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# Effects of Experimental Releases of Oil and Dispersed Oil on Arctic Nearshore Macrobenthos. II. Epibenthos.

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ABSTRACT. An experimental subsurface release of chemically dispersed oil at Cape Hatt, northern Baffin Island, resulted in short-term relatively high oil concentrations in the waters of two adjacent bays, whereas untreated oil released onto the surface of a third bay could not be detected in the water below a depth of 1 m. The only immediate response in epibenthos observed by divers was narcosis in urchins and starfish following the dispersed oil release. Analysis of data from *in situ* counts in the three test bays and in a fourth (reference) bay during the open water seasons of 1980-83 showed that densities of the starfish *Leptasterias polaris* were not affected by either oil release and that effects on urchin densities were minor or transitory: *Strongylocentrotus droebachiensis* apparently made immediate and transitory attempts to avoid dispersed oil in the water and possibly tried to avoid untreated and dispersed oil in sediments two years after oiling.

Analysis of airlift samples collected at 3 and 7 m depths in the four bays during 1980-83 showed no major effects of either oil release on densities of epibenthic crustaceans; taxa examined included all crustaceans, all cumaceans, one species of cumacean, all amphipods and eight individual amphipod taxa. The overall trend was toward increases in epibenthic crustacean densities over the study period. Effects that may have been attributable to oil were found in only 2 of 22 analyses of density data for individual taxa. In those cases, effects were minor: untreated oil in sediments apparently altered the depth distribution of *Anonyx* juveniles, and dispersed oil in the water column apparently had a delayed adverse effect on reproduction in the amphipod family Stenothoidae. Densities of *Pontoporeia femorata* were not affected by oil, but inspection of size-frequency data indicated a possible delayed adverse effect on its reproduction.

Key words: arctic epibenthos, amphipods, echinoderms, oil effects, dispersed oil effects, experimental oil releases, Baffin Island, macrobenthos

RÉSUMÉ. Un déversement expérimental de pétrole chimiquement dispersé sous la surface au cap Hatt (au nord de l'île Baffin), a amené à court terme des concentrations de pétrole relativement élevées dans les eaux de deux baies adjacentes, alors que du pétrole non traité déversé sur la surface d'une troisième baie n'a pu être détecté dans l'eau à une profondeur supérieure à 1 m. La seule réaction immédiate de l'épibenthos observée par des plongeurs était la narcose des oursins et des étoiles de mer à la suite du déversement de pétrole dispersé. L'analyse des données venant du comptage *in situ* dans les trois baies expérimentales et dans une quatrième baie témoin durant les saisons d'eau libre de 1980 à 1983, a montré que les densités de l'étoile de mer *Leptasterias polaris* n'étaient affectées par aucun des deux déversements de pétrole et que les effets sur les densités d'oursins étaient minimes ou passagers: apparemment, les *Strongylocentrotus droebachiensis* ont tout de suite essayé (mais sans persister) d'éviter le pétrole dispersé dans l'eau, et il est possible que, deux ans après le déversement, ils aient essayé d'éviter le pétrole non traité et le pétrole dispersé dans les sédiments.

L'analyse d'échantillons prélevés dans les quatre baies, de 1980 à 1983, à des profondeurs de 3 m et de 7 m, grâce à un système à remontée automatique, n'a pas révélé d'effet important dû à l'un quelconque des déversements de pétrole sur les densités des crustacés de l'épibenthos; les échantillons examinés comprenaient tous les crustacés, tous les cumacés, un genre de cumacé, tous les amphipodes et 8 taxons d'amphipodes individuels. La tendance générale reflétait une augmentation des densités de crustacés de l'épibenthos au cours de la période d'étude. Les effets qui auraient pu être attribués au pétrole ont été trouvés dans seulement 2 des 22 analyses des données sur la densité des taxons individuels. Dans ces cas-là, les effets étaient mineurs: du pétrole non traité dans les sédiments modifiait apparemment la distribution en profondeur des jeunes *Anonyx*, et le pétrole dispersé dans la colonne d'eau avait apparemment un effet négatif différé sur la reproduction des membres de la famille des amphipodes Stenothoidae. Les densités de *Pontoporeia femorata* n'étaient pas affectées par le pétrole, mais l'inspection des données sur la taille et le nombre indiquaient un effet négatif possible différé sur sa reproduction.

Mots clés: épibenthos arctique, amphipodes, échinodermes, effets dus au pétrole, effets dus au pétrole dispersé, déversements expérimentaux de pétrole, île Baffin, macrobenthos

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## INTRODUCTION

In a recent appraisal of the fate and effects of oil and dispersants in Canadian marine environments (Sprague *et al.*, 1981, 1982), several major data gaps were identified. These included the fate and effects of dispersants in general, the fate and effects of oil in the Arctic and knowledge of natural processes in the marine environment, particularly in the Arctic. In spite of early recommendations that field studies of oil effects be carried out (e.g., Moore and Dwyer, 1974; National Academy of Sciences, 1975), experimental field studies are still needed (Teal and Howarth, 1984).

The papers in this volume report results of the Baffin Island Oil Spill (BIOS) Project. 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.

This paper describes effects of experimental oil releases on epibenthos, one component of the subtidal macrobenthos. Effects on macroalgae and relatively immobile infauna are reported elsewhere in this volume (Cross *et al.*, 1987; Cross and Thomson, 1987), and a general description of subtidal communities in the study area is given in Snow *et al.* (1987). Subtidal benthos are of interest in oil effects studies, but the subtidal habitat has received little attention during studies of major oil spills (Percy, 1982; see also Cross and Thomson, 1987).

In this study, the term epibenthos refers to motile members of the benthic community. Included are those crustaceans capable of rapid movement through the lower part of the water column, plus urchins and starfish. The last two groups move slowly on the sediment surface but are capable of covering relatively large distances because of their large size. Motile epibenthos have been disregarded in some oil effect studies because of sampling

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problems (American Petroleum Institute, 1977:57) or patchy distributions (Sanders *et al.*, 1980:305). Furthermore, it is not possible to distinguish with certainty the relative roles of mortality and emigration in causing any changes in densities (*cf.* Elmgren *et al.*, 1983).

In spite of these interpretational difficulties, effects of oil on motile epibenthos were examined because of their important trophic positions. Epibenthic crustaceans include grazers, detritivores and scavengers and are themselves important in the diets of arctic fish and birds (e.g., Lowry and Frost, 1981; Craig *et al.*, 1984) and, to a lesser extent, marine mammals (e.g., McLaren, 1958; Finley, 1978). The urchin *Strongylocentrotus droebachiensis* is a herbivore whose impact on benthic algal populations is considerable on both the east and west coasts of Canada (Miller and Mann, 1973; Foreman, 1977) and in northern Norway (Hagen, 1983). The starfish *Leptasterias polaris* is a top predator feeding primarily on large bivalves, and hence may be affected indirectly by oil either through changes in bivalve populations or by consuming prey containing elevated hydrocarbon concentrations.

## METHODS

Study design and methods are described in Snow *et al.* (1987). Only a brief summary is given here. A discussion of possible sources of error and design rationale and evaluation are also given in Snow *et al.* (1987).

Four shallow embayments at Cape Hatt, northern Baffin Island, were selected as experimental bays (Fig. 1). During August 1981, approximately 15 $m^3$ of Lagomedio crude oil was applied to the surface of one bay (Bay 11), and 15 $m^3$ of dispersed oil (10 Lagomedio:1 Corexit 9527) was released underwater in another bay (Bay 9). The oil in both cases had been artificially weathered to remove 8% by volume. Surface oil in Bay 11 did not penetrate below 1 m depth in the 30 h following the release. The dispersed oil release, on the other hand, resulted in a severe exposure to benthos at 3 and 7 m depths in Bay 9, a lower and more realistic exposure in the third study bay (Bay 10) and very light exposure in the fourth (reference) bay (Bay 7). Details of the oil releases and of oil concentrations during the releases are given in Dickins *et al.* (1987) and in Humphrey *et al.* (1987) respectively.

Sampling of epibenthos was carried out in these bays during each of the two ice-free months (August and September) between September 1980 and August 1983; two of these six sampling periods (September 1980 and August 1981) preceded the experimental oil releases.

Three contiguous 50 m transects parallel to the shoreline were sampled at each of two depths (3 m, 7 m) in each of the four bays during five or six sampling periods. On each transect, eight randomly located replicate samples, each covering 0.0625 $m^2$, were collected using a diver-operated airlift fitted with a 1 mm mesh collecting bag. These samples were used to enumerate crustaceans. *In situ* counts of urchins and starfish were made within five 1 × 10 m belts along each transect line at 7 m depth. Additional counts were made 2 or 4 d after the dispersed oil release in 1981.

All animals retained on a 1 mm sieve were sorted from the airlift samples using flotation and decantation of water, flotation in a zinc chloride solution and hand sorting under binocular microscopes. Specimens were identified to species where possible, counted and weighed (± 0.5 mg) after gently blotting dry. Amphipod lengths were measured (± 0.5 mm).

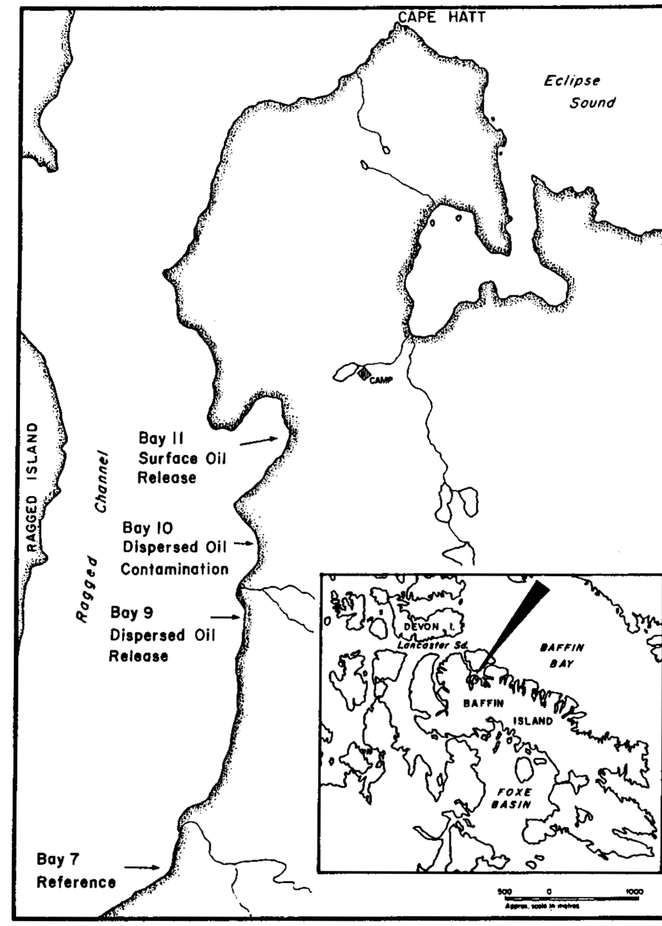


FIG. 1. BIOS site at Cape Hatt, Baffin Island, showing the locations of study bays and oil treatments applied in August 1981.

To determine whether oil had an effect, temporal changes in densities of epibenthos in the four bays were compared using three-factor (periods, bays and transects) fixed-effects analysis of variance (ANOVA), with transects nested within periods and bays. In statistical terms, a significant interaction between spatial and temporal effects indicated a possible oil effect (Green, 1979; see also Snow *et al.*, 1987). Because of the nested design, the among-transects term rather than the residual error term was used to test the significance of main effects (periods, bays) and of the interaction between the main effects. When interaction terms involving transects were non-significant ($P \leq 0.05$), they were pooled with the transect term before testing for main effects. When interactions involving transects were significant ($P > 0.05$), they were not pooled with the transect term, which was used alone as the denominator in the tests.

All data were log-transformed (log [x + 1]) prior to analysis in order to reduce the skewness inherent in such data. Data from the two depths sampled were analyzed separately. ANOVA was applied to densities of 11 epibenthic crustacean taxa at each of 3 and 7 m depths and to densities of urchins and starfish at 7 m depth. ANOVA was performed by the GLM procedure of the SAS computer program package (Helwig and Council, 1979; Freund and Littell, 1981).

The design of the experiment was unbalanced because there were no data from one bay (Bay 7) in the first pre-spill sampling period or from another bay (Bay 10) in the last post-spill sampling period. The unbalanced design necessitated the use of three different analytical procedures including three different combinations of bays and sampling periods (see Snow *et al.*, 1987), as results of a single analysis with two missing cells would have been ambiguous. In most parts of this paper, the results of only one analysis type are presented — the analysis including data from all four bays and excluding data from 1980 and 1983. However, when an oil effect was indicated only in one or both of the other types of analysis, this fact is mentioned.

## RESULTS

These results are based on the "optimal impact study design" of Green (1979:70), in which the evidence for impact effects is a significant area-by-times interaction. Such an interaction would occur when temporal change in benthos was inconsistent among the study bays, each of which received a different oil treatment. Under the present study design, for such change to be considered significant in both statistical and practical terms, it would have to be large relative to variability within the bays. Within-bay variation included both variability among the transects (the "transect" term) and temporal variability that was not consistent among the transects (the "period-by-transect" term).

Significant periods-by-bays interaction terms could arise because of (1) actual effects of oil, (2) some other temporal change in only some bays or (3) type I errors in statistical inference (such errors are expected when a large number of tests are done). The third possibility is discussed for this study in Snow *et al.* (1987), and the second is treated in general by Hurlbert (1984). Because the experimental oil releases were carried out in the field, it was not possible to randomly allocate oil treatments to replicate samples, nor was it practical to replicate oil treatments (i.e., to release oil in the same manner in two or more bays). Hence, we are guilty of "pseudoreplication" as defined by Hurlbert (1984), and it is not possible to reach unequivocal conclusions on the effects of oil. To reduce the possibility of committing type I errors or of confounding oil effects with natural changes that were inconsistent among bays, the nature of each significant interaction was examined in relation to the type of oil treatment (surface vs. dispersed) and the concentrations of oil, both in the water during and immediately after the oil releases and in the subtidal sediments during 1981-83. Only if change in the benthos corresponded with change in oil concentrations was it concluded that a probable oil effect had occurred.

### *Crustaceans*

Epibenthic crustaceans collected in the study bays at Cape Hatt included ostracods, amphipods, cumaceans, isopods, decapods and nebaliaceans. Ostracods, the numerically dominant taxon, constituted 63.5% of total crustaceans collected during the study. Amphipods and cumaceans made up 29.8% and 6.5% of total numbers respectively. Isopods, decapods and nebaliaceans were present in very small numbers. Crustacean taxa collected in the study area are listed in Table 1.

The available data on highly motile epibenthic crustaceans at Cape Hatt were from the same airlift samples upon which infaunal results were based (Cross and Thomson, 1987). Density estimates for epibenthic crustaceans are not likely to be as accurate as those for infauna because some organisms escaped from the area sampled and some others inadvertently were drawn into the airlift from outside the 0.0625 m$^2$ sampling area. No quantitative estimates are available for the extent to which epibenthic crustaceans were over- or underestimated in the present study.

TABLE 1. List of species of crustaceans collected by airlift at Cape Hatt, northern Baffin Island, during September 1980, August and September 1981 and 1982 and August 1983

| | |
|---|---|
| AMPHIPODA | |
| *Ampelisca macrocephala* | *Monoculodes latimanus* |
| *Anonyx laticoxae* | *Monoculodes longirostris* |
| *Anonyx nugax* | *Monoculodes schneideri* |
| *Anonyx sarsi* | *Monoculodes* sp. |
| *Apherusa borealis* | *Monoculopsis longicornis* |
| *Apherusa glacialis* | *Oediceros saginatus* |
| *Apherusa megalops* | *Onisimus glacialis* |
| *Atylus carinatus* | *Onisimus litoralis* |
| *Bathymedon longimanus* | *Onisimus nanseni* |
| *Bathymedon obtusifrons* | *Opisa eschrichti* |
| *Boeckosimus plautus* | *Orchomene minuta* |
| *Byblis gaimardi* | *Parapleustes gracilis* |
| *Centromedon pumilus* | *Paroediceros lynceus* |
| *Corophium clarencense* | *Photis reinhardi* |
| *Gammaracanthus loricatus* | *Phoxocephalus holbolli* |
| *Gammarus setosus* | *Pleusymtes glaber* |
| *Gammarus wilkitzkii* | *Pontogeneia inermis* |
| *Guernea nordenskioldi* | *Pontoporeia femorata* |
| *Haploops laevis* | *Protomedia fasciata* |
| *Harpinia serrata* | *Tmetonyx* sp. |
| *Ischyrocerus* sp. | *Westwoodilla brevicalcar* |
| *Melita dentata* | *Westwoodilla megalops* |
| *Metopa* sp. | *Weyprechtia pinguis* |
| *Metopella carinata* | Unidentified Calliopiidae |
| *Monoculodes borealis* | Unidentified Pleustidae |
| *Monoculodes kroyeri* | Unidentified Stenothoidae |
| CUMACEA | |
| *Brachydiastylis resima* | *Eudorella hirsuta* |
| *Brachydiastylis* sp. | *Lamprops fasciata* |
| *Campylaspis rubicunda* | *Lamprops fuscata* |
| *Diastylis dalli* | *Leptostylis macrura* |
| *Diastylis edwardsi* | *Leucon nasica* |
| *Diastylis lepichini* | *Leucon nasicoides* |
| *Diastylis lucifera* | *Leucon pallidus* |
| *Diastylis rathkei* | *Leucon* sp. |
| DECAPODA | |
| *Argis dentata* | *Sclerocrangon boreas* |
| *Lebbeus microceros* | *Sclerocrangon ferox* |
| *Lebbeus polaris* | *Spirontocaris phippsi* |
| *Sabinea sarsi* | Unidentified Pasiphaeidae |
| OSTRACODA | |
| *Eucytheridea bradii* | *Philomedes globosa* |
| *Eucytheridea punctillata* | *Rabilimis mirabilis* |
| *Finmarchinella finmarchica* | Unidentified Podocopa[a] |
| OTHER CRUSTACEA | |
| Unidentified Mysidacea[a] | Unidentified Tanaidacea[a] |
| Unidentified Nebaliacea | Unidentified Isopoda |

[a]Not included in analyses.

*Density:* Oil and dispersed oil released at Cape Hatt in 1981 did not cause any marked reductions in densities of subtidal epibenthic crustaceans (Fig. 2). Some of the largest density decreases occurred between the two pre-spill sampling periods, and the overall trend was toward density increases over the study period. Period-by-bay interaction effects were not significant for 8 and 10 of the 11 variables analyzed at 3 and 7 m depths respectively. Tests of period-by-bay interactions showed possi-

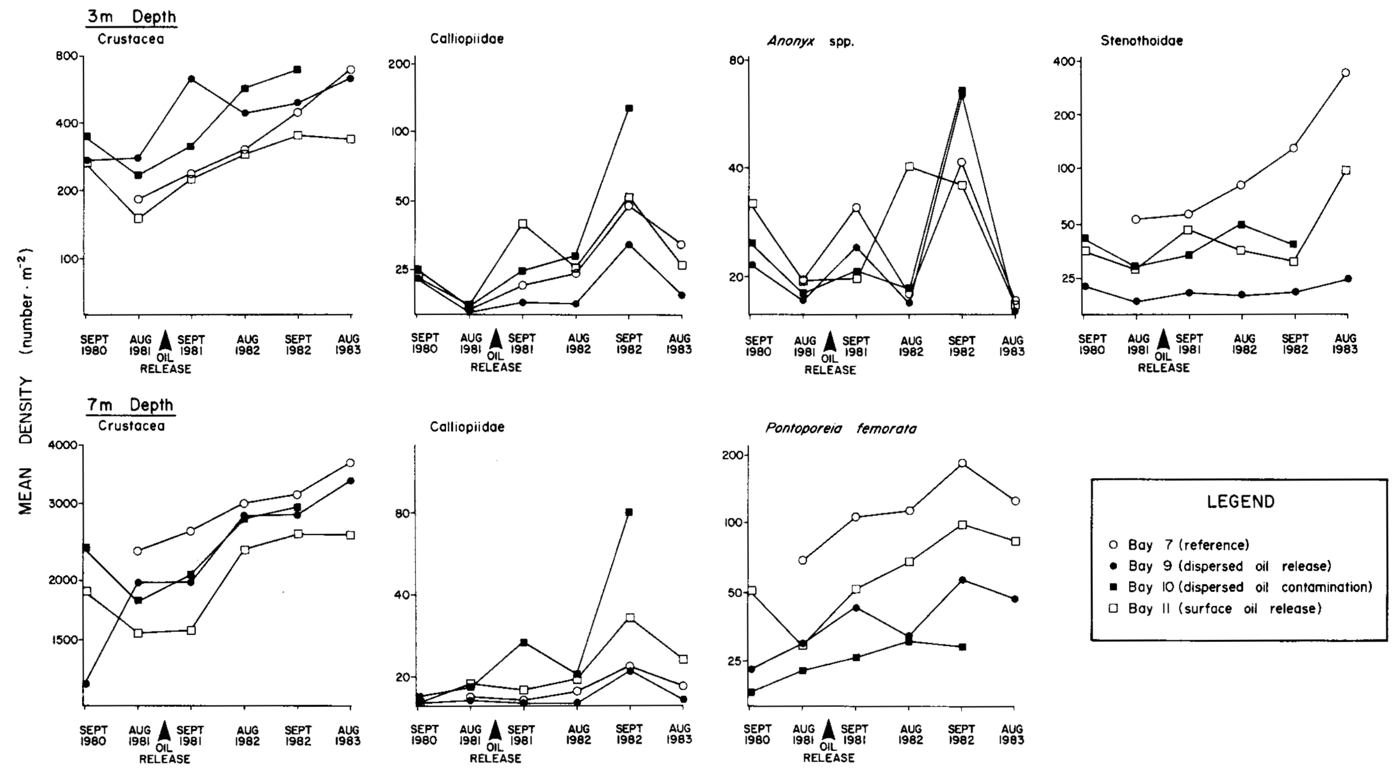


FIG. 2. Mean density of total crustacean epibenthos, and of each taxon where analysis indicated possible oil effects, in four bays at Cape Hatt, northern Baffin Island, during pre- and post-spill sampling periods, September 1980-August 1983. Each symbol represents the back-transformed mean of log-transformed data from 24 replicate 0.0625 $m^2$ airlift samples for each depth, bay and period.

ble effects of oil on three amphipod taxa at 3 m depth (the families Stenothoidae and Calliopiidae and the genus *Anonyx*) and on Calliopiidae at 7 m depth (Table 2).

Calliopiid amphipods included three species of *Apherusa* (Table 1) and were represented almost entirely by *Apherusa* juveniles. Likely sources of the period-by-bay interactions were more pronounced seasonal (August-September) density increases in Bay 10, the dispersed oil contamination bay, and in Bay 11, the surface oil release bay (Fig. 2). Neither of those increases could be related to changes in oil concentrations, however, either in the water column during the 1981 oil releases or in sediments during 1981 and 1982 (see Boehm *et al.*, 1987). In each case where density increased disproportionately in one bay (Fig. 2), oil concentrations in the sediments of that bay were similar to those in the reference bay (at or slightly above background levels). Furthermore, the pattern of disproportionate increases among bays was not similar to the distribution of dispersed oil in the water during 1981, viz., highest in Bay 9, intermediate in Bay 10 and low in Bays 7 and 11 (Humphrey *et al.*, 1987). The similarity of density trends in Bays 7, 9 and 11 and the similarity at both depths in Bay 10 (Fig. 2) suggested that the changes were attributable to biological rather than random factors. There was no evidence that oil or dispersed oil affected Calliopiid densities.

Density changes that probably were responsible for the period-by-bay interaction for Stenothoid amphipods were the density increases between 1982 and 1983 in Bays 7 and 11 (reference and surface oil bays) but not in Bay 9 (dispersed oil release bay); the interaction was evident only in the one analysis type that included data from 1983 (Table 2). Implicit in the present study design is the assumption that temporal change in the reference bay is a natural change that, in the absence of any treatment effect, would also be expected in the treatment bays. Therefore, the lack of a marked increase in Stenothoid density in Bay 9 can be interpreted as a treatment effect. The occurrence of an effect only in Bay 9, where dispersed oil concentrations in the water during 1981 were higher than in any other bay, suggested that oil in the water column during the dispersed oil release, rather than oil in sediments, may have adversely affected densities one to two years after oiling.

Probable sources of the period-by-bay interaction for the amphipod genus *Anonyx* at 3 m depth were density changes in Bay 11 (surface oil release bay) during 1981 and 1982, which differed from the pattern of seasonal (August-September) increase common to the other three bays (Fig. 2). The lack of such an increase in Bay 11 during 1981 was not an effect of oil, as oil concentrations in 3 m Bay 11 sediments had increased only slightly by 8 September 1981. The low density in September 1981 may have been an artifact of the somewhat earlier sampling date in this bay (2 September) than in the other bays (5-7 September). By August 1982, however, sediment oil concentrations at 3 m depth had increased considerably in Bay 11 (1.4-10 ppm) and were near background levels in the other bays (Boehm *et al.*, 1987). It is possible that the earlier density increases in Bay 11 during 1982 (August rather than September) resulted from this increase in the concentration of oil in sediments. This possible effect of the surface oil release is considered further in the following section.

*Population Structure:* In the present section, length-frequency data are presented for two amphipod species, *Anonyx nugax* and

TABLE 2. Three-factor analyses of variance for the densities of dominant epibenthic crustaceans in four bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982

| | | Source of variation and df[a] | | | | |
|---|---|---|---|---|---|---|
| Depth | Taxon | Period 3,8 or 32 | Bay 3,8 or 32 | Period by bay 9,8 or 32 | Transect (bay) 8,334 | Per by trans (bay) 24,334 |
| 3m | Total epibenthos | 2.83 ns | 1.87 ns | 0.24 ns | 9.00 *** | 1.84 * |
| | Amphipoda | 5.04 * | 1.33 ns | 0.33 ns | 5.69 *** | 1.66 * |
| | *Guernea* sp.[b] | 0.94 ns | 12.82 ** | 0.39 ns | 8.26 *** | 1.57 * |
| | Stenothoidae[b] | 2.61 ns | 32.37 *** | 1.61 ns[d] | 2.85 ** | 1.42 ns |
| | Calliopiidae[b] | —[c] | —[c] | 4.38 *** | 1.89 ns | 0.80 ns |
| | *Anonyx* spp.[b] | —[c] | —[c] | 4.45 *** | 1.54 ns | 1.29 ns |
| | *Orchomene minuta* | 0.93 ns | 4.18 * | 0.59 ns | 6.70 *** | 1.44 ns |
| | *Monoculodes* spp.[b] | 3.32 ns | 5.00 * | 1.00 ns | 4.39 *** | 2.25 *** |
| | *Paroediceros lynceus* | 0.36 ns | 2.83 ns | 0.12 ns | 9.79 *** | 1.86 ** |
| | Cumacea | 1.13 ns | 6.38 ** | 0.54 ns | 13.29 *** | 1.15 ns |
| | *Lamprops fuscata* | 1.19 ns | 6.59 ** | 0.54 ns | 12.84 *** | 0.99 ns |
| 7 m | Total epibenthos | 6.27 ** | 2.89 ns | 0.16 ns | 6.42 *** | 1.50 ns |
| | Amphipoda | 18.09 *** | 6.35 ** | 0.87 ns | 2.28 * | 1.22 ns |
| | *Guernea* sp.[b] | 11.37 *** | 7.70 *** | 0.80 ns | 1.71 ns | 1.18 ns |
| | Calliopiidae[b] | —[c] | —[c] | 6.38 *** | 0.98 ns | 0.73 ns |
| | *Anonyx* spp.[b] | 3.95 ns | 3.35 ns | 1.18 ns | 3.28 ** | 1.98 ** |
| | *Monoculodes* spp.[b] | 7.82 *** | 2.71 ns | 1.87 ns | 1.71 ns | 0.96 ns |
| | *Paroediceros lynceus* | 0.96 ns | 18.56 *** | 0.81 ns | 5.33 *** | 0.71 ns |
| | *Pontoporeia femorata* | 4.59 ** | 16.50 *** | 0.48 ns | 13.02 *** | 1.46 ns |
| | Cumacea | 3.45 * | 34.95 *** | 1.65 ns | 1.51 ns | 1.22 ns |
| | *Lamprops fuscata* | 3.10 * | 9.28 *** | 1.63 ns | 1.60 ns | 0.96 ns |
| | Ostracoda (Myodocopa) | 1.87 ns | 5.83 ** | 0.19 ns | 8.10 *** | 1.41 ns |

F-values are shown with significance levels (ns = $P>0.05$; *$P\leq0.05$; ** $P\leq0.01$, *** $P\leq0.001$).
[a]Where period-by-transect (bay) interaction was ns, it was pooled with transect (bay) effect to test bay, period and period-by-bay effects; where period-by-transect (bay) was significant ($P\leq0.05$), transect (bay) alone was used to test main effects.
[b]Stenothoidae includes *Metopella* and *Metopa*; Calliopiidae includes *Apherusa*. Genera indicated include species listed in Table 1.
[c]Interpretation of main effects confounded by significant interaction of period-by-bay term.
[d]In analysis excluding data from Bay 10 (dispersed oil contamination) and including data from August 1983, the period-by-bay interaction term was significant (F = 3.96; df = 8,30; P = 0.003).

*Pontoporeia femorata*, in order to assess the effects of oil and dispersed oil on reproduction, and hence recruitment, in these species at Cape Hatt. *Anonyx* spp. (primarily *A. nugax* and unidentified juveniles) and *P. femorata* were among the dominant epibenthic taxa at Cape Hatt in terms of biomass (ranked second and third respectively) and, to a lesser extent, density (ranked fifth and fourth respectively).

Length-frequency distributions of *Anonyx nugax* and *Anonyx* juveniles are given in Figure 3. The *Anonyx* juveniles were probably *A. nugax*, because all other *Anonyx* species were rare at Cape Hatt. Several aspects of the life history of *A. nugax* were apparent in these data, but there was no strong evidence of size-specific mortality or of effects of oil on recruitment. Juveniles in the dispersed oil bays (Bays 9 and 10) were dominated by the 8-9 mm size class one year before and by the 4-6 mm size class one year after the oil releases. The same shift in dominance was apparent in the reference bay between September 1981 and September 1982. The abundance of all size classes was reduced in 1981 and again in 1983, but this was true in all bays and in the pre-spill as well as the post-spill sampling period in 1981. These annual differences probably represented natural events rather than effects of oil.

Larger *Anonyx nugax* and *Anonyx* juveniles showed a clear preference for the 7 m over the 3 m depth in August and September (Fig. 3). Numbers of large individuals increased in September, probably by immigration from deeper water. The smallest size class, on the other hand, preferred shallow water and apparently moved from 7 to 3 m depth in Bays 9 and 10 between August and September 1982. In Bay 11, however, this size class was common at 3 m depth in August 1982, accounting for the observed increase in density (Fig. 2) and indicating an altered pattern of movement between deep and shallow water. This may have been a behavioural response to oil in sediments; oil concentrations in 1982 were higher in Bay 11 than in Bays 7, 9 and 10. Because of the low numbers of *Anonyx* juveniles collected in August 1981, however, it is not known whether the difference among bays in 1982 was an oil-related or a natural phenomenon.

There was no indication that densities of *Pontoporeia femorata* were affected by oil (Table 2). Length-frequency data, however, suggested that population structure may have been affected in the surface oil release bay (Fig. 4). Polymodality in the length-frequency distributions was evident in that bay, and in the reference bay, with modal size classes at 2 or 3 mm, 5-6 mm, 8-10 mm and about 14 mm. In the surface oil release bay, juveniles released in the previous spring (3 mm long) were rare in August 1983, whereas recruitment of this size class was relatively strong in the two previous years; in the reference bay, recruitment was strong in all three years. It is possible that oil in Bay 11 sediments during 1982 (see Boehm *et al.*, 1987) disrupted some aspect of reproduction in *P. femorata* adults during the winter of 1982. It is also possible that oil concentrations in Bay 11 during 1983, which were considerably higher than those in 1982, directly caused mortality or emigration of the newly released juveniles.

### *Echinoderms*

The urchin *Strongylocentrotus droebachiensis* and the star-

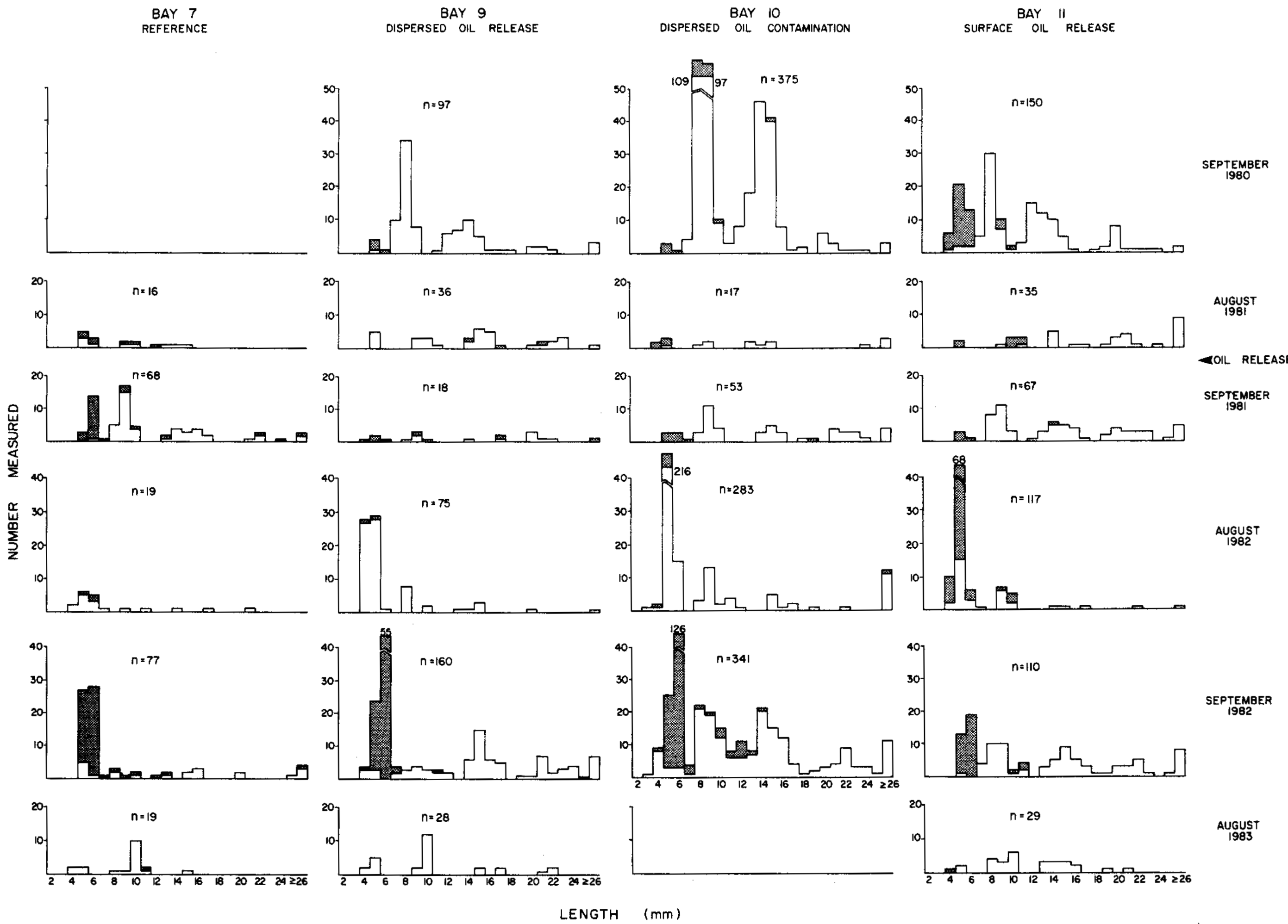


FIG. 3. Length-frequency distributions of *Anonyx nugax* (> 10 mm long) and *Anonyx* juveniles (≤ 10 mm) at 3 m depth (dark portion of each histogram) and at 7 m depth (light portion) in four bays at Cape Hatt, northern Baffin Island, during pre- and post-spill sampling periods, September 1980-August 1983. Sample sizes are given for all undamaged individuals in 24 samples from each bay and period.

fish *Leptasterias polaris* were common in the study area, and populations were composed primarily of large individuals (approximately 3-6 and 15-20 cm diameters respectively). Densities at 7 m depth are shown in Figure 5; too few individuals were present at 3 m depth in the study bays to warrant discussion. Divers observed that urchins and starfish were apparently not affected by the surface oil release, whereas exposure to dispersed oil produced marked short-term effects in Bays 9 and 10 (dispersed oil release and contamination bays). During the two days following the release, both species were lying on the substrate in unnatural postures (e.g., upside down); some individuals responded slowly when prodded, whereas others showed no response. Within one or two weeks behaviour seemed normal, except that some urchins were feeding on bivalves that had emerged from the substrate in response to the oil release (see also Cross and Thomson, 1987).

Analysis of variance results (Table 3) showed differences among bays and among periods in the density of *Leptasterias polaris*, but there was no indication of an oil effect. Analytical results and inspection of the data for *Strongylocentrotus droebachiensis*, however, suggested that dispersed oil and possibly surface oil did affect urchins. Probable sources of the significant period-by-bay interaction term were (1) the marked density decrease and subsequent increase in Bay 9 and the increase in Bay 10 following the dispersed oil release and (2) decreases in the three oiled bays, but not the reference bay, between the last two sampling periods.

The changes in abundance of urchins in Bays 9 and 10 immediately following the dispersed oil release were apparently directly related to the high concentrations of dispersed oil in Bay 9 and, to a lesser extent, in Bay 10. The density decrease in Bay 9 probably reflected emigration rather than mortality; diver observations 1-2 d post-spill revealed no mortality in response to the dispersed oil release. Dispersed oil entered Bay 10 at a depth of approximately 8-10 m (Green *et al.*, 1982), and this may have caused a movement from deeper water to 7 m depth. In both bays, densities had returned to pre-spill levels within two weeks of the dispersed oil release.

Decreases in abundance of *Strongylocentrotus droebachiensis* in the oiled bays (Bays 9, 10 and 11) between 1982 and 1983 may have been a result of the concurrent increases in sediment oil concentrations, at least in Bays 9 and 11 (Boehm *et al.*, 1987; there are no 1983 hydrocarbon data for Bay 10). Oil concentrations increased in the reference bay between 1982 and 1983, but concentrations were considerably lower than in Bays 9 or 11 (Boehm *et al.*, 1987). Urchins at Cape Hatt are herbivores and

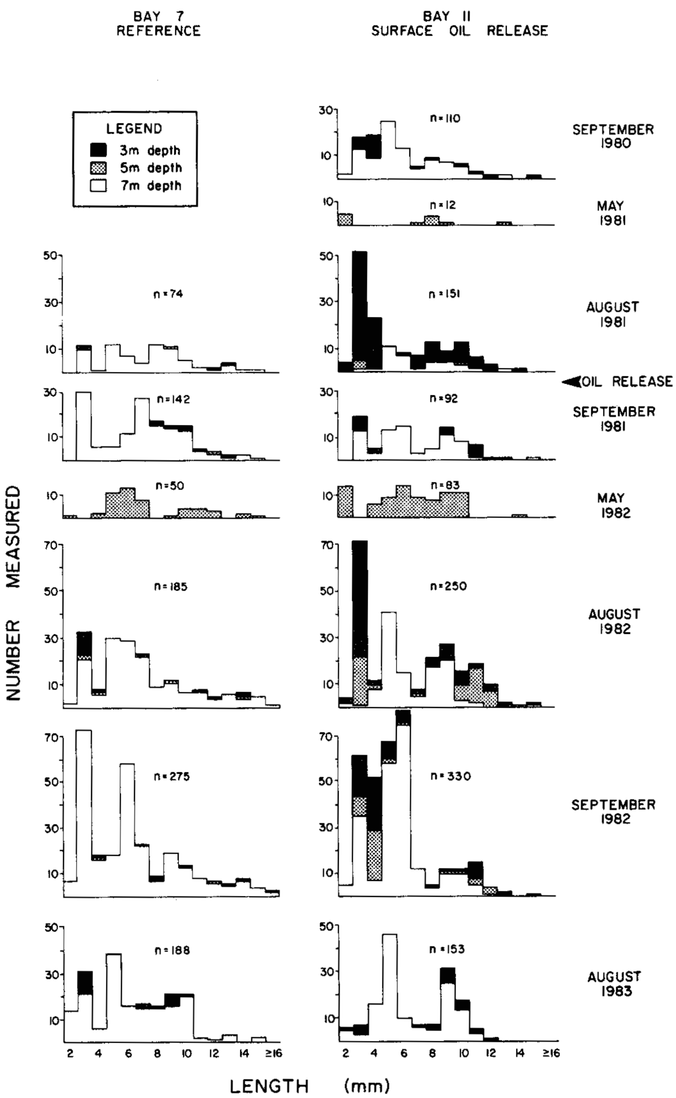


FIG. 4. Length-frequency distributions of *Pontoporeia femorata* in two bays at Cape Hatt, northern Baffin Island, during pre- and post-spill sampling periods, September 1980-August 1983. Sample sizes are given for all undamaged individuals in 24 (3 and 7 m depths) or 10-16 (5 m depth) samples from each bay and period. The two other bays studied are not included because very few specimens were collected.

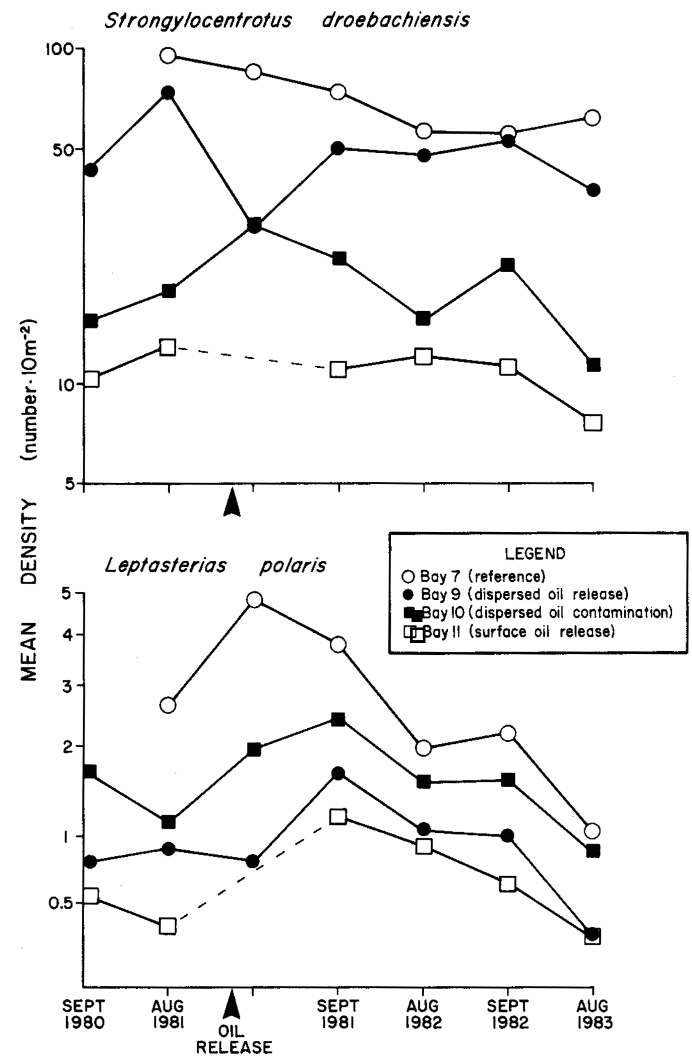


FIG. 5. Densities of urchins (*Strongylocentrotus droebachiensis*) and starfish (*Leptasterias polaris*) at 7 m depth in four bays at Cape Hatt, northern Baffin Island, during pre- and post-spill sampling periods, September 1980-August 1983. Data are based on 15 *in situ* counts, each covering 10 m$^2$, from each bay and period.

surface deposit feeders. Thus oil in the sediments on which they feed, even at relatively low levels, may have caused avoidance of the oiled bays, probably through migration to deeper, uncontaminated areas. Densities in August 1983, however, were only slightly lower than pre-spill values.

## DISCUSSION

Oil and dispersed oil released at Cape Hatt did not cause any marked reductions in densities of subtidal epibenthos during the two years following the experimental oil releases. This lack of major density decreases was probably a result of the relatively short time that high concentrations of dispersed oil were present in the water column and the relatively low levels of oil in the sediments of any bay. In the concurrent study of infaunal benthos at Cape Hatt, Cross and Thomson (1987) reached the same conclusion concerning the lack of large-scale mortality or changes in community structure.

### *Acute Effects of Oil in the Water Column*

Concentrations of dispersed oil reached a "sustained average" of 50 ppm for about 6 h during the release at Cape Hatt (Green *et al.*, 1982). Previous laboratory studies of acute oil effects on arctic epibenthos indicate that higher concentrations, longer exposures or both would be required to cause widespread mortality. For example, Foy (1982) reported 50% mortality in arctic amphipods exposed to dispersed crude oil in measured concentrations of 45-162 ppm, but the exposure period was 96 h. In even longer exposures (10 weeks), Busdosh (1981) reported 50% mortality in the arctic amphipod *Boeckosimus affinis* exposed to mechanically dispersed oil in concentrations as low as 0.2 ppm. Conversely, 6 h exposures to dispersed crude oil caused significant mortality of the urchin *Strongylocentrotus droebachiensis*, but only at measured concentrations in excess of 200 ppm (Engelhardt *et al.*, 1983).

We can be reasonably confident that significant mortality in epibenthos would not result from an application of dispersants

TABLE 3. Three-factor analyses of variance for densities of urchins (*Strongylocentrotus droebachiensis*) and starfish (*Leptasterias polaris*) at 7 m depth in four bays at Cape Hatt, northern Baffin Island, during August and September 1981 and 1982 and August 1983

| | Source of variation and df[a] | | | | |
|---|---|---|---|---|---|
| Species | Period 5,46 | Bay 3,46 | Period by bay 14,46 | Transect (bay) 8,276 | Per by trans (bay) 38,276 |
| *Strongylocentrotus droebachiensis* | —[b] | —[b] | 6.09 *** | 1.25 ns | 0.86 ns |
| *Leptasterias polaris* | 12.88 *** | 34.80 *** | 1.33 ns | 0.64 ns | 0.97 ns |

F-values are shown with significance levels (ns = P>0.05; *P≤0.05; ** P≤0.01, *** P≤0.001).
[a]Period-by-transect (bay) interaction was pooled with transect (bay) effect to test bay, period and period-by-bay effects.
[b]Interpretation of main effects confounded by significant interaction of period-by-bay term.

to an actual spill of crude oil in the Arctic, because the exposure to dispersed oil at Cape Hatt was more severe than would be expected in a real situation (Sergy and Blackall, 1987). Concentrations of dispersed oil have rarely been measured during accidental or experimental spills. However, where concentrations as high as those at Cape Hatt have been reported, they have been restricted to the immediate vicinity of dispersant application (McAuliffe, 1977) or to very shallow depths (Nilsen, 1985), or they have persisted for very short periods (Cormack and Nichols, 1977; McAuliffe *et al.*, 1981).

### *Acute Effects of Oil in Sediments*

The surface and dispersed oil releases at Cape Hatt both resulted in measurable contamination of subtidal sediments (Boehm *et al.*, 1987), but the contamination was minor relative to that caused by several major oil spills in temperate and boreal waters (see Cross and Thomson, 1987). Following the *Florida*, *Tsesis* and *Amoco Cadiz* oil spills, large amounts of oil reached subtidal sediments, resulting in immediate and almost total mortality of amphipods (Sanders *et al.*, 1980; Elmgren *et al.*, 1983; Gundlach *et al.*, 1983) and, in one case, urchins (Cabioch, 1980). Very few studies have addressed the acute effects on epibenthos of lower concentrations of oil in sediments, but it is again clear that concentration and exposure time must be considered together. The amphipod *Anonyx laticoxae* survived an 18 d exposure to sediment containing 292 ppm hydrocarbons (Anderson *et al.*, 1979), whereas amphipod abundance in experimental ecosystems decreased by 98% during 25 weeks' exposure to sediments that contained 109 ppm hydrocarbons (Grassle *et al.*, 1981; Elmgren and Frithsen, 1982). In the present study, no major mortality or emigration of epibenthos was evident, either in 1982 when sediment oil concentrations in Bay 11 were 1.4-10 ppm or in 1983 when concentations in the same bay were 12-119 ppm (Boehm *et al.*, 1987). Sampling of epibenthos and sediments in 1983 was completed early in the open water period (10 and 13 August respectively), however, so any effects of continued exposure and of possible increases in oil concentrations during summer 1983 would not have been detected.

### *Sublethal Effects*

Oil effects studies carried out on individual species in the laboratory have identified a wide range of sublethal effects (see review by Connell and Miller, 1981), some of which may reduce the survival potential of individuals or their offspring. In the present study, the only effects indicated were immediate and transitory narcosis and attempted avoidance in echinoderms, altered migration patterns of juvenile amphipods one year after oiling and reduced reproductive output of two amphipod species two years after oiling. For several species of infauna, effects of the oil releases at Cape Hatt were similar: altered behaviour, reduced condition and decreased reproductive output (Cross and Thomson, 1987).

Changes in urchin densities following the oil releases at Cape Hatt appeared to be the result of avoidance behaviour. Urchins apparently moved rapidly away from high concentrations of dispersed oil and returned shortly thereafter, when oil concentrations in the water were much reduced. This had no obvious negative consequences and may in fact have prevented adverse effects. The mechanism of the escape or avoidance, however, is not clear. Increased locomotory activity is a common avoidance response to oil in motile benthos (Swedmark *et al.*, 1973), and Engelhardt *et al.* (1983) observed rapid linear movement in *Strongylocentrotus droebachiensis* within minutes of being exposed to dispersed oil concentrations between 50 and 250 ppm. However, immediately after the rapid movement phase, urchins became completely immobilized (Mageau *et al.*, 1987).

Long-term avoidance of oil in sediments of the surface and dispersed oil release bays was indicated by decreases in urchin densities between 1982 and 1983, together with concurrent increases in oil concentrations in sediments and in the urchins themselves (Boehm *et al.*, 1984, 1987). In contrast to the short-term avoidance of dispersed oil, long-term avoidance of oiled sediments may have had significant ecological consequences later in the summer of 1983 or in subsequent years. Elsewhere, changes in urchin densities not related to oil have caused major changes in abundance and structure of macroalgal communities (e.g., Paine and Vadas, 1969; Himmelman *et al.*, 1983). Massive algal blooms have been attributed to oil-related depletion of other herbivores (e.g., North *et al.*, 1965). The significance of urchin depletion in the Arctic is uncertain, however, because urchin diets and feeding rates are poorly known and because urchins are much less abundant than in boreal or temperate waters.

In contrast to the avoidance of oil by urchins, the altered depth distribution of *Anonyx* juveniles is difficult to interpret and of uncertain ecological significance. Juvenile *Anonyx* in the surface oil release bay may have moved to shallow water earlier in summer 1982 because of an attraction to oil in sediments; sediment oil concentrations were considerably higher at 3 m than at 7 m depth (Boehm *et al.*, 1987). Previous studies, however, generally have shown the opposite to be true, i.e., that amphipods avoid oil. In a study of effects of experimental oiling of tidepools, Bonsdorff (1983) noted that amphipods displayed avoidance reactions to very low levels of oil. In the laboratory, the arctic amphipod *Boeckosimus* ( = *Onisimus*) *affinis* avoided oiled sediment and oil-tainted food, although high concentrations of oil in sediments or pre-exposure to dispersed oil in water reduced or cancelled this avoidance behaviour (Percy, 1976, 1977). Busdosh *et al.* (1978) have also reported that the length of exposure to oiled sediment determined whether *B. affinis* preferred clean to oiled sediment or showed no preference. The only evidence, to our knowledge, of attraction of crustaceans to oil are field observations of possible attraction of lobsters to spilled oil (Blumer, 1970). In the absence of detailed knowledge of ecological requirements of *Anonyx* spp., the observed change in depth distribution likely should be considered a "subcritical" effect, i.e., of direct consequence only to the individual organism (Percy, 1982).

Delayed adverse effects of both the dispersed and surface oil releases were indicated by density changes in Stenothoid amphipods and size-frequency data for *Pontoporeia femorata*. That effects were not detected until two years after the oil releases indicates that some aspect of reproduction may have been disrupted. Elmgren *et al.* (1983) reported a greater frequency of abnormal eggs in *Pontoporeia affinis* following the *Tsesis* spill, and Gundlach *et al.* (1983) reported a lower frequency of egg-carrying lobsters in commercial catches after the *Amoco Cadiz* spill. In the laboratory, exposure of *Gammarus oceanicus* to oil resulted in decreased copulatory behaviour and reduced production and growth of larvae (Linden, 1976a,b; Butler *et al.*, 1982). Reduced fecundity caused by sublethal oil concentrations would probably result in population decreases and must be considered an effect of serious ecological consequence. This is particularly true for benthic organisms without pelagic larval stages (e.g., amphipods), because recolonization of large disturbed areas would be slow (Chia, 1970).

### *Dispersed vs. Surface Oil Release*

The primary objective of the BIOS Project was to compare oil effects in the dispersed oil release bay with those in the surface release bay and to make inferences about the effects of dispersing oil with chemical agents. It can be concluded that the effects of dispersed oil on epibenthos were minor. Cross and Thomson (1987) reached similar conclusions concerning infauna. The only effects on epibenthos specifically attributable to dispersant use were immediate but transitory post-spill narcosis and attempted avoidance in echinoderms and a delayed adverse effect on populations of the amphipod family Stenothoidae. The option of allowing an oil slick to beach resulted in oil concentrations in subtidal sediments that apparently altered the seasonal depth distribution of *Anonyx* juveniles and may have caused an adverse effect on reproduction in another amphipod, *Pontoporeia femorata*. Oil in sediments of both the dispersed and surface oil release bays apparently caused a reduction in urchin densities two years after the releases, which may lead to alterations in macroalgal communities in subsequent years. Thus, dispersed and untreated oil apparently caused relatively minor damage to only a few species of shallow water epibenthos.

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