THE EFFECT OF THE EXXON ICE ISLAND ON THE BENTHIC BIOTA OF THE NEARSHORE BEAUFORT SEA

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PREFACE

During the winter of 1978-79 Exxon Company, U.S.A. constructed an experimental ice island north of Prudhoe Bay in west Stefansson Sound. The circular, dome shaped island was built on the fast ice in water 3 to 3.5 m deep using a large, rotating sprinkler system. The completed island was 400 m in diameter and was approximately 10 m thick at the center, tapering to 5 to 6 m thick at the perimeter. The island persisted most of the 1979 summer, but erosion from the combination of wave action and melting caused it eventually to break up and float away in early September.

Prior to construction of the Ice Island, a baseline study of the benthic animal population at the site was conducted by SubAquatic Research in November, 1978. The results of this survey were presented in a report to Exxon on April 1, 1979. SubAquatic Research then followed with two more benthic surveys under an agreement with Exxon to assess the effects of the Ice Island on the biological environment. These surveys were done on July 26 while the Ice Island was grounded and on November 12 and 13, two months after its disappearance. In this report we present in comparative form, the results of these field studies.

SUMMARY OF OBJECTIVES
CONCLUSIONS AND RECOMMENDATIONS

A study of the seafloor at the Exxon Ice Island site in which divers collected data on the distribution and abundance of benthic organisms during and following the ablation of the Ice Island is completed.

The specific objectives of this study were to:

1. Compare the density and biomass of benthic organisms at the Ice Island site before its construction and following its ablation.
2. Determine the Ice Island's 'sphere of influence' on the surrounding region with respect to the biota.
3. Compare the abundance, distribution, and condition of biota at different distances from the Ice Island during the same sampling period.
4. Describe the physical characteristics of the seafloor, ice and seawater at the Ice Island site.

The major conclusions of this study are:

1. At the geographic center of the Exxon Ice Island site and within 225 m of its center, a majority of the resident benthic organisms were eliminated.
2. No adverse effects were observed on the infaunal population 300 m west of the Ice Island center, thus indicating that the influence of the Island was limited to its physical extent.
3. The Ice Island had the greatest impact of infaunal and benthic species, and the least impact on swimming epibenthic animals.
4. At two sites located under the former Ice Island, bivalves and ostracods were present in numbers equal to or exceeding those at sites distant from the Ice Island. These organisms either survived the impact of the Ice Island or were washed into the area from surrounding regions following ablation of the island.
5. The presence of juveniles, but no gravid adult polychaete worms, at the Ice Island site in November, 1979, indicates recruitment of larvae released from gravid adult worms from the surrounding area is occurring.
6. A high percentage of young adult polychaete worms at the Ice Island site in November, 1979, suggests that this age group either survived the impact of the Ice Island, or juveniles recruited into the area after break-up of the Island had grown into the young adult stage.

The recommendation of this study is:

1. That repopulation of the Exxon Ice Island site by benthic organisms continues to be monitored on an annual or semi-annual basis in an effort to document the site's earliest return to pre-island conditions.

INTRODUCTION

The effects of a large mass of grounded ice on benthic organisms in arctic regions not normally subjected to such events are largely unknown. Each winter along the arctic coast the seafloor in waters less than 2 meters in depth freezes due to contact with shore-fast ice. Benthic sampling of these shallow areas in the summer months has shown organisms to be present (Broad, 1979), indicating the rapid recolonizing ability of such species or their tolerance to being frozen in for long periods. The inhabitants of these shallow nearshore regions are different from those found in deeper waters. Therefore it is difficult to predict the response of benthic populations outside of the shore-fast ice zone to grounded ice.

The Exxon Ice Island has provided the unique opportunity to test, (1) the ability of populations to survive major environmental changes; and (2) the potential recolonizing capabilities of the various organisms.

General Nature and Scope of Study

We examined the benthic community in the vicinity of the Ice Island on two different occasions since its construction. The first field study was conducted on July 26 during the Island's ablation; the second on November 12 and 13, two months after its disappearance. On both occasions we ran transects from the Ice Island site westward. Each transect consisted of three dive sites. As a minimum requirement, the following data and samples were collected at each dive (sampling) site: (1) six benthic cores, (2) a sediment sample, and (3) physical and biological characteristics of the seafloor.

Since visual observations are an important source of data, we used an underwater communications system to transmit information to the surface where it could be taped. A dive plan which outlined tasks and procedures was followed by the divers on instruction from the surface support personnel. The divers were tethered to the surface and were equipped with a complete back-up air support system. Our field team consisted of two divers, one back-up diver and a marine technician.

Transportation and Logistic Support

Base operations for this project were located at Mukluk Camp #1 in Deadhorse. Helicopter support and the use of a Boston Whaler for transportation to and from the Ice Island, lodging, and field logistics were provided by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) office in Fairbanks.

A diving shelter that consisted of two canvas tents connected end to end provided some protection from the wind and cold during our November sampling period. For the summer period we used a 21 foot Boston Whaler as a dive platform and for transportation.

STUDY AREA

The center of Exxon's proposed 1200 foot diameter Ice Island (70°23.5'N, 148°17.2'W) is located approximately ten kilometers north of the Prudhoe Bay East Dock (Fig. 1). The research effort was carried out at six sampling or Dive Sites located on a line from the geographic center of the Ice Island to approximately 500 meters west of the center.

Location of Dive Sites

Fig. 2 shows the location of Dive Sites 2-7 and Dive Site (DS)-1, the 1978 pre-Ice Island sampling site. DS-1 is a control site and was not sampled in 1979. DS-2 is marked acoustically with a pinger that was deployed by Exxon following the break up of the Ice Island. Although visual contact was never made with this pinger in November we feel confident that our DS-2 was within 35 meters (≈ 100 feet) of the pinger. Our difficulty in locating the unit may be a result of several factors: (1) signals received from the pinger appeared either deflected or masked in some way; (2) poor underwater visibility, and (3) limited time. Our estimate of maximum range from the pinger is based on: (1) we received the pinger code on our underwater communications receiver which has a maximum range of 40 meters at that frequency; (2) we believe our triangulation using the pinger signals to be accurate, and (3) our DS-2 site was within 50 meters of the Ice Island center as calculated independently by USGS using a Del Norte trisponder positioning system.

On July 26 we ran a westerly transect from the Ice Island starting at DS-4, located 25 m (meters) from the edge of the ice cliff. The island at this time was about 400 m in diameter (Reimnitz et al., 1979) but was undercut several meters below the water line. The second two sites, DS-6 and DS-7 were located 150 m and 300 m west respectively from the edge of the Ice Island.

In November we cut holes in the ice canopy at the following locations: DS-2, the geographic center of the former Ice Island; DS-3, 140 m west of DS-2; and DS-5, 300 m west of DS-2.

The water depth at all the Dive Sites ranged between 3.1 and 3.3 m, approximately 10.2 to 10.8 feet. Ice thickness on November 12, our first day of diving at the Ice Island site was 35 cm (≈ 14 inches).

Figure 1. Map of the Prudhoe Bay region showing the location of the Exxon Ice Island.

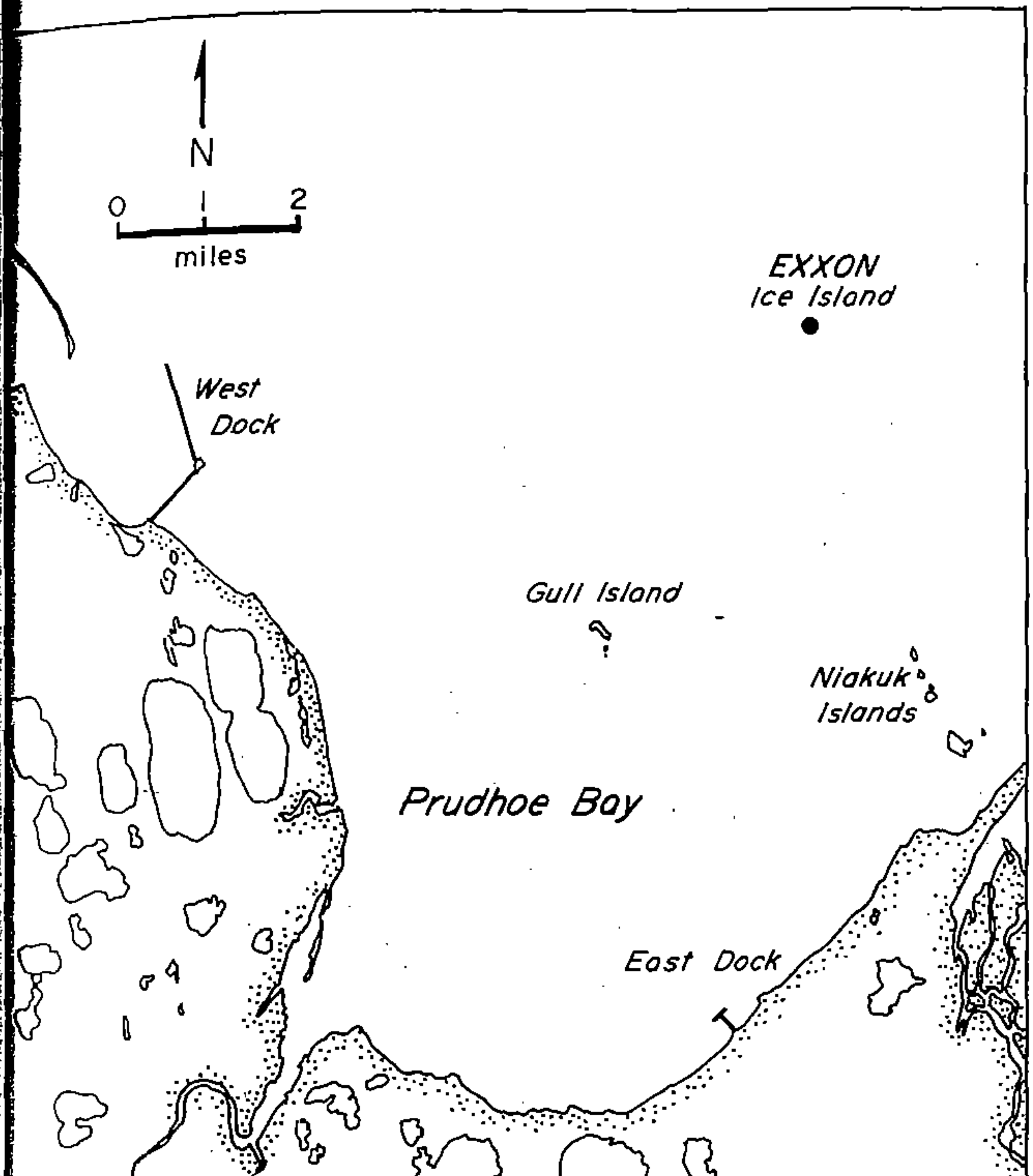
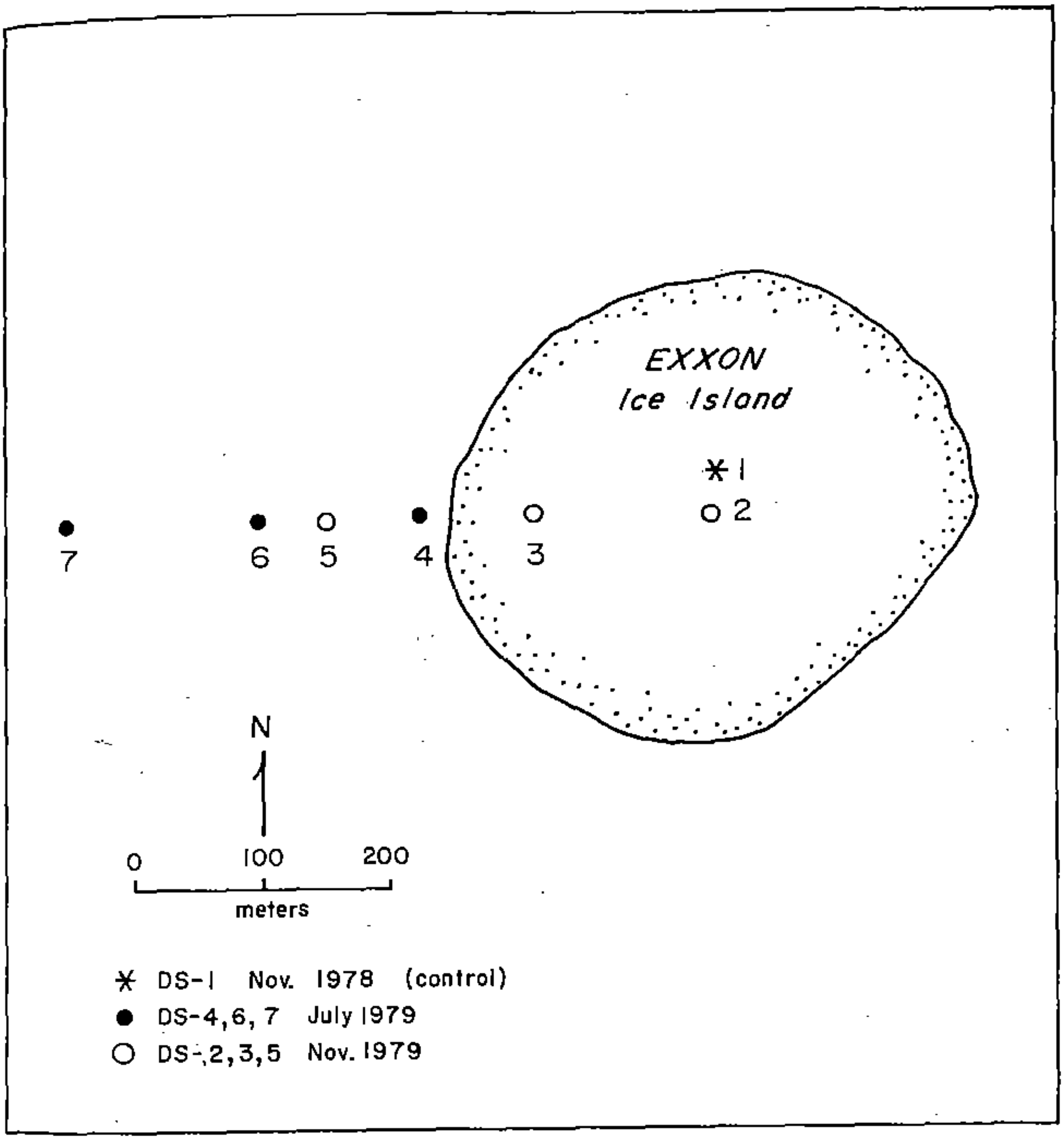

N
0
1
2
miles
EXXON
Ice Island
West
Dock
Gull Island
Niakuk
Islands
Prudhoe Bay
East Dock

Figure 2. The location of the Dive Sites in relationship to the Exxon Ice Island. The Island is drawn as seen in late July, 1979.


EXXON
Ice Island
1
2
3
4
5
6
7
N
0
100
200
meters
DS-1 Nov. 1978 (control)
DS-4, 6, 7 July 1979
DS-,2,3,5 Nov. 1979

METHODS AND RATIONALE OF DATA COLLECTION

The primary emphasis of the study was to quantify the benthic fauna at the Exxon Ice Island site and determine the nature and extent of the Island's influence on the biota in the immediate region. Therefore the collection of benthic samples for quantitative analysis and the visual semi-quantitative observations made by the divers were the primary sources of our information. Photography was used to document some of these in situ observations. No surface deployed sampling equipment was used.

Qualitative Sampling and Diving Observations

Collection of Organisms

Epibenthic biota was collected with a modified dip net and by hand. The dip net was designed to be escape proof so that divers could collect quick swimming and darting organisms such as fish and mysids without having to surface regularly and unload their catch. The net was constructed out of 1 mm mesh nylon screening and consisted of a cone which was sewn into a large dip net, thereby functioning in the same way as a fish trap. Large organisms, such as isopods and kelp were collected by hand and placed in a dive bag underwater.

Visual Observations and Photography

Through communication with surface personnel, divers were periodically asked to photograph and provide information on the physical and biological habitat. This included:

1. The physical environment, which included data on approximate water depth, water turbidity, visibility, ice appearance and currents.
2. The sea floor, which included comments on the nature of the sediments, topographical features, surface detritus, algal cover, and the predominant organisms seen.
3. The biota, which involved a description of the organisms, taken one by one, on their approximate density, location and their behavior (swimming, feeding, etc.).

.05 m^2 Quadrats

In situ quantitative estimates of animal distribution were calculated from the analysis of several .05 m^2 quadrats. When algae were observed, it too was noted. These quadrats were placed on the bottom by the diver who quickly noted (verbally) the animals seen within the frame. The number of quadrats an organism was found within divided by the total number of quadrats analyzed gave a measure of the animal's frequency, which was expressed as a percentage. We found this sampling technique helpful in quantifying the visual observations made by the divers.

Quantitative Sampling

Statistical Analyses

All data in this study were analyzed by a completely randomized design analysis of variance (ANOV). The student-Newman-Keuls test (SNK) was used in multiple range comparisons. A significance level of 5% was chosen before calculating the statistic.

Core Samples

In November, 1978, six cores, 10 cm square and 10 cm deep ($.01m^2$ x 10 cm), were used to sample the benthic infauna at Dive Site #1. Since no airlift was available for this work the divers carefully dug out each core with a small trowel and placed the entire sample in a container which was capped and brought to the surface. For the July and November 1979 sampling periods an airlift was used to take $.01m^2$ x 10 cm cores. Five cores were taken at each of three dive sites in July and six airlift cores were made at each of three dive sites in November except DS-7. There, three airlift and three trowel cores were taken to test if these two methods of collection were comparable. Statistical analysis (ANOV) showed that they were not significantly different from each other in biomass or density.

All cores were carefully wet sieved through a 0.5 mm mesh screen, bottled and formalized.

Sediment Samples

In November, 1978 and in November, 1979 sediment samples were collected for grain analysis at several locations. The samples were scooped from the seafloor to a depth of 4-5 cm directly into a 2 quart container which was then capped and brought to the surface. The sediments collected in 1978 were given directly to Exxon for analysis while those retrieved in 1979 were analyzed by SubAquatic Research.

Hydorgraphid Data

Measurements of salinity and temperature were taken during each sampling period. A SCT meter (YSI, Model 33) was used to collect data at the surface and at one meter intervals to the bottom.

Laboratory Techniques

Sorting, Identification, and Weighing of Fauna

All core and epifaunal samples were sorted and the organisms identified under a dissecting microscope. Biota from the core samples were separated to species, counted and weighed. All organisms were in an entire state except some of the polychaetes. Only the head portion of the worm was counted as an individual. No tubes or nonliving fractions were included in the biomass except for the shells of pelecypods, gastropods and ostracods. The biomass was determined from a wet weight taken after the excess water was blotted off the animal. The organisms were weighed on a Sartorius balance accurate to ± 1 mg.

Grain Size Analysis of Sediments

Each grain sample was spread out in an 8" x 8" pan and left to air dry until damp. They were then placed in an oven and dried for 24 hours. The grain size analysis outlined in Folk (1974) was followed. The sample was run through a splitter to gain a workable size, then placed on the top of a set of screens with one PHI increments (-2 to 4). The stack of screens was placed in a Ro-Tap for 15 minutes and the subsequent size fractions weighed.

RESULTS AND DISCUSSION

General Description of the Benthic Community

The marine benthic community in the general vicinity of the Exxon Ice Island is characterized by an epifauna of small fish and crustaceans and by an infaunal assemblage of polychaete worms, tiny molluscs, ostracods, and foraminiferan protozoans (Dunton, 1979). Kelp and red algae, attached to small pebbles or other consolidated substrates are common as drift in this area. Isopods, mysids, and amphipods are the most common mobile epibenthic organisms; the polychaete worm, Ampharete vega, is the most conspicuous sedentary organism. Its tubes protrude from the mud bottom and form a low-level forest 1 to 2 cm high. A cumulative list of the benthic organisms seen and collected in the Ice Island area by divers from SubAquatic Research is presented in Table 1.

Physical Observations: Seafloor and Ice

July, 1979

The sandy-mud bottom at all three Dive Sites in July (DS-4,6,7) was smooth with small ripples oriented in a northwest (290°) to southeast (110°) direction. At DS-4, 25 m from the Ice Island itself, divers reported patches of bottom where the ripple marks were interrupted. These flattened patches appeared to range from 30 cm to 60 cm in diameter. Small mounds of sediment were also observed on the seafloor near the Ice Island pedestal.

No pebbles were seen at any of the Dive Sites except those attached to drifting algae. Scattered shell fragments and detritus were seen at all Dive Sites, but this material was least abundant at DS-4. The detritus consisted of worm tubes of Ampharete and terrestrial debris (peat and twigs). Numerous dead isopods and isopod parts were observed at DS-4. Divers reported visibility to be about 1.2 m (≈ 4 feet) and noted a northerly current at these Dive Sites on July 26.

November, 1979

The sandy-mud bottom at all Dive Sites in November (DS-2,3,5) was marked by a regular ripple train of 8 to 12 cm wavelength, with crests 4 to 5 cm high. At DS-3 these crests were oriented in a northwest (280°) to southeast (100°) direction. At DS-2 divers noted crests oriented slightly different, in a 345° to 165° direction (Fig. 3).

Table 1. A cumulative list of the benthic organisms seen or collected by divers during the three sampling periods. The location and time period in which the organism was observed is marked with an (X).

Organism	November, 1978	July, 1979			November, 1979		
	DS-1	DS-4	DS-6	DS-7	DS-2	DS-3	DS-5
INVERTEBRATES							
HYDROZOA							
Tubularia sp.			X				
ANTHOZOA							
ACTINARIA			X				
POLYCHAETA							
Ampharete vega	X		X	X	X		X
GASTROPODA							
Polinices pallidus	X	X			X		
PYCNOGONIDA							
Nymphon grossipes					X		
COPEPODA							
CALANOIDA	X	X	X	X	X	X	X
MYSIDACEA							
Mysis litoralis	X	X	X	X	X	X	X
CUMACEA							
Brachydiastylis resima				X			
ISOPODA							
Saduria entomon	X	X	X		X	X	X
Saduria siberica	X						
AMPHIPODA							
Atylus carinatus			X				
Boekosimus affinis				X			
Gammarus setosus		X					
Halirages sp.		X	X				
Monoculopsis longicornus		X	X		X		X
Monoculopsis packardi					X		X

Table I, continued

Organism	November, 1978	July, 1979			November, 1979		
	DS-1	DS-4	DS-6	DS-7	DS-2	DS-3	DS-5
Pontoporeia femorata				X			
Rozinante fragilis					X		X
<u>EUPHAUSIACEA</u>							
Thysanoessa raschii	X						X
<u>BRYOZOA</u>							
Alcyonidium disciforme	X						
<u>CTENOPHORA</u>							
Beröe sp.	X						
<u>CHAETOGNATHA</u>							
Sagitta elegans	X						
<u>VERTEBRATES</u>							
Liparis (juveniles)	X						
Liparis herschelinus	X						
Artediellus scaber	X						
<u>ALGAE</u>							
Laminaria solidungula	X	X	X	X	X	X	X
Phycodrys rubens	X	X				X	

Figure 3. A large isopod swims above a seafloor characterized by ripple marks at DS-2, the geographic center of the Exxon Ice Island. The photograph was taken in November. Scattered shell fragments lie in the troughs of the wave train. Distance between troughs is 8-12 cm.

At Dive Sites 2 and 3, located under the former Ice Island, the bottom was lacking in both worm tubes and detrital debris both found in this region at DS-1 in November, 1978 and at DS-5 (Fig. 4 and 5). Isopods were noted crawling on the seafloor (Fig. 7) at DS-2 and DS-3 and several pieces of buried kelp were found. The kelp were attached to small pebbles and buried as deep as 10 to 15 cm in silt and mud. Visibility was approximately 2 m and lights were needed to illuminate the seafloor at all locations due to minimum daylight. An easterly current was observed on the days of sampling (November 12 and 13).

The ice canopy at all Dive Sites was smooth and hard, approximately 35 cm (14 inches) thick. Light penetrated this ice and lit the seafloor dimly. Approximately 5 m south of DS-2 turbid ice characterized the ice undersurface. This turbid ice extended irregularly toward the seafloor and was highly variable in thickness (up to 2 m). This type of ice contains considerable amounts of finely disseminated sediments and has been reported and described at our Dive Site 11 in Stefansson Sound (Reimnitz and Dunton, 1979).

Hydrographic Data

Salinity and temperature measurements were recorded at all three Dive Sites in July and at DS-2 in November. Results are presented in Tables 2A and 2B.

In July, a gradient of increasing temperature and slightly higher salinities was observed on a westerly transect from the Ice Island (Fig. 2A). The lower temperatures are a result of a mixing of melt water from the Island with waters of normal temperature. The salinity differences are small and not entirely consistent from site to site. Reimnitz (1979) reported higher salinities on the downdrift side of the Island than on the updrift side and attributed this to the higher average salinity of the Ice Island itself. At DS-2 in November salinities were recorded as being near 37 ppt (Table 2B) which is almost 10 ppt higher than those reported in November, 1978.

Sediment Grain Size Analysis

Samples of sediment were taken at each Dive Site in November, 1979. The results of the analysis of these samples and those collected in November, 1978 is depicted in Fig. 6.

Figure 4. A photograph of the seafloor 30 m north of the center of the Exxon Ice Island site in November, 1978, before construction of the Island. Numerous worm tubes, shell fragments, and detritus litter the bottom.

Figure 5. A photograph taken one year later at approximately the same location (DS-2) in November, 1979, following ablation of the Ice Island. Shell fragments are numerous, but worm tubes and detrital material are almost non-existent.

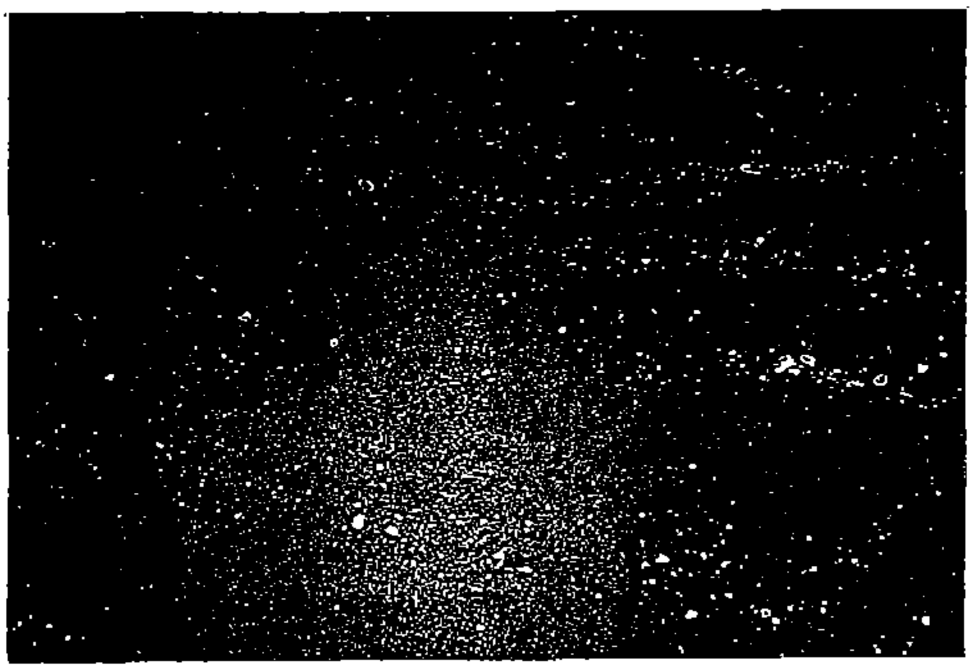


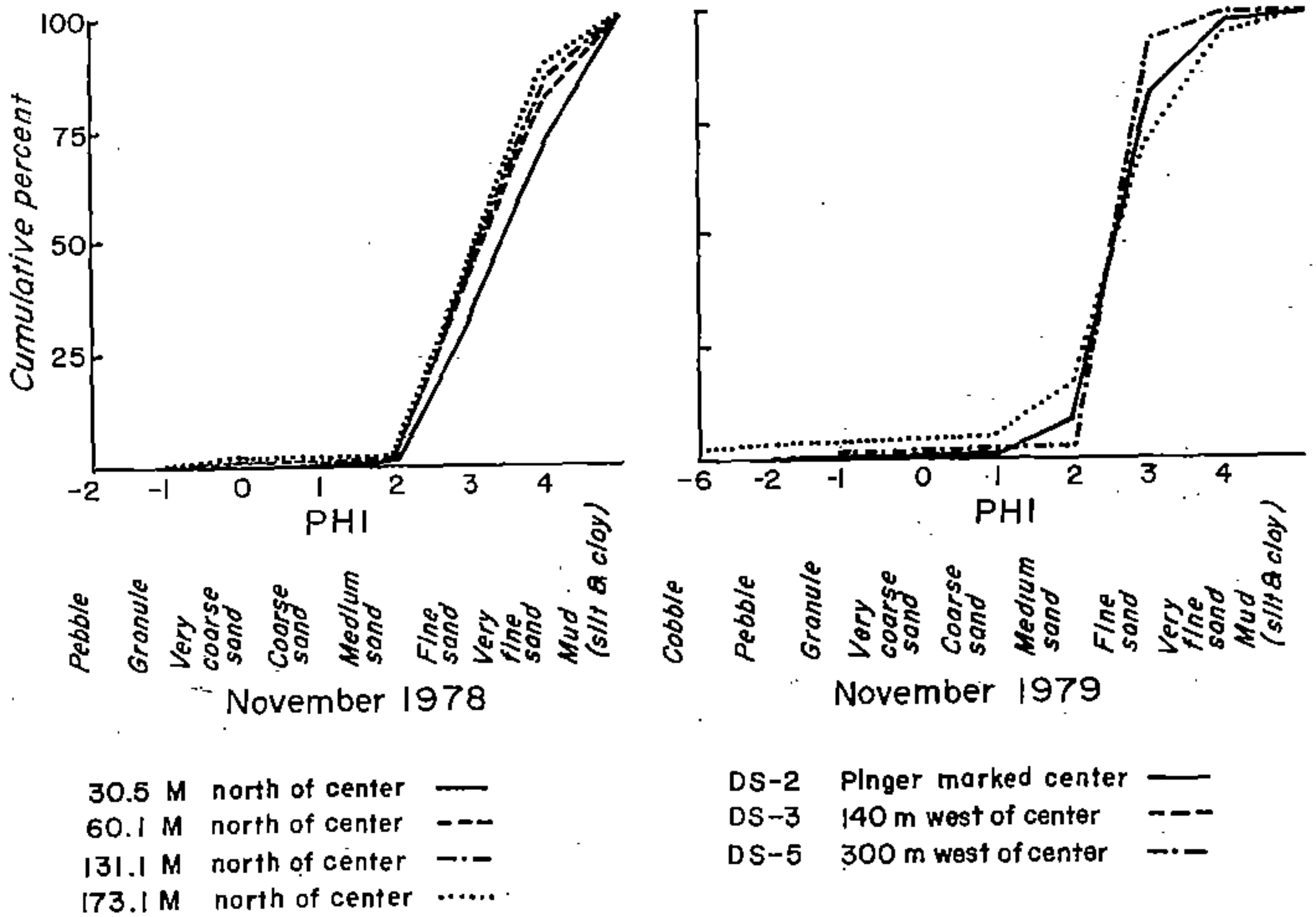
Table 2A. Temperature and salinity measurements recorded at three diving sites in July 1979. See Fig. 2 for dive site locations with respect to the Ice Island.

Depth	Salinity (ppt)			Temperature (°c)		
	DS-4	DS-6	DS-7	DS-4	DS-6	DS-7
surface	13.0	12.5	14.8	4.0	6.0	6.2
1 m	19.8	16.8	17.3	4.8	5.0	5.1
2 m	21.2	22.0	22.8	4.2	3.9	3.5
3 m	23.2	22.9	24.0	3.2	3.5	4.0
3.3 m (bottom)	24.0	27.0	27.3	0.8	2.6	2.7

Table 2B. Temperature and salinity measurements recorded at DS-2 in November, 1979.

Depth	Salinity (ppt)	Temperature (°C)
surface	36.2	-2
1 m	37.7	-2
2 m	37.9	-2
3 m	37.6	-2
3.2 m (bottom)	37.6	-2

Figure 6. A visual representation of the sediment grain size distribution at the Exxon Ice Island sampling sites. Data from sediments collected in November, 1978 and 1979 are shown.



100
75
50
25
Cumulative percent
-2 -1 0 1 2 3 4
PHI
Pebble
Granule
Very coarse sand
Coarse sand
Medium sand
Fine sand
Very fine sand
Mud (silt & clay)
November 1978
30.5 M north of center
60.1 M north of center
131.1 M north of center
173.1 M north of center
-6 -2 -1 0 1 2 3 4
PHI
Cobble
Pebble
Granule
Very coarse sand
Coarse sand
Medium sand
Fine sand
Very fine sand
Mud (silt & clay)
November 1979
DS-2 Pinger marked center
DS-3 140 m west of center
DS-5 300 m west of center

It is well documented that many marine organisms have substrate preferences. In experiments now in progress in the Stefansson Sound boulder patch a pattern is emerging that shows some polychaetes and bivalves to extensively populate looser substrates, but to be in reduced numbers in adjacent clays. Therefore we thought it important that the substrates at the sampling sites in the Ice Island area be tested for consistency, thereby eliminating a factor which could contribute to a non-uniform distribution of organisms.

As illustrated in Fig. 6, the substrates at the three November, 1979 Dive Sites are very similar to each other. Most of the grains fell into the 2-3 PHI range, which is medium to fine sand in the Wentworth size classification system. The samples taken in November, 1978 also show uniformity. A majority of the grains were in the 2-3 PHI size range, but a higher percent of mud was found in these samples. The data shows a large portion of this mud to be the silt fraction and a smaller amount to be clay. Therefore, a slight coursening of the sediments seems to have occurred at the Ice Island site between November, 1978 and November, 1979. Both sets of data however, show basic substrate uniformity, temporally and spatially, in the Ice Island area. Substrate can be eliminated as being a variable influence on density and biomass measurements at the various sampling sites.

Biological Observations: Epibenthic Organisms

The results and discussion in this section are based on observations made by divers, the collection of organisms by hand, and the inadvertent collection of epibenthic animals in airlift cores. The frequency of occurrence of benthic and epibenthic animals at each Dive Site, as observed by divers, is shown in Table 3.

July, 1979

At DS-4, located 25 m from the edge of the Ice Island, divers reported a high mortality of the isopod *Saduria entomon*. In the fifteen 0.05 m^2 epibenthic quadrats made at this dive site, nine had no living organisms. One live gastropod, one isopod and several mysids were observed in the quadrats. No *Ampharete* tubes, previously so common in this general area, were observed here. Several Calanoid copepods, mysids (*Mysis litoralis*), isopods (*Saduria entomon*) and amphipods (*Gammarus setosus*, *Halirages* sp. and *Monoculopsis longicornus*) were found in the near-bottom water column.

Table 3. The distribution of benthic and epibenthic organisms at the dive sites determined from *in situ* analysis of .05 m^2 quadrats. Frequency = (number of quadrats in which organism observed/total number of quadrats (N)) X 100.

Dive Site	Number of Quadrats	Frequency (%) of Occurrence							
		Algae	Ampharete Worm Tubes	Mysids	Amphipoda	Isopoda	Gastropoda	Hydrozoa	Burrowing Actinaria
2	10	0	0	40	60	0	10	0	0
3	10	0	0	80	70	0	0	0	0
4	15	7d	0	27	7+7d	7+7d	7+7d	0	0
5*	-	-	abdt	abdt	abdt	-	-	-	-
6	15	20d	100	20	7	20	7d	7	7
7	15	13d	47	47	7	7	0	0	0

*These are qualitative observations only and therefore not complete.

d: Organism(s) found dead.

abdt: abundant

At DS-6, 150 m from the Island edge, the bottom looked more typical with abundant Ampharete tubes, but the epifauna was sparse. Worm tubes, a few mysids, three live isopods, a Tubularia, and one burrowing anenome were observed in the fifteen quadrats made. (Table 3). Some Calanoid copepods, and the amphipods Atylus carinatus, Halirages sp., and Monoculopsis longicornus were collected from the near-bottom water column.

At DS-7, 300 m from the Island edge, frequent patches of Ampharete tubes were seen. Mysids were more widespread and in greater numbers than at DS-4 or DS-6. Only three quadrats out of fifteen had no live organisms. In the near-bottom water column several animal species were collected. They included numerous Calanoid copepods, mysids, the cumacean Brachydiastylis resima, Pagurus larvae and the amphipods Boeckosimus affinis, and Pontoporeia femorata.

Deteriorating red algae and laminaroids were commonly seen at DS-6 and DS-7. They appeared to have drifted into the area as no young or healthy individuals were found.

November, 1979

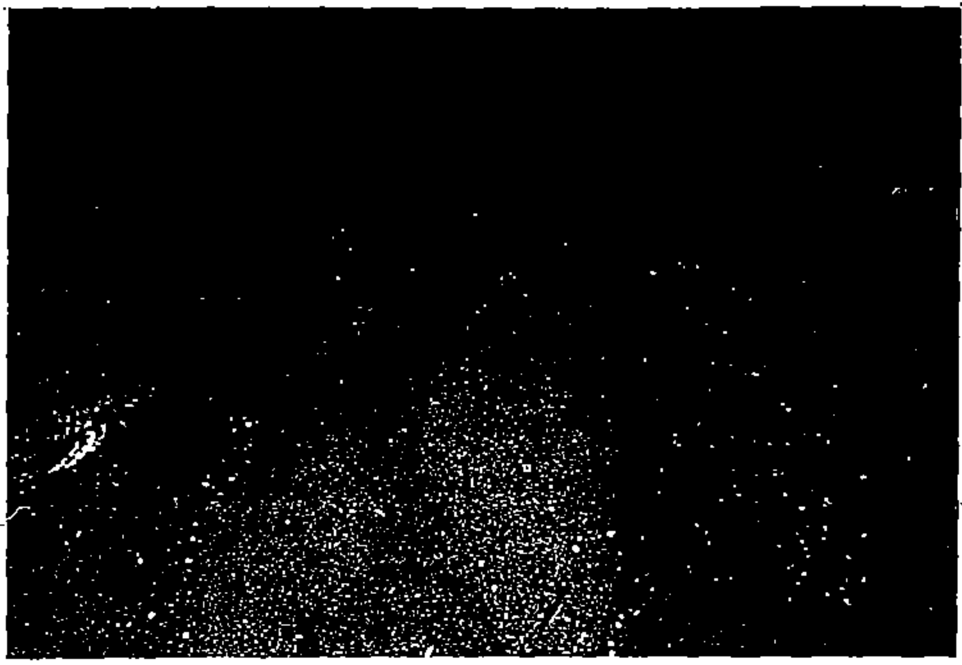
At DS-2, located at the geographic center of the former Ice Island, divers observed many amphipods and mysids, a few small snails, one pycnogonid, and five isopods. Very few Ampharete tubes existed in the area (Fig. 7). Several pieces of algae (Fig. 8) were seen, some of them half buried in sediment. Many Calanoid copepods, the mysid Mysis litoralis and the amphipod Monoculopsis longicornus were collected from the near-bottom water column. Two other amphipods, Monoculodes packardi and Rozinante fragilis, were found in water column samples.

Mysids were observed in great numbers at DS-3, located 140 m west of DS-2. Amphipods were also common, and one isopod was seen. No Ampharete tubes existed here. In the near-bottom water column some copepods and the amphipod, Pareodiceros lynceus were collected.

Divers only spent a few minutes on the bottom at DS-5, 300 m west of DS-2, but reported seeing an abundance of Ampharete tubes, mysids, and amphipods. Large numbers of Calanoid copepods, some mysids (Mysis litoralis) and two isopods (Saduria entomon) were sampled from the near-bottom area. Amphipods were represented by Monoculodes packardi, Monoculopsis longicornus and Rozinante fragilis. Several Euphausid shrimp, Thysanoessa raschii, were also collected.

Figure 7. A photograph of the seafloor at DS-2 in November, 1979. Isopods are conspicuous and mysids although present are barely discernable in this picture. Note the lack of detritus and worm tubes in the ripple troughs.

Figure 8. A piece of rope provides a substrate for the red alga Phyllophora truncata at DS-2 in November.



Summary and Comparative Analysis

It is often difficult to judge the effects of in situ disturbances on free swimming epibenthic organisms due to their mobility and unpredictable behavior. The distribution of more sessile species (e.g., worms, bivalves, and snails) is more meaningful as these organisms, instead of escaping, are forced to deal with changes in their natural environment. Nonetheless, we have collected comparative data on the distribution of motile organisms at the Exxon Ice Island site and in its vicinity which are discussed here.

The presence of several dead isopods and amphipods may explain the lower densities of these animals adjacent to the Ice Island in July. But these lower densities were limited to within 150 m of the ice edge. At DS-6, 150 m distant, no dead amphipods or isopods were seen, and the density of these organisms had increased slightly.

By November the effects the Ice Island had on the distribution of isopods, mysids, or amphipods appeared somewhat diminished. Mysids and amphipods were abundant but only a few isopods were noted by divers. In November, 1978 we found isopods abundant here and calculated their density to be between 4 and $8/m^2$.

The clingfish Liparis herschelinus was seen in the adult stage and as numerous juveniles in November, 1978. Another species of fish, Artediellus scaber was also collected then. No fish were seen at any of the sites in July or November, 1979, but they may have been missed in our sampling effort. Reimnitz (1979) photographed an arctic cod (Boreogadus saida) under the ice pedestal (Fig. 12) in July which may indicate that not all species were affected.

Amphipods were seen and collected in July and November, 1979, but were not reported in November, 1978. It is quite probable some small varieties were present but because a trowel was used to make the cores, they avoided collection. The airlift sucks in water at the water-bottom interface, adding animals from the lower water column to the sample. These small epibenthic animals (copepods, most amphipods, mysids, etc.) are subtracted from the core sample in the lab. When a trowel core is made, these epibenthic animals are absent.

The two animals that appeared most diminished at sites close to or covered by the Ice Island (DS-2,3,4) were the moon snail Polinices pallidus and the tubeworm Ampharete vega. Polinices was commonly observed in November, 1978. Only a few juvenile snails were seen at Dive Sites 2, 3 and 4. Several dead individuals were noticed by divers at DS-4 in July.

Ampharete worm tubes were widespread at DS-1 in November, 1978. They were also abundant at all other sites except Dive Sites 2, 3, and 4 which had previously been under the Ice Island or on its fringe. Only a few worm tubes were seen at DS-2 and DS-4 and none at DS-3. This suggests that the presence of ice on (or near) the sediment effectively eliminated this species in the ice contact area. The core samples confirm this observation. (Table 4A). The density of Ampharete at DS-2 was 16.7/m^2, at DS-3 zero, and at DS-4, 50/m^2. At DS-5, 300 m west of the Ice Island center, Ampharete tubes were abundant and their density, based on core samples, was 1916.7/m^2.

Benthic Infaunal Biota

A total of thirty-two species were collected in all from November, 1978, July, 1979 and November, 1979. Nineteen of the species were polychaete worms. The molluscs had the next largest representation with seven species. These two groups accounted for most of the total biomass in the samples. Total mean density and biomass for each species at each of the sampling sites are given in Table 4A and 4B. Using these tables it is possible to follow any organism of interest through the seasons or sites to observe population patterns. The Dive Sites in the tables are listed in order beginning with DS-1, the 1978 control site 30 m north of the center of the Ice Island, to DS-7, 500 m west of the center.

Foraminifera

In November, 1978, one species of foram (Type B) was collected consistantly. This species was collected again in November, 1979 but a second species (Type A) was also present in core samples collected in July and November. Both types exhibited much lower densities at Dive Sites 2, 3, and 4 than either the control site (DS-1) or DS-5, located 300 m distant from the Ice Island center.

Table 4A. Mean densities of the invertebrates sampled at each of the Dive Sites. These data are calculated from either five or six .01 m² x 10 cm cores taken at the sites.

	Nov., 78[1]	Nov., 79[2]		July, 79[3]	Nov., 79[4]	July, 79[4]	
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7
	N/m²	N/m²	N/m²	N/m²	N/m²	N/m²	N/m²
FORAMINIFERA							
TYPE A		16.7	16.7	25.0	50.0		
TYPE B	66.7	16.7			100.0		
NEMATODA		33.3		25.0	83.3		20.0
NEMERTEA					50.0	40.0	20.0
ANNELIDA							
Ampharete vega	183.3	16.7		50.0	1916.7	360.0	420.0
Chaetozone setosa	150.0	16.7		25.0	533.3	800.0	420.0
Chone duneri					50.0		
Chone sp.					33.3		20.0
Eteone longa			16.7		66.7	40.0	
Exogone naidina				25.0	16.7		
Exogone sp.				25.0			20.0
Haploscoloplos elongatus	16.7						
Ophryotrocha sp.				25.0			40.0
Orbinia sp.					16.7	80.0	20.0
Orbiniidae fragments					0.0	0.0	
Prionospio cirrifera	316.7		100.0		150.0	400.0	20.0
Pygospio elegans							

Table 4A, continued

	Nov., 78[1]	Nov., 79[2]		July, 79[3]	Nov., 79[4]	July, 79[4]	
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7
	N/m²	N/m²	N/m²	N/m²	N/m²	N/m²	N/m²
Scolecolepides arctius	16.7	16.7	33.3			20.0	
Scoloplos sp.					50.0		
Scoloplos armiger		33.3	16.7			80.0	20.0
Spio filicornis		66.7			133.3	80.0	
Terebellides stroemi					33.3	40.0	260.0
Tharyx sp.					66.7	20.0	
Travisia forbesii		16.7	16.7		83.3	20.0	
<u>OLIGOCHAETA</u>					33.3		
<u>MOLLUSCA</u>							
GASTROPODA							
Cylichna occulta	33.3		16.7			20.0	20.0
Retusa obtusa	16.7				16.7		20.0
BIVALVIA							
Boreocola vadosa	400.0	816.7	50.0	50.0	333.3	580.0	260.0
Portlandia arctica	16.7						20.0
Portlandia intermedia	83.3	33.3	66.7		16.7	100.0	20.0
<u>ARTHROPODA</u>							
CRUSTACEA							
OSTRACODA	233.3	283.3	1066.7	75.0	450.0	540.0	80.0

Table 4A, continued

	Nov., 78[1]	Nov., 79[2]		July, 79[3]	Nov., 79[4]	July, 79[4]	
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7
	N/m^2	N/m^2	N/m^2	N/m^2	N/m^2	N/m^2	N/m^2
PRIAPULIDA							
Halicriptus spinulosus				50.0	16.7	60.0	40.0

Footnotes
1. Before Island was built.
2. Previously under the Ice Island.
3. Close to edge or previously under Ice Island.
4. Down current (west) from Island. Never under the Ice Island.

Table 4B. Mean biomass of the invertebrates sampled at each of the Dive Sites. These data are calculated from either five or six .01 m^2 x 10 cm cores taken at the sites.

Organism	Nov., 78[1]	Nov., 79[2]		July, 79[3]	Nov., 79[4]	July, 79[4]	
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7
	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
FORAMINIFERA							
TYPE A		0.02	0.02	0.03	0.05		
TYPE B	0.07	0.02			0.03		
NEMATODA		0.03		0.05	0.05		0.02
NEMERTEA					0.90	0.54	0.20
ANNELIDA							
Ampharete vega	2.47	0.02		0.08	18.45	6.18	7.30
Chaetozone setosa	2.38	0.36		0.10	7.23	19.04	3.90
Chone duneri					0.03		
Chone sp.					0.03		0.02
Eteone longa			0.07		0.10	0.02	
Exogone naidina				0.03	0.02		
Exogone sp.				0.03			0.02
Haploscoloplos elongatus	0.02						
Ophryotrocha sp.				0.03			0.04
Orbinia sp.					0.33	1.14	0.44
Orbiniidae fragments					0.03	0.52	
Prionospio cirrifera	2.67		0.07		0.43	2.20	0.02
Pygospio elegans						0.08	

Table 4B, continued

Organism	Nov., 78[1]	Nov., 79[2]		July, 79[3]	Nov., 79[4]	July, 79[4]	
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7
	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
Scolecolepides arctius	0.80	0.67	1.15			0.76	
Scoloplos sp.					0.03		
Scoloplos armiger		0.05	0.02			2.02	0.02
Spio filicornis		0.07			0.08	0.10	
Terebellides stroemi					0.03	3.96	0.12
Tharyx sp.					0.05	0.02	
Travisia forbesii		0.07	0.03		0.32	1.92	
<u>OLIGOCHAETA</u>					0.02		
<u>MOLLUSCA</u>							
GASTROPODA							
Cylichna occulta	0.48		0.02			0.02	0.48
Retusa obtusa	0.07						
BIVALVIA							
Boreocola vadosa	0.38	0.75	0.03	0.10	0.17	0.34	0.16
Portlandia arctica	5.08						0.06
Portlandia intermedia	0.67	0.13	0.30		0.05	2.28	0.02
<u>ARTHROPODA</u>							
CRUSTACEA							
OSTRACODA	0.15	0.13	0.48	0.03	0.13	0.28	0.08

Table 4B, continued

Organism	Nov., 78[1]	Nov., 79[2]		July, 79[3]	Nov., 79[4]	July, 79[4]	
	DS-1	DS-2	DS-3	DS-4	DS-5	DS-6	DS-7
	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2	g/m^2
PRIAPULIDA							
Halicriptus spinulosus				20.20	1.07	0.42	3.74

Footnotes 1. Before Island was built.
2. Previously under the Ice Island.
3. Close to edge or previously under Ice Island.
4. Down current (west) from Island. Never under the Ice Island.

Nemertea

No nemertean worms were in the November, 1978 samples nor the three sites that fell under, or very close to the Ice Island (DS-2,3,4). The areas away from the Island in both November and July, 1979 had a small but consistent representation of this group.

Polychaeta

Polychaete worms are divided into two large groups; Errantia (motile) and Sedentariate (non-motile). Of the nineteen species of worms represented in our samples, all but three were from the Sedentariate group. As could be predicted, ice sitting on the sediment this group inhabits had an adverse effect. However, a few individuals representing eleven species were found alive in the samples from sites that had been under or very near to the Ice Island (DS-2,3,4).

In July, 1979, three of the five core samples from the site nearest the Ice Island (DS-4) contained deteriorating worms. The decomposing worms were still identifiable by their setae and general form to be the species Ampharete vega and Chaetozone setosa. Other animals in the same cores were well preserved indicating it was not poor sample treatment.

Reimnitz et al. (1979) refers to the wide base of the Ice Island as the ice pedestal. His idealized sketch of the shape of the Ice Island shows the ice pedestal extending further outward than the surface ice overhang. If this is the case then it is possible that DS-4, although 25 m from the Island's edge in July, actually was in close contact with the pedestal earlier. Thus the cores with deteriorating animals may have been in contact with the ice at some point, while the others were either just beyond the edge of the ice foot, or under an area of ice that was lifted well above the substrate.

Polychaete worms at DS-2 and DS-3 showed much smaller densities and biomass than Dive Site 5, located outside of the Ice Island perimeter. The samples taken at the pinger-marked center (DS-2) and 140 m to the west (DS-3) contained portions of deteriorated polychaete flesh. These materials appeared more decomposed than seen in July and were only recognized to be of polychaetes because of the setae present. Polychaetes at DS-3 showed more decomposition than those at DS-2. This may be because this area was under ice longer due to the uneven decay of the Ice Island. The Island eroded away from the northeast side (Reimnitz, et al., 1979) which indicates that the seafloor nearest the Island center was washed with waters of a normal salinity and temperature, and was ice free before the site 140 m west of the center.

Figure 9 gives a graphic representation of the total mean density and biomass of the polychaete worms at each sampling site. The sites are arranged as in Tables 4A and 4B, from the island center to the sites furthest west of the center. The three sites sampled in 1979 that were either under or closest to the Ice Island had a diminished polychaete fauna. It is interesting to note however, that some individuals of this sedentary group did survive.

Gastropoda

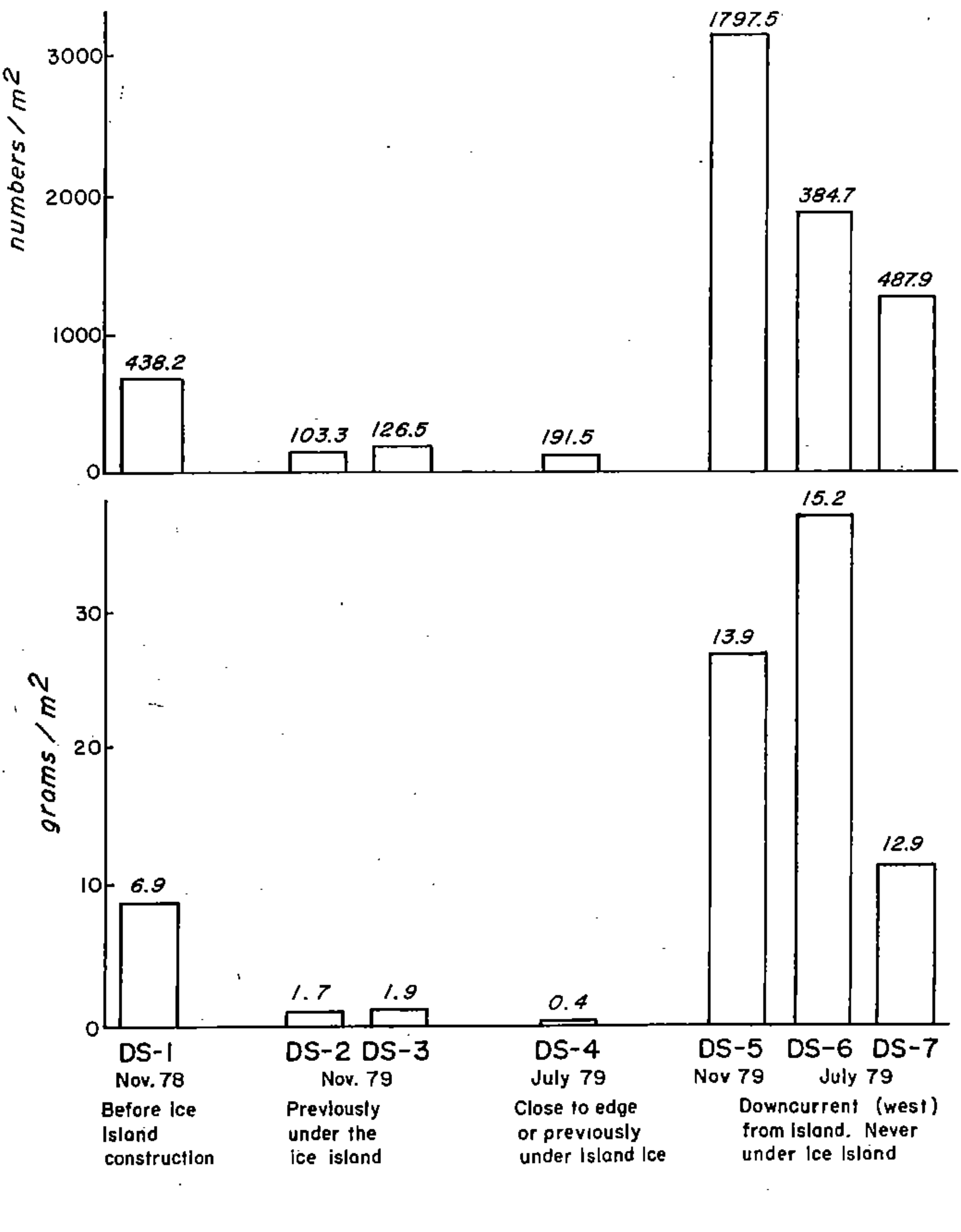
This group was not prominant in our samples. The species Cylichna occulta and Retusa obtusa, both sediment dwellers, were represented. A few Cylichna occulta were found at DS-3 in November, 1979 but all other specimens came from either November, 1978 or sites from 1979 that were never under the Ice Island.

Bivalvia

This taxonimic group was represented by three species. The tiny clam Boriocola vadosa was very numerous and consistently distributed in the samples. In Dunton (1979) this species was called Mysella sovalilei. A name change by the molluscin taxonomist F. R. Bernard has been officially accepted, so we are using the new name. Live specimens of B. vadosa and Portlandia intermedia were sampled from DS-2 and DS-3, both which were previously covered by the Ice Island. B. vadosa was found at all sites, but in markedly reduced quantities at DS-3 and DS-4. In November, 1979 at DS-2 this bivalve was found in remarkably high densities. This is puzzling, and will be discussed later.

In July, 1979 many clams of the species Boreocola vadosa and Portlandia spp. were found gaping and in a deteriorated state at DS-4. But in the two sites distant from the Island, DS-6 and DS-7, these bivalves were healthy. More gaping, dead individuals were found in samples collected in November, 1979 from sites that were previously under the Ice Island. Again as in the polychaetes, it was the site west of the center of the Island (DS-3) that

Figure 9. Mean density and biomass of polychaete worms at the various sampling sites. The number on top of each column is the standard deviation.


numbers / m2
3000
2000
1000
0
438.2
103.3
126.5
191.5
1797.5
384.7
487.9
grams / m2
30
20
10
0
6.9
1.7
1.9
0.4
13.9
15.2
12.9
DS-1
Nov. 78
Before Ice Island construction
DS-2 DS-3
Nov. 79
Previously under the ice island
DS-4
July 79
Close to edge or previously under Island Ice
DS-5
Nov 79
DS-6 DS-7
July 79
Downcurrent (west) from Island. Never under Ice Island

showed the most bivalve deterioration. One of the Boreocola vadosa clams collected at DS-2 was full of tiny, immature clams, indicating that reproduction was still occurring in this species despite the effects of the Ice Island.

In Figure 10 the mean density and biomass of the bivalves at each sampling site is presented. Density and biomass do not follow the same patterns at each site in this figure. Where the densities are high and biomass low (DS-2,5,7) a large portion of the samples are Boreocola vadosa, a tiny clam. When the densities are low but biomass is high (DS-1), more of a larger species, Portlandia spp., are present.

Ostracoda

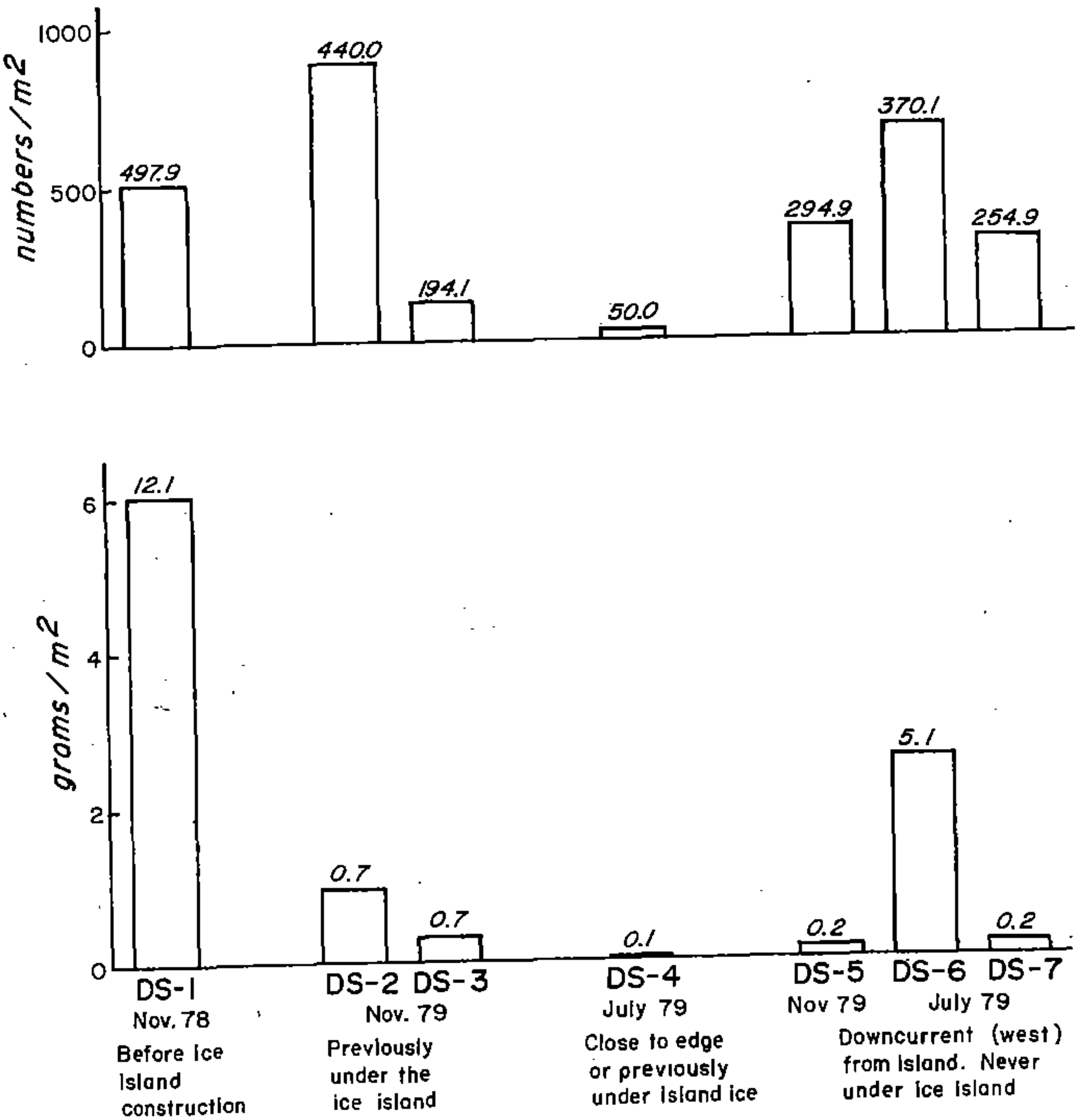
This crustacean is a tiny, shell covered animal that is quite abundant in all the samples. Large numbers of this group were collected and each individual was opened and inspected since up to 75% of them contained only chitonous remains. We believe that this is a normal cycle and not related to environmental stress caused by the Ice Island. In fact, the densities of these animals in November at sites previously under the Ice Island (DS-2, DS-3) are as high or higher than the densities at other locations.

Summary and Comparative Analysis

Figure 11 gives a graphic representation of the total mean density and biomass of the infaunal organisms at each sampling site. The densities and biomass of the three sites that were previously under or on the edge of the Ice Island (DS-2,3,4) are lower than in the sites away from the Island. The density of DS-2 was not significantly different from DS-1 or DS-7. The biomass of Dive Sites 2, 3, and 4 were not significantly different from each other but were significantly lower than the biomass at all other sites not under or on the edge of the Ice Island (ANOV, SNK).

It is not possible to determine from the core samples the actual cause of death in the infaunal organisms collected at Dive Sites 2, 3, and 4. Reimnitz et al. (1979) reported that along most of its perimeter, the ice pedestal was slightly raised off the seafloor, forming a basal gap from 3 to 25 cm (Fig. 12). Thus, it is possible that some benthic organisms were not killed by freezing, but as a result of being subjected to supercooled waters of high salinity concentration. These effects, however,

Figure 10. Mean density and biomass of bivalves at the various sampling sites. The number on top of each column is the standard deviation.



numbers / m2
1000
500
0
497.9
440.0
194.1
50.0
294.9
370.1
254.9
grams / m2
6
4
2
0
12.1
0.7
0.7
0.1
0.2
5.1
0.2
DS-1
Nov. 78
Before ice island construction
DS-2 DS-3
Nov. 79
Previously under the ice island
DS-4
July 79
Close to edge or previously under island ice
DS-5
Nov 79
DS-6 DS-7
July 79
Downcurrent (west) from island. Never under ice island

Figure 11. Total mean density and biomass of infaunal organims at the various sampling sites. Numbers on top of the bars are the standard deviation. See page 47 for explanation of dotted bars.

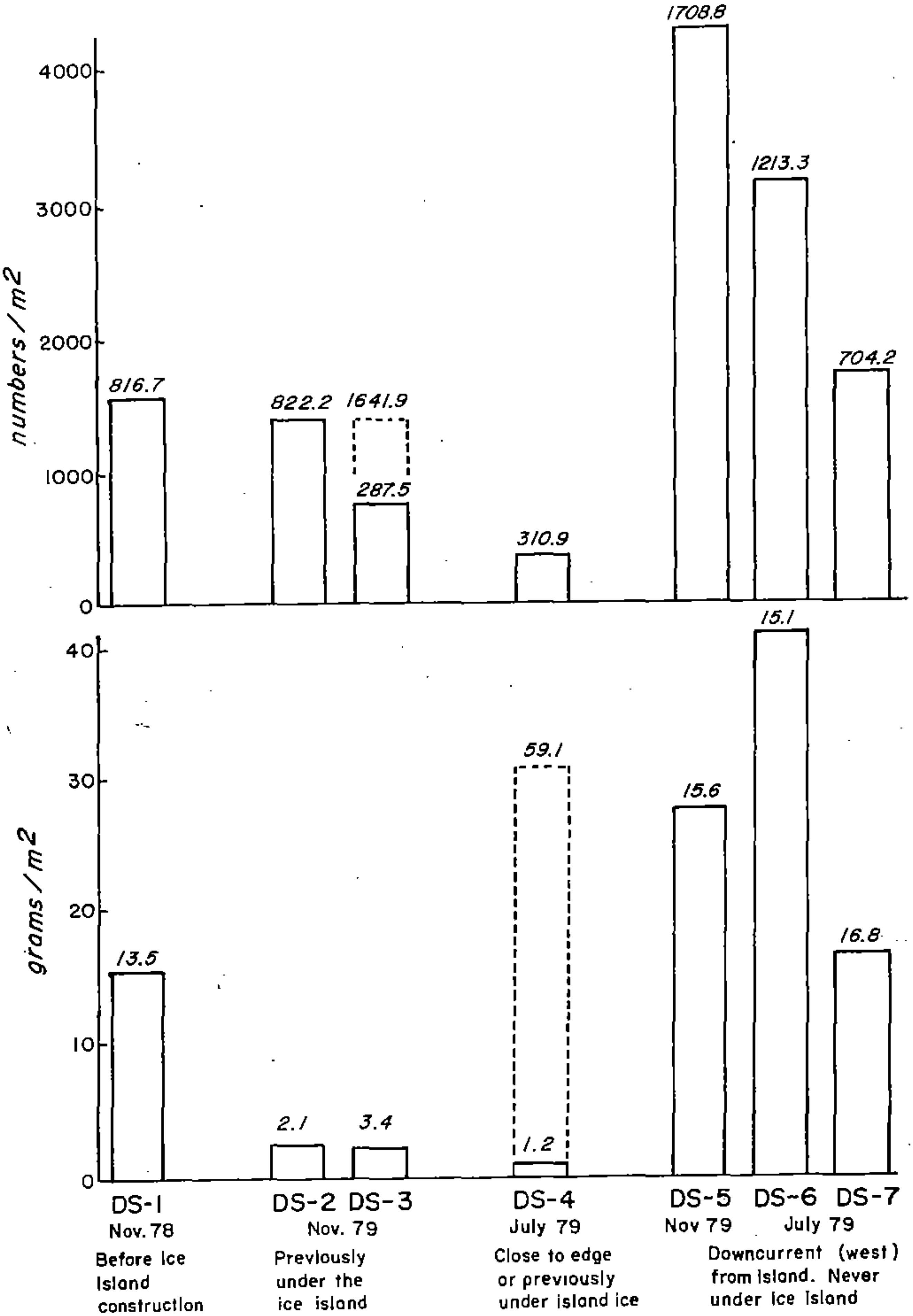
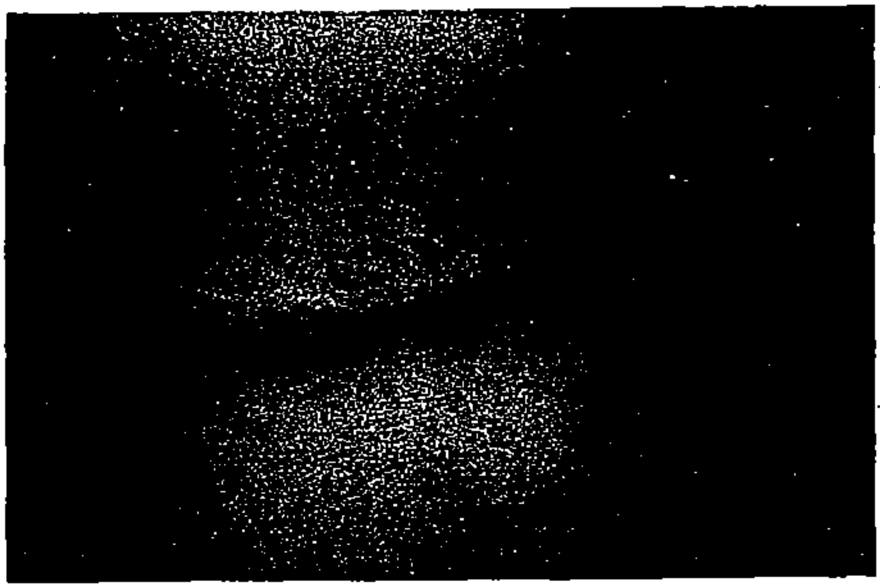

numbers / m2
4000
3000
2000
1000
0
816.7
822.2
1641.9
287.5
310.9
1708.8
1213.3
704.2
grams / m2
40
30
20
10
0
13.5
2.1
3.4
59.1
1.2
15.6
15.1
16.8
DS-1
Nov. 78
Before Ice Island construction
DS-2 DS-3
Nov. 79
Previously under the ice island
DS-4
July 79
Close to edge or previously under island ice
DS-5
Nov 79
DS-6 DS-7
July 79
Downcurrent (west) from island. Never under ice island

Figure 12. Underwater photograph of the ice pedestal, slightly raised above the seafloor. An arctic cod (Boreogadus saida) is shown at center under ice rim. From Reimnitz, et al. (1979).



were restricted to the sites under or at the edge of the Ice Island, as infaunal organisms were not affected at any of the other sites. Dive Site 5, 300 m from the Ice Island center, had a healthy and normal population of animals as did other sites west of DS-5.

It is difficult to determine from the core data which organisms survived the effects of the Ice Island due to the nature of the sampling effort. At the three Dive Sites located under or at the edge of the Ice Island (DS-2,3,4) deteriorating bivalves and polychaetes and live individuals of the same species were found in the cores. The smallest density and biomass of animals occurred in the cores collected in July at DS-4 (Fig. 11). The sites sampled in November (DS-2 and DS-3), two months after the Island disappeared, had greater numbers of live animals, and several species were more abundant than at the control sites away from the Island. At DS-2 the clam Boreocola vadosa was present in extremely high numbers but in the same core many deteriorating individuals were found. This suggests that some members of this species either survived under the Ice Island or were present due to subsequent recruitment.

In this respect, the repopulation of Dive Sites 2 and 3 may have occurred as a result of organisms being washed into the area from surrounding regions. This may have been partially accomplished by the violent fall storms that occurred before freeze-up in late October. Most of the living species here included the bivalves Boreocola vadosa and Portlandia intermedia and ostracods.

In Figure 11, the dotted area on the DS-3 density bar indicates the actual mean number of individuals found in the cores at this site. The high standard deviation of 1641.9 indicates that these samples have a high variability between means. This was caused by a single species in a single sample. In this sample, a high density cluster of small ostracods was collected, which radically increased the number of animals found in that core from $700/m^2$ to $4700/m^2$. The other five samples from that site were homogeneous and had low numbers of all animals. Animals can and do occur in concentrated clusters, but we believe if a large quantity of cores were taken at DS-3 that we would not find an average approaching $4000/m^2$. The solid bar shows the mean of this site without the ostracods from the one sample. Note the standard deviation is much lower (287.5).

The dotted portion on the DS-4 biomass bar shows the increase in grams/m^2 caused by a single huge priapulid. The solid bar is the mean biomass after this one animal is subtracted. The biomass of this priapulid (119.4 g/m^2) was so huge compared to the rest of the sample that it erroneously made the sample look populated, which in fact it wasn't. Again, it is rather doubtful that there is an average priapulid biomass of 119.4 g/m^2 at this site.

Reproduction and Size Classification of the Polychaete Worms

Through this study and others, we have been given the opportunity to examine hundreds of individual polychaetes during the summer and winter months. It has become apparent that the most common species, Ampharete vega, Chaetozone setosa, Prionospio cirrifera, and Terebellides stroemi, have distinct size classifications. An age group we have called juvenile for all these species is a tiny consistently sized 2-4 mm individual, that is quite distinguishable from the next older group called young adults. The young adult group is the most variable in size and weight, encompassing those individuals that are not juveniles, nor adults. The adult group is defined for each species as the size in which a large portion of individuals are gravid. On a species by species basis this is a rather consistent (±2 mm) length and weight (±0.003).

Table 5 shows the percent of polychaetes within the three classes of maturity and the percent of adult worms that were gravid at each Dive Site. The November, 1978 (DS-1) samples showed a large percent of adults, some young adults and few juveniles.

All three sites in July (DS-4,6,7) showed adults to be between 60% and 70% of the sampled population. Juveniles were the next most common group composing between 20% and 38.7% of the total. No young adults were collected from DS-4 or DS-7 in July. The July site closest to the island (DS-4) appeared to have similar ratios to the sites further from the island, with one exception. Of the 66.6% representation of adults, not a single individual was gravid. The other sites (DS-6 and DS-7) showed 39.3% and 51.0% of the adults to be gravid. In a reproductive state these worms' bodies and parapodia swell up with hundreds of eggs. It seems probable

Table 5. The percent of polychaetes within three classes of maturity, and the percent of gravid adult worms from the sampling sites.

Number of meters from Island center	Site & Date	% of juveniles (length 2-4 mm)	% of young adults	% of adults	% of adults that are gravid
30 m north	1-Nov. 78	4.8	10.5	85.7	79.6
pinger-marked center	*2-Nov. 79	20.0	60.0	20.0	0
140 m west	*3-Nov. 79	8.3	58.3	33.3	0
225 m west	*4-July 79	33.3	0	66.6	0
300 m west	5-Nov. 79	43.4	10.1	46.5	38.0
350 m west	6-July 79	20.0	17.8	62.2	39.3
≈500 m west	7-July 79	38.7	0	61.3	51.0

*Indicates sites that were previously covered by the Ice Island or near its edge.

that a worm in this condition is in a weakened state and would be less tolerant to environmental stress. Among the deteriorated flesh collected at DS-4 were eggs indicating one or more of the succumbed individuals were gravid.

The November, 1979 sites that were previously under the Ice Island (DS-2, DS-3) showed a majority of the samples (60% and 58.3%) to be young adults. Adults were represented by 20% and 33.3% while juveniles comprised 20% and 8.3% respectively. This higher proportion of young adults is very interesting and different from all the other sites. It appears that juveniles have been successfuly recruited into this area after the Ice Island decayed and have settled, growing to the young adults stage in September, October and part of November. It is also likely that the young adult stage is a particularly hardy stage in the polychaete life cycle allowing a larger proportion of this age group to survive under the Ice Island. It is very interesting to note that not one of the adults in either sample (DS-2 or DS-3) was gravid. Probably they are hardy individuals that survived from under the Ice Island. Juveniles were present even though no gravid adults were found. This implies that recruitment of this age group from surrounding areas is occuring. Dive Site 5, located outside of the Island area, showed almost equal numbers of adults and juveniles and few young adults. This high proportion of juveniles is surrounding areas would be a good source of worms for further repopulation in the Ice Island area. Thirty-eight percent of the adults at DS-5 were gravid.

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