Biophysical inventory during late winter for the Paktoa exploratory drill site, Beaufort Sea, Northwest Territories

Peter A. Cott, Andrew R. Majewski, and James D. Reist

Fisheries and Oceans Canada
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A proposal to conduct offshore exploratory drilling in the Beaufort Sea prompted an investigation of the biophysical conditions that prevail in the area during the winter. The drilling was to be conducted at the Paktoa site, approximately 50 km North East of Garry Island in the Mackenzie Delta, Northwest Territories, using a steel drilling caisson (SDC) surrounded by an ice-rubble pad. To assist in assessing potential impacts from this drilling program, a multi-trophic level biophysical inventory was initiated during March, 2005. Also, a visual assessment of sea bed habitat in the project area was conducted using a remote operated vehicle. This report documents the methods used and the results of the inventory. The seabed habitat in the study area was predominantly featureless depositional mud with few biota present. Exploratory drilling at the Paktoa site would affect the habitat directly under the footprint of the drilling pad, but the impacts would be localized and transient. The information herein, adds to the existing knowledge of the Beaufort Sea environment, however, the geographic scope was limited to the Paktoa area. In order to more effectively predict and mitigate potential impacts, further study on the winter ecology of the Beaufort Sea is warranted in advance of future industrial development.

Key Words: NWT, Beaufort Sea, fish, seals, exploratory drilling, under-ice, oil and gas

RÉSUMÉ

Cott, P.A., Majewski, A.R., and Reist, J.D. 2014. Biophysical inventory during late winter for the Paktoa site, Beaufort Sea, Northwest Territories. Can. Manuscr. Rep. Fish. Aquat. Sci. 3037: viii + 30p.

Une proposition visant à procéder à des forages exploratoires au large dans la mer de Beaufort a incité une enquête sur les conditions biophysiques qui prévalent dans cette région durant l'hiver. Les forages, sur le site de Paktoa à environ 50 km au Nord-Est de l'île de Garry dans le delta du Mackenzie, dans les Territoires du Nord-Ouest, devaient être menés au moyen de caisson en acier (*steel drilling caisson - SDC*) entouré d'une zone tampon composée de débris de glace. Pour aider à évaluer les impacts potentiels de ce programme de forage, un inventaire biophysique de niveau multi-trophique a été lancé en Mars 2005. De plus, une évaluation visuelle de l'habitat du fond marin dans la zone du projet a été réalisée à l'aide d'un véhicule actionné à distance. Ce rapport documente les méthodes utilisées et les résultats obtenus de l'inventaire. L'habitat du fond marin dans la zone d'étude est principalement constitué de boue sédimentaire sans relief et avec peu de biotes présents. Les forages exploratoires sur le site de Paktoa affecteraient l'habitat sous l'empreinte directe du forage mais les impacts seraient restreints et transitoires. Les informations obtenues ajoutent à la connaissance actuelle de l'environnement dans la mer de Beaufort mais la portée géographique est cependant limitée à la zone de Paktoa. Afin de prévoir et d'atténuer les impacts potentiels de manière plus efficace, des études plus approfondie sur l'écologie hivernale de la mer de Beaufort sont à prévoir pour l'avancement des développements industriels futurs.

Mot clés: TN-O, mer de Beaufort, poisson, phoque, forages exploratoires, sous la glace, pétrol et du gaz

1. INTRODUCTION

There is renewed interest in oil and gas exploration and development in both the nearshore and offshore Beaufort Sea in the Northwest Territories (NWT) (Timco and Frederking 2009). The short ice-free season dictates that the majority of exploration and developments in coastal and nearshore areas are likely to occur during early winter through spring when adequate land-fast ice is available, permitting access and transportation. Industrial activities may include exploratory drilling, vibroseis and explosives-based seismic exploration, ice-road construction, and construction of ice-islands to be used as offshore exploratory drilling pads, and pipeline development (Cott et al. 2003).

Environmental impact statements (EIS), submitted as part of environmental assessment processes, often lack a discussion on the impacts of development on Arctic fish. This is a significant gap in most EISs and is attributed to a lack of available information. While there are some data available for fisheries resources for the nearshore Beaufort Sea, information on the offshore areas, particularly in the winter, is sparse (Thorsteinson et al. 1991; KAVIK-AXYS Inc. 2004; Majewski et al. 2006, 2009a, 2009b).

Anadromous fish with subsistence and commercial value (e.g., whitefishes and chars) have garnered the most interest (Sekerak et al. 1992; KAVIK-AXYS Inc. 2004). These fishes typically occur in the nearshore Beaufort Sea in the open-water season and some species may also over-winter in freshened coastal or estuarine waters, or in lakes and rivers along the Arctic coast or the Mackenzie River (Craig 1984; Reist and Bond 1988; K. Chang-Kue, DFO (retired), pers. com.). The paucity of information regarding winter fish habitat usage in the offshore Beaufort Sea is due inpart to restrictions in the types of sampling equipment that can be used in these habitats (Thorsteinson et al. 1991), logistics, costs, and the challenges of sampling through heavy ice cover in winter. There are a wide variety of fish species, however, that may be present (Coad and Reist 2004), as well as seals (Harwood et al. 2007), and invertebrates such as mussels, clams, scallops, cockles, octopus, shrimp, crabs, sea urchins, starfish and sea cucumbers (Stewart et al. 1993).

To address data gaps regarding the under-ice ecology of the shallow, nearshore Beaufort Sea in the vicinity of the Mackenzie River, Fisheries and Oceans Canada (DFO) conducted an inventory of the winter ecology and habitat near Devon Canada Corporation’s proposed Paktoa exploratory drill site during March 2005. This was the first site proposed for offshore hydrocarbon exploratory drilling in recent years.

This report is intended to:

a) provide an assessment of the late winter habitats available to marine biota at the Paktoa site;

b) inventory biotic, physical, and chemical conditions present in the area at this time of the year;

c) recommend needs and designs for future sampling; and

d) discuss the winter-time productivity of fish habitat in this area.

In late winter, the Beaufort Sea ice is a harsh environment, presenting challenges for researchers and scientific equipment. Therefore, this report also documents the successes and failures associated with the methodology and equipment used during this study, to benefit future researchers working in similar environments.

2. MATERIALS AND METHODS

2.1 LOCATION AND SITE DESCRIPTION

Sampling was conducted approximately 15 km south-west of Devon Canada Corporation's Paktoa exploratory drilling target (N69.65064°, W136.49289°) on the Canadian Shelf, approximately 50 km north-west of Garry Island, Mackenzie Delta, NWT (Figure 1). A severe storm in January of 2005 caused extensive ice rubble fields in Beaufort Sea (B. Wright and Associates 2005; Harwood et al. 2007), making it necessary to confine our sampling to an area of flat ice (about 2 km wide), within the ice-rubble field. Sampling was conducted between March 18 and 24, 2005. Sampling was also conducted at the Paktoa site itself to confirm that the habitat in the northern sampling site was representative of the area (Table 1). The water depth in the study area ranged between 12.7 and 13.7 m.

Table 1. Sampling site locations, Beaufort Sea, NWT.

Station	Latidude °N	Longditude °W
1a	69.66751	136.50558
1b	69.66737	136.50403
1c	69.66698	136.50592
1d	69.66683	136.50444
1e	69.66709	136.50424
2a	69.66547	136.50833
2b	69.66586	136.50943
3a	69.66674	136.49789
3b	69.66625	136.49736
4a	69.66846	136.50203
4b	69.66885	136.50313
Paktoa	69.65064	136.49289

Sample locations were determined using a Garmin® C60 handheld Global Positioning System. Daily air temperatures were measured using the temperature sensor on the helicopter. A four-person (6 m^2 footprint) expedition-rated nylon tent was set up on-site and secured to the ice with ice screws. It was heated with a catalytic propane heater and was used primarily for storage of battery-powered instruments and as an emergency shelter. An armed polar bear monitor was present on-site at all times. Aside from one night spent at the sampling site, the area was accessed daily by helicopter from Inuvik, NWT. Transportation between stations was on foot, using a toboggan to tow gear.

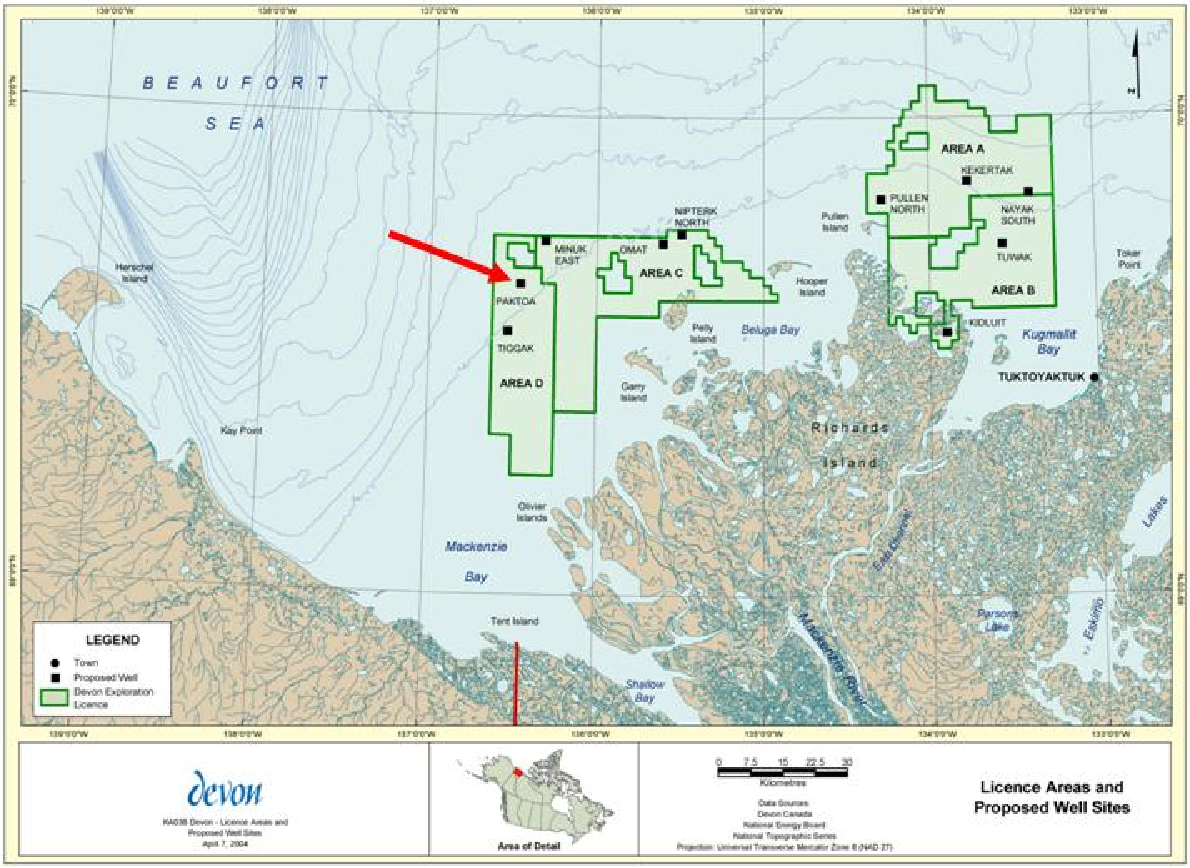

Figure 1. Location of Devon Canada Corporation's proposed Paktoa exploratory drill site, Beaufort Sea, Northwest Territories (KAVIK-AXYS 2007).

2.2 AQUATIC HABITAT

Water chemistry profiles, ice, snow and water depth measurements, sediment samples, and in-situ observations were used to assess physical habitat. A Hydrolab® Quanta portable multi-parameter probe was used to profile water chemistry parameters. Initially at each station, salinity, temperature, dissolved oxygen, pH, and turbidity were measured, at one meter intervals, from the under-ice surface to within one meter of the substrate. During subsequent profiles at the same station, measurements were taken immediately below the ice, at mid-depth in the water column, and within one meter of the bottom in order to examine if conditions had changed significantly between profiles or sites.

Ice depths were taken using a series of meter sticks attached to a pole with an “L” bracket fixed to the bottom to catch the lower surface of the ice. Snow depths were taken beside each hole using a meter stick by pushing into the snow until the stick met resistance at the ice surface. Water depths were taken using an incremented and weighted steel cable.

A 15 cm x 15 cm Ekman grab was used to collect sediment and benthic samples at three locations within the project area (1A, 1B, and 1C), including one sample at the Paktoa drill site. Samples were bagged and preserved in a 10% by volume formalin solution for subsequent analysis. In the laboratory, sediment samples were subsampled and fractioned by particle size down to 400 µm. Percent particle size and composition were then determined. Sub-samples were also ashed to determine percent organic content.

A Videoray® Pro III XE Remotely Operated Vehicle (ROV) was used to assess bottom subtrate, habitat features, and under-ice characteristics. The ROV was equipped with lights, as well as forward and rear cameras which were linked to a VCR and monitor on the surface via a 100 m cable. The cable attaching the ROV to the receiving unit was 100 m long, therefore the habitat surveyed using the ROV covered a maximum area of approximately 125,000 m^2, although the actual area surveyed was likely less. Run times beneath the surface were recorded with observations expressed as time in the following categories:

1) under-ice: any time the under-ice surface was in view;
2) water column: any time neither the under-ice surface nor the seabed was in view; and
3) bottom: any time the seabed was in view.

In order to deploy large gear such as the Ekman dredge and ROV, a cloverleaf pattern was drilled with a 25 cm diameter ice auger and the remaining ice between the drilled holes was removed with an ice chisel. We used custom-made ice chisels with segmented shafts that could be threaded together to achieve the desired length. This greatly facilitated transport on a helicopter compared to full-length ice chisels (Figure 2).

2.3 BENTHOS

Benthic invertebrates were collected with the Ekman grab at 4 locations (in conjunction with sediment sampling at 1A, 1B, 1C, and Paktoa) and preserved *in situ* with the sediment samples using 10% by volume formalin solution. Invertebrates were later separated during sediment analysis and enumerated by taxa and weight by major group.

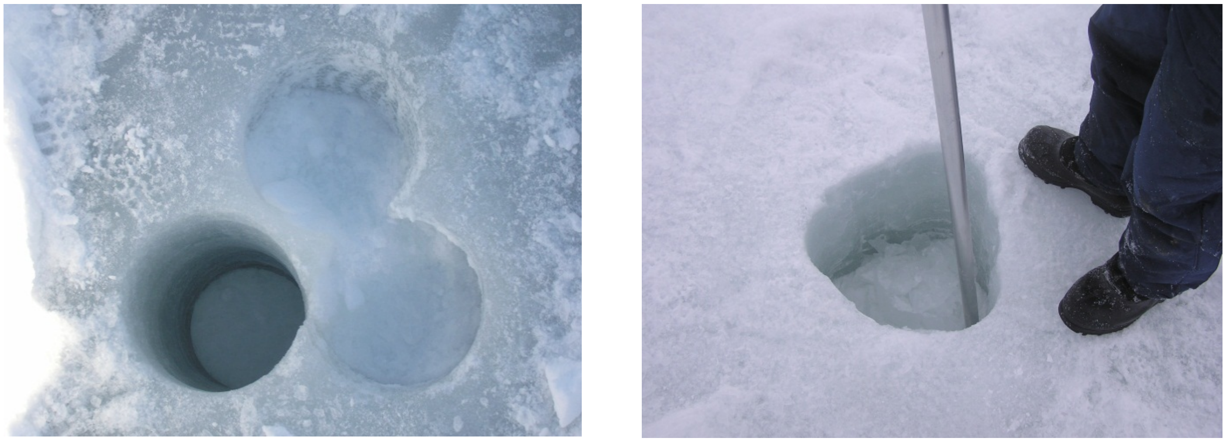

Figure 2. Holes were drilled with an ice auger using a clover leaf pattern. The holes were drilled 10-20 cm of breaking through. The remainder of the ice was carefully chipped around the perimeter with an ice chisel. This enabled an undisturbed piece of ice to be retrieved for ice algae sampling, while preparing a hole to deploy larger sampling gear.

2.4 ICE ALGAE AND PLANKTON

Ice algae, phytoplankton and zooplankton were sampled at one site that was arbitrairily selected within a 150 m x 300 m rectangle within the study area, as per Hopky et al. (1994b). Additional ice algae and phytoplankton samples were taken at the Paktoa drill site.

Ice algae cores were obtained at four sites (1C, 1D, 1E, and 3A). Holes were drilled with a 25 cm (10 inch) auger through the ice, stopping approximately 20 cm short of the water-ice interface. The perimeter of the last 20 cm was chiseled out allowing the ice-pan to float to the surface where it was retrieved (Figure 2). Care was taken not to disturb the under-side surface when retrieving the ice-pan. Two samples were taken from each recovered ice-pan by hammering a 5 cm inner diameter, stainless steel core tube into the under-side of the ice, removing a core containing undisturbed ice algae (Figure 3). One sample was frozen for chlorophyll-*a* concentration analysis, and the other was fixed in a 1% by volume Lugol’s solution for later taxonomic identification and quantification.

Phytoplankton samples were collected using a Kemmerer bottle set at mid-depth in the water column at sites 1A, 1B, 1C, and 1D. By design, Kemmerer bottles allow water to pass through until the desired depth is achieved, at which time a messenger is dropped down the line tripping the bottle to close, trapping 4.2 L of water from that depth within the bottle. Triplicate 30 mL sub-samples were collected and fixed in a 1% by volume Lugol’s solution for later taxonomic identification and quantification.

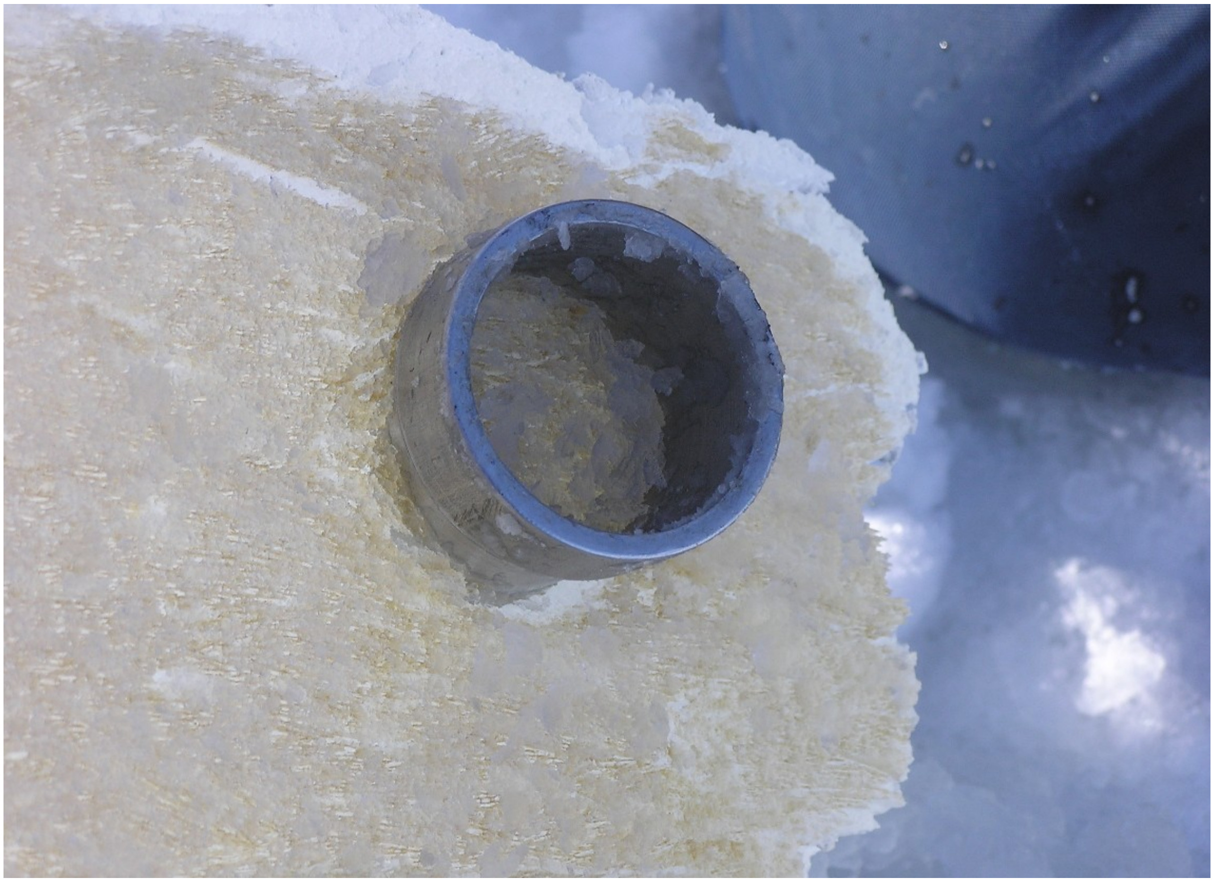

Figure 3. Algae from the sub-surface of the Beaufort Sea ice were removed using a 5 cm core.

Vertical tows of the water column were conducted to sample zooplankton using a 25 cm diameter, one meter long, 63 µm mesh plankton net. The net was slowly lowered to the sea floor and then retrieved vertically at a rate of 1 $m \cdot s^{-1}$ to the surface, sampling an average of 2.6 m^3 of water per tow. After each haul, the outside of the mesh was rinsed with sea water prior to removing the codend and emptying its contents into a 250 mL plastic sample jar with formalin added to make up a 10% by volume preservative. Samples were later identified to species and quantified.

2.5 FISH AND MACRO-INVERTEBRATES

Sampling for fish and macro-invertebrates was conducted using a variety of gear types. Gill nets and longlines were used to target fish, whereas baited traps, bait-filled mesh pouches were used to collect macro-invertebrates. Incidental eveidence of larval fish and macro-invertebrates were anticipated from plankton tows and Ekman grab samples. Additionally visual observation from the ROV, and from analysis of ringed seal (*Phoca hispida*) stomachs and scat were used as ancillary evidence of fish and macro-invertebrate presence.

Gillnet sets were spatially separated 250 m apart. Gillnets were set using 4.5 mm diameter nylon sideline strung between two holes, spaced 60 m apart, in a “clothesline” fashion. Initially, rope was fed under ice between holes using a modified World War II torpedo (modifications designed by Frozen Sea Research Group, Institute of Ocean Sciences, Victoria, B.C.) powered by four 12 volt marine batteries (Figure 4). The methods used to deploy the torpedo are described in Chiperzak et al. 1991. Difficulty with negotiating the slack in the power cable attached to the torpedo, failing power supplies, resulted in limited success using the torpedo. Ultimately, the torpedo was abandoned in favour of using the ROV to set sideline rope between gillnet holes.

The ROV was navigated between holes by taking a compass bearing prior to deployment and then navigating the under-ice surface using the video output and on-screen compass display. A rope and grapple hook, sometimes with a light stick attached, was suspended beneath the ice to use as a visual marker and to aid in ROV retrieval (Figure 5). The size of both the torpedo and the ROV required that three holes be cut in a clover leaf pattern using the 25 cm auger in order to deploy and/or retrieve the gear. All gill nets used were 50 m long by 2 m deep. Bottom sets were conducted using experimental nets [1”-5” (2.54-12.7 cm) and 1.5”-5.5” (3.81-13.97 cm) stretched mesh], while mid-column and under-ice sets were 1” or 1.5” (2.54 or 3.81 cm) mesh (stretched) nets. Green lightsticks (Omniglow Corp. 13 cm Snaplight®) were used as a potential attractant on alternate sets and were placed mid-panel every 10 m along a net. Soak time varied depending upon weather and the ability to access the sites. A 1.5 m length of chain was used as an anchor at each end of bottom-set nets; mid-water and under-ice sets were anchored to the ice surface.

A longline with 35 No. 2 size hooks spaced at 1.9 m intervals and baited with squid was set between holes spaced 60 m apart in the same “clothesline” fashion as described for gill-net sets. Approximatley 50 m (27 hooks) of longline rested on the sea floor, and with approximately 15 m (8 hooks) in the water column spanning from the sea floor to the ice ceiling. Five bait-filled pouches, made of 0.625 cm mesh, were attached to the hooks near one end of the longline. Each pouch contained approximately 200 g of squid. Two of the pouches were set on the bottom while the remaining three were suspended vertically. Upon retrieval, pouches and their contents were bagged and frozen for invertebrate identification and enumeration.

Galvanized Gee minnow traps were set at various locations throughout the sample area. Traps were set directly under the ice-ceiling, mid-depth in the water column, and on the sea floor. Under-ice, and mid-column sets, were oriented vertically with the top hole pinched closed to prevent escape, while the bottom sets were oriented horizontally with both holes open. Each trap was baited with one tin of sardines packed in oil. Approximately six 5 mm holes were punched in both the top and bottom of each can to allow for oils to escape, to act as an attractant, and to allow invertebrates to crawl into the tins (Figure 6). As with the gillnets, alternate trap sets were also baited with a lightstick. Upon trap retrieval, contents of the traps, including the can, were bagged and frozen for invertebtrate identification and enumeration.

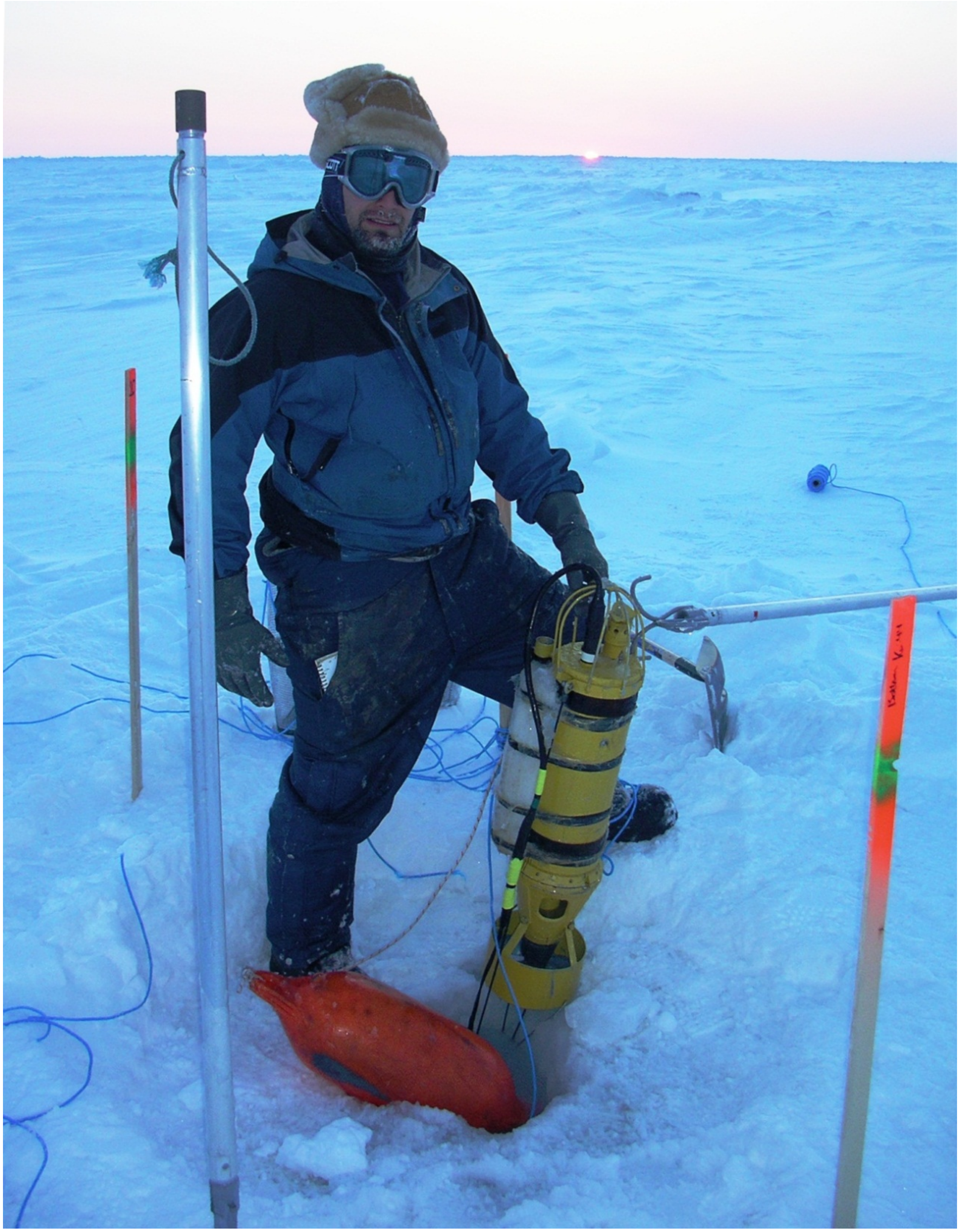

Figure 4. The “Torpedo” being recovered with A.R.M. A WWII vintage torpedo was used (with limited success) to pull a line that was then was used to set a gill net under the Beaufort Sea ice.

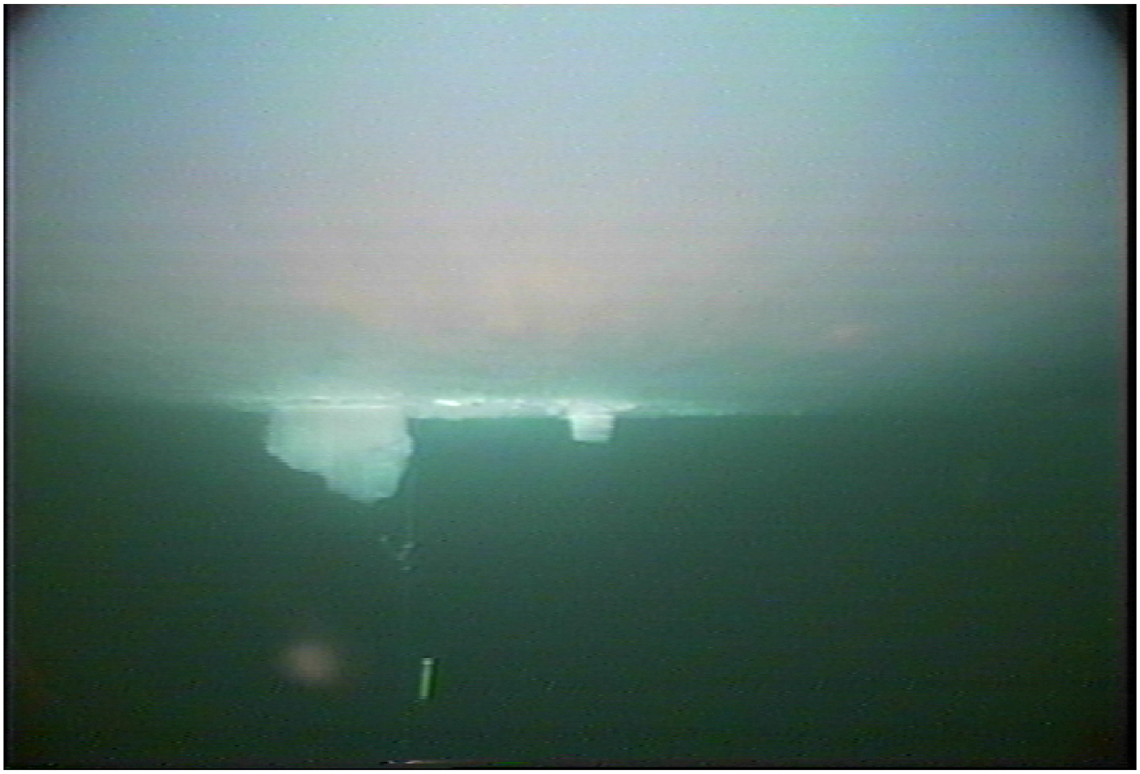

Figure 5. An aluminum pole with a grapple hook was positioned under the ice to assist in the retrieval of the Remote Operated Vehicle (ROV). The compass function in the ROV was unreliable so a glow stick was attached to the grapple to facilitate orientation.

Any incidental catches of macro-invertebrates collected during plankton sampling were preserved with a 1% per volume Lugol's solution along with plankton samples to later be identified during plankton sample analysis. The ROV was used to observe fish and/or macro-invertebrates *in situ*. Any time the ROV was in the water its view was being recorded on a VHS tape for analysis as per the description of habitat assessment above. A seal scat sample was obtained from one of eight ringed seals tagged in the adjacent seal research camp. The scat was bagged and frozen to be examined for remnants of fish and/or invertebrates. Seal stomachs (n=22) were collected by hunters from Tuktoyaktuk during May 2005 and later examined for fish and/or invertebrate remnants.

3. RESULTS AND DISCUSSION

3.1 SURFACE CONDITIONS

The ice thickness at the study site ranged from 131-163 cm and snow depths ranged from 1-30 cm, the latter were highly variable due to snow drifting. The water depths ranged from 12.7-13.7 m; the water depth at the Paktoa site was 13.0 m (Table 2). The air temperatures during the survey fluctuated between -18 and -35ºC.

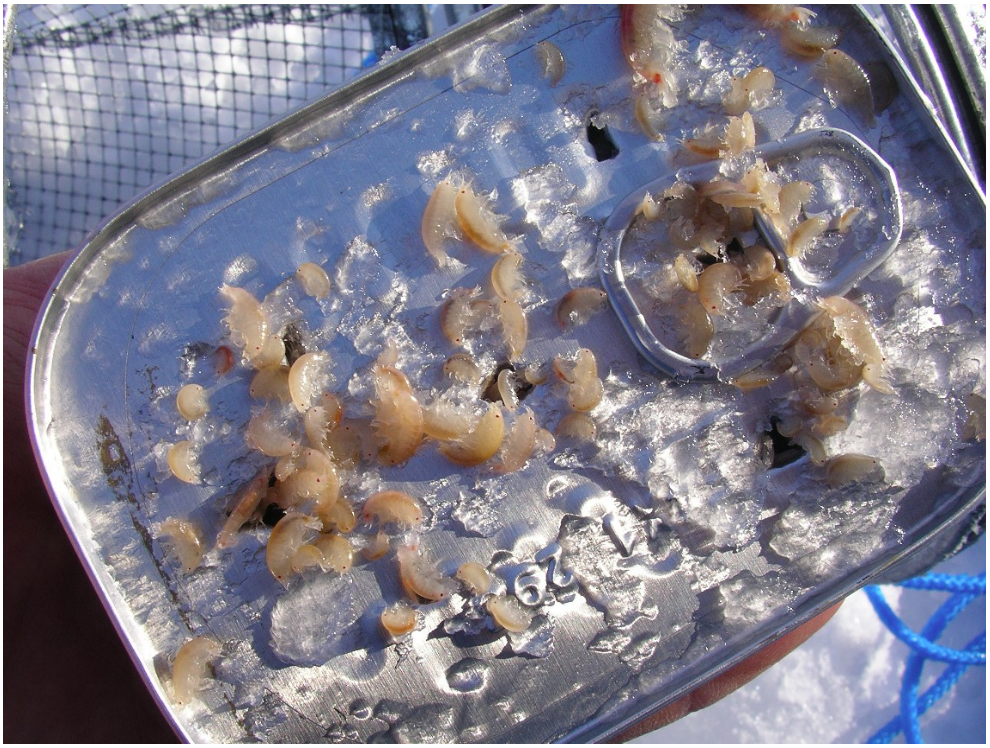

Figure 6. Sardine cans with the lids pictured were used as bait in Gee minnow traps deployed under the Beaufort Sea ice. This method allowed the scent of the bait to escape and inadvertently acted as an amphipod trap within the minnow trap.

Table 2. Snow, ice and water depths per site, March 2005, Beaufort Sea, NWT.

Station	**Snow Depth (cm)**	**Ice Depth (cm)**	**Water Depth* (m)**
1a	8.5	135.0	12.70
1b	19.0	131.0	13.50
1c	--	--	13.50
1d	5.0	134.0	13.65
1e	2.2	141.0	--
2a	30.0	135.0	13.50
2b	8.0	162.0	13.00
3a	29.0	117.0	13.15
3b	13.5	141.0	13.20
4a	7.0	134.0	13.50
4b	4.0	163.0	13.65
Paktoa	1.0	156.0	13.00

*water depth measured from ice surface

3.2 AQUATIC HABITAT

The study area was a true marine environment with no halocline detected during sampling. In the study area, salinities ranged between 28.7 and 31.0 ppt, with the Paktoa site ranging from 28.4 to 30.0 ppt. Water temperatures were similar in the study area and the Paktoa site, ranging from -1.7 to -1.9°C. The mean dissolved oxygen concentration was 10.3 $mg \cdot L^{-1}$ at both sample locations. The mean pH was 7.6 within the study area and 7.7 at the Paktoa site. The mean turbidity value was slightly higher at the Paktoa site than the study area however, maximum values were similar at 5.5 and 5.6 NTU, respectively. Water chemistry data are summarized in Table 3.

With few exceptions noted below, the ROV-based observations showed that the sea floor was predominantly flat and featureless (Figure 7). The sea floor sediments were easily stirred up by the propellers on the ROV (Figure 8), but settled within a few seconds of the ROV remaining stationary. The only habitat features observed on the sea floor were mud “boulders” and ice scour marks. The mud boulders are likely ploughed up by scouring ice keels. Both of these features add some variability to the seabed habitat. Blasco et al. in Carmack and MacDonald (2002), estimate that the bed of the Beaufort Sea in this area is 100% ice scoured over a period of 50 years from shore to the 50 m isobath. This ice scouring ploughs the entire seabed over time, eliminating any permanent habitat features. The undulations caused by the scour marks comprise the dominant habitat structure, regardless of how transient they may be.

Table 3. Mean water quality parameters measured, March 2005, Beaufort Sea, NWT.

Station	**Temp** (°C)	**ScP** (mS/cm)	**DO** (mg/L)	**pH**	**Salinity** (pss)	**DO** (%)	**Turbidity** (NTU)
1	-1.8	48.6	10.3	7.6	30.0	84.2	3.7
2	-1.8	48.8	10.2	7.6	30.1	83.6	4.4
3	-1.8	51.0	10.1	7.6	30.0	82.8	4.3
4	-1.8	48.7	10.2	7.4	30.0	83.5	3.7
Paktoa	-1.8	47.1	10.3	7.7	28.9	84.1	4.3

The compass on the ROV was not reliable and the camera and monitor were used to navigate. It was very difficult to keep the path of the ROV straight. To facilitate navigation, the under-ice surface was used as a horizontal bearing rather than the sea-bed as the positive buoyancy of the ROV was easy to maintain. Also, unlike the bottom, there was ample natural light penetration and no sediments to stir up and impede vision. Due to the reasons listed above, and the use of the ROV to set gillnet lines, most underwater observations were made for the under-ice habitat, rather than the seafloor. No measure of water transparency or light penetration was made, but visibility with the ROV was good, estimated at 7 m using a light stick suspended below the ice.

Benthic grab samples were taken at sites 1A, 1B, 1C and at the Paktoa drill site. The substrate is composed of, by volume, an average of 62% silt/clay, 28% sand, and 10% organic matter (Table 4). The inorganic portion of the sediment contains exclusively sand (31%) and clay (69%); there were no particles present in the samples greater than 1 mm in size (Table 5). The source of these sediments is the Mackenzie River, the largest source of sediments in the Arctic (MacDonald et al. 1998; Carmack and MacDonald 2002).

Most of the available habitat structure was in the form of the ice itself. Although the survey area had a relatively flat ice ceiling, there were still cracks and fissures present. The presence of these features increased towards the periphery of our sample area, encroaching on the ice-rubble. These ice features are the primary habitat type utilized by Arctic cod (*Boreogadus saida*) (Lønne and Gulliksen 1989).

Figure 7. Seafloor view from ROV, Paktoa Area, Beaufort Sea.

Figure 8. Seafloor view from ROV, Paktoa Area, Beaufort Sea.

Table 4. Sediment composition by volume from benthic samples collected, March 2005, Beaufort Sea, NWT.

Site	**Date**	**Dry Weight (g)**	**Ashed Weight (g)**	**Sand (g)**	**Sand (%)**	**Silt/Clay (g)**	**Silt/Clay (%)**	**Organic (g)**	**Organic (%)**
1A	18-Mar-05	33.977	30.882	10.215	30.1	20.667	60.8	3.095	9.1
1B	18-Mar-05	49.643	45.343	10.207	20.6	35.136	70.8	4.300	8.7
1C	18-Mar-05	33.267	30.483	10.073	30.3	20.410	61.4	2.784	8.4
Pakota	24-Mar-05	30.308	27.618	10.155	33.5	17.463	57.6	2.690	8.9

Table 5. Particle size composition of inorganic sediment sub-samples, March 2005, Beaufort Sea, NWT.

Site	**Date**	**Particle Size Composition (%)**						**Sand**	**Silt/Clay**
		>2 mm	**>1 mm**	**>500 µm**	**>250 µm**	**>125 µm**	**>63 µm**	**<2 mm**	**<63 µm**
1A	18-Mar-05	0.000	0.000	8.257	8.257	8.264	8.299	33.0	66.9
1B	18-Mar-05	0.000	0.000	5.608	5.619	5.630	5.652	22.5	77.5
1C	18-Mar-05	0.000	0.000	8.244	8.257	8.267	8.277	33.0	67.0
Pakota	24-Mar-05	0.000	0.000	9.175	9.172	9.182	9.240	36.8	63.2

3.3 BENTHOS

Benthic organisms were found in the sediment samples collected at sites 1A, 1B, 1C and the Paktoa drill site. Three hundred and twenty-six organisms were collected in three grabs within the study area representing 19 species (Table 6). At the Paktoa site, 114 organisms were collected in a single grab, representing 10 species (Table 6). The two most dominant species found in the study area were *Alagaophamus neotenus* (polychaete) and *Nonion incisum* (protozoan), found in abundance at all four sites, including the Paktoa drill site.

3.4 ICE ALGAE AND PLANKTON

Ice algae samples taken for taxonomy and chlorophyll-*a* analysis were collected at sites 1C, 1D, 1E and 3A. Under-ice species assemblage composition, biomass and chlorophyll-*a* concentration varied considerably among stations, however, overall under ice algal assemblages were dominated by the pennate diatoms *Nitzschia* spp. and *Navicula* spp. together comprising, on average, 88% of the algal population. *Nitzschia frigida* prevailed, comprising 47% of the pennate diatoms. Average biomass and chlorophyll-*a* concentrations from ice algae core samples are presented in Table 7. Chlorophyll-*a* concentrations at sites 1C and 3A were below the detectable limit of 0.47 $mg \cdot m^{-2}$; chlorophyll-*a* concentrations at sites 1D and 1E were 4.24 $mg \cdot m^{-2}$ and 3.77 $mg \cdot m^{-2}$, respectively. Because chlorophyll-*a* concentrations are used as a proxy for biomass, it is not surprising that the relative areal biomass concentrations reflected the chlorophyll-*a* data. Sites 1C and 3A had very low areal biomass concentrations, 39.03 $mg \cdot m^{-2}$ and 1.59 $mg \cdot m^{-2}$ respectively. Sites 1D and 1E had higher concentrations of areal biomass, 430.94 $mg \cdot m^{-2}$ and 1046.59 $mg \cdot m^{-2}$, respectively.

Ice algae constitute 10-15% of the primary production on the Canadian Shelf and the majority of carbon flux available to benthos (Carmack and MacDonald 2002). Ice algae normally form a thin veneer under the ice in patches that range from a few centimeters to several meters in diameter. The algae were easily displaced by the ROV scraping along the ice ceiling (Figure 9). Ice algae growth did not appear to be solely associated with areas of maximum light transmission. It was observed that some areas of thinner ice with good light penetration had ice algae, whereas other similar areas were relatively devoid of ice algae. Further, some areas of thicker ice with poorer light transmission had substantive algal cover. It is possible that blowing snow may account for this discrepancy. Ice may get blown clear of snow in some areas allowing light penetration and subsequent algal growth, or drift over areas that were previously clear. Ice thickness and snow cover greatly reduce light penetration and subsequent photosynthesis (Welch and Kalff 1975). Also, older ice may develop a denser growth of ice algae. However, ice algae colonization may not solely depend on light penetration through the ice. Ice algae were also associated with frazil-ice formations hanging from the ice ceiling. These chandelier-like formations, with their many interstitial spaces, appeared to act as a medium for algae colonization (Figure 10), which in turn provided a habitat for macro-invertebrates. Mysids and amphipods in association with these algal colonies were observed by the ROV.

Table 6. Benthic organisms, March 2005, Beaufort Sea, NWT.

Species	Group	1C	Paktoa
Aceroides latipes	Amphipoda		0
Ephipia	Cladocera		0
Diastylis rathkei	Cumacea		0
Cylichna alba	Gastropoda		1
Nemata	Nemata		0
Ostracoda	Ostracoda		5
Yoldiella fraterna	Pelycepoda		4
Portlandia arctica	Pelycepoda		6
Trochochaeta multisetosa	Polychaeta		1
Alagaophamus neotenus	Polychaeta		40
Nephtys ciliata	Polychaeta		0
Potamilla neglecta	Polychaeta		3
Lumbrineris sp.	Polychaeta		0
Tharxy spp	Polychaeta		0
Bylgides sarsi	Polychaeta		0
Ampharete sp.	Polychaeta		0
Minuspio cirrifera	Polychaeta		0
Nonion incisum	Protozoa (caste)		45
Reophax sp	Protozoa (caste)		4
Leptognathia gracilis	Tanaidacea		5

Table 7. Chorophyll-*a* concentrations from ice algae core samples, March 2005, Beaufort Sea.

Site	**Total Volume (mL)**	**Total Biomass (mg•m^{-3})**	**Areal Biomass (mg•m^{-2})**	**Chl-*a* (mg•m^{-2})**
1C	90	920.9	39.03	<0.47
1D	50	18304.1	430.94	4.24
1E	66.5	33423.5	1046.59	3.77
3A	116	29.1	1.59	<0.47

Figure 9. ROV track through ice algae, Paktoa Area, Beaufort Sea, during March.

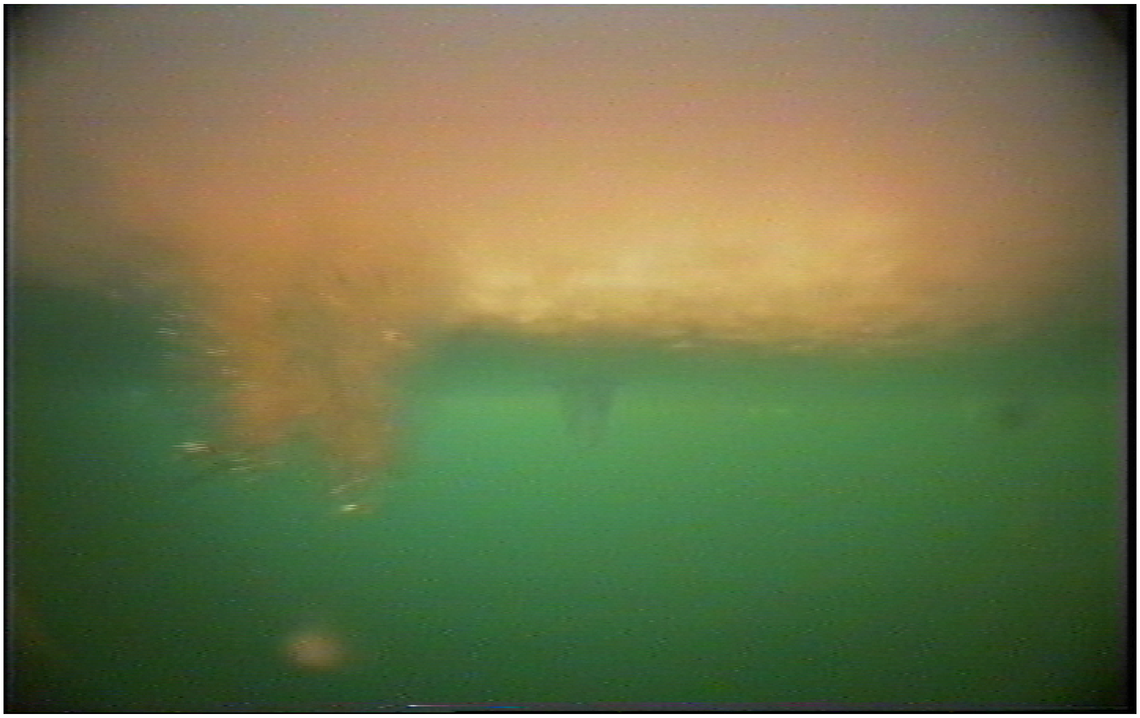

Figure 10. Ice algae colonies, Paktoa Area, Beaufort Sea, during March.

Phytoplankton samples were collected in triplicate from the water column at stations A, B, C and D. The average biomass and cell concentration per site are presented in Table 8. At all four stations, the dominant class of phytoplankton found in the mid-water column was Peridineae which contributed on average 37% of the population. Of the Peridineae the dominant genus present was *Gymnodinium*. The other two most common classes were Chlorophyta (25%) and Chrysophyceae (23%). The average mid-water column biomass ranged from 2.2 $mg\cdot m^{-3}$ to 6.5 $mg\cdot m^{-3}$; the highest biomass was at station 1D.

Zooplankton samples were collected at sites 1A, 1B, 1C, and 3C. Zooplankton population was dominated by calanoid copepods, which comprised 94% of the total zooplankton collected. Taxonomic data and number per station can be found in Table 9.

3.5 FISH AND MACRO-INVERTEBRATES

The techniques used to determine the presence of fish were also used to observe or collect macro-invertebrates. Gillnets were fished for a total soak time of 281 h 33 min, minnow traps for 841 h 44 min, and long-line and squid pouches for 66 h. Despite this sampling effort, no fish were collected or observed, however, some macro-invertebrates were collected using fishing gear.

The gillnet sets caught Ctenophora (*Beroe* sp.; n=10), a type of comb jelly. All the Ctenophora were caught in 1.5" mesh panels (Figure 11). Hyperidae amphipods (*Hyperia galba*) were also captured (n=8), with some being trapped within Ctenophores (n=6) (Figure 12). The polychaete noted above was the only other organism captured with gillnets (Figure 13).

While Arctic cod can be readily captured using benthic trawls in open water (Majewski et al. 2009b), capturing small fish under sea ice is difficult (Fuiman 2002). During the study, nets were set in an attempt to capture Arctic cod; however, their body shape tends to allow escape through mesh and none were captured or seen in the area despite the presence of suitable food items such as copepods and amphipods. Lønne and Gulliksen (1988) seldom encountered Arctic cod in areas where the under-ice was flat, but rather in cracks, crevices and melt holes present in rougher ice. They also had the most success collecting Arctic cod using SCUBA equipment and long-handled dip-nets that were used to reach cod hiding deep in ice crevices.

Table 8. Average phytoplankton biomass and cell concentration at mid-water column depth, March 2005, Beaufort Sea, NWT.

Site	**1A**	**1B**	**1C**	**1D**
Biomass ($mg\cdot m^{-3}$)	2.2	3.4	3.8	6.5
Concentration ($cells\cdot L^{-1}$)	28326	15858	19370	24537

Table 9. Number and percent composition of each zooplankton species, March 2005, Beaufort Sea, NWT.

Data	**1A**	**1B**	**1C**	**3A**	**Total**	**Percent**
copepod nauplii	1	1	1	1	4	0.15%
Calanoid copepodite	440	603	1192	190	2425	93.16%
Calanus hyperboreas	1	1	2	1	5	0.19%
Calanus glacialis	1			1	2	0.08%
Pseudocalanus minutus	1	2			3	0.12%
Oithona similis	20	33	88	8	149	5.72%
Cyclops edax			2		2	0.08%
Daphnia pulex group			2		2	0.08%
Epischura nevadensis			1		1	0.04%
Halitholus pauper			2		2	0.08%
Bosmina longiremis			1		1	0.04%
Diaptomus sp.			1		1	0.04%
Harpatacoida sp.	1				1	0.04%
Diptera adult			1		1	0.04%
Acartia longiremis		1		1	2	0.08%
Daphnia retrocurva		1	1		2	0.08%
				Total	**2603**	

Figure 11. Ctenophore, *Beroe* sp., Paktoa Area, Beaufort Sea, during collected March.

Figure 12. Hyperidae amphipods, *Hyperia galba*. , Paktoa Area, Beaufort Sea, collected during March 2005.

Figure 13. Photograph of the polychaete *Lumbineris* sp. collected March 2005, Paktoa Area, Beaufort Sea.

We had most success catching invertebrates using baited Gee minnow traps as shown in Table 10. Of all the invertebrates collected with the traps (n=1418), the amphipod *Onisimus nanseni* was by far the most common species, representing 99.8% of the overall catch in terms of numbers (n=1416). The bottom seems to be the preferred habitat for *O. nanseni* with 99.8% of the catch being from bottom sets. The majority of the total trap catch (78.4%) was at site 1C where light-sticks were used, perhaps due to amenable micro-habitat in that particular set area and/or the light acted as an attractant. Further investigation on the use of light as an attractant for capturing Arctic under-ice biota is warranted.

Table 10. Number of invertebrates captured by depth, using Gee traps, March 2005, Beaufort Sea, NWT.

Location	**Depth**	**Date**	**Taxa**	**N**
1B	1.5	22/03/2005	none	0
1B	7	22/03/2005	none	0
1C	1.5	21/03/2005	*O.nanseni*	1
1C	13.5	21/03/2005	*O.nanseni*	502
1C	13.5 (light)	21/03/2005	*O.nanseni*	716
1D	bottom am lift	22/03/2005	*O.nanseni*	43
1E	1.5	25/03/2005	*O. nanseni*	1
1E	7	25/03/2005	none	0
1E	bottom	25/03/2005	none	0
2B	1.5	23/03/2005	none	0
2B	7	23/03/2005	none	0
2B	bottom	23/03/2005	*O.nanseni*	153
4A	1.5	25/03/2005	none	0
4A	7	25/03/2005	none	0
4A	bottom	25/03/2005	*O. glacialis*	2

Similar capture successes resulted from long lines and baited squid pouches; data are presented in Table 11. Of the 42 amphipods collected, all were *O. nanseni,* and all were from the pouches that were in contact with the bottom.

Table 11. Number of invertebrates captured per site using squid pouches and long-lines, March 2005, Beaufort Sea, NWT.

Location	**Depth**	**Date**	**Taxa**	**#**
1B-1D	vertical # 1	25/03/2005	none	0
1B-1D	vertical # 2	25/03/2005	none	0
1B-1D	vertical # 3	25/03/2005	none	0
1B-1D	bottom # 1	25/03/2005	*O.nanseni*	18
1B-1D	bottom # 2	25/03/2005	*O.nanseni*	24

Cameras have been used as a method of observing fish under sea ice by other researchers, where conventional sampling methods have proved fruitless. Fuiman (2002) used cameras mounted on seals to observe predator prey interactions of fish under the Antarctic ice-pack. The ROV was used here for a total survey time of 1 h 56 m (Table 12). Although we did not locate fish using this method, we did have some success observing macro-invertebrates. One large marine isopod was observed on the bottom (Figure 14). Amphipods and *Mysis* sp. were also observed at the bottom as well as at the under the ice in association with the hanging ice-algae colonies. It is possible to collect larval fish under sea ice using plankton sampling equipment (Stewart et al 1993; Evseenko 1994). However, no fish larvae or macro-invertebrates were collected during our plankton tows.

Table 12. Observations of under-ice habitat using ROV, Paktoa site, Beaufort Sea, 2005.

View	**Time (h:m:s)**	**Notes**
under ice	1:17:06	Ice intact, not fractured, relatively flat some undulations. Ice algae colonized in areas where ice is flat, not necessarily where there is good light transmission through ice. Less ice algae colonization where ice is irregular. Some "icicles" and frazzle ice formations under ice surface. Hanging colonies of ice algae in association with some frazzle ice formations. A few amphipods seen under ice surface. Overall good light transmission, did not require lights on ROV.
water column	0:23:15	Water color blue to blue green. Water clarity and light transmission good, did not need lights on ROV.
sea bed	0:12:50	Bottom relatively flat and featureless. Some mud "boulders" and some ice scour marks. Substrate silty, suspended easily by ROV. Observed large isopod, a few amphipods and several mysids. No vegetation. Some light transmission at bottom but ROV lights used. Depth 12.7 m - 13.65 m.
Total	**1:56:11**	

Ringed seals feed primarily on Arctic cod (Smith and Harwood 2001). Otoliths and fish vertebrae were found in a seal scat collected by seal researchers at the nearby seal camp confirmed that some fish were present in the Paktoa area as the daily foraging distance of a ringed seal is within 14 km^2 (Harwood et al. 2007). The scat analysis also showed that the seal was eating invertebrates. This was similar to stomach content analysis of seals collected near Tuktoyaktuk (Table 13) that revealed that seals were feeding predominantly on macro-invertebrates. Fish remains were identified, but represented only a small amount of the wet weight of the stomach contents analyzed (Table 13). The seals were collected in May and were in excellent body condition and having normal reproduction while having a diet dominated by isopods (Harwood et al. 2007). The fish remains in the seal scat indicate that fish are likely present at, or near, the Paktoa area in March.

Figure 14. Isopod on seafloor, Paktoa Area, Beaufort Sea, during March.

3.6 OTHER WILDLIFE

Ringed seals are known to inhabit the Paktoa area, with 10 ringed seals live-captured at the nearby seal research camp (Harwood et al. 2007). One seal birthing den was located on the eastern perimeter of our sample area by our polar bear monitor. When bottom gillnet set 4a-4b (24-Mar-05) was retrieved, the 5.5" panel was riddled with large holes, in an otherwise sound net, the observed damage was likely caused by seals (Tom Smith, E.M.C. pers. comm.). Arctic fox (*Alopex lagopus*) tracks were observed crossing our sample area, south to north. The fox stopped where our squid bait was prepared and moved on. A polar bear (*Ursus maritimus*) sow with two cubs was seen 7 km from our sample area (Tom Smith, E.M.C. pers. comm.).

3.7 SUGGESTIONS FOR FUTURE WINTER SURVEYS

For this study a B2 class helicopter was used to transport personnel and equipment to and from the sample site. Although a B2 or B3 class helicopter has a higher hourly rate compared to a standard A-Star, it was more economical over the course of the project. The increased payload and range of the B2 eliminated the need for a refueling stop en route to site. Once on site, having a small snowmobile and toboggan to tow behind would be useful, particularly if heavy equipment and/or a larger sampling area are required.

Keeping electronic instruments with sensitive membranes and probes functional in extremely cold temperatures is often difficult, but we had no problem with our Hydrolab® by using a 20% methyl hydrate solution in place of water in the probe's storage cap. Also, disposable hot-packs were placed under the probe, batterypack and LCD screen. The unit was held in a padded Pelican® case.

The cloverleaf method is easier than trying to drill one large hole with a large diameter hand-operated ice auger. Regardless of the method, several auger extensions should be on hand. Our ice chisel was made from lightweight 150 cm shaft segments allowed the length of chisel to be adjusted depending on ice thickness. When disassembled, the segments were short enough to fit into the compartment of a helicopter. However, including an intermediate length (75 cm as opposed to 1.5 m lengths that we had on-site) would be useful as a chisel can become unwieldy and awkward to manage at 3 m long.

The “clothesline” technique described in the methods worked very well for setting gill nets. In order to keep nets from ripping upon retrieval, the ice chips and slush from the auger hole should be thoroughly cleared away from the sampling area leaving a smooth surface in the vicinity of the auger hole. If the slush pile created from drilling the auger hole is not smoothed over, then the net will catch and may tangle or rip on the uneven surface during hauling. Using heavy chain for gill net anchors proved successful. The chain is heavy enough to hold nets in position while still allowing for easy retrieval. When sampling through almost 2 m of sea ice there is little recourse to free a stuck anchor. Chain is also easier to obtain than specialized anchors and is compact, facilitating transport to site. Although fractured and uneven ice is much more difficult to sample compared to flat ice, future surveys to sample Arctic cod in the winter should be conducted using ROVs targeting areas of ice with such structure as it is more likely to be Arctic cod habitat.

3.8 POTENTIAL HABITAT DISTURBANCE FROM SDC

Devon selected the Steel Drilling Caisson (SDC) as the drilling platform to conduct exploratory drilling at the Paktoa site (KAVIK-AXYS 2007; Figures 15 and 16). The SDC has a large reinforced steel pad that rests on the seabed, and is protected from movement and ice damage by the creation of a thickened ice rubble base around its location. The footprint of the SDC is 162 m x 110 m with the complete drill platform including the ice rubble pad is 260 m x 320 m (KAVIK-AXYS 2007). The large footprint of the SDC or an ice island, will impact habitat in the area by displacing the available marine habitats proportional to the size of the drilling structure. There would be localized sediment re-suspension during mobilization and demobilization of the structure. The majority of the macro-invertebrate species collected was either motile or semi-motile and would be able to move away from and re-colonize a disturbed site quickly. The Paktoa area is within a high ice scour area and in the depositional influence of the Mackenzie River with new silts being deposited seasonally. From a strictly physical habitat standpoint (not taking into account accidental spills, drill cutting disposal, wastewater disposal, etc.), the placement of a temporary drilling platform such as the SDC or an ice island would not likely disturb fish and invertebrates or their habitats beyond the footprint of the structure. There is potential for ice island construction to create favorable habitat, for species such as Arctic cod, through the creation of ice rubble zones with extensive features such as cracks and crevices.

Table 13. Ringed seal stomach content analysis from seals collected near Tuktoyaktuk, NWT. All units are wet weight (g).

Sample Number	Total contents	Invertebrates	Fish remains	Otoliths	Unidentified
TUK-05-01	98.402	83.141	-	did not read	19.354
TUK-05-02	73.092	60.428	-	did not read	12.784
TUK-05-03	9.113	-	-	-	9.113
TUK-05-04	0.358	0.358	-	-	-
TUK-05-05	92.169	66.437	-	0.138	1.159
TUK-05-06	4.339	did not read	-	-	4.339
TUK-05-07	2.129	1.076	-	-	1.159
TUK-05-08	13.894	-	-	-	3.563
TUK-05-09	5.686	-	0.003	-	4.003
TUK-05-10* (A)	4.620	-	did not read	-	3.952
TUK-05-10* (B)	2.704	-	-	-	2.704
TUK-05-11	43.090	23.071	-	did not read	19.183
TUK-05-12	13.138	0.047	0.007	-	1.863
TUK-05-13	6.832	0.252	-	-	6.070
TUK-05-14	5.900	5.264	did not read	-	1.209
TUK-05-15	196.100	153.284	-	-	35.264
TUK-05-16	20.534	5.689	6.428	0.243	13.462
TUK-05-17	12.126	-	-	-	12.126
TUK-05-19	8.243	4.638	-	-	5.238
TUK-05-20	5.849	-	-	-	2.849
TUK-05-21	4.917	did not read	-	-	4.917
TUK-05-22	9.733	2.710	-	0.027	2.743

4. SUMMARY

The Paktoa area appears to be sparsely populated by pelagic fauna during the late winter. Although no fish were captured during sampling, there were fish present in the area (determined through fish remains in seal scat). Many marine species that inhabit the benthic environment may be relatively inactive, therefore may not be vulnerable to the types of passive fishing gear used in this study. Future survey efforts should include increased use of ROV technology, with a skilled operator, in order to better assess fish presence on the sea floor and to target areas of potential Arctic cod habitat. Phytoplankton, zooplankton, ice algae and benthic invertebrates were present but limited in numbers and diversity.

In general, little research focus is given to late winter sampling in the Canadian Beaufort Sea. Many species of fish that are common to the region spawn during the ice-covered period, however, little has been documented regarding the timing of spawning and the distribution and habitat requirements of most marine species during this critical period. Late winter is when industrial activities, such as hydrocarbon development, are likely to be most intense, thus there is an immediate need to establish baselines for biotic communities, and to assess the importance of potentially affected habitat, particularly at critical life stages. Future work is required to address these information gaps prior to major developmental activities.

Figure 15. The Steel Drilling Caisson (SDC).

Figure 16. The Steel Drilling Caisson (SDC) staged off Herschel Island in the Beaufort Sea.

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6. REFERENCES

B. Wright and Associates Ltd. 2005. Ice observations taken at the Paktoa B-60 drilling site during a field reconnaissance trip on March 17, 2005. Submitted to Devon Canada, Calgary, Alberta. p.9.

Carmack, E.C., and MacDonald, R.W. 2002. Oceanography of the Canadian Shelf of the Beaufort Sea: a setting for marine life. Arctic 55 (Supp. 1): 29-45.

Chiperzak, D.B., Hopky, G.E., and Lawrence, M.J. 1991. Fish catch data from the landfast ice of the Mackenzie River estuary, March 1985, and May 1986, 1987. Can. Data Rep. Fish. Aquat. Sci. 847: v + 28p.

Coad, B.W., and Reist, J.D. 2004. Annotated list of the Arctic marine fishes of Canada. Can. Manuscr. Rep. Fish. Aquat. Sci. 2674: iv + 112p.

Cott, P.A., Hanna, B.W., and Dahl, J.A. 2003. Discussion on seismic exploration in the Northwest Territories 2000–2003. Can. Manuscr. Rep. Fish. Aquat. Sci. 2648: vi + 36p.

Craig, P.C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: a review. Trans. Am. Fish. Soc. 113: 265-282.

Evseenko, S.A. 1994. Larval and juvenile fishes from collections made under the ice in the Weddell Sea. J. Ichth. 34 (2): 128-133.

Fuiman, L.A., Davis, R.W., and Williams, T.M. 2002. Behavior of midwater fishes under the Antarctic ice: observations by a predator. Mar. Biol. 140: 15-822.

Harwood, L., Smith, T.G., and Melling, H. 2007. Assessing the potential effects of near shore hydrocarbon exploration on ringed seals in the Beaufort Sea Region 2003-2006. Environmental Studies Research Funds Report No. 162. 103p.

Hopky, G.E., Lawrence, M.J., and Chiperzak, D.B. 1994. NOGAP B2; Zooplankton data from the Canadian Beaufort Sea shelf, 1986. Can. Data Rep. Fish. Aquat. Sci. 923. p. 225.

Hopky, G.E., Lawrence, M.J., Chiperzak, D.B., and McRae, S.M. 1994. NOGAP B2; Data on *in situ* water irradiance, temperature and fluorescence, solar irradiance, and ice algae and related physical parameters from the Canadian Beaufort Sea shelf, 1985 to 1988. Can. Data Rep. Fish. Aquat. Sci. 934. p.112.

Kavik-Axys Inc. 2004. Devon Canada Corporation Beaufort Sea exploratory drilling program baseline reports. Prepared for Devon Canada Corporation by Kavik-Axys Inc. January 30, 2004.

Kavik-Axys Inc. 2007. Environmental effects monitoring report. Devon Canada Corporation Beaufort Sea exploratory drilling program 2003-2006. Prepared for Devon Canada Corporation by Kavik-Axys Inc. September 2007.

Lønne, O.J., and Gulliksen, B. 1989. Size, age and diet of polar cod, *Boreogadus saida* (Lepechin 1773), in ice covered waters. Polar Biol. (1989) 9: 187-191.

Majewski, A.R., Reist, J.D., and Sareault, J.E. 2006. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, August 2004 aboard the CCGS *Nahidik*. Can. Manuscr. Rep. Fish. Aquat. Sci. 2771: vi + 37p.

Majewski, A.R., Reist, J.D., Park, B.J., Sareault, J.E., and Lowdon. M.K. 2009a. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, July and August, 2005, aboard the CCGS *Nahidik*. Can. Data Rep. Fish. Aquat. Sci. 1204: vii + 53p.

Majewski, A.R., Reist, J.D., Park, B.J., and Lowdon. K.M. 2009b. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, August 2006, aboard the CCGS *Nahidik*. Can. Data Rep. Fish. Aquat. Sci. 1218: vi + 37p.

McAllister, D.E. 1975. Ecology of the marine fishes of arctic Canada. Proceedings of Circumpolar Conference on Northern Ecology II. National Museum of Natural Sciences, Ottawa. pp.49-65.

MacDonald, R.W., Solomon, S.M., Cranston, R.E., Welch, H.E., Yunker, M.B., and Gobiel, C. 1998. A sediment and organic carbon budget for the Canadian Beaufort Shelf. Mar. Geol. 144: 255-273.

Mecklenburg, C.W., Mecklenburg, T.A., Thorsteinson, L.K. 2002. Fishes of Alaska. American Fisheries Society. Bethesda, Maryland. xxxvii + 1037p.

Milne, A.R., and Smiley, B.D. 1976. Offshore drilling for oil in the Beaufort Sea: a preliminary environmental assessment. Beaufort Sea Project, Environment Canada, Victoria, B.C., Environ. Can. Tech. Rep. 39: 40-43.

Reist, J.D., and Bond, W.A. 1988. Life history characteristics of migratory coregonids of the lower Mackenzie River, Northwest Territories, Canada. Finnish Fish. Res. 9: 133-144.

Sekerak, A.D., Stallard, N., and Griffiths W.B. 1992. Distribution of fish and fish harvest in the nearshore Beaufort Sea and Mackenzie delta during ice-covered periods, October-June. Environmental Studies Research Fund Report 117: 157p. + appendices.

Smith, T.G., and Harwood, L.A. 2001. Observations of neonate ringed seals, *Phoca hispida*, after early break-up of the sea ice in Prince Albert Sound, Northwest Territories, Canada, spring 1998. Polar Biol. 24: 215-219.

Stewart, D.B., Ratynski, R.A., Bernier, L.M.J., and Ramsey, D.J. 1993. A fishery development strategy for the Canadian Beaufort Sea-Amundsen Gulf area. Can. Tech. Rep. Fish. Aquat. Sci. 1910: p.127.

Thorsteinson, L.K., Jarvela, L.E., and Hale, D.A. 1991. Arctic fish habitat use investigations: nearshore studies in the Alaskan Beaufort Sea, summer 1990. National Oceanic and Atmospheric Administration, National Ocean Service. Anchorage, Alaska. xv + 166p.

Timco, G.W., and Frederking, R. 2009. Overview of Historical Canadian Beaufort Sea Information. NRC Canadian Hydraulics Centre Technical Report CHC-TR-057. 95p.

Welch, H.E., and Kalff, J. 1974. Benthic photosynthesis and respiration in Char Lake. J. Fish. Res. Bd. Can. 31: 609-620.