In Situ STUDIES OF EFFECTS OF OIL AND DISPERSED OIL ON PRIMARY PRODUCTIVITY OF ICE ALGAE AND ON UNDER-ICE AMPHIPOD COMMUNITIES

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EXECUTIVE SUMMARY

Effects of *in situ* applications of oil and dispersed oil on the abundance and productivity of under-ice algae and on behaviour, mortality and distribution of under-ice amphipods were studied at Cape Hatt, northern Baffin Island. Immediate effects of oil on ice algae and amphipods were studied by injecting oil into small chambers on the under-ice surface. In addition, distribution and life history data were collected for amphipods occupying under-ice, intertidal and shallow sublittoral habitats. The latter component of the study utilizes the large-scale experimental spills carried out at the BIOS (Baffin Island Oil Spill) site in August 1981; we obtained pre-spill (May and August 1981) and post-spill (September 1981) data.

Field studies were carried out during 16-31 May, 10-19 August and 7-8 September 1981 from the BIOS project base camp located at Cape Hatt, Baffin Island. All under-ice and sublittoral sampling and experimental work was carried out by SCUBA divers working through holes in the ice (May) or from small inflatable boats (August and September). Studies on amphipod distribution and population structure were conducted in three small bays at a depth of 3-5 m, or on the ice undersurface at the same location; intertidal sampling was carried out on the beach between two markers, 150 m apart, which demarcated the BIOS study bays. Experimental studies on amphipods and ice algae were conducted on the under-ice surface in another two bays over water depths of 8 and 12 m, respectively.

Productivity of under-ice algae was determined by a modification of the standard ^{14}C light and dark bottle technique (Strickland and Parsons 1972).

Ice and water samples were incubated *in situ* for 5-7 h periods, and ice algal biomass was estimated from chlorophyll *a* concentrations in the incubation chambers. Light was measured under the ice and used as a covariate in analyses of covariance (ANCOVA). Analysis of variance (ANOVA) and ANCOVA were used to examine field and laboratory techniques, temporal differences in biomass and productivity, and the effects of various levels of oil and dispersed oil on ice algal biomass and productivity.

Amphipods were captured and contained against undisturbed areas of the under-ice surface in cylindrical plexiglass chambers. Following exposures to different levels of oil for 3 and 15 h, and to the same levels of dispersed oil for 3 h, amphipods within the chambers were returned to the laboratory. Live and dead amphipods were separated, live amphipods were transferred to clean seawater, and live-dead separations were continued daily for 4 post-exposure days. Effects of oil level and exposure on behaviour and mortality were examined using correlation and ANOVA techniques,

Quantitative samples of amphipods were collected in the under-ice habitat at two times in May, in the shallow (3-5 m) sublittoral habitat in May, August and September, and in the intertidal habitat in August and September. Amphipods were identified, counted, weighed and measured. Spatial, seasonal and habitat variability in species composition, distribution and population structures were examined using ANOVA techniques.

Salinities and concentrations of nutrients (phosphate, nitrite,nitrate and silicate) at the productivity study site were typical of those found elsewhere in the Arctic, and sufficient to support the growth of sea ice

microalgae. Biomass and productivity of phytoplankton in the water immediately beneath the ice were low and typical for the season; biomass was 2 to 3 orders of magnitude lower than biomass of ice algae in the soft bottom layer of ice, and productivity values were near-zero. Ice algal biomass and productivity under control conditions were comparable to values reported elsewhere in the Arctic; biomass increased from about 6 to 11 mg Chl *a*/m^2 over the study period (16-30 May), and productivity ranged from 0.3 to 3.3 mg C/m^2/h at different times and in different locations in the 25-m-radius study area.

The highest oil level used (nominal concentration of 10,000 ppm) significantly suppressed algal productivity during each experiment, but in most cases productivity at lower levels (10 and 300 ppm) were not statistically distinguishable. In some cases, productivity at these lower oil levels was not different from productivity in control chambers. Results were consistent on the two days that untreated oil was used, but when dispersed oil was used, algal productivity was suppressed to a greater extent at the highest level (10,000 ppm) and there was some evidence of stimulation of photosynthesis at the lowest dispersed oil level (10 ppm). High productivity values in some dark (oiled) chambers and oil-related interference with measurement of chlorophyll and radiocarbon concentrations caused some interpretational difficulties.

Behavioral observations on oiled amphipods were performed *in situ*, and results refer to all amphipods. Most of the amphipods used in these experiments were later identified as *Weyprechtia pinguis*. Containment or handling effects were apparent both *in situ* (crowding within chambers and

availability of additional substrate) and in the laboratory, where mortality of control animals was sometimes high.

In the control chambers many amphipods were observed on the under-ice surface and in the water column. Prolonged exposure to oil resulted in the occurrence of a high proportion of these amphipods on the chamber bottoms (80-100% at the highest oil levels, 130 and 400 ppm). Impairment of locomotor ability by direct coating with oil may have been the cause. Degree of oiling (as measured on preserved amphipods) was directly related to mortality; only very lightly oiled amphipods survived for any length of time following exposure.

Immediate mortality of Weyprechtia pinguis (i.e. mortality at the end of the exposure period) increased significantly at higher levels of untreated oil. Immediate mortality was highest following the 15 h exposure to oil alone, (58.5%), and delayed mortality was highest following the 3 h exposure to oil alone (40.6%). Total mortality was similar following 15 or 3 h exposures to undispersed oil (66.5, 68.6%), but much greater than total mortality after a 3 h exposure to dispersed oil at the same three levels. Total mortality after exposure to dispersed oil was less than half of that following exposure to oil alone.

The under-ice macrofauna in the three study bays included arctic cod (Boreogadus saida) and mysids (Mysis spp.), but otherwise consisted entirely of gammarid amphipods. Cod were observed only in the large tide cracks just inshore of the entry holes in each of the bays. Mysids were present throughout the water column in each bay, and were generally concentrated in

the first metre of water just below the ice; densities were extremely high and variable both within and among bays.

Ten species of gammarid amphipods were collected on the under-ice surface at Cape Hatt. Two species, Ischyrocerus sp. and Weyprechtia pinguis, together accounted for 61.9% of total numbers, and three species, Weyprechtia pinguis, Gammarus setosus and Onisimus litoralis, together accounted for 86.1% of total biomass. By comparison, species diversity was considerably lower in the intertidal habitat (samples from August and September 1981) and considerably higher in the sublittoral habitat (samples from May, August and September 1981). Four amphipod species were found in the intertidal habitat; Gammarus setosus was dominant both in terms of numbers (93.2% of total) and biomass (76.8% of total). In the shallow (3-4 m) sublittoral habitat, 31 identified species and at least seven distinct but unidentified species were collected. Orchomene minuta, Guernea sp. and Protomedia fasciata together accounted for 50.7% of total numbers collected in May, August and September, and Anonyx nugax, Anonyx sarsi, Orchomene minuta and Paroediceros lynceus together accounted for 62.9% of total biomass.

All four species found in the intertidal habitat were also found on the under-ice surface. Three and seven of the 10 amphipod species found under the ice also occurred in samples from the shallow sublittoral habitat in spring and summer, respectively. Species occurring on the under-ice surface in May were of very little importance in the sublittoral habitat in May (0.3% of numbers, 1.1% of biomass), and of considerably higher importance in August and September (8.6% of numbers, 23.6% of biomass).

In general, abundance and biomass of all amphipods were highest in the sublittoral habitat, intermediate in the intertidal habitat, and lowest on the under-ice surface. Considerably fewer amphipods occurred on the under-ice surface in mid-May ($<15/m^2$) than in the sublittoral habitat at the same time ($>200/m^2$); differences in biomasses were less marked, but still very considerable. However, the species that dominated the under-ice habitat were more numerous there than on the bottom. Four dominant species, Ischyrocerus Sp., Weyprechtia pinguis, Onisimus litoralis and Gammarus setosus, were present on the under-ice surface in relatively low abundances in mid-May. Of these, only Ischyrocerus and Weyprechtia were collected in the sublittoral habitat at that time, and then only in one bay. These data indicate a very strong preference for the under-ice habitat in May for the four dominant species on the under-ice surface. In sublittoral samples from August and September, Gammarus and Ischyrocerus were not present. Weyprechtia and Onisimus were absent or very rare in September,

Two cohorts (year classes) were apparent in length-frequency data for Onisimus litoralis and Weyprechtia pinguis, and at least three cohorts were present for Gammarus setosus. Growth (as estimated by mean size of a cohort) over the study period (May to August or September) was apparent for all species and cohorts. Weyprechtia was significantly variable in size among bays, but Onisimus and Gammarus were not. Juvenile Gammarus had apparently been released from brooding females before the study period began. Release of Weyprechtia occurred during the study period (17-31 May) and juvenile Onisimus were too few to warrant discussion.

In general, there were pronounced among-bay differences in abundances and biomasses of total amphipods and dominant species of amphipods on the

under-ice surface. Furthermore, differences in abundance or biomass from one time to another (mid-May to late May, or August to September) were not consistent among bays; conversely, differences among bays were not consistent from one time to another.

Lagomedio crude oil was spilled as a surface slick in one bay between the August and September sampling periods, and a relatively even coating of oil was deposited on the beach (intertidal area) by the falling tide. Observations following the spill and results of the present study indicate that oil affected the amphipods that occupied the intertidal habitat. The numbers of intertidal Gammarus setosus decreased somewhat in dispersed oil bays from August to September, but the corresponding decrease in the bay contaminated with a surface slick was much more marked. Onisimus litoralis was absent or rare in the intertidal habitat in dispersed oil bays, but, like Gammarus, numbers decreased drastically in the intertidal area of the bay receiving the surface slick.

The absence or low abundance of Gammarus in the sublittoral habitat, and its abundance in the intertidal habitat, indicate that the latter is the source of recruitment for this species to the under-ice habitat. Thus, Gammarus may be less abundant on the ice in the bay contaminated with a surface slick in 1982 than in 1981. Sampling of all three habitats is continuing in 1982, and any effects of the summer spills on the under-ice communities in the following spring, as well as any recovery in the intertidal zone, should be particularly easy to detect for this species.

The results of the present study indicate that exposure to high levels of dispersed oil may suppress ice algal productivity more than exposure to

the same (nominal) levels of untreated oil; procedural difficulties, however, render this conclusion tentative. Recovery of oiled algal communities subsequently exposed to clean water was not studied.

Amphipods exposed in situ to various concentrations of dispersed oil for a relatively short (3 h) period of time, however, were less affected than those exposed to oil masses together with low concentrations of dissolved oil components for relatively short (3 h) or long (15 h) periods of time. Amphipods in the intertidal habitat were apparently not affected by a large-scale dispersed oil spill, whereas mortality was high where untreated oil was spilled. These results indicate that the chemical dispersion of oil may be less harmful to amphipods in under-ice and intertidal communities than the accumulation of untreated oil in these habitats. Dispersed oil may contact much larger areas of the under-ice surface, however, resulting in greater total mortality. Further studies are required concerning the relative toxicities of dispersed and untreated oil at realistic concentrations, the recovery of communities exposed to oil, and, in particular, the behaviour of oil and dispersed oil under the ice.

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INTRODUCTION

In spring, a dense growth or bloom of microalgae occurs on and in the soft bottom layer of arctic sea ice. This algal layer begins to develop in April and the bloom peaks in May (Homer 1976, 1977). Productivity of ice algae during the relatively short bloom in April and May can be quite-high. The bloom has been estimated to provide between 6 and 33% of the total annual primary production in various arctic locations (Alexander 1974; Homer et al. 1974; Welch and Kalff 1975). In addition, this bloom is important because its production occurs before there is significant production by planktonic and benthic algae during the open water season (Apollonio 1965). Thus, ice algal production is available to herbivores earlier in the season than is planktonic production (Dunbar 1968). This availability is further enhanced by the concentration of ice algae in two dimensions on the bottom of the ice and, near the end of the bloom, by their occurrence as macroscopic 'detrital' masses on the under-ice surface and in the water column (Cross 1982).

Ice algal concentrations are utilized by invertebrates occurring on the under-ice surface and in the water column (Bradstreet and Cross 1982). The largest and most conspicuous invertebrates inhabiting the under-ice surface are gammarid amphipods. Dominant species on the undersurface of the ice have included, at various places and times, Onisimus litoralis or O. glacialis (Green and Steele 1975; Buchanan et al. 1977; Thomson et al. 1978; Cross 1980, 1982; Grainger and Hsiao 1982), Gammarus setosus (Thomson et al. 1978), Ischyrocerus anguipes (Cross 1980, 1982) and Apherusa glacialis (Golikov and Scarlato 1973; Cross 1980, 1982). Most of these species are herbivores that

consume ice algae (e.g. , Homer and Alexander 1972; Buchanan et al. 1977; Brads treet and Cross 1980, 1982); O. litoralis is also known as a scavenger of dead animal material (e.g., MacGinitie 1955). The habitats of these species in the absence of landfast ice include the undersurface of pan ice, the water column, and shallow sublittoral and intertidal areas. In the absence of ice, Apherusa glacialis and Onisimus glacialis are pelagic species (Dunbar 1954; Barnard 1959), although A. glacialis often associates with pan ice in late summer (e.g., Stephensen 1942; MacGinitie 1955; Divoky 1978; Thomson et al. 1978) and O. glacialis is also an epibenthic species in some locations (Griffiths and Dillinger 1981). Onisimus litoralis and Gammarus setosus occupy intertidal or nearshore sublittoral habitats in the open water season (Dunbar 1954; MacGinitie 1955; Steele and Steele 1970; Thomson and Cross 1980).

Distributional and dietary information indicates that the ice habitat is important to amphipods during spring. However, the relative importance and seasonal. utilization of pelagic, benthic and under-ice habitats by these species is not known. Although the abundance and biomass of nearshore amphipods have been reported for intertidal, sublittoral and under-ice habitats in the eastern Arctic, simultaneous sampling of under-ice and benthic substrates and consecutive sampling of one area through the season (i.e. under fast ice and during the open water season) have not been carried out .

Ice-associated invertebrates are important food items for arctic cod (Bain and Sekerak 1978; Bradstreet and Cross 1980, 1982; Craig et al. 1982), various marine birds (Bradstreet 1976, 1980; Divoky 1978; Johnson and

Richardson 1981; Bradstreet and Cross 1982), and ringed seals (Finley 1978). In addition, the arctic cod is a major prey species of arctic marine mammals and birds in the Canadian Arctic (Dunbar 1941, 1949; McLaren 1958; Bradstreet 1976, 1977, 1979, 1980, 1982; Finley 1976; Davis and Finley 1979; Finley and Gibb 1982, in press; Finley et al. 1982) and elsewhere. Thus, under-ice communities may be critical elements of arctic marine food webs. Damage to the under-ice communities could have effects on the mammals and birds that occupy the higher trophic levels of the food webs.

Studies on plant and animal communities inhabiting the undersurface of arctic sea-ice, and in particular studies allowing direct observations by use of SCUBA methods, have become a focus of attention only recently. To date, few quantitative studies of this type have been conducted. Recent reviews of published research on under-ice biota in the Arctic and Antarctic are given by Homer (1976, 1977). These include details of research carried out by a group from the University of Alaska who used surface-operated and SCUBA methods to study microaglae and primary productivity during 1972-1974. SCUBA-based quantitative studies of under-ice communities in the central and eastern parts of the Canadian Arctic are those of Buchanan et al. (1977), Thomson et al. (1978) and Cross (1980, 1982).

In the event of a marine oil spill or blowout, large quantities of oil are most likely to accumulate in the under-ice, intertidal and shallow sublittoral habitats. Data on the effects of treated and untreated oil on the biota of these habitats would be of use in decisions regarding the use of chemical countermeasures for oilspills in ice-covered waters. Productivity and biomass of phytoplankton under oiled ice have been reported (e.g., Adams

1975), and laboratory experiments concerning effects of oil and dispersed oil on arctic phytoplankton have been carried out (e.g., Hsiao 1978), but similar studies of oil effects on ice algae have not been done. Laboratory studies concerning the acute toxicity of oil to arctic marine invertebrates have also been conducted, both in the Beaufort Sea (Percy 1974, 1976, 1977a,b; Percy and Mullin 1975, 1977; Busdosh and Atlas 1977) and in the eastern Arctic and sub-Arctic (Fey 1978, 1979), These studies have provided useful information on the relative sensitivities of a range of organisms, including some under-ice amphipod species, but laboratory studies cannot be used to predict the effects of oil contamination in a natural field situation (Fey 1978, 1979). In situ studies of oil effects on nearshore arctic benthos were initiated in 1980 (Cross and Thomson 1981, 1982), but similar studies have not previously been carried out in arctic intertidal or under-ice habitats.

The present study examines effects of in situ applications of oil and dispersed oil on the abundance and productivity of under-ice algae and on behaviour, mortality and distribution of under-ice amphipods. Immediate effects of oil on ice algae and amphipods were studied by injecting oil into small chambers on the under-ice surface. In addition, distribution and life history data were collected for amphipods occupying under-ice, intertidal and shallow sublittoral habitats. The latter component of the study utilizes the large-scale experimental spills carried out at the BIOS (Baffin Island Oil Spill) site in August 1981; we obtained pre-spill (May and August 1981) and post-spill (September 1981) data.

MATERIALS AND METHODS

Field studies were carried out during 16-31 May, 10-19 August and 7-8 September 1981 from the BIOS (Baffin Island Oil Spill) project base camp located at Cape Hatt, Baffin Island. The study area consisted of four shallow embayments in Ragged Channel, some 5-8 km SSE of Cape Hatt (72°27'N, 79°51'W). Bays 9 and 10 are shallow indentations in the coastline, each about 500 m in length, separated by the delta of a small stream and a distance of somewhat less than 500 m. Bay 13 is similar in size and configuration, located about 3 km to the north. Bay 11 has been designated as the lower half and Bay 12 as the upper half of a deeper embayment approximately 1 km x 1 km in dimensions, located approximately 1 km north of Bay 10 (Fig. 1).

All under-ice and sublittoral sampling and experimental work was carried out by SCUBA divers working though holes in the ice (May) or from small inflatable boats (August and September) . Studies on amphipod distribution and population structure were conducted in Bays 9, 10 and 11 (Fig. 1), at a depth of 3-5 m or on the ice undersurface at the same locations. Intertidal sampling was carried out on the beach between two markers, 150 m apart, which demarcated the BIOS study bays. Experimental studies on amphipods and ice algae were conducted on the under-ice surface in Bays 12 and 13 over water depths of 8 and 12 m, respectively.

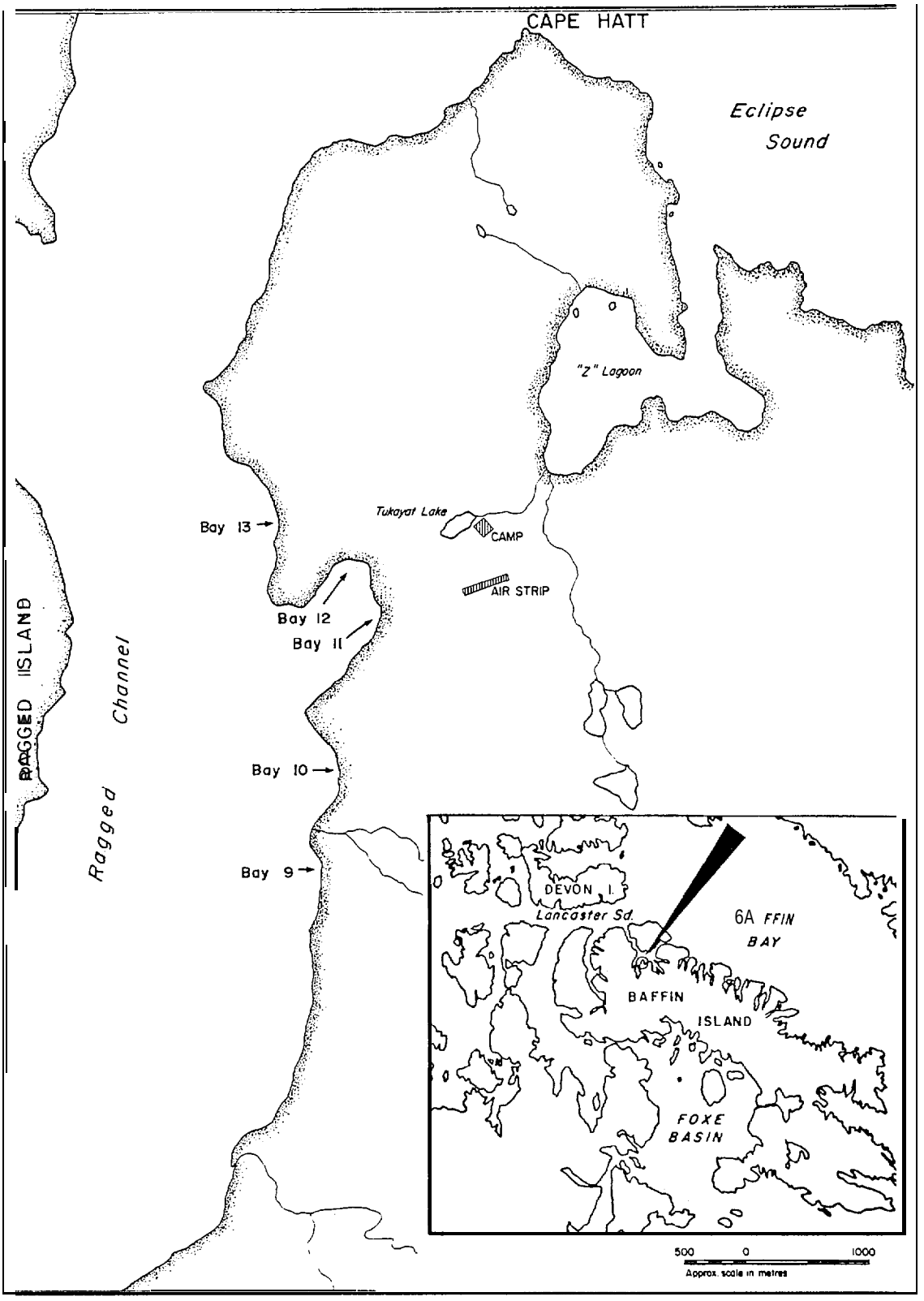

FIGURE 1. Locations of study bays at the BIOS project site at Cape Hatt, Baffin Island.

Ice Algal Biomass and Productivity

Productivity of under-ice algae in Bay 13 was determined by a modification of the standard ^{14}C light and dark bottle technique (Strickland and Parsons 1972). The 'bottles' in this case were cylindrical plexiglass chambers with an area of 20.27 cm^2 and a length of 15 cm (volume = 304 cc). Samples of ice algae were collected by inserting the chambers about 1-2 cm into the soft bottom layer of ice, severing the cores with a plexiglass spatula> and capping the chambers. Separate samples were collected in the same way for the determination of salinity, alkalinity and inorganic nutrient concentrations. Chambers to be used for productivity determinations were replaced immediately in their original positions, and ^{14}C-sodium bicarbonate (New England Nuclear Corp.) with a specific activity of 53 $\mu Ci/\mu mol$ was then injected to yield a final concentration of 50.0 $\mu Ci/L$. Incubations began between 1200 and 1430 h and were allowed to proceed for a period of 5-7 hours. At the end of the incubation periods, 1 mL of concentrated formalin was injected and the chambers were returned to the field laboratory in insulated containers.

To avoid disturbance from air respired by divers, samples were collected, and chambers replaced, in rows along ridges on the under-ice surface. Adjacent chambers were about 20 cm apart. Light was measured with a photometer (InterOcean model 510) at each end of the row of chambers below the layer of ice algae, and above the algal layer, after scraping this layer away. These measurements were made at the beginning and end of each incubation, and simultaneous measurements above the ice were made with a surface cell so percent transmission through the ice could be calculated. A

recording pyranometer (Kipp and Zonen, model CM-6) located at the Cape Hatt base camp recorded incoming radiation (W/m^2) during the 4 weeks that the camp was occupied.

Three types of experiments were carried out:

1. Control Measurements. On each of 16 and 21 May, a set of nine chambers was placed in each of two locations within a 25 m radius of the dive hole (total of 4 sets of 9 chambers). Each set consisted of five light and two dark chambers including water and ice as described above, and one light and one dark chamber including water only. The 'water only' chambers were collected immediately below the undersurface of the ice. Further control measurements were available from the other types of experiments (below).

2. Oil Effect Experiments. The effects of untreated oil were studied on 23 and 24 May, and dispersed oil effects were examined on 30 May. Unweathered Lagomedio crude oil (Esso Resources Canada Ltd.), and a 10:1 mixture of Lagomedio : Corexit 9527 (Exxon Chemical Corp.) were the types of oil and dispersed oil used. Three oil levels (nominal concentrations of ~ 10 ppm, 300 ppm and 10,000 ppm) and a control were used on each day; one dark and three light chambers were used for each oil level (including control). Each chamber was numbered and the same chambers were used for the same oil levels on each day. Oil was injected into the chambers before the injection of ^{14}C-bicarbonate.

3. Test of experimental technique. On 29 May a test was made to determine the effectiveness of the chambers in containing the ^{14}C-bicarbonate

solution, and the effect of detaching the ice algal layer from the under-ice surface prior to incubation. Samples were collected, and incubations carried out, in six Light chambers as described above under control measurements, An additional six light chambers from the same location were treated identically except that the ice cores contained within the chambers were not severed, and the tops of the chambers were not capped, until the end of the incubation period.

Carbonate alkalinity was calculated according to the methods of Strickland and Parsons (1972). A Fisher Accumet pH meter (model 630, accuracy ± 0.02 pH) was used for the measurement of pH, and salinity was calculated from Knudsen tables us ing temperature and specific gravity measurements obtained with a hydrometer (Fisher, 1.000-1.070) .

lce in samples from incubation chambers was allowed to melt at room temperature ; unoiled samples were then stirred thoroughly, and subsampled for ^{14}C (50. mL) and chlorophyll (100 mL) determinations. All samples were filtered under a vacuum pressure of 200 mm Hg. ^{14}C samples were filtered through 0.45 µm Metricel membrane filters; the filters were then rinsed twice with 15 mL filtered seawater and placed in 20 mL Aquafluor (NEN Corp.) in borosilicate glass scintillation vials. Chlorophyll samples were filtered through 0.7 µm Whatman glass microfibre filters (GF/F), with a few drops of $MgCO_3$ added at the end of filtration. The filters were placed in glassine envelopes and frozen in plastic bags containing silica gel.

The contents of incubation chambers containing oil were, after melting and stirring, poured into 500 mL pear-shaped separator funnels and allowed

to stand for 1/2 h. The lower 300 mL were then withdrawn and treated as for control chambers. Chambers containing dispersed oil were treated in the same way except that those containing the highest oil level were allowed to stand in the separator funnels for 12 h. The effect of this procedure (use of separator funnels to separate oil from water) was tested as follows: After subsampling control chambers for the 'experimental technique' test (above), the remaining contents of the 12 chambers were combined and diluted with filtered seawater to form a uniformly labelled stock mixture. Sixteen incubation chambers were filled with this solution, and oil was injected as in the in situ incubations (i.e. 4 chambers of each of 0, 10, 300, and 10,000 ppm). The chambers were then processed as for the in situ incubations (separator funnels, filtration) except that 100 mL was filtered for ^{14}C samples.

^{14}C radioactivity was measured at the Arctic Biological Station at Ste-Anne-de-Bellevue, Quebec, using a Nuclear Chicago Isocap 300 Scintillation counter; counting inefficiencies were corrected by using the channel ratios method. Chlorophyll a concentrations were determined using a Turner model III Fluorometer at excitation and emission wavelengths of 430 nm and 630 nm, respectively (A.P.H.A. 1975). Nutrient concentrations were determined using a dual beam Beckman Acts 3 spectrophotometer (A.P.H.A. 1975). Chlorophyll and nutrient concentrations were measured at Guelph Chemical Laboratories Ltd., Guelph, Ontario.

Analyses of variance (ANOVA) and covariance (ANCOVA) were performed by the SAS general linear models (GLM) program (Helwig and Council 1979). In analyses of covariance, light level (W/m^2) during the experiment was used as

a covariate for productivity (mg C/m^2 /h), and percent transmission was used as a covariate for biomass (mg chlorophyll _a/m^2). Light levels were estimated from solar radiation at the Cape Hatt camp and percent transmission through the ice at the location of each experimental chamber. Percent transmission was calculated as 100 times the average of the light readings below and above the ice algal layer, divided by the reading at the upper surface of the ice, Percent transmission for each replicate (chamber) was estimated by linear interpolation between the measured values at each end of the row of chambers. Solar radiation falling during l/2-h periods through the incubations was calculated by planimetry from the recording pyranometer records. These figures were multiplied by the percent transmission during these l/2–h periods (assuming a linear change in percent transmission with time of day) to give in situ irradiance. ANOVA and ANCOVA were supplemented with multiple comparisons (Duncan's multiple range test, $\alpha = 0.05$).

Oil Effects on Under-ice Amphipods

Amphipods were captured and contained against undisturbed areas of the under-ice surface in cylindrical plexiglass chambers with an area of 188.7 cm^2 and a length of 20 cm (volume = 3774 cc). Air-filled plexiglass collars around the chambers held them in place against the under-ice surface. The bottoms of the chambers were covered with 1 mm mesh netting with a centrally located valve through which oil was injected.

Three types of exposure to oil were tested: On 26 and 27 May, chambers containing unweathered Lagomedio crude oil were left in place for 15 hours and 3 hours, respectively. On 28 May, chambers containing dispersed oil (10 Lagomedio:1 Corexit 9527) were left in place for 3 hours. On each day, three

oil levels and a control were used; three replicate chambers were used for each oil level (including control). Volumes of 0.1, 0.5 and 1.5 mL of oil were used to give nominal concentrations of approximately 30, 130 and 400 ppm. Oil, dispersed oil, or water (controls) was introduced through the chamber bottoms by vigorously pumping a 3 mL syringe ten times. Oil/Corexit mixtures became evenly dispersed throughout the chambers and persisted during the three hour exposure. In oil alone treatments, droplets rose to the ice and persisted in the form of small, evenly distributed spheres. Droplet size increased from approximately 0.5 to 2 mm in diameter with increasing oil level, and at all levels the water within the chambers became noticeably discolored. Each chamber was numbered, and the same chambers were used for the same oil levels on each day.

The numbers of amphipods on the ice, in the water and on the bottom of the chamber were recorded before injection, immediately after injection, and at the end of the incubation period. These observations were possible only for exposures to oil alone, as the reduced visibility within dispersed oil chambers hindered or precluded observations, After the last set of observations, the ice core contained within the chamber was severed with a plexiglass spatula, and the chamber was capped. Chambers were returned to the field laboratory in insulated containers.

Upon arrival at the field laboratory, amphipods and ice from each chamber were transferred into clean seawater (- 33 $^{0}/_{00}$) in large trays. Live and dead animals were separated, the criterion for death being failure to move when prodded. Dead animals were transferred into 5% formalin, and live animals were placed in glass jars of seawater and maintained at 0°C in

incubators. The animals were checked, and live-dead separations made at 24-h intervals thereafter until 96 h after exposure, at which time live amphipods were transferred into separate vials containing 5% formalin. Thus each replicate (chamber) produced a maximum of 6 preserved samples: those dead on arrival (day 0), those dying on 4 successive days (days 1-4), and those surviving (day 5).

Subsequent laboratory analysis was carried out within one month. For each amphipod in each sample, the following data were recorded (where possible): species, sex, length (mm), wet weight (mg), and degree of oiling (light, medium, heavy) on each of eight body areas: coxae, pleopods, mouth parts, head/peraeon, pleon, urosome/uropods/telson, gnathopods/peraeopods , and antennae.

Behavioral data were analyzed using the non-parametric Spearman rank correlation method (hand computation). All other data were coded for computer. processing and analyzed using SAS programs (Helwig and Council 1979). Variation among oil levels and exposures in percent mortality, both immediate and delayed, and in percent survival, was analyzed by two-factor ANOVA (oil level x exposure) and separate one-factor ANOVA's for both abundance and biomass data, The difference in mean size between all amphipods in a chamber and those dying was calculated where sample sizes were ≥ 3, and among-treatment differences in these values were analyzed by two-factor ANOVA. Contingency tables were compiled for degree of oiling vs. day of death for each amphipod in oil alone treatment chambers (excluding controls), and a X^2 value was computed.

Under-ice Arnphipod Distributions and Population Structures

Quantitative samples of amphipods were collected in under-ice, intertidal and shallow (3-5 m) sublittoral habitats in each of BIOS study Bays 9, 10 and 11 (Fig. 1). The under-ice surface was sampled at two times, on 17-19 May and 31 May 1981 (10-16 replicates per bay per time).- The intertidal habitat was also sampled at two times, on 17-19 August and on 7 September 1981, and the shallow sublittoral habitat was sampled at three times, on 17-19 May, 10 August and 8 September 1981 (10 replicates per habitat per bay per time). In late August 1981, 15 m^3 of untreated Lagomedio oil was released within booms on the surface of Bay 11, and an additional 15 m^3 of the same oil treated with the dispersant Corexit 9527 (10 oil:1 Corexit) was released underwater in Bay 9 (Fig. 1). Currents carried the dispersed oil into Bay 10, which had originally been designated as the control bay. This resulted in a relatively high level of contamination of Bay 10--approximately one order of magnitude lower than that in the dispersed oil spill bay.

All systematic sampling on the under-ice surface was at least 5 m from the entry hole to avoid disturbance artifacts. Macrofauna (mainly amphipods) on the “under-ice surface were sampled by scraping fine mesh (1 mm) dip nets with a 40 cm flat top for 10 m distances along the under-ice surface in areas not previously disturbed by respired SCUBA air. These 10 m transects extended radially from the entry hole (5-15 m, 15-25 m) and were relatively evenly distributed in the semi-circle seaward of the hole. Entry holes were located just seaward of major tide cracks, and the area sampled consisted only of relatively flat, smooth ice.

Intertidal sampling was carried out at or near low 'tide. A 0.25 m2 aluminum quadrat was placed in the water 0.5 m seaward from the water line, the substrate was manually disturbed, and all of the enclosed animals were removed by using a small aquarium net. Sampling locations were randomly selected along 150 m segments of the bays that corresponded with the BIOS study benthic transects. Substrates consisted of mixed sand, pebble and cobble.

Sublittoral sampling was carried out using a self-contained diver-operated airlift. The airlift consisted of a weighted 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 an aluminum ring containing an area of $0.15 m^2$. Motile epibenthos within the 0.15 m^2 area were contained, and those outside were excluded, by 1 mm mesh netting covering the top of each ring. The netting over each ring contained a capped central receptacle to receive the 'mouth' of the airlift.

The airlift frame was placed on the bottom and pushed as far as possible into the substrate to contain shallow infauna. The airlift was attached to the net, the air was turned on, and the mouth of the airlift was moved around to cover thoroughly the area within the ring. The net on the airlift was then removed, capped and replaced.

In May, sublittoral sampling locations were randomly selected at a depth of 3–5 m within an area on the bottom below the under-ice sampling area. In August and September, samples of epibenthic and shallow infaunal amphipods were again collected at the same depths, but in areas only approximately corresponding to those sampled in May. The substrate consisted of coarse to fine sand with pebbles and cobble (up to 10 cm).

All samples were preserved in 10% formalin. Amphipods were identified, counted and weighed at species level (whenever possible) and amphipod lengths were measured to the nearest mm. Amphipods of the genus Onisimus were not identified to species if <6 mm long; most Ischyrocerus collected were damaged and hence were only identified to generic level. Wet weights were obtained by gently blotting dry and weighing on a Mettler PT200 balance to the nearest milligram.

The resulting data were analyzed with one- and two-factor analyses of variance, using the SAS general linear models (GLM) program (Helwig and Council 1979). Variables analyzed included abundance (nos./m^2) and biomass (mg/m^2) of all amphipods and of dominant species, and, only for dominant species, mean size of each cohort in each sample where n (in a cohort) >3. Cohorts (year classes) were identified from size-frequency plots for each species for each month. All data were log-transformed prior to analysis.

RESULTS AND DISCUSSION

Ice Algal Biomass and Productivity

Site Description

The under-ice surface in the study area was smooth and relatively flat, with shallow hummocks and ridges. Productivity studies were carried out in these areas of thicker ice, and ice depth was, therefore, somewhat greater than the measured depth of 135 cm at the entry hole. Snow depths over the study area (a semi-circle 25 m in radius) were 15.8 ± SD 5.1 cm, 19.5 ± 7.2 cm and 17.2 ± 5.4 cm on 16 May, 21 May and 1 June, respectively (n = 24-26 in each case). The amount of light penetrating the snow and ice cover in the study area varied both spatially (primarily because of variable snow cover), and temporally; temporal variation, within and among days, resulted from changes in cloud conditions and in solar elevation. Total *in situ* radiation varied among incubation periods by almost an order of magnitude.

Salinity of ice and ice/water samples ranged from 30.8 to 33.6 °/oo; no consistent differences were apparent either between water and ice/water samples, or among days on which determinations were made (16-30 May). The number of stalactites on the undersurface of the ice increased over the study period, probably indicating increased drainage caused by increased surface temperature. Snow melt was also beginning near the end of May, but no obvious effects were observed under the ice. A thin (several cm) fresh water layer was observed immediately beneath the ice in other bays, but within the productivity study area no such layer was evident.

Nutrient samples were collected in duplicate on 21, 23, 24, 29 and 30 May. Phosphate concentrations were somewhat higher on 23 May (4.86 and 18.23 µmol/L) than on other days (1.31 to 3.19 µmol/L), whereas nitrate concentrations were lower on 21 and 23 May (<0.01 to 1.81 µmol/L) than on the following days (4.13 to 6.01 µmol/L). Nitrite and silicate concentrations were relatively constant over the study period (<0.04 to 0.08 µmol/L and 6.12 to 14.45 µmol/L, respectively). Consistent differences between water and ice + water samples were not evident for any nutrient. With the exception of the high phosphate concentrations on 23 May, which may indicate contamination, nutrient concentrations fall within ranges previously reported (e.g., Alexander et al. 1974; Cross 1980, 1982; Grainger and Hsiao 1982), and are sufficient to support the growth of ice microalgae (Hsiao 1980).

Phytoplankton Biomass and Productivity

Biomass (as estimated by chlorophyll *a* concentration) and productivity were very low in the water immediately beneath the ice on 16 and 21 May. The concentration of chlorophyll *a* in water samples (1.19 ± SD 0.47 mg/m^3; n = 8) was similar to that reported in other locations (Alexander et al. 1974; Cross 1980, 1982; Grainger and Hsiao 1982). After correction for dilution (sampled ice depth = 1 to 2 cm; chamber depth = 15 cm), the algal biomass per unit volume was lower in the water than in the ice by 2 to 3 orders of magnitude.

Productivity in the near-ice water was also low; indeed, after dark ^{14}C uptake (0.28 ± 0.09 mg C/m^3/h; n = 4) was subtracted from light ^{14}C fixation, productivity values were slightly but consistently negative (-0.033 ± 0.023 mg C/m^3/h; n = 4). Alexander et al, (1974) also reported low productivity

estimates for phytoplankton in May at Barrow, Alaska: averages of (1.30 and 0.23 mg $C/m^3/h$ for 1972 and 1973, respectively.

Ice Algal Biomass and Productivity

Ice algal biomass, as estimated by chlorophyll content in the ice, increased significantly over the study period (ANOVA; F = 5.1; df = 5, 45; P = 0.0009). Mean values (± SD) ranged from 6.56 ± 1.95 mg $Chl\underline{a}/m^2$ (n = 14) on 16 May to 10.93 ± 0.64 mg $Chl\underline{a}/m^2$ (n = 4) on 30 May. These data are comparable to those of Dunbar and Acreman (1980) for two arctic locations in May, and those of Clasby et al. (1973) for Barrow, Alaska, in late May, but are considerably lower than chlorophyll concentrations at fast ice stations in Pond Inlet during May and June reported by Cross (1982), viz 17.6 to 182.6 mg $Chl\underline{a}/m^2$. This probably is attributable to the relatively deep snow present at the Cape Hatt study area; the lowest mean biomass reported for Pond Inlet (above) was at the station with the highest mean snow depth (15.8 cm), and a significant negative correlation between snow depth and biomass was found at some stations (Cross 1982). An inverse relationship between ice chlorophyll and snow depth has also been observed by Alexander et al. (1974).

Based on the data above, the net increase in epontic algal biomass was 4.37 mg $Chl\underline{a}/m^2$ for the two week period, or 0.31 mg $Chl\underline{a}/m^2/d$.

Mean ice algal productivity on any day in any location (control data only) ranged from 0.26 ± SD 0.07 mg $C/m^2/h$ (n = 5) to 3.34 ± 1.96 mg $C/m^2/h$ (n = 5); the overall mean for the study period was 1.83 ± 1.39 mg $C/m^2/h$

(n = 35). When total productivity during incubation periods was compared with the amount of *in situ* radiation present during the incubations on a day/location basis, the correlation was significant and positive ($r = 0.87$, $n = 8$, $P<0.01$). When productivity data from different day/location combinations were compared using ANOVA, differences were significant ($F = 5.71$; $df = 7, 26$; $P<0.001$); however, when light data were used as a covariate (ANCOVA), the day/location differences became non-significant ($F = 1.73$; $df = 7, 26$; $P = 0.146$).

These data are comparable to those of Clasby et al. (1973) at Barrow, Alaska, who reported mean productivity values between 4 and 4.5 mg $C/m^2/h$ on 6 and 21 May, and values between 1 and 1.5 mg $C/m^2/h$ between 25 May and 5 June. It appears that the under-ice algal bloom, and concomitant high productivity, had begun to decline earlier at Barrow in 1972 than at Cape Hatt in 1981.

The- increase in biomass from 16 to 30 May (see above) can be compared with our productivity estimates. Using a C/Chl*a* ratio of from 23 to 79 (Parsons et al. 1977, Table 11), and the daily rate of Chl*a* increase calculated above, the net amount of carbon fixed per day during the study period was 7.1 to 24.5 mg C. Total ^{14}C productivity during 5 to 7 h incubation periods ranged from 1.5 to 17.6 mg C/m^2 (overall average of 10.7 mg C/m^2). Assuming that productivity continues at this rate from 12 to 24 h per day (the latter is not likely), average daily productivity would be about 20 to 40 mg C/m^2. Admittedly these are very rough calculations, but it is evident that the two methods provide estimates that are at least within the same order of magnitude. A refinement of this productivity estimate would

require, at the very least, productivity measurements during the arctic 'night' in spring, and these are presently not available.

Two methods of collecting microalgal samples for incubations were compared: (1) inserting the chambers, cutting the core, and capping before ^{14}C injection and incubation, and (2) inserting the chamber before. ^{14}C injection but cutting and capping after the incubation. Biomass of epontic algae did not differ significantly between the two methods (ANOVA, $F = 1.53$; $df = 1, 9$; $P = 0.247$). Productivity, however, was significantly higher with the second method (2.89 ± 0.44 mg $C/m^2/h$) than with the first (1.58 ± 0.46 mg C/m*/h) according to ANOVA, and, more appropriately, ANCOVA with light as the covariate ($F = 16.99$; $df = 1, 9$; $P = 0.0026$). This probably was attributable to disturbance of the epontic algae when the core was cut prior to incubation. If there was any leakage of ^{14}C-bicarbonate when we used the second method (not strictly a closed system), then this disturbance effect would be even greater than our data indicate. The second method was the one used by Clasby et al. (1973), and clearly is the preferred method. The first method was the one used in the rest of our experiments, and hence our productivity estimates are low by a factor of approximately two.

Oil Effects

Laboratory Techniques

Oil or dispersed oil was injected into the incubation chambers at the start of incubation with ^{14}C, and remained there throughout the incubation periods. Previous investigators studying oil effects on productivity have

not discussed effects of oil on laboratory techniques; this is a concern because of possible quenching effects on scintillation counts and interference in the fluorometric determination of chlorophyll concentrations. *A priori* tests of the former indicated that only small amounts of oil could be tolerated in scintillation cocktails, and therefore we attempted to separate the oil from the incubation medium before filtration (see 'Methods'). Interference by oil in fluorometry was not investigated.

In order to determine whether the separation of oil and incubation medium had any effect on ^{14}C activity or apparent chlorophyll concentrations, we performed a separate test using a uniformly labelled stock to which the three oil levels were added (see 'Methods'). Specifically, it was suspected that labelled algae may have remained with the oil in the separator funnels. The results of this test were as follows:

Nominal Oil level (ppm)	^{14}C Activity (dpm) mean ± SD (n = 4)	Chlorophyll_a (mg/m^3) mean ± SD (n = 4)
0	7255.5 ± 234.34	25.11 ± 3.66
10	6098.5 ± 131.58	20.18 ± 0.90
300	4069.0 ± 680.60	17.20 ± 3.51
10,000	3665.3 ± 381.63	15.25 ± 0.73

Results of ANOVA showed that the decrease with increasing oil level was significant, both for chlorophyll *a* and for ^{14}C activity. Correction factors were then calculated for each variable, and applied to the results of the *in situ* incubations (23, 24 May) using the same oil levels. A similar test was not conducted using dispersed oil, and so those data were not corrected.

A comparison of the results for oil incubations using corrected and uncorrected data, however, indicated that the *in situ* addition of oil did not have the same effect as did the laboratory addition of oil. ANCOVA on uncorrected biomass (Chl *a*) data showed non-significant variation among oil levels, both on 23 May ($F = 2.29$; $df = 3, 11$; $P = 0.14$) and on 24May ($F = 0.77$; $df = 3, 11$; $P = 0.54$). The same analyses using 'corrected' biomass data showed marginally significant differences among oil levels on 23 May ($F = 3.71$; $df = 3, 11$; $P = 0.046$) and highly significant differences on 24 May ($F = 6.57$; $df = 3, 11$; $P = 0.008$), Moreover, the differences in corrected data were not those expected--on both days higher corrected biomass values were calculated for the two higher oil levels than for the control or the lowest oil level. A possible explanation is that, in the laboratory experiment , algae in chambers were dispersed throughout the water column, and hence more susceptible to entrainment by the injected oil than were the algae in the *in situ* experiments, which were concentrated in the ice.

Another probable artifact became apparent only after inspection of the scintillation counts. In most cases, dark ^{14}C uptake in oiled incubation chambers (169 to 606 dpm) was within the range of dark ^{14}C uptake values measured in control chambers. Relatively high values, however, were recorded in some of the dark chambers to which oil was added: 1792 dpm (23 May, 300 ppm); 2266 dpm (24 May, 10,000 ppm); 13,168 dpm (30 May, 100 ppm); 1751 dpm (30 May, 300 ppm). Dark values were routinely subtracted from each of the corresponding replicate light values in the calculation of productivity to account for dark ^{14}C uptake by algae; high dark uptake from other sources (biotic or abiotic) would lead to significant underestimates of algal productivity. Thus , we present productivity data (below) based on (1)

measured dark values at each oil level on each day, and (2) control dark values for each day, applied to all oil levels.

Ice Algal Productivity

Data on the effects of oil and dispersed oil on ice algal productivity are given in Table 1. The results of 3 methods of calculation are included: data corrected for ^{14}C loss resulting from the separation of oil from the incubation medium prior to filtration (see above), and uncorrected data using dark incubation values from (1) chambers containing oil and (2) control chambers (see also above). The productivity values vary among calculation methods, but the results of ANCOVA are similar for all methods.

High oil levels suppressed productivity significantly on each day, regardless of the method of calculation used. One-factor ANCOVA with oil level as the factor and light as the covariate revealed a significant ($P<0.01$) oil effect in every case. In all cases, productivity was lower at the highest oil level than at any other level including controls (Table 1). Results of multiple comparisons, however, showed that differences among, O, 10 and 300 ppm oil levels were not consistent either among days or types of data. In most cases productivity at the lowest levels (10 and 300 ppm, or O, 10 and 300 ppm) were not statistically distinguishable (Table 1).

Two-factor ANCOVA for the two days when untreated oil was used showed significant variation among oil levels ($P< 0.001$), but no significant variation between days ($P>0.07$) and no significant interaction between days and oil levels ($P>0.65$). This was true regardless of which of the three

Table 1. Effects of oil and dispersed oil on the productivity (mg C/m²/h) of under-ice algae at Cape Hatt, Baffin Island, during May 1981. Data shown are mean ± SD (n = 3) for each date and oil level; results are shown for 3 different methods of calculation.

Date[1]	Nominal Oil Level (ppm)	Ice Algal Productivity (mg C/m²/h)		
		Uncorrected Data[2]		Data corrected for oil/medium separation[2]
		Oil level dark values	Control dark values	
23 May	0	1.92 ± 0.43	1.92 ± 0.43	1.92 ± 0.43
	10	2.17 ± 0.28	2.19 ± 0.28	2.58 ± 0.33
	300	1.32 ± 0.13	1.47 ± 0.13	2.36 ± 0.23
	10,000	0.38 ± 0.18	0.36 ± 0.18	0.76 ± 0.35
	Multiple Comparisons[3]	3<2<0,1	3<0,1,2; 2<1	3<0,1,2
24 May	0	2.21 ± 0.33	2.21 ± 0.33	2.21 ± 0.33
	10	0.82 ± 0.22	0.81 ± 0.22	0.97 ± 0.26
	300	0.74 ± 0.07	0.73 ± 0.07	1.31 ± 0.12
	10,000	0.13 ± 0.13	0.34 ± 0.13	0.26 ± 0.26
	Multiple Comparisons[3]	3<1,2<0	3<0,1; 1,2<0	3<1,2<0
30 May	0	1.64 ± 0.21	1.64 ± 0.21	
	10	0.88 ± 0.21	2.63 ± 0.21	
	300	0.61 ± 0.15	0.81 ± 0.15	–
	10,000	0.01 ± 0.01	-0.01 ± 0.01	
	Multiple Comparisons[3]	3<1,2<0	3<2<0<1	

1 Untreated Lagomedio crude oil was used on 23 and 24 May; 10 Lagomedio:1 Corexit 9527was used on 30 May.

2 See text for methods of calculation.

3 Duncans multiple range test, $\alpha = 0.05$; tales 0-3 represent nominal oil levels 0, 10, 300 and 10,000 ppm, respectively.

methods of calculation were used. Thus, results were consistent on the two days when untreated oil was used.

The effects of dispersed oil on ice algal productivity appeared to differ from those of untreated oil in two ways. (1) The highest oil level (10,000 ppm) resulted in near zero productivity in the case of dispersed oil, whereas it resulted in much reduced but still positive productivity in the case of untreated oil. Laboratory treatment of the highest dispersed oil level, however, was unique (longer time in separator funnels), so it is uncertain whether the greater apparent decrease in productivity was real. (2) The only significant increase in productivity with increasing oil level occurred on 30 May (dispersed oil day): productivity was 60% greater at 10 ppm dispersed oil than in controls (Table 1), but only when control dark values were used. Hsiao et al, (1978) presented some evidence of a stimulation of photosynthesis when 'dispersed oil' (10 ppm Pembina crude oil + 10 ppm Corexit) was added to natural arctic phytoplankton communities, but it is not clear whether their results are based on dark bottles containing dispersed oil. In the absence of an adequate explanation for the high dark values observed within oiled chambers in the present study, the validity of the observed stimulation of productivity cannot be assessed.

Despite the procedural and interpretat ional difficulties discussed above, it is clear that the highest oil level studied had a pronounced effect on ice algal productivity. At this level, dispersed oil apparently had a larger effect (total suppression of productivity) than did undispersed oil, but even in the latter case productivity was much reduced from control levels. Nominal concentrations of oil and dispersed oil were the same at

each level; actual concentrations were not measured but were undoubtedly much lower in the case of undispersed oil. Hsiao et al. (1978) reported oil effects on productivity of arctic marine phytoplankton in oil-seawater dispersions at concentrations as low as 10 ppm; at concentrations between 43 and 147 ppm values were 20 to 40% of control productivity, depending on type of oil. Similar results on diatom growth were obtained when oil was added directly to algal cultures to give nominal concentrations between 10 and 10,000 ppm (Hsiao 1978). After 10 day's exposure, diatom growth was reduced at all concentrations for all oils tested, but the highest concentration was lethal only to some combinations of species and oils. Further studies are required in order to determine if the observed effects on growth and productivity are reversible, particularly in the case of chemically dispersed oil which would likely only contact the ice for a limited period of time.

Oil Effects on Under-ice Amphipods

Site Description

Amphipod experiments were carried out in Bay 12 (Fig. 1) overawater depth of approximately 8 m. Ice depth at the entry hole was 156 cm, and snow depth in the study area (a circle of 25 m radius) was 26.2 ± SD 5.6 cm (range of 12-38 cm; n = 40). A layer of fresh water several cm thick was observed just beneath the ice on each of the study days (25-28 May). Amphipods were collected in the incubation chambers and the chambers were then placed on shallow hummocks or ridges on the under-ice surface. In this way we avoided both disturbance of the under-ice surface by respired air from SCUBA and any effects of the fresh water layer occurring under thinner ice.

The most abundant amphipod in the study area, and hence in the experimental chambers, was Weyprechtia pinguis (76.5% of total number in chambers). The remaining 23.5% of the total number included 7 distinct species as well as unidentified damaged and juvenile amphipods. One or more of the chambers at each oil level on 26 May contained only a few amphipods (2 to 11), so for that day the results for two chambers at each oil level were pooled to provide adequate numbers for analysis (behavioral data excluded). All results below are concerned only with Weyprechtia (except for behaviour, when amphipods were not identified), as numbers of other species were too low to allow meaningful analysis.

Behaviour

Most of the amphipods in the study area occurred on the undersurface of the ice; when disturbed, amphipods either dropped, motionless, through the water column, or began swimming downwards. In either case, upward motion began within a few seconds and the amphipods resumed their positions on the ice, sometimes leaving and returning to the ice several times before settling. Similar behaviour was observed within incubation chambers, although containment effects were also apparent. Of the enclosed amphipods, only half were on the under-ice surface prior to oiling, and the rest were distributed evenly between the water column and the chamber bottoms (averages of 50.2% on ice, 26.0% in water, and 23.8% on bottom; all chambers included). The lower proportion of amphipods on the ice relative to that outside of the chambers (close to 100%) probably was attributable to the availability of another surface (chamber bottom) or to crowding on the ice within the chambers. When oil, dispersed oil or water was injected through

the chamber bottom, most amphipods left the ice and swam around the chamber and upwards towards the ice; a prolonged setting process was again observed. Approximately five minutes after 'oiling', fewer amphipods were on the under-ice surface, and more were in the water and on the chamber bottoms than prior to 'oiling' (averages of 31.0% on ice, 39.7% in water and 29.3% on bottom; dispersed oil chambers not included).

During the observation period there was no apparent avoidance of oil by amphipods; in fact, direct contact between amphipods and oil droplets was often observed while amphipods were settling on the under-ice surface. We observed no obvious differences in amphipod behaviour among oil levels (controls included), and the proportions of amphipods on the under-ice surface before or shortly after oiling were not correlated with oil level during any experiment (Spearman rank correlation, maximum $r_s = -0.40$ for $n = 11$). 'Abnormal' behaviour, i.e. circular swimming, prolongedsettlingtime and reduced numbers of amphipods on the ice, occurred in both control and treatment chambers and hence must have been the result of confinement in the relatively small chambers or disturbance due to the injection of oil or water.

Prolonged exposure to oil was the only factor that markedly affected the percentage of the amphipods that dropped to the bottom of the chamber. Occurrence of amphipods on the chamber bottoms was not significantly correlated with oil level either before or immediately after the injection of oil, during either exposure period (Fig. 2). In most cases, more than 50% of the amphipods were in the water column or on the ice. At the end of the 3 h exposure period, amphipod distribution in control chambers was similar to

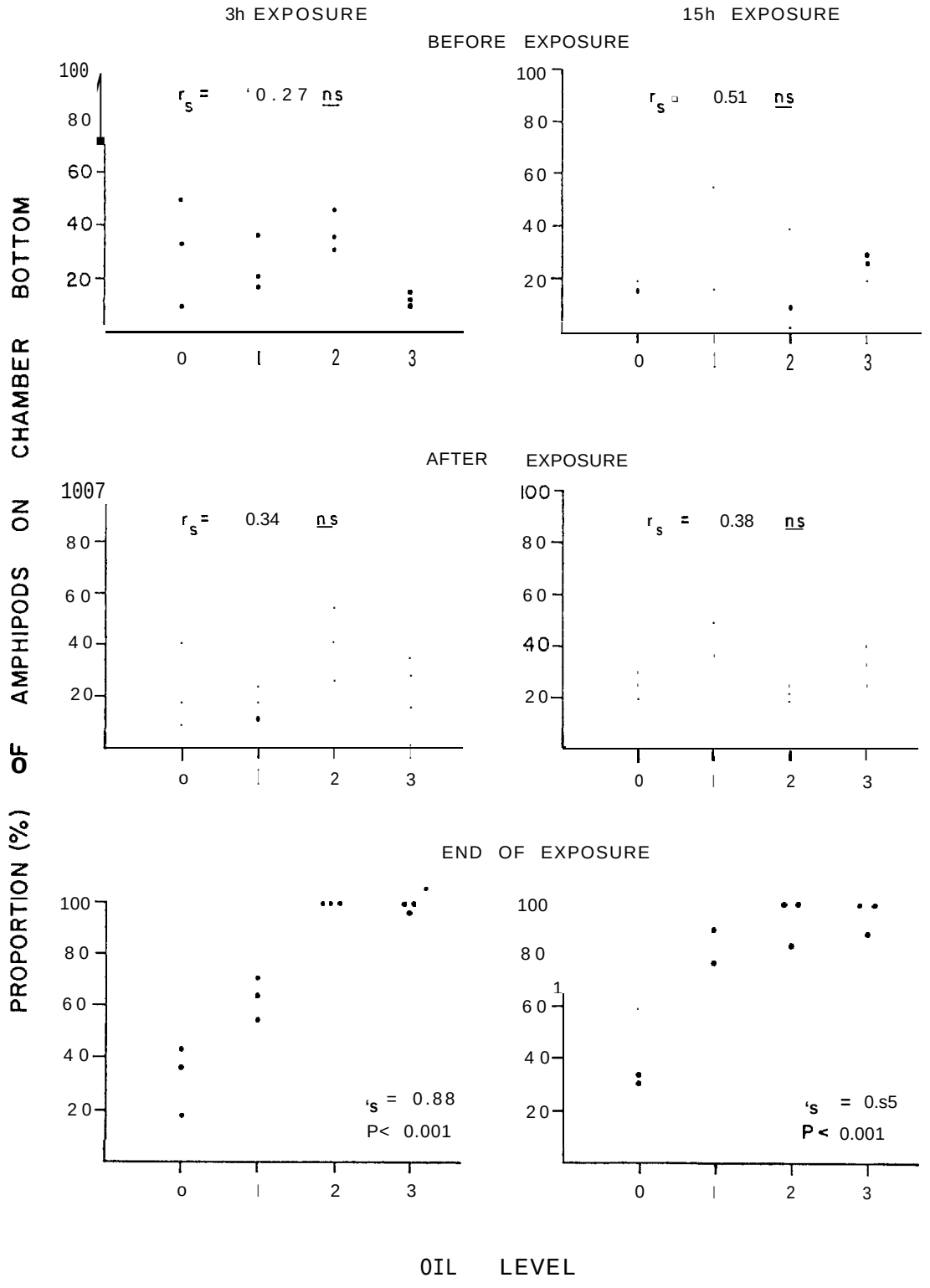

FIGURE 2. Immediate and delayed reaction of amphipods to oil in chambers. Oil levels 0, 1, 2 and 3 represent nominal concentrations of 0, 30, 130 and 400 ppm untreated Lagomedio crude oil.

that at the start of the experiment ; a somewhat higher proportion of amph ipods were on chamber bottoms at the end of the 15 h exposure. However , at all oil levels in both exposures the percentage of amphipods on the chamber bottoms had increased by the end of the exposure period; at the two higher concentrations (130 and 400 ppm) it was between 80 and 100%. The correlation between amphipod distribution and oil level was highly significant at the end of both experiments ($P<0.001$, Fig. 2),

Some of the amphipods at the chamber bottoms at the end of the exposure period probably were already dead. Those still alive probably were at the chamber bottoms because of impaired locomotor ability or impaired ability to remain on the ice rather than avoidance of the oil on the under–ice surface. Percy and Mullin (1977) reported impairment of locomotoryactivityinthe arctic amphipod Boeckosimus affinis after 24 h exposures to all oil concentrations tested (nominal concentrations of 50-2000 ppm). Our exposures were shorter, but many of the amphipods at all oil levels were apparently unable to swim at the end of the exposure periods.

During our observation periods there was no apparent avoidance of the oil at the under-ice surface. Previous studies have demonstrated an avoidance reaction in Boeckosimus affinis to sediments contaminated with 4 types of oil (Percy 1977a) and to crude oil and oil-tainted food (Percy 1976). The avoidance reaction was diminished, however, if the oil was weathered or if the amphipods were pre-exposed to oil (Percy 1976), or when high concentrations of oil were mixed with sediments (Percy 1977a). Responses varied with type of oil (Percy 1976, 1977a), and Busdosh and Atlas (1977) found a complete lack of an avoidance response to surface slicks of a

different type of oil in B. affinis and Gammarus zaddachi. The importance of this susceptibility to oiling in the case of amphipods living and feeding on the under-ice surface, where oil slicks may accumulate, has already been pointed out (Percy 1974, 1975; Busdosh and Atlas 1977).

Mortality

Data on (1) immediate post-exposure mortality, (2) delayed mortality within four days of exposure, and (3) survival for four days post-exposure, are shown in Tables 2 and 3. Each of these three variables was calculated as a percentage of the total numbers or biomass of amphipods for each chamber (replicate). The three variables are clearly not independent, since the three values for a chamber total 100%; this must be considered in the interpretation of results.

Control mortality immediately following each exposure was low (≤3.3% of numbers, ≤0.2% of biomass; Table 2). Delayed mortality in controls, however, was somewhat higher, particularly following the dispersed oil exposure (31.9% of numbers, 17.4% of biomass). The latter may have been due to the larger numbers of control amphipods maintained in small containers in the laboratory following the dispersed oil exposure (50) as compared with those maintained following exposure to oil alone (20, 27). In any case, delayed control mortality must be attributable to some aspect of the field or laboratory procedures. There was no evidence, however, of any form of contamination of controls by oil during or following exposures.

Table 2. Effects of oil level on immediate and delayed mortality of under-ice amphipods. Data presented are means of percentages within replicate chambers (n = 2 for 15 h exposure, 3 for 3 h exposures).

Exposure	Variable	Percent of Numbers				Percent of Biomass				ANOVA[1] Significance	
		Control	30 ppm	130 ppm	400 ppm	Control	30 ppm	130 ppm	400 ppm	numbers	biomass
Oil-15 h	Immediate mortality	0	25.0	62.9	87.5	0	11.8	41.7	92.2	P = 0.025 *	P = 0.032 *
	Delayed mortality	14.3	41.7	16.9	8.3	11.9	9.0	20.6	5.3	P = 0.344 ns	P = 0.646 ns
	Survival	85.7	33.3	20.2	4.2	88.1	79.2	37.6	2.5	P = 0.022 *	P = 0.025 *
Oil-3 h	Immediate mortality	3.3	3.2	23.3	67.4	0.2	0.8	1.3	36.6	P = 0.003 **	P = 0.053 ns
	Delayed mortality	7.5	64.5	52.3	27.4	2.1	23.0	52.1	41.7	P = 0.014 *	P = 0.128 ns
	Survival	89.2	32.3	24.4	5.3	97.7	76.3	46.6	21.7	P = 0.002 **	P = 0.031 *
Dispersed Oil-3 h	Immediate mortality	0	16.1	15.9	6.1	0	9.5	3.0	8.1	P = 0.502 ns	P = 0.671 na
	Delayed mortality	31.9	45.8	27.8	5.2	17.4	39.7	22.3	37.4	P = 0.545 ns	P = 0.506 ns
	Survival	68.1	38.0	56.2	28.7	82.6	50.8	74.8	54.5	P = 0.123 ns	P = 0.246 ns

1 One-factor ANOVA for oil levels, including controls. ns means $P>0.05$, * means $0.05 \geq P>0.01$, and ** means $0.01 > P > 0.001$.

Table 3. Effects of length of exposure to oil and dispersed oil on immediate and delayed mortality of under-ice amphipods. Each value represents the mean percent mortality in all oiled chambers less mean control mortality; n = 9 except for 15 h exposure where n = 6.

	Oil - 15 h		Oil - 3 h		Dispersed Oil - 3 h		ANOVA Significance	
	% of numbers	% of biomass	% of numbers	% of biomass	% of numbers	% of biomass	numbers	biomass
Immediate mortality	58.5	48.6	28.0	12.7	16.1	6.8	P = 0.023	P = 0.013
Delayed mortality	8.0	-0.3	40.6	36.8	11.0	15.7	P = 0.015	P = 0.011
All mortality	66.5	48.3	68.5	49.5	27.1	22.6	P = 0.001	P = 0.157

Oil Level Effects

Following the 15 hour exposure to oil alone, immediate mortality and survival of Weyprechtia pinguis (based on percent of numbers and of biomass) varied significantly among oil levels (0, 30, 130 and 400 ppm), whereas delayed mortality did not (Table 2). Immediate mortality increased and survival decreased with increased oil level. Following the three hour oil exposure all variables based on numbers differed significantly with oil level; when based on biomass, only survival differed significantly among oil levels, although directions of trends were the same as for numbers. Again, there was a progressive increase in immediate mortality and a progressive decrease in survival with increasing oil level. Delayed mortality generally decreased with increasing oil level, but this trend was simply a result of the lack of independence among variables. Total mortality increased with increasing oil level in both oil-alone experiments.

Foy (1978) also reported increased mortality with increasing oil level in the arctic amphipods Onisimus litoralis and Boeckosimus edwardsii. oil-seawater dispersions were used in the laboratory, with nominal (added) concentrations of 50-800 ppm and measured concentrations of 20-47 ppm; from the lowest to the highest concentrations, mortality after 96 h exposures increased from 0% to 45% in Onisimus and from 0% to 83% in Boeckosimus. Delayed mortality was not measured, but the condition of the test animals indicated that it could be substantial (Fey 1978). In further studies with Onisimus and other arctic amphipods, additional mortality was indeed observed in 24 h post-exposure periods (Fey 1979).

Following the three hour exposure of Weyprecht ia pinguis to dispersed oil, differences among oil levels (including controls) were not significant for any variable ($P \geq 0.123$ in each case; Table 2). This was only partly attributable to relatively high mortality in controls. Survival in Weyprechtia at high oil levels was consistently higher when the amphipods had been exposed to dispersed oil then when exposed to untreated oil. The trends apparent after exposure to untreated oil (progressive increases or decreases with increasing oil level) were not apparent in any variable after exPosure to dispersed oil. The results of Foy (1978) for short exposures to Corexit-dispersed oil are similar: very little mortality was observed after 24 h laboratory exposures at concentrations up to 213 ppm (nominal concentration of 400 ppm) in the amphipods Onisimus litoralis and Boeckosimus edwardsii. At a higher concentration (800 ppm nominal, 355 ppm measured), however, 24 h mortality was >50% in both species.

Exposure Effects

The type of exposure had a significant effect on the amount and timing of mortality (Table 3). One demonstration of this is the fact that there was a significant 'oil level x exposure type' interaction term in 2-way ANOVAs of immediate mortality ($P = 0.005$ for biomass, $P = 0.011$ for numbers). Immediate mortality was highest following the 15 hour exposure to oil alone (58.5% of numbers, 48.6% of biomass) and delayed mortality was highest following the three hour exposure to oil alone (40.6% of numbers, 36.8% of biomass). Total mortality was similar following 15 or 3 h exposures to undispersed oil (66.5, 68.6% of numbers; 48.3, 49.5% of biomass), but much greater than total mortality after 3 h exposure to dispersed oil at the same

three oil levels. Total mortality after exposure to dispersed oil was less than half of that following exposure to oil alone (Table 3).

Size effects

Differences between mean size of *Weyprechtia pinguis* in the sample and mean size of those dying within four post-exposure days were small (dead amphipods were smaller by an overall average of 1.0 mm); mean size of dead *Weyprechtia* was greater than mean size of the whole sample in only two of 28 cases, and smaller in 21 of 28 cases. There were no significant differences in this variable (the difference in mean size between all amphipods and dead amphipods), however, either among exposures ($P = 0.89$) or among oil levels, including controls ($P = 0.39$). This suggests that any size selective mortality that occurred was due to handling, either *in situ* or in the laboratory.

Degree of Oiling vs. Mortality

The relationship between mortality and degree of oiling (i.e. evidence of oil on preserved amphipods) was examined using a contingency table. Only oil levels 1, 2 and 3 were considered (89.4% of these amphipods were oiled to some extent); the inclusion of control data could produce a significant relationship merely because no control amphipods were oiled. As dispersed oil did not adhere to amphipods, only data from 'oil alone' exposures were used.

The resultant contingency table is shown in Table 4. At higher levels of oiling (right half of table), immediate mortality was not related to extent of oiling; none of these amphipods survived beyond the end of the exposure. In order to evaluate the effects of low to moderate oiling on survival, statistical tests were carried out only on the left half of the contingency table (low to intermediate degree of oiling). The X^2 statistic for this table was highly significant ($df = 4$; $P = 0.0001$). Immediate mortality increased and survival for any length of time decreased with increased oiling when only the low to moderate levels of oiling were considered.

The results of the present field study on the effects of untreated oil on under-ice amphipods corroborate those of Percy (1974) and Busdosh and Atlas (1977), who concluded from laboratory studies that amphipods that come into direct contact with oil have little chance of survival. Amphipods either have no apparent avoidance response to oil (present study; also Busdosh and Atlas 1977), or an observed avoidance response is diminished in the presence of high concentrations of oil (Percy 1976, 1977a). This further indicates the susceptibility of these animals to oil spills. This study extends the results of laboratory experiments to actual conditions on the under-ice surface, and supports the concern of previous investigators (e.g., Percy 1974, 1975; Busdosh and Atlas 1977; Foy 1978) that under-ice communities may be particularity susceptible to oil spills.

The use of chemical dispersants increases the dispersion of oil in water, generally leading to higher mortalities in test organisms for a given amount of oil added (e.g., Foy 1978, 1979). These previous results are based

Table 4. Degree of oiling vs. immediate mortality, delayed mortality and survival of Weyprecht ia pingu is. 'Degree of oiling' is the sum of oil codes (light, medium, heavy = 1, 2, 3) on 8 body parts (see 'Methods') of each amphipod exposed to oil alone (controls not included).

	Degree of Oiling						
	o-3	4-7	8-11	12-15	16-19	20-24	-Total
Immediate mortality	6	22	30	17	17	11	103
Delayed mortality	56	25	3	0	0	0	84
Survival	39	3	0	0	0	0	42
Total	101	50	33	17	17	11	229

on relatively long (24–96 h) exposures to mechanically dispersed oil-water or dispersant-oil-water mixtures, however, and thus do not simulate a realistic spill situation. In the present study, amphipods exposed in situ to various concentrations of Corexit-oil-water mixtures for a relatively short (3 h) period of time were less affected than were those exposed to oil masses together with low concentrations of dissolved oil components for relatively short (3 h) or long (15 h) periods of time. Sublethal effects on metabolism, activity or nutritional state (Percy 1977b) were not studied, but our results on immediate mortality and survival for a 4-day post exposure period indicate that the chemical dispersion of oil may be less harmful to amphipods in the under-ice community than the accumulation of untreated oil on the ice under-surface. Dispersed oil may contact much larger areas of the under-ice surface, however, resulting in greater total mortality. Further studies are required on the relative toxicities of dispersed and untreated oil at realistic concentrations, and, in particular, on the behaviour of oil and dispersed oil under the ice.

Under-ice Amphipod Distribution and Population Structures

Site Description

Under-ice amphipods were sampled in Bays 9, 10 and 11 at Cape Hatt (Fig. 1) through dive holes over a water depth of 3-4 m. In each bay, holes were located just offshore (within 10 m) of the furthest tide crack from shore; the area sampled was seaward of the dive hole and consisted of smooth, relatively flat ice. Ice depths at the dive holes were 122, 152 and 163 cm in Bays 9, 10 and 11, respectively, and snow depths on 31 May were 14.3 ± SD

4.2 cm (n = 39), 14.3 ± 4.9 cm (n = 27) and 8.9 ± 5.5 cm (n = 39). In each bay a relatively light-coloured algal layer was present on the ice under-surface, and its distribution was patchy on a scale of metres or tens of metres.

Intertidal and shallow sublittoral substrates consisted of fine to coarse sand mixed with pebble and cobble; finer sediments became increasingly predominant with increasing depth. The shoreline was icebound to a depth of 2 or 3 m during May, and very little drifting or grounded ice was present during August and September.

The under-ice macrofauna in the three study bays included arctic cod (Boreogadus saida) and mysids (Mysis spp.), but otherwise consisted entirely of gammarid amphipods. Cod were observed only in the large tide cracks just inshore of the entry holes in each of the bays. The edges of these cracks were rounded and about 1/2 m apart at the bottom, and only a few cm wide at a distance. of about 1/2 m from the bottom of the ice; most cod moved up into the cracks when disturbed. Mysids were present throughout the water column in each bay, and were generally concentrated in the first metre of water just below the ice. Densities of mysids were extremely variable both within and among bays; estimates based on amphipod dip net samples were as high as 225 individuals or 6 g/m^2. These are underestimates, probably by at least an order of magnitude, because our nets sampled only a part of the water column and because mysids actively avoided the nets. The following results concern only the amphipods collected in this study, and only those amphipods occurring on the under-ice surface are treated in detail.

Species Composition

Ten species of gammarid amphipods were collected on the under-ice surface at Cape Hatt (Table 5). Two species, Ischyrocerus sp. and Weyprechtia pinguis, together accounted for 61.9% of total numbers, and three species, Weyprechtia pinguis, Gammarus setosus and Onisimus litoralis, together accounted for 86.1% of total biomass. Eight of the 10 species have previously been collected in spring on the under-ice surface at various localities in the central and eastern Arctic (Green and Steele 1975; Buchanan et al. 1977; Thomson et al. 1978; Cross 1980, 1982); the exceptions were Weyprechtia pinguis and Pontogenieia inermis. Those two species have previously been collected on the under-ice surface only in late February in the western Arctic (Griffiths and Dillinger 198).

By comparison, species diversity was considerably lower in the intertidal habitat (samples from August and September 1981) and considerably higher in the sublittoral habitat (samples from May, August and September 1981). Four amphipod species were found in the intertidal habitat; Gammarus setosus was dominant both in terms of numbers (93,2% of total) and biomass (76.8% of total). In the shallow (3-4 m) sublittoral habitat, 31 identified species and at least 7 distinct but unidentified species were collected. Orchomene minuta, Guernea sp. and Protomedia fasciata together accounted for 50.7% of total numbers collected in May, August and September, and Anonyx nugax, Anonyx sarsi, Orchomene minuta and Paroediceros lynceus together accounted for 62.9% of total biomass.

All four species found in the intertidal habitat were also found on the under-ice surface. Three and seven of the 10 amphipod species found under

Table 5. Species composition (Z of total numbers and biomass] of amphipods in under-ice, intertidal and benthic habitats in three bays at Cape Hatt during May, August and September 1981.

Species	Intertidal (Aug, Sept)		Under-ice (May)		Sublittoral (May)		Sublittoral (Aug, Sept)	
	% of numbers	% of biomass	% of numbers	% of biomass	% of numbers	Z of biomass	% of numbers	% of biomass
Onisimus litoralis	3.8	14,0	8.0	28.5			1.8	10.6
Gammarus wilkitzkii	0.7	4.6	0.1	1.1			<0.1	0.1
Gammarus setosus	93.2	76.8	8.8	26.3				
Gammaracanthus loricatus	0.2	4.1	0.5	1.5				
Ischyrocerus sp.			41.5	7.6	<0.1	<0.1	0.2	<0.1
Weyprechtia pinguis			20.4	31.3	<0.1	0.5	6.2	11.9
Onisimus glacialis			1.8	1.9			0.2	0.5
Pontogeneia inermis			0.2	0.2	0.3	0.6	0.2	<0.1
Onisimus nanseni			<0.1	0.1			<0.1	0.5
Apherusa glacialis			1.0	0.4				
Orchomene minuta					25.0	24.8	15.4	7.8
Guernea sp.					27.3	3.5	10.7	0.7
Protomedeia fasciata					13.6	2.5	3.2	0.7
Paroediceros lynceus					4,7	8.5	9.9	12.7
Monoculopsis longicornis							14.0	0.9
Monoculodes borealis					0.7	3.3	12.2	4.7
Boeckosimus plautus					2.5	2.6	4.9	4.4
Corophium clarenscense					3.9	0.6	0.3	<0.1
Stenothoidae spp.					0.9	0.2	4.2	0.3
Monoculodes latimanus					3.3	2.1	0.7	0.3
Call iopiidae spp.					2.4	1.1	1.7	0.2
Oedicerotidae spp. (2 species)					0.1	<0.1	2.9	0.2
Anonyx nugax					1.2	34.6	0.9	11.1
Pontoperaia femorata					1.0	2.2	1,2	0.6
Oediceros borealis					1.0	0.5		
Anonyx sarsi					<0.1	0.3	1.2	28.3
Westwoodilla megalops					0.4	<0.1	<0.1	<0.1
Monoculodes longirostris					0.3	1.7		
Atylus carinatus							0.2	1.1
Bathymeden obtusifrons					0.2	<0.1		
Melitadentata					0.1	0.1		
Monoculodes schneideri							0.3	0.2
Boeckosimus edwardsii							<0.1	<0.1
Lysianassidae sp.					<0.1	<0,1		
Monoculodes packardi							<0.1	<0.1
Phoxocephalus holbolli					<0.1	<0.1		
Westwoodilla brevicalcar							<0,1	<0,1
Total %[1]	97.9%	99.5%	82.3%	98. 9%	88.9%	89.7%	92.5%	97. 8%
Total number or biomass (g)	969	16.312	4127	49.122	1782	7.549	1268	13.24
Total no./m^2 or g/m^2	194	3,262	13	0.154	1188	5.033	423	4.41

1 Does not include unidentified, juvenile or damaged amphipods.

the ice also occurred in samples from the shallow sublittoral habitat in spring and summer, respectively (Table 5). Gammarus setosus and Gammaracanthus loricatus were not collected on the bottom (but were present in the intertidal habitat); these species have previously been reported to occur in the nearshore benthos (e.g., MacGinitie 1?55; Steele and Steele 1970) and were found in low numbers in samples collected by Cross and Thomson (1981, 1982) at 3 and 7 m depths in the same bays at Cape Hatt (LGL Ltd., unpubl. data). Apherusa glacialis formed a small part of the under-ice community, but was found in neither intertidal nor sublittoral habitats, either in this study or in that of Cross and Thomson (1982). This species is pelagic (Dunbar 1954) and often associates with pan ice in late summer (Stephenson 1942; MacGinitie 1955; Divoky 1978; Thomson et al. 1978). Species occurring on the under-ice surface in May were of very little importance in the sublittoral habitat in May (0.3% of numbers, 1.1% of biomass), and considerably higher importance in August and September (8,6% of numbers, 23.6% of biomass; Table 5).

Percent composition of total numbers and biomass of under-ice amphipods in each bay during mid-May and late May are shown in Figure 3. Differences among bays were more marked than differences between mid- and late May. In terms of numbers, percent composition changed very little from mid- to late May. In terms of biomass, the most obvious temporal difference is the reduced relative importance of Weyprechtia pinguis in late May.

In terms of numbers, Weyprechtia pinguis and Ischyrocerus sp. were the most important species on the under-ice surface. At both times in May, Weyprechtia was dominant in Bay 9 and Ischyrocerus was dominant in Bays 10

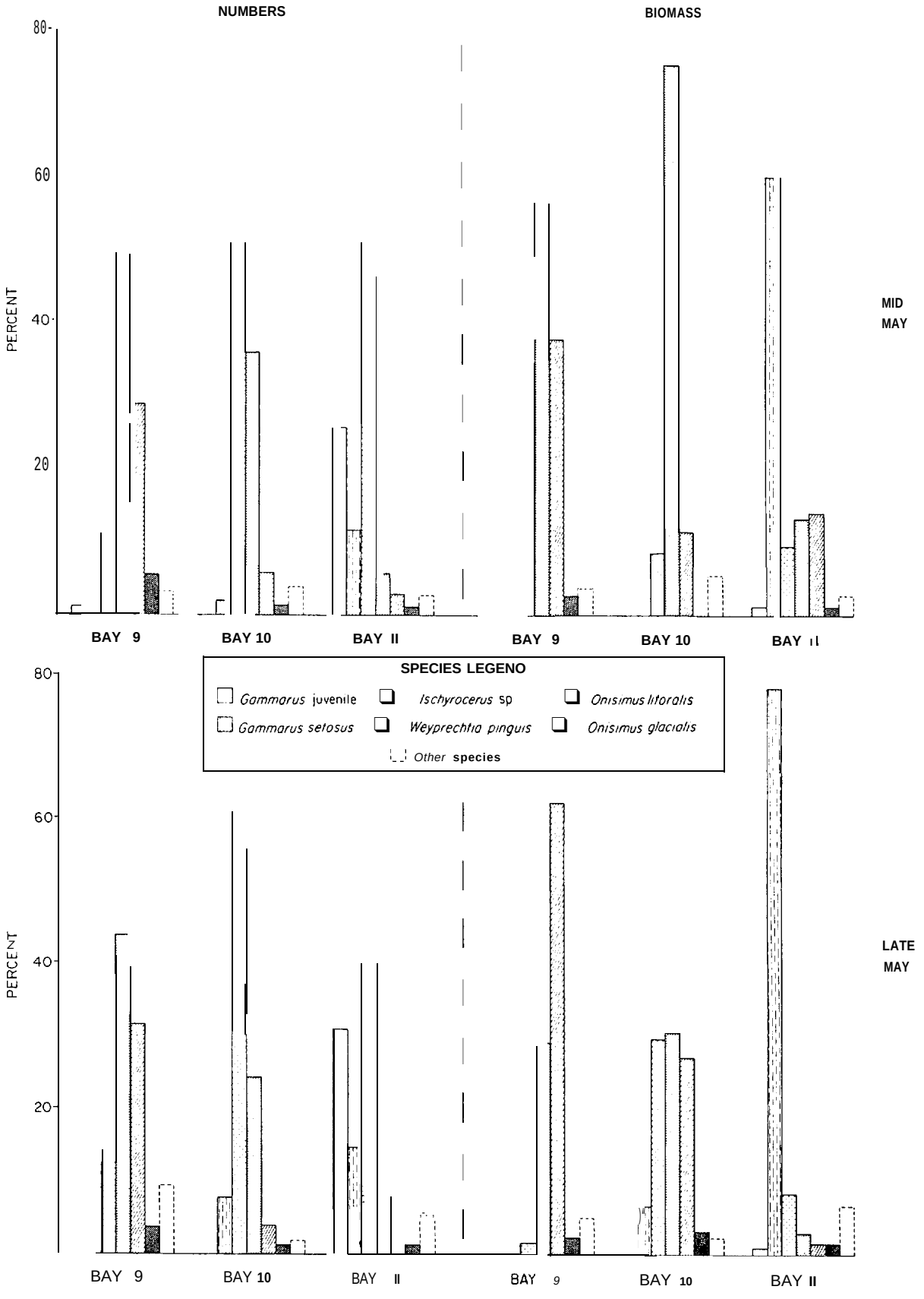

FIGURE 3. Percent composition of numbers and biomass of under-ice amphipods in systematic net samples collected during 17-19 May and 31 May 1981 in three bays at Cape Hatt, Baffin Island.

and 11; both species were among the top 3 contributors to total numbers in each bay at each time. Onisimus litoralis and Onisimus glacialis comprised higher percentages of numbers in Bay 9 than in Bays 10 or 11. Gammarus setosus and Gammarus juveniles together accounted for 37.0% and 45.3% of total numbers in Bay 11 in mid- and late May, respectively, and contributed much less (<9%) to total numbers in Bays 9 and 10.

In terms of biomass, Ischyrocerus was much less important (Fig. 3); at both times in May, Weyprechtia was dominant in Bay 10 and Gammarus setosus was first-ranked in Bay 11. Onisimus litoralis was more important in Bay 9 than in Bays 10 or 11, and was dominant (62.1% of biomass) in Bay 9 on 31 May.

Abundance and Biomass

Abundance (nos./m^2) and biomass (g/m*) of all amphipods in under-ice, intertidal and sublittoral habitats are shown for each of the 3 bays and 4 sampling periods in Figure 4. In general, abundance and biomass were highest in the sublittoral habitat, intermediate in the intertidal habitat, and lowest on the under-ice surface. However, intertidal habitats sometimes contained more amphipods than sublittoral ones. From August to September, sublittoral abundance and biomass remained similar or increased in most cases, whereas intertidal amphipods usually decreased (Fig. 4).

Considerably fewer amphipods occurred on 'the under-ice surface in mid-May (<15/m^2) than in the sublittoral habitat at the same time (>200/m^2); differences in biomasses were less marked, but still very considerable.

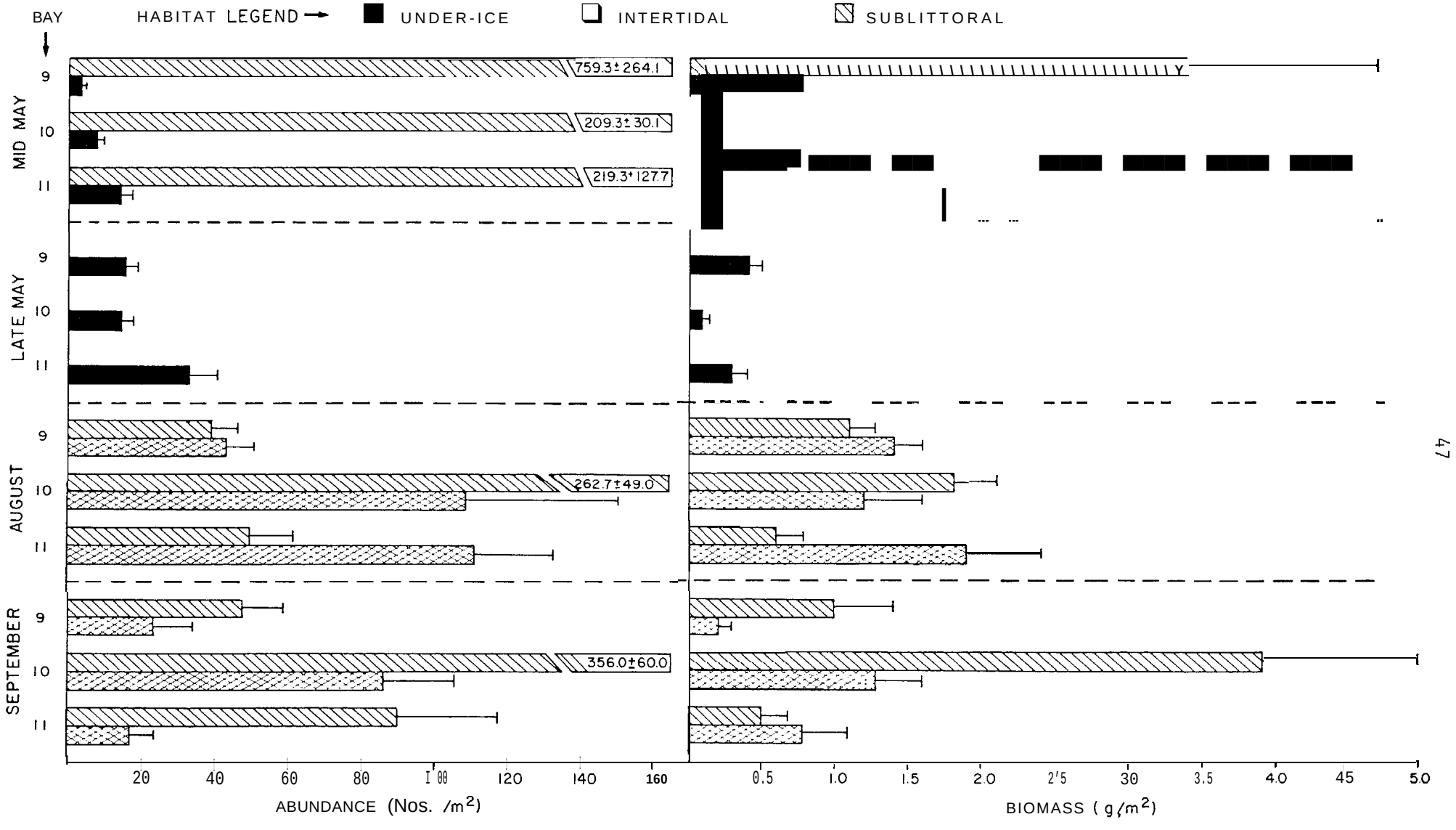

FIGURE 4. Abundance and biomass of all amphipods in under-ice, intertidal and sublittoral habitats in three bays and at four times at Cape Hatt, Baffin Island. Data are given as mean (boxes) ± S.E. (lines).

However, the species that dominated the under-ice habitat were more numerous there than on the bottom. Four dominant species, Ischyrocerus Sp., Weyprechtia pinguis, Onisimus litoralis and Gammarus setosus, were present on the under-ice surface in relatively low abundances in mid-May (0.1 to 7.1 indiv./m^2). Of these, only Ischyrocerus and Weyprechtia were collected in the sublittoral habitat at that time, and then only in one bay (Table 6); for Ischyrocerus, this was the only occurrence in the sublittoral samples. In this bay, numbers of Weyprechtia in the sublittoral habitat increased from May to August, and decreased in September; in Bays 10 and 11, Weyprechtia was absent in sublittoral samples in May, present in August, and again absent in September (Table 6). Similarly, Onisimus was present in the sublittoral habitat only in August. Gammarus was not present in samples from the sublittoral habitat; it was found on the ice in all three bays, but was common only in Bay 11. These data indicate a very strong preference for the under-ice habitat in May for the four dominant species on the under-ice surface. This preference apparently varies among species and with locality: Percy (1.975) reported that Boeckosimus affinis congregates near the ice in winter, but is still present in the sediment, and leaves the ice in late May to return to the bottom. Griffiths and Dillinger (1981) reported that Weyprechtia pinguis was collected both on the bottom and on the under-ice surface in Prudhoe Bay in late February.

A comparison of under-ice and intertidal habitats also shows species and locality differences. Gammarus setosus was present either on the under-ice surface (May) or in the intertidal habitat (August, September) in all 3 bays; in each case abundances were highest in August and lowest in May. Densities were considerably higher in the intertidal area (12.8 to 102.4 indiv./m^2

depending on bay and month) than on the under-ice surface (0.1 to 4.8 indiv./ m^2). Onisimus litoralis was also present in each bay on the under-ice surface in May, and was found in the intertidal area in August and September, but only in Bays 10 and 11. Densities were similar in both habitats in Bay 10, and higher in the intertidal habitat in Bay 11. Weyprechtia pinguis and Ischyrocerus sp. were absent from the intertidal areas of all three bays (Table 6).

Analyses of variance were used to compare abundances and biomasses of all amphipods and of four dominant species in different bays and at different times (Table 7). In most two-way ANOVA's, interactions between the bay and time factors were significant ($P<0.05$; Table 7). This indicates that differences in abundance or biomass from one time to another (mid-May to late May, or August to September) were not consistent among bays; conversely, differences among bays were not consistent from one time to another. These interactions necessitated the use of separate one-factor ANOVAs (bay effects) for each time period.

In general, there were pronounced among-bay differences in abundances and biomasses of total amphipods and dominant species of amphipods, Among-bay differences were somewhat more pronounced in late May than in mid-May: in mid-May there were no differences among bays in the biomass of total amphipods, or in the density or biomass of Onisimus litoralis, whereas in late May densities of all taxa and biomasses of all taxa but Ischyrocerus sp. differed significantly among bays. In the intertidal habitat, the numbers and biomass of Onisimus litoralis differed significantly among bays only in August, whereas numbers and biomass of Gammarus setosus differed among bays only in September (Table 7).

Table 6. Densities (nos./m^2) of dominant under-ice amphipod species in under-ice, intertidal and shallow sublittoral habitats during May, A.gust and September 1981 in three bays at Cape Hatt, Baffin Island. Data are expressed as mean * SD and based on 10-16 replicates.

Species	Habitat	Bay 9				Bay 10				Bay 11			
		Mid May	Late May	Aug	Sept	Mid May	Late May	Aug	Sept	Mid May	Late May	Aug	Sept
Weyprechtia pinguis	Under-ice/Intertidal[1]	1.5 * 1.0	6.7 * 5.2	0	0	2.6 * 3.5	3,4 ± 3.6	0	0	0.8 * 1.5	2.6 * 3.1	0	0
	Shallow Sublittoral[2]	0.7 ± 2.1		9.3 * 11.4	1.3 ± 2.8	0		41.3 * 26.1	0	0		0.7 ± 2.1	0
Onisimus 1 itoralis	Under-ice/Intert idal	0.9 * 1.2	4.9 *4.7	0	0	0.4 * 0.8	0.6 ± 0.7	0.8 ± 1.7	0.4 ± 1.3	0.3 ± 1.0	0.1 * 13.3	12.8 * 7.3	0.8 * 1.7
	Shallow Sublittoral	0		4.7 ± 7.1	0	0		2.0 * 3.2	0	0		8.7 ± 9.5	0
Ischyrocerus sp .	Under-ice/Intert idal	0.3 ± (3.3	1.2 ± 1.5	0	0	3.7 ± 3.2	8,6 ± 10.2	0	0	7.1 * 7.4	13.1 * 9.9	0	0
	Shallow Sublitoral	0.7 ± 2.1		0	0	0		0	0	0		0	0
G— s setosus	Under-ice/Intertidal	0.1 ± 0.1	0.1 *0.1	42.0 ± 21.6	23.6 * 34.1	0.1 * 0.2	1.1 * 1.9	102.4 ± 129.4	85.2 ± 61.4	1.6 ± 1.7	4.8 ± 3.1	95.2 * 58.9	12.8 ± 20.6
	Shallow Sublittoral	0		0	0	0		0	0	0		0	0
Total amphipods	Under-ice/Intert idal	2.9 ± 2.0	15.3 ± 11.8	43.2 ± 22.7	23.6 *34.1	7.3 ± 5.7	14.1 ± 12.2	108.0 * 135.0	86.4 ± 60.6	13.9 ± 11.9	32.5 ± 24.5	111.6 ± 67.5	16.8 ± 21.7
	Shallow Sublittoral	759.3 ± 835.2		39.3 ± 23.0	47.3 ± 35.1	209.3 * 95,0		262.7 ± 155.0	3%.0 ± 190.0	219.3 ± 404.0		50.0 ± 36.8	90.0 ± 85.9

- no samples collected.
1 Under-ice in May and intertidal in August and September.
2 Depth 35 m.

Table 7. Comparison of bianasses and densities of amphipods in under-ice and intertidal habitats in three bays at two times at Cape Hatt, Baffin Island. F - values are shown with associated significance levels (ns = P>0.05; * P<0.05; ** P<0.01; *** P<0.001). In the 2-way ANOVAs, significance levels are not given for the main effects when the interaction term was significant.

			Source of variation and df[1]				
			Two-factor ANOVA			One-factor ANOVA (bays)	
Habitat	Variable	Taxon	Bay 2,74(54)	Time 1,74(54)	Bay x Time 2,74(54)	Bay[2] 2,45(27)	Bay[3] 2,45(27)
Under-ice Habitat	Biomass	Total amphipods	2.16	14.92	6.73 **	0.42 ns	5.91 **
		Gammarus setosus	32.82	10.01	9.06 ***	15.69 ***	18.99 ***
		Onisimus litoralis	12.24	12.09	12.11 ***	1.10 ns	11.88 ***
		Weyprechtia pinguis	6.77	0.08	5.25 **	4.07 *	13.01 ***
		Ischyrocerus sp.	6.76 **	8.12 **	1.22 ns	6.66 **	2.78 ns
	Abundance	Total amphipods	9.38 ***	23.24 ***	1.96 ns	8.54 ***	3.35 *
		Gammarus setosus	63.35	25.49	6.89 **	35.08 ***	31.25 ***
		Onisimus litoralis	21.23	13.24	12.37 ***	2.14 ns	39.98 ***
		Weyprechtia pinguis	5.70 **	14.48 ***	2.17 ns	4.05 *	3.37 *
		Ischyrocerus sp.	23.19 ***	6.91 *	0.24 ns	14.08 ***	9.14 ***
Intertidal Habitat	Biomass	Gammarus setosus	0.20	3.22	6.34 **	2.07 ns	4.81 *
		Onisimus litoralis	29.98	24.40	21.95 ***	31.79 ***	1.04 ns
	Number	Gammarus setosus	1.34	6.90	9.92 ***	1.90 ns	11.12 ***
		Onisimus litoralis	29.68	23.43	18.69 ***	36.38 ***	1.08 ns

[1] Denominator df are shorn for under-ice habitat, followed by intertidal habitat (in parentheses).
[2] Bay effects for mid-May (under-ice) or August (intertidal).
[3] Bay effects for late May (tier-ice) or September (intertidal).

Lagomedio crude oil was spilled in Bay 11 between the August and September sampling periods, and a relatively even coating of oil was deposited on the beach (intertidal area) of Bay 11 by the falling tide. Observations following the spill (Cross and Thomson 1982), inspection of the data (Table 6) and significance of the bay x time interaction terms in Table 7 all indicate that oil affected the amphipods that occupied the intertidal habitat. The numbers of intertidal Gammarus setosus decreased somewhat in Bays 9 and 10 from August to September, but the corresponding decrease in Bay 11 was much more marked (September densities were 56.2, 83.2 and 13.4% of August values in Bays 9, 10 and 11, respectively). Onisimus litoralis was not found in the intertidal habitat in Bay 9, and was very sparsely distributed in Bay 10, but, like Gammarus, numbers decreased drastically in the intertidal area of Bay 11,

The absence or low abundance of Gammarus setosus in the sublittoral habitat, and its abundance in the intertidal habitat, indicate that the latter is the source of recruitment for this species to the under-ice habitat. Thus, Gammarus may be less abundant on the ice in Bay 11 in 1982 than in 1981. Sampling of all 3 habitats is continuing in 1982, and any effects of the summer spills on the under-ice communities in the following spring, as well as any recovery in the intertidal zone, should be particularly easy to detect for this species in Bay 11.

Population Structures

Length-frequency histograms for Weyprechtia pinguis and Onisimus litoralis collected on the under-ice surface in May, and in intertidal

(Onisimus) or sublittoral (Weyprechtia) habitats in August, are shown in Figure 5. Both species are of a similar size, and two cohorts (year classes) are apparent for each. Too few of the first year class of Onisimus were collected to warrant analysis or discussion.

The second year class of Onisimus increased significantly in size from 12.2 to 15.2 mm over the mid-May to late May to August study period ($F = 34.57$, $df = 2,30$; $P<0.0001$), but only the increase from May to August was significant (Duncan's Multiple Range Test, $P<0.05$). Two-factor ANOVA (bays, times) for Onisimus from the under-ice surface only, showed no significant differences in size either between the two May sampling periods ($F = 3.54$, $df = 1,18$; $P = 0.076$) or among the bays ($F = 1.06$, $df = 2,18$; $P = 0.368$).

The first year class of Weyprechtia pinguis was considerably more abundant in late May than in mid-May, and the reverse was true for the second year class (Fig. 5; areas sampled were 576 m^2 and 384 m^2 in mid- and late May, respectively). This indicates that release of juveniles was occurring between the two dates. Juveniles increased significantly in length over the mid-May to August study period, from 3.6 to 7.2 mm ($F = 155.27$, $df = 2,36$; $P\leq0.0001$), and significant growth occurred in both the mid-May to late May and the late May to August periods (Duncan's Multiple Range Test, $P<0.05$). Similarity, the second year class of Weyprechtia increased significantly in length over the study period ($F = 23.01$, $df = 2,33$; $P\leq0.0001$). Results of two-factor ANOVA and multiple comparisons showed that the first year class was significantly smaller in Bay 11 than in Bays 9 and 10 ($F = 8.87$, $df = 2,26$; $P = 0.0012$), and that the second year class decreased progressively in size from Bay 9 to Bay 10 to Bay 11 ($F = 5.44$, $df = 2,28$; $P = 0.0101$).

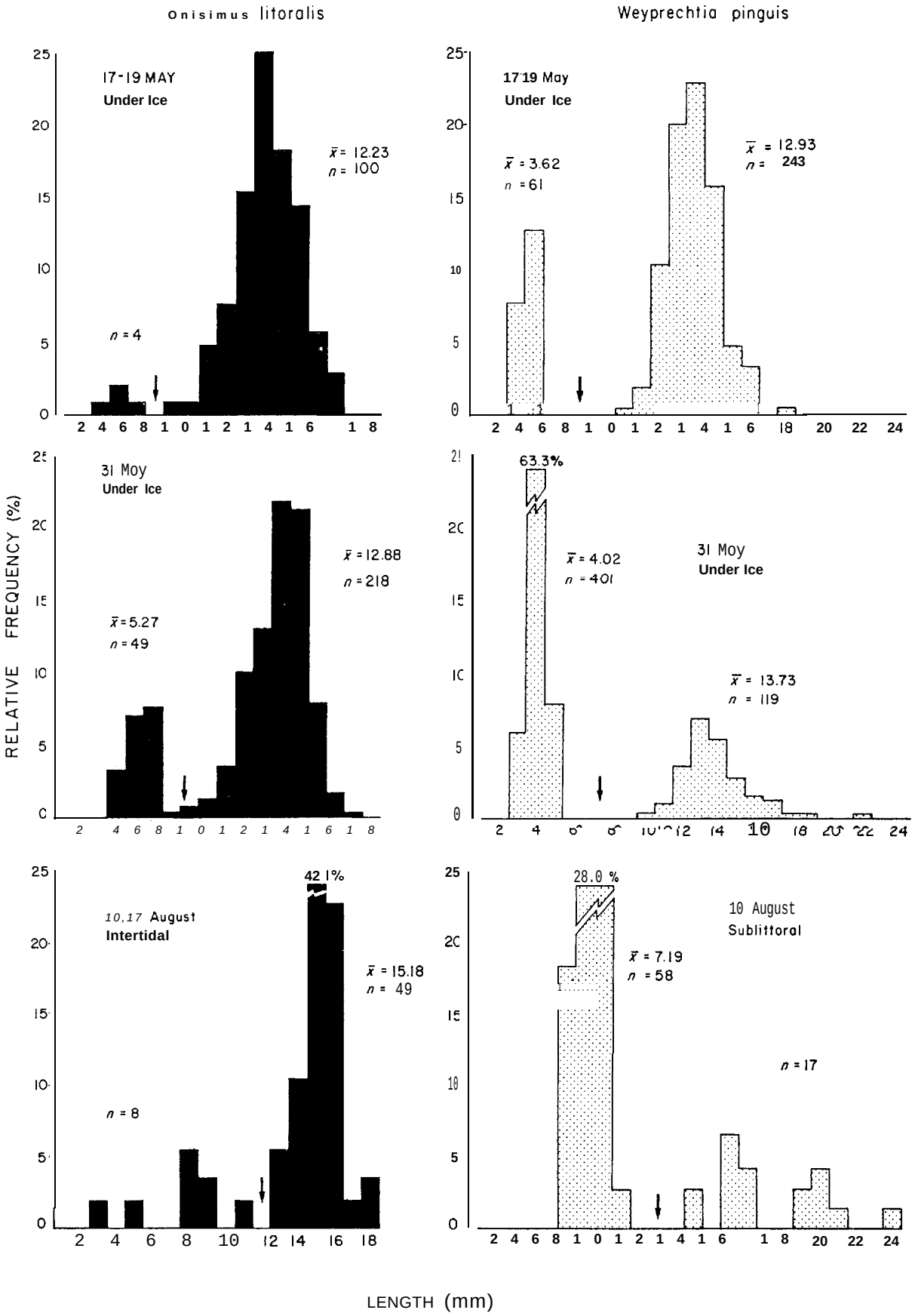

FIGURE 5. Length-frequency histograms for Onisimus litoralis and Weyprechtia pinguis in under-ice (Nay) and intertidal or sublittoral (August) habitats at Cape Hatt, Baffin Island, in 1981. Arrows indicate divisions between cohorts for mean size calculations.

Length-frequency histograms for Gammarus setosus (+ Gammarus juveniles) collected on the under-ice surface in mid- and late May, and in the intertidal habitat in August and September, are shown in Figure 6. At least three cohorts are present; the largest probably consists of two or more year classes, but numbers are too low to allow distinction or further discussion. The smallest cohort had apparently been released prior to our first sampling period. These juveniles grew significantly, from 3.0 to 5.7 mm on average, between mid-May and mid-September ($F = 204.7$, $df = 3,44$; $P<0.0001$). Growth was not apparent between the two sampling dates in May, likely because amphipods were measured only to the nearest mm. Mean sizes were significantly different, however, in each of May, August and September (Duncan's Multiple Range test; $P<0.05$). The second year class increased in length from 7.1 to 12.8 mm during the study period (Fig. 6). Again, this increase was significant ($F = 144.5$, $df = 3,36$; $P<0.0001$), but for this year class, increase in length was significant between each of the sampling dates.

Two-factor (bays, months) ANOVA for mean size data on Gammarus setosus collected in the intertidal habitat showed non-significant interaction effects between bay and month factors in either cohort ($F = 1.93$, $df = 2,33$; $P = 0.1617$ for cohort 1 and $F = 0.14$, $df = 2,13$; $P = 0.8673$ for cohort 2). There were also no differences among bays in the mean sizes of Gammarus in either cohort ($F = 2.26$, $df = 2,33$; $P = 0.1202$ for cohort 1 and $F = 1.91$, $df = 2,33$; $P = 0.1877$ for cohort 2). These results, together with inspection of Figure 6, indicate that there was no size-selective mortality in Gammarus resulting from the spill in late August.

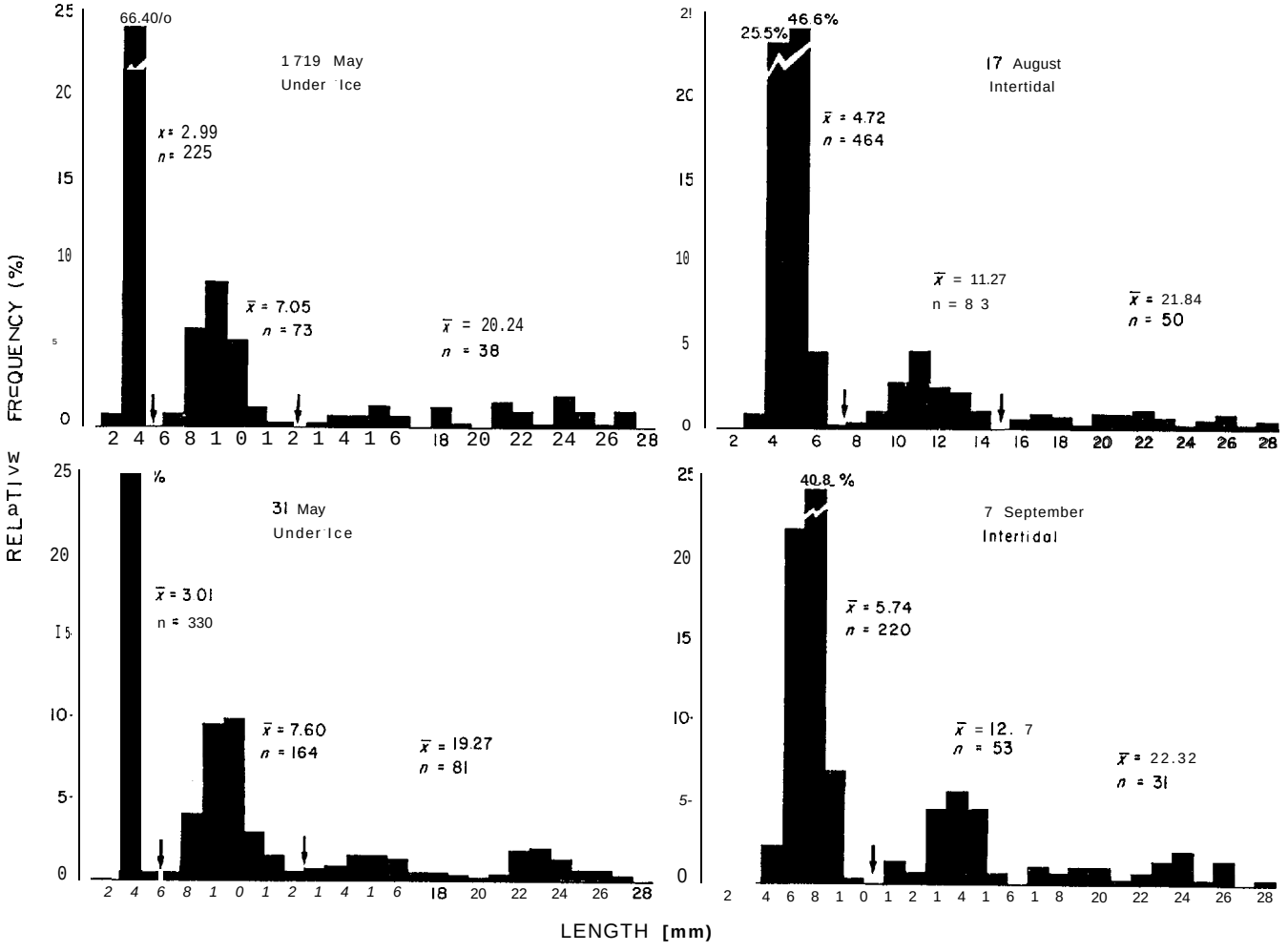

FIGURE 6. Length-frequency histograms for Gammarus setosus in under-ice (May) and intertidal (August, September) habitats at Cape Hatt, Baffin Island, in 1981.

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