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Effects of Oil and Chemically Treated Oil on Nearshore Under-Ice Meiofauna Studied *in situ*

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ABSTRACT. Meiofauna collected during May 1982 in the soft bottom layer of nearshore landfast ice at Cape Hatt, northern Baffin Island, were dominated by cyclopoid copepods, harpacticoid copepods, nematodes and polychaete larvae (73.5, 15.4, 6.3 and 3.5% of total numbers respectively). Also included were rotifers, gastropod veligers and calanoid copepod nauplii; calanoid nauplii were probably present in the near-ice water and not on or in the ice. Average abundance of all ice meiofauna was 54 000 individuals·m^{-2}. Densities of all meiofauna groups were spatially variable, but only nematodes and cyclopoid copepods showed evidence of progressive temporal change between 18 May and 2 June.

Undisturbed, enclosed areas of the under-ice surface were treated with oil on 23-24 May. Dispersed oil (Venezuela Lagomedio + Corexit 9527, BP CTD or BP 1100 WD) was in contact with the ice for 5 hours, whereas untreated oil and solidified oil (BP treatment) remained in the enclosures for the duration of the study (12 days post-treatment). Sampling was carried out in areas where oil contacted the ice and moved away or in areas near oil that remained in contact with the under-ice surface. Five hours after treatment, oil concentrations in the water within the enclosures were similar (0.15-0.28 ppm) in untreated oil, solidified oil and control enclosures. In contrast, dispersed oil concentrations were 5.8-36.5 ppm. Densities of all copepods and polychaetes decreased dramatically in each dispersed oil enclosure by the second post-spill day, and slight density increases were evident by the tenth post-spill day. Harpacticoid copepods apparently were more sensitive to dispersed oil than were cyclopoid copepods. Densities of nematodes and cyclopoid copepod nauplii were not affected by dispersed oil. Densities of nematodes, polychaetes and all copepods were not affected by untreated or solidifed oil, but there was some evidence of a stimulatory effect of those treatments on some copepod groups and life stages.

Key words: Arctic, ice meiofauna, ice copepods, ice polychaetes, ice nematodes, oil effects, dispersed oil effects, solidified oil effects, Baffin Island

RÉSUMÉ. Des échantillons de méiofaune recueillis durant le mois de mai 1982 dans la couche tendre du fond de la banquise située près de la côte au cap Hatt, au nord de l'île Baffin, consistaient principalement en copépodes cyclopidés, en copépodes harpacticoïdes, en nématodes, et en larves de polychètes (pourcentages de 73,5, 15,4, 6,3 et 3,5% respectivement). Il y avait de plus des rotifères, des véligères gastéropodes et des nauplius copépodes calanoïdes; des nauplius calanoïdes étaient sans doute présents dans l'eau près de la glace mais pas sur sa surface ou à l'intérieur. L'abondance moyenne de toute le méiofaune glaciaire était de 54 000 individus·m^{-2}. Les densités de tous les groupes de la méiofaune variaient spatialement, mais seuls les nématodes et les copépodes cyclopidés ont montré des signes de changements progressifs entre le 18 mai et le 2 juin.

Des endroits non perturbés et fermés de la surface de la glace immergée ont été traités avec du pétrole les 23 et 24 mai. Du pétrole dispersé (Lagomedio du Vénézuéla avec Corexit 9527, BP CTD ou BP 1100 WD) a été en contact avec la glace pendant 5 heures, tandis que du pétrole non traité et du pétrole solidifié (traitement BP) sont restés dans ces zones fermées pendant toute la durée de l'étude, soit 12 jours après le traitement. Des échantillons ont été relevés dans des endroits où le pétrole avait touché la glace et s'était déplacé, et dans des endroits proches de là où le pétrole était resté en contact avec la surface de la glace immergée. Cinq heures après le traitement, les concentrations de pétrole dans l'eau à l'intérieur des endroits fermés étaient semblables (de 0,15 à 0,28 p.p.m.) dans les zones fermées exposées au pétrole non traité, au pétrole solidifié et dans les zones témoins. Par contre, les concentrations de pétrole dispersé étaient de 5,8 à 36,5 p.p.m. Les densités de tous les copépodes et de tous les polychètes ont diminué de façon radicale dans chaque zone fermée exposée au pétrole dispersé dès le deuxième jour après le déversement, et de légères augmentations étaient notables dès le dixième jour après le déversement. Les copépodes harpacticoïdes étaient apparemment plus sensibles au pétrole dispersé que les copépodes cyclopidés. Les densités de nématodes et de nauplius copépodes cyclopidés n'étaient pas affectées par le pétrole dispersé. Les densités de nématodes, de polychètes et de tous les copépodes n'étaient pas affectées par le pétrole non traité ou solidifié, mais il y a eu quelques évidences d'un effet stimulateur de ces traitements sur certains groupes de copépodes et sur le développement des individus.

Mots clés: arctique, méiofaune glaciaire, copépodes glaciaires, polychètes glaciaires, nématodes glaciaires, effets dus au pétrole, effets dus au pétrole dispersé, effets dus au pétrole solidifié, île Baffin

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INTRODUCTION

Communities inhabiting the undersurface of arctic sea ice include autotrophs (ice algae) and heterotrophs. The heterotrophic component includes a number of microscopic organisms, including bacteria, fungi, colourless flagellates and ciliated protozoans (Horner, 1976, 1977, 1985). Also included is a wide variety of metazoans that graze on ice algae (Horner and Alexander, 1972; Bradstreet and Cross, 1982; Grainger and Hsiao, 1982) and, presumably, on bacteria as well. The smallest of these metazoans — copepods, nematodes, polychaetes and turbellarians — are termed meiofauna. Interest in this community has increased in recent years. The existing literature is largely limited to sublittoral and intertidal habitats, but quantitative data on under-ice meiofaunal communities in arctic waters are becoming increasingly available (Thomson *et al.*, 1978; Carey and Montagna, 1982; Cross, 1982; Grainger and Hsiao, 1982; Kern and Carey, 1983; Carey, 1985). The impact of these grazers on ice algal production and their contribution to higher trophic levels (e.g., arctic cod — Bradstreet and Cross, 1982) are not well understood. In consideration of their high abundances (on the order of 10^5 individuals·m^{-2}), however, they may be extremely important in both respects.

In other latitudes, meiofauna have become a focus of pollution studies in recent years. Intertidal and benthic meiofauna have been increasingly used as indicators of pollution of various types. Small samples provide a large number of individuals, thereby facilitating sampling design and reducing costs. Although there is conflicting evidence concerning the effects of oil on meiofauna, the sensitivity of some meiofaunal groups to pollution and the insensitivity of others has led to a recent postulation that simple ratios of abundances (e.g., nematode: copepod ratios) may be useful as pollution indicators (Raffaelli and Mason, 1981; Warwick, 1981a). The use of such simple ratios is attractive because of the great reduction in effort and cost required to detect pollution.

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The possibility of accidental oil releases into arctic and subarctic marine habitats is increasing with the acceleration of oil exploration and development. In the event of an oil spill or subsea blowout in arctic or subarctic waters, hydrocarbons will most likely accumulate in the under-ice, intertidal and shallow subtidal habitats. Data concerning 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 oil spills. In this study, we attempted to create realistic scenarios for the impingement of oil onto the under-ice surface: low concentrations of dispersed oil contacting the ice for a short period of time, and untreated oil and solidified oil remaining in place on the under-ice surface. Studies described herein address the effects of oil, solidified oil and dispersed oil (three different chemical dispersants) on under-ice meiofaunal density and species composition. By using spatial and temporal controls we examined the initial impact on and subsequent recovery of under-ice meiofauna subjected to a single application of these treatments.

The papers in this volume report results of the Baffin Island Oil Spill (BIOS) Project, which provided administrative and logistic support for the present study (see Acknowledgements). The BIOS Project assessed the use of chemical dispersants on an oil slick in arctic nearshore waters by comparing the fate and effects of dispersed oil with those resulting from the option of allowing the untreated oil slick to contact the beach and be removed by natural processes. The effectiveness of various shoreline cleanup techniques was also evaluated in separate study areas. Sergy and Blackall (1987) summarize the rationale, design and overall results of the BIOS Project.

METHODS

Field Procedures

Field studies were carried out during 14 May-2 June 1982 from the BIOS (Baffin Island Oil Spill) Project base camp located at Cape Hatt, Baffin Island (72°27'N, 79°51'W). The study area consisted of a shallow embayment (Bay 13) in Ragged Channel, some 3 km to the north of the BIOS Project study bays (Fig. 1). All under-ice sampling and experimental work was carried out by scuba divers working through a hole in the ice over a water depth of 10 m and about 200 m from shore.

Under-ice meiofauna were treated *in situ* with crude oil (Venezuela Lagomedio), solidified oil (BP treatment), oil dispersed with three different chemical dispersants (Corexit 9527, BP 1100 WD and BP CTD) and no oil (control). Each treatment was applied to the under-ice surface within buoyant plexiglass enclosures 1.2 m in diameter and 30 cm in depth. There were two enclosures for each of the six treatments; one set of six enclosures was established under the ice at each of two locations (Locations 1 and 2) separated by approximately 30 m.

Each oil-treated enclosure (volume 365 *l*) received 36.5 ml of oil, for a nominal concentration of 100 ppm if the oil was evenly dispersed. Oil and dispersants (10:1 ratio) were mixed with seawater in 9 *l* air-pressurized fire extinguishers. Dispersed oil, untreated oil and water (control and solidified oil treatments) were introduced from the extinguishers into the enclosures. In this way, any disturbance of the under-ice surface that resulted from the use of fire extinguishers was similar for all treatments. Solidified oil was prepared at the surface, transferred to a polyethylene bag and passively introduced into the enclosure

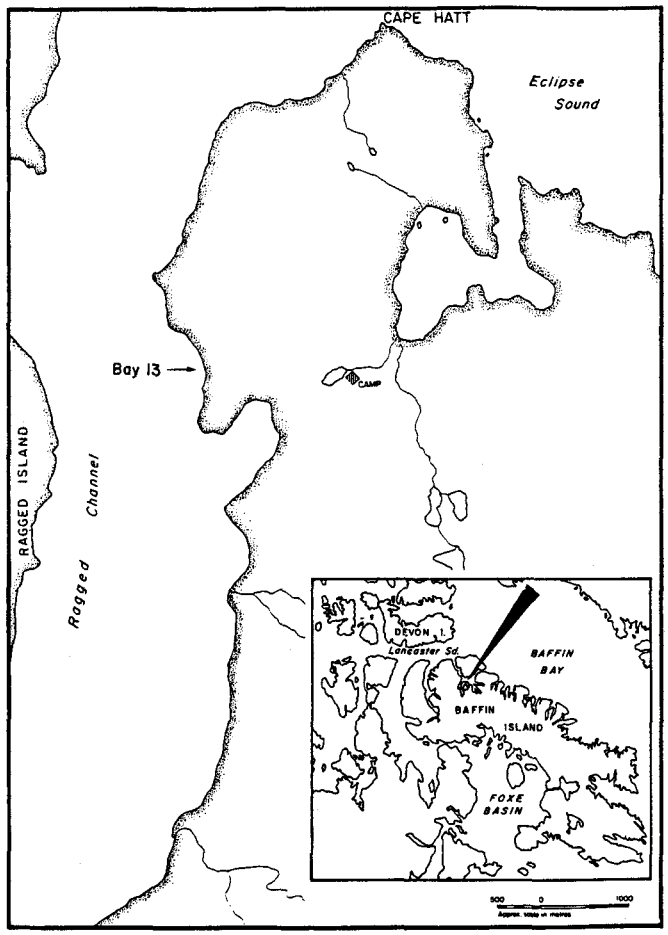

FIG. 1. BIOS site at Cape Hatt, northern Baffin Island (72°27'N, 79°51'W), showing the location of the study bay.

after the control injection of water. The bottom of each enclosure was covered by polyethylene sheeting during the application of treatments. Dispersed oil was contained within the enclosures for a period of 4-5 h and then the bottom sheet was removed; control, oil and solidified oil enclosures remained covered during the release of the dispersed oil from other enclosures. During the exposure period, water within the dispersed oil enclosures appeared very murky, whereas that in the other enclosures appeared clear. Untreated oil and solidified oil remained in localized areas (less than 10% of the under-ice surface) within the enclosures throughout the study. Just before the covers were removed from enclosures, two water samples from each enclosure were collected in 50 ml polypropylene syringes and frozen for hydrocarbon analysis.

Sampling was carried out within the enclosures during five periods, each consisting of 2 d: 18-19, 21-22, 26-27, 28-29 May and 1-2 June. Treatments were applied on 23-24 May. In each of these 2 d periods, Locations 1 and 2 were sampled (or treated) on the first and second day respectively. In untreated and solidified oil enclosures, sampling was carried out within the enclosures but not directly in the oiled areas. It is reasonable to assume that meiofauna would be killed, or at least displaced from their habitat, directly above a pool of oil or a mass of chemically solidified oil. Hence, the areas sampled were areas where oil

contacted the ice but moved away or areas in near proximity to untreated or solidified oil.

Cylindrical plexiglass chambers with an area of 78.6 cm^2 and a length of 15.3 cm (volume = 1202 ml) were inserted about 1-2 cm into the soft bottom layer of ice and left *in situ* for a period of 2-2.5 h as part of a concurrent primary productivity study (Cross, 1987). At the end of the incubation periods, ice cores were severed, the chambers were capped and 1 ml of formaldehyde solution (37% w/w) was injected into each.

During each sampling period, four replicate samples of ice (+ water) were taken in each enclosure. Because each treatment was applied to two enclosures, there was a total of eight chambers per treatment and sampling period. Separate samples of ice (+ water) were collected in the same way and returned immediately to the field laboratory for the determination of salinity, alkalinity and ambient inorganic concentrations (see Cross, 1987).

Light was measured with an underwater irradiometer (Kahlsico model 268 WA310) below the layer of ice algae and above the algal layer (after scraping this layer away) in each enclosure at the beginning and end of each incubation. Measurements above and below the ice algal layer were averaged for subsequent calculations. Simultaneous measurements above the ice were made with a surface cell so that percent transmission through the ice could be calculated.

Chambers were returned to the field laboratory immediately after the incubation period and processed within 8 h. Actual sample volumes varied to a maximum of 1350 ml and were sometimes very low because chambers leaked during transport to the laboratory. There was, however, no way in which one sample could have contaminated another. Data from chambers where actual volume was <1100 ml (26 of 240 ice samples; 13 of 60 water samples) were not included in the analyses. The nominal chamber volume of 1200 ml was used in calculations for all chambers. Subsampling, filtering and laboratory procedures for the determination of chlorophyll *a* concentrations, primary productivity and species composition of under-ice algae are given in Cross (1987).

Meiofaunal analysis was based on subsamples (approximately 500 ml) from each chamber, filtered through 40 μm mesh netting (to reduce the volume) and preserved in 5% formalin. Major taxonomic groups (copepods, nematodes and polychaetes) in each 500 ml subsample were enumerated using a binocular microscope and Ward zooplankton counting wheel (Wildco No. 1810). Copepods in one-half of the total number of samples were identified to species level and counted. Data on meiofauna densities were analyzed with two- and three-factor analyses of variance, using the SAS general linear models (GLM) program (Helwig and Council, 1979).

Oil concentrations were measured by ultraviolet fluorescence (UV/F) analysis using a Turner Designs Fluorometer. Prior to analysis, each frozen water sample was thawed, placed in a 125 ml separatory funnel and extracted twice with 10 ml hexane. The hexane extract was dried over anhydrous Na_2SO_4 and combined with a third 10 ml hexane that had been used to extract any remaining oil from the empty 50 ml polypropylene syringe used to collect the sample.

RESULTS

Site Description

General information on the biology of the study area can be found in Snow *et al.* (1987). The under-ice surface was smooth and relatively flat, with shallow hummocks and ridges. Ice depth was 135 cm at the entry hole. Snow depths on 3 June 1982 were 9.8 ± s.d. 1.7 cm (n = 14) and 18.2 ± 7.4 cm (n = 30) in Locations 1 and 2 respectively. 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. *In situ* radiation during incubations varied among enclosures and periods by almost an order of magnitude (Cross, 1987).

Salinity of ice (+ water) samples ranged from 30.1 to 32.4‰; no consistent differences were apparent among days (18 May-1 June). Snow melt began near the end of May, but no obvious effects were observed under the ice. Mean biomass of chlorophyll *a* in control samples ranged from 3.4 to 16.7 $mg \cdot m^{-2}$, depending on location and period. Productivity was from – 0.1 (after accounting for dark uptake) to 3.0 mg $C \cdot m^{-2} \cdot h^{-1}$. Total microalgal densities ranged from 1.7 to 384.7 × 10^7 $cells \cdot m^{-2}$. Data on biomass, density, productivity and species composition of ice algae are described further in a companion paper (Cross, 1987).

Community Description

The under-ice meiofauna collected in control samples at Cape Hatt were dominated by copepods, which constituted 92.3% of total numbers collected during the study. Nematodes and polychaetes made up 4.0% and 3.2% of total numbers respectively. Rotifers and gastropod veligers were present in very small numbers.

Cyclopoid and harpacticoid copepods constituted 83.2% and 16.3% respectively of the ice copepod fauna (Table 1). Calanoid copepods were only represented by nauplii and accounted for the remainder of total numbers (0.5%). A total of six copepod

TABLE 1. Percent composition and occurrence of under-ice copepod species from Cape Hatt, northern Baffin Island, during 18 May-2 June 1982[a]

Taxon	% of total numbers	Occurrence: % of samples	Occurrence: Rank
Cyclopoida (total)[b]	82.3		
Cyclopina schneideri	24.6	96.2	2
Oithona similis	0.1	11.3	9
Oithona copepodite	<0.1	7.5	11
Oncaea minuta	<0.1	9.4	10
Oncaea copepodite	0.2	26.4	7
Unidentified copepodite[c]	54.5	100.0	1
Unidentified nauplii	2.2	88.7	3
Harpacticoida (total)	17.2		
Tisbe furcata	13.1	100.0	1
Tisbe copepodite	1.9	79.2	4
Microsetella sp.	0.1	11.3	9
Microsetella copepodite	<0.1	5.7	12
Dactylopodia vulgaris	0.1	15.1	8
Unidentified copepodite	0.1	7.5	11
Unidentified nauplii	2.0	67.9	5
Calanoida			
Unidentified nauplii	0.5	60.4	6

Data are based on 13 539 individuals collected in 53 ice core samples.
[a]Data from only pre-spill periods and control treatments in post-spill periods are included.
[b]Total % includes unidentified adults.
[c]Majority identified as *Cyclopina* sp.

species were collected in systematic samples. *Cyclopina schneideri* and cyclopoid copepodites (mostly *Cyclopina* sp.) were presented in most samples and together made up over 75% of total copepods identified. The harpacticoid copepod *Tisbe furcata* occurred in all control ice samples and represented an average of 13.1% of total copepod numbers. Other cyclopoids (*Oithona similis* and *Oncaea minuta*) and harpacticoids (*Microsetella* sp. and *Dactylopodia vulgaris*) were rare, both in terms of abundance and occurrence; each contributed less than 1% to total copepod numbers during the study. One solitary individual of the species *Harpacticus superflexus* was present in a non-quantitative sample.

Abundance and Distribution

Total meiofaunal densities in control ice (+ water) samples averaged approximately 54 000 individuals·m^{-2}. Water samples taken just below the ice-water interface included all major ice-associated taxa, but their abundance was much lower than in the ice above: about 13 000 individuals·m^{-3} or 2000 ind·m^{-2} (based on 184 individuals in 24 control water samples). Most of the meiofauna in ice (+ water) samples, therefore, occurred in the bottom layer of ice.

Meiofauna were relatively evenly distributed on a small scale (i.e., within the 1.2 m^2 enclosures); the standard deviation was usually much less than the mean for each of the major meiofaunal groups. Variation on a larger scale (among enclosures) was considerable and was evident for all meiofaunal groups. There are several possible sources of this large-scale variability, including snow depth, light and concentrations of microalgae. In all control samples taken together (n = 104), light was positively correlated with densities of nematodes (r = 0.58; P<0.001), copepods (r = 0.52; P<0.001) and, to a lesser extent, polychaetes (r = 0.27; P<0.01). Similar correlations were evident between chlorophyll *a* concentrations and the densities of each of these groups. Light and chlorophyll concentrations were also positively correlated (r = 0.68; P<0.001). From a correlation analysis of this type it is not possible to identify causal relationships.

In each of the two locations, nematode densities increased from 18 May to 2 June 1982; mean density in control samples increased from 1100 individuals·m^{-2} to 4900 ind·m^{-2} (Fig. 2).

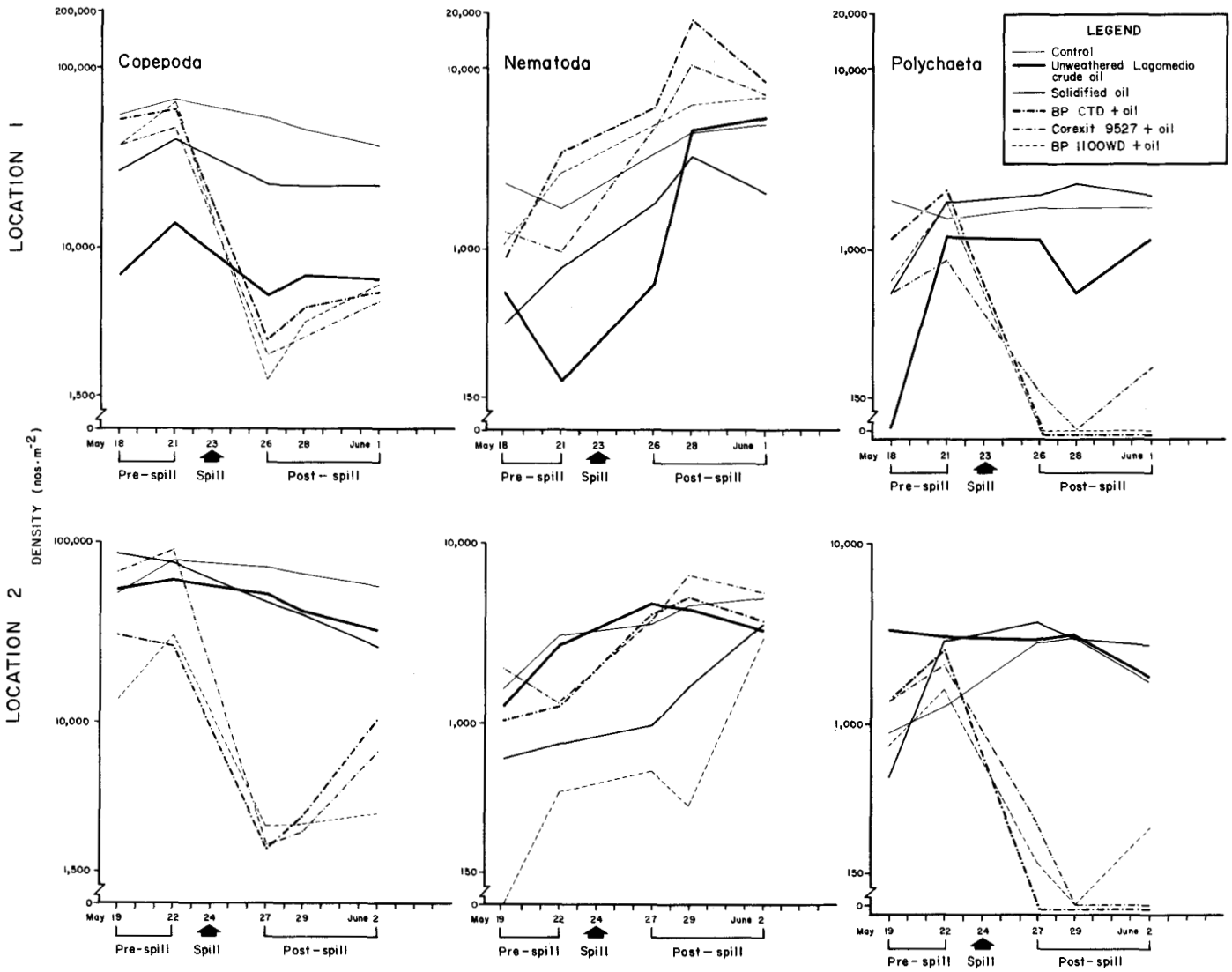

FIG. 2. Densities of major meiofaunal groups exposed to oil and chemically treated oil on the under-ice surface in two locations at Cape Hatt, northern Baffin Island, during 18 May-2 June 1982. Values for each date, treatment and location are means of densities in 3 or 4 replicate ice core samples (10 cm diameter).

Copepod and polychaete abundances in control samples, on the other hand, were relatively constant over the study period (Fig. 2). However, this was not true for all particular types of copepods. Cyclopoid copepodites decreased from 34 300 individuals·m^{-2} on 18-19 May to 9000 ind·m^{-2} on 1-2 June. At the same time, cyclopoid adults increased from 6300 to 24 500 ind·m^{-2}. In contrast, harpacticoid copepods showed no obvious temporal variation related to stages of development.

Oil Effects

Oil treatments were applied on 23-24 May, and oil concentrations in the water within the enclosures were measured about 5 h after treatment application. Oil concentrations in the water are shown in Table 2. Dispersed oil in concentrations between 5.8 and 36.5 ppm (as measured by ultraviolet fluorescence) was contained within enclosures beneath the ice for approximately 5 h and then released. In contrast, oil concentrations in the water within enclosures containing oil and solidified oil, measured 5 h after treatment, were similar to control values; in these cases, most of the fluorescence was derived from the polypropylene syringes used to collect samples. Oil and solidified oil remained in the enclosures on the under-ice surface during the 12 d post-treatment sampling period; the solidified oil mass remained on the under-ice surface, whereas the pool of untreated oil was overgrown by ice within 2 d of treatment (diver observations). Ice growth was also apparent around the plexiglass enclosures and around polyethylene syringes left on the under-ice surface.

Abundance: The study design involves five oil treatments plus a control in each of two locations and two pre-spill and three post-spill sampling periods. Three-factor analyses of variance (locations, treatments, periods) were carried out, but significant interactions involving location precluded unambiguous interpretation of period-by-treatment interactions and main effects. Therefore, separate two-factor analyses of variance (treatments and periods) were carried out for each of the two locations for each of three variables: densities of copepods, nematodes and polychaetes. Treatment-by-period interactions were highly significant ($P<0.001$) for two of these groups, copepods and polychaetes, in each of the locations (Table 3). The significant interaction terms mean that period-to-period variation was not consistent among treatments, indicating the possibility of an oil effect (Green, 1979).

Copepod and polychaete densities decreased dramatically between pre-spill and post-spill periods in each of the three dispersed oil treatments in each location; densities in the other three treatments (control, solidified oil and oil) remained relatively constant (Fig. 2). As previously mentioned, these results apply to areas where untreated or chemically dispersed oil contacted the ice and moved away or areas near untreated or solidified oil that remained in contact with the under-ice surface. Nematodes were completely unaffected by any of the oil treatments; densities increased throughout the study period in each treatment and in each location (Fig. 2). The observed response in copepods and polychaetes was similar for the three types of dispersants and the two locations, irrespective of the differences in oil concentrations measured within the enclosures (6-37 ppm).

Densities of polychaetes and copepods in dispersed oil treatments increased slightly between post-spill Periods 1 and 3. This increase was more pronounced for copepods than for polychaetes, probably indicating a faster recovery rate (Fig. 2).

Group Composition: Densities of all copepods considered together were not affected by untreated or solidified oil (Table 3). However, there was some evidence of a possible stimulatory effect of these treatments on some copepod groups and life stages. In the solidified oil enclosures, densities of harpacticoid adults and copepodites increased through all or most of the study period, whereas densities in control enclosures decreased earlier or showed no temporal trend (Table 4). Also, densities of cyclopoid nauplii in untreated and solidified oil enclosures decreased later in the study period than did those in controls. This apparent stimulation may be related to a similar stimulatory effect observed for ice algal biomass and productivity (see Cross, 1987).

Although total copepod densities decreased in all dispersed oil treatments (Table 3), cyclopoid and calanoid nauplii apparently were not adversely affected by dispersed oil. Pre- to post-spill decreases in cyclopoid nauplii densities were similar to those in controls, whereas calanoid nauplii densities in control and dispersed oil treatments did not decrease until the last post-spill sampling period (Table 4). Calanoid copepods are pelagic, and most calanoid nauplii in ice (+ water) samples were probably present in the water and not on or in the ice: in samples of near-ice water, densities of calanoid nauplii ranged from 110 ind·m^{-2} in Post-spill Period 1 ($n = 4$, all treatments combined) to 460 ind·m^{-2} in Post-spill Periods 1 and 2 ($n = 13$).

There was some evidence of differential sensitivity among groups and life stages of those copepods that were adversely affected by dispersed oil. Harpacticoid adults showed a greater

TABLE 2. Oil concentrations (average ppm in two samples) from each under-ice enclosure at Cape Hatt, northern Baffin Island, measured 5 h after treatment application on 23-24 May 1982

Treatment	Oil concentration (ppm)	
	Location 1	Location 2
Control	0.24	0.28
Oil	0.19	0.22
Solidified oil	0.15	0.15
BP CTD + oil	5.80	6.70
BP 1100 WD + oil	15.50	26.50
Corexit 9527 + oil	14.50	36.50

TABLE 3. Two-factor analyses of variance for densities of meiofauna exposed to oil[a] and chemically treated oil[a] on the under-ice surface at Cape Hatt, northern Baffin Island, during 18 May-2 June 1982[b]

Taxon	Location	Source of variation (df)		
		Period (4,77)	Treatment (5,77)	Period by treatment (20,77)
Copepoda	1	42.31	35.14	5.10 ***
	2	28.12	45.99	5.34 ***
Nematoda	1	36.91 ***	11.58 ***	1.60 ns
	2	11.55 ***	12.34 ***	0.87 ns
Polychaeta	1	5.73	15.55	2.91 ***
	2	8.24	20.93	3.32 ***

F-values are shown with significance levels (ns = $P>0.05$; * $P\leq0.05$; ** $P\leq0.01$; *** $P\leq0.001$). Significance levels are not shown for main effects when the interaction term was significant.
[a]Unweathered Lagomedio crude oil.
[b]Oil treatments were applied on 23 and 24 May 1982.

TABLE 4. Mean densities (individuals·10·m^{-2}) of copepod orders and life stages exposed to oil and chemically treated oil on the under-ice surface at Cape Hatt, northern Baffin Island, during 18 May-2 June 1982

Order	Life stage	Period[a]	Treatment					
			Control	Oil[b]	Solidified oil[b]	BP CID + oil[b]	BP 1100 WD + oil[b]	Corexit 9527 + oil[b]
Cyclopoida	Adult	Pre-1	631	510	676	459	536	775
		Pre-2	2339	821	1922	1495	1212	1899
		Post-1	3080	999	1583	35	84	62
		Post-2	2956	1017	1143	125	177	132
		Post-3	2454	692	621	461	308	401
	Copepodite	Pre-1	3433	2780	3736	2244	2792	3462
		Pre-2	3475	2590	4968	2758	3506	3964
		Post-1	1801	1023	1053	26	37	72
		Post-2	1465	1001	1240	75	117	91
		Post-3	899	546	857	205	112	180
	Nauplius	Pre-1	96	102	102	140	182	105
		Pre-2	123	163	82	199	133	125
		Post-1	77	213	114	121	83	37
		Post-2	64	241	134	21	50	45
		Post-3	50	112	87	20	8	20
Harpacticoida	Adult	Pre-1	842	714	230	612	239	956
		Pre-2	1037	539	272	446	462	1032
		Post-1	1236	726	446	44	18	29
		Post-2	919	574	415	54	33	94
		Post-3	890	339	699	125	120	121
	Copepodite	Pre-1	182	13	26	179	77	67
		Pre-2	99	48	75	156	60	114
		Post-1	202	52	130	54	0	14
		Post-2	114	31	179	139	7	11
		Post-3	182	19	117	34	0	8
	Nauplius	Pre-1	48	77	0	89	19	29
		Pre-2	207	85	155	127	31	162
		Post-1	303	34	171	9	0	0
		Post-2	241	31	274	10	0	15
		Post-3	134	36	87	24	9	13
Calanoida	Nauplius	Pre-1	29	13	38	0	38	19
		Pre-2	30	33	10	14	15	43
		Post-1	43	42	73	44	65	52
		Post-2	45	84	67	85	53	64
		Post-3	8	41	8	0	15	8

Based on 3-5 ice core samples (10 cm diameter) from each treatment and period; data from two locations combined.
[a]Pre-1 = 18, 19 May; Pre-2 = 21, 22 May; treatments applied 23, 24 May; Post-1 = 26, 27 May; Post-2 = 28, 29 May; Post-3 = 1, 2 June.
[b]Unweathered Lagomedio crude oil.

immediate response to dispersed oil than did copepodites, whereas harpacticoid copepodites were the only affected group to show little, if any, recovery by the third post-spill period (Table 4). Rare harpacticoid species (*Microsetella* sp. and *Dactylopodia vulgaris*) disappeared completely in dispersed oil treatments, and only a few individuals were present in the third post-spill sampling. Rare cyclopoid species (*Oithona similis* and *Oncaea minuta*), on the other hand, were still present in dispersed oil enclosures immediately after the spill.

DISCUSSION

The qualitative group and species composition of under-ice meiofauna at Cape Hatt, northern Baffin Island, were similar to those reported in other arctic locations. Nematodes, copepods and polychaetes are characteristic of the soft bottom layer of the ice, and the copepod genera *Cyclopina*, *Harpacticus*, *Oithona*, *Oncaea* and *Tisbe* have been consistently found in under-ice habitats of arctic and Antarctic regions (Andriashev, 1968; Thomson *et al.*, 1978; Cross, 1982; Grainger and Hsiao, 1982; Kern and Carey, 1983). One major difference among locations in quantitative group composition is that copepods were dominant in control samples from Cape Hatt. Thomson *et al.* (1978) also reported that copepods were predominant (79.0% of total meiofauna) in samples from the under-ice surface in Brentford Bay, Boothia Peninsula. Elsewhere, however, nematodes are usually the most abundant group of under-ice meiofauna (Carey and Montagna, 1982; Cross, 1982; Grainger and Hsiao, 1982; Kern and Carey, 1983).

This apparent variability among locations may be partly attributable to temporal effects. Nematode densities increased during May at Cape Hatt, and similar increases during the spring bloom have been reported in Frobisher Bay during 1981 (20 700-293 000 ind·m^{-2}; Grainger and Hsiao, 1982) and in the Beaufort Sea during 1980 (350-25 000 ind·m^{-2}; Kern and Carey, 1983). Copepod and polychaete abundances at Cape Hatt were relatively constant over the study period. Kern and Carey (1983) reported significant temporal variation in copepod and poly-

chaete densities in the Beaufort Sea during May 1980, but no progressive change was evident in either group. Numbers of both groups, however, decreased substantially between early and late May in Frobisher Bay (Grainger and Hsiao, 1982).

Smaller-scale spatial variability in the distribution of under-ice meiofauna at Cape Hatt was likely attributable to variability in light, ice algal biomass or both. Available information indicates that nematode densities may be more strongly influenced by light and copepod densities by algal concentrations. Cross (1982) reported that copepod abundance, but not nematode abundance, was significantly greater in brown ice (indicative of high ice algal biomass) than in clear ice at one station in Pond Inlet. At another station, both nematode and copepod numbers were significantly greater in a dense, loose algal layer under clear ice than in brown ice. Over 92% of the nematodes found by Thomson *et al.* (1978) in 16 core samples collected in Brentford Bay were in 3 samples taken under an area of ice that previously had been cleared of snow. At the same time there was no corresponding increase in copepod density or in apparent algal growth.

Other factors may also influence the distribution of meiofauna. Carey and Montagna (1982) suggested that ice meiofauna may be recruited from benthic or pelagic habitats by means of vertical migration or advective forces. Hence, their distribution and abundance may also be influenced by water depth and prevailing currents. Differences among groups would be expected for swimming (copepods and some polychaetes) and non-swimming (nematodes and other polychaetes) forms. Predation may also affect ice copepod densities, but this would not appear to be the case for nematodes. Warwick (1981b) pointed out that meiobenthic nematodes are rarely or never found in stomach contents of benthic predators, whereas meiobenthic copepods are known to form a significant item in their diets. Small copepods of the Antarctic ice fauna were found in fingerlings of *Trematomus borchgrevinki* by Andriashev (1968), and ice copepods dominated the diet of arctic cod near the Pond Inlet ice edge (Bradstreet and Cross, 1982); in each case nematodes were not mentioned.

Dispersed oil contained under the ice for 5 h at Cape Hatt caused dramatic decreases in densities of copepods and polychaetes. It is not known whether the copepods or polychaetes were killed outright or merely displaced from the under-ice surface. Narcosis commonly precedes death following exposure of invertebrates to oil, and whether the narcosis is reversible depends on oil concentration and exposure time. For example, Bergudo *et al.* (1977) reported narcosis followed by complete mortality of the calanoid copepod *Eurytemora affinis* after 6 h exposure to >2 ppm oil, but recovery from narcosis was evident at concentrations <2 ppm or at exposure times <1 h. Exposure times or concentrations required to kill under-ice copepods are not known; lethal threshold levels vary widely among copepod species (Wells, 1982). Even if complete recovery had occurred, however, ice-associated meiofauna that left the ice would likely be susceptible to increased predation on the bottom (shallow water) or would have little chance of returning to the ice (deep water).

The difference in our results for copepods and nematodes exposed to dispersed oil (major adverse effect and no effect respectively) is consistent with a current theory that the ratio of nematodes to copepods is a potentially useful tool in monitoring pollution (Raffaelli and Mason, 1981; Warwick, 1981a). In arctic regions, where ice is present most of the year, under-ice meiofaunal communities might be useful for oil spill monitoring. However, apparently conflicting results concerning effects of oil on meiofauna of other latitudes have been reported, particularly with regard to differential species or group sensitivity (see Martin and Cross, 1986). In view of these contradictory and limited data we must be cautious in using such a simple ratio as a pollution indicator (see Coull *et al.*, 1981). In addition, too few data are available concerning the composition of the under-ice meiofaunal community under pristine conditions and on natural factors affecting the distributions of copepods and nematodes.

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