offshore marine waters and the freshwater discharge from the Colville River. Water temperatures and salinities were highly variable across the bay; they ranged from 0 to 9°C, and from 15.5 to 35 ppt. Two trends were noted. First, surface waters were, on the average, slightly warmer (approximately 1°C) and less saline (approximately 2.6 ppt) than bottom waters. A well-developed temperature/salinity stratification was apparent 3-4 m below the surface in more than half the sonar records. Second, nearshore waters were slightly warmer and less saline than offshore waters in both surface and bottom layers (Figs. 2 and 3).

A small surface intrusion of relatively cold water off the Colville Delta (shown in Fig. 2) was examined in more detail since a sonar transect went through this region. Based on the sonar record, which shows the location and depth of the transition layer along a north-south transect, and the data presented in Figures 2 and 3, a schematic cross-section of water masses in Harrison Bay near Thetis Island was constructed (Fig. 4). Warmest and freshest waters occurred in the nearshore zone, especially off the Colville River. A surface lens of relatively warm and brackish water covered most of the bay out to 15-30 km. Colder and more saline waters lie underneath this surface lens. Variations in temperatures and salinities in subsurface waters probably reflect complex mixing patterns. Additional temperature and salinity profiles in Harrison Bay are presented by Barnes et al. (1977).

Fish

Species Composition and Relative Abundance

Although collection efforts were limited, species of fish caught in Harrison Bay (Table 2) were similar to those present elsewhere in coastal waters of the Beaufort Sea (Craig and McCart 1976; OCSEAP 1978). Gillnet and trawl samples included anadromous species (ciscoes, smelt) and marine species (primarily arctic cod and fourhorn sculpin).

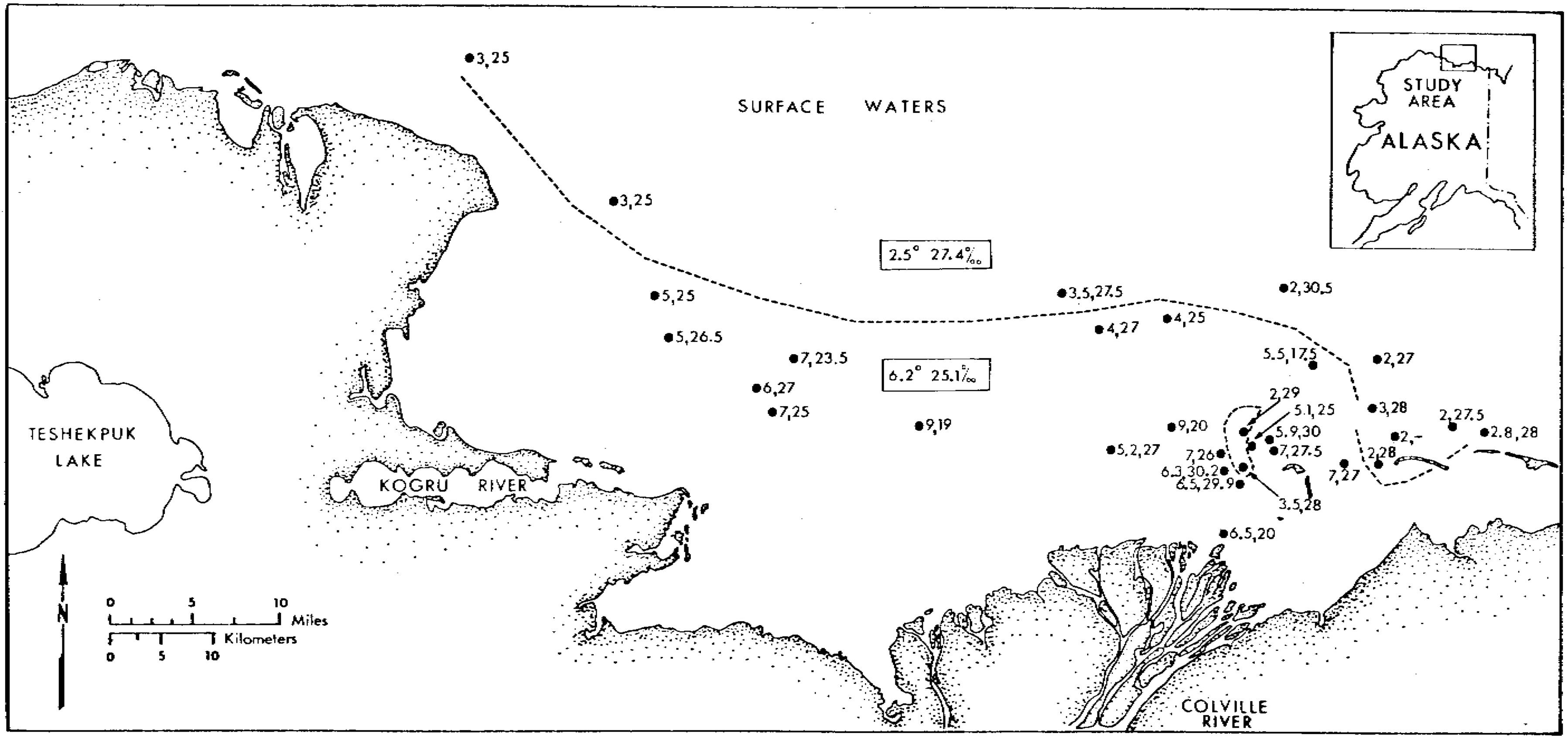

Figure 2. Surface temperatures and salinities in Harrison Bay, 3-14 August 1980. At each site, the temperature value (°C) precedes salinity (ppt). A dashed line separates offshore waters less than 4°C; average values for nearshore and offshore surface waters are indicated in boxes.

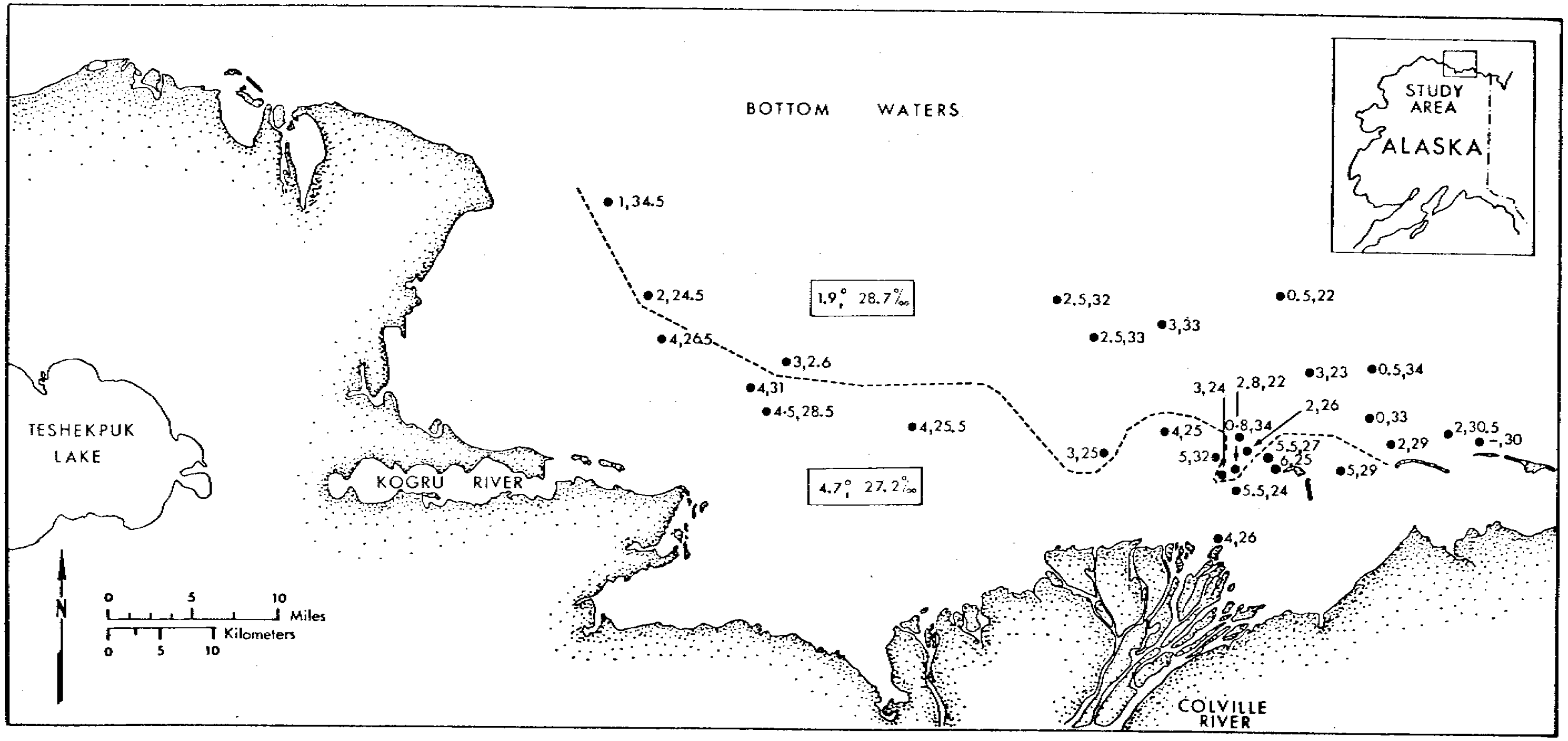

Figure 3. Bottom temperatures and salinities in Harrison Bay, 3-14 August 1980. At each site, the temperature values (°C) precedes salinity (ppt). A dashed line separates offshore waters less than 4°C; average values for nearshore and offshore bottom waters are indicated in boxes.

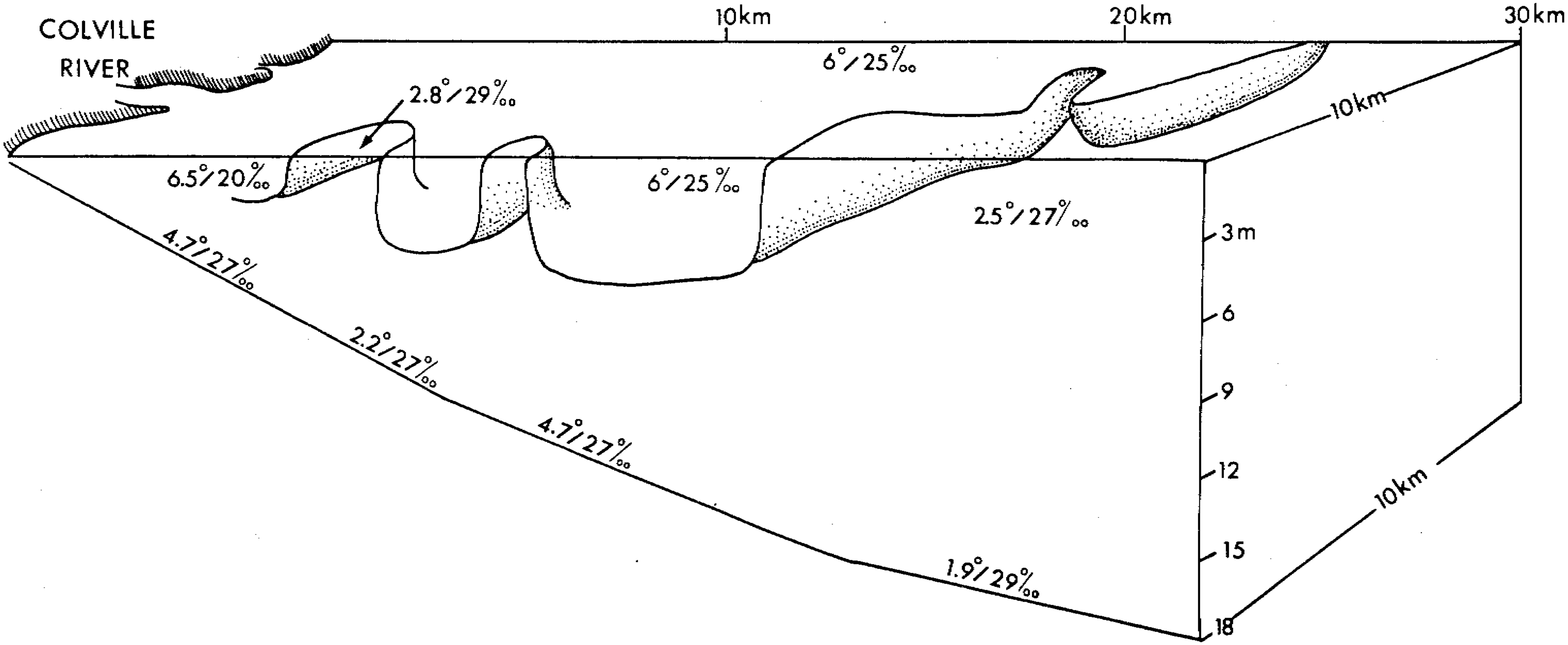

Figure 4. Schematic cross-section of Harrison Bay near Thetis Island. Surface and bottom temperature and salinity values are averages (see Fig. 2 and 3).

Table 2. Gillnet and trawl catch results in Harrison Bay, August 1980. Station data are provided in Table 1 and Figure 1. Tri-net trawl data are from Broad et al. (pers. comm.).

	Number of Fish			
	Gillnets		Otter Trawl	Tri-net Trawl*
	Thetis n=2	Kogru n=1	Thetis n=2	Harrison Bay n=63
Anadromous				
Arctic cisco	5	8	-	-
Least cisco	-	5	-	-
Boreal smelt	-	2	-	-
Marine				
Arctic cod	-	-	-	75+
Fourhorn sculpin	6	32	-	2
Liparidae	-	-	-	3
Gunnel?	-	-	-	1
Totals	11	47	0	81+
Catch Per Unit Effort				
Fish/gillnet day	1.2	102		
Fish/trawl h			0	2.3+

* Data from C. Broad (pers. comm.). Bottom or mid-water trawls were collected with a shrimp tri-net trawl (4 m opening), 1-6 August 1980. Tows were about 1.6 km in length (0.5 h at 2 knots). In samples where the presence or absence of fish was recorded, 75 arctic cod were counted in 19 trawls and listed as 'present' in 11 others.

Few fish were caught because of few completed fishing efforts. Only three of the seven gillnets operated successfully without disruption by ice flows, currents or seals. These included two sets in offshore waters near Thetis Island and one set behind the Eskimo Islands at the mouth of the Kogru River (Fig. 1, Tables 1 and 2). The low catch per unit effort (CPUE) in offshore waters near Thetis Island is similar to that reported for other offshore waters near Simpson Lagoon (Craig and Haldorson 1981). The high CPUE in the Kogru River (a lagoon environment) is primarily due to a large catch of fourhorn sculpin.

No fish were caught during our 3 h of trawling in offshore waters near Thetis Island (Fig. 1, Table 2), but fish were caught in approximately half of 63 tri-net trawls taken in Harrison Bay by C. Broad (pers. comm.) during 1-6 August 1980. Although they were trawling for invertebrates, Broad's crew caught four species of marine fish in offshore waters: arctic cod, fourhorn sculpin, liparids and possibly a gunnel (Table 2). Over 90% of their catch consisted of arctic cod and these fish were widely distributed (Fig. 5).

Hydroacoustic Surveys

Fish densities along offshore transects were highly variable, ranging from 0 to 39.2 fish/10^4 m^3 (Table 3; see Methods for a discussion of the accuracy of these density indices). Densities were highest in the eastern portion of the study area (Fig. 6) but it is not known whether this pattern reflects a distributional trend or merely the date of sampling -- virtually all of the highest densities were recorded during the first cruise. Thereafter, the sampling regime was divided into several disjunct segments interrupted by storms and twice separated by intervals of several days. Furthermore, in contrast to these hydroacoustic records, C. Broad (pers. comm.) noted that trawl catches of arctic cod, which presumably account for most of our fish targets, were greater in the western side of the bay during this same time period.

Fish targets were generally positioned throughout the water column, both above and below the temperature/salinity transition layer (Fig. 7). Although the fish in Figure 7 seem numerous on the hydroacoustic chart,

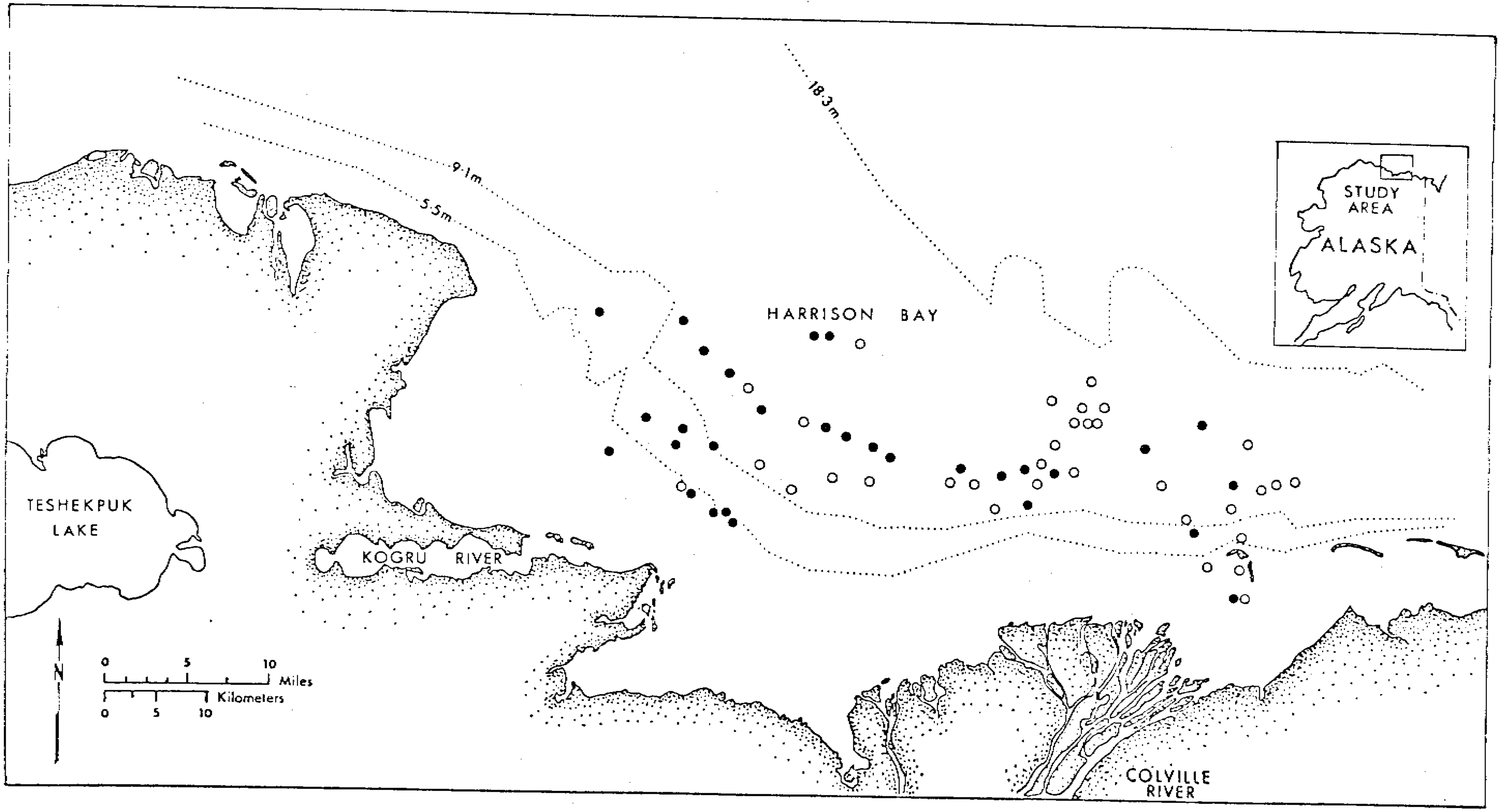

Figure 5. Distribution of arctic cod, August 1980 (data from C. Broad, pers. comm.). Solid circles indicate the presence of arctic cod in bottom or mid-water otter trawls; open circles indicate that no arctic cod were caught.

Table 3. Density indices of fish along hydroacoustic transects in Harrison Bay, August 1980. Transect locations are indicated on Figure 6.

Transect No.	Date	Time	Transect Length (km)	Mean Depth* (m)	No. Fish Targets	Volume Sampled ($10^4 m^3$)	Density Index (fish/$10^4 m^3$)
1	3 Aug	21:55-22:35	8	10.7	36	22.0	1.6
2	4 Aug	01:20-02:26	8	12.0	424	27.7	15.3
3		02:33-03:18	4.8	14.0	350	22.6	15.5
4		03:42-05:04	4.4	10.2	423	11.0	38.5
5		05:08-07:07	13	14.3	1054	63.8	16.5
6		07:20-10:12	18	11.9	1442	61.2	23.6
7		15:13-17:51	19	9.6	552	42.0	13.1
8		18:55-20:20	11	13.9	376	51.0	7.4
9		20:51-21:45	3.6	13.3	364	15.3	23.8
10	5 Aug	00:06-02:00	12	14.5	1722	60.6	28.4
11	7 Aug	20:19-21:15	8.7	6.4	5	8.6	0.6
12		21:16-22:57	4.1	8.7	0	7.5	0
13		23:59-06:30	114	15.2	85	632.4	0.1
14	8 Aug	06:30-07:45	7.8	15.2	0	43.3	0
15		07:45-08:30	4.5	18.3	0	36.2	0
16		09:30-10:30	7.2	4.6	145	3.7	39.2
17		10:30-12:10	3.5	12.6	153	13.3	11.5
18		12:10-13:40	12.5	21.2	146	134.9	1.1
19		13:40-14:40	14.6	13.6	49	64.8	0.8
20		15:48-16:32	15.4	6.2	70	14.2	4.9
21		17:32-18:30	11.5	6.4	53	11.3	4.7
22		19:10-20:30	8.5	5.0	9	5.1	1.8
23	9 Aug	12:40-14:10	16.5	2.0	17	1.6	10.6
24		14:10-14:28	6	8.2	15	9.7	1.5
25		15:00-16:00	13	19.2	22	115.1	0.2
26		16:35-17:35	12.5	19.0	8	108.3	0.1
27		18:04-19:04	14	19.0	15	121.3	0.1
28		19:34-21:17	23.3	21.0	24	246.7	0.1
29		21:20-22:00	7.5	19.8	12	70.6	0.2
30	13 Aug	15:48-17:48	13.2	5.5	7	9.6	0.7
31		19:20-20:32	21	6.5	11	21.3	0.5
32		20:32-22:30	20	6.5	2	20.3	0.1
33	14 Aug	12:15-14:30	18	10.5	29	47.6	0.6
34		14:47-17:32	24.1	13.0	21	97.8	0.2
35		18:25-19:30	7.5	11.1	5	22.2	0.2

* Average of depths at beginning and end of transect.

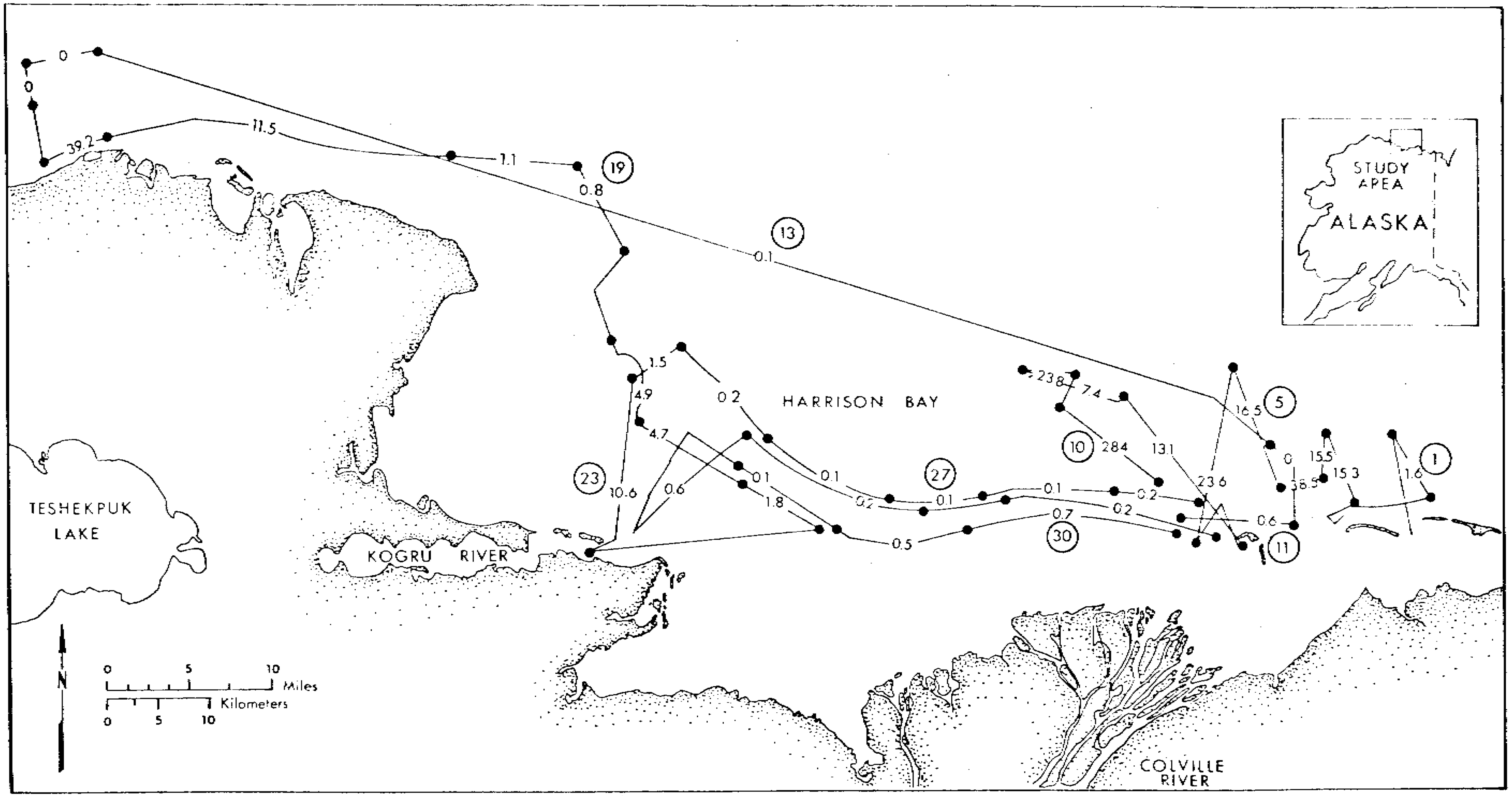

Figure 6. Density indices for fish along hydroacoustic surveys, August 1980. Units: no. fish "targets"/ 10^4 m^3. Circled numbers refer individual transects and are provided as a reference to transects listed in Table 3.

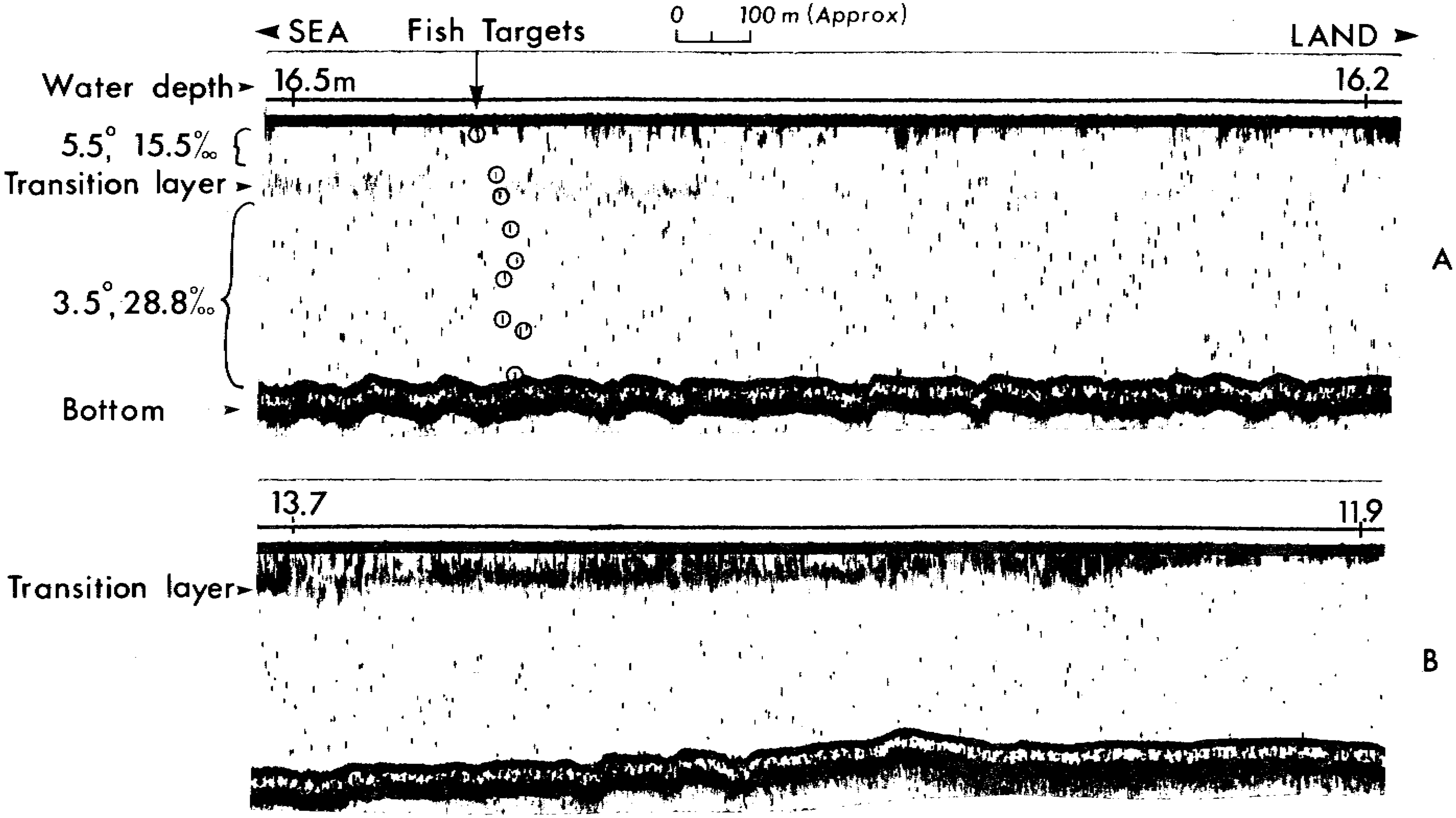

Figure 7. Hydroacoustic transect record (T-9, 4 August 1980) showing (A) fish "targets" throughout the water column and transition layer, and (B) fish "targets" concentrated in the upper water layer as the transition layer intersects the water surface. Chart strip B is a continuation of strip A after a 2 km interval. Each strip covers about 1.6 km. This area of marine "upwelling" is schematically shown in Figure 4.

this is an artifact due to differing horizontal and vertical chart scales. The horizontal chart scale is much compressed relative to the vertical scale (27:1), and so 1 mm vertically represents 0.3 m in the water column whereas 1 mm represents 8 m in the horizontal plane.

The transect illustrated in Figure 7 is located at the edge of a brackish water lens overlying cooler, more saline water. In Figure 7a, the brackish water lens (5.5°C, 15.5 ppt) is approximately 4.5 m deep; in Figure 7b, the same lens intersects the surface as cool saline water (3.5°C, 28.8 ppt) pushed up or swirled to the surface. An accumulation of fish targets was apparent at the edge of the surface lens as indicated by fish densities in the brackish water areas of Figures 7a and 7b. In Figure 7a, the densities of fish in the vertical area above the transition layer was approximately 0.016 fish targets/m^2 (177 fish targets/7380 m^2); in Figure 7b, the vertical area of the lens decreased while the density of fish increased ten-fold to 0.15 fish targets/m^2 (333 fish targets/2160 m^2). As shown in Figure 4, there were actually two of these small "upwellings" of marine water, but fish were concentrated around only one of them.

Moulton et al. (1980), who conducted hydroacoustic surveys in Prudhoe Bay, observed a wide range of fish densities. Densities were 0-7.8 fish/10^4 m^3 in July 1979 and 0-329 fish/10^4 m^3 in August-September 1979. Moulton also noted an association between fish distribution and the landward edge of the bottom layer of relatively marine water. Highest densities of fish targets were in the brackish surface waters just above the leading (landward) edge of the bottom marine water mass.

Although data are limited, in both the Prudhoe Bay and Harrison Bay situations the concentrations of fish in the brackish water layer were not particularly associated with the transition layer *per se*, but rather with the area just above the edges of the marine water mass wherever they might occur. This is a reasonable strategy for nekton to adopt since planktonic invertebrate densities are often more abundant in such interfacial areas (Baker and Brook 1971; Harris 1972; Anderson 1969; Karl 1978; Chester 1978) and have been observed in this area specifically (Tarbox and Moulton 1980).

This could be an environmentally stressful zone for these planktonic animals. Such conditions would make the plankton easier prey for the more mobile fishes.

Epibenthic Invertebrates

The abundance and biomass of epibenthic invertebrates collected in Harrison Bay are summarized in Table 4. *Mysis litoralis* and *Mysis relicta*, the most common species of mysids found along the Alaskan Beaufort Sea coast, accounted for the major portion of the total biomass at each station. The absence of *M. relicta* at Station 4 may be related to salinity, since the salinity at this station was higher than at any of the other three stations (31°/₀₀ vs 24-27°/₀₀). Griffiths and Dillinger (1981) found this species to be significantly more abundant at shallow nearshore stations (warmer temperatures and lower salinities) than at marine or nearshore barrier island stations.

Amphipods were the only other group of epibenthic invertebrates collected by the drop nets in Harrison Bay during this brief survey. The number of species and biomass were low, when compared to samples collected in Simpson Lagoon (Griffiths and Dillinger 1981), possibly due to the nature of the substrate. In the region of Harrison Bay where the samples were collected, the bottom is composed of silt and sand, which presumably was deposited by the Colville River. Deposition continues throughout the open water season, producing a habitat that is apparently more favorable for burrowing amphipods -- the most common types collected. One exception was the amphipod *Apherusa glacialis*, which is an ice-associated species in these waters (Griffiths and Dillinger 1981). Its presence was possibly due to the large amounts of broken ice present in Harrison Bay during the sampling period.

Geographic comparisons of biomass for major groups of epibenthic invertebrates along the Alaskan Beaufort Sea coast are confounded by a variety of factors. These include the time of collection and natural variations in the densities of the organisms. Natural variations are caused, in part, by the responses of the organisms to various physical conditions (wind, temperature, salinity, ice, etc.). With these limitations in mind,

Table 4. Abundance (No./m^2) and biomass (mg/m^2 wet weight) of epibenthic invertebrates collected in Harrison Bay, 13 August 1980. Sampling locations are shown in Figure 1. N=5 drop net samples for each station.

		Station 1 70°35.5'N 150°17.1'W		Station 2 70°35.0'N 150°42.6'W		Station 3 70°34.1'N 151°15.6'W		Station 4 70°35.5'N 151°00.0'W	
		Abun.	Biomass	Abun.	Biomass	Abun.	Biomass	Abun.	Biomass
MYSIDS									
Mysis litoralis	$\bar{x}$	46.0	252.5	33.8	225.3	24.0	149.2	17.0	243.1
	SD	39.6	243.3	29.6	168.4	13.4	123.8	8.4	225.1
Mysis relicta	$\bar{x}$	3.0	91.8	8.8	335.3	5.0	190.3	-	-
	SD	4.5	136.9	14.4	546.5	5.0	203.6	-	-
Mysis spp.	$\bar{x}$	-	-	-	-	1.0	6.3	-	-
	SD	-	-	-	-	2.3	14.1	-	-
All Mysids		49.0	344.3	42.6	560.6	25.0	345.8	17.0	243.1
AMPHIPODS									
Pontoporeia affinis	$\bar{x}$	-	-	1.3	9.4	-	-	-	-
	SD	-	-	2.5	18.8	-	-	-	-
Apherusa glacialis	$\bar{x}$	-	-	1.3	6.3	3.0	6.6	-	-
	SD	-	-	2.5	12.5	4.5	10.9	-	-
Hyperiid Juvenile	$\bar{x}$	-	-	1.3	1.3	-	-	-	-
	SD	-	-	2.5	2.5	-	-	-	-
Calliopid	$\bar{x}$	11.0	10.0	2.5	2.5	34.0	28.0	27.0	25.0
	SD	10.8	10.6	2.9	2.9	41.3	30.9	13.0	1.0
Oedicerotid	$\bar{x}$	5.0	21.0	-	-	-	-	1.0	7.0
	SD	6.1	28.8	-	-	-	-	0.4	3.1
Unidentified Amphipod	$\bar{x}$	1.0	1.0	-	-	-	-	-	-
	SD	2.3	2.3	-	-	-	-	-	-
All Amphipods		17.0	32.0	6.4	19.5	37.0	34.6	28.0	32.0
All Mysids and Amphipods		66.0	376.3	49.0	580.1	62.0	380.4	45.0	275.1
Bottom temperature °C		3.0		3.0		3.8		4.0	
Bottom salinity °/₀₀		24.0		25.0		26.8		31.0	
Water depth (m)		6.1		6.7		6.1		6.7	

the results of drop-net collections taken by Griffiths and Dillinger (1981) in Simpson Lagoon in 1978 and 1979, by us in Prudhoe Bay in 1980, and by us in Harrison Bay in 1980 are compared in Figure 8. It appears that the biomass of epibenthic invertebrates is highest in Simpson Lagoon, primarily because of higher *Mysis litoralis* biomass and higher total amphipod biomass. However, it is interesting to note that the biomass of *Mysis relicta*, a nearshore brackish species, was similar among the three areas and the three years sampled. These limited results suggest that the offshore waters of Harrison Bay support relatively sparse populations of the epibenthic invertebrates that are important food items for higher trophic levels (birds and fish). This may, in part, explain the low number of fish recorded in Harrison Bay during this study. In turn, this suggests that Simpson Lagoon is, relative to Harrison Bay, a more important feeding area for fish.

It must be stressed that these results and conclusions are based on information collected during a single day at four stations in Harrison Bay. Before these comparisons can be made with some confidence, more samples collected over a wider temporal and spatial framework would be required.

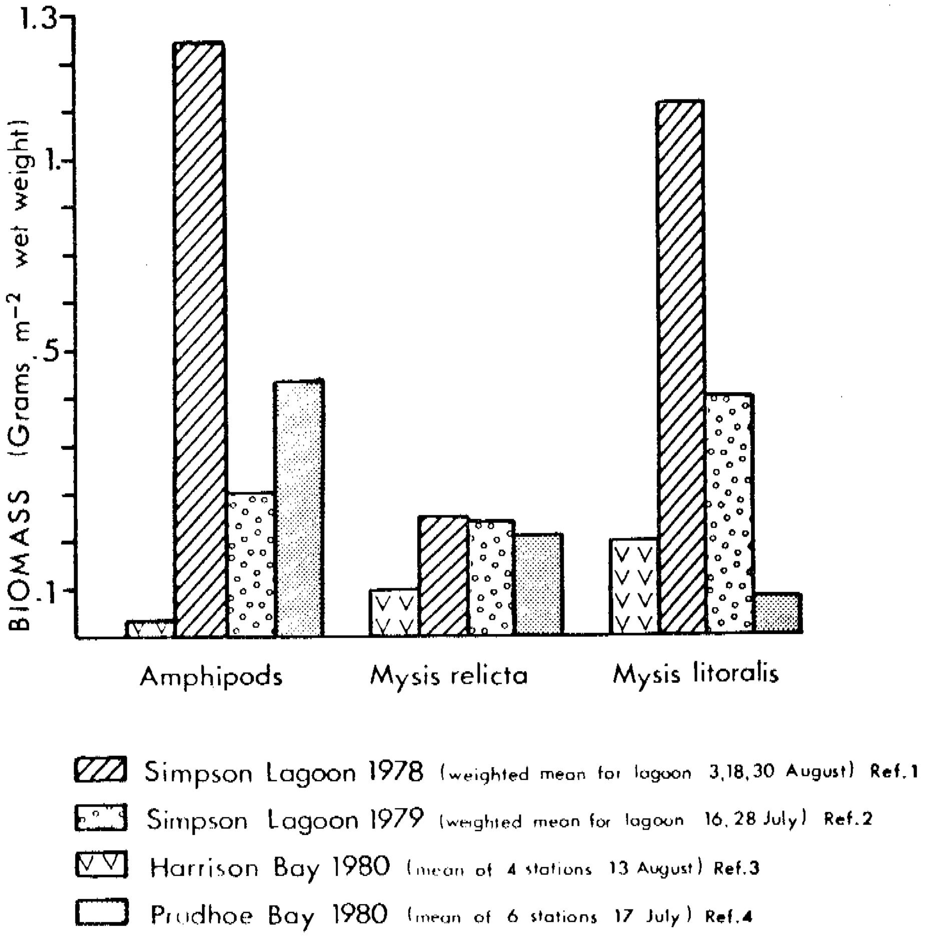

Figure 8. Biomass of epibenthic invertebrates (mysids and amphipods) in Harrison Bay, Simpson Lagoon, and Prudhoe Bay, 1978-1980.
References: 1 and 2 (Griffiths and Dillinger),
3 (this study),
4 (Griffiths, unpubl. data).

PART 2

Winter survey of fish and epibenthic invertebrates in Beaufort Sea coastal waters (November 1979, April-May 1980)

SUMMARY

Fish and epibenthic invertebrates were collected during early and late winter at coastal locations between the Colville and Canning rivers and at one site 175 km offshore. Arctic cod, boreal smelt, fourhorn sculpin, and snailfish were caught under the ice. The catch per unit effort for arctic cod was 30 times greater at the offshore site than at a nearshore site. Mysids and amphipods were the most abundant groups of epibenthic invertebrates collected. These organisms appear to reproduce in October-November. Several species of amphipods occupy shallow (about 2.5 m) nearshore waters year round. The species composition of invertebrates overwintering in shallow lagoons and in somewhat deeper nearshore waters differs.

INTRODUCTION

This section represents a continuation of winter research efforts reported by Griffiths and Dillinger (1981) and Craig and Haldorson (1981). The purpose of the winter program is to provide distributional and life-history information for fishes and epibenthic invertebrates overwintering in Simpson Lagoon and adjacent coastal areas of the Beaufort Sea in Alaska. Locations of sampling stations included nearshore sites between the Colville and Canning rivers and one site 175 km north of Prudhoe Bay (Fig. 9).

METHODS

Two winter surveys were conducted, 1-17 November 1979 and 29 April-6 May 1980. Sampling sites were reached by helicopter, and a Global Navigation System 500 and a VHF homing device were used to relocate the station 175 km offshore. Specific locations and descriptions of sampling sites are listed in Table 5.

Fish

Sampling gear included gill nets (47.2 m long with panels of stretched mesh sizes ranging from 1.9-8.9 cm) and fyke nets (with four 27.4 m lead nets and a common trap). Nets were usually set at or near the bottom of the water column to avoid freezing with surface ice. The offshore nets were set under the ice surface.

Invertebrates

Amphipod traps were cylindrical with a recessed, funnel-shaped entrance. Traps measured 25 cm in length, 7 cm in diameter and were constructed of 1 mm wire mesh. They were baited with meat, lowered through holes in the ice to the bottom, and retrieved after approximately 24 h.

Epibenthos was qualitatively sampled in Stefansson Sound (Boulder Patch) and at Flaxman Island in November 1979 using a Wildco scrape/skid dredge (61 cm long, 36 cm wide, 36 cm in height, with a 1.05 mm mesh). The dredge was towed 50 m along the bottom between two holes in the ice.

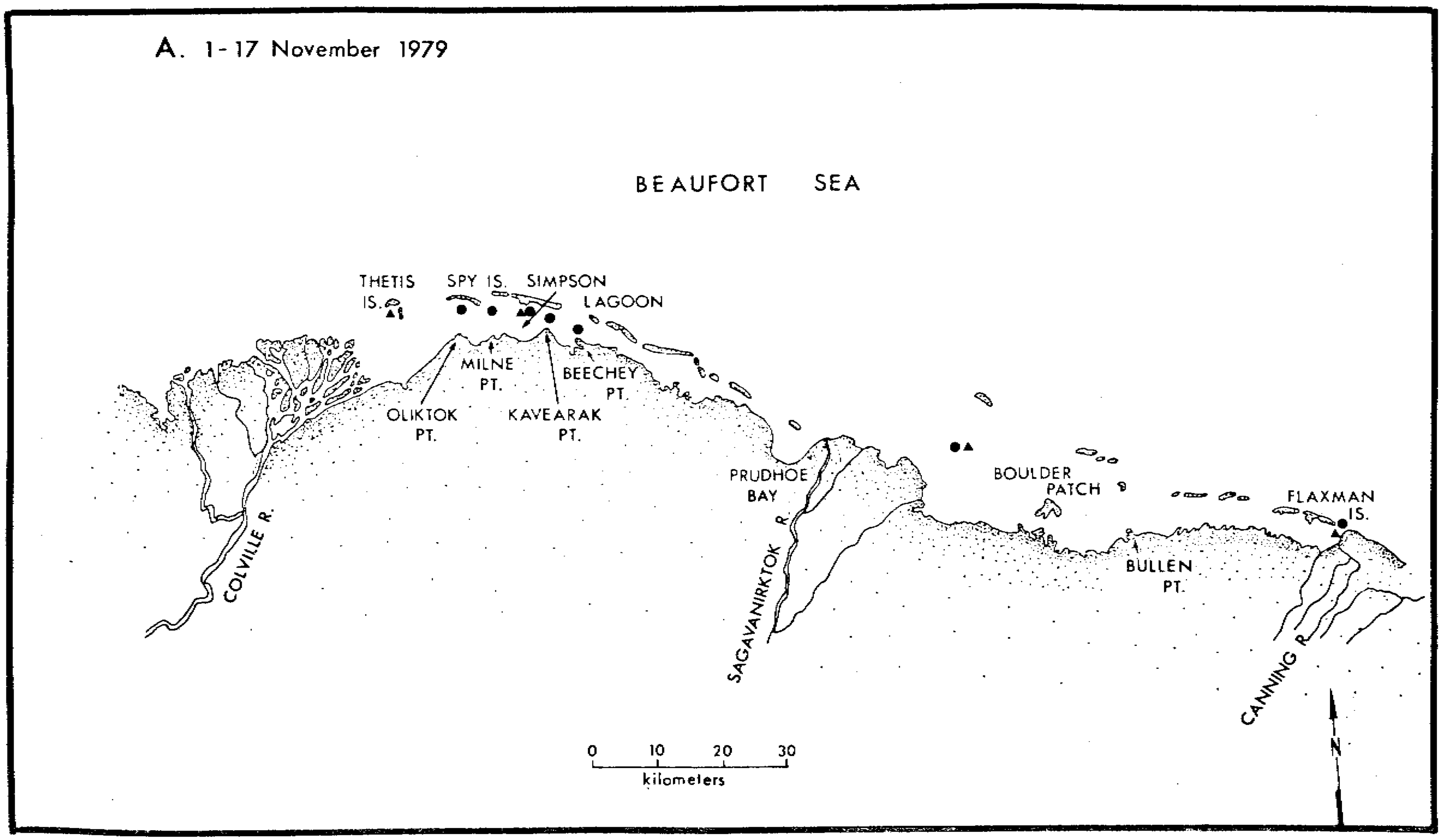

Figure 9a. Winter sampling locations for fish (triangles) and invertebrates (circles) during (A) 1-17 November 1979, and (B) 29 April-6 May 1980.

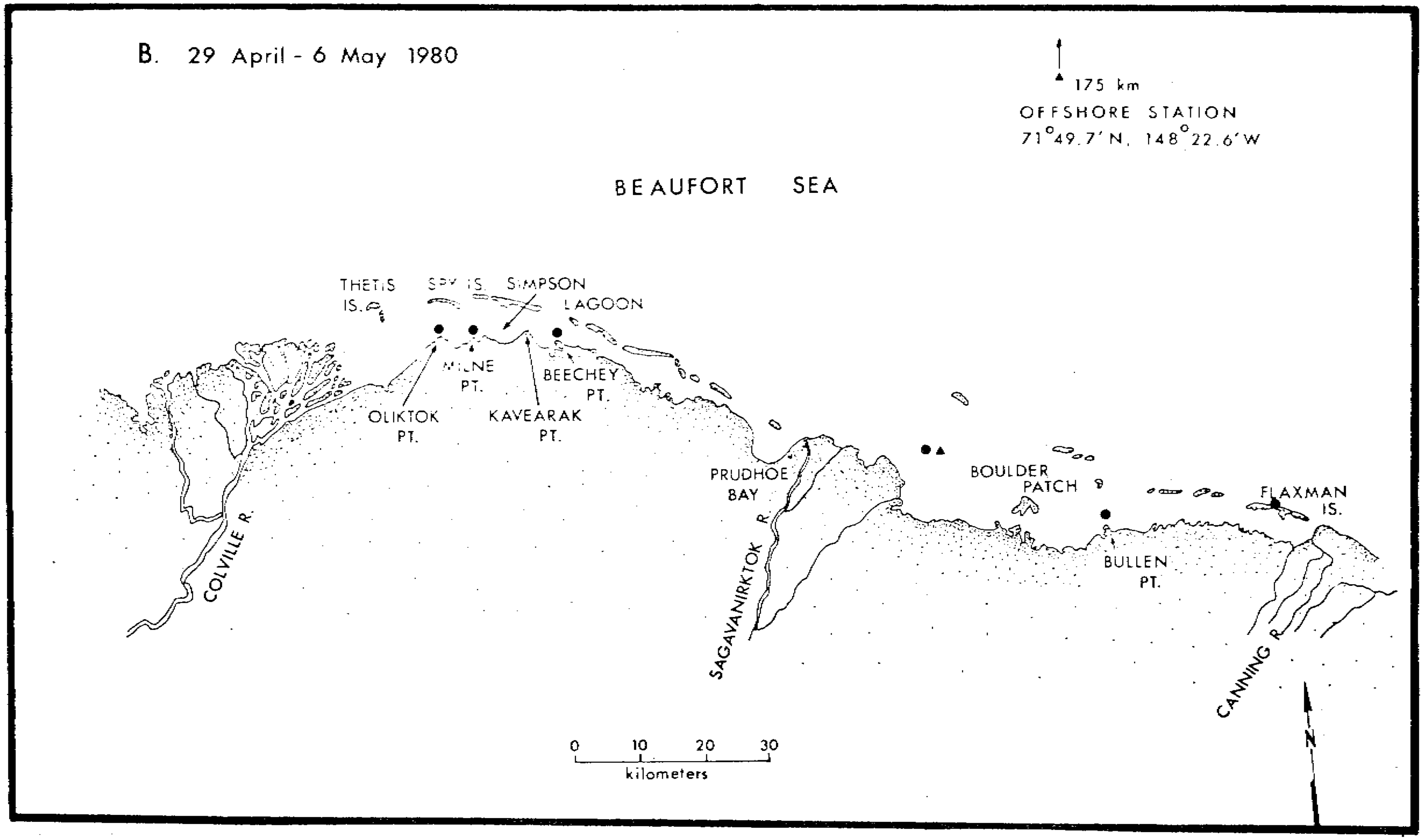

Figure 9b. Winter sampling locations for fish (triangles) and invertebrates (circles) during (A) 1-17 November 1979, and (B) 29 April-6 May 1980.

Table 5. Sampling locations and descriptions.

Site	Latitude	Longitude	Sample type and period*		Water Depth** (m)	2-13 Nov. 1979		2 May 1980***	
			Fish	Invert		Temp. (°C)	Salinity (ppt)	Temp. (°C)	Salinity (ppt)
Thetis Island - 2 km S	70°32'	150°13'	1		1.7	-	-		
Oliktok Pt. - lagoon center	70°32'	149°50'		1,2	0.5	-1.0	30	-	-
Spy Island - 2 km SE of E end	70°32'	149°45'		1	0	0.5	25		
Simpson Lagoon/Milne Pt. - lagoon center	70°32'	149°30'	1	1,2	0.5	0.5	30.5	-	-
Kavearak Pt. - lagoon center	70°31'	149°17.5'		1	0	-0.5	16.5		
Beechey Pt. - lagoon center	70°30'	149°9'		1,2	0	-0.5	32	-	-
Boulder Patch - 11 km S Narwhal Is.	70°18'	147°33'	1,2	1,2	4.6	-	-	-2	-
Bullen Pt. - 4.5 km N Bullen Point	70°12'	146°51'		2	3			-	-
Flaxman Is. - 2 km S of E end	70°9.5'	145°57'	1		0.5	-0.5	18		
- 1 km E of E end	70°10.5'	145°56'		1	0.5				
- 1 km N of mid island	70°12'	146°1'		2	3.0			-0.5	-
175 km offshore	71°49.7'	148°22.6'	2		2500+			-2	30

* Sampling periods: 1(1-17 Nov. 1979), 2(29 April-6 May 1980).

** Approximate late-winter water depth below the ice.

*** Equipment failure.

All samples were preserved in 10% formalin and returned to the laboratory for analysis. Samples were sieved through a 1.024 mm mesh nylon screen, washed with water, and examined under a low-power binocular microscope. Where possible, amphipods, mysids, copepods and isopods were identified to species, while other organisms were sorted into major taxonomic groups. Individual species or taxonomic groups were weighed (wet) on a Mettler PL200 electronic balance (± 0.001 g).

Limitations and Biases

Each of the two types of sampling gear samples only a portion of the biota present. The baited amphipod trap attracts carnivores. The Wildco dredge suffers from the same limitations as other dredges and trawls; namely, motile epibenthic organisms (mysids and amphipods) can avoid capture by taking evasive action as the dredge approaches.

Limtations and biases of laboratory techniques are discussed in some detail by Griffiths and Dillinger (1981).

RESULTS AND DISCUSSION

Fish

Arctic cod, boreal smelt and fourhorn sculpin were the major species caught during the early and late winter surveys:

	% Composition	
	Nov. 1979	Apr./May 1980
arctic cod	33	100
boreal smelt	40	
fourhorn sculpin	21	
snailfish	4	
unident. skeleton	1	
n =	70	67

A summary of winter catch data by date and location is listed in Table 6. As in our previous winter studies, boreal smelt were abundant only near the Colville River where they presumably gather for a spring spawning run into the river. Arctic cod were encountered at all stations but the catch per unit effort (CPUE) was highest offshore -- in the late winter collection period, when a single type of sampling gear (fyke net) was used, the CPUE was over 30 times greater 175 km offshore than in the Boulder Patch in Stefansson Sound.

More detailed analyses of arctic cod and boreal smelt, the principal species caught, are presented in other reports (Craig et al. 1981; Haldorson and Craig in prep.).

Invertebrates

Epibenthic invertebrates were collected at several nearshore locations along the coastline (Tables 7 and 8, Fig. 9). The under-ice sampling techniques used during the early winter and late winter surveys were qualitative in nature. Therefore, the results are presented as percent composition of invertebrate samples rather than numbers per unit area. The results have been organized seasonally.

Table 6. Summary of 1979-1980 winter catch by date and location. Catch per unit efforts (CPUE) are listed for combined gill and fyke net catches per day.

		CPUE (Fish/Net-Day)				
Date	Fish	Thetis Island	Simpson Lagoon	Boulder Patch	Flaxman Island	175 km Offshore
4-15 Nov. 1979	arctic cod	2.0	0.3	0.3	4.5	
	boreal smelt	2.0	1.2	0	0	
	fourhorn sculpin	0	0.4	0.1	3.5	
	snailfish	0	0	0.2	0	
	unident. skeleton	0	0	0	0.5	
	Total CPUE	4.0	1.9	0.6	8.5	
	Effort (days)*	2(2/0)	20(11/9)	15(12/3)	2(2/0)	
29 Apr. - 6 May 1980	arctic cod			0.3		10.8
	Total CPUE			0.3		10.8
	Effort (days)*			7(0/7)		6(0/6)
Approximate late-winter water depth (m)		1.7	0.5	4.6	0.5	2500+

* Listed in parentheses: number of gill net days/number of fyke net days

Table 7. Percent composition of invertebrates (biomass) collected at various locations along the Beaufort Sea coast during November 1979.

	November 1979 Wildco Dredge		November 1979 Baited Amphipod Trap*						
			Simpson Lagoon						
	Boulder Patch	Flaxman Lagoon	Oliktok Point	East Spy Is.	Milne Point	Kavearak Point	Beechey Point	Boulder Patch	Flaxman Lagoon
AMPHIPODS									
Onisimus glacialis	1.2	10.3	66.6	62.4	100.0	100.0	91.7	-	93.6
Onisimus litoralis	-	-	-	1.1	-	-	-	27.2	0.1
Gammarus setosus	-	3.5	-	-	-	-	8.3	-	3.2
Gammaracanthus loricatus	-	0.2	-	-	-	-	-	-	0.1
Pontoporeia affinis	-	30.6	33.3	-	-	-	-	-	-
Boeckosimus affinis	6.2	-	-	35.5	-	-	-	40.8	-
Acanthostepheia malmgreni	0.6	-	-	-	-	-	-	-	-
Oediceros saginata	-	0.3	-	-	-	-	-	-	-
Weyprechtia heugleni	-	-	-	-	-	-	-	6.8	-
Anonyx nugax	-	-	-	-	-	-	-	5.4	-
Melita sp.	-	15.1	-	-	-	-	-	-	-
Calliopidae	38.3	0.3	-	-	-	-	-	6.1	0.1
Oedicerotidae	11.1	7.1	-	-	-	-	-	-	-
Unidentified Amphipod	-	0.3	-	-	-	-	-	-	-
MYSIDS									
Mysis litoralis	2.5	15.9	-	-	-	-	-	8.8	-
Mysis relicta	-	2.7	-	-	-	-	-	-	0.2
Mysis spp.	-	2.9	-	-	-	-	-	-	1.6
EUPHAUSIID									
Thysanoessa raschii	-	-	-	-	-	-	-	4.1	-
COPEPODS									
Calanus hyperboreus	5.6	4.3	-	-	-	-	-	-	-
Calanus glacialis	1.2	1.1	-	-	-	-	-	-	-
Pseudocalanus minutus	-	<0.1	-	-	-	-	-	-	-
Metridia lucens	0.6	-	-	-	-	-	-	-	0.1
Actididae	-	0.3	-	-	-	-	-	-	-
Calanoid	25.9	-	-	-	-	-	-	-	-
ISOPODS									
Saduria entomon	1.2	1.2	-	-	-	-	-	-	0.8
CUMACEANS	0.6	0.4	-	-	-	-	-	-	-
ECHINODERMS	-	-	-	-	-	-	-	0.6	-
CHITONS	0.6	-	-	-	-	-	-	-	-
POLYCHAETES	1.2	2.1	-	-	-	-	-	-	-
HYDROIDS	-	<0.1	-	-	-	-	-	-	-
GASTROPODS	1.2	0.4	-	-	-	-	-	-	-
NUDIBRANCHS	0.6	-	-	-	-	-	-	-	-
SEA STARS	1.9	-	-	-	-	-	-	-	-
Total	100.5	99.0	99.9	99.0	100.0	100.0	100.0	99.1	99.9
Total No. of organisms	162	1174	3	93	1	95	12	147	1411
Total No. of samples	4	4	1	1	1	1	1	2	2

* **Traps were usually set for one or two days.**

Table 8. Percent composition of invertebrates collected in baited amphipod traps (24 h sets) at various locations along the Beaufort Sea coast during May 1980.

	% Composition in Baited Amphipod Trap 3-4 May 1980					
	Oliktok Point	Milne Point	Beechey Point	Boulder Patch	Bullen Point	Flaxman Island (Ocean side)
AMPHIPODS						
Onisimus glacialis	95.6	69.2	87.5			
Boeckosimus affinis	4.3	30.8	12.5	57.4	66.7	51.8
Onisimus litoralis				15.2		47.5
Anonyx nugax				27.3		0.2
Gammarus setosus						0.2
HYDROIDS					16.7	
GASTROPODS				0.1	16.7	
Total No. of organisms	115	286	1635	915	6	444
Total No. of samples	1	1	1	4	1	1

Early Winter (November 1979)

A total of 33 species or groups were represented in the early winter collections, and catches varied considerably between sampling methods and sites. In the shallow waters (~2 m) of Simpson and Flaxman lagoons, *Onisimus glacialis* was the most common amphipod collected in baited traps (Table 7). Similar findings were reported for Simpson Lagoon using this technique in November 1978 (Griffiths and Dillinger 1981). The Wildco dredge tended to collect a more diverse array of organisms than the amphipod trap, probably because the amphipod trap collects carnivores only. Dredge samples from Flaxman Lagoon were dominated by the burrowing amphipods *Pontoporeia affinis* and *Melita* sp.

The composition of invertebrates in both amphipod traps and Wildco dredge samples was different in the deeper waters (4.6 m) of the Boulder Patch than in the shallow lagoons (Table 7). Two amphipods, *Onisimus litoralis* and *Boeckosimus affinis*, dominated the samples from amphipod traps in the deeper waters, while *O. glacialis* dominated in the shallow waters. In the case of Wildco dredge samples, calliopid amphipods and calanoid copepods were the major invertebrates collected in the Boulder Patch, while the amphipods *P. affinis* and *O. glacialis* and the mysid *M. litoralis* dominated the shallow waters of Flaxman Lagoon. These differences in species composition between shallow lagoons and the deeper waters at the Boulder Patch were also evident in November 1978 [reported by Griffiths and Dillinger (1981)] and may be a reflection of the unusual habitat associated with the kelp community in the Boulder Patch (for a description of this community, see Dunton and Schonberg 1979, 1980).

As in November 1978, most samples contained gravid females of both mysid and most amphipod species; this appears to confirm that most epibenthic and pelagic invertebrates in the nearshore waters of the Beaufort Sea breed shortly after ice formation.

Late Winter (May 1980)

Due to time constraints, only amphipod traps were used in May 1980. The results from the Simpson Lagoon stations were similar to those reported by Griffiths and Dillinger (1981), who used similar methods during the late winter (May-June) of 1978 and 1979. In all samples from Simpson Lagoon, *Onisimus glacialis* was the dominant amphipod and *Boeckosimus affinis* was of secondary importance (Table 8).

The samples collected at the Boulder Patch, at Bullen Point and on the ocean side of Flaxman Island showed *Boeckosimus affinis* to be the dominant amphipod. In general, the species composition of samples from these three sites was similar to that previously found on the ocean side of the barrier islands of Simpson Lagoon (Griffiths and Dillinger 1981).

CONCLUSIONS

The November collections in both 1978 and 1979 show that a variety of amphipod and mysid species are present in the nearshore Beaufort Sea in early winter. The presence of gravid individuals of nearly all the species collected suggests that epibenthic invertebrates spawn shortly after ice formation. The species composition of the epibenthic invertebrate community was generally similar in November of the two years.

Samples collected in three years of late winter (May-June) sampling show that several amphipod species (particularly *O. glacialis* and *B. affinis* utilize the shallow nearshore waters of the Beaufort Sea year-round. The late-winter data indicate (1) a similarity between years of study, and (2) a difference in species composition between lagoon and non-lagoon (marine) habitats at this time of year.

PART 3

Epibenthic invertebrates: transport into nearshore waters and distribution around the ARCO causeway, Prudhoe Bay

The importance of epibenthic invertebrates (particularly mysids) in the trophic pathways of the nearshore environment of the Alaskan Beaufort Sea has been extensively documented and is summarized by Griffiths and Dillinger (1981). These authors suggested that the transport of epibenthic organisms into the nearshore system is an important process in maintaining an adequate level of food items for the higher trophic levels (birds and fish).

The present study examines further the movements and distribution of the epibenthos in nearshore waters. Samples were collected in the Egg Island entrance of Simpson Lagoon (Fig. 10) during July 1980 in order to estimate transport rates of epibenthic invertebrates into the lagoon. In addition, a preliminary survey of epibenthic invertebrates was conducted on both sides of the ARCO causeway, a solid-fill gravel structure, 2.8 km in length, to determine if the biomass of selected species or groups varied in relation to the side on which they were collected and to their distance from the causeway. The results of this sampling are of interest since the placement of the causeway has altered nearshore temperature and salinity regimes -- the west side of the causeway tends to be 2-4°C cooler and 10 ppt more saline than the east side during the open-water season (Mungall et al. 1978). The present investigation would give a preliminary assessment of the effect of this artificial structure on the biomass of epibenthic invertebrates in the area and would allow the determination of the number of samples that would be required to demonstrate a change of 10% in the biomasses of the key species at the 0.95 confidence level.

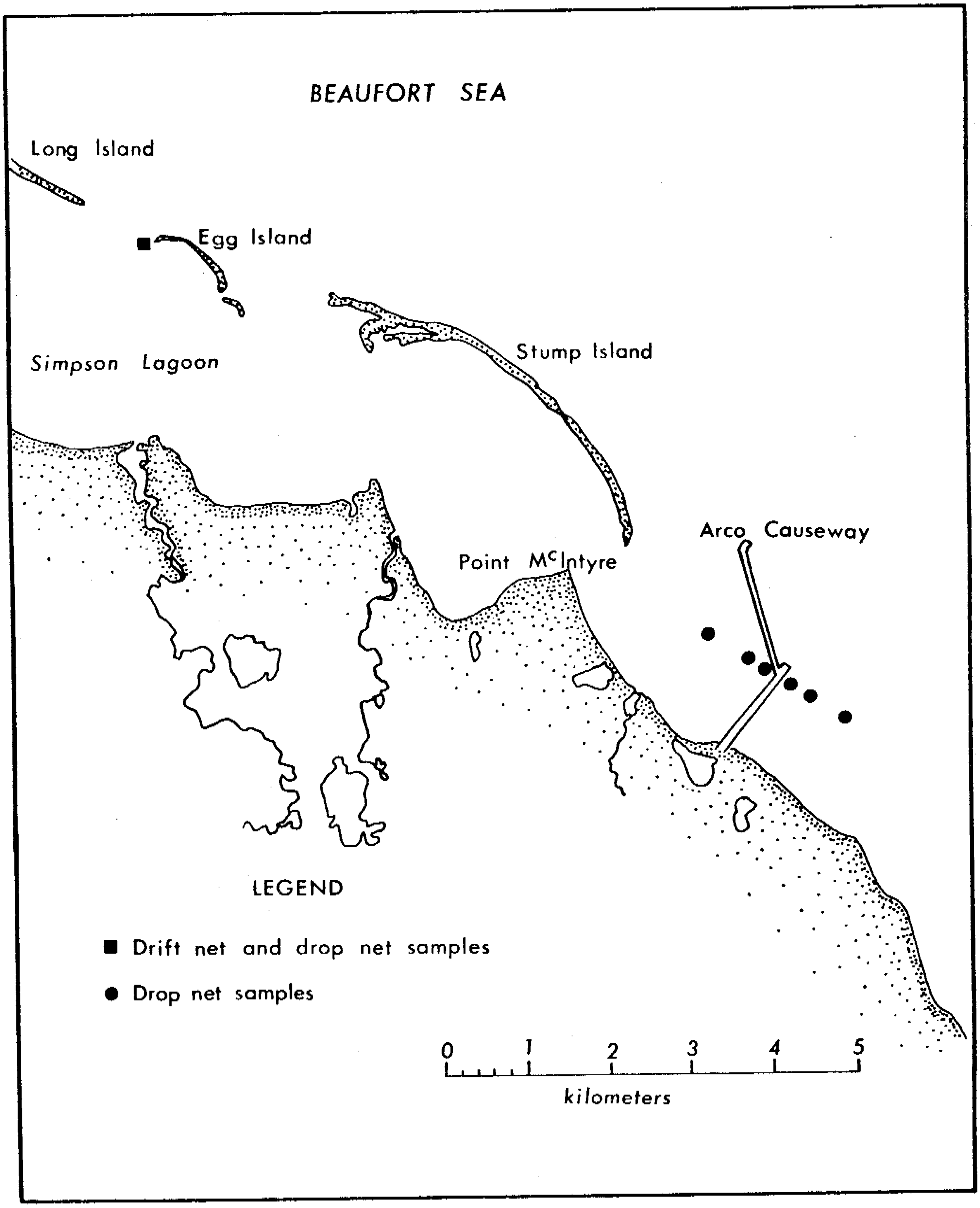

Figure 10. Locations of sampling stations in the Egg Island entrance to Simpson Lagoon and around the ARCO causeway in Prudhoe Bay.

METHODS

Invertebrate transport studies in the Egg Island channel were conducted during 22-26 July 1980, and epibenthos distributions around the ARCO causeway in Prudhoe Bay were examined on 17 July and 8 August 1980. Samples were collected by drop net and drift net as described below.

Drop Net

The deep-water version of the drop net described in an earlier report (Griffiths and Dillinger 1981) was used during both parts of this study. All net screening was 1.0 mm nitex, and the purse collar was nylon ballistics cloth with 0.65 cm^2 atlas netting around the margin. For the transport study, five drop net samples were collected on each date approximately 10 m upstream of the drift net. For the distribution studies, five drop net samples were taken on the east and west sides of the ARCO causeway at distances of 50, 500 and 1000 m from the edge of the causeway.

Drift Net

A 2.8 m long tapering drift net (1.024 mm mesh size) was used to collect current-borne invertebrates moving through the Egg Island entrance of Simpson Lagoon. The net was attached to a 1.0 m x 0.2 m metal frame and was set with its long axis horizontal in water about 1 m deep. Thus the net sampled the lower 20 cm of the water-column to the bottom. The sample trap attached to the net was emptied at approximately 60 min intervals and replaced by a new trap. The volume of water filtered was calculated using time and a digital readout flowmeter (General Oceanics, Inc., model 2030). On all occasions, the current direction was from the ocean into Simpson Lagoon.

Physical and Chemical Measurements

Surface and bottom temperatures and salinities were recorded at each station-date combination using a YSI-33 salinity/conductivity meter (± 0.6°C; ± 1.1°/₀₀). Turbidity was measured using a H.F. Instruments DRT-15 Turbidimeter.

Laboratory Techniques

All samples were preserved in 10% formalin and shipped to the laboratory for analyses. Samples were sieved through a 1.024 mm mesh nylon screen, washed with water, and examined under a low-power binocular microscope. All whole or partial organisms were separated into major taxonomic groups (mysids, amphipods, etc.), measured and counted. Biomass was determined either by directly weighing the organisms on a Mettler PL200 electronic balance (± 0.001 g) or by using best-fit equations for the relationship between total length and wet weight (Griffiths and Dillinger 1981). The limitations and biases of these methods are discussed in detail by Griffiths and Dillinger (1981).

RESULTS AND DISCUSSION

Invertebrate Transport

Since the transport rate of epibenthic invertebrates is probably a function of the number of organisms upstream and the speed of the water current, two types of invertebrate samples were collected in order to estimate both the standing crop (using the drop net samples) and transfer rate (using the drift net samples) of organisms.

Mysids, the dominant food item in the diets of birds and fish, comprised most of the biomass in the drift samples. As in 1978, the biomass of *Mysis litoralis* greatly exceeded that of *M. relicta* (the only other common species in the area). Consequently, only *M. litoralis* biomass was considered in this analysis. Data are presented as the biomass of *M. litoralis* passing through a square meter vertical plane in one hour. A logarithmic transformation was applied to all invertebrate biomass data prior to carrying out the statistical analyses.

There were significant correlations between the biomass of *M. litoralis* transported and current speed ($r = 0.465$; $n = 36$; $p < 0.02$) and between that transported and the standing crop of *M. litoralis* biomass on or near the bottom ($r = 0.684$; $n = 36$; $p < 0.001$) (Fig. 11). In each case, the biomass transported increased with increased current speed or increased standing crop.

Stepwise multiple regression analysis showed that immigration rate, expressed on a logarithmic scale, was strongly dependent on current speed and on the standing crop of *M. litoralis* on the ocean side of the barrier islands ($F = 31.08$; df = 2.33; $p < 0.001$; $R = 0.808$) (Fig. 12). While both factors were positively correlated with the rate of immigration, bottom biomass appeared to be the most important predictor of this rate for *M. litoralis* (F to remove of 41.59 vs 17.65 for current speed). These results are similar to those reported for the samples collected between Pingok and Peat islands in 1978 (Griffiths and Dillinger 1981). However, because of the extended sampling period in 1978, an additional factor, date (i.e., seasonal change in standing crop), was found to have a significant effect The 1980 data were collected over too brief a period (five days) to warrant examination of any temporal trend.

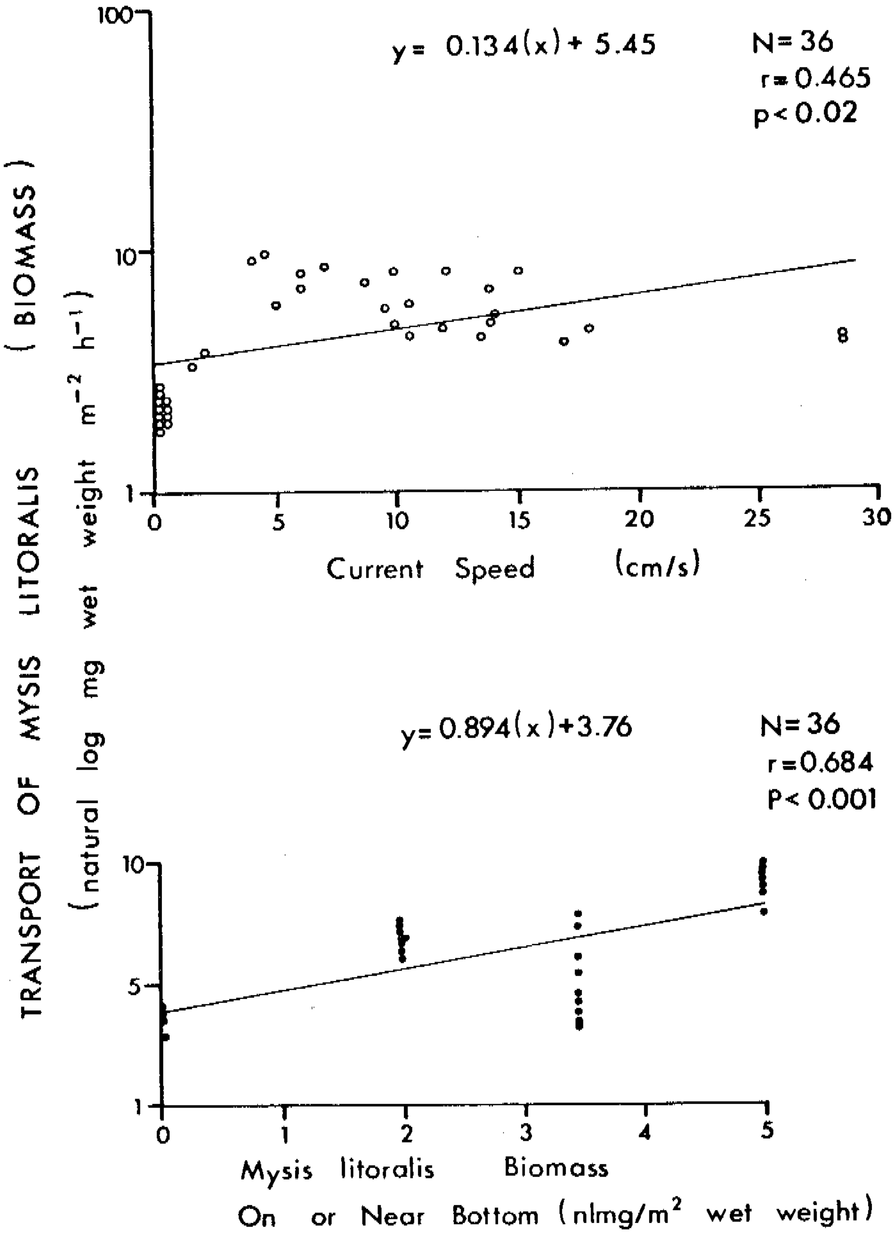

Figure 11. Relationships between the biomass of *Mysis litoralis* transported into the lagoon and (a) current speed, and (b) *M. litoralis* biomass on or near the bottom.

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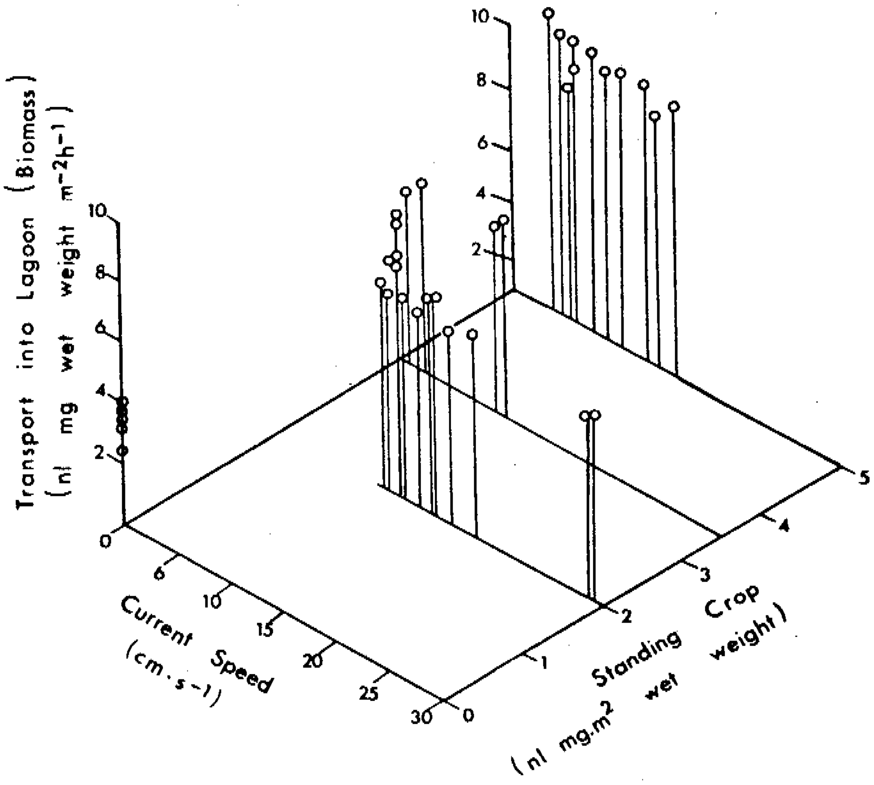

Figure 12. Relationships among current speed, *Mysis litoralis* biomass on or near the bottom, and the transfer rate of *Mysis litoralis* through a vertical meter^2 plane in one hour.

The importance of mysid immigration in maintaining food levels in the Simpson Lagoon system was illustrated by Griffiths and Dillinger (1981). They showed that the density of mysids in the lagoon would not support the predator populations until the end of the open water season without new immigration. Nonetheless, over the two years of the Simpson Lagoon study (1977-1978), food did not appear to be a limiting factor for the higher trophic levels (birds and fish). Thus, immigration of *M. litoralis* into the system was adequate to support the vertebrates that feed on *M. litoralis*. Any factor that might reduce this immigration rate (e.g., by reducing or closing the gaps between the barrier islands) could adversely effect the food supply available to the fish and birds. The result of such a reduction might have a significant regional effect due to the lower biomass of epibenthic invertebrates in nearby Harrison Bay (see Part 1); fish and birds could not simply move out of Simpson Lagoon into Harrison Bay to obtain their needed food requirements, since this would necessitate foraging on a sparser food base and in different physical conditions.

Epibenthic Invertebrates Around the ARCO Causeway

Although the distribution and abundance of infaunal invertebrates in relation to the ARCO causeway has been investigated (Feder and Schamel 1976), the effect of this structure on epibenthic invertebrates has received less attention; therefore, the purpose of this study was to provide preliminary data on the distributions and abundances of trophically important epibenthic invertebrates around the ARCO causeway.

Drop net samples were collected on both sides and at distances of 50, 500 and 1000 m from the causeway on 17 July and 8 August 1980 (Fig. 10). Only trophically important invertebrates were analyzed; these included two mysids (*Mysis litoralis*, *M. relicta*), amphipods, and the isopod *Saduria entomon*. The biomass data for these organisms were logarithmically transformed and analyzed using an analysis of variance with repeated measures, which were (1) direction from the causeway, (2) distance from the causeway, and (3) collection date. Temperature and salinity data were not considered formally in these analyses due to the limited data available. However, from Figures 13 and 14 it appears that there were no consistent relationships between these two physical measurements and the biomasses of the organisms.

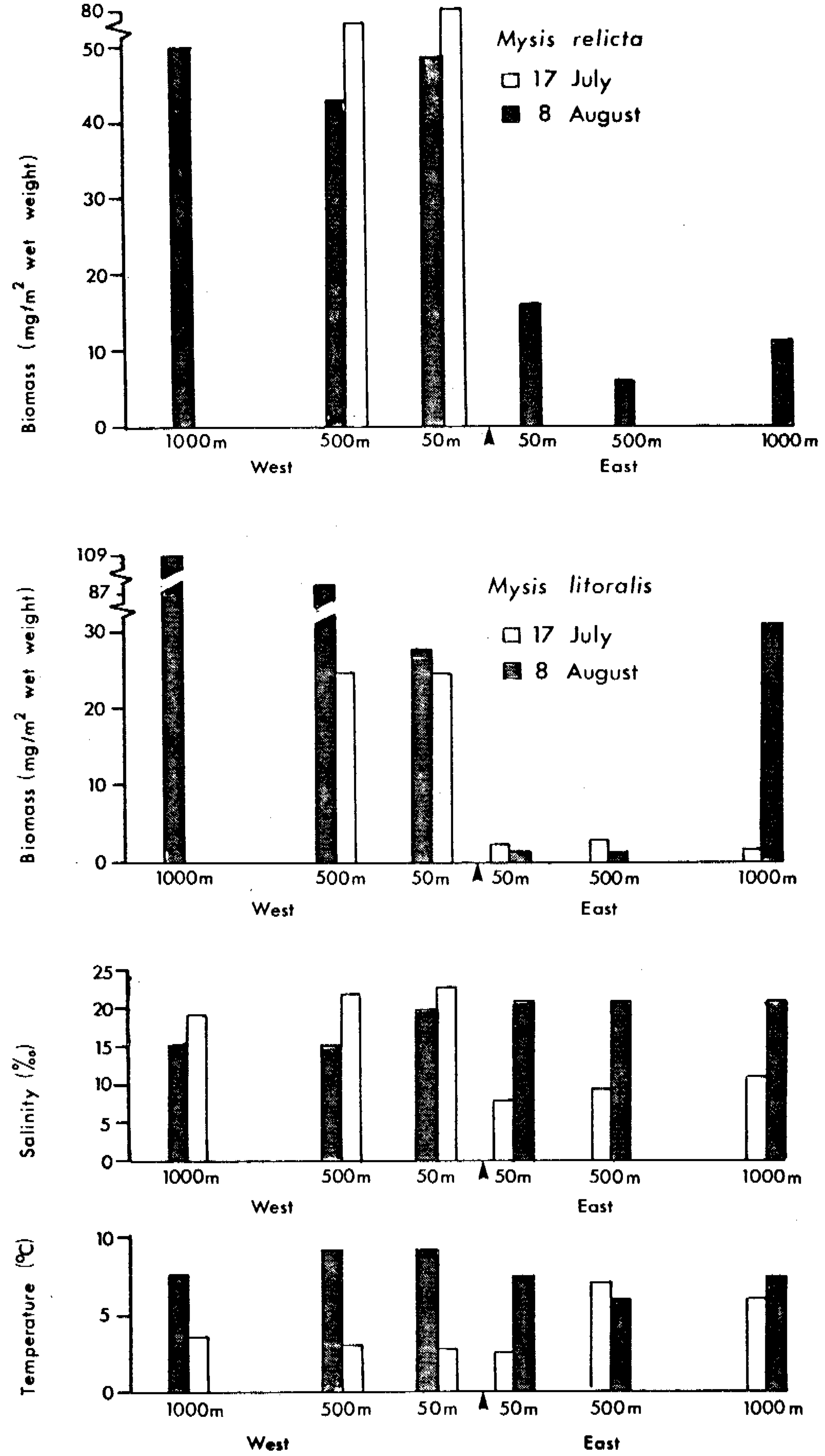

Figure 13. *Mysis relicta* and *Mysis litoralis* biomasses (mg/m² wet weight) around the ARCO causeway in relation to date and distance from the causeway. Temperature (°C) and salinity (°/₀₀) regimes are also shown. A triangle indicates the location of the causeway on each graph.

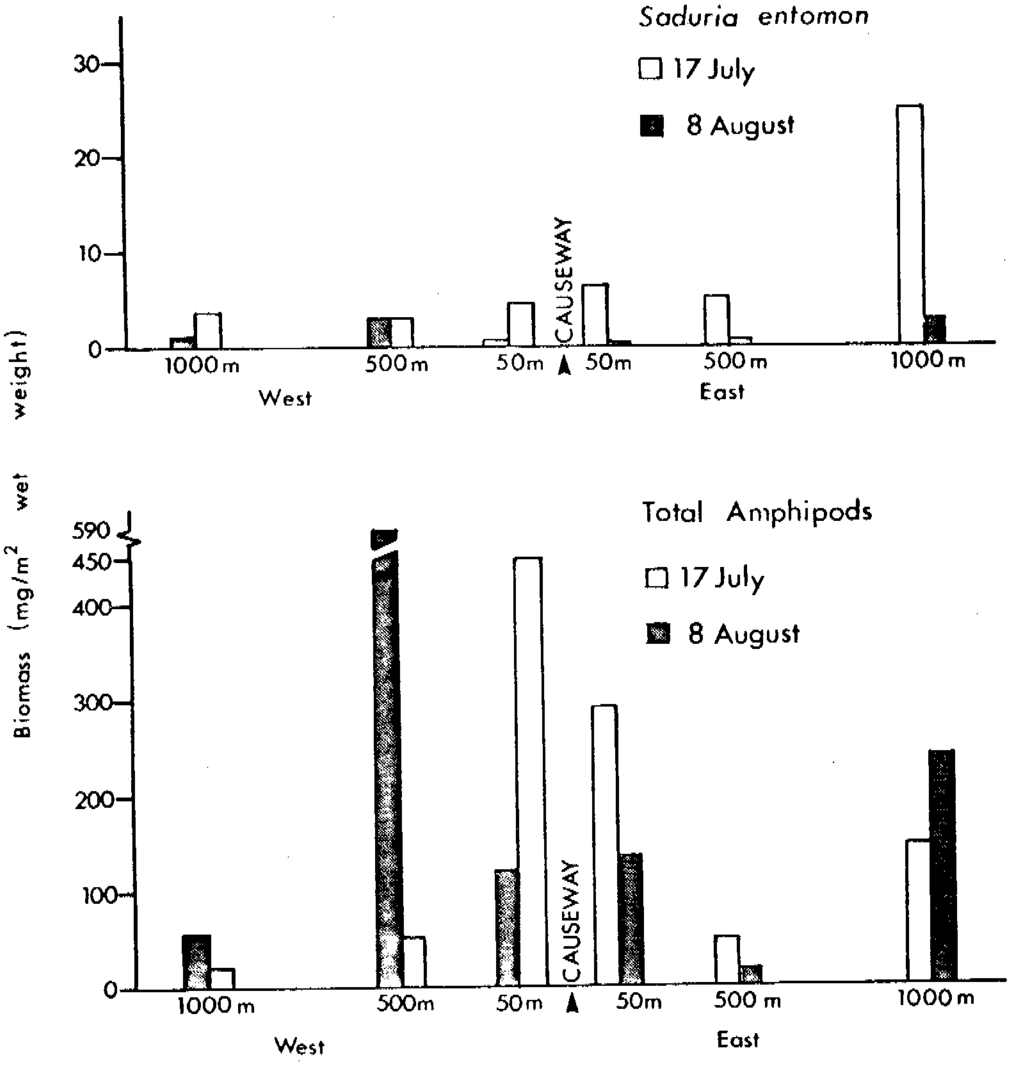

Figure 14. *Saduria entomon* and total amphipod biomass (mg/m² wet weight) around the ARCO causeway in relation to date and distance from the causeway.

The results of this analysis indicate a high degree of variability although some trends were apparent (Figs. 13 and 14, Table 9). For both species of mysids, there were significant differences in sample biomass in relation to the date on which collections were made and the side of the causeway on which the samples were taken (Table 9). From Figure 13, it is apparent that the biomasses of both species were generally greater in August than in July. This kind of seasonal variation in mysid biomass is common in the Simpson Lagoon region (Griffiths and Dillinger 1981).

Both species of mysid were more abundant, in terms of biomass, on the west side of the causeway during each of the two sampling periods (Table 9; Fig. 13). This distribution pattern may be a response to the prevailing wind-driven current in this region. This current typically moves in an east to west direction. This causes the water moving around the causeway to form a back eddy on its western side, possibly entraining organisms (e.g., mysids) with this water.

The interaction terms (i.e., side x distance, date x distance and side x date) for the two mysid species are shown in Table 9. There were significant differences in all three cases for *M. litoralis* but only for the side x date interaction in the case of *M. relicta*. *M. relicta* biomass was significantly lower at the 1000 m station on both sides of the causeway than at either the 50 m or 500 m stations (Table 9; Fig. 13). However, the distance effect was evident on 17 July, but not on 8 August.

Although there were wide fluctuations in the total amphipod biomass, there were no significant differences in relation to date, side of the causeway or distance from the causeway (Table 9; Fig. 14). No accumulation of amphipod biomass was noted on the west side of the causeway, contrary to the case with mysids, possibly due to the burrowing behavior of several of the species or groups involved (e.g., *Onisimus glacialis, O. litoralis* and *oedicerotids*). Burrowing behavior may increase the resistance of these species to current-induced movements.

In the case of the slow moving isopod *Saduria entomon*, there were no significant differences in biomass between sides of the causeway or with distance from the causeway; however, there was a significant decline in its biomass between 17 July and 8 August (Table 9; Fig. 14).

Table 9. Comparison of selected species of epibenthic invertebrates (as wet wt. mg/m^2) and the number of species in relation to the side of the causeway, the distance from the causeway and the month of capture. Data were analyzed using an analysis of variance. Each station-date combination was the mean of five dropnet samples.

Group or species		Variable tested: Side of* causeway (df=1,48)	Variable tested: Distance from** causeway (df=2,48)	Variable tested: Date of collection (df=1,48)	Interaction terms: Side x distance (df=1,48)	Interaction terms: Date x distance (df=2,48)	Interaction terms: Side x date (df=2,48)
Mysis litoralis	F value	57.37	0.64	25.52	6.60	8.26	20.27
	P	<<0.01	0.53	<<0.01	0.01	<0.01	<<0.01
Mysis relicta	F value	26.48	4.71	17.62	1.64	2.62	5.21
	P	<<0.01	0.01	<<0.01	0.21	0.08	0.01
Saduria entomon	F value	1.51	0.24	9.66	4.21	0.39	0.89
	P	0.23	0.79	<0.01	0.05	0.68	0.42
All amphipods	F value	0.05	3.00	0.12	1.89	6.50	2.29
	P	0.83	0.06	0.73	0.18	<0.01	0.11

* Samples collected on either east or west side of causeway.

** Samples collected 50, 500 and 1000 m from the causeway.

The results of this preliminary sampling around the ARCO causeway were analyzed in an effort to determine the number of samples that would be required to demonstrate a change of 10% in the biomasses of *M. litoralis*, *M. relicta* and *S. entomon* at the 0.95 confidence level. The data were transformed to log (x+1) and were analyzed by the method outlined by Green (1979, p. 43) using side of the causeway and date of collection as the two factors. In Green's example it is assumed that the samples are collected randomly throughout the whole area; however, while the samples used in this analysis do not technically conform to this assumption, we believe they come close enough to give credence to the results. The results are outlined below and show the number of drop net samples required on a single sampling date to demonstrate a 10% change in biomass, p = 0.95.

Species	Number of Samples
Mysis litoralis	20
Mysis relicta	44
Saduria entomon	160

The significant temporal and spatial variations in biomass evident for most epibenthic species and groups are a common phenomenon along the Beaufort Sea coast (Griffiths and Dillinger 1981) and depending on species, could easily mask any biomass changes due to the effects of the causeway. Consequently, a large sample size collected repeatedly over the open water season will be required in order to distinguish the effects of the causeway from the natural variation in the system.

PART 4

Population dynamics of arctic and least cisco

Craig and Haldorson (1981) suggested that large-scale changes in anadromous cisco populations in the Colville River region have occurred in recent years -- numbers of "catchable" arctic cisco (*Coregonus autumnalis*) declined roughly 86% from 1976 to 1979 while least cisco (*C. sardinella*) increased 82% during the same period. "Catchable" fish were defined as those ciscoes large enough to be caught in the commercial fishery in the Colville Delta. These include immature recruits and mature non-spawners (although some spawned-out least ciscoes are taken). Both of these groups frequent coastal waters in summer and return to overwinter in areas like the Colville Delta.

In an effort to monitor changes in cisco populations, a tagging program has been conducted each summer since 1977 to provide a basis for estimates of the "catchable" segment of each of these species. The basic procedure has been to tag arctic and least cisco in coastal waters of Simpson Lagoon or Prudhoe Bay, recapture them in the commercial fishery in the Colville Delta, and then calculate population estimates based on mark/recapture ratios. Limitations of this procedure are discussed by Craig and Haldorson (1981). In this report we present the 1980 data.

METHODS

From 19 July to 9 August 1980, fish were caught by seine and fyke net in Prudhoe Bay between Point McIntyre and the old dock on the east side of the bay. Sampling locations were initially near the base of the ARCO causeway, but nets were repositioned in search of higher catches of large fish to tag. Proportions of tagged fish from each side of the ARCO causeway which were recaptured in the commercial fishery have been analyzed separately (Craig 1981). (Very small discrepancies between data presented in this report for total numbers of ciscoes tagged in the Prudhoe Bay and those presented by Craig (1981) for the same data analyzed separately for east and west sides of the ARCO causeway are due to weighting or rounding-off differences.)

Large ciscoes (>220 mm) were measured to the nearest millimeter and tagged with numbered Floy anchor tags. In order to compare sizes of fish tagged with those recaptured in the commercial fishery, 100 arctic ciscoes and 100 least ciscoes from the 1980 fishery were measured.

RESULTS AND DISCUSSION

Size Correction for Tagged Fish

As in previous studies, an adjustment was made for fish that were either too large or too small to be vulnerable to the commercial fishery. Figure 15 compares size compositions of least and arctic cisco in the commercial fishery with sizes of these species tagged on the east and west sides of the causeway. An adjustment was made when sizes of some tagged fish fell outside the size frequency distribution of the commercial catch (from Ricker 1975). For each size interval where this occurred, the difference in percent composition was calculated, and the sum of these differences equalled the total adjustment. The number of tagged fish was then reduced by this percentage to estimate the number of tagged fish susceptible to the fishery. Correction factors were 30.1% for least cisco and 39.0% for arctic cisco, leaving totals of 745 tagged least cisco and 140 tagged cisco susceptible to the fishery (Table 10).

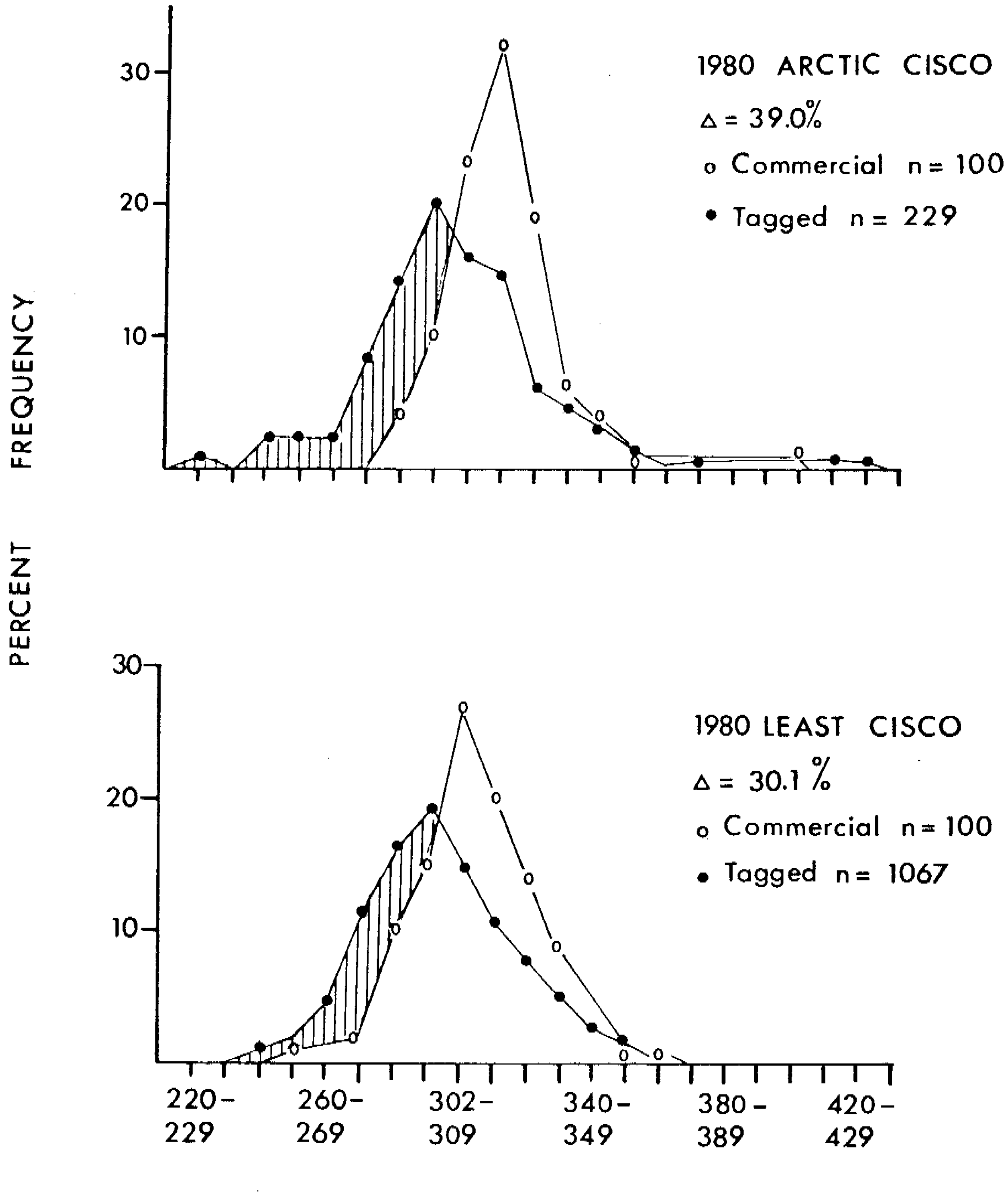

Figure 15. Comparison of sizes of arctic and least cisco tagged in Prudhoe Bay with sizes caught in the Colville Delta commercial fishery. Shaded areas represent the percentage (Δ) of tagged fish which were too small to be caught in the fishery.

Table 10. Estimates of the "catchable" segments of the arctic and least cisco in the Colville River sea-going population, 1980.

	Arctic cisco 1980	Least cisco 1980
Total tagged	229	1067
Correction for size	39.0%	30.1%
Effective number tagged	140	745
No. in commercial catch	14,743	30,989
No. recaptured (range)*	7-10*	32-35*
(average)	8.5	33.5
Population estimate (unbiased)	218,832	670,103
95% confidence limits		
lower	114,857	482,340
upper	415,781	928,083
Exploitation rate (R/M)	3.7%	3.1%

* The identity of three recaptured ciscoes was inconsistent in tagging and recapture records; therefore, these three recaptures were divided equally between the two species for convenience of subsequent calculations.

Population Estimates of "Catchable" Ciscoes

Population estimates were calculated by the unbiased estimate of the Peterson mark/recapture formula (Chapman 1951, modified by Ricker 1975):

$$N = \frac{(M + 1)\ (C + 1)}{R + 1}$$

where N is the population size, M is the number of marked fish in Prudhoe Bay (corrected for size), C is the sample taken for census (the commercial catch), and R is the number of recaptured fish in the sample. These data are summarized in Table 10.

The 1980 data indicate that numbers of arctic cisco remain at a relatively low level (Fig. 16). Least cisco are more abundant, but a considerable drop occurred between 1979 and 1980. Reasons for these changes are not known and require further investigation involving analyses of population age structures, and recruitment and mortality rates. This problem is discussed in more detail by Craig and Haldorson (1981).

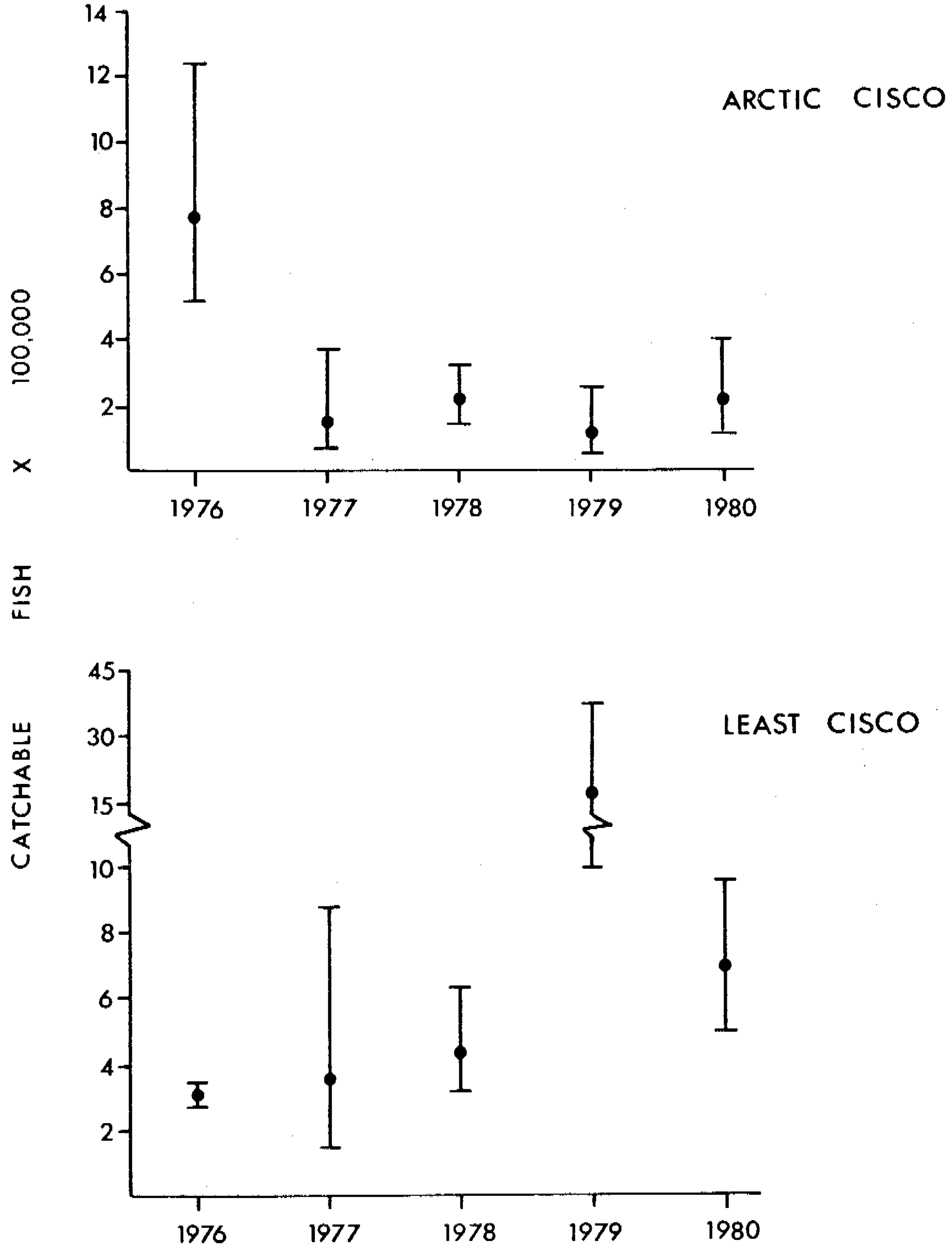

Figure 16. Estimates of "catchable" arctic and least cisco in the Colville River seagoing populations, 1976-1980. Bars indicate 95% confidence limits of mark/recapture estimate. Data for 1976-1979 are from Craig and Haldorson (1981).

PART 5

A fish survey in the Chandler and Colville rivers, Alaska

An intriguing problem that emerged in earlier studies involved the whereabouts of the spawning grounds of the arctic cisco (*Coregonus autumnalis*) on the Alaskan North Slope. Although this species plays an important role in subsistence and commercial fisheries, and although evidence suggests that its population size has declined in recent years, major gaps still remain in our understanding of the life-history of the arctic cisco (Craig and Haldorson 1981).

McElderry and Craig (1981) presented an analysis of this problem and gave reasons for suspecting that the Colville River is a potentially important drainage for cisco spawning. However, no spawners were found during earlier surveys, leaving McElderry and Craig (1981) to conclude that, "if arctic cisco do indeed spawn in this drainage, spawning may occur in larger tributaries or the mainstem between the delta and Umiat". The present report describes a brief survey in one of the larger tributaries in this region, the Chandler River, and portions of the mainstem (Fig. 17).

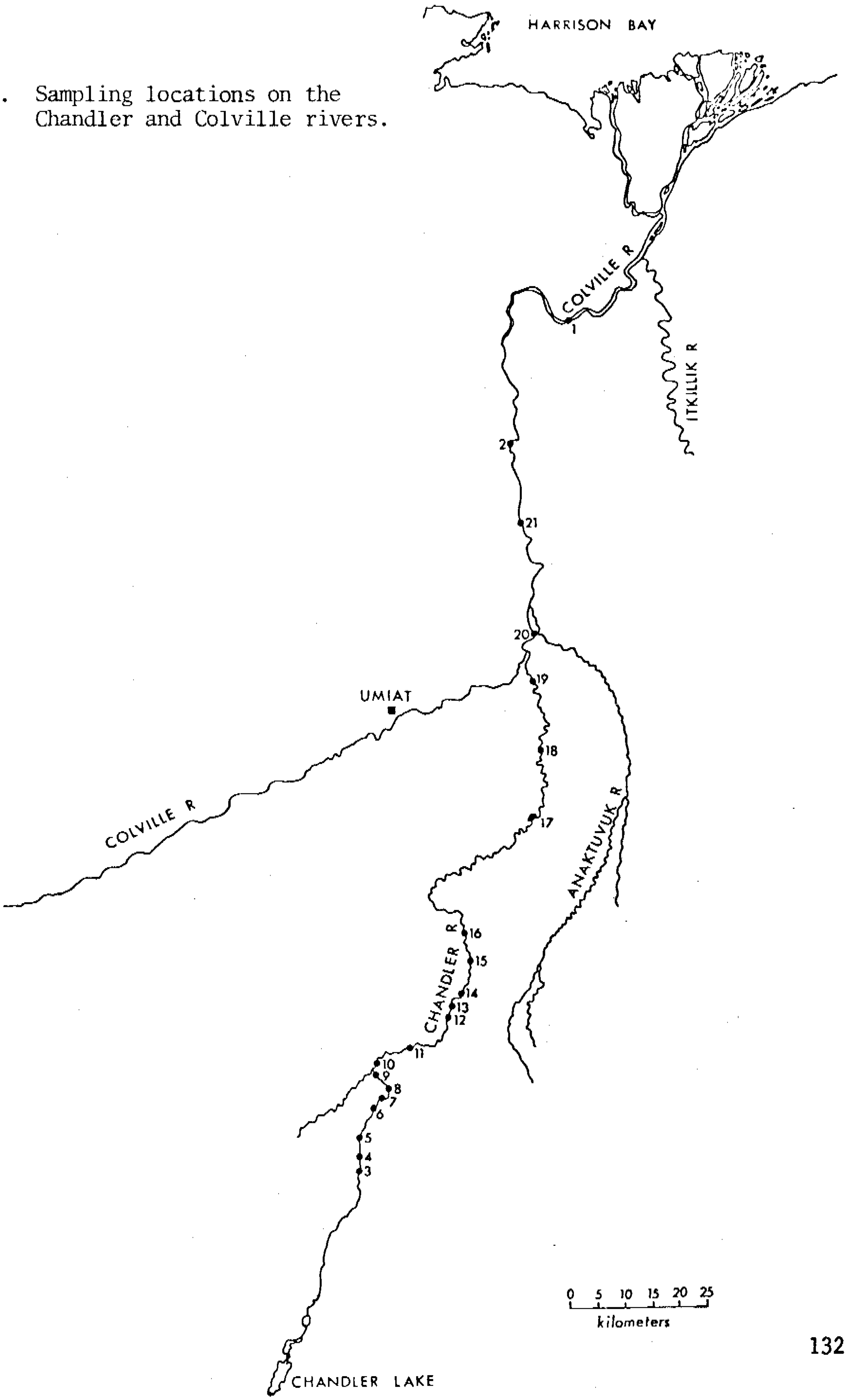

Figure 17. Sampling locations on the Chandler and Colville rivers.

METHODS

Surveys were conducted on 5 August by float plane and on 13-21 August 1980 by boat. By this time, it was assumed that at least some spawners would be on or near their spawning grounds. Ciscoes are fall spawners and available evidence suggests that spawners leave coastal waters and enter rivers by early July (Craig and Haldorson 1981, p. 541).

During the boat survey, the Chandler River was floated from its upper reaches near Castle Mountain downstream into the Colville River about 28 km below the Chandler confluence. Fish were sampled primarily by gillnets, which were 45.7 m long with five mesh sizes (stretched): 2.5, 4.6, 6.1, 7.6 and 10.6 cm. One or two nets were usually set at each site in backwater eddies or sloughs for short periods (1-2 h) or overnight. On two occasions, the gillnet was used in a seining fashion. Fish samples were identified and measured.

RESULTS AND DISCUSSION

Survey efforts in August 1980 concentrated on the Chandler River -- nineteen sites were sampled from its upper reaches to its confluence with the Colville (Fig. 17, Table 11). Four sites in the middle reaches of the Colville mainstem were also sampled.

Eight fish species were caught:

	Abbreviation	No. Caught
Grayling (*Thymallus arcticus*)	GRAY	47
Round whitefish (*Prosopium cylindraceum*)	RDWF	28
Longnose sucker (*Catostomus catostomus*)	LNSR	14
Humpback whitefish (*Coregonus pidschian*)	HBWF	5
Arctic char (*Salvelinus alpinus*)	CHAR	4
Broad whitefish (*Coregonus nasus*)	BDWF	2
Burbot (*Lota lota*)	BURB	1
Slimy sculpin (*Cottus cognatus*)	SLSC	1

Table 11. Locations of sampling sites in Chandler and Colville rivers.

Site No.	Waterbody	Date sampled	Location
1	Colville R.	05 August 80	70°02'N 151°16'W
2	Colville R.	05 August 80	69°49'N 151°33'W
3	Chandler R.	13 August 80	68°34'N 152°22'W
4	Chandler R.	13 August 80	68°35'N 152°22'W
5	Chandler R.	14 August 80	68°37'N 152°22'W
6	Chandler R.	14 August 80	68°40'N 152°20'W
7	Chandler R.	15 August 80	68°41'N 152°19'W
8	Chandler R.	15 August 80	68°42'N 152°14'W
9	Chandler R.	15 August 80	68°44'N 152°20'W
10	Chandler R.	15 August 80	68°45'N 152°19'W
11	Chandler R.	15 August 80	68°46'N 152°10'W
12	Chandler R.	15 August 80	68°49'N 151°59'W
13	Chandler R.	16 August 80	68°51'N 151°58'W
14	Chandler R.	17 August 80	68°52'N 151°55'W
15	Chandler R.	17 August 80	68°57'N 151°55'W
16	Chandler R.	18 August 80	69°01'N 151°55'W
17	Chandler R.	19 August 80	69°11'N 151°30'W
18	Chandler R.	19 August 80	69°20'N 151°26'W
19	Chandler R.	20 August 80	69°26'N 151°30'W
20	Colville R.	20 August 80	69°31'N 151°28'W
21	Colville R.	21 August 80	69°42'N 151°31'W

Grayling, round whitefish and longnose suckers were the main species caught and they accounted for 87% of the 102 fish taken. Species catches and sizes of fish collected at each sample location are listed in Tables 12 and 13.

The failure to catch any cisco species during this survey is particularly noteworthy. Due to the number of sites examined along the course of the Chandler River, it seems unlikely that this Colville tributary is utilized by arctic or least cisco for spawning.

Table 12. Summary of fishes caught at sampling locations.

Site No.	Waterbody	Fish Species								No. Sets	Total Soak Time (h)	Total Catch	Fish/h
		GRAY	RDWF	LNSR	HBWF	CHAR	BDWF	BURB	SLSC				
1	Colville R.						1			1	2.0	1	0.5
2	Colville R.			1	3	1	1			1	0.8	6	7.5
3	Chandler R.									1	0.8	0	0
4	Chandler R.	1								1	14.5	1	0.1
5*	Chandler R.			1						1	-	1	-
6	Chandler R.			1						1	0.3	1	3.0
7	Chandler R.									1	1.0	0	0
8	Chandler R.	4	1							1	16.0	5	0.3
9	Chandler R.									1	1.0	0	0
10	Chandler R.		1					1		1	1.5	2	1.3
11*	Chandler R.									1	-	0	-
12	Chandler R.	2		1						1	1.0	3	3.0
13	Chandler R.	3	11						1	4	31.7	15	0.5
14	Chandler R.	1		2						2	5.5	3	0.5
15	Chandler R.									1	12.3	0	0
16	Chandler R.	1								3	6.0	1	0.17
17	Chandler R.	12	1	5		2				3	44.5	20	0.5
18	Chandler R.	3	7							2	4.2	10	2.4
19	Chandler R.	6	1	2						2	-	9	-
20	Colville R.	6	1							1	4.5	7	1.6
21	Colville R.	8	5	1	2	1				2	25.0	17	0.7
	Species total:	47	28	14	5	4	2	1	1			102	

* seine

Table 13. Lengths of fishes collected.

Site No.	Waterbody	Species	Number Caught	Fork length (mm) range	Fork length (mm) mean
1	Colville R.	BDWF	1	121	
2	Colville R.	HBWF	3	375-400	390
		BDWF	1	355	
		CHAR	1	530	
		LNSR	1	430	
4	Chandler R.	GRAY	1	248	
5	Chandler R.	LNSR	1	440	
6	Chandler R.	LNSR	1	415	
8	Chandler R.	GRAY	4	255-355	290
		RDWF	1	295	
10	Chandler R.	RDWF	1	175	
		BURB	1	780*	
12	Chandler R.	GRAY	2	265-295	280
		LNSR	1	310	
13	Chandler R.	RDWF	11	170-325	222
		GRAY	3	194-244	224
		SLSC	1	116*	
14	Chandler R.	LNSR	2	430-440	435
		GRAY	1	275	
16	Chandler R.	GRAY	1	305	
17	Chandler R.	LNSR	5	175-450	335
		CHAR	2	465-545	505
		GRAY	12	98-375	249
		RDWF	1	360	
18	Chandler R.	RDWF	7	292-494	326
		GRAY	3	268-297	285

* total length

PART 6

Fish tag and recapture data, Beaufort Sea coastal regions

During the course of RU467 studies, anadromous fish in coastal waters of the Beaufort Sea have been tagged annually since 1977. Purposes of the tagging studies have been described previously (Part 4, this report; Craig and Haldorson 1981). Recognizing that tag and recapture data may be useful in other studies, we list in Table 14 all information gathered since our initial list was prepared (Appendix 1 in Craig and Haldorson 1981). Most of the new recaptures are of fish tagged during the 1980 program in Prudhoe Bay (Craig 1981).

Table 14. Tag and recapture data (for the period November 1979 to June 1981) for fish recovered during this study. Site abbreviations are listed below.

	Tag		Recapture	
F.L.†	Site	Date	Site	Date
	LEAST CISCO			
300	KP	18-07-79	CD	06-11-80
335	KP	18-07-79	CD	18-10-80
260	KP	20-07-79	CD	15-10-80
310	KP	18-07-79	CD	09-10-80
300	KP	18-07-79	CD	06-11-80
345	BP	23-07-79	CD	01-10-80
295	BP	23-07-79	CD	31-10-80
330	WA	19-07-80	CD	04-11-80
315	WA	19-07-80	CD	30-10-80
331	WA	20-07-80	CD	25-10-80
330	WA	21-07-80	CD	04-11-80
301	WA	21-07-80	CD	18-10-80
317	WA	21-07-80	CD	04-11-80
350	WA	22-07-80	CD	17-10-80
315	WA	22-07-80	CD	27-10-80
300	WA	24-07-80	CD	23-10-80
296	WA	24-07-80	CD	24-10-80
295	WA	24-07-80	CD	15-10-80
315	WA	01-08-80	CD	13-10-80
301	WA	01-08-80	CD	24-10-80
308	WA	01-08-80	CD	24-10-80
318	WA	26-07-80	CD	24-11-80
309	WA	26-07-80	OP	29-07-80
298	WA	01-08-80	CD	24-11-80
310	WA	01-08-80	CD	17-10-80
292	WA	01-08-80	CD	15-11-80
299	WA	28-07-80	CD	21-10-80
295	WA	28-07-80	CD	13-12-80
322	WA	28-07-80	EA	06-08-80
325	WA	01-08-80	CD	24-10-80
332	WA	03-08-80	CD	15-10-80
270	ED	05-08-80	CD	18-10-80
285	EA	22-07-80	CD	21-11-80
330	EA	22-07-80	CD	17-10-80
305	EA	23-07-80	CD	11-11-80
345	EA	23-07-80	CD	18-10-80
325	EA	23-07-80	CD	18-10-80
337	EA	24-07-80	CD	07-11-80
320	ED	26-07-80	CD	11-10-80
300	ED	07-08-80	CD	17-10-80
478	ED	07-08-80	CD	21-10-80
302	ED	07-08-80	CD	16-10-80
297	ED	05-08-80	EA	07-08-80
295	KP	27-07-79	CD	21-11-80

	Tag		Recapture	
F.L.†	Site	Date	Site	Date
	LEAST CISCO (cont'd)			
325	MP	28-07-79	CD	01-10-80
305	KP	28-07-79	CD	24-10-80
334	* PB	26-07-76	EA	23-07-80
-	KP	18-07-79	CD	24-10-80
290	MP	15-06-78	OP	10-08-80
320	MP	11-07-78	CD	08-10-80
325	MP	22-07-78	CD	09-10-80
310	MP	17-07-78	CD	16-10-80
310	MP	19-07-78	CD	17-10-80
305	MP	18-07-78	CD	21-10-80
300	MP	15-07-78	CD	24-10-80
305	KP	28-07-79	CD	24-10-80
310	MP	26-07-78	CD	24-10-80
260	MP	22-07-78	CD	25-10-80
325	MP	17-07-78	CD	25-10-80
335	MP	22-07-78	CD	27-10-80
310	MP	19-07-78	CD	27-10-80
335	MP	17-07-78	CD	27-10-80
340	MP	10-07-78	CD	27-10-80
290	KP	08-08-78	CD	30-10-80
305	KP	08-08-78	CD	31-10-80
295	BP	23-07-79	CD	31-10-80
300	PI	27-07-78	CD	04-11-80
315	MP	15-07-78	CD	07-11-80
295	KP	27-07-79	CD	21-11-80
	ARCTIC CISCO			
285	KP	18-07-79	UP	23-07-79
245	KP	17-07-79	CD	18-10-80
260	UP	18-07-79	CD	06-12-80
303	WA	01-08-80	CD	27-10-80
326	WA	01-08-80	CD	29-10-80
-	EA	23-07-80	CD	21-11-80
295	ED	05-08-80	CD	13-10-80
345	ED	05-08-80	CD	06-12-80
300	ED	05-08-80	CD	08-11-80
315	ED	05-08-80	CD	22-11-80
360	ED	06-08-80	CD	27-10-80
309	ED	07-08-80	CD	28-11-80
240	KP	24-07-79	CD	06-12-80
245	KP	23-07-79	CD	04-11-80
	ARCTIC CHAR			
410	ED	27-07-80	EA	11-08-80
302	ED	05-08-80	ED	09-08-80
360	PI	27-07-80	ED	28-07-80

	Tag		Recapture	
F.L.†	Site	Date	Site	Date
	HUMPBACK WHITEFISH			
390	KP	19-07-79	OP	02-08-80

† F.L. Fork Length (mm)

* Tagged by the Alaska Dept. Fish and Game

Sites

BP - Beechey Point (Simpson Lagoon)
CD - Colville Delta
EA - East ARCO causeway (Prudhoe Bay)
ED - East dock (Prudhoe Bay)
KP - Kavearak Point (Simpson Lagoon)
MP - Milne Point (Simpson Lagoon)
OP - Oliktok Point (Simpson Lagoon)
PB - Prudhoe Bay
PI - Pingok Island (Simpson Lagoon)
UP - Unnamed point between Kavearak and Beechey points (Simpson Lagoon)
WA - West ARCO causeway (Prudhoe Bay)

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Trophic Relationships Among Ice-Inhabiting Phocid Seals and Functionally Related Marine Mammals

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1 April 1981

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I. Summary

Field work was conducted in the Beaufort Sea during August and September 1980 to examine the distribution and foods of seals as well as the distribution and abundance of their prey and the foods eaten by arctic cod. Field work was staged from Pingok Island (eastern Harrison Bay) from 20 August to 1 September and from Beaufort Lagoon (between Barter Island and the U.S.-Canada Demarcation line) from 4 to 19 September.

Ringed seals were the most abundant marine mammal in both areas. With the exception of a large lead near Beaufort Lagoon where seals were very abundant (8.2/boat hour), they were quite uniformly distributed throughout the nearshore sea ice. Overall abundance near Pingok was similar to that near Beaufort Lagoon. Bearded seals were much less common than ringed seals with a greater abundance near Pingok. Four bowhead whales, 2 walrus, and 1 spotted seal were seen near Beaufort Lagoon.

All eight ringed seals collected near Pingok had eaten primarily arctic cod. Of the 16 ringed seals collected near Beaufort Lagoon, 8 had eaten mostly arctic cod, 6 had eaten primarily euphausiids, and 2 had eaten mostly benthic organisms. Two seals collected in the large lead where they were particularly abundant had been eating euphausiids. Arctic cod eaten by seals were large in comparison to those caught nearby in otter trawls. Two bearded seals collected had eaten a variety of benthic organisms. One spotted seal collected had eaten a single capelin.

Arctic cod was the most abundant fish species caught in otter trawls. They were overall more abundant near Pingok than Beaufort Lagoon. Arctic cod were most abundant in shallow water trawls in both areas. Near Pingok, large fishes comprised a greater proportion of the catch in trawls made in 5-10 m water depths.

Near Beaufort Lagoon, most of the stomach contents of arctic cod consisted of crustaceans including 56 percent (by weight) copepods, 20 percent gammarid amphipods, 8 percent euphausiids, and 6 percent mysids. Large arctic cod (>100 mm in length) caught in shallow (5-10m) water near Pingok contained 33.5 percent fishes, primarily arctic cod, in their stomachs. Smaller arctic cod ate mostly mysids and gammarid amphipods nearshore in open water and copepods, euphausiids, and gammarid amphipods offshore in the ice. The abundance of copepod species in cod stomachs was generally similar to that in plankton tows done near where the cod were caught.

Results of 1980 field work complement those from previous studies which allows a somewhat more comprehensive description of distribution, abundance, and foods of ringed seals and arctic cod in the Beaufort Sea. Those two species are of particular ecological importance in the area since they provide food for and compete for food with many other vertebrate consumer species. Further studies of the relationship between the distribution and food habits of these predators and the distribution and abundance of their prey are needed.

II. Introduction

Since 1975 this project has been investigating the foods and trophic relationships of ice-inhabiting marine mammals. Initially the project dealt only with four species of seals: ringed seals (Phoca hispida), bearded seals (Erignathus barbatus), spotted seals (Phoca largha), and ribbon seals (Phoca fasciata). Later, walruses (Odobenus rosmarus) and belukha whales (Delphinapterus leucas) were included in the investigation. Material purchased from subsistence hunters in the northern Bering and Chukchi Seas provided the majority of specimens examined. As the investigation progressed, it became desirable to collect specimens in areas (e.g. the Bering Sea ice edge and the Beaufort Sea) and at seasons (e.g. winter) during which the animals were not harvested by coastal hunters. Such collections were made using OCSEAP provided ship and helicopter logistic support.

As leasing schedules became finalized and sale dates approached, we were directed by OCSEAP to concentrate our efforts in proposed sale areas of the Beaufort Sea. Specimens obtainable from coastal hunters in that area were limited to small numbers of ringed seals taken near Barrow in late spring and summer and occasional subsamples of stomach contents of bowhead whales (Balaena mysticetus) taken at Barrow and Kaktovik. Although we obtained and examined all such available samples (Lowry et al. 1977, 1978; Lowry and Burns 1980), it was impossible to obtain adequate geographical and seasonal coverage of the area. We therefore initiated a systematic program to sample the foods of ringed seals, the most abundant marine mammal species in the Beaufort. Collections were made from helicopters during the months of November to May in two general areas, off Point Barrow and north and east of Prudhoe Bay in the vicinity of the proposed joint Federal/State lease sale. Those collections were uniformly successful and resulted in adequate broad-scale geographical and temporal coverage for late autumn, winter, and spring (Lowry et al. 1979). During summer months we attempted to obtain ringed seal specimens by participating in multidisciplinary cruises on U.S.

Coast Guard icebreakers. Results of those efforts were very variable and frequently unsatisfactory (Lowry et al. 1979). We continued to collect specimen material from bearded seals and bowhead whales on an opportunistic basis.

The summer period of open water appears to be a time when ringed seals (and other vertebrates such as bowhead whales and seabirds) feed intensively in the Beaufort Sea. Our limited observations indicate that during summer ringed seals are not uniformly distributed throughout the area, but rather occur in high densities in a few restricted areas where prey are presumably very abundant. In late August 1976 and early September 1977 areas with high densities of ringed seals were located within the proposed sale #71 lease area, more specifically north and east of Harrison Bay. Therefore, in summer 1980 we conducted field work in the Harrison Bay area to examine the relative abundance and distribution and foods of ringed seals there. In addition, we attempted to determine the relative abundance and distribution of the primary ringed seal prey species in the area, and we examined the foods utilized by arctic cod (Boreogadus saida).

Subsequent to the field work at Harrison Bay, complementary studies were conducted east of there near Beaufort Lagoon with funding provided by the National Marine Fisheries Service (NMFS), National Marine Mammal Laboratory. Results of that work will be incorporated in this report where appropriate.

III. Current State of Knowledge

The results of all collections we have made in the Beaufort Sea prior to 1980 have been analyzed and discussed in a final report submitted to OCSEAP (Lowry et al. 1979). The following summary is taken primarily from that report.

A total of 203 ringed seal and 20 bearded seal stomachs containing food was analyzed. These specimens were collected primarily in two areas: the vicinity of Point Barrow and near Prudhoe Bay. Samples were collected at several times of year in order to assess seasonal changes in feeding patterns. Due to the nature of available logistics, the poorest sample coverage was obtained in spring and summer.

Foods eaten by ringed seals in the Beaufort Sea showed pronounced seasonal variation. In late winter and early spring crustaceans were the primary food. The species eaten were primarily benthic forms such as shrimps and gammarid amphipods. In summer crustaceans were still the primary food. However, nektonic forms such as euphausiids and hyperiid amphipods were most commonly eaten. In most of the seals collected in fall, winter, and early spring, arctic cod were the main food. The main exception to this pattern was a collection of seals made just off shore from the barrier islands within the joint Federal/State lease area in November 1978. Those seals had eaten almost entirely crustaceans, mostly mysids and gammarid amphipods. Based on an analysis of material collected throughout Alaskan waters, Lowry et al. (1980) concluded that ringed seals are able to consume largest quantities of food when feeding on arctic cod or nekton. Arctic cod and nektonic crustaceans appear to be particularly suitable foods because they are sometimes present in dense concentrations. These concentrations appear to occur in localized areas.

Ringed seals are abundant in the Beaufort Sea and are present throughout the year. Shorefast ice is their preferred breeding habitat. They compete for food with seabirds, bowhead whales, and some fishes, and provide food for polar bears and arctic foxes. They are obviously a very important species in the trophic structure of the area.

Small sample sizes precluded detailed analysis of the foods of bearded seals in the Beaufort Sea. The most commonly eaten foods were crabs and shrimps. Clams were eaten only in summer months. Arctic cod were eaten in substantial quantities only in November and February. Bearded seals are not abundant in the Beaufort Sea. They are tied predominantly to a benthic food web and feed on a large number of species.

Foods eaten by bowhead whales in the Beaufort Sea were reported by Lowry et al. (1978) and Lowry and Burns (1980). Although benthic organisms were occasionally found in the stomach contents samples, most of the contents was comprised of calanoid copepods and euphausiids.

Lowry and Frost (1981) reported on the relative abundance and distribution and foods of arctic cod in the northeastern Chukchi and Beaufort Seas. Arctic cod were most abundant in the northeastern Chukchi Sea and least abundant in the central Beaufort Sea. Foods eaten in waters greater than 40 m deep were primarily calanoid copepods and pelagic/ice-associated gammarid amphipods (Apherusa). Craig and Haldorson (1981) examined foods of arctic cod in Simpson Lagoon and nearby marine waters. Mysids and gammarid amphipods were major foods in both summer and winter. Copepods comprised a major portion of the diet in cod collected in summer 1978.

The combined results of these studies allowed the construction of a provisional food web dealing with major vertebrate consumers in the pelagic trophic system of the Beaufort Sea (Fig. 1).

IV. Study Area

OCSEAP funded field work in summer 1980 was conducted in the area between Harrison Bay and Prudhoe Bay (Fig. 2). The NARL facility at Pingok Island was used as a base camp. Our operations were limited to within about 90 km of the base camp due to the safe operating range of our research vessel. To the north our range was limited by pack ice; we operated generally within 30 km of shore in water up to 21 m deep.

NMFS funded studies were conducted from an abandoned DEW line site at Beaufort Lagoon which is presently maintained by the U.S. Fish and Wildlife Service. Operations there were generally within 50 km of camp in water up to 45 m deep.

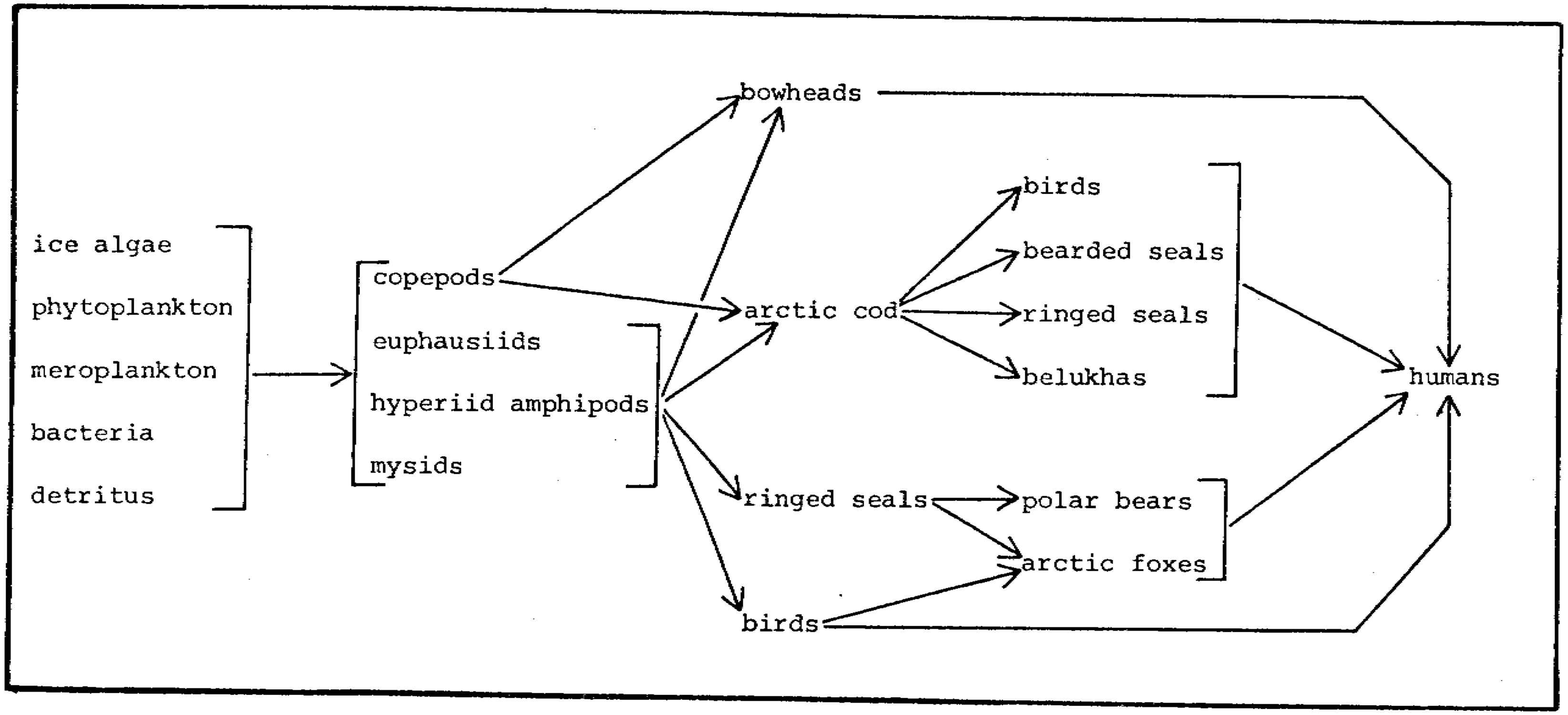


Fig. 1. Diagrammatic representation of the major trophic connections in the pelagic food web of the Beaufort Sea.

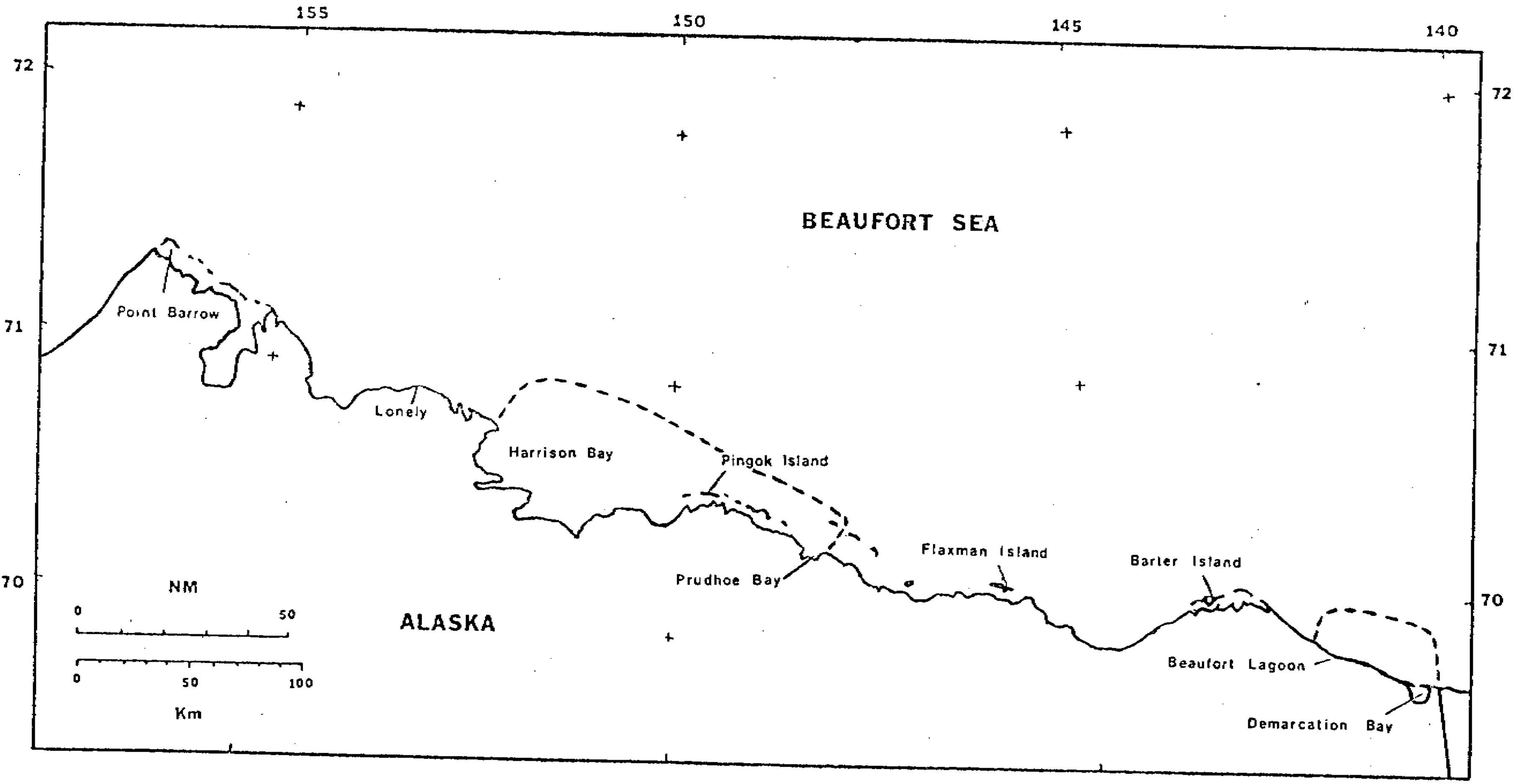


Fig. 2. Map of the Beaufort Sea indicating areas where field work was conducted in summer 1980 (dashed lines).

V. Methods

A. Field Work

A 20-foot (6.1m) long Boston Whaler was purchased (by NMFS) and equipped as a research vessel for this project. The boat was powered by twin 90-horsepower Mercury engines and equipped with standard steering, controls, and safety equipment. A stainless steel A-frame was designed, constructed, and installed. The A-frame allowed nets to be handled either over the stern or alongside the boat. A small gasoline-powered capstan (Gowan Nu-Way Hauler) was installed to facilitate retrieval of nets. A depth sounder (Datamarine Model S200D) provided a digital read-out of depths from 0-200 feet (0-60 m) in 1-foot (0.3 m) intervals.

We attempted to do five types of sampling from the research vessel (Fig. 3) whenever weather and ice conditions permitted. These are briefly described as follows:

1. A record was kept of all marine mammals sighted. Number and identity of marine mammals involved were noted along with time of day, water depth, general location, ice conditions, and any other relevant observations.

2. Seals were collected for stomach contents analysis. They were shot with a high-powered rifle and retrieved by harpooning, then weighed, measured, and necropsied. Samples collected included stomachs, reproductive tracts, and claws and lower jaws which were used for age determination.

3. In areas where ringed seals were collected, as well as at several other locations, otter trawls were conducted. The net used was a semi-balloon design with a 3.8-m headrope, with 3.6-cm stretch mesh body, 3.2-cm stretch mesh cod end, and a 2.5-cm stretch mesh knotless cod end liner. The net was rigged with 30.5-cm by 50.8-cm trawl doors, four floats on the headrope, and galvanized chain on the footrope. Bridles from the trawl doors were attached by swivels to 183 m long, 1.0-cm diameter double-braided nylon rope which was used to tow the net. The towline was marked at 5-m intervals for the first 50 m and at 50-m intervals thereafter. The towline was run through a block on the A-frame and enough towline was let out (approximately 4-5 times the water depth) for the net to reach the bottom. It was towed on the bottom at a speed of 2-4 km/hr for 20 minutes. The net was retrieved using the capstan. Contents of the catch were washed and sorted, and the body cavities of all arctic cod caught were injected with 10 percent formalin using a syringe. Organisms were then placed in fine-mesh nylon bags, labeled, and immersed in a 10 percent formalin-seawater solution.

4. Vertical plankton tows were done wherever otter trawls were conducted. The net used was 0.5 m in diameter with a 4:1 open area ratio, 505-micron mesh net, quick-release sampling cup, and a crossbar with single-tow bridle. A 5-kg weight was attached to the sampling cup. The towline was run through a block on the A-frame and attached to the tow bridle. The net was allowed to sink to the bottom, then was retrieved by hand at a speed of 30-40 m/minute. The net was washed at the surface, then collected samples were poured into labeled whirl-pac containers and

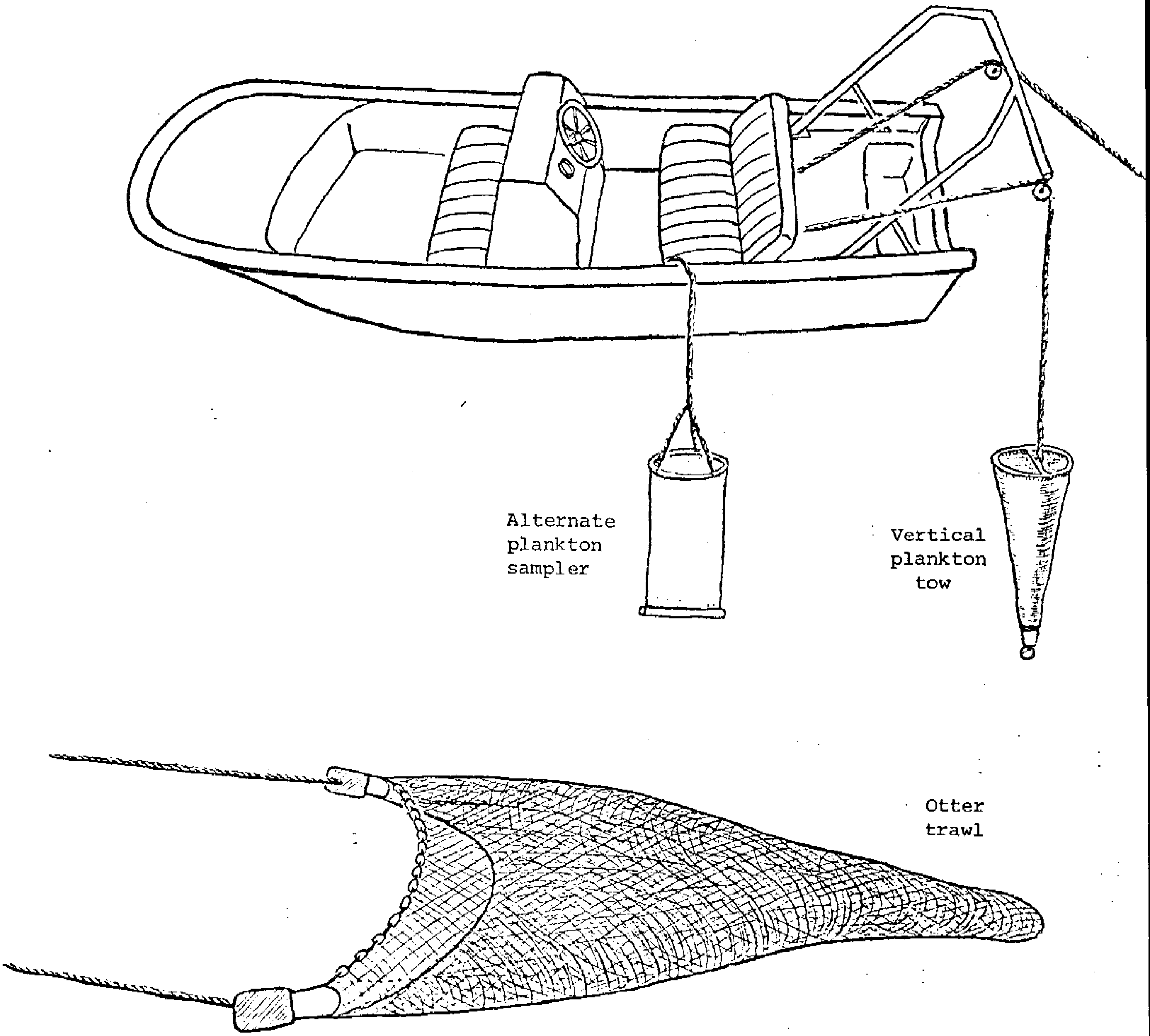


Figure 3. Drawing of research vessel and sampling gear.

preserved with 10 percent formalin-seawater. At locations where otter trawls were conducted, one to three replicate tows were made.

5. We attempted to design and construct an Alternate Plankton Sampler of the type described by Brodie (1978). The purpose of such a sampling device was to adequately collect comparatively large, mobile nektonic organisms such as euphausiids and hyperiid amphipods. The device used by Brodie consisted of a 40-cm sheetmetal cylinder on which was loaded a length of thin polyethylene tubing. The tubing was tied shut at one end so that as the sheetmetal cylinder moved through the water the polyethylene bag became filled. In principle such a sampler eliminates the "bow wave effect" caused by nets and simulates the gulping action of baleen whales which should allow the capture of motile organisms. Using the design suggestions of Brodie (1978), we designed and constructed a sampler that could store up to 50 m of tubing wrapped around a filter apparatus constructed of 5.0-cm diameter plastic pipe. Unfortunately, time did not allow testing of the sampler before field work commenced. The sampler proved deficient in several respects, particularly in the rate of water filtration allowed by the plastic pipe filtering apparatus. We modified the filtering arrangement of the sampler, but the modifications were not successful. Further development and testing are required before equipment of this type will be useful on a routine basis.

B. Laboratory and Analytical Procedures

1. Vertical plankton tows

Organisms caught in the vertical plankton tows were sorted, identified, and enumerated by Kenneth Coyle, University of Alaska, Institute of Marine Science. Samples were washed from the whirl-pacs and the excess fluid removed. In most tows the entire catch was processed. For a few tows in which very large numbers of copepods were caught, large organisms were removed from the sample and counted, the remainder was then diluted and several (usually 3-4) subsamples were taken and examined until a total of 100-200 of the most common species was counted. Organisms were identified to the lowest possible taxonomic level which, with the exception of some larval forms, was usually to species. Copepods were identified by age category and sex where possible and were enumerated separately by age and sex class.

Computer programs were developed for entry and analysis of zooplankton data. In analysis programs a subsampling factor was applied to subsample counts (based on the ratio of the volume counted to total sample volume) to derive for all species the estimated total number in the sample. This was then expressed as the number of individuals of each species per cubic meter of water by dividing by the amount of water filtered by the tow (area of net opening x tow depth). For stations with replicate tows, results were expressed as the mean and range in number of individuals caught.

2. Otter trawls

Contents of otter trawl catches were washed and sorted into major taxonomic groups which were then enumerated where appropriate and weighed (wet weight to 0.1g). Fishes were usually identified to species. Arctic cod were individually measured (fork length to 1.0mm) and weighed (wet weight to 0.1g), and the sex was noted and the stomach removed. Contents of the stomach were examined under a binocular microscope, and components of the stomach contents were sorted to species, enumerated to the extent possible, and weighed (wet weight to 0.01g).

Computer programs were written for entry and analysis of arctic cod data. One program calculated the mean length and length distribution of cod caught in tows. Measured lengths of specimens were increased by 2.1 percent to compensate for shrinkage due to preservation (Lowry and Frost 1981). A second program analyzed the contents of stomachs in terms of mean weight and number of individuals and frequency of occurrence (number of stomachs in which an item occurred/total number of stomachs in sample) of each item in the stomachs examined. Only stomachs containing recognizable food were included in this analysis.

3. Ringed seal stomach contents

Preserved stomach contents from ringed seals were gently washed on a 1.00-mm mesh sieve, then sorted into major categories. Prey items were identified to the lowest possible taxonomic category, counted, and the water displacement volume measured (to the nearest 0.1ml) in graduated cylinders. Estimates of the number of individuals of each prey consumed were based on counts of intact organisms and characteristic parts such as otoliths of fishes. Otoliths from arctic cod eaten were measured (to the nearest 0.1 mm) with vernier calipers. All otoliths were measured in those stomachs containing fewer than 20. In those containing more than 20 otoliths, a randomly selected subsample of about 20 was measured.

Existing computer programs were used to analyze components of ringed seal stomach contents. For each of the two major collection areas the percent of the total stomach contents volume comprised of each category and the frequency of occurrence was calculated. The percent of the total number of fishes eaten which belonged to each taxon was also calculated. The estimated lengths of arctic cod eaten were calculated based on otolith measurements using the formula: fish fork length (cm) = 2.198 otolith length (mm) + 1.588 (Frost and Lowry 1981a).

VI. Results

A. Distribution and Abundance of Marine Mammals

At Pingok Island boat operations were conducted on 6 days between 20 August and 1 September. A major storm occurred from 25-31 August and precluded operations during that time. Sea ice, comprised mostly of heavy floes with 3-6 octa coverage, usually occurred within 3-8 km of the barrier islands. Our operations generally were conducted in the shoreward fringe of the ice. On 4 days we operated within 30 km of Pingok, northeast, north, and northwest of camp. On 23 August we worked westward across Harrison Bay to a point about 40 km north of Cape Halkett. On 1 September we worked east of camp to about 40 km north of Prudhoe Bay.

The only marine mammals sighted were ringed and bearded seals. With the exception of one ringed seal and two bearded seals, all animals were seen in the water. In 34.6 boat hours a total of 81 ringed seals (2.3/hour) and 21 bearded seals (0.6/hour) was seen. Seals were very uniformly distributed throughout the area. Daily abundance estimates ranged from 1.2-4.5 ringed seals and 0.2-1.2 bearded seals per boat hour. No unusual concentrations of seals were seen and no clear geographical patterns of abundance were evident. The abundance of ringed seals seen while working across Harrison Bay and back (2.1/hour) was similar to the abundance seen near Pingok (1.8-4.5/hour) and slightly greater than that observed between Pingok and Prudhoe (1.2/hour). These differences are probably not significant.

At Beaufort Lagoon boat operations were conducted on 12 days between 4 and 19 September. On three of those days most of the time was spent doing trawls and/or plankton tows. As a result, marine mammal sightings from those days were not comparable to the others and were not included in abundance calculations which are based on a total of 55.9 boat hours. Sea ice, comprised of heavy floes with 3-6 octa overall coverage, usually occurred adjacent to the barrier islands and never moved more than 2 km offshore. A huge lead approximately 6-8 km wide and perhaps 20 km long occurred approximately 12 km north of Beaufort Lagoon on 8 and 9 September. Operations were conducted north of the camp to about 15 km offshore and east-southeast along the coast as far as the Canadian border.

Near Beaufort Lagoon we recorded a total of 6 bearded seals, 1 spotted seal, probably 2 walrus, and 4 bowhead whales. All bowhead sightings occurred after 9 September although blows were heard on the previous day. The overall abundance of bearded seals (0.1/boat hour) was considerably less than that observed near Pingok. Ringed seals were regularly sighted throughout the area in which we worked. Overall abundance in the ice north and northeast of Beaufort Lagoon was 2.6/boat hour (range 0.8-3.2). Ringed seals were seen less commonly to the east and east-southeast (average 1.5/boat hour, range 0.9-1.8).

Unusually large numbers of ringed seals were seen on 8 and 9 September in the large lead previously described. Estimated abundance in the lead was 7.8 seals/boat hour on 8 September and 9.4/hour on 9 September with an average for the 2 days of 8.2/hour. It should be noted that sighting conditions were excellent in the lead (calm, ice-free water) and it was sometimes difficult to eliminate duplicate sightings. Nonetheless, seals were obviously much more abundant in the lead than elsewhere near Beaufort Lagoon or Pingok Island.

B. Foods of Seals

1. Ringed seals

As part of field studies conducted in summer 1980, we collected and examined the stomach contents of 24 ringed seals. Eight seals were collected in the vicinity of Pingok Island between 21 August and 1 September in water 14-21 m deep (Fig. 4). Arctic cod comprised 98 percent of the overall stomach contents of those seals, and the remainder was primarily benthic crustaceans (Table 1). The largest volumes of contents were

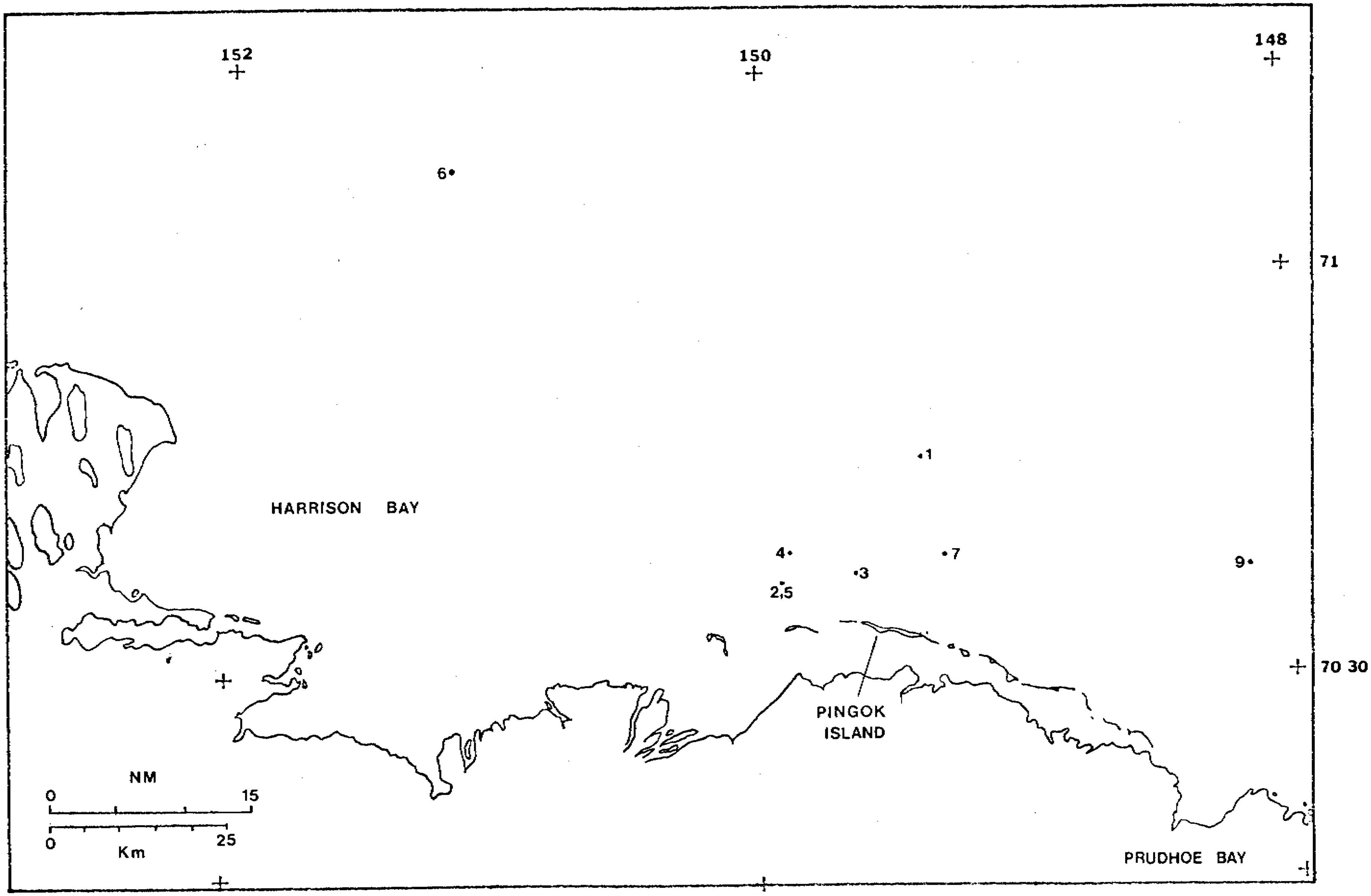


Fig. 4. Locations where ringed seals were collected near Pingok Island, 21 August-1 September 1980. Numbers correspond to seal numbers in Table 2.

Table 1.

RINGED SEAL STOMACH CONTENTS - PINGOK ISLAND, AUGUST 1980 25-Mar-81

Species or Tax Code	Tot Vol (ml)	% Vol	Tot #	% #	# of Ocurr.	Freq of Occur.
Mysis sp.	5.1	.4			5	62.5
MYSIDS	5.1	.4			5	62.5
Onisimus sp.	.6	.1			1	12.5
Anonyx sp.	1.0	.1			1	12.5
Unidentified Amphipod	.2	.0			2	25.0
GAMMARID AMPHIPODS	1.8	.2			2	25.0
Eualus gaimardii	10.0	.8			3	37.5
SHRIMPS	10.0	.8			3	37.5
Thysanoessa sp.	.0	.0			2	25.0
EUPHAUSIIDS	.0	.0			2	25.0
Unidentified Hyperiid	.4	.0			1	12.5
Unidentified Cumacean	.6	.1			1	12.5
OTHER	1.0	.1			1	12.5
TOTAL INVERTEBRATE	17.9	1.5			7	87.5
Family Cottidae			1	.2	1	12.5
Boreogadus saida			639	99.8	8	100.0
TOTAL FISHES	1173.5	98.1	640	100.0	8	100.0
Rock, Stick, etc.	4.5	.4			1	12.5

TOTAL VOL (ml)	1195.9
MEAN VOL (ml)	149.5
# W/FOOD	8
# MALES	3
# FEMALES	5
# EMPTY STOM	0
DATE RANGE	821 - 901

found in seals whose stomachs contained greater than 90 percent arctic cod (Table 2). Major components of the diet of seals collected at Beaufort Lagoon from 4 to 17 September were arctic cod and euphausiids (Table 3). Of the 16 seals collected, 6 had eaten primarily euphausiids, 8 had eaten mostly arctic cod, and the remaining 2 had eaten mostly benthic organisms (Table 4, Fig. 5). Arctic cod occurred in seals collected throughout the entire depth range investigated (3-40m), while euphausiids were found only in seals collected in water 15-40 m deep. In the six seals which had eaten mostly euphausiids, mean total contents volume was 79.5 ml (range 23.0-160.0ml) while stomachs of eight seals that had eaten mostly arctic cod had a mean volume of 59.5 ml (range 9.2-165.0).

There was no clear relationship between the number of cod found in seal stomachs and the number caught in otter trawls done nearby (Fig. 6). In collections near Pingok there was a tendency for seals taken in shallow water to contain greater numbers and volumes of arctic cod (Table 5). This relationship was not apparent in collections made at Beaufort Lagoon.

We compared the estimated sizes of arctic cod eaten by ringed seals with the measured sizes of cod caught in otter trawls. At Beaufort Lagoon the mean length of fishes caught by trawls (80mm) was much smaller than that eaten by seals (120mm). Over 76 percent of the fishes eaten were over 110 mm long while in trawls only 1 percent of the fishes caught were that large (Fig. 7). At Pingok seals ate slightly larger fishes (mean 127mm) and larger fishes were caught in trawls (mean 100mm). The proportion of fishes longer than 110 mm in seals (69%) was again much greater than that caught in trawls (25%) (Fig. 8).

2. Bearded seals

Only two bearded seals were collected during August-September 1980: one near Pingok Island and one near Beaufort Lagoon (Table 6). Stomachs of both contained over 98 percent invertebrates, although the seal collected near Beaufort Lagoon contained otoliths from an estimated 25 fishes belonging to three species or species groups (sculpins, eelpout, and arctic cod). The bearded seal collected near Pingok Island had eaten mostly isopods, clams, and gammarid amphipods. The one taken near Beaufort Lagoon had eaten shrimps, polychaete worms, and gammarid amphipods.

3. Spotted seals

One spotted seal was collected near Beaufort Lagoon on 14 September 1980 in 8.5 m water depth. The stomach contained only the remains of one capelin (Mallotus villosus).

C. Distribution and Abundance of Arctic Cod

In August-September 1980 arctic cod was the most abundant fish species caught near both Pingok Island and Beaufort Lagoon (Table 7). Only two other groups of fishes were commonly encountered: sea snails (Liparis sp.) and sculpins (including the genera Triglops, Icelus, Artediellus, Gymnocanthus, and Myoxocephalus). Arctic cod comprised 78

Table 2. Ringed seal stomach contents, Pingok Island, August 1980

Seal No.	Water Depth (m)	Percent of Contents		Total Volume (ml)
		Arctic Cod	Other	
PRUP-1-80	19	97.6	2.4	297.0
PRUP-2-80	14	99.4	0.6	468.0
PRUP-3-80	15	100.0	-	150.0
PRUP-4-80	14	98.5	1.5	167.5
PRUP-5-80	14	81.3	18.7	36.9
PRUP-6-80	16	100.0	-	60.0
PRUP-7-80	18	83.3	16.7	13.2
PRUP-9-80	21	75.8	24.2	3.3

Table 3.

RINGED SEAL STOMACH CONTENTS-- BEAUFORT LAGOON, SEPTEMBER 1980   20-Apr-81

Species or Tax Code	Tot Vol (ml)	% Vol	Tot #	% #	# of Ocurr.	Freq of Oc
Mysis sp.	.5	.0	5	10.0	3	18.8
MYSIDS	.5	.0	5	10.0	3	18.8
Acanthostepheia sp.	4.0	.4	5	10.0	1	6.3
Onisimus sp.	2.6	.2	14	28.0	1	6.3
Anonyx sp.	30.0	2.8	0	.0	1	6.3
Melita sp.	.4	.0	1	2.0	1	6.3
Gammarus sp.	2.0	.2	4	8.0	3	18.8
Gammaracanthus sp.	.6	.1	1	2.0	1	6.3
Unidentified Amphipod	1.0	.1	6	12.0	4	25.0
GAMMARID AMPHIPODS	40.6	3.8	31	62.0	6	37.5
Sabinea septemcarinata	.4	.0	1	2.0	1	6.3
Unidentified Shrimp	.4	.0	2	4.0	2	12.5
SHRIMPS	.8	.1	3	6.0	3	18.8
Thysanoessa raschii	289.5	26.9	0	.0	6	37.5
Thysanoessa inermis	177.5	16.5	0	.0	6	37.5
Thysanoessa sp.	.0	.0	2	4.0	1	6.3
EUPHAUSIIDS	467.0	43.5	2	4.0	7	43.8
Parathemisto libellula	.2	.0	1	2.0	1	6.3
Unidentified Hyperiid	.4	.0	2	4.0	2	12.5
Synidotea sp.	1.5	.1	5	10.0	1	6.3
Unidentified Polychaete	70.2	6.5	1	2.0	3	18.8
Unidentified Invertebrate	.3	.0	0	.0	1	6.3
OTHER	72.6	6.8	9	18.0	5	31.3
TOTAL INVERTEBRATE	581.5	54.1	50	100.0	12	75.0
Liparis sp.			1	.3	1	6.3
Gymnocanthus sp.			3	.8	2	12.5
Lycodes sp.			1	.3	1	6.3
Boreogadus saida			371	98.7	15	93.8
Unidentified Fish			0	.0	1	6.3
TOTAL FISHES	492.4	45.8	376	100.0	15	93.8
Rock, Stick, etc.	.7	.1			3	18.8

TOTAL VOL (ml)	1074.6
MEAN VOL (ml)	67.2
# W/FOOD	16
# MALES	6
# FEMALES	10
# EMPTY STOM	0
DATE RANGE	904 - 919

Table 4. Ringed seal stomach contents, Beaufort Lagoon, September 1980.

Seal No.	Depth (m)	Percent of Contents Arctic Cod	Euphausiid	Polychaete	Gammarid	Other	Total Volume (ml)
BLP-1-80	15	100.0	-	-	-	-	9.2
BLP-2-80	14	19.4	-	75.3	5.2	0.2	87.7
BLP-3-80	19	100.0	-	-	-	-	20.0
BLP-4-80	13	89.7	-	0.9	-	9.4	22.3
BLP-5-80	25	0.0	100.0	-	-	-	23.0
BLP-6-80	23	100.0	-	-	-	-	165.0
BLP-7-80	27	95.0	-	-	-	5.0	66.3
BLP-8-80	29	100.0	-	-	-	-	55.0
BLP-9-80	40	12.3	87.7	-	-	-	57.0
BLP-10-80	40	0.0	100.0	-	-	-	160.0
BLP-11-80	20	82.2	-	9.4	1.9	6.6	42.6
BLP-12-80	31	3.0	94.2	-	2.6	0.2	46.7
BLP-14-80	22	0.0	0.0	-	98.2	1.8	33.8
BLP-15-80	15	0.0	99.7	-	-	0.3	70.2
BLP-16-80	20	-	100.0	-	-	-	120.0
BLP-18-80	3	99.2	-	-	0.6	0.2	95.8

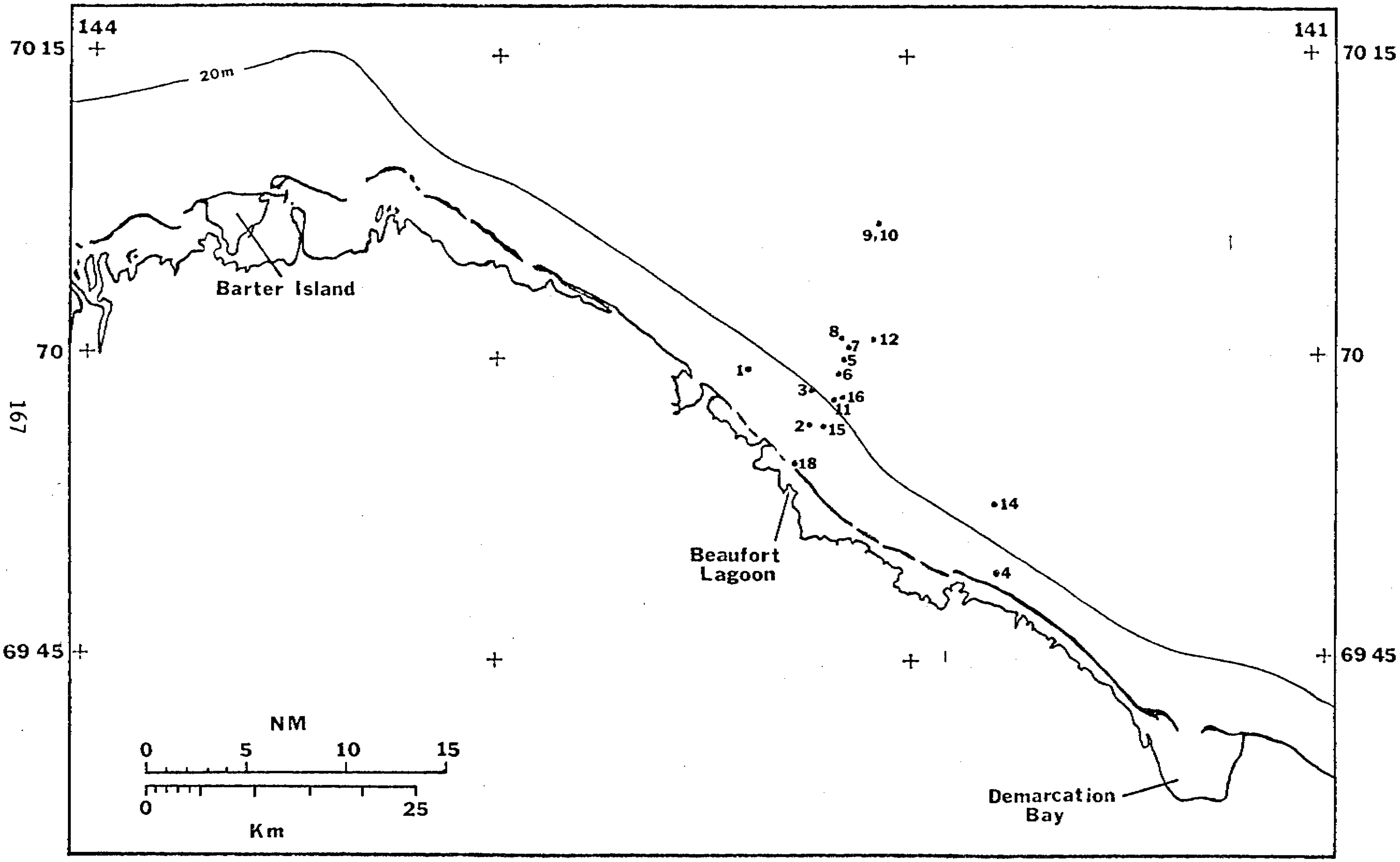


Fig. 5. Locations where ringed seals were collected near Beaufort Lagoon, 4-17 September 1980. Numbers correspond to seal numbers in Table 4.

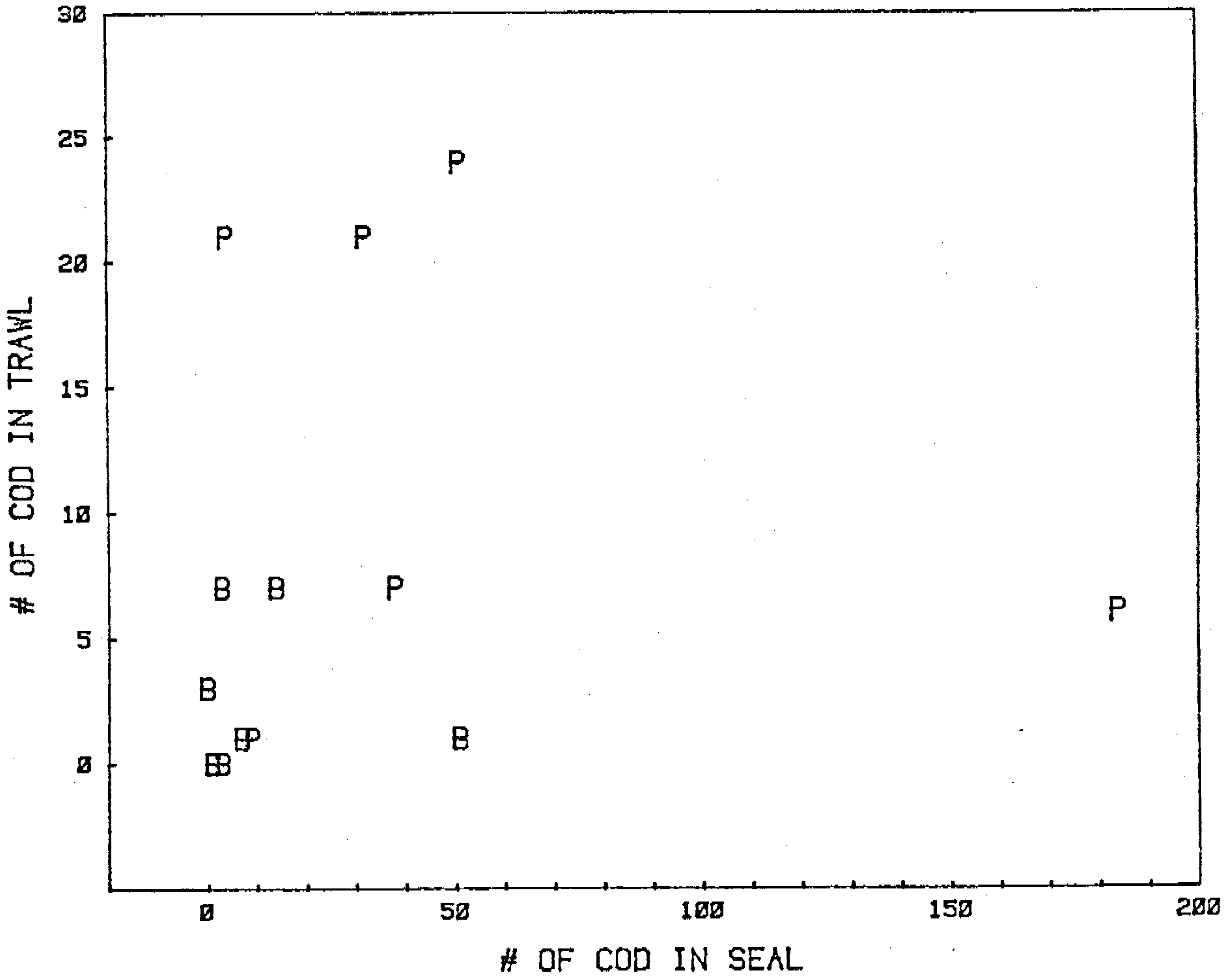
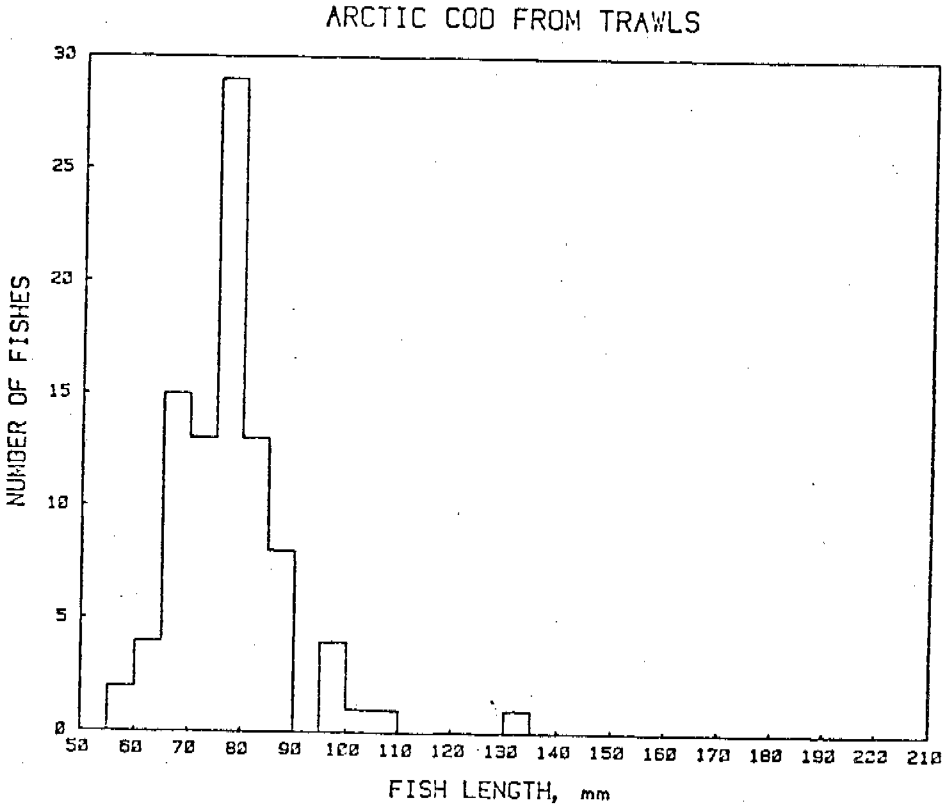


Figure 6. Relationship between the number of cod in seal stomachs and the and the number of cod caught in otter trawls done nearby (Beaufort Lagoon - B, Pingok Island - P).

Table 5. Relationship between quantities of arctic cod in seals and depth at which seals were collected.

Depth (m)	N	Mean #	Range	Mean Volume (ml)	Range
BEAUFORT LAGOON					
< 20	9	20.4	0-83	21.8	0-95.0
> 20	8	23.8	1-83	36.4	0-165.0
PINGOK ISLAND					
< 15	4	98.5	4-320	202.5	30.0-465.0
> 15	4	61.3	1-184	90.9	11.0-290.0



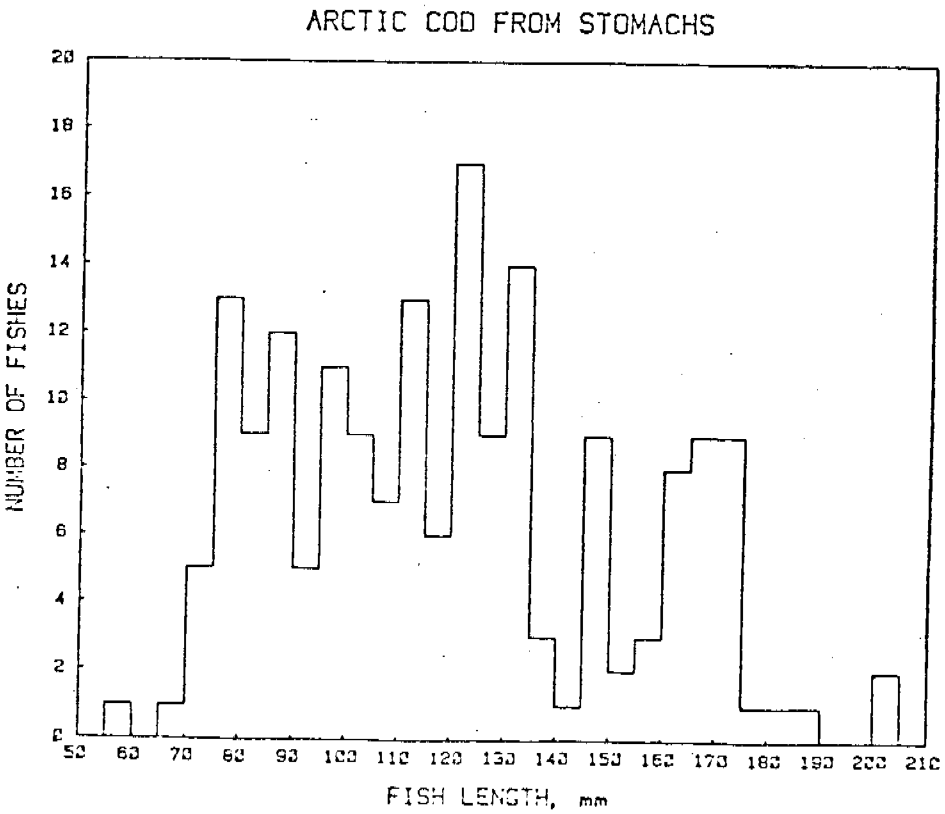
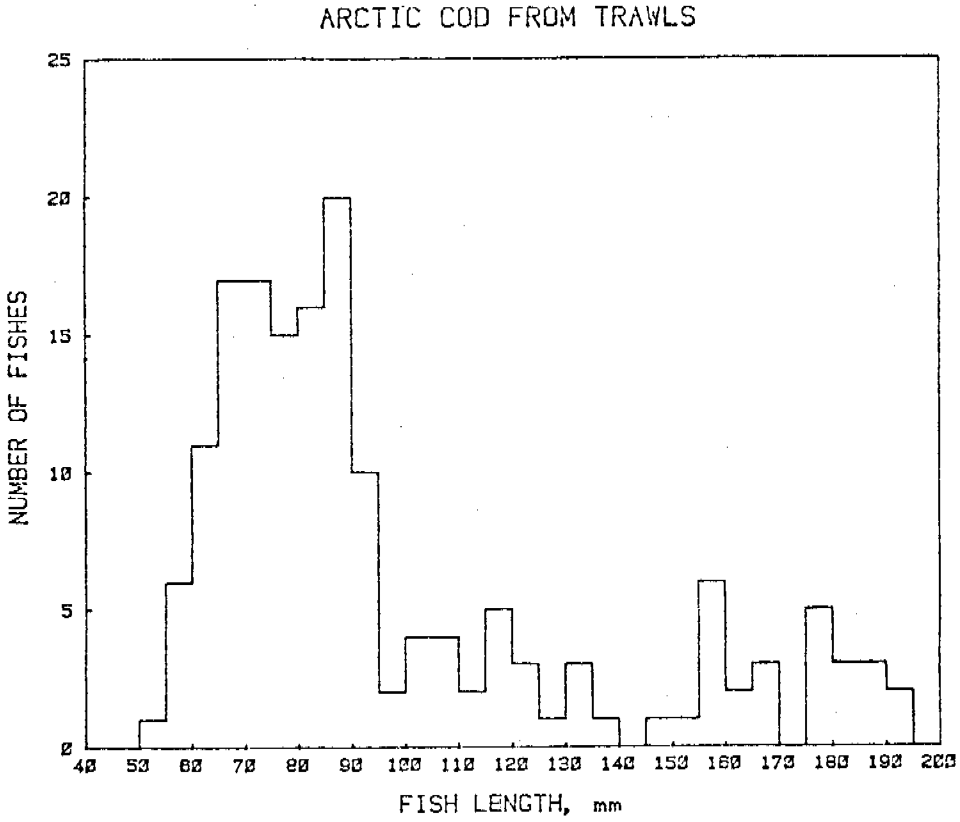


Figure 7. Length distribution of arctic cod measured from otter trawls and estimated from otoliths in ringed seals collected at Beaufort Lagoon, September 1980.



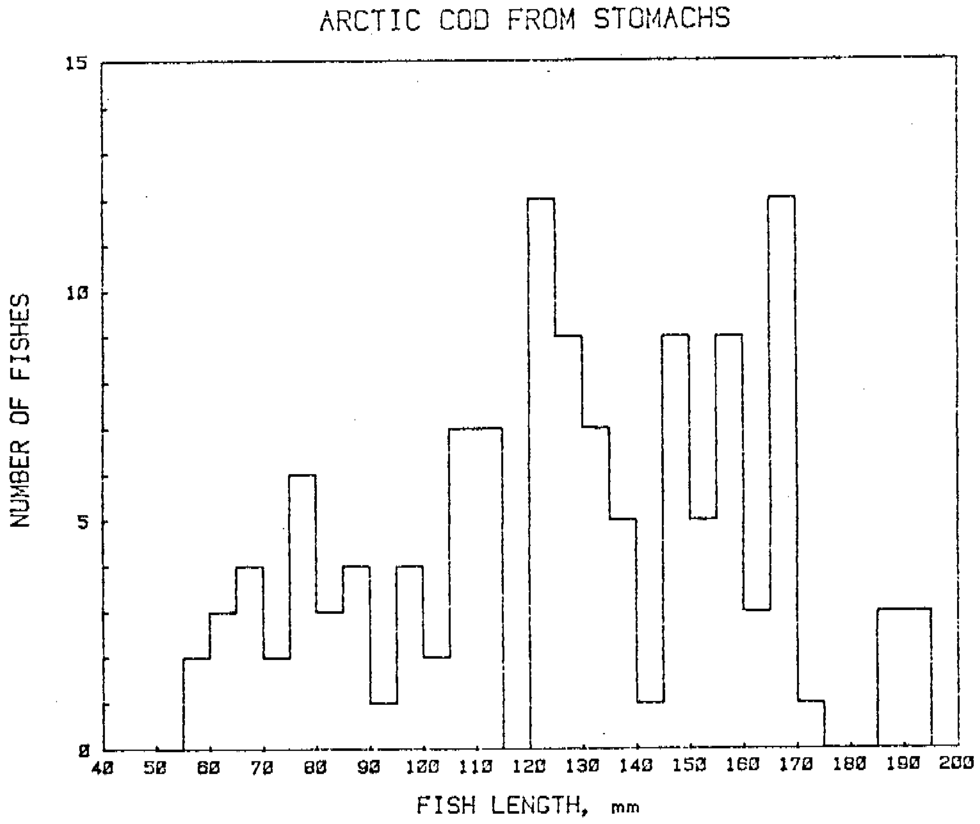


Figure 8. Length distribution of arctic cod measured from otter trawls and estimated from otoliths in ringed seals collected at Pingok Island, August 1980.

Table 6. Bearded seal stomach contents, Pingok Island and Beaufort Lagoon, September 1980. Numbers represent percent of total volume of stomach contents. Major prey species within a taxon are listed in parentheses.

Prey Species	Pingok Island 1 September 1980, 14 m N=1	Beaufort Lagoon 17 September 1980, 23 m N=1
SNAIL	2.7	2.9
CLAM (*Serripes* sp.)	18.1	5.5
GAMMARID AMPHIPOD (*Acanthostepheia* sp.; *Anonyx* sp., *Weyprechtia* sp., *Gammaracanthus* sp.)	11.9	12.1
SHRIMP (*Sabinea septemcarinata*, *Eualus gaimardii*)	-	37.8
ISOPOD (*Saduria entomon*, *Saduria sabini*)	47.4	1.9
POLYCHAETE	1.0	37.7
UNIDENTIFIED INVERT	18.7	-
TOTAL INVERTEBRATE	99.9	98.2
TOTAL FISHES	trace	1.6
Volume (ml)	69.6	73.0

Table 7. Summary of abundance of arctic cod and other fishes caught by otter trawl in the Beaufort Sea during August and September 1980.

Fish Species or Group	Pingok Island 20 Aug.-1 Sept. 1980				Beaufort Lagoon 3-19 Sept. 1980			
	Number	% of Total	Weight (g)	% of Total	Number	% of Total	Weight (g)	% of Total
Arctic cod	169	78.2	1785.5	87.4	91	54.2	365.7	79.8
Sea snails	28	13.0	120.1	5.9	28	16.7	21.4	4.7
Sculpins	17	7.9	134.6	6.6	41	24.4	30.1	6.6
Other	2	0.9	2.8	0.1	8	4.8	41.2	9.0
Number of tows	9				14			
Depth range (m)	5-19				3-40			

percent of the total number of fishes caught near Pingok, with an average of 18 cod per trawl, and 54 percent of those caught near Beaufort Lagoon, with an average of 7 cod per trawl.

Arctic cod were most abundant in shallow water (5m) trawls in both areas. Abundance decreased as water depth increased (Table 8). We found no consistent relationship between length of fishes caught and water depth at Beaufort Lagoon (Table 9). Near Pingok larger cod were more abundant in shallow (<10 m) trawls done than farther off shore in the ice. Mean length of all fishes caught at Pingok (100mm) was greater than at Beaufort Lagoon (80mm). There were no arctic cod longer than 140 mm in the Beaufort Lagoon trawls, and only 2 percent overall were from 105 to 140 mm. In contrast, 16 percent of the Pingok catch was longer than 140 mm and 12 percent from 105-140 mm in length.

D. Feeding of Arctic Cod

We examined stomach contents from 91 arctic cod collected near Beaufort Lagoon. Otter trawls from which the cod were obtained were all done in water depths of 5-30 meters in 2-6 octa ice. Eighty-six of the stomachs contained recognizable food which consisted of 56 percent (by weight) copepod, 20 percent gammarid amphipod, 8 percent euphausiids, 6 percent mysids, 5 percent larval fishes (principally arctic cod), 4 percent polychaete worms, and 1 percent hyperiid amphipod (Table 10). Copepod species eaten, in order of decreasing numerical abundance in the total sample, were Pseudocalanus sp., Derjuginia tolli, Limnocalanus sp., Calanus glacialis, and C. hyperboreus. There was no clear relationship between foods eaten and depth of collection or size of cod (few large cod were caught). Vertical plankton tows were done at each location where cod were collected. Rank order of abundance of crustaceans eaten by cod and caught in tows is compared in Table 11. Apherusa glacialis, Mysis litoralis, and Thysanoessa raschii were much more common in cod than tows, probably due to avoidance of the net by these large mobile species. The rank order of abundance of copepod species was generally similar in cod and tows, while the very small barnacle larvae were caught more commonly by plankton tows than by cod.

In tows conducted in the vicinity of Pingok Island we caught 178 arctic cod of which 173 had recognizable food remains in the stomach. Tows were made over a greater geographical range than at Beaufort Lagoon and included more large fishes. Most of the large fishes were caught in tows made at 5 and 10 m depths in open water just north of Pingok. Twenty-six out of 98 fishes in those tows had eaten other fishes. Of those 26, three were less than 100 mm in length while the remainder ranged from 109-196 mm.

In order to examine size related differences in foods, we sorted the stomach contents data from those two trawls into two fish size classes (Table 12). Major differences in the composition of the diet were evident. Small fishes (≤100 mm long) ate mostly mysids, gammarid amphipods, and cumaceans. Fish and euphausiids comprised a greater proportion of the diet of larger cod. Fishes eaten included approximately 284 arctic cod, 2 sculpins, and 1 sea snail.

Table 8. Relationship between number of arctic cod caught in otter trawls and water depth near Pingok Island and Beaufort Lagoon in August-September 1980.

Water Depth (m)	Pingok Island			Beaufort Lagoon		
	No. of Trawls	Number/Trawl		No. of Trawls	Number/Trawl	
		$\bar{x}$	Range		$\bar{x}$	Range
3-7	1	55	55	1	28	28
8-12	1	48	48	2	10	0-19
13-17	6	10	1-24	6	5	0-14
18-22	1	6	6	2	5	3-7
23-27	-	-	-	-	-	-
28-32	-	-	-	1	1	1
33-37	-	-	-	-	-	-
38-42	-	-	-	1	0	0

Table 9. Relationship between water depth and lengths of arctic cod caught in otter trawls near Pingok Island and Beaufort Lagoon in August-September 1980.

Water Depth (m)	Pingok Island					Beaufort Lagoon				
	$\bar{X}$ length (mm) (range)	N	Percent in length class			$\bar{X}$ length (mm) (range)	N	Percent in length class		
			<105mm	105-140mm	>140mm			<105mm	105-140mm	>140mm
5	97 (74-196)	53	85	6	9	80 (67-90)	28	100	0	0
10	132 (59-191)	45	29	31	40	78 (59-91)	19	100	0	0
14-15	80 (52-192)	59	93	2	5	77 (59-112)	27	96	4	0
18-20	86 (66-120)	7	86	14	0	95 (70-134)	10	90	10	0

Table 10. Stomach contents of arctic cod collected near Beaufort Lagoon, September 1980.

Species or Tax Code	Tot Wgt (g)	% Wgt	Tot #	% #	# of Ocurr.	Freq of Occur.
Unid Harpactacoid copepod	.00	.0	1	.0	1	1.2
Limnocalanus grimaldi	.00	.0	26	.2	5	5.8
Derjuginia tolli	.11	1.3	3373	28.2	25	29.1
Pseudocalanus	1.72	20.3	8132	68.1	59	68.6
Calanus glacialis	.00	.0	16	.1	3	3.5
Calanus hyperboreus	.02	.2	4	.0	2	2.3
Calanus sp.	.00	.0	3	.0	3	3.5
Unid Calanoid copepod	2.85	33.7	179	1.5	36	41.9
COPEPODS	4.70	55.6	11734	98.2	72	83.7
Mysis littoralis	.49	5.8	33	.3	25	29.1
MYSIDS	.49	5.8	33	.3	25	29.1
Monoculodes zernovi	.00	.0	1	.0	1	1.2
Monoculodes longirostris	.00	.0	1	.0	1	1.2
Acanth. behringiensis	.05	.6	2	.0	2	2.3
Apherusa glacialis	1.20	14.2	120	1.0	35	40.7
Acanthonotozoma sp.	.05	.6	1	.0	1	1.2
Unid Gammarid	.36	4.3	21	.2	16	18.6
GAMMARIDS	1.66	19.6	146	1.2	51	59.3
Thysanoessa raschii	.65	7.7	19	.2	3	3.5
EUPHAUSIIDS	.65	7.7	19	.2	3	3.5
Brachyuran crab	.00	.0	2	.0	2	2.3
Pagurid zoea	.00	.0	1	.0	1	1.2
Hippolytid zoea	.00	.0	1	.0	1	1.2
Parathemisto libellula	.10	1.2	1	.0	1	1.2
Barnacle cyprid	.00	.0	10	.1	4	4.7
Unid Crustacean	.09	1.1	0	.0	3	3.5
Polychaete	.31	3.7	1	.0	1	1.2
Unid Invert	.02	.2	0	.0	1	1.2
OTHER	.52	6.1	16	.1	11	12.8
TOTAL INVERTEBRATE	8.02	94.8	11948	100.0	86	100.0
Fish (larval)	.44	5.2	12	100.0	8	9.3
TOTAL FISHES	.44	5.2	12	100.0	8	9.3

TOTAL WGT (g) 8.46
MEAN WGT (g) .10 (empties not included)

# TOTAL FISHES	91	# MALES	45
# W/FOOD	86	# FEMALES	44
# EMPTIES	5	# UNKNOWN SEX	2

DATE RANGE 904 - 917

Table 11. Rank order of abundance of crustaceans in arctic cod stomachs and vertical plankton tows near Beaufort Lagoon

	In Cod	In Tows
Pseudocalanus sp.	1	1
Derjuginia tolli	2	2
Apherusa glacialis	3	not present
Mysis litoralis	4	7
Limnocalanus grimaldi	5	5
Thysanoessa raschii	6	not present
Calanus glacialis	7	4
Barnacle larvae	8	3
Calanus hyperboreus	9	6

Table 12. Stomach contents of arctic cod caught in trawls made at 5 and 10 m water depths in open water just north of Pingok Island, 30 August 1980.

Fish Size Class	N	Percent of Total Weight							Mean Weight of contents (g)
		Copepod	Euphausiid	Gammarid Amphipod	Mysid	Cumacean	Other Invertebrate	Fish	
≤ 100 mm	55	0.9	0.3	22.5	56.1	12.4	4.9	2.9	0.16
> 100 mm	43	3.1	7.5	20.1	16.8	1.5	15.5	33.5	1.52

Composition of the stomach contents of arctic cod from all trawls in which five or more cod were caught is summarized in Table 13. In the two tows in which large cod were common, only cod less than or equal to 100 mm in length were included in the analysis. In general, the importance of copepods in the diet was greatest in deeper tows made in the ice while mysids comprised a greater proportion of the stomach contents in shallower tows made in open water. The relative importance of euphausiids and cumaceans in the diet was quite variable.

Nine vertical plankton tow stations were conducted near Pingok, generally in areas where otter trawls were done. Abundance of copepods in these tows is summarized in Table 14. In two tows done in western Harrison Bay, Calanus glacialis was the only abundant copepod species. At stations north of Pingok, Calanus hyperboreus, Pseudocalanus sp., and Derjuginia tolli were all comparatively abundant. Of particular interest is the fact that very few C. hyperboreus were caught in the tow made at the 15 m depth in open water while in tows made at 14-19 m in the ice, this species was quite abundant. At the 15 m open water station only three arctic cod were caught, none of which had eaten significant amounts of copepod. At the 14 and 15 m in ice stations, 8 and 22 arctic cod were caught and copepods comprised 46.4 and 72.4 percent of the stomach contents.

The rank order of abundance of copepods in vertical plankton tows and arctic cod stomachs at four locations is shown in Table 15. At the station in western Harrison Bay, very good agreement was found between tows and cod stomachs. The situation is less clear at the stations north of Pingok. It appears that Pseudocalanus, Derjuginia, and Calanus glacialis may have been selected for by cod.

VII. Discussion and Conclusions

A limited amount of field work was conducted in Harrison Bay during a brief period in August. The nature of our operations was in marked contrast to previous summers when we participated in longer, multidisciplinary cruises on U.S. Coast Guard icebreakers. When working from icebreakers it was impossible to work nearshore, we could not effectively tow nets in the ice, and our ability to work in general was severely limited by ongoing operations of the ship and other scientific projects. Although the icebreaker cruises allowed us to cover large areas and work far offshore, our work was seldom productive and on numerous occasions we were unable to investigate unusual biological events due to lack of flexibility inherent in large ship operations. During the August 1980 field work we used a properly equipped small boat and staged our operations from a base camp on Pingok Island. Although we experienced a long period of bad weather, we were able to work efficiently at other times and feel that our results were overall very satisfactory and cost-efficient. However, it should be noted that the effective and safe range of small boat operations is limited and we could not work in the ice if it were extremely far offshore.

Based on our previous observations, we expected to find ringed seals distributed unequally in the study area, i.e. small areas with high seal abundance and large areas with few seals. We intended to

Table 13. Stomach contents of arctic cod collected by otter trawls from 22-30 August 1980. With the exception of OT-5-80, which was done in western Harrison Bay, all tows were done generally north of Pingok. In OT-6 and 7-80, only fishes less than or equal to 100mm in length are included.

Tow #	Water Depth (m)	Setting	N	Percent of Total Weight							Mean Weight of Contents
				Copepod	Euphausiid	Gammarid Amphipod	Mysid	Cumacean	Other Invertebrate	Fish	
OT-6-80	5	Open water	42	0.5	0	23.5	56.3	16.3	3.4	0	0.16
OT-7-80	10	Open water	13	2.2	1.3	19.6	55.4	0.9	8.9	11.6	0.17
OT-3-80	14	3 okta ice	8	46.4	21.4	14.3	17.9	0	0	0	0.56
OT-4-80	15	3 okta ice	22	72.4	3.2	10.9	10.0	0.5	0	3.2	0.10
OT-5-80	15	3 okta ice	25	71.1	2.0	4.3	2.3	0	20.3	0	0.12
OT-2-80	19	3 okta ice	6	15.5	16.9	23.5	4.7	16.9	22.5	0	0.36

Table 14. Abundance of copepods (#/m^3) in vertical plankton tows done near Pingok Island, 21 August-1 September 1980.

Depth (m)	Location	Calanus sp.	Calanus hyperboreus	Calanus glacialis	Pseudocalanus sp.	Derjuginia tolli	Metridia sp.	Limnocalanus sp.	Euchaeta sp.
5	N. Pingok open water	-	-	-	26.3	7.0	-	0.7	-
10	N. Pingok open water	3.0	0.2	0.7	17.2	54.7	-	10.0	-
15	N. Pingok open water	-	0.5	0.2	0.9	19.8	-	0.2	-
14	N. Pingok in ice	3.3	25.5	1.8	25.4	56.8	7.3	1.5	-
15	N. Pingok in ice	1.4	34.0	1.3	24.1	19.7	51.6	2.7	0.3
15	W. Harrison Bay in ice	1.0	1.7	45.8	1.3	-	0.4	-	-
18	E. Pingok in ice	-	-	0.6	5.1	-	-	-	-
19	N. Pingok in ice	9.4	23.8	3.2	45.0	15.8	3.8	8.8	0.3
20	W. Harrison Bay in ice	0.3	0.8	49.1	2.0	0.3	1.3	0.3	-

Table 15. Rank order of abundance of copepods in arctic cod stomachs and vertical plankton tows near Pingok Island.

Copepod Species	14 m, N of Pingok		15 m, N of Pingok		19 m, N of Pingok		15 m, W Harrison Bay	
	In Cod	In Tows	In Cod	In Tows	In Cod	In Tows	In Cod	In Tows
Calanus hyperboreus	-	2	3	2	3	2	2	2
Calanus glacialis	3	5	4	6	2	-	1	1
Pseudocalanus sp.	2	3	1	3	1	1	3	3
Derjuginia tolli	1	1	2	4	-	3	4	-
Metridia sp.	3	4	-	1	-	5	-	4
Limnocalanus sp.	-	6	-	5	-	4	-	-
Euchaeta sp.	-	-	5	7	4	6	-	-

sample the stomach contents of seals and the abundance of prey in areas of high and low seal abundance and to compare the results to see if and in what manner seal abundance, prey selection, and feeding rate were influenced by prey abundance and distribution. We expected that areas of high seal abundance would correspond to areas with dense concentrations of nektonic crustaceans (euphausiids or hyperiid amphipods) and that seals in those areas would be feeding intensively as indicated by large quantities of food in the stomachs. Low seal abundance was expected in areas where nektonic crustaceans were not abundant and seals in those areas were expected to have small amounts of benthic crustaceans and perhaps arctic cod in their stomachs.

In the region between Harrison Bay and Prudhoe Bay we did not find the expected distribution of seals. Seals were quite uniformly distributed throughout the area. Unfortunately, due to a combination of ice and weather conditions and the limited duration of the study, our coverage of the area was less intense than desirable and we were unable to reach areas where concentrations of seals occurred in past years (Fig. 9). We cannot therefore say with certainty that high ringed seal abundance areas did not occur in the Sale 71 area in August 1980.

Arctic cod comprised the majority of the stomach contents of all ringed seals collected near Pingok. Volumes of food in the stomachs varied from 468.0 to 3.3. ml. The number of cod caught in tows did not correlate well with the number in seal stomachs. However, seals collected in shallow water where cod were generally more abundant had larger amounts of cod in the stomachs. Interestingly, we found by far the greatest abundance of cod in open water just offshore from Pingok, and although seals were seen three times near the barrier islands they were not particularly abundant there. However, the proportion of large fishes eaten by seals (Fig. 8) suggests that they may have fed in shallow waters (5-10 m) where large cod were comparatively more abundant (Table 9). The largest volumes of food (60.0-468.0 ml, $\bar{x}$=228.5 ml) were found in six seals the stomach contents of which contained over 97 percent arctic cod. Much smaller volumes of food (3.3-36.9 ml, $\bar{x}$=17.8 ml) occurred in the other three seals whose stomach contents consisted of 75-84 percent arctic cod. Overall this suggests that arctic cod were more abundant in water less than 15 m deep and that seals fed more intensively there and concentrated their feeding on arctic cod. In deeper water, cod were less abundant and seals fed less effectively and consumed a greater proportion of benthic crustaceans.

The alternate plankton sampler which we intended to use to sample nekton did not work. Therefore, we were unable to directly measure nekton abundance. A total of three euphausiids occurred in the stomachs of two of the ringed seals we collected near Pingok (PRUP-2 and 3-80). The majority of the stomach contents of both those seals consisted of recently ingested arctic cod. In an otter trawl done nearby (OT-3-80) eight arctic cod were caught. Although copepods were by far the most numerous prey in those cod, euphausiids comprised over 20 percent of the combined weight of stomach contents. The euphausiids found in the seal stomachs may have been obtained secondarily from cod stomachs. In another trawl (OT-2-80) euphausiids comprised about 17 percent of the combined weight of arctic cod stomach contents (n=6). The stomach of a

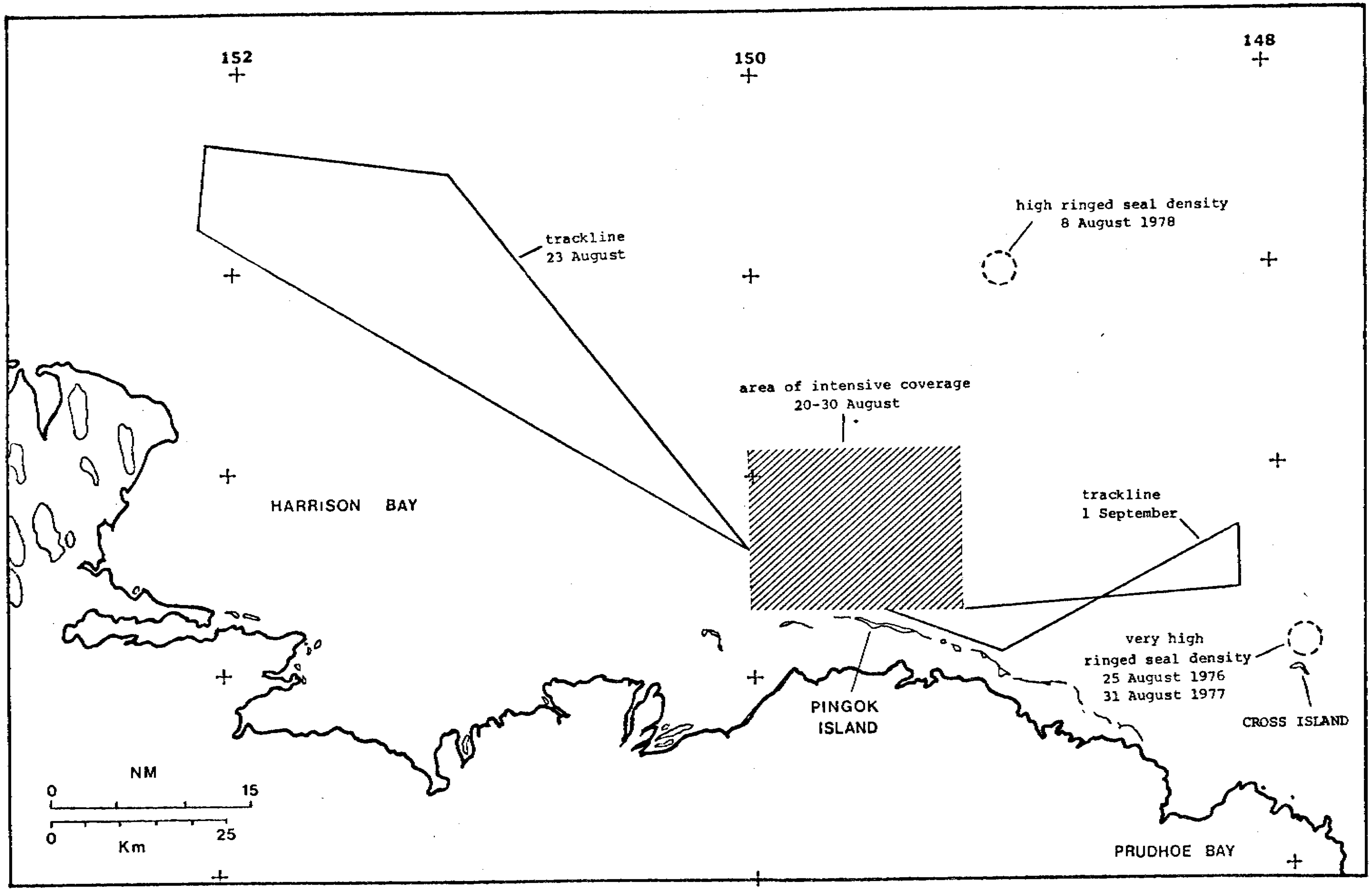


Fig. 9. Areas covered during marine mammal observations in August-September 1980 and areas where high densities of ringed seals were observed during previous summers.

seal taken nearby contained mostly recently eaten arctic cod and no euphausiids. Although euphausiids were obviously present in these two circumstances, ringed seals fed instead on arctic cod. Based on trawl catches cod were not particularly abundant in these areas. An independent measure of euphausiid abundance would obviously have been of great value.

Near Beaufort Lagoon we did encounter an area with a particularly high abundance of ringed seals. Seals collected there (BLP-9 and 10-80) had eaten mostly euphausiids and contained substantial amounts of food (57.0 and 160.0ml). Four other seals collected in the Beaufort Lagoon area had also eaten mostly euphausiids although they were collected in areas with only average seal abundance. Overall the seals which had eaten mostly euphausiids contained somewhat more food than those that had eaten mostly arctic cod. At Beaufort Lagoon, the average amount of food in seals that had eaten mostly cod (59.5ml) was less than that found in seals at Pingok (149.5ml). This corresponds well with the difference in abundance of arctic cod indicated by otter trawls in the two areas.

Euphausiids occurred in the stomachs of only three of 91 arctic cod we examined from Beaufort Lagoon. The fish were from three separate trawls made north of the lagoon entrance in 10-20 m of water. A seal collected near one of those trawls (BLP-16-80) had eaten entirely euphausiids. In the large lead where seals were very abundant and eating euphausiids, the bottom was muddy and it was difficult to successfully complete a trawl. In the one successful trawl we did there, no arctic cod were caught.

The results of our investigations of ringed seal feeding in August-September 1980 require some modification to the description of summer ringed seal foods which we have previously presented (Lowry et al. 1979, 1980). Although euphausiids and hyperiid amphipods are major summer foods in some circumstances, in some areas arctic cod is the major prey. It still appears that ringed seals are most abundant where nektonic crustaceans are abundant enough to be the principal prey. The functional relationship between prey abundance and utilization by ringed seals remains unclear.

The results of our work on arctic cod complement well previous studies done in more nearshore and offshore waters of the Beaufort Sea (Craig and Haldorson 1981, Craig et al. in prep., Lowry and Frost 1981). The combined results of these studies indicate that in August-September cod are most abundant in nearshore waters less than 15 m deep and they sometimes move into lagoon systems and bays in massive numbers. They appear to be overall less abundant east of Prudhoe Bay than west of there. The greatest proportion of mature size fish have been caught in nearshore (<15 m deep) and deep offshore (101-400m) waters.

Foods eaten by arctic cod vary considerably but include mostly zooplankton and nektonic, epibenthic, and ice-associated crustaceans. The diet during the summer open water period is most well known. In lagoons and very nearshore marine waters, mysids, gammarid amphipods, and sometimes copepods are eaten. In water deeper than about 15 m principal foods are copepods, euphausiids, and gammarid and hyperiid amphipods. Large arctic cod are sometimes cannabalistic and also appear to eat more euphausiids and hyperiid amphipods than do small cod. In winter, mysids comprised the bulk of the diet in fishes collected nearshore, while at a deep (>2,500m) offshore station principal foods were fish, copepods, euphausiids, and amphipods (Craig et al. in prep.).

The species we have primarily discussed in this report, ringed seals and arctic cod, are major ecological components of the Beaufort Sea fauna. Arctic cod are the most abundant fish species in arctic marine waters and provide food for many species of vertebrate consumers (Frost and Lowry 1981a and b). They form a major trophic link between pelagic and epibenthic crustaceans and marine mammals and seabirds. When feeding on epibenthos they compete for food with birds such as oldsquaw (Clangula hymenalis) and anadromous fishes such as whitefish (Coregonus spp.) (Craig and Haldorson 1981). In offshore waters where they feed on copepods, euphausiids, and hyperiid amphipods they compete for food to a small extent with ringed seals and to a large extent with bowhead whales (Balaena mysticetus) (Lowry and Burns 1980, Frost and Lowry 1981b). Ringed seals are the major predator of arctic cod and compete for food with seabirds and bowheads (Frost and Lowry 1981b). They in turn provide the bulk of the diet of polar bears (Stirling and Smith 1975, Stirling and Archibald 1977).

The possible effects of OCS development on arctic cod and ringed seals have been discussed in detail (OCSEAP 1978, Lowry et al. 1979) and will be dealt with briefly here. A real potential exists for a detrimental effect of oil activities on arctic cod. Arctic cod eggs are released in winter under the ice and develop there near the ice-water interface (Rass 1968). Oil spilled under the ice would therefore have a high probability of contacting the developing eggs. A decrease in arctic cod abundance would have a major effect on populations of marine mammals and seabirds. The effects of oil on ringed seals are unclear (Geraci and Smith 1976) as are the possible responses to disturbance factors. An understanding of major ecological linkages is obviously necessary in order to assess the possible implications of population changes caused by OCS activities. This project is contributing to the attainment of such an understanding.

VIII. Needs for Further Study

Although considerable progress has been made in describing the diet of ringed seals in the Beaufort Sea, we think a second summer (August) of field work in the Harrison Bay/Sale 71 area is warranted. Particularly, we would like to conduct more extensive boatwork to determine if and where important feeding areas occur. In addition, we would like to develop a functional alternate plankton sampler and use it to sample nekton in areas where seals are collected in order to examine the relationship between prey abundance and seal food consumption.

Further studies of the biology and hydrocarbon sensitivity of arctic cod are urgently needed. During our proposed summer field work, we will continue to collect arctic cod and zooplankton to further clarify the summer feeding ecology of this species. Winter studies of distribution, food habits, and reproductive biology of arctic cod should be designed and conducted.

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MODERN POPULATIONS, MIGRATIONS, DEMOGRAPHY, TROPHICS, AND HISTORICAL STATUS OF THE PACIFIC WALRUS

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SUMMARY

The primary objectives of this study are (1) to bring together and synthesize all historical documentation of the depletion and recovery of the Pacific walrus population, (2) to fill the autumn-winter gaps in knowledge of the distribution of walruses in the Bering and Chukchi seas, (3) to contribute to understanding of the sex/age composition of the population, (4) to encourage development of programs for assessing the site fidelity of individuals and degree of reproductive isolation of the main wintering groups, (5) to delineate the time and location of mating and calving, (6) to contribute to understanding of the feeding habits and trophic relations of walruses on a year-round basis, and (7) to define the responses of walruses to man-made disturbances. In this reporting period, shipboard surveys of distribution, age/sex composition, and activities were conducted in two areas in southeastern Bering Sea, in and adjacent to the St. George and North Aleutian Shelf lease areas. This work in February-March was from the Soviet icebreaking vessel ZRS *Zvyagino* and in April from the ADF&G vessel R/V *Resolution*. A number of specimens were collected as well for information on physical condition, reproductive status, and feeding habits.

More than 90% of a major concentration of animals in southern Kuskokwim Bay in February-March was made up of herds of adult females and young of both sexes; those in Bristol Bay in April were mainly adult males. Group size and composition were sampled, and responses to disturbance by the ship and by men on the ice were recorded. Judging from the behavior of the animals in Kuskokwim Bay and the condition of their reproductive organs, these were breeding herds, and the mating season was coming to an end in early March. The digestive tracts of adult males there were empty and shrunken, indicating that they had not been feeding; the adult females and young were preying primarily on tellins and surf clams, as were the males in Bristol Bay. The physical condition of the collected walruses was appreciably poorer than of specimens taken 10 to 20 years earlier, and their reproductive rate appeared to be lower, as well. These findings suggest that the population has reached or is approaching its upper limit in numbers.

INTRODUCTION

General Nature and Scope of Study

The Pacific walrus population is the largest in the world and has been a staple source of food and other materials for coastal Eskimos and Chukchi of the western American and eastern Soviet Arctic for several thousand years. It continues to play a major role in the daily life of those people today. Since the 1950's the Pacific walrus population has been recovering from a prolonged depression of numbers that was brought about by commercial overharvesting by Russians and Americans in the late 19th and early 20th centuries. Since 1960, the population appears to have at least doubled in size, as indicated by aerial census results and expansion of range (Fay, in press). That it is showing signs of approaching its upper limit, the carrying capacity of its environment, is inferred by increased natural mortality and decreased physical fitness (Fay and Kelly, 1980). Coastal natives in Alaska have expressed concern that the population stressed by overabundance may "crash" in the near future. Although a precipitous decline is improbable in a long-lived, *K*-selected species (Estes, 1979), the balance of numbers and pattern of distribution may be more easily upset by secondary factors under such circumstances. Conceivably, OCS oil exploration and development, with attendant increase in air and ship traffic, could depress the walrus population and/or upset its normal migrations by placing further stresses on the animals in certain of their critical habitats.

The biology and ecology of the Pacific walrus have been studied rather intensively over the past 30 years by biologists in Alaska and in the Soviet Far-East. Nevertheless, several major information gaps still exist, some of which could be of major importance to decision-makers dealing with known and potential impacts of oil and gas development and transport. The goal of this project is to fill those gaps and to encourage the responsible management agencies in this country and the Soviet Union to fill the rest.

The major problems which this study will address are:

A. Historical Perspective

The history of events in the decline and recovery of the Pacific walrus population is poorly documented in the scientific literature. There is, however, a large amount of supplementary information in unpublished reports, private journals, and field notes that should be brought to light. A thorough compilation and synthesis of those materials is needed at this time to place the status of the present population in clearer perspective, especially as regards its changes in the past 30 years. This will provide the users and managers of the walrus population, whose disparate opinions in some instances are based more on hearsay than on fact, with a clearer view on which to base their mutual decisions in the future. The lessons of history may be particularly useful for plotting the course ahead and for identifying convenient means for monitoring the population along that course.

B. Distribution During Spring and Fall Migrations and in Mid-Winter

Information currently available provides a reasonably clear picture of the overall distribution of the Pacific walrus population, indicating residence in the Bering Sea in winter and in the Chukchi Sea in summer. The locations of most of the major concentrations in March to September are known (Fay, in press), but there are major gaps that need to be filled concerning knowledge of the spring migration routes and calving areas. The distribution during the autumn migration (October-December) and in January-February, when most of the mating probably takes place, also has not been documented adequately for identification of migration corridors or mating areas. Soviet scientists are attempting to fill the gaps in the spring distribution records on their side of the International Date Line (G. A. Fedoseev, personal communication). On both sides, a large amount of additional information is needed during the autumn and winter. Most of the data available from October to February are from reports of walruses sighted along the coast; very few have been sighted at sea, for there have been no extensive shipboard or aerial surveys over the Bering-Chukchi region in that period. This void will not be filled very quickly by researchers on either side of the Date Line, for the daylight is short in winter, and the weather and sea conditions often are not favorable for flying or for operation of vessels other than icebreakers. It will not be filled at all, however, unless both nations address this need and take specific action to meet it.

C. Sex and Age Composition

Complementary to description of the seasonal distribution and main migration routes is the need to determine the sex and age composition of the animals in each area. Walruses do not mix uniformly throughout their distribution, but tend to segregate into groups, for example, of adult males, immature males, adult females with new calves, adult females with older offspring, etc. The composition of the groups changes somewhat with the seasons. Groups of similar composition seem to form clusters in certain areas and to travel together in migration. Some information on group composition in late winter, late spring, and late summer is available from previous Soviet and American aerial and shipboard surveys, but much more is needed, especially, for delineation of calving and mating areas.

D. Extent of Commingling of the Main Wintering Concentrations

The data available suggest that, in most winters, the population tends to be centered in two areas: (1) north-central Bering Sea, to the west and southwest of St. Lawrence Island, and (2) southeastern Bering Sea, in Bristol and Kuskokwim Bays and near the Pribilof Islands (Fay, in press). Since mating appears to take place in winter, mainly while these two groups are in semi-isolation, it is reasonable to assume for management purposes that they are reproductively separate units, which require individual consideration relative to impact of offshore development and transport. Apart from analogy and inference, however, nothing is known of the extent of their commingling in this or other seasons or of their fidelity to the mating areas. If they are essentially separate and fidelitous, then their respective contributions to harvest in various localities and their representations in prospective oil lease areas in other seasons should be defined. Information on these subjects eventually may be obtained through radio-tracking of individuals, but this still is in a primitive stage of development. To obtain information more immediately on movements to and from the wintering areas, a large scale program of visual marking is needed to label large numbers of individuals in each area. Their subsequent movements should be documented by re-sightings and by animals taken in native harvests, in both Alaskan and Siberian waters.

E. Time and Location of Mating and Calving

Until very recently, the time of mating of walruses was believed to be in the spring, just after calving. Data obtained by the P.I. (Fay, in press) and by Soviet investigators (Gol'tsev, 1978) indicate, however, that adult males are in rut mainly from November to March and suggest that the adult females are in estrus principally in mid-winter. The exact timing of their estrus and of mating is not known. Until this information is available for use in combination with that on distribution and composition, the principal mating areas cannot be delineated.

Information on time of calving is somewhat better but not precise. By inference from the first sighting of a newborn calf and the last record of a full-term fetus, births appear to take place mainly between mid-April and mid-June, with probable peak numbers in mid-May (Fay, in press). Additional shipboard surveys are needed to define this precisely and to delineate the principal calving areas.

F. Feeding Habits

The feeding habits of walruses in spring in the St. Lawrence Island-Bering Strait area are well documented from stomach contents obtained in 1975 (Fay *et al.*, 1977), 1979 (K. J. Frost and L. F. Lowry, unpublished data), and 1980 (R. D. Jones, Jr., pers. comm.), but there are only fragmentary data (mainly qualitative) from walruses in other areas and in other seasons (Nikulin, 1941; Brooks, 1954; Tikhomirov, 1964; Krylov, 1971). These suggest that the diet varies seasonally, regionally, and between sexes and age classes. There is no substantive information on feeding habits in autumn and winter. Hence, the trophic relations of walruses actually are not known but mainly inferred from samples of very limited scope in space and time, which may not be representative. Soviet and American investigators are trying to fill this wide gap on an opportunistic basis in a few key areas (e.g., Bristol Bay), but a concerted effort will be needed to fill it completely. Because many of the foods eaten by walruses have no indigestible hard parts, analysis of fecal samples is not adequate for identification of all species of prey or for assessment of their relative importance in the diet; analyses must be based on stomach contents. Some new information to help in filling this gap can be obtained from animals harvested in Eskimo villages outside the Bering Strait area in spring and summer, and in the Bering Strait area in autumn and winter.

G. Responses to Man-made Disturbances

The reaction of walruses to man and his machines can be described generally as "escape response" and attributed to visual, auditory, and olfactory cues. All walruses do not respond in the same way, however, for many other factors appear to play a part in the severity of the response, including sex and age of the animal(s), group size and location (on ice, in water, on land), distance from the disturbance, kind and level of activity (or inactivity), weather, sea state, etc. The reactions of walruses to disturbance by man have not been well documented; even uncritical anecdotal accounts are scarce. Furthermore, there is no real understanding of potential effects of repeated disturbance, for example, on such major biological events as mating, calving, or feeding. A study devoted to qualitative and quantitative documentation of response to disturbance clearly is needed, before any potential oil impact takes place.

Specific Objectives This Reporting Period

1. To investigate the distribution, composition, social organization, activities, feeding habits, and reproductive status of walruses in the Bristol-Kuskokwim Bay wintering concentration.
2. To finalize plans and arrangements for field activities scheduled for the fourth quarter of FY81 and first quarter of FY82.

Relevance to Problems of Petroleum Development

All of the proposed OCS oil lease areas on the Bering-Chukchi shelf lie within the known range of the Pacific walrus population (Figure 1). Some probably will impinge on major wintering (feeding, mating) areas, some on migration corridors and calving areas, and others on major summering (feeding, nursery) areas. Oil transport routes could impinge on all of those critical habitats. The extent of those habitats, the composition and relative densities of animals in each of them, and the potential effects on the animals, directly by disturbance and indirectly through the food chain are not adequately known at this time. Because the entire population is confined to the shelf and is dependent on its resources, and because the OCS lease areas nearly blanket the entire range of the population east of the Soviet-American convention line, the possibility of some major impact by oil development on the population seems high, at this stage of our knowledge. Until more definitive information is available, however, our predictive ability will be poor and, perhaps, unrealistic.

CURRENT STATE OF KNOWLEDGE

A. History

The Pacific walrus population was estimated to comprise at least 200,000 animals before the middle of the 19th century, when it apparently inhabited the continental shelf of the Bering-Chukchi region in a pattern comparable to that seen today (Fay, 1957). Even so, it was somewhat reduced from its pre-European-contact level by Russian incursions into the southern Bering Sea a hundred years earlier. There, for example, the Russians extirpated a herd of several thousand animals from the Pribilof Islands (True, 1899). From about 1850 to 1880, extensive harvests of walruses by Yankee whalers, probably coupled with increased taking by Alaskan and Siberian natives, brought about a catastrophic decline in the walrus population (Clark, 1887; Allen, 1895). Thereafter, it was depressed further by continuing harvests until about 1915, when world markets for

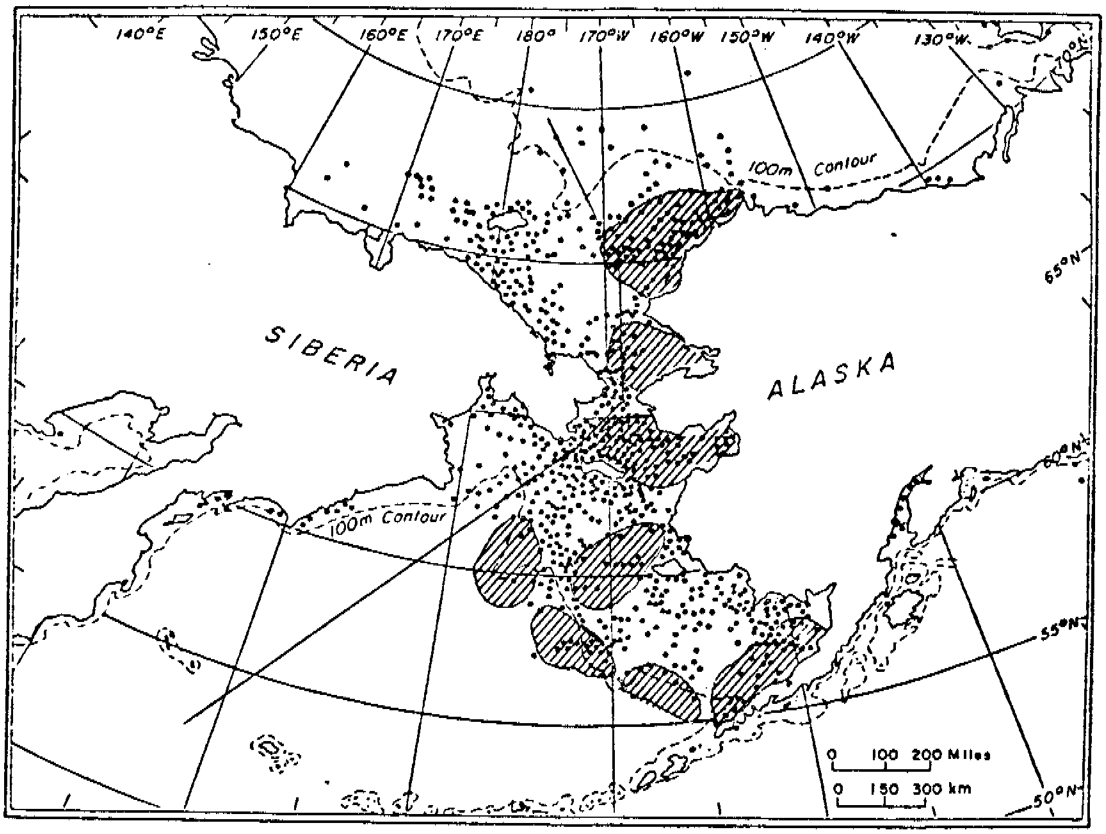

Fig. 1. Distribution of recorded sightings of walruses in the Bering-Chukchi region, in relation to the location of the major OCS petroleum basins. Each dot represents one sighting of a group of walruses (1930-79, all seasons). Hatchured areas are oil basins.

the ivory and hides collapsed (Madsen and Douglas, 1957; Bockstoce and Botkin, 1980). Significant recovery of the population by 1930 is inferred by its reoccupation of much of the former range and by recurrent instances of high natural mortality (Nikulin, 1941; Fay and Kelly, 1980). Then, however, it was again heavily impacted by large commercial harvests, this time by the Soviet Union (Zenkovich, 1938; Krylov, 1968). Again, the result was depletion of the population to perhaps the lowest level in history (Fay, in press). It is that level, reached in the 1950's (Geller, 1957; Kleinenberg, 1957; Fay, 1957), from which the population presently is recovering. Since 1970, nearly all of the former range has been reoccupied, and natural mortality again has risen dramatically (Fay and Kelly, 1980). This suggests that the population once more has attained or is approaching its former maximum.

B. Distribution and Migrations

The annual distribution of the Pacific walrus population is reasonably well documented for the period March to October but is not adequately known during November to February (Figures 2, 3). The existence of two major concentrations of animals in winter, one in north-central and the other in southeastern Bering Sea, is suggested by the distribution of sightings in March and April. Movement of animals from the southeastern area toward St. Lawrence Island and Bering Strait is indicated during April to June. At the same time, most of those from the north-central area pass through Bering Strait, some of them heading toward Barrow and others toward Wrangell Island. The main course of the migration from the Bering to the Chukchi Sea seems to be completed by late June or early July. From July to September, most of the population concentrates in the western Chukchi Sea and to a lesser extent near Barrow and Icy Cape. These western and eastern groups appear to merge somewhat toward the end of that period. Southward migration toward the wintering areas begins mainly in October and probably continues through December and January.

The majority of the animals taking part in the migrations are adult females with young of both sexes. Large groups of adult males remain throughout the summer in Bristol Bay, the Gulf of Anadyr, and Bering Strait.

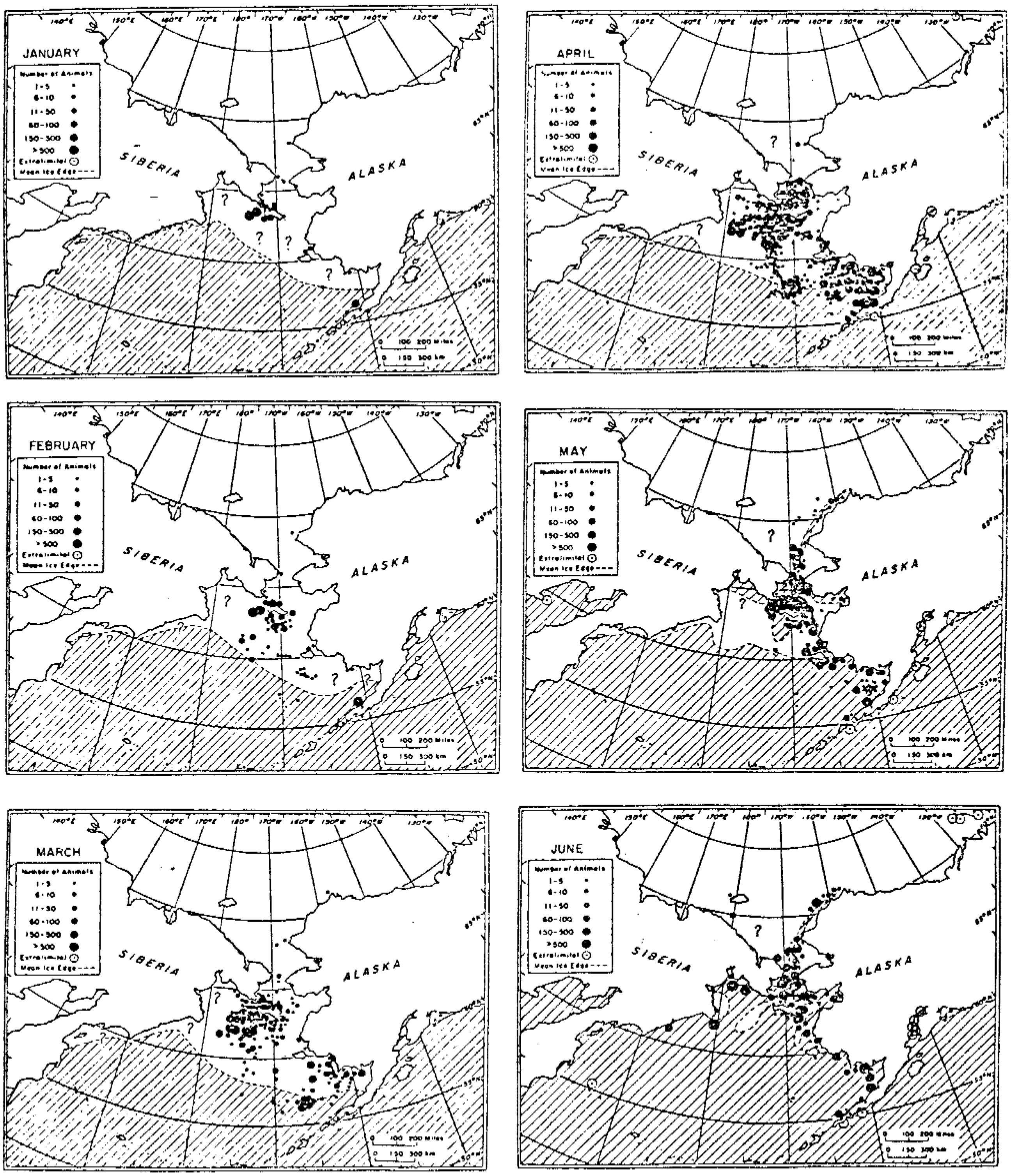

Fig. 2. Distribution and relative numbers of walruses sighted in the Bering-Chukchi region, January to June 1930-79, in relation to the mean extent of the pack ice. Cross-hatched areas are open water (ice-free). Question marks indicate areas from which data are lacking. (From Fay, in press)

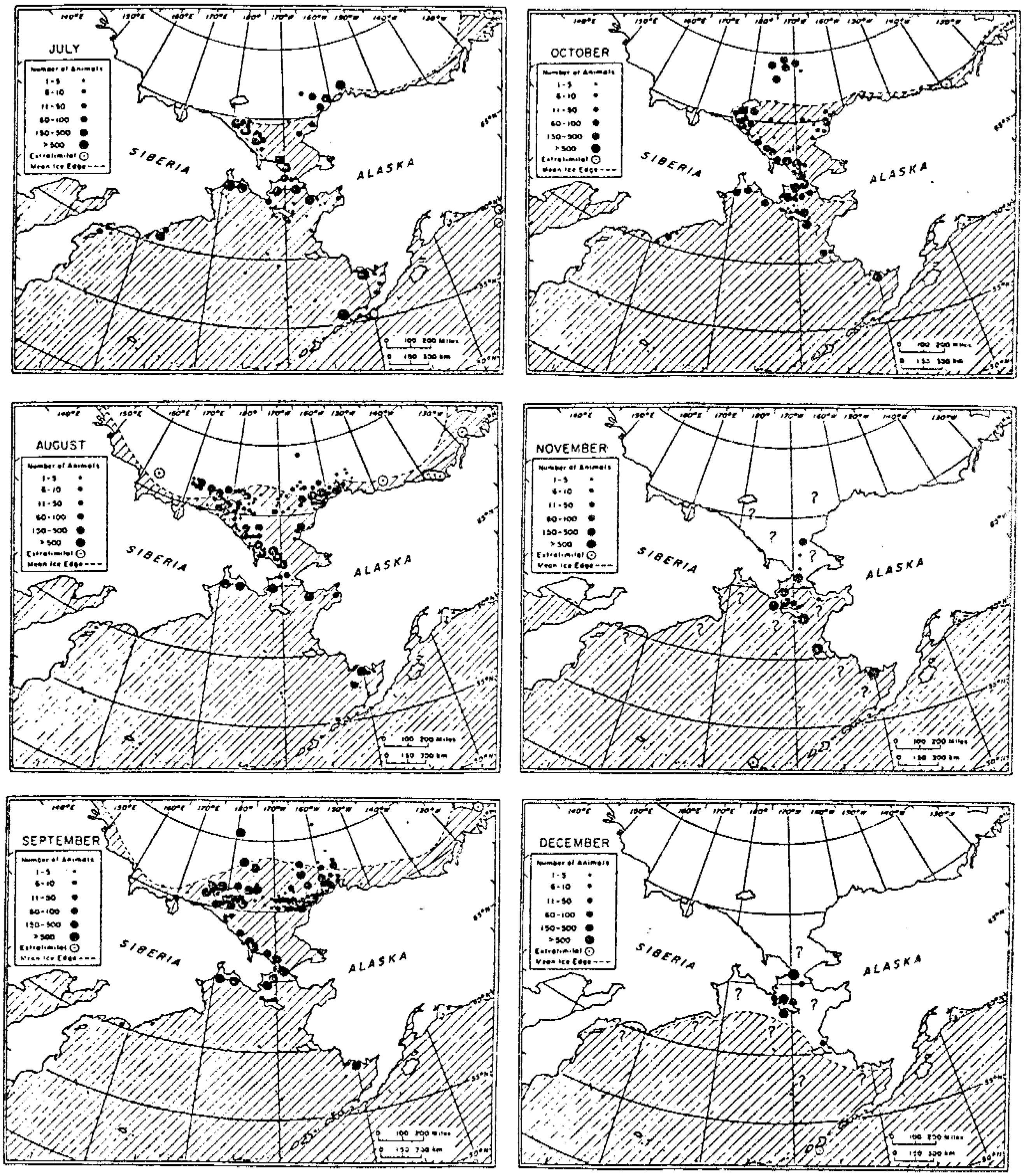

Fig. 3. Distribution and relative numbers of walruses sighted in the Bering-Chukchi region, July to December 1930-79, in relation to the mean extent of the pack ice. Cross-hatched areas are ice-free. Question marks indicate areas from which data are lacking. (From Fay, in press)

Mating apparently takes place mainly in the wintering areas in the Bering Sea, where the adult males and females mix (Fay, in press). Calving takes place during the northward migration in spring (Burns, 1965).

C. Sex and Age Composition

Drawing on a wide variety of published and unpublished sources, Fay (in press) summarized the available information on the sex and age composition of the Pacific walrus population in the 1960's and 70's and concluded that the population as a whole was made up of about 40% males and 60% females, of which about 45% were immature and 55% were adults; the sex ratio of adults was about 1 male:3 or 4 females. These estimates were imprecise because of the small samples on which they were based and because of the lack of data from some parts of the known distribution.

The animals in the central parts of the wintering areas in March appeared to be mainly adult females and young, attended by small numbers of adult males (sex ratio of adults about 1 male: 10 females). Most of the juvenile and subadult males, with the remainder of the adults, were sighted in the peripheral parts of the wintering areas, away from the females and young. This is assumed to be typical of the distribution by age and sex during the mating season (January-March).

Based on observations mainly near St. Lawrence and Little Diomede Islands, I suspect that the first migrants through the northern Bering Sea and Bering Strait in spring are subadult males and non-pregnant females, followed by larger herds of females and young, and finally by herds of juvenile to adult males. Since most of the births take place in May, calving is judged to occur at least from the vicinity of St. Lawrence Island to the central Hope Basin, Chukchi Sea. This is mainly speculation, however, for there are few records of births.

About two-thirds of the summering herds in the western Chukchi Sea appear to be made up of adult females and young, with a few juvenile and subadult males. The rest are herds of juvenile to adult males. Compositional data for summering herds in the eastern Chukchi Sea are lacking, but judging from those animals taken by Eskimos at Barrow and Wainwright, both sexes and all age classes are represented. Summering herds to the south in Bristol Bay, Anadyr Gulf, and Bering Strait appear to be made up principally of adult males. There are no data on the makeup of herds during the southward migration in autumn.

D. Extent of Commingling of the Main Wintering Concentrations

No information.

E. Time and Location of Mating and Calving

Since the 18th century, the mating season of walruses has been assumed to be in the spring, coincident with or slightly after the time of birth (Allen, 1880; Chapskii, 1936; Brooks, 1954; Krylov, 1969). For the Pacific walrus, this would place it during the spring migration, in the Norton and Hope Basins. By histological examination of the testes of males taken each month from November to August, however, Fay (in press) found that testicular development in adults reaches its zenith in mid-winter and its nadir in late spring and summer. By analogy with other pinnipeds, this suggested a mid- to late-winter mating season, which would place it in the two main wintering areas in the Bering Sea. This was confirmed in part by the condition of the reproductive organs of a few females taken in those areas in February-March (Gol'tsev, 1978; Fay, in press), but much larger samples are needed to delineate the start and end of the mating period for the population as a whole and to relate this to distribution and sex/age composition of the herds.

The time of birth of walruses has been known in a general way to be in spring (April - June), but this has been based mainly on inference rather than on documentation of occurrence (Chapskii, 1936; Nikulin, 1941; Mansfield, 1958; Burns, 1965; Krylov, 1969). Drawing on all available data (Figure 4), Fay (in press) estimated that nearly all births take place between mid-April and mid-June, with a probable peak in mid-May. At that time, the Pacific population is in motion from its wintering areas in the Bering Sea to summering areas in the Chukchi Sea. Most of the records of births in this region are from the vicinity of St. Lawrence

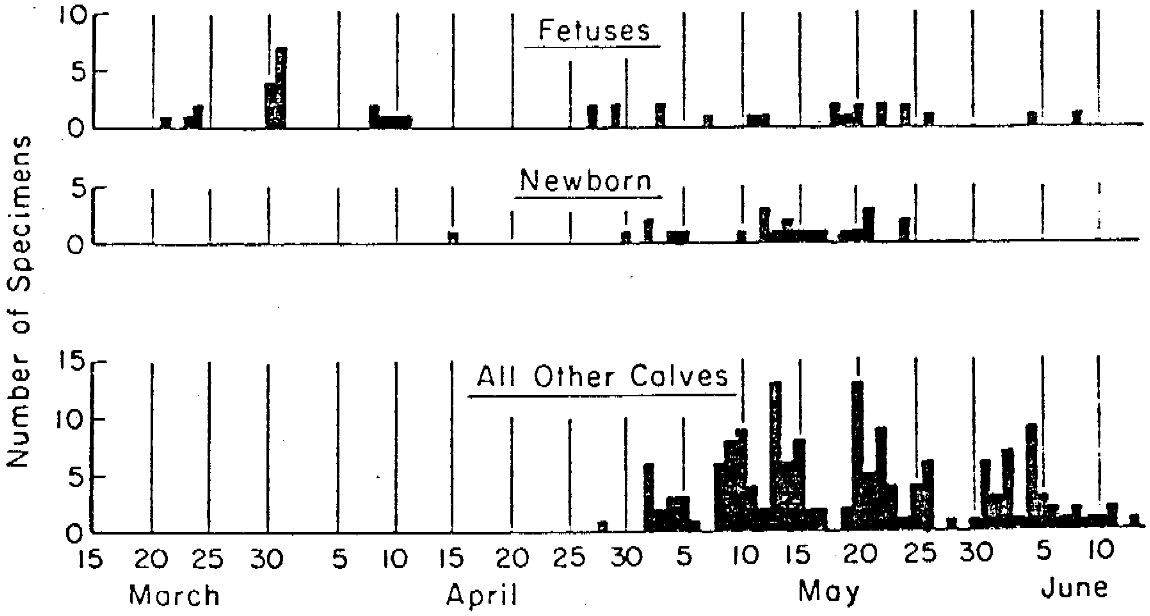

Fig. 4. Frequency of occurrence of near-term fetuses (upper), newborn calves less than 48 h old (center), and older calves of uncertain age (lower) during mid-March to mid-June. (From Fay, in press)

Island, probably because this is the area in which observers have been concentrated. Since the potential impact of disturbance on the walrus population may be greatest during the calving period, a much broader survey of possible calving areas is needed for definition.

F. Feeding Habits

Fay *et al.* (1977) examined the stomach contents of 107 walruses taken in five locations within the St. Lawrence Island to Bering Strait area in late April to early June 1975 and found that 66 to 88% by weight of the identifiable prey were mollusks. Four genera of bivalves (*Hiatella, Mya, Spisula,* and *Serripes*) made up more than 80% of the total wet weight biomass in the stomachs. These are the only reliable quantitative data on feeding habits of Pacific walruses at present, and because of their limited scope in space and time, they cannot be taken as representative of habits year-round or over the entire range of the animals. Qualitative information from other areas and in other seasons (Nikulin, 1941; Brooks, 1954; Tikhomirov, 1964; Krylov, 1971) suggest that the walrus' choice of foods varies geographically, probably in relation to availability, and that deposit-feeding mollusks, polychaetes, echinoderms, priapulids and echiurids are the principal prey in all areas. Since the greatest potential impact of oil spills on walruses appears to be through the food chain (Geraci and St. Aubin, 1980; Kelly, 1980), more definitive information on feeding habits in all areas and all seasons would be useful for evaluating that potential.

G. Responses to Man-Made Disturbances

Loughrey (1959) and Brooks (1954) judged that the walrus' vision is poor, but the senses of smell and hearing are keen, implying that most man-made disturbances elicit responses on the basis of odor and sound. Loughrey observed that a man on foot could walk upright to within 20 m of walruses on the downwind side before they became alarmed and headed for the water. If the person crawled toward them, he could approach to within 6 m without causing alarm. Conversely, when approached from the upwind side, the animals detected human odor and rushed into the water, even without visual contact. Brooks observed that walruses hauled out on shore were alarmed by the sound of an aircraft passing by at an altitude of about 300 m. They appeared not to be disturbed by gunfire or by the sound of outboard engines on small boats at distances of 400 m or more.

Salter (1979) recognized three levels of response by walruses to disturbance: Head-raising (animal raises head and, usually, looks toward the disturbance); orientation (animal shifts position and orients toward the sea in preparation for escape); and escape (animal goes into the water). On this basis, he classified the responses of a small herd of walruses on shore when approached by aircraft and observed that, (a) with the aircraft at distances of 2.5 km or more and altitudes of > 300 m, the only responses were head-raising, (b) aircraft at distances of 1 km or less and altitudes of < 150 m, caused some animals to orient and escape, but some others remained on the haulout apparently undisturbed, (c) even when frightened into the water, the animals usually remained near the beach and eventually hauled out again, and (d) females with calves or yearlings were most responsive to the disturbance; adult males were least responsive. Tomilin and Kibal'chich (1975) observed that a low overflight (150 m) by a twin-engine aircraft (IL-14) caused a large herd of females and young to stampede into the water. The result of the stampede was that 21 young were trampled to death, and 2 adult females aborted their fetuses.

STUDY AREA

The study area is the continental shelf of the Bering and Chukchi Seas. In this reporting period, sampling was limited to the southeastern Bering Sea wintering area, in and adjacent to the St. George and North Aleutian Shelf oil lease areas (Figure 5).

SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

Shipboard surveys of distribution, sex/age composition, and activities of walruses in the southeastern Bering Sea wintering area were conducted from 25 February to 15 March aboard the Soviet icebreaking trawler ZRS

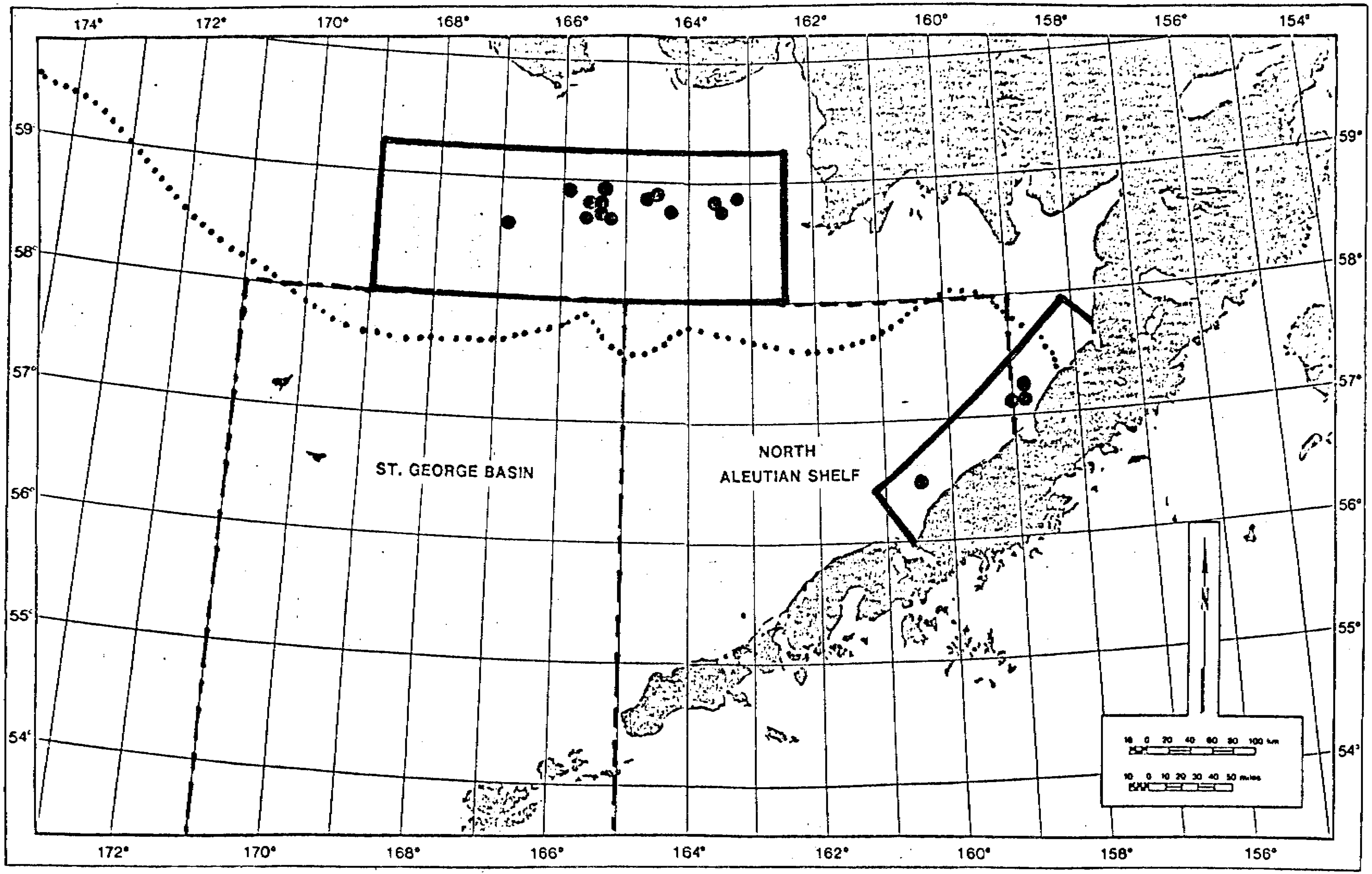

Fig. 5. Sampling areas (solid, dark outlines) and locations where specimens were collected in this reporting period, in relation to the St. George and North Aleutian Shelf oil lease areas (dashed outlines). Dotted line is the southern limit of the pack ice on 26 February.

Zvyagino and from 8 to 20 April aboard the ADF&G vessel R/V *Resolution*. On each cruise, samples of walruses also were collected for information primarily on physical condition, reproductive status, and feeding habits. The *Zvyagino* cruise was carried out in connection with the Marine Mammal Project (02.05-61) of the US-USSR Environmental Protection Agreement, and the PI's participation was supported in part by the Soviet Ministry of Fisheries, which provided the vessel with accommodations for four American and five Soviet scientists. The other participants, whose aid is hereby acknowledged, were R. Nelson (ADF&G), A. Akeya (Eskimo Walrus Commission), and K. Lourie (USFWS); the Soviet participants were L. Popov and A. Kibal'chich (VNIRO), Y. Bukhtiarov (TINRO), M. Yurakhno (Simferopol State University), and S. Somov (Okhotskrybvod). The cruise of the R/V *Resolution* was conducted primarily for information on use by walruses of a proposed clam fishery area in Bristol Bay and was supported jointly by the North Pacific Fisheries Management Council (NPFMC) and the ADF&G. Assistance was provided by R. Smith (ADF&G) and E. Muktoyuk (private contractor), as well as by the crew of the vessel.

The area investigated during the *Zvyagino* cruise was selected on the basis of configuration of the pack ice (Figure 5) and previous knowledge of the distribution of walruses in February-March (Figure 2). Also, an aerial survey of Bristol Bay on 10 February (L. Lowry, pers. comm.), showed that walruses were scarce east of Cape Pierce (162°W). The area investigated during the *Resolution* cruise was predetermined by the NPFMC as the most probable for potential development of a commercial surf clam fishery.

Sampling of age/sex composition of walruses in the study areas was accomplished by observation from the bridge of each vessel along 1-km-wide transects (0.5 km on each side of the ship's track) during all hours when the ships were underway. Animals sighted outside the transects also were recorded, but their group size and composition could not be ascertained accurately. Ground truth counts of groups by observers on foot (on the ice) indicated that numbers generally were underestimated by 10 to 100% when the groups were more than 0.5 km from the ship. Age classes were identified primarily on the basis of known relationships between length of tusks and depth and breadth of the snout (Figure 6). The sex of each

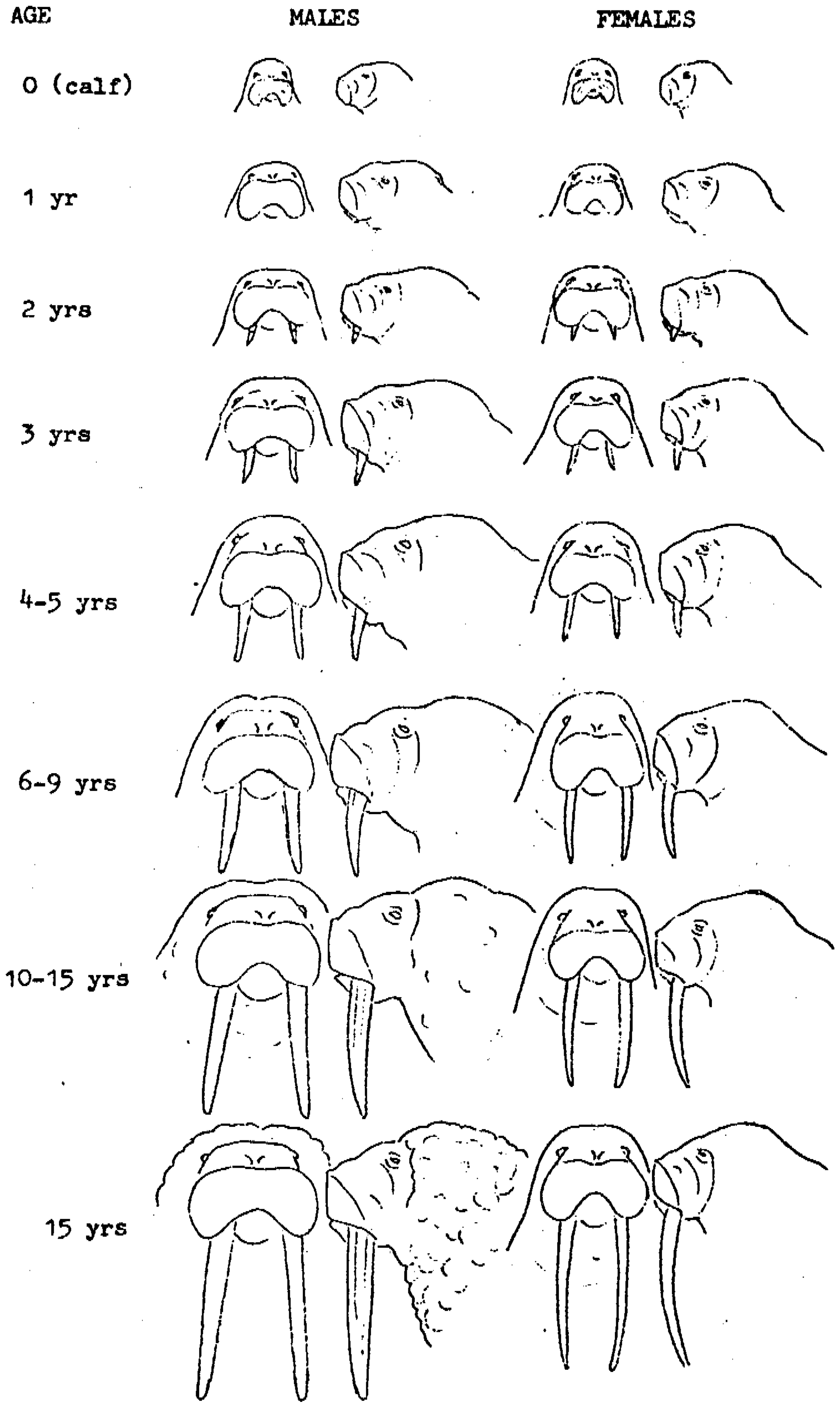

Fig. 6. Relationship of tusk length and shape to facial characteristics of male and female Pacific walruses in relation to age.

animal was identified on the basis of a suite of sexually dimorphic characters (Fay, in press), principally shape and color of tusks, form of the head, neck, and body, and topography and color of the skin, especially on the neck and shoulders. All sightings were recorded in relation to time, weather, and ice conditions.

Collected specimens were taken from groups lying on the ice (*Zvyagino* cruise) and feeding in the water (*Resolution* cruise). Each specimen was brought aboard the ship where its whole weight, standard length, tusk length, and sternal blubber thickness were measured. One tooth was collected for age determination, and reproductive organs and stomach contents were preserved in 10% formalin for subsequent analysis. In addition, pathological conditions were noted and blood serum samples were taken for serum antibody analysis. Soviet investigators also examined the digestive organs and musculature for helminthic infections.

RESULTS

A. Cruise of the ZRS *Zvyagino*

At least 486 groups of walruses containing about 9,400 individuals were sighted during this cruise. These were mainly in herds of 20 to 250 animals (Table 1). Nearly all groups of 4 or more animals were composed of adult females and young; most groups of 1 to 3 animals were adult males. In the area of greatest concentration of animals, about 100 km south of Etolin Strait, the sex ratio of adults was about 1 male: 10 females. Conversely, in the peripheral areas to the east, west, and south, most of the animals sighted were subadult and juvenile males. A ground truth sample of 176 animals in herds of females and young yielded counts of 94 (53%) adult females (6 yrs and older) and 82 (47%) younger animals of both sexes. In these and other herds, the cohorts of young in age classes 1, 2, and 3 years appeared to be remarkably uniform in numbers. A ground truth sample yielded 26, 24, and 26, respectively, which suggests that the survival rate of the young from age 1 to age 3 years has been very high.

TABLE 1

FREQUENCY OF OCCURRENCE OF GROUP SIZES OF WALRUSES IN THE SOUTHEASTERN BERING SEA WINTERING AREA, 25 FEBRUARY TO 15 MARCH 1981

	Group size												
	1	2	3	4-5	6-8	10	12-15	20-25	30-35	40-50	70-100	200-250	Total
No. of groups	202	43	16	17	12	18	11	28	16	15	6	2	386
Percentage of groups	52	11	4	4	3	5	3	7	4	4	2	1	100
No. of animals	202	86	48	78	82	180	143	600	695	710	470	450	3744
Percentage of animals	5	2	1	2	2	5	4	16	19	19	13	12	100

Within about 2 km of each herd of females and young on the ice lay a few isolated bulls. In many instances, one or more bulls also were sighted in the water, alongside each herd. These latter bulls were engaged in mating displays, which involve both visual and vocal signals in a steriotyped sequence (Ray and Watkins, 1975). On two occasions, adjacent displaying bulls were seen fighting violently. Many of the adult males taken as specimens bore numerous wounds and deep bruises, presumably resulting from such fights.

The herds of females and young seemed to be rather synchronous in their feeding schedule. Generally, either all of the animals sighted during a given day or part of a day were in the water, apparently feeding, or they all were on the ice, resting. A tabulation of sightings per day of animals in the water versus on the ice (Table 2) suggests that the walruses were spending 24 to 36 hours feeding for every 36 to 48 hours at rest on the ice. Nearly all of the adult males sighted were either sleeping on the ice or engaged in mating displays in the water; none appeared to be feeding.

In general, herds of females and young on the ice reacted to presence of the ship and to presence of the hunters on foot at longer distances than did the adult males. In most instances, they appeared to be awakened by the sound of the ship's engines or of the hunters' footsteps in the snow, then to locate the source of the sound visually before responding further. The herds of females and young frequently did not retreat into the water until the moving ship was within 0.5 km of them; sleeping adult males often stayed in place until the ship approached to within 100 m. By approaching from upwind and taking cover behind the rough ice, the hunters usually were able to approach to within 20 m of herds of females and young and, occasionally, to within 2 m of sleeping bulls. Animals in the water seemed less responsive to the passing ship than those on ice; when the ship was not in motion, they often swam within 20 m without apparent fear.

The specimens collected were 90 males and 90 females, taken from 25 February to 10 March. Most of these were adults. This was not a representative sex ratio; it was specified by the federal permit under which the collections were authorized. Otherwise, the specimens were

TABLE 2

PERCENTAGES OF ANIMALS SIGHTED ON THE ICE (RESTING) VERSUS IN THE WATER (FEEDING) EACH DAY

Date	No. of animals sighted	Percentage	
		On ice	In water
25 Feb	272	99	1
26 Feb	169	83	17
27 Feb	599	2	98
28 Feb	15	100	0
1 Mar	129	95	5
2 Mar	396	99	1
3 Mar	400	26	74
4 Mar	139	76	34
5 Mar	No data		
6 Mar	63	52	48
7 Mar	13	54	46
8 Mar	231	100	0
9 Mar	44	93	7
10 Mar	155	36	64
11 Mar	63	95	5
12 Mar	36	20	80
13 Mar	484	51	49
14 Mar	2144	98	2
15 Mar	94	73	27

taken non-selectively. The determination of age of these specimens has not been completed, hence the age composition and age/size data have not yet been analyzed. Sternal blubber tended to be about equal in thickness on immature males and females, somewhat thinner on mature males, thicker on mature females, and thickest on mature females carrying a near-term fetus (Table 3).

The testes of males were weighed by Soviet investigators and samples were taken for histological analysis, the results of which are not yet available. Epididymal smears at the time of collection showed that nearly all of the subadult and adult males had spermatozoa in their epididymides, indicating that they were in rut. In many of the mature adults, however, the sperms were non-motile, indicative of retrogressive change. In the sample of 73 fertile females, 27 (37%) bore near-term fetuses, 26 (36%) already had newly developing corpora lutea of pregnancy (17 to 31 mm in diameter) in their ovaries, 8 (11%) had ripe follicles (9 to 20 mm) indicative of estrus, and 12 (16%) apparently were barren. Two cases of premature births were sighted among the animals on the ice. In the first instance (1 March), the fetus was dead; in the second (3 March), the fetus was still alive but uncoordinated in its movements (unable to stand).

The stomachs of all adult males were empty and, in most cases, their digestive tracts were greatly shrunken, suggesting that they had not fed recently. Fifteen of the adult females and young taken on 2, 6, and 8 March did have significant amounts of food in their stomachs, and several others had traces of food. The organic materials in the 15 stomachs amounted to about 33.1 kg and ranged in amount from 0.09 to 5.8 kg per stomach (Table 4). The numbers of prey per stomach ranged from 12 to 827 (mean, 391). In addition to the food, the 15 stomachs contained a total of about 1.2 kg of sand and gravel.

About 96% of the food in the stomachs consisted of fleshy parts of bivalve mollusks, mainly tellins (*Tellina lutea*) and surf clams (*Spisula polynyma*), with lesser amounts of Greenland cockles (*Serripes groenlandicus*) and razor clams (*Siliqua patula*). A total of only 59 g (1 to 9 g/stomach) of fragments from the shells of those mollusks were

TABLE 3

THICKNESS OF STERNAL BLUBBER IN COLLECTED SPECIMENS OF WALRUSES IN RELATION TO SEX, APPROXIMATE AGE, AND PREGNANCY

Sex and maturity[a]	No.	Blubber thickness (cm)[b] Range	Mean
Males			
Juveniles and subadults	22	2.0 - 4.5	3.4
Adults	63	1.5 - 5.4	3.2
Females			
Juveniles and subadults	18	2.4 - 4.6	3.3
Adults			
Lacking fetus	42	2.8 - 5.4	3.9
Carrying fetus	27	2.5 - 6.8	4.5

[a] Males about 1-6 years old are juveniles, 7-14 yrs are subadults, 15 yrs and older are adults; females about 1-3 yrs are juveniles, 4-5 yrs are subadults; 6 yrs and older are adults (Fay, in press). Ages were estimated from tusk lengths.

[b] Measured vertically in 5 cm slit over anterior end of the sternum.

TABLE 4

ANALYSIS OF STOMACH CONTENTS BY WEIGHT (grams) FROM WALRUSES TAKEN IN SOUTHERN KUSKOKWIM BAY (58°37'N-58°51'N, 164°40'W-166°56'W) DURING 2-8 MARCH 1981 AT DEPTHS RANGING FROM 25 TO 45 METERS

Walrus specimen no.	Polychaetes	Echiurids	Gastropods	Bivalves					Crustaceans	Tunicates	Total
				Serripes	Tellina	Spisula	Siliqua	Fragments[a]			
48	12	27	7	86	1,830	308	58	278	0	0	2,606
49	3	0	3	0	761	330	49	285	1	0	1,432
50	0	0	2	110	645	244	38	170	0	0	1,218
51	80	55	6	202	3,300	1,450	94	432	0	13	5,632
52	7	0	1	162	3,650	650	150	281	0	0	4,901
53	10	0	8	145	2,000	560	82	230	0	0	3,035
55	0	0	1	0	316	291	0	181	3	0	792
113	131	645	12	720	2,950	666	156	515	5	0	5,800
115	2	42	0	240	1,260	296	92	167	1	0	2,100
116	0	27	28	403	1,219	215	115	203	0	0	2,210
131	2	3	0	17	161	123	7	111	17	0	441
132	0	0	0	2	4	41	0	39	1	0	87
133	0	0	7	7	139	66	7	77	15	0	318
135	7	14	12	127	1,850	65	135	141	9	0	2,360
137	0	0	0	0	90	47	2	72	0	0	211
TOTAL	254	813	87	2,221	20,184	5,352	985	3,182	52	13	33,143

[a] Pieces of bivalves not assignable to genus, due to partial digestion.

present in the stomachs. A few polychaetes, echiurids (*Echiurus echiurus*), snails (genera *Buccinum, Neptunea, Natica,* and *Polinices*), hermit crabs (*Pagurus* sp.), tanner crabs (*Chionoecetes* sp.), pandalid shrimps, benthic amphipods, and tunicates also had been eaten.

B. Cruise of the R/V *Resolution*

The area covered during this cruise was ice-free, hence most of the sightings were of scattered groups in the water. About 60 such groups were sighted, all but two of which were composed only of adult males; in two groups there was one each subadult male about 10-12 years old. Group size ranged from 1 to 7 individuals (mean, 3). Most of these appeared to be feeding; four groups were sleeping in the water. All were within about 16 km of shore in waters 20 to 40 m deep.

These animals were ranging out along the coast, from the vicinity of Port Moller to Ugashik Bay, apparently returning occasionally to Cape Seniavin (56°23'N, 160°08'W) to haul out on the beach and rest. At least 1,000 adult and subadult males were on the beach at Seniavin when we arrived there on 8 April at 10:00 a.m. The number on the beach was reduced to 0 within 8 hours, due to disturbance by low-flying aircraft (3 fixed-wing, 1 helicopter; altitudes 60 to 80 m). About 100 animals were back on the beach by 8:00 a.m. on 9 April, but half of those left before evening, following another assault by a fixed-wing aircraft. About 100 were present also on 10 April at 11:00 a.m. but were stampeded from the beach at midday by another passing aircraft. By the evening of 11 April, only 30 animals remained in the area.

Four specimens were collected at sea between 12 and 20 April from groups that appeared to be feeding. Precise ages of these have not yet been determined, but all were mature males more than 15 years old, ranging in weight from 1090 to 1200 kg. Sternal blubber thickness was from 1.9 to 2.9 cm. Analyses of their stomach contents have not yet been completed, but preliminary examination indicates a predominance by weight of surf clams (*Spisula polynyma*) with lesser amounts of tellins, cockles, and razor clams, and a few anemones, snails, crabs, polychaetes, echiurids, and amphipods.

DISCUSSION

The distributional information obtained during the cruise of the ZRS *Zvyagino* in late February to mid-March has contributed substantially to filling major gaps in the available data for those months and has confirmed further that a significant concentration of walruses winters in the Kuskokwim-Bristol Bay area. This area south of 60°N and east of 167°W is covered by comparatively thin, broken ice in most winters, whereas the ice immediately to the west and north tends to be much heavier and more compact (Burns *et al.*, 1980). The north-central walrus concentration in winter, west and south of St. Lawrence Island, also lies in an area of relatively thin, broken ice, surrounded by areas of heavier, more consolidated pack. During both shipboard and aerial surveys in this and previous years, walruses were found to be conspicuously scarce to absent in the heavy ice between the St. Lawrence and the Bristol-Kuskokwim areas (Kenyon, 1960, 1972, and unpublished data; Burns and Harbo, 1977; Krogman *et al.*, 1979; Fay, in press and unpublished data). Those surveys also indicated that the distribution of walruses within the Bristol-Kuskokwim area varies with ice conditions. In winters with very extensive, heavy ice, such as 1971-76, the animals tended to be concentrated farther southward near the Pribilof Islands and eastward in Bristol Bay; in winters with average to light ice cover, such as 1978-81, the concentrations tended to be in the northwestern part of the area, in Kuskokwim Bay.

The condition of the reproductive organs of the adult and subadult males collected during the *Zvyagino* cruise indicated that most were in rut. The decreased motility of spermatozoa in the epididymides of many of the older males was consistent with the findings of Fay (in press), who observed that the spermatogenetic cycle of the fully mature males reaches its peak earlier (December-January) than in the subadult and younger animals (February-March). By late March and April, the older bulls are no longer fertile, yet some of the younger males are fertile well into the spring. Principally on that basis and by anology with other pinnipeds, Fay (in press) predicted that the mating season of walruses is in mid-winter (January-February), following the peak of rut in the mature adults, rather than in spring when only the subadult and younger males are fertile. The adult females collected during this cruise tended to confirm that prediction. Most of those that were potentially capable of mating (i.e., not carrying a near-term fetus) appeared to have been bred some weeks before they were taken; only a few were still in estrus. Those findings, plus the fact that the percentage of females newly impregnated was virtually the same as that of females with fetuses, indicates that the mating season was coming to an end in late February and early March.

The spatial arrangement and composition of groups sighted within the main area of congregation was comparable to that seen previously in the St. Lawrence concentration area in late February to early March 1972 (Fay *et al.*, in prep.). The tendency for resting herds of females and young to be closely attended by a few displaying males appears to be the typical organization during the mating season. The disproportionate sex ratio of adults indicates that walruses are polygynous, rather than monogamous. Their mating system, however, is remarkably different from that of other polygynous pinnipeds such as sea lions and fur seals. Walruses breed in the moving ice, rather than on shore, and the males establish their "territories" alongside in the water, rather than on the substrate with the females. The dominant males fight for display positions within the "arena"; subordinate males take positions outside the arena and do not display. Apparently, most of the subadult males shun the mating areas, probably because they are unable to compete with the larger, older bulls.

Judging from their atrophied digestive system, empty stomachs, and general leanness, I presume that the adult males in the mating areas take little or no food there. This could confer a considerable benefit on the population as a whole through reduction of impact on the food supply available to the congregated females and young. Feeding by adult males seems to take place mainly in spring, summer, and autumn, when they mostly resort to other areas, away from the females and young (Fay, in press).

The animals taken in Kuskokwim Bay in early March had been preying mainly on the deposit-feeding bivalve, *Tellina lutea*, which is common in that area (Feder *et al.*, 1980). Secondarily, they were taking other deposit-feeders (*Serripes groenlandicus* and *Echiurus echiurus*), suspension-feeders (*Spisula polynyma, Siliqua patula* and tunicates), and some predators and scavengers (polychaetes, gastropods, and crustaceans). This varied assortment of organisms and feeding types is comparable to those found in walruses in the Bering Strait-Norton Basin region in spring (Fay *et al.*, 1977). Also comparable was the fact that most of the biomass of identifiable prey was made up of fleshy parts of bivalve mollusks. The adult males taken in the Bristol Bay-North Aleutian Shelf area had been feeding mainly on *S. polynyma* and to a lesser degree on most of the same prey as were taken by the females and young in Kuskokwim Bay. Although walruses appear to be facultative to some degree in their choice of prey, they mostly appear to be highly selective, taking mainly the largest bivalves.

Most of the walruses collected appeared to be in good to excellent physical condition, with the exception of a few of the leanest bulls. Their blubber thicknesses (males mainly 2-4 cm; females mainly 3-6 cm), however, were about 2 cm less than those recorded by Fay (in press) in animals taken 10 to 20 years ago in the same season of the year (males mainly 4-6 cm; females mainly 5-8 cm). This finding is consistent with the Eskimos' reports in recent years of appreciably leaner animals (Fay, 1978) and suggests that the walrus population has increased to the point of depressing or depleting its food supply. Comparable records of unusual leanness were obtained also from animals killed at St. Lawrence Island in autumn 1978 (Fay and Kelly, 1980) and in Bering Strait in spring 1980 (T. E. Smith, unpublished data).

Other indications of high population, such as decreasing reproductive rate, decline in age at first reproduction, and increasing juvenile mortality (Siniff *et al.*, 1978), have not yet been demonstrated for this population, but some of these may be reflected by the data obtained during the *Zvyagino* cruise. In the non-selective samples of adult females taken during this and an earlier cruise (March-April 1976) in the same region, the percentages of new and near-term pregnancies were 36 and 37% (1981) and 44 and 41% (1976), respectively. These differences between years are not significant, for the samples are small; nonetheless, they are suggestive of a declining reproductive rate. Also suggestive is the fact that the youngest females in near-term pregnancy in the *Zvyagino* sample were not less than 7 years old (based on tusk lengths of 27-30 cm), whereas term pregnancies were not uncommon in animals 5 and 6 years old in earlier samples (Burns, 1965; Krylov, 1966; Gol'tsev, 1975; Fay, in press). Finally, the compositional data from the herds of females and young observed during this cruise imply either a reduced birth rate or increased calf mortality, or both. Whereas 94 adult females could be predicted to produce about 35 calves (based on the observed 37% term pregnancy rate), the numbers of 1-, 2-, and 3-year-old young that were with them amounted to only 17, 23, and 20, respectively. Comparative counts by Fay (in press) in earlier years showed that 66 adult females (predicted to produce 24 calves) were accompanied by 24, 22, and 10 young in the 1-, 2-, and 3-year-old classes. Again, however, the samples are small, hence only suggestive of change.

CONCLUSIONS

The results of the *Zvyagino* and *Resolution* cruises have contributed much toward understanding the patterns of distribution, composition, and social organization of walruses residing in the southeastern Bering Sea in late winter to early spring. The highlight of these cruises was the acquisition of data confirming that the mating season of walruses is virtually at an end by early March and that the primary prey of the animals in this region (as elsewhere) are the larger bivalve mollusks.

The main function of the St. Lawrence and Bristol-Kuskokwim wintering concentrations appears to be mating. Because of their semi-isolation during this period, they conceivably comprise two breeding units that should be given separate treatment when considering resource management and oil impact scenarios.

The decline in physical condition of the animals since the early 1970's indicates that the growing population is now at some disadvantage in dealing with a reduced food supply. Reduction in birth rate, increase in age of first reproduction, and rising natural mortality can be expected to follow and already may have begun.

NEEDS FOR FURTHER STUDY

Much additional information on the distribution of the population in winter, especially in December to early February, is needed to define the wintering areas more fully and to determine the degree of isolation at the time of the mating concentrations. This probably can be accomplished by aerial surveys, though it will be difficult to complete because of adverse weather, short daylight, and the international distribution of the population. Of course, the onset and peak of the mating season itself will need to be delineated in relation to time, ice, and location. The time of onset of mating probably will be determined within the next two years by another joint Soviet-American investigation, the plans for which already are underway. Whether the animals show site fidelity in returning to the same mating areas each year and/or using the same migration routes and summering areas remains unknown and will be difficult to resolve without radio-tracking or massive mark-recapture programs. These are beyond the scope of this study but will be encouraged and implemented to the degree possible on a cooperative basis.

The location of major calving areas and the nature of cow-calf bond in relation to susceptibility to disturbance need to be investigated further because of possible conflict with oil development. This can be done through combined aerial and shipboard surveys in spring, coupled with periods of intensive observation of the animals on the ice and on coastal hauling grounds. Because the coastal haulouts appear to be of critical importance as rest stops during the southward migration, and because natural mortality of both juveniles and adults seems to be highest there, the nature of activities of those haulouts needs to be investigated in detail. This will be begun in FY82 on the Punuk Islands in northern Bering Sea.

Additional quantitative information on feeding habits in different parts of the winter and summer range could be useful for evaluating potential oil impacts. At present, the only quantitative data available are those from the St. Lawrence-Bering Strait area in spring and from the two samples obtained during the *Zvyagino* and *Resolution* cruises this year. Most of the qualitative data from other areas in other seasons also indicate reliance on bivalve mollusks, but this needs to be confirmed by quantitative analysis. The possible importance of organisms taken in small quantities as sources of scarce but essential nutrients also needs to be evaluated. Because deposit-feeding mollusks generally accumulate hydrocarbons more than suspension-feeders, walruses may be exposed more than other marine mammals to long-term hydrocarbon accumulation (Geraci and St. Aubin, 1980). The potential effects on walruses of such accumulation are unknown but eventually may be monitored in the natural environment following oil spills. Since the greatest impact of OCS oil development on walruses is likely to be via the food chain, and since the Pacific walrus population appears to be already at or near imbalance with its food supply, further experimental studies of the effects of oil spills, drilling muds, and other manmade materials on the bivalves of the Bering and Chukchi Seas appear to rank very high in priority.

SUMMARY OF 4TH QUARTER OPERATIONS

Ship or Field Trip Schedule

17 - 31 July	CGC *Polar Star*, Chukchi ice edge and front (Fay, Kelly, Hayton, Sease, Hoover, and consultants). Survey of age/sex composition and activities of walruses summering in the eastern Chukchi Sea.
early September	St. Lawrence-Punuk Islands (Kelly with FWS and EWC cooperators). Establish field camp for investigation of walrus numbers, composition, and activities on the Punuk Island autumn hauling ground.

Laboratory Activities

Complete processing of materials and analyses of data from the *Zvyagino*, *Resolution*, and *Polar Star* cruises. Begin documentation of historical record of depletions and recoveries of the Pacific walrus population.

MILESTONES

The "Soviet-American cruise" was completed a few days later than anticipated, and because it was followed immediately by the *Resolution* cruise (NPFMC project) and the St. George Synthesis Workshop, the "data submission" and this report are somewhat delayed. The "CGC *Glacier* cruise", originally scheduled to take place from 21 July to 4 August has been replaced by the CGC *Polar Star* cruise scheduled for 17-31 July. The "CGC *Polar Star* cruise" originally requested for late October to late November has been cancelled due to lack of ship support at that time.

PROBLEMS ENCOUNTERED/RECOMMENDED CHANGES

None.

ESTIMATE OF FUNDS EXPENDED

See attached.

DATA SUBMISSIONS

None during this period.

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MILESTONE CHART

RU #: 611 PI: F. H. Fay

Major Milestones: Reporting, data management and other significant contractual requirements; periods of field work; workshops; etc.

MAJOR MILESTONES	1980			1981												1982			
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
Soviet-American cruise						△▲													
Data submission (sighting)								△											
Annual Report								▲											
CGC Polar Star ~~XXXXXXX~~ cruise										△									
Data submission (sighting)													△						
Punuk Islands shore camp														△					
~~CGC *Polar Star* cruise~~ (cancelled)														~~△~~					
~~Data submission (sighting)~~																	~~△~~		

△ Planned Completion Date ▲ Actual Completion Date

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RECEPTORS-PLANKTON
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Annual Report

Contract #: 03-78-B01-6
Research Unit #: 359
Reporting Period: 1 Apr 1979-31 Mar 1980
Number of Pages: 142

Beaufort Sea Plankton Studies

Rita A. Horner

31 March 1980

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I. Summary of Objectives, Conclusions, and Implications with Regard to OCS Oil and Gas Development

The objectives of this research unit are to assess the winter density distribution of planktonic organisms, ice algae, and benthic microalgae in Stefansson Sound; to complete a final summary report on winter results; to analyze available plankton samples from the Chukchi and Beaufort seas, and write a final report on icebreaker data from these areas; and to complete a comprehensive literature review and synthesis of data concerning phytoplankton, ice algae, and zooplankton in the Chukchi Sea.

Preliminary conclusions indicate that distributions of individual zooplankton and phytoplankton species are widespread and may, especially for zooplankton, be influenced by hydrography. Primary productivity is highest at depth and where diatoms are the most abundant organisms. Of the dominant plankton species, all have been reported previously from the Chukchi and Beaufort seas, however, undescribed species of copepods are being found in Stefansson Sound. An ice algal community is present in Stefansson Sound in spring, but its distribution is patchy and its contribution to the Stefansson Sound ecosystem is unknown at present.

These data will provide information on the zooplankton, phytoplankton, and ice algae communities so that decisions can be made that will allow for oil and gas development as well as protect the ecosystem.

II. Introduction

A. General Nature and Scope of Study

The purpose of this project is to provide basic seasonal information on the organisms at the lower end of the trophic system. These organisms, the phytoplankton and zooplankton, are the primary producers and primary and secondary consumers in the ecosystem, providing food for all higher trophic levels, including fish, birds, and mammals. An understanding of the species present, their abundance and distribution throughout the year is necessary to understand their relationships within the ecosystem.

B. Specific Objectives

The objectives of this study are to:

1. Assess the winter density distribution of zooplankton and phytoplankton in Stefansson Sound

2. Analyze available phytoplankton and zooplankton samples from the Chukchi and Beaufort seas (1972, 1974, 1976 icebreaker cruises)

3. Complete and submit a final summary report on winter results

4. Conduct field studies in conjunction with RU's 6 and 537 to assess winter distribution and environmental requirements of zooplankton, phytoplankton, ice algae, and benthic microalgae in the nearshore area of

the Beaufort Sea

5. Complete a comprehensive literature review and synthesis of available data concerning phytoplankton, ice algae, and zooplankton in the Chukchi Sea.

C. Relevance to Problems of Petroleum Development

Petroleum development in the nearshore Beaufort Sea continues to have an impact on the marine environment. Suggestions made to decision-makers by OCSEAP investigators are being included in regulations for this development. Studies on the productivity, species composition, distribution, abundance, life cycles, and migration patterns of planktonic organisms are necessary in order to assess the impact of this development and to predict changes that might occur as a result of it. Winter studies are especially important because exploratory drilling will probably be limited to that season.

III. Current State of Knowledge

The literature concerning plankton studies in the Beaufort Sea has been reviewed (English and Horner 1977) and summarized (Horner 1978, 1979). Studies on ice algae have been reviewed (Horner 1976). A comprehensive literature review and synthesis of available data concerning plankton and productivity in the Chukchi Sea will be done as part of this FY 80 project.

IV. Study Areas

Samples from three areas have been analyzed during 1979-80. Analysis of zooplankton samples collected during the 1976 OCSEAP icebreaker cruise in the Chukchi Sea (Fig. 1) has been completed. Copepods collected during the 1978-79 winter studies in Stefansson Sound, 70°19'N, 147°34.4'W, have been identified to species and stage. Phytoplankton and ice algae standing stock samples and primary productivity and plant pigment samples collected from Stefansson Sound during 1978-79 winter studies have been analyzed. Selected zooplankton samples collected by Dr. Bruce Wing, Auke Bay Fisheries Lab., during the 1972 WEBSEC cruise (Fig. 2) were analyzed. One hundred twenty-seven phytoplankton samples from the Chukchi Sea (Fig. 3) collected during an icebreaker cruise in 1974 have been counted and species identified.

V. Sources, Methods and Rationale of Data Collection

A. Zooplankton

1. Chukchi Sea samples, CGC *Glacier*, 1976

Samples were collected with 60 cm diameter bongo nets with mesh sizes of 335 and 500 µm and 0.75 m diameter ring nets with mesh

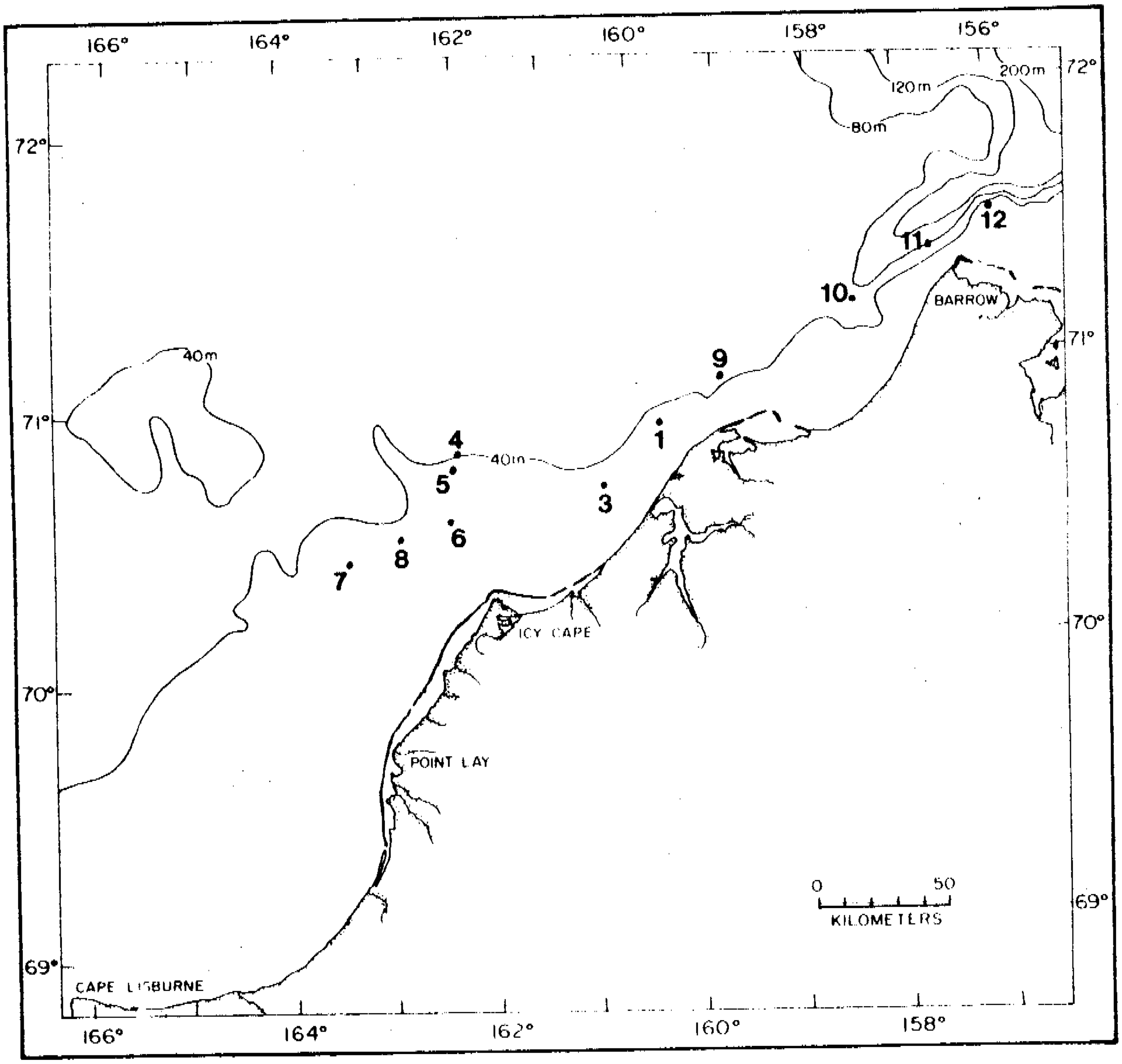

Fig. 1. Station locations, Chukchi Sea, CGC *Glacier*, 7 Aug - 4 Sep 1976.

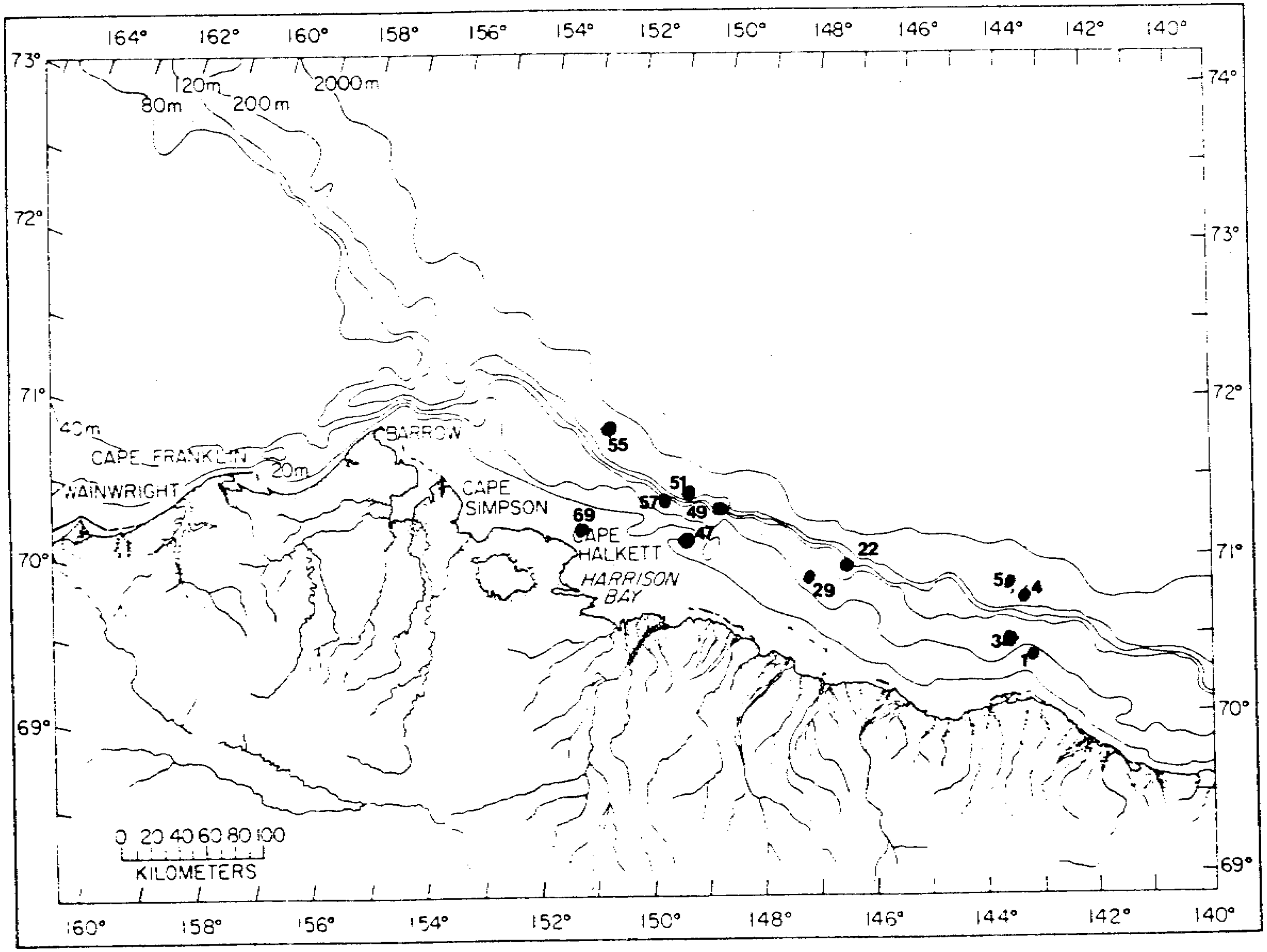

Fig. 2. Station locations for WEBSEC-72 samples collected for the Auke Bay Fisheries Laboratory, Auke Bay, Alaska, 4 Aug - 6 Sep 1972.

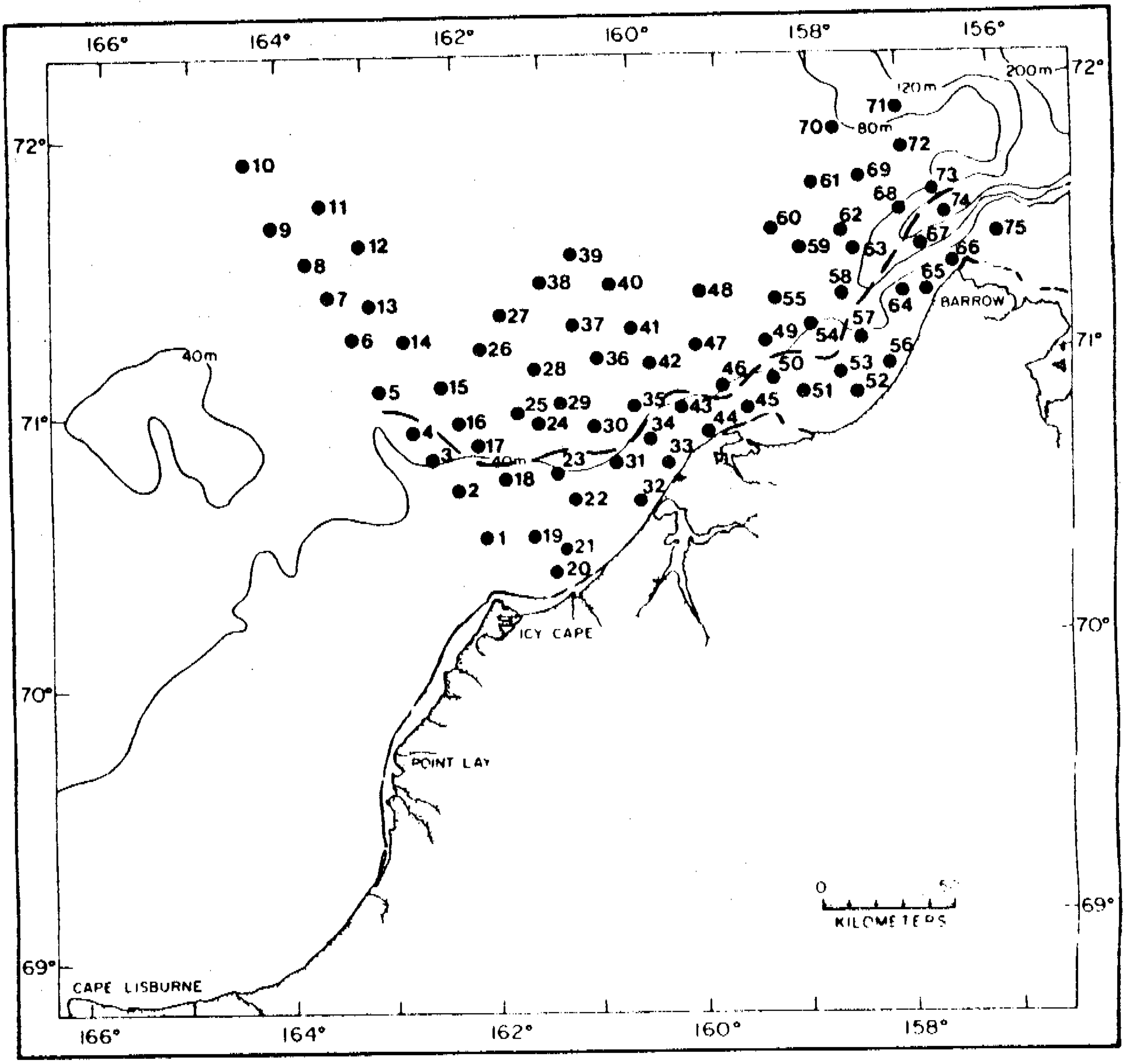

Fig. 3. Station locations, Chukchi Sea, CGC *Staten Island*, 4 - 15 Aug 1974. Dashed line indicates approximate ice edge.

size of 308 μm. A TSK flowmeter (InterOcean Systems, San Diego, CA.) was mounted in the mouth of each bongo net to determine the amount of water filtered. The bongo tows were double oblique with deployment at *ca.* 50 m per min, a 30 sec soaking time at depth, and retrieval at *ca.* 20 m per min. Sampling depth varied depending on water depth, but the net was placed as close to the bottom as possible.

The ring net was lowered to a predetermined depth, usually 10 or 20 m, soaked for 10 sec, and vertically hauled to the surface. Two or more tows were made at each station depending on water depth.

The samples were concentrated by swirling in the net collection cup to remove excess water. The bongo net samples contained large quantities of phytoplankton and some were therefore subsampled before preservation. Subsampling was done by pouring the concentrated sample into a calibrated container which was then thoroughly mixed to homogenize the sample. A subsample was poured into a 500 ml jar and the fraction retained was noted on the sample label.

All samples were preserved with 37% formaldehyde buffered with a saturated solution of sodium borate.

2. Stefansson Sound winter samples, 1978-79

Samples were collected in November 1978 with a 0.75 m diameter ring net with a mesh size of 308 μm. Samples collected in March 1979 and one sample collected in May 1979 as part of the BLM-sponsored Project Whales, were taken with a 0.5 m diameter ring net with a mesh size of 209 μm. Vertical tows were made by lowering the net to the bottom and retrieving by hand at a constant rate. Horizontal tows were made by extending a line from the sampling hole to an ice piton located on the surface *ca.* 12 m away from the sampling hole. The net was clipped to a pulley on the line, pulled backward by the net ring to the ice piton and forward to the sampling hole. Tows were timed with a stopwatch to obtain an approximate speed of tow. The samples were concentrated and preserved with 37% formaldehyde buffered with saturated solutions of sodium borate and sodium acetate.

3. Beaufort Sea samples, WEBSEC-72

Samples were collected with 0.5 and 1.0 m diameter ring nets with mesh size of 560 μm and with a 1.8 m Isaacs-Kidd mid-water trawl with a mesh size at the mouth of 38 mm (Wing and Barr 1977). The 0.5 and 1.0 m ring nets were lowered at 60 m per min to 3 to 4 m from the bottom and vertically hauled to the surface at 40 m per min. The Isaacs-Kidd midwater trawl was towed for 30 min at 3 to 4 kt.

B. Phytoplankton

1. Chukchi Sea samples, CGC *Staten Island*, 1974

Samples were collected at standard depths throughout the water column using 5 ℓ Niskin bottles. Portions of the water samples were poured into 250 ml jars and preserved with about 5 ml 4% formaldehyde buffered with sodium acetate.

2. Stefansson Sound winter samples, 1978-79

All samples were collected by a diver. The sampling site was a dive hole used by RU 526 and located about 100 m west of the parcoll set up at Dive Site 11 (RU 356).

Water samples were collected in 2 ℓ polyethylene bottles from just under the ice (0 m) and near the bottom (4 m). Portions of these samples were poured into 60 ml reagent bottles, two light and one dark bottle for each depth, and inoculated with 2 ml $Na_2H^{14}CO_3$ solution. The samples were incubated *in situ* by attaching the bottles to a line suspended from the bottom of the ice. Another portion of the water sample was poured into a 250 ml jar and preserved with 5 to 10 ml 4% formaldehyde for a phytoplankton standing stock sample. The remainder of the water sample, usually about 1.5 ℓ was returned to the shore laboratory and filtered for plant pigment, nutrient, and salinity determinations.

Experiments to determine *in situ* primary productivity of the ice algae community were done using combination incubation chamber-samplers (Clasby *et al.* 1973; Alexander *et al.* 1974). Two light and one dark chamber were placed in the ice and inoculated with 2 ml $Na_2H^{14}CO_3$ solution. Following a 3 to 4 hr incubation period the ice cores and water samples were retrieved. The ice cores were transferred to 250 ml jars and preserved with 5 ml 4% formaldehyde to prevent further uptake of the isotope by the cells. The water samples were kept in the dark until they could be processed at the shore laboratory.

Three to five additional ice cores were collected using the combination samplers. These cores were placed in 250 ml jars that had been darkened with black plactic tape and returned to the shore laboratory to be processed for salinity, nutrient, and plant pigment concentrations. One core was immediately preserved with 5 ml 4% formaldehyde for a standing stock sample.

At the shore laboratory at Mukluk Camp, the remainder of the water sample, 1 to 1.5 ℓ, was filtered through 0.47 mm, 0.45 μm HA Millipore filters and the filters were frozen for determination of plant pigments. Some of the filtered water was put into a 250 ml polyethylene bottle to be used to determine salinity and some was put into a 125 ml polyethylene bottle and frozen to be used to determine nutrient concentrations.

One of the extra ice cores was filtered through a 47 mm, 0.45 μm Millipore filter and the filter was frozen for determination of plant pigments. The remaining two or three ice cores were also filtered through 47 mm, 0.45 μm filters. These filters were also frozen for pigment determinations; the water was put into 125 ml polyethylene bottles; one bottle was frozen to be used for nutrient determinations and one was used for salinity determinations.

The primary productivity samples were all filtered through 25 mm, 0.45 μm Millipore filters which were rinsed with 5 ml 0.01 N HCl and 5 ml filtered seawater before being placed in labeled glass scintillation vials.

All samples were returned to Seattle for analysis.

VI. Results

A. Zooplankton

1. Chukchi Sea samples, CGC *Glacier*, 1976

Seventy-four categories of zooplankton were identified in 39 bongo and ring net samples, including 29 species and 45 other categories such as larval stages and categories where identification was made to some taxonomic rank higher than species (Tables 1 and 2). References used to identify the organisms are given in Table 3.

Copepods, polychaete and barnacle larvae, *Fritillaria borealis* and *Fritillaria* spp. were the most abundant organisms at all stations and depths collected with 0.75 m ring nets. Decapod larvae were also caught at all stations and depths. *Sagitta elegans*, unidentified chaetognaths, and unidentified invertebrate eggs were abundant at nearly all stations and depths. Unidentified mollusc larvae were abundant at stations 5, 6, and 7. *Rathkea octopunctata* and unidentified Hydrozoa were abundant at stations 4, 5, 6, 7, and 9 located west of Point Franklin with numbers decreasing drastically at stations 10, 11, and 12 close to Point Barrow. Other Hydrozoa were present in smaller numbers at other stations. Species of amphipods and euphausids were present at some stations, but were never abundant.

Copepods, polychaete and barnacle larvae, *Fritillaria borealis* and *Fritillaria* spp. were also the most abundant organisms in all samples collected with bongo nets. *Sagitta elegans* and unidentified chaetognaths were abundant at most stations, while unidentified invertebrate eggs were present in relatively large numbers at stations 6 and 7. Unidentified mollusc larvae were numerous at stations 4, 5, 6, and 7 west of Point Franklin. *Rathkea octopunctata* and unidentified Hydrozoa were present in small numbers at all stations. Gammarid amphipods were present in small numbers at stations east of Point Franklin, but were not present at stations west of Point Franklin. Hyperiid amphipods and euphausids were present in small numbers at all stations.

2. Stefansson Sound winter samples, 1978-79

Thirty-seven categories of zooplankton were identified in 18 ring net hauls collected in November 1978, March and May 1979, including 31 species, 3 genera, and 3 higher categories of unidentified organisms (Tables 4 and 5).

Among the copepods, *Pseudocalanus elongatus* stage IV males were the dominant form in the November 1978 samples. Stage IV females were also abundant followed by the stage V males and females. Adult *Derjuginia tolli* males and females occurred only in the fall. *Limnocalanus macrurus* occurred only as adults and only in November. One male *Microcalanus pygmaeus* was

Table 1. Abundance (number per 1000 m^3) of zooplankton taxa found in vertical net hauls from the Chukchi Sea, CGC *Glacier*, 7 Aug - 4 Sep 1976. All samples were collected with a 0.75 m ring net, mesh size 308 μm. Where no number is present, no animals were found.

Station Number	4	4	5	5	6	6	7	7
Taxon Max. Depth of Tow (m)	10	20	10	20	10	20	10	20
Cnidaria								
Hydrozoa								
Aglantha digitale	500	440	1000	330		220	12000	
Bougainvillia superciliaris								
Calycopsis birulai								
Corymorpha flammea								
Coryne tubulosa cf.								
Obelia longissima cf.					1250			110
Perigonimus vesicarius								
Perigonimus spp.				220				
Perigonimus spp. *cf.*			250					
Plotocnide borealis cf.								
Rathkea octopunctata	750	670	500	440	7000	1220	20000	14220
Unidentified Hydrozoa	64000	1440	160250	56890	656000	99560	32000	42890
Scyphozoa - unidentified	500	220						
Ctenophora								
Beroë cucumis								
Pleurobrachia pileus cf.							250	
Polychaeta - unidentified larvae	64000	56890	1632000	1095110	120000	277330	4000	64000
Mollusca								
Gastropoda - Pteropoda								
Clione limacina							750	330
Limacina helicina	1000		1750	1110	750	440	1500	2000
Unidentified mollusc larvae			32000	227560	16000	341330		14440
Pycnogonida - unidentified								

Table 1. (continued)

Taxon	Station Number	4	4	5	5	6	6	7	7
	Max. Depth of Tow (m)	10	20	10	20	10	20	10	20
Crustacea									
Ostracoda - unidentified									
Copepoda									
Calanoida - adults			21330		14220			44000	35560
Calanoida - juveniles		160000	7110	128000	256000	24000	106670	80000	85330
Cyclopoida		160000	320000	672000	881780	344000	988440	72000	163560
Harpacticoida									
Unidentified nauplii		64000	170670	384000	611560	160000	526220	16000	85330
Cirripedia									
Unidentified nauplii			49780	704000	241780	8000	78220		
Unidentified cyprids		64000	99560	1824000	625780	80000	305780	16000	56890
Mysidacea									
Mysis spp.									
Cumacea - unidentified									
Amphipoda									
Caprellidea - unidentified									
Gammaridea									
Calliopiidae									
Apherusa glacialis									
Lysianassidae									
Boeckosimus (= Onisimus) nanseni									
Boeckosimus sp.									
Onisimus (=Pseudalibrotus) glacialis									
Oedicerotidae *cf.*									
Podoceridae									
Dulichia spp.									
Unidentified Gammaridea									
Hyperiidea									
Hyperoche medusarum									
Parathemisto abyssorum									
Parathemisto libellula									
Unidentified Hyperiidea									

Table 1. (continued)

	Station Number	4	4	5	5	6	6	7	7
Taxon	Max. Depth of Tow (m)	10	20	10	20	10	20	10	20
Euphausiacea									
Thysanoëssa inermis									
Thysanoëssa longipes									
Thysanoëssa raschii									
Unidentified furcilia				500	110		330		
Unidentified calyptopis *cf.*					110				
Unidentified nauplii *cf.*									
Decapoda									
Anomura zoea			560	2500	2670		890		
Brachyura zoea		1750	670	250		500	560	1000	1110
Caridea zoea									
Crangonidae									
Hippolytidae				250	780		110		
Unidentified Caridea									
Unidentified Crustacea									
Echinodermata - unidentified									
Appendicularia									
Fritillaria borealis		3328000	2232890	3200000	1678220	800000	448000	440000	995560
Fritillaria spp.		3264000	1614220	3232000	2005330	888000	632890	572000	1251560
Oikopleura labradoriensis				500					
Oikopleura vanhöffeni				750					
Chaetognatha									
Sagitta elegans			21330		14220			4000	
Unidentified Chaetognatha		96000	92440	96000	56890	176000	163560	36000	71110

Table 1. (continued)

	Station Number	4	4	5	5	6	6	7	7
Taxon	Max. Depth of Tow (s)	10	20	10	20	10	20	10	20
Pisces									
Eggs									
Pleuronectidae									
Hippoglossoides robustus									
Unidentified eggs									
Larvae									
Ammodytidae									
Ammodytes hexapterus									
Cottidae									
Gymnocanthus sp.			110						
Myoxocephalus sp.									
Gadidae									
Boreogadus saida									
Unidentified Gadidae									
Stichaeidae									
Lumpenus sp.									
Unidentified Stichaeidae									
Other organisms									
Foraminifera									
Nematoda									
Unidentified invertebrate eggs			42670	320000	42670		135110		28440
Unidentified animals									

Table 1. (continued)

Station Number	9	9	9	10	10	10	11	11
Taxon Max. Depth of Tow (m)	10	20	50	10	20	50	10	20
Cnidaria								
Hydrozoa								
Aglantha digitale	750	890	550		440	180	750	220
Bougainvillia superciliaris							250	
Calycopsis birulai						50		
Corymorpha flammea						50		
Coryne tubulosa cf.								
Obelia longissima cf.		110						
Perigonimus vesicarius								
Perigonimus spp.		110				140		
Perigonimus spp. *cf.*								110
Plotocnide borealis cf.								
Rathkea octopunctata	1250	1780		500	110		500	670
Unidentified Hydrozoa	72000	12560	5910			500	8000	
Scyphozoa - unidentified	2500	670	230	500	330	180	500	440
Ctenophora								
Beroë cucumis		110						
Pleurobrachia pileus cf.			180					
Polychaeta - unidentified larvae	64000	55110	93090	64000	106670	81450	128000	227560
Mollusca								
Gastropoda - Pteropoda								
Clione limacina								
Limacina helicina	1000	220	90	2000				
Unidentified mollusc larvae	8000		140				4000	10670
Pycnogonida - unidentified								

Table 1. (continued)

	Station Number	9	9	9	10	10	10	11	11
Taxon	Max. Depth of Tow (m)	10	20	50	10	20	50	10	20
Crustacea									
Ostracoda - unidentified									
Copepoda									
Calanoida - adults		8000	21330	49450		49780	104730	20000	7110
Calanoida - juveniles		104000	245330	365090	128000	533330	622550	44000	323560
Cyclopoida		256000	87110	27640	480000	78220	29090	60000	135110
Harpacticoida		8000	7110	2910			8730	8000	7110
Unidentified nauplii		72000	17780	10180	608000	120890	40730	40000	135110
Cirripedia									
Unidentified nauplii		208000	371560	298180	64000	135110	55270	284000	1073780
Unidentified cyprids		104000	115560	87270	64000	49780	55270	188000	192000
Mysidacea									
Mysis spp.							50		
Cumacea - unidentified				90					
Amphipoda									
Caprellidea - unidentified									
Gammaridea									
Calliopiidae									
Apherusa glacialis			220	410		110			
Lysianassidae									
Boeckosimus (= Onisimus) nanseni									
Boeckosimus sp.									
Onisimus (=Pseudal.) glacialis		250		50					
Oedicerotidae *cf.*				90					
Podoceridae									
Dulichia spp.									
Unidentified Gammaridea						110			330
Hyperiidea									
Hyperoche medusarum									
Parathemisto abyssorum						110			
Parathemisto libellula				50					
Unidentified Hyperiidea			220						

Table 1. (continued)

	Station Number	9	9	9	10	10	10	11	11
Taxon	Max. Depth of Tow (m)	10	20	50	10	20	50	10	20
Euphausiacea									
Thysanoëssa inermis				50					
Thysanoëssa longipes									
Thysanoëssa raschii									
Unidentified furcilia			110						
Unidentified calyptopis *cf.*									
Unidentified nauplii *cf.*			1780	1450		110			560
Decapoda									
Anomura zoea		1500	1560	1640	2000	560	550	1250	560
Brachyura zoea		1000	440	90	3000	890	270	3000	1000
Caridea zoea									
Crangonidae									
Hippolytidae		750	330	680	250	110	140	1250	1000
Unidentified Caridea									
Unidentified Crustacea									
Echinodermata - unidentified									
Appendicularia									
Fritillaria borealis		904000	330670	62550	4224000	1052440	506180	424000	540440
Fritillaria spp.		768000	259560	75640	3840000	1230220	293820	88000	103110
Oikopleura labradoriensis									330
Oikopleura vanhöffeni									
Chaetognatha									
Sagitta elegans			5330	20360		7110	2910	4000	7110
Unidentified Chaetognatha		296000	158220	48000	96000	56890	20360	64000	39110

Table 1. (continued)

Taxon	Station Number Max. Depth of Tow (m)	9 10	9 20	9 50	10 10	10 20	10 50	11 10	11 20
Pisces									
Eggs									
Pleuronectidae									
Hippoglossoides robustus									110
Unidentified eggs									
Larvae									
Ammodytidae									
Ammodytes hexapterus									
Cottidae									
Gymnocanthus sp.									
Myoxocephalus sp.									
Gadidae									
Boreogadus saida									
Unidentified Gadidae									
Stichaeidae									
Lumpenus sp.									
Unidentified Stichaeidae									
Other organisms									
Foraminifera									
Nematoda			1780			7110			
Unidentified invertebrate eggs		24000	30220	17450		92440	23270	24000	39110
Unidentified animals			12440	14550				4000	60440

Table 1. (continued)

	Station Number	11	11	12	12	12	12	12
Taxon	Max. Depth of Tow	50	100	10	20	50	100	160
Cnidaria								
Hydrozoa								
Aglantha digitale		500	1450	250	780	140	200	
Bougainvillia superciliaris								
Calycopsis birulai								
Corymorpha flammea								
Coryne tubulosa cf.								
Obelia longissima cf.			20					
Perigonimus vesicarius		50						30
Perigonimus spp.							20	
Perigonimus spp. *cf.*								
Plotocnide borealis cf.								30
Rathkea octopunctata				2000	780	140		450
Unidentified Hydrozoa		4860	1450			90		40
Scyphozoa - unidentified		50		2000	440	50	20	10
Ctenophora								
Beroë cucumis								
Pleurobrachia pileus cf.			730					
Polychaeta - unidentified larvae		97450	47270	304000	256000	101820	58180	22540
Mollusca								
Gastropoda - Pteropoda								
Clione limacina		90						
Limacina helicina		50		2500	670		50	
Unidentified mollusc larvae		2910	2910					450
Pycnogonida - unidentified								

Table 1. (continued)

Taxon	Station Number Max. Depth of Tow (m)	11 50	11 100	12 10	12 20	12 50	12 100	12 160
Crustacea								
Ostracoda - unidentified								30
Copepoda								
Calanoida - adults		65450	65450	80000	14220	49450	58180	48230
Calanoida - juveniles		482910	388360	80000	113780	253090	256000	195150
Cyclopoida		50910	20360	256000	199110	49450	14550	3150
Harpacticoida		1450	1450		14220	5820	1450	1800
Unidentified nauplii		33450	16730	336000	298670	32000	27640	7210
Cirripedia								
Unidentified nauplii		277820	166550	80000	2147560	616730	256000	77970
Unidentified cyprids		40730	18910	16000	142220	81450	14550	13070
Mysidacea								
Mysis spp.								
Cumacea - unidentified								10
Amphipoda								
Caprellidea - unidentified								
Gammaridea								
Calliopiidae								
Apherusa glacialis			90				70	150
Lysianassidae								
Boeckosimus (= Onisimus) nanseni								
Boeckosimus sp.							20	
Onisimus (=Pseudalibrotus) glacialis								
Oedicerotidae *cf.*								
Podoceridae								
Dulichia spp.								
Unidentified Gammaridea		140				50	70	100
Hyperiidea								
Hyperoche medusarum								
Parathemisto abyssorum								
Parathemisto libellula		50						10
Unidentified Hyperiidea								

Table 1. (continued)

	Station Number	11	11	12	12	12	12	12
Taxon	Max. Depth of Tow (m)	50	100	10	20	50	100	160
Euphausiacea								
Thysanoëssa inermis								
Thysanoëssa longipes								
Thysanoëssa raschii								
Unidentified furcilia								
Unidentified calyptopis *cf.*								
Unidentified nauplii *cf.*								
Decapoda								
Anomura zoea		450	110		1560	640	160	70
Brachyura zoea		550	200	7750	2220	500	360	130
Caridea zoea								
Crangonidae								
Hippolytidae		180	70		330	360		
Unidentified Caridea								
Unidentified Crustacea								40
Echinodermata - unidentified								
Appendicularia								
Fritillaria borealis		152730	72000	2848000	2033780	509090	170180	41920
Fritillaria spp.		58180	21820	4496000	2033780	546910	165820	26140
Oikopleura labradoriensis		1450	1450					
Oikopleura vanhöffeni								
Chaetognatha								
Sagitta elegans		1450	3640		14220		1450	900
Unidentified Chaetognatha		42180	20360		42670	8730	2910	1800

Table 1. (continued)

	Station Number	11	11	12	12	12	12	12
Taxon	Max. Depth of Tow (m)	50	100	10	20	50	100	160
Pisces								
Eggs								
Pleuronectidae								
Hippoglossoides robustus					110			
Unidentified eggs								
Larvae								
Ammodytidae								
Ammodytes hexapterus								
Cottidae								
Gymnocanthus sp.								
Myoxocephalus sp.								
Gadidae								
Boreogadus saida								
Unidentified Gadidae								
Stichaeidae								
Lumpenus sp.								
Unidentified Stichaeidae								
Other organisms								
Foraminifera			730					1800
Nematoda								
Unidentified invertebrate eggs		21820	29820		28440	46550	17450	7660
Unidentified animals		34910	17450				4360	6760

Table 2. Abundance (number per 1000 m^3) of zooplankton taxa found in net hauls from the Chukchi Sea, CGC *Glacier*, 7 Aug - 4 Sep 1976. All samples were collected with 60 cm bongo nets. Where no number is present, no animals were found. Net hauls were subsampled in the field except where indicated by †.

	Station Number	4	4*	5	5	6	6	7	7
Taxon	Mesh Size (μm)	335	500	335	500	335	500	335	500
Cnidaria									
Hydrozoa									
Aglantha digitale							20380	22120	11380
Bougainvillia superciliaris									
Calycopsis birulai							60		
Corymorpha flammea							190		
Coryne tubulosa cf.			30						
Obelia longissima cf.					90		120		
Perigonimus vesicarius					50				360
Perigonimus spp.							190		
Perigonimus spp. *cf.*			90	320	90				
Plotocnide borealis cf.									
Rathkea octopunctata		800	270	480	380	1800	1310	16590	3790
Unidentified Hydrozoa		22000	27360		27110	16430	10000	55290	49330
Scyphozoa - unidentified			60	160	50		60		
Ctenophora									
Beroë cucumis									
Pleurobrachia pileus cf.								350	590
Polychaeta - unidentified larvae		1147730	316580	1548390	246960	345080	262000	414710	129030
Mollusca									
Gastropoda - Pteropoda									
Clione limacina					50				
Limacina helicina		270	120	160	990		380	520	360
Unidentified mollusc larvae		286000	78200	495480	9080	156110	4000	453410	75900

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* Volume of tow estimated: ship speed x mouth area of net x duration of tow

Table 2. (continued)

	Station Number	4	4*	5	5	6	6	7	7
Taxon	Mesh Size (µm)	335	500	335	500	335	500	335	500
Pycnogonida - unidentified									
Crustacea									
Ostracoda - unidentified									
Copepoda									
Calanoida - adults		68270	7820	82580	15060	73950	26000	105060	68310
Calanoida - juveniles		614400	117250	1114840	99390	903780	108000	724350	223900
Cyclopoida		1437870	293130	2085160	162640	550490	76000	652470	113850
Harpacticoida		25600	19540	41290	3010	8220		11060	
Unidentified nauplii		891730	300950	1672260	120470	451890	50000	309650	94870
Cirripedia									
Unidentified nauplii		102400	31270	103230	63250	16430	22000	22120	3790
Unidentified cyprids		315730	46900	1362580	24090	213620	14000	38710	7590
Mysidacea									
Mysis spp.									
Cumacea - unidentified							60		
Amphipoda									
Caprellidea - unidentified									
Gammaridea									
Calliopiidae									
Apherusa glacialis									
Lysianassidae									
Boeckosimus (= Onisimus) nanseni									
Boeckosimus sp.									
Onisimus(=Pseudalibrotus) glacialis									
Oedicerotidae *cf.*									
Podoceridae									
Dulichia spp.									
Unidentified Gammaridea									

Table 2. (continued)

	Station Number	4	4*	5	5	6	6	7	7
Taxon	Mesh Size (μm)	335	500	335	500	335	500	335	500
Hyperiidea									
Hyperoche medusarum									
Parathemisto abyssorum							60		
Parathemisto libellula		130	30		90				
Unidentified Hyperiidea		130				260			
Euphausiacea									
Thysanoëssa inermis			30		50		120		120
Thysanoëssa longipes									
Thysanoëssa raschii		270	30		280		60		120
Unidentified furcilia		270	460	160	190	260	190	520	
Unidentified calyptopis *cf.*		130							
Unidentified nauplii *cf.*						260			
Decapoda									
Anomura zoea		1200	370	1290	1180	260	810	520	710
Brachyura zoea		6530	5220	160	240	1540	1620	1900	2490
Caridea zoea									
Crangonidae									
Hippolytidae		530	240	160	240	260	120	520	710
Unidentified Caridea									
Unidentified Crustacea		106670							
Echinodermata - unidentified									
Appendicularia									
Fritillaria borealis		580270	410380	2374190	508990	410810	218000	740940	390870
Fritillaria spp.		2530130	1207690	2972900	774020	246490	80000	1260710	387080
Oikopleura labradoriensis									
Oikopleura vanhöffeni									

Table 2. (continued)

Taxon	Station Number Mesh Size (μm)	4 335	4* 500	5 335	5 500	6 335	6 500	7 335	7 500
Chaetognatha									
Sagitta elegans		4270	7820		27110			11060	
Unidentified Chaetognatha		76800	23450	123870	45180	41080	62000	38710	26560
Pisces									
Eggs									
Pleuronectidae									
Hippoglossoides robustus									
Unidentified eggs									
Larvae									
Ammodytidae									
Ammodytes hexapterus			30						
Cottidae									
Gymnocanthus sp.									
Myoxocephalus sp.			30						
Gadidae									
Boreogadus saida									
Unidentified Gadidae		1200	610	650	380		60		120
Stichaeidae									
Lumpenus sp.									
Unidentified Stichaeidae									
Other organisms									
Foraminifera									
Nematoda									7590
Unidentified invertebrate eggs		25600					12000	105060	7590
Unidentified animals					3010	90380	38000		

Table 2. (continued)

Taxon	Station Number Mesh Size (μm)	9† 335	9† 500	10 335	10*† 500	11† 335	11† 500	12† 335	12† 500
Cnidaria									
Hydrozoa									
Aglantha digitale			120	810			220		
Bougainvillia superciliaris									
Calycopsis birulai									
Corymorpha flammea									
Coryne tubulosa cf.						5			
Obelia longissima cf.									
Perigonimus vesicarius					30		10		
Perigonimus spp.		20	40		40	20	5	5	4
Perigonimus spp. *cf.*									
Plotocnide borealis cf.									
Rathkea octopunctata				200	10				4
Unidentified Hydrozoa		10	10		20	20	70		150
Scyphozoa - unidentified		110	40		100	40	30	5	30
Ctenophora									
Beroë cucumis									
Pleurobrachia pileus cf.			50		30				
Polychaeta - unidentified larvae		62840	220	155730	31700	13220	660	17660	8960
Mollusca									
Gastropoda - Pteropoda									
Clione limacina		10	20			5	30		
Limacina helicina			220		2440	300	150	1260	
Unidentified mollusc larvae			50				370	1260	1000

Table 2. (continued)

	Station Number	$9^{\dagger}$	$9^{\dagger}$	10	$10^{*\dagger}$	$11^{\dagger}$	$11^{\dagger}$	$12^{\dagger}$	$12^{\dagger}$
Taxon	Mesh Size (µm)	335	500	335	500	335	500	335	500
Pycnogonida - unidentified									4
Crustacea									
Ostracoda - unidentified									
Copepoda									
Calanoida - adults		50040	6440	77870	17070	53480	21990	81970	16930
Calanoida - juveniles		269960	9150	279020	29260	163460	17460	337970	13950
Cyclopoida		22110		227110	19500	18030	70	128630	20920
Harpacticoida				6490				3780	
Unidentified nauplii		9310		181690	2440	21030	70	41620	19920
Cirripedia									
Unidentified nauplii		553890	1820	1297780	97520	52880	5040	324100	43830
Unidentified cyprids		10470	290	12980		9620	220	58010	1000
Mysidacea									
Mysis spp.					10		5	5	4
Cumacea - unidentified								10	20
Amphipoda									
Caprellidea - unidentified			10						
Gammaridea									
Calliopiidae									
Apherusa glacialis		80	50	200	20	90	50	60	30
Lysianassidae									
Boeckosimus (= Onisimus) nanseni					10	5			
Boeckosimus sp.									
Onisimus (=Pseudalibrotus) glacialis			10		30		10	5	
Oedicerotidae *cf.*									
Podoceridae									
Dulichia spp.								10	
Unidentified Gammaridea		50	30		30	20	30		90

Table 2. (continued)

	Station Numbers	9†	9†	10	10*†	11‡	11†	12†	12†
Taxon	Mesh Size (μm)	335	500	335	500	335	500	335	500
Hyperiidea									
Hyperoche medusarum									4
Parathemisto abyssorum						10			4
Parathemisto libellula		50	10		10	10	50	5	40
Unidentified Hyperiidea		10							20
Euphausiacea									
Thysanoëssa inermis		20	20			20	20	110	90
Thysanoëssa longipes			10			5		5	
Thysanoëssa raschii		20				20	20	60	40
Unidentified furcilia		10			10		10	10	10
Unidentified calyptopis *cf.*									
Unidentified nauplii *cf.*						5			
Decapoda									
Anomura zoea		710	500	810	710	220	200	740	830
Brachyura zoea		440	260	410	220	560	600	1830	3120
Caridea zoea									
Crangonidae						5	5		
Hippolytidae		100	140	200	350	110	90	370	320
Unidentified Caridea		10							10
Unidentified Crustacea									20
Echinodermata - unidentified								5	
Appendicularia									
Fritillaria borealis		140800		837070	297450	85930	1530	79450	109570
Fritillaria spp.		80290		1511910	292570	61300	580	146290	87660
Oikopleura labradoriensis									
Oikopleura vanhöffeni									

Table 2. (continued)

	Station Number	9†	9†	10	10*†	11†	11†	12†	12†
Taxon	Mesh Size (μm)	335	500	335	500	335	500	335	500
Chaetognatha									
Sagitta elegans		3490	5700	2640	3050	2400	10080		4980
Unidentified Chaetognatha		47710	530	51910	17070	6610	880		6970
Pisces									
Eggs									
Pleuronectidae									
Hippoglossoides robustus									
Unidentified eggs			10						
Larvae									
Ammodytidae									
Ammodytes hexapterus					10				10
Cottidae									
Gymnocanthus sp.									
Myoxocephalus sp.									
Gadidae									
Boreogadus saida						20			
Unidentified Gadidae		40	30		20	120	140	80	120
Stichaeidae									
Lumpenus sp.									4
Unidentified Stichaeidae			10						
Other organisms									
Foraminifera									
Nematoda									
Unidentified invertebrate eggs		4650				3610			
Unidentified animals			100				220		20

Table 3. References used to identify zooplankton from the Chukchi Sea, CGC *Glacier*, 1976.

- Cnidaria
  - Naumov, D. V., 1960
  - Shirley, D. W., and Y. M. Leung, 1970

- Ctenophora
  - Leung, Y. M., 1970b

- Polychaeta
  - Yingst, D. R., 1972

- Mollusca
  - Leung, Y. M., 1971

- Pycnogonida
  - Smith, R. I., and J. T. Carlton, 1975

- Copepoda
  - Vidal, J., 1971

- Cirripedia
  - Smith, R. I., and J. T. Carlton, 1975

- Mysidacea
  - Leung, Y. M., 1972b

- Cumacea
  - Smith, R. I., and J. T. Carlton, 1975

- Amphipoda
  - Barnard, J. L., 1969
  - Gurjanova, E., 1951
  - Sars, G. O., 1895
  - Tencati, J. R., 1970

- Euphausiacea
  - Lebour, M. V., 1926
  - Leung, Y. M., 1970a

- Decapoda
  - English, T. S., 1976

- Chaetognatha
  - Dawson, J. K., 1971

- Appendicularia
  - Leung, Y. M., 1972a

Table 4. Zooplankton taxa identified from Stefansson Sound winter studies samples, Nov 1978, Mar and May 1979.

- Cnidaria
  - Anthozoa
    - *Halitholus cirratus* Hartlaub, 1913

- Ctenophora
  - *Pleurobrachia pileus* (O. F. Müller, 1776)

- Aschelminthes
  - Nematoda - unidentified species

- Annelida
  - Polychaeta - unidentified species

- Arthropoda
  - Cirripedia
    - Unidentified larvae
    - Unidentified parasitic larvae
  - Copepoda
    - Calanoida
      - *Calanus glacialis* Jashnov, 1955
      - *Calanus hyperboreus* Krøyer, 1838
      - *Microcalanus pygmaeus* (G. O. Sars, 1900)
      - *Pseudocalanus elongatus* (Boeck, 1864)
      - *Pseudocalanus major* G. O. Sars, 1900
      - *Derjuginia tolli* (Linko, 1913)
      - *Eurytemora richingsi* Heron and Damkaer, 1976
      - *Metridia lucens* Boeck, 1964
      - *Limnocalanus macrurus* G. O. Sars, 1863
      - *Acartia longiremis* (Lilljeborg, 1853)
    - Cyclopoida
      - *Oithona similis* Claus, 1866
      - *Cyclopina gracilis* (Claus, 1963)
      - *Cyclopina* sp. A
      - *Cyclopina* sp. B
      - *Cyclopinodes* sp. A
      - *Oncaea borealis* G. O. Sars, 1918
    - Harpacticoida
      - *Pseudobradya minor* (T. and A. Scott, 1896)
      - *Harpacticus superflexus* Willey, 1920
      - *Tisbe furcata* (Baird, 1837)
  - Malacostraca
    - Mysidacea
      - *Mysis litoralis* (Banner, 1948)
      - *Mysis oculata* (Fabricius, 1780)
      - *Mysis relicta* Lovén, 1861

Table 4. (continued)

- Amphipoda
  - Gammaridea
    - Atylidae
      - *Atylus carinatus* (Fabricius, 1793)
    - Gammaridae
      - *Weyprechtia pinguis* (Krøyer, 1838)
    - Lysianassidae
      - *Anonyx nugax* (Phipps, 1774)
      - *Boeckosimus plautus* (Krøyer, 1845)
      - *Onisimus litoralis* (Krøyer, 1945)
      - *Orchomenella pinguis* (Boeck, 1861)
    - Oedicerotidae
      - *Acanthostepheia behringiensis* (Lockington, 1877)
  - Hyperiidae
    - *Parathemisto libellula* (Lichtenstein, 1822)

- Chordata
  - Appendicularia (Larvacea)
    - Fritillariidae
      - *Fritillaria borealis* Lohmann, 1896

- Chaetognatha
  - *Sagitta elegans* Verrill, 1873

Table 5. Abundance (number per 1000 m^3) of zooplankton taxa found in ring net hauls from Stefansson Sound. November 1978 and March 1979 samples were collected with a 0.75 m net, mesh size 308 μm; May 1979 sample collected with a 0.50 m net, mesh size 209 μm. Where no number is present, no animals were found.

	Station Number	8 Nov		8 Nov		9 Nov		9 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Anthozoa									
Halitholus cirratus									
Ctenophora									
Pleurobrachia pileus									
Polychaeta - unidentified larvae									
Crustacea									
Cladocera									
Eubosmina longispina									
Ostracoda - unidentified									
Copepoda									
Calanoida									
Calanus glacialis	VI								
	V								
	IV								
	III		20576						
	II								
	I								
Calanus hyperboreus	VI								
	V		20576						
	IV								
	III								
	II								
	I								

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* If sex could not be determined, number of animals is placed between symbols

Table 5. (continued)

Taxon	Station Number	8 Nov		8 Nov		9 Nov		9 Nov	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Microcalanus pygmaeus	VI								
	V								
	IV								
	III								
	II								
	I								
Pseudocalanus elongatus	VI		349794		349794		205761		205761
	V	534979	102880	730452	185185	514403	144032	1111111	226337
	IV	1255144	1028807	1790124	1399177	2057613	1728395	3436214	2098765
	III		411523		493827		267490		452675
	II		20576						
	I								
Pseudocalanus major	VI		20576						41152
	V	144033	20576						20576
	IV	349794	205761						
	III		185185						
	II		20576						
	I								
Derjuginia tolli	VI	41152	20576						
	V	20576							
	IV		20576						
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V								
	IV		20576						
	III								
	II								
	I								

Table 5. (continued)

	Station Number	8 Nov		8 Nov		9 Nov		9 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Metridia lucens	VI						20576		
	V								
	IV								
	III								
	II								
	I								
Limnocalanus macrurus	VI	20576	20576						
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI				10288				20576
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified									
Cyclopoida									
Oithona similis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5 (continued)

	Station Number	8 Nov		8 Nov		9 Nov		9 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Oncaea borealis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis									
Mysis oculata									
Mysis relicta				412					
Isopoda									
Epicaridean - unidentified									
Amphipoda									
Hyperiidea									
Parathemisto libellula				412					
Gammaridea									
Atylidae									
Atylus carinatus								412	
Gammaridae									
Weyprechtia pinguis									

Table 5. (continued)

	Station Number	8 Nov		8 Nov		9 Nov		9 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax						412		823	
Acanthostepheia behringiensis				412					
Boeckosimus plautus						823		1235	
Onisimus litoralis									
Orchomenella pinguis									
Cirripedia									
Balanus - unidentified nauplii									
Unidentified parasitic larvae									
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans									
Nematoda - unidentified									

Table 5. (continued)

	Station Number	10 Nov		10 Nov		11 Nov		11 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Anthozoa									
Halitholus cirratus									
Ctenophora									
Pleurobrachia pileus									
Polychaeta - unidentified larvae									
Crustacea									
Cladocera									
Eubosmina longispina									
Ostracoda - unidentified									
Copepoda									
Calanoida									
Calanus glacialis VI									
V									
IV									
III									
II									
I									
Calanus hyperporeus VI									
V									
IV									
III									
II									
I									

Table 5. (continued)

Taxon	Station Number Sex*	10 Nov ♂	10 Nov ♀	10 Nov ♂	10 Nov ♀	11 Nov ♂	11 Nov ♀	11 Nov ♂	11 Nov ♀
Microcalanus pygmaeus	VI								
	V								
	IV								
	III								
	II								
	I								
Pseudocalanus elongatus	VI	20576	205761	20576	205761		267490	41152	185185
	V	1090535	123457	1419753	246914	720165	185185	720165	144033
	IV	4506173	1687243	3580247	2942387	2448560	1646091	2757202	1769547
	III		329218		699589		185185		432099
	II								
	I								
Pseudocalanus major	VI		20576						
	V	514403	164609						
	IV	432099	1255144						
	III		144033						
	II								
	I								
Derjuginia tolli	VI			20576			20576	20576	
	V				20576		41152		
	IV								
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

	Station Number	10 Nov		10 Nov		11 Nov		11 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Metridia lucens	VI								
	V								
	IV								
	III								
	II								
	I								
Limnocalanus macrurus	VI		20576						
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI		20576			20576	20576	20576	
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified									
Cyclopoida									
Oithona similis	VI				20576				
	V								
	IV								
	III								
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number Sex*	10 Nov ♂	 ♀	10 Nov ♂	 ♀	11 Nov ♂	 ♀	11 Nov ♂	 ♀
Oncaea borealis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis				823					
Mysis oculata									
Mysis relicta									
Isopoda									
Epicaridea - unidentified									
Amphipoda									
Hyperiidea									
Parathemisto libellula									
Gammaridea									
Atylidae									
Atylus carinatus									
Gammaridae									
Weyprechtia pinguis									

Table 5. (continued)

Taxon	Station Number	10 Nov		10 Nov		11 Nov		11 Nov	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax								823	
Acanthostepheia behringiensis									
Boeckosimus plautus				412		1235		412	
Onisimus litoralis								412	
Orchomenella pinguis									
Cirripedia									
Balanus - unidentified nauplii									
Unidentified parasitic larvae									
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans									
Nematoda - unidentified									

Table 5. (continued)

	Station Number	12 Nov		12 Nov		13 Nov		13 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Anthozoa									
Halitholus cirratus									
Ctenophora									
Pleurobrachia pileus									
Polychaeta - unidentified larvae		453							
Crustacea									
Cladocera									
Eubosmina longispinus									
Ostracoda - unidentified									
Copepoda									
Calanoida									
Calanus glacialis	VI								
	V								
	IV								
	III								
	II								
	I								
Calanus hyperboreus	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number	12 Nov		12 Nov		13 Nov		13 Nov	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Microcalanus pygmaeus	VI								
	V								
	IV								
	III								
	II								
	I								
Pseudocalanus elongatus	VI		113122	22624	361991	22624	203620	11312	147059
	V	633484	22624	904977	135747	407290	113122	373303	90498
	IV	3235294	3099548	3416290	2194570	1855204	1447964	1877828	1210407
	III		497738		180996		316742		79186
	II								
	I								
Pseudocalanus major	VI						11312	22624	
	V		45249						
	IV								
	III								
	II								
	I								
Derjuginia tolli	VI	45249							
	V				22624				
	IV		22624						
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

	Station Number	12 Nov		12 Nov		13 Nov		13 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Metridia lucens	VI								
	V								
	IV								
	III								
	II								
	I								
Limnocalanus macrurus	VI								
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI				22624			11312	
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified									
Cyclopoida									
Oithona similis	VI								
	V								11312
	IV								
	III								
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

	Station Number	12 Nov		12 Nov		13 Nov		13 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Oncaea borealis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis						905		905	
Mysis oculata		453							
Mysis relicta									
Isopoda									
Epicaridean - unidentified									
Amphipoda									
Hyperiidea									
Parathemisto libellula									
Gammaridea									
Atylidae									
Atylus carinatus						905		905	
Gammaridae									
Weyprechtia pinguis									

Table 5. (continued)

Taxon	Station Number	12 Nov		12 Nov		13 Nov		13 Nov	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax									
Acanthostepheia behringiensis									
Boeckosimus plautus		453		453				1358	
Onisimus litoralis						4525		1810	
Orchomenella pinguis		453				905		453	
Cirripedia									
Balanus - unidentified nauplii									
Unidentified parasitic larvae									
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans						905		453	
Nematoda - unidentified									

Table 5. (continued)

	Station Number	14 Nov		14 Nov		14 Nov		14 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Anthozoa									
Halitholus cirratus									
Ctenophora									
Pleurobrachia pileus									
Polychaeta - unidentified larvae									
Crustacea									
Cladocera									
Eubosmina longispina									
Ostracoda - unidentified									
Copepoda									
Calanoida									
Calanus glacialis	VI						11312		
	V								
	IV								
	III								
	II						11312		
	I								
Calanus hyperboreus	VI								9434
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued

	Station Number	14 Nov		14 Nov		14 Nov		14 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Microcalanus pygmaeus	VI						11312		
	V								
	IV								
	III								
	II								
	I								
Pseudocalanus elongatus	VI		101810	67872	339360		192308	18868	150943
	V	825792	305430	1108576	203616	294118	45249	349057	188679
	IV	1527149	1470588	1719424	1470560	1006787	780543	1235849	971698
	III		135747		113120		124434		160377
	II								
	I								
Pseudocalanus major	VI	56561	11312						
	V	67873	45249			45249	22624	37736	56604
	IV			452480	113120			66038	18868
	III								
	II								
	I								
Derjuginia tolli	VI			67872	90496		11312		28302
	V				67872		11312		
	IV								
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

	Station Number	14 Nov		14 Nov		14 Nov		14 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Metridia lucens	VI								
	V								
	IV								
	III								
	II								
	I								
Limnocalanus macrurus	VI		11312		22624		11312		
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI		11312		22624				
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified									
Cyclopoida									
Oithona similis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number Sex*	14 Nov ♂	 ♀	14 Nov ♂	 ♀	14 Nov ♂	 ♀	14 Nov ♂	 ♀
Oncaea borealis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis									
Mysis oculata		453							
Mysis relicta		1358							
Isopoda									
Epicaridean - unidentified									
Amphipoda									
Hyperiidea									
Parathemisto libellula									
Gammaridea									
Atylidae									
Atylus carinatus									
Gammaridae									
Weyprechtia pinguis									

Table 5. (continued)

	Station Number	14 Nov		14 Nov		14 Nov		14 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax									
Acanthostepheia behringiensis									
Boeckosimus plautus									
Onisimus litoralis									
Orchomenella pinguis									
Cirripedia									
Balanus - unidentified nauplii									
Unidentified parasitic larvae									
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans									
Nematoda - unidentified									

Table 5. (continued)

	Station Number	15 Nov		16 Nov		16 Nov		16 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Halitholus cirratus									
Ctenophora									
Pleurobrachia pileus		453							
Polychaeta - unidentified larvae									
Crustacea									
Cladocera									
Eubosmina longispina									
Ostracoda - unidentified									
Copepoda									
Calanoida									
Calanus glacialis	VI								
	V								
	IV								
	III								
	II								
	I								
Calanus hyperboreus	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number Sex*	15 Nov ♂	15 Nov ♀	16 Nov ♂	16 Nov ♀	16 Nov ♂	16 Nov ♀	16 Nov ♂	16 Nov ♀
Microcalanus pygmaeus	VI								
	V								
	IV								
	III								
	II								
	I								
Pseudocalanus elongatus	VI		497738	22624	282805	11312	248869		147059
	V	1425339	135747	475113	56561	509050	180995	475113	90498
	IV	4117647	4072398	2013574	1549774	1414027	961538	2013574	1538462
	III		1018100		169683		113122		79186
	II								
	I								
Pseudocalanus major	VI							11312	
	V	22624			22624				11312
	IV								
	III								
	II								
	I								
Derjuginia tolli	VI								
	V								
	IV								
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number	15 Nov		16 Nov		16 Nov		16 Nov	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Metridia lucens	VI								
	V								
	IV								
	III								
	II								
	I								
Limnocalanus macrurua	VI			11312			11312		
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI		45249				11312		11312
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified									
Cyclopoida									
Oithona similis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

	Station Number	15 Nov		16 Nov		16 Nov		16 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Oncaea borealis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis		905		1810					
Mysis oculata									
Mysis relicta									
Isopoda									
Epicaridean - unidentified									
Amphipoda									
Hyperiidea									
Parathemisto libellula									
Gammaridea									
Atylidae									
Atylus carinatus									
Gammaridae									
Weyprechtia pinguis		453							

Table 5. (continued)

	Station Number	15 Nov		16 Nov		16 Nov		16 Nov	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax				453				453	
Acanthostepheia behringiensis									
Boeckosimus plautus				1810				905	
Onisimus litoralis									
Orchomenella pinguis				453				905	
Cirripedia									
Balanus - unidentified nauplii									
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans				453				1358	
Nematoda - unidentified									

Table 5. (continued)

	Station Number	12 Mar		12 Mar		13 Mar		13 Mar	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Anthozoa									
Halitholus cirratus				905		452			
Ctenophora									
Pleurobrachia pileus									
Polychaeta - unidentified larvae									
Crustacea									
Cladocera									
Eubosmina longispina								452	
Ostracoda - unidentified								452	
Copepoda									
Calanoida									
Calanus glacialis VI									
V									
IV									
III									
II									
I									
Calanus hyperboreus VI									
V									
IV									
III									
II									
I									

Table 5. (continued)

	Station Number	12 Mar		12 Mar		13 Mar		13 Mar	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Microcalanus pygmaeus	VI		452		905		452		
	V		452						
	IV		452				452		
	III						1357		
	II								
	I								
Pseudocalanus elongatus	VI								452
	V	2714	905	5430					
	IV	15837	20814	19910	20814	9502	5882	452	5882
	III		52036		95023		29412		
	II		5882		9050		5430		905
	I		1357		1810		1357		
Pseudocalanus major	VI								
	V					905			
	IV					3167	4977		
	III						452		
	II								
	I						452		
Derjuginia tolli	VI								
	V								
	IV								
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V								
	IV		452						
	III								452
	II								
	I								

Table 5. (continued)

Taxon	Station Number Sex*	12 Mar ♂	 ♀	12 Mar ♂	 ♀	13 Mar ♂	 ♀	13 Mar ♂	 ♀
Metridia lucens	VI								
	V								
	IV								
	III		452				452		
	II				1810		452		452
	I		905						905
Limnocalanus macrurus	VI								
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI								
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified		9434		9050		7240		7692	
Cyclopoida									
Oithona similis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

	Station Number	12 Mar		12 Mar		13 Mar		13 Mar	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Oncaea borealis	VI								
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis									
Mysis oculata									
Mysis relicta									
Isopoda									
Epicaridean - unidentified									
Amphipoda									
Hyperiidea									
Parathemisto libellula									
Gammaridea									
Atylidae									
Atylus carinatus									
Gammaridae									
Weyprechtia pinguis									

Table 5. (continued)

	Station Number	12 Mar		12 Mar		13 Mar		13 Mar	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax									
Acanthostepheia behringiensis									
Boeckosimus plautus									
Onisimus litoralis									
Orchomenella pinguis									
Cirripedia									
Balanus - unidentified nauplii		1810							
Unidentified parasitic larvae									
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans									
Nematoda - unidentified									

Table 5. (continued)

	Station Number	14 Mar		14 Mar		15 Mar		16 Mar	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Cnidaria									
Anthozoa									
Halitholus cirratus				1810					
Ctenophora									
Pleurobrachia pileus									
Polychaeta - unidentified larvae		452				453			
Crustacea									
Cladocera									
Eubosmina longispina									
Ostracoda - unidentified									
Copepoda									
Calanoida									
Calanus glacialis VI									
V									
IV									
III							1810		
II									
I			3168				453		
Calanus hyperboreus VI									
V									
IV									
III									
II									
I									

Table 5. (continued)

Taxon	Station Number	14 Mar		14 Mar		15 Mar		16 Mar	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Microcalanus pygmaeus	VI						453		453
	V								
	IV					453			
	III						453		453
	II								
	I								
Pseudocalanus elongatus	VI	452			453		905		905
	V	6335	452	1358	1810	1358	453	1810	453
	IV	14027	28507	39267	54751	6335	6787	13122	13575
	III		33937		138009		24887		45249
	II		7692		6335		453		4072
	I		452		1358		453		
Pseudocalanus major	VI								
	V			7692	453				
	IV								
	III								
	II								
	I								
Derjuginia tolli	VI								
	V								
	IV								
	III								
	II								
	I								
Eurytemora richingsi	VI								
	V		452						
	IV		452			453	1358		
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number Sex*	14 Mar ♂	14 Mar ♀	14 Mar ♂	14 Mar ♀	15 Mar ♂	15 Mar ♀	16 Mar ♂	16 Mar ♀
Metridia lucens	VI								
	V								
	IV								
	III								
	II						453		
	I								
Limnocalanus macrurus	VI								
	V								
	IV								
	III								
	II								
	I								
Acartia longiremis	VI					453			
	V								
	IV								
	III								
	II								
	I								
Calanoid nauplii - unidentified		10860		12670		7240		2715	
Cyclopoida									
Oithona similis	VI			905	11765	453	4977	453	4977
	V				14480		14027		7692
	IV				17647		5882		5882
	III				905				905
	II								
	I								
Cyclopina gracilis	VI								
	V								
	IV								
	III								
	II								
	I								

Table 5. (continued)

Taxon	Station Number	14 Mar		14 Mar		15 Mar		16 Mar	
	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Oncaea borealis	VI				1810	453	453	1358	
	V								
	IV								
	III								
	II								
	I								
Cyclopina sp. A	VI								
Cyclopina sp. B	VI								
Cyclopinodes sp.	VI								
Harpacticoida									
Pseudobradya minor									
Harpacticus superflexus									
Tisbe furcata									
Mysidacea									
Mysis litoralis									
Mysis oculata									
Mysis relicta									
Isopoda									
Epicaridean - unidentified								453	
Amphipoda									
Hyperiidea									
Parathemisto libellula									
Gammaridea									
Atylidae									
Atylus carinatus									
Gammaridae									
Weyprechtia pinguis									

Table 5. (continued)

	Station Number	14 Mar		14 Mar		15 Mar		16 Mar	
Taxon	Sex*	♂	♀	♂	♀	♂	♀	♂	♀
Lysianassidae									
Anonyx nugax									
Acanthostepheia behringiensis									
Boeckosimus plautus									
Onisimus litoralis				453		453			
Orchomenella pinguis									
Cirripedia									
Balanus - unidentified nauplii									
Unidentified parasitic larvae								453	
Appendicularia									
Fritillaria borealis									
Chaetognatha									
Sagitta elegans				453				453	
Nematoda - unidentified									

Table 5. (continued)

Taxon	Station Number	16 Mar		16 May	
	Sex*	♂	♀	♂	♀
Cnidaria					
Anthozoa					
Halitholus cirratus					
Ctenophora					
Pleurobrachia pileus					
Polychaeta - unidentified larvae					
Crustacea					
Cladocera					
Eubosmina longispina					
Ostracoda - unidentified					
Copepoda					
Calanoida					
Calanus glacialis	VI				
	V				
	IV				
	III				
	II				
	I		452		
Calanus hyperboreus	VI				
	V				
	IV				
	III				
	II				
	I				

Table 5. (continued)

	Station Number	16 Mar		16 May	
Taxon	Sex*	♂	♀	♂	♀
Microcalanus pygmaeus	VI		452		
	V	905			
	IV	452		385	1154
	III	452			385
	II				
	I				
Pseudocalanus elongatus	VI			2038	3846
	V			8846	4231
	IV	8597	8597	1539	8846
	III		34842		5000
	II		2715		
	I		452		2692
Pseudocalanus major	VI				
	V				
	IV				
	III				
	II				
	I				
Derjugnia tolli	VI				
	V				
	IV				
	III				
	II				
	I				
Eurytemora richingsi	VI				
	V				
	IV		452		
	III				
	II				
	I				

Table 5. (continued)

	Station Number	16 Mar		16 May	
Taxon	Sex*	♂	♀	♂	♀
Metridia lucens	VI				
	V				
	IV				
	III				
	II				
	I				
Limnocalanus macrurus	VI				
	V				
	IV				
	III				
	II				
	I				
Acartia longiremis	VI			1539	385
	V				
	IV				
	III				
	II				
	I				
Calanoid nauplii - unidentified		5882		39231	
Cyclopoida					
Oithona similis	VI			3846	21923
	V				19231
	IV				4231
	III				1923
	II				
	I				
Cyclopina gracilis	VI				4615
	V				
	IV				
	III				
	II				
	I				

Table 5. (continued)

	Station Number	16 Mar		16 May		
Taxon	Sex*	♂	♀	♂	♀	
Oncaea borealis	VI					
	V					
	IV					
	III					
	II					
	I					
Cyclopina sp. A	VI			769	3462	
Cyclopina sp. B	VI				1539	
Cyclopinodes sp.	VI				1153	
Harpacticoida						
Pseudobradya minor						27308 juveniles
Harpacticus superflexus	VI			5000	769	26923 juveniles
Tisbe furcata	VI			385		
Mysidacea						
Mysis litoralis						
Mysis oculata						
Mysis relicta						
Isopoda						
Epicaridean - unidentified						
Amphipoda						
Hyperiidea						
Parathemisto libellula						
Gammaridea						
Atylidae						
Atylus carinatus						
Gammaridae						
Weyprechtia pinguis						

Table 5. (continued)

	Station Number	16 Mar		16 May	
Taxon	Sex*	♂	♀	♂	♀
Lysianassidae					
Anonyx nugax					
Acanthostepheia behringiensis					
Boeckosimus plautus					
Onisimus litoralis					
Orchomenella pinguis					
Cirripedia					
Balanus - unidentified nauplii					
Unidentified parasitic larvae					
Appendicularia					
Fritillaria borealis					
Chaetognatha					
Sagitta elegans					
Nematoda - unidentified					

present in November.

Other animals in the fall samples included *Mysis litoralis, M. oculata, M. relicta, Parathemisto libellula, Atylus carinatus, Anonyx nugax, Acanthostepheia behringiensis, Boeckosimus plautus, Onisimus litoralis, Orchomenella pinguis, Weyprechtia pinguis, Sagitta elegans,* unidentified ctenophores, and polychaete larvae.

In March, *Pseudocalanus elongatus*, stage III, was the most abundant form. Younger stages were also present with stage II occurring more frequently than stage V or adults. Other copepods present in March included *Oithona similis, Oncaea borealis, Eurytemora richingsi, Microcalanus pygmaeus,* and a few nauplii.

Other animals present in early spring were *Halitholus cirratus, Onisimus litoralis, Sagitta elegans,* polychaete and barnacle larvae, and unidentified ctenophores.

The May sample was also dominated by *Pseudocalanus elongatus* males, females, and juveniles. Other calanoid copepods included *Microcalanus pygmaeus, Eurytemora richingsi,* and *Acartia longiremis*. This sample also contained several species of harpacticoids and cyclopoids that are not usually found in the plankton, including *Cyclopina gracilis, Cyclopina* spp., *Cyclopinodes* sp., *Pseudobradya minor, Harpacticus superflexus* and *Tisbe furcatus*. Planktonic cyclopoids found in this sample were *Oithona similis* and *Oncaea borealis*.

No animals other than copepods were identified from the May samples.

References used to identify organisms in the winter samples included Barnard (1959, 1969); Gurjanova (1951); Holmquist (1965, 1970); Jashnov (1948); Lang (1948); Lindberg (1953); Sars (1885, 1903-1911, 1913-1918, 1921); and Willey (1920).

3. Beaufort Sea samples, WEBSEC-72

Sixty-one categories of zooplankton were identified from 13 vertical ring net hauls and 6 Isaacs-Kid midwater trawls, including 31 species and 30 other categories such as larval stages and categories where identification was made to some taxonomic rank higher than species (Table 6). References used to identify the organisms are listed in Table 7.

At stations 1, 3, 4, and 5 off Barter Island, adult female copepods and juvenile copepods, along with *Parathemisto libellula,* unidentified *Oikopleura* spp., and *Eukrohnia hamata* were the most abundant organisms. At stations farther west, off Prudhoe and Harrison bays, juvenile copepods, barnacle larvae (nauplii and cyprids), *Oikopleura vanhöffeni,* and *Sagitta elegans* were the most abundant organisms. *Aglantha digitale* was relatively abundant in all ring net hauls. Unidentified polychaetes and decapod larvae were more abundant west of Prudhoe Bay.

Few animals were caught in the Isaacs-Kidd midwater trawl because of the large mesh size at the mouth of the net. Fish larvae were caught only

Table 6. Abundance (number per 1000 m^3) of zooplankton taxa found in net hauls from the Beaufort Sea collected during WEBSEC-72. Samples were collected with a 0.5 m ring net, mesh size 560 μm, except where noted. Where no number is present, no animals were found.

	Station Number	1	3	4	4	4	5*	5*	5*
Taxon	Maximum depth (m)	25	55	50	50	475	50	50	100
Cnidaria									
Hydrozoa									
Aeginopsis laurentii									
Aglantha digitale		611	1273	500		11	506	1012	899
Halitholus cirratus§		611							
Plotocnide borealis			91						
Rathkea octopunctata									
Dimophyes arctica, polygastric phase			182			11			
Dimophyes arctica, eudoxid phase						21			
Unidentified medusae									
Siphonophora - unidentified						74			
Ctenophora - unidentified									13
Polychaeta - unidentified		407							
Mollusca									
Gastropoda - Pteropoda									
Limacina helicina						84			
Unidentified pteropods						10			

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* Samples collected with a 1 m ring net, mesh size 560 μm

† Samples collected with an Isaacs-Kidd midwater trawl, mesh size 38 mm at the mouth

§ *Halitholus cirratus* has been reported previously as *Perigonimus yoldia-arcticae*. They are the same animal.

Table 6. (continued)

	Station number	1	3	4	4	4	5*	5*	5*
Taxon	Maximum depth (m)	25	55	50	50	475	50	50	100
Crustacea									
Copepoda									
Calanoida, adult ♀		30957	4909	4400	19000	2232	14785	9823	8658
Calanoida, adult ♂		7332	91			42	203		51
Calanoida, juveniles		10591	6636	7100	13600	6190	12760	8607	7089
Calanoida, nauplii						42			
Cirripedia									
Nauplii		611	91						
Cyprids							25	51	
Mysidacea									
Boreomysis arctica						21			
Mysis litoralis		204							
Mysis oculata		204							
Mysis sp.									
Neomysis rayii									
Amphipoda									
Gammaridea									
Apherusa glacialis		611							13
Lagunogammarus (=Gammarus) wilkitzkii									
Onisimus (= Pseudal.) glacialis		204							
Boeckosimus (= Onisimus) nanseni				100					
Metopa invalida		204							
Unidentified gammarids		408		100				51	

Table 6. (continued)

	Station number	1	3	4	4	4	5*	5*	5*
Taxon	Maximum depth (m)	25	55	50	50	475	50	50	100
Hyperiidea									
Hyperia galba									
Hyperia medusarum									
Hyperoche medusarum									
Parathemisto abyssorum		204	636	600	1400	295	658	658	760
Parathemisto libellula					200				13
Parathemisto spp.					100				
Euphausiacea									
Thysanoessa inermis			91	100					
Thysanoessa raschii		91							
Unidentified furcilia									
Ostracoda									
Conchoecia borealis maxima			91	1500	1300	2400	51		114
Conchoecia elegans									13
Unidentified ostracods							25		
Decapoda - all larval stages									
Unidentified brachyuran									
Pandalus goniurus III									
Pandalus goniurus V									
Unidentified Hippolytidae									
Unidentified Paguridae									
Chionoecetes spp.									
Oregoniinae sp.									
Unidentified crustacean eggs						present			

Table 6. (continued)

	Station number	1	3	4	4	4	5*	5*	5*
Taxon	Maximum depth (m)	25	55	50	50	475	50	50	100
Echinodermata									
Ophiuroidea - unidentified larvae			91	100					38
Unidentified echinoderm pluteus									
Appendicularia (Larvacea)									
Fritillaria sp.		204							
Oikopleura vanhöffeni							25		13
Oikopleura spp.		10591	13455	1000	3200	137	405	582	468
Chaetognatha									
Sagitta elegans		204	364		200		177	51	63
Eukrohnia hamata		815	364	600	600	253	1190	911	544
Unidentified chaetognaths							51		13
Ascidiacea									
Unidentified ascidians				100					
Pisces									
Hippoglossoides robustus eggs									
Unidentified fish larvae									

Table 6. (continued)

Taxon	Station number Maximum depth (m)	22 50	29 40	47 20	49 40	51† 100	51† 150	51 250	55† 50
Cnidaria									
Hydrozoa									
Aeginopsis laurentii			125						
Aglantha digitale			750	5750	6250	2	14	143	< 1
Perigonimus yoldia-arcticae			500						
Plotocnide borealis			1875						
Rathkea octopunctata			1875					41	
Dimophyes arctica, polygastric phase									
Dimophyes arctica, eudoxid phase									
Unidentified medusae					125	< 1			
Siphonophora - unidentified									
Ctenophora - unidentified								41	
Polychaeta - unidentified		100	1375	250	125	< 1	< 1	2980	
Mollusca									
Gastropoda - Pteropoda									
Limacina helicina		200	125						
Unidentified pteropods									

Table 6. (continued)

Taxon	Station number	22	29	47	49	51†	51†	51	55†
	Maximum depth (m)	50	40	20	40	100	150	250	50
Crustacea									
Copepoda									
Calanoida, adult ♀			2000			3	1	3265	
Calanoida, adult ♂						< 1			
Calanoida, juveniles		39600	50500	51000	1625	12	4	33633	
Calanoida, nauplii									
Cirripedia									
Nauplii		6600	33750	60000	33500	7	13	20735	
Cyprids		10000	250	5000	2000	2	4	1875	
Mysidacea									
Boreomysis arctica									
Mysis litoralis									
Mysis oculata							< 1		
Mysis sp.									
Neomysis rayii						< 1			
Amphipoda									
Gammaridea									
Apherusa glacialis								122	
Lagunogammarus (=Gammarus) wilkitzkii						< 1			
Onisimus (= Pseudalibrotus) glacialis									
Boeckosimus (= Onisimus) nanseni							< 1		
Metopa invalida				250	125				
Unidentified gammarids									

Table 6. (continued)

	Station number	22	29	47	49	51†	51†	51	55†
Taxon	Maximum depth (m)	50	40	20	40	100	150	250	50
Hyperiidea									
Hyperia galba		200				< 1			
Hyperia medusarum							< 1		
Hyperoche medusarum									
Parathemisto abyssorum		200			125	< 1	< 1	102	
Parathemisto libellula		200				< 1	2	20	
Parathemisto spp.				250			< 1		
Euphausiacea									
Thysanoëssa inermis						46	14	41	
Thysanoëssa raschii						32	10		
Unidentified furcilia			125		125		< 1	82	
Ostracoda									
Conchoecia borealis maxima		400				< 1		102	
Conchoecia elegans									
Unidentified ostracods		100							
Decapoda - all larval stages									
Unidentified brachyuran							< 1		
Pandalus goniurus III									
Pandalus goniurus V						2	1		
Unidentified Hippolytidae			250	500	375				
Unidentified Paguridae		100	250	250	125	< 1	< 1		
Chionoecetes spp.			375	500					
Oregoniinae sp.			125						
Unidentified crustacean eggs									

Table 6. (continued)

	Station number	22	29	47	49	$51^{\dagger}$	$51^{\dagger}$	51	$55^{\dagger}$
Taxon	Maximum depth (m)	50	40	20	40	100	150	250	50
Echinodermata									
Ophiuroidea - unidentified larvae		300	3250			< 1			
Unidentified echinoderm pluteus			500						
Appendicularia (Larvacea)									
Fritillaria sp.									
Oikopleura vanhöffeni			11500	9750	3250		< 1	2367	
Oikopleura spp.		500	6875	6500	3875	< 1	33	3918	
Chaetognatha									
Sagitta elegans		1200	1750	2250	500	17	9	1327	
Eukrohnia hamata								306	
Unidentified chaetognaths		500							
Ascidiacea									
Unidentified ascidians									
Pisces									
Hippoglossoides robustus eggs			125						
Unidentified fish larvae						< 1	2		< 1

Table 6. (continued)

	Station number	55†	57†	69†
Taxon	Maximum depth (m)	200	50	0
Cnidaria				
Hydrozoa				
Aeginopsis laurentii				
Aglantha digitale		3	< 1	
Perigonimus yoldia-arcticae				
Plotocnide borealis				
Rathkea octopunctata				
Dimophyes arctica, polygastric phase				
Dimophyes arctica, eudoxid phase				
Unidentified medusae		< 1		
Siphonophora - unidentified				
Ctenophora - unidentified		< 1		
Polychaeta - unidentified		< 1		
Mollusca				
Gastropoda - Pteropoda				
Limacina helicina				
Unidentified pteropods			< 1	

Table 6. (continued)

	Station number	$55^{\dagger}$	$57^{\dagger}$	$69^{\dagger}$
Taxon	Maximum depth (m)	200	50	0
Crustacea				
Copepoda				
Calanoida, adult ♀		17	< 1	
Calanoida, adult ♂				
Calanoida, juveniles		16	< 1	< 1
Calanoida, nauplii				
Cirripedia				
Nauplii		< 1	< 1	
Cyprids		1	1	< 2
Mysidacea				
Boreomysis arctica				
Mysis litoralis				
Mysis oculata				
Mysis sp.				< 1
Neomysis rayii				
Amphipoda				
Gammaridea				
Apherusa glacialis				
Lagunogammarus (=Gammarus) wilkitzkii				
Onisimus (= Pseudal.) glacialis		< 1		3
Boeckosimus (= Onisimus) nanseni				
Metopa invalida				
Unidentified gammarids		< 1		

Table 6. (continued)

	Station number	55†	57†	69†
Taxon	Maximum depth (m)	200	50	0
Hyperiidea				
Hyperia galba		< 1		
Hyperia medusarum				
Hyperoche medusarum		< 1		
Parathemisto abyssorum		1		< 1
Parathemisto libellula		< 1		< 1
Parathemisto spp.		< 1		
Euphausiacea				
Thysanoëssa inermis		5		
Thysanoëssa raschii		4		
Unidentified furcilia				
Ostracoda				
Conchoecia borealis maxima				
Conchoecia elegans				
Unidentified ostracods				
Decapoda - all larval stages				
Unidentified brachyuran				< 1
Pandalus goniurus III		< 1		
Pandalus goniurus V		< 1		
Unidentified Hippolytidae		< 1		
Unidentified Paguridae				
Chionoecetes spp.				
Oregoniinae sp.				
Unidentified crustacean eggs				

Table 6. (continued)

	Station number	55†	57†	69†
Taxon	Maximum depth (m)	200	50	0
Echinodermata				
Ophiuroidea - unidentified larvae				
Unidentified echinoderm pluteus				
Appendicularia (Larvacea)				
Fritillaria sp.				
Oikopleura vanhöffeni				
Oikopleura spp.		6	< 1	
Chaetognatha				
Sagitta elegans		2	< 1	
Eukrohnia hamata		< 1		
Unidentified chaetognaths		< 1		
Ascidiacea				
Unidentified ascidians				
Pisces				
Hippoglossoides robustus eggs				
Unidentified fish larvae		< 1	2	< 1

Table 7. References used to identify zooplankton from the Beaufort Sea WEBSEC-72 samples.

General
- Barnes, R. D., 1974
- Smith, D. L., 1977
- Wing, B. L., 1974

Amphipoda
- Barnard, J. L., 1969
- Bousfield, E. L., 1979
- Gurjanova, E., 1951
- Sars, G. O., 1895
- Sars, G. O., 1900
- Tencati, J. R., 1970

Chaetognatha
- Dawson, J. K., 1971

Cnidaria
- Hartlaub, C., 1933
- Naumov, D. V., 1960
- Shirley, D. W., and Y. M. Leung, 1970
- Totton, A. K., 1965

Decapoda
- Hart, J. F. L., 1960
- Haynes, E. B., 1973
- Haynes, E. B., 1978

Euphausiacea and Mysidacea
- Banner, A. H., 1948a
- Banner, A. H., 1948b
- Banner, A. H., 1950
- Leung, Y. M., 1970
- Leung, Y. M., 1972b
- Sars, G. O., 1870
- Zimmer, C., 1933

Mollusca
- Leung, Y. M., 1971

Ostracoda
- Leung, Y. M. 1972c

Appendicularia
- Lohmann, H., 1933
- Leung, Y. M., 1972a

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by the trawl.

B. Phytoplankton

1. Chukchi Sea samples, CGC *Staten Island*, 1974

Phytoplankton standing stock samples have been analyzed for 22 stations. All species found have been recorded previously for the Chukchi Sea. Small flagellates, < 10 μm in diameter, were the most abundant organisms in samples collected near the surface and at all depths in samples collected near shore (Fig. 4). The southern limit of the ice was approximately the 40 m isobath (Fig. 3). Nearshore stations are considered to be those shallower than 40 m and were, therefore, ice free. Diatoms, especially *Nitzschia* spp. and *Thalassiosira* spp., were abundant in deeper water and at stations deeper than 40 m. Species of the genus *Chaetoceros* were more abundant at offshore stations and at depth at some nearshore stations. *Bacterosira fragilis* Gran and *Porosira glacialis* (Grun.) Jörg. were present at some stations. Dinoflagellates, especially *Gymnodinium lohmanni* Paulsen and *Peridinium* spp., were often present at nearshore ice free stations, but never comprised more than 10% of the population.

Chlorophyll *a* (Table 8) ranged from 0.37 mg m^{-3} at station 14-0 to 25.16 mg m^{-3} at station 15-20. Highest chlorophyll values occurred at depth and generally where diatoms were the most abundant organisms.

Cell numbers ranged from 6 x 10^6 cells per liter at station 2-10 to 8.6 x 10^6 cells per liter at station 15-20. A small organism, tentatively identified as *Pelagococcus subviridis* Norris comprised about 50% of the cells at station 2-10. Sixty-three percent of the cells at station 15-20 were species of the genus *Chaetoceros*; other diatom species comprised 18% of the total number of cells.

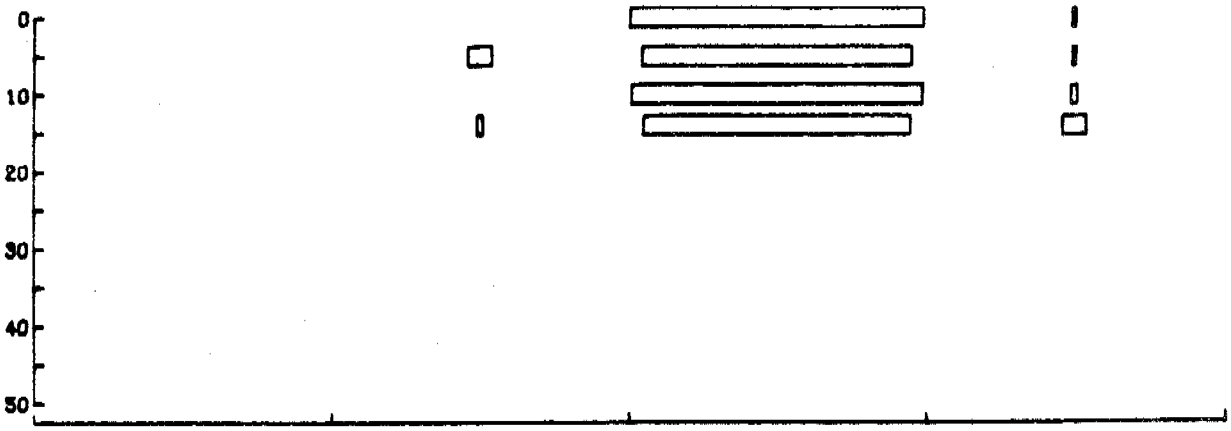
Vertical profiles showing temperature, salinity, chlorophyll *a*, and standing stock are given in Fig. 5.

References used to identify the phytoplankton include Hustedt (1930, 1959-62); Schiller (1933-37); and Hendey (1964).

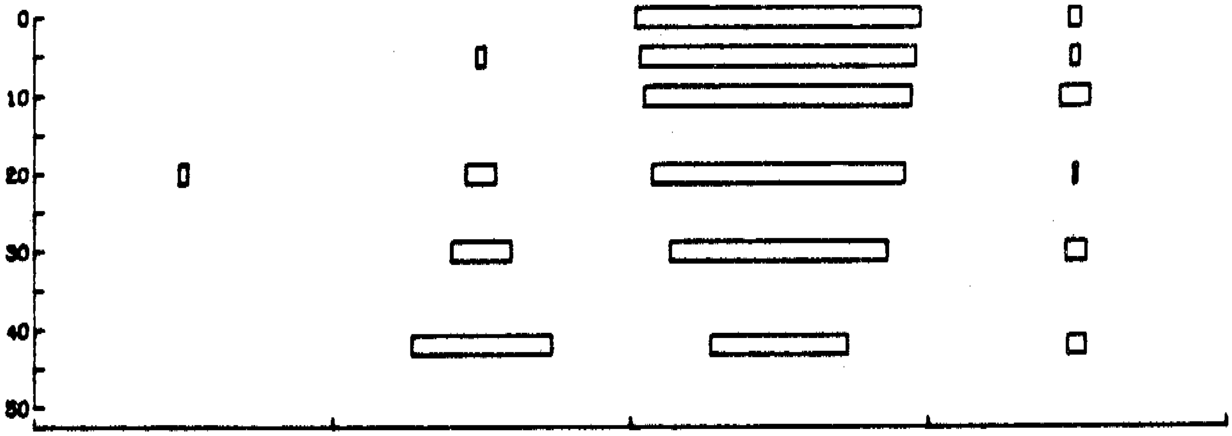
2. Stefansson Sound winter samples, 1978-79

Phytoplankton levels in the water column in Stefansson Sound were low during the winter period (Tables 9 and 10). In November, 1978, unidentified flagellates, mostly < 6 μm in diameter, were the most common organisms. A few diatoms, including spores of *Chaetoceros* spp. and cells of *Navicula* spp. and *Nitzschia* spp., were also present. Although the diatoms contained chloroplasts, they did not appear to be healthy. Chlorophyll *a* levels were barely detectable.

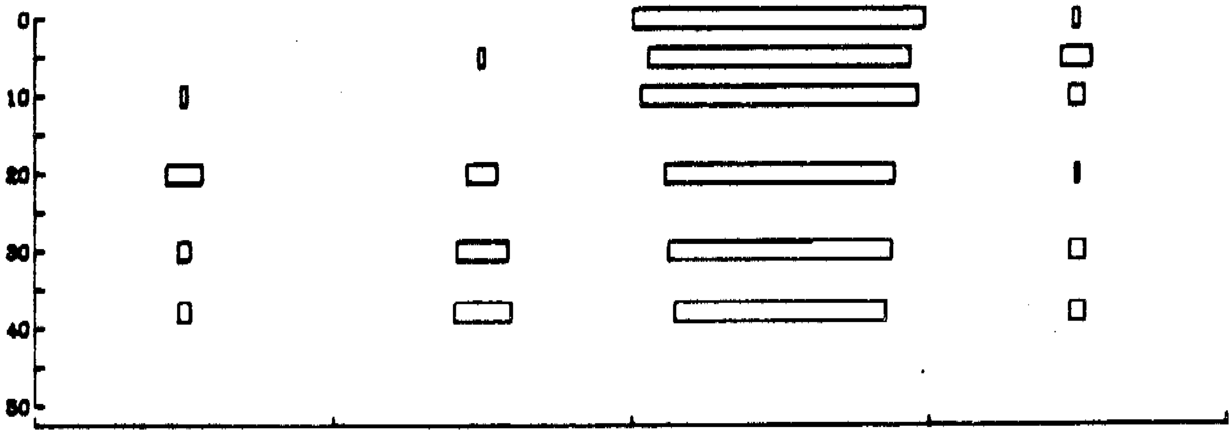
Phytoplankton levels remained low in February and March with unidentified small flagellates being the most numerous organisms. A few pennate diatoms were also present. In February, there were many small detritus particles in the water sample collected from just beneath the ice (0 m) which made phytoplankton counting difficult. The detritus particles probably



Station 1



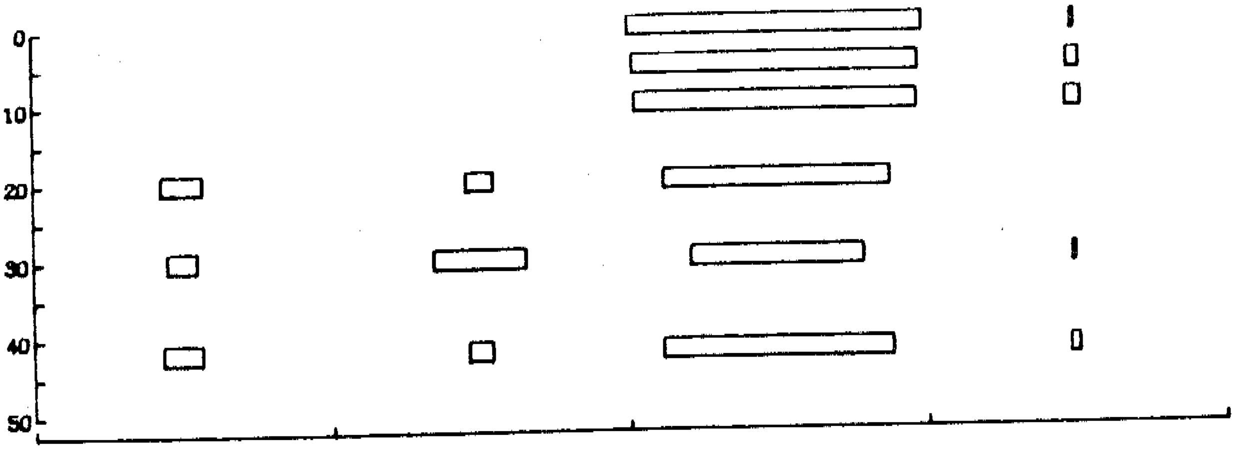
Station 2



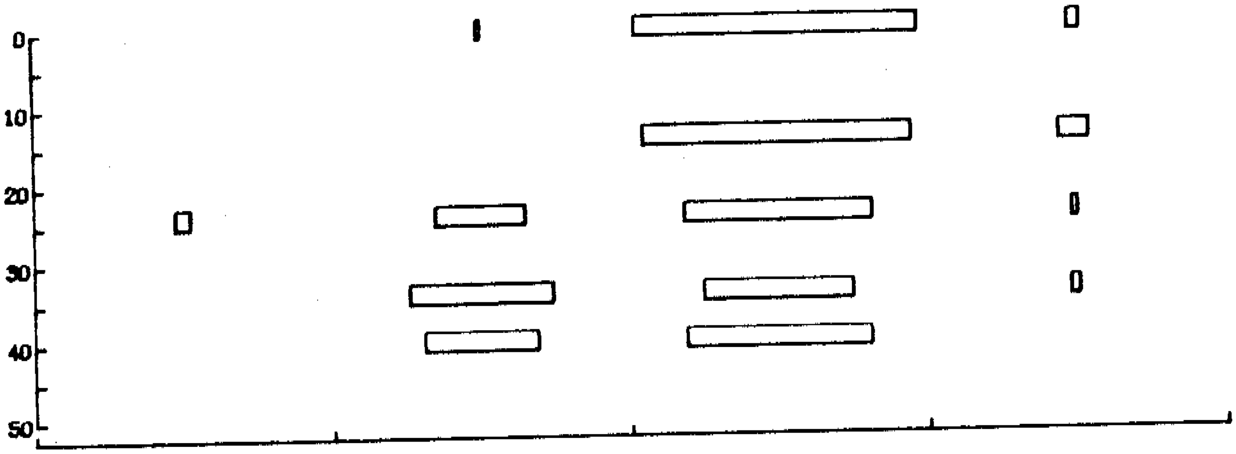
Station 3

Chaetoceros All Other Diatoms Flagellates Dinoflagellates

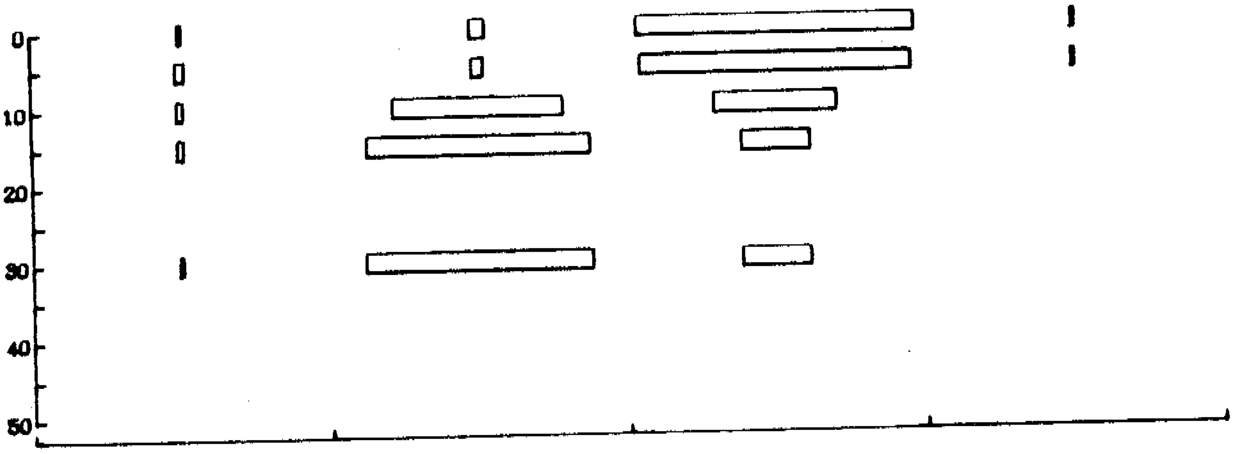
Fig. 4. Percentage of phytoplankton by major category by depth for each station. Where no number is present, no cells were found. Percentages add up to 100% running from left to right across the diagram.



Station 4



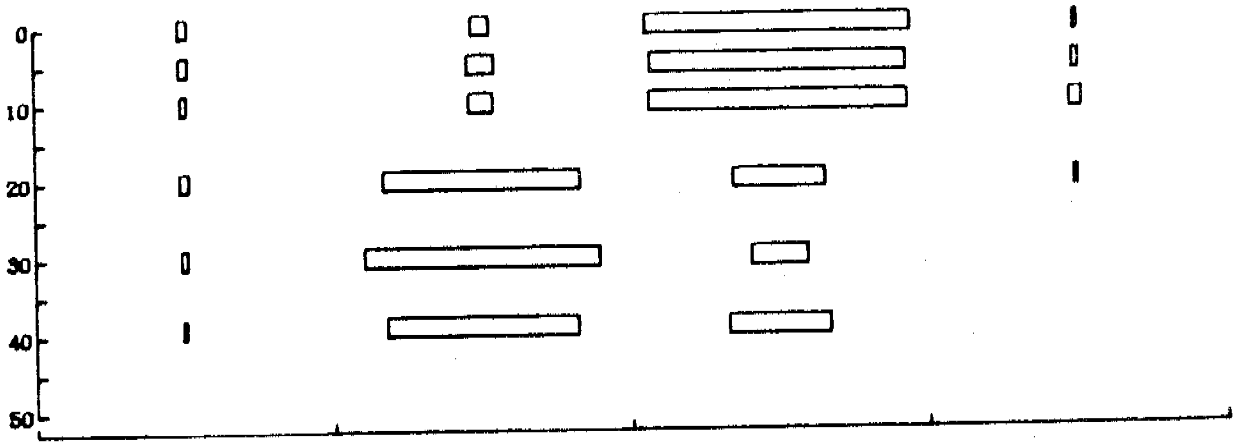
Station 5



Station 6

Chaetoceros All Other Diatoms Flagellates Dinoflagellates

Fig. 4 (continued)



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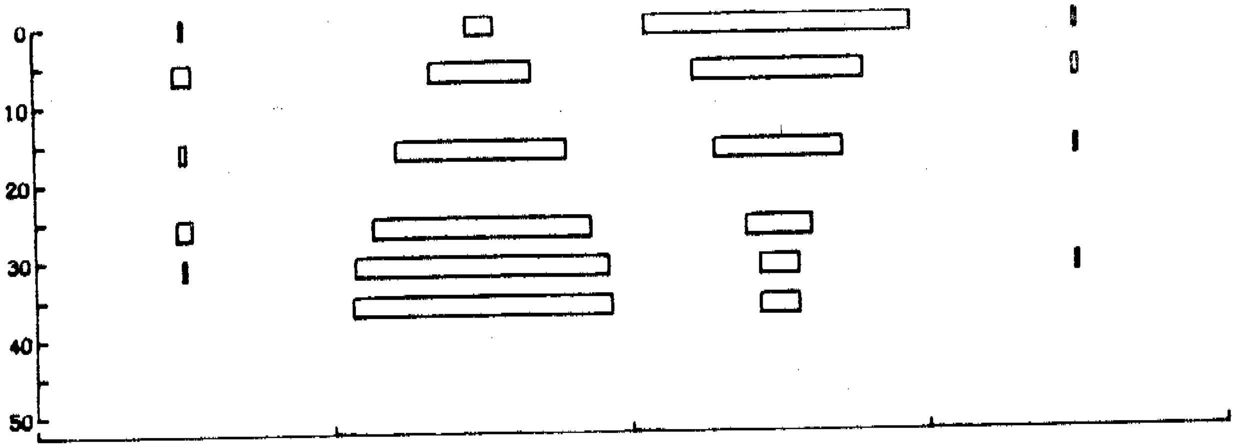
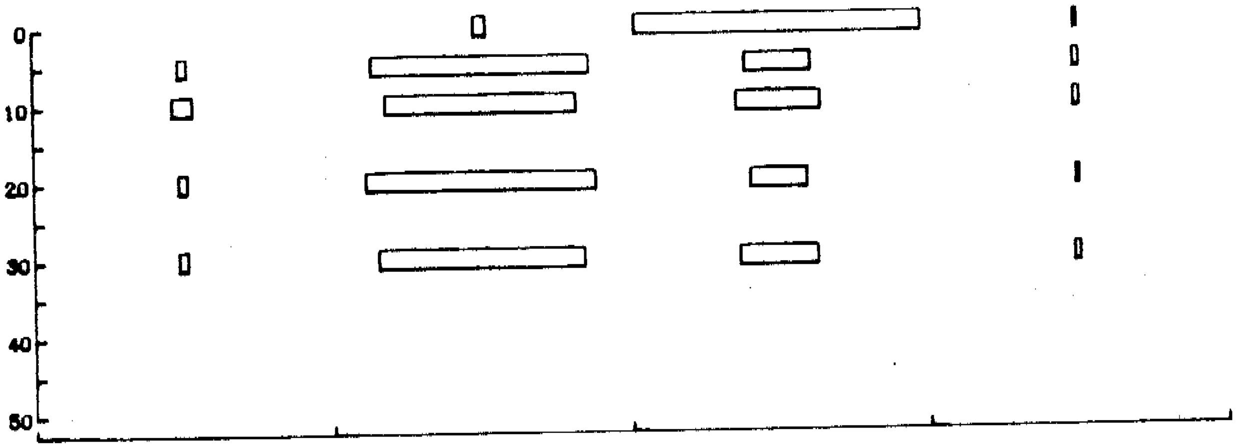


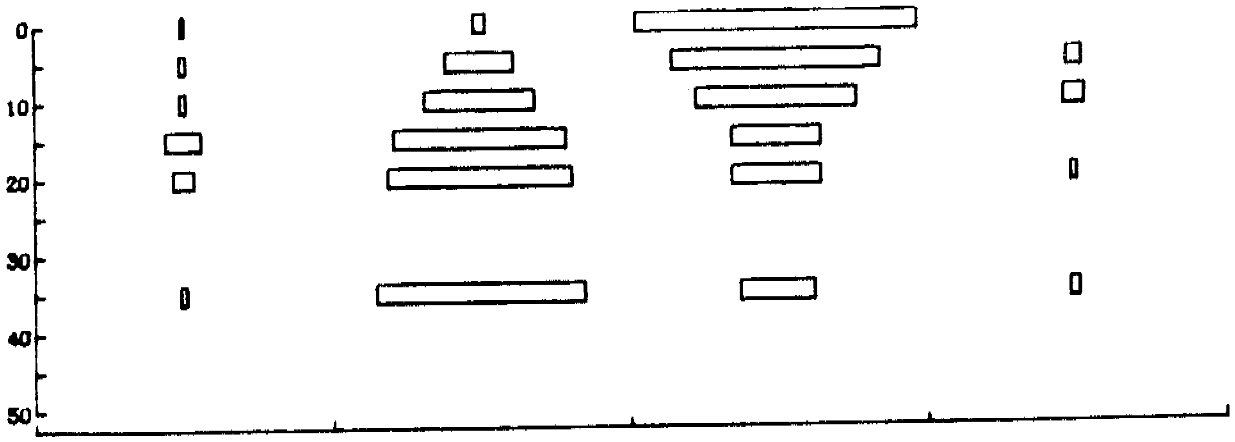
Station 8



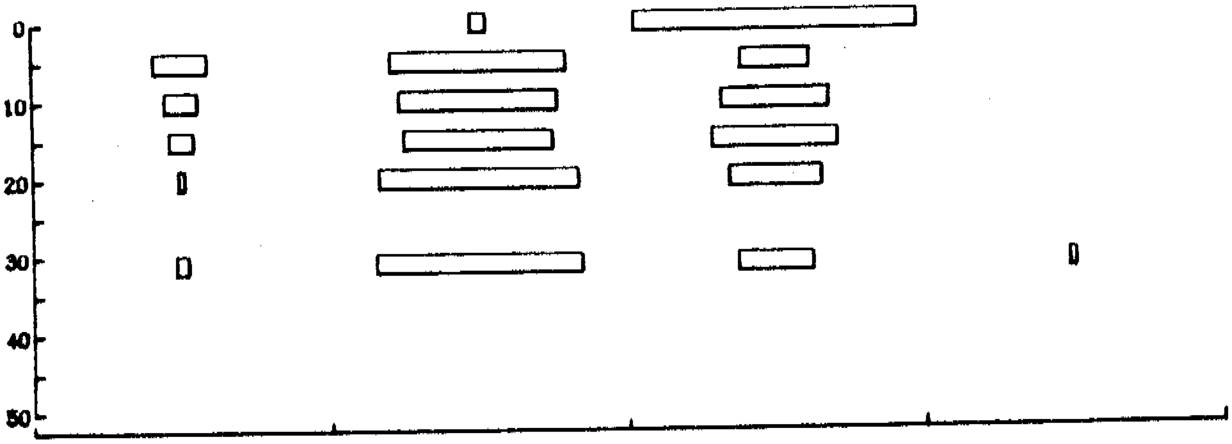
Station 9

Chaetoceros All Other Diatoms Flagellates Dinoflagellates

Fig. 4. (continued)



Station 10



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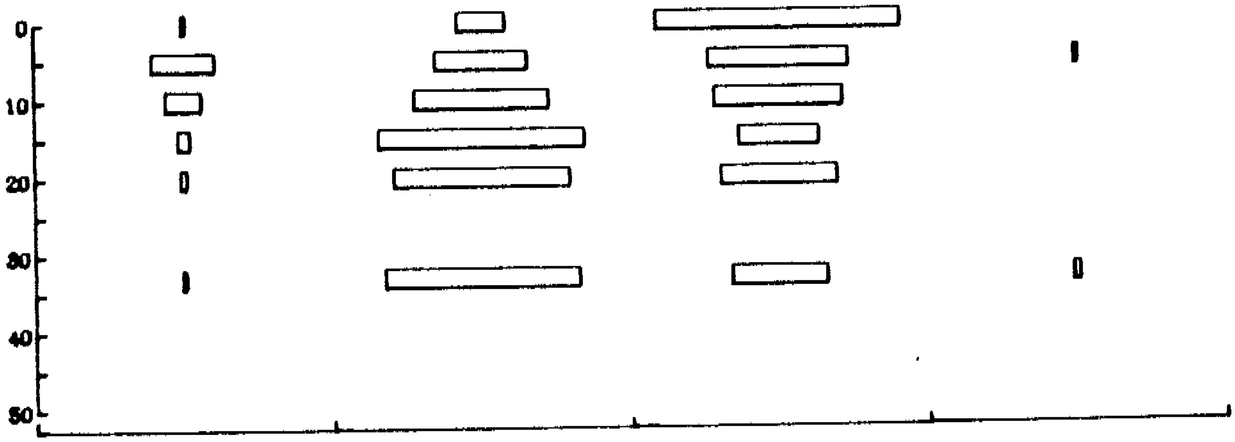
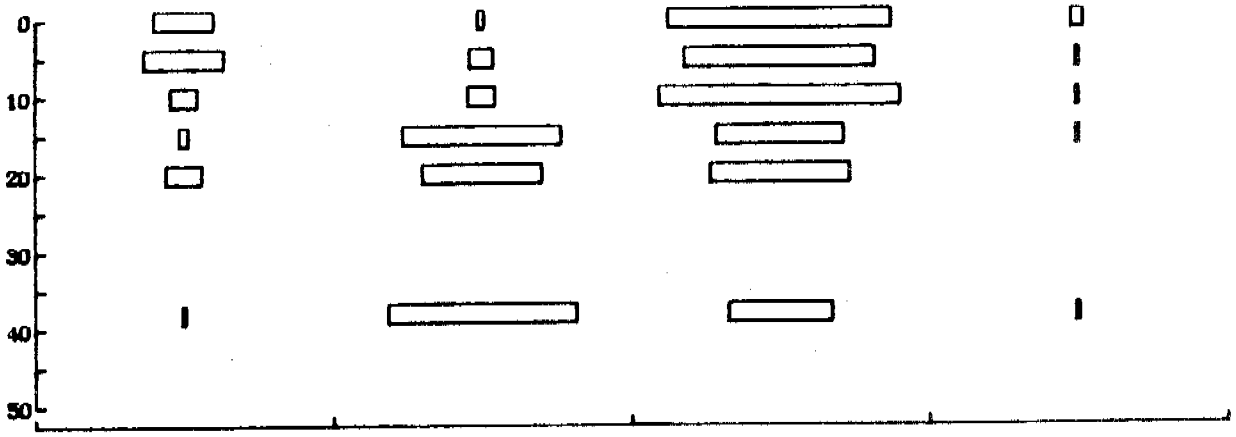


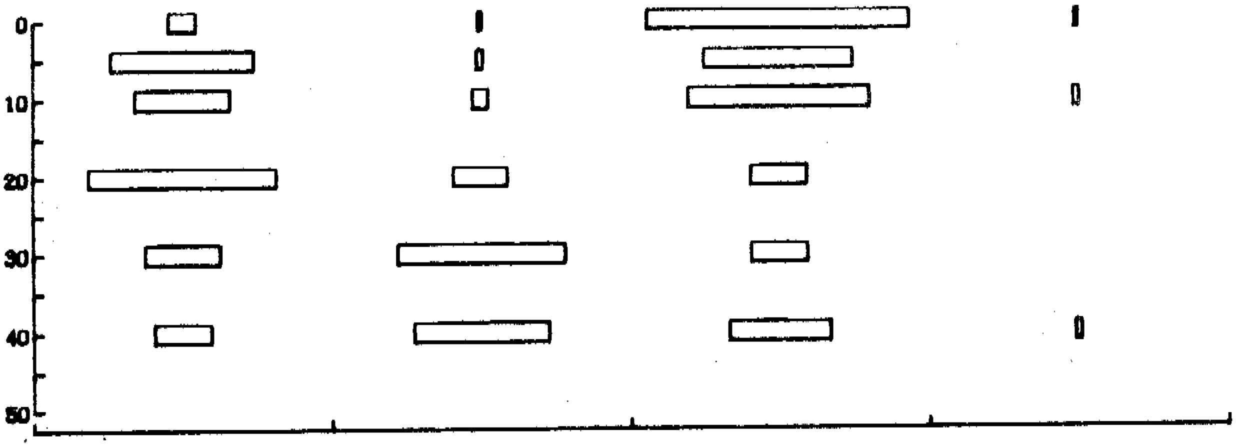
Station 12

Chaetoceros All Other Diatoms Flagellates Dinoflagellates

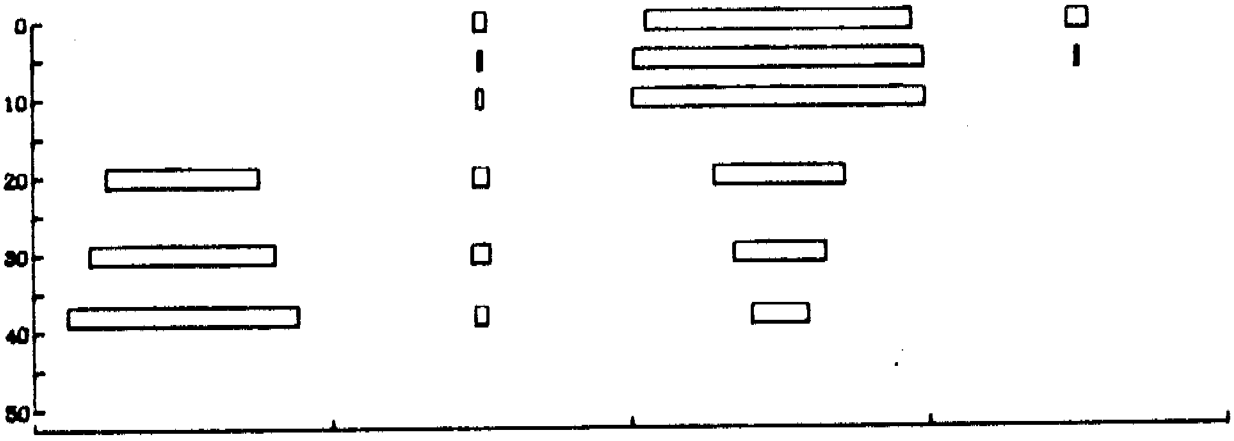
Fig. 4. (continued)



Station 14

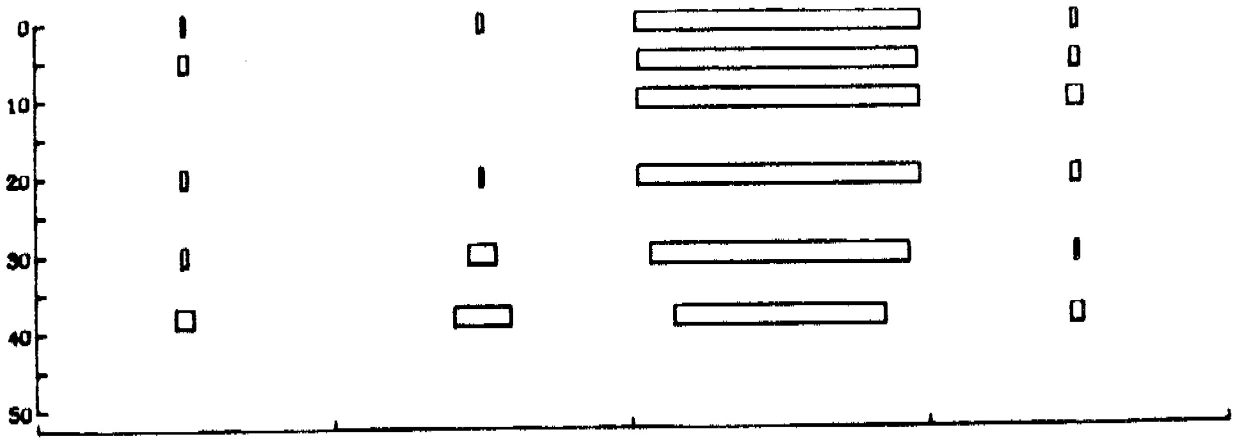


Station 15



Station 16

Fig. 4. (continued)



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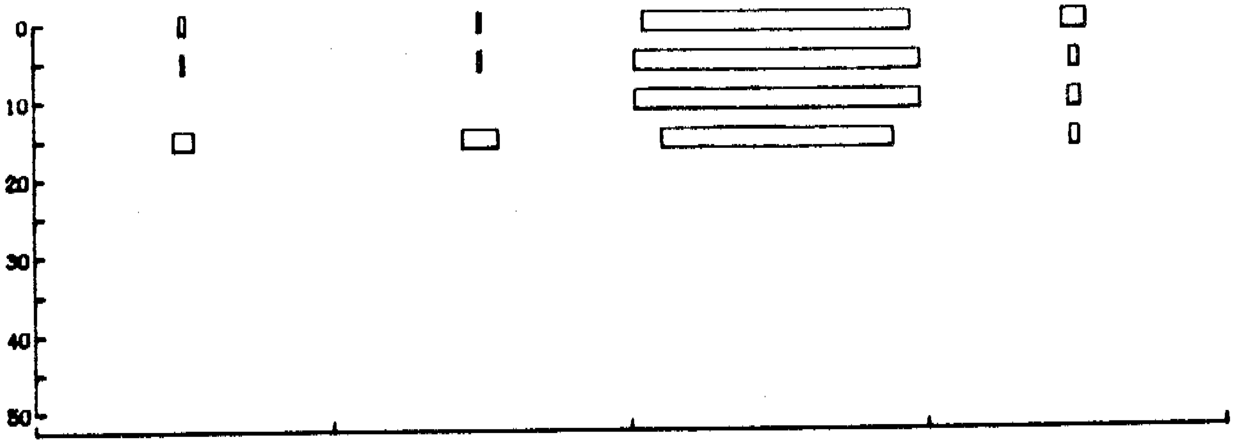
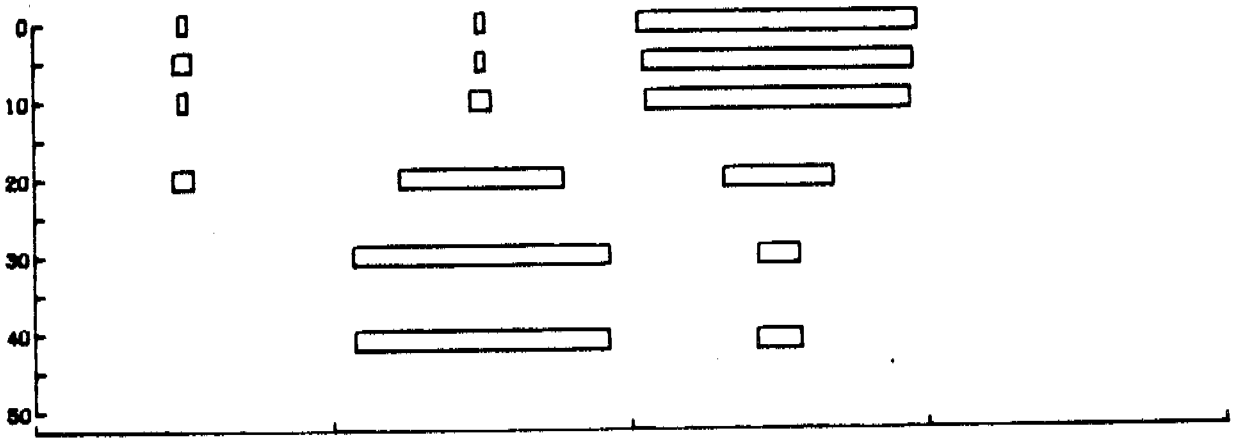
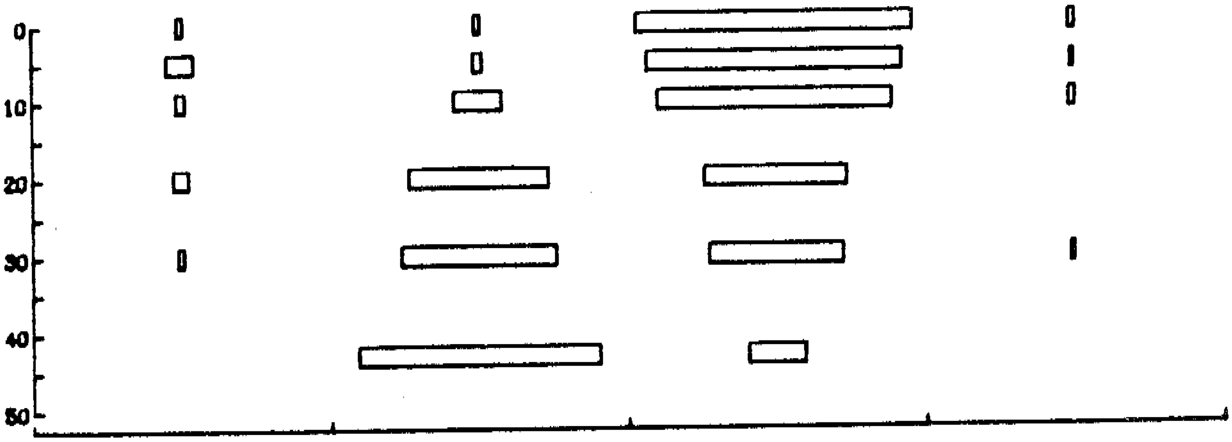


Station 20

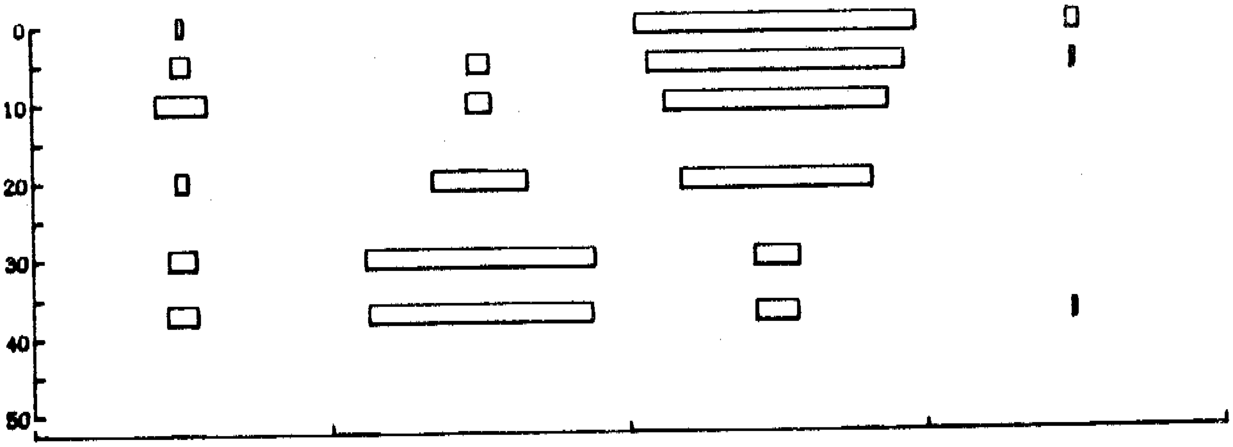


Station 27

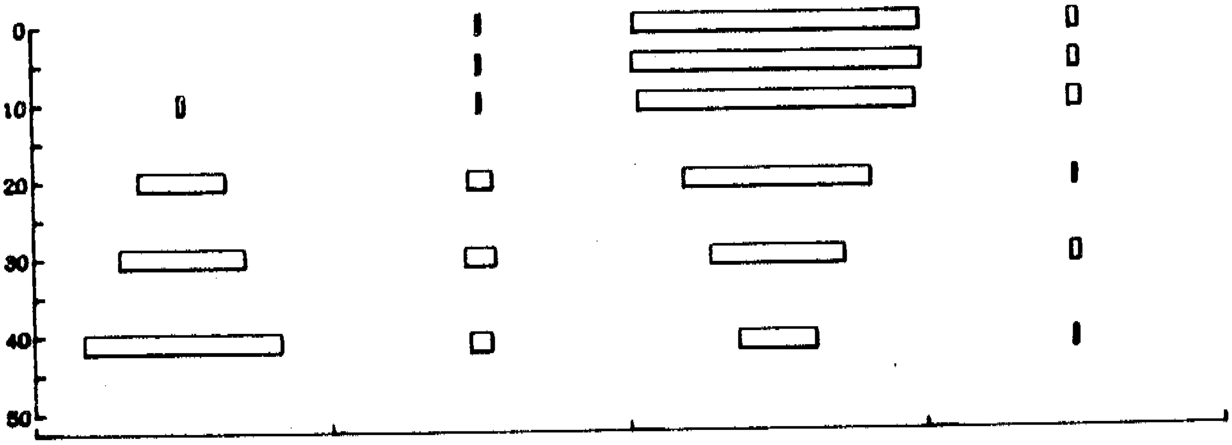
Fig. 4. (continued)



Station 28



Station 29



Station 30

Chaetoceros All Other Diatoms Flagellates Dinoflagellates

Fig. 4. (continued)

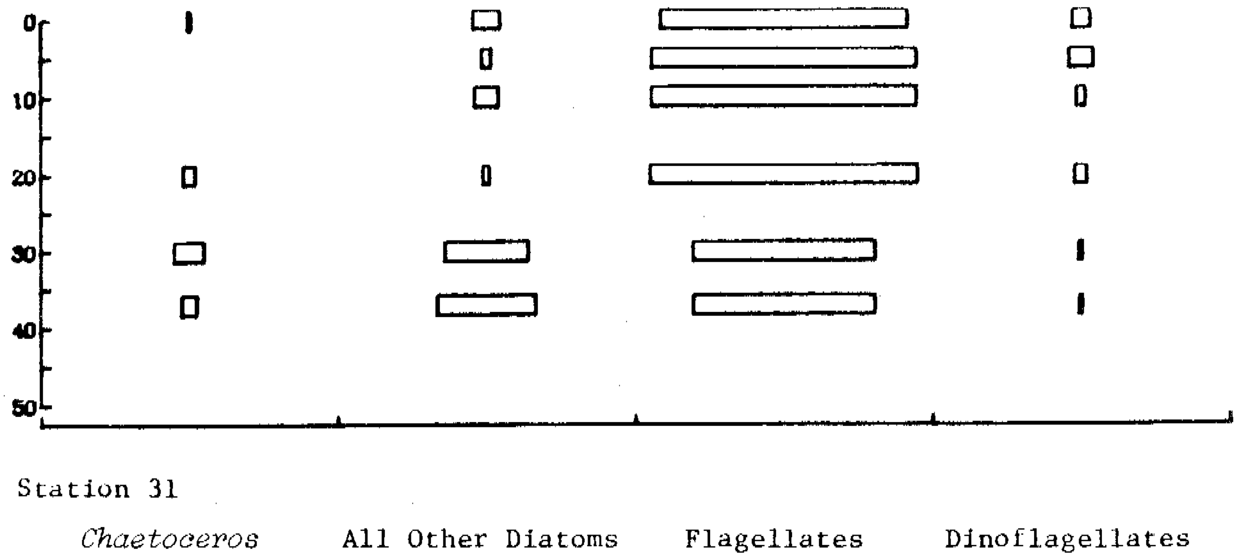


Fig. 4. (continued)

Table 8. Summary of station locations, hydrography, and chlorophyll *a* concentrations in the Chukchi Sea between Icy Cape and Point Barrow, CGC *Staten Island*, 7 - 15 Aug 1974.

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
01	000	7 Aug	70°31'	161°58'	7.32	30.188	0.97
	007				7.30	30.188	0.83
	010				6.62	30.640	0.87
	014				4.95	31.778	0.91
02	000	7 Aug	70°40.6'	162°17.5'	0.60	28.374	0.87
	005				1.44	28.975	0.69
	010				0.00	30.286	0.62
	020				-1.21	32.316	1.32
	030				-1.42	32.625	7.42
	042						7.96
03	000	7 Aug	70°49.7'	162°30.9'	0.60	27.860	0.82
	005				2.10	28.025	0.66
	010				0.01	31.241	1.32
	020				-1.46	32.361	4.05
	030				-1.65	32.832	9.05
	038						10.59
04	000	8 Aug	70°58'	162°39'	0.59	27.372	0.94
	005				0.40	28.591	1.00
	010				-0.90	30.191	1.28
	020				-1.46	32.403	2.30
	030				-1.70	33.083	7.89
	042				-1.68	33.126	4.04

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
05	000	8 Aug	71°08.0'	163°00.0'	0.37	26.542	0.95
	014				-1.11	30.433	1.23
	024				-1.49	32.321	2.19
	034				-1.74	33.278	2.82
	039				-1.71	33.298	4.51
06	000	8 Aug	71°16.9'	163°16.4'	0.70	22.574	0.95
	005				-0.60	30.547	1.01
	010				-1.14	31.61	2.10
	020				-1.67	32.92	7.72
	030				-1.75	33.32	4.90
07	000	8 Aug	71°24.1'	163°29.4'	0.57	25.117	0.74
	005				-0.66	30.707	0.69
	010				-1.23	31.821	0.52
	020				-1.70	33.098	8.65
	030				-1.77	33.325	3.79
	039				-1.75	33.367	2.54
08	000	8 Aug	71°32.0'	163°44'	0.80	17.499	1.06
	006				-1.16	31.382	1.22
	016				-1.39	31.974	3.01
	026				-1.70	32.810	15.03
	031				-1.77	33.255	3.79
	036				-1.76	33.324	4.05
09	000	8 Aug	71°40.6'	164°06'	1.53	6.511	0.99
	005				-1.36	31.959	4.27
	010				-1.53	32.232	9.02
	020				-1.67	32.915	12.84
	030				-1.77	33.372	3.45

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
10	000	8 Aug	71°53.4'	164°18.6'	0.83	6.951	1.06
	005				-1.15	30.930	0.74
	010				-1.30	31.908	1.19
	015				-0.60	32.327	5.97
	020				-1.65	32.875	7.10
	035				-1.72		3.90
11	000	8 Aug	71°43'	163°33'	-0.61	25.787	1.19
	005				-1.28	31.870	3.50
	010				-1.49	32.209	8.39
	015				-1.62	32.499	14.33
	020				-1.71	33.228	12.73
	031				-1.75	33.390	3.98
12	000	8 Aug	71°36'	163°17.5'	-0.50	24.752	1.34
	005				-1.13	31.415	1.98
	010				-1.54	32.355	7.00
	015				-1.63	32.553	19.07
	020				-1.68	33.147	11.21
	033				-1.74	33.284	3.74
13	000	8 Aug	71°23.7'	163°02.2'	-0.76	25.535	0.72
	005				-1.19	31.611	0.75
	015				-1.55		0.39
	025				-1.72	33.285	5.10
	039				-1.75	33.298	4.00

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/oo)	Chl *a* (mg m^{-3})
14	000	8 Aug	71°19'	162°41'	0.78	24.970	0.37
	005				-0.21	30.430	0.44
	010				-1.20	31.646	0.42
	015				-1.53	32.279	1.07
	020				-1.72	32.884	18.32
	038				-1.75	33.375	3.99
15	000	9 Aug	71°09.3'	162°31.7'	0.51	25.721	0.42
	005				-0.67	29.549	0.82
	010				-1.14	30.661	0.97
	020				-1.63	32.745	25.16
	030				-1.72	33.340	3.97
	040				-1.74	33.361	4.47
16	000	9 Aug	71°01.5'	162°16.8'	-0.15	27.107	0.54
	005				-0.15	28.748	0.53
	010				-0.97	30.043	0.85
	020				-1.54	32.505	2.55
	030				-1.68	33.168	2.65
	038				-1.70	33.162	2.92
17	000	9 Aug	70°53'	161°59'	2.39	27.763	0.60
	005				0.08	29.380	0.53
	010				-0.76	31.334	1.19
	020				-1.55	32.583	3.90
	030				-1.62	32.866	10.06
	038				-1.63	32.880	10.13

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m⁻³)
18	000	9 Aug	70°43'	161°45'	3.15	27.779	0.77
	005				0.94	28.860	0.47
	010				-0.45	30.731	0.53
	020				-1.20	32.375	0.61
	030				-1.41	32.658	10.09
	038				-1.44	32.662	9.16
19	000	9 Aug	70°34.2'	161°26.3'	6.62	29.929	0.89
	005				7.03	30.113	0.68
	010				4.90	31.494	0.70
	015				1.40	32.150	1.07
	020				1.27	32.19	0.96
20	000	9 Aug	70°27.5'	161°17'	6.58	31.085	0.70
	005				6.61	31.084	0.57
	010				5.95	31.332	0.67
	015				4.98	31.993	1.73
21	000	9 Aug	70°30'	160°39'	6.77	30.106	0.54
	005				6.83	30.106	0.58
	010				6.04	30.388	0.51
	012				6.43	31.226	0.52
22	000	9 Aug	70°38.5'	160°59'	6.50	29.876	0.55
	005				6.64	29.951	0.51
	010				0.19	31.442	0.68
	015				0.23	32.408	1.09
	020				0.29	32.413	1.15
	027				0.29	32.413	1.19

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
23	000	9 Aug	70°46.8'	161°10.7'	3.75	28.426	0.72
	005				1.71	28.928	0.44
	010				0.46	30.045	0.47
	020				-1.08	32.228	4.07
	030				-1.47	32.704	5.08
	037				-1.50	32.707	4.93
24	000	9 Aug	70°56.6'	161°27.2'	0.97	27.417	0.53
	005				0.15	28.936	0.58
	010				-0.98	30.527	1.08
	020				-1.52	32.410	2.11
	030				-1.64	33.068	6.86
	038				-1.66	33.065	7.15
25	000	9 Aug	71°04'	161°42'	0.38	26.909	0.87
	005				-0.43	28.639	0.59
	015				-1.46	32.222	1.07
	025				-1.72	33.226	3.89
	039				-1.73	33.252	3.23
26	000	9 Aug	71°14.4'	161°57.2'	0.23	24.537	0.50
	003				-0.24	29.266	0.65
	008				-1.07	31.519	0.52
	018				-1.60	32.665	3.43
	028				-1.73	33.317	4.29
	041				-1.75	33.417	4.13

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/oo)	Chl a (mg m^{-3})
27	000	9 Aug	71°20.2'	161°32.9'	0.22	19.772	0.72
	005				-0.76	30.803	0.40
	010				-1.26	31.593	0.52
	020				-1.63	32.820	18.52
	030				-1.72	33.287	3.40
	041				-1.74	33.285	3.61
28	000	10 Aug	71°10.5'	161°20.4'	0.81	25.335	0.50
	005				-0.65	30.038	0.43
	010				-1.22	31.744	0.53
	020				-1.58	32.671	6.97
	030				-1.73	33.386	3.93
	043				-1.75	33.426	4.46
29	000	10 Aug	71°04.5'	161°11.2'	0.55	25.809	0.64
	005				-0.37	29.113	0.46
	010				-0.94	31.294	0.52
	020				-1.55	32.763	0.86
	030				-1.73	33.402	5.51
	037				-1.75	33.399	4.30
30	000	10 Aug	70°53.7'	160°48.5'	2.07	27.529	0.58
	005				0.80	28.329	0.42
	010				-0.95	30.201	0.54
	020				-1.52	32.552	2.65
	030				-1.64	33.075	6.53
	041				-1.66	33.075	6.62

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
31	000	10 Aug	70°45'	160°34'	3.07	28.723	0.54
	005				2.78	28.860	0.38
	010				0.00	30.334	0.39
	020				-1.03	32.351	0.74
	030				-1.09	32.618	2.90
	037				-1.09	32.619	2.61
32	000	10 Aug	70°36.0'	160°19.0'	6.57	29.818	0.78
	005				5.19	30.258	0.86
	010				5.05	31.795	1.72
	017				5.05	31.794	1.89
35	000	10 Aug	71°00.5'	160°21.8'	0.29	26.704	0.99
	010				-0.99	31.488	0.53
	020				-1.51	32.404	3.43
	030				-1.71	33.232	8.72
	040				-1.71	33.236	7.86
	049				-1.72	33.234	9.68
36	000	10 Aug	71°10.8'	160°39.5'	-0.03	27.308	0.89
	005				-0.74	30.229	0.71
	010				-1.16	31.732	0.82
	020				-1.64	32.826	7.64
	030				-1.72	33.262	3.74
	040				-1.75	33.389	3.36

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
37	000	10 Aug	71°17.4'	160°48'	-0.56	29.214	0.91
	005				-1.04	31.364	0.77
	010				-1.18	31.856	0.78
	020				-1.59	32.651	17.76
	030				-1.72	33.236	2.63
	043				-1.74	33.288	4.33
38	000	10 Aug	71°28'	161°10'	-1.03	29.243	1.14
	005				-1.36	31.278	1.53
	010				-1.41	31.643	1.96
	020				-1.64	32.571	7.34
	030				-1.73	33.228	2.07
	041				-1.74	33.284	3.00
39	000	11 Aug	71°32.9'	160°49.8'	-0.54	21.280	1.52
	005				-1.27	30.539	1.03
	010				-1.32	30.809	1.59
	020				-1.56	31.772	7.61
	030				-1.72	32.700	5.09
	041				-1.73	33.163	2.64
40	000	11 Aug	71°25.8'	160°33.6'	-0.16	6.845	1.26
	005				-1.34	30.205	0.90
	010				-1.31	30.634	1.35
	020				-1.56	31.827	6.31
	030				-1.72	32.968	2.93
	039				-1.74	33.149	2.40

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl a (mg m^{-3})
41	000	11 Aug	71°15.8'	160°17.9'	-1.12	29.263	0.80
	005				-1.17	29.741	0.94
	010				-1.25	31.137	0.96
	020				-1.47	32.000	2.16
	046				-1.73	33.245	4.41
42	000	11 Aug	71°08.5'	160°06.3'	-0.29	26.111	1.11
	010				-1.24	31.585	0.66
	020				-1.54	32.237	2.22
	030				-1.70	33.128	9.27
	040				-1.73	33.349	3.50
	052				-1.75	33.360	3.47
43	000	11 Aug	70°58.0'	159°44'	2.56	28.166	0.59
	005				2.54	28.166	0.53
	010				-0.38	29.707	0.74
	020				-0.93	32.344	1.31
	030				-0.78	32.371	1.37
	047				-0.84	32.387	1.24
46	000	11 Aug	71°03.9'	159°12.3'	0.02	27.043	0.87
	010				-0.90	30.58	0.71
	020				-1.21	32.51	3.49
	030				-1.23	32.53	3.78
	050				-1.26	32.57	4.42
	076				-1.55	32.815	6.28

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl a (mg m^{-3})
47	000	11 Aug	71°11'	159°36'	-1.22	28.908	1.09
	010				-1.28	30.789	1.57
	020				-1.49	31.646	3.12
	030				-1.65	32.355	5.12
	050				-1.73	33.212	3.74
	070				-1.75	33.334	4.29
48	000	11 Aug	71°25'	159°22'	-0.76	26.754	0.63
	010				-1.37	30.278	1.62
	020				-1.43	31.078	3.99
	030				-1.68	31.904	5.38
	040				-1.70	32.137	1.36
	045				-1.73	32.556	1.44
49	000	12 Aug	71°11.7'	158°49.8'	-0.49	25.539	0.70
	010				-1.16	29.890	0.75
	025					31.694	1.72
	050				-1.72	33.216	6.33
	075				-1.72	33.279	8.27
	093				-1.73	33.283	7.55
54	000	12 Aug	71°13'	158°24'	-0.23	27.281	0.75
	010				-0.55	30.199	0.78
	025				-1.43	32.459	2.49
	050				-1.52	32.727	6.26
	075				-1.54	32.801	6.53
	090				-1.62	32.959	7.29

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
55	000	12 Aug	71°22'	158°32'	-0.70	26.746	0.50
	010				-1.34	29.473	0.68
	020				-1.50	30.742	1.65
	030				-1.53	31.412	3.21
	040				-1.67	31.849	4.65
	050				-1.73	32.667	1.81
58	000	13 Aug	71°20'	157°58'	-0.30	27.157	0.89
	010				-0.71	29.684	0.92
	025				-1.45	31.918	3.95
	050				-1.70	33.164	5.96
	075				-1.69	33.182	6.23
	110				-1.71	33.195	8.06
59	000	13 Aug	71°30.9'	158°21.5'	-0.54	27.285	0.91
	010				-0.89	29.393	0.95
	020				-1.04	31.075	2.91
	030				-1.67	31.603	2.50
	040				-1.66	31.788	0.72
	054				-1.71	32.110	1.46
60	000	13 Aug	71°37.6'	158°31.8'	-0.47	27.019	0.69
	010				-1.53	30.099	2.89
	020				-1.59	30.705	2.85
	030				-1.65	31.229	3.73
	040				-1.64	31.632	3.94
	050				-1.72	32.281	0.85

Table 8. (continued)

Sta	Depth (m)	Date	Latitude (N)	Longitude (W)	Temperature (°C)	Salinity (°/₀₀)	Chl *a* (mg m^{-3})
61	000	13 Aug	71°43'	158°10.9'	-0.13	23.780	1.10
	010				-1.04	28.45	0.70
	020				-1.54	30.943	6.40
	030				-1.62	31.253	2.49
	040				-1.68	31.835	5.43
	050				-1.72	32.121	1.57

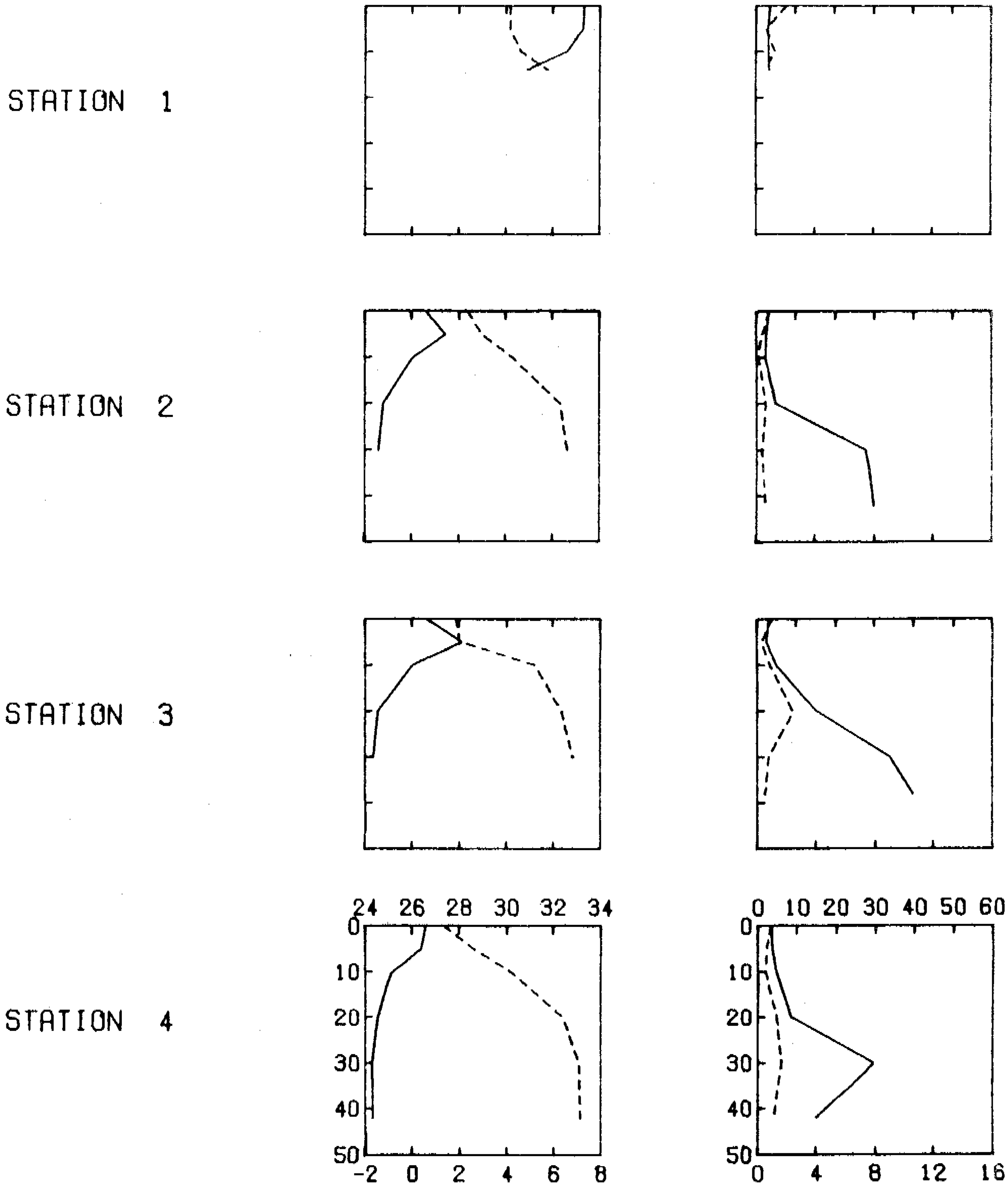


Fig. 5. Depth profiles of temperature-salinity and chlorophyll *a*-standing stock in the Chukchi Sea, 7 - 15 Aug 1974. Salinity (°/oo) ---; temperature (°C)___; standing stock (number of cells per liter) ---; chlorophyll *a* (mg m^{-3}) ___.

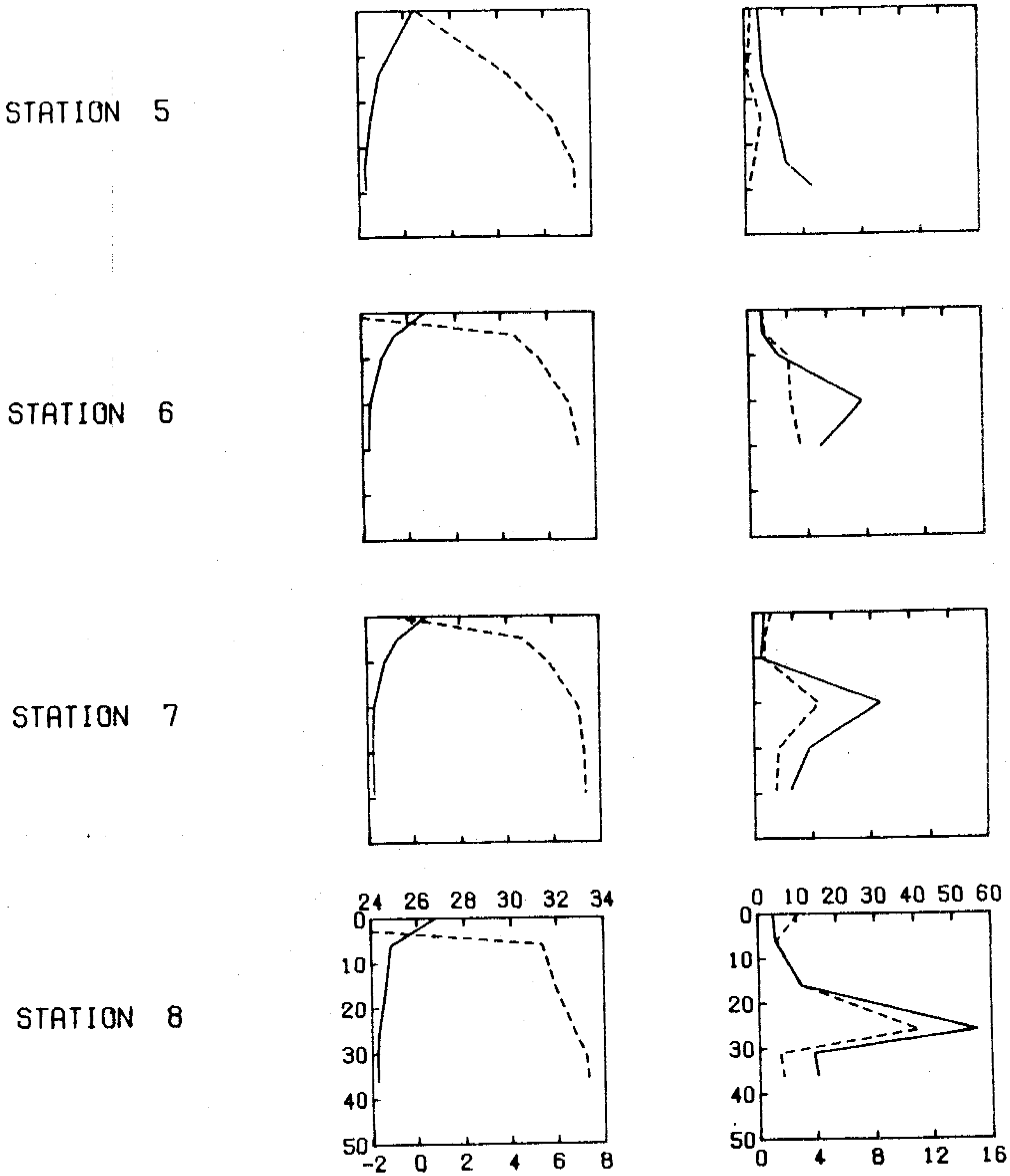


Fig. 5. (continued)

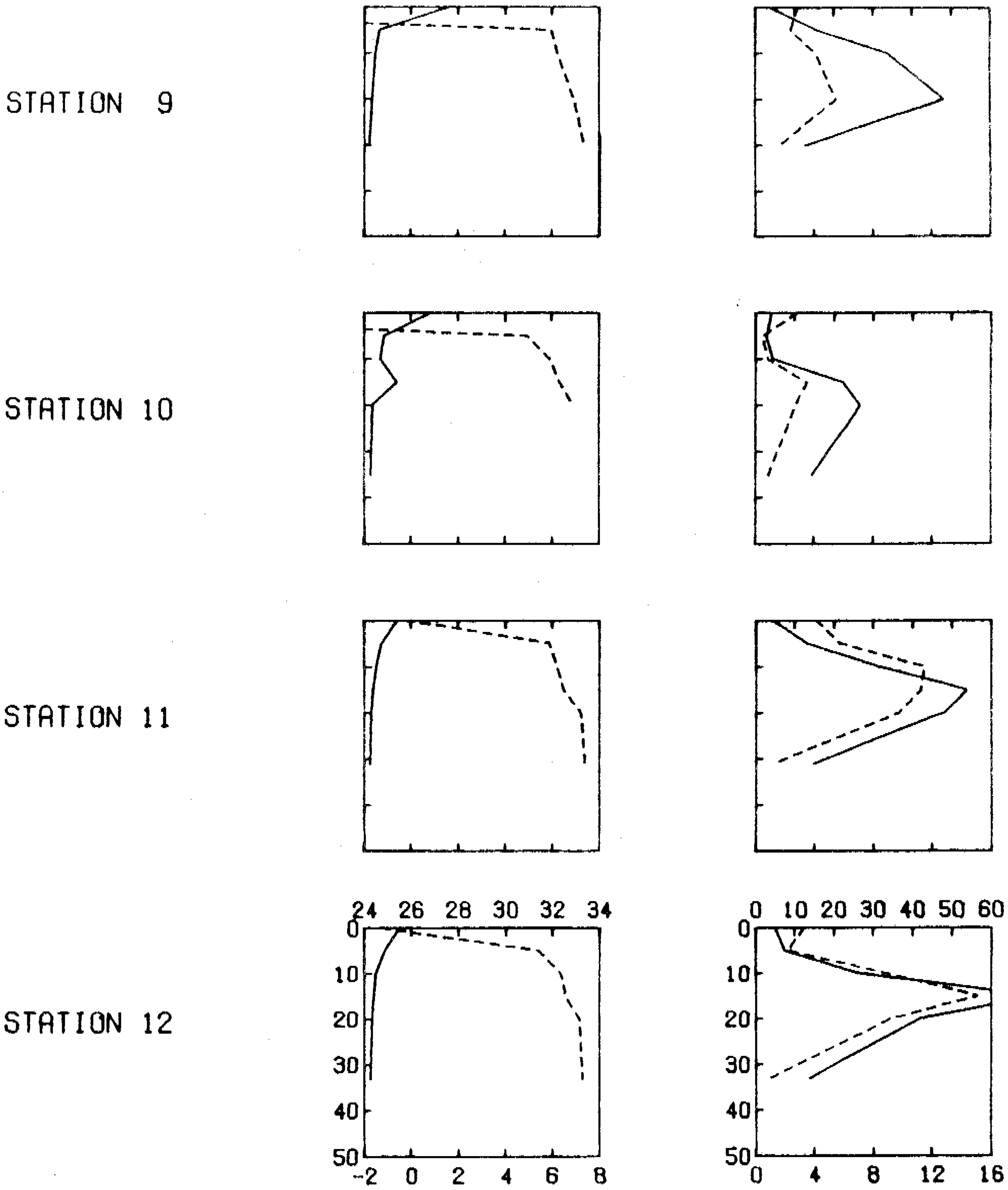


Fig. 5. (continued)

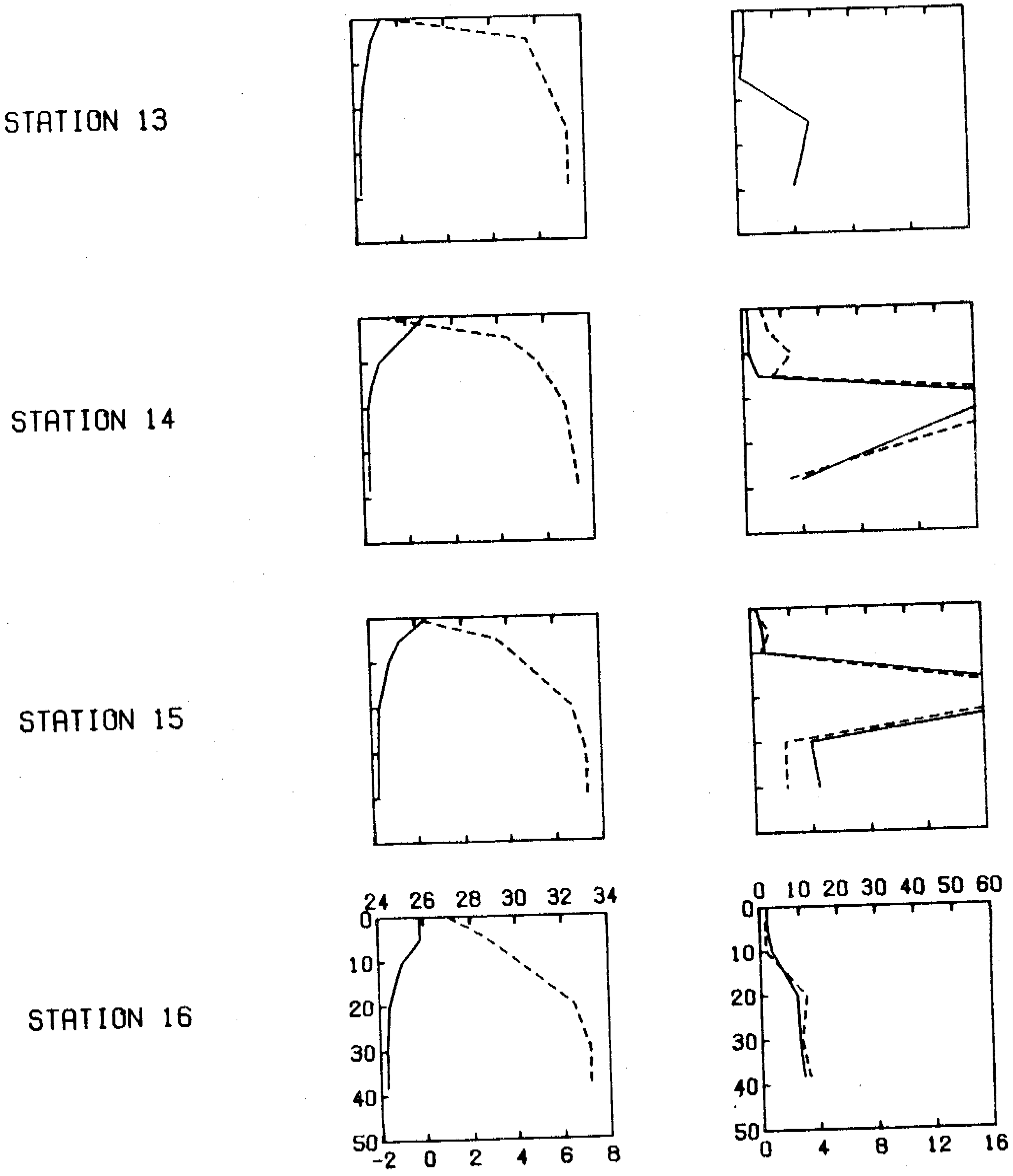


Fig. 5. (continued)

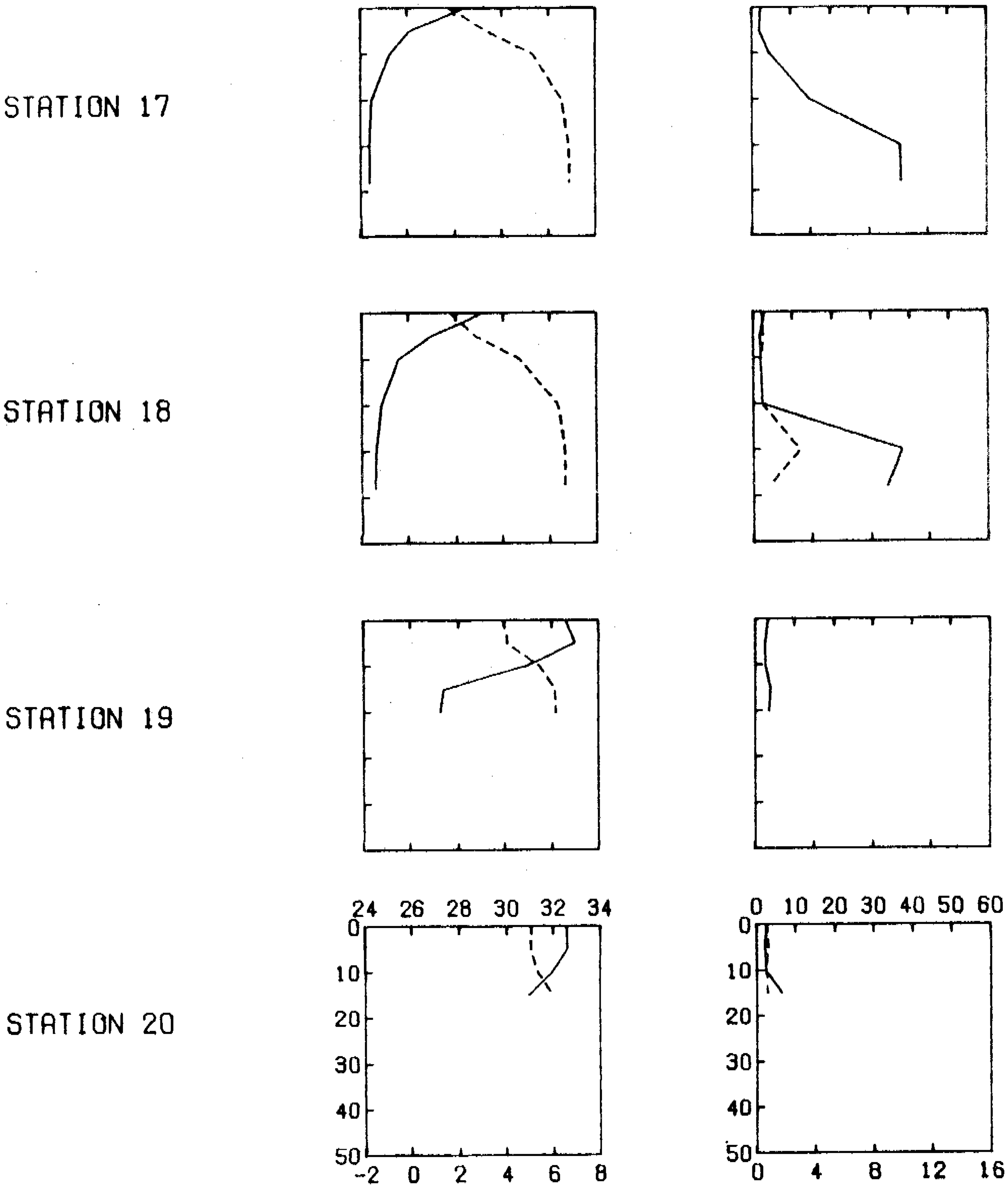


Fig. 5. (continued)

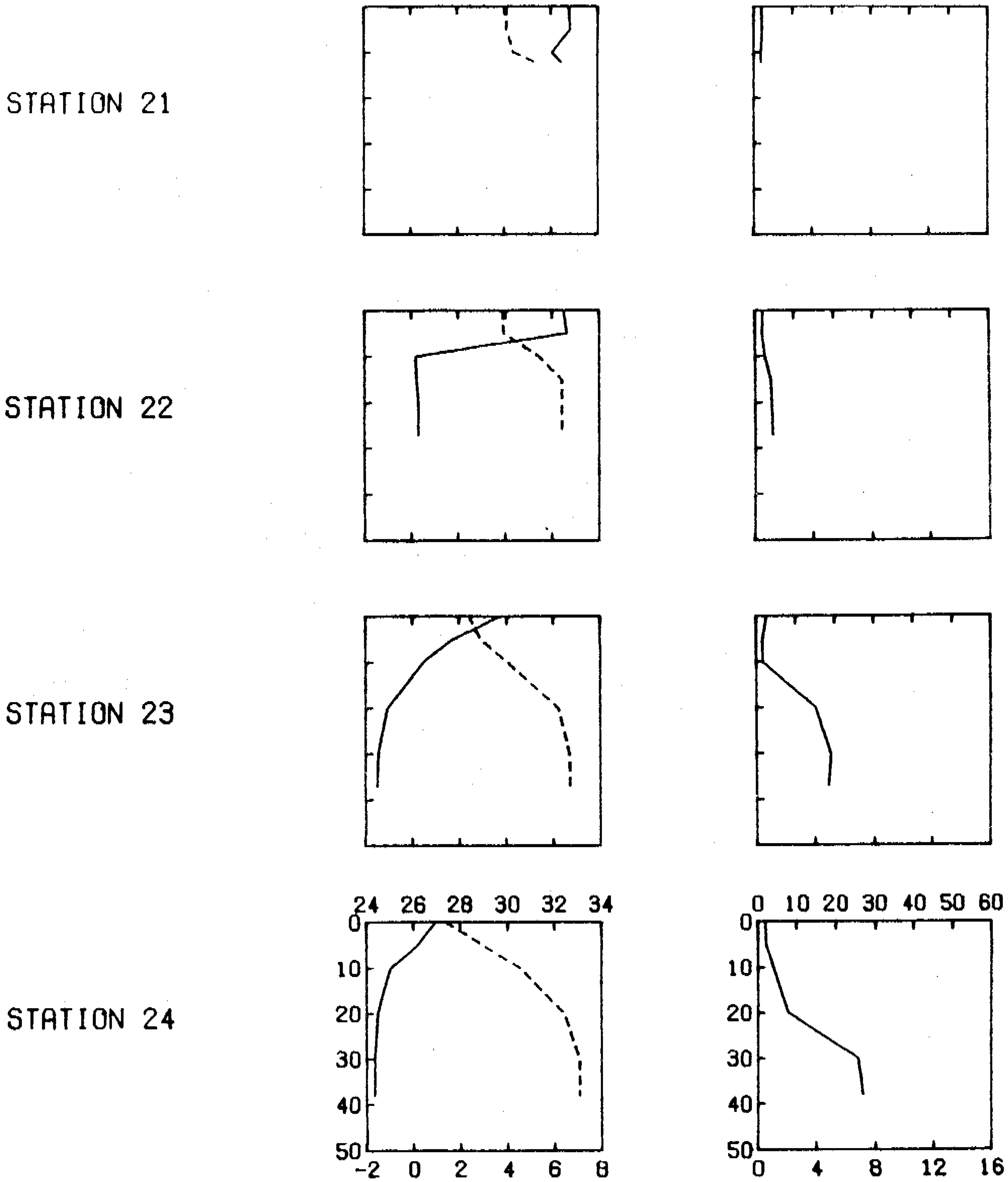


Fig. 5. (continued)

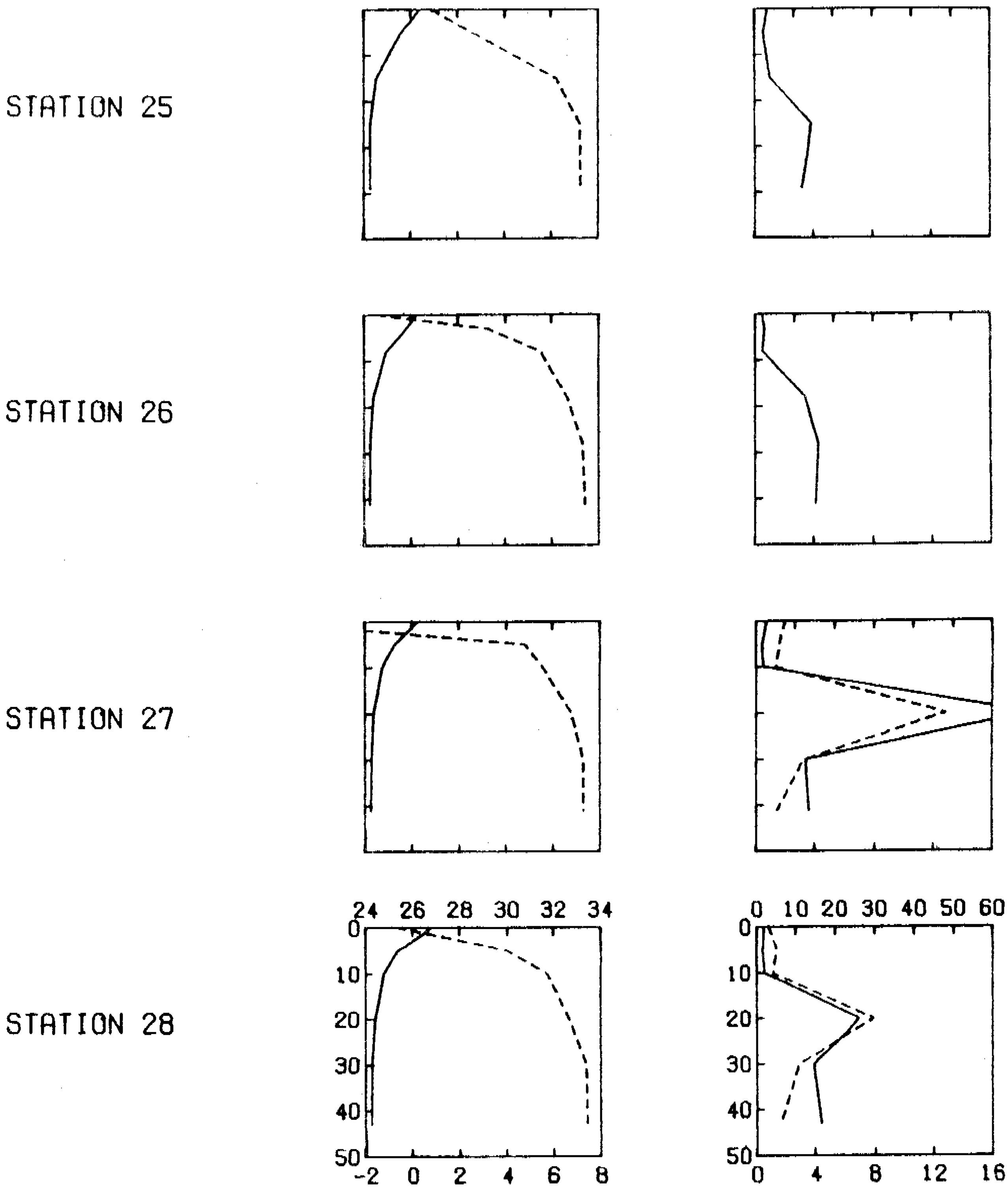


Fig. 5. (continued)

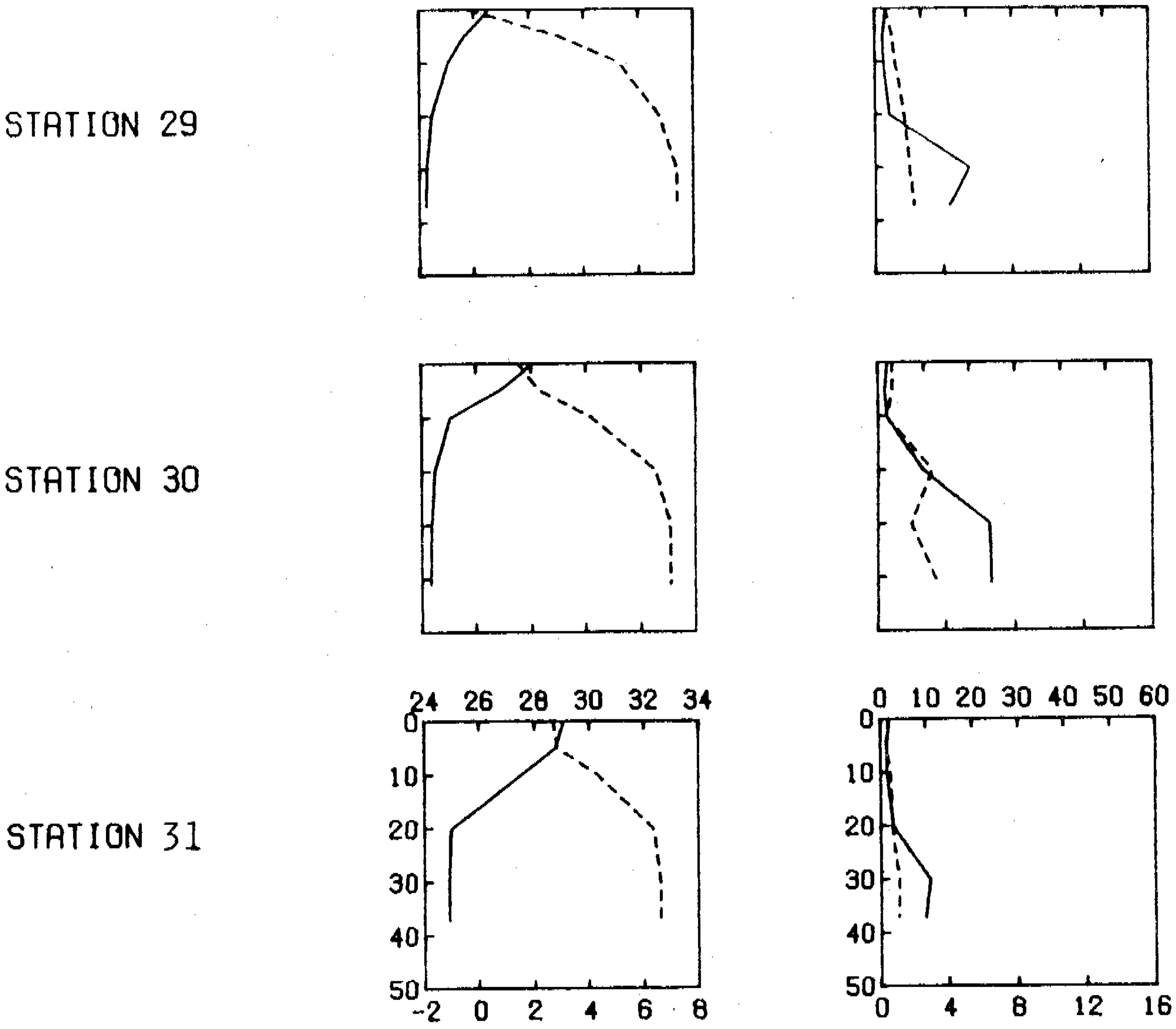


Fig. 5. (continued)

Table 9. Standing stock, plant pigment concentrations, and primary productivity from Stefansson Sound winter studies, 1978-79. Plant pigment concentrations in mg m^{-3} for water and mg m^{-2} for ice; productivity values in mg C m^{-3} hr^{-1} for water and mg C m^{-2} hr^{-1} for ice; standing stock in number of cells per liter.

	Standing Stock			Chlorophyll *a*			Phaeopigments			Prim Prod		
	Water		Ice	Water		Ice	Water		Ice	Water		Ice
	0 m	4 m		0 m	4 m		0 m	4 m		0 m	4 m	
8 Nov 78	26000	14000		0.06			0.07					
9	24000	18000		0.02	0.02		0.12	0.12				
10				0.06	0.06		0.06	0.08				
11				0.05	0.05		0.04	0.05				
12				0.06	0.04		0.07	0.06				
13				0.06	0.04		0.05	0.06				
14				0.07	0.04		0.05	0.05				
15				0.05	0.06		0.06	0.06				
16	46000	46000		0.06	0.06		0.05	0.05				
15 Feb 79	36000	22000		0.02	0.01		0.07	0.04				
12 Mar 79	46000	34000		0.01	0.00		0.03	0.02				
13				0.00	0.01		0.02	0.03				
14			38000	0.00	0.01		0.03	0.03				
15				0.01	0.01		0.03	0.07				
16	60000	82000		0.01	0.01		0.03	0.03				
15 May 79						6.50			9.16			1.50
						1.05			1.78			
18	162000	38000		0.42	0.17	3.26	1.13	0.24	6.83	0.16	0.12	1.42
						5.68			3.47			
19				0.67	0.24	3.44	1.05	0.43	4.83	0.16	0.80	0.31
						4.30			3.28			
20	208000	36000	2307000	1.19	0.23	6.10	0.89	0.33	1.71	0.11	0.26	1.42
						2.78			3.71			

Table 10. Phytoplankton and ice core standing stock (number of cells per liter) from Winter Studies samples, Stefansson Sound, 1978-79.

	8 Nov 78		9 Nov 78		16 Nov 78		15 Feb 79	
Taxon	0	4	0	4	0	4	0	4
Diatoms								
Amphiprora spp.								
Amphiprora hyperborea								
Chaetoceros spp.	2000		2000			8000	2000	
Chaetoceros septentrionalis								
Cylindrotheca closterium		2000						2000
Gyrosigma spp.								
Licmophora spp.								
Melosira spp.								
Navicula spp.				2000				
Navicula marina								
Navicula pelagica								
Nitzschia spp.								
Nitzschia delicatissima								
Nitzschia frigida								
Nitzschia grunowii								
Nitzschia seriata cf.								
Thalassiosira spp.								
Thalassiosira antarctica cf.								
Thalassiosira gravida								
Tropidoneis sp.								

Table 10. (continued)

Taxon	8 Nov 78		9 Nov 78		16 Nov 78		15 Feb 79	
	0	4	0	4	0	4	0	4
Unidentified pennate diatoms								
< 10 µm		2000						
11 - 20 µm								
21 - 30 µm								
31 - 40 µm								
41 - 50 µm								
51 - 75 µm								
76 - 100 µm								
101 - 150 µm								
Unidentified flagellates								
< 10 µm	20000	10000	20000	14000	44000	36000	32000	18000
11 - 20 µm					2000			
21 - 30 µm	2000							
31 - 40 µm								
41 - 50 µm								
Identified flagellates								
Calycomonas gracilis								
Unidentified choanoflagellates								2000
Unidentified cryptomonads								
Dinobryon petiolatum								
Eutreptiella sp. *cf.*								
Unidentified euglenoid *cf.*								
Urceolus sp.								
Platymonas sp. *cf.*	2000		2000					

Table 10. (continued)

Taxon	8 Nov 78		9 Nov 78		16 Nov 78		15 Feb 79	
	0	4	0	4	0	4	0	4
Dinoflagellates								
Gonyaulax sp.								
Peridinium spp.								
Unidentified Peridiniales							2000	
Unidentified dinoflagellates				2000		2000		

Table 10. (continued)

Taxon	12 Mar 79 0	12 Mar 79 4	14 Mar 79 ice core	16 Mar 79 0	16 Mar 79 4	18 May 79 0	18 May 79 4
Diatoms							
Amphiprora spp.							
Amphiprora hyperborea							
Chaetoceros spp.		2000	4000				
Chaetoceros septentrionalis							
Cylindrotheca closterium				2000		4000	
Gyrosigma spp.							2000
Licmophora spp.							
Melosira spp.							
Navicula spp.			2000				
Navicula marina							
Navicula pelagica							
Nitzschia spp.		4000	2000	2000	2000	8000	
Nitzschia delicatissima							
Nitzschia frigida						6000	
Nitzschia grunowii			2000			14000	
Nitzschia seriata cf.						6000	
Thalassiosira spp.			6000				
Thalassiosira antarctica cf.			12000				
Thalassiosira gravida							
Tropidoneis sp.							

Table 10. (continued)

Taxon	12 Mar 79		14 Mar 79	16 Mar 79		18 May 79	
	0	4	ice core	0	4	0	4
Unidentified pennate diatoms							
< 10 µm			2000		2000	2000	2000
11 - 20 µm			6000			2000	
21 - 30 µm							
31 - 40 µm					8000	4000	
41 - 50 µm							
51 - 75 µm							
76 - 100 µm							
101 - 150 µm							
Unidentified flagellates							
< 10 µm	40000	22000	2000	46000	64000	84000	34000
11 - 20 µm	2000			2000		8000	
21 - 30 µm							
31 - 40 µm							
41 - 50 µm							
Identified flagellates							
Calycomonas gracilis							
Unidentified choanoflagellates	4000	6000		6000			
Unidentified cryptomonads					2000		
Dinobryon petiolatum							
Eutreptiella sp. *cf.*						2000	
Unidentified euglenoid *cf.*						2000	
Urceolus sp.							
Platymonas sp. *cf.*						4000	

Table 10. (continued)

Taxon	12 Mar 79		14 Mar 79	16 Mar 79		18 May 79	
	0	4	ice core	0	4	0	4
Dinoflagellates							
Gonyaulax sp.							
Peridinium spp.						14000	
Unidentified Peridiniales				2000	4000	2000	
Unidentified dinoflagellates							

Table 10. (continued)

	20 May 79	20 May 79	
Taxon	ice core	0	4
Diatoms			
Amphiprora spp.	50000		
Amphiprora hyperborea	60000	6000	
Chaetoceros spp.	280000	4000	
Chaetoceros septentrionalis		2000	
Cylindrotheca closterium	80000	12000	4000
Gyrosigma spp.	130000	2000	
Licmophora spp.	530000	2000	
Melosira spp.	40000		
Navicula spp.	550000	2000	
Navicula marina	80000		
Navicula pelagica	860000		
Nitzschia spp.	2560000	10000	
Nitzschia delicatissima		4000	
Nitzschia frigida	6080000	14000	
Nitzschia grunowii	5880000		
Nitzschia seriata cf.		12000	
Thalassiosira spp.			
Thalassiosira antarctica cf.			
Thalassiosira gravida			
Tropidoneis spp.	10000		

Table 10. (continued)

	20 May 79	20 May 79	
Taxon	ice core	0	4
Unidentified pennate diatoms			
<10 µm	190000	2000	
11 - 20 µm	850000		
21 - 30 µm	870000	4000	
31 - 40 µm	320000		
41 - 50 µm	200000	2000	2000
51 - 75 µm	350000		
76 - 100 µm	30000		
101 - 150 µm	80000		
Unidentified flagellates			
< 10 µm	2740000	98000	28000
11 - 20 µm	320000	6000	
21 - 31 µm	20000	4000	
31 - 40 µm	10000	2000	
41 - 50 µm	20000		
Identified flagellates			
Calycomonas gracilis			2000
Unidentified choanoflagellates			
Unidentified cryptomonads	20000	2000	
Dinobryon petiolatum		2000	
Eutreptiella sp. *cf.*	10000	2000	
Unidentified euglenoid *cf.* *Urceolus* sp.	30000		
Platymonas sp. *cf.*	50000	2000	

Table 10. (continued)

	20 May 79	20 May 79	
Taxon	ice core	0	4
Dinoflagellates			
Gonyaulax sp.		2000	
Peridinium spp.	20000	8000	
Unidentified Peridiniales			
Unidentified dinoflagellates	60000	2000	

came from sediment-laden slush ice that formed a thick layer on the underside of the ice canopy (Dunton pers comm.). Not as much detritus was found in the sample collected near the sea floor. Chlorophyll *a* levels remained low.

By March, the number of individual diatom cells and the number of diatom species increased with species that are common in the water column in spring beginning to appear. Chlorophyll *a* levels were still extremely low.

One ice core collected 14 March was also analyzed for species present. The core, about 30 cm long and 2.5 cm in diameter, was collected from the slush ice layer on the underside of the ice. *Navicula* sp., *Nitzschia* spp. and unidentified pennate diatoms were present, along with *Thalassiosira* spp. The large amount of detrital material made positive identification of the *Thalassiosira* spp. impossible.

By May, more diatom cells were present in the water column, including species of *Chaetoceros, Cylindrotheca, Navicula,* and *Nitzschia*. Unidentified flagellates, usually < 10 µm in diameter, were abundant, along with a few cryptomonad, chrysophyte, and euglenoid species. Unidentified *Peridinium* spp. and other unidentified dinoflagellates were present in low numbers. Chlorophyll *a* levels in the water column were still low, but beginning to increase.

One ice core, approximately 4.8 cm in diameter and 2 cm long, collected with the combination-incubator samples (Clasby *et al.* 1973; Alexander *et al.* 1974) was analyzed. More than 23 x 10^6 cells per liter were present, including diatoms and flagellates. *Nitzschia* spp. were the most abundant organisms. *Nitzschia frigida* Grunow and *N. grunowii* Hasle comprised nearly 50% of the total population. Both of these species are common in the ice in the Barrow area with *N frigida* found in large numbers only in the ice, while *N. grunowii* is also a prominent component of the phytoplankton in spring (Alexander *et al.* 1974; Horner 1976). Other typical ice organisms found included *Eutreptiella cf. braarudii* Throndsen and *Urceolus* sp., probably *U. macromastix* Skuja. *Eutreptiella* sp. is sometimes found in the water column also, but only when ice is present (Horner unpubl obs.). Neither of these species occurred in large numbers. Chytridiaceous fungi were found parasitizing some of the pennate diatoms.

Chlorophyll *a* levels in the ice cores were variable and phaeopigments were high (Table 9), probably because of the length of time elapsing between collecting and processing, usually about 4 hr.

Primary productivity was low in the water column, averaging about 0.15 mg C m^{-3} hr^{-1}. In the ice, primary productivity on 15, 18, and 20 May was *ca.* 1.50 mg C m^{-2} hr^{-1}, but on 19 May, productivity was only 0.3 mg C m^{-2} hr^{-1}.

Nutrient and salinity data are given in Table 11.

Table. 11. Nutrient and salinity data from the May 1979 winter studies program in Stefansson Sound. Where no number is present, no sample was taken.

Date	Nutrient Concentrations (μg at/ℓ) NO_3	NO_2	NH_3	PO_4	SiO_4	Salinity (°/₀₀)
15 May						
0 m						
4 m						
ice	1.35	0.14	2.68	1.38	19.90	
18 May						
0 m	1.55	0.04	1.07	0.20	24.06	18.28
4 m	4.69	0.17	0.84	1.42	13.34	35.20
ice	1.19	0.06	2.85	0.74	20.62	15.26
19 May						
0 m	1.57	0.06	1.68	0.39	26.27	18.32
4 m	4.72	0.16	0.24	0.95	13.23	35.19
ice	1.24	0.05	1.87	0.50	21.02	15.94
20 May						
0 m	1.01	0.05	1.04	0.24	24.53	16.57
4 m	4.46	0.16	0.79	0.91	13.43	34.76
ice	0.76	0.06	2.66	0.46	20.56	14.05

VII. Discussion

A. General

This year has been spent primarily analyzing samples already available from the Chukchi and Beaufort seas, including zooplankton samples collected during an OCSEAP cruise in the Chukchi Sea in 1976, zooplankton samples collected in the Beaufort Sea during WEBSEC-72 by Dr. Bruce Wing, and phytoplankton samples collected in the Chukchi Sea by U.S. Coast Guard personnel in 1974. A field program in May 1979 provided preliminary information on the ice algae and phytoplankton communities in Stefansson Sound. Taxonomic and life history studies on the copepods collected in Stefansson Sound during the winter sampling program in 1978-79 have been finished.

There is a discrepancy between this report and all previous RU 359 reports concerning mesh sizes of the zooplankton nets used. The manufacturer of the nylon material used to make the plankton nets has recently been able to measure the mesh sizes more accurately. New sizes are 500 μm instead of 505 μm, 335 μm instead of 333 μm, and 209 μm instead of 216 μm (Halstead, East Side Net Shop pers comm.).

B. Zooplankton

Zooplankton abundances for samples from the Chukchi and Beaufort seas will be added to distribution maps already given (Horner 1979) and, along with hydrography, life cycles, and other data, will be included in the final report on icebreaker cruises in 1976, 1977, and 1978 in the northern Chukchi Sea and Beaufort Sea to be submitted in December 1980.

The presence of large numbers of polychaete and barnacle larvae in western areas may reflect the wider continental shelf and shallower water in those areas (Johnson 1956). The paucity of amphipods and euphausids, especially in ring net tows, was probably caused by the gear used rather than scarcity of animals. These animals may also live closer to the bottom and were not caught by our tows which were kept above the bottom.

C. Phytoplankton

All species and other taxonomic categories have been reported previously from the Chukchi Sea with the possible exception of *Coscinodiscus lacustris* Grunow. This centric diatom was present at stations 8, 9, 11, 12, and 27, all well into the ice. This species has also been found in sea ice collected in the Beaufort Sea near Pt. Barrow (Grant and Horner 1976), but was not a major component of the ice algae community. It grew well in culture, tolerating salinities from 10 to 50 °/₀₀, but growing best between 20 and 35 °/₀₀. Elsewhere, this species is reported in coastal waters of northern Europe and is especially common in brackish water at river mouths. It is also known from freshwater (Hustedt 1930). Horner (1969) did not report it from plankton samples collected in the Barrow area. Perhaps this is another species that is found only associated with ice in the Chukchi-Beaufort area.

Diatoms were more abundant at depth, with the chlorophyll maximum often at the interface between the relatively warm, lower salinity Alaskan coastal water ($\sim$ 5°C, $< 31.5\ ^{\circ}/_{\circ\circ}$) and the cold, higher salinity Chukchi bottom water (> -1.6°C, $> 33\ ^{\circ}/_{\circ\circ}$) (Hannon unpub ms.). Small flagellates were more abundant near the surface and at stations close to the coast.

An organism similar to *Pelagococcus subviridis* Norris was found at some coastal stations. Cells found in the Chukchi Sea samples are similar in size and colony shape to those found in the North Pacific (Lewin *et al.* 1977) on which the original description is based. Positive identification could not be made from the preserved samples.

D. Stefansson Sound

Phytoplankton levels from November through March were low, averaging about 38 x 10^3 cells per liter with most of the cells being unidentified flagellates < 10 µm in diameter. These cells were probably not photosynthetic judging from the low chlorophyll *a* levels. By May, diatoms were more abundant, although unidentified, small flagellates were still the most abundant group of organisms in the water column. Chlorophyll *a* levels were slightly higher in May.

An ice core collected 14 Mar 1979 contained few diatoms, but by May, a well-developed ice algae community was present in some areas. The extent of this community in Stefansson Sound is not known although ice cores taken to determine a good sampling location indicated patchiness within a relatively small area around Dive Site 11 (RU 356).

Chlorophyll *a* levels in the ice cores were extremely variable. Reasons for this include the patchiness of the ice community, possibly within a very small area, and the difficulty in retrieving the sampling corers from the ice. A variable and unknown amount of ice could easily have been lost during the retrieval. Patchiness may also be the reason for the decrease in primary productivity on 19 May.

With the exception of Horner *et al.*(1974), there is little available information concerning the plankton in the Stefansson Sound area in summer. These authors found three phytoplankton communities in Prudhoe Bay and out to Reindeer Island. Pennate diatoms were the most abundant organisms inside Prudhoe Bay, while small flagellates were dominant in low salinity surface water in the lagoon area. Centric diatoms were more common in deeper, more saline water in the lagoon and north of Reindeer Island. Whether the same situation occurs farther east in Stefansson Sound is not known. Copepods were the most diverse (10 species) and abundant group of zooplankters in the summer and that was the case in winter 1978-79. Other summer zooplankton taxa included coelenterates, a few polychaete larvae, a few amphipods, barnacle and crab larvae, mysids, chaetognaths, and fish. With the exception of the copepods, each of these groups, in general, comprised less than 1% of the population at stations where they occurred.

The fact that most of the zooplankton present during the winter were juvenile copepods probably indicates that the lagoon system is a major habitat for these organisms.

In a study of Arctic Ocean zooplankton, Grainger (1965) found that eight copepod species accounted for more than 99% of the total copepod individuals in the upper 50 m. Seven of these eight species were found in Stefansson Sound samples: *Calanus glacialis*, *C. hyperboreus*, *Pseudocalanus elongatus*, *Microcalanus pygmaeus*, *Metridia longa*, *Oithona similis*, and *Oncaea borealis*. With the exception of *Metridia longa*, these species were the most abundant copepod species found in Tanquary Fjord, Ellesmere Island (Cairns 1967).

Calanus glacialis and *C. hyperboreus* are considered to be predominantly Arctic species, although *C. hyperboreus* has been recorded from the Gulf of Maine (Sherman 1965) and *C. glacialis* has been found southeast of Newfoundland (Grainger 1963) and, rarely, in the Bering Sea (Minoda 1958).

Pseudocalanus elongatus (identified as *P. minutus*) is a common copepod in neritic areas of the Arctic Basin (Grainger 1965) and throughout North American Arctic waters. Minoda (1971) reported it (as *P. minutus*) as abundant above 100 m in the Bering Sea and northwestern North Pacific. The taxonomy of this genus is being revised by Frost, who says the shallow water species is not *P. minutus* and tentatively should be called *P. elongatus* (Frost pers comm.). *Pseudocalanus major* also occurs in this area, but is difficult to distinguish from the smaller, more abundant *P. elongatus* by size. It was recorded only when there was no doubt as to its identification.

Microcalanus pygmaeus has a distribution similar to *Pseudocalanus*, but is much less abundant.

Derjuginia tolli was described from Siberian coastal specimens and originally was thought to be limited to slightly fresh water, however Johnson (1963) and Minoda (1967) have found this species also in samples collected in the central Arctic Basin.

Juvenile stages of *Eurytemora richingsi* occurred in March samples and one stage IV in November. The sparse records of this species from Stefansson Sound are interesting because the original description of this species is based on adults collected from 350 to 1000 m in the Canadian Basin (Heron and Damkaer 1976). This species was also reported from one OCSEAP sample collected in a 20 m bongo net haul off Pitt Point in September 1976 (English and Horner 1977). The mature female *Eurytemora* sp. reported from the Beaufort Sea by Hansen *et al.* (1971) fits the description of *E. richingsi*. Hansen *et al.* (1971) said it was unusual for *Eurytemora* to be found in the Beaufort Sea because it is usually restricted to fresh or brackish water.

Metridia longa is usually the only species of this genus listed from Arctic Ocean samples, however copepodids of *M. lucens* occurred in the Stefansson Sound samples. Grainger (1965) thought that *M. lucens* (as *M. pacifica*, see Park 1968) was found only in the Canadian Basin, but it also occurs in shelf waters of the Atlantic and eastern Pacific and as far south as Dabob Bay, Washington (Damkaer 1964).

Limnocalanus macrurus is known from the Kara Sea eastward to the Beaufort Sea and from the Baltic Sea and East Greenland, but is apparently absent from the Pacific Ocean (Grainger 1965).

Acartia longiremis is regarded as a surface, subarctic, neritic species (Grainger 1965). Minoda (1958) reported it in the shallow, eastern Bering Sea.

Oithona similis is a dominant copepod in Arctic and boreal seas (Tidmarsh 1973). In Stefansson Sound, it was primarily a spring species. One female carried an egg cluster on 14 Mar and another female carried a spermatophore on 15 Mar.

Oncaea borealis is an Arctic species that is also found in shelf waters of the subarctic Atlantic and Pacific oceans (Sars 1918; Ussing 1938; Campbell 1929).

The May sample contained several species of harpacticoids and cyclopoids that are not usually considered to be planktonic species. This sample also contained numerous fibers and fine sand grains, suggesting that these are probably benthic or epibenthic species.

The three harpacticoids, *Pseudobradya minor*, *Harpacticus superflexus*, and *Tisbe furcata*, were also reported by Willey (1920) from samples collected during the Canadian Arctic Expedition.

Three of the four cyclopoid species of the family Cyclopininae could not be identified as any of the 30 species already described for this family (Lindberg 1953). Members of this family are small, fragile, and considered to be rare; however, rarity probably reflects collection methods rather than lack of occurrence. Literature regarding the family is confusing because of the various forms that have been described for some species. These forms could be different species. Several species of this family have been described as benthic inhabitants, found among algae or occurring where the bottom consists of coarse sand (Sars 1913-18).

The paucity of larger animals such as amphipods and euphausids may be an artifact caused by our sampling gear. The only gear we used sampling through a hole in the ice was ring nets that were usually hauled vertically from the bottom to the surface. Larger animals are able to avoid this net, usually by swimming upwards and sideways. In November, we sampled horizontally by anchoring a line and pulley just beneath the ice, but hauling a net by hand is not fast enough to catch the larger organisms.

VIII. Conclusions

A. In the northern Chukchi Sea and Beaufort Sea, distribution of individual zooplankton species is widespread, often influenced by hydrography.

B. Pelagic larvae of polychaetes, barnacles, and decapods are often abundant in western areas where the continental shelf is broad and the water shallow.

C. Primary productivity is highest at depth and where diatoms are the most abundant organisms.

D. Of the dominant species, all have previously been reported from the Chukchi and Beaufort seas.

E. The distribution of one species, *Leptocylindrus minimus* Gran, is apparently influenced by hydrography because it was always found in Bering Sea water.

F. The distribution of most phytoplankton species is widespread and patchy.

G. Copepods are by far the most abundant group during winter in Stefansson Sound.

H. Cyclopoid and harpacticoid species were taken from near the bottom in the Boulder Patch area. Some of the cyclopoids are probably undescribed species, however, this is not to imply that they are unique to the Boulder Patch, but only that they are small and difficult to catch. More extensive sampling in other areas would probably also catch them.

H. Phytoplankton standing stock is low during the winter with small flagellates being the most abundant organisms.

I. An ice algal community occurs in spring but its distribution is extremely patchy, depending on snow cover and the absence of a layer of sediment in the ice, both of which attenuate light making photosynthesis impossible.

J. Nutrient concentrations are high in spring.

K. Primary productivity is relatively low in the water column under the ice in spring, but productivity of the ice algae is relatively high.

IX. Needs for Further Study

Little is known about the summer plankton community in Stefansson Sound. RU 356 has extensively studied the littoral areas, but the plankton has been neglected except for the earlier study done by Horner *et al.* (1974) in the immediate Prudhoe Bay area.

Another major data gap is the area between the barrier islands and the 20 m isobath. Some zooplankton work has been done inside the barrier islands (RU's 172, 356, 467) and RU 359 has studied the zooplankton and phytoplankton outside the 20 m isobath. Lack of an adequate sampling platform is one reason for this data gap.

A recently identified problem is that of slush ice. The effects of this phenomenon on the presence of ice algae, organic matter transfer, and grazing are not known.

X. Summary of January - March Quarter

A. Laboratory Activities

1. Personnel

a. Thomas Kaperak - Oceanographer I: sorting, identifying and counting of zooplankton samples collected in the Chukchi Sea, CGC *Glacier*, 7 Aug to 4 Sep 1976.

b. David Murphy - Student Helper, Oceanographer I: sorting, identifying, counting of zooplankton samples collected by Dr. Bruce Wing during WEBSEC-72; identification of shrimp from all samples collected by RU 359; preparation for 1980 field season.

c. Gayle Heron - Oceanographer II: sorting, identifying, and counting of copepods and other zooplankton in winter samples from Stefansson Sound.

d. Leanne Stahl - Oceanographer I: counting, identifying fish eggs and larvae from Chukchi Sea samples collected by RU 359.

e. Carl Schrader - Oceanographer II: preparation for spring field season at Prudhoe Bay.

f. Rita Horner - Principal Investigator: enumeration of phytoplankton samples collected in the Chukchi Sea, CGC *Staten Island*, 7 to 15 Aug 1974; report writing; data management; preparation for field season.

2. Laboratory Methods

a. Zooplankton

1. Chukchi Sea samples, CGC *Glacier*, 1976

The samples were first sorted for large or rare organisms, including amphipods, euphausids, shrimp, fish eggs, and fish larvae, then each sample was split in a Folsom plankton splitter until a subsample containing about 100 specimens of the most abundant remaining taxon was obtained. The organisms were identified and counted using a dissecting microscope. The number of each taxon per 1000 m^3 was calculated using the equation:

$$\text{No per } 1000 \text{ m}^3 = (\#\text{ counted}) \times \left[\frac{1000}{(\text{volume}) \times (\text{fraction retained})}\right] \times 2^n$$

where # counted = number of specimens counted in the subsample; volume = volume of water filtered (m^3); fraction retained = amount of sample sorted for large and rare organisms; n = number of times the sample was split.

References used to identify the animals are given in Table 3.

2. Stefansson Sound winter samples, 1978-79

Formalin was drained from each sample temporarily while the organisms were being identified and counted. Organisms large enough to interfere with subsampling (fishes, shrimp, euphausids, amphipods) were removed from each sample, identified and counted. The sample was then poured into a graduated pharmaceutical cylinder and enough water added so the sample could be thoroughly mixed, usually up to 100 ml. A subsample was removed with a quantitative, calibrated pipette while the plankton was dispersed. The size of the subsample depended on the zooplankton volume in each sample. At least 100 specimens of the dominant species was considered to be a representative subsample. In cases of low zooplankton volume, all organisms in the sample were identified and counted.

A clear, plastic, open tray, marked in 1 cm squares, was used for holding the subsample. Counts were made using a dissecting microscope with at least 50 x magnification. A compound microscope was used for difficult or unusual identification.

Copepods were identified and enumerated, separated by sex and developmental stages. Abundance was expressed as the number per 1000 m^3.

Voucher specimens were separated and recorded. All specimens and samples are stored in formalin.

3. Beaufort Sea samples, WEBSEC-72

Samples were poured onto a 209 μm mesh screen, rinsed with tap water , and allowed to stand in tap water during sorting. Larger samples were split into subsamples with a Folsom plankton splitter. The subsamples were successively sorted until at least 100 specimens of each taxon were removed. Only a fraction of each sample was sorted for abundant species, while the whole sample was sorted for rare species. Animals removed for identification were preserved in buffered 4% formaldehyde.

Identifications were made using dichotomous keys including Univ. So. Calif. Tech. Reports, Naumov 1960, and Barnard 1969, and by comparison with descriptions and illustrations in the literature. References used are listed in the bibliography and Table 7.

The number of animals per 1000 m^3 was calculated using:

$$\text{No per } 1000\ m^3 = 1000\,\frac{AB}{V}$$

where A = number of animals identified in a subsample; B = reciprocal of the fraction the subsample is of the whole sample (= 1 when whole sample was counted); V = volume of water filtered by the net.

Voucher specimens were kept for all taxonomic categories.

b. Phytoplankton

1. Chukchi Sea samples, CGC *Staten Island*, 1974

Standing stock samples are being analyzed using a Zeiss phase contrast inverted microscope and Zeiss 5 and 50 ml counting chambers. Rare and large organisms (> 100 μm) are being counted at 125 x magnification in 50 ml chambers, while abundant, small organisms (< 100 μm) are being counted at 312 x magnification in 5 ml chambers. One-tenth of the 5 ml chamber and one-fifth of the 50 ml chamber is being counted.

Chlorophyll *a* concentrations were determined in 1974 using spectrophotometric methods. The filters were ground in *ca.* 12 ml 90% acetone and centriuged 3 times for a total of 30 min. The supernatant liquid was made up to 14.5 ml with 90% acetone and poured into 5 cm path length spectrophotometric cells. The extinction was measured against a cell containing 90% acetone at 7500, 6630, 6450, 6300, and 4800 Å using a Beckman DU-2 spectrophotometer. Chlorophyll *a* concentrations were calculated using SCOR/UNESCO equations (Unesco 1966) where

$$\text{Chl } a = 11.64E_{6630} - 2.16E_{6450} + 0.10E_{6300}$$

after subtracting the 7500 (blank) reading from the 6630, 6450, and 6300 values. Phaeopigment concentrations were not determined.

2. Stefansson Sound winter samples, 1978-79

Standing stock samples from the water column were analyzed as described for the Chukchi Sea samples. An ice core was settled in the usual way, but so many cells were present that it was impossible to count in either the 5 or 50 ml chamber. Instead, a 1 ml subsample was taken from the sample jar after the jar was thoroughly shaken. The 1 ml subsample was put into a 5 ml counting chamber and 4 ml distilled water were added. After settling overnight, one-tenth of the subsample was counted.

Plant pigments were determined using fluorometric techniques (Strickland and Parsons 1968).

Primary productivity samples were analyzed using a Packard Tricarb Scintillation Spectrometer using Aquasol (New England Nuclear) as the scintillation cocktail. Carbon uptake was calculated using the equation:

$$\text{Ps (mg C m}^{-3}\text{ hr}^{-1}) = \frac{(L - D) \times W \times 1.05}{R \times T}$$

where L - D = light minus dark count in disintegrations per minute; W = total carbonate alkalinity; 1.05 = ^{14}C uptake factor; R = activity of the ^{14}C added to the sample in disintegrations per minute; T = incubation time (Strickland and Parsons 1968).

XI. Auxiliary Material

A. References Used (Bibliography)

1. Zooplankton

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RESEARCH SUMMARY - RU 537

PRIMARY PRODUCTION, TROPHIC DYNAMICS AND NUTRIENT REGIMES OF THE HARRISON BAY - SALE 71 AREA

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INTRODUCTION

This summary represents a distillation of the data acquired by RU 537 with special emphasis on the Sale 71 area in Harrison Bay, Alaska. The data presented are necessarily out of context for brevity and the readers are referred to the annual and cumulative summary reports for details. The author has included information acquired during past EPA and Sea Grant projects in this region as well as results from summer 1980 OCSEAP field work.

The author is indebted to many other OCSEAP investigators for supporting information and contributions to the synthesis of these data.

COLVILLE RIVER INPUTS

Unlike temperate rivers the Colville River flows only during the summer - fall season. By early December, the flow from tributaries has essentially ceased and the ice freezes to the bottom in the shallow bars, sealing off downstream flow. In the delta, where the river channel bottom is below sea level for 60 km or so inland, seawater flows upstream and replaces the freshwater in the delta channels. By the end of October, the west channel was saline to the head of the delta and by April seawater penetrates as far upstream as the mouth of the Itkillik River. No freshwater is present anywhere in the delta channels beneath the ice by spring indicating that freshwater flow downstream is neglible or non-existent. The saltwater is oxygenated throughout winter but microbiological nitrification and respiration processes reduce initial concentrations of dissolved oxygen by half over the course of the winter.

By late May surficial meltwater begins to pond on the ice and flow commences in the headwaters. The arrival of meltwater at the delta is usually dramatic and the entire saltwater content of the delta can be flushed out in 2-3 days (Walker, 1974). Flooding of the delta can be extensive as overflow water floods downstream on bottomfast ice and onto Harrison Bay where typically 500 - 700 km^2 is covered by sediment laden water. Most of the meltwater which enters Harrison Bay on top of the ice rapidly drains through the ice via numerous cracks and holes. Typically overflow water rarely extends more than 7 km seaward of the delta whereas the freshwater wedge rapidly expands to a final extent of over 35-40 km seaward. The most singlar feature of break-up is that over 50%

of the annual flow of about 12 x 10^9 m^3 is discharged in break-up and post break-up flood in early June (Walker, 1973) and over 70 percent of the annual discharge of suspended load (Arnborg, et al., 1967). Sediment carried by the water is left deposited on the ice and the greatly lowered albedo contributes to rapid melting of the sea ice. By early July, the Harrison Bay area has melted open and by mid-July is usually ice free in the shallower areas. In the northwestern area, ice ridge remnants persist until late summer.

The river water input rapidly declines following the spring melt. By late June, when river levels return to normal, large quantities of inorganic and organic matter have been transported into Harrison Bay. The peak concentrations coincide with peak flow and approximately 6 x 10^6 metric tons of mineral sediment (Arnborg et. al, 1967) and 90,000 tons particulate organic matter and 40,000 tons of dissolved organic carbon reach the marine environment. Carbon isotope studies on the particulate organic matter transported reveal a progressive depletion in ^{14}C-content as break-up progresses indicating that the initial stages of runoff carries large quantities of leaf litter and twigs from the tundra surface but as the snow disappears and river levels fall, the organic matter shifts to a composition typical of peat derived from eroding riverbanks. Over the course of the hydrologic year, an estimated 120 x 10^6 kg particulate C accompanied by 18 x 10^6 kg organic N and enters Harrison Bay. The inorganic nutrient concentrations represent a considerably smaller quantity, estimated at 4 x 10^3 kg N principally as NO_3-N and a much smaller quantity of phosphorus. Inorganic phosphate concentrations were often below limits of detection in river water samples (0.02 micromolar), and total inputs wre not estimated. The Colville River is therefore a major source of both carbon and nitrogen to the marine environment in Harrison Bay.

PRIMARY PRODUCTION

Studies on Harrison Bay primary production by Alexander, 1974 and this program confirm that overall carbon fixation is low by temperate standards. Measured ^{14}C-bicarbonate uptake rates extrapolated to an 18 hour day yield approximately 8 g C/m^2 fixed during August. This is a low figure for estuaries and can be attributed to four factors

1) Euryhaline conditions due to freshwater input stress phytoplankton populations.

2) Intense turbidity results from resuspension of particulates during prevailing NNE winds.

3) Low nutrient concentrations limit growth under otherwise favorable conditions.

4) Shallow water depths result in low integrated primary production figures on a m^2 basis.

The net result of the above conditions is an estimated annual fixation input of 23 x 10^6 kg C over an area of 2600 km^2 (includes ice algae). Heterotrophic production based upon allocthonous carbon is believed to be of the same magnitude and is very significant to the food chain (see below).

NUTRIENT REGIMES

The Harrison Bay region in summer represents the input area for large quantities of organic nitrogen to a strongly nitrogen-limited environment. The atom ratio of N:P offshore is very low, ranging between 5-10 in contrast to biologically preferred uptake ratios of approximate 16. Thus the input of organic nitrogen represents a potential benefit once mineralization occurs as most phytoplankton cannot directly use organic nitrogen (Schell, 1975). Heterotrophic production followed by mineralization of organic nitrogen to ammonia and nitrate is the principal pathway of nitrogen transfer. Schell, (1974) reported mineralization rates of organic nitrogen to nitrate and ammonia during the winter period in Colville Delta channels and in eastern Harrison Bay. Alexander (1974) reported August ammonification rates of 0-0.3 ug N/liter-hr for Simpson Lagoon and 0.012-0.019 ug N/liter-hr for coastal Beaufort Sea waters. These compare with 0.05 ug N/liter-hr combined ammonification and nitrification rates in winter Colville delta water. The addition of amino acids to samples greatly increased mineralization rates indicating that the limiting step is probably the microbial degradation of the polymeric-structure of the peat detritus. Where a large quantity of organic matter is present, nutrient regeneration rates are higher-estimated at 0.13 ug N/liter-hr in the overall water column in the delta during winter. Actively feeding invertebrate and fish populations overwintering in the delta also undoubtably contribute to nutrient regeneration rates.

Phosphate is extremely depleted in the Colville runoff waters and for all practical purposes, the sole source of dissolved inorganic P can be assumed to be advected offshore waters. Some input (2×10^5 kg P/yr) occurs from river input of particulate organic phosphorus. No data are available on the rate of release to the water column or loss to sediments for this fraction.

TROPHIC SYSTEM ENERGETICS AND DETRITAL FOODWEBS

The input of organic carbon from the Colville River to Harrison Bay and inputs by shoreline erosion dominate the energy input to this system. Figure 1 shows the relative inputs and current best estimates of their magnitude. This large input of allochthonous carbon is utilized by microorganisms and the secondary production is transferred up the foodweb to comprise a large fraction of the carbon in amphipods sampled from Harrison Bay during November, based on the carbon-14 content of the amphipods. Figure 2 shows the basis for peat/primary production allocation using C-14 content. Figure 3 shows C-13 abundances versus C-14 abundances for anadromous fish, marine fish and obligate freshwater fish taken from the Simpson Lagoon-Harrison Bay-Colville River complex. The anadromous entering marine waters attain an isotopic composition typical of marine fish by late summer. Upon entering the freshwater system, however, the foodweb dependencies shift drastically and by spring, the anadromous fish sampled (least cisco, broad whitefish) were almost completely freshwater carbon derived primarily from peat as indicated by a large depression in C-14 content. These data indicate two critical facts regarding anadromous fish populations.

1) Overwintering anadromous fish in the Colville River feed actively and turn over their entire body carbon. They do <u>not</u> overwinter on fat reserves acquired during summer marine feeding.

2) Overwintering fish are heavily dependent upon peat as an energy source, probably via insect larvae as chief consumers. By June, least cisco and broad whitefish are 60-65 percent peat carbon.

The author suspects but does not have supportive data other than the relatively high November peat content in amphipods, that Harrison Bay organisms are heavily dependent upon peat during winter months. The high terrestrial carbon inputs relative to marine carbon fixation would make this thesis probable and the observed freshwater seasonal variations provide a ready example. Annual variation in C-14 content in arctic grayling from the Colville River are shown in Figure 4. Since no marine carbon is involved with this species, the observed oscillation represents seasonal variation inpeat input to their diet via detrital foodwebs. These fish are minimally about 25% peat carbon in late summer and increase to nearly 50 percent peat carbon by the end of the ice cover season (June).

Overall, peat is being found to assume an increasingly important role in the ecosystem energetics of the Colville River-Harrison Bay aquatic environment.

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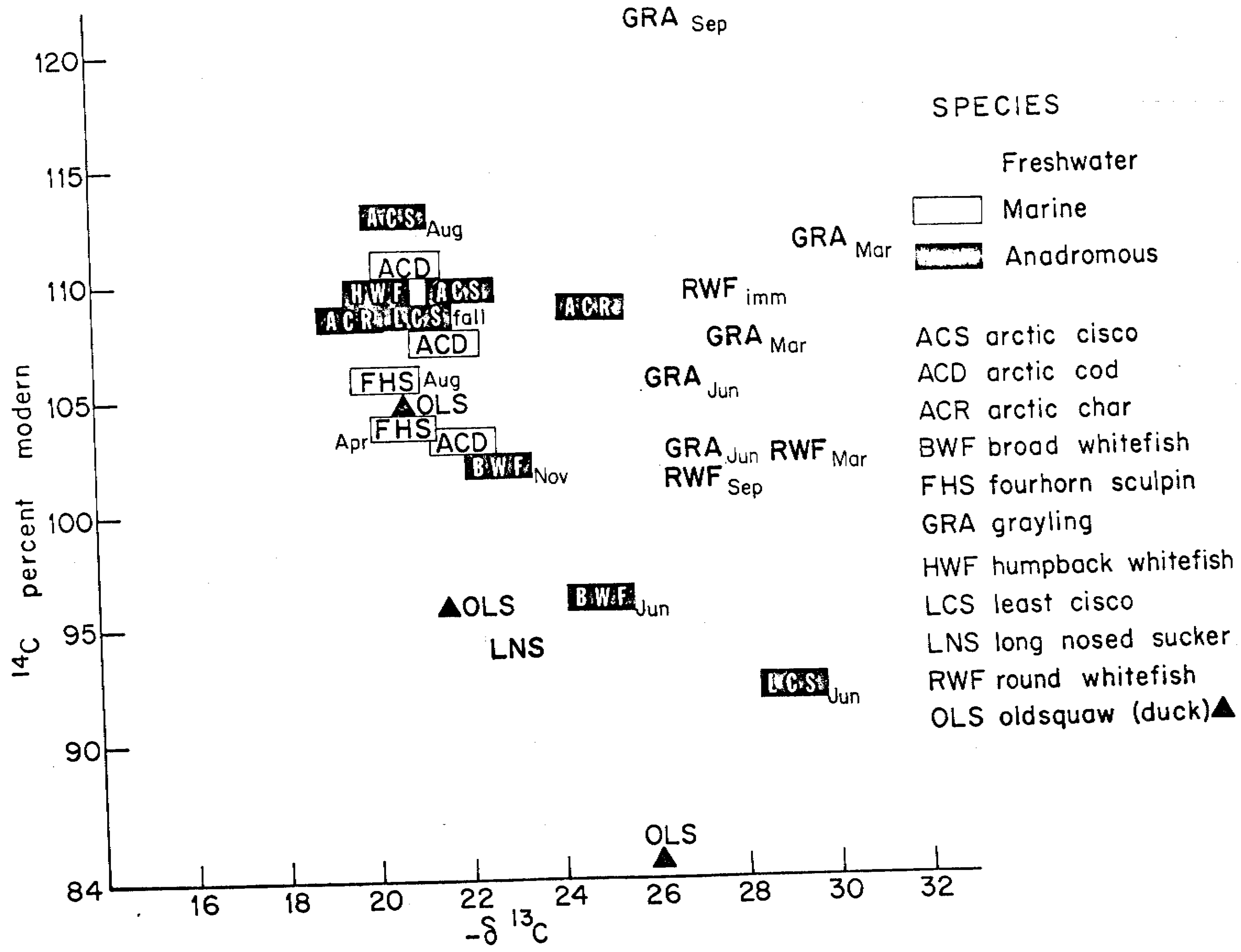
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RWF imm
GRA Mar
GRA Jun
GRA Jun
RWF Mar
RWF Sep
OLS
BWF Jun
LNS
LCS Jun
OLS
ACS arctic cisco
ACD arctic cod
ACR arctic char
BWF broad whitefish
FHS fourhorn sculpin
GRA grayling
HWF humpback whitefish
LCS least cisco
LNS long nosed sucker
RWF round whitefish
OLS oldsquaw (duck)▲
^{14}C percent modern
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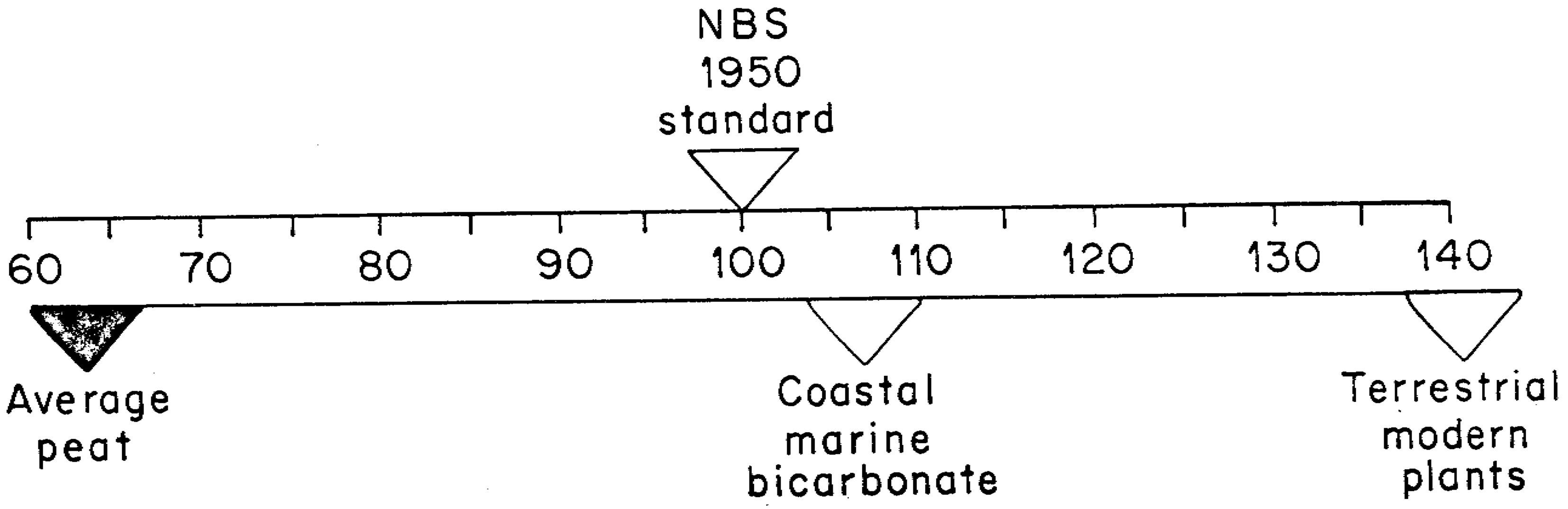
RADIOCARBON CONTENT OF CARBON SOURCES — ARCTIC ALASKA

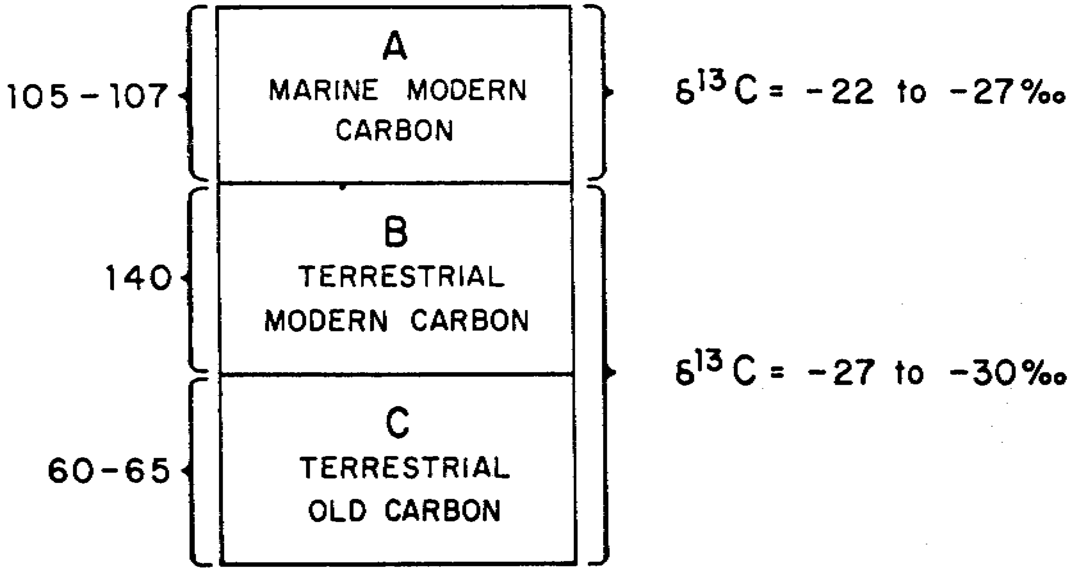


DETERMINATION OF HERBIVORE-DETRITIVORE CARBON SOURCE

IS CARBON SOURCE RECENT OR OLD ?

HERBIVORE-DETRITIVORE BIOMASS

IS CARBON SOURCE MARINE OR TERRESTRIAL ?



PERCENT MODERN=

105 - 107

A
MARINE MODERN CARBON

$\delta^{13}C$ = -22 to -27‰

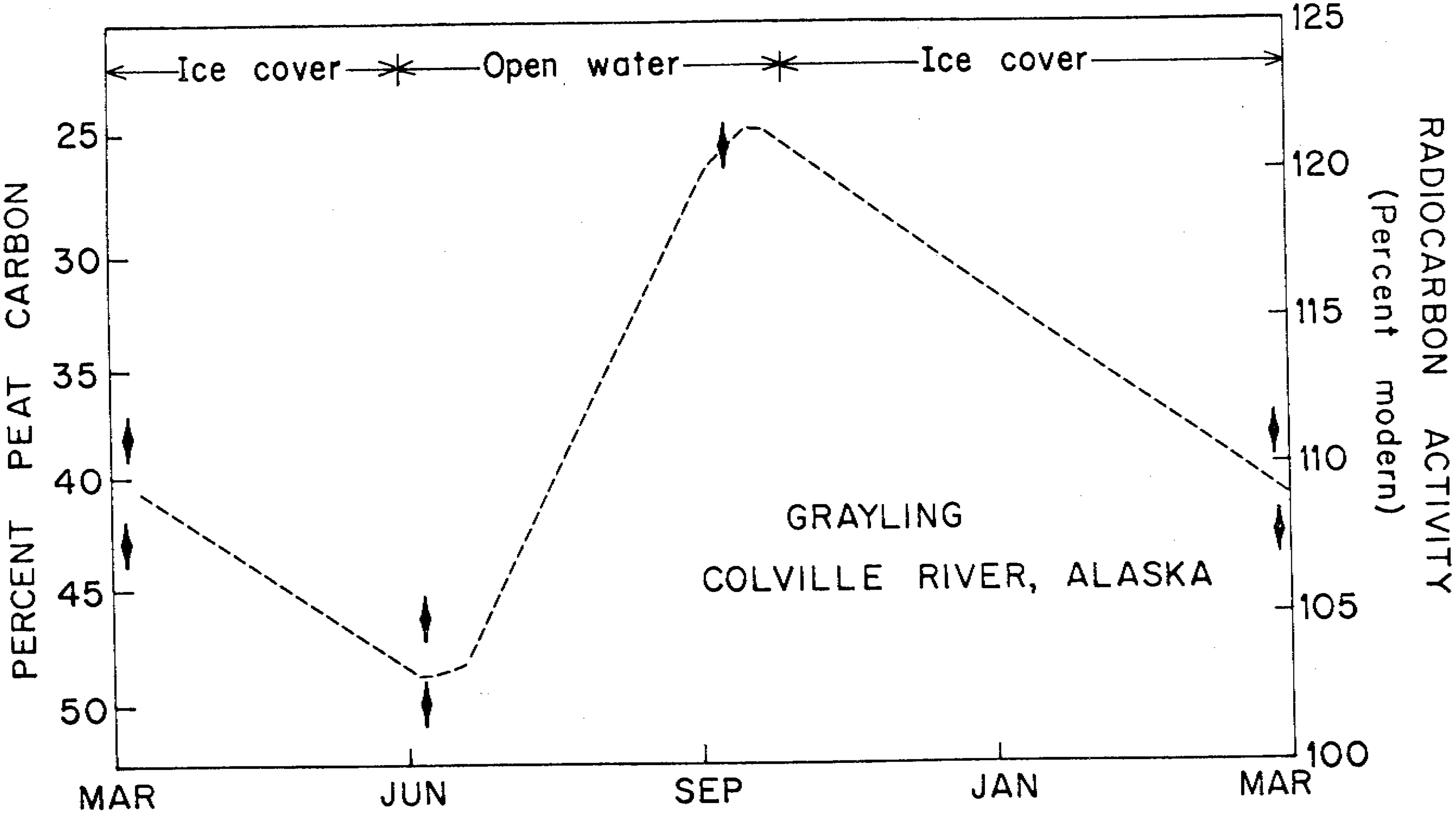
140

B
TERRESTRIAL MODERN CARBON

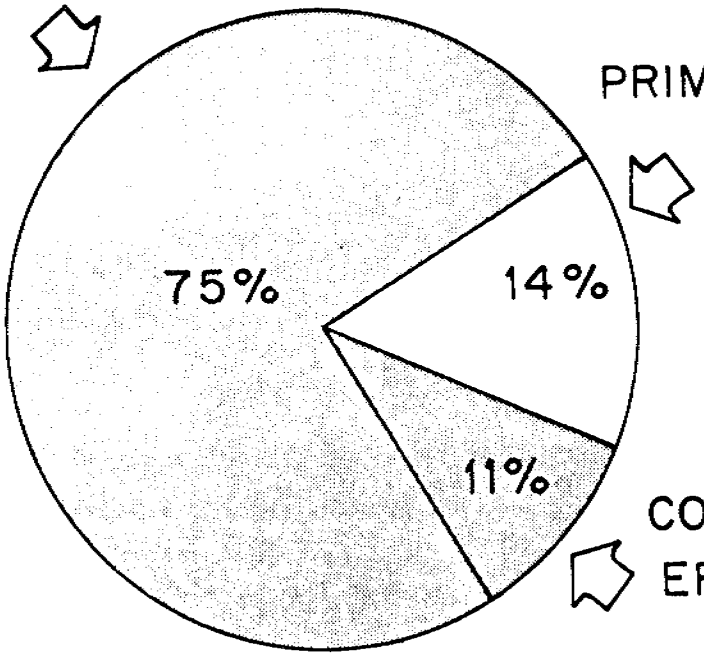
60-65

C
TERRESTRIAL OLD CARBON

$\delta^{13}C$ = -27 to -30‰

Ice cover
Open water
Ice cover
PERCENT PEAT CARBON
25
30
35
40
45
50
RADIOCARBON ACTIVITY (Percent modern)
125
120
115
110
105
100
MAR
JUN
SEP
JAN
MAR
GRAYLING
COLVILLE RIVER, ALASKA

HARRISON BAY
ENERGY INPUT
10^6 kg C/year



COLVILLE RIVER
RUNOFF 120

PRIMARY PRODUCTION

Ice algae	3
Pelagic	20
	23

COASTLINE
EROSION 18

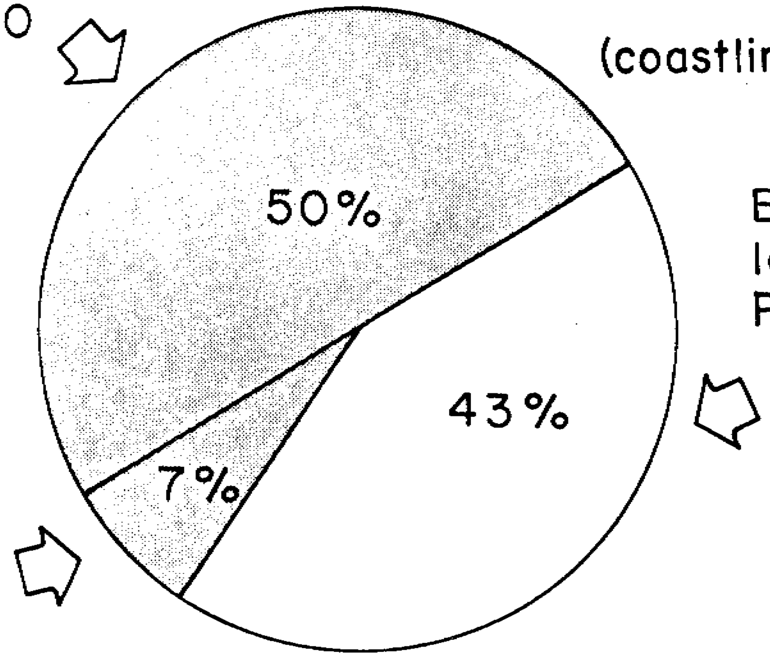
TOTAL ANNUAL INPUT 161

BEAUFORT SEA COASTAL ZONE ENERGY INPUT

10^6 kg C/year

TERRESTRIAL
RUNOFF 230

PRIMARY PRODUCTION
(coastline out to 10m depth
≈ 10km)



Benthic	4
Ice algae	22
Pelagic	174
	200

COASTLINE
EROSION 33

TOTAL ANNUAL INPUT 460

RECEPTORS-LITTORAL

CONTENTS

Contract 03-5-022-81
Research Unit 356
April 1, 1980 to March 31, 1981
3 pages plus 215 appended pages

ANNUAL REPORT

Environmental Assessment of Selected Habitats in Arctic Littoral Systems

Principal Investigator: A. C. Broad,
Western Washington University

A. C. Broad
Mark Childers
Ken Dunton
James Hanes
Helmut Koch
D. E. Schneider
Susan Schonberg
Jonathan Zehr

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TABLE OF CONTENTS

1. Summary of objectives and conclusions; Introduction.

The objectives of RU 356 during the year were:

A. Continuation of the ongoing investigation of the Stefansson Sound kelp communities with particular emphasis on growth of important species, investigations of the biota of turbid ice, measurements of physical parameters including sediment analysis, and the collection of quantitative information on both infaunal organisms of the vicinity of the boulder patches and on the epifauna and epiflora of the rocks themselves: The year's research and conclusions currently offered are contained in Appendix I.

B. Reconnaissance of the Stefannson Sound boulder patches by observation: Results of this effort are included in Appendix I.

C. Completion of winter process studies: Laboratory work was ended in September, 1980. Appendix II is a current report.

D. Participation in joint studies of Harrison Bay by conducting a survey for possible kelp or other macrophyte communities and by furthering our knowledge of the benthic infauna: This work is reported in Appendix III.

E. Continue the laboratory analysis of biological samples taken in field studies: Appendix IV is a presentation of available population and growth data on several predominant invertebrate species based on samples taken in prior years, usually in connection with faunistic surveys.

SUMMARY OF FOURTH QUARTER OPERATIONS

1. Field and laboratory activities
    - A. Field Work
        - 1. Personnel
            - a. at Dearhorse and Stefannson Sound Dive Site 11
                - 1. Contract divers James Hanes, John Olson, Eugene Cinkovich, March 23 to end of quarter (departed April 7).
            - b. Kenneth H. Dunton, March 26 to end of quarter (departed April 5).
            - c. Susan V. Schonberg, March 31 (departed April 5).
        - 2. Field Trip Schedule
            - a. March 23. Contract Divers arrive at Dearhorse.
            - b. March 24-26. Preparation for moving equipment to DS-11.
            - c. March 27. Set up camp at DS-11; cut dive hole.
            - d. March 28-April 4. Field work (diving) at DS-11.
            - e. April 5. Remove equipment from DS-11.
            - f. April 6. Clean and store equipment at Deadhorse.
            - g. April 7. Depart Deadhorse.
    - B. Scientific Party (except as noted, all of Western Washington University)
        - 1. A. C. Broad, Principal Investigator (not on salary)
        - 2. Kenneth H. Dunton, Associate Investigator (also University of Alaska; not on salary)
        - 3. Helmut Kock, Laboratory Supervisor
        - 4. Mark Childers, Research Aide
        - 5. Susan V. Schonberg (also University of Alaska; not on salary)
        - 6. Jonathan Zehr, Research Aide
        - 7. Laboratory Assistants (hourly wages)
            - a. James Bock
            - b. Susan Burgdorff
            - c. Kara Cameron
            - d. Dawn Christman

        e. Geoffrey Pounds
        f. Gary Smith
        g. Russell Thorson
    8. Contracted services (not University employees)
        a. Eugene Cinkovich, diver
        b. James Hanes, diver
        c. John Olson, diver

C. Methods: see text of appropriate sections

D. Sample locations. DS-11 is located at 70°19.25'N, 147°35.1'W.

E. Data collected and analyzed: see appropriate appendices.

F. Milestone update: none required.

II. Results: Refer to appropriate appendices.

III. Estimate of funds expended.

	Amount Budgeted[1]	Amount Spent	Amount Remaining
Salary PI	72,563	74,633	-2,070
Salaries, Associates	153,278	161,130	-7,852
Salaries, Other	333,532	336,794	-3,262
Fringe	107,955	92,303	15,652
Travel and Freight	80,161	67,695	12,466
PI Logistics	41,613	37,860	3,753
Supplies and Contracts	86,168	86,666	-498
Equipment Costs	50,697	30,512	20,185
Computer	12,134	14,518	-2,384
Overhead	256,270	255,564	11,706
Totals	1,194,371[2]	1,146,675	47,696

1. Includes original contract and modifications 1 through 13.

2. Mod 12 total is 1,194,390.

Ecology of the Stefansson Sound Kelp Community:
II. Results of *In Situ* and Benthic Studies

K. H. Dunton and S. V. Schonberg

INTRODUCTION

The summer of 1981 will mark the anniversary of three years of research conducted by this group in the Stefansson Sound kelp community. Accordingly, a comprehensive final report on the results of this research will be submitted in December, 1981. In this third annual report, we briefly discuss the results of experiments and surveys conducted in the past year.

In Table 1, a list of experiments and/or studies currently underway or completed at DS-11 in Stefansson Sound is presented. The results of many of these studies have been discussed in two previous annual reports.

The major objectives of our work in Stefansson Sound in FY 81 were: (1) continued monitoring of *in situ* experiments addressing the growth, behavior, and feeding patterns of key species, recolonization of both natural and artificial substrata and sedimentation rates; (2) continued observation of the turbid ice phenomenon and its biological significance; (3) to conduct experiments or collect samples in an effort to determine how the spatial distribution of infaunal animals is affected by substrate composition; (4) to complete quantitative analyses of the benthic infaunal and epilithic communities; and (5) to continue exploration of the areas of Stefansson Sound identified by geophysical means to possess live bottom communities. All of the above objectives will be addressed in this report.

STUDY AREA

The major portion of the diving effort is conducted at Dive Site 11 (DS-11) in the Stefansson Sound Boulder Patch (70^{0}19.25'N, 147^{0}35.1'W). The site is located between Foggy Island Bay to the south and the McClure Islands to the north. The Sagavanirktok River discharges into Stefansson Sound about six miles southwest of DS-11. Water depth at this site ranges from 5.5 to 6.5 meters. The cover of boulders and cobbles on the seafloor at DS-11 averages 42 percent. This represents the densest concentration of rocky material that we have seen in Stefansson Sound.

Table 1. Experiments and/or studies currently underway or completed at DS-11 in Stefansson Sound.

STUDIES	STATUS
Taxonomic survey of the flora and fauna	Completed*
Seasonal pattern of linear growth in *L. solidungula* and *L. saccharina*	Completed
Processes of recolonization on denuded rock substrata	In Progress Since 8/78
Effect of light on the winter linear growth of *L. solidungula*	Completed
Seasonal pattern of sedimentation in Stefansson Sound	In Progress Since 8/78
Process of recolonization on artificial substrata	In Progress Since 4/80
Growth of the sponge, *Choanites lutkenii*	In Progress Since 4/80
Behavior of the soft coral, *Eurephytes rubiformis*	In Progress Since 4/80
Primary productivity in *L. solidungula*	In Progress Since 11/79
Physical and biological investigations of the turbid ice phenomenon	In Progress Since 11/78
Quantitative analyses of the epilithic flora and fauna (density and biomass)	In Progress Since 3/79
Quantitative analyses of the density and biomass of the benthic infaunal organisms	Completed
Vertical distribution of infaunal animals	In Progress
The effect of sediment grain size on the spatial distribution of infaunal organisms	In Progress Since 7/79
Feeding and migratory behavior of seastars	In Progress Since 2/80
Survey of the distribution of cobbles and boulders in Stefansson Sound (focus is now on Block 700, which has not been surveyed using geophysical methods)	In Progress Since 7/78

The area about DS-11 supports a well established kelp community characterized by several species of red and brown algae, and a diverse assortment of invertebrate life representing every major taxonomic group. The most conspicuous and dominant member of the community is the kelp, Laminaria solidungula which is circumpolar in distribution. Two other kelp species, Laminaria saccharina and Alaria esculenta, appear occasionally and together with L. solidungula form a brown algal overstory. Of the invertebrate phyla, the sponges and the cnidarians are the most conspicuous. These include the sponges Phakettia cribrosa and Choanites lutkenii and the soft coral Eunephtya rubiformis. Other common organisms include seastars, hydroids, sea anemones, sea squirts, nudibranchs, chitons and bryozoans.

MATERIALS AND METHODS

Divers are used almost exclusively in monitoring experiments and in collecting samples in the Stefansson Sound kelp community (See Dunton and Schonberg, 1979, 1980). Methodology varies widely depending on the type of experiment or desired product and is reported in the appropriate subsections of this report.

Transport to and from the dive site typically involves the use of a 21 foot Boston Whaler, the Arctic Char, in the summer and either helicopters or rolligons in the winter. Since April, 1980 we have become less dependent on helicopters as we now live on site in the winter period. A six man camper and a 30 kw generator provides all the living comforts needed on the ice at a reasonable cost. The parcoll remains our laboratory and diving facility.

The procedures and equipment used by our group in diving in the Arctic have been reported in detail previously (Dunton and Schonberg, 1980).

RESULTS AND DISCUSSION

The Strategy of Growth in the Kelp Laminaria solidungula

The arctic kelp L. solidungula is the dominant member of the Stefansson Sound Boulder Patch in both numbers and biomass. Its importance to the marine environment as a source of carbon is now being studied, although its utilization as both a substrate for other organisms or in some cases as food is well documented.

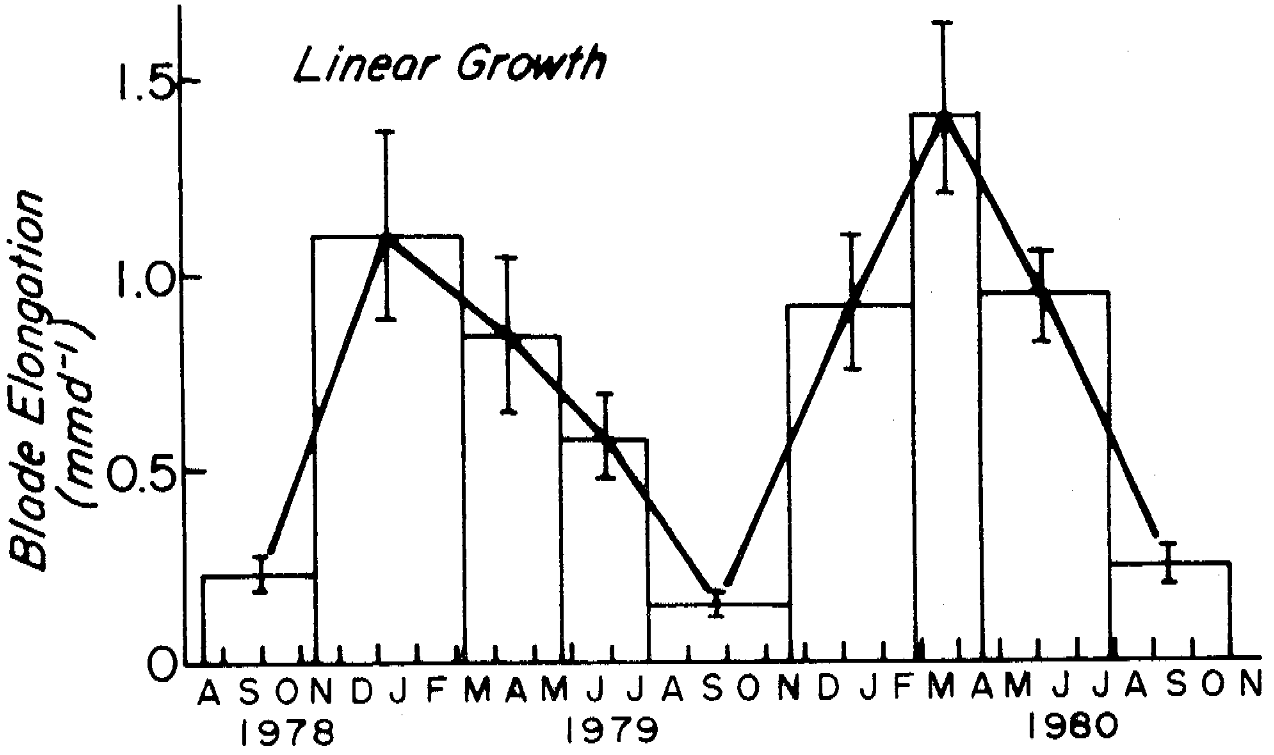
As a result of almost three years of study on this plant, we have a fairly good understanding of its growth habits and its strategy of growth. The pattern of linear growth reflects the availability of nutrients, mainly nitrate in the seawater (Fig. 1). Winter linear growth, at least initially, is dependent on stored carbohydrate reserves located in the older blades. If the plants are not exposed to light under the ice canopy their linear growth is entirely dependent on these reserves. Over 90 percent of the linear growth occurs during the late winter and early spring months. Carboyhydrate reserves are accumulated during the summer months, when the plants are actively photosynthesizing. But linear growth during the summer is minimal due to limiting concentrations of nitrate.

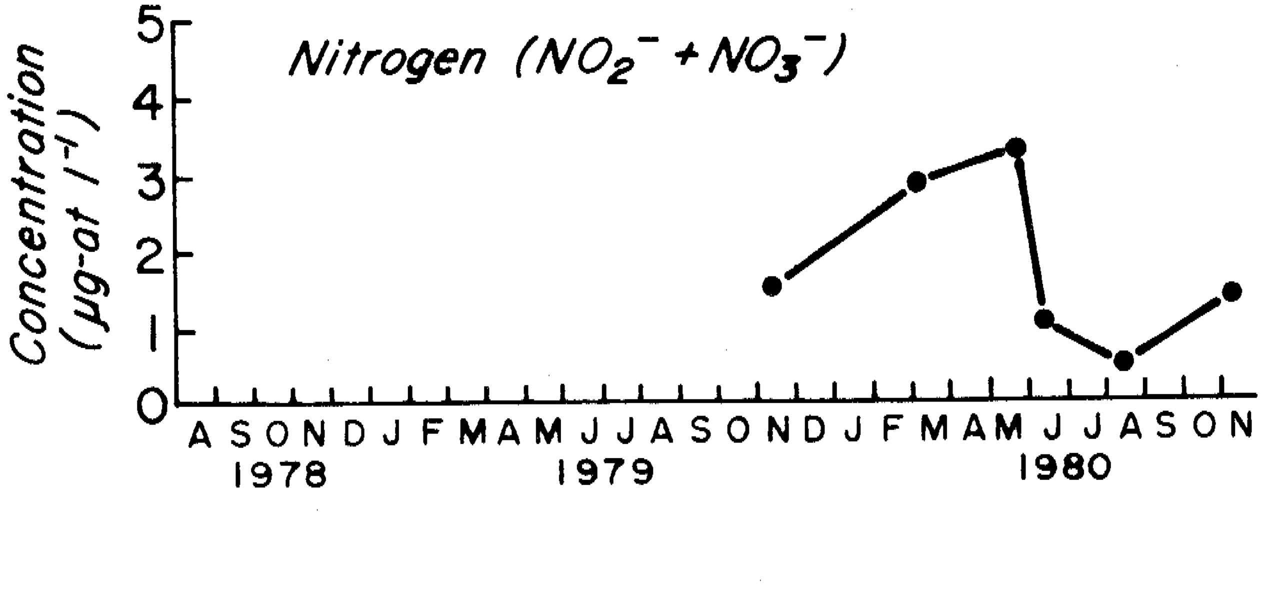
The mode of growth in *L. solidungula* makes it a potentially valuable plant for monitoring purposes. The annual linear growth is easily measured since the plant produces a distinct blade for every year of growth. The amount of linear growth has been shown to reflect the character of the ice canopy (opaque or translucent) in any given year (Dunton and Schonberg, 1980). The amount of linear growth may also be reflective of water turbidity. Extremely turbid water will decrease the amount of light reaching the plants, especially during the critical summer months when the plant does most of its photosynthesis. If photosynthesis was restricted during the summer months, the production of a new blade and linear growth during the winter months may also be measurably reduced.

Growth of the Sponge, *Choanites lutkenii*

Of the epilithic invertebrates in the Boulder Patch, sponges and soft corals are the most conspicuous and also among the most abundant of the invertebrates. Since the soft corals are difficult animals to work with, we chose to do growth experiments on one of the two most common sponges, the crescent sponge *Choanites lutkenii*. Up to that time we had surmised that growth rates of the animals were slow, based on the extremely slow recolonization rates. Yet we had not examined the growth of mature animals *in situ*.

Figure 1. The seasonal pattern in blade growth (means ± 95% confidence limits) and nitrogen concentrations.


Linear Growth
Blade Elongation (mmd⁻¹)
1.5
1.0
0.5
0
A S O N D J F M A M J J A S O N D J F M A M J J A S O N
1978
1979
1980


Nitrogen (NO₂⁻ + NO₃⁻)
Concentration (μg-at l⁻¹)
5
4
3
2
1
0
A S O N D J F M A M J J A S O N D J F M A M J J A S O N
1978
1979
1980

In April 1980 six sponges (Choanites) were chosen to monitor growth in this group. Spikes with numbered flourescent tags were driven into the seafloor adjacent to each sponge and then were photographed using .05m^2 framer. Subsequently in August and November 1980, the sponges were relocated and photographed.

The photographs of one sponge, No. 2, is shown in Fig. 2. The other five sponges exhibited almost identical changes in size from one field period to the next.

The noted changes are: (1) a decrease in size between April and August 1980 with a simultaneous change in color from a dirty yellow to a rich yellow. Also apparent was a change from higher porosity and lower density to a lower porosity and greater density; (2) a doubling in size from August to November 1980, with the sponge assuming a character and texture similar to that of April, 1980; (3) a 50% increase in size from November 1980 to April 1981 (photograph not shown) with no changes in texture or character.

It is not known at this time whether increases in size are accompanied by an increase in dry weight. Samples collected in April 1981 and continued study of these sponges in the summer of 1981 should shed more light in understanding the growth of these animals.

Biological Investigation of the Turbid Ice at DS-11 in November, 1980

During our November 1980 field season, we spent on dive at DS-11 examining the turbid ice. We first observed this phenomenon in November 1978 and have since studied it with other scientists, particularly Reimnitz and Barnes (RU-205). Biological investigations are important since several types of organisms are found associated with this substrate, including arctic cod (Fig. 3), different species of amphipods, and polychaete worms. Often however, our observations have been helpful in describing the structure of the turbid ice and in the discovery of biological benthic material in the ice canopy as was seen in November 1980 (Fig. 4).

Ice thickness at DS-11 in November 1980 was 37 cm, with no distinguishable turbid ice layer as in previous years. Large sediment particles were not observed in the ice although the ice block itself did appear dirty. The second major difference in this ice was the inclusion of benthic

Figure 2. Changes in size and appearance of the sponge _Choanites lutkenii_ over a six month period. Refer to text for discussion.

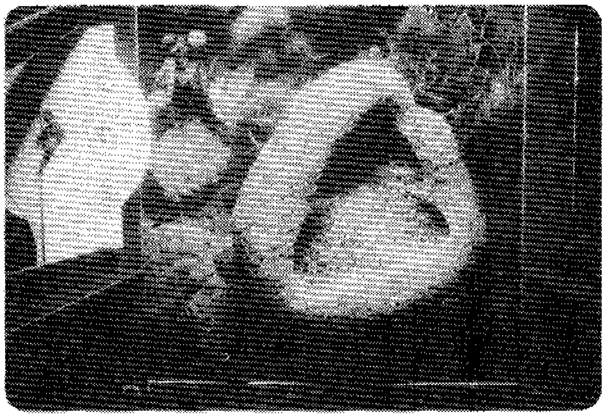
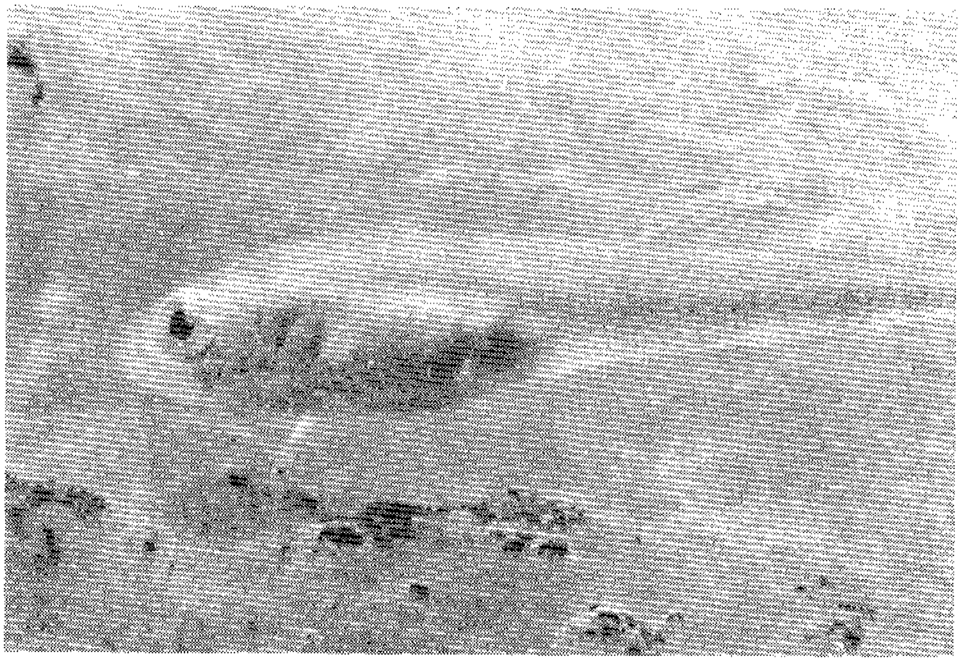


Figure 3. An arctic cod, *Boreogadus saida*, in the turbid ice at DS-11.

Figure 4. Biological material collected in the turbid ice at DS-11 in November, 1980. See text for discussion.



organisms in the turbid ice layer. These included many types, many of them epilithic species with some still attached to their substrate (Fig. 4). Among them were Laminaria saccharina (attached to detrital material and a shell), Phycodrys rubens (attached to a pebble), a large bryozoan, and a large heavy mass of detrital material with four live mussels (Musculus) attached. We found that all of these materials sank quickly after being freed of the ice canopy.

Although anchor ice has never been undisputably documented in the Beaufort Sea, the occurrence of these benthic organisms in the ice canopy adds support to the notion that it does exist. With respect to the mechanisms involved with the formation of turbid ice, this adds yet another dimension to keep geologists and physical scientists busy.

Verification of the Results of the Geophysical Survey of the Boulder Patch by Harding-Lawson Associates for Exxon*

In August 1980, Harding-Lawson Associates (HLA) completed a comprehensive survey of the distribution of cobbles and boulders in Stefansson Sound. One of the main purposes of this survey was to provide Exxon with information to satisfy Federal Lease Stipulation No. 7 and State Stipulation No. 5. These stipulations require certain lessees within the Joint Beaufort Sea Sale Area to conduct environmental surveys for the purpose of locating significant biological habitats.

HLA used a variety of acoustical systems, all of which were calibrated at pre-determined sites prior to the geophysical survey (one of the sites was OCSEAP's DS-11). Calibration involved the use of instruments at sites which possessed different percentages of rock cover and then matching the characteristic signal returns with the known seabed rock cover. This process was repeated until an accurate estimate of rock cover ($< 10\%$, 10-25%, $> 25\%$) could be made based on the character of signal returns. Divers from Kinnetic Laboratories, Inc., determined the percentage of rock cover exposed on the seafloor at each site. Within 100 meters of DS-11 they determined rock cover as 33%. Independently, in 1978 at DS-11 we determined rock cover at 41%. These numbers are sufficiently close especially considering the two surveys were done by different divers at two locations in the same general area.

In late July 1980, our group did some random mapping of the seafloor at various locations in Stefansson Sound. Our survey tool was a dive sled (Fig. 5) built at the Western Washington University shop. The sled was a modified design of one described by Sigl (1969)** and used off the coast of Greece. Using the same precise navigation system used by HLA (a Motorola Mini-Ranger III), and hard wire communications, we 'flew' some 10 km of seafloor at several different locations. In this section we compare our direct seabed observations from one transect with the geophysical results obtained by HLA.

Of our four sled transects, one of them crossed a seafloor of varying degrees of rock cover and is thus best suited for the comparison. In Fig. 6 we have reproduced a portion of the map that shows the percent cover of rocks based on geophysical data (Plate 4 from Rock Habitat Report). The transect line shown is our sled line. The numbered points along this transect can be matched with the observations of the diver, listed in Table 2.

The comparison reveals an excellent correlation between the diver's observations and what is predicted in terms of rock cover using geophysical methods. Other independent observations (by K. D.) in other locations in Stefansson Sound have also added validity to the work done by Harding-Lawson under the direction of Larry Toimil.

It should be noted, however, that a geophysical survey does not give any information about the biological richness of an area. Biologically important areas can be inferred from the percent rock cover, with any rock cover greater than 10% deemed potentially significant until proven otherwise. Even areas with rock covers less than 10% should be given consideration as added insurance that a potentially biologically rich habitat will not be destroyed.

---

*We refer here to a two volume report entitled, "Investigation of Rock Habitats and Sub-Seabed Conditions, Beaufort Sea, Alaska", by Harding-Lawson Associates in cooperation with Kinnetic Laboratories, Inc. The report was prepared for Exxon Company, USA and is proprietary. The information presented here with respect to this report is given by permission of Exxon.

** Our thanks to E. Reimnitz for coming up with this paper.

Figure 5. Diver Dan Pope cruises on the WWU dive sled with the crab *Hyas coarctatus* (under windshield) in 5 m of water in Stefansson Sound. This sled was used by RU-356 in ground truthing areas of Stefansson Sound prior to the geophysical survey done by Harding-Lawson Associates for Exxon.

Figure 6. A portion of the area mapped by HLA showing the distribution and density of boulders. The trackline shown is the transect across the same region done by RU-356 four weeks earlier. See Table 2 for discussion of divers' observations along this transect.

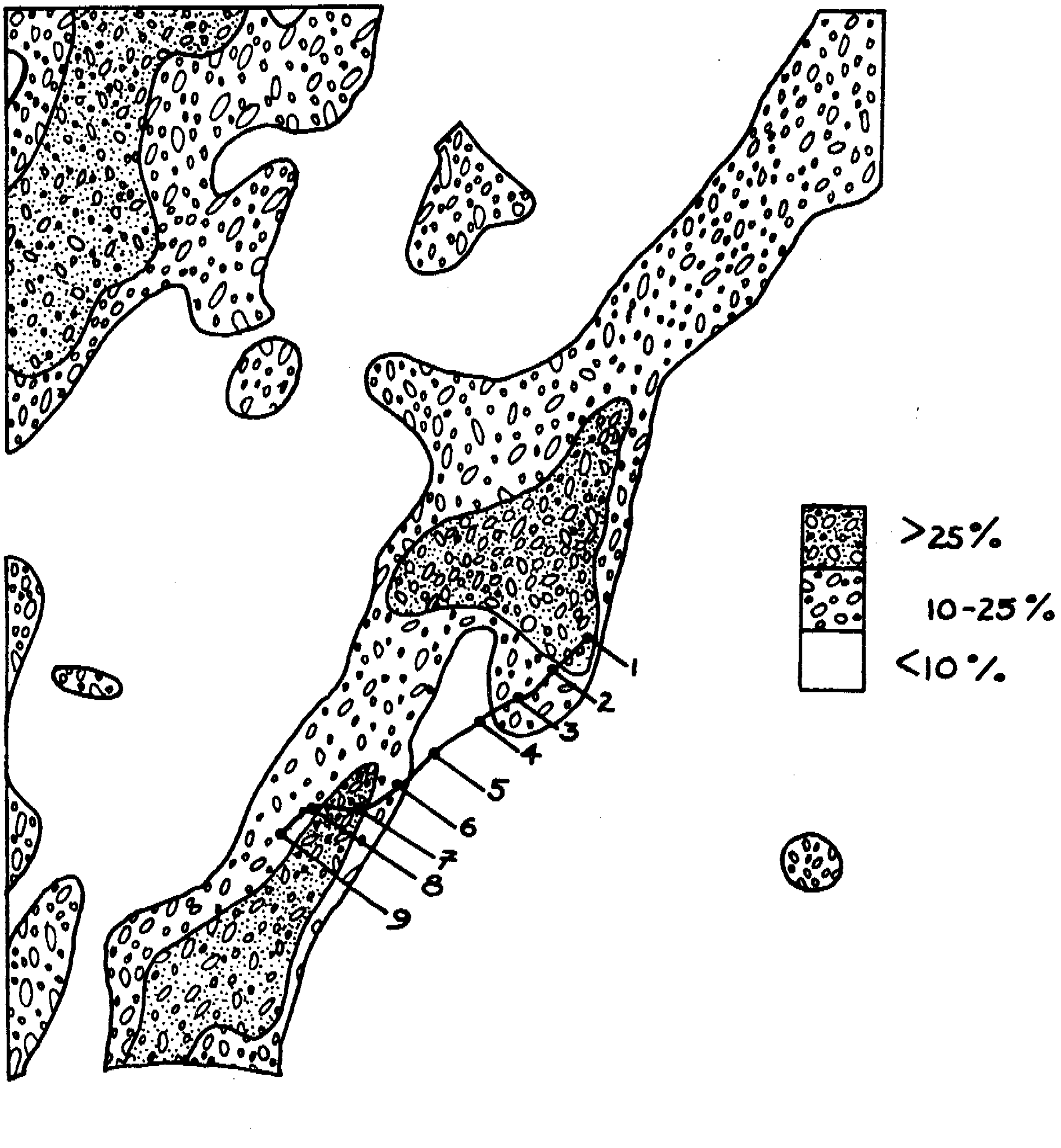

1
2
3
4
5
6
7
8
9
>25%
10-25%
<10%

Table 2. Comparison of rock cover determined from geophysical data (HLA-Rock Habitat report) and observations made by OCSEAP divers at selected points along a dive sled transect (Fig. 6). Agreement is good, with differences due to higher geophysical estimate of rock cover.

Transect Point	Estimated Rock Cover (%) (HLA-Exxon)	Divers' Observations (RU-356 OCSEAP)
1	> 25	100% cover of pebbles and small cobbles, occasional boulders, Laminaria, soft corals, hydroids, red algae present. Diverse community.
2	10-25	Visibility decreases, bottom turns muddy, pebbles and cobbles scattered. Algae infrequent.
3	10-25	Scattered pebbles on mud bottom, boulders and cobbles rare.
4	< 10	Flat muddy bottom, kelp only as drift. Rocks extremely rare.
5	< 10	Flat muddy bottom. Rocks extremely scattered. Peat ledges observed.
6	10-25	Small boulder patch traversed, then a muddy bottom with fewer rocks, rock cover estimated at 15-20%. No boulders, all cobbles and pebbles.
7	> 25	Rocks (mostly pebble size) in windrows on bottom with attached marine life. Rocks very angular. Occasional boulder.
8	10-25	Flat muddy bottom, tubeworms dense (Amphorete). Rocks (pebbles) scattered.
9	10-25	Flat muddy bottom, tubeworms scattered, very few rocks, but rocks angular with red algae, hydroids, and soft corals attached.

Grain Size Sediment Analyses

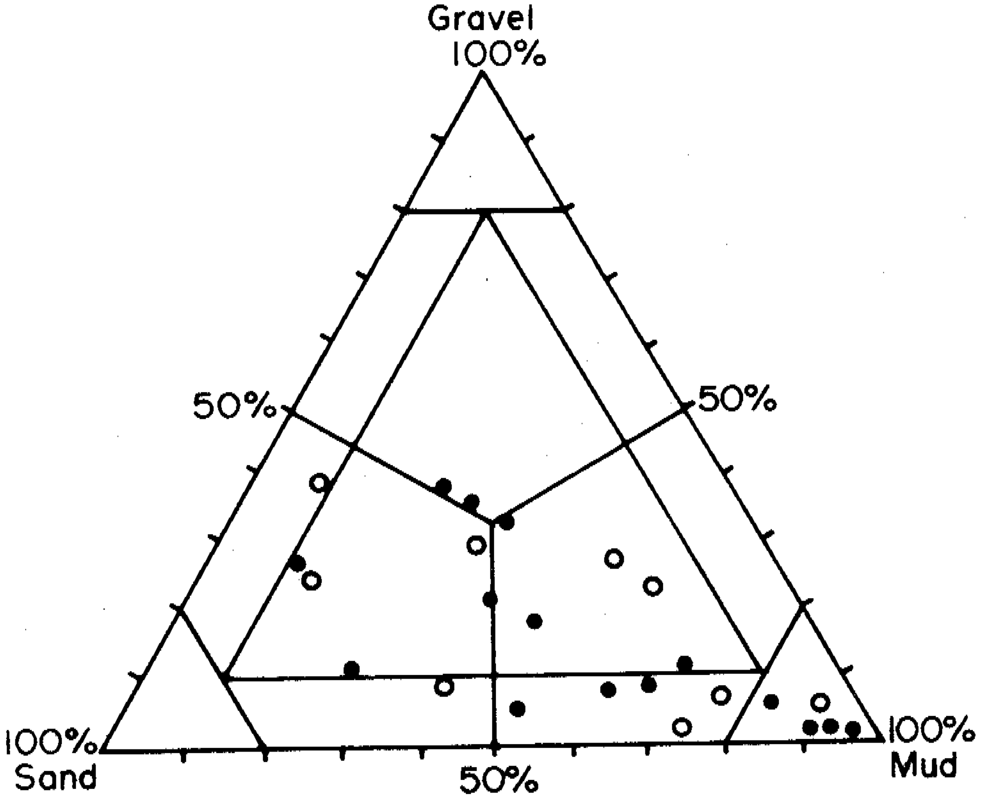
In 1979 sediment samples were randomly collected by divers from between rocks in open areas and under large cobbles or boulders. The purpose of this sampling was to determine the types of sediment present in the DS-11 area. This information would be used for monitoring purposes in assessing changes in substrate composition as a result of oil exploration or development activities.

Samples were scooped to the greatest depth possible by divers using glass sampling jars. The jars were capped underwater following collection of the sample. In the laboratory each of the 9 between-rock and 15 under-rock samples were divided into 3-5 subsamples and air dried. They were then dry sieved with a standard sieve screen set with one PHI increments. The amount caught on each screen was weighed and recorded. The sediments that passed through the 4 PHI mesh were used for pipette analysis. The procedures used here are adopted from Folk (1974).

Figure 7 is a triangular graph presentation of sediment grain size composition from between rock and under rock samples. Each point represents an average of the subsamples taken from the original sample. The lower triangle shows the grain size categories that the plotted points fall into as presented by Buchanan and Kain (1971). Gravel, sand, silt and clay are all represented in the samples but the points tend to be lower on the graph (i.e., closer to the mud (silts and clays) and sand portions of the triangle).

Table 3 shows the mean percent by weight of grain size classes after arcsine transformation of the original percentages. This method was used because theoretically, a mean cannot be determined for proportions (percentages) because proportions are binomial rather than normal in distribution (Zar, 1974). The number in parenthesis under the percent is the 95% confidence interval. The 95% confidence intervals overlap on all the grain size classes except the silts. This infers that the percent by weight of silts in the under rock samples is significantly higher than in the between rock samples.

Figure 7. A triangular graph of sediment grain size composition from between rock and under rock samples. Each point represents the average of 3-5 subsamples. Under rock samples are designated by solid circles, and the open circles designate between rock samples. The bottom graph shows the grain size categories as presented by Buchanan and Kain (1971).


Gravel
100%
50%
50%
100%
Sand
50%
100%
Mud

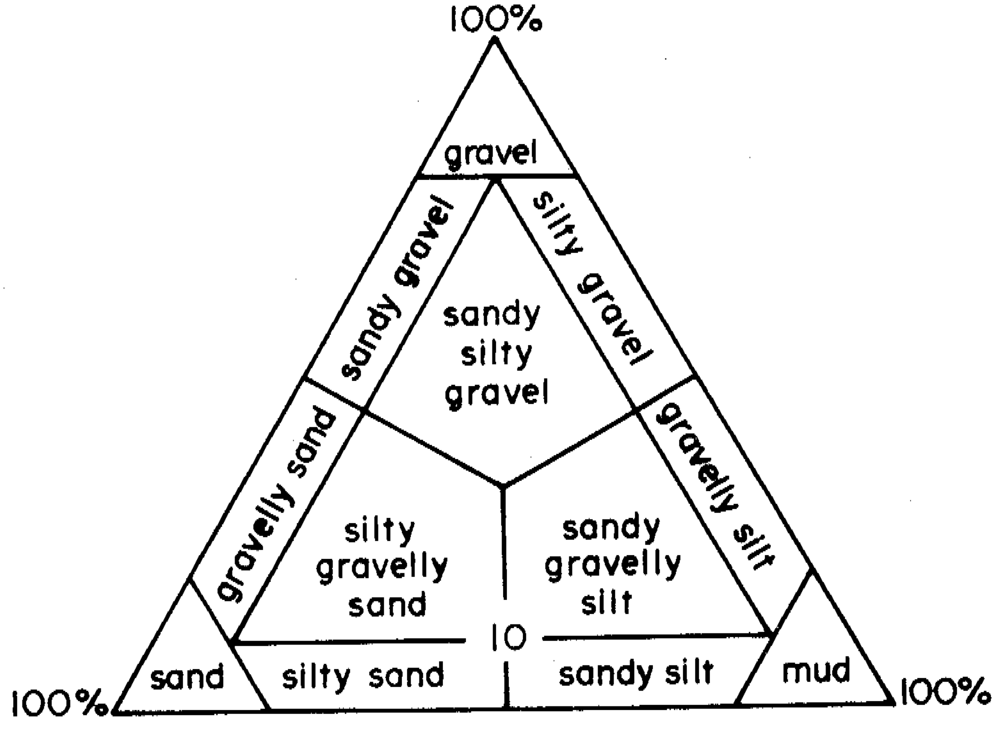

100%
gravel
sandy gravel
silty gravel
sandy silty gravel
gravelly sand
gravelly silt
silty gravelly sand
sandy gravelly silt
10
sand
silty sand
sandy silt
mud
100%
100%

Table 3. Mean percent by weight of grain size classes after arcsine transformation of original percentages (Zar, 1974, p. 185-186). Back-transformation applied. Numbers in parentheses are 95% C.I. Data is based on all subsamples.

Grain Size Class	Between Rocks N=25	Under Rocks N=43
Gravel	18.0% (11.4-25.8)	11.8% (7.4-17.1)
Sand	38.6% (29.7-47.9)	28.2% (21.8-35.2)
Silt	25.8% (16.2-36.7)	44.3% (34.6-54.2)
Clay	7.1% (4.0-10.9)	11.5% (5.1-19.9)

The Spatial Distribution of Infaunal Organisms in Four Habitat Types at DS-11

The random collection of sediment samples at DS-11 in 1979 (see previous section) led to the discovery by divers that they were able to visually identify four distinct benthic habitats: (1) between rocks-gravel, (2) under rock-gravel, (3) between rock-clay, and (4) under rock-clay. Although we have not yet documented this visual impression by grain size analysis of the sediments in these four locations, we felt that our observations justified a biological analysis of the four habitat types. The objective of the study would be two-fold, (1) to establish the differences in infaunal assemblages based on substrate type and protection (i.e., between or under rocks) and (2) to determine the vertical distribution of organisms in the sediments in the four different habitats.

The knowledge gained would be useful in assessing the effects of various disturbances to the benthic infauna. These disturbances include heavy siltation, oil on the sediment surface, addition of new substrate, and gouging or movement of the substrate. The results would also provide valuable information on the validity of various benthic sampling techniques, especially with repsect to the penetration of a given sampling device.

On July 28 and 29, 1980, a diver collected 48 cores (12 each of the four habitat types) using a series of modified 50 cc hypodermic syringes. The cores were injected with 10% formalin in the field and the syringes plugged to keep the sample intact. In the laboratory the core was removed and sliced into 1 cm sections. These samples were rinsed through a 0.5 mm screen, sorted and the organisms identified, weighed and counted.

Appendix Table 1 lists all the species collected and is organized by core depth. Appendix Table 2 is similar except only major taxa are listed. For each major taxon the number of species, the mean number of organisms, and the frequency of occurrence are presented. Biomass was eliminated in Appendix Table 2 because most species weighed less than 0.001 g and therefore could not be accurately added together for a taxon representation.

Appendix Table 3 shows the data off which Figure 8 is plotted. It presents the mean number of animals and total number of species for each depth increment and habitat type. It also shows totals for core depths of all habitat types and total mean numbers of organisms and species numbers for each habitat type.

Figure 8 shows the relationship between the number of species and depth within the four habitat types. Figure 9 displays the relationship between the total number of organisms in the sample to core depth. Figure 10 shows the total number of species present in all samples combined for each depth increment.

All three figures (8, 9, 10) show a general decrease in the number and kinds of animals present as core depth increases, regardless of habitat type. The gravel substrates appear to contain a larger number of species than the clay substrates except in the top 1 cm of between rock-clay. This may be due to anoxic conditions in the clays in that the oxidation-reduction potential discontinuity is placed relatively closer to the sediment-water interface of the muddy substrates than in sandy sediments. Six cm and deeper the number of species found in all of the substrate types is very low and similar to each other.

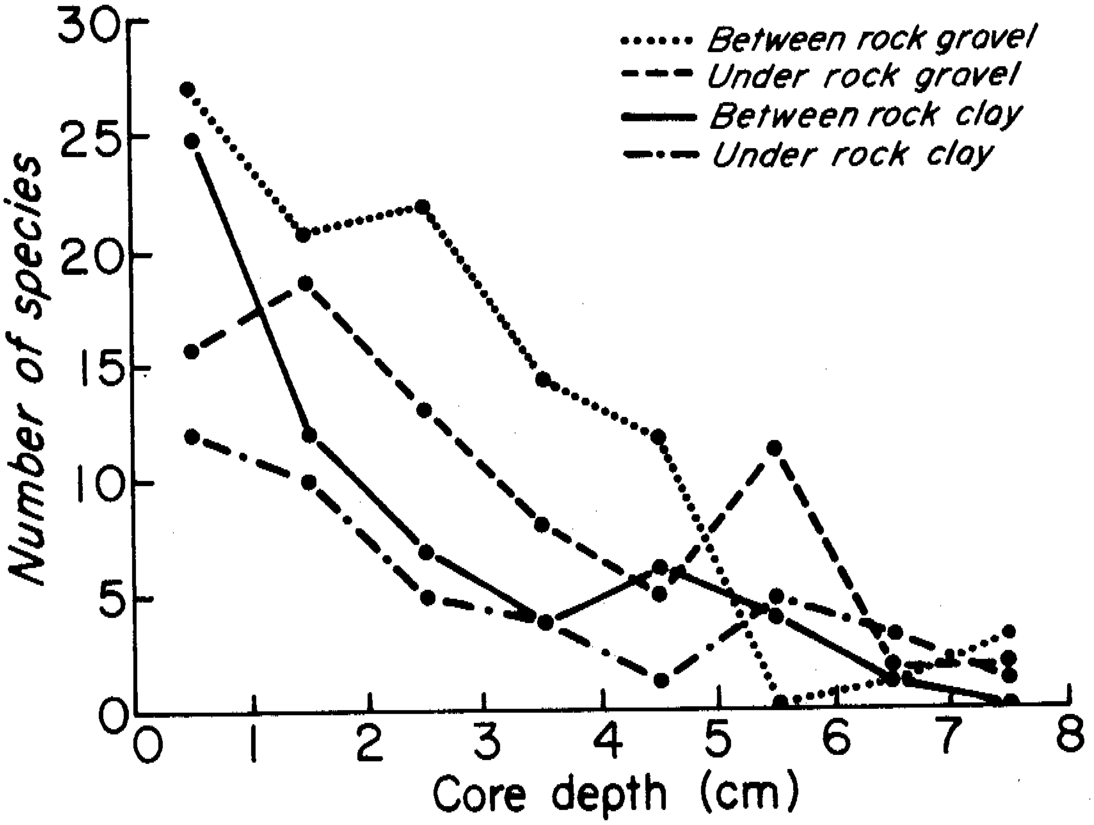
Figure 9 shows the number of organisms as a function of core depth. The gravel substrates seem to possess a greater number of organisms than do the clay substrates but at 6 cm and deeper the four lines almost merge. Figure 8 shows that the number of species in both gravel and clay substrates decrease with depth. There is a fairly large drop at the 3 cm depth and another at the 6 cm depth.

These data show that a majority of the infauna live very close to the sediment-water interface. Therefore any disturbance involving the top 7 cm of substrate would be altering the infaunal structure.

It is interesting to note that our method of airlifting a .01 m^2 core for infaunal sampling has revealed substantially more species to be present at DS-11 than were found in these 47 syringe cores. Usually the substrate is so hard that the airlift sample doesn't penetrate below 5-6 cm and thus these other species must not come from greater depths. The most apparent discrepancy is with the molluscs. Of the 47 syringe cores analyzed only a couple of juvenile <u>Astarte</u> sp. and one unknown bivalve were collected (Appendix Table 1). In 17 .01 m^2 airlift cores, 11 species of bivalves and 7 species of gastropods were collected (Appendix Table 4). It appears that a sampling device as small as the syringe (2.5 cm diameter) could not be used to successfully look at infauna in a quantitative manner.

Figure 8. The number of species identified in each of the four habitat types as a function of core depth.

Figure 9. The total number of organisms in each of the four habitat types as a function of core depth.


Between rock gravel
Under rock gravel
Between rock clay
Under rock clay
Number of species
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
Core depth (cm)

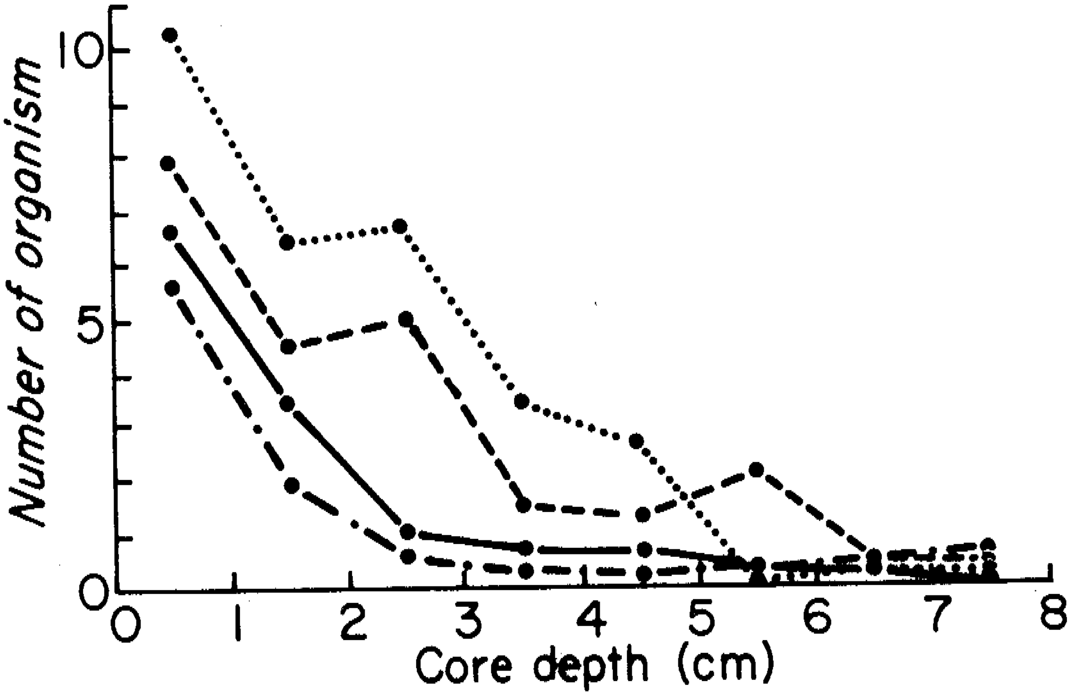
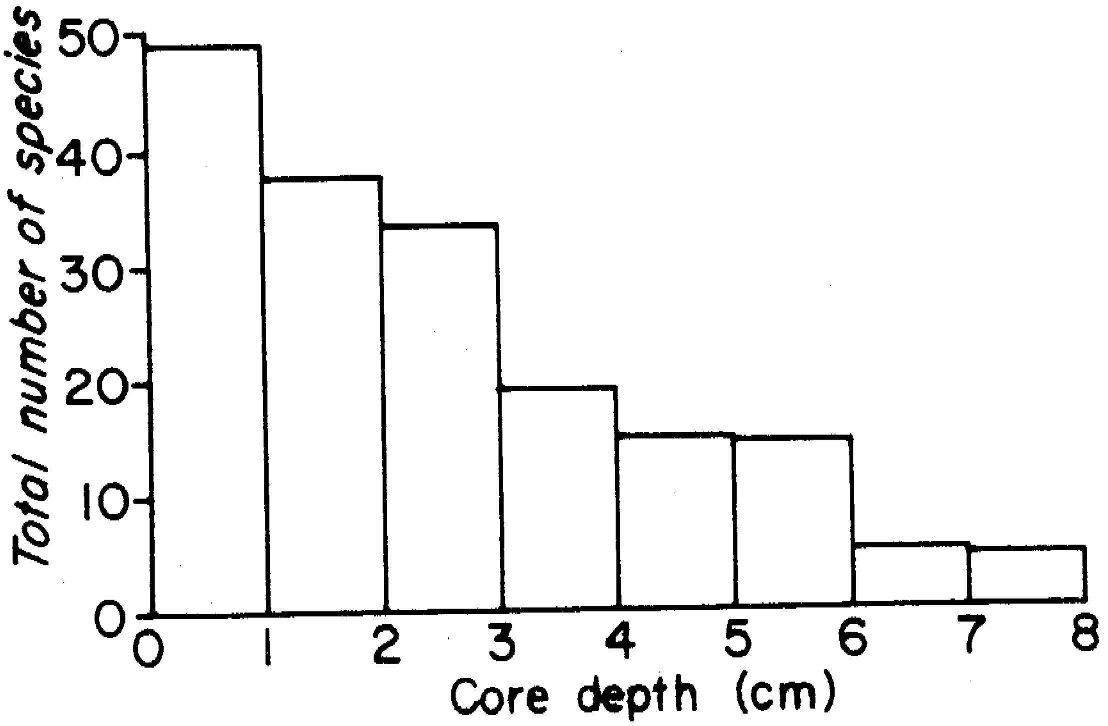

Number of organism
10
5
0
0
1
2
3
4
5
6
7
8
Core depth (cm)

Figure 10. A histogram of the total number of species in the cores from all habitat types as a function of substrate depth.


Total number of species
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
Core depth (cm)

Quantitative Analyses of the Benthic Infauna

Benthic cores at DS-11 are collected using a diver operated airlift. Material collected in a 1 mm nylon mesh bag is brought to the surface where it is placed in a sample jar and preserved. Cores are taken both between and under rocks (cobbles or small boulders). A comparison of the mean species density, biomass and frequency between these two areas is presented in Appendix Table 4. A summary of this data in terms of the major taxonomic groups is shown in Table 4 of the text. In general, there is both greater number and biomass of organisms living in substrates located under rocks.

Qualitative Analyses of the Epilithic Flora and Fauna

Determination of species composition, density and biomass of epilithic organisms was accomplished through the scraping of .05 m^2 areas on rock surfaces. Divers worked in teams of two, one scraping and the other air-lifting the scraped material into a 1 mm nylon mesh bag. Rocks were scraped using a stainless steel paint scraper, which removed 98% of the animals and plants present. Samples were placed in jars and formalized after being brought to the surface.

The mean density and biomass of species collected is presented in Appendix Table 5. A summary of this data for the major taxonomic groups is shown in Table 5 of the text. Of the invertebrate biomass, polychaetes predominate, followed by bryozoans, chitons, hydroids and sponges. The algae is dominated by several species of Rhodophytes and constitutes over 60% of the total biomass.

Table 4. A comparison of mean density ($\bar{N}$) and mean biomass ($\bar{g}$) of major taxonomic groups collected in .01 m^2 airlift cores collected between rocks and under rocks. The cores combined to generate these data were taken in March or May 1979, July 1979, November 1979, February 1980, and April 1980.

	UNDER ROCKS			BETWEEN ROCKS		
Group	# Species	$\bar{N}/m^2$	$\bar{g}/m^2$	# Species	$\bar{N}/m^2$	$\bar{g}/m^2$
Foraminifera	7	722.60	0.2670	8	1452	0.6112
Porifera	2		0.0384	5		1.979
Cnidaria						
Hydrozoa	2		0.4740	4		2.590
Anthozoa					3	0.221
Nemertea		31.7	0.082		45	0.302
Nematoda		467.0	0.088		486	0.091
Annelida						
Polychaeta	41	3514.20	23.725	28	1379	3.716
Oligochaeta		25.0	0.018			
Mollusca						
Prosobranchia	4	50.0	2.7770	5	52	0.294
Polyplacophora	1	8.3	0.550	1	3	0.001
Pelecypoda	7	111.60	6.5740	7	100	1.771
Arthropoda						
Ostracoda		26.7	0.013		41	0.009
Copepoda		747.2	0.262		576	0.200
Cumacea	3	216.60	0.3540	4	151	0.192
Tanaidacea	1	81.7	0.029	1	61	0.032
Amphipoda	17	270.10	1.7497	13	331	1.721
Mysidacea	1	10.0	0.1160			
Euphausicacea	1	1250.0	37.597	1	94	2.443

Table 4 (continued)

	UNDER ROCK			BETWEEN ROCK		
Group	# Species	$\bar{N}/m^2$	$\bar{g}/m^2$	# Species	$\bar{N}/m^2$	$\bar{g}/m^2$
Sipuncula					5	0.005
Priapulida	1	5.0	1.1225	1	5	0.400
Bryozoa	14		5.980	10		1.680
Echinodermata						
Asteroidae		10.0	2.66		9	0.223
Chordata						
Urochordata Ascidacea		3.3	0.003		12	0.184
Algae						
Rhodophyta	4		7.583			
Unknown algae				7		26.642

Table 5. These data show the mean densities ($\bar{N}$) and biomass ($\bar{g}$) of major taxonomic groups occurring in .05 m^2 scrape samples. The scrapes were taken in 8-2-79 (N=6), 3-4-80 (N=5) and 4-25-80 (N=6).

Groups	$\bar{N}/m^2$	$\bar{g}/m^2$
Foraminifera	5505.47	0.4005
Porifera		8.5314
Cnidaria		
Hydrozoa		10.3163
Scyphozoa		
Anthozoa	4.0	0.2854
Nemertea	62.23	0.0897
Nematoda	94.0	0.0077
Annelida		
Polychaeta	1978.97	43.8279
Mollusca		
Prosobranchia	37.52	0.2985
Opisthobranchia	4.67	0.0059
Polyplacophora	27.33	13.2270
Pelecypoda	274.90	0.1669
Arthropoda		
Halicaridae	52.0	0.0058
Crustacea		
Ostracoda	4.0	0.0007
Copepoda	108.44	0.0184
Cirripedia	2.43	0.0043
Cumacea	22.21	0.0161
Tanaidacea	2.67	0.0003

Table 5 (continued)

Groups	$\bar{N}/m^2$	$\bar{g}/m^2$
Arthropoda (continued)		
Crustacea		
Isopoda	17.11	0.0046
Amphipoda	635.0	2.4049
Mysidacea	13.33	0.1096
Euphausiacea	152.0	4.6900
Bryozoa		20.7865
Enchinodermata		
Asteroidea	9.33	0.1720
Chordata		
Urochordata		
Ascidiacea	13.77	3.1459
ALGAE		
Phaeophyta		37.1294
Rhodophyta		141.7651
Diatoms		0.3632

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Appendix Table 1. Organisms identified in syringe cores from each habitat type and separated by core depth (0 to -1 cm, -1 to -2 cm, etc.). Mean number of individuals ($\bar{N}$), biomass ($\bar{g}$) and frequency of occurrence (f) of each species is also shown.

CORE DEPTH : 0-1 cm

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Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
FORAMINIFERA												
Elphidiella sp.	1.5	<0.001	75	2.4	<0.001	100	0.5	<0.001	27	1.1	<0.001	42
Guttulina sp.	0.2	<0.001	8				0.1	<0.001	9	0.2	<0.001	17
Lagena sp.	0.2	<0.001	17	0.2	<0.001	8						
Nonionidae	1.8	<0.001	75	2.4	<0.001	83	0.5	<0.001	50	1.8	<0.001	17
Triloculina sp.				0.1	<0.001	8	0.1	<0.001	9	0.1	<0.001	8
Unknown forams	0.3	<0.001	33	0.7	<0.001	50				0.1	<0.001	8
PORIFERA												
Unknown sponge							-	<0.001	9			
HYDROZOA												
Lafoeina maxima	-	<0.003	8									
Sertularia sp.				-	<0.001	17						
Hydrozoan fragments	-	<0.001	17	-	<0.001	17	-	<0.001	18	-	<0.001	9
NEMATODA	2.6	<0.001	100	0.6	<0.001	42	2.0	<0.001	82	1.0	<0.001	25
POLYCHAETA												
Allia sp.				0.1	<0.001	8						
Ampharete acutifrons							0.1	<0.001	9			
Brada villosa	0.1	<0.001	8									
Capitella capitata				0.3	<0.001	25				0.1	<0.001	8
Chone sp.							0.2	<0.001	18			
Cirratulus sp.							0.1	<0.001	9			
Exogone dispar	0.1	<0.001	8	0.2	<0.001	17	0.3	<0.001	27			
Exogone naidina	0.9	<0.001	58				0.7	<0.001	36			
Lumbrineris fragilis				0.1	<0.001	8	0.1	<0.001	9			
Lumbrineridae							0.1	<0.001	9			

CORE DEPTH: 0-1 cm

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
Maldanidae	0.2	<0.001	17									
Paraonidae	0.1	<0.001	8									
Pista cristata	0.1	<0.001	8				0.2	<0.001	18			
Prionospio cirrifera	0.1	<0.001	8				0.2	<0.001	18			
Schistomeringos sp.	0.2	<0.001	17									
Sphaerodoropsis minuta							0.1	<0.001	9			
Sphaerosyllis erinaceus										0.1	<0.001	8
Spionidae	0.1	<0.001	8	0.1	<0.001	8	0.2	<0.001	18			
Syllidae	0.1	<0.001	8				0.1	<0.001	9			
Terebellidae	0.1	<0.001	8									
Terebellides stroemi	0.3	<0.001	25	0.1	<0.001	8	0.1	<0.001	9			
Polychaete fragments	-	<0.001	33	-	<0.001	8	-	<0.001	36	-	<0.001	8
GASTROPODA										0.1	<0.001	8
BIVALVIA												
Astarte sp.							0.1	<0.001	9			
OSTRACODA	1.0	<0.001	58	0.5	<0.001	50	0.6	<0.001	36	1.0	<0.001	42
COPEPODA HARPACTICOIDA	0.1	<0.001	8				0.1	<0.001	9			
CUMACEA												
Brachidiastylis resima				0.1	<0.001	8						
Diastylis sp.	0.1	<0.001	8									
TANAIDACEA												
Leptognathia gracilis	0.1	<0.001	8									

CORE DEPTH: 0-1 cm

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Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
BRYOZOA												
Callopora lineata							-	<0.001	9			
Eucratea loricata												
Hippothoa hyalina	-	<0.001	8	-	<0.001	25				-	<0.001	17
Unknown Bryozoan #1	-	<0.001	8									
Unknown Bryozoan #2				-	<0.001	17	-	<0.001	9	-	<0.008	17
Bryozoan fragments	-	<0.001	8	-	<0.001	8				-	<0.002	25
ALGAE												
Lithothamnium sp.	-	<0.001	8									
Odonthalia dentata	-	<0.001	8									
Phycodrys rubens							-	<0.001	9			
Unknown alga	-	<0.001	8									
EGGS	0.6	<0.001	25									

CORE DEPTH: 1-2 cm

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\overline{N}$	B	f	$\overline{N}$	B	f	$\overline{N}$	B	f	$\overline{N}$	B	f
FORAMINIFERA												
Elphidiella sp.	1.3	<0.001	67	1.4	<0.001	50	0.4	<0.001	36	0.9	<0.001	17
Guttulina sp.	0.2	<0.001	17	0.1	<0.001	8						
Lagena sp.	0.1	<0.001	8	0.1	<0.001	8				0.1	<0.001	8
Miliolinella sp.	0.3	<0.001	8									
Nonionidae	1.6	<0.001	83	1.0	<0.001	58	0.4	<0.001	36	0.3	<0.001	17
Quinqueloculina sp.				0.1	<0.001	8						
Unknown forams	0.3	<0.001	17	0.1	<0.001	8	0.1	<0.001	9	0.1	<0.001	8
PORIFERA												
Haliclona rufescens				0.1	<0.001	8						
Unknown sponge				0.1	<0.001	8						
HYDROZOA												
Lafoeina maxima										-	<0.001	8
Hydrozoan fragments	-	<0.001	25	-	<0.001	8						
NEMATODA	1.3	<0.001	50	0.3	<0.001	17	1.3	<0.001	55	0.2	<0.001	17
POLYCHAETA												
Ampharete acutifrons	0.1	<0.001	8									
Brada villosa	0.1	<0.001	8									
Capitella capitata							0.1	<0.001	9			
Exogone dispar	0.1	<0.001	8	0.1	<0.001	8						
Exogone naidina	0.1	<0.001	8	0.1	<0.001	8	0.1	<0.001	9			
Lumbrineris fragilis				0.2	<0.001	17						
Maldanidae	0.2	<0.001	17									
Pista cristata	0.1	<0.001	8									

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
Prionospio cirrifera							0.1	<0.001	9			
Schisteromeringos sp.				0.1	<0.001	8						
Sphaerosyllis erinaceus				0.1	<0.001	8						
Spionidae				0.1	<0.001	8						
Syllidae							0.1	<0.001	9			
Terebellides stroemi	0.1	<0.001	8	0.1	<0.001	8						
Polychaete fragments	-	<0.001	17	-	<0.001	8	-	<0.001	18			
GASTROPODA										0.1	<0.001	8
BIVALVIA												
Astarte sp.	0.1	<0.001	8	0.1	<0.001	8						
OSTRACODA	0.1	<0.001	8	0.3	<0.001	25	0.5	<0.001	45	0.3	<0.001	17
CUMACEA												
Brachidiastylis resima	0.1	<0.001	8				0.1	<0.001	9			
Diastylis							0.1	<0.001	9			
TANAIDACEA												
Leptognathia gracilis							0.1	<0.001	9			
BRYOZOA												
Hippothoa hyalina	-	<0.001	8	-	<0.001	17				-	<0.001	17
Bryozoan fragments	-	<0.001	8	-	<0.001	17				-	<0.001	25
ASCIDIACEA	0.1	<0.001	8									
ALGAE												
Odonthalia dentata	-	0.004	8									
Phyllophora truncata	-	0.005	8									
EGGS	0.1	<0.001	8							0.1	<0.001	8

CORE DEPTH: 2-3 cm

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
FORAMINIFERA												
Cornuspira involvens	0.1	<0.001	8	0.1	<0.001	8						
Elphidiella sp.	1.1	<0.001	58	1.7	<0.001	42				0.3	<0.001	17
Lagena sp.	0.3	<0.001	8									
Nonionidae	1.0	<0.001	50	1.4	<0.001	58						
Unknown forams	0.2	<0.001	8	0.2	<0.001	17						
PORIFERA												
Unknown sponge				0.2	<0.001	17						
HYDROZOA												
Lafoeina maxima										-	<0.001	8
Hydrozoan fragments	-	<0.001	50	-	<0.001	17						
NEMATODA	1.9	<0.001	67	0.5	<0.001	42	0.4	<0.001	27	0.1	<0.001	8
POLYCHAETA												
Ampharete acutifrons	0.1	<0.001	8									
Capitella capitata	0.1	<0.001	8									
Chone sp.	0.1	<0.001	8									
Cirratulidae	0.1	<0.001	8									
Exogone dispar	0.3	<0.001	25									
Exogone naidina	0.7	<0.001	25	0.1	<0.001	8	0.1	<0.001	9			
Lumbrineris fragilis				0.1	<0.001	8						
Maldanidae	0.1	<0.001	8									
Nereis sp.				0.1	0.005	8						
Pista cristata	0.2	<0.001	17				0.1	<0.001	9			
Schistomeringos sp.	0.1	<0.001	8									

CORE DEPTH: 2-3 cm

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
Spionidae	0.1	<0.001	8				0.1	<0.001	9			
Spirorbis sp.				0.1	<0.001	8						
Syllidae							0.1	<0.001	9			
Tauberia gracilis							0.1	<0.001	9			
Terebellides stroemi												
Polychaete fragments	-	<0.001	17	-	<0.001	8	-	<0.001	36			
GASTROPODA							0.1	<0.001	9			
BIVALVIA												
Unknown bivalve										0.1	<0.001	8
OSTRACODA	0.2	<0.001	17	0.4	<0.001	25				0.2	<0.001	17
CUMACEA												
Brachidiastylis resima	0.1	<0.001	8									
BRYOZOA												
Hippothoa hyalina	-	<0.001	8	-	<0.001	25						
Unknown bryozoan #1	-	<0.001	8									
Bryozoan fragments										-	<0.001	8
ALGAE												
Lithothamnium sp.	-	<0.001	8									
Phycodrys rubens	-	<0.001	8									
EGGS	0.1	<0.001	8	0.7	<0.001	8						

CORE DEPTH: 3-4 cm page 8 of 12

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=11			Between Rock-Clay N=11			Under Rock-Clay N=11		
	$\overline{N}$	B	f	$\overline{N}$	B	f	$\overline{N}$	B	f	$\overline{N}$	B	f
FORAMINIFERA												
Cornuspira involvens				0.1	<0.001	9						
Elphidiella sp.	0.4	<0.001	25	0.5	<0.001	18	0.2	<0.001	18			
Lagena sp.	0.1	<0.001	8									
Nonionidae	0.2	<0.001	17	0.5	<0.001	36				0.1	<0.001	9
HYDROZOA												
Hydrozoan fragments	-	<0.001	17	-	<0.001	18						
NEMATODA	0.8	<0.001	33	0.3	<0.001	27	0.5	<0.001	18	0.1	<0.001	9
POLYCHAETA												
Brada villosa	0.1	<0.001	8									
Exogone naidina	0.3	<0.001	17									
Maldanidae	0.2	<0.001	17									
Nereis zonata				0.1	0.020	9						
Schistomeringos sp.				0.1	<0.001	9						
Spionidae	0.1	<0.001	8									
Syllidae	0.1	<0.001	8									
Terebellides stroemi	0.1	<0.001	8									
Polychaete fragments							-	<0.001	36			
BIVALVIA (unknown)										0.1	<0.001	9
OSTRACODA	0.8	<0.001	33	0.2	<0.001	9	0.1	<0.001	9			
COPEPODA-HARPACTICOIDA	0.1	<0.001	8									
CUMACEA												
Brachidiastylis resima	0.1	<0.001	8									

CORE DEPTH: 3-4 cm

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=11			Between Rock-Clay N=11			Under Rock-Clay N=11		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
BRYOZOA (fragments)										-	<0.001	9
ALGAE												
Phycodrys rubens	-	<0.001	8				-	<0.001	9	-	<0.001	9
Unknown algae				-	<0.001	9						
EGGS	0.3	<0.001	17									

CORE DEPTH: 4-5 cm

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Taxon	Between Rock-Gravel N=11			Under Rock-Gravel N=11			Between Rock-Clay N=11			Under Rock-Clay N=10		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
FORAMINIFERA												
Cornuspira involvens	0.1	<0.001	9									
Elphidiella sp.	0.6	<0.001	18	0.2	<0.001	9	0.1	<0.001	9	0.1	<0.001	10
Nonionidae	0.3	<0.001	27	0.9	<0.001	45	0.1	<0.001	9			
Unknown forams	0.1	<0.001	9									
HYDROZOA (fragments)	-	<0.001	9									
NEMATODA	0.4	<0.001	18	0.2	<0.001	18	0.2	<0.001	18			
OLIGOCHAETA							0.1	<0.001	9			
POLYCHAETA												
Exogone naidina	0.2	<0.001	18	0.1	<0.001	9						
Lumbrineris fragilis	0.2	<0.001	18									
Maldanidae	0.1	<0.001	9									
Prionospio cirrifera							0.1	<0.001	9			
Spio filicornis							0.1	<0.001	9			
Syllis sp.	0.2	<0.001	9									
Terebellidae	0.1	<0.001	9									
Polychaete fragments	-	<0.001	9	-	<0.001	9						
OSTRACODA	0.3	<0.001	18	0.2	<0.001	9						
CUMACEA												
Brachidiastylis resima	0.1	<0.001	9									

CORE DEPTH: 5-6

Taxon	Between Rock-Gravel N=6			Under Rock-Gravel N=11			Between Rock-Clay N=10			Under Rock-Clay N=8		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
FORAMINIFERA												
Elphidiella sp.				0.7	<0.001	45	0.1	<0.001	10	0.1	<0.001	12
Lagena sp.				0.1	<0.001	9						
Nonionidae				0.3	<0.001	18				0.1	<0.001	12
Triloculina sp.				0.2	<0.001	9						
HYDROZOA (fragments)				-	<0.001	9						
NEMATODA				0.2	<0.001	18						
NEMERTEA				0.1	<0.001	9				0.1	<0.001	12
POLYCHAETA												
Capitella capitata				0.1	<0.001	9						
Exogone naidina							0.1	<0.001	10			
Nereis sp.				0.1	0.009	9						
Terebellides stroemi				0.1	<0.001	9						
Polychaete fragments										-	<0.001	12
OSTRACODA				0.1	<0.001	9						
CUMACEA												
Diastylis sp.							0.1	<0.001	10			
TANAIDACEA												
Leptognathia gracilis				0.1	<0.001	9						
BRYOZOA (fragments)				-	<0.001	9						
ALGAE (fragments)							-	<0.001	10			

CORE DEPTH: 6-7 cm

Taxon	Between Rock-Gravel			Under Rock-Gravel			Between Rock-Clay			Under Rock-Clay		
	N=5			N=8			N=5			N=5		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
FORAMINIFERA												
Nonionidae	0.2	<0.001	20							0.4	<0.001	40
NEMATODA				0.1	<0.001	12						
POLYCHAETA												
Eteone longa							0.2	<0.001	20			
OSTRACODA				0.1	<0.001	12						
BRYOZOA (Unknown #1)										-	<0.001	20

CORE DEPTH: 7-8 cm

Taxon	Between Rock-Gravel			Under Rock-Gravel			Between Rock-Clay			Under Rock-Clay		
	N=8			N=5			N=1			N=2		
	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f	$\bar{N}$	B	f
FORAMINIFERA												
Elphidiella sp.	0.1	<0.001	12	0.2	<0.001	20						
Nonionidae										0.5	<0.001	50
NEMATODA	0.1	<0.001	12	0.4	<0.001	20						
POLYCHAETA												
Scoloplos armiger	0.1	<0.001	12									

Appendix Table 2. The major taxa recorded from syringe cores from each habitat type separated by core depth (0 to -1 cm, -1 to -2 cm, etc.). The number of species in each major taxon, the mean number of animals ($\bar{N}$) and frequency (f) are listed.

CORE DEPTH: 0-1 cm

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	#species	$\bar{N}$	f	#species	$\bar{N}$	f	#species	$\bar{N}$	f	#species	$\bar{N}$	f
FORAMINIFERA	5	4.0	100	5	5.8	92	4	1.2	63	5	3.3	42
PORIFERA							1	-	9			
HYDROZOA	1	-	25	1	-	42						
NEMATODA	?	2.6	100	?	0.6	42	?	2.0	82	?	1.0	25
POLYCHAETA	12	2.4	92	6	0.9	42	13	2.5	90	2	0.2	25
GASTROPODA										1	0.1	8
BIVALVIA							1	0.1	9			
OSTRACODA	?	1.0	58	?	0.5	50	?	0.6	36	?	1.0	42
COPEPODA	1	0.1	8				1	0.1	9			
CUMACEA	1	0.1	8	1	0.1	8						
TANAIDACEA	1	0.1	8									
BRYOZOA	2	-	17	2	-	50	2	-	18	2	-	33
ALGAE	3	-	25				1	-	9			

CORE DEPTH: 1-2 cm page 2 of 7

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	#species	$\overline{N}$	f	#species	$\overline{N}$	f	#species	$\overline{N}$	f	#species	$\overline{N}$	f
FORAMINIFERA	6	3.8	100	6	2.8	75	3	0.9	55	4	1.4	42
PORIFERA				2	0.2	17						
HYDROZOA										1	-	8
NEMATODA	?	1.3	50	?	0.3	17	?	1.3	55	?	0.2	17
POLYCHAETA	7	0.8	67	7	0.8	25	4	0.4	27			
GASTROPODA										1	0.1	8
BIVALVIA	1	0.1	8	1	0.1	8						
OSTRACODA	?	0.1	8	?	0.3	25	?	0.5	45	?	0.3	17
CUMACEA	1	0.1	8				2	0.2	18			
TANAIDACEA							1	0.1	9			
BRYOZOA	1	-	8	1	-	17	1	-	17			
ASCIDIACEA	1	0.1	8									
ALGAE	2	-	17									

CORE DEPTH: 2-3 cm page 3 of 7

Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=12			Between Rock-Clay N=11			Under Rock-Clay N=12		
	#species	$\overline{N}$	f	#species	$\overline{N}$	f	#species	$\overline{N}$	f	#species	$\overline{N}$	f
FORAMINIFERA	5	2.7	67	4	3.4	67				1	0.3	17
PORIFERA				1	0.2	17						
HYDROZOA										1	-	8
NEMATODA	?	1.9	67	?	0.5	42	?	0.4	27	?	0.1	8
POLYCHAETA	10	1.9	58	5	0.5	17	5	0.5	45			
GASTROPODA							1	0.1	9			
BIVALVIA										1	0.1	8
OSTRACODA	?	0.2	17	?	0.4	25				?	0.2	17
CUMACEA	1	0.1	8									
BRYOZOA	2	-	17	1	-	25						
ALGAE	2	-	17									

CORE DEPTH: 3-4 cm

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Taxon	Between Rock-Gravel N=12			Under Rock-Gravel N=11			Between Rock-Clay N=11			Under Rock-Clay N=11		
	#species	N	f	#species	N	f	#species	N	f	#species	N	f
FORAMINIFERA	3	0.7	42	3	1.1	45	1	0.2	18	1	0.1	9
NEMATODA	?	0.8	33	?	0.3	27	?	0.5	18	?	0.1	9
POLYCHAETA	6	0.9	42	2	0.2	9						
BIVALVIA										1	0.1	9
OSTRACODA	?	0.8	33	?	0.2	9	?	0.1	9			
COPEPODA-HARPACTICOIDA	1	0.1	8									
CUMACEA	1	0.1	8									
ALGAE	1	-	8	1	-	9	1	-	9	1	-	9

CORE DEPTH: 4-5 cm

Taxon	Between Rock-Gravel N=11			Under Rock-Gravel N=11			Between Rock-Clay N=11			Under Rock-Clay N=10		
	#species	N	f	#species	N	f	#species	N	f	#species	N	f
FORAMINIFERA	4	1.1	27	2	1.1	45	2	0.2	18	1	0.1	10
NEMATODA	?	0.4	18	?	0.2	18	?	0.2	18			
OLIGOCHAETA							1	0.1	9			
POLYCHAETA	5	0.8	36	1	0.1	9	2	0.2	18			
OSTRACODA	?	0.3	18	?	0.2	9						
CUMACEA	1	0.1	9									

CORE DEPTH: 5-6 cm

	Between Rock-Gravel			Under Rock-Gravel			Between Rock-Clay			Under Rock-Clay		
		N=6			N=11			N=10			N=8	
Taxon	#species	$\bar{N}$	f	#species	$\bar{N}$	f	#species	$\bar{N}$	f	#species	$\bar{N}$	f
FORAMINIFERA				4	1.3	45	1	0.1	10	2	0.2	12
NEMATODA				?	0.2	18						
NEMERTEA				1	0.1	9				1	0.1	12
POLYCHAETA				3	0.3	18	1	0.1	10			
OSTRACODA				1	0.1	9						
CUMACEA							1	0.1	10			
TANAIDACEA				1	0.1	9						

Appendix Table 3. A summation of the syringe core data. The mean number of individuals ($\overline{N}$) and total number of species is given for each core depth and substrate type. The right column gives the total number of species found in each core depth. The bottom row shows the mean number of individuals and total number of species found in each of the four substrate types. The number in parenthesis indicates the number of replicates used to generate the mean number of individuals.

Core Depth (cm)	Between Rock Gravel		Under Rock Gravel		Between Rock Clay		Under Rock Clay		Total	
	$\overline{N}$	# Species	$\overline{N}$	# Species	$\overline{N}$	# Species	$\overline{N}$	# Species	$\overline{N}$	# Species
0 - 1	10.3 (12)	27	7.9 (12)	16	6.5 (11)	25	5.6 (12)	12	7.6	49
1 - 2	6.3 (12)	21	4.5 (12)	19	3.4 (11)	12	2.0 (12)	10	4.1	37
2 - 3	6.8 (12)	22	5.0 (12)	13	1.0 (11)	7	0.7 (12)	5	3.4	33
3 - 4	3.4 (12)	14	1.8 (11)	8	0.8 (11)	4	0.3 (11)	4	1.6	19
4 - 5	2.7 (11)	12	1.6 (11)	5	0.7 (11)	6	0.1 (10)	1	1.3	15
5 - 6	0.0 (6)	0	2.1 (11)	11	0.3 (10)	4	0.3 (8)	3	0.8	14
6 - 7	0.2 (5)	1	0.2 (8)	2	0.2 (5)	1	0.4 (5)	2	0.2	5
7 - 8	0.3 (8)	3	0.6 (5)	2	0.0 (1)	0	0.5 (2)	1	0.4	4
	T = 30.0	43	23.7	34	12.9	35	9.9	17		

Appendix Table 4. A comparison of mean density ($\bar{N}$) and mean biomass ($\bar{g}$) of species in .01 m^2 airlift cores collected from between rocks and under rocks. The cores combined to generate this data were taken in March or May 1979, July 1979, November 1979, February 1980, and April 1980.

Species	Between Rocks		Under Rocks	
	$\bar{N}/m^2$	$\bar{g}/m^2$	$\bar{N}/m^2$	$\bar{g}/m^2$
FORAMINIFERA				
Cornuspira sp.	12.2	0.007	22.2	0.011
Cornuspira foliacea	42.9	0.054	16.7	0.039
Cornuspira involvens	32.2	0.075	16.7	0.033
Elphidiella sp.	1027.0	0.295	555.5	0.128
Foraminifera	259.0	0.155	38.9	0.010
Guttulina sp.	9.5	0.0012	5.6	0.001
Lagena sp.	5.6	0.001		
Miliolinella sp.	6.7	0.002	22.2	0.006
Nonionidae	28.6	0.001	22.2	0.006
Triloculina sp.	28.6	0.020	22.6	0.033
PORIFERA				
Choanites lutkenii		0.114		
Halichondria sp.		.069		
Halichondria panicea		0.140		
Haliclona gracilis				0.016
Haliclona rufescens		1.512		
Leucandra sp.		0.084		
Phakettia cribrosa				0.0224
Unknown sponge		0.170		
CNIDARIA				
HYDROZOA				
Calicella syringa		0.068		
Hydrozoa fragments		0.005		0.028
Lafoeina maxima		0.361		0.090
Sertularia sp.		2.018		0.003
Sertularia cupressoides		0.138		0.353
ANTHOZOA				
Eunephyta sp.				0.001
Eunephyta rubiformis				0.060
Unknown			2.9	0.160
NEMERTEA	31.7	0.082	44.8	0.302
NEMATODA	467.0	0.088	486.3	0.091
ANNELIDA				
POLYCHAETA				
Allia sp.	15.7	0.031	48.3	0.153
Ampharete sp.	18.3	0.008		

Appendix Table 4 (continued)

Species	Between Rocks		Under Rocks	
	$\bar{N}/m^2$	$\bar{g}/m^2$	$\bar{N}/m^2$	$\bar{g}/m^2$
POLYCHAETA (continued)				
Ampharete acutifrons	15.7	0.021	6.7	0.020
Ampharete vega	40.0	0.053	116.7	0.072
Ampharetidae			6.7	0.003
Aricidea sp.			6.7	0.040
Aricidea sp. cf. ushakovi			26.7	0.028
Brada villosa			83.3	0.597
Capitella capitata	77.9	0.078	706.7	0.812
Capitellidae	3.3	0.001		0.025
Chaetozone setosa	34.8	0.082	38.3	0.039
Chone sp.	43.3	0.007	13.3	0.004
Chone duneri			70.0	0.045
Cirratulidae	8.6	0.023	6.7	0.002
Cirratulus cirratus	5.0	0.015	33.3	0.185
Clymenura polaris			18.3	0.028
Eteone longa			5.0	0.015
Euchone analis	2.9	0.002	3.5	0.013
Exogone dispar	113.9	0.032	261.7	0.062
Exogone naidina	458.9	0.093	711.7	0.102
Flabelligera affinis			3.5	0.123
Haploscoloplos elongata	18.3	0.285	98.3	6.891
Harmathoe imbricata			3.3	1.090
Hesionidae	8.0	0.002	13.3	0.007
Lumbrineris fragilis	122.9	0.204	193.3	0.256
Maldanidae	17.9	0.028	79.1	0.033
Melaenis loveni			0.2	4.300
Nereimyra sp.			25.0	0.010
Nereimyra aphroditoides	4.0	0.004		
Nereis zonata	4.0	2.312	23.4	2.942
Orbiniidae				0.195
Parahesione sp.			10.0	0.010
Paramphitrite tetrabranchia			3.5	0.007
Pholoe minuta			25.0	0.195
Pionosyllis sp.			15.0	0.015
Pista sp.	2.9	0.002		
Pista cristata	43.3	0.117	70.0	0.115
Polychaeta	25.0	0.050		0.083
Polycirrus sp.	2.9	0.020		
Polycirrus medusa			98.3	3.913
Polydora caulleryi			6.7	0.002
Prionspio cirrifera	16.2	0.004	15.0	0.0125
Pygospio elegans			20.0	0.005
Scalibregma inflata	2.9	0.002		
Schistomeringos sp.	80.7	0.042	175.0	0.175
Scoloplos armiger	14.9	0.152		

Appendix Table 4 (continued)

Species	Between Rocks $\bar{N}/m^2$	Between Rocks $\bar{g}/m^2$	Under Rocks $\bar{N}/m^2$	Under Rocks $\bar{g}/m^2$
POLYCHAETA (continued)				
Sphaeroderopsis minuta	3.3	0.010		
Sphaerosyllis erinaceous			15.0	0.007
Spio filicornis	55.5	0.019	131.7	0.051
Spionidae	10.0	0.010		
Spirorbis sp.	30.0	0.010		
Spirorbis granulatus			3.5	0.001
Tauberia gracilis	3.3	0.001		
Tharyx sp.	5.0	0.005	95.0	0.038
Terebellidae			10.0	0.008
Terebellides stroemi	87.6	0.276	213.0	0.985
OLIGOCHAETA	25.0	0.018		
<u>MOLLUSCA</u>				
PROSOBRANCHIA				
Gastropoda	6.7	0.002	11.7	0.048
Lacuna sp.			3.3	0.001
Margarites vorticifera	5.0	0.390		
Oenopota sp.	20.0	0.345	23.3	0.178
Plicifusus sp.	13.3	1.800		
Polinices sp.			3.3	0.043
Polinices pallidus	5.0	0.240		
POLYPLACOPHORA				
Ischnochiton sp.	3.3	0.420	2.9	0.001
Ischnochiton albus	5.0	0.130		
PELECYPODA				
Astarte sp.	23.3	0.049	35.8	0.139
Astarte borealis	25.0	5.280		
Astarte montagui			5.0	0.015
Bivalvia			7.3	0.002
Boreacola vadosa	5.0	0.005	15.0	0.010
Liocyma fluctuosa	10.0	0.008	15.3	0.006
Macoma sp.	15.0	0.080	9.5	0.205
Macoma alaskensis	15.0	0.410		
Macoma loveni	5.0	0.090	5.0	1.195
Macoma moesta			4.0	0.196
Nucula sp.			3.3	0.003
Nucula bellotii	3.3	0.027		
OPISTOBRANCHIA				
Cylinchna occulta			4.0	0.012
Retusa sp.			2.9	0.002
Retusa obtusa			3.3	0.010

Appendix Table 4 (continued).

Species	Between Rocks		Under Rocks	
	N/m^2	g/m^2	N/m^2	g/m^2
ARTHROPODA				
CRUSTACEA				
Calanoida	575.9	0.200	747.2	0.262
Cumacea				
Brachydiastylis resima	137.3	0.144	198.3	0.343
Diastylidae	3.3	0.0008		
Diastylis glabra	3.3	0.040		
D. sulcata	3.3	0.003		
Leucon sp.			13.3	0.006
Leucon sp. cf. nathrostii	4.0	0.004		
Leucon nasicoides			5.0	0.005
Euphausiacea				
Thysanoessa raschii	93.5	2.443	1,250	37,597
Mysidae			3.3	0.001
Mysis sp.			6.7	0.002
Ostracoda	41.3	0.009	26.7	0.013
Tanaidacea				
Leptognathia gracilis	60.7	0.032	81.7	0.029
AMPHIPODA				
Amphipoda	2.9	0.006	13.3	0.0117
Anonyx nugax	16.9	0.047	28.5	0.293
Apherusa sp.			3.3	0.001
Apherusa megalops	2.9	0.002		
Boeckosimus plautus	74.3	0.296	46.7	0.297
Byblis gaimardi	5.0	0.070		
Halirages sp.	140.2	0.053	43.3	0.073
Metopa sp.			10.0	0.003
Monoculodes sp.	12.3	0.009	25.0	0.073
Monoculodes sp. cf. borealis			6.7	0.010
Monoculodes sp. cf. longirostris			3.3	0.040
Monoculodes packardi	14.5	0.025	3.3	0.007
Monoculodes tuberculatus	18.9	0.010	30.0	0.026
Oedicerotidae	5.0	0.010		
Onisimus litoralis	4.0	0.060	10.0	0.103
Paroediceros lynceus	14.7	1.081	11.7	0.707
Paroediceros propinquus			5.0	0.005
Pleusymptes sp.	5.0	0.005		
Pleusymptes karianus	5.7	0.004	3.3	0.003
Rhacotropis inflata	5.0	0.010	16.7	0.032
Rozinante fragilis	3.3	0.033	5.0	0.060
Stenothoidoe			5.0	0.005
BRYOZOA				
Alcyonidium sp.		1.110		0.311
Alcyonidium gelatinosum		0.135		
Alcyonidium mytili		0.530		
Bryozoan fragments				0.111

Appendix Table 4. (continued)

Species	Between Rocks $\bar{N}/m^2$	Between Rocks $\bar{g}/m^2$	Under Rocks $\bar{N}/m^2$	Under Rocks $\bar{g}/m^2$
BRYOZOA (continued)				
Bryozoan #1		0.073		0.007
Bryozoan #2		0.047		0.120
Bryozoan #3				0.004
Bryozoan #4				0.004
Bryozoan #5				0.004
Bryozoan #8				0.003
Callopora lineata		0.283		0.284
Cauloramphus intermedius		0.110		
Electra crustulenta		0.275		
Eucratea loricata		0.468		0.061
Flustrella sp.		0.135		
Flustrella fragments		0.890		
Hippothoa hyalina		1.322		0.771
Porella saccata		0.415		
Phamphostomella sp.		0.130		
Umbonula arctica		0.010		
Unknown bryozoa		0.047		
ECHINODERMATA				
ASTEROIDAE	9.0	0.223	10.0	2.66
UROCHORDATA				
ASCIDIACEA	12.0	0.184	3.3	0.003
ALGAE				
Algae fragments		0.154		2.280
Amphipleura sp.		0.005		
Chained diatoms		0.0014		
Lithothamnion sp.		5.250		2.580
Neodilsea intergra		7.000		
Phycodrys rubens		6.213		0.413
Phyllophora truncata		8.018		0.943
Rhodomela subfusca		0.001		1.367

Appendix Table 5. These data show the mean density ($\bar{N}$) and biomass ($\bar{g}$) of species collected in $.05m^2$ scrapes from 8-2-79 (N=6), 3-4-80 (N=5) and 4-25-80 (N=6).

Species	$\bar{N}/m^2$	$\bar{g}/m^2$
FORAMINIFERA		
Cornuspira foliacea	2.67	0.0333
Cornuspira involvens	1.33	0.0107
Cornuspira sp.	1.33	0.0067
Elphidiella sp.	20.90	0.0049
Miliolinella sp.	171.67	0.0066
Nonionidae	2820.67	0.1860
Unknown forams	2486.90	0.1523
PORIFERA		
Halichondria panicea		0.3382
Haliclona rufescens		2.9240
Lencandra sp.		0.2459
Phakettia cribosa		3.0044
Unknown sponge		1.5314
CNIDARIA		
HYDROZOA		
Abietinaria sp.		0.0027
Calicella syringa		0.0203
Hydrozoan frags		0.1618
Lafoeina maxima		0.7491
Obelia sp.		0.0080
Rathkea sp.		0.0067
Sertularia cupressoides		9.3664
Sertularia sp. cf. albimaris		0.0013
ANTHOZOA		
Anemone	4.0	0.0363
Eunephtyes rubiformis		0.2491
NEMERTEA	62.23	0.0897
NEMATODA	94.0	0.0077
ANNELIDA		
Ampharete sp.	1.33	0.0003
Ampharete acutifrons	1.33	0.0013
Autolytus sp.	2.67	0.0007
Brada villosa	6.67	0.0217
Capitella capitata	43.33	0.0340
Capitellidae	1.33	0.0003
Chaetozone setosa	1.33	0.0053
Chone sp.	4.0	0.0013
Cirratulus cirratus	160.3	1.9916

Appendix Table 5 (continued)

Species	$\bar{N}/m^2$	$\bar{g}/m^2$
Exogone naidina	474.0	0.0627
Exogone dispar	8.0	0.0013
Flabelligera affinis	5.11	0.0527
Harmothoe sp.	2.44	0.3056
Harmothoe imbricata	1.11	0.5089
Hesionidae	7.56	0.0044
Lumbrineris fragilis	11.56	0.0107
Nereimyra aphroditoides	2.67	0.0007
Nereis zonata	36.0	1.6951
Nicolea zostericola	9.11	0.0037
Pholoe minuta	5.11	0.0112
Polychaete frags		0.9452
Pista cristata	1.11	0.0003
Polycirrus medusa	1.33	0.1627
Polydora caulleryi	2.67	0.0040
Pygospio elegans	1.33	0.0003
Schistomeringos sp.	4.0	0.0033
Sphaerodorum sp.	1.11	0.0003
Sphaerosyllis erinaceus	1.33	0.0003
Spinther sp.	1.33	0.0160
Spinther miniaceus		
Spio filicornis	22.67	0.0033
Spirorbis sp.	993.0	37.4206
Spirorbis granulata	111.1	0.0836
Spirorbis spirillum	3.33	0.0056
Syllidae	6.67	0.0003
Terebellidae	20.23	0.4442
Terebellides stroemi	23.10	0.0244
MOLLUSCA		
Amicula vestita	24.0	13.2267
Gastropoda	20.43	0.0479
Margarites sp.	4.0	0.1253
Margarites costalis	4.43	0.0600
Musculus sp.	197.57	0.0416
Musculus discors	76.0	0.1013
Macoma calcarea	1.33	0.0240
Nudibranch	4.67	0.0059
Oenopota sp.	4.0	0.0307
Plicifusus sp.	3.33	0.0333
Polyplacophora	3.33	0.0003
Solariella sp.	1.33	0.0013
ARTHROPODA		
Halicaridae	52.0	0.0058

Appendix Table 5 (continued)

Species	$\bar{N}/m^2$	$\bar{g}/m^2$
ARTHROPODA (continued)		
CRUSTACEA		
Acanthonotozoma sp.	2.67	0.0227
Amphipoda	10.0	0.0008
Anonyx nugax	10.22	0.0527
Apherusa sp.	13.33	0.0122
Apherusa megalops	8.0	0.0071
Atylus carinatus	1.33	0.0003
Balanus sp.	2.43	0.0043
Boeckosimus plautus	44.22	0.2891
Brachydiastylis resima	13.33	0.0127
Calanoida	93.33	0.0168
Cyclopoida	14.0	0.0013
Diastylis sp.	1.33	0.0003
Gammaraconthus loricatus	2.67	1.6173
Halirages sp.	340.67	0.1314
Halirages nilssoni	2.67	0.0187
Harpacticoida	1.11	0.0003
Isopoda	4.0	0.0010
Leucon sp.	5.33	0.0017
Leucon nasicoides	2.22	0.0014
Leptognathia gracilis	2.67	0.0003
Metopa sp.	64.67	0.0179
Metopa boecki	2.67	0.0013
Metopella carinata	9.33	0.0013
Monoculodes sp.	11.78	0.0148
Monoculodes longirostris	1.33	0.0173
Monoculodes packardi	4.67	0.0036
Monoculodes tuberculatus	29.33	0.0544
Munna sp.	11.78	0.0033
Mysis littoralis	5.33	0.1093
Neomysis sp.	8.0	0.0003
Onisimus litoralis	1.33	0.0253
Ostracods	4.0	0.0007
Paroediceros propinquis	4.0	0.0043
Pleurogonium sp.	1.33	0.0003
Pleusymtes sp.	12.0	0.0240
Pleusymtes karianus	46.0	0.0709
Pontoporeia femorata	1.33	0.0067
Rhachotropis sp.	1.33	0.0013
Rhachotropis inflata	4.43	0.0056
Stenula sp.	3.78	0.0036
Thysanoessa raschii	152.0	4.69
Weyprechtia pinguis	1.33	0.0003
Cladoceran	3.33	0.003

Appendix Table 5 (continued)

Species	$\bar{N}/m^2$	$\bar{g}/m^2$
BRYOZOA		
Alcyonidium sp.		1.1518
Callopora lineata		3.2567
Carbasea carbasea		0.1078
Cyclostomata		0.0073
Dendrobeania sp.		0.0053
Eucratea loricata		5.4673
Flustrella sp.		0.1240
Hippothoa hyalina		6.3769
Unknown Bryozoan #1		3.5027
Unknown Bryozoan #2		0.5361
Unknown Bryozoan #3		0.0413
Unknown Bryozoan #4		0.0240
Unknown Bryozoan #5		0.1700
Unknown Bryozoan #6		0.0053
Unknown Bryozoan #7		0.0100
ECHINODERMATA		
Asteroidea	9.33	0.1720
CHORDATA		
UROCHORDATA (ASCIDEACEA)		
Chelyosoma maceayanum	5.11	0.6296
Molgula sp. cf. siphonalis	1.33	1.4400
Molgula griffithsii	1.33	0.0973
Unknown Ascidean	6.0	0.9790
ALGAE		
Algae fragments		0.2833
Filimentous algae		0.0003
Laminaria saccharina		31.8227
Laminaria solidungula		5.3067
Neodilsea intergra		19.3318
Odonthalia dentata		0.4821
Phycodrus rubens		80.4236
Phyllophora truncata		35.5931
Rhodomela subfusca		5.9342
Amphipleura sp.		0.3616
Unknown Chained Diatoms		0.0016

PHYSIOLOGICAL RESPONSES OF ARCTIC BENTHIC AND EPIBENTHIC INVERTEBRATES TO SALINITY AND CRUDE OIL STRESS UNDER WINTER CONDITIONS

by

D. E. Schneider and J. Hanes

INTRODUCTION

Investigations during the winter of 1978-79 focused upon the response of selected arctic epibenthic invertebrates to winter salinity stress and exposure to Prudhoe Bay crude oil (Schneider, 1980). These epibenthic animals were generally found to be euryhaline and most tolerated salinities as high as 50-55 $^{o}/oo$. However, as the upper salinity limit was approached, the activity of these animals diminished and spontaneous locomotion usually ceased at salinities 2 to 5 $^{o}/oo$ below the upper tolerance limit. Exposure to Prudhoe Bay crude oil dispersions prepared by agitating oil with seawater over a range of concentrations (50-500 μl oil/l seawater) generally increased mortality and inhibited locomotor activity of the epibenthic invertebrates studied. In many cases the effect of crude oil exposure was found to be more severe at elevated salinities. The effect of salinity and crude oil exposure on the metabolic rate of several epibenthic crustaceans was also studied during the winter of 1978-79. Oxygen consumption of two species, the mysid *Mysis littoralis* and the amphipod *Boeckosimus affinis*, was independent of salinity over a wide range but became depressed at elevated salinities of 45 and 50 $^{o}/oo$ respectively. A third species, the amphipod *Anonyx nugax*, was more sensitive to salinity change and had a depressed metabolic rate at 20 and 40 $^{o}/oo$. Exposure to dispersions of Prudhoe Bay crude oil significantly altered the metabolic rates of all those species and the effects were often more pronounced at elevated salinities (Schneider, 1980).

Salinities of the deepest areas of Beaufort Sea lagoon systems frequently approach 55-60 $^{o}/oo$ in early spring (Schell, 1975). These are close to or may even exceed the tolerance limits found for many epibenthic invertebrates as described above. In view of the mobility of epibenthic species it seems likely that they normally avoid extreme salinity stress by migrating to more favorable regions. More sessile benthic infaunal species may not be able to employ an avoidance strategy when faced with hypersaline stress. Our studies conducted during the winter of 1979-80 and presented in this report have focused upon the response of selected benthic infaunal species to salinity and crude oil exposure. In addition to extending our investigations to this other shallow-water faunal group, we have also continued investigation of some of the epibenthic species in an effort to further refine our information on those species.

METHODS

Collection of Animals for Physiological Experiments

Benthic infaunal species were collected with an airlift operated by a SCUBA diver. The animals collected by this method usually were not visibly injured and appeared in good physiological condition. Two dive sites were maintained near Barrow, Alaska throughout the winter for these collections. The Elson Lagoon dive site was located a short distance inside Plover Point near Eluitkak Pass in about 3.0 meters of water. The Chukchi Sea dive site was located several hundred meters offshore adjacent to the Naval Arctic Research Laboratory in about 4.5 meters of water. A heated dive hut was maintained at each site and upon collection the species were transferred immediately to buckets of freshly collected seawater to prevent thermal shock. Epibenthic species were collected with amphipod traps baited with sardines as described by Schneider (1980). The traps were usually deployed through the dive hole at the dive sites.

Laboratory Maintenance of Animals

Animals were maintained at 32 $^{o}/oo$ salinity unless the experimental protocol demanded some other salinity. The animals were held at -1.0° C. and in the dark in Percival constant temperature incubators under static water conditions. Holding containers were either polystyrene or polyethylene boxes and were not aerated. The oxygen content of the water was checked at intervals by Winkler titration and was found not to fall below 75% of saturation. Animals were not fed during maintenance or experimental procedures. Survival was excellent under these maintenance conditions and the animals appeared to be in good health for periods exceeding one month. Laboratory maintenance for the experimental animals was usually held to no more than 2 or 3 weeks to avoid problems associated with long-term storage.

Salinity Tolerance Experiments

Two types of salinity tolerance experiments were run on most of the species studied. Acute tolerance experiments were conducted by immediately transferring animals from their normal maintenance salinity of 32 $^{o}/oo$ to a test salinity either above or below this point. Survival of the animals was monitored every 12 hours for 7 days. In addition, some attempt was made to subjectively rate the activity level of each individual at each observation if the species behavior pattern allowed such a rating. The activity rating scale used for each species is presented below. The second type of salinity experiment is termed gradual salinity tolerance. Animals were transferred in 5 $^{o}/oo$ increments upwards or downwards from their normal maintenance salinity of 32 $^{o}/oo$ every 2 days. Survival and, where possible, activity level were rated daily. Salinity transfers usually continued until no survivors remained.

All salinity tolerance experiments were conducted at a temperature of -1.0^{o} C. and in the dark. Salinities above that of normal seawater were prepared by adding brine obtained by freezing buckets of seawater. Dilute salinities were obtained by diluting seawater with distilled water. Salinity was measured with an A-O Goldberg optical salinometer. The animals were held in plastic boxes similar to those used for maintenance during the salinity tolerance experiments. Ten animals were exposed to each test salinity in the acute tolerance experiments. In the gradual salinity tolerance experiments each transfer series was started with 10 animals.

Subjective Activity Rating Scales and Criteria for Death

The subjective activity rating scale used for the epibenthic amphipod *Boeckosimus affinis* and for the benthic amphipods *Pontoporeia femorata* and *Aceroides latipes* was the same as that used by Schneider (1980):

4 - normal locomotor activity
3 - slightly reduced locomotion but still spontaneous or only requiring slight prodding
2 - loss of spontaneous locomotion. Some locomotion is still possible but requires extensive prodding.
1 - greatly reduced activity, only minor appendage movement is possible and no locomotion occurs.
0 - dead, no appendage movement even with extensive prodding.

The above rating scale is relatively unambiguous and can be used with fairly good precision. The rating scales developed for the other species are somewhat more subjective and required thorough familiarity with the behavior patterns of the species. For this reason all observations on each species were made by the same observer.

The activity rating scale used for the polychaete worm, Brada villosa, is described below:

4 - Normal activity - constant slow crawling, lateral "testing" movements of the anterior end, palps and bronchia extended and sensitive to physical disturbance.

3 - Slightly reduced activity - somewhat intermittent crawling, lateral movements of the anterior end less than normal, palps and bronchia occasionally extended, somewhat reduced sensitivity to physical disturbance.

2 - Reduced activity - only occasionally moving and slower than above, anterior end fairly inactive, palps and bronchia only partly extended if at all, greatly reduced sensitivity to physical disturbance.

1 - Greatly reduced activity - no movement, palps and bronchia may be partially extended but are not retracted in response to physical disturbance, general appearance of the worms is normal though.

0 - Dead - pale discoloration of the body, localized swelling or protrusion of the gut through the body wall.

Worms that received a rating of 1 on the above scale usually show some signs of recovery if transferred to 32 ^{o}/oo seawater, however the recovery may take as long as a week. Those that received a 0 rating on the scale did not show any recovery.

Anemones (taxonomic identity unknown at this time but under investigation) were difficult to subject to an activity rating scale. However differences in responsiveness and general appearance were noted as the animals became increasingly stressed. These have been incorporated into the following, admittedly very subjective, rating scale:

4 - Normal - almost all attached to the container, column and tentacles fully extended, tentacles retract by

about 25% and column is contracted in response to slight prodding, recovery from physical disturbance is rapid (3-5) minutes, column color cream-white, oral disc color yellow-brown.

3 - Slightly reduced - most are attached, column and tentacles only about 75% extended and tentacles may droop, sensitivity to physical disturbance unchanged from normal, color normal.

2 - Reduced - most are unattached, column less than 50% extended, tentacles either not extended or only partly extended and droop, greatly reduced sensitivity to physical disturbance and recovery very slow, color dull white to uniform light gray.

1 - Greatly reduced - None are attached, column and tentacles are not extended, no response to physical disturbance, color dull light gray, will show partial recovery if transferred to 32 ^{o}/oo seawater at this stage.

0 - Dead - some sign of body deterioration such as a mucous coating.

The bivalve mollusc Axinopsida orbiculata was impossible to subject to an activity rating scale as the animals have very few overt behavioral patterns. The criterion for death used in the salinity tolerance experiments was the gaping of the valves. Although this event may not exactly coincide with the actual death of the animal, it is probably the most obvious behavioral response associated with lethal stress in this species. Presumably a bivalve mollusc that gapes is close to death and subject to predation.

Oil Tolerance Experiments

Tolerance to seawater dispersions of Prudhoe Bay crude oil was determined for anemones at 32, 40, 45, and 50 ^{o}/oo salinity and for Brada villosa at 32 ^{o}/oo. The detailed procedure used in these experiments and the method of preparing oil-seawater dispersions is described in Schneider (1980). In these experiments, the animals were exposed to an oil-seawater dispersion for a period of 4 days and the survival and activity were monitored every 12 hours. Animals were transferred to a freshly prepared oil dispersion at 24 hour intervals immediately following an observation.

Effect of Salinity and Oil-Seawater Dispersions on Metabolic Rates

The effect of elevated salinity on the rate of metabolism was studied in a number of benthic species. Metabolic rates were determined with a Gilson Differential Respirometer as described by Schneider (1980). For most of the species studied, metabolism was determined at the normal maintenance salinity of 32 ^{o}/oo and at a single sublethal high salinity close to the tolerance limit. The following list indicates the species studied in this way along with the elevated stress salinity shown in parentheses: the amphipods Pontoporeia femorata (50 ^{o}/oo) and Aceroides latipes (50 ^{o}/oo), the isopod Saduria sabini (55 ^{o}/oo), the polychaete worms Brada villosa (45 ^{o}/oo) and Pectinaria hyperborea (45 ^{o}/oo). The anemone and the bivalve mollusc, Liocyma fluctuosa were studied over a range of salinities: anemone (32, 40, 45 and 50 ^{o}/oo), L. fluctuosa (32, 55 and 65 ^{o}/oo). Metabolic rates were corrected to a standard body weight that approximated the mean for each species following the procedure outlined in Schneider (1980). Weight correction was not possible for the two amphipods P. femorata and A. latipes since the small size of these animals necessitated running 5 individuals in each respirometer flask.

The effect of crude oil dispersions on metabolic rates was studied in two species, the anemone and Brada villosa. Anemones were exposed to two oil dispersion strengths (250 and 750 μl oil/500 ml seawater) at three different salinities (32, 40 and 45 ^{o}/oo). B. villosa was exposed to two oil dispersions (250 and 750 μl oil/500 ml seawater) at the normal salinity of 32 ^{o}/oo only. Animals were acclimated to the experimental salinities for 5 days and exposed to the oil-seawater dispersions for 36 hours prior to determination of the rate of metabolism.

Quantitative Activity Measurements

Quantitative estimates of the locomotor activity level of the two epibenthic invertebrates exposed to different salinities were made. These experiments were undertaken to provide quantitative verification for the subjective activity rating system used by Schneider (1980) in the tolerance experiments on epibenthic invertebrates. The design of these experiements is similar to that used by Percy and Mullin (1975). The test chamber was in the form of an annular channel provided by nesting a 5 inch (12.7 cm) diameter circular glass dish inside an 8 inch (20.4 cm) diameter glass dish. The annular channel was divided into 12 equal parts by a series of lines radiating from the center of the larger dish. The test chamber was held in a constant temperature water bath at -1.0° C. during the activity measurements.

Twenty individuals of the amphipod Anonyx nugax and the isopod Saduria entomon were subjected to either increasing or decreasing salinities in a manner similar to that used for the gradual salinity tolerance tests. Every two days the salinity was changed by an increment of 5 ^{o}/oo. Activity measurements were made after the two day exposure to each new salinity by transferring each animal to the annular channel. Following a three minute adjustment period, the activity was monitored by counting the number of lines crossed during two consecutive one minute periods and calculating the mean. Ten animals were measured from each treatment group except at extreme salinities where mortality reduced the number of available animals. In these cases all of the available animals were run.

Oiled Sediment Preference Experiments

Several simple behavioral experiments were conducted with the benthic amphipod Pontoporeia femorata to determine its preference for oiled vs. non-oiled sediments. The test chamber was a 13.5 x 19.0 x 7.5 cm high plastic box divided into two equal areas by a partial partition. Different types of sediment were placed in the compartments to a depth of about 2.5 cm and the box was carefully filled with seawater so as not to disturb the sediments. Ten amphipods were then placed in the box and after two days the sediment from each compartment was sieved separately to locate the position of the animals.

Oiled sediment was prepared by thoroughly mixing either 1.9 or 2.5 ml of Prudhoe Bay crude oil with 250 ml mud in a glass beaker. Seawater was then added to the beaker and the mixture was allowed to stand overnight. The sediment, mainly silt and clay, was obtained either from the Chuckchi Sea or the Elson Lagoon dive sites.

RESULTS AND DISCUSSION

Acute Salinity Tolerance Experiments

The results of acute salinity tolerance tests on arctic shallow water epibenthic invertebrates presented in the last annual report (Schneider, 1980) indicated that many of these mobile species are euryhaline and may tolerate salinities as high as 50 to 55 ^{o}/oo. At the outset of the present studies on benthic infaunal species we postulated that these more sessile animals would be even more tolerant of hypersaline stress than the motile epibenthic forms. Surprisingly, this postulate is not born out by the results of our experiments presented below.

Acute salinity transfers of the benthic amphipod *Pontoporeia femorata* indicate a tolerance range extending from about 7 to 58 ^{o}/oo based upon 50% survival over a 4 or 7 day period (Fig. 1). Similar experiments with another benthic amphipod, *Aceroides latipes*, indicate a tolerance range from about 13 to 55 ^{o}/oo based upon a 7 day exposure period (Fig. 1). This latter species showed a striking increase in mortality at low salinities between 4 and 7 days exposure. The activity ratings made during these acute tolerance experiments provide a more ecologically relevant basis for tolerance ranges than the survival curves. It is evident from the curves shown in Fig. 2 that both of these amphipods can maintain spontaneous activity over a considerably narrower range of salinities than the survival ranges reported above. Both species are spontaneously active (rating $>$ 2) from about 12 to 45 ^{o}/oo. Activity of *P. femorata* is significantlly depressed at 25 and 40 ^{o}/oo compared to that at 32 ^{o}/oo according to Mann-Whitney tests. Similar analyses indicate that the activity of *A. latipes* is significantly depressed from the level at 32 ^{o}/oo at salinities of 15 and 40 ^{o}/oo. Although these species of benthic amphipods are moderately euryhaline, their ability to tolerate salinity extremes is not particularly impressive when compared to that of the epibenthic species found in the same general habitat (Schneider, 1980).

Acute salinity transfers of the polychaete worm, *Brada villosa*, indicate they can tolerate salinities as high as 48 ^{o}/oo based upon 50% survival over a 7 day period (Fig. 3). Salinities up to about 53 ^{o}/oo can be tolerated if the stress is applied for only 4 days. The activity rating system used for this species does not permit a clear designation of the point at which spontaneous activity is lost. Nevertheless, activity is severely depressed at a rating of 2 and that level on the scale most nearly approximates the point of spontaneous activity loss used for the more active species. *B. villosa* reaches an activity rating of 2 at about 46 ^{o}/oo with a 7 day exposure period (Fig. 3). With a 4 day exposure period this activity rating is reached at about 48 ^{o}/oo.

Anemones exposed to acute salinity transfers tolerated salinities from about 22 to 52 ^{o}/oo over a 7 day period (Fig. 4). The tolerance range extends slightly lower, to about 17 ^{o}/oo, if the exposure period is reduced to 4 days. The activity rating system used for this species is not comparable to that

Figure 1. Acute salinity tolerance of the benthic amphipods, *Pontoporeia femorata* and *Aceroides latipes*, exposed to test salinities at -1.0° C.

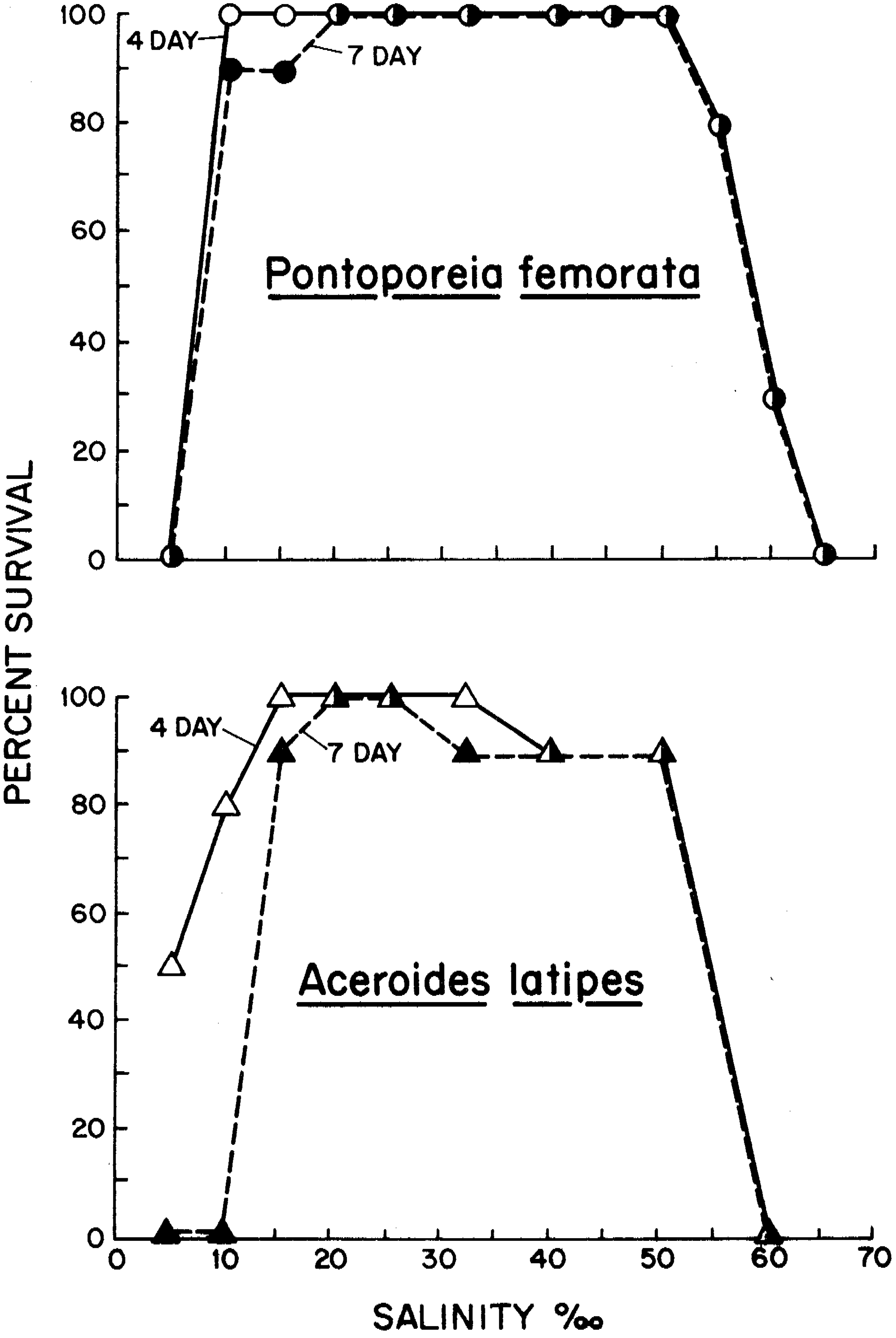

PERCENT SURVIVAL
Pontoporeia femorata
Aceroides latipes
4 DAY
7 DAY
4 DAY
7 DAY
100
80
60
40
20
0
100
80
60
40
20
0
0
10
20
30
40
50
60
70
SALINITY ‰

Figure 2. Activity levels of benthic amphipods following 96 hr acute exposure to the test salinities at -1.0° C. The following subjective activity rating scale was used:

4 = normal
3 = slightly reduced
2 = loss of spontaneous locomotion
1 = only minor appendage movement
0 = dead, no movement

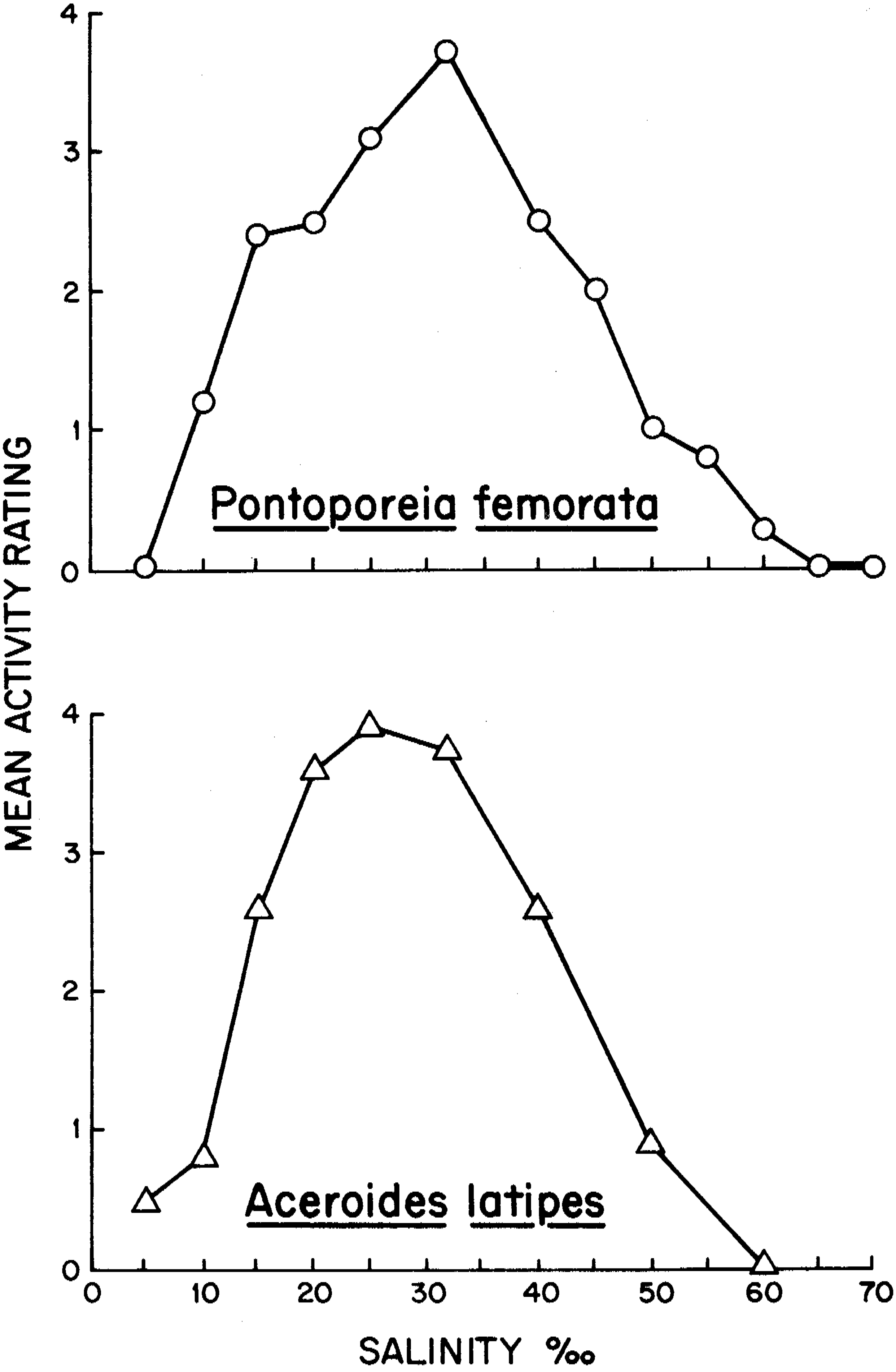

MEAN ACTIVITY RATING
4
3
2
1
0
Pontoporeia femorata
4
3
2
1
0
Aceroides latipes
0
10
20
30
40
50
60
70
SALINITY ‰

Figure 3. Acute salinity tolerance and activity of the benthic polychaete worm, Brada villosa, exposed to test salinities at -1.0° C. The following subjective activity rating scale is described in detail in the methods:

4 = normal
3 = slightly reduced
2 = reduced
1 = greatly reduced
0 = dead

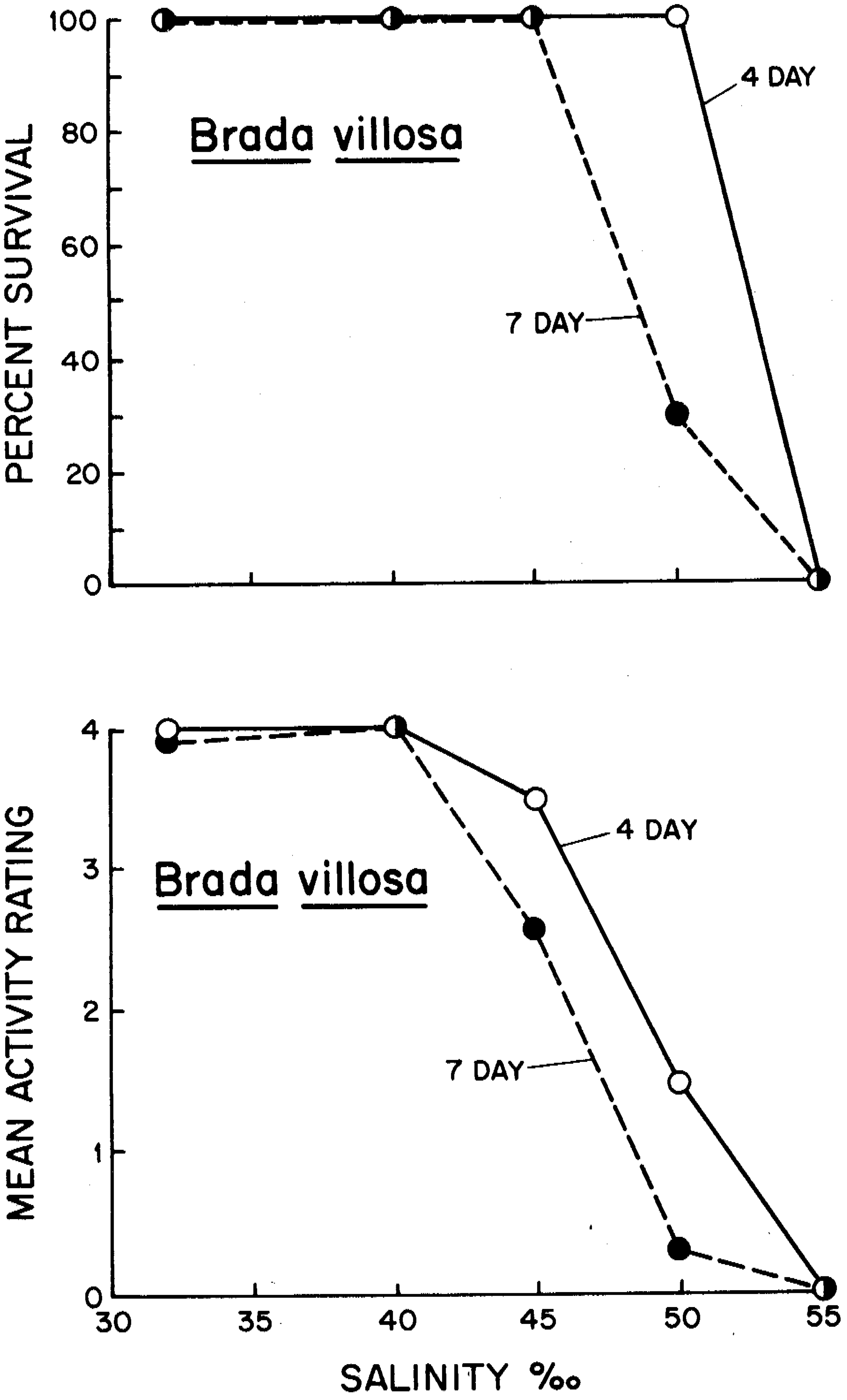
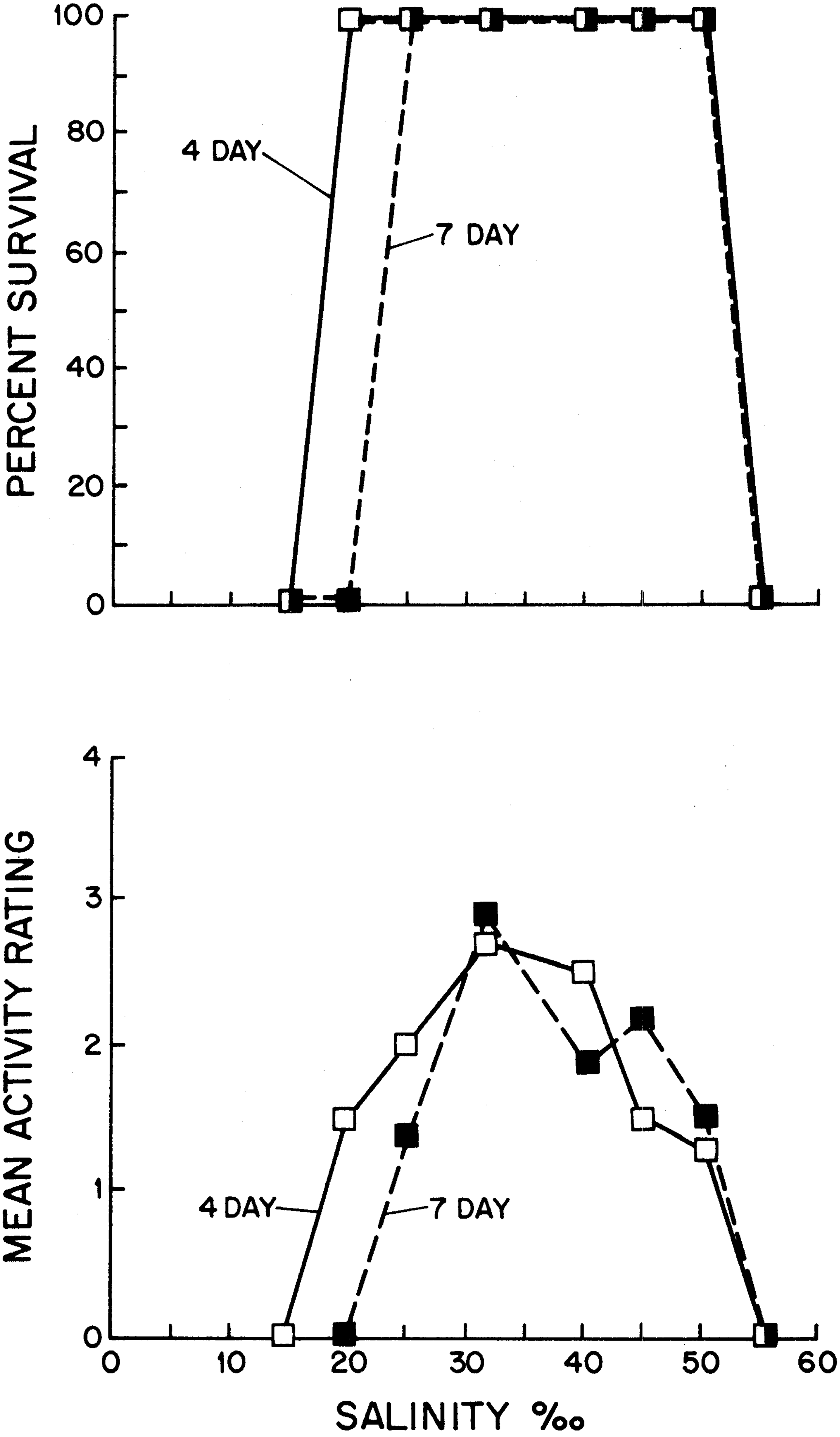

PERCENT SURVIVAL
100
80
60
40
20
0
Brada villosa
4 DAY
7 DAY
MEAN ACTIVITY RATING
4
3
2
1
0
Brada villosa
4 DAY
7 DAY
30
35
40
45
50
55
SALINITY ‰

Figure 4. Acute salinity tolerance and activity rating on an arctic sea anemone (species not yet determined) exposed to test salinities at -1.0° C. The following subjective activity rating scale is described in detail in the methods:

4 = normal
3 = slightly reduced
2 = reduced
1 = greatly reduced
0 = dead



PERCENT SURVIVAL
0
20
40
60
80
100
4 DAY
7 DAY
MEAN ACTIVITY RATING
0
1
2
3
4
4 DAY
7 DAY
0
10
20
30
40
50
60
SALINITY ‰

used for the other benthic and epibenthic animals. However, a fairly distinct change in behavior occurs at a rating of 2 on the scale in that most of the individuals fail to attach to a surface and recovery from disturbance is very slow. An activity rating >2 is maintained between about 27 and 46 ^{o}/oo for a 7 day exposure period, and for a 4 day exposure this range is from about 25 to 42 ^{o}/oo. The failure of any of the groups to reach a normal activity rating may indicate some deterioration of performance under the static laboratory maintenance conditions. However, anemones that received a rating of 3 on the scale are still responding normally to physical disturbance and show normal coloration. The main difference between ratings of 3 and 4 is the degree of extension of the column and tentacles. This difference may be trivial in terms of the physical condition of the animals and could be related to a lack of available food in the water.

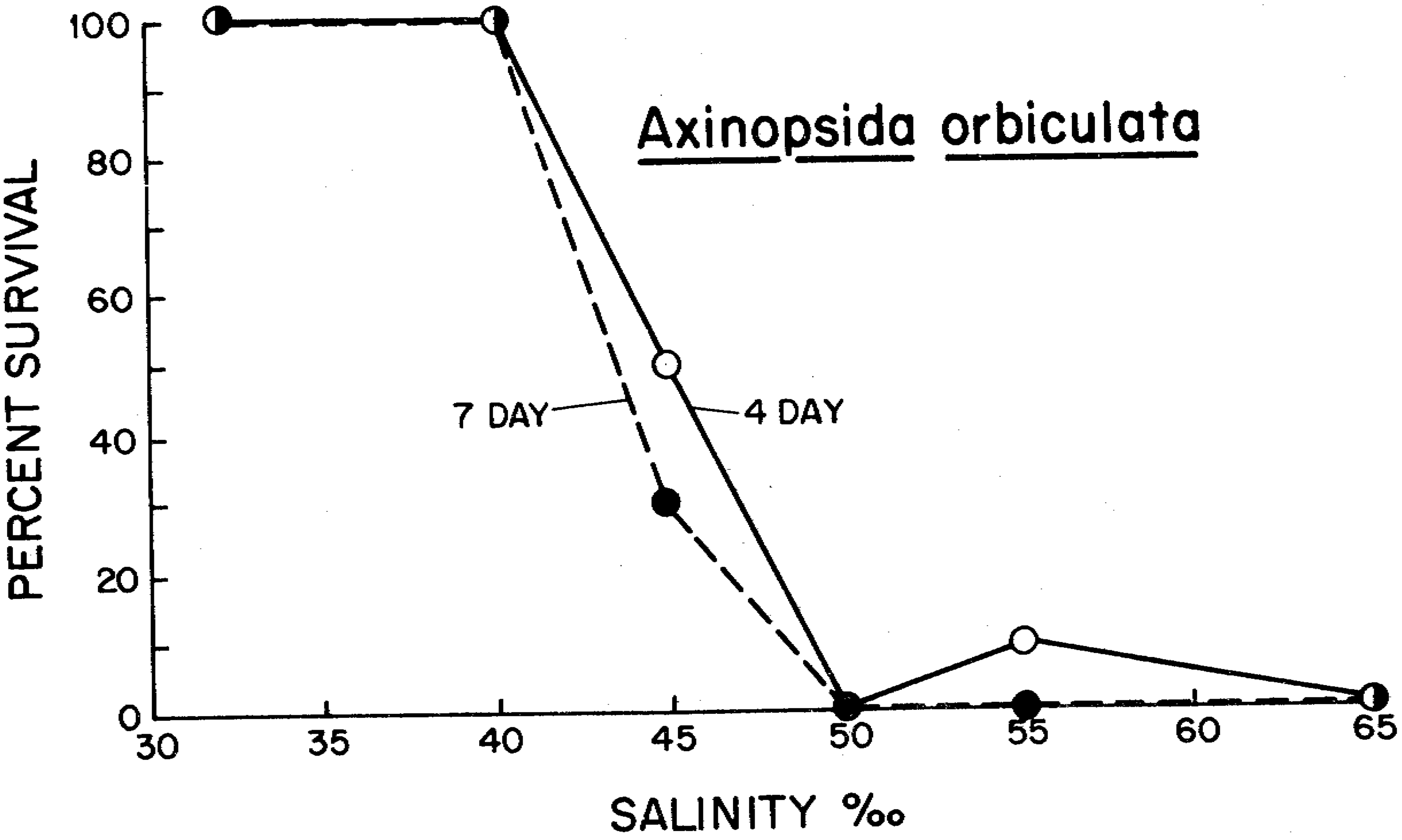
The bivalve mollusc, *Axinopsida orbiculata*, tolerates acute salinity transfers up to 45 ^{o}/oo for a 4 day period based upon 50% of the animals showing gaped valves (Fig. 5). The response over a 7 day exposure period is only slightly poorer in that the tolerance limit drops to about 44 ^{o}/oo.

Gradual Salinity Tolerance Experiments

Gradual salinity transfers of 5 ^{o}/oo every 2 days allowed the epibenthic amphipod, *Boeckosimus affinus*, to survive low salinities down to about 2 ^{o}/oo and high salinities up to about 77 ^{o}/oo (Fig. 6). However, spontaneous locomotion was only maintained down to about 6 ^{o}/oo and up to about 59 ^{o}/oo. Acute salinity experiments performed on this species previously (Schneider, 1980) indicate that the upper tolerance limit is about 65 ^{o}/oo and that loss of spontaneous activity occurs at about 55 ^{o}/oo. Gradual salinity transfers only moderately extend the range for spontaneous activity but substantially extend the actual tolerance range for this species.

Gradual salinity transfers of the two benthic amphipods result in survival of *Pontoporeia femorata* between about 4 and 68 ^{o}/oo and survival of *Aceroides latipes* between about 7 and 63 ^{o}/oo (Fig. 7). In the same experiments, spontaneous activity was maintained between 10 and about 45 ^{o}/oo for *P. femorata* and between about 12 and 50 ^{o}/oo for *A. latipes* (Fig. 8). Compared to the acute salinity transfer experiments these represent about an 8 to 10 ^{o}/oo increase in tolerance range and, in the case of *A. latipes* only, an increase of 5 ^{o}/oo in the spontaneous activity range associated with gradual salinity change.

Figure 5. Acute salinity tolerance of the bivalve mollusc, Axinopsida orbiculata exposed to test salinities at -1.0° C.



Axinopsida orbiculata
PERCENT SURVIVAL
100
80
60
40
20
0
7 DAY
4 DAY
30
35
40
45
50
55
60
65
SALINITY ‰

Figure 6. Tolerance and activity response of the epibenthic amphipod *Boeckosimus affinis* to gradual salinity transfers at -1.0° C. The following subjective activity rating scale was used:

4 = normal
3 = slightly reduced
2 = loss of spontaneous activity
1 = only minor appendage movement
0 = dead, no movement

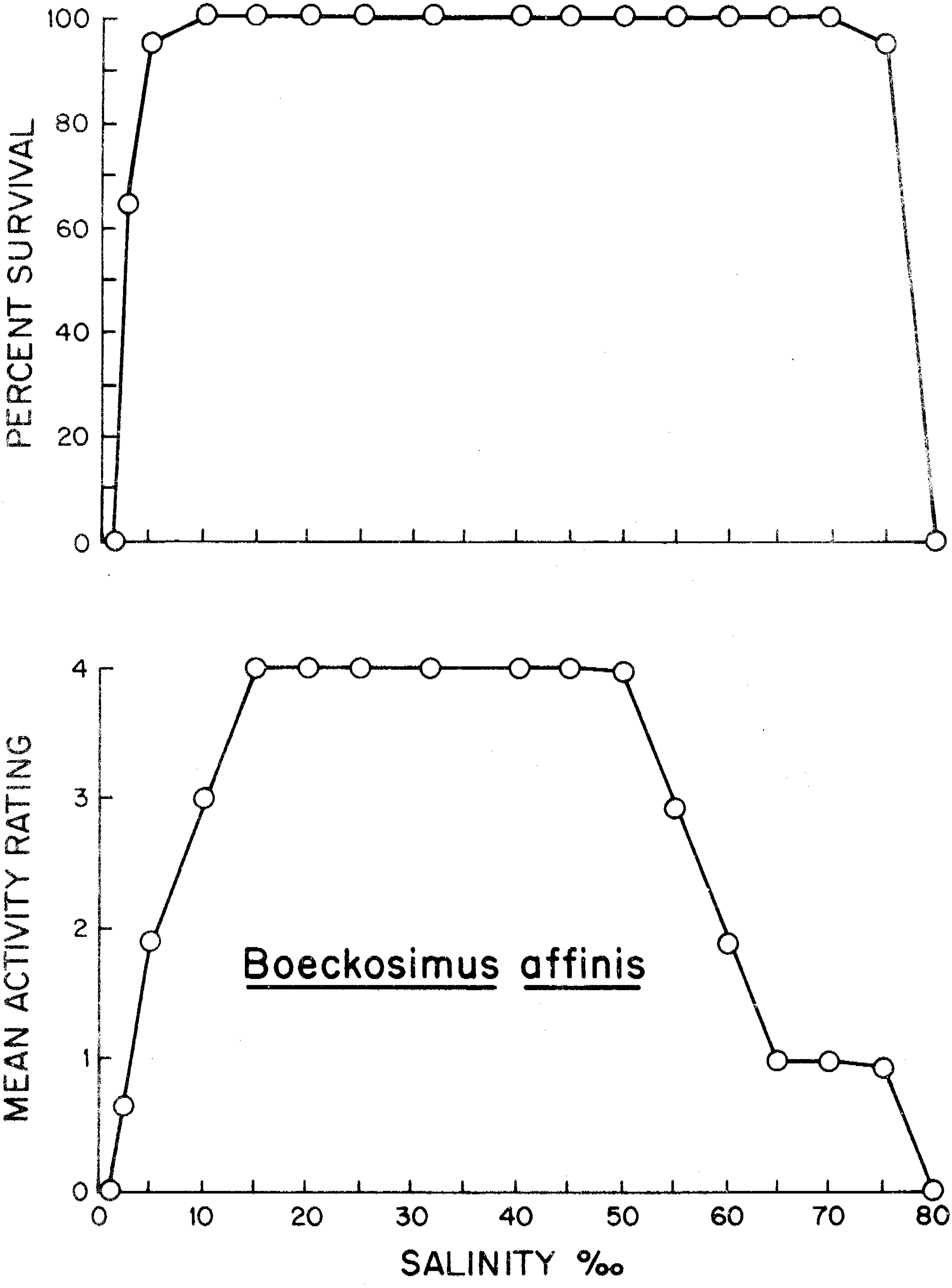

100
80
60
40
20
0
PERCENT SURVIVAL
4
3
2
1
0
MEAN ACTIVITY RATING
Boeckosimus affinis
0
10
20
30
40
50
60
70
80
SALINITY ‰

Figure 7. Tolerance of the benthic amphipods, *Pontoporeia femorata* and *Aceroides latipes*, to gradual salinity transfers at -1.0° C.

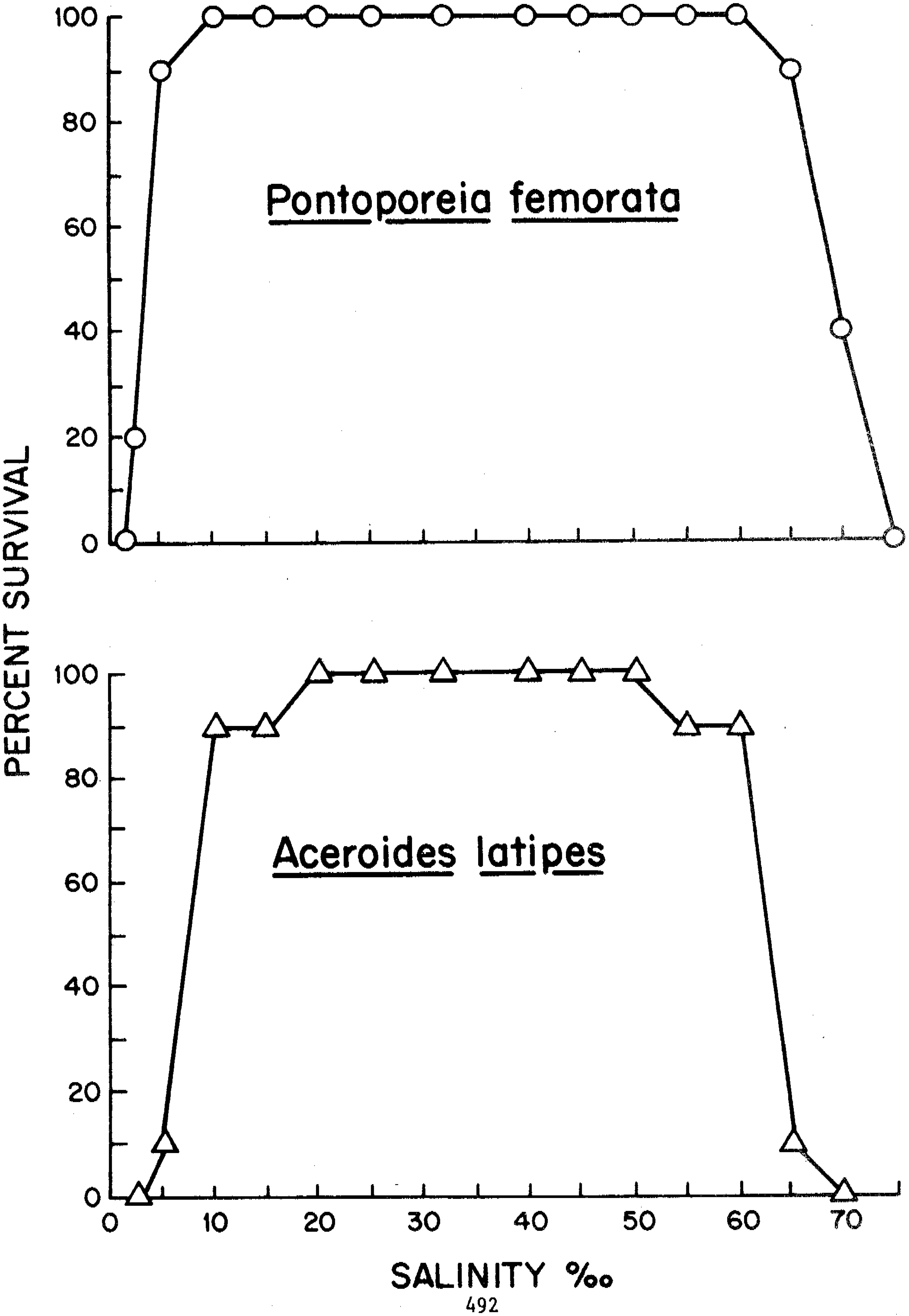
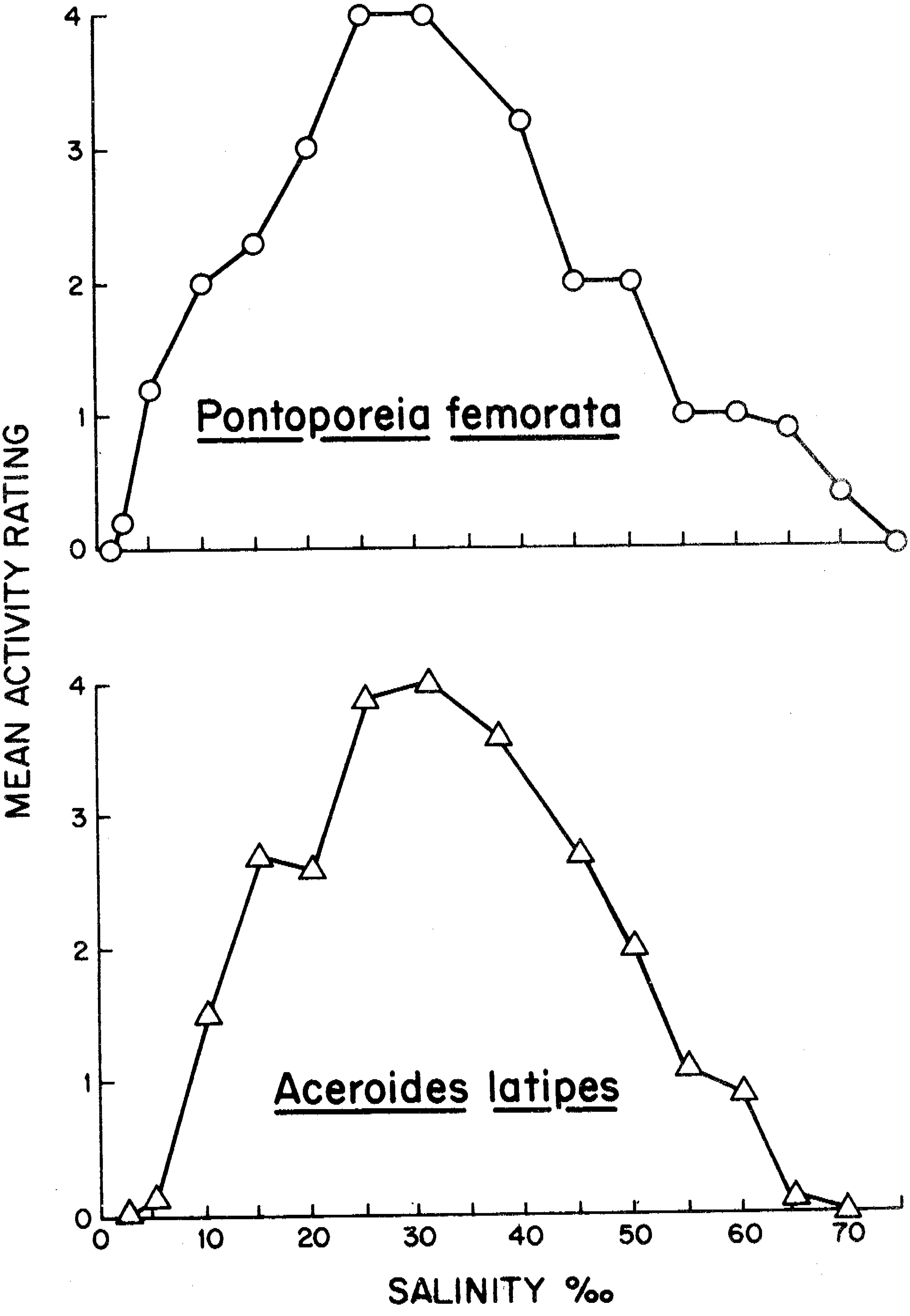

100
80
60
40
20
0
Pontoporeia femorata
PERCENT SURVIVAL
100
80
60
40
20
0
Aceroides latipes
0
10
20
30
40
50
60
70
SALINITY ‰

Figure 8. Activity response of the benthic amphipods, Pontoporeia femorata and Aceroides latipes, exposed to gradual salinity transfers at -1.0° C. The following subjective activity rating scale was used:

4 = normal
3 = slightly reduced
2 = loss of spontaneous locomotion
1 = only minor appendage movement
0 = dead, no movement



4
3
2
1
0
Pontoporeia femorata
4
3
2
1
0
Aceroides latipes
MEAN ACTIVITY RATING
0
10
20
30
40
50
60
70
SALINITY ‰

The response of anemones to salinity stress was not appreciably enhanced by gradual transfers. This species tolerated salinities down to only 22 ^{o}/oo (Fig. 9), the same value observed in acute transfer experiments, and up to about 48 ^{o}/oo, a value below that seen in acute transfers. An activity rating >2 was maintained between about 22 and 48 ^{o}/oo. This is only a slight improvement over the range seen in the acute transfer experiments.

Gradual salinity tolerance experiments were conducted on the benthic polychaete worm *Brada villosa*. This species tolerates salinities down to about 12 ^{o}/oo and up to aboue 53 ^{o}/oo under these conditions (Fig. 10). The upper limit is only 4 ^{o}/oo higher than that seen in the acute salinity tolerance experiments. The limits for activity, based upon a rating of 2 or less, lie at about 19 and 46 ^{o}/oo for this species (Fig. 10). The upper salinity limit for activity does not appear to be enhanced by gradual salinity transfers in this case, as this is the same value obtained in the acute tolerance experiment.

Conclusions from Salinity Tolerance Experiments

The benthic infaunal animals we investigated had surprisingly poor tolerance for hypersaline conditions compared to some of the epibenthic invertebrates. Most died in acute transfer experiments at salinities less than 55 ^{o}/oo and had severely depressed activities at around 45 ^{o}/oo. Gradual salinity transfers in most cases resulted in less than a 5 ^{o}/oo increase in the upper tolerance limit and almost no improvement in the upper limit for activity. These results raise the question of how these benthic infaunal invertebrates are able to deal with hypersaline stress during late winter and early spring. Schell (1975) reported salinities of 38-40 ^{o}/oo routinely in shallower areas of Simpson and Elson Lagoons in late April or May. In the deepest parts of Simpson Lagoon and in certain areas of Elson Lagoon salinities of 55-60 ^{o}/oo were not uncommon. Based upon the results of our experiments, the species we studied should be able to deal with the maximum salinities found in the shallower or better mixed areas of lagoons. However, none of the infaunal species seem capable of surviving in the hypersaline regions of the deepest areas. Unfortunately, for logistics reasons, we were not able to sample or collect our experimental animals from a hypersaline region. The only reported hypersaline region in western Elson Lagoon is too shallow to permit SCUBA diving in the early spring, and the hypersaline regions in the eastern part of the Lagoon are too distant for routine diving operations. Therefore, we do not know

Figure 9. Tolerance and activity response of arctic sea anemones (species not yet determined) exposed to gradual salinity transfers at -1.0° C. The following subjective activity rating scale is described in detail in the methods:

4 = normal
3 = slightly reduced
2 = reduced
1 = greatly reduced
0 = dead

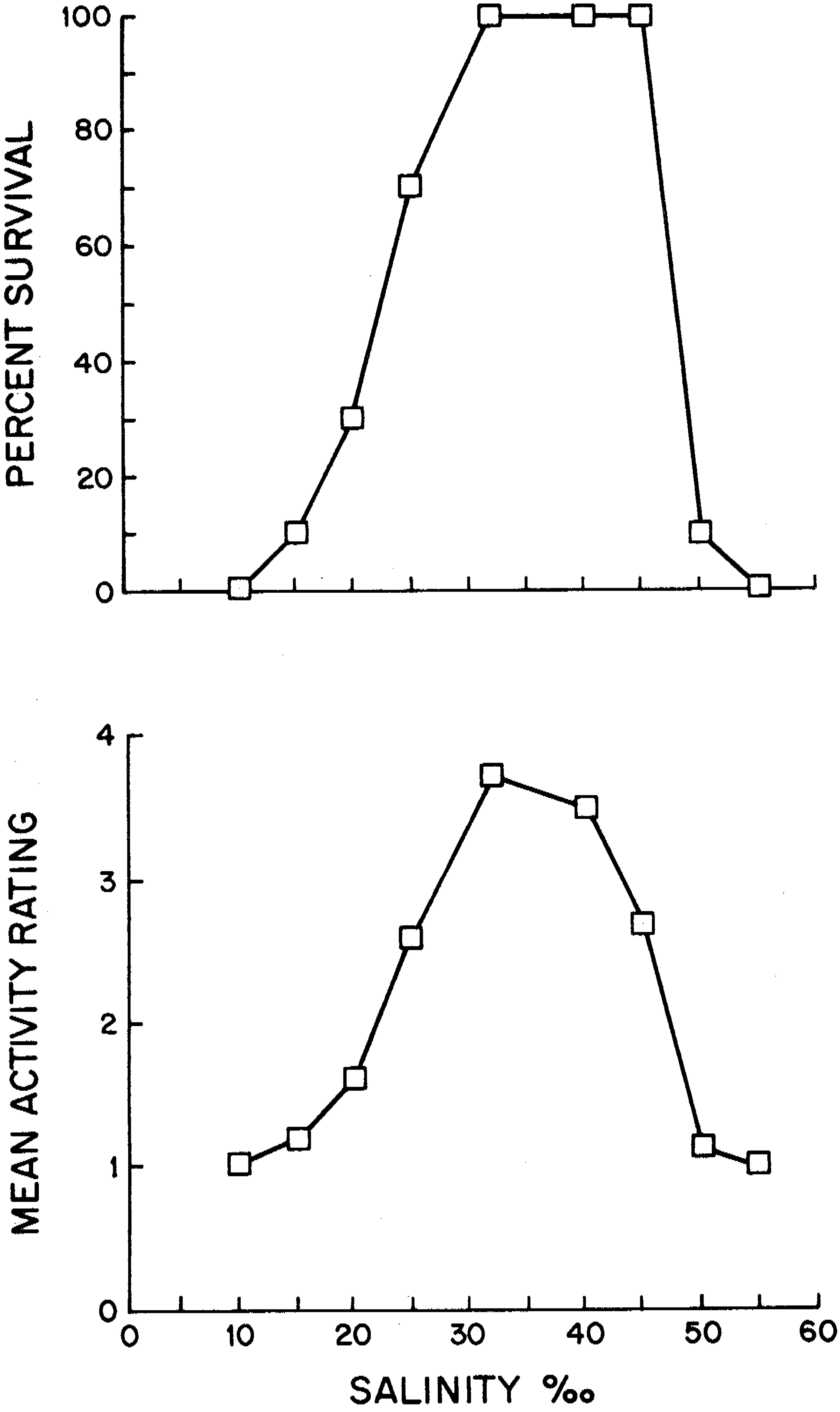
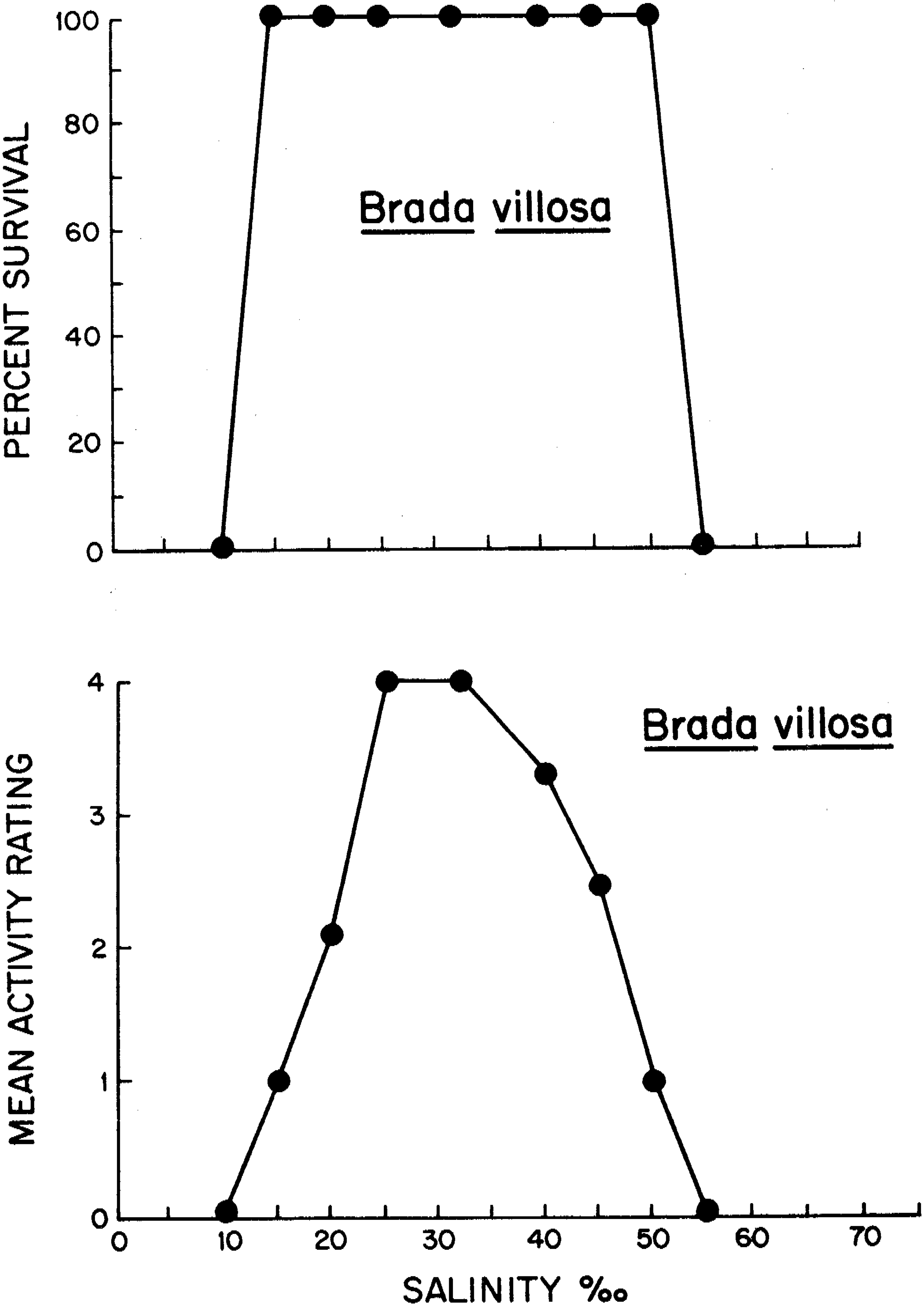

100
80
60
40
20
0
PERCENT SURVIVAL
4
3
2
1
0
MEAN ACTIVITY RATING
0
10
20
30
40
50
60
SALINITY ‰

Figure 10. Tolerance and activity response of the benthic polychaete worm *Brada villosa* exposed to gradual salinity transfer at -1.0° C. The following subjective activity rating scale is described in detail in the methods:

4 = normal
3 = slightly reduced
2 = reduced
1 = greatly reduced
0 = dead


Brada villosa
PERCENT SURVIVAL
100
80
60
40
20
0
Brada villosa
MEAN ACTIVITY RATING
4
3
2
1
0
0
10
20
30
40
50
60
70
SALINITY ‰

whether the species we worked with are actually found under extreme hypersaline conditions. There is a possibility that with prolonged gradual acclimatization to hypersaline conditions, these species could survive. The results of our gradual salinity transfer experiments, though, do not suggest that these animals have good salinity acclimation capabilities. However, the rate of salinity change in these experiments is much more rapid than the natural rate of salinity change, and long-term salinity acclimation experiments would have to be undertaken to fully evaluate the capabilities of these species. The lack of running seawater facilities made this approach infeasible for our present study.

Quantitative Activity Measurements

Quantitative estimates of locomotor activity levels were undertaken with two species subjected to gradual changes in salinity. The purpose of these experiments was to provide some verification of the subjective activity rating system used in previous experiments (Schneider, 1980) and in the experiments on epibenthic species presented in this report. The results are presented on a relative scale of lines/minute crossed in the activity chamber. These values can be crudely converted into linear distance in cm/minute by multiplying the lines/minute by 4.3, the average distance in cm. between the lines in the annular activity chamber.

Activity of the epibenthic amphipod Anonyx nugax is shown in Fig. 11. Swimming activity is severely depressed at salinities of 20 and 45 $^{o}/oo$ and is eliminated at 15 and 50 $^{o}/oo$. This agrees very closely with the limits for spontaneous activity recorded for this species previously using the subjective activity rating scale (Schneider, 1980). In these similar gradual salinity transfer experiments A. nugax lost spontaneous activity at about 18 and 46 $^{o}/oo$.

Activity of the isopod Saduria entomon exposed to gradual salinity transfers is shown in Fig. 12. This species is capable of locomotor activity over an exceptionally wide salinity range. Activity is only reduced by 50% of the maximum value at about 3 and 50 $^{o}/oo$ and some locomotion occurs at less than 1 $^{o}/oo$ and at 70 $^{o}/oo$. For comparison the survival of S. entomon in the same gradual salinity transfer experiments is shown in Fig. 13. At least 50% of the speciments survived transfers down to about 1.5 $^{o}/oo$ based upon their ability to show some appendage movement when disturbed. Transfers up to 85 $^{o}/oo$ were tolerated by 87.5% of the specimen. The actual upper salinity tolerance for this species was not determined since salinity transfers were not carried

Figure 11. Locomotor activity levels of the epibenthic amphipod Anonyx nugax exposed to gradual salinity transfers at -1.0° C. The activity in lines/min. crossed in the activity chamber can be roughly converted into linear distance in cm/min. by multiplying the values by 4.3.

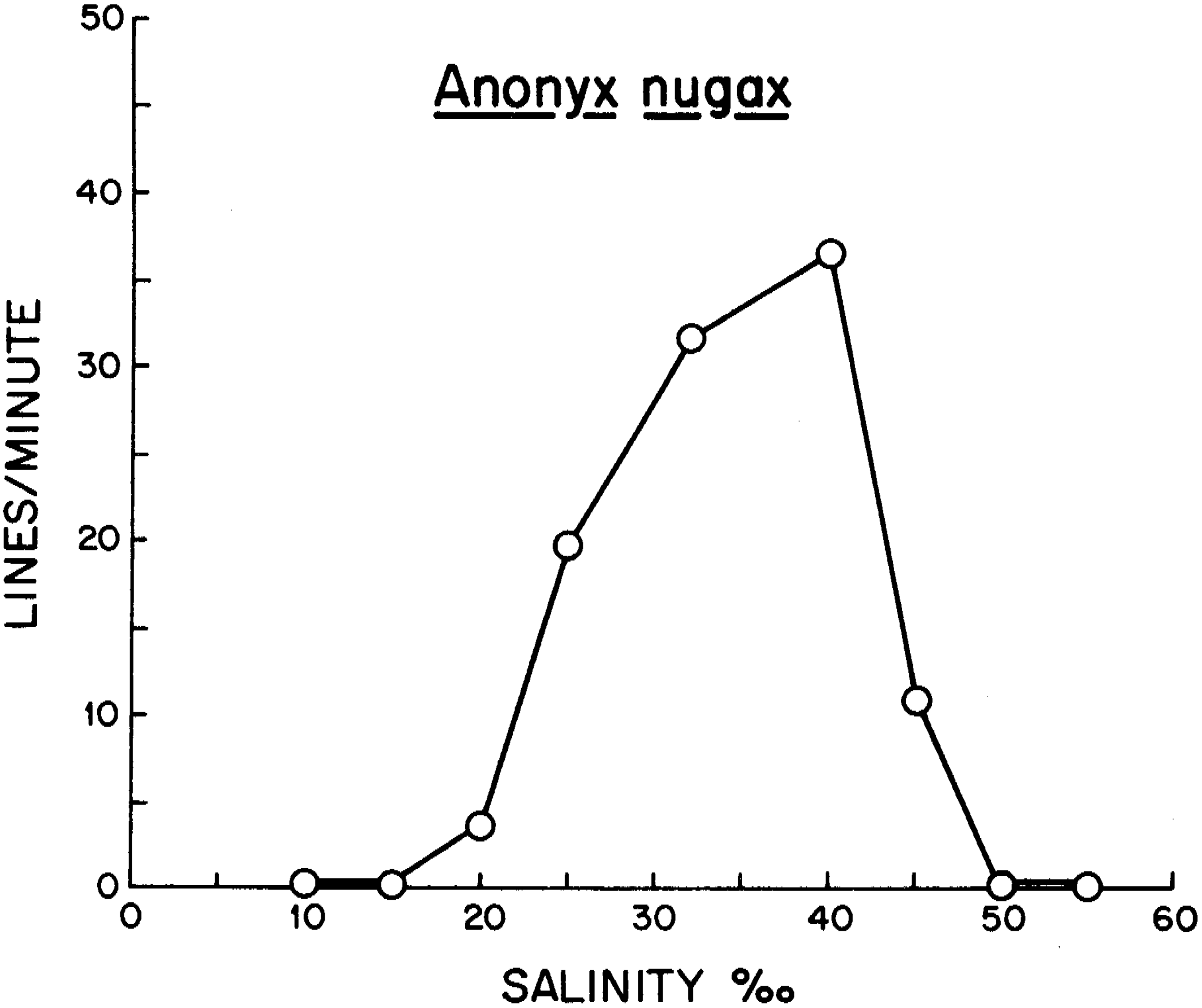

Anonyx nugax
LINES/MINUTE
50
40
30
20
10
0
0
10
20
30
40
50
60
SALINITY ‰

Figure 12. Locomotor activity levels of the isopod *Saduria entomon* exposed to gradual salinity transfers at -1.0° C. The activity in lines/min. crossed in the activity chamber can be roughly converted into linear distance in cm/min. by multiplying the values by 4.3.

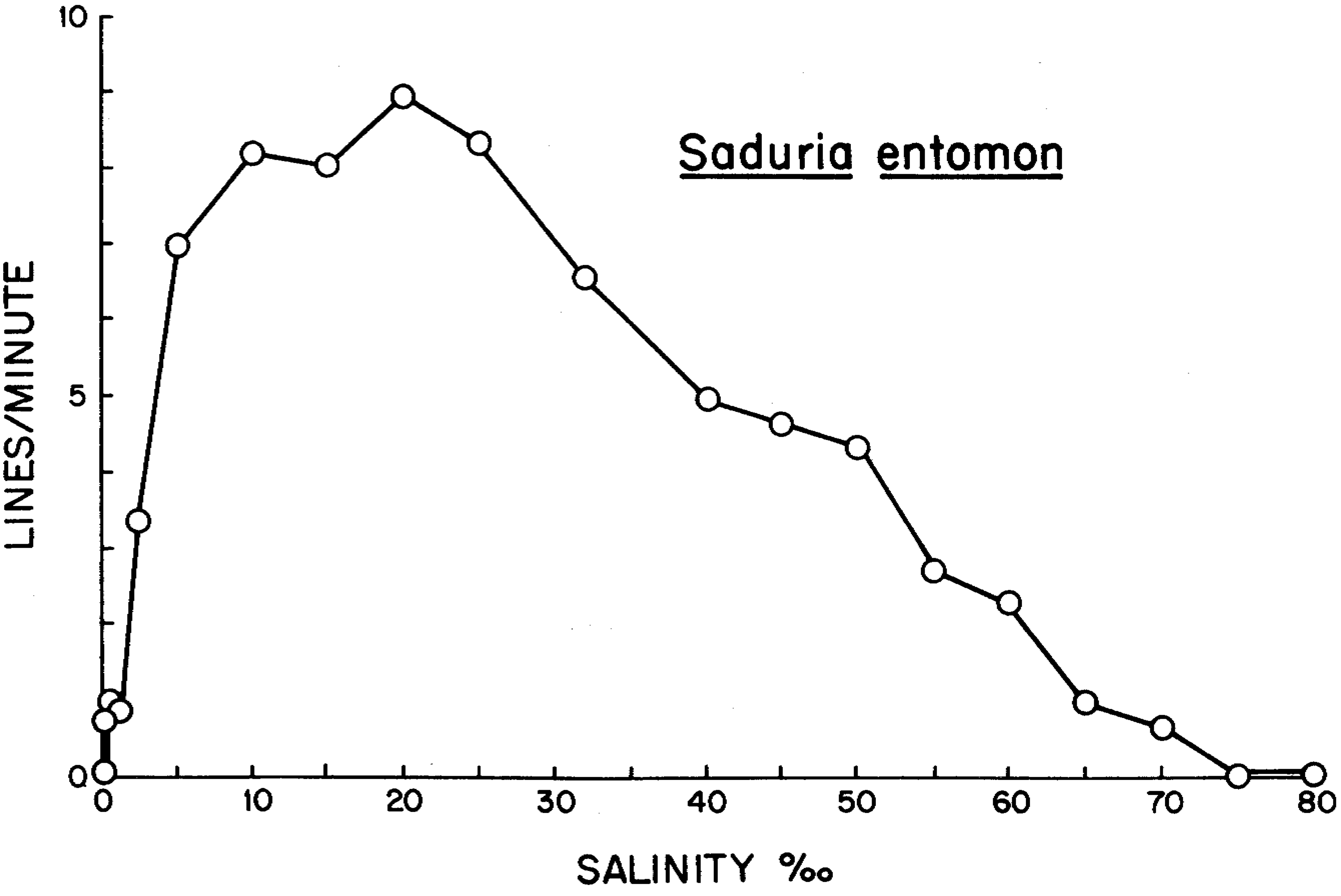
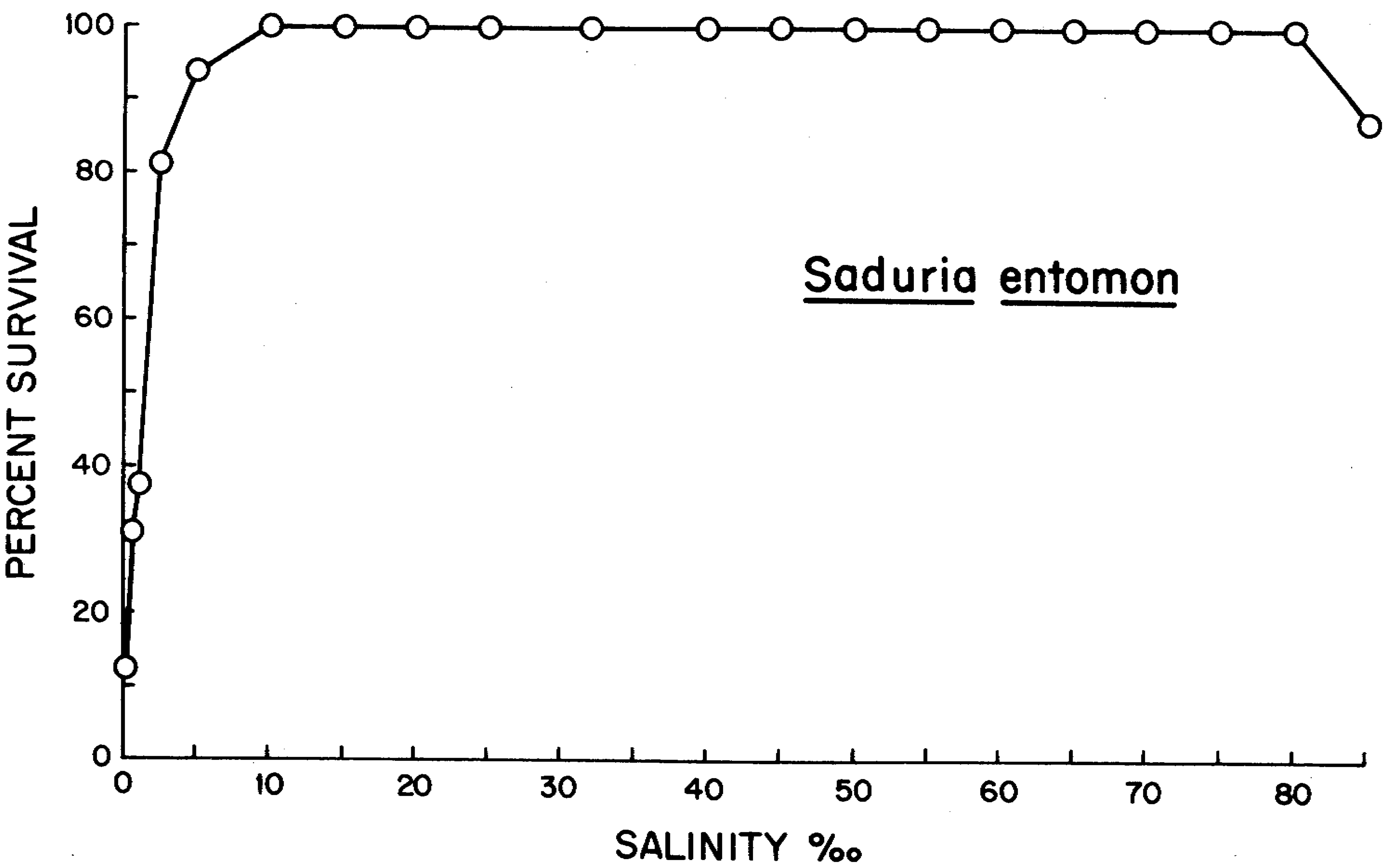

Saduria entomon
LINES/MINUTE
10
5
0
SALINITY ‰
0
10
20
30
40
50
60
70
80

Figure 13. Tolerance of the isopod *Saduria entomon* exposed to gradual salinity transfers at -1.0^{0} C.


Saduria entomon
PERCENT SURVIVAL
0
20
40
60
80
100
SALINITY ‰
0
10
20
30
40
50
60
70
80

beyond 85 ^{o}/oo. The wide salinity limits for locomotor activity in S. entomon would appear to allow this species to be active in most lagoon areas during late winter and early spring.

Effect of Salinity on Metabolic Rates

The effect of hypersaline conditions on metabolic rates was studied in seven species of benthic animals. For five of these species, metabolism at a single high salinity just below their upper tolerance limit was compared to metabolism at a more normal salinity of 32 ^{o}/oo. Two species, the amphipod Aceroides latipes and the isopod Saduria sabini, had metabolic rates significantly (ANOV, $p < .05$) decreased by exposure to hypersaline conditions (Fig. 14). The amphipod Pontoporeia femorata and the polychaete worm Pectinaria hyperborea did not show a significant (ANOV, $p > .05$) effect of hypersaline conditions on their metabolic rates. The metabolic rate of the polychaete worm Brada villosa was significantly (ANOV, $p < .05$) increased by exposure to hypersaline conditions (Fig. 14). In two other species metabolic rates were determined over a range of hypersaline conditions. Anemone respiration was significantly (ANOV, $p < .05$) affected by hypersaline conditions (Fig. 15), but a Newman-Keuls multiple range test indicates that only the rate at 50 ^{o}/oo is significantly different from the control rate at 32 ^{o}/oo. Metabolism in this species is apparently only weakly affected by elevated salinity and is essentially independent of salinity over the range 32 to 45 ^{o}/oo. Respiration of the bivalve mollusc Liocyma fluctuosa was also significantly (ANOV, $p < .05$) decreased by hypersaline conditions (Fig. 16). A Newman-Keuls multiple range test indicates that the rates at both 55 and 65 ^{o}/oo are significantly different from the rate at 32 ^{o}/oo. Since no intermediate measurements were made between 32 and 55 ^{o}/oo it is not known whether L. fluctuosa exhibits salinity independent respiration over a range of less stressful salinities.

Most of the species examined show a trend for decreased metabolic rate at some elevated salinity. In those cases where we have information on the activity levels for the species, the salinities that depress metabolism correspond reasonably well with those that depress physical activity. Aceroides latipes shows failure of spontaneous locomotion at 50 ^{o}/oo (Fig. 8) and has metabolism significantly depressed at this same salinity. Anemone activity becomes severely depressed at 50 ^{o}/oo (Fig. 9), the same salinity that produces a significant decrease in metabolic rate. Although in this case the change in metabolism appears far less dramatic than the change in activity, but this may be an artifact

Figure 14. The effect of salinity on the oxygen consumption of arctic benthic invertebrates held at -1.0° C. The presence of a solid triangle signifies those cases where the metabolic rate under hypersaline conditions was significantly different (ANOV, $p < .05$) from that at the control salinity of 32 $^{o}/oo$. The salinity at which the determinations were made is shown above each bar.

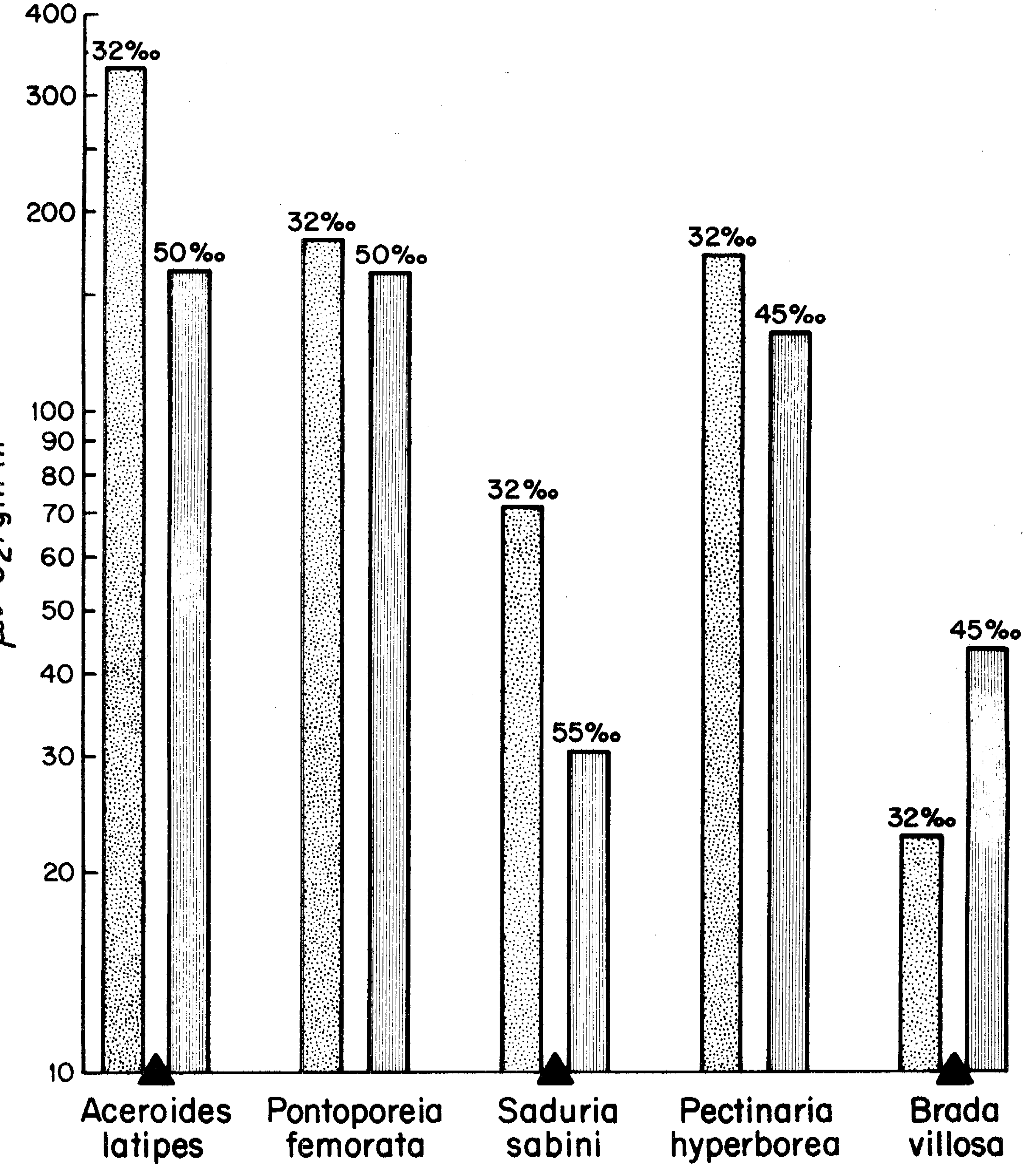

μℓ O$_2$/gm hr
400
300
200
100
90
80
70
60
50
40
30
20
10
32‰
50‰
32‰
50‰
32‰
55‰
32‰
45‰
32‰
45‰
Aceroides latipes
Pontoporeia femorata
Saduria sabini
Pectinaria hyperborea
Brada villosa

Figure 15. The effect of salinity on the oxygen consumption of an arctic sea anemone (species not yet identified) held at -1.0° C. The vertical bars indicate the 95% confidence intervals for the means.

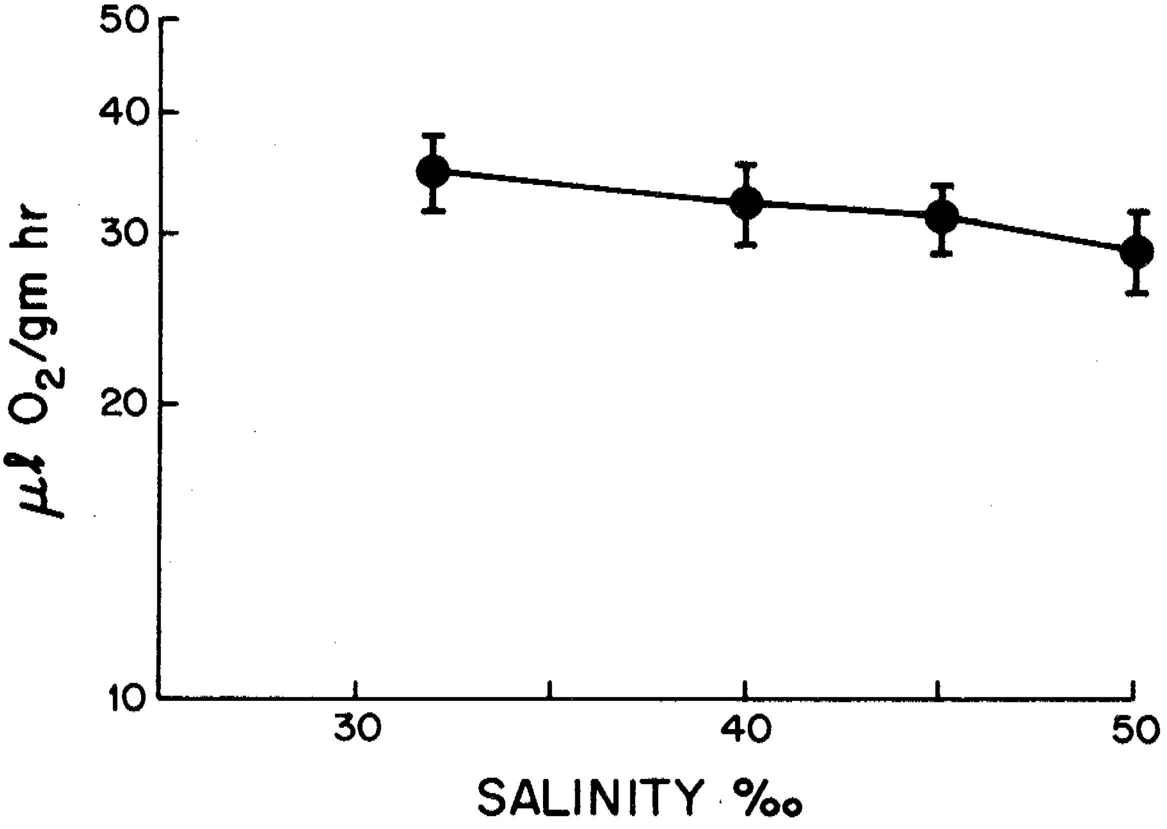
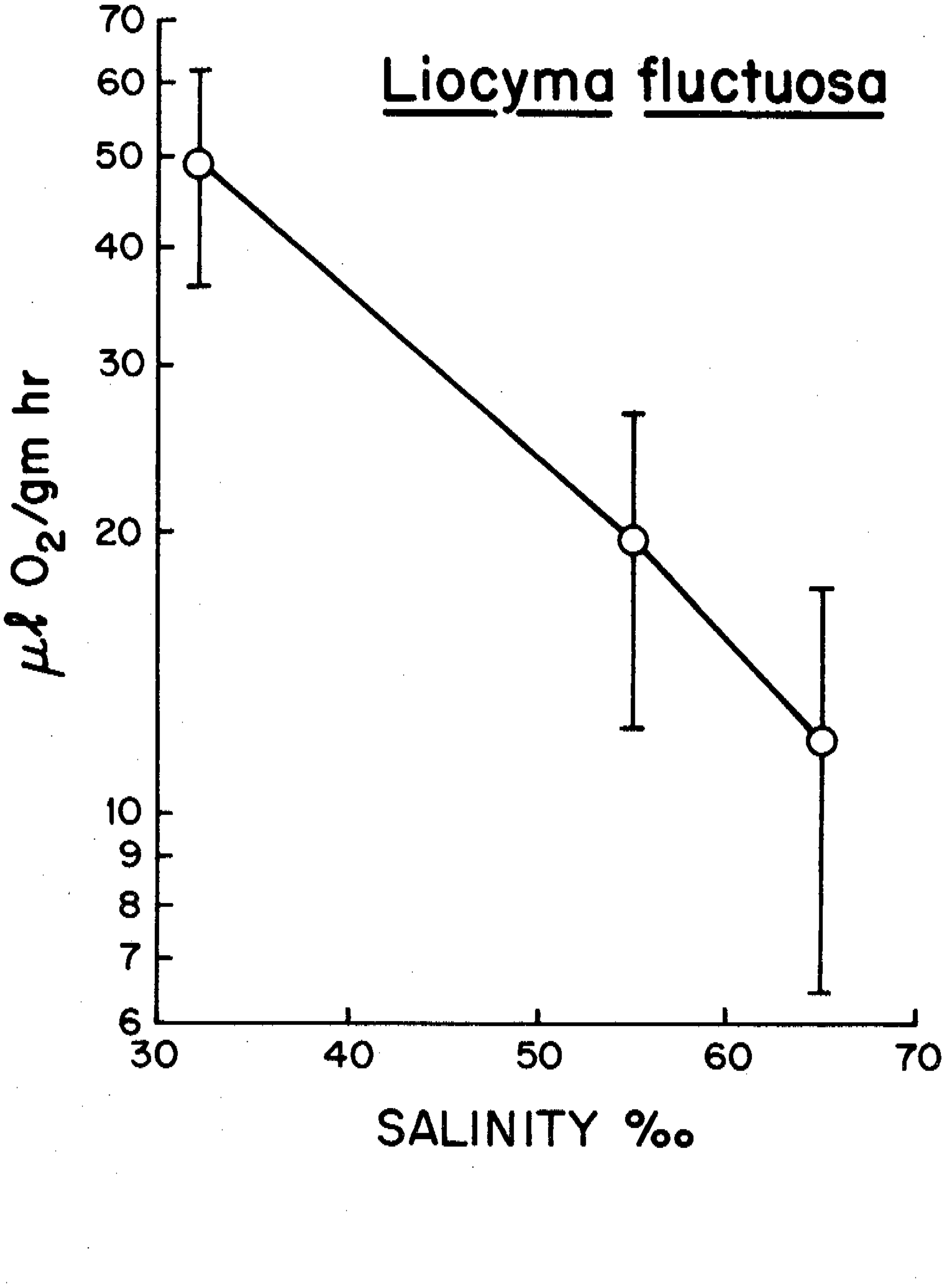

50
40
30
20
10
$\mu l\ O_2$/gm hr
30
40
50
SALINITY ‰

Figure 16. The effect of salinity on the oxygen consumption of the bivalve mollusc, Liocyma fluctuosa, held at -1.0^{0} C. The vertical bars indicate the 95% confidence intervals for the means.


Liocyma fluctuosa
70
60
50
40
30
20
10
9
8
7
6
$\mu \ell$ O_2/gm hr
30
40
50
60
70
SALINITY ‰

of the activity rating system used. Pontoporeia femorata may be an exception to the above correlation in that spontaneous activity is lost at around 45 to 50 ^{o}/oo (Fig. 8) but respiration is not significantly depressed at 50 ^{o}/oo. Depressed metabolism at high salinities is consistent with previous data on arctic epibenthic invertebrates (Busdosh and Atlas, 1975; Percy and Mullin, 1975; Schneider, 1980) and has been frequently reported for temperate zone invertebrates (see review by Kinne, 1971, p. 874). Causal relationships for this trend are apt to be complex and may range from biochemical changes associated with intracellular isosmotic regulation (Hulbert et al, 1976) to changes in locomotor activity.

The increased metabolism seen in Brada villosa at high salinity is a less common type of response and is apparently typical of a few euryhaline crustaceans (Kinne, 1971). Our tolerance and activity data do not suggest that this polychaete is particularly euryhaline as activity is severely depressed between 45 and 50 ^{o}/oo and the upper tolerance limit lies near 53 ^{o}/oo (Fig. 10). It is therefore difficult to explain the pronounced stimulation of metabolism when B. villosa is held at 45 ^{o}/oo (Fig. 14).

The metabolic rates measured for the benthic infaunal species appear to be lower than those of the epibenthic species studied previously (Schneider, 1980). Table 1 shows the metabolic rates determined at 32 ^{o}/oo and -1.0^{o} C. for both the epibenthic and benthic species studied in this contract. In the first two columns, the approximate mean body weight for each species appears with the rate of oxygen consumption corrected to that weight. The last column shows the rate of oxygen consumption for each species corrected to a standard dry body weight of 100 mg using a slope of -0.27 for the metabolism vs. weight regression. This allows comparison of the metabolic rates of all species independent of the effects of body size. The slope of -0.27 used in this correction is approximately the mean value determined for a large number of organisms when the log of weight specific metabolism is regressed against the log of body weight (Schmidt-Nielsen, 1972). The mean metabolic rate for the benthic species (34.2 μlO_2/gm hr) is about 5 times lower than the mean metabolic rate of the epibenthic species (182.7 μlO_2/gm hr). This reduction of metabolic rates is probably largely a result of decreased locomotor activity in the more sessile benthic infaunal species. However, a reduction of oxygen consumption rates has been reported as an adaptation to the low oxygen availability in the interstitial water of sediments (Thompson and Pritchard, 1969) and may be a factor here.

Table 1. Rates of oxygen consumption of arctic marine invertebrates at -1.0° C and 32 $^{0}/oo$ salinity. Metabolic rates shown in the last column have been corrected to a standard dry body weight of 100 mg using the slope b = -0.27 in the following equation: $\log M_s = \log M_o + b (\log W_s - \log W_o)$ where M_s and M_o are the standardized and observed metabolic rates respectively and W_s and W_o are the standardized and observed dry body weights respectively.

Species	W_o mg	M_o μl O_2/gm hr	M_s μl O_2/gm hr
Epibenthic			
Anonyx nugax	45	198.1	159.7
Boeckosimus affinis	20	202.5	131.1
Mysis littoralis	7	527.5	257.3
Benthic			
Asceroides latipes	1.7	330.1	13.9
Pontoporeia femorata	2.7	181.7	8.7
Saduria sabini	65	71.5	63.6
Pectinaria hyperborea	3	172.0	66.7
Brada villosa	45	22.9	18.5
Liocyma fluctuosa	20	49.3	31.9
Sea anemone*	115	34.8	36.1

*Taxonomic identity of this species has not yet been determined.

Crude Oil Tolerance Experiments

Two species were investigated to determine their tolerance to crude oil exposure. Anemones were exposed to five different oil-seawater dispersions of Prudhoe Bay crude oil at 32, 40, 45 and 50 ^{o}/oo salinity. Mortalities only occurred at 50 ^{o}/oo and less than 20% of the animals died during 96 hour exposure in dispersions of 500 µl oil/500 ml of seawater or less. Mortality rose to 40% at 50 ^{o}/oo salinity and 750 µl oil/500 ml seawater. The polychaete worm *Brada villosa* was exposed to five different oil-seawater dispersions at 32 ^{o}/oo only. Mortality was only 10% at a dispersion strength of 750 µl oil/500 ml seawater after 96 hours of exposure and no mortalities occured in weaker dispersions.

Subjective activity ratings of these species during the above oil tolerance tests provide a more sensitive index than the above mortality data. The activity rating of the anemones after 96 hours of exposure to the oil-seawater dispersions is shown in Fig. 17. Activity appears slightly reduced at most oil dispersion strengths and at salinities of 45 ^{o}/oo and below but none of these is significant from the control animals without oil according to Mann-Whitney tests ($p < .05$). The activity of all of the treatment groups at 50 ^{o}/oo is significantly decreased from that of the other groups at lower salinities, but none of the oil treatments at 50 ^{o}/oo is significantly different from the no oil control (Mann-Whitney tests, $p > .05$). Within the range of oil dispersions tested (0 to 750 µl oil/500 ml seawater), there is no apparent effect on the activity response of the anemones.

The polychaete worm *Brada villosa* appears to be somewhat more sensitive to oil than the anemones. Exposure to oil-seawater dispersions at 32 ^{o}/oo for 96 hours caused significant (Mann-Whitney Test, $p < .05$) decreases in the activity rating from the no oil control group at all of the oil dispersion strengths tested (Fig. 18). Furthermore, the activity rating significantly decreases between 25 and 250 µl oil/500 ml seawater and between 500 and 750 µl oil/500 ml seawater.

Compared to the epibenthic invertebrates previously studied (Schneider, 1980), the benthic animals we investigated are more tolerant of exposure to crude oil dispersions. Dispersions prepared at 100 µl oil/500 ml seawater or less were sufficient to abolish spontaneous locomotion in the epibenthic animals. In *Brada villosa* dispersions of 500 µl oil/500 ml seawater were necessary to produce a comparable inhibition of activity. The anemones were not sensitive

Figure 17. The effect of 96 hour exposure to Prudhoe Bay crude oil on the activity on an arctic sea anemone (species not yet determined) at different salinites. Open circles - 32 ^{o}/oo, close circles - 40 ^{o}/oo, open triangles - 45 ^{o}/oo, and open squares - 50 ^{o}/oo. The following subjective activity rating scale is described in detail in the methods:

4 = normal
3 = slightly reduced
2 = reduced
1 = greatly reduced
0 = dead

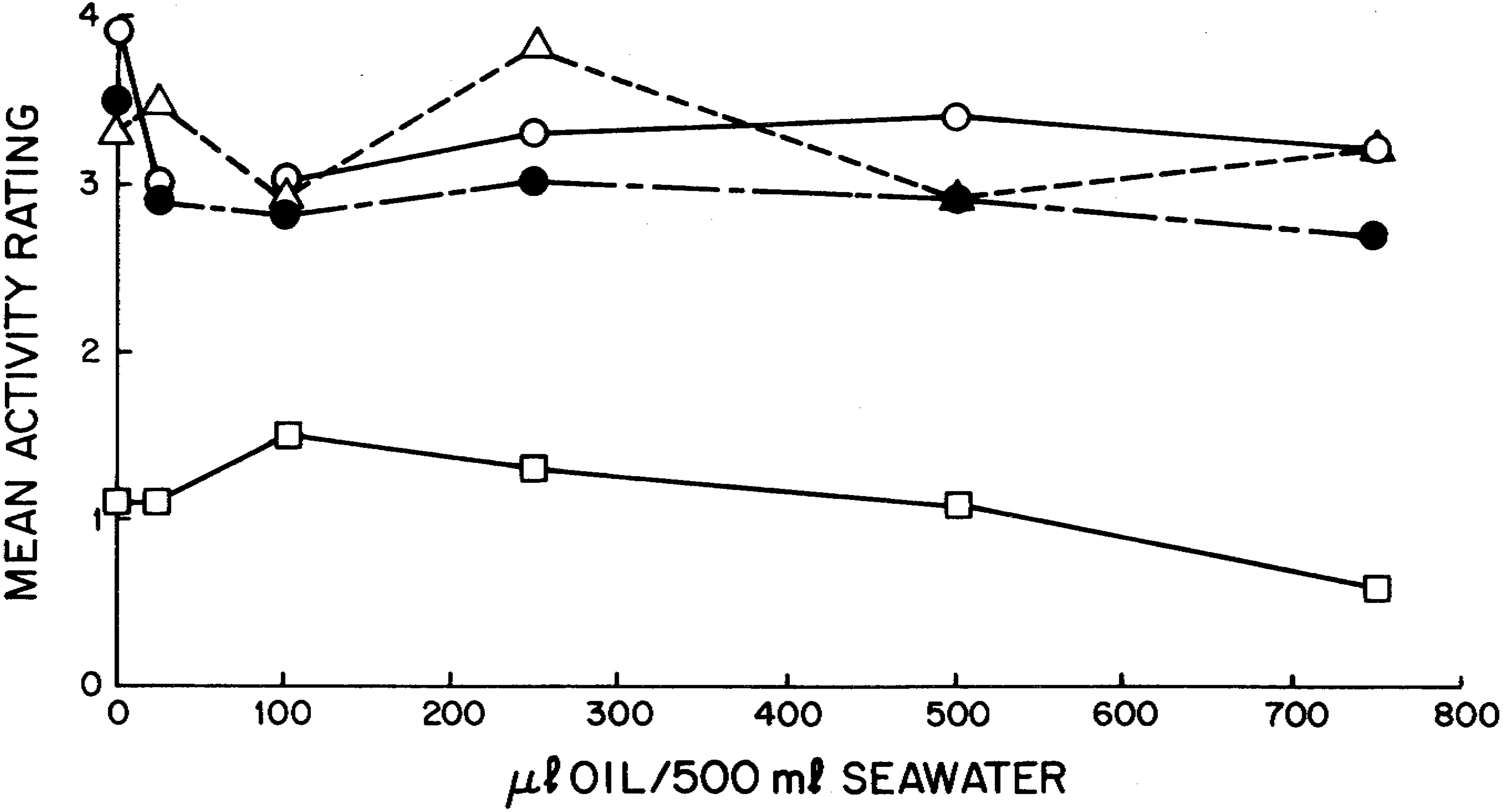
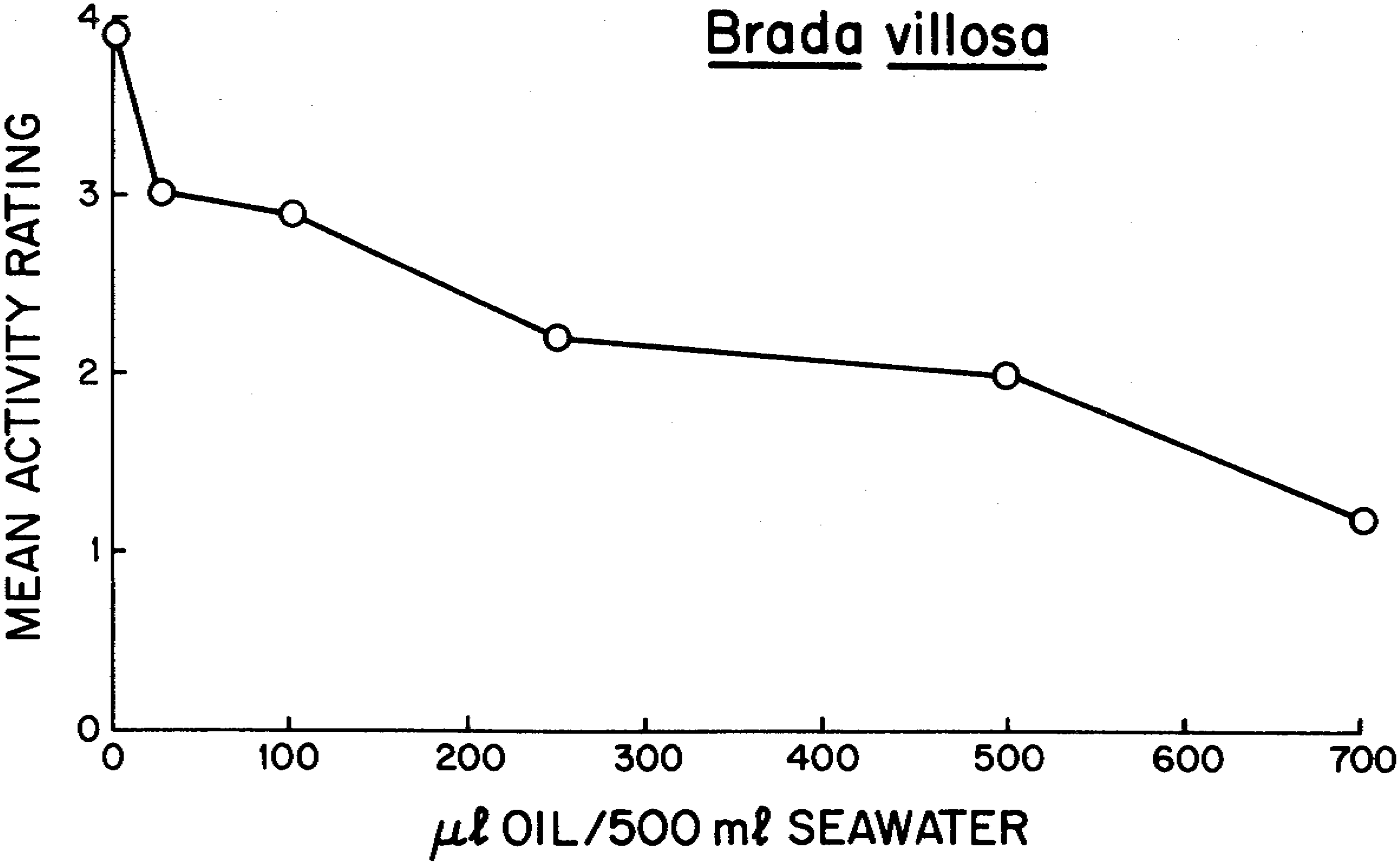

MEAN ACTIVITY RATING
0
1
2
3
4
0
100
200
300
400
500
600
700
800
μℓ OIL/500 mℓ SEAWATER

Figure 18. The effect of 96 hour exposure to Prudhoe Bay crude oil on the activity of the polychaete worm, *Brada villosa*, at 32 ^{o}/oo salinity. The following subjective activity rating scale is described in detail in the methods:

4 = normal
3 = slightly reduced
2 = reduced
1 = greatly reduced
0 = dead


Brada villosa
MEAN ACTIVITY RATING
0
1
2
3
4
0
100
200
300
400
500
600
700
μℓ OIL/500 mℓ SEAWATER

to oil up to a dispersion strength of 750 μl oil/500 ml seawater, the highest strength tested. Percy and Mullin (1975) found that the oil sensitivity of the species they worked with in the Canadian arctic fell into two distinct categories, sensitive and resistant, based upon their survival in oil dispersions of 1000 μl oil/500 ml seawater. Both of the benthic species we worked with should probably be considered resistant species in view of their high survival in the 750 μl oil/500 ml seawater dispersions.

Effect of Oil Dispersions on Metabolic Rates

In an attempt to investigate sublethal effects of oil on benthic species, the metabolic rates of both the anemones and Brada villosa were determined following a 36 hour exposure to crude oil-seawater dispersions. The anemones were tested at three different salinities (32, 40 and 45 ^{0}/oo) whereas B. villosa was only examined at 32 ^{0}/oo.

The metabolic response of the anemones is shown in Fig. 19 as the percent change in oxygen consumption rate compared to the no oil control group. Both the 250 and 750 μl oil/500 ml seawater dispersions significantly increased the metabolism of anemones at a salinity of 40 ^{0}/oo (ANOV $p < .05$)) but not at the other two salinities. Sensitivity of metabolism to oil in this species is apparently salinity dependent and enhanced at moderately elevated salinities.

The metabolic rate of Brada villosa is also increased by exposure to crude oil dispersions. Fig. 20 shows the rate of oxygen consumption at three different levels of oil dispersion. The rates of worms exposed to both the 250 and 750 μl oil/500 ml seawater dispersions are significantly higher than the rate of the no oil control group (ANOV $p < .05$).

Stimulation of metabolic rates by exposure to crude oil or petroleum hydrocarbons has been commonly reported in the literature (Laughlin and Neff, 1977; Percy and Mullin, 1975; Percy, 1977; Stainken, 1978). The response tends to be dependent upon the hydrocarbon concentration and may show reversal with increasing concentrations (Percy and Mullin, 1975). The limited range of dispersion strengths tested in this study do not permit classifying the response of these two benthic species. No trend for reversal of the stimulatory effect was evident and the moderately high strengths of the dispersions used does not permit speculation about the response to lower levels of oil. Brada villosa metabolism appears unusually sensitive to oil, though, as there is about a 2.6 fold increase in the rate after exposure to the oil dispersions. This is a larger response than was seen in any of the other species we have studied (Schneider, 1980).

Figure 19. The effect of Prudhoe Bay crude oil dispersions on the metabolic rate of an arctic sea anemone (species not yet determined) at -1.0° C. The volumes of oil indicated were dispersed in 500 ml of seawater at each salinity. Cases where the metabolic rate of the treated group differs significantly from the control group (ANOV, $p < .05$) are designated with a solid triangle.

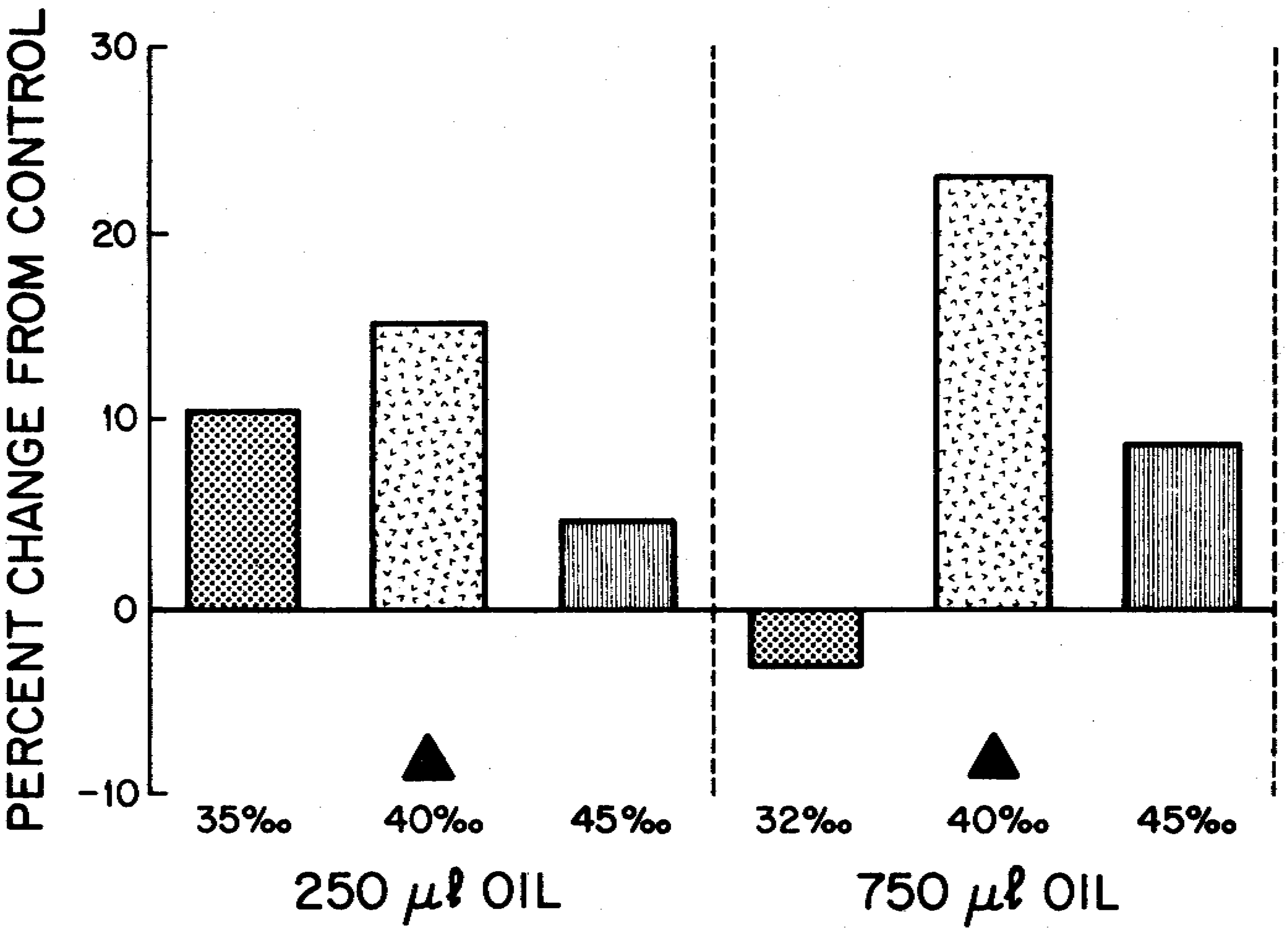
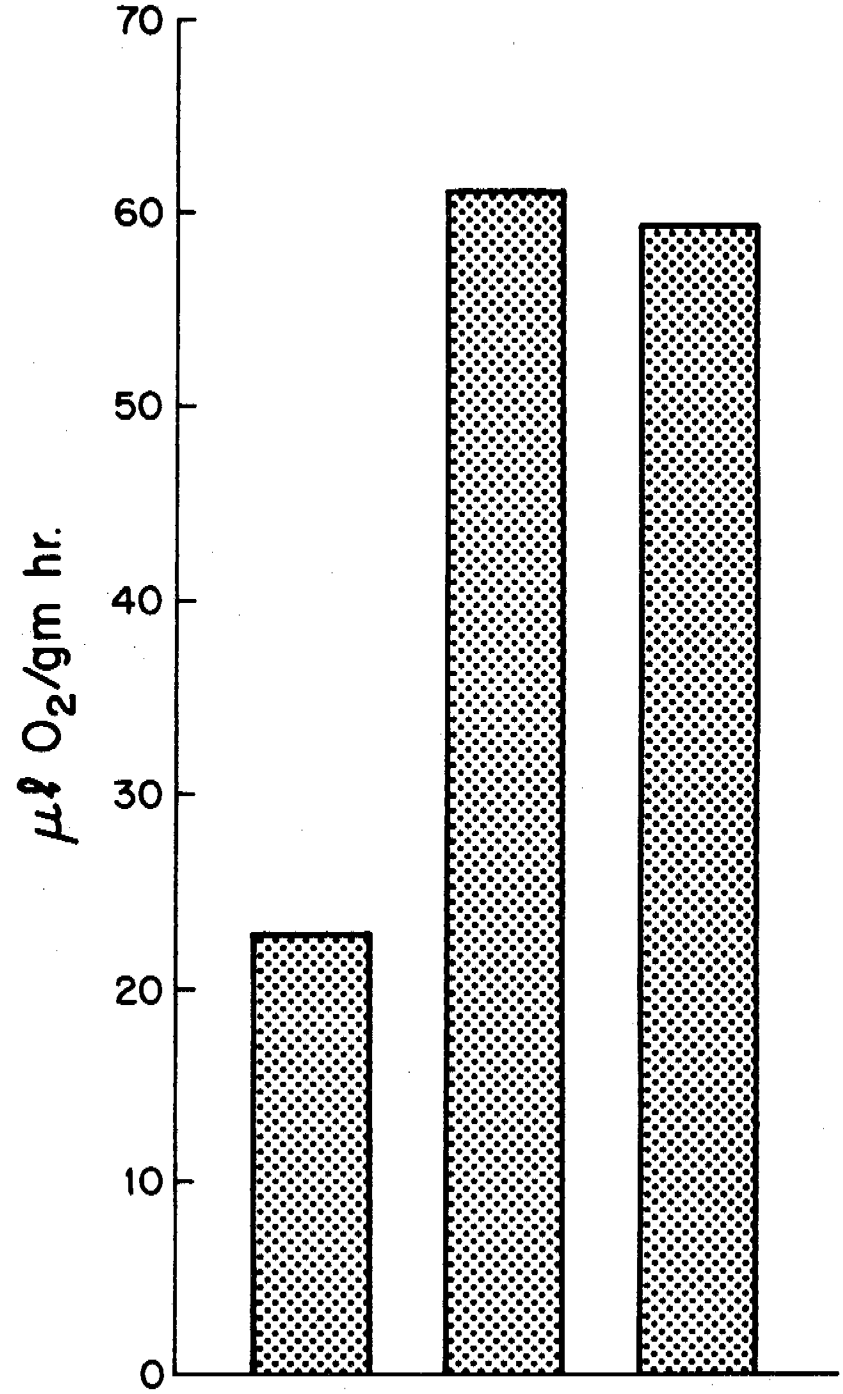

PERCENT CHANGE FROM CONTROL
30
20
10
0
−10
35‰
40‰
45‰
32‰
40‰
45‰
250 µl OIL
750 µl OIL

Figure 20. The effect of Prudhoe Bay crude oil dispersions on the metabolic rate of the polychaete worm, Brada villosa, at -1.0° C and 32 $^{o}/oo$ salinity. The volumes of oil indicated were dispersed in 500 ml of seawater.


70
60
50
40
30
20
10
0
μl O_2/gm hr.
NO OIL
250 μl OIL
750 μl OIL

Oiled Sediment Preference Experiments

Two experiments were performed with the benthic amphipod *Pontoporeia femorata* to determine its response to oil contaminated sediment. The amphipods were presented with a choice of oil contaminated sediment and sediment that had not been exposed to oil. The distribution of the 10 amphipods in the test chamber was determined after two days. In the first experiment 1.9 ml of crude oil was mixed with 250 ml of Elson Lagoon sediment. When the amphipods were offered a choice of this vs. uncontaminated sediment from Elson Lagoon, all of the amphipods chose the uncontaminated sediment. Similar results were obtained with the second experiment where 2.5 ml of oil were mixed with 250 ml of Chuckchi Sea mud. In that experiment 80% of the animals were alive and burrowed in the uncontaminated sediment. The remaining two animals were found dead on the surface of the oil contaminated sediment. *Pontoporeia femorata* clearly tends to avoid oil contaminated sediment, at least at the levels we used, and there is an indication that oil contaminated sediment may be lethal to those amphipods that attempt to burrow in it. Percy and Mullin (1975) found similar avoidance of oil contaminated sediment in the amphipod, *Boeckosimus* (*Onisimus*) *affinis*, but not in the amphipod *Corophium clarencense* or the isopods *Saduria entomon* and *S. sibirica*. Species differences occur in the response to oil contaminated sediment and our results suggest that *Pontoporeia femorata* should be considered among the more sensitive arctic species studied. The oil levels used in our experiments fall somewhere between the light and medium oil contamination levels used by Percy and Mullin (1975).

SUMMARY AND CONCLUSIONS

Both acute and gradual salinity tolerance tests and associated activity ratings indicate that the arctic shallow-water benthic invertebrates studied are not more tolerant to hypersaline stress than the epibenthic invertebrates. Acute salinity transfers resulted in high mortality at salinities of 55 ^{o}/oo or less and severely depressed activity at around 45 ^{o}/oo. Gradual salinity transfers in most cases resulted in less than a 5 ^{o}/oo increase in the upper tolerance limit and almost no improvement in the upper limit for activity.

Quantitative activity measurements with the epibenthic amphipod, *Anonyx nugax*, agree very closely with the subjective activity ratings made previously (Schneider, 1980) and indicate that this species' activity is severely depressed at 20 and 45 ^{o}/oo. Similar measurements with the isopod Saduria entomon indicate that this species' activity is only reduced by 50% of the maximum level at salinities of about 3 and 50 ^{o}/oo and that some locomotion occurs at less than 1 ^{o}/oo and at 70 ^{o}/oo. S. entomon is the most euryhaline invertebrate studied in this project and will survive salinities greater than 70 ^{o}/oo.

Metabolic rates of benthic invertebrates at -1.0° C were usually depressed by hypersaline conditions. In two of the species studied, though (Pontoporeia femorata and Pectinaria hyperborea), the decrease was not significant at the test salinity used. An exception to this trend is seen in the polychaete worm Brada villosa where metabolism was strongly increased by hypersaline conditions (45 ^{o}/oo salinity).

The metabolic rates of arctic shallow-water benthic invertebrates at -1.0 °C are about a factor of 5 lower than the metabolic rates of epibenthic species from the same habitat. This may result from decreased locomotor activity in sessile benthic animals or may be an adaptation to low oxygen availability in interstitial waters of sediments.

Two benthic species, sea anemones and Brada villosa, were found to be more tolerant of exposure to seawater dispersions of Prudhoe Bay crude oil than the epibenthic species studied previously (Schneider, 1980). Survival of both species is high in dispersions strengths of up to 750 μl/500 ml seawater. Activity of sea anemones is not significantly influenced by dispersion strengths of up to 750 μl oil/500 ml seawater and there are no apparent interacting effects of salinity on this species. Oil dispersion strengths of about 300-500 μl oil/500 ml seawater were required to severely depress the activity of Brada villosa.

Metabolic rates of both sea anemone and Brada villosa were significantly increased by exposure to oil dispersion strengths of 250 μl oil/500 ml seawater or higher. Salinity influences the oil effect in sea anemones in that metabolism is only significantly increased at 40 ^{o}/oo and not at 32 ^{o}/oo or 45 ^{o}/oo. Brada villosa metabolism is more strongly stimulated by crude oil exposure than the other species previously studied (Schneider, 1980).

Pontoporeia femorata appears to avoid sediments that have been contaminated by Prudhoe Bay crude oil.

The physiological responses to hypersaline stress in the benthic invertebrates studied suggest that most of these species are unable to live in areas of lagoons that exceed salinities of about 50 to 55 ^{o}/oo. These species may therefore be absent from certain regions in the deepest parts of the lagoons. Two species, the epibenthic amphipod Boeckosimus affinis and the isopod Saduria entomon, appear capable of surviving at least limited exposure to the hypersaline extremes seen in Beaufort Sea lagoon systems during late winter and early spring.

Limited experiments on crude oil tolerance suggest that benthic species may not be as sensitive to low levels of oil contamination as epibenthic species. However, the number of species studied so far is too low to substantiate such an hypothesis. Motile epibenthic and benthic species may offset high sensitivity to crude oil by behavioral avoidance of contaminated areas. Thus the impact of an oil spill on motile vs. sessile species may be more similar than is suggested by their tolerance levels.

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A Survey of the Benthos of Harrison Bay

A. C. Broad

INTRODUCTION

In 1980, RU356 participated in two aspects of the joint studies of Harrison Bay conducted in August and designed to provide information for the Environmental Impact Statement relative to Sale-71. We were responsible for a search for possible macrophytic communities and, as ship time was available, adding to the existing data base on infaunal invertebrates of the area.

Prior to 1980, we had made 15 benthic stations in Harrison Bay (see Table 11) and nine others in the Sale-71 area, in addition to stations in Simpson Lagoon. These varied in depth from 1.0 m to 10.0 m and extended from the vicinity of Pingok Island (70° 34.5'N; 149° 30.0'W) to Lonely (71° 00.0'N; 153° 15.3'W). Data from these stations have been presented in our Quarterly or Annual Reports for December, 1977, March, 1979, and September, 1979, and are available through NODC (TR 3117, TR 3274, TR 4137, 030800 121). On the basis of these samples, the infaunal benthos of Harrison Bay and the Sale-71 area could be characterized as follows: The principal members of the benthos are polychaete worms (especially _Prionospio cirrifera_, _Scolecolepides arctius_, _Terrebellides stroemi_ and other species) and bivalve mollusks (primarily _Portlandia arctica_ and _Cyrtodaria kurriana_). _Cyrtodaria_ and _Scolecolepides_ dominate in shallower water (generally under 5 m in depth), and _Portlandia_ and _Prionospio_ are predominant at 5 and 10 m. The isopods, _Saduria entomon_ or _S. sabini_; the lugworm, _Arenicola glacialis_; an ascidian, _Molgula griffithsii_; the bivalves, _Macoma loveni_ or _M. calcarea_; or the priapulid, _Halicryptus spinulosus_, although never numerically abundant, are large enough to affect the biomass data when caught. Sometimes very abundant species of oligochaete worms (Enchytraeids in shallow water and tubificides at greater depths), copepods, cumaceans (_Diastylis lucifera_), and other small crustaceans result in high numbers of individuals without contributing greatly to biomass. Consequently, the quantitative data for the Harrison Bay/Sale 71 area are highly variable, probably reflecting patchy distribution of all species.

We have taken 77 individual grab samples of which the mean wet-weight biomass is 41.99 g/m^2 with a standard deviation of 50.21. The mean number of organisms in our samples 4,115.94/m^2 ± 3,743.17 (standard deviation).

Not enough trawl or other bottom net samples had been taken in Harrison Bay to offer any characterization. Virtually all of our sediment samples indicate predominance of fines (silt and clay) in the surface sediment.

Methods

All samples taken in 1980 were made from D. W. HOOD, a 32-foot motor vessel chartered by the OCSEA Program from Kinnetics Laboratories, Inc. of Santa Cruz, California. RU356 had the use of the vessel on August 1 and 2, 5 and 6, 12 and 15. Our original plan was to cover as much of Harrison Bay as possible with other trawls (Gulf of Mexico shrimp try nets) overboard.

Divers were aboard prepared to investigate any areas in which either macro-algae or other epifaunal organisms suggestive of live bottom areas were caught in the nets or to dive on any area in which the nets were torn, as might have resulted from trawling over boulders.

An early plan to tow two nets simultaneously from port and starboard booms proved not to be possible from D. W. HOOD. The survey for macrophyte communities was conducted with a single trawl towed directly astern from an A-frame. The trawls used were semi-balloon otter trawls of 2" stretched mesh with an opening of about 12 feet and were towed from a single warp with a bridle.

Benthic infauna were sampled with a 0.10 m^2 Smith-McIntyre grab deployed from the aft A-frame with HOOD at anchor. Three replicate samples were taken at each station and stored in plastic shipping pails lined with polyethylene garbage bags. All samples were transferred to a shore station on Anachlik Island in the mouth of the Colville River for washing.

Samples were washed in the Oregon State University cascading seive (0.50 mm controlling mesh) using Colville River water pumped from the river with a portable, gasoline-powered pump. All samples were washed within 48 hours at the time of collection. This unusual procedure was chosen to make the most effective use of the vessel in collecting samples and because the very small size of HOOD did not allow for operation of both the grab and the washing seive. There were obvious disadvantages: some of the smaller organisms may have disintegrated due to the long storage or the use of fresh water; fresh water plankton organisms were introduced with the wash water.

These were ignored in the laboratory. During washing, we found the vast majority of soft-bodied organisms (worms) to be living, and most of the species recovered were identifiable, although the specimens were not in the best condition.

Organisms were preserved in 70%, hexamine-buffered formalin and shipped to our laboratory in Bellingham for identification, counting and weighing by methods used by us since 1975 and previously reported.

Salinity and temperature profiles at all grab stations were made with a Yellow Springs Instruments model 33 SCT meter. This meter may be read to the nearest 1 $^{0}/oo$ of salinity and to the nearest $1^{0}C$. Aliquots of about one kg of sediments were taken from a grab sample made for sediment, double-bagged in Whirl-Packs and shipped to Fairbanks. Analysis for phi distribution was done in the laboratory of Dr. A. S. Naidu of the University of Alaska Institute of Marine Science.

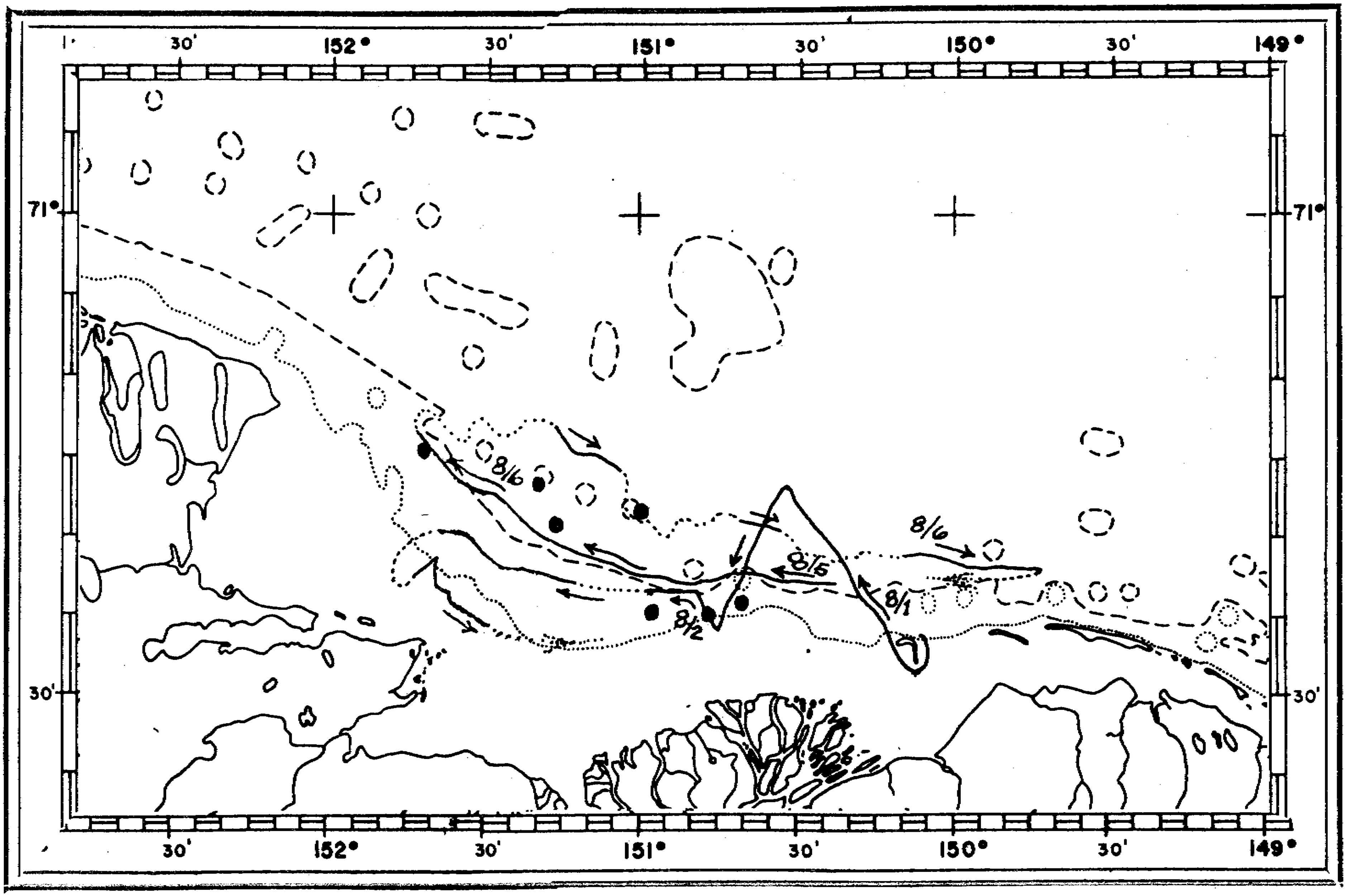
Station location presented particular problems because of the malfunction of the principal navigation instrument, a Miniranger (Motorola III). In the final analysis, station location was by dead reckoning based on continuous soundings (Coastal Navigator LCD depth indicator) and occasional radar fixes (Raytheon 2800).

Results

The results of 81 trawls made on August 1, 2, 5 and 6 are summarized in Table 1. A cruise track is shown in Figure 1. None of these catches can be construed as a quantitative sample. Virtually every tow was made in soft mud (silt/clay or fine sand). Macroalgae were encountered only in extreme eastern Harrison Bay, and these never included holdfasts. On one tow (No. 63), a single, small granitic boulder (*ca* 40 x 23 x 18 cm) was caught in a net otherwise filled with soft mud. This stone contained barnacle bases, a hydroid fragment (not living), two or three small worm tubes (*Spirorbis* sp.), not living, and one sea anemone. The condition of the stone and its sparse epifauna indicated that it had been dug out of the bottom by the trawl. Adjacent tows yielded only mud.

The data from seven benthic stations sampled on August 13 and 15 are presented in Tables 2-8 and a distribution of the 21 individual sample date is given in Table 9. The biomass of these samples is comparable to that previously reported as are the species most frequently encountered (also

Figure 7. Cruise track of D. W. HOOD, August 1, 2, 5 and 6, 1980, and location of benthic sampling stations visited on August 13 and 15. Cruise tracks shown by solid lines were made with a trawl overboard continuously. Cruise tracks indicated by dotted lines were steamed without the trawl. Benthic stations are indicated by closed circles.



30'
152°
30'
151°
30'
150°
30'
149°
71°
71°
30'
30'
8/6
8/6
8/5
8/1
8/2

Table 1

Trawls Made From D. W. HOOD, August, 1980

Trawl No.	Date/Time (at end)	Duration of Tow (min)	Depth (ft)	Dead Reckoned Position		Remarks
				N. Latitude	W. Longitude	
1	8/1/1830	< 30		70° 33.4'	150° 06.9'	mud bottom, inverts. 1 liparid, myoxocephalus
2	1900	< 30		70 32.7	150 05.9	algae, mud, inverts.
3	1930	< 30	7	70 31.9	150 05.6	algae, peat, inverts.
4	2000	< 30		70 31.7	150 08.8	1 boreogadus, inverts.
5	2030	< 30		70 32.5	150 12.1	woodchips, algal frags.
6	2100	< 30		70 33.7	150 14.2	1 boreogadus only!
7	2130	< 30		70 34.9	150 16.4	1 amphipod only!
8	2200	< 30	36	70 36.4	150 19.1	net empty!
9	2230	< 30	41	70 37.8	150 21.6	1 saduria, peat, algal frags.
10	2300	< 30	49	70 39.3	150 24.2	1 boreogadus, inverts. Much sticky mud.
11	8/2/0000	42	53	70 41.3	150 29.2	Mud and unknown animals Too heavy! Dumped.
12	0030	17	53	70 42.1	150 30.8	inverts; mud
13	0100	20	56	70 42.9	150 32.9	1 munopsis! bridle twisted
14	0200	45	53	70 41.7	150 35.5	mud, polychaetes, inverts,
15	0230	16?	51	70 40.5	150 36.5	too much mud, dumped
16	0330	16?	47	70 39.2	150 39.0	1 scaleworm, 1 sand collar
17	0400	< 30	42	70 37.9	150 40.6	2 liparids, worms, inverts.
18	0430	26	37	70 36.6	150 42.1	mud, shells

continued

Table 1--continued

Trawl No.	Date/Time (at end)	Duration of Tow (min)	Depth (ft)	Dead Reckoned Position N. Latitude	Dead Reckoned Position W. Longitude	Remarks
19	8/2/0500	19	27	70° 35.7'	150° 43.3'	1 boreogadus, 10 saduria
20	0530	< 30	< 15	70 34.5	150 44.6	mud-dumped
21	0630	26	39	70 35.9	150 47.8	net empty
22	0700	< 30	39	70 36.8	150 49.8	net empty
23	0730	25	37	70 37.3	150 53.9	1 amphipod
24	0815	30	37	70 37.1	150 58.2	mud - too heavy to lift - dumped
25	1010	< 30	33	70 37.4	151 15.9	1 amphipod
26	1040	26	33	70 37.6	151 19.5	1 amphipod
27	1115	30	33	70 37.9	151 23.4	mud balls, 1 hydroid
28	1145	28	33	70 38.5	151 26.8	1 clam! (live), no mud
29	1230	29	31	70 39.3	151 30.1	12 boreogadus, lots of inverts., etc.
30	1300	25	30	70 40.0	151 33.3	6 boreogadus, lots of inverts., mud
31	1330	25	24	70 40.5	151 37.3	15 boreogadus, lots of inverts.
32	1440	17	15	70 37.8	151 41.9	net filled with sand nodules, too heavy, dump!
33	1500	20	20	70 38.1	151 41.2	1 boreogadus, invertebrates
34	1530	23	20	70 38.5	151 39.4	4 boreogadus, few inverts.
35	1620	13	18	70 37.1	151 38.7	1 myoxocephalus, 6 saduria, sand nodules
36	1630	< 10	21	70 37.0	151 38.0	1 boreogadus, 1 amphipod
37	1645	< 15	18	70 36.7	151 37.2	mud/sand - dumped

continued

Table 1--continued

Trawl No.	Date/Time (at end)	Duration of Tow (min)	Depth (ft)	Dead Reckoned Position		Remarks
				N. Latitude	W. Longitude	
38	8/2/1715	17	18	70° 36.3'	151° 35.6'	mud/sand - 150 lbs - dumped
39	1800	15	18	70 35.8	151 33.1	mud/sand - filled - dumped
40	1820	< 19	16	70 35.5	151 32.1	cod end untied, no catch
41	1900	35	16	70 35.0	151 30.0	4 boreogadus, 1 saduria
42	1930	30	18	70 34.7	151 28.4	6 boreogadus, algal frags. few crustaceans, sticks
43	2000	25	15	70 34.3	151 26.7	1 boreogadus, 2 amphipods
44	8/5/1315	25	40	70 37.2	150 23.2	cod end untied, no catch
45	1345	21	41	70 37.3	150 26.9	cod end untied, no catch
46	1415	15	44	70 37.4	150 30.1	200 lbs mud, isopods, etc. dumped
47	1500	25	40	70 37.6	150 32.7	net empty!
48	1530	17	40	70 37.5	150 36.7	net full: mud, inverts. few boreogadus - dumped
49	1600	23	40	70 37.4	150 40.3	"exactly as before but less mud"
50	1630	21	40	70 37.4	150 43.9	"as before - quite a few cod, many inverts."
51	1700	18	38	70 37.5	150 47.6	"about as before - dumped"
52	1730	18	38	70 37.5	150 51.1	large amount mud, 2 spp. saduria, boreogadus, etc.
53	1800	21	38	70 37.6	150 54.8	mud - dumped
54	1830	13	38	70 37.8	150 59.6	mud - dumped

continued

Table 1--continued

Trawl No.	Date/Time (at end)	Duration of Tow (min)	Depth (ft)	Dead Reckoned Position N. Latitude	Dead Reckoned Position W. Longitude	Remarks
55	8/5/1900	24	41	70° 38.2'	151° 04.1'	1 boreogadus, few inverts., mud
56	1930	20	40	70 38.7	151 07.3	1 boreogadus, saduria (5), mud
57	2000	24	42	70 39.3	151 10.8	4 boreogadus, inverts., mud
58	2030	27	42	70 39.8	151 14.3	mud with boreogadus and inverts. - dumped
59	2100	45	42	70 40.4	151 17.6	mud and invertebrates
60	2200	20	42	70 41.2	151 23.6	12 boreogadus, many inverts.
61	2230	28	42	70 42.6	151 25.0	mud - many inverts.
62	2300	28	39	70 42.9	151 30.0	mud - many inverts., arctic cod
63	8/6/0000	30	33	70 43.7	151 34.9	mud - arctic cod, inverts., one rock!
64	0110	30	33	70 45.2	151 38.8	boreogadus, few inverts., hard sand, mud
65	0140	< 30	35	70 46.3	151 41.5	boreogadus, saduria, mud, sand
66	0330	20	50	70 46.2	151 14.7	ca. 200 lbs mud with saduria, boreogadus, worms
67	0400	20	51	70 45.7	151 11.9	ca. 200 lbs mud with inverts., wood frags, boreogadus
68	0430	23	51	70 45.2	151 09.2	cod end untied - no catch
69	0500	20	51	70 44.7	151 06.4	ca. 300 lbs mud - a "Gunnel" caught
70	0530	< 30	51	70 44.2	151 03.7	net so loaded (mud) cannot be lifted - dumped
71	0830	19	51	70 40.6	150 40.8	mud and inverts.
72	0900	16	50	70 40.3	150 39.1	150-200 lbs mud and invertebrates

continued

Table 1--continued

Trawl No.	Date/Time (at end)	Duration of Tow (min)	Depth (ft)	Dead Reckoning Position		Remarks
				N. Latitude	W. Longitude	
73	8/6/0930	15	48	70° 40.0'	150° 37.4'	20 lbs mud, misc. inverts.
74	1000	< 30	49	70 39.6	150 35.5	200 lbs mud, inverts.
75	1200	20	51	70 39.1	150 10.8	1 boreogadus, mud, inverts.
76	1230	25	48	70 39.0	150 06.5	5 lbs mud, misc. inverts.
77	1300	22	48	70 38.8	150 02.4	net twisted
78	1330	30	46	70 38.0	149 58.4	2 boreogadus, inverts.
79	1430	30	48	70 38.4	149 52.3	soft bottom inverts. drift laminaria
80	1515	30	47	70 38.3	149 48.7	invertebrates
81	1545	< 30	47	70 38.2	149 45.4	drift laminaria, lamphipod

- END -

TABLE 2. 1980 Data from D. W. Hood Cruise: Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station J3A (70°36.0'N; 150°32.0'W; 10 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
				g/m^2		
POLYCHAETES	10.31	3.82	7.68	7.27	28	Antinoella sarsi, Prionospios cirrifera; Trochochaeta carica; Nephythus longasetosa!
GASTROPODS						
BIVALVES	1.13	0.71	0.61	0.82	3	
ISOPODS	37.51	6.02	1.35	14.96	58	Saduria sabini!
AMPHIPODS	0.01	1.94	2.01	1.32	5	Boeckosimus affinus! acanthostepheia behringiensis
OTHER	3.86	0.01	0.04	1.30	5	Priapulus caudatus!
Σ	52.82	12.50	11.69	25.67	99	
				n/m^2		
POLYCHAETES	2,069.00	1,325.00	704.00	1,366.00	86	Prionospio cirrifera Trochochaeta carica Cirratulidae unk.
GASTROPODS						
BIVALVES	110.00	70.00	110.00	97.00	6	
ISOPODS	20.00	20.00	10.00	17.00	1	
AMPHIPODS	30.00	30.00	20.00	27.00	1	
OTHER	30.00	50.00	150.00	77.00	5	
Σ	2,259.00	1,495.00	994.00	1,584.00	99	

REMARKS:

TABLE 3. 1980 Data from D. W. Hood Cruise: Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station J4B (70° 35.7'N; 150° 46.0'W; 10 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
			g/m^2			
POLYCHAETES	1.21	5.04	4.71	3.65	15	Prionospio cirrifera!
GASTROPODS						
BIVALVES	0.23	1.38	0.60	0.74	3	Portlandia arctica!
ISOPODS			57.58	19.19	81	Saduria entomon; S. Sabini
AMPHIPODS	0.03					
OTHER	0.10	0.43	0.06	0.20	1	
Σ	1.57	6.85	62.95	23.78	100	
			n/m^2			
POLYCHAETES	152.00	1,275.00	1,086.00	838.00	82	Trochochaeta carica! Prionospio cirrifera! Sphaerodoropsis minuta
GASTROPODS						
BIVALVES	10.00	50.00	90.00	50.00	5	
ISOPODS			30.00	10.00	1	
AMPHIPODS	10.00			3.00	0	
OTHER	40.00	50.00	290.00	127.00	12	Copepods, unk.
Σ	212.00	1,375.00	1,496.00	1,028.00	100	

REMARKS:

TABLE 4. 1980 Data from D. W. Hood Cruise: Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station J5A (70° 35.7'N; 150° 57.5'W; 10 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
				g/m^2		
POLYCHAETES	12.68	1.52	19.83	11.34	36	Sternaspis scutata! Antinoella sarsi Prionospio cirrifera
GASTROPODS	1.05			0.35	1	Oenopota sp.
BIVALVES	0.73	2.20	0.86	1.26	4	Portlandia arctica!
ISOPODS	41.13		12.05	17.73	56	Saduria entomon, S. sabini
AMPHIPODS	0.06	1.77	0.24	0.69	2	Boekosimus affinis!
OTHER	0.00	0.04	0.11	0.05	0	
Σ	55.65	5.53	33.09	31.42	99	
				n/m^2		
POLYCHAETES	1,051.00	952.00	434.00	812.00	66	Prionospio cirrifera Sphaerodoropsis minuta
GASTROPODS	10.00			3.00	0	Portlandia arctica
BIVALVES	20.00	260.00	30.00	103.00	8	
ISOPODS	20.00		50.00	23.00	2	
AMPHIPODS	40.00	250.00	20.00	103.00	8	Boekosimus affinis
OTHER	60.00	180.00	300.00	180.00	15	Tubificidae, unk.!
Σ	1,201.00	1,642.00	834.00	1,224.00	99	

REMARKS:

TABLE 5. 1980 Data from D. W. Hood Cruise: Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station K0A (70° 42.0'N; 151° 00.7'W; 15 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
				g/m^2		
POLYCHAETES	0.99	2.59	0.50	1.36	3	Sternaspis scutata
GASTROPODS						
BIVALVES	20.90	45.09	16.85	27.61	51	Portlandia arctica!; Nucola bellotti; Liocyma fluctuosa; Macoma calcarea; Astarte borealis
ISOPODS		23.44		7.81	14	Saduria entomon
AMPHIPODS	0.14	3.62	0.02	1.26	2	Ampelisca macrocephala
OTHER	0.62	2.58	45.18	16.13	30	Pelonaia corrugata![1]
Σ	22.65	77.32	62.55	54.17	100	
				n/m^2		
POLYCHAETES	1,201.00	516.00	875.00	864.00	54	Sphaerodoropsis minuta Scolecolepides arctius Prionospio cirrifera
GASTROPODS						
BIVALVES	370.00	230.00	350.00	317.00	20	Portlandia arctica!
ISOPODS		10.00		3.00	0	
AMPHIPODS	50.00	70.00	50.00	57.00	4	
OTHER	70.00	30.00	990.00	363.00	23	Harpacticoida, unk. Leptognatha gracilis Peolonaia corrugata[1]
Σ	1,691.00	856.00	2,265.00	1,604.00	101	

REMARKS: [1] an ascidian

TABLE 6. 1980 Data from D. W. Hood Cruise: Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station K1A (70^0 44.2'N; 151^0 19.2'W; 16 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
			g/m^2			
POLYCHAETES	2.69	2.70	36.35	13.91	21	Antinoella sarsi; Sternaspis scutata! Nephtys longasetosa; Pectinaria hyperborea
GASTROPODS						
BIVALVES	78.32	9.25	13.14	33.57	50	Portlandia arctica! Nucula belloti Macoma calcarea
ISOPODS	54.82			18.27	27	Saduria sabini
AMPHIPODS	0.03	1.19	2.73	1.32	2	Protomedia sp. Boeckosimus affinis
OTHER	0.0	0.0	0.07	0.02	0	
Σ	135.86	13.14	52.29	67.09	100	
			n/m^2			
POLYCHAETES	807.00	212.00	754.00	591.00	52	Trochochaeta carica; Prionospio cirrifera; Nephtys cornuta; Cossura longocirrata; Sternaspis scutata
GASTROPODS						
BIVALVES	430.00	310.00	190.00	310.00	27	Portlandia arctica!
ISOPODS	50.00			17.00	2	
AMPHIPODS	20.00	190.00	220.00	143.00	13	
OTHER	80.00	30.00	110.00	73.00	6	
Σ	1,387.00	742.00	1,274.00	1,134.00	100	

REMARKS:

TABLE 7. 1980 Data from D. W. Hood Cruise: Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station K1B (70^0 36.5'N; 151^0 15.5'W; 9.5 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
				g/m^2		
POLYCHAETES	0.40	1.40	1.60	1.13	2	
GASTROPODS			0.00	0.00	0	
BIVALVES	3.27	3.94	2.33	3.18	6	Portlandia arctica!
ISOPODS			157.08	52.36	92	Saduria entomon!
AMPHIPODS	1.23	0.06	0.05	0.45	1	Boeckosimus affinis!
OTHER	0.15	0.12	0.02	0.10	0	
Σ	5.05	5.52	161.08	57.22	101	
				n/m^2		
POLYCHAETES	660.00	939.00	689.00	763.00	59	Prionospio cirrifera
GASTROPODS			10.00	3.00	0	
BIVALVES	340.00	200.00	230.00	257.00	20	Portlandia arctica! Sphaerodoropsis minuta
ISOPODS			20.00	7.00	1	
AMPHIPODS	50.00	180.00	90.00	107.00	8	Aceroides latipes!
OTHER	30.00	380.00	90.00	167.00	13	Harpacticoida, unk.!
Σ	1,080.00	1,699.00	1,129.00	1,304.00	101	

REMARKS:

TABLE 8. 1980 Data from D. W. Hood Cruise; Wet weight biomass and number of individuals of six categories of macrobenthic animals/m^2 at Station K3C (70^0 45.5'N; 151^0 38.4'W; 11 m depth) on August, 1980. Data are derived from catch of 0.1 m^2 Smith-McIntyre grab screened through 0.50 mm mesh. Principal species are those represented in sample by either 1.0 g of wet weight biomass or 100 individuals/m^2 in at least one sample. If followed by ! , the species accounted for virtually all of the mass or number of that taxonomic category in at least one sample.

TAXONOMIC CATEGORY	A	B	C	$\bar{X}$	% OF TOTAL	PRINCIPAL SPECIES
				g/m^2		
POLYCHAETES	0.03	14.02	0.39	4.81	96	Sternaspis scutata!
GASTROPODS		0.00		0.00	0	
BIVALVES	0.20	0.21	0.14	0.18	4	
ISOPODS						
AMPHIPODS		0.00	0.01	0.00	0	
OTHER		0.00	0.00	0.00	0	
Σ	0.23	14.23	0.54	4.99	100	
				n/m^2		
POLYCHAETES	70.00	125.00	267.00	154.00	73	Sternaspis scutata!
GASTROPODS		20.00		7.00	3	
BIVALVES	30.00	20.00	10.00	20.00	9	
ISOPODS						
AMPHIPODS		10.00	20.00	10.00	5	
OTHER		30.00	30.00	20.00	9	
Σ	100.00	205.00	327.00	211.00	99	

REMARKS:

Table 9. Data from D. W. HOOD cruise: Means and standard deviations of grams of wet weight biomass and number of individuals of six categories of macrobenthic animals in 21 Smith-McIntyre grab samples taken in Harrison Bay during August, 1980.

	g/m^2		n/m^2		% of sample in which occurs
	$\bar{x}$	s	$\bar{x}$	s	
Polychaetes	6.21	8.72	769.67	486.93	100
Gastropods	0.05	0.23	1.90	5.12	14.3
Bivalves	9.62	19.03	164.76	137.46	100
Isopods	18.62	37.11	10.95	16.10	42.9
Amphipods	0.72	1.09	64.29	76.91	85.7
Other	2.54	9.82	143.81	219.81	95.2
Sample Totals	37.77	44.35	1,155.38	616.74	----

see Table 11). The number of individual organisms per sample, while within the range of prior Harrison Bay samples, is low.

Physical data from the seven benthic stations are presented in Table 10. The bottom water encountered was cold (-1.0 to +4.0 C; 0.8 average) and saline (24 to 32 ^{o}/oo; 28.3 average). The surface sediments were overwhelmingly a mixture of silt, clay and very fine sand.

A cruise report that includes a day by day chronology of the events reported here has been filed with the Arctic Project Office.

Conclusions and Implications for Oil and Gas Development

1. Harrison Bay probably does not contain epilithic, sessile communities similar to those found in Stefannson Sound and, possibly, elsewhere in the eastern Beaufort Sea. This conclusion is based on almost continuous trawling in much of the ice-free part of Harrison Bay (see Figure 1) and on the nature of the known sediments in the Bay.

Special precautions or conditions placed on particular sites or lease areas for Sale 71 seem not to be indicated.

2. The benthos of Harrison Bay and the Sale 71 area is generally similar to that of the inshore or coastal zone of the Western Beaufort Sea. Previously, we have reported means of station means by regions (Quarterly Report, September, 1979). Means of wet-weight biomass varied from 27.86 to 48.41 g/m^2 (1977 and 1978 data from Stemp Island to Point Barrow) and of numbers of individuals from 4,570 to 3,131/m^2. All of the 1980 data from Harrison Bay as well as the prior data (1976 to 1978) from the Sale 71 area fall within the general population of numbers so averaged. Our 1979 Annual Report characterizes the fauna of the region. The organisms found in the Sale 71 area are those encountered elsewhere.

There is no reason to be found in the benthic infauna of the coastal zone of the Sale 71 area to place special conditions on development of this area.

Table 10. Data from D. W. HOOD cruise: Physical data from benthic stations visited in 1980.

						Percent Composition of Sediment				
						Sand		Fine Sand		Clay & Silt
						Phi Distribution				
Station	Latitude	Longitude	Depth (M)	Temp °C	Salinity °/oo	1.0	2.0	3.0	4.0	> 4.0
J3A	70°36.0'N	150°32.0'W	10.0	-1.0	28	0.2	2.3	41.1	31.8	24.7
J4B	70 35.7	150 46.0	10.0	+4.0	24	0.0.	0.2	0.2	6.0	93.5
J5A	70 35.7	150 57.5	10.0	-0.5	32	0.0	0.2	1.8	10.6	87.4
K0A	70 42.0	151 00.7	15.0	2.0	30	0.0	0.0	3.9	54.4	41.3
K1A	70 44.2	151 19.2	16.0	0.0	29	0.0	0.0	3.3	15.2	80.9
K1B	70 36.5	157 15.5	9.5	0.0	--[1]	0.0	0.0	0.0	8.2	91.4
K3C	70 45.5	151 38.4	11.0	1.0	27	0.0	0.4	3.4	3.6	92.7

[1] Equipment failure

Table 11. Mean number and biomass of benthic animals in samples from Harrison Bay made by RU356 in 1976, 1977 and 1978.

Station	Depth (m)	Year	Samples	mean biomass g/m^2	Mean Count of Organisms no/m^2	Description
I5G	1.0	76	3 EKMAN	1.32	840	amphipods and mysiids
I5H	2.5	76	3 EKMAN	35.90	6,997	polychaetes, bivalves, Crustaceans
J0A	3.5	76	3 EKMAN	22.63	8,309	polychaetes, bivalves, Crustaceans
J0B	3.0	76	3 EKMAN	64.31	8,641	polychaetes, bivalves, Crustaceans, urochardates, priapulids
J0B	3.0	78	4 SMITH-MC	117.71	5,598	
J0C	3.5	76	2 SMITH-MC	6.46	6,105	polychaetes, oligochaetes, crustaceans
J1A	5.0	76	2 SMITH-MC	160.64	15,260	polychaetes, bivalves crustaceans, priapulids
J1A	5.0	78	4 SMITH-MC	44.22	5,120	
J2A	2.0	77	3 SMITH-MC	0.50	615	polychaetes, oligochaetes
J2B	5.0	77	3 SMITH-MC	39.79	4,012	polychaetes, bivalves
J2C	10.0	77	3 SMITH-MC	29.38	4,806	polychaetes, bivalves
J2C	10.0	78	4 SMITH-MC	22.99	4,567	
K2A	10.0	77	3 SMITH-MC	24.34	5,200	polychaetes, bivalves
K3A	5.0	77	3 SMITH-MC	54.41	3,428	polychaetes, bivalves isopods
K4A	2.0	77	3 SMITH-MC	60.79	16,171	polychaetes, oligochaetes, priapulids, bivalves, crustaceans
L0A	10.0	77	3 SMITH-MC	29.35	3,592	polychaetes, bivalves, crustaceans
L1A	2.0	77	1 SMITH-MC	6.79	577	polychaetes, isopods
L1B	5.0	77	1 SMITH-MC	14.02	4,184	polychaetes, bivalves

Preliminary Population Statistics on some Major Nearshore and Inshore Invertebrate Species of the Beaufort and Chukchi Seas

H. Koch, J. Zehr and M. Childers

INTRODUCTION

This section presents preliminary population data on a number of principal nearshore and inshore invertebrates of the western Beaufort Sea and the Chukchi Sea. The results are based on summer collections made between 1975 and 1978 by RU 356. The data are provisional and are presented primarily for reference purposes. They can serve as guidelines for future investigations into the population structure and reproductive biology of critical nearshore and inshore invertebrates of the Alaskan Arctic.

METHODS

Animals analyzed for this study were collected between July and September, 1975-1978. Epibenthic species were sampled primarily with a sled net dredge (1.05 mm mesh). A number of amphipod samples were collected with baited amphipod traps and several mysid samples were taken with a seine (10 mm stretched mesh webbing). Infauna were collected either with an Ekman (0.023 m^2) or a Smith McIntyre grab (0.1 m^2). Samples were screened on 0.5 mm mesh in the field and in the laboratory. All samples were initially preserved in 10% hexamine-buffered formalin. Sorted specimens were transferred to either 75% ethanol or 35% iso-propanol.

Animals were measured to the nearest millimeter with a ruler attached to the bottom of a clear petrie dish. All length measurements were made under a 3X Luxo magnifier-illuminator. Mysids and amphipods were straightened by using a combination of jeweler's forceps and insect pins. Mysids were measured from the tip of the rostrum to the tip of the telson. Amphipods were measured from the anterior edge of the cephalon to the distal end of the first uropods. The height and thickness of bivalves were measured to the nearest millimeter with a vernier caliper. Dry weights of mysids and amphipods were determined to the nearest milligram on a Sartorius top-loading balance (Sartorius 2355) after drying the animals at 60°C for 24 hours in a forced-air oven. Percent organic content of amphipods and mysids was determined after ashing the dried animals in a muffle furnace at 550°C for 24 hours.

Population and other parameters are presented for seven species. They are: *Cyrtodaria kurriana* (Bivalve, Beaufort Sea); *Liocyma fluctuosa* (Bivalve, Beaufort Sea); *Gammarus setosus* (Amphipod, Beaufort Sea); *Onisimus glacialis* (Amphipod, Beaufort Sea); *Mysis relicta* (Mysid, Beaufort Sea); *Neomysis intermedia* (Mysid, Chukchi Sea); *Neomysis mirabilis* (Mysid, Chukchi Sea). Our investigations have shown that these species are critical components of nearshore and inshore ecosystems of the Beaufort and Chukchi seas. With the exception of the *Neomysis* species, each species will be dealt with separately in the following pages:

Species	Pages
Crytodaria kurriana	558 - 560
Liocyma fluctuosa	561 - 566
Gammarus setosus	567 - 583
Onisimus glacialis	584 - 587
Mysis relicta	588 - 600
Neomysis mirabilis and N. intermedia	601 - 620

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Cyrtodaria kurriana

Distribution: Panarctic and high latitude N. Atlantic, Canadian Arctic Archipelago, Greenland, Hudson Bay; Siberian and Chukchi sea; northern part of Bering Sea; Beaufort Sea (Bernard, 1979).

C. kurriana is abundant in nearshore and inshore regions of the western Beaufort Sea (Hulsemann, 1962). In coastal lagoons, it attains its highest densities between 2 and 2.5 meters water depth (Koch, 1980). Population densities drop off sharply in shallower and deeper water. Bernard (1979) suggested that its morphological modifications are adaptations for rapid and active burrowing in unstable shallow-water habitats. Nesis (1965) indicated that the species is adapted to oligohaline conditions. It is a suspension feeder; larval development is pelagic (Feder and Schamel, 1976).

The longest living specimen of C. kurriana found in the Beaufort Sea by Hulsemann (1962) was 22 mm long; the longest dead shell was 31.7 mm long. Hulsemann reported many drilled shells in his collections. Drilled shells were also common in our samples.

Bernard (1979) reported an average height-length ratio of 1:3 for C. kurriana. The average height-length ratio of our specimens was approximately 1:2.3.

Length-frequency, height and thickness data on C. kurriana are shown in Figures 1 and 2. The data are based on samples collected with an Ekman grab at depths of 2.0 to 3.5 meters in coastal lagoons during July and August, 1976. Most of the populations sampled consisted of juvenile individuals less than 10 mm long. Large, deep-burrowing adults may have been undersampled by the Ekman which has a penetration depth of only about 20 cm. The largest living specimen in our samples was 23 mm long.

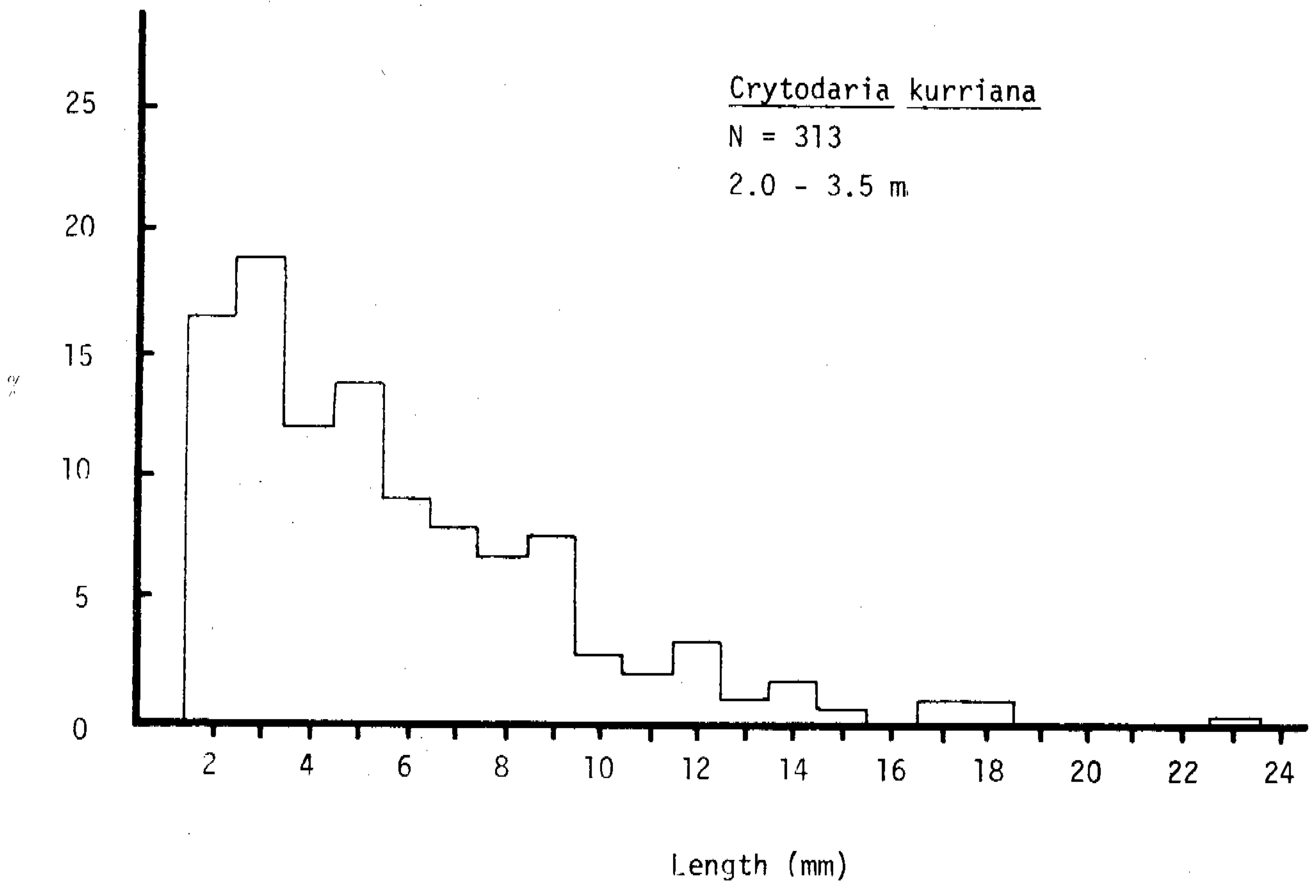
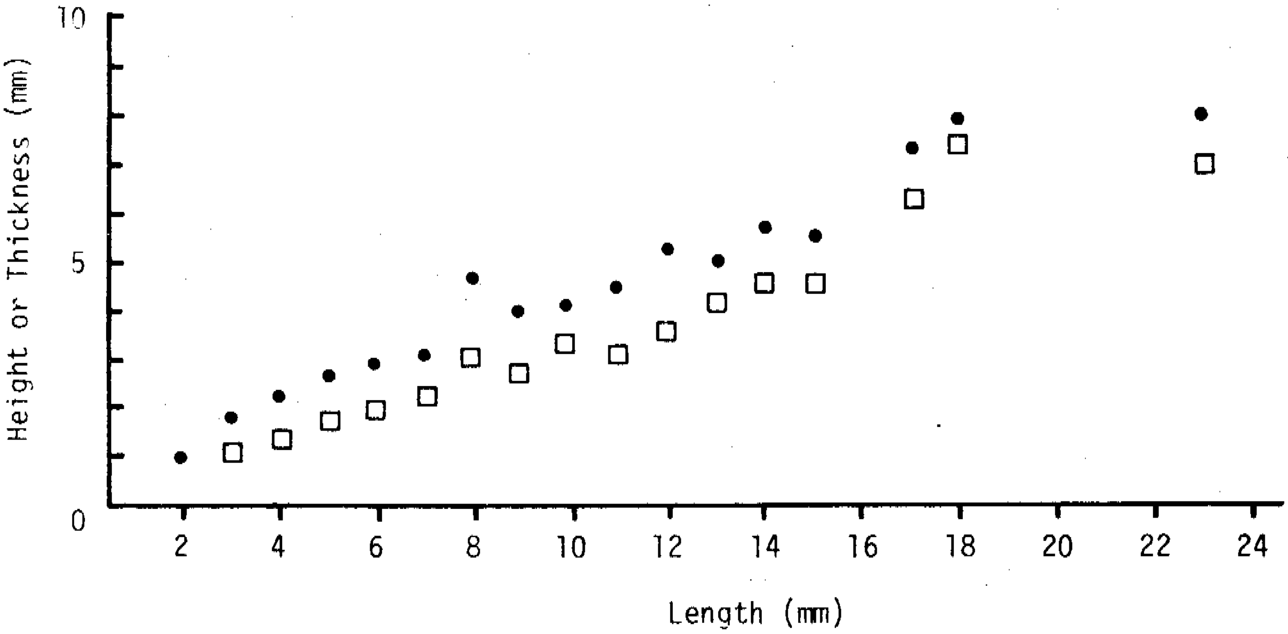


Figure 1 . Length-frequency distribution of Beaufort Sea lagoon population of *Crytodaria kurriana* July-August, 1976. Ekman grab.



Crytodaria kurriana

Figure 2 . Length-height and length-thickness relationships in *Cyrtodaria kurriana* from the Beaufort Sea.
● = Height □ = Thickness.

Liocyma fluctuosa

Distribution: Panarctic and circumboreal. Canadian Arctic Archipelago, Greenland, Iceland, Norway; Hudson Bay, Labrador, Nova Scotia. Bering and Okhotsk seas. Northern Japan. On the American coast as far south as Washington State. Along the Eurasian Arctic coast to Siberia and Chukchi Sea. Beaufort Sea. (Bernard, 1979).

Liocyma fluctuosa is abundant and ubiquitous in inshore benthic communities of the Beaufort Sea. It generally does not occur in water shallower than 2.5 meters (pers. obs.). It is the 3rd to 5th most abundant species in coastal lagoons at depths of 3 to 4 meters (Koch, 1980). Hulsemann (1962) reported it as the second most frequent bivalve species between 4 and 23 meters in the Beaufort Sea. The largest living shell in his collections was 16 mm long and 12.2 mm high. The smallest specimen was 3.5 mm long. He found a large dead shell that was 27.5 mm long. Most of his samples contained a higher proportion of smaller than larger individuals.

Our lagoon samples (Fig. 3) contained mainly small individuals between 1 and 4 mm long. There was a higher porportion of larger animals (7-10 mm) in the deeper parts of lagoons. The longest specimen collected between 2.5 and 4.0 m in the lagoons was 12.0 mm long.

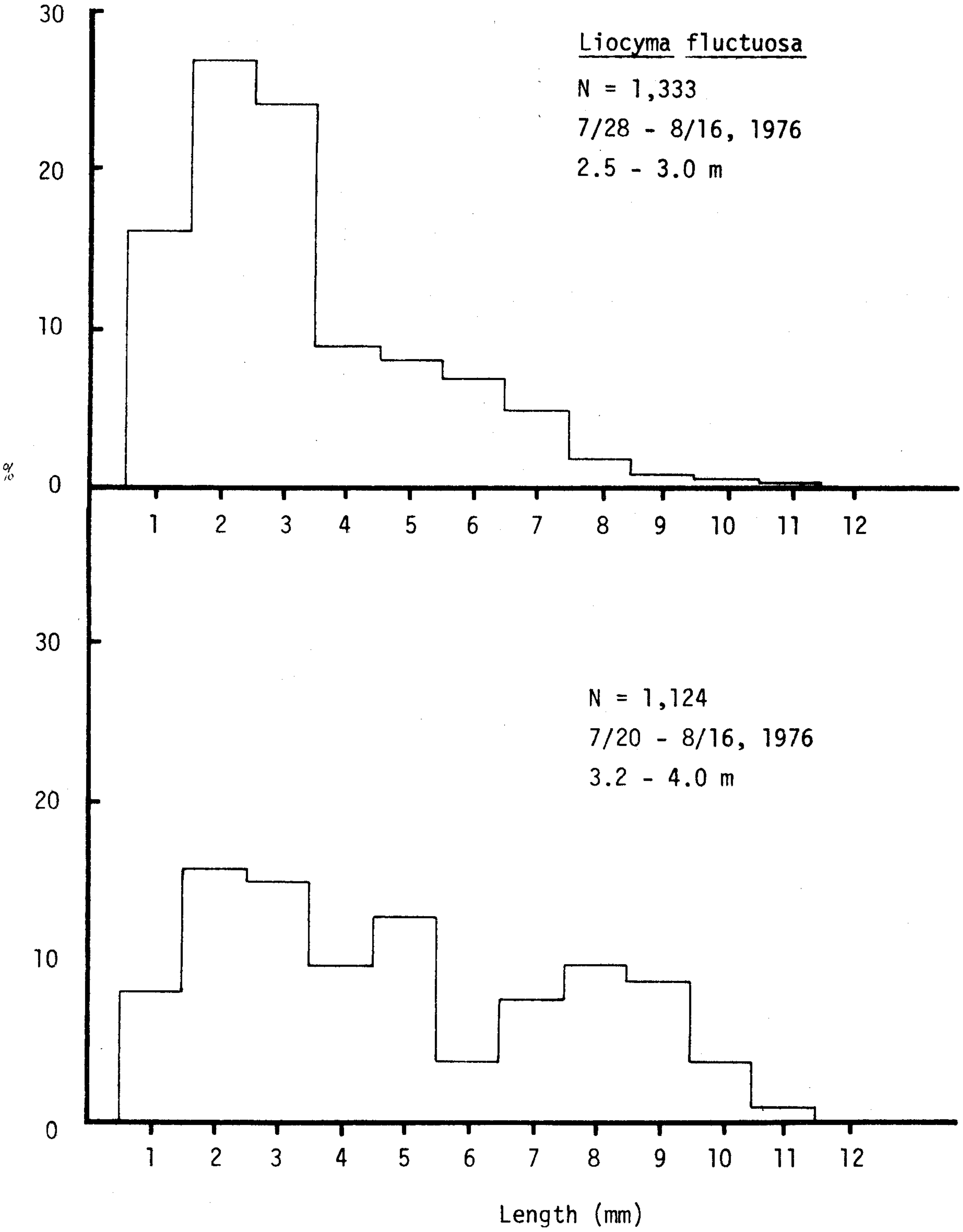
Size frequency distributions of Liocyma fluctuosa collected at 5 and 10 m outside the lagoons showed patterns similar to those of lagoon populations (Fig. 4). Most of the animals were between 1 and 6 mm long. There was a slightly higher proportion of larger animals at 10 than at 5 meters. The largest specimens collected at 5 and 10 m were 13.0 and 16.0 mm long, respectively.

The size frequency distributions shown in Figures 3 and 4 are based only on living specimens. Our samples always contained a high percentage of dead, drilled shells. Gastropod predation appears to be even more intense on Liocyma fluctuosa than on Cyrtodaria kurriana.

This may be partly related to the different depth distribution of the two species.

Length-height and length-thickness relationships for L. fluctuosa are shown in Figure 5 . Small individuals ($\leq$ 2.0 mm) have a height-length ratio close to 1:1. In larger individuals the height-length ratio is approximately 1:1.3.

Figure 3 . Length-frequency structure of Beaufort Sea lagoon populations of _Liocyma fluctuosa_, July and August, 1976. Ekman grab.


Liocyma fluctuosa
N = 1,333
7/28 - 8/16, 1976
2.5 - 3.0 m
30
20
10
0
%
1
2
3
4
5
6
7
8
9
10
11
12
N = 1,124
7/20 - 8/16, 1976
3.2 - 4.0 m
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Length (mm)

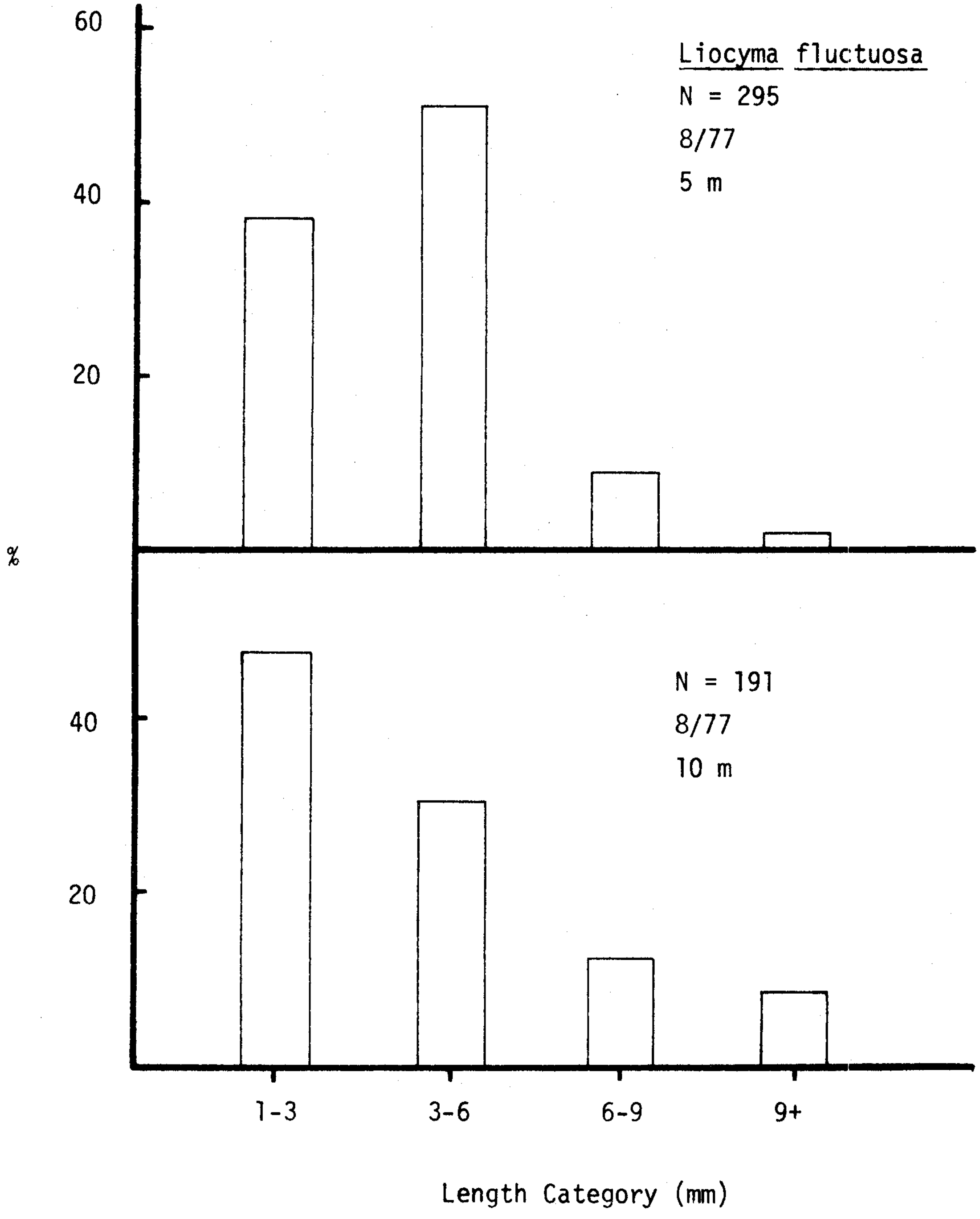


Figure 4 . Grouped length-frequency structure of Liocyma fluctuosa collected from 5 and 10 meters in the Beaufort Sea. August, 1977; Smith McIntyre grab.

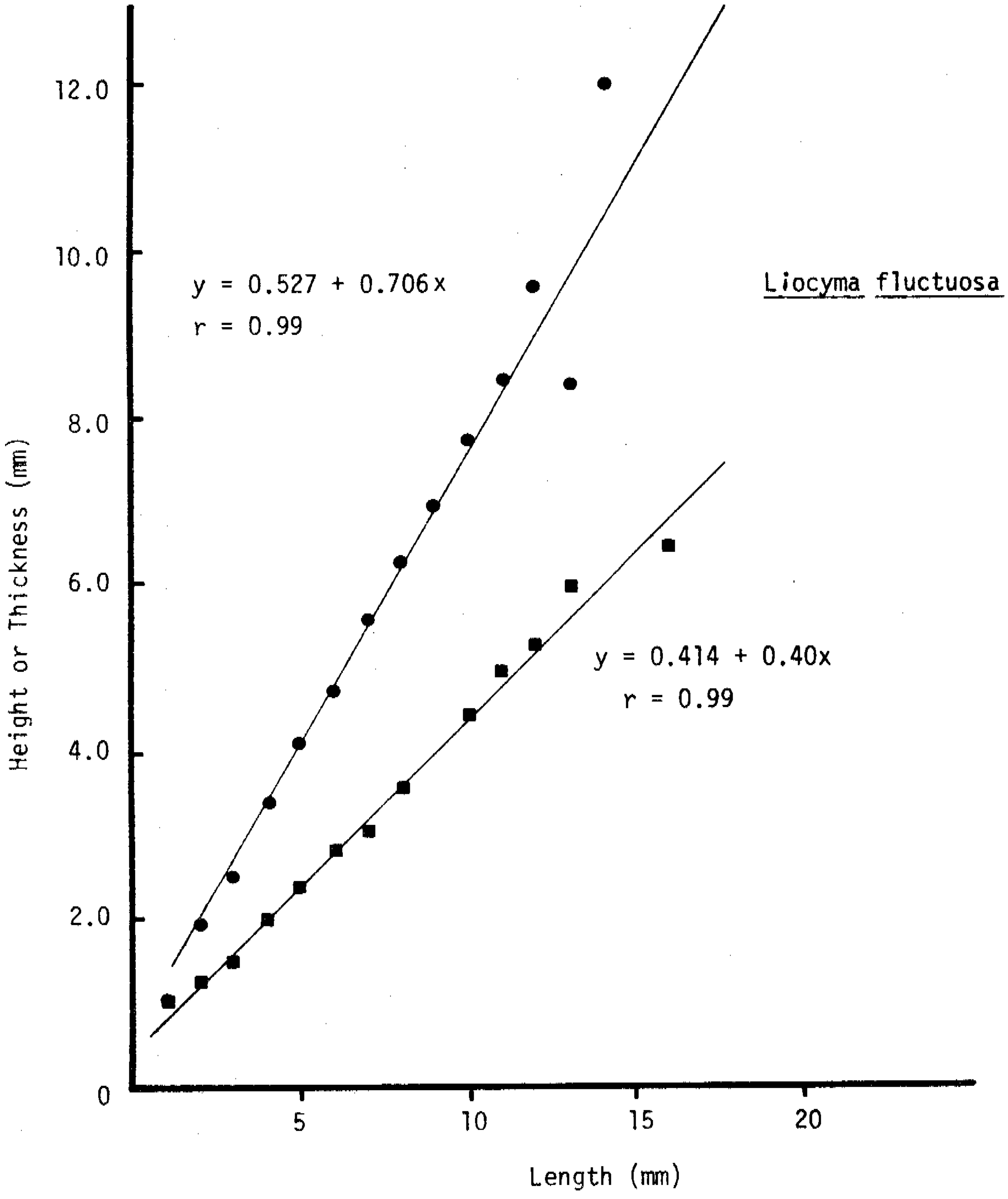


Figure 5 . Length-height and length-thickness relationships in Liocyma fluctuosa from the Beaufort Sea. ● = Height ■ = Thickness

Gammarus setosus

Distribution: Circumpolar, subarctic-boreal. In shallows of cold-water habitats. In the northwestern Atlantic, as far south as the Bay of Fundy of New Brunswick. From British Columbia to the Chukchi and Beaufort seas (Bousfield, 1973; Steele and Steele, 1970).

Gammarus setosus is widely distributed and abundant in nearshore and inshore regions of the Chukchi and Beaufort seas. In coastal lagoons of the Beaufort Sea, it is one of the four most abundant species of amphipods (Koch, 1980). Although Steele and Steele (1970) have suggested that it is mainly carnivorous, Schneider and Koch (1979) have shown that it is also able to utilize the refractory organic matter of coarse peat particles.

G. setosus is euryhaline and can survive salinities as low as 3 ^{o}/oo (Bousfield, 1973; Steele and Steele, 1970). Maximum length of adult individuals is between 25 and 30 mm (Bousfield, 1973; Steele and Steele, 1970).

Synopsis of data on arctic G. setosus, Steele and Steele (1970):

1. Breeding begins in September and continues into winter as successive females have broods.
2. Young are released primarily in the spring and early summer, although some females may not release young until July.
3. Females produce a single brood per year.
4. The timing of the release of young in spring and early summer may be presumed to coincide with optimum conditions for their survival, in particular the phytoplankton bloom.
5. Females mature at a relatively large size and live longer than one year; the number of embryos produced per female is large (40-60/20 mm female) and compensates for the production of only one brood per year.
6. At 3°C, males attain a body length of 14 mm after 317 days; females attain a body length of 12 mm after 346 days. Animals are sexually mature at these lengths.

Gammarus setosus was collected by epibenthic dredge and baited amphipod trap in late summer of 1975, 1977, and 1978. The data are presented as size frequency diagrams in Figs. 6-15 . Figure 16 shows the relationship between length and dry weight.

Data from collections made in early and late August, 1975, are presented in Figs. 6 and 7 , respectively. The juvenile and one year-old size classes can be easily differentiated. The juvenile size classes had a mean length of 5.0 mm in early August and a mean length of 5.6 mm 17 days later. This represents a change in mean length of 1.1 mm/month. The one year-old size classes had a mean length of 10.5 mm in early August, and a mean length of 13.2 mm 17 days later. This is a change of mean length of 4.7 mm/month.

The presence of 3-5 mm juveniles in early and late August is evidence for the late spring-early summer release of juveniles described by Steele and Steele (1970). There were no ovigerous females and only a few females with setose brood plates in our July and August samples. This indicates that release of young had occurred earlier in the summer.

The population structure of Gammarus setosus was also evaluated from baited amphipod trap collections. These data are from August 1975, and are shown in Figs. 8 - 10. The juvenile size classes were not represented in the traps, presumably because the older animals are more active in scavenging. Little progression of the adult size classes can be seen in the trap data from the seaside of barrier islands between middle and late August (Figs. 8 and 9). The mean length of amphipods caught between 8/8/75 and 8/18/75 on the seaside was 15.5 mm (Fig. 8). The mean length of those caught in lagoons on 8/5/75 was 14.7 mm (Fig. 10).

The 1977 data (Figs. 11 and 12) do not show a significant progression of size classes over the 10-15 day sampling period, but do show the same size frequency patterns as the 1975 data (Figs. 6, 7, and 8). The mean length of the juvenile classes was 5.6 mm, and that of the one year-old classes was 12.8 mm.

In 1978, the sampling period began in late July, and data were obtained for seaside and lagoon populations (Figs. 13 and 14). The mean length of juveniles was 3.6-3.7 mm, which indicates that these animals had recently been released. The mean adult length was 8.3 mm on the seaside, and 11.4 mm in the lagoon. The seaside was resampled on 8/8/ 78(Fig. 15). The mean juvenile length at that time was 5.5 mm and the mean adult length was 12.0 mm. This represents a change in mean length of 2.8 mm and 5.8 mm per month for juveniles and adults, respectively. These figures appear to be too high to be attributable to growth alone.

The data are summarized in the following table:

Year	Sampling Date	Mean Length Juveniles	Mean Length Adults	Fig. #
1978	7/20 (seaside)	3.7 mm	8.3 mm	8.
1978	7/21 (lagoon)	3.6	11.4	9.
1978	8/8 (seaside)	5.5	12.0	10.
1975	8/8 - 8/13	5.0	10.5	1.
1977	8/14 - 8/19	5.6	12.8	6.
1975	8/25 - 8/30	5.6	13.2	2.
1977	8/30	5.6	12.7	7.

There is agreement between the three years of data with respect to mean size of juveniles and one year-olds. Juveniles are released in early summer and attain a length of 5.6 mm by the end of August. The previous year's offspring attain a length of about 13 mm by the end of their second August.

The average increase in length of spring-summer released juveniles during July and August is about 1.5-2.0 mm/30 days. The average monthly increase in length of one-year olds between late July and late August appears to be generally greater but more variable than for juveniles. The reasons for this variability are not clear, but sampling inconsistencies cannot be ruled out. From the above table, it appears that the average size of one-year-olds at the beginning of August may be around 10.0-11.5 mm. At the end of August, they are about 13 mm long. This represents a "growth rate" of 1.5-3.0 mm/month. Higher water temperatures in August probably have an affect on growth. A substantial increase in mean length between early and late August may ensure that a major segment of the population is ready to start breeding in September. Sexual maturity in Gammarus setosus is attained at a body length of 12-14 mm (Steele and Steele, 1970).

Migration, size-selective predation, and selective capture of size classes by sampling gear could be some of the factors affecting _Gammarus_ size frequency distributions. Some other questions which may be answered by further study are:

1. Is the population structure of _Gammarus setosus_ different in the protected lagoon areas, as opposed to the more exposed seaside regions?

2. How does the growth rate of _Gammarus_ vary and what are the the factors influencing it? Our data suggest that there may be an acceleration of growth rate of adult animals in August.

3. Do segments of the _Gammarus_ population migrate or occupy different niches, thereby distorting results of population studies based on one type of sampling method?

Table 1 presents data on the percent organic content of _G. setosus_.

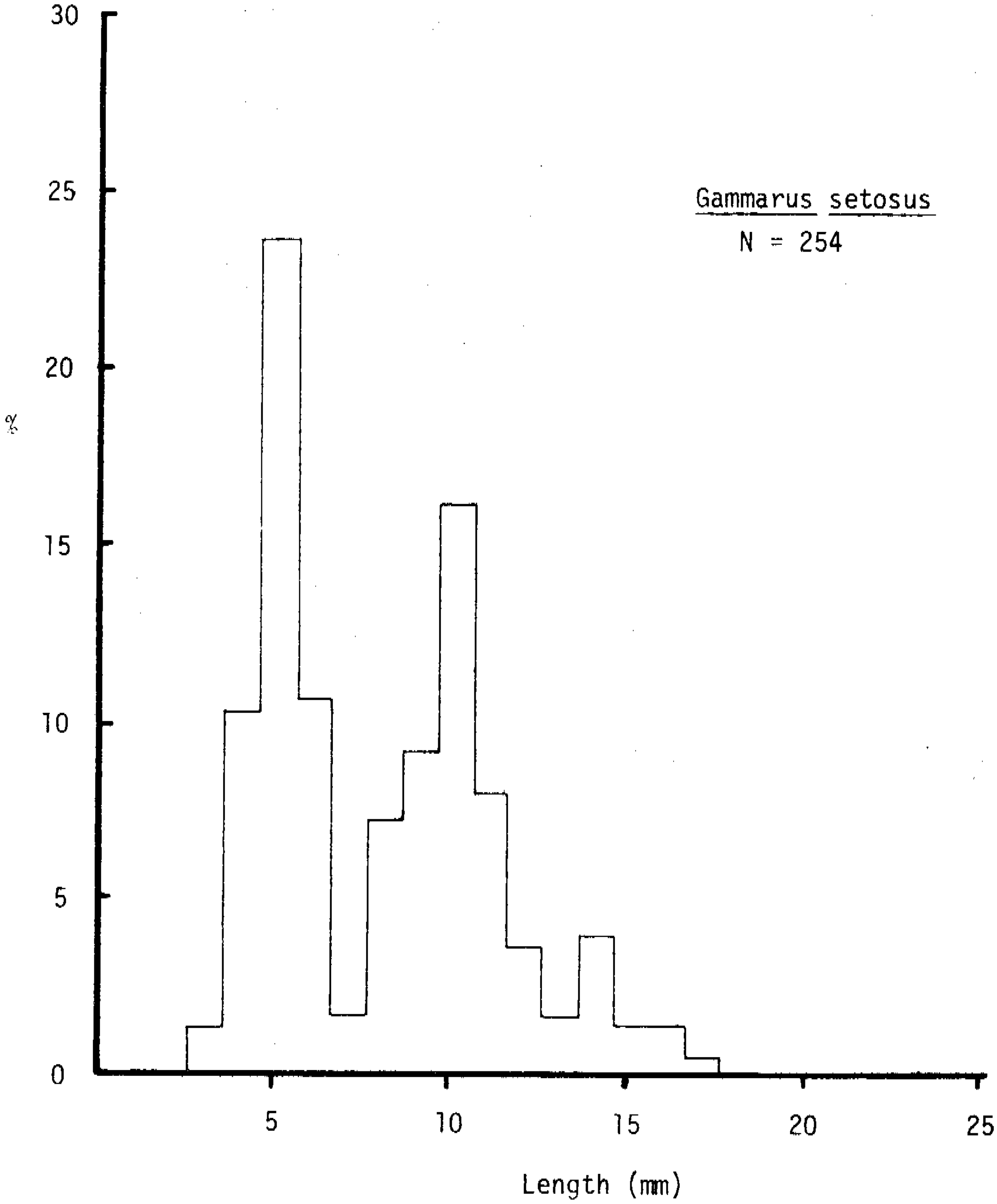


Fig. 6 . Size frequency diagram for Gammarus setosus collected by epibenthic dredge between 8/8/75 and 8/13/75; 1.5-2.5 m depth.

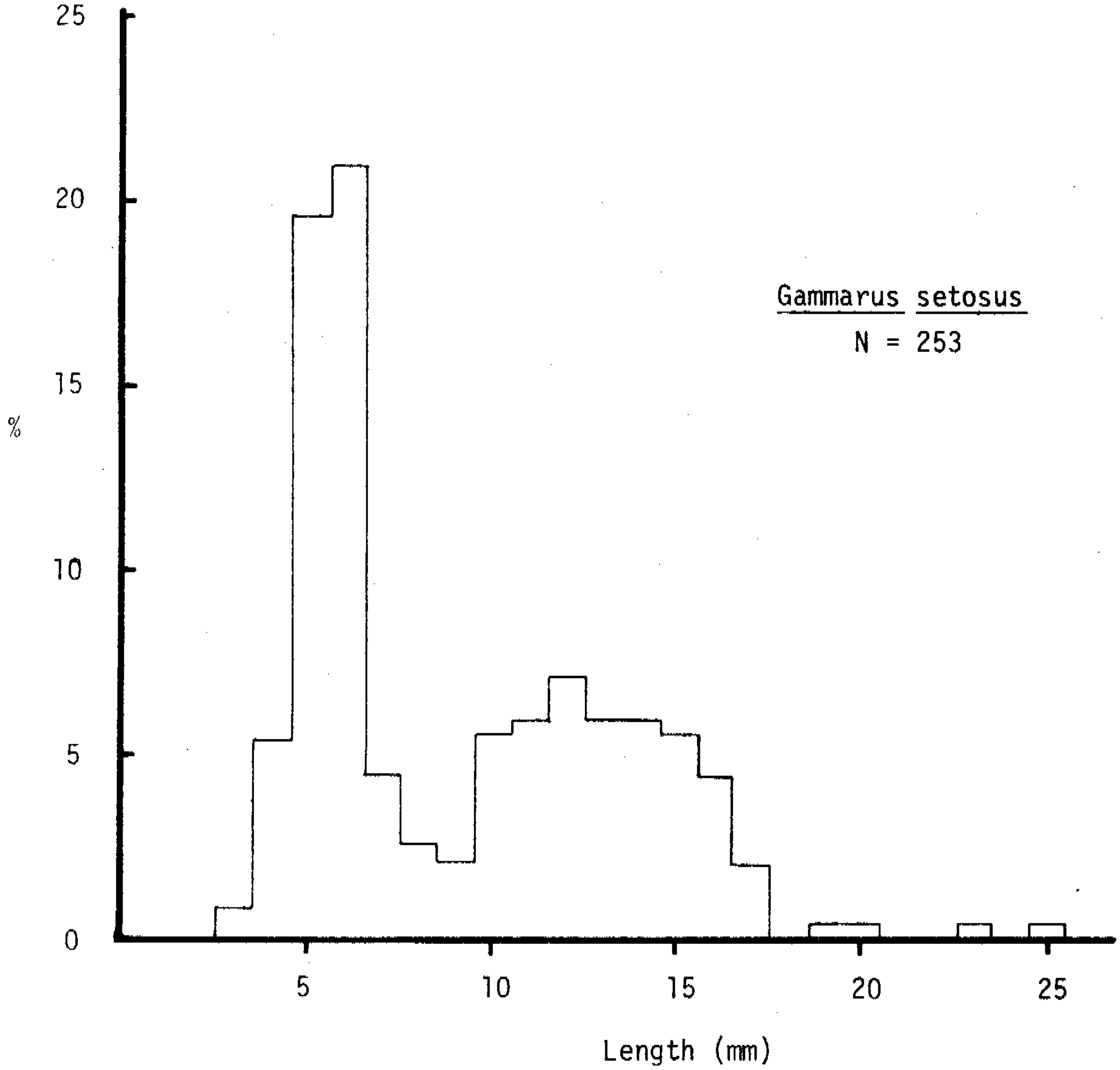


Fig. 7 . Size frequency diagram, *Gammarus setosus*, collected by epibenthic dredge between 8/25/75 and 8/30/75; 0.5 to 1.0 m depth.

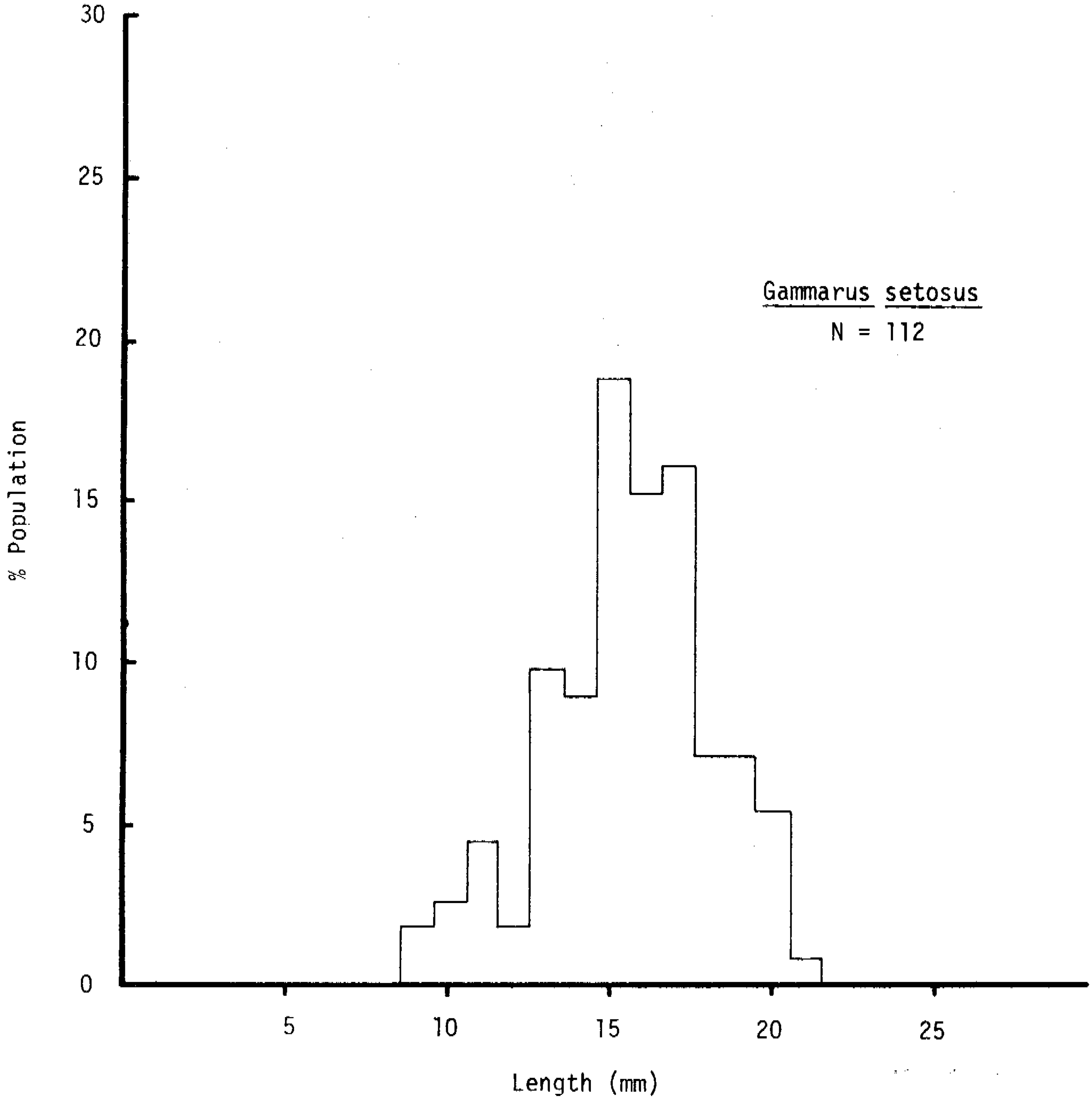


Fig. 8 . Size frequency diagram for Gammarus setosus collected by amphipod trap seaside of barrier islands between 8/8/75 and 8/18/75; 0.2 to 0.5 m depth.

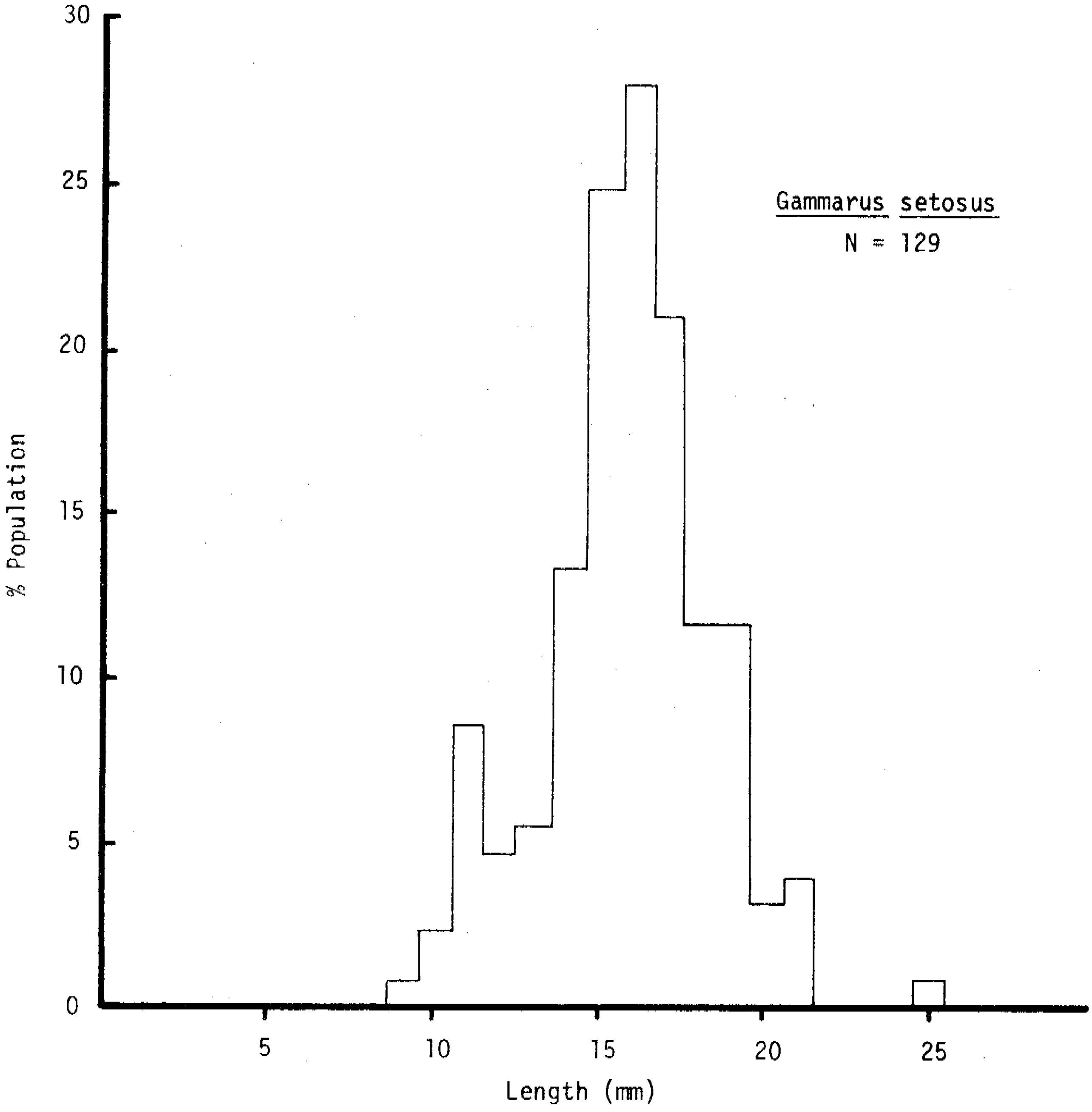


Fig. 9 . Size frequency diagram for Gammarus setosus collected by amphipod trap seaside of barrier islands between 8/19/75 and 8/30/75; 0.5 m depth.

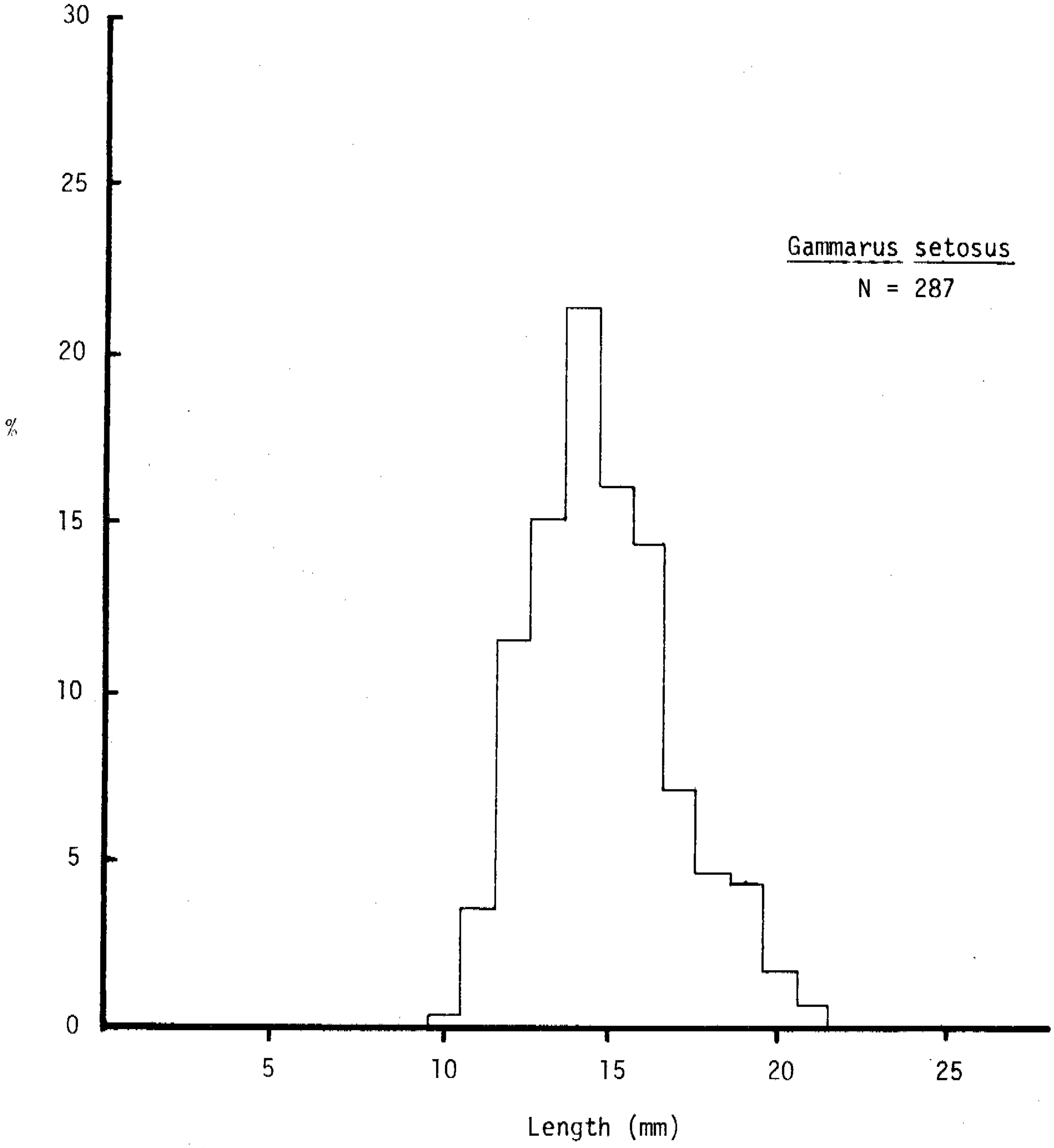


Fig. 10 . Size frequency diagram for Gammarus setosus collected by amphipod trap in Beaufort Sea lagoons on 8/5/75; 0.1 m depth.

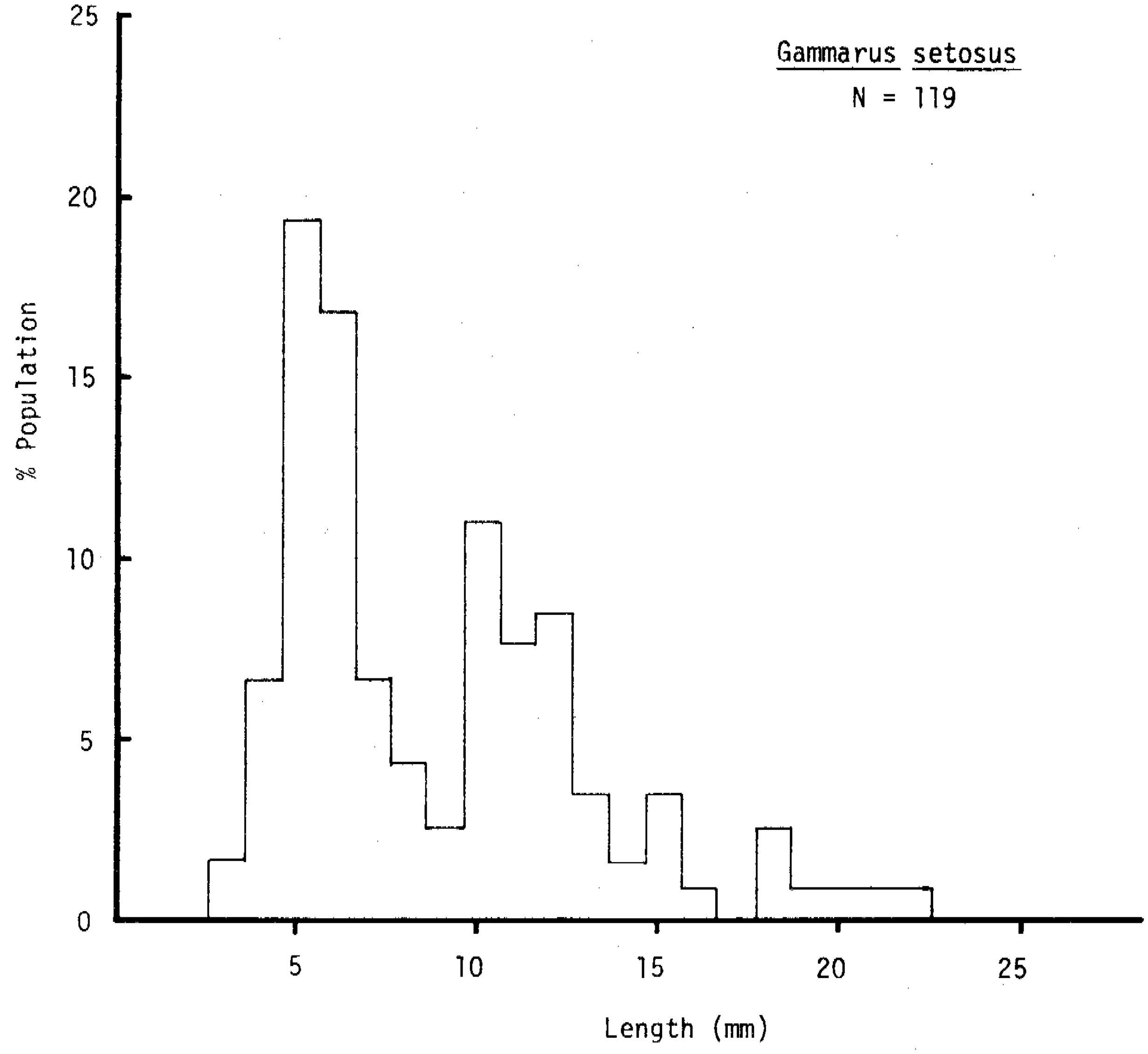


Fig. 11. Size frequency diagram for Gammarus setosus collected by epibenthic dredge between 8/14/77 and 8/19/77; 0.5 to 3.0 m depth.

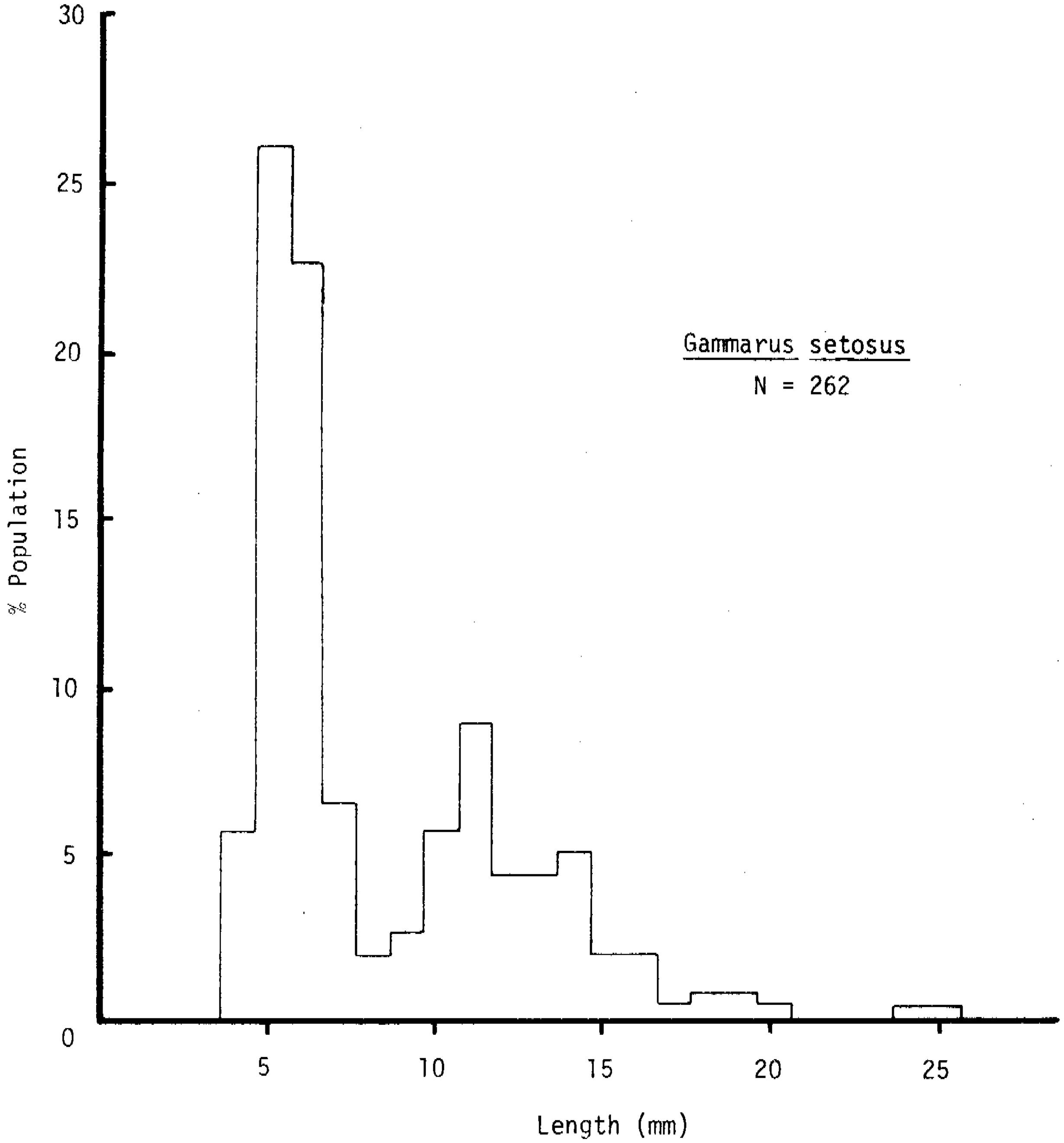


Fig. 12 . Size frequency diagram for Gammarus setosus collected by epibenthic dredge on 8/30/77; 0.5 to 3.0 m depth.

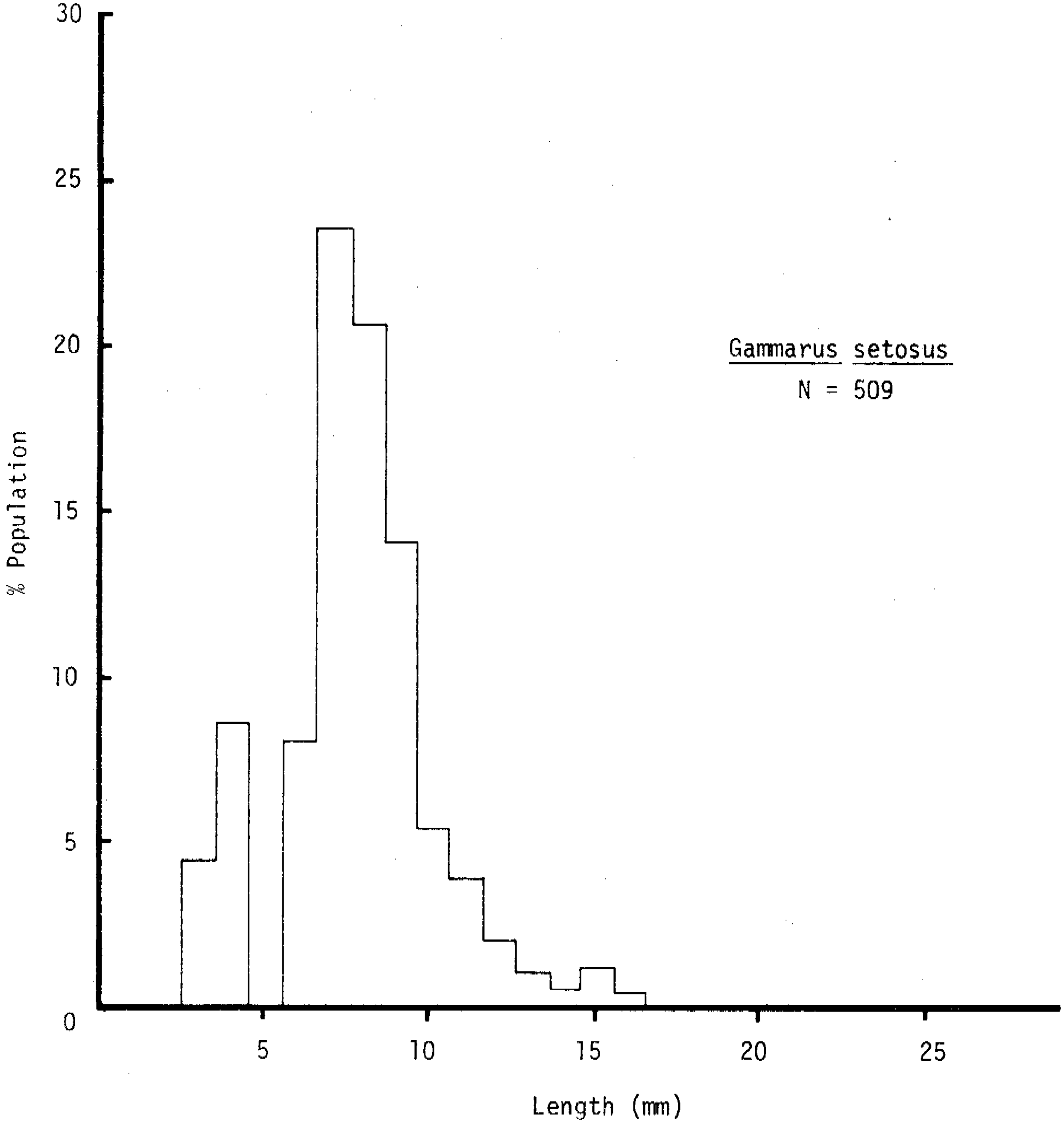


Fig. 13 . Size frequency diagram for <u>Gammarus setosus</u> collected by epibenthic dredge seaside of barrier islands, on 7/20/78; 0.5 m depth.

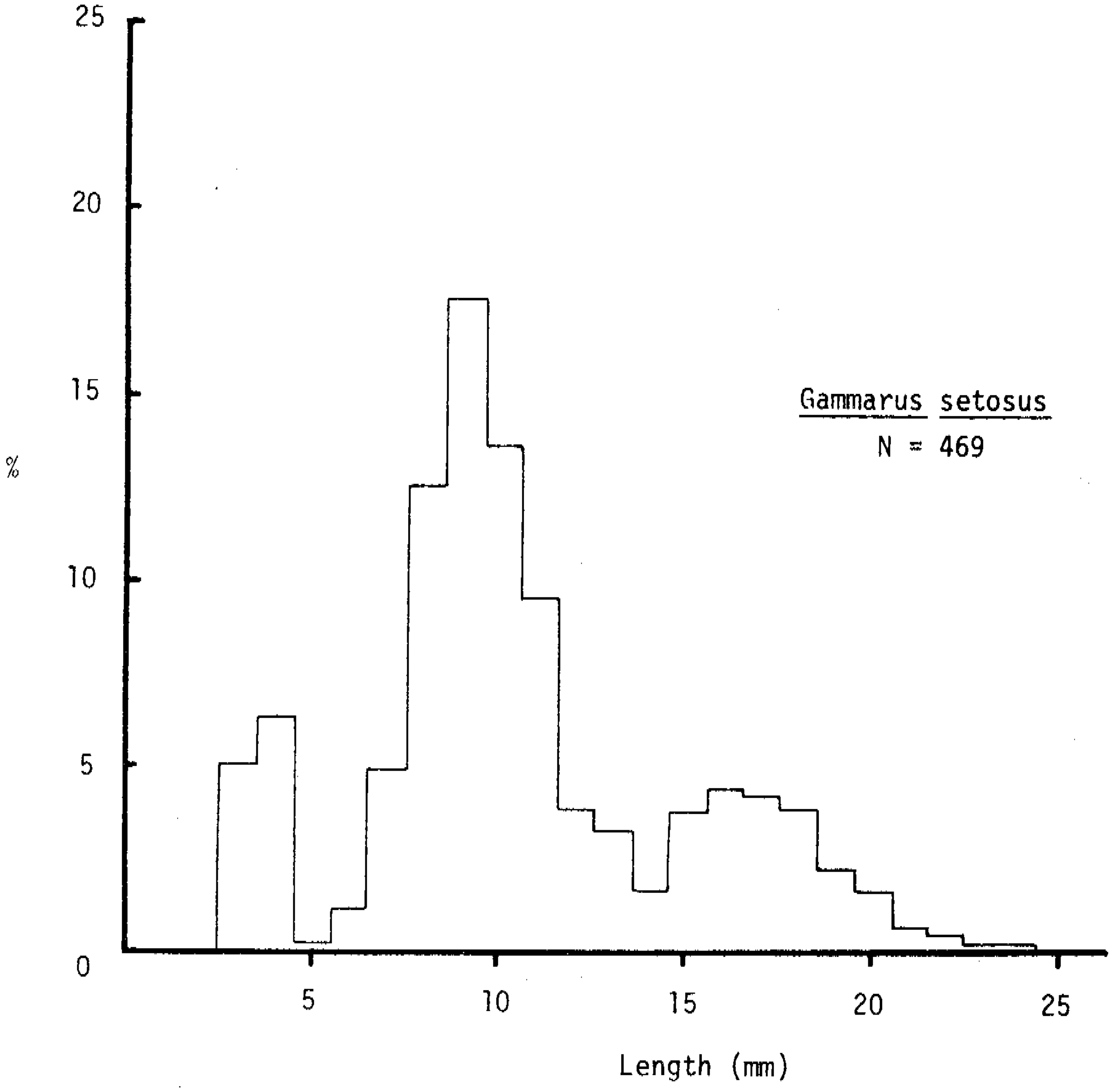


Fig. 14 . Size frequency diagram for Gammarus setosus collected by epibenthic dredge in lagoons, on 7/21/78; 0.5 m depth.

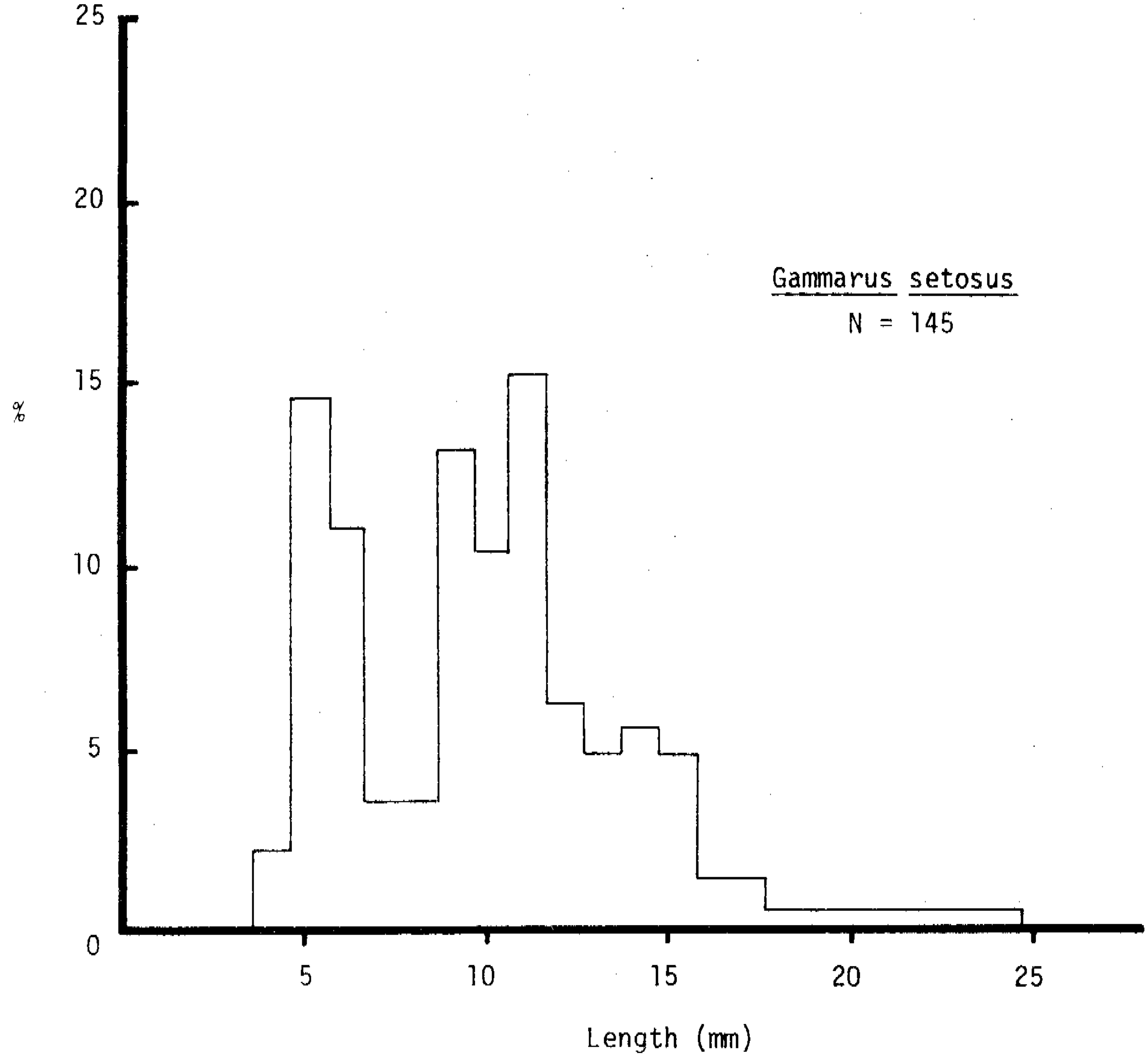


Fig. 15. Size frequency diagram for Gammarus setosus collected by epibenthic dredge seaside of barrier islands, on 8/8/78; 0.5 m depth.

Fig. 16 . Relationship between length and dry weight in *Gammarus setosus*.

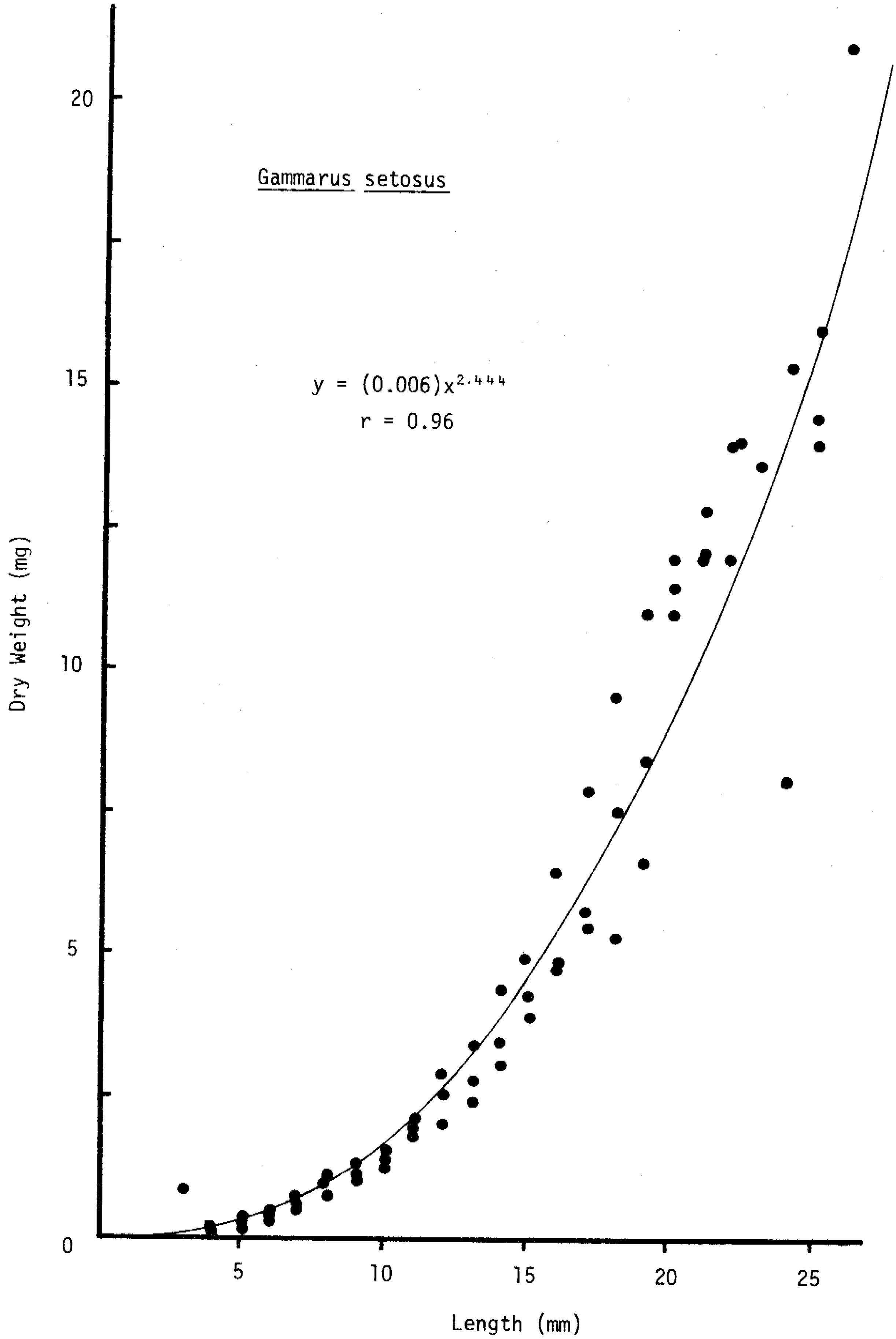

Gammarus setosus
y = (0.006)x^2.444
r = 0.96
Dry Weight (mg)
Length (mm)
0
5
10
15
20
5
10
15
20
25

Table 1. Organic content of Gammarus setosus collected during the summers of 1975-1978; animals preserved in 10% formalin and 35% iso-propanol prior to analysis.

Size category (mm)	Dry Weight (g)	Ash Weight (g)	Ash-free Dry Weight (g)	% Organic
4-6	0.266	0.041	0.225	84.6
7-8	0.396	0.061	0.335	84.6
9-11	1.098	0.178	0.920	83.8
12+	6.162	1.166	4.996	81.1

Onisimus glacialis

Distribution: Restricted to Arctic and subarctic waters (Bousfield, 1973). Common in nearshore regions of the Chukchi and Beaufort seas, Alaska.

During the summer open-water season, *O. glacialis* is the most abundant epibenthic macroinvertebrate in Beaufort sea lagoons at depths of 0.5 to 2.5 meters (Koch, 1980). Griffiths and Dillinger (1979) investigated the biology of the species in Simpson lagoon during the 1978 open-water season. Their results indicate a two-year life cycle. First-year individuals released in the spring of the current year attained a mean length of 5.1 mm by the end of September. Second-year animals that were recruited into the population during the spring of the previous year had a mean length of 9.7 mm near the end of their second September.

Our results indicate a mean length of 3.9 mm for first-year individuals in early July (Fig. 17). Second year individuals had a mean length of 8.4 mm. There was a much higher proportion of 3-4 mm animals in the 7/20 samples than in the 7/8-7/11 samples (Fig. 17). This segment of the population was probably undersampled between 7/8 and 7/11. If extensive release of young had occurred after 7/11, there should have been a higher proportion of 2 mm animals in the 7/20 samples. The mean length of first-year animals on 7/20 was 3.3 mm. The mean length of the second-year individuals was 8.8 mm.

Between 8/18 and 8/25, 1978, the mean length of first-year animals increased to 4.2 mm (Fig. 18). The mean length of second-year individuals was about 10 mm at this time.

Griffiths and Dillinger (1979) calculated an average length increase of 0.8 mm/30 days for first-year *O. glacialis* during the open-water season. Our results indicate an average length increase of 0.9 mm between 7/20 and 8/22, 1978. Second-year individuals increased by an average of 1.0 to 1.2 mm during this time.

These results must be considered as highly provisional since they are based on only a few samples. Nevertheless, they are in general agreement with those of Griffiths and Dillinger (1979). Summer populations of _O. glacialis_ are dominated by juveniles (< 7.0 mm). Most of these animals were probably released during the spring. There were no ovigerous females in any of our summer samples. The main breeding peak seems to occur in the fall (Griffiths and Dillinger, 1979). Our results suggest that most of the second-year individuals would be sexually mature ($\geq$ 10 mm long) by the middle of the fall breeding season.

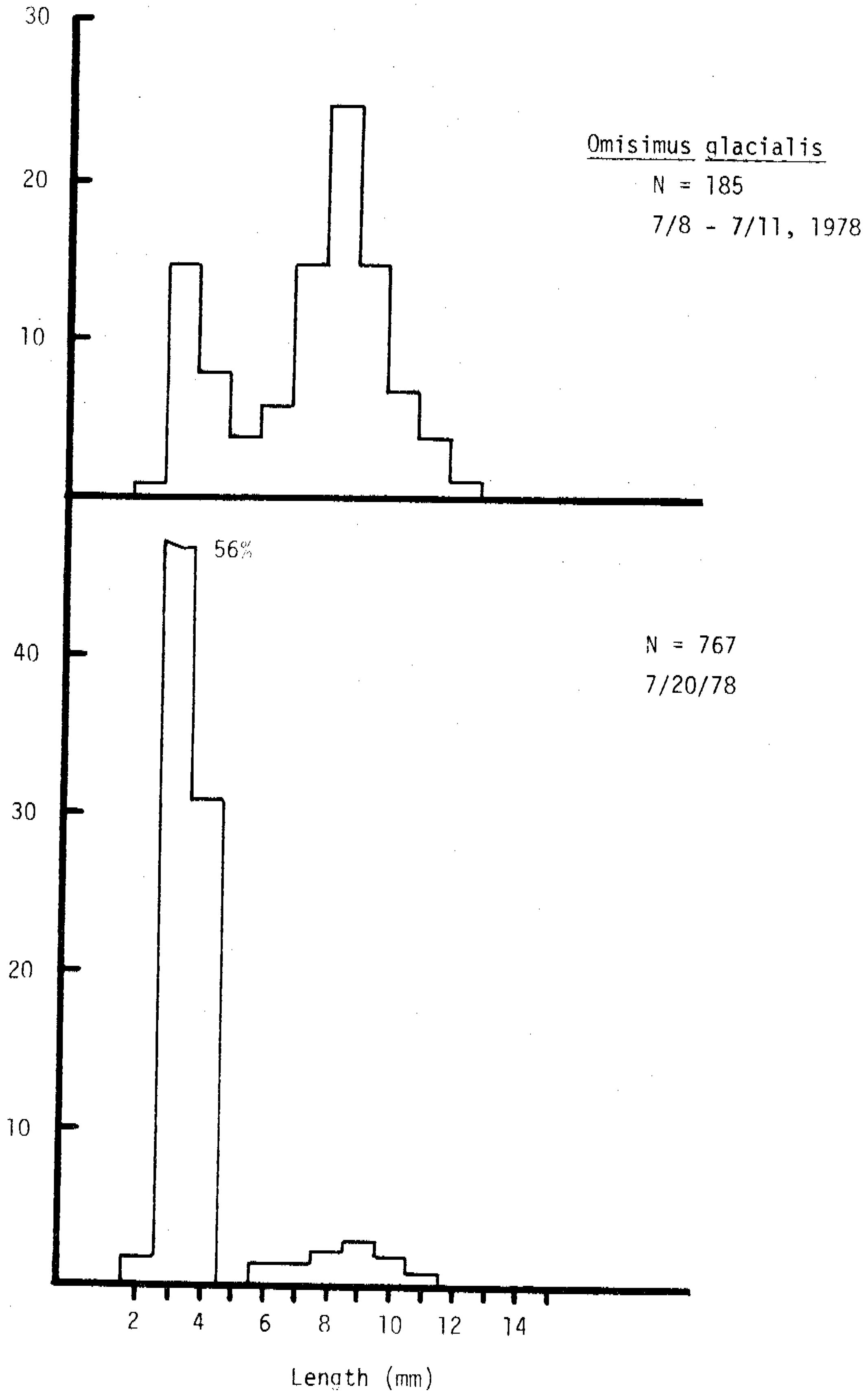
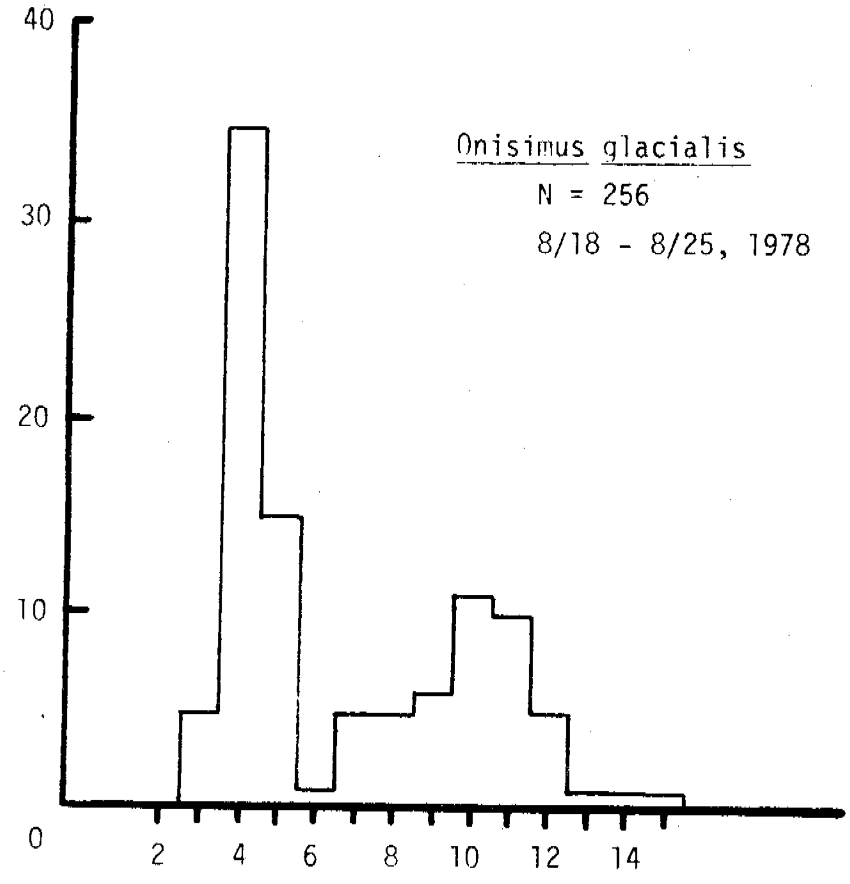


Fig. 17. Length-frequency distribution of O. glacialis between 7/8 and 7/11, 1978 and on 7/20/78. Beaufort Sea, 0.5-2.0 m; epibenthic sled net.



Length (mm)

Fig. 18. Length-frequency distribution of *O. glacialis*, 8/18 - 8/25, 1978. Beaufort Sea, 0.5 - 0.75 m; epibenthic sled net.

Mysis relicta

Distribution: In lakes of N. America, Spitzbergen, Scandinavia. Baltic Sea, White Sea (USSR). American Arctic, Chukchi and Beaufort seas (Holmquist, 1963, 1973; Tattersall, 1951).

According to Holmquist (1949), M. relicta is a marine glacial relict. It is a predominantly fresh to brackish water species. It is frequently found in association with Mysis litoralis and M. oculata in lagoons of the northern Alaskan coast (Beaufort Sea). In the nearshore Chukchi Sea, it may be found together with Neomysis intermedia and N. mirabilis. The species occurs mainly in coastal regions at depths of 1 to 3 meters; in fresh water, it occurs at greater depths (Holmquist, 1973).

Griffiths and Dillinger (1979) reviewed the life span records for fresh water populations of M. relicta. Life span increases with latitude and water depth and appears to be slightly longer than two years for high Arctic populations. They found that M. relicta began to breed in late September in Simpson lagoon. Breeding animals were 16-20 mm long and were second year individuals. Young (2-4 mm) are released during the following spring and summer and attain a mean length of 8-10 mm (range: 4-11 mm) by the end of September. These individuals do not breed until the following year.

Griffiths and Dillinger (1979) determined an average growth rate of 2.2 mm/30 days for first year individuals between early July and late September, 1978. During this same time span, second year individuals grew an average of 0.9 mm/30 days.

Our data support some of these findings although there was variability between sampling years. Size-frequency distributions for samples collected during the summers of 1975, 1977 and 1978 are given in figures 1-4. Samples collected on 8/17/75 (Fig. 19) showed a distinct bimodal size frequency distribution. The mean length of first year individuals on this date was 7.6 mm (5-11 mm). The mean length of second year individuals was 15.1 mm (12-18 mm). These results are in agreement with those of Griffiths and Dillinger (1979).

Samples from 8/30/75 (Fig. 19) generally lacked larger animals and had a higher proportion of 4 and 5 mm animals than the 8/17/75 samples. These size classes may have been undersampled on 8/17/75 but their presence in late August suggests that some females probably do not release young until late spring or early summer. The higher proportion of 8 to 11 mm animals in the 8/30/75 samples compared to the 8/17/75 collections reflect growth among first year individuals within this 13-day period.

Figure 20 shows the size frequency distributions of animals collected in August, 1975 with a seine. The seine (10 mm mesh) sampled only animals larger than 11 mm which represent second year individuals (Fig. 19). The mean length of these animals was 15.2 mm on 8/6/75 and 15.7 mm on 8/20/75. This represents a length increase of 0.5 mm in 14 days, or about 1.1 mm in 30 days. This agrees with the 0.9 mm/ 30 days growth rate calculated by Griffiths and Dillinger (1979). The sex ratio for both distributions in Figure 20 was approximately 1:1.

Samples collected between July and September 1977 (Figure 21) consisted mainly of first year individuals (4-11 or 12 mm). A progression of advancing size classes is evident between 7/29/77 and 9/1/77. However, the average increase in length during this 33-day period was only about 1.0 to 1.1 mm, even when 4 and 5 mm animals are excluded from the analysis (note that there was a slightly higher proportion of 5 mm animals in the 9/1/77 samples than in the earlier collections). This increase in length is only half as much as that reported by Griffiths and Dillinger (1979) for first year individuals during the summer of 1978.

Size-frequency distributions for July and August of 1978 are shown in Figure 22 . Both the first and second year individuals increased in length between early July and late August, as shown by the table below:

Date	$\bar{X}$ length of 1st year animals (mm)	$\bar{X}$ length of 2nd year animals (mm)
7/9/78	4.5	13.1
7/24/78	5.7	--
8/16/78	7.7	--
8/25/78	8.3	16.5

Based on these results the length of first and second year individuals increased by about 2.4 mm/30 days and 2.1 mm/30 days respectively. The former figure is similar to the 2.2 mm/30 days summer growth rate of first year individuals reported by Griffiths and Dillinger (1979). The 2.1 mm/30 days length increase of second year individuals is considerably higher than Griffiths and Dillinger's (1979) value of 0.9 mm/30 days, and our own estimate of 1.1 mm/30 days from 1975 summer collections (Fig. 19). The reasons for these discrepancies are not clear. They may be partly due to sampling inconsistencies, but may also be caused by annual variability in physical and biological factors (time of ice break-up, extent and duration of the phytoplankton bloom).

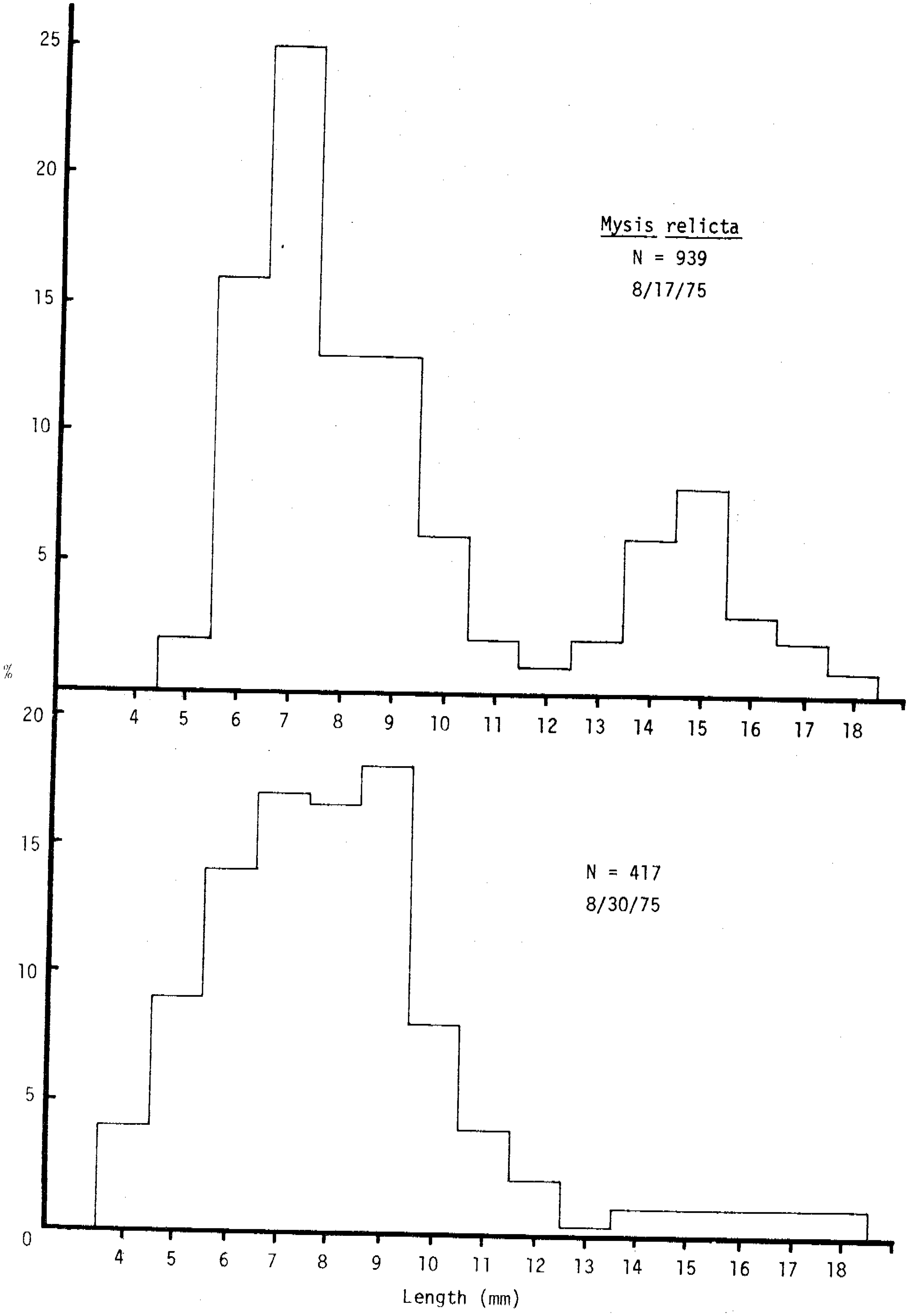
In summary, our summer data on nearshore and inshore populations of *M. relicta* in the western Beaufort Sea indicate that:

1) Young are released mainly before July; there were no ovigerous females or females carrying young in any of our early July-early September samples.
2) First year individuals (released in spring, early summer) reach an average length of 8-9 mm by the end of August. The average increase in length of these individuals may vary between 1.0 to 2.4 mm/30 days between July and September.
3) Second year individuals reach an average length of 16 to 17 mm by the end of August. Summer growth rates of these individuals may vary between 1.1 and 2.1 mm/30 days.
4) The results of (2) and (3) above suggest that the growth rates of first year individuals decreases during the winter months. A continual growth rate of 1.0 to 2.4 mm/30 days during the winter

and spring would result in second year individuals with a mean length of 20 to 36 mm at the end of the following August.

Figure 23 shows the relationship between length and dry weight in M. relicta. The organic content of 4-12 mm (grouped) individuals was 92.9% (ash-free dry weight/dry weight). The organic content of animals larger than 12 mm was about 95%.

Fig. 19 . Length-frequency distributions for <u>Mysis</u> <u>relicta</u> collected with an epibenthic sled net between 0.5 and 1.0 m in the western Beaufort Sea. August, 1975.



Mysis relicta
N = 939
8/17/75
N = 417
8/30/75
%
25
20
15
10
5
20
15
10
5
0
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Length (mm)

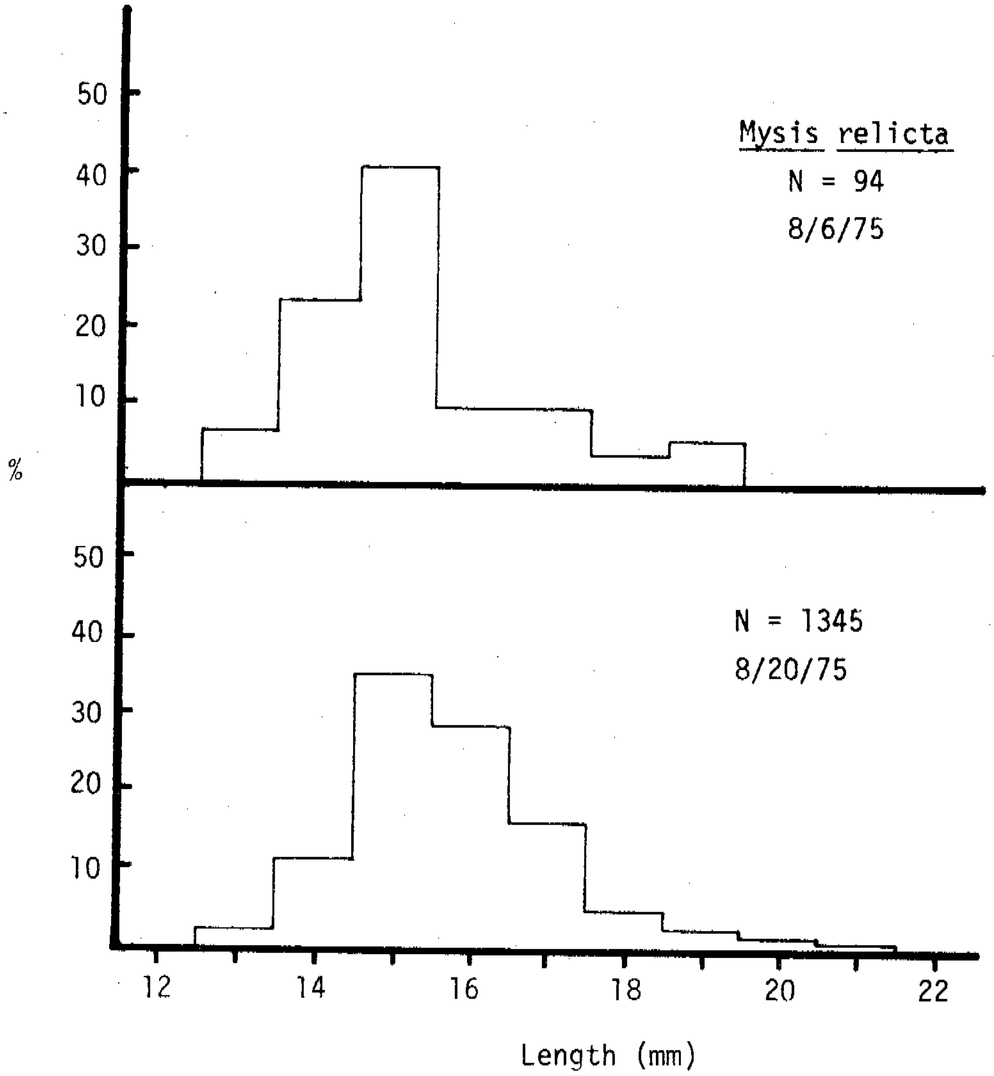
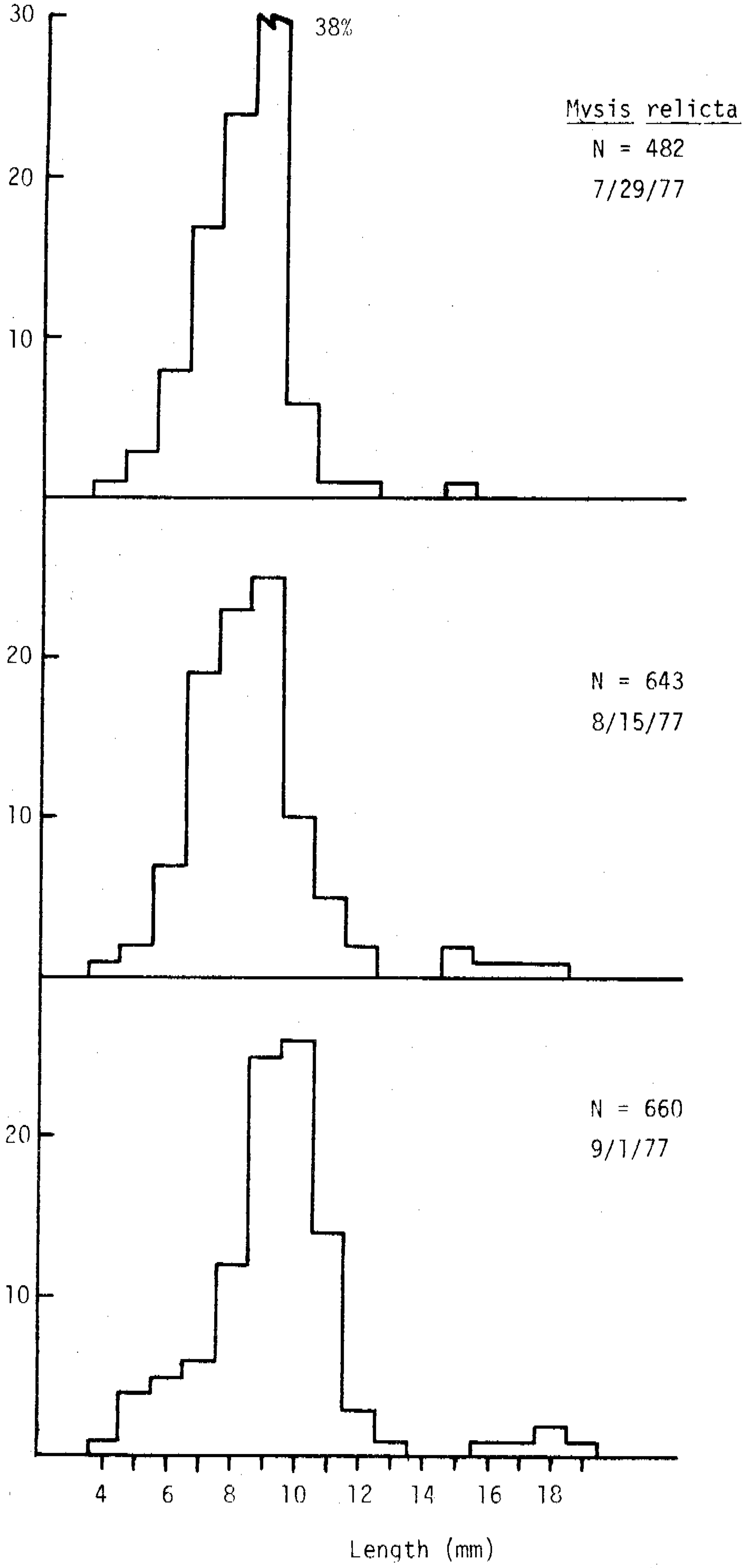


Fig. 20 . Length frequency distribution of Mysis relicta sampled with a seine between 0.5 and 1.0 m in Simpson lagoon, western Beaufort Sea.

Fig. 21 . Length-frequency distributions of Mysis relicta, July-September, 1977. Samples were collected between 0.5 and 3.0 m with an epibenthic sled net. Western Beaufort Sea.



30
20
10
38%
Mysis relicta
N = 482
7/29/77
20
10
N = 643
8/15/77
20
10
N = 660
9/1/77
4
6
8
10
12
14
16
18
Length (mm)

Fig. 22. Size-frequency distributions for <u>Mysis relicta</u> collected with an epibenthic sled net between 0.5 and 2.0 m in the Western Beaufort Sea. July-August, 1978.

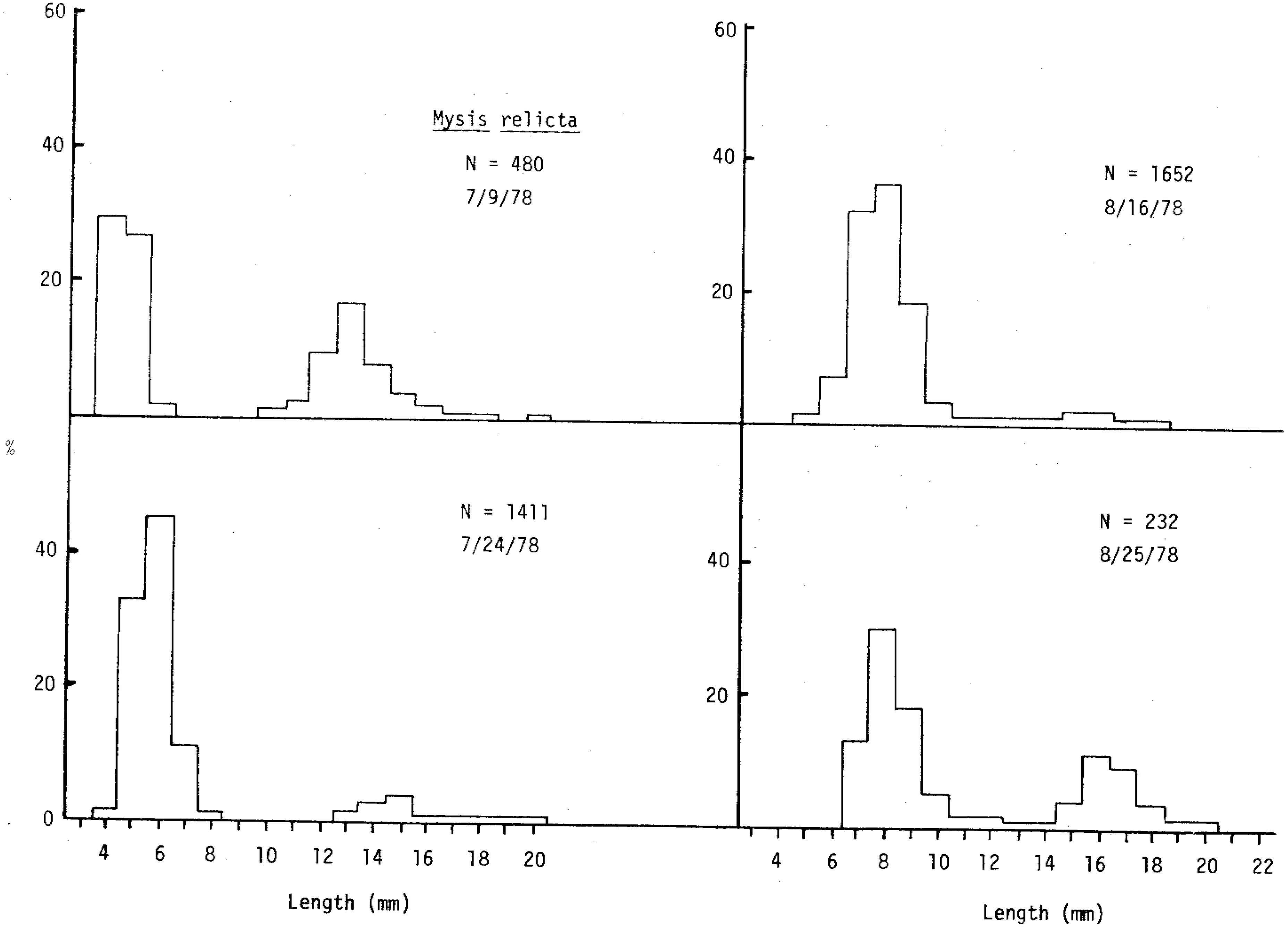
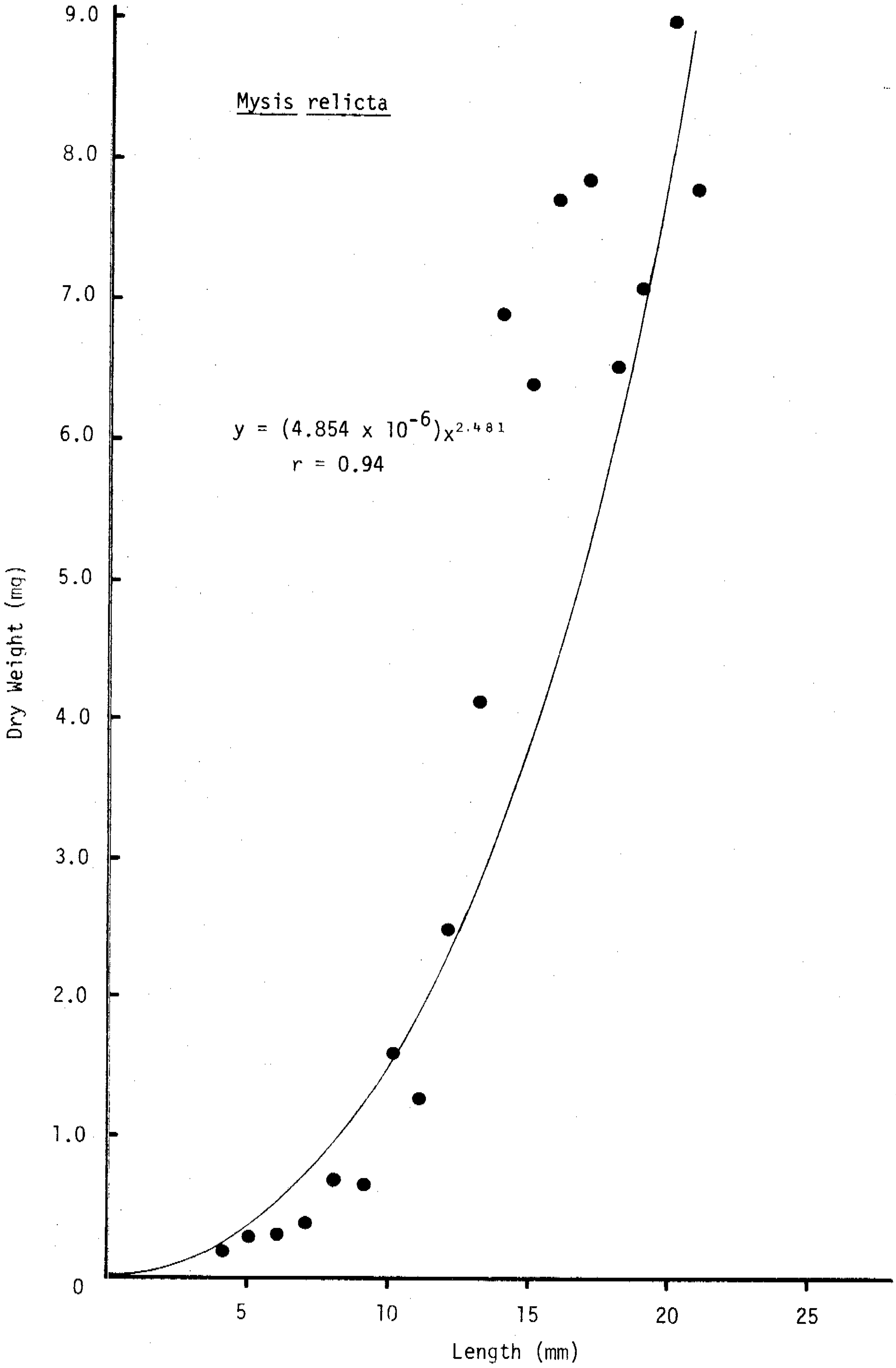

Mysis relicta
N = 480
7/9/78
N = 1652
8/16/78
N = 1411
7/24/78
N = 232
8/25/78
60
40
20
0
%
4
6
8
10
12
14
16
18
20
22
Length (mm)
Length (mm)

Fig. 23. Length-dry weight relationship in <u>Mysis relicta</u> from the Western Beaufort Sea.


Mysis relicta
$y = (4.854 \times 10^{-6})x^{2.481}$
$r = 0.94$
Dry Weight (mg)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
5
10
15
20
25
Length (mm)

Neomysis mirabilis and N. intermedia

Neomysis mirabilis

Distribution: Asiatic Russia, Kamchatka, Japan. Chukchi Sea, Alaska (Tattersall, 1951).

We were unable to locate any background information on N. mirabilis. Information presented in the following pages is based on samples collected in the Chukchi Sea by RU 356. All samples were collected with an epibenthic sled net at a depth of 0.5 meters.

Population Structure

Size frequency data (Figs. 24 - 29) for N. mirabilis collected in July, 1977 show that juveniles are released at this time. A large number of gravid females were present on 7/11/77 (Fig. 24). Juveniles were not present until 7/22 (Fig. 25). Figure 25 is a composite of the results of two sampling dates; 7/16 and 7/22. No juveniles were collected on 7/16, whereas the 7/22 collection consisted entirely of juveniles (Fig. 25). The apparent change in population composition indicates that migration, sampling variability, or size-selective predation may be involved. Adult individuals may migrate in response to food availability or other factors.

Size

The mean length of males was 9.9 mm, and that of females was 18.9 mm. The largest male captured was 24 mm long, which indicates that the calculation of mean length of males is based on a predominantly juvenile male population. Males can be recognized at 4 mm, since the fourth pleopod often is enlarged by the time the animal has attained this length. Females cannot be positively identified before the animals have reached a length of 10 mm. The largest female captured was 30 mm long. The positive identification of males at smaller sizes is a factor in the smaller mean length of males.

The relationship between length and dry weight in N. mirabilis is shown in Fig. 27 .

Reproduction

The mean lengths of females bearing eggs or young were 16.6 mm and 19.9 mm, respectively. The number of eggs per female increased with female size (Fig. 28). The number of young per female also increased with female length (Fig. 29). Larger females carried more eggs than young. This indicates that larger females lose proportionately more eggs than smaller females (Table 1). Although the data are incomplete, a comparison of Figures 28 and 29 demonstrates this phenomenon. Loss of eggs could occur in the field or upon preservation of the specimens.

Neomysis intermedia

Distribution: In brackish waters in Japan, the east coast of Asiatic Russia, China; American Arctic, Chukchi Sea, Alaska (Holmquist, 1973; Tattersall, 1951).

The species occurs in fresh and salt water. In marine waters, it occurs primarily in coastal regions at depths of 1 to 6 meters. It is most abundant in lagoons, inlets, estuaries and bays (Holmquist, 1973). It is a hardy euryhaline and eurythermal species, able to withstand salinity fluctuations of as much as 27 $^{o}/oo$ (Holmquist, 1973). In the Chukchi Sea, it is found in association with Mysis relicta and Neomysis mirabilis. Holmquist (1973) stated that N. intermedia breeds mainly during the winter months and that embryonic development and growth occur within the marsupium between winter and spring. Our data indicate that in the Chukchi Sea, breeding may not be restricted to the winter since many of our July and August samples contained ovigerous females. The results presented in the following pages are based on epibenthic sled net samples from depths of 0.5 to 2.0 meters.

Population

Population diagrams for N. intermedia collected in mid-August show a large number of juveniles (Figs. 30 - 32). The adult population (10-18 mm) was dominated by gravid females. Release of young may occur later in N. intermedia than in N. mirabilis populations (Figs. 28 - 29 and Fig. 34). However, the N. mirabilis and N. intermedia data were accumulated in different years, so direct comparison of the data is speculative. Yearly variations in environmental factors could affect the time of release of young.

Size

The mean length of male N. intermedia was 9.9 mm, the same as that of male N. mirabilis. The largest male collected was 14 mm long. Some N. intermedia could be identified as males at a length of 7 mm. Females could not be positively identified at lengths less than 10 mm. This is a factor in the difference in mean length between males and females.

The mean length of N. intermedia females was 14.4 mm. This is 4.5 mm less than the mean length of female N. mirabilis. The largest N. intermedia female collected was 17 mm long.

The relationship between length and dry weight in N. intermedia is shown in Fig. 27 .

Reproduction

The mean length of females bearing eggs or young were 14.7 mm and 14.6 mm, respectively. Although the mean lengths of N. intermedia females bearing eggs or young are not significantly different, the mean length of N. mirabilis females bearing young was 3 mm longer than that of females bearing eggs. The number of eggs per female does not increase as dramatically with female length as in N. mirabilis (Figs. 28 and 33). However, N. intermedia females have a lower percent egg loss as a function of length than do N. mirabilis females (Tables 1 and 2; Figs. 29 and 34). This may be due to the smaller size of N. intermedia females. Smaller females may be able to hold eggs within their marsupium more effectively. The increase in percent egg loss with increasing length of N. mirabilis females (Table 1) lends support to this hypothesis.

The relatively large number of gravid females of N. mirabilis and N. intermedia in the Chukchi Sea during July and August is in sharp contrast to the total lack of gravid Mysis relicta females in the Beaufort Sea during these months. However, we also examined numerous M. relicta females from July-August Chukchi Sea samples. Some of these females were also gravid. This suggests that the timing of breeding and overall reproductive activity among mysids is different in these regions, and is probably related to seasonal differences in physical and biological factors.

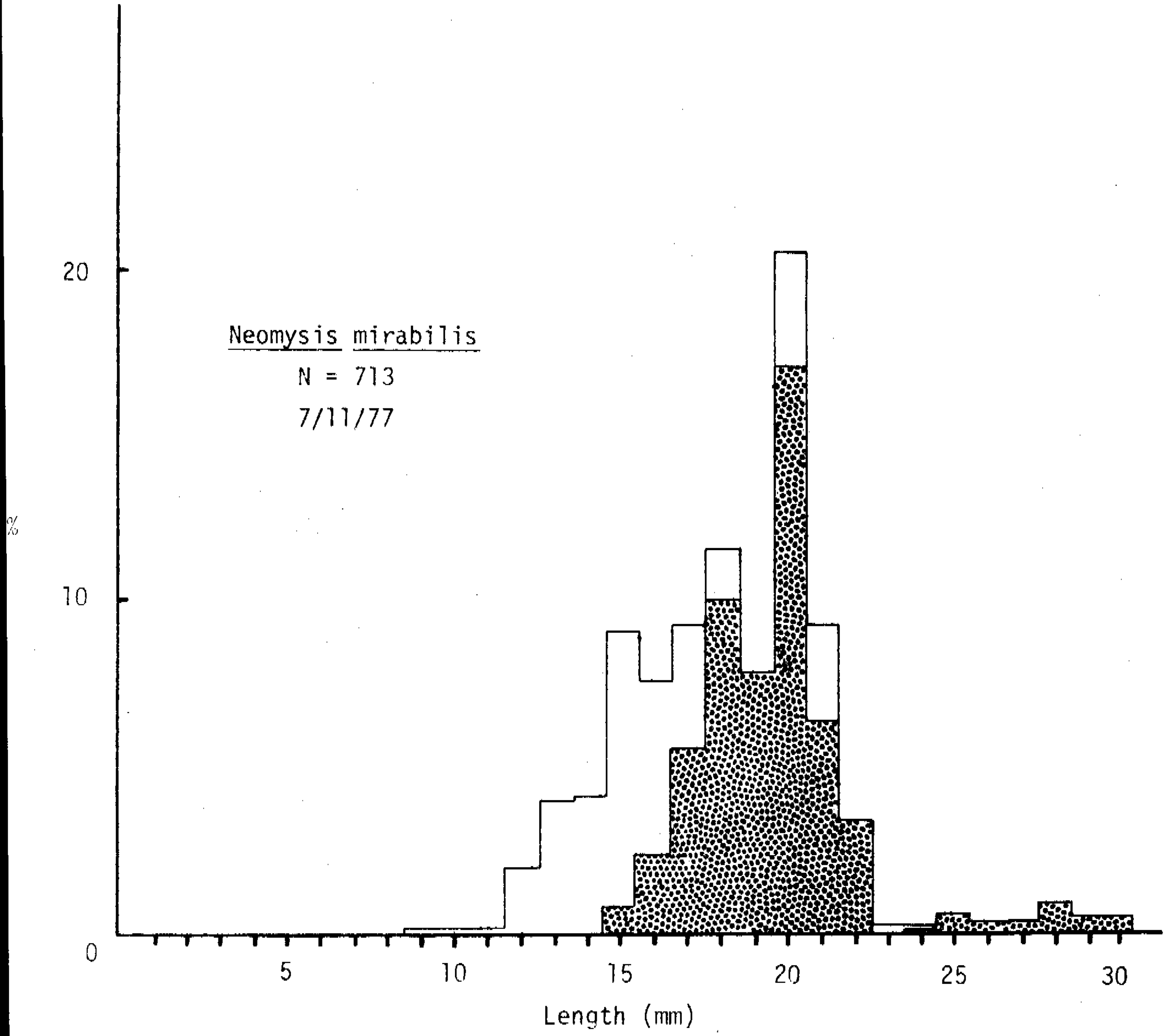


Figure 24. Size-frequency distribution of N. mirabilis on 7/11/77, Chukchi Sea. Shading = gravid females.

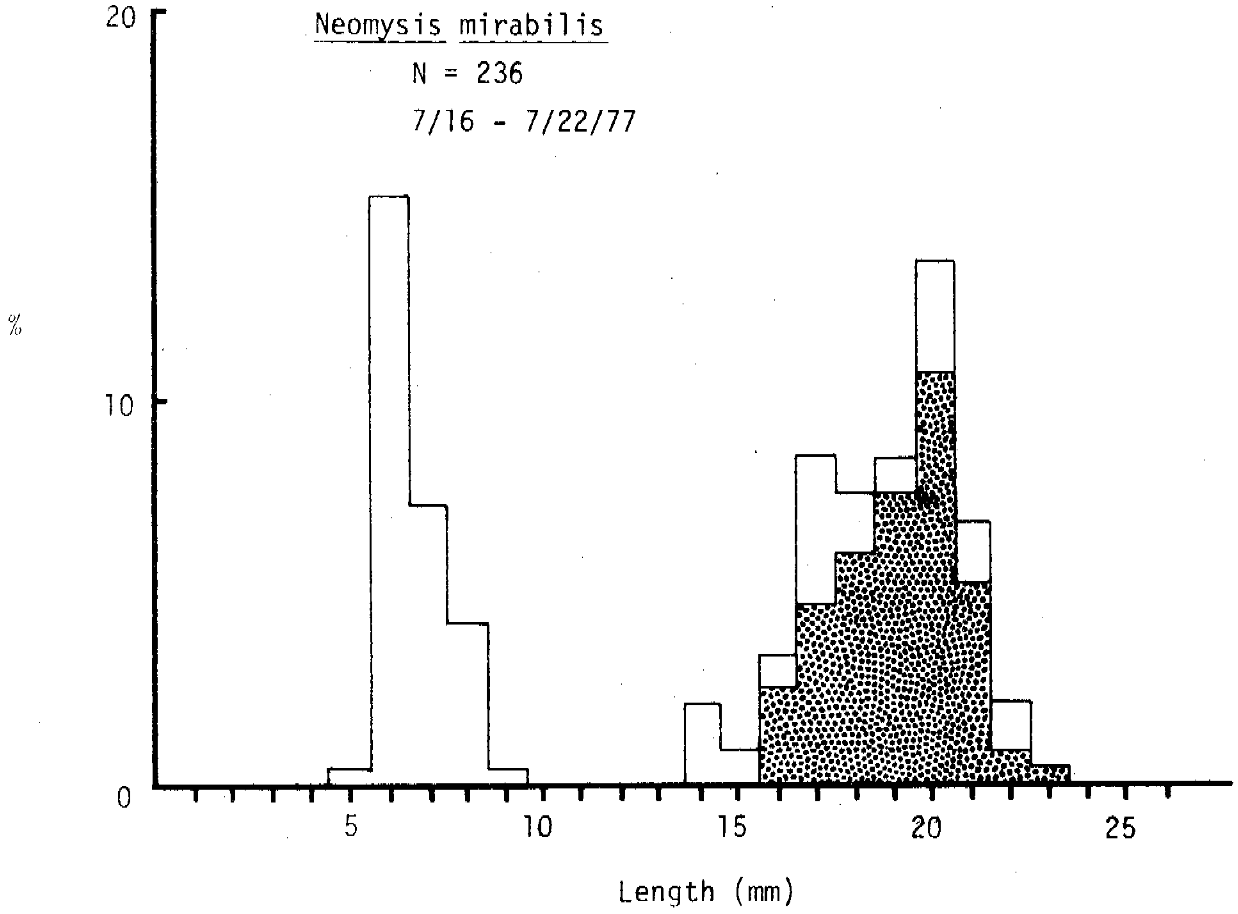


Figure 25 . Size frequency distribution of N. mirabilis on 7/16 - 7/22, 1977. Chukchi Sea. Shading = gravid females.

Figure 26 . Size frequency distribution of N. *mirabilis* on 7/28/77. Chukchi Sea. Shading = gravid females.

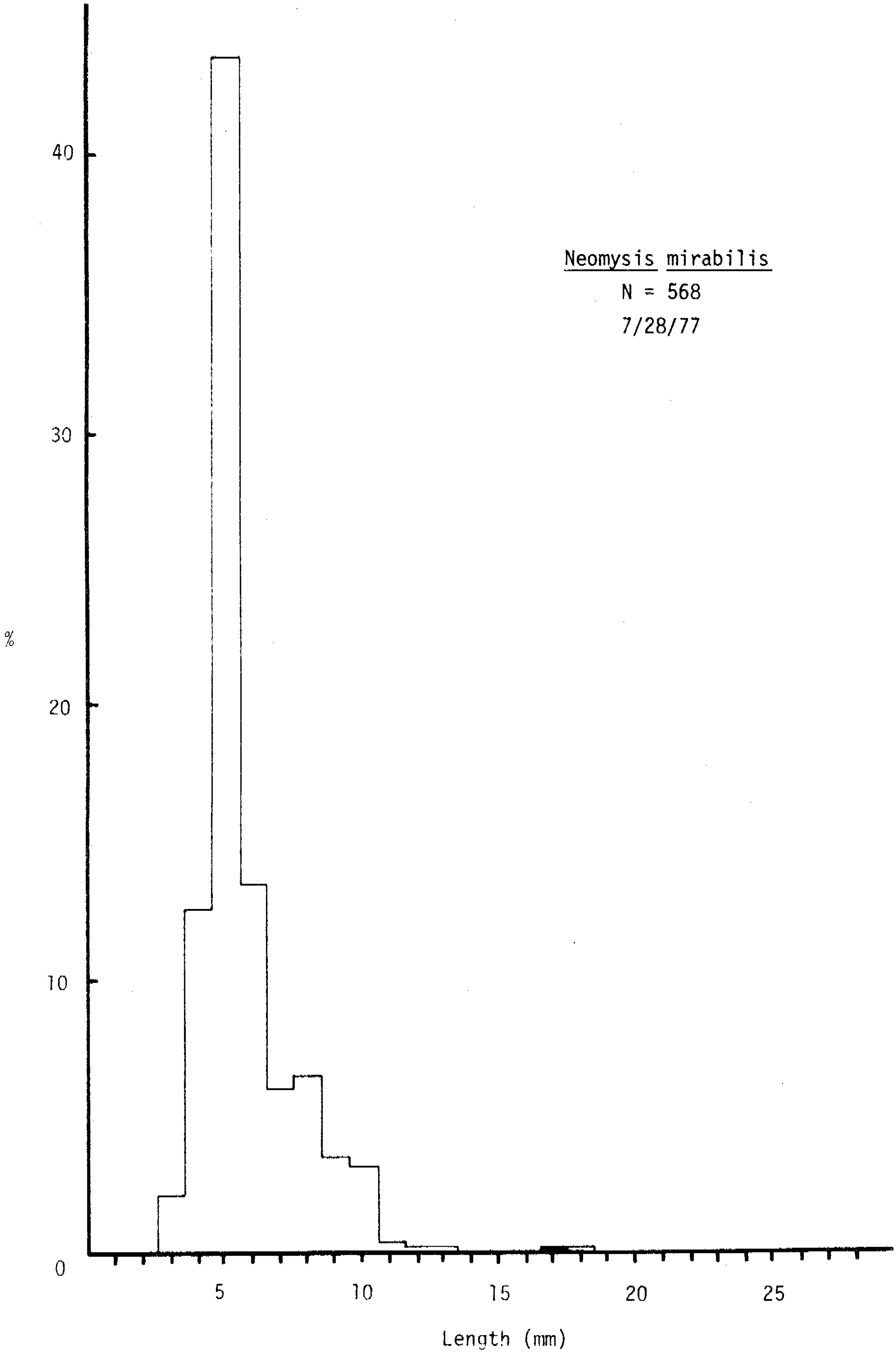
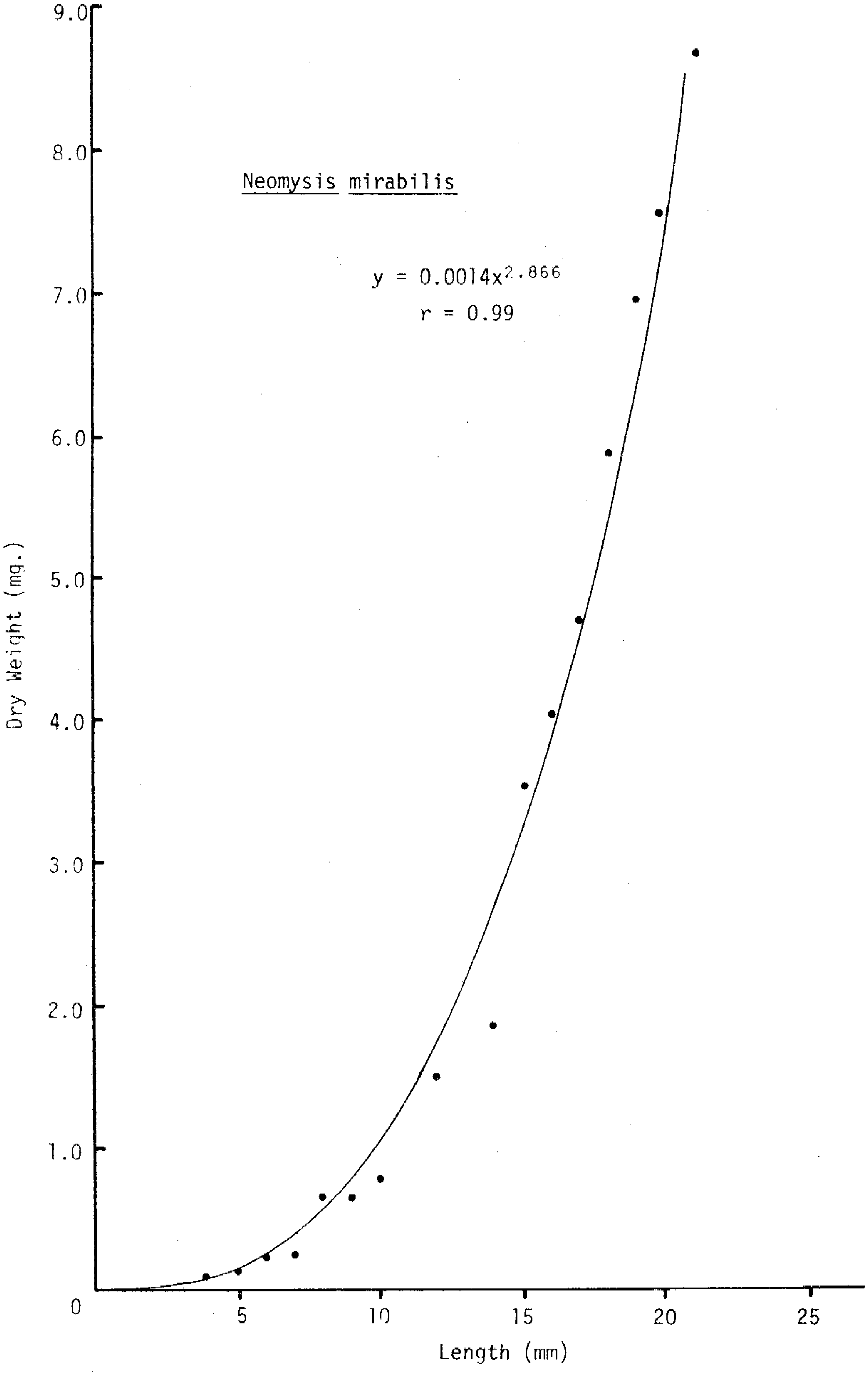

Neomysis mirabilis
N = 568
7/28/77
%
40
30
20
10
0
5
10
15
20
25
Length (mm)

Figure 27 . Relationship between length and dry weight in *N. mirabilis*.


Neomysis mirabilis
y = 0.0014x^2.866
r = 0.99
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
5
10
15
20
25
Dry Weight (mg.)
Length (mm)

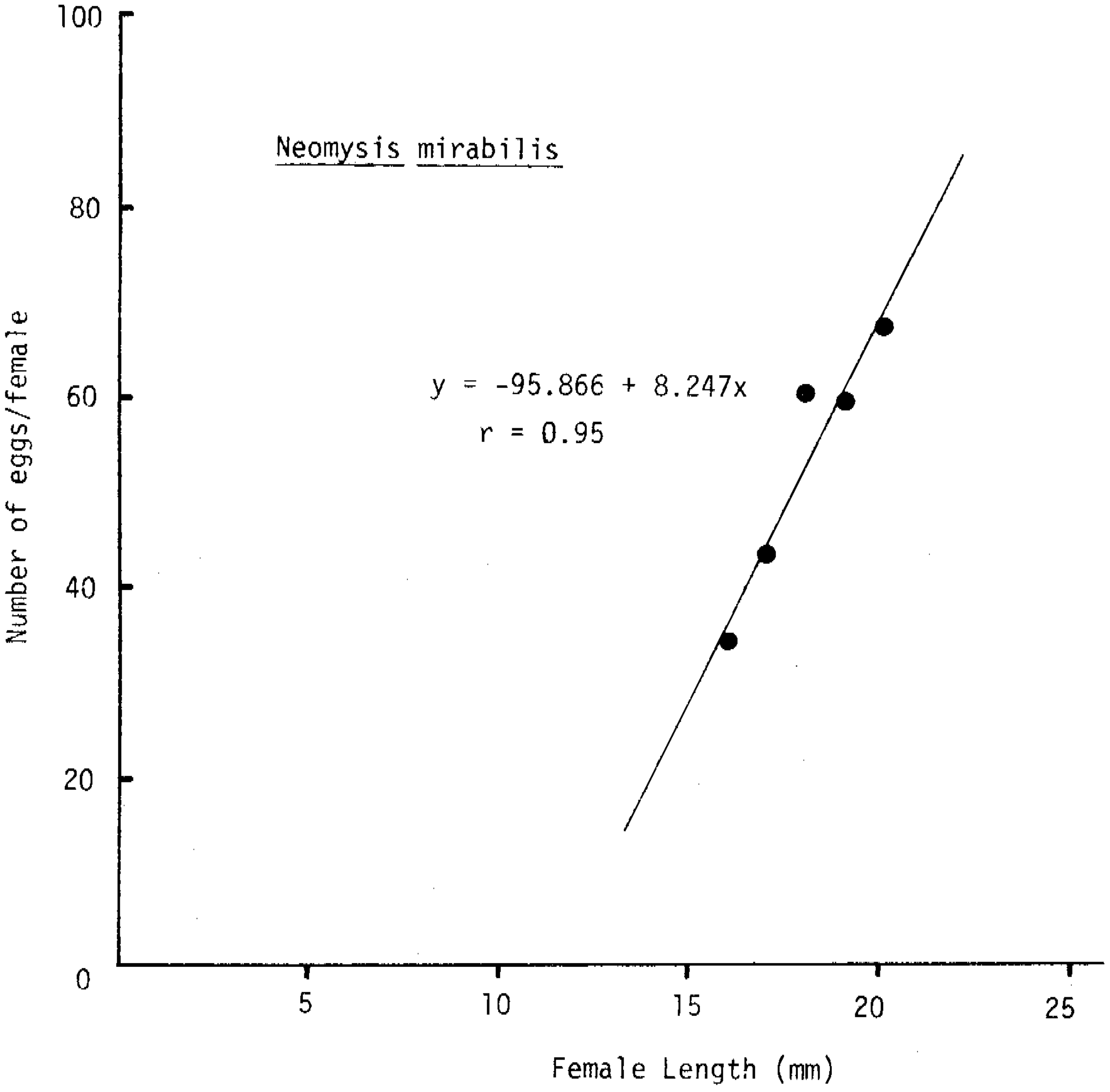


Figure 28. Relationship between female length and brood size (eggs) in *N. mirabilis*.

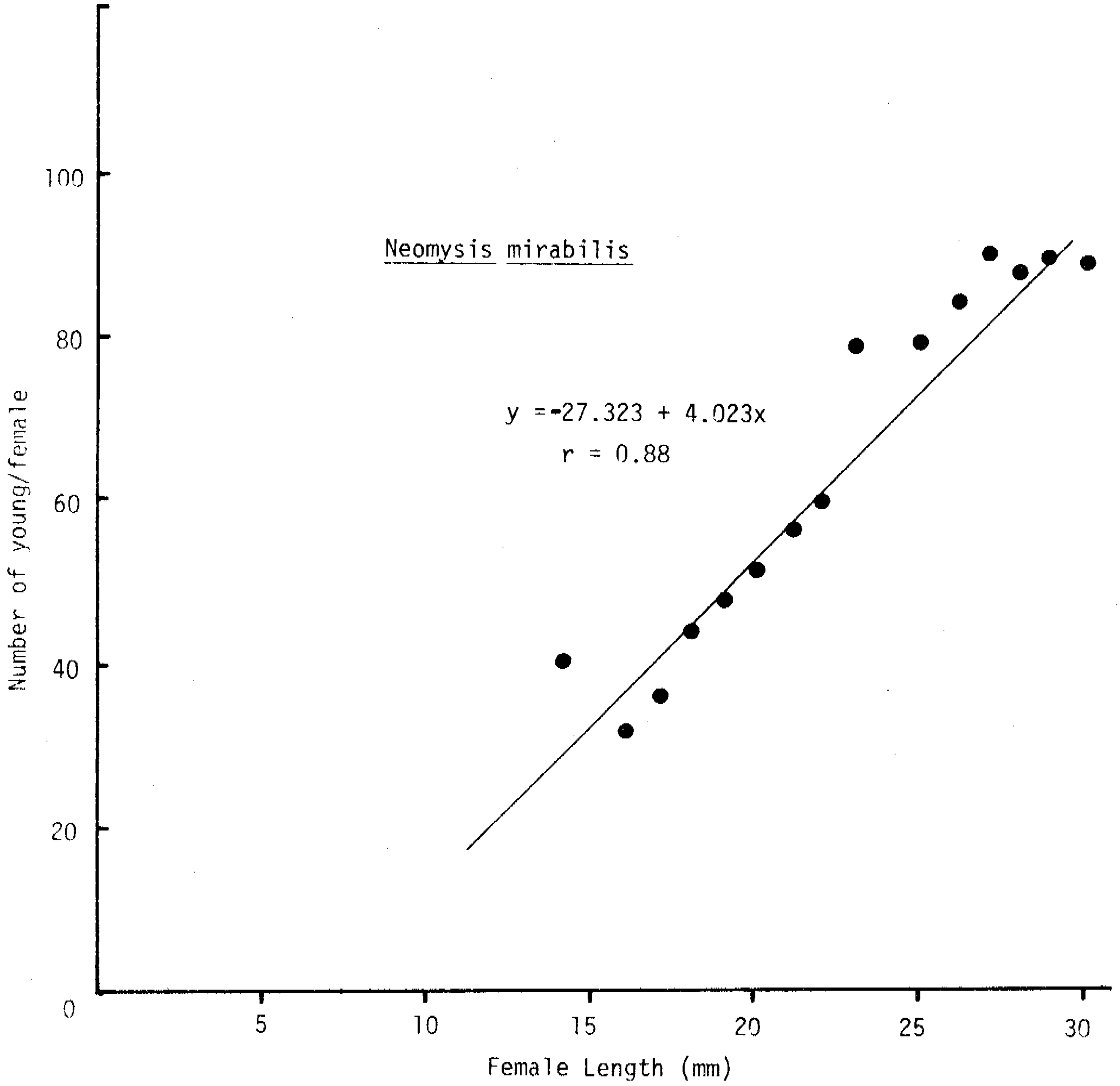


Figure 29. Relationship between female length and brood size (young) in N. mirabilis.

Table 1. Percent eggs lost by *N. mirabilis* females of different sizes.

Length of female (mm)	#Eggs/female	#Young/female	Percent egg loss
16	33.9	31.9	5.9%
17	42.7	36.8	13.8
18	60.3	44.1	26.9
19	59.0	48.4	18.0
20	67.0	51.2	23.6

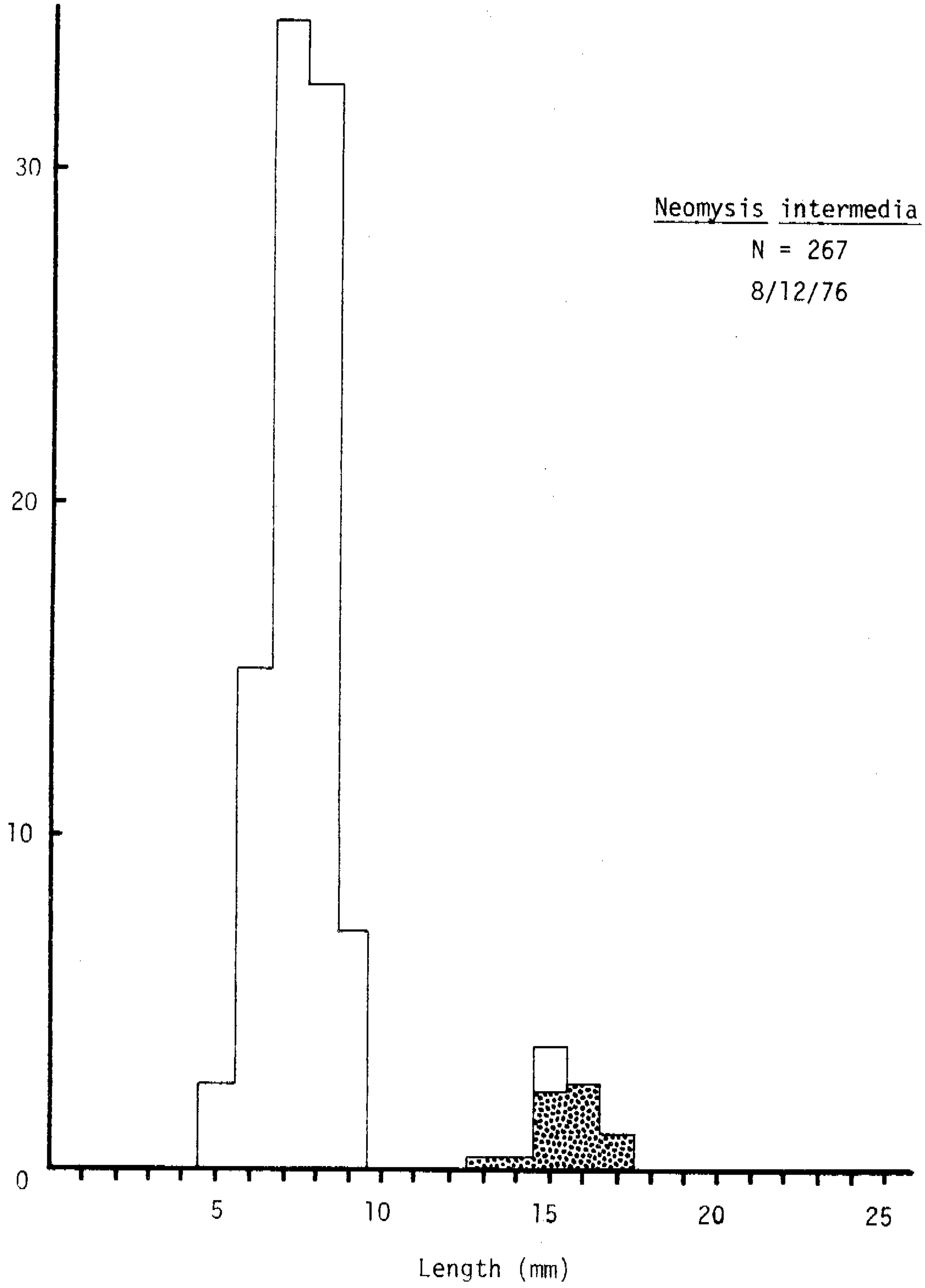


Figure 30. Size-frequency distribution of *N. intermedia*. on 8/12/76. Chukchi Sea. Shading = gravid females.

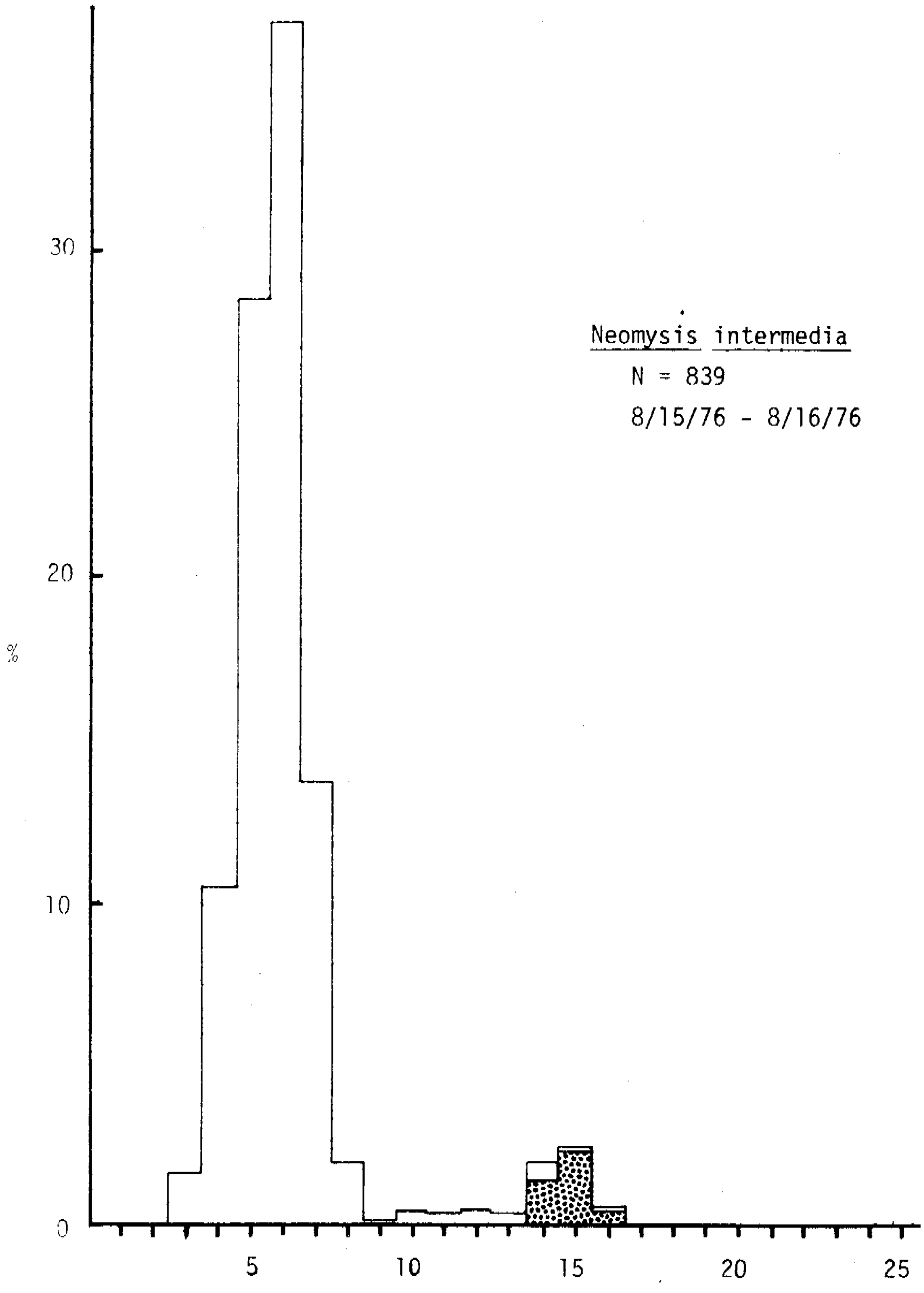


Figure 31 . Size frequency distribution of N. intermedia on 8/15 - 8/16, 1976. Chukchi Sea. Shading = gravid females.

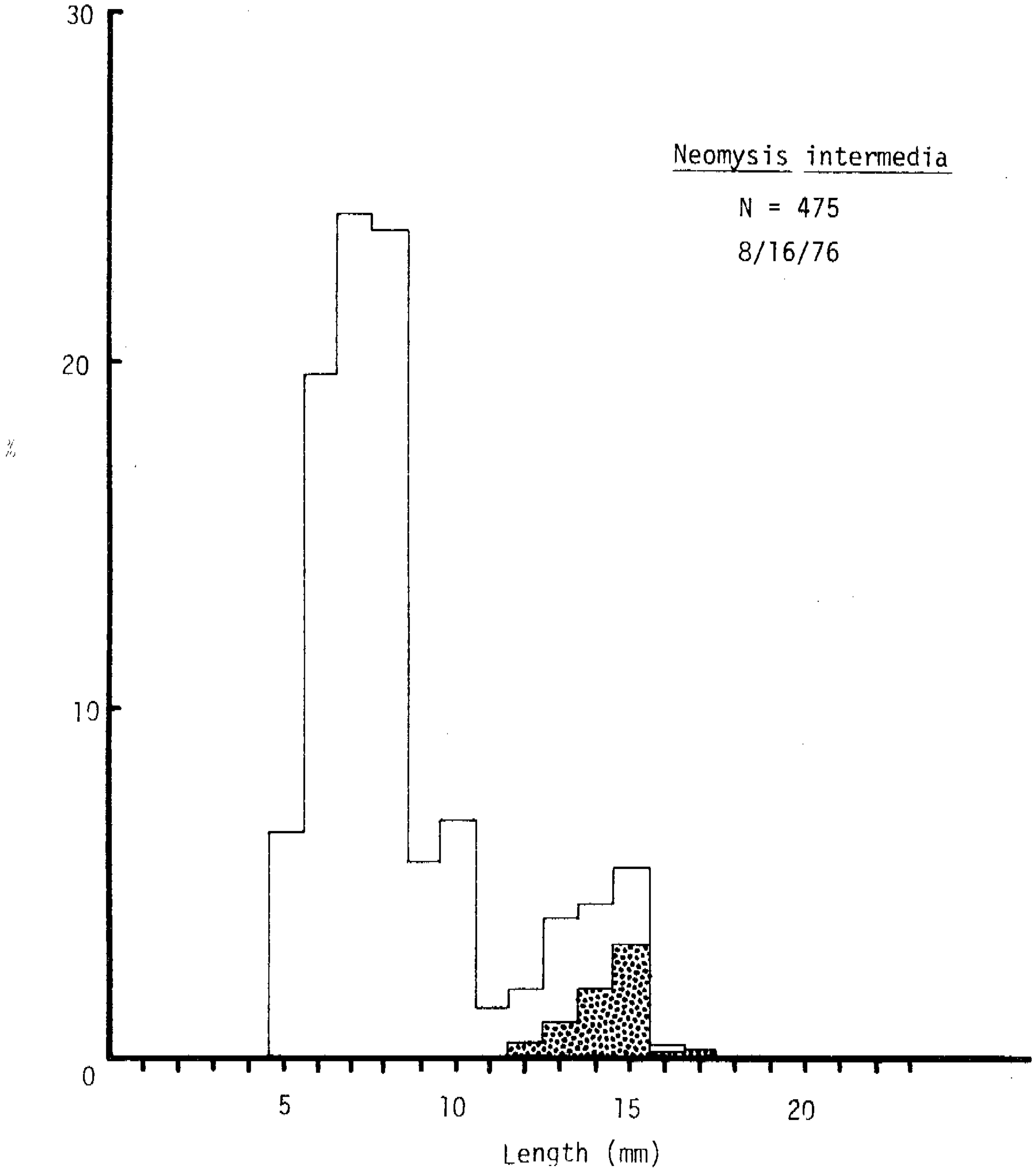


Figure 32 . Size frequency distribution of N. intermedia on 8/16/76. Chukchi Sea. Shading = gravid females.

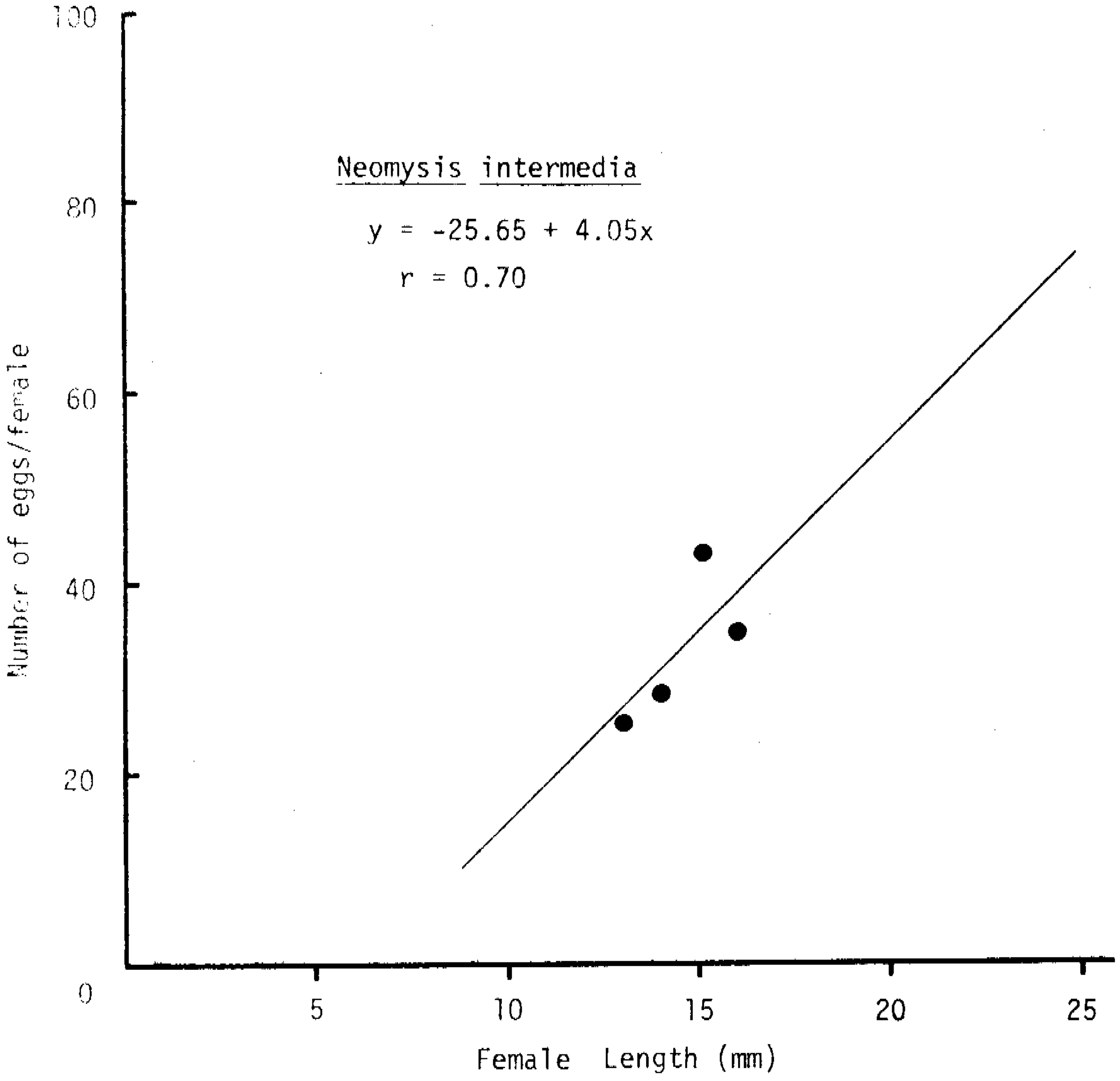


Figure 33. Relationship between female length and brood size (eggs) in *N. intermedia*. Chukchi Sea.

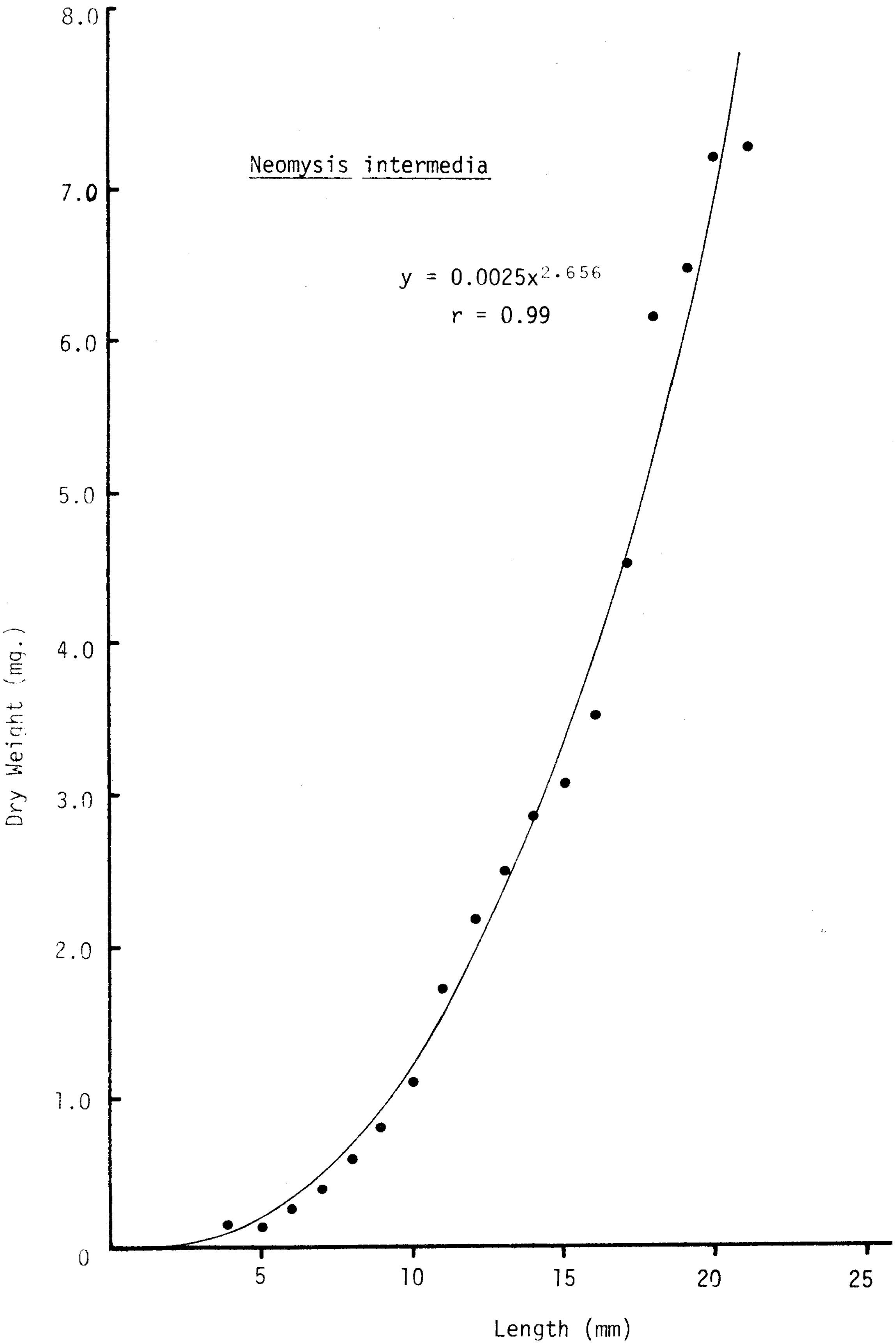


Figure 35 . Relationship between length and dry weight in *N. intermedia*.

Table 2. Percent eggs lost by N. intermedia females of different sizes.

Length of females (mm)	#Eggs/female	#Young/female	Percent egg loss
13	26.0	22.7	12.7%
14	28.7	34.4	0
15	42.8	38.2	10.8
16	34.8	47.8	0

Table 3. % Organic content (ash-free dry weight/dry weight) of Neomysis mirabilis and N. intermedia. July-August, Chukchi Sea.

Size category (mm)	N. mirabilis % Organic	N. intermedia % Organic
< 11	95.6	94.3
≥ 11	94.3	93.4

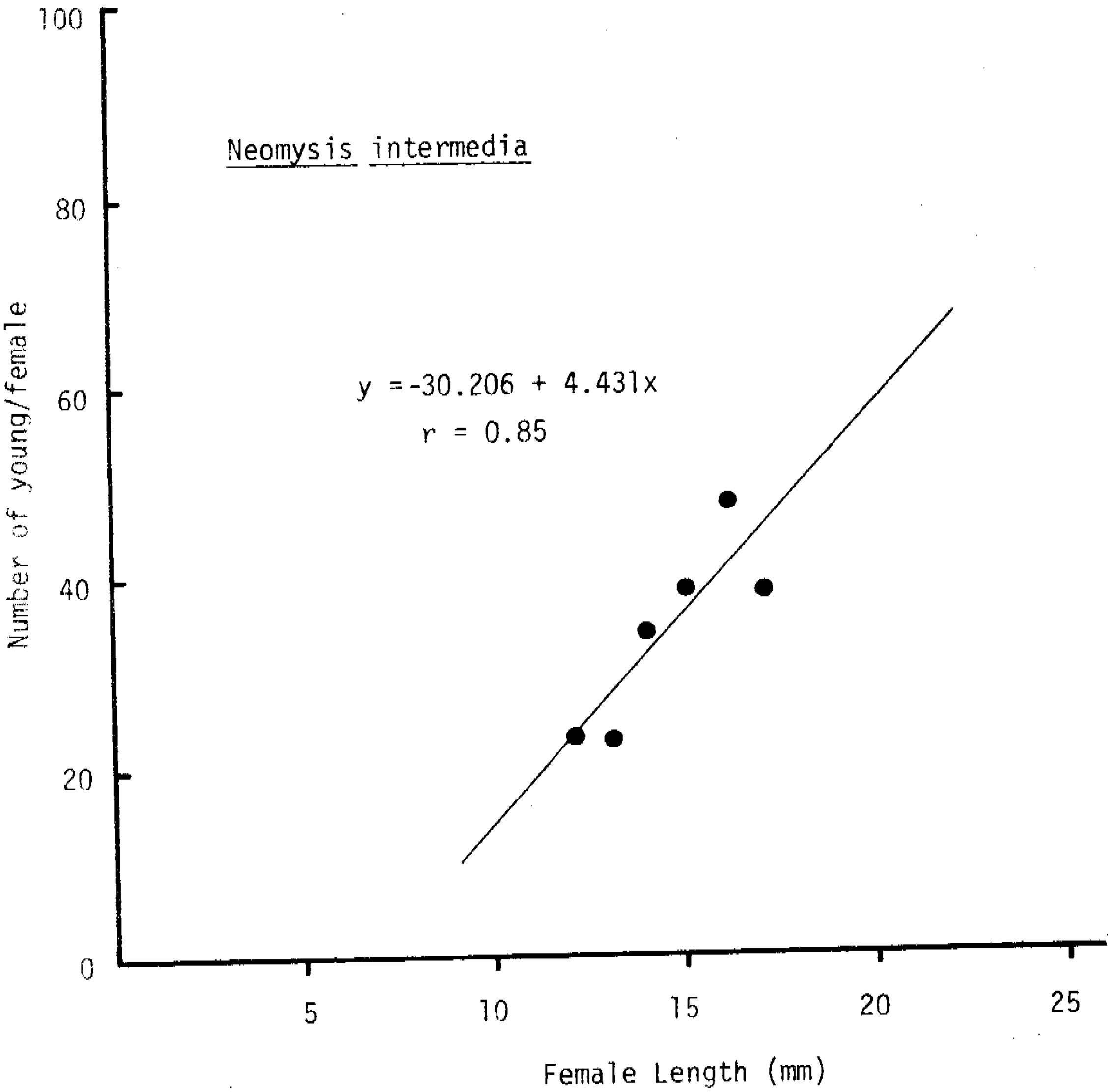


Figure 34. Relationship between female length and brood size (young) in *N. intermedia*. Chukchi Sea.

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