A summary and synthesis of benthic literature from southeastern Beaufort Sea

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by
Pooi-Leng Wong
302-2395 Pembina Highway
Winnipeg, MB
R3T 2H4

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Summary

Oil companies conducted the majority of the benthic studies in southeastern Beaufort Sea and they were concentrated in the Mackenzie Delta region in the 1970s and 80s. This was the result of the discovery of a major oil field in Atkinson Point, Tuktoyaktuk Peninsula, which accelerated petroleum and gas exploration activities in the region. The greatest influence on the benthic community in the Delta is the Mackenzie River. It discharges 3.7×10^{11} m^3 of warm, turbid freshwater annually into the shelf making it the most estuarine in the Arctic Ocean. This freshwater mixes with cold, saline marine water to produce a highly variable saline environment especially in waters of less than 5 m. The shallow waters (< 2 m) also freezes to the bottom in winter and in spring landfast ice cause scouring of the seabed. Such nearshore shallow regions (< 5 m) are inhabited predominately by mobile euryhaline epifauna namely amphipods (*Boeckosimus* sp., *Gammaracanthus loricatus*), isopods (*Mesidotea entomon*), and mysids (*Mysis relicta*) whose mobility enables them to escape the freezing of water column in winter and scouring by landfast ice in spring. Infauna comprising of the annelid-pelecypod assemblage usually found beyond the 5 m water depth, showed a general increase in abundance, density and diversity with increasing depth and salinity. Common pelecypods are *Cyrtodaria kurriana* and *Portlandica arctica*. Protected bays such as Mason Bay, near the entrance of Mallik Bay and on leeward sides of Hooper Island and Pelly Island have high concentrations of benthos. These areas are under limited influence of the Mackenzie River and waters are usually calm and clear. They also have high concentrations of freshwater and anadromous fish. Substrate characteristics play a major role in structuring the benthic community. Highest biomass and diversity are found in heterogeneous substrate and species included mobile epi- and infauna as well as sedentary infauna. Lowest biomass and diversity are found in homogeneous, silt-clay substrate, inhabited by mainly sedentary infauna. Epifauna especially isopods, amphipods and mysids constituted a major portion of the diet of many freshwater and anadromous fish inhabiting in and around the Mackenzie Delta. Construction of artificial islands smothers the benthos and modifies their habitats. Severity of these effects is dependent on the size of the island; effects were evidenced further away from larger islands (e.g. 900 m from Issungnak O-61) compared to smaller islands (300 m from Netserk F-40). Ampipods, *Boeckosimus affinis* and *Gammarus oceanicus* significantly avoided the three oils (Norman Wells, Atkinson Point, Venezuela crude). *B. affinis* reacted to more volatile components of crude oil as evidenced by its reduced avoidance behaviour to weathered oils. 80-90% of *B. affinis* when given a choice would avoid the tainted food. In contrast, the isopod, *Mesidotea entomon* showed little or no response to the three fresh oils and fed equally on tainted and untainted food. Young *M. entomon* subjected to chronic exposure to three kinds of oils at three concentrations showed no sensitivity to them during ecdysis and effects on the duration of intermolt periods were variable.

Introduction

The Oceans Act was enacted on Jan. 31 1997. Part of the Act mandated the development of Marine Protected Areas (MPA) and the establishment of Marine Environmental Quality (MEQ) guidelines, objectives and criteria with respect to estuaries, coastal and marine waters. MPA are designated to conserve and protect fishery resources, mammals, endangered or threatened marine species, their habitats and areas of high biodiversity or biological productivity. MEQ evaluates the health of marine ecosystems by assessing the effects of man-made (e.g. pollution, climate change) and natural activities (castastrophes) on the physical, chemical and biological parameters of these systems. Benthos are key components of the marine ecosystems as they are important food sources of fish and mammals. Accordingly, habitats that produce high diversity and productivity of benthos may likely be critical areas for their predators. Therefore, assessing the benthic communities may be an important aspect of any evaluation of areas to be designated as marine protected areas. Benthos could contribute to MEQ programs by being used as indicator species in monitoring the health of marine ecosystems because these animals, being mostly sedentary, will be greatly affected by any perturbations. Their limited mobility could help locate the source of any disturbance.

Benthos are invertebrates, which inhabit the bottom of lakes, streams and oceans. They are usually classified into two major categories namely infauna and epifauna. Infauna refers to animals that live most of their adult lives beneath the substrate and are mostly sedentary with limited mobility. They are usually filter-feeders on particulate matter. Examples of infauna are the annelid worms such as polychates, sipunculoids, and oligochaetes and pelecypods (mollusks). Epifauna refers to animals whose adult lives are spent above the substrate and venture occasionally into the water column. In unconsolidated substrate such as silt-clay, they are typically mobile and wander the seabed searching for food and suitable habitat. Examples of epifauna are the various crustaceans (amphipods, isopods, mysids and cumaceans), gastropods and foraminiferans. They are either filter feeders (mysids and cumaceans), predatory (isopods, mysids, gastropods) or grazers (amphipods).

The federal Fisheries Research Board of Canada conducted benthic invertebrate research in the Canadian Beaufort Sea initially. The first study was carried out on aboard the C.G.M.V. Cancolim II in the summer of 1951. The bulk of the federal research was conducted on board the M.V. Salvelinus in the summers of 1960-63, 1971, and 1975.

Collections were made over the entire Beaufort Sea from the Yukon coast and Herschel basin to Amundsen Gulf and Banks Island Shelf (CODIS 1997). These studies and others were devoted to the morphometric description, geographic distribution and habitat description of species. They included work on annelids by Berkeley and Berkeley (1956), pycnogonids by Hedgpeth (1963), ascidians by Trason (1964), echinoderms by Grainger (1966), bryozoans by Powell (1968), decapod crustaceans by Squires (1969), thecate and athecate hydroids by Calder (1970, 1972), mollusks by Wagner (1977) and cumacean crustaceans by Corey (1981).

The discovery of a major oil field in Atkinson Point, Tuktoyaktuk Peninsula in 1970 accelerated petroleum and gas exploration activities in the Mackenzie Delta region (Keith et.al. 1976). This region then became the focus of both the federal and territorial governments and oil and gas companies (Table 1). These studies concentrated on the influences of various environmental factors (natural or man-made) on the community structures of benthos. Federal agencies devoted their efforts in identifying the general distribution and community structures of benthos across the entire southeastern Beaufort Sea (Wacasey 1974a) as well as collecting baseline information in a particular region such as the Eskimo Lakes (Wacasey 1974b) and the Yukon coast (Allan and Mackenzie-Grieve 1983). The private sector's benthic research was concentrated only in oil and gas exploration sites. They gathered data from these sites prior to any activity and compared them to those collected from post-activities (e.g. drilling, dredging, artificial island construction) to demonstrate any effects that oil and gas exploration may have on the benthic communities (Slaney 1973a,b, 1974a,b,c, 1975, 1977, Thomas 1978a,b, 1979, 1988, Thomas and Heath 1982, Thomas et.al. 1981, 1982,1983).

There was collaborative work between the government and industry, resulting in the Beaufort Sea Project that was initiated in the spring of 1974. The purpose was to acquire adequate physical, chemical and biological information on the Beaufort Sea to enable the federal government to regulate future offshore exploration of oil and gas. Benthos were the focus of one study by Wacasey (1975) and part of fish studies as a food resource under this program. These fish studies included work by Galbraith and Fraser (1974), Galbraith and Hunter (1979), Percy (1975), and Kendel et.al. (1975).

In 1982, the Canadian Federal government gave approval to the Northern Hydrocarbon Development Strategy allowing northern hydrocarbon production to proceed in a phased manner. Part of this strategy was an eight-year research program called Northern Oil and Gas Action Program (NOGAP). Under this program, benthos from Tuktoyaktuk Harbour and Mason Bay were investigated. To date, the information collected has only been reported in data reports by Hopky et.al. (1990, 1994a,b) and Lawrence et.al. (1993).

This account is a summary and a synthesis of all the benthic studies that were conducted in southeastern Beaufort Sea. Conclusions and recommendations will be presented. Geographic locations of artificial islands and areas where studies were conducted are illustrated in Fig. 1.

Influence of water mass on diversity and abundance of benthos

Characteristics of the water and substrate are the major environmental factors which have the most influence on benthic community structures. Waters in southeastern Beaufort Sea are defined by six water masses each with its own unique salinity, temperature and depth characteristics (Carmack et.al. 1989) (Table 2). Salinity and temperature of the Polar Mixed Layer situated within 50 m of water are subject to the most seasonal variations. The causes of these variations are the Mackenzie River discharge, yearly variable rates of ice melt, and summer storms. Other water characteristics, which affect the benthos include ice scouring, ice keel gouging, and bottom currents.

A silt-clay layer covers most of the seabed of southeastern Beaufort Sea. There are, however, a few areas with sandy or gravelly substrates, most notably around Herschel Island, Banks Island and the western coast of the Tuktoyaktuk Peninsula. The substrates are affected seasonally by summer bottom currents, ice scouring and ice keel gouging.

Wacasey (1975) analyzed the relationship between water depth, salinity and temperature of the water and benthic indices, such as species diversity and dry biomass, based on data collected during the open-water season of 1971-1975. The result was the division of southeastern Beaufort Sea into four biogeographic zones namely, (1) estuarine zone, (2) transitional zone, (3) marine zone and, (4) continental slope zone. Characteristics of these zones are illustrated in Table 3. The two zones and part of the third of Wacasey (1975) are within the Polar Mixed Layer water mass of Carmack et.al. (1989).

Within the Polar Mixed Layer, the greatest influence on the benthic communities living there is the Mackenzie River discharge. The Mackenzie River discharges 3.7×10^{11} m^3 of freshwater annually into the shelf making it the most estuarine in the Arctic Ocean. Annual mean sediment discharge of the Mackenzie River has been estimated at 1.25×10^8 tonnes a^{-1}. Maximum discharge occurs in May and early June attaining daily mean values of 25,000 m^3s^{-1}. Lowest values of less than 5000 m^3s^{-1} are attained in the winter months (Lewis 1988 in Hill et.al. 1991).

The Mackenzie River plume lowers the salinity of the nearshore waters of the Mackenzie Delta and the effects of this on the benthic communities are well documented with studies showing increases in the benthic biological indices with increasing salinity and distance from shore.

Slaney (1975) in July-Sept. 1974 conducted a detailed study on benthos in East Mackenzie Bay. Abundance and diversity of the benthic infauna increased with increasing distance from shore. This distribution gradient of benthos is positively correlated with depth and salinity. In waters of less than 3 m, the bottom salinity was < 1 to $0^{o}/_{oo}$ and the mean abundance was 0.56. In waters of 3-5 m, the bottom salinity was < $5^{o}/_{oo}$ and the mean abundance was 5.26. In waters of 6-13 m, the bottom salinity was > $14^{o}/_{oo}$ and the mean abundance was 59.49. Mean density in less than 3 m of water was 0.0-3.2, in 3-5 m was 1.7-9.6 and in greater than 5 m was 51.6-65.5 organisms/grab. Diversity in less than 3 m of water was 2 to 7 in 3-5 m was 11 and in greater than 5 m was 13 taxa. In waters of less than 3 m, diversity was highest (7 taxa) in areas where the salinity was $1.5\text{-}5.0^{o}/_{oo}$ and lowest (1 taxon) in areas where the salinity was $0.0^{o}/_{oo}$. Polychaetes dominated the study area, representing 49% of total abundance and they were found most abundantly in greater than 5 m of water where salinity is high and absent in less than 3 m of water. Pelecypods particularly *Portlandia arctica* and *Cyrtodaria kurriana* comprised 28% of total abundance and their distribution is similar to that of the polychaetes. Slaney (1976) found that *C. kurriana* occurred more frequently in Kugmallit Bay while *P. arctica* was more common on the seaward side of the Barrier islands.

The epifaunal community of east Mackenzie Bay also followed the general trend of increasing density and diversity with increasing depth and salinity. The mysid, *Mysis relicta*, was most common, comprising 85%. The amphipod, *G. loricatus* comprised 14% of the total trawl catch (Slaney 1976). Slaney (1975) recognized two epifaunal groups. One group included an isopod (*Idotega entomon* = *Mesidotea entomon*), a mysid (*Mysis relicta*), and amphipods (*Boeckosimus* sp., G*ammaracanthus loricatus*) found in all three regions (0-> 5 m of water) indicating they have a wide tolerance of variable salinity and depth regimes. *Mysis relicta* has been reported in freshwater as well as brackish waters (Pennak 1953). Salinity varies throughout the open season within East Mackenzie Bay. Low salinity and warm Mackenzie River water dominate in early spring and summer but mid-Aug. colder saline water intrudes along the seabed due to onshore winds and storms and by mid-Sept. the entire Bay is under relatively cold, saline waters (Slaney 1973a).

The second group of benthos included the euphausid (*Thysanoessa raschi*), cumaceans (*Diastylis* sp.), coelenterate medusae and amphipods (*Acanthostepheia* sp., *Gulbarentsia* sp., *Weyprechtia* sp.) and they were found only in 0-5 m of water. This group of epifauna has narrower requirements of salinity and depth.

Slaney (1974c) conducted benthic studies around Adgo, Immerk and Pullen artificial islands located near the Barrier islands of Richards Island in East Mackenzie Bay during the winter of 1973 and 1974. Sampled areas in less than 8 m of water had salinities of less than $4^{o}/_{oo}$ and were inhabited by amphipods (54%), polychaetes (8%) and nematodes (4%) with a mean density ranging from 1.1 to 3.7 organisms/m^2 and mean diversity of 3.6 taxa. Similarly, Slaney (1973a) found epifauna (mainly amphipods) comprised 72% of 1972 summer benthos east of the Barrier islands. In comparison, sampled areas in waters between 8 and 12 m had salinities that were greater than $20^{o}/_{oo}$. These areas were inhabited by polychaetes (61%), pelecypods (19%) and oligochaetes (7%) with mean density ranging from 24.3 to 39.9 organisms/m^2 and mean diversity of 10 taxa. Foraminferans were only found in stations with high bottom salinities.

Thomas et.al. (1981) and Heath et.al. (1981) analyzed the benthic data collected in Tuktoyaktuk Harbour during July and Sept. 1980 prior to the dredging of the east entrance channel. Most stations were in silt-clay or fine sand substrate. Pycnocline, a region of the water where density increases rapidly with a small change in depth, was at 6 m. Salinity in shallow waters (< 6 m and above the pycnocline) was less than $21^{o}/_{oo}$ compared to that in deeper waters (> 6 m), which was greater than $23^{o}/_{oo}$. The overall average biomass for the harbour was 2.75±3.11 in July and 4.01±3.24 g/m^2 in Sept.

The depth of the water with its associated salinity influenced the distribution of the infauna in Tuktoyaktuk Harbour. Two distinct benthic communities were observed. One favoured shallow waters (< 6m) where salinity fluctuated widely (euryhaline species) comprised of amphipods (*Aceroides latipes, Lysianassa* sp., *P. affinis*), polychates (*Ampharete acutifrons, Spio filicornis*) and pelecypods (*C. kurriana, Macoma inconspicua*). The other community that favoured deeper waters (> 6m) where salinity is stable (stenohaline species) was comprised of polychaetes (*Antinoella sarsi, Castalia aphroditoides, Chaetozone setosa, Cossura soyeri, Nephtys* sp., *Prionospio cirrifera, Scoloybs armiger, Terebellides stroemi*), gastropods (*Cylichna alba*), and a priapulid (*Halicriptus spinulosis*). Species diversity was similar in both communities where it was 2.15 taxa in July and 2.44 taxa in Sept. in the shallow water community and 1.82 taxa in July and 2.26 taxa in Sept. in the deeper water community. However, average dry biomass was higher in the shallow water community (4.31±3.52 in July and 5.25±3.62

g/m^2 in Sept.) than that in the deeper water community (0.93±0.95 in July and 2.50±2.18 g/m^2 in Sept.). The higher biomass was due primarily to the major contributor, the pelecypod *C. kurriana*.

Two other rivers, which drain into southeastern Beaufort Sea also influence benthic communities. Nunaluk Lagoon, located along the Yukon coast, is encircled by the deltas of the Firth and Malcolm Rivers in the south and the Nunaluk Spit in the north. In mid-summer, the lagoon with clay-silt substrate has warmer water (8.6^{0}C) with lower, less variable salinity (2.5$^o/_{oo}$) compared to the seaward side of the spit (4.4^{0}C, 5.6$^o/_{oo}$) that had medium gravel pebble to sand gravel. Density of benthos (649.6-4161.0 organisms/m^2) and species diversity (5.7 taxa/station) in the lagoon was significantly higher than those in the seaward side of the spit (24.6-649.5 organisms/m^2, 2 taxa/station) (Griffiths et.al. 1975). The lagoon was inhabited predominately by oligochaetes and to a less extent by dipteran larvae and pupae while offshore of the spit, epibenthos were the dominant group.

Wagner (1977) found that species of mollusks (pelecypods and gastropods) in southeastern Beaufort Sea were distributed according to the depth of the water and that optimum depths of nine of the 14 dominant species occur within 50 m of water. In < 6 m of water, *C. kurriana* was dominant followed by *Portlandia arctica aestuariorum*. *Yoldiella intermedia* and *Macoma balthica* , in low prevalence were also found in these shallow waters. In 6-35 m of water, *Portlandia arctica siliqua* was dominant followed by *Cyclichna occulta*. In 35-60 m of water, *Yoldiella lenticula* and *C. occulta* were equally dominant. In 60-100 m, *Y. lenticula* and *Portlandia arctica arctica* were equally dominant. The highest prevalence of *Y.* lenticula was found in 100-200 m, with *Thyasira flexuosa* being the next most dominant species at water depth. In > 200 m, *T. flexuosa* was the most dominant followed by *Axinopsida orbiculata*.

<u>Substrate characteristics and their relationship to benthic communities</u>

Substrate characteristics of the Mackenzie Delta are a function of the intensity of the Mackenzie River outflow (particularly between May and early June), which resulted in bottom currents, waves generated during summer storms and scouring by ice keels. Sediments under the intense influence of currents and waves tend to be homogeneous while low current and waves produce heterogeneous sediments with patchy spatial distribution of particles and high variation of particles sizes.

Heath et.al. (1982) studied the effects of gravel dredging of a borrow site (69^{O} 31' 55"N, 138^{O} 45' 45"W) near Herschel Island in Mackenzie Bay. Sampling was conducted in July, prior to dredging, and in Sept. after dredging was complete. Depths of sampling sites were 7-12 m in July and 10.1-14.6 m in Sept.

The area has a heterogeneous sediment environment as evident by the high degree of variation in particle size distribution. This environment was the result of scouring by grounded ice producing patchy or clumped benthic distributions as indicated by the high degree of variability in wet biomass in sampling stations located in substrate with greater than 33$^{o}/_{oo}$ gravel. Grounded ice may have been the cause of reduced biomass by the physical destruction of organisms and/or by increased turbidity due to currents flowing around ice scours. Mean wet biomass for July was 5.34±4.01 and for Sept. was 13.63±19.66 g/m^2. In July, 158 species belonging to 87 families were identified and the mean number of families per station was 35.3±14.4. In Sept. 81 families were identified and the mean number of families per station was 32.7±12.6.

Three benthic communities were observed in the Mackenzie Delta. **(1)** The first community inhabited mainly gravel substrate and included amphipods (*A. latipes, Anonyx nugax, Byblis gaimardi, Caprella microtuberculata, Caprella punctata, Erichthonius difformis, Ischyrocerus anguipes, Ischyrocerus megacheir, Melita dentata, Metopa pusilla, Metopa sinuata*), pelecypods (*Delectopecton greenlandicus, Macoma moesta*), a gastropod (*Buccinum polare, Propebela* sp.), an isopod (*Pleurogonium spinosissmum*), a cumacean (*Brachydiastylis resima*) and a tanaid (*Leptognathia gracilis*). **(2)** The second community inhabited predominately sandy substrates and included amphipods (*Apherusa megalops, Gammarus locustris*, *Monoculodes packardi, Onisimus botkini, Orchomene* sp., *Paroediceros lynceus*), pelecypods (*Hiatella arctica, T. flexuosa*), a gastropod (*Oenopota* sp.), an isopod (*Synidotea bicuspida*) and, a cumacean (*Diastylis edwardsii*). **(3)** The third community inhabited both gravel and sandy substrates and they included amphipods (*Ampelisca eschrichti, Caprella ciliata, Erichthonius* sp.), pelecypods (*Astarte montagui, Liocyma fluctuosa, Mya truncata, Thracia* sp.), cumaceans (*Diastylis rathkei, Diastylis tumida*), an isopod (*Mesidotea sibirica*), and a gastropod (*Retusa obtusa*).

The Yukon coast, at 5 m depth, also have a heterogeneous seabed ranging from gravel to fine sand around Stokes Point and a mixture of coarse sand and gravel and silt around King Point (Allan and Mackenzie-Grieve 1983). Areas of Stokes Point with fine sand substrate have higher diversity (H' = 0.3-0.96; 7.9 (3-12) species/station) and density (130-2000 organisms/m^2) compared with areas in King Point that have a mixture of gravel and silt (H' =0.0-0.38; 1.6(0-3) species/station, density 0-300 organisms/m^2). Both of these areas have similar salinity ranging from 29.3 to 34.1^O/oo. Kendel et.al. (1975) reported 4 species/station at 2.5 m and 25 species/station at 12.5 m at Stokes Point and 9 species/station at 13-16 m at King Point.

Thomas et.al. (1982) studied benthos at the artificial island East Tarsuit N-44 (69^O 53' 49" N, 136^O 11' 39" W) and the adjacent borrow site, South Tarsiut (69^O 44' 06" N, 135^O 58' 36" W) located immediately NNW of Pelly Island in East Mackenzie Bay. East Tarsiut N-44 was constructed in 1980-1981. Benthos at the island site were sampled with a Ponar grab (0.055 m^2) while those at the borrow site were sampled by a Van Veen grab (0.1 m^2).

At East Tarsiut N-44, the sampling sites were in 10-21 m of water. Highest diversity (27-36 species/grab), wet biomass (2.90-12.54 g/m^2) and density (871-1361 organisms/m^2) were found in sampling sites that had salinities greater than 27.93$^o/_{oo}$ and silt-clay substrates (94.8-98.4% silt-clay). Sampling sites with lower salinities (< 26$^o/_{oo}$) and sandy substrates (1.2-3.3% silt-clay) had lower diversity (8-16 organisms/grab), wet biomass (0.40-2.79 g/m^2) and density (24-471 organisms/m^2). One site with silty-sand substrate (60.6% silt-clay) also had a high diversity of 35, wet biomass of 5.37 and a density of 603. In terms of wet biomass, sites with higher salinity and with silt-clay substrates were dominated by the pelecypods (*A. montagui, C. kurriana, P. arctica*), a gastropod (*Scaphander punctostriatus*), a polychaete (*Leitoscoloplos panamensis*) and a holothurid (*Myriotrochus rinkii*). Sites with lower salinity and with sandy substrates were dominated by an amphipod (*Boeckosimus derjugini*) and a pelecypod (*T. flexuosa*).

Overall mean density at East Tarsiut N-44 Island was 626±411 organisms/m^2, mean wet biomass was 4.26±4.03 g/m^2 and mean species diversity was 20.8±9.6 taxa/grab. Overall, the island's benthic community consisted of polychaetes (*Aricidea* sp., *Eteone* sp.), pelecypods (*T. flexuosa*) and foraminiferans (*Dentalina obliqua, Miliolina seminulum*). These species were rare or absent in the borrow site (south Tarsiut).

The borrow site sampling locations were in water depths between 8.0 and 13.0 m and salinity ranged from 24.90 to 25.63$^o/_{oo}$. There appeared to be no differences in density, wet biomass and diversity between sites with sandy and silt-clay substrates. However, there were differences in their species compositions. Sandy substrate areas were dominated, in terms of wet biomass, by pelecypods (*C. kurriana, P. arctica*), an isopod (*M. sabini*), spionid polychaetes (*Malacoceros* sp., *Prionospio* sp.) and a polychaete (*Nephtys cornuta*). Areas with silt-clay substrates were dominated by a pelecypod (*P. arctica*), an isopod (*M. sabini*), a polychaetes (*L. panamensis*) and a priapulid (*Priapulus caudatus*).

The borrow site had overall average wet biomass of 16.39±12.9 g/m^2 and mean density of 1330±503 organisms/m^2 and species diversity of 22.4±3.9 taxa/grab. Overall, the benthic community of the borrow site consisted of polychaetes (*A. sarsi, Cossura* sp., *L. panamensis, Lumbrineris* sp., *Nephtys* sp., *Phyllodoce groenlandica, Prionospio* sp.1, *Sphaerodoropsis minuta*), an isopod (*M. sabini*), a pelecypod (*C. kurriana*) and an amphipod (*Boeckosimus plautus*) and an unidentified sipunculid. These species were rare or absent from the island site.

Benthos found commonly in both borrow and island sites included polychaetes (*Chaetozone spinosa, Malacoceros* sp. *Scolelepsis* sp., *Trochochaeta multisetosa*, Sabellid), gastropods (*Propebela* sp., *R. obtuse, S. punctostriatus*), a foraminiferan (*Cornuspira foliacea*), a bivalve (*Macoma* sp.), an ophiuroid (*Ophiura* sp.), a hydroid (*Perigonimus yoldia-arcticae*), a brozoan (*Eucratea loricata*), and an unidentified nemertean.

Thomas and Heath (1982) studied the benthos of the artificial island Kaglulik (70^{O} 33' 51.2"N, 130^{O} 51' 39.5"W), and Uviluk (70^{O} 15' 48.1"N, 132^{O} 18' 44.6"W). These sites were located off the NW coast of Tuktoyaktuk Peninsula. Samples were collected from 16.5 to 44.8 m of water, prior to the construction of the islands.

In general, mean diversity was 44.3±15.1 taxa/station, dry biomass was 9.37±8.80 g/m^2 and wet biomass was 49.6±43.0 g/m^2, and density was 3984±4554 organisms/m^2. Three benthic communities were recognized by their affinities to particular depths of water and sediment characteristics. One community inhabited shallow (< 24 m), sandy (< 19% silt-clay) substrates with low total organic carbon content (< 0.40%). It was represented by the polychaete *Polydora pygidialis* and the amphipod *Corophium crassicorne*. The second community inhabited deeper water (25-45 m) with silty to muddy (23-93% silt-clay) substrates and high total organic carbon content (> 60%). It was represented by polychaetes *A. latipes, Tharyx* spp. and *Leucon nasica*. The third community inhabited either shallow, silty or deeper, sandy substrates with intermediate levels of total organic carbon content. It was represented by species found in the other two communities and had, therefore, the highest species diversity.

Jones and Den Beste (1977) studied the infauna and epibenthos of Tuft Point and the surrounding bays (Hutchinson Bay, Beluga Bay and unnamed bay), located along the western shore of Tuktoyaktuk Peninsula. This region is in the broad mixing zone where the Mackenzie River freshwater mixes with the clear saltwater of the Beaufort Sea. This mixing is due primarily to the strong wind-induced currents. As a result, the salinities vary widely from 5.6 to $23.9^{o}/_{oo}$ in July to $5.9\text{-}21.0^{o}/_{oo}$ in Aug.-Sept. Sand deposits, from eroding sand cliffs, characterized the coast and extends for a considerate distance from shore. All the sampling sites were in less than 10 m of water.

For the region, the benthic infauna standing crop was 2863 (70-10,147) organisms/m^2 in July and 3694 (245-18,106) in late Aug.-early Sept. The Shannon-Weaver diversity index was 2.05 (0.4-3.0) in July and 2.73 (1.7-3.62) in Sept. Polychaetes were most abundant (55-57.6%), followed by pelecypods (17.7-26%), oligochaetes (10.5-11.0%) and crustaceans (5.6-10.9%). Polychaetes exhibited patchy distribution patterns as indicated by high variations in standing crop at adjacent sampling stations. This reflects the patchy spatial distribution of gravelly substrates. Amphipods (13 species) and polychaetes (12 species) were the most diverse groups of benthos. Most common amphipods were *Boeckosimus affinis, Gammarus* spp., and *Princillina armata*. The first two species were widely distributed throughout the region while the third species were found only along the coast near the Imperial Oil barge camp. Dominant polychates included *Ampharete vega, Malacoceros fuliginosus, Micronephthys minuta,* and *P. cirrifera*. The commonest cumacean was *D. rathkei* (55.8-152.3 organisms/m^2).

Jones and Den Beste (1977) reported that stations with coarse sandy substrate, just offshore of Tuft Point and along the shore, had lower densities (70-1117 vs 715-18106 organisms/m^2) and lower species diversity (3-11 vs 15-24 species/station) compared with stations with other types of substrate (not specified). Species found commonly in the sand substrates included polychaetes (*Lumbrineris* sp., *M. minuta, P. cirrifera, Terebellidea stroemi?*) oligochaetes (*Peloscolex* sp.), amphipods (*G. locustris, Gammarus oceanicus, P. armata*), a cumacean (*D. rathkei*), an isopod (*M. entomon*) and pelecypods (*Cyrtodaria kurriana, Macoma calcata*).

Highest densities were found in the protected entrance to Beluga Bay (10,147 organisms/m^2) and on the leeward side of a pointed peninsula within the unnamed bay (18,106 organisms/m^2). Wacasey (1975) also reported high average dry biomass (5 g/m^2) and mean density (5754 (770-14175 organisms/m^2)) in the protected and shallow (4-6 m) Mason Bay, Richards Island.

Epibenthos standing crop was 194.3(22-526) organisms/1000 m in July and 834.8(10-5834) organisms/1000 m in Aug. at Tuft Point. The Shannon-Weaver diversity index was 2.60(1.45-3.23) in July and 2.39(0.92-3.67) in Sept. Epibenthos were dominated by crustaceans (45.3-59.8%) followed by polychaetes (15.0-24.3%) and pelecypods (14.4-20.4%). Amphipods (9 species) and polychaetes (7 species) were the most diverse groups. Epibenthic amphipods common in this region included *Acanthostephia behringiensis, G. oceanicus, G. loricatus and Monoculodes latimanus*.

Heath and Thomas (1984) reported on pre- and post-gravel dredging studies on benthos near Banks Island in 1981 and 1983, respectively. The dredged area was located in southwestern Banks Island, off the mouth of the Rufus River in 10-25 m of water. This area is at the eastern margin of the Beaufort Sea and at the entrance to Amundsen Gulf.

At Banks Island, the substrate was heterogeneous ranging from gravelly to silt. A layer of silt overlaid areas that have coarser and poorly sorted sediments. One year after dredging, the two stations in the dredged trenches had mean species diversity (38.7±6.8, 42.3±7.7 taxa/sample), mean density (1,698±983, 2,619±1,407 oganisms/m^2), and mean wet biomass (11.9±8.3, 8.6±3.7 g/m^2) approaching or near those at a nearby reference site (40.0±4.6 taxa/sample, 2,873±690 organisms/m^2, 25.0±20.5 g/m^2), respectively.

Epibenthos such as sea urchin *Strongylocentrotus droebachiensis*, soft coral *Gersemia rubiformis*, nudibranchs, amphipods, gastropod *Volutopsius* sp were found in the dredge site. This assemblage was similar to that in the reference site although the abundance was lower.

Community analyses distinguished three assemblages of benthos. The assemblage in the dredged area was intermediate between the two main assemblages present in the region. One main assemblage inhabited sandy substrate in less than 10 m of water. It is distinguished principally by the bivalve *Thyasira gouldii*. Other species in this assemblages included polychaetes (*A. orbiculata, L. fluctuosa, Pygospio elegans*), amphipods (*I. megacheir, Monoculodes longirostris*), cumacean (*Lamprops fuscata*), a tanaid (*L. gracilis*) and a gastropod (*S. punctostriatus*). The other main assemblage (the reference sites) inhabited heterogeneous substrate that included a silty layer over sandy to gravelly sediments in greater than 10 m of water. It was dominated by the polychaetes (*A. acutifrons*, *Chone duneri*, *P. elegans*), a pelecypod (*A. orbiculata*) and a gastropod (*S. punctostriatus*). Other less common members of this assemblage included polychaetes (*Aricidea lopezi, Capitella* sp., *Pholoe minuta, P. groenlandica, Tharyx/Chaetozone* complex, *Travisia forbesii*), amphipods (*Atylus carinatus, B. gaimardi, M. dentate, Monoculodes borealis, Paradulichia typica, P. lynceus*), a cumacean (*D. edwardsi, Diastylis oxyrhyncha*) and a pelecypod (*Serripes groenlandicus*). The community structure of the dredged area and a nearby reference site had a heterogeneous substrate and was characterized primarily by amphipods (*Monoculodes borealis, M. longirostris*), a polychaete (*P. groenlandica*) and a cumacean (*L. fuscata*). Other less common members of this assemblage included polychaetes (*Dorvillea* sp., *Euchone analis, Exogena tatarica, L. panamensis, Nephtys cornuta, N. longosetosa, Ophelia limacina, Praxillella* sp.), an amphipod (*A. latipes*), a pelecypod (*Clinocardium ciliatum*), copepods (*Oncaea* sp.), an ascidian, a sipunculid, a harpactid, and a juvenile ophiurid.

There were no significant differences between assemblages in the sandy and dredged sites in their species diversity (44.6±16.4 vs 40.3±6.3 taxa/sample), density (1775.4±945.1 vs 2396.7±1129.9 N/m^2) and wet biomass (31.1±11.8 vs 15.2±14.2 g/m^2). However, species diversity (40.3±6.3 taxa/sample) and density (2396.7±1129.9 N/m^2) were significant reduced in the dredged area when compared with the undredged area (70.3±10.8 taxa/sample and 6694.3±5261.2 N/m^2, respectively).

Some 225 taxa have been identified and they included polychaetes (92 taxa), amphipods (40), bivalves (20), gastropods (19), cumaceans (11) and hydrozoans (8). Thus, southwestern Banks Island has a relatively rich benthic community compared to other shallow areas (< 50 m) of the southeastern Beaufort Sea. This may be attributed to the fact that this region has a heterogeneous substrate, which included rocks and boulders where macroalgae and sessile epifauna can attach. This greatly increases species diversity and added complexity to the general benthic community. Areas without hard substrates and in turbid waters usually lack macroalgae and sessile epifauna.

The effects of construction of the artificial island Isserk F-27 (69^{O} 56’ 21.2”N, 134^{O} 21’ 21.1”W) on the benthic community was studied by Envirocon Ltd (1977). The island, in 12.8 m of water, is located 16.5 km north of Pullen Island on the northwestern section of Richards Island. Sampling sites, around the island, were located in depths ranging from 10.1 to 15.6 m, with bottom salinity ranges from 25 to 30$^{o}/_{oo}$, bottom temperatures varied in July from 0 to –0.7^{O}C and in Aug. from 0.5 to 6.3^{O}C.

In general, the mean diversity for July was 28.8±0.85 and for Aug. 23.0±1.47 species. Mean density for July was 2618±236.2 and for Aug. 1606±209.4 organisms/m^2. Mean wet biomass for July was 12.4±1.42 and for Aug. 9.1±0.80 g/m^2. Shannon-Weaver diversity index for July was 2.7±0.14 and for Aug. 2.7±0.10.

Polychaetes (31-45%), foraminiferans (14%), pelecypods (11%) and gastropods (9%) were the major benthos. Polychaetes were most diverse with 29 species followed by the foraminiferans with 11 species. The foraminiferan, *Elphidiella arctica* was the most abundant species, accounting for over 50% of the total.

Sandy substrates around the island were brought from the nearby borrow site and from Tuft Point. This altered habitat resulted in lower mean density of 1129.5 (624-1920) organisms/m^2 compared to the mean density of 2367.68 (992-4684) in silt-clay substrate habitat, which is the natural background habitat. Although *E. arctica* contributed substantially to this high density in the latter substrate, the polychaete (*Micronepthys* sp.), a pelecypod (*Portlandia yoldiella*), ostracods (*Cythereis* sp., *Loxoconcha* sp.) and a copepod (*Metridia longa*) were also very abundant. Two naturally sandy habitats sampled also had lower densities of 196 and 2068 organisms/m^2. There was a general increase in density with increase distance from the island.

Crippen and McKee (1981) studied the effects of the construction of the artificial island, Issungnak O-61(70^{O} 01'N, 134^{O} 18'W), on the benthos. This island, in 19 m of water, is located north of Richards Island. It was constructed between 1978-1980. The island altered the sediment type from a predominately clay-silt for this region to fine sand within 300 m of the construction site, and a mixture of fine sand and silt-clay between 300-900 m from the island. Beyond 900 m, the sediments were silt-clay, the natural background type.

There was a general trend of increasing benthic biological indices as the distance from the island increased. Mean density increased from 45±25 at 100 m to 1152±495 organisms/m^2 at 3000 m from the island. Likewise, diversity also increased from 13±6 at 100 m to 35±8 at 3000 m from the island. The altered habitats (< 900 m) have lower density and diversity of benthos 13-284 organisms/m^2 and 7-23 species/station, respectively compared to 345-1822 organisms/m^2 and 22-47 species/station in undisturbed areas i.e. beyond 900 m of the island. The Shannon-Weaver diversity index for the undisturbed areas ranged 3.51 to 4.23. Polychaetes and bivalves represented 70% of the total wet biomass. Wet biomass of these two groups ranged from 0.009-0.643 g/m^2 in the construction zone to 1.383-14.15 g/m^2 in undisturbed zone.

The altered sediment environment near the island (within 300 m) harboured a benthic community which included spionid polychaetes (Microspio sp., *Scolecolepides* sp.), other polychaetes (*Aglaophamus neotenus, Caulleriella* spp., *Phyllodoce ?groenlandica*), pelecypods (*Nuculana ?minuta*), and amphipods (*Hyperia* sp., *Onesimus* sp.) The undisturbed sediment (beyond 900 m of the island) had a community, which included polychaetes (*A. neotenus, Aricidea* sp., *Artacoma proboscidea, Cauleriella* spp., *Pectinaria hyperborea*), pelecypods (*Nuculana ?minuta*), amphipods (*Melita* sp., *Protomedia* sp.), ophiurid (*?Ophiocten* sp.), a holothurid (*Myrtotrochus* sp.), gastropods (*Cylichna ?alba, R. obtusa*), and cumaceans (*Diastylis* spp., *Leptognatha* sp.)

<u>Regions of high benthic productivity</u>

Wacasey (1975) reported highest dry biomass (71 g/m^2) and species diversity (71-81 species/station) in the eastern region of the Mackenzie Shelf in water depths ranging from 36-70 m and salinities ranging from 31.13 to 32.8$^o/_{oo}$. Thomas (1979) reported similar high dry biomass (23.60$\pm$16.61 g/m^2) and diversity (78 taxa) of benthos at the Kilannak A-77 artificial island (70^O 46’ 14.33”N, 129^O 21’ 26.24”W) located NW of Cape Dalhousie in 25 m of water and salinity of 32.5$^o/_{oo}$. Polychaetes were the most abundant with densities ranging from 1603.65 to 3787.09 organisms/m^2 and most diverse with 34 species/station. Amphipods were also dominant with densities ranging from 214.56 to 480.02 and diversity of 32 species/station. Kaglulik C-24 and Kaglulik A-75 located southwest of Kilannak A-77 also have high dry biomass (24.81$\pm$16.19 and 15.01$\pm$7.16, respectively) but lower diversity (34 and 22 taxa, respectively) (Thomas 1979).

This high benthic productivity is well correlated with the primary production activities and high nutrient concentrations in this region as reported by Macdonald et.al.. (1987). Nutrient maxima was found in waters with salinities ranging from 32-34$^o/_{oo}$. Maximum silicate was 33 mmol/m^3, phosphate was 2.3 mmol/m^3 and nitrate was 17 mmol/m^3. Primary production usually occurs in regions of high nutrient concentrations. Indeed, Macdonald et.al.. (1987) reported primary production activities to a depth of 50 m in this region as inferred by the noticeable reduction in nutrients along with high oxygen concentrations in 1975. They attributed this to the early opening of the Bathurst

Polynya in the 1975 season, and that the polynya extended and encompassed the eastern region of the shelf.

Wacasey (1975) reported high species diversity (40-70 species/station) in eastern region of the Mackenzie Shelf, particularly around the Mackenzie cannon near Herschel Island. Heath et.al. (1982) reported 35.3±00 taxa/station in July and 32.7±12.6 taxa/station in Sept. near Herschel Island. This high diversity is partly due to the heterogeneity of the substrate, which provide habitat and shelter for many benthos not available in an otherwise homogeneous environment. Another reason for the high diversity may be due to the upwelling that occurs in the Mackenzie canyon, which brings up nutrients from deeper waters. Macdonald et.al.. (1987) identified an upwelling in this region as indicated by the increase of nitrate concentrations and warmer temperatures in this area. This would promote primary production and provide a food resource to the benthos.

<u>Benthos as food resource of fish</u>

Epibenthos constituted a major portion of the diet of freshwater, anadromous and marine fish in and around the Mackenzie Delta. Fish and prey co-exist, in summer, in shallow, protected areas of the delta where the warmer and more stable environment prevails. Slaney (1973a) identified mudflats and lagoons of the Barrier Islands, East Mackenzie Bay as areas with high concentrations of both fish and benthos. These areas included northwest and western sides of Hooper Island and the leeward side of the spit on the east side of Pelly Island. High concentrations of both fish and prey were also found near the entrance to Mallik Bay. All these areas were noted as important feeding areas for juvenile and adult anadromous arctic cisco (*Coregonus autumnalis*), least cisco (*Coregonus sardinella*) and boreal smelt (*Osmerus eperlanus*). Epibenthos such as amphipods and cumaceans were found in the stomachs of these fishes (Slaney 1973a, 1976). Isopods, amphipods and mysid-euphauscids were found in the stomachs of marine fourhorn sculpin (*Myoxocephalus q. quadricornis*), saffron cod (*Eleginus navaga*) and arctic flounder (*Liopsetta glacialis*) in Kugmallit Bay and outer East Mackenzie Bay (Slaney 1976). Envirocon (1977) reported that the gastropod, *Limacina helicina* occurred with highest frequency in the stomachs of fish (mostly those of the arctic cisco) caught around Isserk F-27 artificial island, located 16.5 km north of Pullen Island.

Percy (1975) examined the stomach contents of various fish collected in streams, lakes and coastal waters of the Mackenzie Delta (Table 4). The importance of a benthic taxon in the diet of a particular fish species varies with the habitat in which the fish exists. For example, isopods comprised the highest volume in the diet of humpback whitefish residing in the coastal waters while gastropods constituted the highest volume in the diet of those humpback whitefish inhabiting the lakes and streams of the delta.

Bond and Erickson (1989) concluded that Phillips Bay and adjacent coastal waters of Yukon were important foraging areas for the arctic and least cisco, arctic charr, rainbow smelt, fourhorn sculpin, saffron cod and arctic flounder. Ciscoes fed principally on amphipods, mysids, isopods and copepods while fourhorn sculpin fed exclusively on isopods. The rest of the fish were piscivorous.

Arctic cisco, arctic charr and fourhorn sculpin were the most abundant fish collected in the deltas of the Firth and Malcolm Rivers, their shared lagoon (Nunaluk Lagoon) and offshore of the lagoon spit along the Yukon coast (Griffiths et.al. 1975). Crustaceans especially amphipods, isopods and copepods were of great importance in the diet of all three species of fish. However, there are size-class differences, and seasonally variable dietary habits among the fish. Small arctic cisco (201-300 mm) fed mainly on fresh and brackish water insects (61.4%) mainly chironomids during summer and shifted to crustaceans (72.7%) mainly pelagic copepods in fall. Medium size fish (301-400 mm) fed mainly on crustaceans (40-56%) and insects (24-35%) in spring and summer. In fall, they consumed crustaceans (76.8%) with pelagic copepods and small isopods as the main items. For the large-size fish (401-500 mm), crustaceans were the most important food items throughout the open season with amphipods being prominent in spring and copepods in the fall. The shift to feeding on copepods in the fall by both arctic cisco and arctic charr coincided with the increase population of this crustacean during this period. Small arctic charr (<300 mm) fed principally on insects (68.6%) especially chironomids. Medium-size fish (301-400 mm) relied on amphipods and small isopods and large fish (501-600 mm) were piscivorous (80.4%) feeding particularly on fourhorn sculpin. Fourhorn sculpin of all sizes fed principally on crustaceans with amphipods being the main food item for the smallest fish (0-100 mm) and large isopods becoming increasing important as the fish grew. Apparently, large isopods are consumed only by fourhorn sculpins.

Galbraith and Fraser (1974) reported that mysids and amphipods were most prevalent in the stomachs of the arctic cisco and Pacific herring while copepods were most prevalent in the stomach of least cisco collected in Kugmallit Bay and western coast of Tuktoyaktuk Peninsula.

Fish collected in the vicinity of Tuft Point, Tuktoyaktuk Peninsula also fed mainly on epibenthos. Amphipods and copepods were found most frequently in the stomachs of arctic and least cisco while amphipods, isopods and mysids occurred most frequently in the stomach of the fourhorn sculpin. Isopods, polychaetes and amphipods were most prevalent in the stomach of the arctic flounder while isopods and fish were most common in stomach of the saffron cod (Jones and Den Beste 1977).

Lacho (1991) analysed the stomach content of fish caught in Tuktoyaktuk Harbour from late June to early Sept. Polychaetes were found most frequently in arctic cisco, arctic flounder, blackline prickleback (*Acantholumpenus mackayi*), eelpout (*Lycodes jugoricus*) and slender eelblenny (*Lumpenus fabricii*). Highest occurrence of mysids was found in least cisco, broad whitefish, lake whitefish, rainbow smelt and saffron cod. Although copepods were found most frequently in Pacific herring, they were dominant, numerically, in the diets of ciscoes and whitefish. Saffron cod, arctic flounder, starry flounder, blackline prickleback and slender eelblenny fed on a much wider variety of benthos than the other fishes.

Bond (1982) found that most broad whitefish, lake whitefish and least cisco that were migrating through Tuktoyaktuk Harbour do not feed. But those that feed select different benthos. Broad whitefish fed on chironomids and pelecypods (59% and 43% frequency of occurrence, respectively) and gastropods (26% of total food biomass). Lake whitefish preferred pelecypods, ostracods and amphipods with pelecypods accounting for highest food biomass. Least cisco consumed copepods which occurred in 75% of fish examined and constituted 54% of total food biomass. Arctic cisco overwintering in the harbour fed primarily on polychaetes that were found in 41% of fish examined and comprised of 51% of the total biomass. Copepods (44% frequency of occurrence and 15% of total food biomass were major benthos eaten by Pacific herring and amphipods (38% and 36%) and mysids (31% and 12%) were main food items of rainbow smelt migrating in the harbour.

Lacho (1986) analysed the food habits of arctic cod (*Boreogadus saida*) caught near Herschel Island and offshore of Tuktoyaktuk Peninsula. Copepods were the main food items found with *Pseudocalanus elongatus* being most numerous in the July and *Limnocalanus macrurus* in Sept. Bradstreet et.al. (1986) also reported that copepods especially *Pseudocalanus minutus*, contributed over 99% of the diet of the arctic cod in southeastern Beaufort Sea. Copepods, particularly calanoids, were also found to be very important in the diet of larval arctic cod collected from the entire Beaufort Shelf

(Chiperzak et.al. 1990). They occurred in > 80% of the larval fish and accounted for > 60% of total numbers of food items. Copepods found most frequently or in high numbers were *P. minutus* and *Acarti clausi*.

Bond and Erickson (1993) examined the food habits of fish caught in Liverpool Bay. Arctic cisco of indistinguishable age had a less varied diet than older members simply due to prey size constraints. Copepods (61%), insecta (42%) and cladocerans (37%) were the major food items of this age class of fish. Insecta (Diptera) were more abundant in the diets of these fish in late July than in Sept. In older fish, amphipods (57%) and isopods (47%) were the dominant food accounting for 9 and 10% of the total food biomass, respectively. In terms of biomass, insects, cumaceans and copepods were more important to fish that were < 250 mm in length.

In terms of biomass, isopods (39%), copepods (15%) and amphipods (12%) were dominant food items of least cisco. In early summer, adult insects were vital as they were found in 88% of the stomachs and accounted for 22% of the food biomass. Amphipods (27%) were the principal food (by biomass) of lake whitefish in Liverpool Bay.

Calanoid copepods were found most frequently (50%) and were also the most abundant (84.8% by number) food item of larval fourhorn sculpin; *P. minutus* occurred most frequently (84.6%) in larval staghorn sculpin (*Gymnocanthus tricuspis*) in the Beaufort Sea shelf (Chiperzak et.al. 1990).

<u>Heavy metal contaminants in benthos</u>

Thomas (1978b,c, 1979) analyzed heavy metal concentrations in benthos from drill wells in southeastern Beaufort Sea (Table 5). There was no apparent correlation between concentrations of heavy metal in benthos and distance from the Tingmiark K-91 and Kopanoar D-14 wells.

Crippen and McKee (1981) found metal concentrations in polychaete and bivalve tissues from nearby Issungnak O-61 artificial island occurred in the order Hg<Pb<Cd<As<Cr<Zn. This was similar to the order of metal concentrations (Hg<Cd<As<Cr<Pb<Zn) found in the sediments, except Pb. Within 3000 m of the island, metal concentrations in tissues were: Hg (0.053±0.0423 to 0.95±0.037 wet wt. µg/g), As (1.6±0.7 to 5.5), Cd (0.5 to 2.4±1.1), Cr (3.1 to 10.0), Pb (0.6±0.2 to 1.5) and Zn (23.6±3.4 to 52.6). There were significant correlations between the levels of Cr, Pb and

Zn in tissues and those in the sediment although the regression line for Pb was almost vertical.

Thomas and Heath (1982) analysed 10 species and 2 orders of benthos collected from pre-construction sites of Kaglulik, Kaglulik South and Uviluk islands located off the NW coast of Tuktoyaktuk Peninsula (Table 6). There was no correlation between metal concentrations in the sediments and those in the benthos. Thomas and Heath (1982) pointed out that interpretation of heavy metal concentrations in benthos was difficult because of the inherent natural variability of heavy metals in the benthos, high variation between individuals within a species, large differences between sex and age of individual organisms and seasonal variation in concentration by a factor of two.

<u>Histopathological study of clams</u>

Thomas et.al. (1981) reported that the health and condition of the pelecypod, *C. kurriana* from Tuktoyaktuk Harbour were in decline in Aug. and Sept. compared to clams collected in July. They had high rates of digestive transformation (disintegration of epithelial cells) and poor digestive condition as indicated by extreme vacuolation of the digestive epithelium (i.e. low nutrient levels). There was poor kidney condition as evidenced by sloughing of tubule epithelium into lumen, destruction of epithelium and presence of concretions and deposition in kidney tubule lumen and/or epithelium.

Gills of the clams were heavy infected with the thigmotrich ciliate parasite, *Ancistrum* sp. Gill filaments were damage as a result of large infestation in some regions of the gill. Some parasites have penetrated the gill epithelium and entered the blood system and infected the heart, kidneys, connective tissues of the digestive gland and reproductive tract, the adductor muscle and the mantle. The parasite elicited a serious inflammatory response indicated by the high numbers of granulocytes and hyalinocytes in the blood.

Two explanations were provided for the poor condition. One explanation was that the condition was the result of reproductive activity of the clams; they were either spawning or very near spawning with very ripe gametes. Clams collected in July were not as advance in their reproductive processes. Nutrient reserves are depleted during gametogenesis and after spawning the clams are in poor physiological and cytological condition. The other explanation was that chronic stress from the environment may have reduced the ability of the clams to resist the parasitic infestation.

Effects of oil and gas exploration on benthos

Construction of artificial islands smothers the benthos and modifies their habitat. The extent of these effects is dependent on the size of the islands. For example, at Netserk F-40, just off Pelly Island, Richards Island the alterations did not extend beyond 300 m of the construction site while a larger island such as Issungnak O-61, its effect was evident to 900 m.

Amphipods, *B. affinis* and *G. oceanicus* from Eskimo Lakes and the isopod, *M. entomon* from Kugmallit Bay exhibited varying degrees of avoidance of different fresh crude oil masses (Percy 1976). Amphipods significantly avoided all the three oils that were tested but Atkinson Point crude evoked the greatest response. Weathered Atkinson Point and Venezuela oils elicited no responses from *B. affinis* and its avoidance of weathered Norman Wells oils was only slightly reduced from that shown to the fresh material. On the other hand, the isopod showed little or no response to all the three fresh oils.

Feeding responses of *B. affinis* also varied according to the type of oil used to taint the food fed to them. Norman Wells oil evoked the greatest response. When presented with a choice of untainted or tainted food, 80-90% of these animals opted for the untainted food. In contrast, *M. entomon* when tested with Norman Wells oil tainted food fed equally on tainted and untainted food (Percy 1976). Similar behavioural responses of *B. affinis* and *M. entomon* were observed when they were exposed to oil contaminated sediments (Percy 1977). The former consistently avoided the oils while the latter showed no behavioural changes to the oiled sediments. *B. affinis* exhibited greatest response when exposed to relatively low concentrations of oil (0.05 ml/15 g dry sediment) but its ability to distinguished between clean and oiled sediment was totally impeded with heavily oiled sediment.

Mesidotea entomon, hatched in the laboratory from females collected in Ptarmigan Cove, Herschel Island, were subjected to chronic exposure to three kinds of oils at three concentrations (Percy 1978). Animals showed no evidence of sensitivity to petroleum during ecdysis. In fact there was a slight acceleration of the onset of the next ecdysis when they were exposed to high levels of extracts (50 and 100%) of weathered Normal Wells and Pembina crudes. Effects of oil on the duration of intermolt periods were variable. Higher concentration of oil (100% weathered Norman Wells) resulted in a significantly prolonged first intermolt period and lower concentration (50%) produced a prolonged first and second intermolt periods. At the lower concentrations of exposure, subsequent intermolt periods were significantly shorter than normal. Growth of the young isopods also recovered from the initial depressed growth at 84 d of exposure (1.79 mm vs 5.52 mm in the control animals).

Thomas et.al. (1982) reported that in the East Tarsiut N-44 island site, mean density increased from 288±197 at 50 m to 755±335 at 500 m and 713±353 at 3000 m from the island. Habitat alteration and decreased levels of benthos were confined to within 500 m of the island caissons. The upper sandy slopes of the berm were colonized by benthos soon after the installation of the concrete caisson in 1981; diversity at 50 m was only marginally lower. First colonizers of the island were the bivalve *T. flexuosa*, which favours sand and gravel and polychaetes of families Nephtyidae and Sabellidae, which prefer heterogeneous sediments. New material brought to the artificial island from borrow sites at south Tarsiut, Herschel Island vicinity, Isserk and Ukalerk islands could be potential new substrates for colonizers. These material from borrow sites could contain benthos which potentially become the first colonizers. Animals with a protective hard outer layer, such as clams and some crustaceans, may be able to survive the dredging processes involved in borrow sites (Thomas et.al.. 1982). Impact of dredging in the borrow site could not be distinguished from those caused by ice scouring (Thomas et.al. 1982, Heath and Thomas 1984).

The actual loss of benthos in a dredged area is confined to the high impact zone i.e. the dredged trenches in Banks and Herschel Islands (Heath and Thomas 1984).

The alteration of the substrate by gravel dredging near Herschel Island was equivalent to that caused by ice scouring. This resulted in decreased biomass and disruption of faunal distribution in the narrow parallel dredged trenches. Although dredging reduced the number of benthic families from 12 to 2, mobile immigrants such as isopods, amphipods and drifting benthos, such as soft coral, were observed by video recording in the trenches shortly after dredging. Low abundance of polychaetes, amphipods, isopods, and starfish have re-colonized the trenches one year after dredging activities and several years will undoubtedly be required for the development of a mature benthic community comparable to that in undisturbed areas (Heath and Thomas 1984).

Conclusions

1. The Mackenzie River has the greatest influence on the benthos inhabiting the Mackenzie Delta. The river discharges warm, turbid waters for three months of the open water season. This freshwater is continually mixed with the cold, saline marine water of the Beaufort Sea by bottom currents, summer storm generated waves and wind producing a highly variable saline environment. Such an environment is most pronounced in waters of less than 5 m. Besides the variable salinity, the shallow waters, especially in < 2 m, also freezes to the bottom in winter and in spring the landfast ice causes scouring of the seabed. In deeper waters, the salinity is more stable and the seabed is disturbed each spring by the gouging by ice keels. These environmental factors have a profound impact on the benthic community in the delta.
2. Nearshore shallow regions (< 5 m) are inhabited mainly by mobile euryhaline epifauna such as amphipods (*Boeckosimus* sp., G*ammaracanthus loricatus*), isopods (*Mesidotea entomon*), and mysids (*Mysis relicta*) whose mobility enables them to escape the freezing of the entire water column in winter and scouring by landfast ice in spring. As euryhaline species they can tolerate the wide range of salinity that exists in the shallow waters during the open water period.
3. There is a general increase in abundance, density and diversity of infauna with increasing depth and salinity. Infauna is lowest in waters of less than 5 m where low and variable salinity prohibits the establishment of many species and the yearly winter destruction of the few low salinity tolerant immobile species by the complete freezing of the water column. Therefore, in higher and more stable salinity areas, beyond 5 m of water, stenohaline species of the polychaete-pelecypod infauna as well as gastropods and priapulids dominate. Common pelecypods are *Cyrtodaria kurriana* and *Portlandia arctica*.
4. Protected bays such as Mason Bay have higher density, biomass and diversity of benthos. Comparatively high densities were also found on the leeward side of a pointed peninsula in an unnamed bay near Tuft Point and in the protected entrance to Beluga Bay, near Tuft Point. They are under limited influence of the Mackenzie plume and thus have more stable salinity regimes. They are also not subjected to summer storms, which disrupt the substrates and increase the turbidity of the water.

5. Leeward sides of islands such as Hooper Island and Pelly Island and near the entrance to Mallik Bay in East Mackenzie Bay have high concentrations of benthos. Waters in these areas are usually calm and clear. They also have high concentrations of freshwater and anadromous fish.
6. Substrate characteristics play a major role in structuring the benthic community. Grounded ice scouring and ice keel gouging cause the physical destruction of benthos resulting in reduced biomass in affected areas. They also tend to produce habitat with heterogeneous substrate and this lends to patchy benthic distribution. Highest biomass and diversity are found in heterogeneous substrate and lowest biomass and diversity in silt-clay substrate. Species found in heterogeneous substrate include mobile epi- and infauna and sedentary infauna while those inhabiting homogeneous substrate are mainly sedentary infauna.
7. Substrates that include rocks and gravel are found only in southwestern Banks Island and in the ridge near Herschel Island. The presence of rocks or boulders especially in Banks Island contribute substantially to the high species diversity because these substrates provide space for macroalgae and sessile epifauna to attach. Macroalgae provide food, habitat and shelter for many benthos.
8. Epifauna particularly isopods, amphipods and mysids constituted a major portion of the diet of many species of fish inhabiting in and around the Mackenzie Delta.
9. The amphipod, *B. affinis* reacted to the more volatile components of crude oil as evidenced by its reduced avoidance behaviour to weathered oils and its total avoidance to fresh oils. 80-90% of *B.* affinis when given a choice would avoid the tainted food. In contrast, the isopod, *M. entomon* showed little or no response to fresh oils and they fed equally on tainted and untainted food. Young *M. entomon* subjected to chronic exposure to three kinds of oils at three concentrations showed no sensitivity to them during ecdysis and effects on the duration of intermolt periods were variable.
10. Construction of artificial islands smothers the benthos and modifies their habitats. Extent of these effects is dependent on the size of the islands; effects were evident further away from the larger islands (e.g. 900 m from Issungnak O-61) compared to smaller islands (300 m from Netserk F-40). Impact of dredging is equivalent to that caused by ice scouring but it would require several years for the development of a mature benthic community.

Recommendations

1. Future studies should use standard sampling methods to lend the data to comparative interpretation. Sediment depth and area of the sample are influenced by the sampler type and size. The type of substrate plays a role in determining the efficiency of a particular type of sampler. Standard size sieves should be used to sort the benthos to allow for analysis of numerical measurements such as density, and age structure of benthos. In terms of biomass, organic carbon i.e. dry weight should be used as this is a more meaningful biological term.
2. Epifauna represents a significant biomass of nearshore environment and they are major food sources of fish. Therefore, concerted efforts should be employed i.e. using trolling trawls to sample the population. In many previous studies the reported epifauna were only those that were collected while sampling the infauna using various grabs. Grabs are very inefficient in sampling epifauna because these mobile animals can easily move away.
3. Studies that examine the food webs of ecologically significant fish and their prey, the benthos particularly along protected coasts of islands, bays and lagoons.
4. Studies need be conducted in waters greater than 50 m where there is scant information on basic distribution, abundance, and species composition. This would provide critical baseline information prior to any future human activities at such depths. Furthermore, benthic-pelagic coupling studies could be conducted at such depths since nutrient maxima have been found to occur in waters with salinities between 32-34$^{o}/_{oo}$. These salinities occur in > 50 m. No such studies have been conducted in southeastern Beaufort Sea.
5. Histopathological studies on ecologically significant species of benthos. Such studies would compliment the numerical studies.

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