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075 Monitoring the Long-Term Fate and Effects of Spilled Oil in an Arctic Marine Subtidal Environment

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MONITORING THE LONG-TERM FATE AND EFFECTS OF SPILLED OIL IN AN ARCTIC MARINE SUBTIDAL ENVIRONMENT

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SUMMARY

This study is a continuation of the Baffin Island Oil Spill (BIOS) project, during which oil was experimentally released during 1981 in nearshore waters at Cape Hatt, northern Baffin Island. The objectives of this study are to monitor the fate and effects of the oil in subtidal sediments four years after the oil release. To accomplish these objectives, data collected during 1985 in two of the BIOS study bays (surface oil release and reference) have been analyzed together with corresponding data collected during 1981-1983 (including pre- and post-spill sampling periods). This study tests the predictions of increased oiling of sediments and effects on deposit-feeding benthos; elucidates whether the observed short-term biological effects improved, persisted, or worsened; and allows the opportunity of detecting possible long-term delayed effects that were not apparent in the second post-spill year.

Hydrocarbons were still present in subtidal sediments of both bays in 1985, four years after the oil releases, but the oil content in sediments appears to have stabilized between 1983 and 1985. Gas chromatograms and mass spectra of hydrocarbons in sediment during 1985 indicate that hydrocarbons were predominantly biogenic in all samples from the reference bay and in most samples from the oiled bay. Weathering indices indicate that any oil present in both bays during 1985 was highly weathered.

Ultraviolet/fluorescence analysis of tissues of three species of benthos show that low levels of oil remained in most tissue samples during 1985. Oil concentrations in each species were higher in the oiled bay than in the reference bay. Oil concentrations increased between 1983 and 1985 in tissues of the bivalve *Serripes groenlandicus* from the surface oil release bay, and in tissues of the bivalve *Macoma calcarea* and the sea urchin *Strongylocentrotus droebachiensis* from the reference bay. Gas chromatographic analyses indicate that both biogenic and highly weathered petrogenic hydrocarbons were present in tissue samples during 1985. Benthic organisms appear to be taking up the more polar weathered material present in the water column or remaining in the sediments.

To determine whether oil in sediments had affected subtidal benthos, temporal changes in the oiled bay were compared with those in the reference bay, using analyses of variance and covariance. In statistical terms, a significant interaction between spatial and temporal effects indicated a possible oil effect. The nature of each significant interaction was examined in relation to the concentration and composition of oil in subtidal sediments during 1981 to 1985. Variables examined included density and biomass of dominant infaunal taxa, density of epibenthic echinoderms and crustaceans, infaunal community structure, population structure in selected species of bivalves, and size and weight-length relationships in common bivalve species.

Oil effects were apparent on the first and second days after the release of oil in 1981, when intertidal amphipods and some larval fish were visibly affected. Over the four years following the release, oil did not cause

large-scale mortality of infauna or epibenthos, or any significant change in benthic infaunal community structure. This lack of major effects was probably because hydrocarbon levels in the sediments were rather low, similar to those in "lightly oiled" areas reported elsewhere. The same conclusions were reached after the second post-spill year of the BIOS project (Cross and Thomson 1987; Cross et al. 1987).

To test for subtle changes in infaunal density and biomass and in density of epibenthic crustaceans and echinoderms, 52 species- or group-variables were tested. Bay x period interaction terms were significant in six of those analyses of variance, indicating a possible effect of oil. However, inspection of the data and consideration of temporal changes in sediment oil concentration and composition gave little indication that any of the observed density changes were attributable to oil. Where changes in density did correspond with changes in sediment oil concentrations, the density changes were within the range of natural variability observed in the reference bay and during pre-spill sampling periods. These results are consistent with results of effects studies carried out after the second post-spill year of the BIOS project (Cross and Thomson 1987; Cross et al. 1987).

Data on mean size and population structure for three bivalve species at Cape Hatt showed considerable spatial and temporal variability. There was no evidence, however, of oil-related effects on mean size data or size-frequency distributions in any of the three species. Weight-length relationships in one of the three bivalve species examined were apparently affected by the experimental oil release at Cape Hatt. In Macoma calcarea during 1981 and 1982, the normal seasonal (August to September) increase in tissue weight relative to length occurred only in the reference bay. Because sampling was conducted only in August during 1983 and 1985, it was not possible to examine seasonal changes in tissue weight. However, the similarity between bays in the annual change in tissue weight after 1982 indicates that the effect of oil on the weight-length relationship in Macoma calcarea did not persist beyond the first post-spill year, despite increased oil concentrations in sediments.

RÉSUMÉ ADMINISTRATIF

Cette étude fait suite au projet de déversement de pétrole dans l'ile de Baffin (BIOS), au cours duquel on a répandu du pétrole à titre expérimental, pendant l'année 1981, dans les eaux du littoral de Cape Hatt, au nord de l'ile de Baffin. Elle a pour objet de contrôler l'évolution et les effets du pétrole dans les sédiments infralittoraux, quatre ans après le déversement. Pour ce faire, on a analysé les données recueillies en 1985 dans deux des baies de l'étude BIOS (déversement de pétrole en surface et référence) avec les données correspondantes recueillies pendant la période 1981-1983 (y compris les périodes d'échantillonnage pré et post déversement). Cette étude teste les prévisions sur l'accroissement du pétrole dans les sédiments, et les effets sur le dépôt et l'alimentation du benthos; elle élucide la question de savoir si les effets biologiques observés à court terme se sont améliorés, ont persisté ou se sont aggravés; elle permet enfin de détecter les effets différés à long terme qui n'étaient pas apparents dans la seconde année du déversement.

Des hydrocarbures étaient toujours présents dans les sédiments infralittoraux des deux baies en 1985, quatre ans après le déversement, mais la quantité de pétrole dans les sédiments semble s'être stabilisée entre 1983 et 1985. Les chromatogrammes de gaz et le spectre de masse des hydrocarbures dans les sédiments en 1985 montre que les hydrocarbures étaient surtout biogéniques dans tous les échantillons de la baie de référence et dans la plupart des échantillons de la baie contaminée. Les indices de météorisation indiquent que le pétrole présent dans les deux baies en 1985 ne s'est pas beaucoup décomposé.

L'analyse des ultraviolets et de la fluorescence des tissus de trois espèces du benthos montre que de faibles niveaux de pétrole étaient restés dans la plupart des tissus en 1985. Les concentrations de pétrole dans chaque espèce étaient plus élevées dans la baie contaminée que dans la baie du référence. Les concentrations ont augmenté entre 1983 et 1985 dans les tissus du Serripes groenlandicus bivalvé de la baie contaminée en surface dans ceux de Macoma Calcerea bivalvé et de l'oursin Strongylocentrotus droebachiensis de la baie de référence. Les analyses chromatographiques du gaz indiquent que des hydrocarbures biogéniques et pétrogéniques hautement décomposés étaient présents dans les tissus en 1985. Les organismes benthiques semblent absorber le matérial le plus météorisé présent dans la colonne d'eau ou restant dans les sédiments.

Pour savoir si le pétrole présent dans les sédiments a affecté le benthos infralittoral, on a comparé les changements temporels apparus dans la baie contaminée avec ceux de la baie de référence, en utilisant les analyses de variance et de covariance. En termes statistiques, une interaction importante entre les effets spatiaux et temporels indique un effet possible du pétrole. La nature de chaque interaction significative a été examinée en fonction de la concentration et de la composition du pétrole dans les sédiments sous-marins entre 1981 et 1985. Les variables examinées comprenaient la densité et la biomasse des taxums dominants de l'endofaune, la densité des échinodermes et des crustacés épibenthiques, la structure de l'endofaune, la structure de la population de diverses espèces de bivalvés, ainsi que la taille et la relation longueur - poids des espèces bivalvées communes.

Des effets ont été apparents le premier et le deuxième jour après le déversement du pétrole en 1981, les amphiphodes intertidaux et certains poissons larvaires étant visiblement touchés. Pendant les quatre ans qui ont suivi le déversement, le pétrole n'a pas entraîné de mortalité marquante de l'endofaune ou de l'épibenthos, ni de changement important dans la structure communautaire de l'endofaune benthique. Cette absence d'effets importants est certainement due au fait que les niveaux d'hydrocarbures dans les sédiments étaient assez faibles, comparables à ceux des régions "légèrement contaminées" signalées ailleurs. On a abouti aux mêmes conclusions de déversement du projet BIOS (Cross et Thomson 1987; Cross et autres 1987).

Pour tester les modifications subtiles de la densité et de la biomasse endofaunale ainsi que de la densité des crustacés et échinodermes épibenthiques, on a examiné 52 espèces ou groupes. Parmi les analyses de variance effectuées, six ont révelé des termes d'interaction entre baie et période significatifs, laissant entrevoir un effet possible du pétrole. Mais l'inspection des données et l'étude des changements temporels dans la concentration et la composition du pétrole présent dans les sédiments n'a donnée que peu d'indications pour permettre d'avancer que les changements de densité observés aient été dus au pétrole. Lorsque les changements de densité correspondaient effectivement aux changements de concentration du pétrole dans les sédiments, ils se situaient dans les limites de la variabilité naturelle observée dans la baie de référence et pendant les périodes d'échantillonnage précédant le déversement. Les résultats correspondent à ceux des études sur les effets réalisées après la deuxième année de déversement du projet BIOS (Cross et Thomson 1987; Cross et autres 1987).

Les données sur la taille moyenne et la structure de la population des trois espèces bivalvées à Cape Hatt ont montré une variabilité spatiale et temporelle considérable. Mais il n'y avait pas d'indice d'effets pétroliers sur les données concernant la taille moyenne ou les distributions de taille - fréquence dans aucune des trois espèces. La relation poids-longueur d'une des trois espèces bivalvées examinées a été apparemment touchée par le déversement expérimental de pétrole à Cape Hatt. En 1981 et 1982, l'augmentation saisonnière normale (d'août à septembre) du poids du tissu par rapport à la longueur chez les Macoma calcarea ne s'est produite que dans la baie de référence. L'échantillonnage n'ayant été effectué qu'au mois d'août, en 1983 et 1985, il n'a pas été possible d'examiner les changements saisonniers du poids du tissu. Mais la ressemblance entre les changements annuels de poids du tissu après 1982 dans les deux baies montre que l'effet du pétrole sur la relation poids-longueur n'a pas persisté chez les Macoma Calcarea après la première année de déversement, malgré l'augmentation des concentrations de pétrole dans les sédiments.

INTRODUCTION

Considerable attention has been given to the effects of oil on individual species of arctic marine fauna under experimental conditions (Percy and Mullin 1975, 1977; Percy 1976, 1977, 1978; Busdosh and Atlas 1977; Malins 1977; Atlas et al. 1978; Foy 1978, 1979, 1982). The difficulties in extrapolating from laboratory tests to field situations, however, are well known (Sprague et al. 1982) and, to date, the long-term effects of oil on whole communities in the Arctic are unknown. In temperate waters, community studies have been carried out for up to 10 years after a spill (e.g., Sanders et al. 1980), but most of those studies have been after the fact; hence, they lack adequate 'control' data on pre-spill conditions, on naturally occurring changes that would have occurred in the absence of the spill, or both (National Academy of Sciences 1975; cf. Bowman 1978). Another shortcoming of many spill studies has been the lack of supporting data on oceanographic and atmospheric conditions, and on hydrocarbon concentrations in the affected environment (National Academy of Sciences 1975).

To date, no major oil spill has occurred in Canadian arctic waters. In 1978-1979, the Arctic Marine Oil Spill Program (AMOP) examined the need for research associated with experimental oil spills in cold Canadian waters, and, thereafter, initiated the Baffin Island Oil Spill (BIOS) project to study a controlled introduction of oil and dispersed oil onto shorelines and into nearshore arctic waters. The aims of the nearshore biogeochemical and macrobiological components of the BIOS project were twofold. The first objective was to assess the fate of oil and dispersed oil by determining the concentration and composition of oil in the water column, in shoreline and subtidal sediments, and in a suite of benthic organisms that included filter feeders and surface deposit feeders. The second objective was to assess the effects of oil and dispersed oil on the macrophytic algae, the relatively immobile benthic infauna (e.g., bivalves, polychaetes), and the motile epibenthos (e.g., amphipods, urchins) in shallow arctic waters. The results of those studies have been reported in the BIOS project Working Report Series published by EPS (Boehm 1981, 1983; Boehm et al. 1982, 1984; Cross and Thomson 1981, 1982; Cross et al. 1983, 1984; Engelhardt et al. 1983; Gilfillan and Vallas 1984; Green 1981; Green et al. 1982; Humphrey 1983, 1984; Mageau and Engelhardt 1984), and are now being prepared for a special edition of the journal *Arctic*.

The BIOS project was carried out at Cape Hatt, northern Baffin Island. Partially weathered but otherwise untreated oil released onto the surface of a small embayment contacted the beach and was left to be cleaned by natural processes. Oil became incorporated into subtidal sediments within two weeks of the release, and concentrations increased progressively during 1982 and 1983, the two years following the release (Boehm et al. 1984). In 1983, two bivalve species (*Macoma calcarea* and *Serripes groenlandicus*) apparently reached a steady state condition with respect to uptake and depuration of oil, whereas the body burden of oil in the sea urchin *Strongylocentrotus droebachiensis* continued to increase (Boehm et al. 1984). At the end of the second post-spill year, Boehm et al. (1984) predicted that oil concentrations in subtidal sediments would increase further with time, and that deposit-feeding benthos would continue to be affected by oil.

During the first two post-spill years, oil caused neither any large-scale mortality or emigration of infauna or epibenthos, nor any significant change in infaunal community structure. However, a number of species were affected to varying extents. Effects attributable to oil in the sediments included decreased condition (tissue weight relative to length) in *Macoma calcarea*, decreased reproductive output or recruitment in the polychaete *Spio* spp. and the amphipod *Pontoporeia femorata*, altered patterns of depth distribution in juveniles of the amphipod genus *Anonyx*, and slight decreases in urchin densities that may have indicated long-term avoidance of oiled sediments (Cross et al. 1984). Most of those effects either persisted until, or only became apparent in, the second post-spill year.

The objectives of this study are to monitor the fate and effects of the oil in subtidal sediments at Cape Hatt four years after the oil release. To accomplish these objectives, data collected during 1985 in two bays (one oiled by a surface oil release and one used for reference) have been analyzed together with corresponding data collected during 1981-1983 (including pre- and post-spill sampling periods). This study tests the predictions of increased oiling of sediments and effects on deposit-feeding benthos; elucidates whether the observed short-term biological effects improved, persisted, or worsened; and allows the opportunity of detecting possible long-term delayed effects that were not apparent in the second post-spill year. A concurrent study (Hope et al. 1986) examined the fate of stranded oil in the intertidal zone of the oiled bay.

METHODS

STUDY AREA

The study area consisted of two shallow embayments in Ragged Channel, some 5-8 km SSW of Cape Hatt, Eclipse Sound (72°27'N, 79°51'W). Bay 7 (the reference bay) is a shallow indentation in the coastline, about 500 m in length, and Bay 11 (the surface oil release bay) is the lower half of a deeper embayment, approximately 1 km x 1 km in dimensions (Fig. 1).

FIELD PROCEDURES

Observations were made using SCUBA in the study bays during 5 August to 20 September 1981, 30 July to 13 September 1982, 3-29 August 1983, and 15-20 August 1985. Systematic sampling was carried out during 6-17 August and 29 August-10 September 1981, 8-15 August and 3-12 September 1982, 6-10 August 1983, and 15-19 August 1985. All sampling was carried out by divers working from inflatable boats. Preliminary processing and preservation of samples were performed either in tents erected on the beach or at the BIOS project base camp.

Sampling Locations

Three contiguous 50 m transects were set parallel to the shoreline in each of the study bays (Fig. 2). A depth of 7 m was selected as the primary sampling depth because of substrate characteristics and time and depth limitations for divers. Transect locations at 7 m depth were chosen in each bay using two criteria: first, similarity in substrate characteristics and infaunal community composition among transects and bays (as determined during preliminary surveys in August 1980 and 1981), and secondly, facility of sampling (soft substrate with as little surface rock as possible).

Transect locations were marked underwater by driving steel rods about 1 m into the substrate at 50 m intervals along a 150 m line. In each bay, sighting lines at the ends of the transects were established on the shore by placing pairs of markers on the beach. Transects were located in subsequent periods using the surface and underwater markers.

A 150 m transect rope marked at 1 m intervals was set between the permanent stakes. Airlift and sediment sampling locations 1 m^2 in area, immediately seaward or shoreward of the line, were selected using a random numbers table (see Appendix A). The exact location of the samples within each of these areas was selected to avoid large rocks on the surface of the sediment. Photograph locations along each transect were also randomly selected. Sample locations for airlifts and photographs were re-randomized for each transect and period; on any given transect, randomly selected airlift locations were rejected if they had been used during a previous

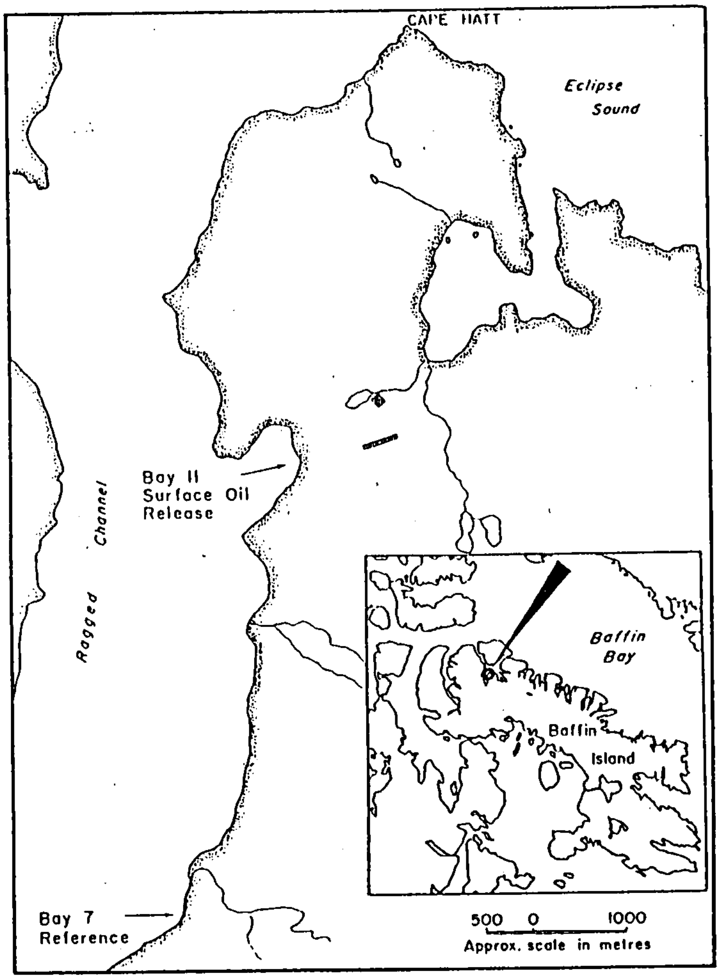

Figure 1. Study area at Cape Hatt, northern Baffin Island, showing the locations of the study bays.

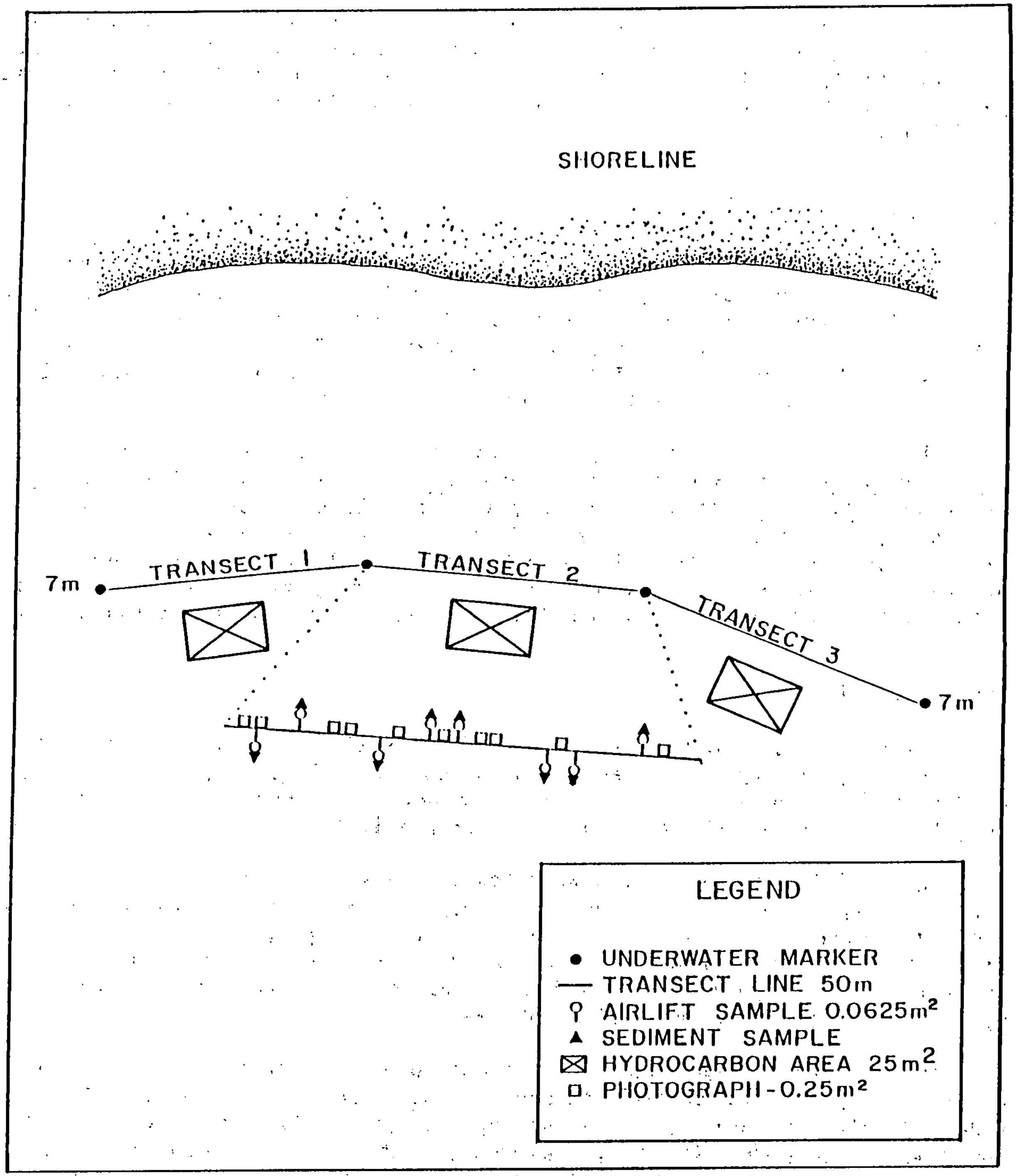

Figure 2. Schematic representation of sampling design for benthos and hydrocarbons.

period. *In situ* counts and supporting collections were made within belts 1 m x 10 m along each transect line. Benthic organisms for hydrocarbon analysis were collected within five areas located at even intervals along the transect line (at 15, 45, 75, 105, and 135 m) and about 5 m seaward of the line. The size of the area was that required to collect the numbers of organisms required for analysis, and was between 5 and 20 m^2. Sediment samples for hydrocarbon analysis were collected from within the areas used for benthic organism collections, and at some or all of the airlift sampling locations.

Hydrocarbon Sampling

Sediment samples for hydrocarbon analysis were collected by divers using baked, 250 mL, wide-mouth glass jars. Closed jars were transported to the bottom, lids were removed, and the top 2 cm of sediment was collected by gently scraping the jar along the substrate. The jars were closed and returned to the surface. FEP (hydrocarbon clean) Teflon liners were placed under the lid, and the samples were frozen until analysis.

Three benthic species were used for hydrocarbon analysis: the bivalves *Macoma calcarea* and *Serripes groenlandicus*, and the sea urchin *Strongylocentrotus droebachiensis*. The urchin was collected by hand, whereas a combination of hand collection and airlift sampling was used to collect the two bivalve species. When the animals were brought ashore they were sorted according to species, and ten individuals of each species from each sampling location were wrapped in aluminum foil and were frozen until analysis (Table 1).

Airlift Sampling

Infauna were sampled by means of a self-contained, diver-operated airlift. Eight replicate samples were obtained from each of three 50 m transects in each bay during each of August and September 1981 and 1982, August 1983, and August 1985 (total of 288 samples).

The airlift consisted of a weighted 2 m length of pipe 8 cm in diameter, fitted at the top with a 1 mm mesh net which retained the sample and could be removed quickly and capped. Air was supplied from a 20 MPa air cylinder fitted with the first stage of a diving regulator, which reduced air pressure to approximately 860 kPa above ambient. Areas to be sampled were demarcated by a ring containing an area of 0.0625 m^2.

The ring was placed on the bottom and pushed as far as possible into the substrate to contain shallow infauna. The airlift was inserted into the ring, the air was turned on, and the mouth of the airlift was moved around to cover the area within the ring thoroughly. The air was turned off when all visible organisms had been collected. The net on the airlift was then removed, capped, and replaced, and the depth of penetration of the airlift into the substrate was measured to the nearest centimetre. A sample of surface sediment was collected in a polyethylene jar immediately beside the excavated area during September 1980 in Bay 11, and during August 1981 in Bay 7. After three or four airlift samples had been taken, they were raised to the boat and were rinsed in the collecting bags to remove fine sediments.

TABLE 1

Numbers of sediment and benthos samples collected for hydrocarbon analysis at Cape Hatt, northern Baffin Island, 1981-1985.

			Sampling period[b]					
			1981			1982	1983	1985
Bay	Sampling location[a]		Aug	Aug/Sept	Sept	Aug	Aug	Aug
Bay 7	Transect[c]	1	0	0	4	0	0	3
		2	0	0	5	0	0	3
		3	0	0	3	0	0	3
	Tissue plot[d]	1	1 (1)[e]	2 (1)[e]	2 (1)[e]	1 (1)	1 (1)	1 (1)
		2	1 (1)[e]	1 (1)	1 (1)	3 (1)	1 (1)	3 (1)
		3	0 (1)	3 (1)	1 (1)	1 (1)	1 (1)	1 (1)
		4	1 (1)	1 (1)	1 (1)[e]	3 (1)	1 (1)	3 (1)
		5	1 (1)	2 (1)	2 (1)	1 (1)	1 (1)	1 (1)
Bay 11	Transect[c]	1	0	0	4	3	3	8
		2	0	0	4	3	3	8
		3	0	0	4	3	3	8
	Tissue plot[d]	1	1 (1)[f]	1 (1)	2 (1)	1 (1)	1 (1)	1 (1)
		2	1 (1)[e]	1 (1)	1 (1)[e]	3 (1)	3 (1)	3 (1)
		3	0 (1)	3 (1)	2 (1)	1 (1)	1 (1)	1 (1)
		4	1 (1)[e]	1 (1)	1 (1)	3 (1)	3 (1)	3 (1)
		5	1 (1)[e]	1 (1)[e]	2 (1)[f]	1 (1)	1 (1)	1 (1)

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[a] See Figure 2.

[b] Aug 1981 = pre-spill sampling; all others are post-spill.

[c] Number of sediment samples.

[d] Number of sediment samples, followed by number of tissue samples in parentheses.

[e] No data for *Serripes groenlandicus*.

[f] No data for *Serripes groenlandicus* or *Macoma calcarea*.

Immediately after each dive all samples were returned to the field laboratory.

Quantitative Photography and In Situ Counts

A photographic record of each transect during each period was obtained on colour slide film using a Nikonos camera with a 15 mm lens, paired Vivitar electronic flashes, and a fixed-focus framer covering a bottom area of approximately 0.25 m^2. Ten photographs were taken at randomly located intervals along each 50 m transect line during each period. Besides providing a permanent visual record of each study area, photographs were used to estimate densities of visible surface fauna that were too sparsely distributed to be represented adequately in airlift samples.

Macrophytes and those invertebrates too large and sparsely distributed to be sampled representatively by airlift or camera were counted in situ. On each 50 m transect during each period, counts of urchins, starfish, and individual kelp plants were made within five strips, 1 m x 10 m, parallel to, and immediately adjacent to, the transect line. Collections of representative plants and animals were also made for species identification.

LABORATORY ANALYSIS PROCEDURES

Hydrocarbons

Extraction of tissue samples. Following the method of Boehm et al. (1984), the required tissue was removed from the shell or exoskeleton with solvent-cleaned utensils, and was homogenized using a Virtis homogenizer. A subsample of the homogenate was taken for wet/dry weight analysis. Internal standards were added to the bulk of the sample, which was digested overnight in 100 mL of 5 N aqueous KOH. The digest was extracted with 5 x 100 mL hexane. The combined hexane extracts were dried and the volume was reduced to about 1 mL.

Prior to ultraviolet/fluorescence (UV/F) analysis, the extracts were eluted through an alumina column to remove interfering polar and biogenic compounds. Depending on sample size, the extracts were applied either to a 6.5 g or to a 25 g column of 7.5% deactivated alumina, and were eluted with 25 mL or 75 mL, respectively, of hexane/dichloromethane (9:1). The eluate volume was reduced to about 2 mL.

After UV/F analysis, tissue extracts were pooled according to species and bay. The pooled samples were then fractionated into non-polar and polar fractions and subsequently were analysed by gas chromatography/flame ionization detection (GC/FID) or by gas chromatography/mass spectrometry (GC/MS).

Extraction of sediment samples. About 100 g of wet sediment was placed in a glass jar, and water was removed with three 75 mL rinses of methanol. Internal standards were added, and the sediment was extracted with 3 x 100 mL dichloromethane/hexane (9:1) by shaking on a platform shaker for four hours per extract. All extracts (methanol and dichloromethane/hexane) were placed in separatory funnel with 100 mL water, and pH was adjusted to 2 with HCl. The dichloromethane layer was removed. Three additional extractions with 100 mL dichloromethane were performed, and the extracts were combined and reduced in volume. The solvent was displaced with methanol, and the methanol extract was digested with 4 mL 10 N aqueous KOH (80°C water bath) for four hours, then extracted with 3 x 15 mL hexane. The combined hexane extracts were reduced in volume.

Extract fractionation. Prior to UV/F analysis, the extracts were eluted through an alumina column to remove interfering polar and biogenic compounds. The extracts were applied to a 6.5 g column of 7.5% deactivated alumina and were eluted with 25 mL hexane/dichloromethane (9:1). The eluate volume was reduced to 2 mL.

After UV/F analysis, selected samples were fractionated into polar and non-polar hydrocarbons, following the method reported in Boehm et al. (1984). Fractionation columns consisted of 11 g 100% activated silica gel, 1 g 5% deactivated alumina, and 1 g copper. The columns were prepared by eluting with dichloromethane, then hexane. The sample hexane extract was placed on the column and was eluted first with hexane to elute the non-polar fraction (f-1), and then with dichloromethane/hexane (1:1) to elute the polar fraction (f-2). The eluates were reduced in volume for subsequent GC/FID or GC/MS analysis.

UV/F analysis. The method used by Boehm et al. (1984) was followed, except that a Perkin-Elmer MFP 66 microcomputer-controlled spectrofluorometer was used. The intensity of fluorescence was measured using an excitation wavelength of 325.5 nm and an emission wavelength of 350.5 nm. This corresponds to the peak maximum of Lagomedio Bay 11 reference oil under synchronous scan conditions ($\Delta\lambda$ = 25 nm). Fluorescence intensities were converted to oil concentrations by interpolating from a standard plot of fluorescence intensity versus Lagomedio oil concentration. A set of standards was prepared from a solution of Lagomedio crude oil which had been eluted through an alumina column in the same way as the sample extracts had been eluted. This prepartion was done as a consequence of experiments which showed a loss of sensitivity for uncolumned oil.

GC/FID analysis. GC/FID analysis was used to quantify the n-alkanes and isoprenoids present. The visual picture of a GC/FID trace, together with several indicator ratios, was used to determine the presence and extent of weathering of the oil.

The nonpolar fraction (f-1) of each sample was analysed by capillary gas chromatography on a Hewlett-Packard 5840A gas chromatograph equipped with a splitless injection port and flame ionization detector. (Instrument conditions are listed in Appendix B). Compounds were identified by comparing retention indices with that of a known standard. Concentrations were calculated by comparing the integrated areas of peaks with the area of the internal standard (perdeuterated hexatriacontane). Finally, the ratio of wet weight to dry weight was used to convert concentrations from a wet weight extraction to a dry weight basis. (Limits of detection for selected alkanes, and an explanation of abbreviations are given in Appendix B.)

Several diagnostic ratios calculated from the data were used to determine if hydrocarbon in a sample was biogenic, petrogenic, or a combination of both. (Calculations for the ratios and typical values of the ratios for Lagomedio fresh and aged oil are given in Appendix B.)

GC/MS analysis. GC/MS analysis was used to determine concentrations of various alkylated (C1-C4) and parent polycyclic aromatic hydrocarbons (PAH), as well as alkylated (C3-C6) benzenes. Alkylation patterns derived from the data were used to infer the presence of oil. If oil was present, the aromatic weathering ratio was used to determine the extent of its weathering. (Typical values of this ratio for fresh and aged oil are given in Appendix B.)

The polar fraction (f-2) from selected samples was analysed by capillary column gas chromatography on a Finnegan 9500/3000 GC/MS equipped with a splitless injection port. The column exists at the ion source. (Instrument conditions and limits of detection for selected PAHs are given in Appendix B.)

Data were acquired in the selective ion monitoring (SIM) mode for parent ions of those compounds of interest. Identification was based on known retention indices as well as on location in the correct ion window. (The SIM plots obtained from a typical sediment extract are shown in Appendix B.) Quantification was based on comparing integrated peak areas with the area of an internal standard (perdeuterated PAH). Relative response factors were calculated from daily calibration runs. Concentrations were converted to a dry weight basis.

Benthos

All samples were processed in the field within 12 h of collection. Samples were emptied into large plastic trays, and nets were carefully rinsed and picked clean. Entire samples (minus large rocks and gravel) were labelled and preserved in 10% formalin : 90% seawater. Macrophytic algae other than those in airlift samples were pressed on herbarium paper and were dried at room temperature.

Detailed laboratory processing and analysis of the samples was carried out within six months of collection. Each sample collected was analyzed separately, except for two samples from the same transect in Bay 11 that were inadvertently mixed during laboratory analysis in 1981. In this case the two samples were combined, processed, and the results divided by two to provide data on one "composite" sample.

Samples initially were rinsed to remove formalin and sediment, and then were separated into five fractions. The first fraction, consisting of all material passing through a 1 mm mesh screen and retained on a 0.45 mm mesh screen, was preserved in alcohol for future reference. The second fraction, separated by rinsing, contained algae, detritus, and most soft-bodied animals. This fraction was examined under a binocular microscope, and animals ≥ 1 mm in length were sorted into major taxonomic groups; the remaining algae and detritus were blotted dry and weighed on a Mettler PT 200 balance. In 14 samples that contained large volumes of algae (>500 mL), large and conspicuous organisms were picked from the entire sample but only a subsample of known weight was examined microscopically.

Fractions three to five were obtained by using nested sieves to separate the balance of the sample into three different size fractions (1-2.8 mm, 2.8-5.6 mm, and $\geq$5.6 mm) containing sand, gravel, molluscs, and some soft-bodied animals. The large fraction was sorted in a glass tray into major taxonomic groups. Large shell fragments and entire bivalve shells were separated, labelled, and stored for future reference.

The 1-2.8 mm and 2.8-5.6 mm fractions from 1981 samples were routinely sorted under a binocular microscope. Careful checking of a number of these samples indicated that about 10% of the smaller organisms remained in the sand and gravel, and were excluded from analysis. Hence, a more efficient method using differential specific gravity (Sellmer 1956) was used in 1982, 1983, and 1985. During 1983, we also applied this improved method to sand and gravel from the 1981 samples. The 1 mm and 2.8 mm sieves were placed on paper towelling to remove excess moisture, and the contents were then emptied into a plastic pail containing a 70% solution (by weight) of $ZnCl_2$ (specific gravity = 2.0). The mixture was gently stirred and organisms that floated to the surface were removed with a 1 mm mesh net. The procedure was repeated a minimum of twice. The specific gravity of the solution was measured before each sample was processed, and was kept relatively constant (s.g. = 1.8-2.0) by adding $ZnCl_2$ as necessary. The combined net contents were sorted into major taxonomic groups, and entire bivalve shells were separated and stored in labelled plastic bags for future reference. The 1981 results in this report differ slightly from those in earlier BIOS reports because they now include animals isolated by the $ZnCl_2$ method. The 1981-1985 results in this report are directly comparable.

All animals were identified to species level whenever possible; unidentified or tentatively identified species were sent to appropriate authorities for identification or verification (see Acknowledgements). In cases where it is generally recognized that additional species descriptions or revisions of higher taxonomic levels are required, questionable species or genera were pooled at the next highest taxonomic level prior to analysis. For each taxon identified, individuals were counted, gently blotted dry, and weighed together to the nearest milligram on a Mettler PT 200 or PC 220 balance. Unless otherwise specified, all weights presented in this report are preserved (10% formalin) wet weights, including mollusc shells but excluding polychaete tubes. Lengths of individuals of all bivalve and amphipod species were measured to the nearest millimetre. After laboratory examination, all taxa were stored in 75% ethanol; a solution of 3% propylene glycol in 75% ethanol was used for crustaceans.

For each of four common bivalve species (_Mya truncata_, _Astarte borealis_, _Macoma calcarea_, and _Serripes groenlandicus_), the relationships between length, wet weight, and dry weight were derived as follows: for each bay and period, about 50 undamaged individuals of each species were selected (where possible) from airlift samples taken along the middle transect. If necessary to obtain a sample size of 50 per bay, animals from the inner ends of the outer two transects were also used. For each individual, the length, wet weight including shell, wet meat weight, and dry (constant) meat weight were determined. Constant dry weight was obtained by drying at 60°C in a Fisher

Isotemp Oven Model 301 for 24 to 48 h (depending on species). Times were established by weighing at daily intervals until constant weight was found.

Methods used in sediment analysis were identical to those of McLaren et al. (1981). The sand fractions ($<4.0\,\Phi$) were separated using $0.5\,\Phi$ interval sieves in the range of $-1.0\,\Phi$ to 4.0Φ. Silt and clay ($>4.0\,\Phi$) were determined using the pipette method. Gravel content was determined for entire samples, but was excluded from all other calculations (grain size, sorting coefficient, and percent composition of sand, silt, and clay).

DATA PROCESSING AND ANALYSIS

Hydrocarbons

Hydrocarbon data were log-transformed prior to analysis. Data are expressed as a geometric mean (i.e., the back-transformed mean of log-transformed data) and 95% confidence limits. Differences between sampling periods were tested using the Student's t-test for two-group experiments (Youmans 1973), using $\alpha = 0.05$ as the criterion for significance.

Benthos

All quantitative data collected in the field and all results from laboratory analyses were coded for computer processing. Sediment data were processed on an Apple II microcomputer; all other data were processed using an IBM 3033/N12 computer. Computer programs developed by LGL were used to generate the sample-by-sample, transect-by-transect, and bay-by-bay tabulations that were used to select species and taxa for further analyses. Other LGL programs were used to organize the data into a format acceptable to packaged statistical programs. Prior to analyses, a logarithmic transformation (log [x+1]) was applied to density and biomass data to reduce the skewness inherent in such data.

To determine whether oil had an effect, temporal changes in the two bays were compared using three-factor (periods, bays, and transects) fixed-effects analyses of variance, with transects nested within periods and bays, using the GLM procedure of the SAS computer program package (Helwig and Council 1979; Freund and Littell 1981). In statistical terms, a significant interaction between spatial and temporal effects indicated a possible oil effect (Green 1979). Because of the nested design, the among-transects term rather than the residual error term was used to test the significance of main effects (periods, bays) and of the interaction between the main effects. When interaction terms involving transects were non-significant ($P > 0.05$), they were pooled with the transect term before testing for main effects. When interactions involving transects were significant ($P \leq 0.05$), they were not pooled with the transect term, which was used alone as the denominator in the tests.

Multivariate methods were used to examine the variability in the benthic community as a whole. Factor analysis (BMDP4M; Dixon 1981) was used to identify recurring groups of species and to reduce the number of variables in subsequent analyses. Species selected for analysis were those that accounted for 1.0% or more of density. The principal components method was used to extract initial factors from the correlation matrix of log-transformed, species abundance data. Final factors were generated by varimax rotation. Six factors with eigenvalues >1 were extracted; they accounted for 61.6% of the variance represented by the 24 species variables. The scoring coefficients produced by the analysis were applied to log-transformed species abundances to produce factor scores for all samples collected during all sampling periods.

The factor scores were used as dependent variables in multivariate analyses of variance (SAS GLM program; Helwig and Council 1979), using the three-way design (periods, bays, transects nested within bays and periods) employed in univariate analyses of variance. Transect effects were used to test main effects, as above. An a priori decision was made to use Pillai's trace as the test of significance in multivariate analyses of variance. Elements of the vectors that were produced for each test of main effects and which accounted for more than 10% of variance were applied to the factor scores to derive discriminant functions.

To provide a graphic summary of the similarities and differences in the benthic communities in the various bays and periods, group centroids were plotted against the discriminant functions representing each test of main effects and interaction.

The functional relationships between lengths and weights of dominant bivalve species were identified by analysis of, first, scatter plots of the 1980 data, and secondly, plots of residuals generated by regression analyses (Cross and Thomson 1981). The type of relationship determined the type of transformation used in subsequent analyses. Analyses of covariance with the corresponding function of length as the covariate were used to test for differences in dry meat weight among periods and bays, using data from all four years. Analyses of covariance were carried out using the SAS GLM procedure (Helwig and Council 1979). This procedure also produces adjusted mean weights for each of the bay/period combinations. These weights have been adjusted for among-bay and among-period differences in mean length; they represent mean weight at a standard length, and allow comparisons of relative weights of bivalves among bays and periods.

The mean lengths of selected bivalve species were calculated for each sample, and analyses of variance were used to test whether mean lengths of these species differed among bays or periods.

RESULTS AND DISCUSSION

EVALUATION OF METHODS

Hydrocarbons

Extraction efficiency of the UV/F method was determined using tissue homogenate samples spiked with Bay 11 standard oil at three concentrations. The method was found to be effectively quantitative at 30 and 100 $\mu g \cdot g^{-1}$, and somewhat less efficient at 3 $\mu g \cdot g^{-1}$ (112% recovery at a spiked level of 100 $\mu g \cdot g^{-1}$, 93% at 30 $\mu g \cdot g^{-1}$, and 45% at 3 $\mu g \cdot g^{-1}$).

Analytical precision of oil measurements by UV/F was estimated by frequent duplicate analyses. The difference between duplicates was found to vary with the mean, so the data were log-transformed prior to analysis. Pooled standard deviations (square root of the within-group mean square) were calculated for log-transformed duplicates, and 95% confidence limits for log data were determined as ± 0.07 for sediments and ± 0.4 for tissues.

These results indicate that the precision of UV/F analyses is better than "order of magnitude", and that the method is useful as a screening tool. The method is subject to interference from non-petroleum fluorescing material, but is not sensitive to minor chemical modification of the oil.

Similar calculations for GC/FID analyses indicate poor precision for analysis of individual compounds, and hence, lower precision for the calculated indices. These values are useful, however, when taken together, and patterns are recognized from the suite of indicators.

Benthos

A detailed evaluation of methods used in the BIOS study was given by Cross et al. (1984). Identical methods were used in the present study. The evaluation of methods is summarized as follows:

- Type I errors in statistical inference (finding apparent effects when there were none) are of concern because of the large number of tests performed. However, the likelihood of making such errors was reduced by examining the nature of each significant bay x period interaction in consideration of measured concentrations of oil.

- The nested analysis design is appropriate because the system studied is inherently variable. The design produces a conservative test for oil effects.

- Significant periods-by-bays interaction terms could arise because of actual effects of oil, but also because of some other temporal change in only one bay. Because the experimental oil releases were carried out in the field, it was not possible to allocate randomly the oil treatment to replicate samples, nor was it practical to replicate the oil treatment (i.e., to release oil in the same manner in two or more bays). Hence, we are guilty of "pseudoreplication" as defined by Hurlbert (1984), and it is not possible to reach unequivocal conclusions on the effects of oil. To reduce the possibility of confounding oil effects with natural changes that were inconsistent between bays, the nature of each significant interaction was examined in relation to the concentration of oil in the subtidal sediments during 1981 to 1985. Only if change in the benthos corresponded with change in oil concentrations was it concluded that a probable oil effect had occurred.

- A mesh size (hence, minimum organism size) of 1 mm was selected because a smaller mesh retained considerably more sand (about five times), and would have greatly increased sample collection and processing time.

- Penetration depth of the airlift sampler was sufficient to collect deeply burrowing organisms (e.g., *Mya truncata*). During 1980-1983, penetration depth did not vary significantly among bays and periods, nor was there any significant bay x period interaction.

- Estimates of the densities of highly motile epibenthic crustaceans likely are not as accurate as those for infauna because of escape of organisms from the area sampled and inclusion of those inadvertently drawn into the airlift from outside the sampling area.

- The area of the sampling unit (0.0625 m^2) was adequate in consideration of the sizes and densities of organisms present.

- The number of replicate samples collected (24 in each bay and period) was adequate to obtain a representative sample of the communities present. Species-area curves (cumulative numbers of species collected

- Our data overestimate benthic abundance and biomass to some extent because sampling was biased toward areas of higher faunal abundance (soft substrates) for practical reasons. However, the bias was consistent for all bays and periods, and does not affect conclusions about oil effects.

- A small amount of year-to-year variability in biomass data may have resulted from different lengths of time in formalin in different years.

- The use of differential specific gravity in sorting benthos from the sediment contained in samples increased accuracy and precision by eliminating human error.

- Year-to-year consistency in species identifications was ensured by the use in all years of permanent staff as taxonomists and as supervisors of temporary staff.

- Dry weights reported herein underestimate actual dry weight because of the use of alcohol as a preservative. Empirically derived correction factors were applied in cases where varying lengths of time in alcohol caused bias among years.

SUBTIDAL SEDIMENTS

Information on the nearshore geology of the study area was reported by McLaren et al. (1981). In this section, we briefly describe substrates in the study bays, and present sediment data based on samples taken in conjunction with airlift sampling on transects.

The two study bays were generally similar in substrate characteristics. The beaches and intertidal zones were composed of a gravel/cobble pavement overlying sand with scattered rocks and boulders. At depths of 1-2 m, a relatively flat, predominantly sand bottom occurred in each of the study bays, and between 2 and 3 m depths, a steep, rocky slope occurred in Bay 7. In both bays, the substrate on transects consisted of a mixture of silt, sand, gravel, and larger rocks. With increasing depth, an unconsolidated silt veneer overlying the substrate became more predominant, and sparsely distributed boulders occurred.

Grain-size data (Table 2) are expressed in logarithmic Φ units. Sand falls in the range of -1.0 Φ (2 mm) to 4.0 Φ (0.0605 mm), silt is in the range of 4.0 Φ to 9.0 Φ (0.002 mm), and clay is finer than 9.0 Φ. Gravel consists of particles greater than 2 mm across.

TABLE 2

Sediment characteristics at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during September 1980 (Bay 11) and August 1981 (Bay 7).

Variable	Bay 7 mean ± SD	Bay 11 mean ± SD
Mean grain size (Φ)	4.09 ± 0.68	3.76 ± 0.51
Sorting coefficient (Φ)	2.07 ± 0.28	3.18 ± 0.26
Gravel[a] (%)	66.96 ± 11.65	19.94 ± 11.05
Sand (%)	60.94 ± 13.19	65.56 ± 7.14
Silt (%)	32.14 ± 10.86	23.75 ± 4.60
Clay (%)	6.92 ± 3.19	10.67 ± 2.92
n	24	21

[a] Gravel is expressed as % of entire sample and ecluded from all other calculations.

There was little within-bay variability in mean grain size, sorting coefficient, and percent sand, silt, and clay (see Table 2). In general, sediments were similar in the two study bays. The greatest differences between the bays were in gravel content (much higher in Bay 7) and clay content (higher in Bay 11).

OIL CONCENTRATION AND COMPOSITION

Water Column

On 19 August 1981, 75 drums (15 m^3) of slightly aged Lagomedio crude oil were released on the surface in Bay 11. About half of this amount was recovered on the day following the release. During the 6 h release and during the 30 h monitoring period that followed, oil concentrations in the top metre of water were low (<3 ppm), and concentrations below a depth of 1 m were below the detection limit of 0.25 ppm (Green et al. 1982). When oil levels at 1 m depth in the water of Bay 11 were integrated over time, the total oil exposure was 1.2-2.1 ppm-h (Green et al. 1982).

On 27 August 1981, an additional 15 m^3 of aged Lagomedio crude oil mixed with 1.5 m^3 of Corexit 9527 dispersant and with seawater (5:1, water:oil) were introduced into another BIOS project study bay from a diffuser pipe that was about 1 m from the bottom and extended from the shore to a depth of 14 m. Near the diffuser pipe, concentrations in the water column were high (>50 ppm) following the release. Horizontal diffusion was rapid, and after four days the dispersed oil was found throughout Ragged Channel at concentrations of 30-50 ppb. Oil was still detectable in the water of the study bays (generally less than 5 ppb) more than two weeks after the dispersed oil release (Boehm et al. 1982, Tables 3.4 to 3.7).

Subtidal Sediments

During 1985, two types of sediment samples from 7 m depth in Bays 7 and 11 were analyzed for oil content and composition. Sediment samples (0-2 cm) were analyzed first, from the tissue plots from which animal samples were collected for tissue analysis, and secondly, from the transects on which benthic communities were sampled. Oil concentrations in sediment samples, determined by UV/F as Lagomedio oil equivalents, are summarized in Table 3.

During 1985, oil concentrations in Bay 11 sediments ranged from 6.4 to 45 $\mu g \cdot g^{-1}$, with a geometric mean and 95% confidence interval of 15 (13, 18) $\mu g \cdot g^{-1}$. During 1983, mean oil concentration at the 7 m depth in Bay 11 (Fig. 3) was 15 (12, 18) $\mu g \cdot g^{-1}$ (Boehm et al. 1984). In Bay 7 sediments, oil concentrations during August 1985 ranged from 2.8 to 7.6 $\mu g \cdot g^{-1}$, with a geometric mean and 95% confidence interval of 4.2 (3.6, 4.8) $\mu g \cdot g^{-1}$. During 1983, oil concentrations at 7 m depth in Bay 7 (Fig. 4) were 3.2 (1.1, 9.2) $\mu g \cdot g^{-1}$ (Boehm et al. 1984). Although hydrocarbons were still present in subtidal sediments four years after the oil release, the similarity between oil concentrations in 1983 and 1985 in both bays indicates that the oil content in sediments has stabilized (see Figs. 3 and 4).

TABLE 3

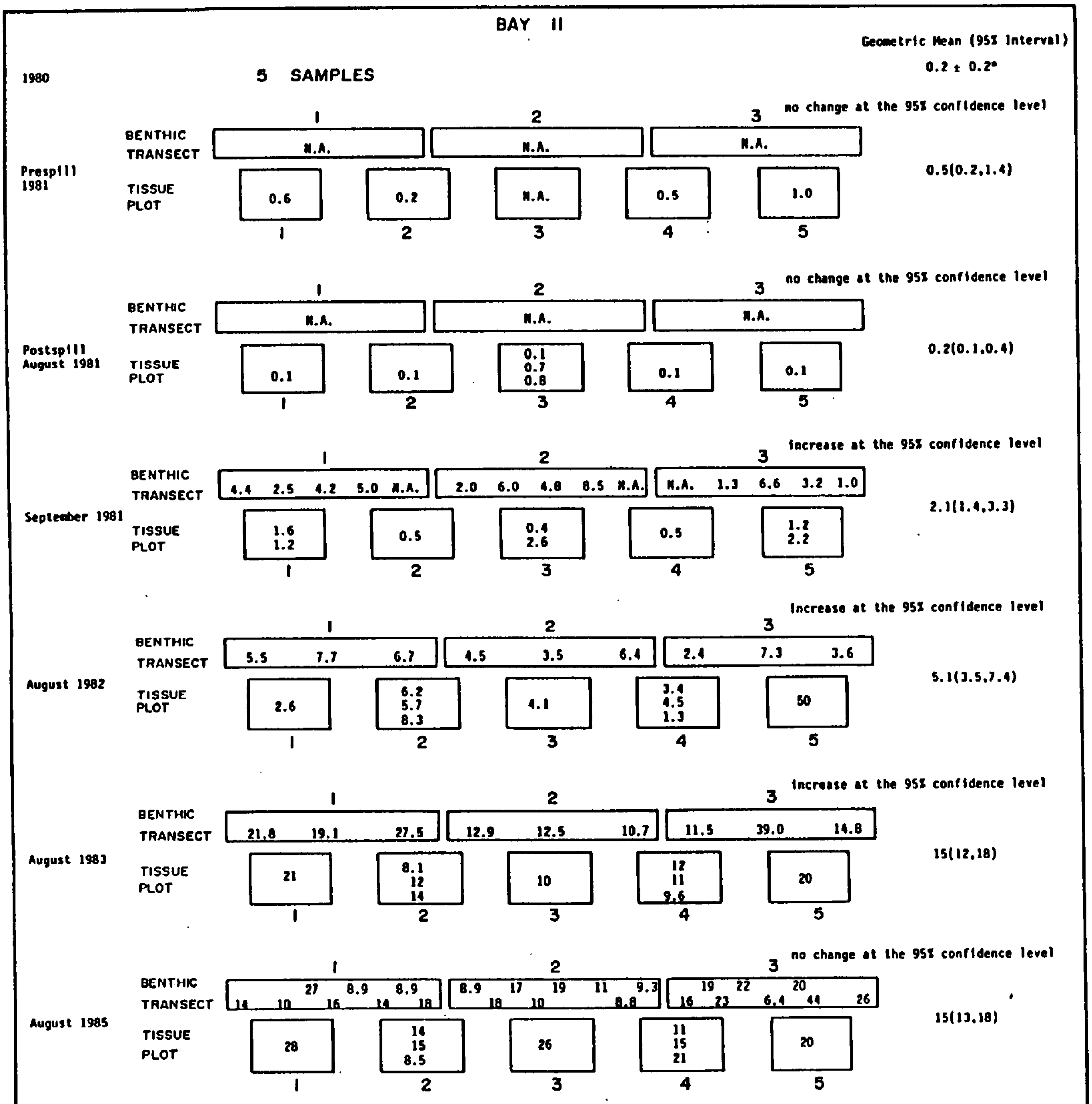
Oil concentrations in subtidal sediments at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1985.

		Oil concentration by UV/F (mg•kg^{-1}, dry)			
Bay	Location	Range	Geometric mean	95% confidence intervals	n
7	Tissue plot	2.8-5.3	4.9	(4.0, 6.1)	9
	Transect 1	3.2-5.9	4.1	(1.8, 9.1)	3
	Transect 2	4.1-5.9	4.7	(2.8, 7.7)	3
	Transect 3	5.4-7.6	6.3	(4.0, 9.7)	3
11	Tissue plot	8.5-28	16	(12, 22)	9
	Transect 1	8.9-27	14	(10, 19)	8
	Transect 2	8.8-19	12	(9, 16)	8
	Transect 3	6.4-45	20	(12, 31)	8

Six samples of subtidal sediments from each of Bays 7 and 11 were analyzed by gas chromatography to examine the composition of oil in each bay. The GC/FID trace of the saturated hydrocarbon fraction (f-1) of each sediment sample is shown in Figure 5. The traces of the Bay 11 samples show only a small envelope attributable to the unresolved complex mixture (UCM) characteristic of petrogenic hydrocarbons. The dominance of n-alkanes containing odd numbers of carbon atoms over those containing even numbers of carbon atoms indicates a biogenic origin for this material. No UCM envelope is evident in the traces of the Bay 7 samples, and the dominance of odd numbered n-alkanes is again evident.

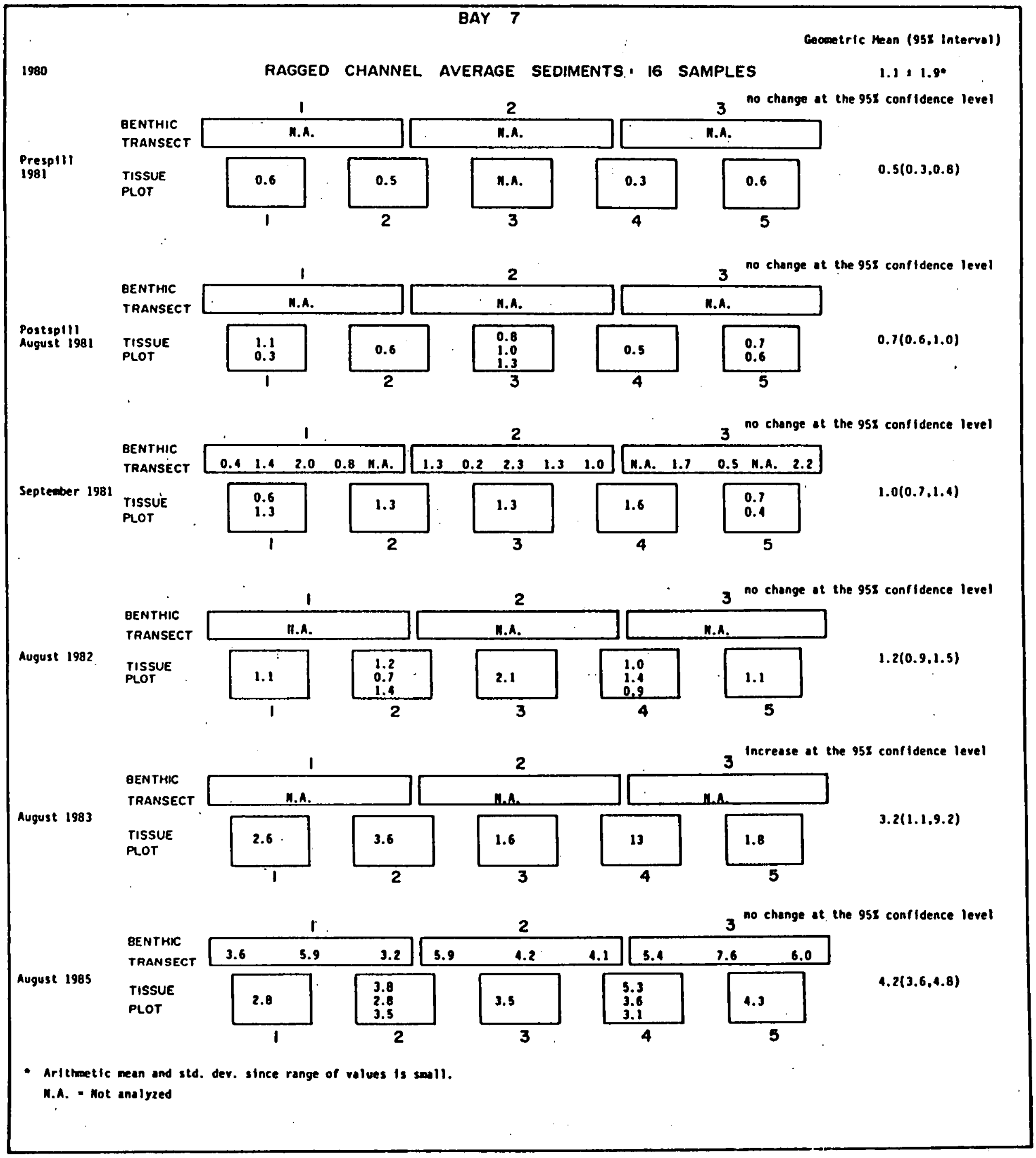
Concentrations of selected alkanes in each of the 12 sediment samples (as determined by GC/FID), together with several diagnostic indices calculated from those data, are given in Table 4. The small values of the saturated hydrocarbon weathering ratio in both bays (SHWR ranging from 1.0 to 1.3) suggest highly weathered oil. The large values of the pristane/phytane ratio (11-42 in Bay 7; 1.5-18 in Bay 11) suggest a dominant biogenic source for the saturated hydrocarbons. All values of this ratio in Bay 7, and all but one value in Bay 11 (1.5), are typical of background levels (Boehm 1981); the low value in Bay 11 occurred in a sample from the southernmost transect, where highest oil concentrations were found (see Fig. 3).

GC/FID traces of the aromatic fraction (f-2) of two sediment samples from each of Bays 7 and 11 are shown in Figure 6. These traces illustrate the complex nature of the mixture of aromatics, and qualitatively demonstrate the dominance of the less degradable 4-ring and 5-ring components.



* Arithmetic mean and std. dev. since range of values is small.
N.A. = Not analyzed

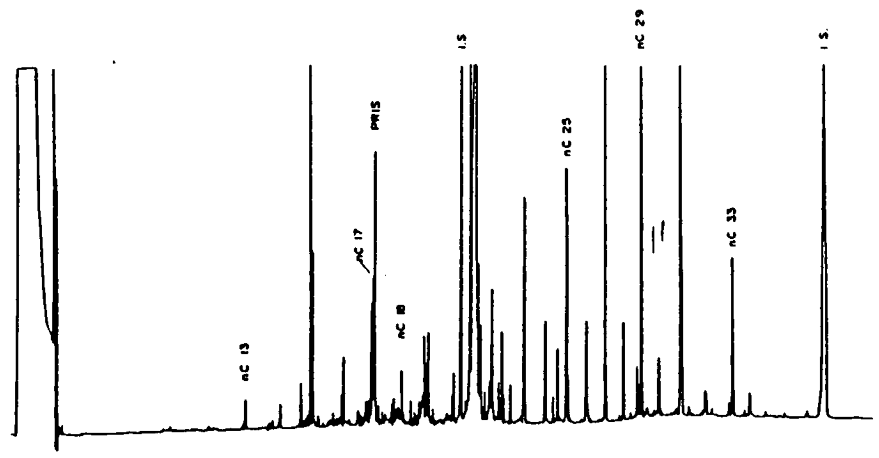
Figure 3. Oil concentrations (by UV/F) in sediment at 7 m depth in an oiled bay at Cape Hatt, northern Baffin Island, during August and September 1981, and August 1982, 1983, and 1985.



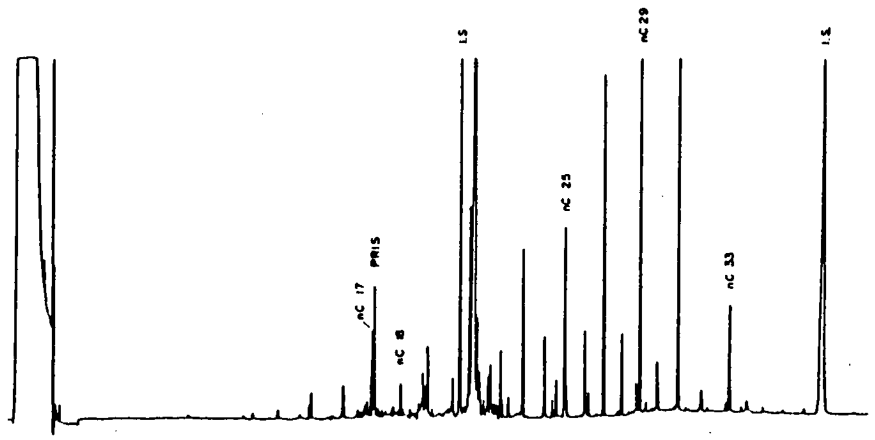
* Arithmetic mean and std. dev. since range of values is small.

N.A. = Not analyzed

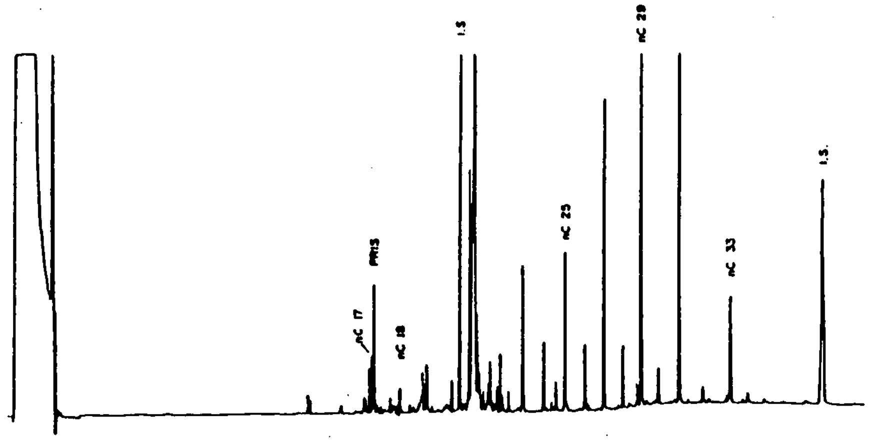
Figure 4. Oil concentrations (by UV/F) in sediment at 7 m depth in a reference bay at Cape Hatt, northern Baffin Island, during August and September 1981, and August 1982, 1983, and 1985.



5242: Bay 7, T1-1

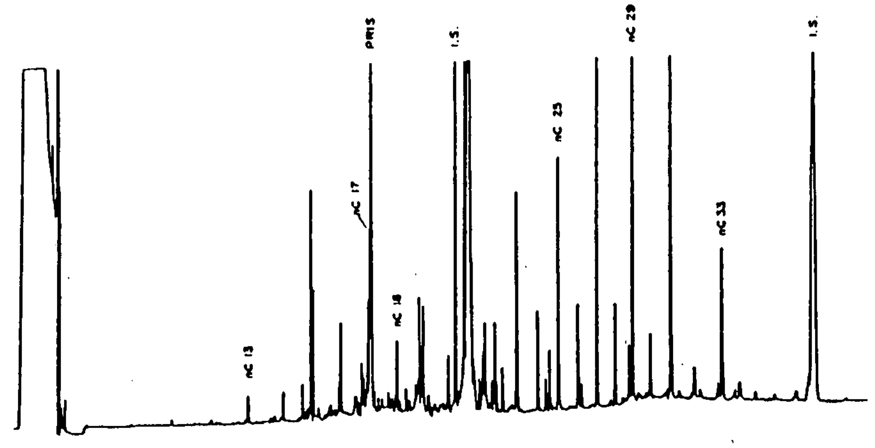


5245: Bay 7, T2-3

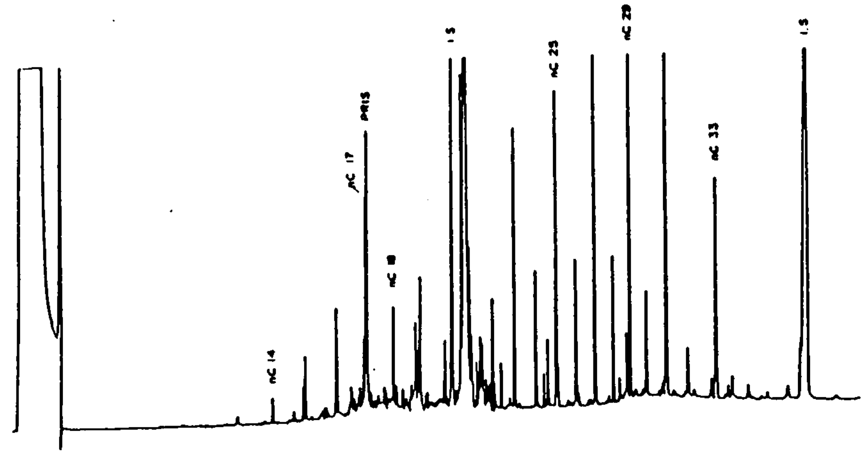


5250: Bay 7, T5-1

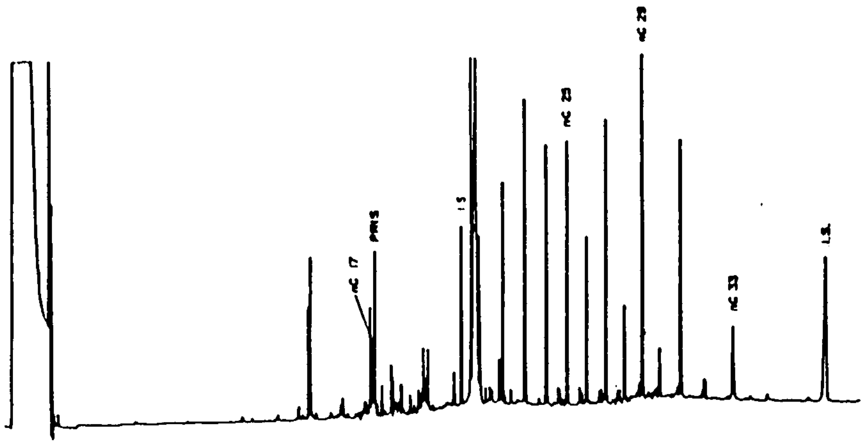
Figure 5. Gas chromatography/flame ionization detection (GC/FID) traces of the saturated hydrocarbon fraction of six sediment samples from 7 m depth in each of two bays at Cape Hatt, northern Baffin Island, during August 1985.



5234: Bay 7, B1-2

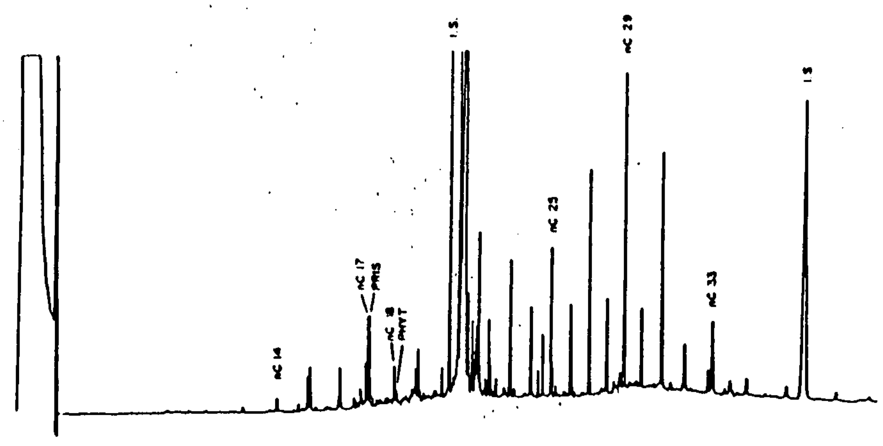


5237: Bay 7, B2-2

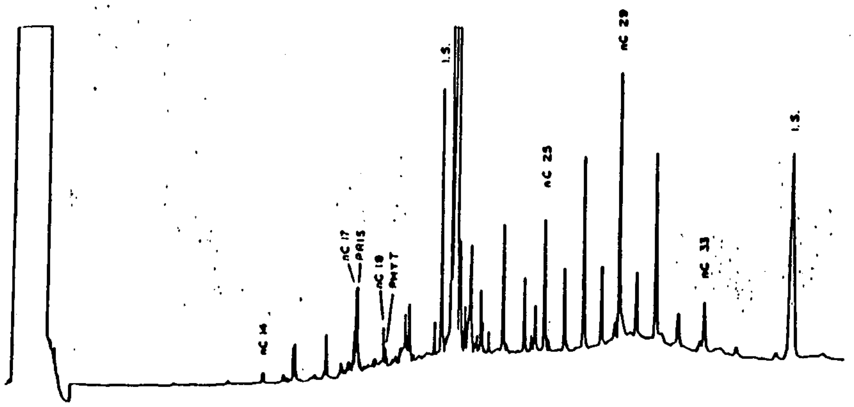


5241: Bay 7, B3-3

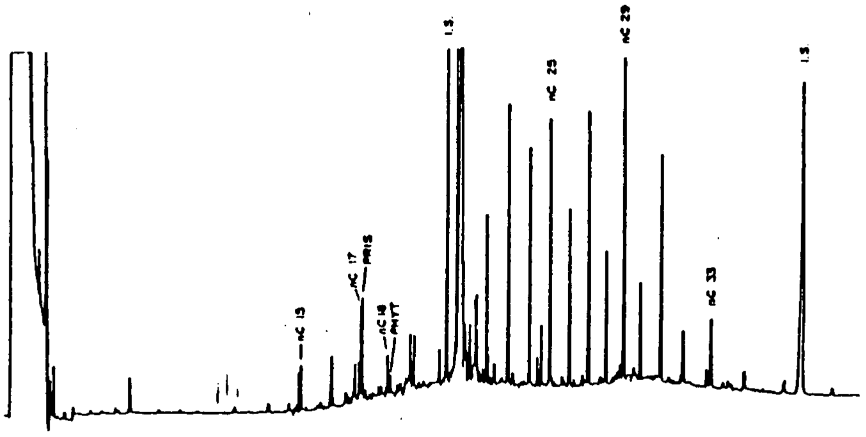
Figure 5. Continued.



5208: Bay 11, T2-3

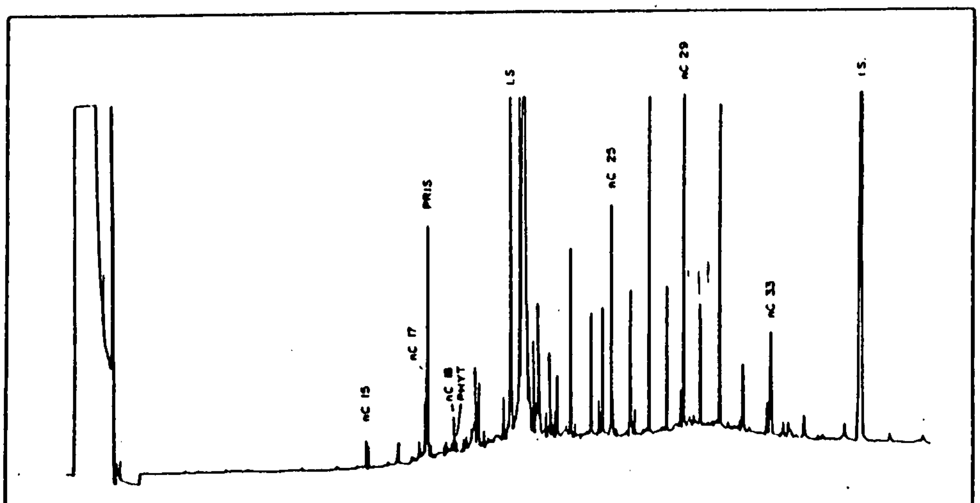


5209: Bay 11, T3-1

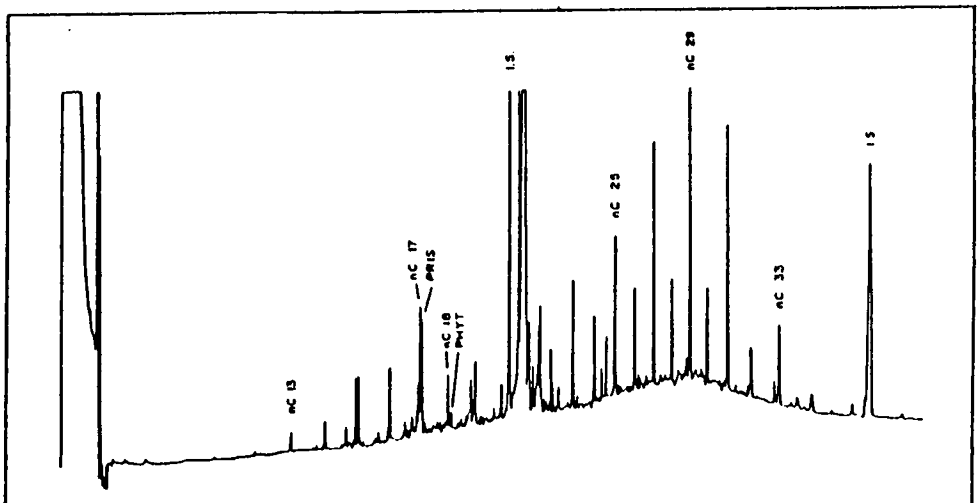


5212: Bay 11, T4-2

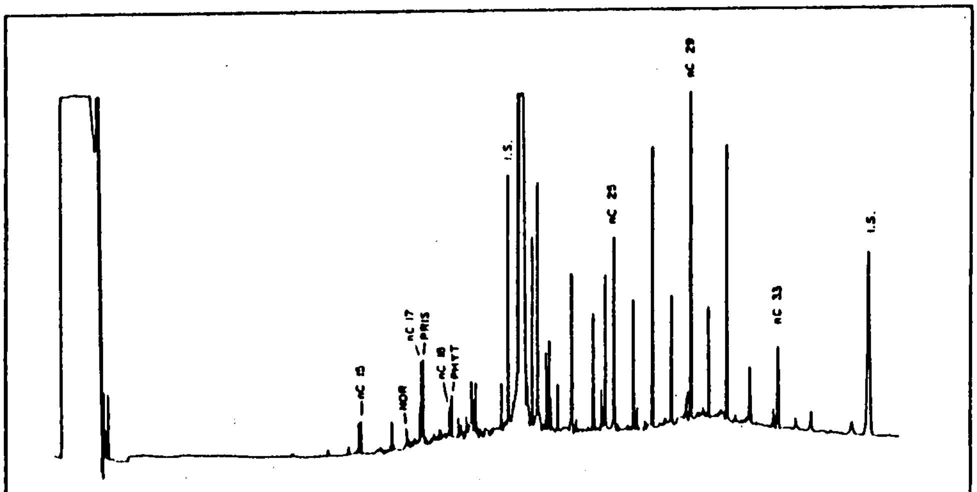
Figure 5. Continued.



5186: Bay 11, B-1, 28m



5067: Bay 11, B-2, 83m



5072: Bay 11, B-3, 122m

Figure 5. Concluded.

TABLE 4

Alkane concentrations and weathering indices (by GC/FID)[a] for sediment samples from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1985.

		Bay 7						Bay 11					
		Tissue plot			Transect			Tissue plot			Transect		
Compound, and Weathering Index[b]		1	2	5	1	2	3	2	3	4	1	2	3
Alkanes	nC12	<1	<1	<2	<1	<0.5	<5	<1	<1	<1	<1	<1	<2
($ng \cdot g^{-1}$, dry)	nC13	5	<1	<2	3	0.6	<5	<1	<1	1	<1	4	<2
	nC14	4	1	<2	3	2	5	3	3	2	<1	6	<2
	nC15	32	2	4	19	6	130	7	8	8	3	14	10
	nC16	11	5	3	10	9	11	7	9	10	3	14	8
	nC17	29	16	18	30	25	71	20	23	23	17	35	34
	nC18	9	6	7	9	10	27	8	11	10	7	13	15
	nC19	16	13	16	14	14	64	11	16	14	12	17	20
	nC20	9	7	10	8	7	19	8	5	4	9	11	21
	nC21	32	21	37	23	15	160	22	29	34	42	23	53
	nC22	17	14	21	14	13	240	20	21	54	19	20	41
	nC23	43	36	51	18	44	370	37	53	99	51	49	85
	nC24	26	20	30	9	23	320	29	33	87	37	32	64
	nC25	66	47	71	54	53	340	54	65	98	68	60	110
	nC26	30	25	34	25	28	230	36	44	74	50	46	88
	nC27	140	98	160	110	110	390	85	103	110	120	98	180
	nC28	29	24	34	26	28	150	37	46	58	51	41	83
	nC29	240	160	280	200	200	540	140	160	150	180	150	270
	nC30	23	20	26	22	25	88	42	50	52	57	50	92
	nC31	250	170	290	210	220	530	150	180	140	180	160	280
	nC32	13	11	13	13	15	44	41	37	42	52	40	68
	nC33	100	69	120	82	94	220	66	69	68	83	77	130
	nC34	3	3	<3	4	5	16	16	14	19	18	16	30
	nC35	<2	<2	<3	<2	<1	<10	<3	<3	<4	<2	<5	<5
	nC36	<2	<2	<3	<2	<1	<10	<3	<3	<4	<2	<5	<5
Total n-alkanes		1100	770	1200	910	950	4000	820	980	1200	1100	970	1700
	FARN	<1	<1	<2	<1	<0.5	<5	<1	<1	<1	<1	<2	<2
	TM13	<1	<1	<2	<1	<0.5	<5	<1	<1	<1	<1	<2	<2
	NORP	<1	1	<2	<1	5	<5	2	<1	6	<1	7	13
	PRIS	51	24	41	91	32	170	20	22	25	48	30	34
	PHYT	2	1	<2	2	3	<5	3	5	5	3	5	23
Weathering indices	SHWR	1.2	1.1	1.3	1.2	1.1	1.1	1.1	1.1	1.1	1.0	1.1	1.0
	ALK/ISO	1.6	1.1	0.8	0.8	1.3	1.4	1.8	2.0	1.5	0.6	1.9	1.0
	C18/Phyt	4.7	4.3	>3.8	4.2	3.3	>5.4	2.5	2.3	1.9	2.5	2.7	0.7
	Pris/Phyt	28	17	>23	42	11	>35	6.5	4.5	4.9	18	6.4	1.5
	CPI	9.1	7.5	9.4	8.5	7.8	4.0	3.9	3.7	2.9	3.8	3.6	3.4

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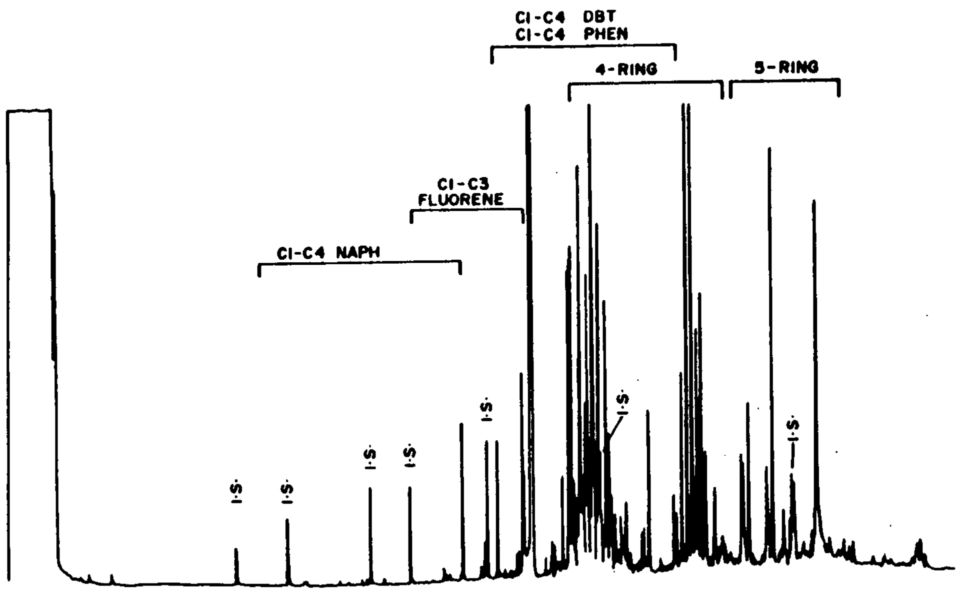
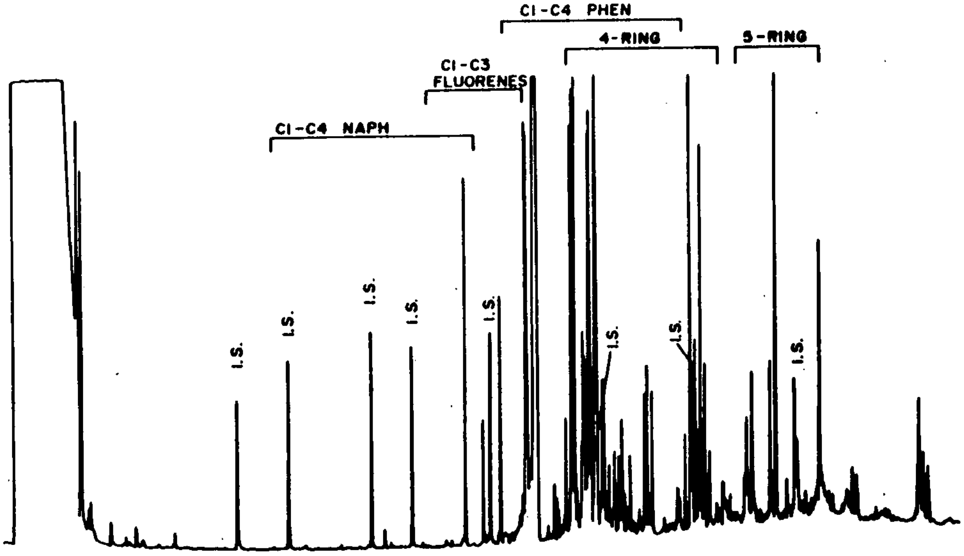
[a] Gas Chromatography/Flame Ionization Detection.

[b] See Appendix A for explanation of abbreviations and methods of calculation.

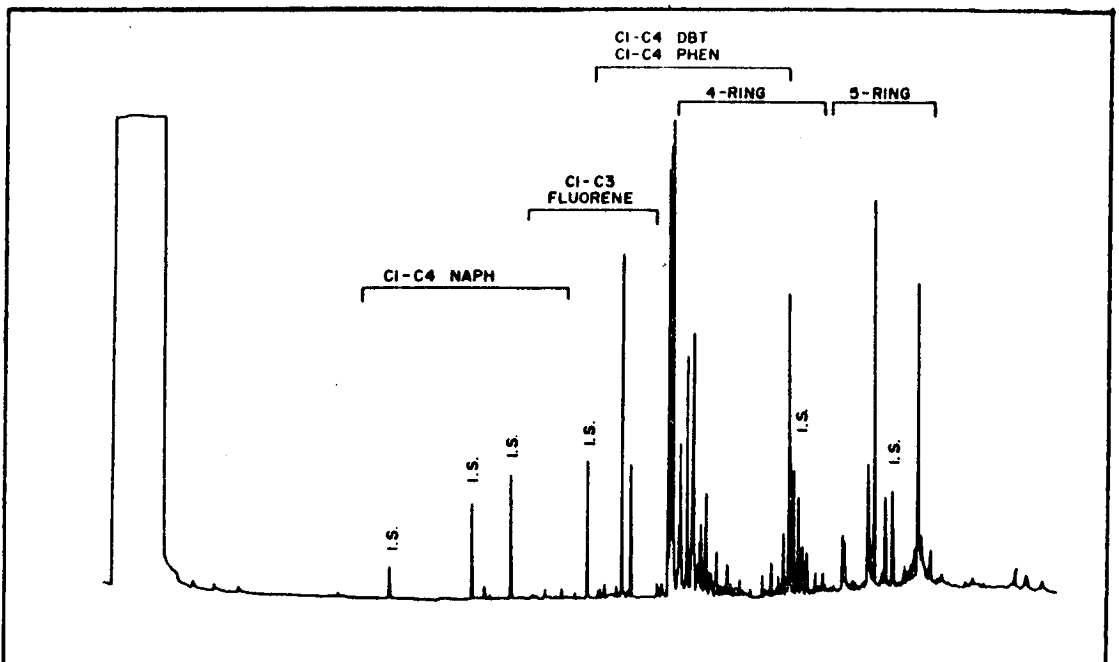


5072: Bay 11, B-3, 122m

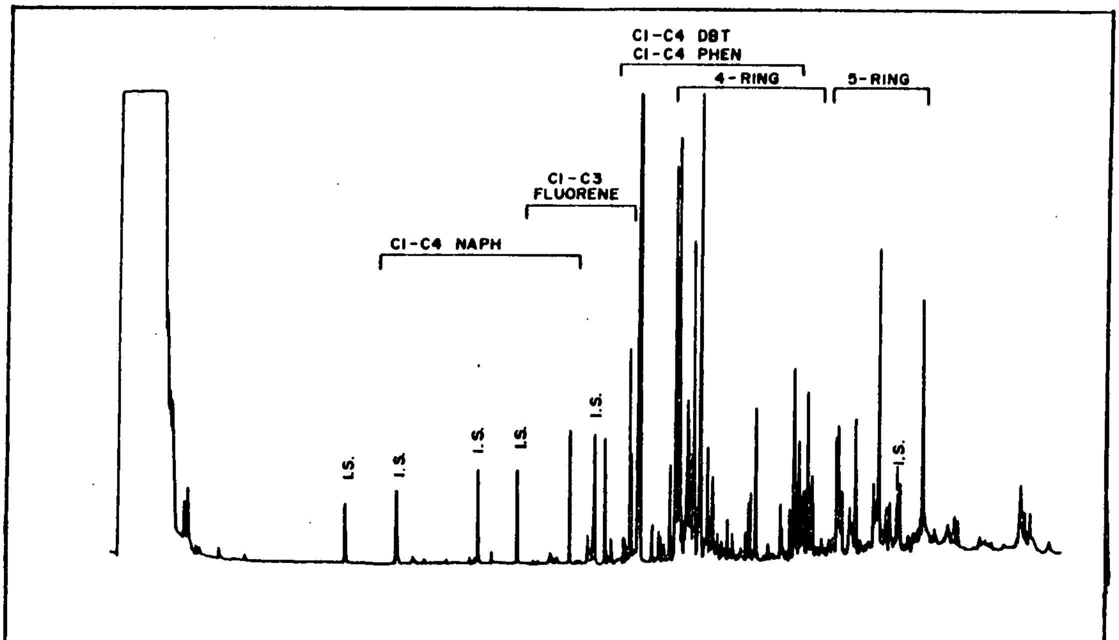


5212: Bay 11, T4-3

Figure 6. Gas chromatography/flame ionization detection (GC/FID) traces of the aromatic hydrocarbon fraction of two sediment samples from 7 m depth in each of two bays at Cape Hatt, northern Baffin Island, during August 1985.



5237: Bay 7, B2-2



5242: Bay 7, T1-1

Figure 6. Concluded.

Quantitative analysis of the aromatic fraction was not attempted by GC/FID, but was carried out by gas chromatography/mass spectrometry (GC/MS). The aromatic fraction (f-2) of each of the 12 sediment samples selected for gas chromatographic analysis was analyzed by GC/MS using the selected ion monitoring (SIM) technique. SIM plots of the f-2 fraction of each sediment sample are shown in Figure 7. The concentrations of selected aromatic components determined from GC/MS analyses are presented in Table 5, together with an aromatic weathering ratio (AWR) calculated from those data. The small values of the AWR (ranging from 1.3 to 2.4) in the samples from both bays also indicates the presence of weathered oil.

Gas chromatograms and mass spectra of hydrocarbons in subtidal sediments at Cape Hatt generally indicate further weathering since 1983. The phytane concentrations, the pristane/phystane ratio, and the carbon preference index (CPI) all indicate that the observed hydrocarbons are becoming less distinguishable from naturally occurring hydrocarbons. A comparison of the GC/FID, GC/MS, and UV/F data indicates that the UV/F method is not measuring the same compounds as are the GC methods. Subjectively, few if any of the GC data indicate the presence of Lagomedio crude oil. The UV/F data, however, indicate that the general aromatic composition of the remaining hydrocarbons is not very different from the original oil. This result is likely because of the retention of the basic ring structures in the remaining material, although the hydrocarbons have been modified, or only substituted aromatics have remained.

Benthos

Samples of *Serripes groenlandicus*, *Macoma calcarea*, and *Strongylocentrotus droebachiensis* from each of the 7-m tissue plots in Bays 11 and 7 were analyzed for oil content. Oil concentrations in the three species, determined by UV/F as Lagomedio oil equivalents, are presented in Table 6.

UV/F data indicate the presence of low levels of oil remaining in most tissue samples during 1985. In each of the three species, oil concentrations in tissues were higher in Bay 11 than in Bay 7 (see Table 6). The mean oil concentration in Bay 11 *Serripes groenlandicus* tissue was significantly higher in 1985 than in 1983 (Fig. 8), whereas oil concentrations in *Macoma calcarea* and *Strongylocentrotus droebachiensis* tissue were not significantly different in 1983 and 1985 (Figs. 9 and 10). In Bay 7, mean oil concentrations in *Macoma calcarea* and *Strongylocentrotus droebachiensis* tissues were significantly higher in 1985 than in 1983 (Figs. 11 and 12), whereas the mean concentration of oil in Bay 7 *Serripes groenlandicus* tissue was not significantly different in 1983 and 1985 (Fig. 13). In both years, oil concentrations in *S. groenlandicus* from Bay 7 were near background levels.

After UV/F analysis, tissue extracts were combined to produce composite samples for gas chromatographic analysis. GC/FID traces of the saturated hydrocarbon fraction (f-1) of the composite samples are shown in Figure 14. A small envelope attributable to the unresolved complex mixture (UCM) characteristic of petrogenic hydrocarbons is evident in the Bay 7 and Bay 11 *Macoma calcarea* samples, and a larger UCM is evident in the Bay 11 *Strongylocentrotus droebachiensis* sample. Concentrations of selected alkanes

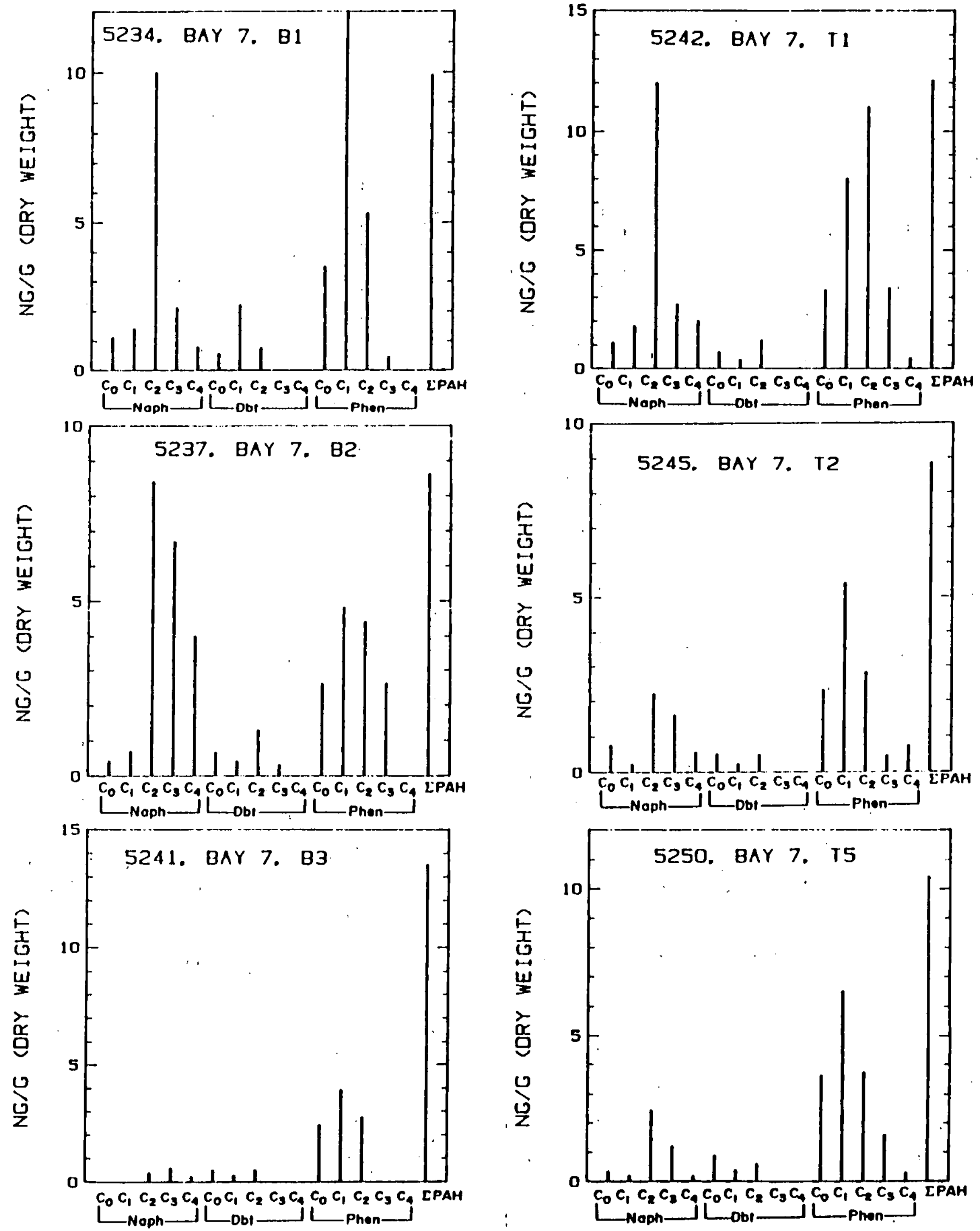


Figure 7. Selected ion monitoring (SIM) plots for gas chromatography/ mass spectrometry (GC/MS) analysis of the aromatic hydrocarbon fraction of six sediment samples from 7 m depth in each of two bays at Cape Hatt, northern Baffin Island, during August 1985.

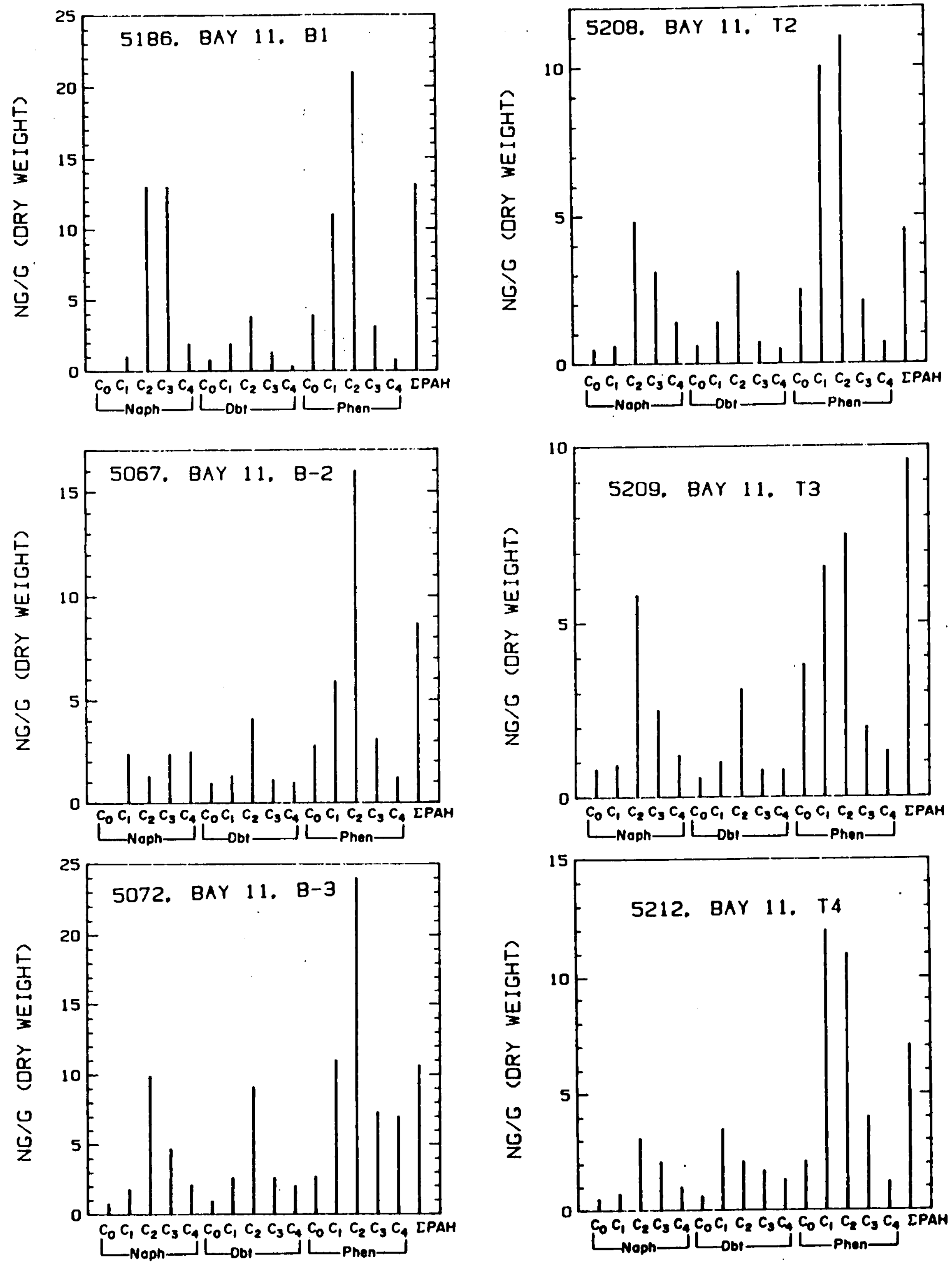


Figure 7. Concluded.

TABLE 5

Polycyclic aromatic hydrocarbon (PAH) concentrations (by GC/MS)[a] in sediment samples from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1985.

		Bay 7						Bay 11					
		Tissue plot			Transect			Tissue plot			Transect		
Compound, and Weathering Index[b]		1	2	5	1	2	3	2	3	4	1	2	3
Benzene	C-3	<0.03	<0.02	<0.05	<0.02	<0.15	-	<0.01	<0.01	<0.01	<1	-	<0.01
	C-4	0.45	<0.02	0.15	0.44	<0.15	-	0.13	0.32	0.16	<1	-	0.11
	C-5	<0.03	<0.02	<0.05	<0.02	<0.15	-	<0.01	<0.01	<0.01	<1	-	<0.01
	C-6	<0.03	<0.02	<0.05	<0.02	<0.15	-	<0.01	<0.01	<0.01	<1	-	<0.01
Naphthalene	C-0	1.1	0.75	0.32	1.1	0.42	-	0.49	0.79	0.49	<1	-	0.76
	C-1	1.8	0.22	0.20	1.4	0.70	-	0.61	0.91	0.70	1.0	2.4	1.8
	C-2	12	2.2	2.4	10	8.4	0.37	4.8	5.8	3.1	13	1.3	9.9
	C-3	2.7	1.6	1.2	2.1	6.7	0.56	3.1	2.5	2.1	13	2.4	4.7
	C-4	2.0	0.55	0.19	0.78	4.0	2.1	1.4	1.2	0.98	1.9	2.5	2.1
Fluorene	C-0	0.70	0.22	0.25	0.55	0.49	0.43	0.64	0.55	0.42	0.60	0.70	0.66
	C-1	2.2	1.4	1.8	0.68	2.6	1.1	1.0	0.81	0.70	1.0	1.4	0.93
	C-2	0.90	0.62	0.72	0.48	0.74	0.70	1.2	0.93	0.39	1.2	1.1	1.2
	C-3	0.78	<0.05	<0.10	1.2	<0.05	<0.05	0.57	0.50	0.98	0.94	0.99	1.1
Dibenzothiophene	C-0	0.70	0.51	0.88	0.57	0.67	0.47	0.61	0.55	0.60	0.76	0.94	0.93
	C-1	0.35	0.22	0.37	2.2	0.42	0.26	1.4	1.0	3.5	1.9	1.3	2.6
	C-2	1.2	0.48	0.58	0.75	1.3	0.46	3.1	3.1	2.1	3.8	4.1	9.1
	C-3	<0.02	<0.02	<0.04	<0.02	0.31	<0.01	0.72	0.76	1.7	1.3	1.1	2.6
	C-4	<0.02	<0.02	<0.04	<0.02	<0.02	<0.01	0.49	0.76	1.3	0.30	0.97	2.0
Phen/Anthracene	C-0	3.3	2.3	3.6	3.5	2.6	2.4	2.5	3.8	2.1	3.9	2.8	2.7
	C-1	8.0	5.4	6.5	14	4.8	3.9	10	6.6	12	11	5.9	11
	C-2	11	2.8	3.7	5.3	4.4	2.7	11	7.5	11	21	16	24
	C-3	3.4	0.45	1.6	0.44	2.6	<0.08	2.1	2.0	4.0	3.1	3.1	7.3
	C-4	0.41	0.72	0.28	<0.04	<0.03	<0.08	0.69	1.3	1.2	0.78	1.2	7.0
Fluoranthene		0.57	0.34	0.37	0.44	0.49	0.44	0.38	0.32	0.35	0.68	0.38	0.43
Pyrene		0.61	0.58	0.92	1.1	0.88	0.89	0.87	0.81	0.74	1.2	0.79	0.93
Benz(a)anthracene		0.29	0.48	0.28	0.30	0.30	1.6	0.28	0.18	0.22	0.74	0.38	0.43
Chrysene		2.6	1.7	2.4	2.4	1.8	2.6	2.1	1.8	1.4	2.6	2.2	2.5
Benzo(e)pyrene		1.4	1.2	1.3	0.95	1.0	1.8	0.72	1.0	0.67	1.1	0.84	1.1
Benzo(a)pyrene		0.32	0.55	0.25	0.26	0.34	2.2	0.14	0.20	0.16	0.38	0.29	0.24
Perylene		6.3	4.0	4.9	4.9	3.8	4.0	0.32	5.3	3.5	6.4	3.8	5.0
Total PAH		58	30	41	61	50	29	60	61	72	94	59	100
Aromatic weathering ratio AWR		1.8	1.7	1.4	1.7	2.4	1.5	1.5	1.5	2.1	1.7	1.3	1.4

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[a] Gas Chromatography/Mass Spectrometry.

[b] All units are $ng \cdot g^{-1}$ (dry sediment basis), except for AWR; see Appendix A for methods of calculation.

- Indicates not quantifiable.

TABLE 6

Oil concentrations in tissue of three species of benthos from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1985.

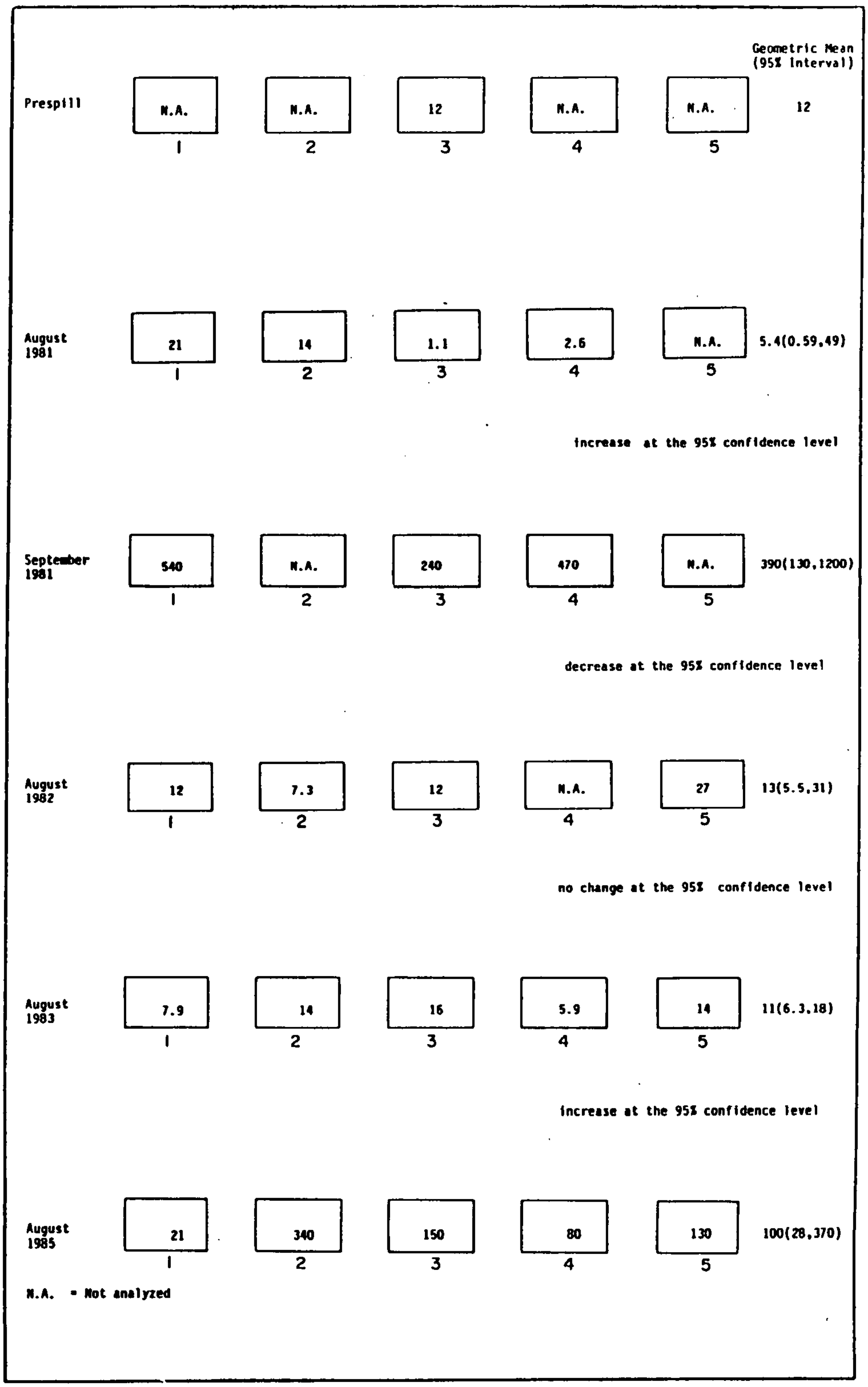
		Oil concentration by UV/F (mg•kg^{-1}, dry)			
Species	Bay	Range	Geometric mean	95% confidence intervals	n
Serripes groenlandicus	7	4.0-11	6.3	(3.6, 11)	5
	11	21-340	100	(28, 370)	5
Macoma calcarea	7	2.7-120	65	(30, 140)	5
	11	65-160	100	(67, 150)	5
Strongylocentrotus droebachiensis	7	38-340	77	(26, 230)	5
	11	99-790	220	(83, 590)	5

in each of the composite tissue samples (determined by GC/FID) are given in Table 7, together with several diagnostic indices calculated from those data. The small values of the saturated hydrocarbon weathering ratio in both bays (SHWR ranging from 1.1 to 2.3) are indicative of highly weathered oil, whereas the large value for the pristane/phytane ratio (ranging from 4.8 to 68 for Bay 11 tissues, and from 32 to 560 for Bay 7 tissues) suggests a dominant biogenic source for the saturated hydrocarbons, particularly for the Bay 7 samples.

GC/FID traces of the aromatic fraction (f-2) of two Bay 11 composite tissue extracts are shown in Figure 15. These traces illustrate the complex nature of the aromatic mixture and qualitatively demonstrate the dominance of the less degradable 4-ring and 5-ring components.

Quantitative analysis of the aromatic fraction was not attempted by GC/FID, but was carried out by GC/MS. The aromatic fraction (f-2) of each of the composite tissue extracts was analyzed by GC/MS using the selected ion monitoring (SIM) technique. SIM plots of the f-2 fraction of each sample are shown in Figure 16. Concentrations of selected aromatic components determined from GC/MS analyses are presented in Table 8, together with an aromatic weathering ratio (AWR) calculated from those data. The small values of the AWR (ranging from 1.1 to 2.2) in the samples is also indicative of the presence of weathered oil.

Thus, oil concentrations in the various environmental compartments of Bay 11 appear to have stabilized (Fig. 17). After an acute increase following the oil releases in 1981, the oil content of the tissues decreased by 1982 and, with the exception of *Serripes groenlandicus*, has remained about the same since. This implies that any input from the beach in Bay 11 is balanced by a loss from the bay. *Serripes groenlandicus*, the only species to



	1	2	3	4	5	Geometric Mean (95% Interval)
Prespill	N.A.	N.A.	12	N.A.	N.A.	12
August 1981	21	14	1.1	2.6	N.A.	5.4(0.59,49)
September 1981	540	N.A.	240	470	N.A.	390(130,1200)
August 1982	12	7.3	12	N.A.	27	13(5.5,31)
August 1983	7.9	14	16	5.9	14	11(6.3,18)
August 1985	21	340	150	80	130	100(28,370)

August 1981 to September 1981: increase at the 95% confidence level

September 1981 to August 1982: decrease at the 95% confidence level

August 1982 to August 1983: no change at the 95% confidence level

August 1983 to August 1985: increase at the 95% confidence level

N.A. = Not analyzed

Figure 8. Oil concentrations (by UV/F) in tissue of the bivalve Serripes groenlandicus from five plots at 7 m depth in an oiled bay at Cape Hatt, northern Baffin Island, during August and September 1981, and August 1982, 1983, and 1985.

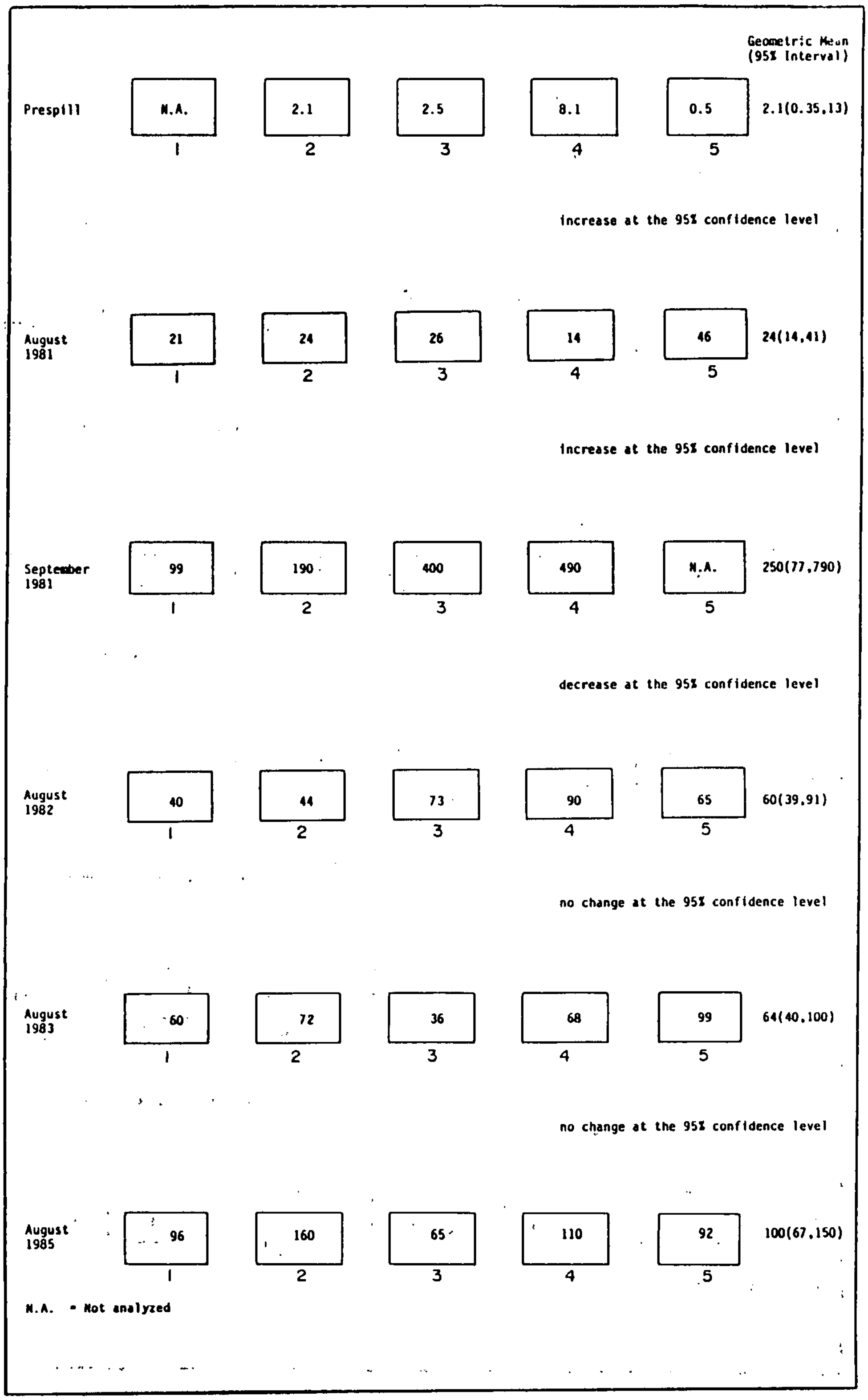


Figure 9. Oil concentrations (by UV/F) in tissue of the bivalve Macoma calcarea from five plots at 7 m depth in an oiled bay at Cape Hatt, northern Baffin Island, during August and September 1981, and August 1982, 1983, and 1985.

	1	2	3	4	5	Geometric Mean (95% Interval)
Prespill	8.8	8.8	9.1	38	12	13(5.7,28)
				increase at the 95% confidence level		
August 1981	600	20	24	330	31	78(11,580)[a]
				no change at the 95% confidence level		
September 1981	2500	190	170	490	370	430(110,1600)[a]
				no change at the 95% confidence level		
May 1982	260	N.A.	N.A.	N.A.	120	180
				decrease at the 95% confidence level		
August 1982	92	38	33	42	42	46(28,76)[a]
				no change at the 95% confidence level		
September 1982	48	48	58	80	130	67(40,110)[a]
				no change at the 95% confidence level		
August 1983	160	200	67	110	48	100(49,214)
				no change at the 95% confidence level		
August 1985	210	230	99	790	140	220(83,590)

N.A. = Not analyzed

Figure 10. Oil concentrations (by UV/F) in tissue of the sea urchin <u>Strongylocentrotus droebachiensis</u> from five plots at 7 m depth in an oiled bay at Cape Hatt, northern Baffin Island, during August 1981-August 1985.

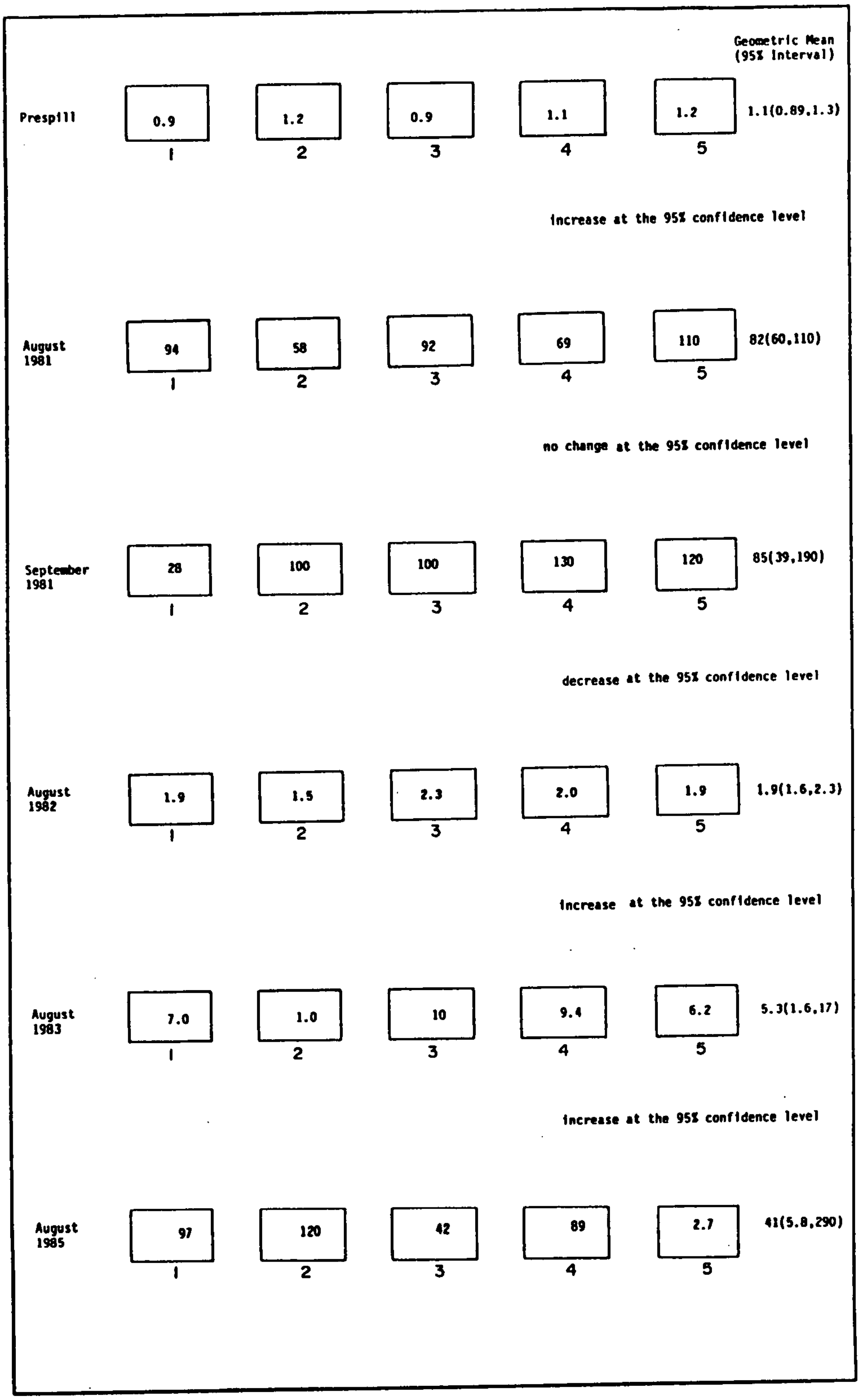


Figure 11. Oil concentrations (by UV/F) in tissue of the bivalve *Macoma calcarea* from five plots at 7 m depth in a reference bay at Cape Hatt, northern Baffin Island, during August and September 1981, and August 1982, 1983, and 1985.

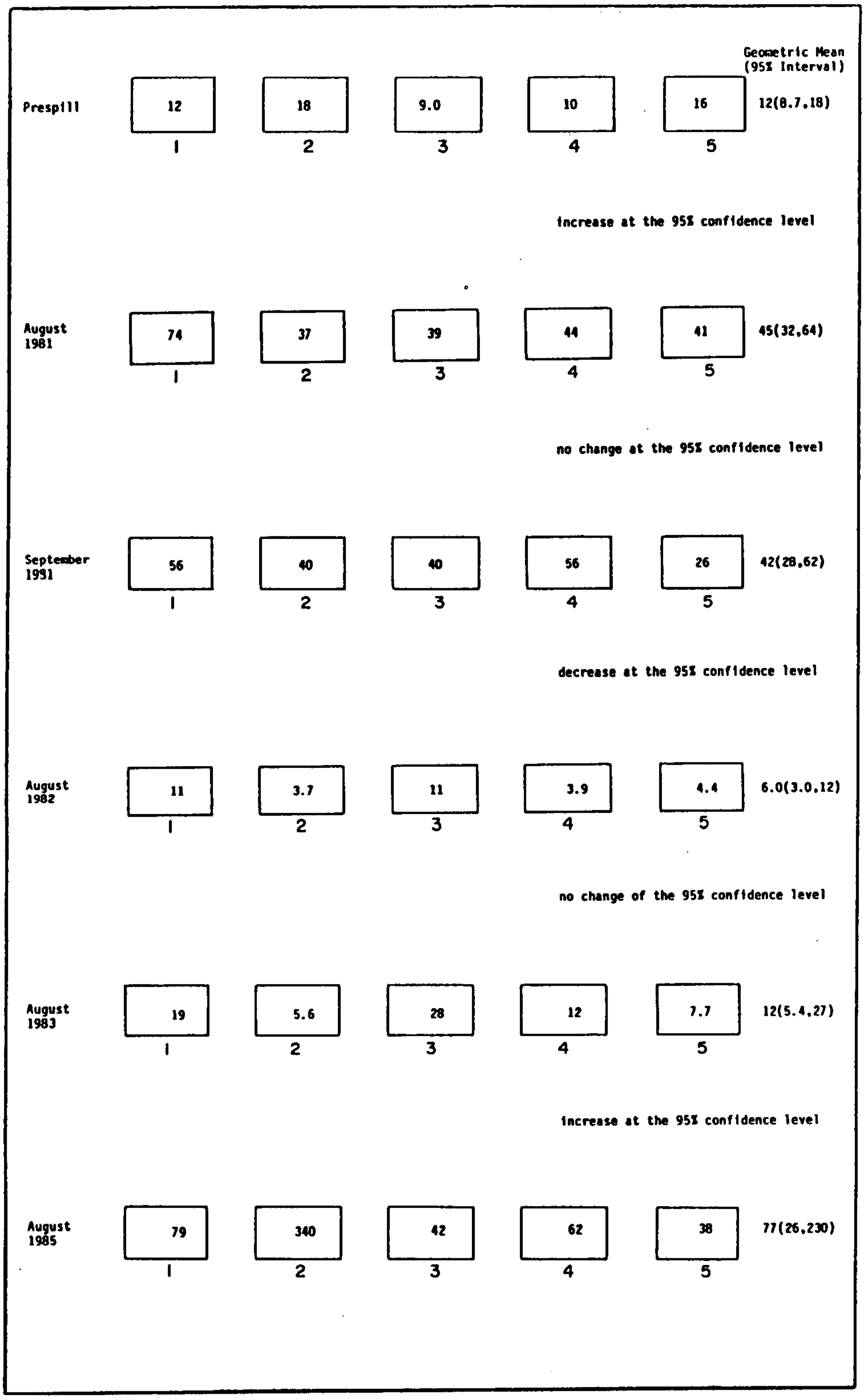


Figure 12. Oil concentrations (by UV/F) in tissue of the sea urchin Strongylocentrotus droebachiensis from five plots at 7 m depth in a reference bay at Cape Hatt, northern Baffin Island, during August 1981-August 1985.

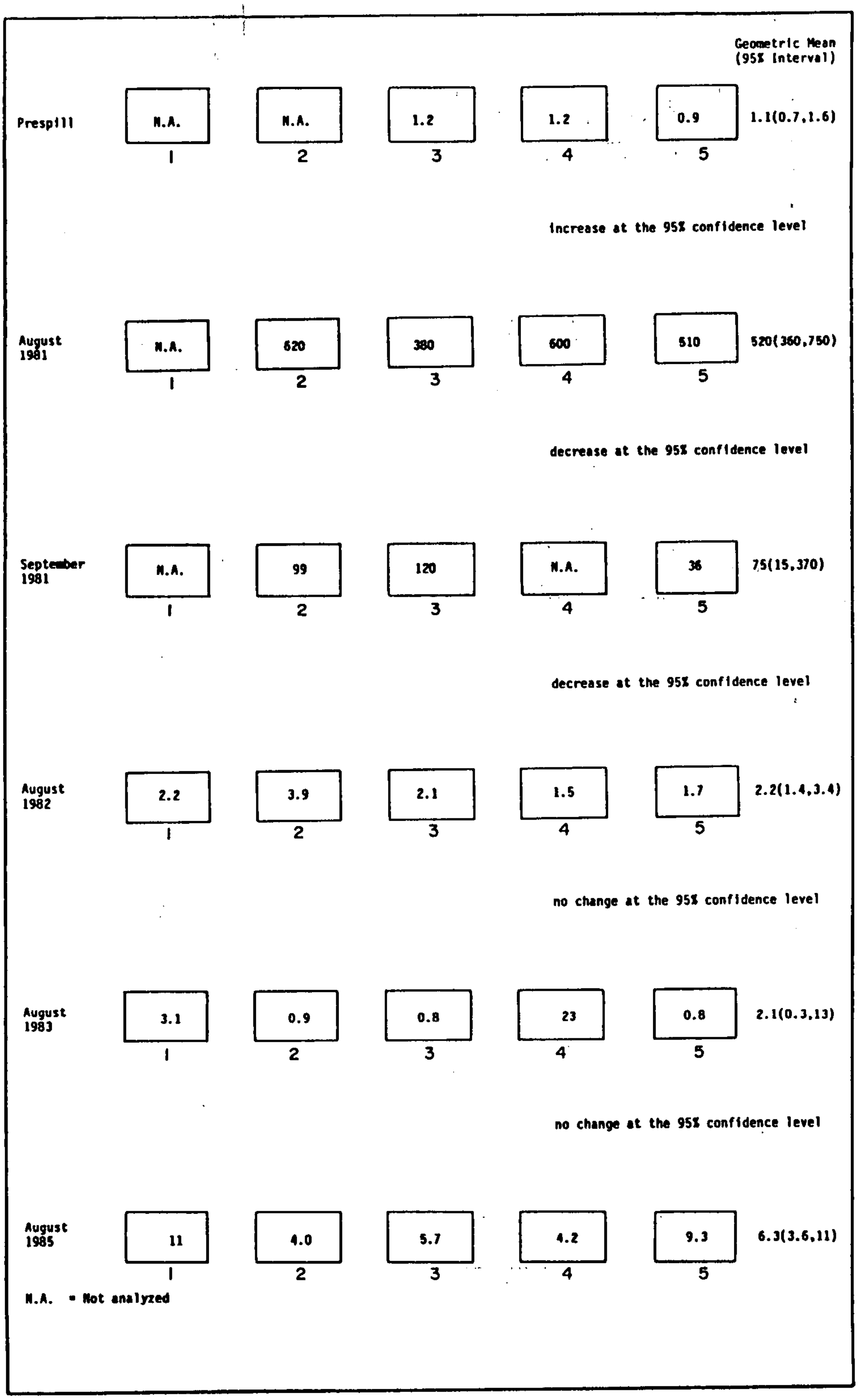
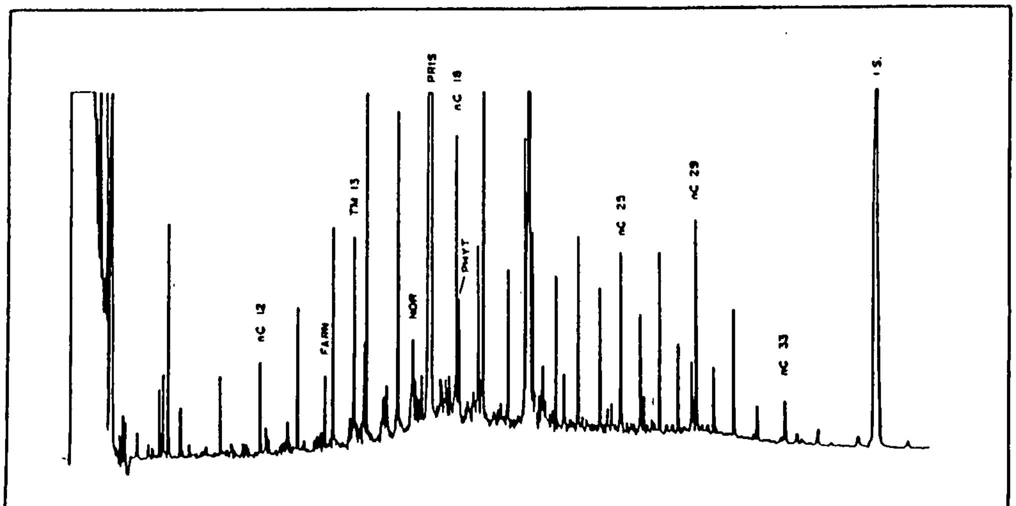
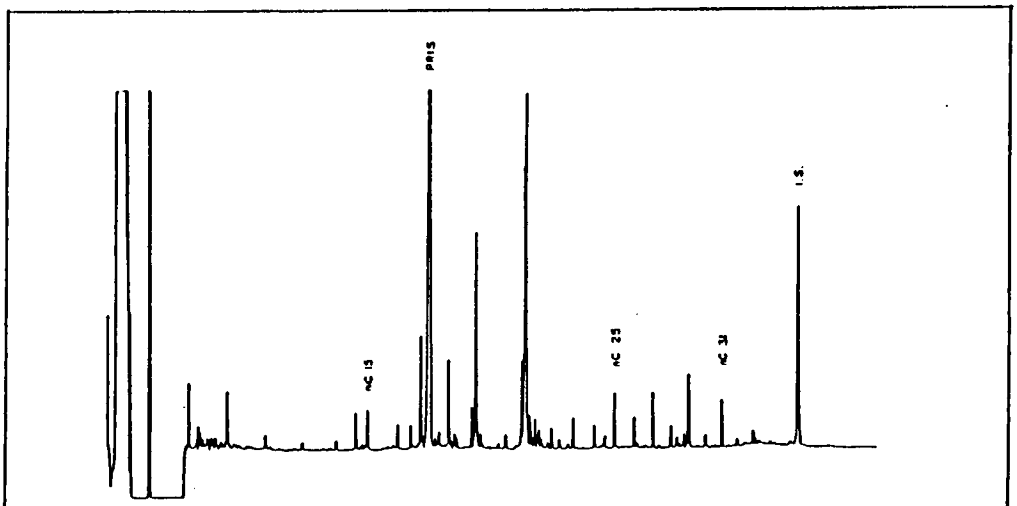


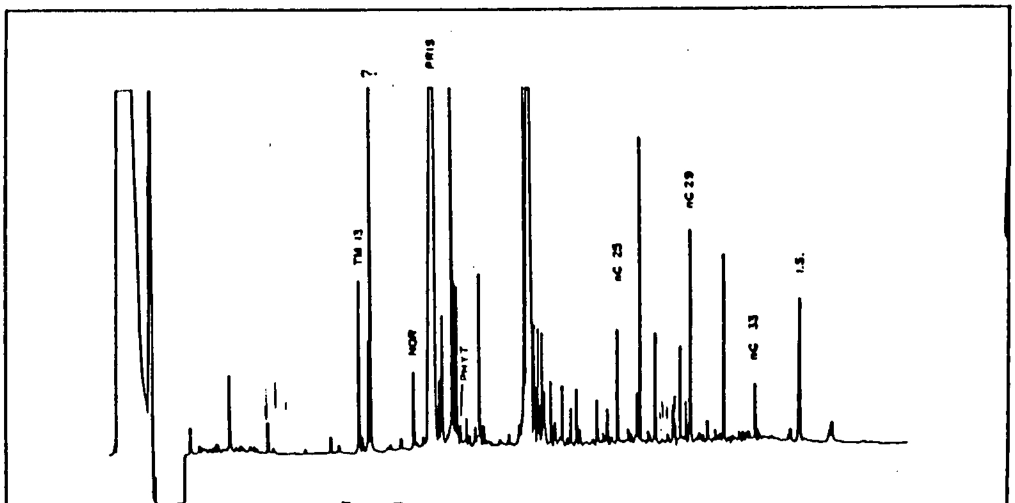
Figure 13. Oil concentrations (by UV/F) in tissue of the bivalve Serripes groenlandicus from five plots at 7 m depth in a reference bay at Cape Hatt, northern Baffin Island, during August and September 1981, and August 1982, 1983, and 1985.



Bay 7, Macoma

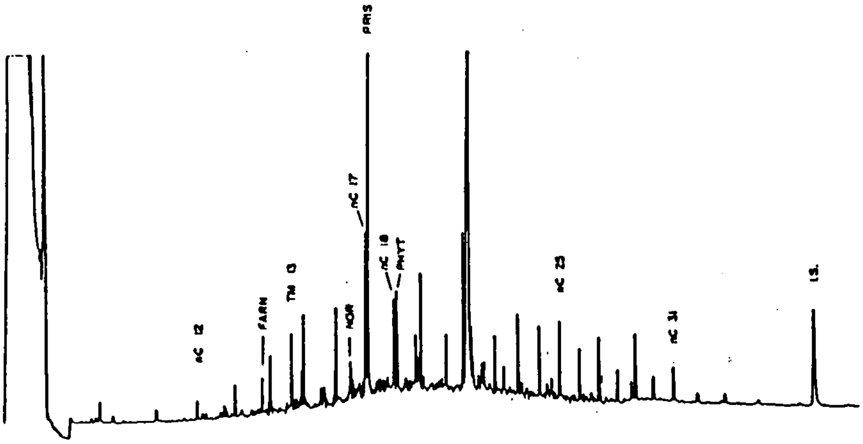


Bay 7, Serripes

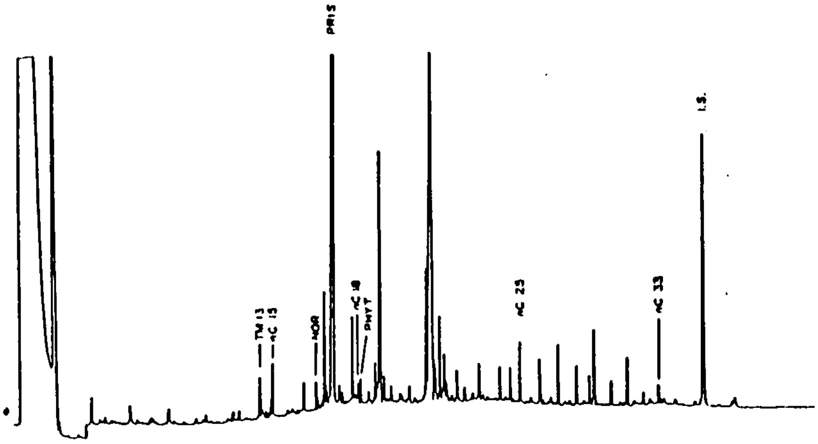


Bay 7, Strongylocentrotus

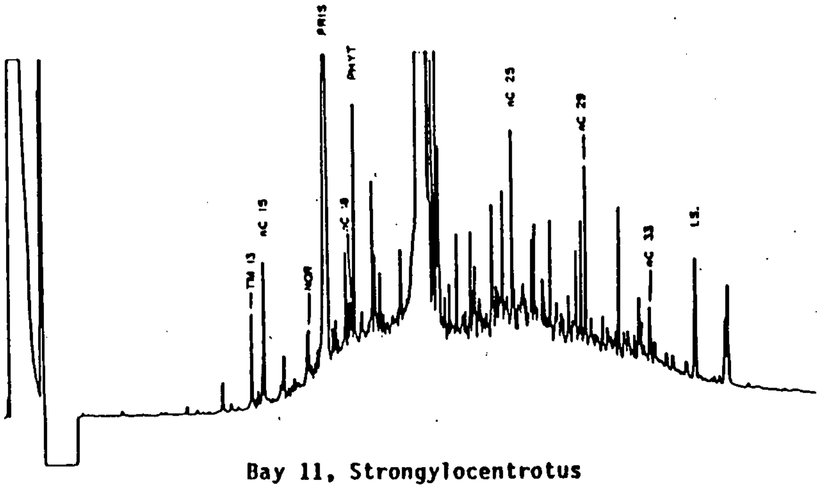
Figure 14. Gas chromatography/flame ionization detection (GC/FID) traces of the saturated hydrocarbon fraction of a composite tissue sample of each of three species of benthos from 7 m depth in each of two bays at Cape Hatt, northern Baffin Island, during August 1985.



Bay 11, Macoma



Bay 11, Serripes



Bay 11, Strongylocentrotus

Figure 14. Concluded.

TABLE 7

Alkane concentrations and weathering indices (by GC/FID)[a] in tissue of three species of benthos from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1985.

Compound, and Weathering Index[b]		Bay 7			Bay 11		
		Macoma calcarea	Serripes groenlandicus	Strongylocentus droebachiensis	Macoma calcarea	Serripes groenlandicus	Strongylocentus droebachiensis
Alkanes	nC12	61	5.4	59	40	11	4.9
($ng \cdot g^{-1}$, dry)	nC13	100	4.2	9.5	85	4.6	4.7
	nC14	170	5.1	11	180	4.4	9.2
	nC15	270	32	840	290	40	250
	nC16	260	18	12	320	21	12
	nC17	1100	-	-	610	-	-
	nC18	220	13	5.3	320	32	65
	nC19	290	15	35	420	24	70
	nC20	150	14	14	280	18	340
	nC21	170	33	-	280	41	-
	nC22	150	28	91	240	29	170
	nC23	210	-	140	370	34	360
	nC24	160	35	130	310	29	500
	nC25	220	73	310	420	74	720
	nC26	160	62	150	300	49	360
	nC27	220	65	320	340	64	390
	nC28	120	44	130	160	51	190
	nC29	280	140	790	500	100	670
	nC30	96	23	82	86	31	240
	nC31	220	66	650	270	69	690
	nC32	76	8.0	<10	58	8.9	97
	nC33	110	11	180	<40	23	250
	nC34	50	<5	<10	<40	7.8	170
	nC35	<10	<5	<10	<40	<4	<50
	nC36	<10	<5	<10	<40	<4	<50
	Total n-alkanes	4900	690	4000	5900	770	5600
	FARN	55	<4	<5	110	3.5	<10
	TM13	210	25	290	290	35	230
	NORP	95	5.5	12	190	13	150
	PRIS	3700	2400	22,000	2300	2200	8900
	PHYT	120	5.8	40	460	33	700
Weathering indices	SHWR	1.3	1.3	2.3	1.3	1.3	1.1
	ALK/ISO	0.5	0.03	0.04	0.5	0.04	0.03
	C18/Phyt	1.9	2.2	0.1	0.7	1.0	0.1
	Pris/Phyt	32	420	560	4.8	68	13
	CPI	2.7	3.2	6.1	3.1	2.6	2.7

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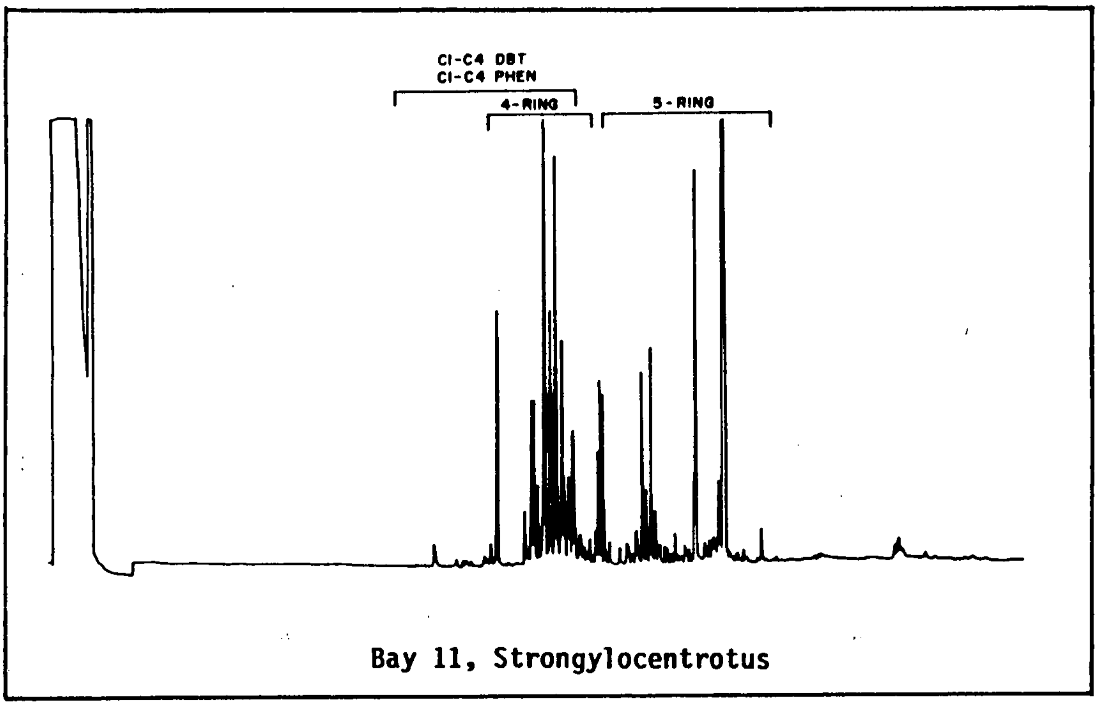
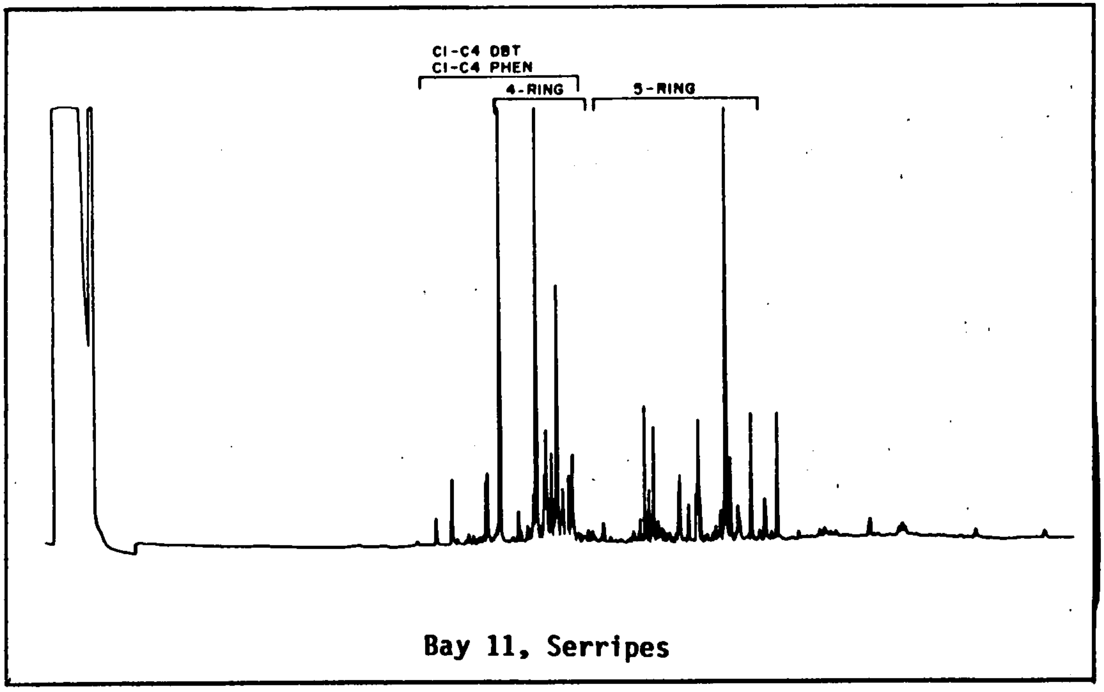
[a] Gas Chromatography/Flame Ionization Detection.
[b] See Appendix A for explanation of abbreviations and methods of calculation.
- Indicates not quantifiable.

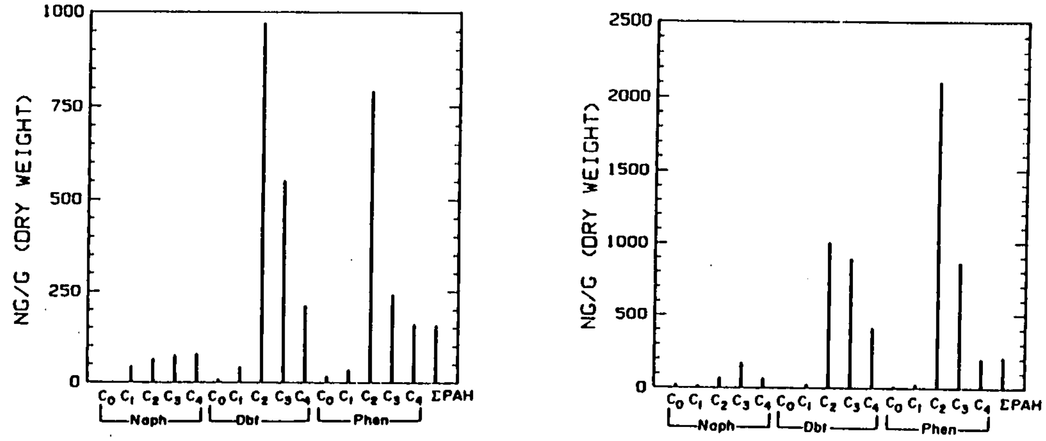


Bay 11, Strongylocentrotus



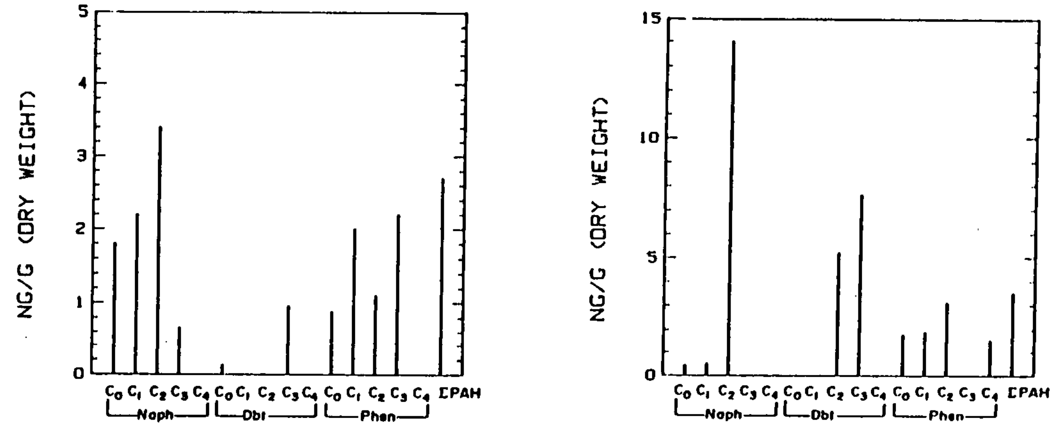
Bay 11, Serripes

Figure 15. Gas chromatography/flame ionization detection (GC/FID) traces of the aromatic hydrocarbon fraction of a composite tissue sample of each of two species of benthos from 7 m depth in the surface oil release bay at Cape Hatt, northern Baffin Island, during August 1985.



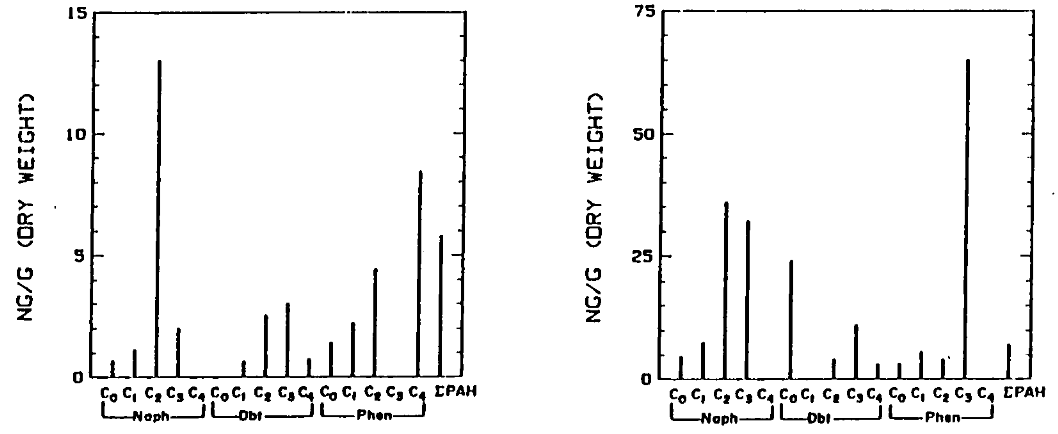
BAY 7. MACOMA

BAY 11. MACOMA



BAY 7. SERRIPES

BAY 11. SERRIPES



BAY 7. STRONGYLOCENTROTUS

BAY 11. STRONGYLOCENTROTUS

Figure 16. Selected ion monitoring (SIM) plots for gas chromatography/mass spectrometry (GC/MS) analysis of the aromatic hydrocarbon fraction of a composite tissue sample of each of three species of benthos from 7 m depth in each of two bays at Cape Hatt, northern Baffin Island, during August 1985.

TABLE 8

Polycyclic aromatic hydrocarbon (PAH) concentrations (by GC/MS)[a] and aromatic weathering indices for tissue of three species of benthos from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1985.

Compound, and Weathering Index[b]		Bay 7			Bay 11		
		Macoma calcarea	Serripes groenlandicus	Strongylocentus droebachiensis	Macoma calcarea	Serripes groenlandicus	Strongylocentus droebachiensis
Naphthalene	C-0	-	18	0.64	21	0.44	4.6
	C-1	43	2.2	1.1	14	0.51	7.4
	C-2	63	3.4	13	67	14	36
	C-3	72	0.66	2.0	170	<0.4	32
	C-4	76	<0.5	<0.4	64	<0.4	<2
Fluorene	C-0	6.9	0.37	0.38	7.1	0.40	0.31
	C-1	11	<0.2	0.45	12	<0.2	<0.3
	C-2	11	<0.2	0.52	11	<0.2	<0.3
	C-3	<0.8	<0.2	<0.3	<0.5	<0.2	<0.3
Dibenzothiophene	C-0	74	0.13	<0.2	4.1	<0.05	24
	C-1	42	<0.1	0.60	24	<0.2	<0.8
	C-2	970	<0.5	2.5	1000	5.2	3.9
	C-3	550	0.95	3.0	890	7.6	11
	C-4	210	<0.5	0.70	410	<1	2.9
Phen/Anthracene	C-0	16	0.88	1.4	11	1.8	3.0
	C-1	35	2.0	2.2	26	1.9	5.5
	C-2	790	1.1	4.4	2100	3.1	3.9
	C-3	240	2.2	<1	860	<1	65
	C-4	160	<1	8.4	200	1.5	<2
Fluoranthene		43	0.35	1.4	52	0.57	1.9
Pyrene		52	0.63	1.1	64	1.6	0.54
Benz(a)anthracene		8.0	0.35	0.59	10	0.40	<0.3
Chrysene		12	0.34	0.30	11	0.35	1.3
Benzo(e)pyrene		12	0.26	<0.1	17	<0.1	<0.2
Benzo(a)pyrene		18	0.26	<0.1	29	<0.1	<0.2
Perylene		12	0.50	2.4	26	0.58	3.3
Total PAH		3500	300	230	6200	330	420
Aromatic weathering ratio AWR		1.1	2.2	1.8	1.1	1.7	1.7

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[a] Gas Chromatography/Mass Spectometry.

[b] All units are $ng \cdot g^{-1}$ (dry), except for AWR; see Appendix A for methods of calculation.

- Indicates not quantifiable.

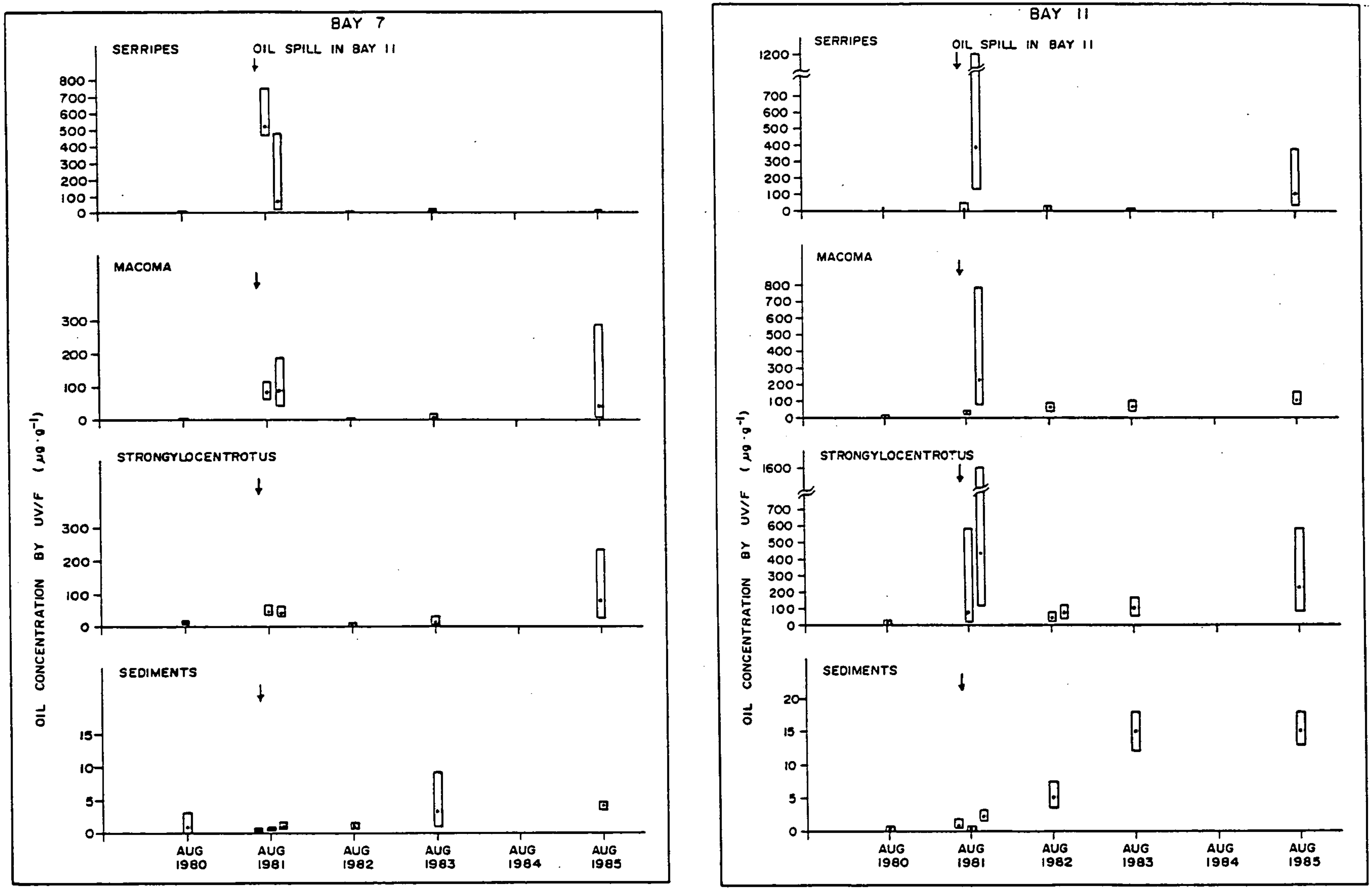

Figure 17. Summary of oil concentrations (by UV/F) in sediment and three species of benthos from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August 1980-August 1985.

increase significantly in oil content since 1983, appears to be retaining material which does not include the alkane or PAH indicators normally associated with petroleum hydrocarbon material. It may be that S. groenlandicus, after the loading of oil in 1981, is now taking up the more polar weathered material present in the water column or remaining in the sediments. Hydrocarbons were not detected in the water column of Bay 11 during 1983 (Boehm et al. 1984), but the methods used would not detect the more polar or partially degraded hydrocarbons that the UV/F technique can measure in tissue samples.

The oil releases in 1981 resulted in an acute oil loading of the tissues in Bay 7, probably because dispersed oil was present throughout Ragged Channel. Oil levels decreased by 1982 to near-baseline levels, and have since shown increases for Macoma calcarea (in 1983 and 1985) and for Strongylocentrotus droebachiensis (in 1985; Fig. 17). Measured concentrations of oil in the various compartments of Bay 7 (as determined by UV/F) are similar to those observed by the same method in Bay 11 in 1982. This observation indicates that oil from Bay 11 reaches Ragged Channel, and that the levels found may be related to distance from the source in Bay 11.

Boehm et al. (1984) made several predictions, some of which pertain to this study. They predicted that the input of oil to subtidal sediments from the beach in Bay 11 would continue, that deposit feeders would continue to be impacted by oil and that in vivo degradation would occur, and that a low level of waterborne hydrocarbon would persist in the water column. The results of the present study suggest that, whereas continued input is likely, weathering is also occurring, leaving concentrations in the sediments and tissues of Bays 7 and 11 that were similar in 1983 and 1985.

INFAUNA

The benthos in the study bays at Cape Hatt consists of a wide variety of plants and animals. For the purposes of this study, the animals have been classified into two groups according to their relative mobility. The term infauna is used to refer to those animals that are either incapable of motion or are able to move only slowly in the sediment or on the sediment surface. This group includes bivalves, polychaetes, gastropods, priapulids, nemerteans, and some echinoderms. Most analyses and discussion in the present study concern infauna, primarily because their relative immobility exposes them to the full effects of oil and facilitates the interpretation of results. Infauna are also of interest because of their dominance of total benthic biomass, and because of their long life spans in the Arctic (Curtis 1977; Petersen 1978). The latter further facilitates interpretation of results because it is indicative of comparatively reduced seasonal and annual variability.

Biomass

Overall average biomass at 7 m depth for both bays and all sampling periods combined was 1242.7 $g \cdot m^{-2}$. This value is considerably higher than mean depth-integrated (5-50 m) biomass reported in other arctic areas:

Location*	Sample size	Mean biomass ($g \cdot m^{-2}$)	Source
Alaskan Beaufort Sea	131	41	Carey (1977)
Bridport Inlet, Melville Is.	78	94	Buchanan et al. (1977)
Brentford Bay, Boothia Pen.	21	188	Thomson et al. (1978)
Lancaster Sound	110	319	Thomson and Cross (1980)
Pond Inlet and Arctic Bay	51	200-438	Ellis (1960)

* Relatively high biomass (up to 1482 $g \cdot m^{-2}$ at one location, n = 7) has also been reported in West Greenland (Vibe 1939).

The apparently high infaunal biomass at Cape Hatt relative to that in other arctic locations is at least in part attributable to the effectiveness of our sampler. About half of the biomass found at 7 m depth at Cape Hatt represented the bivalve Mya truncata. Cross and Thomson (1981) found that this deeply burrowing species was only sampled effectively where the sediment was excavated to a depth of 15 cm. Buchanan et al. (1977) compared results of quantitative underwater photographs with those of shallow penetrating samplers and found that their shallow samples underestimated infaunal biomass by as much as 960 $g \cdot m^{-2}$. Many of the other low values previously reported may also be biased by inadequate sampling.

Group and Species Composition

Group composition of the infauna collected in the study bays at Cape Hatt (bays and periods combined) is shown in Table 9. Bivalves accounted for most of the biomass (94.2%), whereas bivalves and polychaetes together accounted for 86.5% of the number of infaunal animals collected (Table 9).

The ten most common infaunal taxa at Cape Hatt, in terms of numbers and biomass, are shown in Table 10, and a complete species list is included in Appendix C. The ten dominant species accounted for 58.2% of numbers and 92.7% of the biomass of infauna. The two lists of ten species include nine bivalves, three polychaetes, and two gastropods. Five bivalves and one gastropod were dominant (i.e., among the top ten species) in terms of both density and biomass. The contributions of Astarte spp. and Macoma calcarea to density, and to a much lesser extent to biomass, are underestimated in Table 10 because unidentified juveniles of these two genera are not included (4.45 and 2.76% of numbers for Astarte and Macoma, respectively).

In general, the benthos of the study area at Cape Hatt appears to be typical of that in other nearshore, high arctic areas. Several of the dominant infaunal species, including several of those contributing most to biomass (Mya truncata, Macoma calcarea, Astarte borealis, A. montagui, Serripes groenlandicus, and Pectinaria granulata), belong to the arctic Macoma community (Thorson 1957; Ockelmann 1958; Ellis 1960; Thomson 1982). This community is a widespread and common feature of nearshore, high arctic areas and is displaced only under local circumstances (e.g., under estuarine

TABLE 9

Group composition of infauna collected in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

Taxon	% of total infaunal numbers[a]	% of total infaunal biomass[a]
Bivalvia	49.88	94.18
Polychaeta	36.58	2.98
Gastropoda	12.54	1.42
Holothuroidea	0.32	0.06
Sipunculida	0.25	0.81
Ophiuroidea	0.14	0.17
Priapulida	0.13	0.14
Other	0.16	0.23
Total Density (nos$\cdot$m^{-2}) or Biomass (g$\cdot$m^{-2})[a]	3427.2	1242.7

[a] Based on 287 airlift samples, each covering 0.0625 m^2.

influences). A quantitative analysis of community structure in the study bays is presented below.

Community Structure

Perturbation of the benthic marine environment often results in large-scale changes in infaunal community structure (Pearson and Rosenberg 1978). Faunal changes resulting from the introduction of oil may be drastic and the degree of change is related to the intensity and duration of oiling (Sanders et al. 1980). One of the best approaches for detecting oil effects appears to be the community or ecosystem approach (Mann and Clark 1978; Elmgren et al. 1980).

We are using changes in benthic community structure as a test of oil effects in the experimental bays at Cape Hatt. The term community, in these tests, refers to assemblages of benthic animals that occur together. Because distribution of benthic animals may be affected by currents, food availability, substrate, and depth, similar assemblages of animals may be found under similar environmental conditions. The study bays at Cape Hatt were selected on the basis of similarity of infauna. At 7 m depth, the infauna found in both bays was, in a qualitative sense, representative of a typical, high arctic, *Macoma* community. We have used factor analysis to identify assemblages within this community and to detect differences among the study bays and sampling periods.

TABLE 10

Percent contribution of dominant taxa to total infaunal numbers and biomass (wet weight) at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

Dominant taxa by numbers		% of total infaunal numbers[a]	Dominant taxa by biomass		% of total infaunal biomass[a]
Pholoe minuta	(Polychaete)	13.40	*Mya truncata*	(Bivalve)	47.81
Thyasiridae spp.	(Bivalve)	8.90	*Astarte borealis*[b]	(Bivalve)	17.27
Astarte montagui[b]	(Bivalve)	8.12	*Serripes groenlandicus*	(Bivalve)	8.39
Astarte borealis[b]	(Bivalve)	7.72	*Astarte montagui*[b]	(Bivalve)	7.31
Macoma calcarea[b]	(Bivalve)	5.02	*Macoma calcarea*[b]	(Bivalve)	7.17
Mya truncata	(Bivalve)	4.41	*Pectinaria granulata*	(Polychaete)	1.07
Nuculana minuta	(Bivalve)	2.99	*Clinocardium ciliatum*	(Bivalve)	1.01
Cingula castanea	(Gastropod)	2.81	*Hiatella arctica*	(Bivalve)	0.96
Trichotropis borealis	(Gastropod)	2.47	*Nuculana minuta*	(Bivalve)	0.88
Spio spp.	(Polychaete)	2.39	*Trichotropis borealis*	(Gastropod)	0.87
Total % contribution		58.23	Total % contribution		92.74
Total infaunal density ($no \cdot m^{-2}$)[a]		3427.2	Total infaunal biomass ($g \cdot m^{-2}$)[a]		1242.7

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[a] Based on 287 airlift samples, each covering 0.0625 m^2.

[b] Unidentified *Astarte* juveniles ($\leq$3 mm) and *Macoma* juveniles ($\leq$5 mm) are not included.

Either density or biomass data would be adequate for the detection of large-scale change, but subtle faunal changes would be more readily detected in density data. The biomass data are dominated by the presence and abundance of older individuals, and are relatively insensitive to numerical changes in younger individuals. Hence, analyses were performed on density data.

The species considered in analyses of community structure were those that accounted for 1.0% or more of total infaunal numbers. In this way, 24 taxa representing 83% of total numbers were selected for factor analyses. Thus, analyses considered all the common species and more than 80% of the total numbers of infauna.

The results of the factor analysis applied to the most common species collected at 7 m depth during all sampling periods and from both bays are summarized in Table 11. Six factors accounted for 61.4% of the variance represented by the 24 species variables. Each of these factors represents an assemblage of species that usually occur together and the densities of which vary more or less proportionately. Table 11 lists the species with densities that were strongly correlated with each of the factors.

The mean abundance (factor score) of each of these assemblages (factors) for each period/bay combination is presented in Figure 18. It should be noted that it is relative abundance that is depicted in these figures. For example, the first factor (assemblage), representing primarily the species listed under Factor 1 in Table 11, was more strongly represented in Bay 11 than in Bay 7; it was not necessarily absent in the latter bay (Fig. 18).

Differences in community composition among bays and periods were assessed with multivariate analysis of variance using, as dependent variables, the factor scores for each of the factors derived in the previous analysis. This analysis tests for differences in community composition among bays and periods by simultaneously considering the scores for all factors. Because these factors, in turn, represent assemblages of the most common species, the analysis tests for departures from the 'average' community composition. The results of this analysis, together with (univariate) analyses of variance for each assemblage (factor), are given in Table 12.

Spatial Effects. Most of the significant ($P<0.05$) variation in all analyses was spatial, including both variation among transects within bays and variation between bays. Variation among transects was significant according to multivariate analysis, and according to most univariate analyses of assemblages. Only the fourth assemblage (four polychaete species) occurred in similar abundances on the three transects in each bay and sampling period (see Table 12). These results indicate a patchy distribution of most infaunal assemblages on the 50 m scale. However, the lack of significant period x transect interactions shows that all within-bay differences were consistent over time (Table 12). That is, abundances on particular transects were consistently high or low over the four years of sampling.

Among-bay variability was evident for the community as a whole (i.e., in multivariate analysis), and also for three of six individual assemblages (see Table 12). In two cases (Factors 1 and 3), the assemblages were better represented in Bay 11, whereas Factor 2 was more strongly associated with Bay 7 (see Fig. 18).

TABLE 11

Results of factor analysis of the 24 benthic taxa that each represented 1.0% or more of total infaunal numbers collected at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

1. Variance explained	18.8%
Astarte montagui	0.814[a]
Astarte borealis	0.808
Lumbrinereis minuta	0.712
Astarte juveniles	0.703
Nuculana minuta	0.679
Praxillella praetermissa	0.635
Mya truncata	0.600
Maldane sarsi	0.599

2. Variance explained	12.9%
Macoma calcarea	0.798
Thyasiridae spp.	0.779
Macoma juveniles	0.758
Musculus juveniles	0.578
Cingula castanea	0.553

3. Variance explained	9.9%
Retusa obtusa	0.681
Oenopota spp.	0.597
Ampharete acutifrons	0.503
Trichotropis borealis	0.474
Pectinaria granulata	0.455

4. Variance explained	8.9%
Spio spp.	0.758
Capitella capitata	0.695
Pholoe minuta	0.692
Mediomastus sp.	0.632

5. Variance explained	5.6%
Moelleria costulata	0.770

6. Variance explained	5.3%
Diplocirrus spp.	0.844

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[a] The values shown are the correlations between the log-transformed densities of various species (the original variables) and each of the six factors determined in the analysis. Species whose densities were weakly correlated with a factor ($-0.4 < r < 0.4$) are not shown. Also shown is the variance explained by each factor expressed as a percentage of the variance of the original variables.

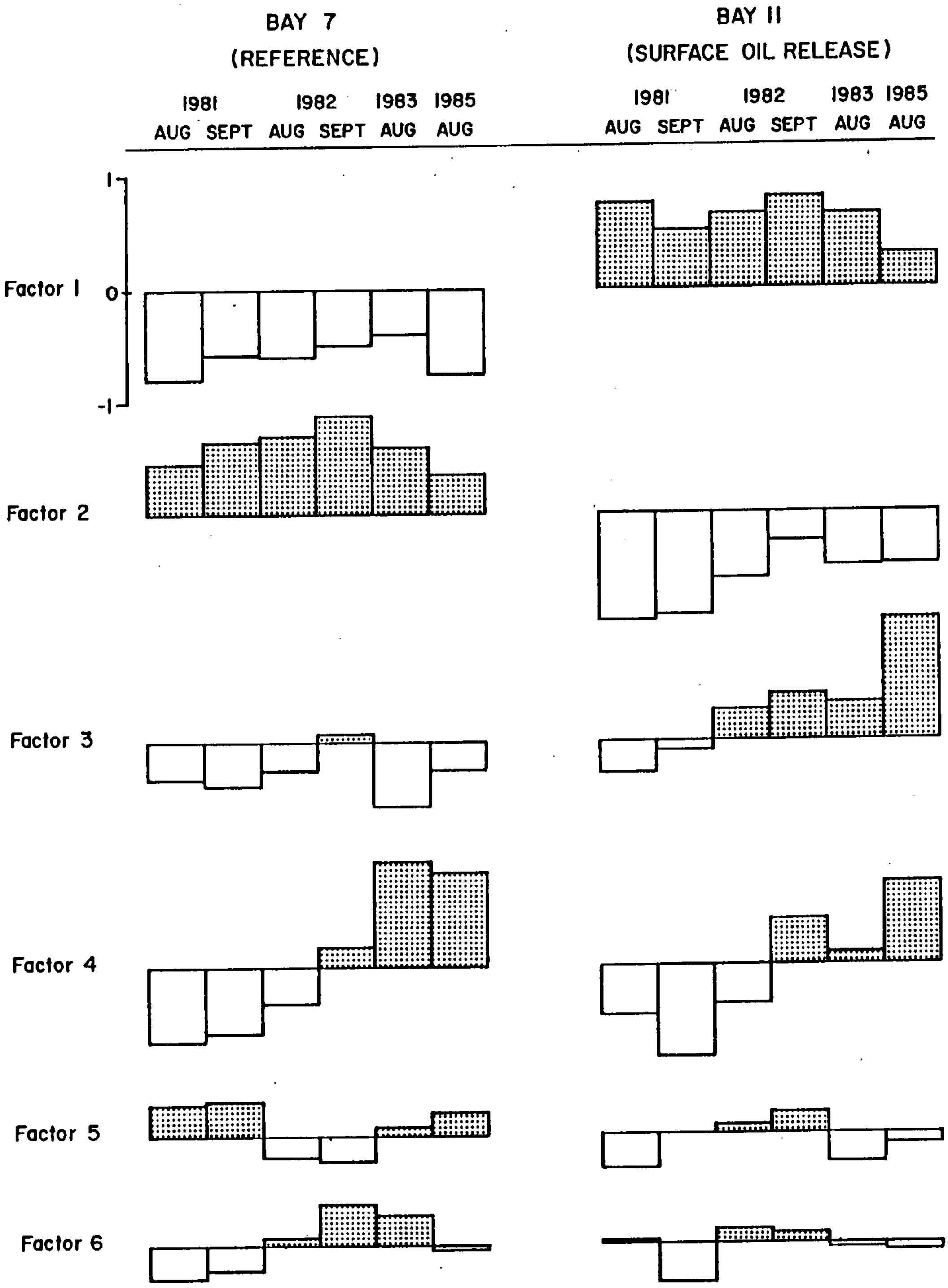

Figure 18. Mean factor scores for each period and bay at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

TABLE 12

Multivariate and univariate analyses of variance (MANOVA and ANOVA) for factor scores determined in factor analysis of infaunal density at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

		Source of variation and univariate df[a]				
Variable		Period 5,24	Bay 1,24	Period x bay[b] 5,24	Transect (bay)[c] 8,334	Period x transect (bay) 24,334
MANOVA						
Pillai's trace	F ->	1.76[d]	204.22	1.24	4.75	1.13
	P ->	0.018	0.000	0.211	0.000	0.155
	df ->	30,115	6,19	30,115	24,996	120,1506
ANOVAS						
Factor 1		0.89 ns[d]	101.74 ***	0.44 ns	5.09 ***	1.11 ns
Factor 2		3.56 *	211.12 ***	1.60 ns	2.89 *	0.40 ns
Factor 3		1.57 ns	9.88 **	1.11 ns	13.48 ***	1.14 ns
Factor 4		21.08 ***	1.29 ns	2.22 ns	1.24 ns	1.39 ns
Factor 5		0.26 ns	1.13 ns	1.43 ns	2.61 *	1.14 ns
Factor 6		1.06 ns	0.18 ns	0.42 ns	3.56 **	1.33 ns

[a] Because period x transect (bay) interaction was ns, it was pooled with transect (bay) effect to test bay, period and period x bay effects.

[b] The "period x bay" term is the test of oil effects.

[c] Transects are nested within bays.

[d] F-values are shown with significance levels (ns = $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$) for univariate analyses, and with actual probabilities for multivariate analysis.

Overall among-bay differences in community structure are illustrated in the graphical representation of the results of the multivariate analysis (Fig. 19). In this figure, distances between points represent differences in community structure. The benthic community in each bay changed relatively little across sampling periods, in comparison with the greater difference between bays.

Temporal Effects. Multivariate analysis showed significant temporal variability in community structure. However, temporal variability appeared to be a less important component of variability in community structure than did spatial variability (see Table 12). The graphical representations of the temporal effects (see Fig. 19) confirm that temporal differences were not nearly as well defined as were bay effects.

Only the fourth assemblage, representing small polychaetes, showed marked temporal variation. In both bays, the abundance of this assemblage increased over the four years of sampling. The abundance of the second assemblage (bivalves and a gastropod) also differed among sampling periods, but temporal change was much less pronounced. In this instance, bay differences appeared to be much larger than period differences (see Fig. 19).

Oil Effects. In this study, effects of oil on community structure would be evident as pre- to post-spill changes that occurred in the oiled bay and not in the reference bay. Such effects would appear as a significant period x bay interaction term. This term was not significant in multivariate analysis of variance or in univariate analysis of any of the six factors (see Table 12).

Thus, oil did not seem to affect community composition or the abundances of dominant species assemblages. This conclusion is based on data collected 2-4 weeks before the oil release as compared to 2-4 weeks, 1 year, 2 years, and 4 years after the oil release.

The graphical representation of this interaction term in Figure 19 shows that the relative locations of periods within bays are quite similar for the two bays. In each bay, community structure in the first three or four sampling periods was similar; the points representing these bay-period combinations form one grouping for each bay. The last two or three sampling periods within each bay also tend to be grouped together (see Fig. 19).

Distribution of Species

The distributions of 25 infaunal taxa at 7 m depth were examined individually based on density data. All of these taxa are included in the analyses of community structure, i.e., each constituted at least 1.0% of total infaunal numbers collected. Densities of these taxa in each bay and period are given in Appendix D. Biomass data are given in Appendix E for the species dominating biomass, but detailed examination of the distribution of biomass was restricted to five species. There was high sample-to-sample variability in the biomasses of the other species, which were rare and were dominant only because individuals were large. Results of analyses of variance for densities and biomasses of the above-mentioned species and for major taxa (density of gastropods, and density and biomass of bivalves, polychaetes, and total infauna) are given in Table 13.

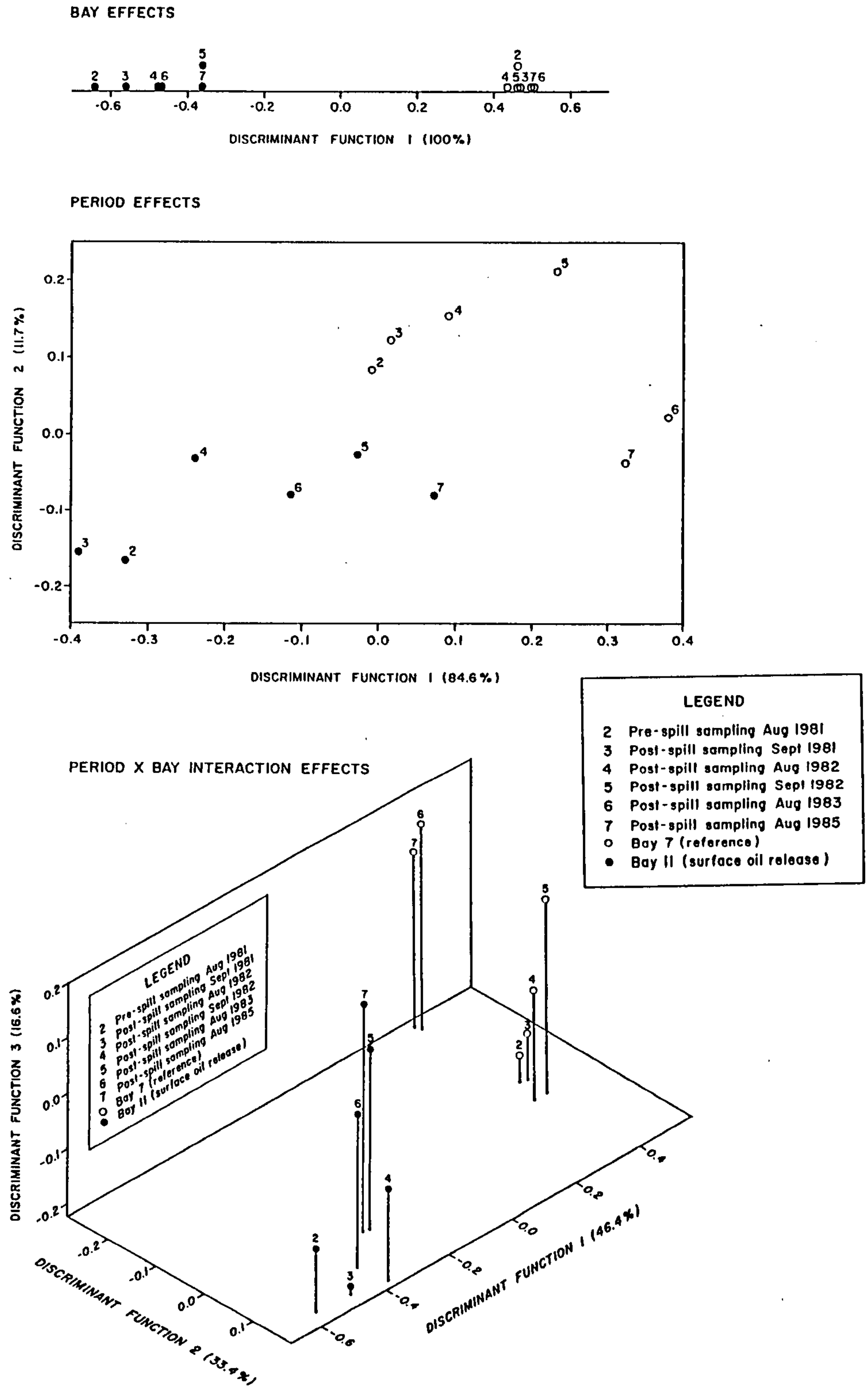

Figure 19. Graphical representation of results in multivariate analysis of variance using data collected at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during pre- and post-spill sampling periods from August 1981 to August 1985.

TABLE 13

Three-factor analyses of variance for the biomasses and densities of major taxa and dominant species of infauna at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

		Source of variation and df[a]				
Variable	Taxon	Period 5,4 or 24	Bay 1,4 or 24	Period x bay[b] 5,4 or 24	Transect (bay)[d] 4,251	Period x transect (bay) 20,251
Biomass	Total infauna	0.59 ns[e]	3.19 ns	0.67 ns	4.48 **	1.00 ns
	Polychaeta	1.37 ns	9.66 **	0.28 ns	3.61 **	0.69 ns
	Bivalvia	0.65 ns	3.30 ns	0.64 ns	4.56 **	1.03 ns
	Mya truncata	1.80 ns	0.09 ns	0.29 ns	4.63 **	0.60 ns
	Astarte borealis	1.38 ns	265.76 ***	1.64 ns	0.51 ns	0.93 ns
	Astarte montagui	0.10 ns	301.61 ***	0.32 ns	2.13 ns	1.78 *
	Macoma calcarea	0.85 ns	56.40 ***	0.31 ns	4.80 ***	1.38 ns
	Serripes groenlandicus	0.62 ns	50.91 ***	0.37 ns	1.35 ns	0.58 ns
Density	Total infauna	5.57 **	2.62 ns	0.54 ns	2.25 ns	1.41 ns
	Polychaeta	15.70 ***	1.35 ns	1.29 ns	2.35 ns	1.56 ns
	Pholoe minuta	8.55 ***	6.24 *	1.50 ns	1.61 ns	1.58 ns
	Pectinaria granulata	0.61 ns	2.03 ns	0.55 ns	7.30 ***	1.27 ns
	Praxillella praetermissa	5.80 **	40.54 ***	0.42 ns	1.12 ns	0.97 ns
	Spio spp.	–[c]	–[c]	2.85 *	1.96 ns	1.57 ns
	Capitella capitata	3.54 *	1.32 ns	1.11 ns	1.73 ns	0.91 ns
	Maldane sarsi	0.53 ns	7.04 *	0.57 ns	15.60 ***	1.00 ns
	Mediomastus spp.	–[c]	–[c]	4.47 **	0.70 ns	0.73 ns
	Lumbrinereis minuta	0.24 ns	47.93 **	0.51 ns	5.38 ***	1.89 *
	Diplocirrus spp.	2.40 ns	7.04 ns	0.61 ns	1.00 ns	1.71 *
	Ampharete acutifrons	1.69 ns	34.83 ***	0.58 ns	2.41 *	1.44 ns
	Bivalvia	0.90 ns	2.34 ns	0.19 ns	3.00 *	0.96 ns
	Mya truncata	1.19 ns	21.08 ***	0.32 ns	3.70 **	0.47 ns
	Thyasiridae spp.	0.72 ns	140.65 ***	0.53 ns	6.48 ***	0.51 ns
	Astarte borealis	2.88 *	119.53 ***	1.21 ns	0.67 ns	0.75 ns
	Astarte montagui	0.05 ns	289.26 ***	0.63 ns	1.86 ns	1.98 **
	Astarte juveniles	1.38 ns	220.86 ***	0.32 ns	0.93 ns	1.43 ns
	Macoma calcarea	0.88 ns	96.42 ***	0.81 ns	4.68 **	1.24 ns
	Macoma juveniles	–[c]	–[c]	5.52 **	2.52 *	0.52 ns
	Nuculana minuta	0.96 ns	11.78 **	0.46 ns	3.33 *	1.06 ns
	Musculus juveniles	5.59 **	36.31 ***	0.51 ns	6.13 ***	0.58 ns
	Serripes groenlandicus	1.02 ns	66.68 ***	0.69 ns	2.02 ns	1.12 ns
	Gastropoda	3.50 *	1.43 ns	0.88 ns	3.22 *	1.02 ns
	Cingula castanea	4.38 **	60.63 ***	0.75 ns	2.20 ns	0.93 ns
	Trichotropis borealis	0.66 ns	14.21 ***	0.49 ns	4.66 **	0.54 ns
	Retusa obtusa	–[c]	–[c]	3.50 *	1.38 ns	0.76 ns
	Moelleria costulata	1.30 ns	1.68 ns	1.06 ns	1.24 ns	1.20 ns
	Oenopota spp.	6.24 ***	72.18 ***	1.39 ns	2.97 *	0.59 ns

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[a] Where period x transect (bay) interaction was ns, it was pooled with transect (bay) effect to test bay, period, and period x bay effects; where period x transect (bay) was significant ($P \leq 0.05$), transect (bay) alone was used to test main effects.

[b] The "period x bay" term is the test of oil effects.

[c] Interpretation of main effects confounded by significant interaction of Period x Bay term.

[d] Transects are nested within bays.

[e] F-values are shown with significance levels (ns = $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$).

Spatial Effects. The smallest scale of variability apparent in our data is that among replicate samples within transects. Cross and Thomson (1981) reported relatively high variability on this scale for most groups and dominant species. Distributions of these species ranged from relatively even to relatively patchy, and even greater extremes of variability were observed for the many uncommon species in the study area. The next smallest scale of variability, that among 50 m transects, is represented by the "transect (bay)" term in Table 13, which presents the results of analyses of variance. About half of the species or groups examined varied significantly among transects within bays. This variation occurred in a similar proportion of polychaete, bivalve, and gastropod species (see Table 13).

The greatest variability in the distribution of infaunal species was that between bays. Of 30 species variables (biomass and density) tested, the only ones that did not differ between bays were densities of the gastropod *Moelleria costulata* and the polychaetes *Capitella capitata*, *Pectinaria granulata*, and *Diplocirrus* spp., and biomass of the dominant bivalve *Mya truncata*. Within each of the dominant groups (Bivalvia, Polychaeta, and Gastropoda), higher numbers or biomasses of some species occurred in Bay 11, whereas other species were more abundant in Bay 7 (Figs. 20 to 23). Most of the groups tested, on the other hand, did not vary significantly among bays; *viz.*, densities and biomasses of all infauna and bivalves, and densities of polychaetes and gastropods (Table 13; Figs. 20 to 23).

Temporal Effects. In general, temporal change was a much smaller component of variability in the abundance and biomass of infauna than was spatial variability: none of the eight biomass variables, and only 10 of 29 species or group densities varied significantly during 1981-1985 (see Table 13). Temporal variability included both seasonal and annual components, and in nearly all cases where temporal variability was significant, densities increased during the study period (see Figs. 20 to 23). Overall, infaunal density increased 40-50% between 1981 and 1985, primarily through increases in densities of polychaetes and, to a lesser extent, gastropods (see Appendix D). Bivalve densities were relatively constant over the study period, and the only infaunal species for which the density decreased significantly over time was the bivalve *Astarte borealis* (see Fig. 21).

Oil Effects. Oil was released on the surface of Bay 11 on 19 August 1981. Observations made by divers and chemical monitoring during the oil release indicated that some oil entered the water column, but did not penetrate deeper than 1 m. On the first post-spill day, many dead and heavily oiled amphipods (*Gammarus setosus*) were observed at low tide in the intertidal zone, and at the same time some *Gammarus* were observed to be swimming just below the surface of the water. On 21 August (two days post-spill) no apparent effects were noted in the benthos, and mysids were active in the water column. Dead fish larvae were observed on the surface just inside the (oiled) booms.

Oil released at Cape Hatt did not cause large-scale mortality of benthic animals during the four years following the oil release; no statistical treatment of the data is required to demonstrate this (see Figs. 20 to 23). The purpose of statistical tests, rather, was to examine more subtle changes in the densities or biomasses of infaunal animals. The criterion for recognizing a possible oil effect was decided, before the experiments began,

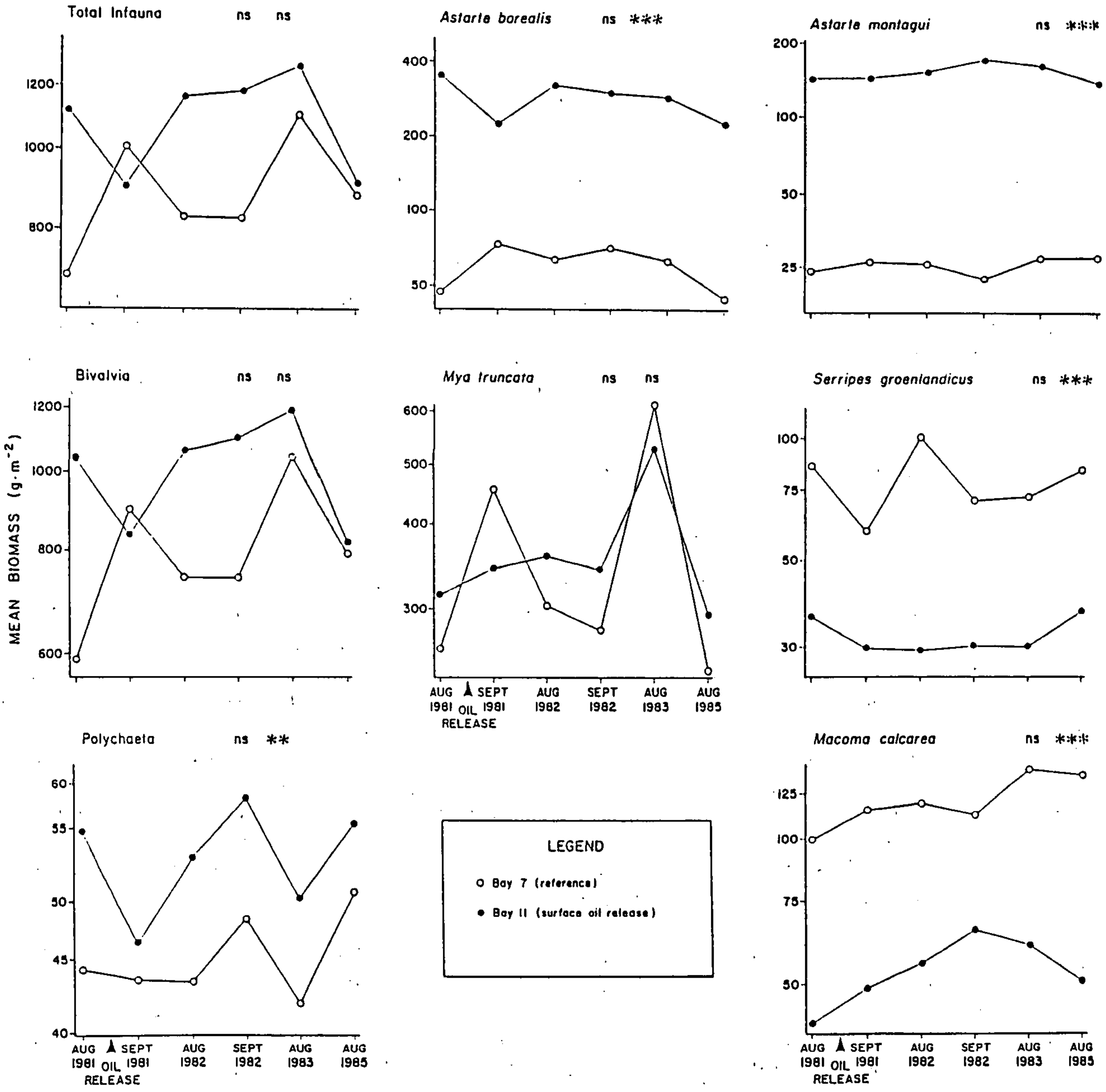

Figure 20. Mean biomass ($g \cdot m^{-2}$) of infaunal groups and dominant bivalve species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as the back-transformed means of log-transformed data from 24 replicate 0.0625 m^2 airlift samples for each bay and period. Significance levels are shown for period effects, followed by bay effects. Note that the ordinate does not always begin at zero.

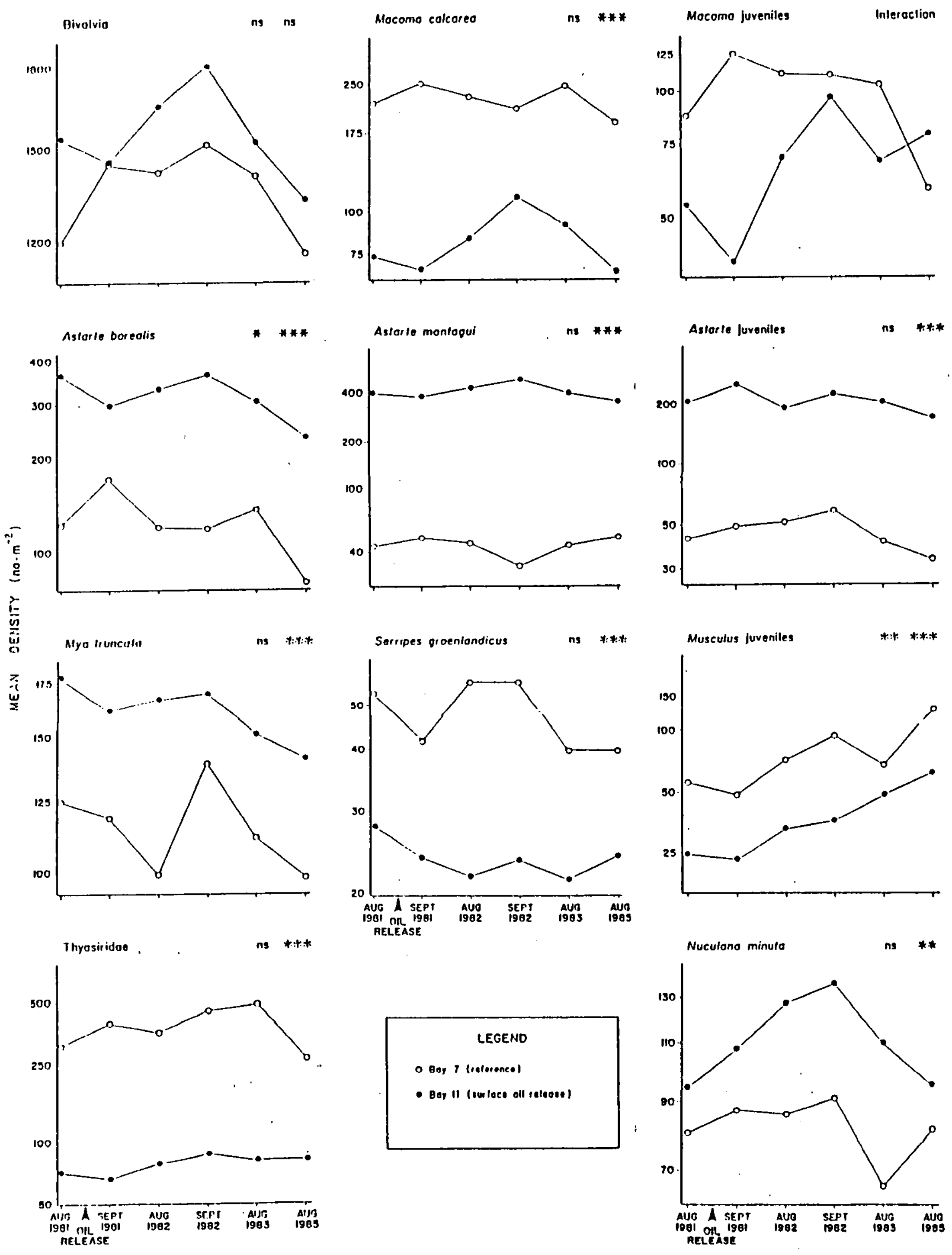

Figure 21. Mean density (no·m^{-2}) of total bivalves and dominant bivalve species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as the back-transformed means of log-transformed data from 24 replicate 0.0625 m^2 airlift samples for each bay and period. Significance levels are shown for period effects, followed by bay effects. Note that the ordinate does not always begin at zero.

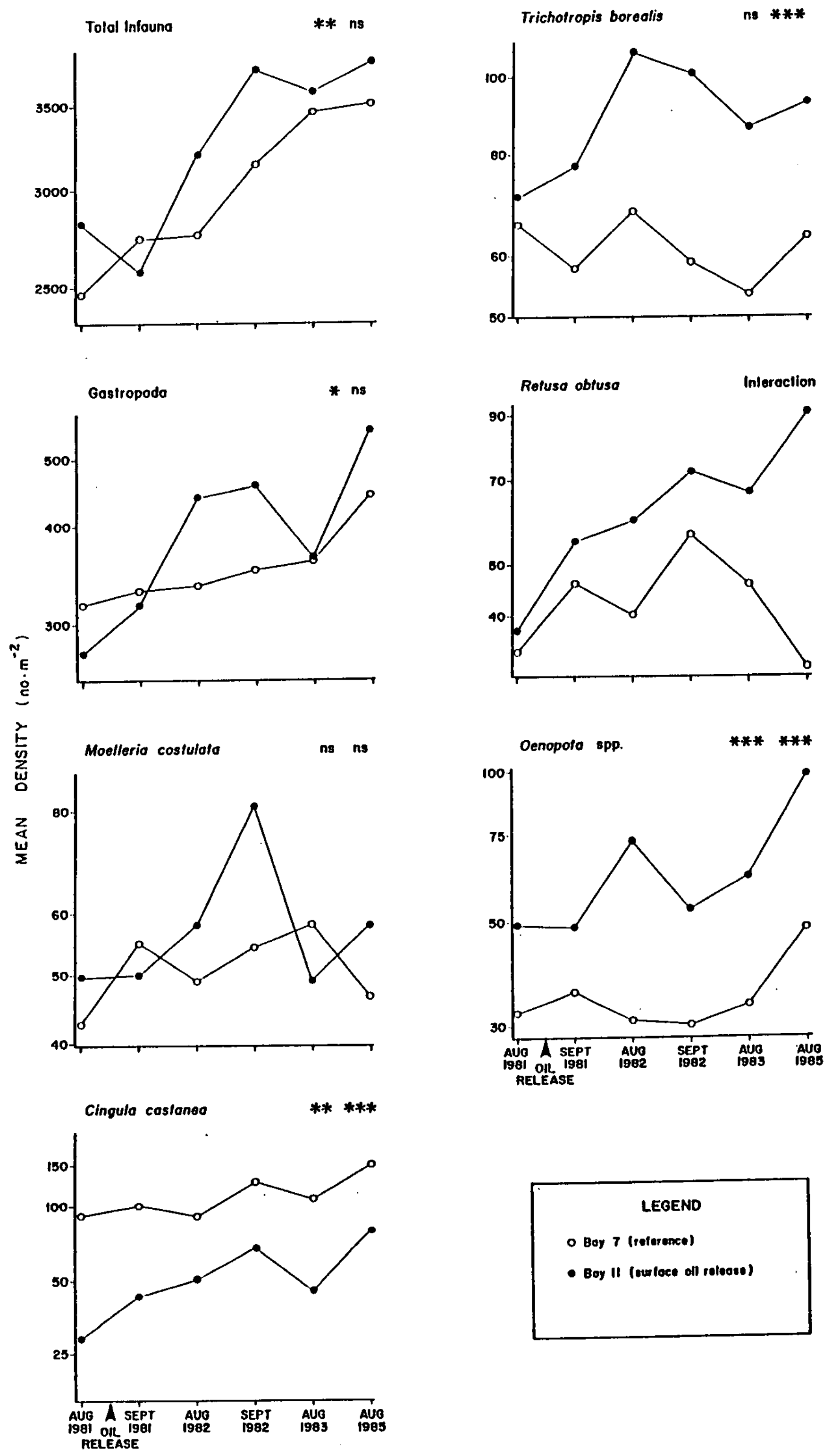

Figure 22. Mean density (no•m^{-2}) of total infauna, total gastropods, and dominant gastropod species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as the back-transformed means of log-transformed data from 24 replicate 0.0625 m^2 airlift samples for each bay and period. Significance levels are shown for period effects, followed by bay effects. Note that the ordinate does not always begin at zero.

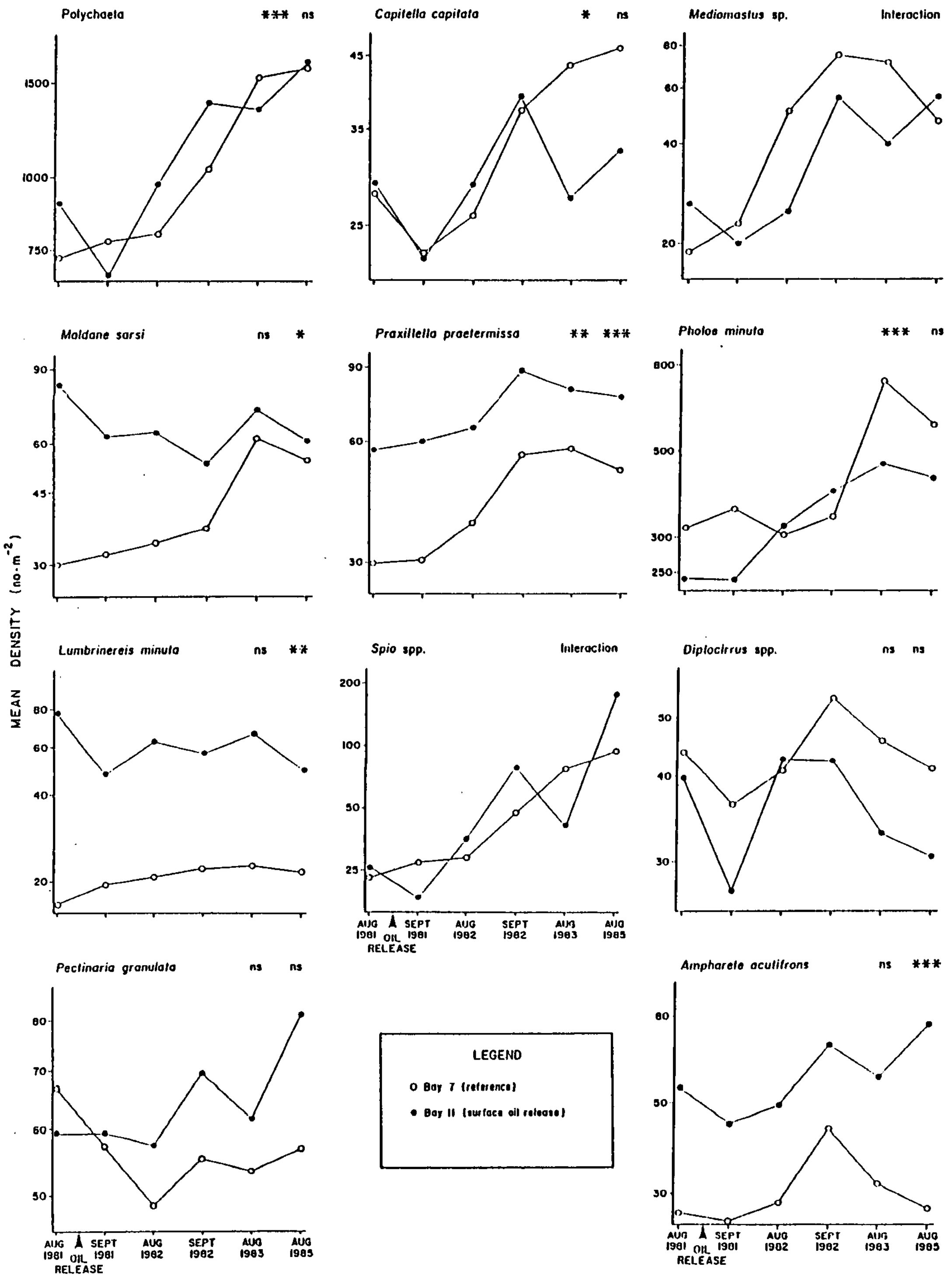

Figure 23. Mean density (no•m^{-2}) of total polychaetes and dominant polychaete species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as the back-transformed means of log-transformed data from 24 replicate 0.0625 m^2 airlift samples for each bay and period. Significance levels are shown for period effects, followed by bay effects. Note that the ordinate does not always begin at zero.

to be the occurrence of a significant period x bay interaction in analysis of variance. Of 37 infaunal species- or group-variables that were tested, the interaction term was significant for only four variables (see Table 13), which included two polychaete genera, juveniles of one bivalve genus, and one gastropod species. Oil effects were not indicated for any group variable or for the biomass of any group or species tested (see Table 13).

Because of the number of variables analyzed and the significance level chosen ($\alpha = 0.05$), one would expect to find two seemingly significant effects by chance if there were no real oil effects. In this section we examine possible sources of the few observed interactions to assess whether the changes could be attributable to the effects of oil.

For one of the four taxa for which the bay x period interaction term was significant, juveniles of the bivalve genus *Macoma*, possible oil effects were also indicated in analysis of data from 1980-1983 (Cross et al. 1984). The source of the significant interaction term was increased density in *Macoma* juveniles between 1981 and 1982 only in Bay 11, and it was suggested that oil in Bay 11 sediments may have enhanced recruitment of *Macoma* larvae from the plankton (Cross et al. 1984); *Macoma calcarea*, unlike other arctic species of *Macoma*, apparently has a pelagic and planktotrophic form of larval development (Ockelmann 1958). The possibility that oil affected recruitment in *Macoma* is discussed further in the following section. However, regardless of the cause of variability in recruitment (natural or oil-related), we agree with Cross et al. (1984) that density changes in Bay 11 were within the range of natural variability observed in Bay 7 (see Fig. 21) and during pre-spill sampling periods (Cross et al. 1984). Furthermore, it is apparent that any possible effects of oil on *Macoma* juveniles during 1981-1982 did not result in effects on densities of *Macoma calcarea* during 1983 or 1985 (see Table 13 and Fig. 21).

Oil effects were also indicated in analyses of density data for the gastropod *Retusa obtusa* and the polychaete genera *Spio* and *Mediomastus*. Oil effects were not indicated in previous analyses of 1980-1983 data on densities of *Retusa obtusa* and *Spio* sp. at 7 m depth at Cape Hatt (Cross et al. 1984; *Mediomastus* sp. not analyzed). This lack of a significant interaction term in previous analyses, together with inspection of the data (Figs. 22 and 23), indicate that the sources of the interactions for *Retusa*, *Spio*, and *Mediomastus* were density changes between August 1983 and August 1985. In all three taxa, density in Bay 11 increased markedly relative to that in Bay 7.

For several reasons, it does not seem likely that the 1983-1985 density increases in Bay 11 were delayed effects of the surface oil release in 1981. First, oil concentrations in sediments had stabilized by 1983, and oil in sediments was increasingly weathered with increasing time after the oil release. Secondly, the fact that the three species used different modes of feeding (*Retusa*--carnivore; *Spio*--suspension/surface deposit feeder; *Mediomastus*--burrowing deposit feeder) indicates the unlikely situation that one factor (oil) produced three different types of effect. Thirdly, increased density, rather than decreased density, suggests an indirect effect of oil (e.g., an indirect effect of oil-related mortality that resulted in decreased competition or predation, or increased food availability), whereas there was no evidence of any such mortality in this or previous studies (e.g., Cross et al. 1984). Lastly, the increases in density occurred so long after oiling (3-4 years) that they likely do not represent the opportunistic type of population increase that has followed disturbance (such as oil spills) elsewhere. For example, *Capitella capitata* and *Mediomastus ambiseta* increased in abundance following *the Florida* spill off Massachusetts in 1969, but populations crashed 1 or 2 years following the spill at sites classified as lightly, intermediately, and heavily oiled (Sanders et al. 1980).

Size-Frequency Distribution

Exposure to oil may cause size-selective mortality of benthic animals in a variety of ways. Not all life stages of marine animals are equally susceptible to the effects of oil (Rice et al. 1975; Linden 1978). Larval stages are generally more susceptible than are adults (Wells and Sprague 1976). Dow (1978) has demonstrated, on the other hand, an instance of selective mortality of large individuals of a bivalve species. The juveniles inhabited clean surface sediments, but as they grew they tended to burrow deeper into the substrate and died when they reached an oil-contaminated layer.

Mean lengths of five bivalve species are shown in Table 14. For two species, *Mya truncata* and *Serripes groenlandicus*, mean sizes of the populations are underestimated because damaged individuals were not measured, and broken shells were more common among the larger individuals in our samples. There is no reason to expect any systematic differences among bays or periods in the sizes of damaged animals, however, so the analyses presented below are still valid. Analysis of size data was not performed for *S. groenlandicus* or *Astarte montagui* because of the small sample sizes in one or both bays (see Table 14).

Mean lengths (log transformed) of individuals in each sample were compared among bays, periods, and transects, using three-factor, nested, analyses of variance (Table 15). Overall, there was little variability in mean length data. In each of the three bivalve species tested, only one of the five possible sources of variation was significant (Table 15). Furthermore, the only apparent variability in mean size data for the two species not tested was a smaller mean size of *Serripes groenlandicus* in Bay 7 than in Bay 11 (see Table 14).

Mya truncata was variable in size on a small scale (among transects within bays). This variability may be the result of patchy settlement patterns in juveniles or of periodic mortality from ice scour or variations in temperature and salinity. Each of these physical factors (particularly ice scour) may vary on a small scale, and any resultant mortality would cause a shift toward smaller (newly settled) bivalves in those areas. Curtis and Petersen (1977) reported size class heterogeneity on an even smaller scale (several metres) in *Macoma calcarea* and the polychaete *Pectinaria granulata* near Disko Island, West Greenland, and attributed this to settling behaviour and competition between year classes.

Variability in mean length between the two bays was evident only for *Astarte borealis* (see Table 15). In Bay 7, *A. borealis* was smaller and also much less abundant than in Bay 11 (see Table 14 and Fig. 21) or in two other BIOS study bays sampled during 1980-1983 (Cross et al. 1984). It is likely

TABLE 14

Mean lengths of five bivalve species from 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

Taxon	Period	Mean lengths (mm) ± SD	
		Bay 7	Bay 11
Mya truncata	Aug 1981	19.0 ± 12.3 (125)[a]	16.2 ± 12.0 (230)
	Sept 1981	21.3 ± 13.7 (126)	17.8 ± 11.1 (191)
	Aug 1982	21.9 ± 13.6 (127)	17.1 ± 10.7 (211)
	Sept 1982	22.4 ± 14.0 (157)	18.5 ± 11.0 (223)
	Aug 1983	23.1 ± 13.9 (102)	21.5 ± 12.2 (189)
	Aug 1985	19.3 ± 15.7 (116)	17.7 ± 11.6 (191)
Macoma calcarea	Aug 1981	13.2 ± 5.1 (364)	13.2 ± 6.7 (99)
	Sept 1981	13.4 ± 5.1 (376)	15.5 ± 6.8 (81)
	Aug 1982	13.8 ± 5.1 (369)	13.8 ± 6.9 (118)
	Sept 1982	13.9 ± 5.0 (360)	13.4 ± 6.5 (159)
	Aug 1983	14.5 ± 4.8 (372)	14.3 ± 6.7 (137)
	Aug 1985	15.6 ± 4.5 (284)	15.5 ± 7.0 (98)
Astarte borealis	Aug 1981	9.6 ± 5.6 (239)	13.8 ± 8.5 (566)
	Sept 1981	10.4 ± 6.0 (286)	12.5 ± 8.1 (496)
	Aug 1982	10.1 ± 6.1 (252)	13.7 ± 8.9 (549)
	Sept 1982	10.0 ± 6.0 (274)	13.2 ± 8.5 (569)
	Aug 1983	10.7 ± 6.4 (227)	14.4 ± 8.9 (514)
	Aug 1985	11.4 ± 6.4 (142)	14.5 ± 9.0 (394)
Astarte montagui	Aug 1981	8.7 ± 3.8 (64)	10.2 ± 3.8 (661)
	Sept 1981	9.5 ± 3.6 (66)	9.9 ± 4.0 (723)
	Aug 1982	9.1 ± 4.2 (68)	9.5 ± 3.9 (747)
	Sept 1982	9.0 ± 3.7 (43)	10.0 ± 3.9 (769)
	Aug 1983	10.6 ± 3.9 (58)	10.2 ± 3.9 (761)
	Aug 1985	9.8 ± 3.3 (76)	9.9 ± 3.8 (735)
Serripes groenlandicus	Aug 1981	15.3 ± 11.2 (37)	20.6 ± 10.4 (18)
	Sept 1981	19.9 ± 12.1 (37)	25.2 ± 12.3 (10)
	Aug 1982	15.6 ± 14.2 (65)	22.3 ± 14.6 (9)
	Sept 1982	15.7 ± 12.3 (58)	19.2 ± 13.7 (10)
	Aug 1983	17.2 ± 14.3 (34)	24.7 ± 15.5 (10)
	Aug 1985	18.9 ± 18.5 (38)	22.4 ± 19.5 (19)

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[a] Numbers in parentheses are number of individuals collected and measured.

TABLE 15

Results of analyses of variance on mean lengths (in each sample) of three bivalve species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

Species	Source of variation and df[a]					Residual df	No. of samples
	Period 5,24	Bay 1,24	Period x bay[b] 5,24	Transect (bay) 4, residual	Period x transect (bay) 20, residual		
Astarte borealis	1.21 ns[c]	71.67 ***	2.14 ns	1.07 ns	1.09 ns	233	269
Mya truncata	0.92 ns	3.38 ns	0.29 ns	5.21 ***	1.06 ns	242	278
Macoma calcarea	4.46 **	0.00 ns	1.78 ns	0.65 ns	0.80 ns	238	274

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[a] Because period x transect (bay) interaction was ns, it was pooled with transect (bay) effect to test bay, period and period x bay effects.

[b] The "period x bay" term is the test of oil effects.

[c] F-values are shown with significance levels (ns = $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$).

that one or more environmental factors unique to Bay 7 (among the BIOS study bays) were unfavourable for A. borealis. Two such factors unique to Bay 7 were first, a high gravel content (see Table 2; see also Cross et al. 1984, Table 2), which may have inhibited burrowing, and secondly, high densities of the seastar Leptasterias polaris (a bivalve predator), which may have resulted in higher predation pressure and mortality in A. borealis than in the other bays.

Variability among sampling periods in mean length was significant only for Macoma calcarea (see Table 15); mean length increased about 2 mm between 1981 and 1985 (see Table 14). The increase was progressive in Bay 7 but not in Bay 11, likely because of the smaller sample sizes in the latter bay (Table 14).

The interaction term in analysis of variance of mean length data, the indicator of a possible oil effect, was not significant for any of the three bivalve species tested (see Table 15). To examine further the possibility of a size-selective effect of oil on the three species, including unidentified Macoma and Astarte juveniles (mean size not analyzed), size-frequency distributions were examined. One likely effect of oil would be reduced recruitment of juveniles to populations inhabiting oiled sediments. Such effects on very small individuals may not have been detected in analysis of mean population size, but would be apparent in size-frequency data.

Size-frequency distributions of Mya truncata in each bay and period are shown in Figure 24. The 1-3 mm and 4-6 mm size classes likely represent newly settled and 1-year-old individuals, respectively. Thorson (1936) reported 1-year-olds to be 3-6 mm long (in June) in Northeast Greenland, and Petersen (1978) found that M. truncata in Northwest Greenland were 2-4 mm long by the end of their first winter. In both locations, larvae settled to the bottom from the plankton in summer. Length/age equations for M. truncata collected at Cape Hatt in September 1980 give a length of about 7 mm for a 1-year-old (Green et al. in prep.). Therefore, recruitment was estimated as the proportion of the population that was in the smallest (1-3 mm) size class.

Recruitment was relatively constant during 1981-1983 both in Bay 7 (2-9% of population) and in Bay 11 (3-10%). In both bays, recruitment was considerably better in 1985 (30% and 17% in Bays 7 and 11, respectively; see Fig. 24). The similar pattern in both bays (reference and oiled) indicates that recruitment was not affected by oil. A possible explanation of the annual variability in recruitment may be periodic spawning in the parent populations, such as that reported for Mya truncata in Northeast Greenland (Thorson 1936). Another indication that oil did not affect population structure in M. truncata at Cape Hatt was that changes over time in the general shape of the size-frequency distributions were similar in both bays (see Fig. 24).

Size-frequency distribution of Macoma calcarea are shown in Figure 25. Recruitment in this species at Cape Hatt is difficult to evaluate. Macoma juveniles likely include M. moesta and M. loveni, but the overwhelming dominance of M. calcarea at Cape Hatt indicates that juveniles are primarily the latter species. Population structure in juveniles (1-5 mm) was sometimes unimodal and sometimes bimodal (see Fig. 25), and the rather prolonged

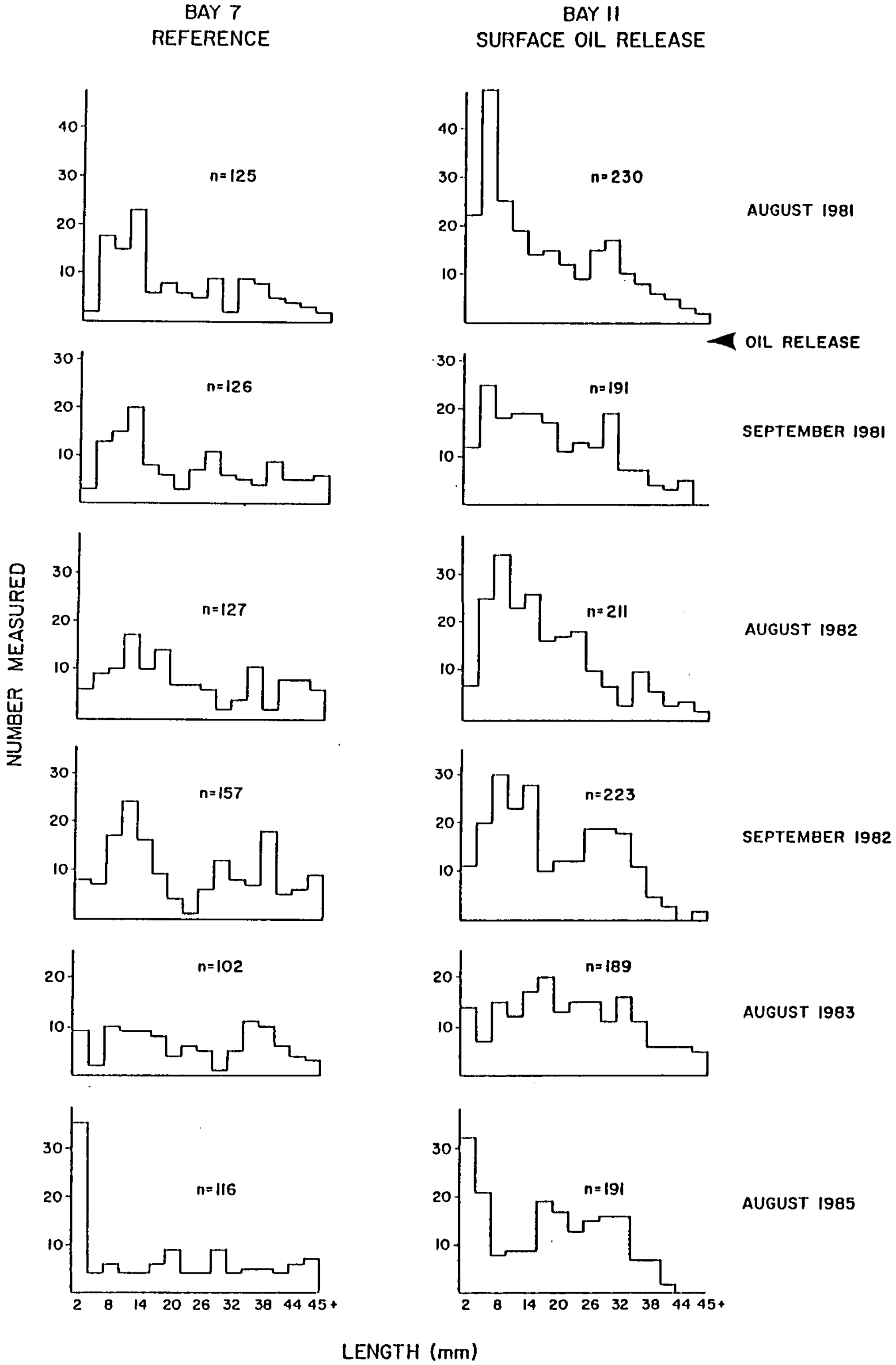

Figure 24. Length-frequency distributions of Mya truncata at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during pre- and post-spill sampling periods from August 1981 to August 1985. Sample sizes represent all undamaged individuals in 24 samples from each bay and period.

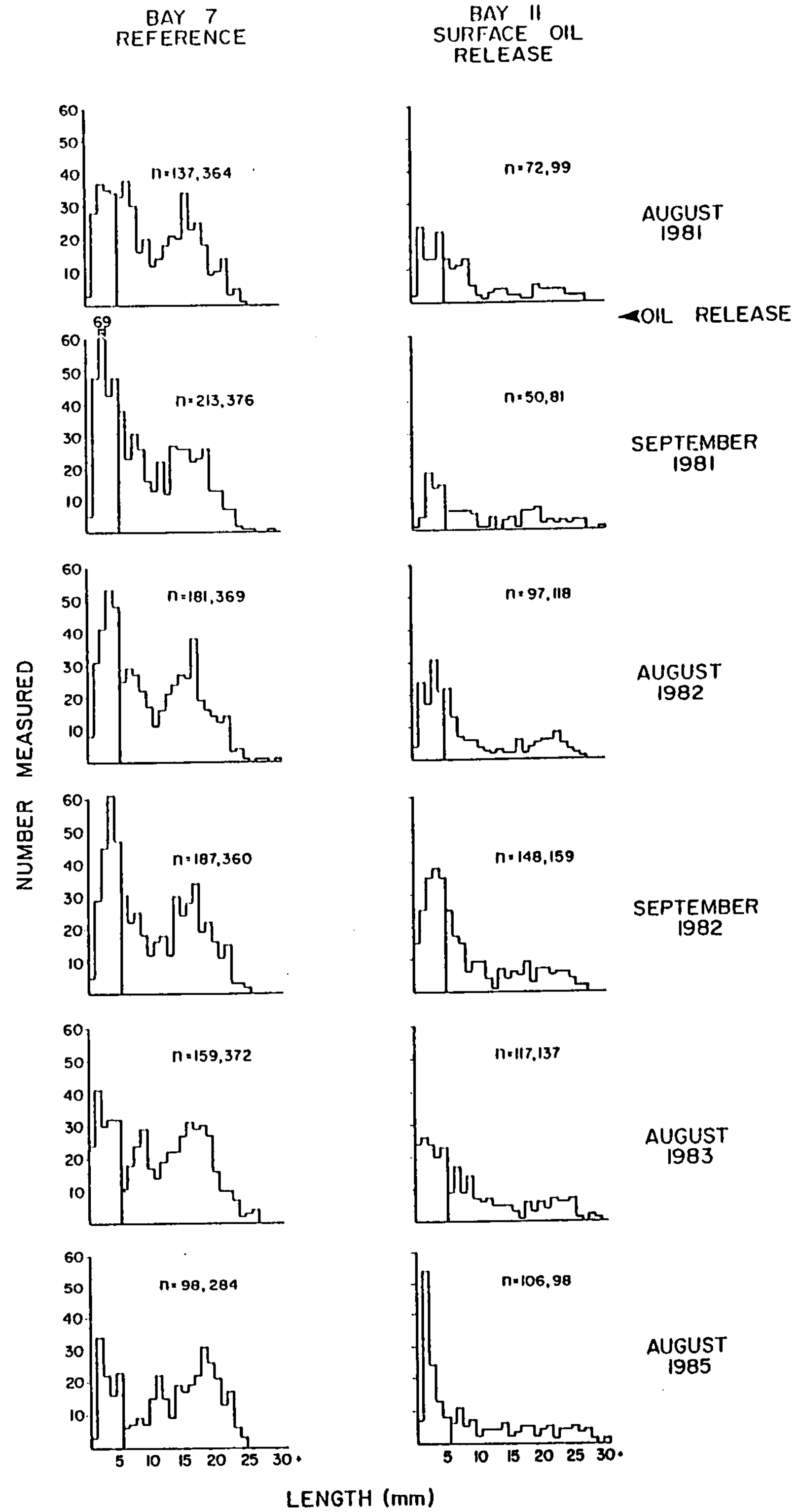

Figure 25. Length-frequency distributions of Macoma calcarea (>6 mm long) and Macoma juveniles (1-5 mm) at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during pre-spill and post-spill sampling periods from August 1981 to August 1985. Sample sizes are given for Macoma juveniles, followed by Macoma calcarea, and represent all undamaged individuals in 24 samples from each bay and period.

spawning period (late June to early August; Thorson 1936, Petersen 1978), together with conflicting reports on growth rates, make it difficult to assess whether juveniles are newly settled, 1-year-olds, or 2-year-olds. Length at 1 year has been variously reported as <1 mm to 3 mm (Petersen 1978), and 4-7 mm or 5-7 mm (Thorson 1936; Green et al. in prep.).

The contribution of *Macoma* juveniles (≤5 mm) to *Macoma* populations at Cape Hatt varied somewhat over time, both in Bay 7 (26-36% of *M. calcarea* plus juveniles) and in Bay 11 (38-52%). Cross et al. (1984) suggested that in Bay 11, recruitment of *Macoma* larvae from the plankton during 1982 may have been enhanced by oil in sediments. There was no evidence of enhanced recruitment in Bay 11 during 1983, whereas in 1985, recruitment again appeared to be better in Bay 11 than in Bay 7 (see Fig. 25).

Yearly differences in the recruitment of *Macoma* juveniles were not consistent with yearly changes in oil concentrations in Bay 11 sediments (see Fig. 3). However, annual and seasonal variability in the availability of *Macoma* larvae in the plankton may be confounded with oil-related variability in settlement patterns of larvae. The observed spatial and temporal variation in population structure at Cape Hatt may, therefore, be a result of variability in recruitment of juveniles that is unrelated to local conditions. The rare and irregular occurrence of *M. calcarea* in East Greenland, and in particular the scarcity of young individuals, led Ockelmann (1958) to suggest that this species either does not spawn every year or is subject to periodic failure of its larval development. In West Greenland, *M. calcarea* is abundant, but Petersen (1978) also reported considerable variability in recruitment among the years and locations studied.

Unlike *Mya truncata* or *Macoma calcarea*, species of *Astarte* in the Arctic are thought to have direct (rather than larval) development. In East Greenland, *Astarte* spp. produce eggs with a mucous and adhesive membrane, and these are thought to be attached to the substrate (Thorson 1936; Ockelmann 1958). Hence, local conditions (including the presence of oil) may affect recruitment of juveniles in a different way than would be the case for species with pelagic development.

To assess the effects of oil on eggs, and hence recruitment, in *Astarte borealis* at Cape Hatt, length-frequency histograms for *Astarte* juveniles (1-3 mm) and *A. borealis* were examined (Fig. 26). In East Greenland, *A. borealis* spawned in October were 3-6 mm long at one year of age (in September; Thorson 1936). Green et al. (in prep.), however, estimated that 1-year-olds at Cape Hatt (in September 1980) were 1.4 mm in Bay 9 and 1.8 mm in Bay 11; three-year-olds were 3.2 and 4.0 mm in length in Bays 9 and 11, respectively.

Figure 26, in general, corroborates the slower growth rates reported by Green et al. (in prep.) for the lower end of the range reported by Thorson (1936). In Bay 11, there is a distinct mode at 2 mm in length, which would represent juveniles produced in the previous year. The histograms for Bay 11 (oiled bay) are similar both before and after the oil release, and recruitment was good in each year. The least stable population structure, and the most variability in population structure among periods, occurred in Bay 7; strong recruitment to the population occurred only in 1982, and most of those juveniles were no longer present in 1983 (see Fig. 26). Thus, variation in population structure was primarily spatial (i.e., differed

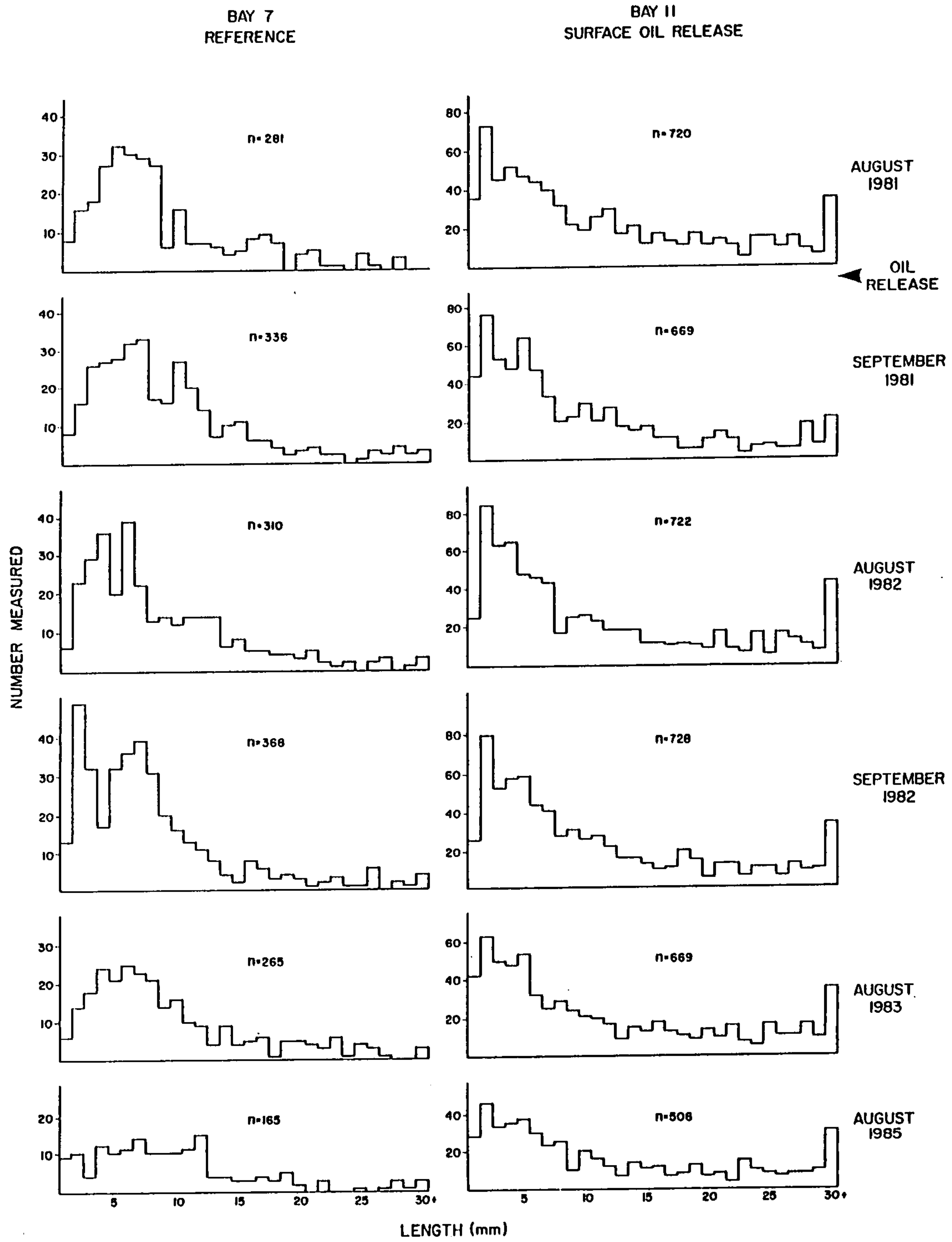

Figure 26. Length-frequency distributions of *Astarte borealis* at 7 m depth in two bays at Cape Hatt, northern *Baffin Island*, during pre- and post-spill sampling periods from August 1981 to August 1985. Individuals 1-3 mm long are the number of unidentified *Astarte* juveniles thought to be *A. borealis* based on the ratio of *A. borealis*: *A. montagui* for each bay and period. Sample sizes are given for undamaged individuals in 24 samples from each bay and period. Note differences in vertical scales.

between the two bays) and temporal (only in the reference bay). There was no evidence of oil effects on the population structure of *Astarte borealis*.

Weight-Length Relationships of Bivalves

Exposure to crude oil may cause physiological changes in marine invertebrates. In bivalves, these changes may be reflected in the dry weight-length relationship (Thomas 1978; Stekoll et al. 1980). The dry weight-length relationship of three bivalve species was used to test for sublethal effects of oil in the experimental bays at Cape Hatt. A fourth species (*Serripes groenlandicus*) analyzed during the BIOS project is not included in the present study, because too few individuals from Bay 11 were measured ($n = 4$-16 per sampling period).

For three species of bivalves (*Mya truncata*, *Macoma calcarea*, and *Astarte borealis*), about 50 individuals from the middle transect at 7 m depth in each of the three bays sampled in September 1980 were measured and weighed. Analysis of scatter plots of the original data and of residuals produced by regression analyses indicated that the weight-length relationship of these animals was best expressed by a power curve ($y = ax^b$) rather than by exponential ($y = ae^x$), linear ($y = a + bx$), or logarithmic ($y = a \log x$) functions (Cross and Thomson 1981). This type of weight-length relationship was expected a priori, and is typical of most animals.

Analyses of covariance were used to assess between-bay and among-period variations in the slopes of the regression lines and in dry weights adjusted for length (Table 16). The slope is the power to which length must be raised to estimate weight (b in the expression $y = ax^b$). The first part of the analysis of covariance is a test of equality of slopes. If the slopes for different bays and periods are similar, then the rate of gain in weight with increasing length is consistent. If slopes are significantly different among bays or periods, interpretation of the remainder of the analysis for that effect or interaction is ambiguous. The second part of the analysis compares weights in different bays and periods after adjustment for any differences in length. If adjusted weights (i.e., weight at a standard length) are significantly different, then at any given length animals are heavier in some bays or periods than in others.

Results of analyses of covariance (see Table 16) showed considerable temporal and spatial variability, both in the slopes of the weight-length regression lines and the dry weights adjusted for length. **Bay differences** were common both in slopes and in adjusted weights. Regression line slopes for *Mya truncata* and *Macoma calcarea* were lower in individuals from Bay 7, i.e. large individuals were lighter, and small individuals were heavier, than in Bay 11. After adjustments for length, mean weight of *Astarte borealis* was higher in Bay 7 than Bay 11. **Temporal differences** in slopes were evident only for *A. borealis*. whereas dry weights adjusted for length differed among sampling periods in the other two species. Adjusted weight of *M. truncata* was least in September 1982, and *M. calcarea* was lightest in August 1981. Each species was heaviest in August, either in 1983 (*M. calcarea*) or 1985 (*M. truncata*).

TABLE 16

Analyses of covariance of difference in dry meat weight, using length as the covariate, for bivalves collected at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

	Equality of group means and numerator df				Equality of slopes and numerator df			
Species	Period 5	Bay 1	Period x bay 5	Denominator df	Period 5	Bay 1	Period x bay 5	Denominator df
Astarte borealis	–[a]	21.52 ***[b]	1.69 ns	563	8.38 ***	0.71 ns	0.64 ns	552
Macoma calcarea	7.86 ***	–[a]	2.58 *	553	1.27 ns	19.15 ***	1.24 ns	542
Mya truncata	3.53 **	–[a]	1.57 ns	585	1.73 ns	18.47 ***	1.60 ns	574

[a] Results of "Equality of Group Means" not shown because of heterogeneity of slopes of regression lines for the effect.

[b] F-values are given with significance levels (ns = $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$).

Bay x period interactions were significant only in the case of adjusted mean dry weight of *Macoma calcarea* (see Table 16). This interaction indicates the possibility that oil affected the weight-length relationship of *M. calcarea*. There was no evidence of oil effects on weight-length relationships in *Mya truncata* or *Astarte borealis*.

The period x bay interaction effect in adjusted dry meat weight of *Macoma calcarea* is evident in Figure 27. In Bay 7, adjusted dry meat weight of *M. calcarea* increased between August and September in 1981 and 1982. Between August and September in Bay 11, weight was constant in 1981, and decreased in 1982. In both bays, weight increased between 1982 and 1983, and decreased between 1983 and 1985.

The August-September increase in body tissue relative to length in Bay 7 during 1981 and 1982 likely represented a natural seasonal increase in storage materials, which are necessary to meet metabolic requirements in winter. Increase in length in *Macoma balthica* apparently ceases during winter in temperate, boreal and arctic waters (Green 1973; Buekema and de Bruin 1977; Chambers and Milne 1979; Bachelet 1980). In the Dutch Wadden Sea (Buekema and de Bruin 1977), *M. balthica* increased in length and tissue weight from March to June; in the subsequent 8-9 months length remained constant, whereas almost two-thirds of the summer's increase in dry tissue weight was lost. Thus the observed seasonal increase in weight relative to length in the reference bay in both 1981 and 1982 is to be expected. The lack of such an effect or its reversal in the oiled bay may be attributable to oil effects on feeding or metabolic processes. *Macoma* spp. consume deposited organic matter with the inhalent siphon (Ockelmann 1958), and a mean oil concentration of 85 $\mu g \cdot g^{-1}$ was found in *M. calcarea* in Bay 11 two weeks following the oil release (Fig.11). Oil has been reported to interfere with feeding behaviour (Atema and Stein 1974; Atema 1976; Hyland and Miller 1979; Augenfeld 1980) and to increase metabolic rate (Hargrave and Newcombe 1973; Fong 1976).

Because sampling was conducted only in August during 1983 and 1985, it was not possible to examine seasonal changes in tissue weight. However, the similarity between bays in the annual change in tissue weight after 1982 indicates that the effect of oil on the weight-length relationship in *Macoma calcarea* did not persist beyond the first post-spill year, despite increased oil concentrations in sediments. This result may have been because oil was increasingly weathered in the second and fourth post-spill years, or because *M. calcarea* had become acclimated to ingesting oiled sediment.

EPIBENTHIC CRUSTACEANS

For the purposes of this study, the term "epibenthos" describes motile members of the benthic community. Included are those animals capable of rapid movement through the lower part of the water column (e.g., crustaceans), and those that move relatively slowly on the sediment surface, but are capable of covering relatively large distances because of their large size (e.g., urchins and starfish). The purpose of this definition is to facilitate the interpretation of any changes in faunal densities in the study bays after oiling. In the cases of such animals, it is not possible to

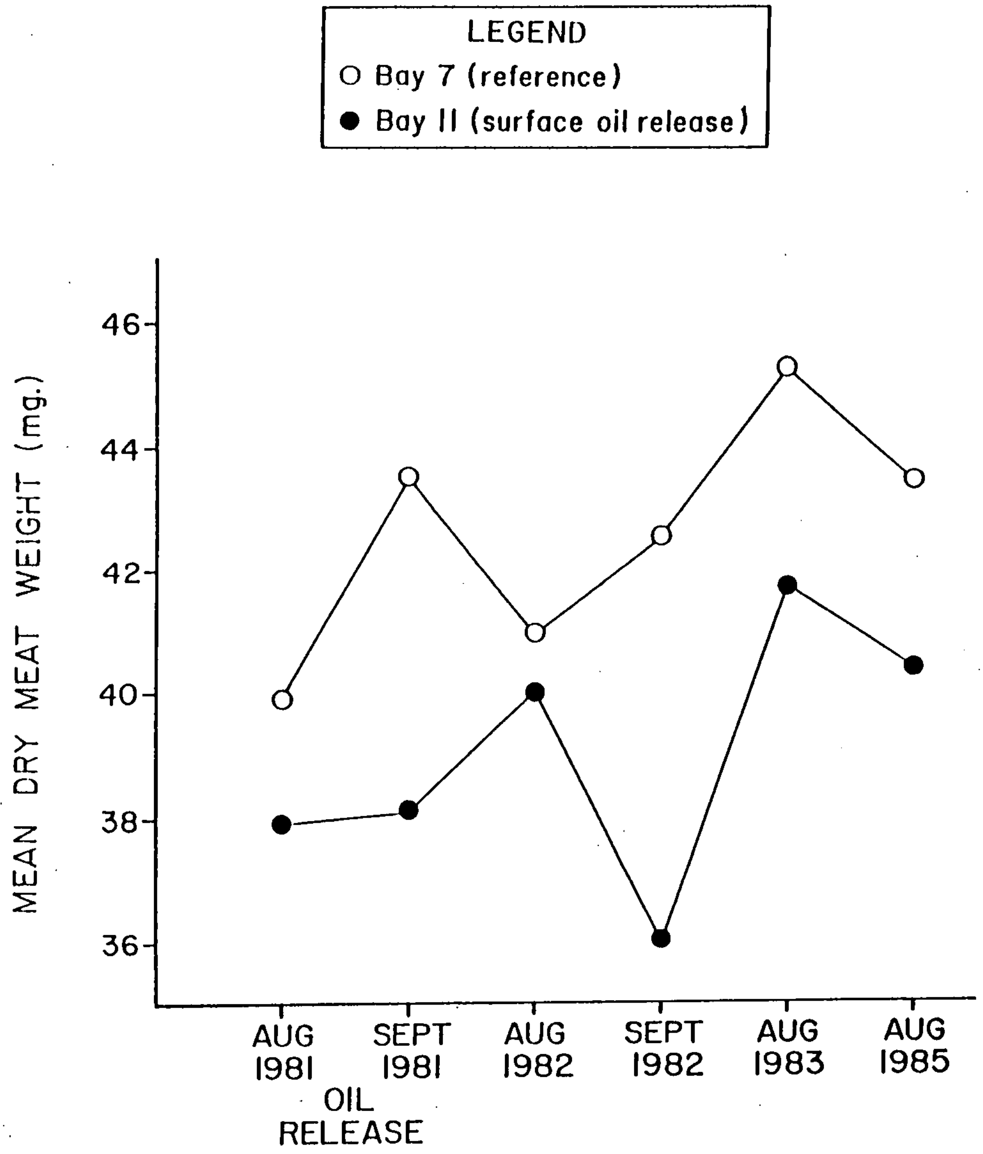

Figure 27. Backtransformed adjusted group mean dry meat weights of *Macoma calcarea* determined in analysis of covariance. Animals were collected at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during pre- and post- spill sampling periods from August 1981 to August 1985.

distinguish with certainty the relative roles of mortality and emigration in determining any changes in densities.

The available data on highly motile epibenthic crustaceans at Cape Hatt are from the same airlift samples upon which infaunal results were based. Estimates for epibenthic crustaceans likely are not as accurate as those for infauna, however, because of escape of organisms from the area sampled and inclusion of those inadvertently drawn into the airlift from outside the sampling area. A modification to the sampler, developed for the EAMES program to overcome this shortcoming (Thomson and Cross 1980), was not practical in the present study because of difficulties in operating the airlift in the mixed sediment-rock substrate. No quantitative estimates are available for the extent to which epibenthic crustaceans were over- or underestimated in the present study.

Group and Species Composition

Epibenthic crustaceans collected in the study bays at Cape Hatt included ostracods, amphipods, cumaceans, isopods, decapods, and nebaliaceans. Ostracods, the numerically dominant taxon, comprised 71.7% of total crustaceans collected. Amphipods and cumaceans made up 21.4% and 6.3% of total numbers, respectively. Isopods, decapods, and nebaliaceans were present in very small numbers. (A complete species list is included in Appendix C.)

The ten dominant epibenthic crustaceans comprised 94.5% and 90.7% of total numbers and biomass, respectively, of epibenthos collected in Bays 7 and 11 during 1981-1985 (Table 17). Seven taxa, including myodocopid ostracods, two cumacean species, and four amphipod species, were dominant in terms of both biomass and density. Two large and sparsely distributed decapods were also included in the taxa dominating epibenthic biomass. All of the species in Table 17 are common in nearshore arctic waters (Steele 1961; Sekerak et al. 1976; Buchanan et al. 1977; Thomson et al. 1978; Thomson and Cross 1980).

Distribution of Species

Spatial effects. There was considerable variability among transects in the densities of crustaceans, indicating patchy distributions on a small scale (50 m). Densities of 11 of 13 taxa differed among transects (Table 18); the exceptions were the cumacean Lamprops fuscata and the amphipod Bathymedon spp., which were evenly distributed along the transects.

Densities of total crustacean epibenthos did not vary between bays, but spatial variation on that scale was considerable for about half of the specific taxa that were examined (see Table 19). Bay 11 (oiled bay) supported the highest densities of total amphipods and cumaceans, and of the amphipod Guernea sp. and the cumaceans Lamprops fuscata and Brachydiastylis resima (Figs. 28 and 29). Myodocopid ostracods and the amphipod Bathymedon spp., on the other hand, were more abundant in Bay 7 than in Bay 11 (see Figs. 28 and 29).

TABLE 17

Percent contribution of dominant taxa to total epibenthic crustacean biomass and density at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

Dominant taxa by numbers		% of total epibenthic numbers[a]	Dominant taxa by biomass		% of total epibenthic biomass[a]
Ostracoda (Myodocopa)		71.71	Ostracoda (Myodocopa)		42.10
Guernea sp.[b]	(Amphipod)	6.56	*Anonyx* spp.[b]	(Amphipod)	20.79
Pontoporeia femorata	(Amphipod)	5.85	*Pontoporeia femorata*	(Amphipod)	12.41
Lamprops fuscata	(Cumacean)	3.57	*Argis* sp.	(Decapod)	4.62
Brachydiastylis resima	(Cumacean)	2.10	*Sclerocrangon boreas*	(Decapod)	3.49
Stenothoidae spp.[b]	(Amphipod)	1.69	*Paroediceros lynceus*	(Amphipod)	2.91
Monoculodes spp.[b]	(Amphipod)	1.15	*Brachydiastylis resima*	(Cumacean)	1.13
Anonyx spp.[b]	(Amphipod)	0.84	*Lamprops fuscata*	(Cumacean)	1.06
Calliopiidae spp.[b]	(Amphipod)	0.52	*Guernea* sp.[b]	(Amphipod)	1.03
Bathymedon spp.[b]	(Amphipod)	0.51	*Monoculodes* spp.[b]	(Amphipod)	1.02
Total % contribution		94.50	Total % contribution		90.72
Total epibenthic density ($no \cdot m^{-2}$)[a]		2930.5	Total epibenthic biomass ($g \cdot m^{-2}$)[a]		8.89

[a] Based on 287 airlift samples, each covering 0.0625 m^2.

[b] Stenothoidae includes *Metopella* and *Metopa*; Calliopiidae includes *Apherusa*. Genera indicated included species listed in Appendix C.

TABLE 18

Three-factor analyses of variance for the densities of dominant epibenthic crustaceans at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

Taxon	Source of variation and df^{a}				
	Period 5,4 or 24	Bay 1,4 or 24	Period x bay^{b} 5,4 or 24	Transect (bay)^{e} 4,251	Period x transect (bay) 20,251
Total epibenthos	1.48 ns^{f}	5.56 ns	0.09 ns	7.94 ***	2.18 **
Amphipoda	7.38 *	8.61 *	0.27 ns	3.21 *	1.92 *
Guernea sp.^{d}	3.64 *	18.68 ***	0.37 ns	2.66 *	1.42 ns
Calliopiidae spp.^{d}	0.85 ns	0.31 ns	0.63 ns	4.96 ***	2.24 **
Anonyx spp.^{d}	0.47 ns	6.11 ns	0.23 ns	5.98 ***	2.58 ***
Monoculodes spp.^{d}	–^{c}	–^{c}	3.27 *	2.85 *	0.62 ns
Bathymedon spp.^{d}	6.77 ***	12.33 **	0.58 ns	1.50 ns	1.54 ns
Stenothoidae spp.^{d}	3.06 ns	1.02 ns	0.03 ns	8.22 ***	2.34 **
Pontoporeia femorata	2.12 ns	2.30 ns	0.22 ns	8.74 ***	2.02 **
Cumacea	2.12 ns	36.86 **	0.23 ns	3.72 **	1.63 *
Lamprops fuscata	7.34 ***	13.23 **	0.67 ns	1.17 ns	1.60 ns
Brachydiastylis resima	0.56 ns	81.03 ***	0.17 ns	11.25 ***	0.91 ns
Ostracoda (Myodocopa)	0.32 ns	8.72 *	0.11 ns	8.56 ***	1.63 *

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[a] Where period x transect (bay) interaction was ns, it was pooled with transect (bay) effect to test bay, period and period x bay effects; where period x transect (bay) was significant ($P < 0.05$), transect (bay) alone was used to test main effects.

[b] The "period x bay" term is the test of oil effects.

[c] Interpretation of main effects confounded by significant interaction of "period x bay" term.

[d] Stenothoidae includes *Metopella* and *Metopa*; Calliopiidae includes *Apherusa*. Genera indicated include species listed in Appendix C.

[e] Transects are nested within bays.

[f] F-values are shown with significance levels (ns = $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$).

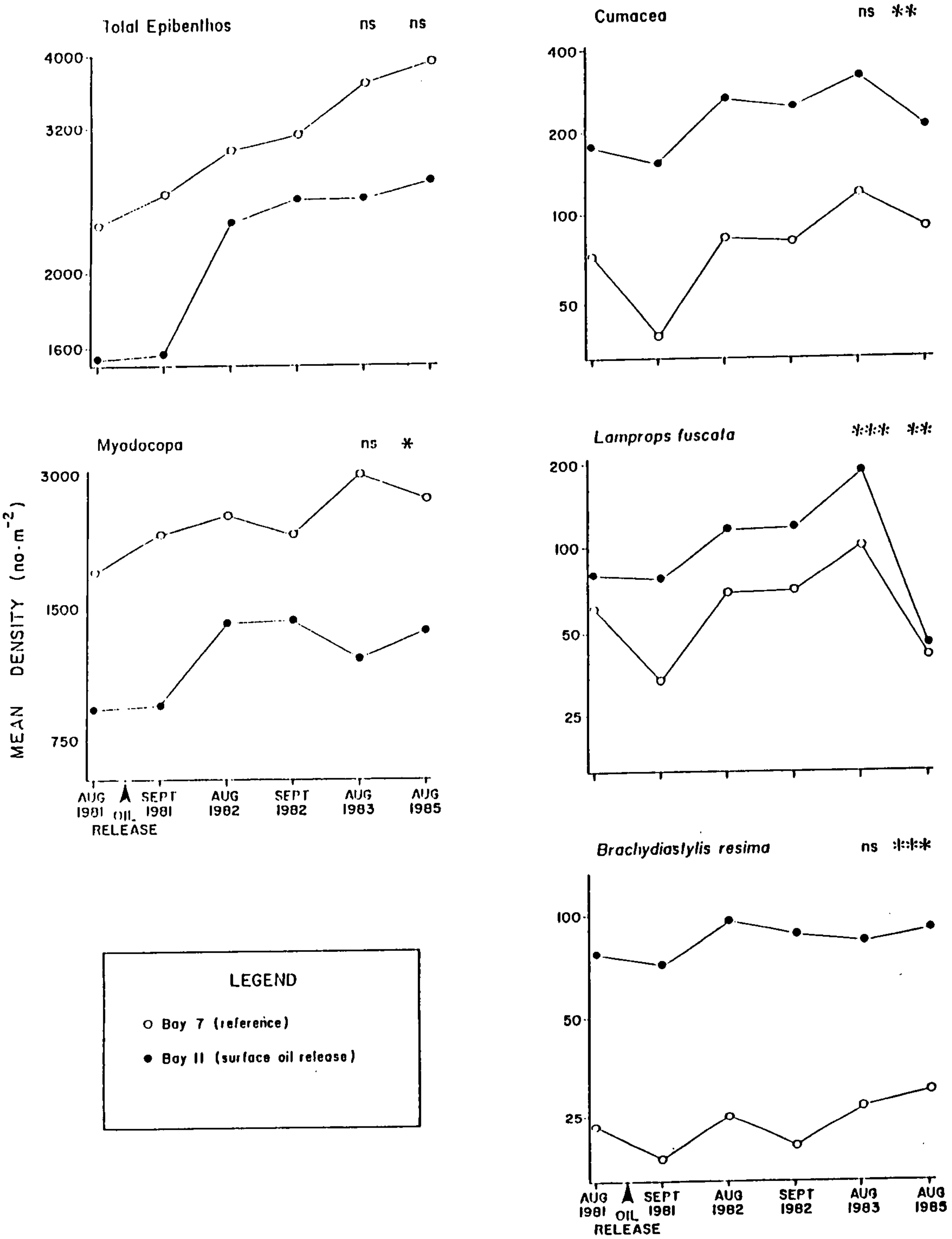

Figure 28. Mean density (no•m^{-2}) of total epibenthos, ostracods, and cumaceans, and of dominant amphipod species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as the back-transformed means of log-transformed data from 24 replicate 0.0625 m^2 airlift samples for each bay and period. Significance levels are shown for period effects, followed by bay effects. Note that the ordinate does not always begin at zero.

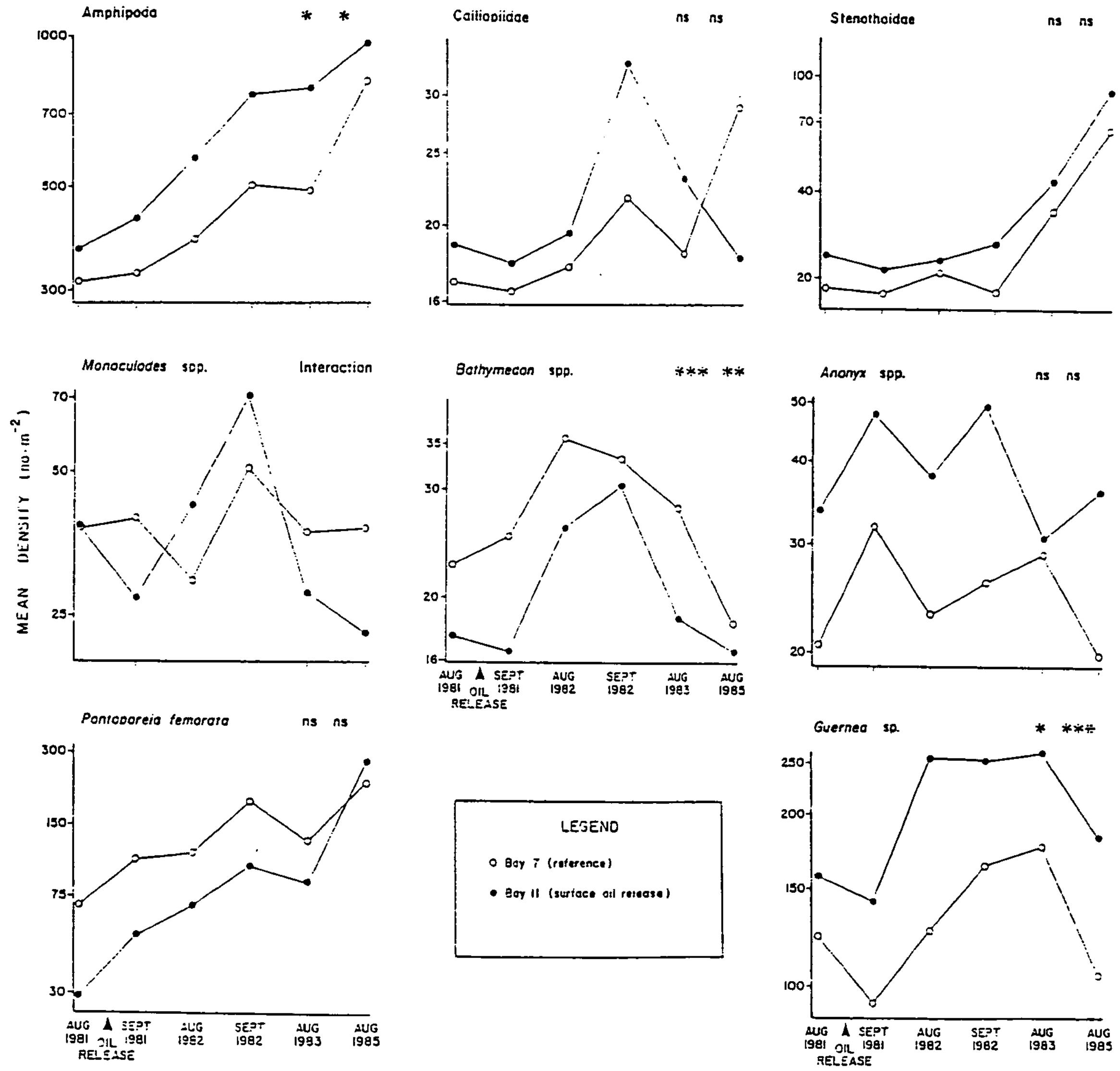

Figure 29. Mean density (no·m^{-2}) of total amphipods and dominant amphipod species at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as the back-transformed means of log-transformed data from 24 replicate 0.0625 m^2 airlift samples for each bay and period. Significance levels are shown for period effects, followed by bay effects. Note that the ordinate does not always begin at zero.

Temporal effects. Temporal variability was less common than was spatial variability; densities of only 4 of 13 taxa varied significantly over the study period (Table 18). Total amphipod density increased progressively between 1981 and 1985, whereas densities of Guernea sp. and Bathymedon spp. showed period-to-period increases and decreases (see Fig. 28); the latter trend was also true for the cumacean Lamprops fuscata (see Fig. 29). In all three species, densities decreased markedly between 1983 and 1985.

Oil Effects. Oil released at Cape Hatt in 1981 caused no marked reductions in densities of subtidal epibenthic crustaceans (see Figs. 28 and 29). In contrast, populations of the dominant intertidal amphipod Gammarus setosus were reduced in the surface oil release bay during the first post-spill sampling period (Cross and Martin 1983). Densities had increased by the following summer, but effects on the population structure of G. setosus were still apparent in the intertidal zone of Bay 11 during spring and summer of 1982.

Analysis of variance results show a possible effect of oil (i.e., a significant period x bay interaction term) in only 1 of 13 crustacean taxa for which density data were analyzed: the amphipod genus Monoculodes (see Table 18). Species of Monoculodes were pooled at the generic level because many undescribed species of that genus occur in the North Atlantic and Arctic[1]. Together, species of Monoculodes ranked seventh and tenth among the crustacean taxa dominating numbers and biomass, respectively, at Cape Hatt (see Table 17).

Inspection of density data for Monoculodes spp. shows a number of possible sources of the observed interaction effect. Density changes in Bay 11 (see Fig. 29) over the study period did not correspond closely with concomitant changes in oil concentrations in the sediment (see Fig. 3). Although decreased density in Bay 11 between 1982 and 1985 could be interpreted as a delayed effect of increased oil concentrations between 1981 and 1983, the decrease was within the range of natural variability: density of Monoculodes spp. in Bay 11 during August 1985 was similar to that in September 1980 (Cross et al. 1984). Therefore, we conclude that the significant interaction term did not indicate an unequivocal effect of oil.

ECHINODERMS

The urchin Strongylocentrotus droebachiensis is widely distributed and often relatively abundant (up to 14 individuals per square metre) in the Lancaster Sound area, whereas the distribution of the starfish Leptasterias polaris is more restricted (Thomson and Cross 1980). Both species are of interest because of their trophic positions. Strongylocentrotus droebachiensis is an herbivore which has a considerable effect on benthic algal populations off both the east and west coasts of Canada (Miller and Mann 1973; Foreman 1977). Leptasterias polaris is a top predator feeding primarily on large bivalves, and hence may be affected indirectly by oil

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[1] D. Laubitz, National Museum, personal communication, 1984.

through changes in bivalve populations. Thus, in spite of the interpretational difficulties caused by the mobility of these animals, densities of urchins and starfish were monitored carefully throughout this study.

Densities of Strongylocentrotus droebachiensis and Leptasterias polaris at 7 m depth in the study bays during each sampling period are shown in Table 19. Results of analyses of variance are given in Table 20.

Differences among transects were not significant for either species, nor was the period x transect interaction term significant. Among-bay differences, on the other hand, were significant for Leptasterias polaris, which was more abundant in Bay 7 than in Bay 11 (see Table 19). Temporal differences were also significant for L. polaris: densities in both bays were highest in September 1981, decreased between 1982 and 1983, and changed little between 1983 and 1985 (see Table 19). Bay and period effects for Strongylocentrotus droebachiensis are not given in Table 20 because of the significant period x bay interaction, but inspection of the data shows that urchins were considerably more abundant in Bay 7 than in Bay 11.

A possible effect of oil on Strongylocentrotus droebachiensis was indicated by the significant period x bay interaction in analysis of variance (see Table 20). Sources of the observed interaction effect likely were first,density decreases only in Bay 7 between August 1981 and 1982, and secondly, a density decrease only in Bay 11 between 1982 and 1983 (see Table 19). The former difference between bays probably does not represent an oil effect, because density decreased in the reference bay and not in the oiled bay. The latter difference, together with additional data from two oiled bays not included in the present study, was interpreted by Cross et al. (1984) as a possible oil effect, because decreases in urchin density corresponded with increases in oil concentration in subtidal sediments. It was suggested that the surface deposit-feeding urchins may have avoided oiled sediment in Bay 11 and two other oiled bays by moving to deeper, uncontaminated areas, but it was also noted that urchin densities in 1983 were only slightly lower than pre-spill values (Cross et al. 1984).

Between 1983 and 1985 there was little change in urchin density in either Bay 7 or Bay 11 (see Table 19), neither was there any significant change in oil concentrations in sediments at 7 m depth. This corroborates the previous suggestion of a possible oil effect, although it is re-emphasized that any changes in urchin density attributable to oiled sediment were minor. Furthermore, data from 1985 indicate that urchin densities were not altered after two years (1983-1985) of living on, and presumably ingesting, oiled sediment.

TABLE 19

Densities of urchins (*Strongylocentrotus droebachiensis*) and starfish (*Leptasterias polaris*) at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

		Bay 7		Bay 11	
Species	Period	Date	Mean ± SD[a]	Date	Mean ± SD[a]
Urchin (no·m^{-2})	Pre-spill 2	15 Aug 1981	10.0 ± 3.4	10 Aug 1981	1.3 ± 0.5
	Post-spill 1	2 Sept 1981	7.8 ± 3.5	1 Sept 1981	1.3 ± 0.7
	Post-spill 2	12 Aug 1982	5.8 ± 2.3	8,14 Aug 1982	1.2 ± 0.5
	Post-spill 3	5 Sept 1982	5.8 ± 2.6	2 Sept 1982	1.2 ± 0.6
	Post-spill 4	9 Aug 1983	6.3 ± 1.8	6 Aug 1983	0.7 ± 0.4
	Post-spill 5	18 Aug 1985	7.0 ± 1.9	19 Aug 1985	0.8 ± 0.4
Starfish (no·10 m^{-2})	Pre-spill 2	15 Aug 1981	3.3 ± 2.5	10 Aug 1981	0.5 ± 0.8
	Post-spill 1	2 Sept 1981	4.5 ± 3.3	1 Sept 1981	1.6 ± 2.0
	Post-spill 2	12 Aug 1982	2.6 ± 2.0	8,14 Aug 1982	1.1 ± 1.0
	Post-spill 3	5 Sept 1982	3.3 ± 3.4	2 Sept 1982	0.7 ± 0.7
	Post-spill 4	9 Aug 1983	1.2 ± 0.9	6 Aug 1983	0.4 ± 0.8
	Post-spill 5	18 Aug 1985	0.9 ± 1.0	19 Aug 1985	0.7 ± 0.7

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[a] Data are based on 15 *in situ* counts, each covering 10 m^2, in each period-bay combination.

TABLE 20

Three-factor analyses of variance for densities[a] of urchins and starfish at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985.

	Source of variation and df[b]				
Species	Period 5,24	Bay 1,24	Period x bay[c] 5,24	Transect (bay) 4,144	Period x transect (bay) 20,144
Strongylocentrotus droebachiensis	–[d]	–[d]	2.64 *[e]	0.96 ns	0.80 ns
Leptasterias polaris	6.70 ***	46.84 ***	2.45 ns	0.36 ns	1.21 ns

[a] Based on log-transformed *in situ* counts within five 1 x 10 m areas on each of three transects in each bay and period.

[b] Because the period x transect (bay) interactions was ns, it was pooled with transect (bay) effect to test bay, period and period x bay effects.

[c] The "period x bay" term is the test of oil effects.

[d] Interpretation of main effects confounded by significant interaction of "period x bay" term.

[e] F-values are shown with significance levels (ns = $P > 0.05$; * $P \leq 0.05$; ** $P \leq 0.01$; *** $P \leq 0.001$).

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APPENDICES

Appendix A. Dates and locations (bay, transect, and number of metres from N to S along the transect line) of each airlift sample collected at 7 m depth in two bays at Cape Hatt, northern Baffin Island in 1981 (Pre-spill Period 2 and Post-spill Period 1), 1982 (Post-spill Periods 2 and 3), 1983 (Post-spill Period 4) and 1985 (Post-spill Period 5).

			Replicate								
Bay	Transect	Period	1	2	3	4	5	6	7	8	Date(s)
7	1	Pre-2	2	6*	24	29	31*	36	39*	45	16 Aug
		Post-1	1*	4	11*	15	24*	33*	40*	42	3 Sept
		Post-2	5	7*	22	30	33	38*	40	46*	13 Aug
		Post-3	10	10*	26	35	36*	37	37*	42*	6 Sept
		Post-4	3	4*	21	29*	43*	46	49	49*	9 Aug
		Post-5	8	12*	14*	19	25	25*	35*	38	18 Aug
	2	Pre-2	0	19	30	31*	35	37	38*	49*	16 Aug
		Post-1	4*	10*	12*	26	28	36	46	48*	3 Sept
		Post-2	1	2	10	11*	14*	17*	31	42	13 Aug
		Post-3	4	8	12	16*	26*	42*	43*	47	6 Sept
		Post-4	0*	1*	3*	24*	31	33	38*	39	9 Aug
		Post-5	5	13	21	23	41*	43	45*	48	18 Aug
	3	Pre-2	5*	9	11*	15	20	22	27	36*	17 Aug
		Post-1	0	5	14	17*	25	25*	29*	48	3 Sept
		Post-2	2	4	4*	15*	19*	33	34	42	13 Aug
		Post-3	11	21*	22*	23*	24	28	36	44	6 Sept
		Post-4	2*	8	18	20*	21	42*	44*	45	9 Aug
		Post-5	8*	9*	10*	14*	17	26	31	48*	18 Aug
11	1	Pre-2	3	8	8*	12*	29*	35*	35*	39*	10 Aug
		Post-1	15	19	25	26	27*	30*	38*	42	1 Sept
		Post-2	0	2	4	7	11*	19*	22	35	8 Aug
		Post-3	6	6*	16	20*	23	38	46	49*	3 Sept
		Post-4	2*	5	12	20	30	36*	41*	47*	6 Aug
		Post-5	9*	16*	25*	26*	28*	34	42*	44	19 Aug
	2	Pre-2	3*	6*	14	35	40	45	47*	48	12 Aug
		Post-1	3	3*	13*	18*	20	22*	30*	47*	1, 2 Sept
		Post-2	4*	10*	11*	15	19	24*	32*	49	8, 15 Aug
		Post-3	0	8	9*	20*	28	28*	31*	37	3 Sept
		Post-4	17*	18	19*	21*	29*	35*	39*	42*	6 Aug
		Post-5	23	27	31	33	38	41*	43	48*	19 Aug
	3	Pre-2	4	6*	8*	14*	34*	35	36	48*	12 Aug
		Post-1	6	8	11	12*	13*	28	30	44	2 Sept
		Post-2	1*	7*	16*	18	23	30*	38	43	15 Aug
		Post-3	1	3	12*	25	31*	41	44*	45	3 Sept
		Post-4	5*	15	17*	18*	23*	24	41*	47*	6 Aug
		Post-5	0*	5	11*	21	22*	31	35*	40*	19 Aug

* Indicates sample taken seaward of the transect line.

Appendix B. Hydrocarbon methodology--analytical conditions, limits of detection, abbreviations and definitions of terminology, methods of calculation, properties of Lagomedio oil, selective ion monitoring (SIM) plots from a typical sediment extract.

GC/FID Analytical Conditions

Column:	25 m x 0.25 mm BP5 5% phenyl, polydimethyl-siloxane bonded phase fused silica column (S.G.E.)
Carrier Gas:	hydrogen
Column Flow Rate:	1.5 mL min-1 (90 cm.s-1 linear rate)
Injector Flow Rate:	60 mL min-1
Injector Pressure:	18 psi
Injector Temperature:	250° C
Detector Temperature:	300° C
Detector Make-Up:	30 mL min^{-1} nitrogen
Split Ratio:	40:1 (approx.)
Temperature Program:	50° C for 1 min, then 10 C° min^{-1} to 300° C, and hold for 10 minutes

All injections made in the splitless mode, and stream splitting resumed after 1.0 minute.

Limit of Detection for Selected Alkanes

Alkane	Detection Limit (ng/sample)
nC12	10
nC16	10
nC20	15
nC28	20
nC36	30

Appendix B. Continued.

Weathering Indices

1. Alkane/Isoprenoid Ratio (Biodegradation)

$$\text{Alk/Iso} = \frac{\text{nC14} + \text{nC15} + \text{nC16} + \text{nC17} + \text{nC18}}{\text{FARN} + \text{TM13} + \text{NOR} + \text{PRIS} + \text{PHYT}}$$

This ratio approaches 0 as the n-alkanes are preferentially depleted.

2. n-C18/Phytane Ratio

This ratio approaches 0 as n-C18 is preferentially depleted. This is a specific case of the Alk/Iso ratio.

3. Pristane/Phytane Ratio

Pristane occurs commonly in biota and in recent sediments as a degradation product of the phytol side chain of plant pigment chlorophyll whereas phytane is not formed and is not commonly found in recent sediments; consequently, non-petrolum derived hydrocarbons generally give rise to a high pristane/phytane ratio. The pristane/phytane ratio has been used as an indicator of the presence or absence of petroleum. Although a high pristane/phytane ratio is generally a reliable indicator of the absence of petroleum, the converse is not necessarily true, that is, low values are less reliable indicators of the presence of petroleum hydrocarbons. Typical background values for this ratio are >5, as reported by Boehm (1981).

4. Saturate Hydrocarbon Weathering Ratio (SHWR)

$$\text{SHWR} = \frac{\text{sum of n-alkanes from nC12 to nC25}}{\text{sum of n-alkanes from nC17 to nC25}}$$

The SHWR approaches 1.0 as low-boiling saturated hydrocarbons (nC12-nC17) are lost by evaporation.

5. Carbon Preference Index (CPI)

$$\text{CPI} = \frac{2\,(\text{nC27} + \text{nC29})}{\text{nC26} + 2\,\text{nC28} + \text{nC30}}$$

CPI 1.0 for petroleum

CPI ranges from 3-6 for terriginous waxes, reflecting the formation mechanism for long chain hydrocarbons.

6. Aromatic Weathering Ratio

$$\text{AWR} = \frac{\substack{\text{Alkyl benzenes} + \text{naphthalenes} + \text{fluorenes} \\ \text{phenanthrenes} + \text{dibenzothiophenes}}}{\text{Total phenanthrenes} + \text{dibenzothiophenes}}$$

The AWR approaches 1.0 as low boiling aromatics are lost by evaporation and/or dissolution.

7. Σ PAH = summation of 4 and 5-ring PAH.

8. Total PAH = summation of alkyl naphthalenes, fluorenes, phenanthrenes, dibenzothiophenes and PAH.

Lagomedio Properties

	Fresh Oil	Aged Oil
Saturates		
SHWR	2.87	2.28
ALK/ISO	2.36	2.50
PRIS/PHYT	0.85	0.74
C18/PHYT	1.64	1.61
Aromatics		
AWR	4.29	3.47

Appendix B. Continued.

Abbreviations and Definitions of Terminology

Alk	alkane
Iso	isoprenoid
Farn	farnesane, an isoprenoid
TM13	trimethyltridecane, an isoprenoid
Nor	norpristane, an isoprenoid
Pris	pristane, an isoprenoid
Phyt	phytane, an isoprenoid
PAH	Polycyclic Aromatic Hydrocarbons
AB	alkylbenzenes (C_3 to C_6)
Naph	naphthalene
Fluor	fluorene
Dbt	dibenzothiophene
Phen	phenanthrene
Anth	anthracene
C-0	no alkyl groups
C-1	methyl
C-2	dimethyl or ethyl
C-3	trimethyl, ethylmethyl, isopropyl, propyl
C-4 to C-6	alkylation patterns from 4 to 6 carbons
I.S.	internal standard

Appendix B. Continued.

GC/MS Analytical Conditions

Column:	25 m x 0.25 mm BP-5 5% phenyl, polydimethyl siloxane bonded phase fused silica column (S.G.E.).
Carrier Gas:	helium
Injector Flow Rate:	60 mL min^{-1}
Injector Pressure:	17 p.s.i.g.
Column Flow:	40 cm s^{-1}
Split Ratio:	40:1 (approximately)
Injector Temperature:	260° C
Injection Sequence:	splitless injection at room temperature, splitting resumed at 1 minute, 100° C at 2 minutes and 10° min^{-1} at 4 minutes to 280° C and hold for 10 minutes. 0.5 µL injections.
Mass Spectrometer:	electron impact source
Source Emission	0.50 mA
Electron Energy:	40 eV
Operating Pressure:	1×10^{-5} torr
Multiplier Voltage:	2000 V (gain > 10^6)
Data System:	data are acquired in the continuous scan mode from 40 to 350 amu from 4 min after sample injection, or, for SIM, one scan per second for four selected ions, with five pre-selected clusters of four ions each
Acquisition Rate:	one scan of 4 selected ions per second, 5 clusters of 4 ions

The GC conditions used provides adequate separation (i.e., resolution with 10% valley or better) for the following isomers:

phenanthrene/anthracene

benz(a)anthracene/chrysene

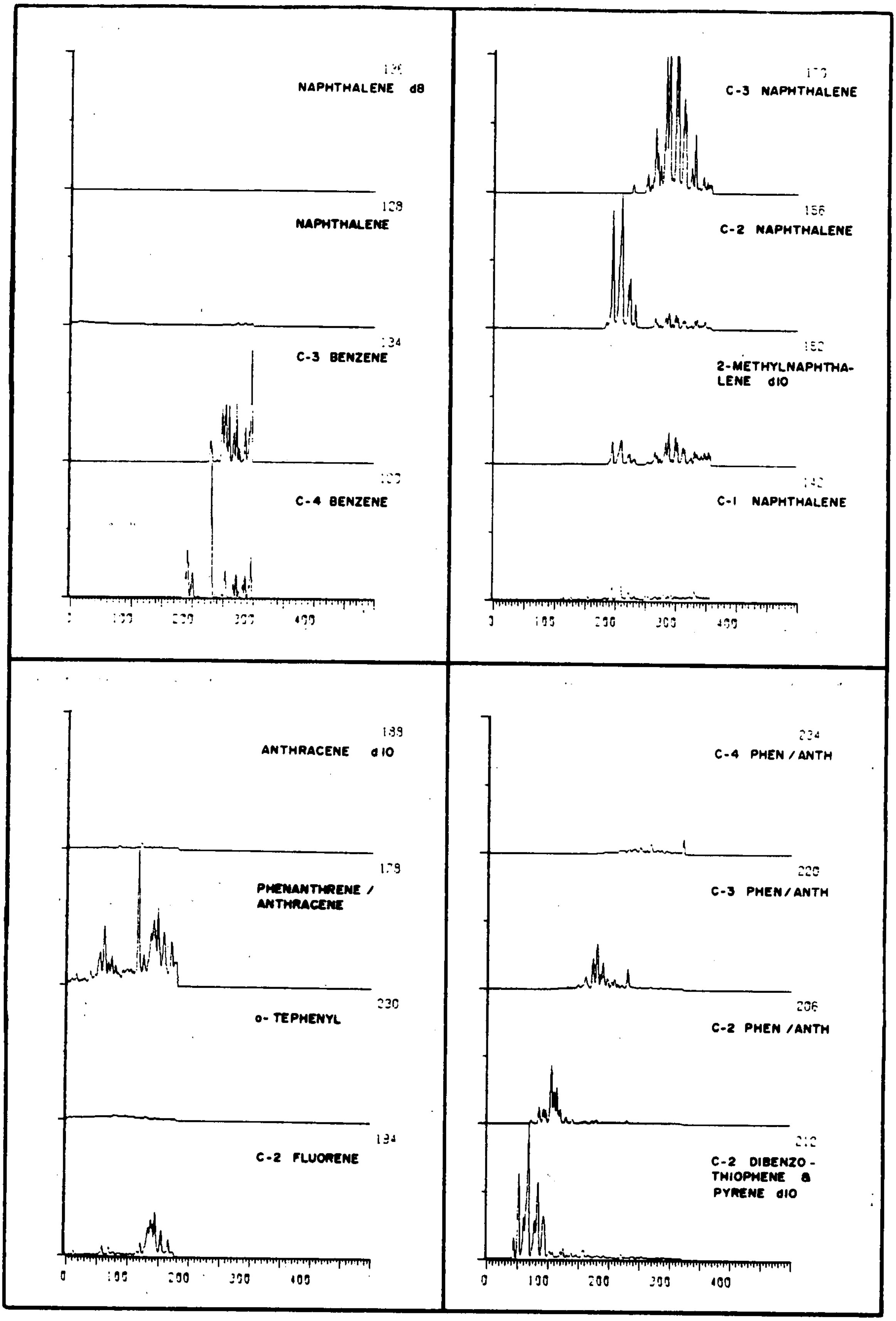
benzo(e)pyrene/benzo(a)pyrene/perylene

Limit of Detection for Selected PAH

Compound	Detection Limit (ng/sample)
naphthalene	0.25
fluorene	0.5
phenanthrene	0.5
pyrene	0.5
chrysene	1.0
benzo(a)pyrene	1.0
perylene	1.0

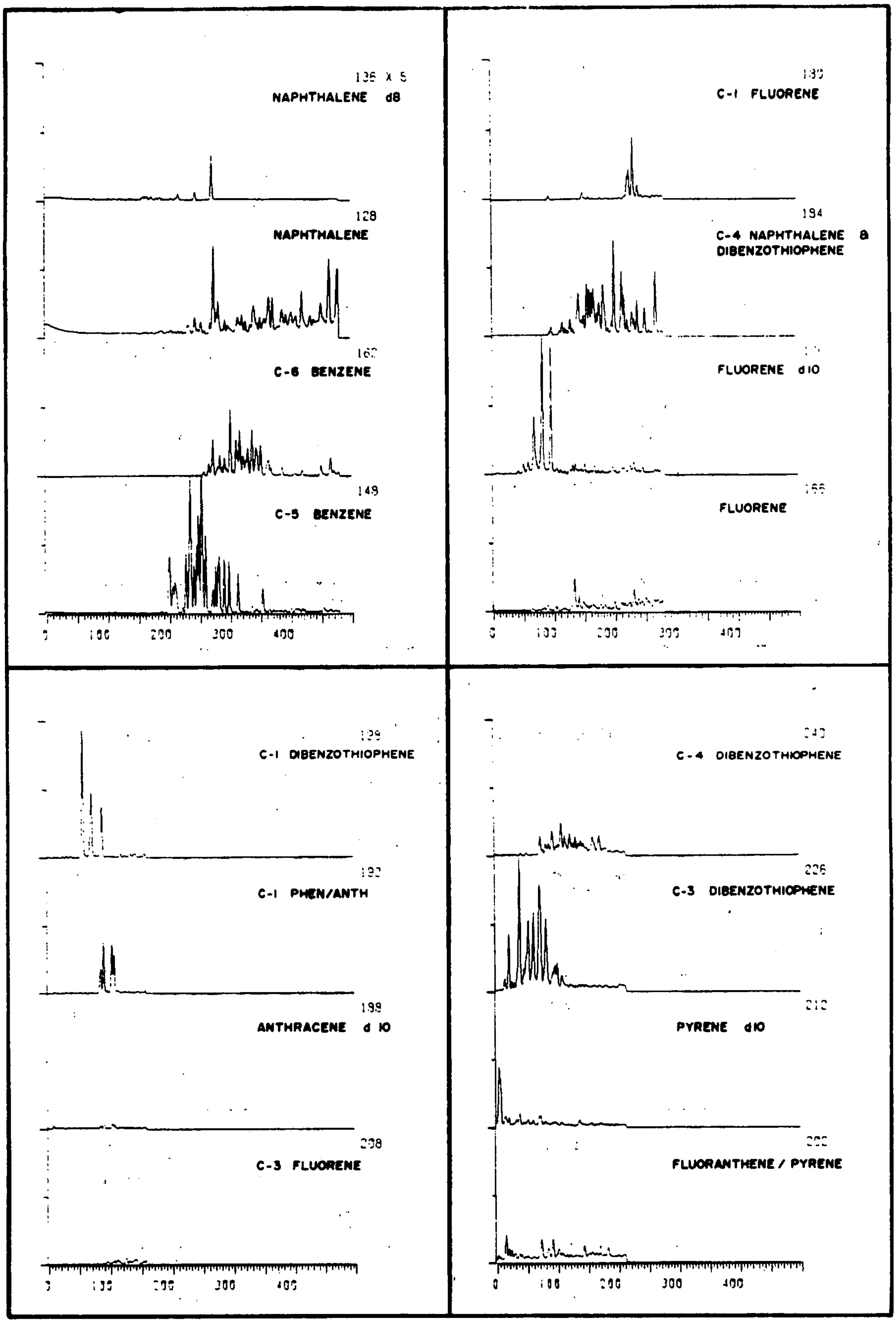
Appendix B. Continued.

Selected Ion Scans



Appendix B. Concluded.

Selected Ion Scans



APPENDIX C. List of species of benthic fauna collected by airlift in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982 and August 1983 and 1985.

ANTHOZOA

Unidentified Anthozoa

NEMERTINEA

Unidentified Nemertinea

NEMATODA

Unidentified Nematoda

POLYCHAETA

Ampharete acutifrons
Amphicteis sundevalli
Amphitrite cirrata
Antinoella sarsi
Apistobranchus tullbergi
Aricidea suecica
Asabellides sibirica
Axiothella catenata
Brada granulata
Brada inhabilis
Brada nuda
Brada villosa
Capitella capitata
Chaetozone setosa
Chone infundibuliformis
Cirratulus cirratus
Cossura longocirrata
Diplocirrus hirsutus
Dysponetus pygmaeus
Ephesiella minuta
Eteone longa
Euchone analis
Exogone verrugera
Gattyana cirrhosa
Glycera capitata
Harmothoe extenuata
Harmothoe imbricata
Laonome kroyeri
Laphania boecki
Lumbrinereis minuta
Maldane sarsi
Marenzellaria wireni
Mediomastus sp.
Melaenis loveni
Myriochele oculata
Nephtys ciliata
Nereimyra punctata
Nereis zonata
Nicolea sp.
Nicomache lumbricalis
Ophelia limacina
Ophelina accuminata
Oriopsis crenicollis
Owenia fusiformis
Paraonis gracilis
Pectinaria granulata
Pectinaria hyperborea
Petaloproctus tenuis
Pholoe minuta
Phyllodoce groenlandica
Pista cristata
Pista maculata

Continued...

Polycirrus medusa
Polydora quadrilobata
Potamilla neglecta
Praxillella praetermissa
Prionospio steenstrupi
Proclea sp.
Pseudomaloceros sp.
Pygospio elegans
Rhodine loveni
Scalibregma inflatum
Scoloplos armiger
Sphaerodoropsis biserialis
Sphaerodoropsis minuta
Spio sp.
Spirorbis sp.
Terebellides stroemi
Tharyx marioni
Travisia forbesi
Trichobranchus glacialis
Unidentified Polychaeta

OLIGOCHAETA

Unidentified Oligochaeta

GASTROPODA

Acmaea rubella
Acmaea testudinalis
Admete couthouyi
Alvania mighelsi
Beringius sp.
Buccinum ciliatum
Buccinum cf. scalariforme
Buccinum sericatum
Buccinum undatum
Cingula castanea
Colus sp.
Colus cf. spitzbergensis
Colus togatus
Colus tortuosus
Frigidoalvania cruenta
Lepeta caeca
Lunatia pallida
Margarites groenlandicus
Margarites helicinus
Margarites umbilicalis
Moelleria costulata
Naticidae sp.
Oenopota arctica
Oenopota cf. bicarinata
Oenopota cf. cinerea
Oenopota decussata
Oenopota elegans
Oenopota incisula
Oenopota pyramidalis
Oenopota reticulata
Oenopota turricula
Oenopota sp.
Philine lima
Rissoidae sp.
Retusa obtusa
Trichotropis borealis
Unidentified Gastropoda

Continued...

POLYPLACOPHORA

Tonicella marmorea

BIVALVIA

Astarte borealis
Astarte montagui
Clinocardium ciliatum
Hiatella arctica
Lyonsia arenosa
Macoma calcarea
Macoma loveni
Macoma moesta
Musculus discors
Musculus niger
Mya truncata
Nucula belloti
Nuculana minuta
Periploma sp.
Serripes groenlandicus
Thracia sp.
Thyasiridae spp.
Yoldiella sp.
Unidentified Bivalvia

CUMACEA

Brachydiastylis resima
Brachydiastylis sp.
Campylaspis rubicundra
Diastylis dalli
Diastylis edwardsi
Diastylis lepechini
Diastylis lucifera
Diastylis rathkei
Diastylis sculpta
Diastylis sp.
Eudorella hirsuta
Lamprops fasciata
Lamprops fuscata
Leptostylis macrura
Leucon nasica
Leucon nasicoides
Leucon pallida
Leucon sp.

OSTRACODA

Eucytheridea bradii
Eucytheridea punctillata
Finmarchinella finmarchica
Philomedes globosa

AMPHIPODA

Ampelisca sp.
Anonyx nugax
Anonyx sarsi
Apherusa megalops
Bathymedon longimanus
Bathymedon obtusifrons
Boeckosimus plautus
Byblis gaimardi
Centromedon pumilus
Corophium clarencense
Gammarus setosus

Continued...

Guernea nordenskioldi
Guernea sp.
Haploops laevis
Haploops tubicola
Harpinia serrata
Ischyrocerus sp.
Melita dentata
Metopa sp.
Metopella carinata
Monoculodes borealis
Monoculodes kroyeri
Monoculodes latimanus
Monoculodes sp.
Monoculopsis longicornis
Oediceros sp.
Onisimus litoralis
Orchomene minuta
Parapleustes gracilis
Paroediceros lynceus
Photis reinhardi
Phoxocephalus holbolli
Pleustidae sp.
Pleusymtes glaber
Pontogeneia inermis
Pontoporeia femorata
Protomedia fasciata
Stenothoidae spp.
Tmetonyx sp.
Westwoodilla brevicalcar
Westwoodilla megalops
Weyprechtia pinguis
Unidentified Amphipoda

DECOPODA

Argis sp.
Lebbeus microceros
Lebbeus polaris
Sclerocrangon boreas
Sclerocrangon ferox

OTHER CRUSTACEA

Unidentified Mysidacea
Unidentified Nebaliacea
Unidentified Tanaidacea
Unidentified Isopoda

ASTEROIDEA

Leptasterias groenlandica
Leptasterias polaris
Stephanasterias albula

OPHIUROIDEA

Amphiura psilopora
Amphiura sundevalli
Ophiocten sericeum
Ophiopus arcticus
Ophiura robusta
Ophiura sarsi

ECHINOIDEA

Strongylocentrotus droebachiensis

HOLOTHUROIDEA

Myriotrochus rinkii

Continued...

Appendix C Concluded.

ASCIDIACEA

Unidentified Ascidiacea

OTHER PHYLA

Priapulus bicaudatus

Priapulus caudatus

Unidentified Echiura

Unidentified Sipuncula

PISCES

Artediellis uncinatus

Eumicrotremus sp.

Gymnelis sp.

Gymnocanthus tricuspis

Appendix D. Mean density (numbers per square metre) of major taxa and species of infauna at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as mean ± standard deviation and are based on 8 replicate 0.0625 m^2 air-lift samples on each of three transects for each period and bay.

Taxon	Period	Bay 7	Bay 11
Total infauna	Aug 1981	2550.7 ± 795.3	2889.3 ± 837.7
	Sept 1981	2771.3 ± 648.8	2791.2 ± 1053.6
	Aug 1982	2929.8 ± 1151.2	3286.6 ± 937.2
	Sept 1982	3352.7 ± 1465.0	3900.7 ± 1234.1
	Aug 1983	3589.3 ± 1061.6	3739.2 ± 111.5
	Aug 1985	3804.1 ± 1732.2	4056.5 ± 1464.8
Polychaeta	Aug 1981	764.7 ± 303.5	944.0 ± 317.8
	Sept 1981	802.7 ± 285.7	714.7 ± 287.6
	Aug 1982	859.8 ± 370.7	1027.1 ± 373.1
	Sept 1982	1138.0 ± 523.2	1534.7 ± 959.0
	Aug 1983	1627.3 ± 648.2	1474.3 ± 686.0
	Aug 1985	2022.5 ± 1712.5	1827.9 ± 971.3
Pholoe minuta	Aug 1981	339.3 ± 163.8	258.7 ± 141.9
	Sept 1981	376.0 ± 193.9	253.5 ± 136.1
	Aug 1982	330.1 ± 183.6	347.8 ± 204.9
	Sept 1982	394.0 ± 227.0	396.7 ± 130.1
	Aug 1983	803.3 ± 395.6	516.3 ± 282.2
	Aug 1985	720.8 ± 501.0	522.3 ± 336.3
Spio spp.	Aug 1981	10.0 ± 15.5	16.0 ± 26.3
	Sept 1981	14.7 ± 15.6	3.5 ± 10.7
	Aug 1982	18.7 ± 23.4	28.7 ± 38.0
	Sept 1982	44.0 ± 42.0	96.7 ± 92.0
	Aug 1983	102.7 ± 120.2	45.3 ± 56.4
	Aug 1985	259.5 ± 568.2	295.9 ± 439.8
Capitella capitata	Aug 1981	20.0 ± 29.2	21.3 ± 32.9
	Sept 1981	10.0 ± 14.8	8.3 ± 10.6
	Aug 1982	18.0 ± 34.6	18.7 ± 23.9
	Sept 1982	28.7 ± 27.1	33.3 ± 35.9
	Aug 1983	80.0 ± 190.5	20.6 ± 35.1
	Aug 1985	182.4 ± 611.4	27.6 ± 36.5
Pectinaria granulata	Aug 1981	62.0 ± 45.3	49.3 ± 29.1
	Sept 1981	50.7 ± 35.2	54.6 ± 47.7
	Aug 1982	42.7 ± 38.8	47.3 ± 29.3
	Sept 1982	48.7 ± 37.3	60.7 ± 32.0
	Aug 1983	50.0 ± 49.1	50.0 ± 26.0
	Aug 1985	50.0 ± 40.9	72.7 ± 38.0

Continued...

Appendix D Continued.

Taxon	Period	Bay 7	Bay 11
Praxillella praetermissa	Aug 1981	18.7 ± 19.3	48.7 ± 31.1
	Sept 1981	19.3 ± 20.6	60.9 ± 49.5
	Aug 1982	24.0 ± 14.2	60.7 ± 42.5
	Sept 1982	48.0 ± 30.6	94.7 ± 68.2
	Aug 1983	53.3 ± 43.7	86.0 ± 61.7
	Aug 1985	60.7 ± 89.0	78.7 ± 52.5
Maldane sarsi	Aug 1981	30.7 ± 53.6	114.7 ± 130.5
	Sept 1981	25.3 ± 33.7	68.5 ± 74.1
	Aug 1982	30.0 ± 38.7	82.7 ± 96.4
	Sept 1982	49.3 ± 108.2	58.7 ± 66.7
	Aug 1983	70.0 ± 71.8	100.0 ± 119.4
	Aug 1985	68.0 ± 77.1	101.3 ± 140.3
Mediomastus spp.	Aug 1981	5.3 ± 14.7	14.7 ± 17.0
	Sept 1981	11.3 ± 18.6	5.6 ± 9.2
	Aug 1982	51.4 ± 46.8	16.0 ± 27.9
	Sept 1982	92.0 ± 92.0	60.7 ± 66.9
	Aug 1983	86.7 ± 83.3	41.3 ± 55.8
	Aug 1985	77.6 ± 200.4	81.5 ± 142.9
Ampharete acutifrons	Aug 1981	15.3 ± 19.2	56.0 ± 58.0
	Sept 1981	14.0 ± 22.3	39.3 ± 35.7
	Aug 1982	21.3 ± 35.8	48.7 ± 50.0
	Sept 1982	40.7 ± 43.8	78.0 ± 71.3
	Aug 1983	23.3 ± 30.9	57.3 ± 47.9
	Aug 1985	17.3 ± 23.3	109.2 ± 135.0
Lumbrinereis minuta	Aug 1981	1.3 ± 6.5	81.3 ± 60.2
	Sept 1981	4.7 ± 7.4	42.8 ± 40.5
	Aug 1982	6.7 ± 10.5	58.0 ± 44.7
	Sept 1982	9.3 ± 15.6	62.0 ± 68.7
	Aug 1983	10.0 ± 14.8	69.3 ± 61.3
	Aug 1985	9.3 ± 18.2	45.3 ± 46.6
Diplocirrus spp.	Aug 1981	38.7 ± 38.0	30.7 ± 26.7
	Sept 1981	32.7 ± 41.3	15.3 ± 18.4
	Aug 1982	44.0 ± 64.4	34.5 ± 29.1
	Sept 1982	49.3 ± 38.0	33.3 ± 26.2
	Aug 1983	36.7 ± 31.8	24.0 ± 25.4
	Aug 1985	35.3 ± 31.6	18.0 ± 16.6

Continued...

Appendix D Continued.

Taxon	Period	Bay 7	Bay 11
Bivalvia	Aug 1981	1406.0 ± 692.7	1608.7 ± 540.0
	Sept 1981	1614.0 ± 636.2	1686.6 ± 703.9
	Aug 1982	1652.0 ± 931.5	1760.7 ± 592.8
	Sept 1982	1791.3 ± 1057.7	1876.7 ± 585.5
	Aug 1983	1541.3 ± 621.9	1776.0 ± 684.4
	Aug 1985	1291.0 ± 619.9	1598.0 ± 768.7
Mya truncata	Aug 1981	128.7 ± 75.9	190.0 ± 105.3
	Sept 1981	121.3 ± 67.9	172.5 ± 89.6
	Aug 1982	101.3 ± 56.7	172.0 ± 90.3
	Sept 1982	147.3 ± 89.5	185.3 ± 101.1
	Aug 1983	104.7 ± 45.0	157.3 ± 85.0
	Aug 1985	100.9 ± 72.1	154.0 ± 90.5
Thyasiridae spp.	Aug 1981	412.7 ± 261.4	77.3 ± 72.6
	Sept 1981	496.7 ± 261.6	99.5 ± 171.9
	Aug 1982	505.3 ± 356.6	87.3 ± 73.4
	Sept 1982	588.7 ± 416.1	88.0 ± 69.2
	Aug 1983	604.0 ± 359.9	87.3 ± 73.8
	Aug 1985	360.7 ± 272.1	81.3 ± 51.2
Astarte borealis	Aug 1981	160.7 ± 129.0	382.0 ± 174.9
	Sept 1981	192.0 ± 111.7	340.5 ± 197.5
	Aug 1982	169.3 ± 131.8	367.3 ± 158.2
	Sept 1982	186.7 ± 209.2	383.3 ± 180.4
	Aug 1983	152.0 ± 92.5	344.7 ± 160.3
	Aug 1985	95.3 ± 92.5	263.3 ± 148.3
Astarte montagui	Aug 1981	44.0 ± 45.1	443.3 ± 208.2
	Sept 1981	44.0 ± 35.1	496.3 ± 294.5
	Aug 1982	45.3 ± 44.7	500.7 ± 233.8
	Sept 1982	28.7 ± 41.9	512.7 ± 224.8
	Aug 1983	38.7 ± 34.3	507.3 ± 249.0
	Aug 1985	50.7 ± 53.1	490.0 ± 308.3
Astarte juveniles	Aug 1981	35.3 ± 33.4	224.0 ± 122.4
	Sept 1981	41.3 ± 32.3	287.0 ± 167.7
	Aug 1982	49.3 ± 45.0	272.0 ± 215.0
	Sept 1982	72.7 ± 96.7	248.0 ± 173.6
	Aug 1983	30.7 ± 24.9	256.7 ± 167.3
	Aug 1985	24.0 ± 25.8	212.7 ± 153.6

Continued...

Appendix D Continued.

Taxon	Period	Bay 7	Bay 11
Macoma calcarea	Aug 1981	262.0 ± 138.8	68.0 ± 40.9
	Sept 1981	266.7 ± 120.0	61.9 ± 37.5
	Aug 1982	257.3 ± 138.1	80.0 ± 47.2
	Sept 1982	253.3 ± 155.7	107.3 ± 47.8
	Aug 1983	256.7 ± 111.4	94.7 ± 55.6
	Aug 1985	193.3 ± 97.0	66.0 ± 47.3
Macoma juveniles	Aug 1981	92.0 ± 60.7	50.0 ± 43.1
	Sept 1981	147.3 ± 110.3	37.2 ± 53.7
	Aug 1982	121.3 ± 92.7	65.3 ± 53.8
	Sept 1982	129.3 ± 101.7	102.0 ± 67.5
	Aug 1983	111.3 ± 71.6	78.0 ± 67.9
	Aug 1985	69.3 ± 77.6	79.3 ± 52.0
Musculus juveniles	Aug 1981	67.3 ± 100.7	12.7 ± 18.9
	Sept 1981	66.0 ± 145.7	13.6 ± 30.6
	Aug 1982	152.0 ± 275.7	22.7 ± 24.9
	Sept 1982	136.7 ± 215.6	32.0 ± 36.5
	Aug 1983	73.3 ± 76.6	49.3 ± 53.6
	Aug 1985	164.1 ± 151.5	74.7 ± 98.4
Nuculana minuta	Aug 1981	76.7 ± 46.0	87.3 ± 42.7
	Sept 1981	92.7 ± 65.5	104.3 ± 45.7
	Aug 1982	101.3 ± 102.4	130.0 ± 74.0
	Sept 1982	90.7 ± 60.4	135.3 ± 79.9
	Aug 1983	62.0 ± 37.2	115.3 ± 64.5
	Aug 1985	76.7 ± 45.0	104.0 ± 66.7
Serripes groenlandicus	Aug 1981	44.7 ± 31.6	17.3 ± 23.6
	Sept 1981	39.3 ± 38.3	13.2 ± 25.4
	Aug 1982	56.7 ± 52.1	8.7 ± 14.1
	Sept 1982	51.3 ± 41.7	10.7 ± 14.7
	Aug 1983	34.0 ± 36.3	8.7 ± 15.6
	Aug 1985	32.0 ± 29.8	14.0 ± 26.0
Gastropoda	Aug 1981	334.7 ± 158.1	318.7 ± 194.1
	Sept 1981	334.0 ± 111.2	367.7 ± 212.3
	Aug 1982	384.0 ± 268.9	474.4 ± 236.1
	Sept 1982	381.3 ± 228.6	468.7 ± 164.3
	Aug 1983	376.7 ± 178.2	423.0 ± 232.9
	Aug 1985	460.7 ± 189.2	603.3 ± 284.7

Continued...

Appendix D Concluded.

Taxon	Period	Bay 7	Bay 11
Cingula castanea	Aug 1981	116.0 ± 108.0	26.0 ± 47.4
	Sept 1981	98.7 ± 56.9	40.3 ± 42.8
	Aug 1982	131.3 ± 151.9	56.5 ± 63.8
	Sept 1982	133.3 ± 80.9	68.0 ± 61.2
	Aug 1983	120.7 ± 78.0	38.0 ± 35.2
	Aug 1985	169.6 ± 116.9	104.6 ± 92.2
Retusa obtusa	Aug 1981	28.7 ± 34.7	33.3 ± 36.5
	Sept 1981	38.0 ± 31.2	51.1 ± 47.8
	Aug 1982	33.3 ± 31.3	60.7 ± 58.9
	Sept 1982	54.7 ± 62.9	70.0 ± 44.5
	Aug 1983	34.7 ± 24.4	60.0 ± 35.4
	Aug 1985	22.0 ± 20.9	91.3 ± 52.2
Trichotropis borealis	Aug 1981	63.3 ± 41.3	78.7 ± 60.8
	Sept 1981	53.3 ± 44.7	86.6 ± 74.8
	Aug 1982	62.0 ± 43.1	125.3 ± 88.6
	Sept 1982	61.3 ± 59.8	113.3 ± 81.3
	Aug 1983	49.3 ± 54.2	100.0 ± 85.9
	Aug 1985	61.3 ± 48.5	118.0 ± 84.5
Moelleria costulata	Aug 1981	33.3 ± 25.8	50.0 ± 52.2
	Sept 1981	47.3 ± 34.8	51.5 ± 56.5
	Aug 1982	44.0 ± 41.7	62.7 ± 71.1
	Sept 1982	44.7 ± 29.1	78.0 ± 52.2
	Aug 1983	50.7 ± 36.1	43.3 ± 37.3
	Aug 1985	36.0 ± 23.2	56.0 ± 53.8
Oenopota spp.	Aug 1981	20.7 ± 21.9	45.3 ± 46.1
	Sept 1981	24.0 ± 20.0	44.5 ± 38.6
	Aug 1982	18.7 ± 17.4	63.9 ± 36.1
	Sept 1982	18.7 ± 19.8	44.0 ± 30.3
	Aug 1983	22.7 ± 21.6	55.3 ± 34.0
	Aug 1985	39.3 ± 30.2	95.3 ± 56.3

Appendix E. Mean biomass (grams per square metre) of major taxa and dominant species of infauna at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as mean ± standard deviation and are based on 10% formalin wet weight in 8 replicate 0.0625 m^2 airlift samples on each of three transects for each period and bay.

Taxon	Period	Bay 7	Bay 11
Total infauna	Aug 1981	932.8 ± 707.4	1335.7 ± 786.1
	Sept 1981	1238.3 ± 639.6	1235.7 ± 761.5
	Aug 1982	1137.5 ± 878.0	1263.0 ± 518.0
	Sept 1982	1075.6 ± 690.6	1458.6 ± 844.7
	Aug 1983	1240.8 ± 553.0	1634.1 ± 886.8
	Aug 1985	1105.1 ± 938.0	1257.9 ± 828.3
Bivalvia	Aug 1981	869.9 ± 695.8	1261.4 ± 776.2
	Sept 1981	1171.4 ± 641.7	1172.9 ± 743.2
	Aug 1982	1078.6 ± 881.4	1180.3 ± 523.6
	Sept 1982	993.5 ± 661.5	1382.7 ± 833.6
	Aug 1983	1180.2 ± 537.9	1553.8 ± 864.5
	Aug 1985	1027.8 ± 948.4	1174.8 ± 806.2
Mya truncata	Aug 1981	481.5 ± 494.8	547.5 ± 540.8
	Sept 1981	728.5 ± 486.4	554.0 ± 504.9
	Aug 1982	592.1 ± 702.7	476.7 ± 361.1
	Sept 1982	588.3 ± 593.1	624.1 ± 537.5
	Aug 1983	727.0 ± 437.2	773.1 ± 645.2
	Aug 1985	564.4 ± 800.0	472.4 ± 389.3
Astarte borealis	Aug 1981	45.3 ± 47.4	389.2 ± 212.5
	Sept 1981	83.8 ± 76.2	288.1 ± 230.8
	Aug 1982	75.0 ± 70.9	398.6 ± 244.8
	Sept 1982	81.6 ± 68.8	374.1 ± 292.8
	Aug 1983	72.4 ± 81.6	396.9 ± 335.5
	Aug 1985	51.7 ± 87.5	322.2 ± 226.4
Astarte montagui	Aug 1981	9.7 ± 11.1	158.6 ± 93.8
	Sept 1981	12.3 ± 13.6	166.4 ± 97.6
	Aug 1982	11.9 ± 13.1	161.7 ± 74.5
	Sept 1982	7.4 ± 9.3	179.7 ± 99.0
	Aug 1983	14.6 ± 17.5	184.6 ± 101.0
	Aug 1985	14.0 ± 15.0	172.9 ± 116.2

Continued...

Appendix E Continued.

Taxon	Period	Bay 7	Bay 11
Serripes groenlandicus	Aug 1981	132.9 ± 145.6	57.8 ± 113.5
	Sept 1981	111.8 ± 149.8	52.5 ± 134.5
	Aug 1982	207.8 ± 280.2	33.4 ± 63.8
	Sept 1982	122.9 ± 160.9	45.6 ± 103.7
	Aug 1983	156.2 ± 221.6	58.0 ± 132.9
	Aug 1985	186.9 ± 230.8	83.1 ± 153.4
Hiatella arctica	Aug 1981	5.3 ± 15.6	20.1 ± 45.8
	Sept 1981	3.3 ± 15.9	11.0 ± 30.6
	Aug 1982	<0.1	12.5 ± 31.2
	Sept 1982	6.4 ± 21.9	48.6 ± 97.7
	Aug 1983	0.1 ± 0.3	16.0 ± 38.6
	Aug 1985	2.9 ± 14.1	17.5 ± 56.8
Macoma calcarea	Aug 1981	111.4 ± 74.4	36.5 ± 39.8
	Sept 1981	117.6 ± 63.6	41.3 ± 28.8
	Aug 1982	130.2 ± 74.1	51.9 ± 45.3
	Sept 1982	130.4 ± 86.4	61.2 ± 47.9
	Aug 1983	140.0 ± 67.2	60.0 ± 47.1
	Aug 1985	133.2 ± 66.7	53.4 ± 54.5
Clinocardium ciliatum	Aug 1981	23.2 ± 77.7	22.5 ± 76.9
	Sept 1981	35.0 ± 100.3	24.9 ± 119.6
	Aug 1982	0.7 ± 3.3	0
	Sept 1982	0	0
	Aug 1983	0	0
	Aug 1985	26.9 ± 118.8	17.7 ± 86.9
Nuculana minuta	Aug 1981	13.8 ± 10.8	7.1 ± 4.2
	Sept 1981	16.2 ± 13.8	9.3 ± 5.6
	Aug 1982	13.3 ± 10.7	9.0 ± 6.0
	Sept 1982	15.1 ± 13.1	9.9 ± 7.8
	Aug 1983	9.5 ± 6.3	8.2 ± 6.2
	Aug 1985	14.4 ± 10.0	5.5 ± 4.0
Polychaeta	Aug 1981	33.1 ± 26.9	45.1 ± 29.9
	Sept 1981	31.0 ± 20.2	34.0 ± 23.4
	Aug 1982	30.7 ± 18.0	39.8 ± 19.7
	Sept 1982	34.8 ± 16.8	45.6 ± 22.8
	Aug 1983	29.5 ± 22.2	38.7 ± 30.1
	Aug 1985	38.7 ± 27.4	43.8 ± 22.2

Continued...

Appendix E Concluded.

Taxon	Period	Bay 7	Bay 11
Pectinaria granulata	Aug 1981	15.5 ± 14.5	13.7 ± 10.7
	Sept 1981	13.5 ± 11.4	14.0 ± 11.9
	Aug 1982	12.7 ± 14.0	11.9 ± 7.9
	Sept 1982	13.2 ± 10.9	13.7 ± 8.7
	Aug 1983	12.3 ± 16.7	9.8 ± 5.0
	Aug 1985	13.7 ± 15.6	15.3 ± 12.0
Gastropoda	Aug 1981	10.1 ± 7.8	16.4 ± 13.3
	Sept 1981	10.9 ± 7.9	24.9 ± 29.4
	Aug 1982	11.0 ± 7.9	30.8 ± 28.3
	Sept 1982	12.0 ± 11.8	23.9 ± 18.0
	Aug 1983	11.0 ± 10.7	26.5 ± 25.0
	Aug 1985	9.1 ± 8.8	25.8 ± 23.0
Trichotropis borealis	Aug 1981	6.6 ± 5.1	11.9 ± 9.9
	Sept 1981	6.4 ± 7.0	14.2 ± 15.1
	Aug 1982	6.6 ± 5.9	20.1 ± 17.4
	Sept 1982	5.4 ± 5.8	17.3 ± 13.6
	Aug 1983	5.0 ± 6.6	15.7 ± 16.8
	Aug 1985	5.2 ± 5.8	15.4 ± 13.8

Appendix F. Mean density (numbers per square metre) of major taxa and dominant species of epibenthic crustaceans at 7 m depth in two bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982, and August 1983 and 1985. Data are expressed as mean ± standard deviation and are based on 8 replicate 0.0625 m^2 airlift samples on each of three transects for each period and bay.

Taxon	Period	Bay 7	Bay 11
Total Epibenthos	Aug 1981	2526.7 ± 957.3	1963.3 ± 1269.3
	Sept 1981	2658.7 ± 651.9	1759.7 ± 1090.6
	Aug 1982	3201.6 ± 1191.1	2613.3 ± 1345.9
	Sept 1982	3526.7 ± 1585.0	2765.3 ± 1161.3
	Aug 1983	3810.0 ± 1100.3	2953.8 ± 1723.3
	Aug 1985	4207.3 ± 1550.0	3130.3 ± 2335.1
Ostracoda	Aug 1981	2103.3 ± 1030.7	1310.7 ± 973.6
	Sept 1981	2279.3 ± 682.3	1097.3 ± 899.1
	Aug 1982	2673.9 ± 1137.4	1727.7 ± 1285.8
	Sept 1982	2912.0 ± 1448.7	1622.7 ± 967.6
	Aug 1983	3117.3 ± 972.8	1593.3 ± 1366.2
	Aug 1985	3127.0 ± 1569.9	1753.8 ± 1619.4
Myodocopa spp.	Aug 1981	2102.0 ± 1031.3	1308.7 ± 971.4
	Sept 1981	2278.7 ± 682.2	1096.7 ± 898.5
	Aug 1982	2673.9 ± 1137.4	1727.7 ± 1285.8
	Sept 1982	2905.3 ± 1450.9	1621.3 ± 968.3
	Aug 1983	3115.3 ± 972.8	1590.0 ± 1365.3
	Aug 1985	3126.3 ± 1569.4	1753.2 ± 1618.3
Cumacea	Aug 1981	72.7 ± 68.0	214.0 ± 155.5
	Sept 1981	31.3 ± 33.9	186.4 ± 124.0
	Aug 1982	103.3 ± 96.3	294.7 ± 157.0
	Sept 1982	82.0 ± 55.1	278.0 ± 165.0
	Aug 1983	159.3 ± 148.0	444.0 ± 313.0
	Aug 1985	109.5 ± 100.1	236.4 ± 137.5
Lamprops fuscata	Aug 1981	59.3 ± 61.8	104.7 ± 97.7
	Sept 1981	25.3 ± 29.1	93.6 ± 81.3
	Aug 1982	84.0 ± 79.7	165.3 ± 126.3
	Sept 1982	72.0 ± 51.0	142.0 ± 102.4
	Aug 1983	141.3 ± 142.1	262.7 ± 213.3
	Aug 1985	51.3 ± 74.3	41.3 ± 49.2

Continued...

Appendix F Continued.

Taxon	Period	Bay 7	Bay 11
Brachydiastylis resima	Aug 1981	11.3 ± 20.3	94.0 ± 93.2
	Sept 1981	3.3 ± 8.1	83.5 ± 76.6
	Aug 1982	16.0 ± 28.7	108.0 ± 99.2
	Sept 1982	6.0 ± 11.4	109.3 ± 107.6
	Aug 1983	16.0 ± 22.1	148.7 ± 185.8
	Aug 1985	24.0 ± 35.3	124.0 ± 114.6
Amphipoda	Aug 1981	345.3 ± 224.5	426.0 ± 269.3
	Sept 1981	344.0 ± 162.5	469.3 ± 241.3
	Aug 1982	423.0 ± 232.2	587.6 ± 208.3
	Sept 1982	532.0 ± 242.3	854.0 ± 570.4
	Aug 1983	526.7 ± 227.5	909.8 ± 576.7
	Aug 1985	956.3 ± 550.9	1135.4 ± 890.8
Guernea sp.[a]	Aug 1981	117.3 ± 48.7	196.7 ± 166.7
	Sept 1981	98.7 ± 72.9	152.3 ± 89.4
	Aug 1982	140.1 ± 86.6	285.2 ± 170.1
	Sept 1982	179.3 ± 122.2	260.7 ± 125.2
	Aug 1983	198.7 ± 110.2	352.8 ± 287.4
	Aug 1985	109.1 ± 65.5	225.1 ± 185.6
Anonyx spp.[a]	Aug 1981	29.3 ± 56.9	26.0 ± 30.5
	Sept 1981	30.7 ± 62.4	47.7 ± 50.4
	Aug 1982	12.7 ± 24.5	53.3 ± 56.9
	Sept 1982	16.7 ± 28.1	53.3 ± 56.9
	Aug 1983	16.0 ± 15.6	20.0 ± 20.7
	Aug 1985	6.0 ± 12.3	28.0 ± 26.8
Pontoporeia femorata	Aug 1981	72.0 ± 59.5	37.3 ± 90.0
	Sept 1981	108.0 ± 71.7	82.8 ± 110.8
	Aug 1982	136.0 ± 107.2	100.0 ± 137.1
	Sept 1982	214.7 ± 151.9	172.0 ± 299.4
	Aug 1983	170.0 ± 142.3	150.7 ± 178.1
	Sept 1985	360.6 ± 320.6	460.1 ± 572.1
Monoculodes spp.[a]	Aug 1981	30.7 ± 30.9	35.3 ± 45.7
	Sept 1981	38.0 ± 47.1	20.1 ± 35.9
	Aug 1982	27.3 ± 52.4	37.0 ± 40.6
	Sept 1982	48.7 ± 49.6	70.0 ± 55.0
	Aug 1983	29.3 ± 31.5	16.7 ± 20.3
	Aug 1985	35.8 ± 41.0	12.0 ± 22.3

Continued...

Appendix F Concluded.

Taxon	Period	Bay 7	Bay 11
Bathymedon spp.	Aug 1981	12.0 ± 24.2	2.0 ± 5.4
	Sept 1981	12.7 ± 16.3	0.7 ± 3.3
	Aug 1982	40.1 ± 73.5	15.3 ± 22.9
	Sept 1982	30.7 ± 49.5	21.3 ± 33.6
	Aug 1983	16.7 ± 19.2	4.0 ± 9.7
	Aug 1985	5.3 ± 18.7	0.7 ± 3.3
Stenothoidae spp.[a]	Aug 1981	3.3 ± 6.6	12.7 ± 19.4
	Sept 1981	2.7 ± 7.7	11.8 ± 32.3
	Aug 1982	14.8 ± 50.3	18.3 ± 51.4
	Sept 1982	2.7 ± 6.1	24.0 ± 64.9
	Aug 1983	25.3 ± 28.3	132.0 ± 311.0
	Aug 1985	193.2 ± 359.9	154.2 ± 251.5
Calliopiidae spp.[a]	Aug 1981	1.3 ± 4.5	8.0 ± 29.8
	Sept 1981	0.7 ± 3.3	6.2 ± 28.1
	Aug 1982	4.0 ± 16.5	6.0 ± 13.2
	Sept 1982	13.3 ± 39.4	70.0 ± 239.7
	Aug 1983	4.0 ± 10.8	23.3 ± 62.1
	Aug 1985	43.7 ± 91.1	3.3 ± 8.1

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[a] Stenothoidae includes Metopella and Metopa; Calliopiidae includes Apherusa. Genera indicated include species listed in Appendix C.