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PRELIMINARY SURVEY OF BURROWING INFAUNA IN PORT GARDNER

by

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PRELIMINARY SURVEY OF BURROWING INFAUNA IN PORT GARDNER

INTRODUCTION

Concerns have been expressed recently about the possibility that some benthic organisms may burrow in the sediments of Puget Sound deeper than previously suspected and, hence, potentially compromise the integrity of the clean cap material of the proposed Navy Homeport RADCAD (Revised Application Deep Confined Aquatic Disposal) site in Port Gardner. Evidence indicates that a species of burrowing shrimp (*Axius serratus*) found off the east coast of Canada can burrow as deeply as 3 m, especially in areas of organically enriched sediments (Pemberton et al. 1976). A related species of burrowing thalassinid shrimp (*Axiopsis spinulicauda*) found in Puget Sound has been observed by us in bottom trawl catches from Port Gardner and has been caught in box cores collected by the U.S. Army Corps of Engineers (COE) (David Kendall, Seattle District COE, personal communication).

To address concerns about deep burrowing organisms and their potential impact on the disposal and capping of contaminated sediments, the COE initiated a short-term project to sample these organisms in Port Gardner. The specific objectives of this project were as follows:

1. Determine the presence of organisms or burrows of deep-burrowing species in the area of the deepwater RADCAD disposal site.
2. Determine the depth to which animals burrow in the area of the site.
3. Determine, to the extent possible, the abundance and spatial distribution of burrows and burrowing organisms in the area of the disposal site.

SAMPLE SITES AND METHODS

Fourteen stations (Fig. 1) in and around the Port Gardner RADCAD site were sampled in early March 1987 for burrowing organisms using two bottom coring devices. The first coring device was a Gray-O'Hara box corer (Fig. 2, top), which collected cores of 0.07 m^2 surface area up to 50 cm in depth. This device was used to "prospect" for areas with high surface burrow densities. The second coring device was a Kasten gravity corer (loaned by PMEL/NOAA; Fig. 2, bottom), which took cores of 0.02 m^2 surface area up to a maximum depth of 3 m. This corer was used to in an attempt to measure the burrowing depths of the resident animals. The specific location of each coring station is summarized in Appendix Table 1.

The depths to which animals burrow were determined by visual inspection of all cores and by sieving the majority of the cores. The box cores were coarsely sieved through a basket with openings approximately 10 X 10 mm (Fig. 3, top). Approximately half of the Kasten cores were sieved through a set of two screens, the bottom screen having a mesh size of 1.7 mm (Fig. 3, bottom).

RESULTS

A variety of animals were caught by both coring devices, including burrowing shrimp (*Axiopsis spinulicauda*), burrowing sea cucumbers (*Molpadia* sp.), polychaetes (a variety of tube-dwelling and free-living forms), bivalves (*Lucinoma*, *Macoma*, *Solemya*), brittle stars, sipunculids, and an echiuroid worm (Table 1). Specific physical data were collected on depth of core penetration, number of surface burrows observed, and depth of the reduced organic

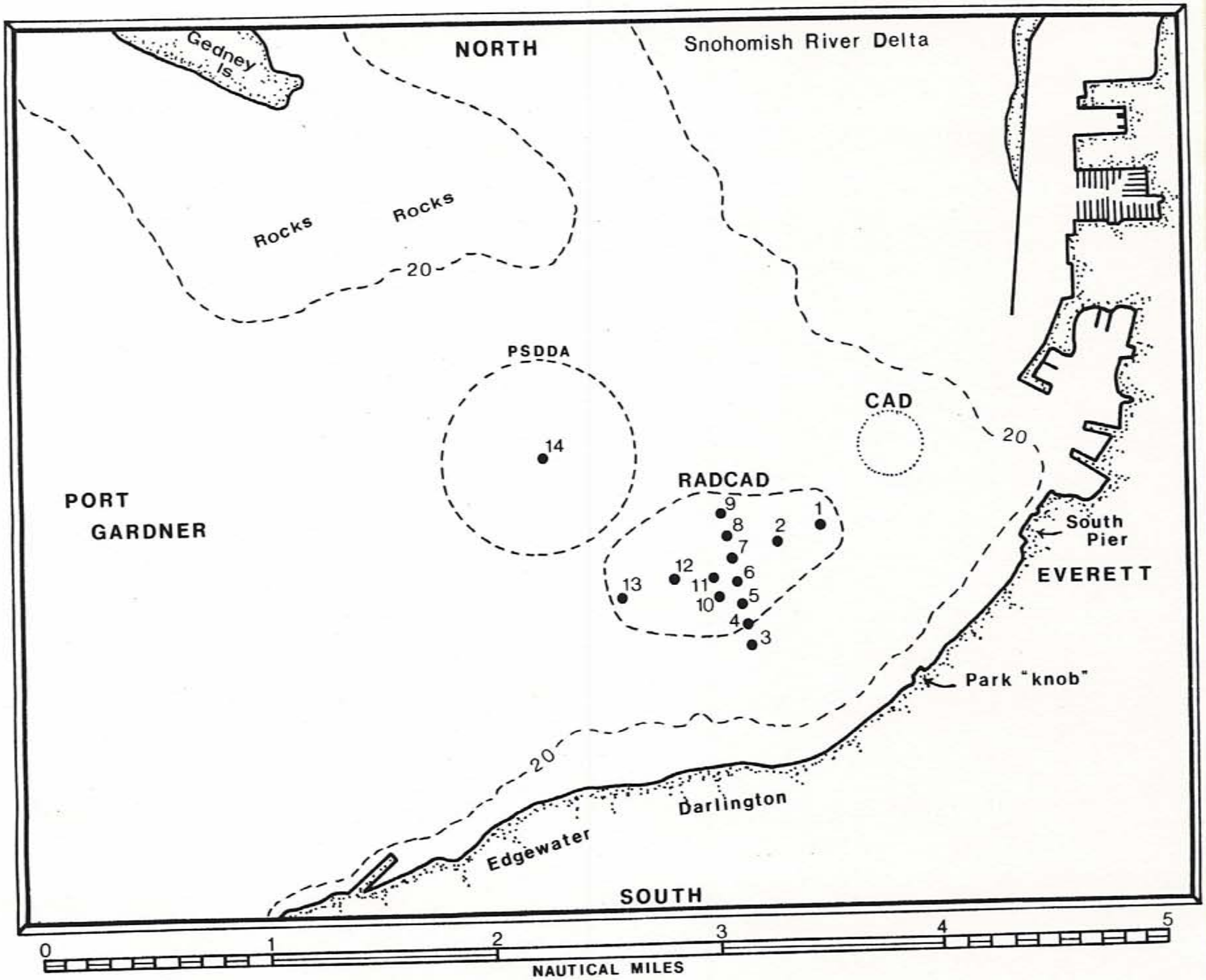

Figure 1. Locations of the stations sampled in Port Gardner with the box and/or Kasten corers in March 1987.

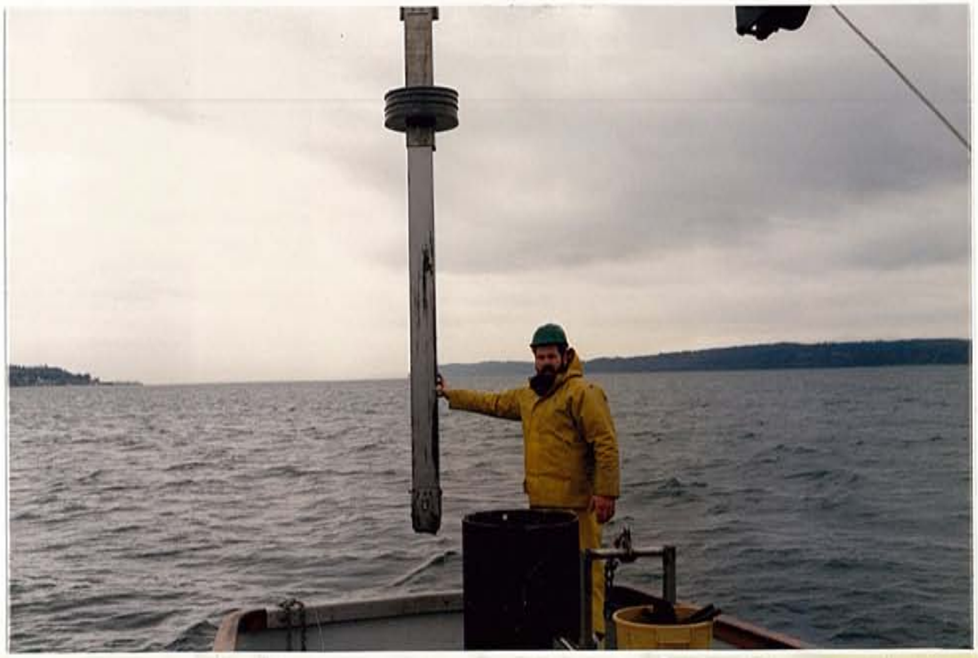

Figure 2. Photographs of the box corer (top) and Kasten corer (bottom) used in this study.

Figure 3. Photographs of the basket used to sieve the box core samples (top) and the pair of screens used to sieve a portion of the Kasten core samples (bottom).

Table 1. List of macrofauna found in the box and Kasten core samples from Port Gardner in March 1987.

Faunal group	Description
Crustaceans	Burrowing shrimp, *Axiopsis spinulicauda*
Echinoderms	Burrowing sea cucumber, *Molpadia*, brittle stars class Ophiuroidea
Molluscan bivalves	Clams, *Macoma* sp., *Yoldia* sp., *Lucinoma annulata*, *Solemya* sp., and small unidentified
Annelids	Burrowing marine polychaetes including *Travisia* sp., various tubeworms (e.g., terebellids and bamboo worms) and free-living forms (e.g., nereids and scale worms)
Sipunculids	Unidentified peanut worm
Echiuroids	Unidentified echiuroid worm

layer, and notations made on depth and occurrence of macrofauna caught in each core (Appendix Tables 2 and 3).

The maximum depth of occurrence of any macrobenthic organism was 72 cm (a burrowing cucumber; Fig. 4), but the deepest that animals occurred in most Kasten cores was 50-60 cm (small polychaetes). Only one burrowing shrimp was found in a Kasten core sample. This shrimp was found at the surface of an obvious burrow descending to 43 cm before curving out of the core. Several other burrows suggestive of *Axiopsis* activity were found to depths of about 60 cm.

A visual inspection was also made of each Kasten core for burrows. Burrows of all sizes were found as deep as 2 m (the maximum depth sampled), but burrows deeper than about 1 m could have been relics of past activity since many of the larger burrows had been filled with loosely consolidated silt and clay. Visual inspections also showed that, on the average, the upper 80 cm of the Kasten cores contained sand and wood chips while core depths below 1 m contained little or no sand or wood chips. The upper 80 cm also showed signs of reduction based on varying degrees of black coloration.

Estimates of the average abundances of burrows and macrofauna were calculated from the 28 box core and 31 Kasten core samples. The calculated average number/m^2 for each core type (summarized in Table 2) showed that the macrofaunal density estimates from the box cores were consistently higher than from the Kasten cores, but that the patterns of relative density between the faunal groups are the same for both devices.

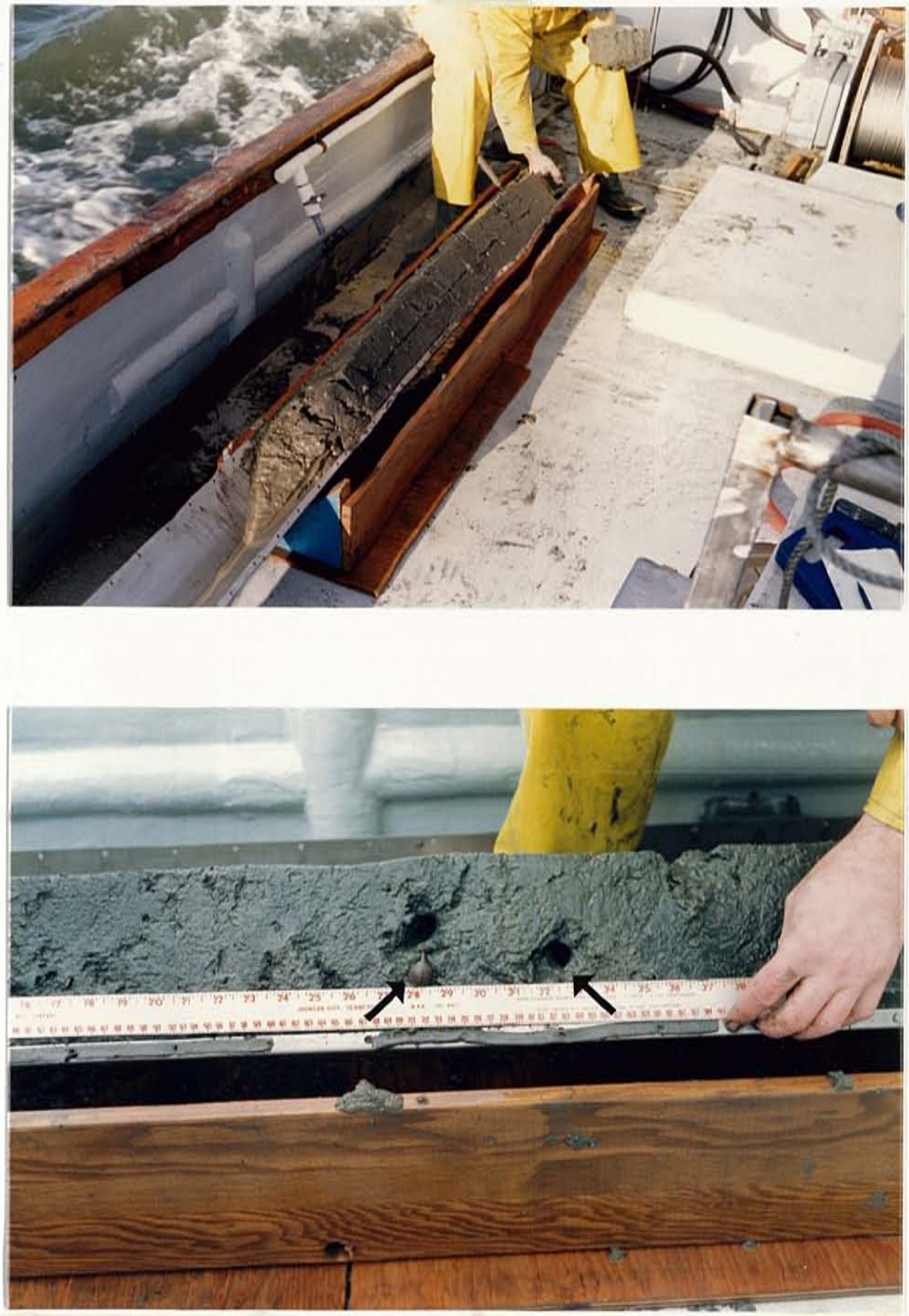

Figure 4. Photographs of Kasten core samples showing a representative core sample approximately 2 m in length (top) and a close-up of a section of a core (bottom) showing a burrowing sea cucumber, *Molpadia*, at a depth of 72 cm (left arrow) and a portion of a burrow at 82 cm (right arrow).

Table 2. Average core depths, depths of the reduced organic layer, and estimated densities of surface burrows and macrofaunal animals as indicated by box and Kasten core samples in and around the Navy RADCAD site collected in Port Gardner during March 1987.

Parameter	Box core 28 samples of 0.07 m^2 each	Kasten core 31 samples of 0.02 m^2 each
Average core depth (range)	32 cm (15-45)	172 cm (100-202)
Estimated average depth of reduced organic layer (range)	Not measured	83 cm (50-120)
Average number surface burrows	8.6/m^2	Not measured
Average number of macrofauna (#m/^{2})		
Axiopsis	5.1	1.5
Molpadia	8.0	3.0
Travisia	3.4	1.5
Sipunculids	2.2	1.5
Echiuroids	0.6	0

Although about 30 samples were collected with each coring device, density estimates such as those presented above are far from definitive since they were not collected randomly and the total surface area sampled was very small (box core = 1.96 m^2; Kasten core = 0.66 m^2).

DISCUSSION

A variety of organisms burrow and/or process sediments at significant depths (>20 cm) in the sediment column. The activities of these deep "bioturbators" include the formation and irrigation of burrows, activities that alter redox conditions and reaction rates (Aller and Yingst 1985; Aller et al. 1983), as well as flush dissolved chemicals and transport particles (e.g., from feeding depths below 20 cm to the sediment-water interface). The general effect of this bioturbation is to extend the reactive surface area of the seafloor, enhancing the rates and magnitudes of chemical reactions and fluxes to depths of 2 m or more in the sediment. Enhancement of reactions and fluxes is most marked when burrows are occupied, but passive physical irrigation of relict burrows may affect sediment chemistry as well (Ray and Aller 1985).

Deep bioturbators typically fall into one of three taxonomic groups: thalassinid shrimp, holothuroids, or large polychaete worms (Carney 1981). Each group may employ different burrowing and feeding strategies, yielding divergent sedimentary and chemical consequences.

Thalassinid shrimp are the deepest burrowers, attaining depths greater than 2 m (e.g., *Axius serratus*, Pemberton et al. 1976; Risk et al. 1978). For most thalassinids, typical (not maximal) burrowing depths are about 0.5-1.0 m (Dworschak 1983). Shrimp burrows often are U- or Y-shaped near the sediment surface, with burrow diameters on the order of 1-3 cm with well-oxygenated walls (Dworschak 1983). Deposit-feeding thalassinids, such as some *Callianassa* spp. and presumably *Axius*, continuously excavate at the bottom of their burrows, creating large burrow systems and ejecting amounts of sediment up to 500 g dry sediment per individual per day; Suchanek 1983). This excavation activity is size-selective, with finer particles ejected and coarser sediments retained in burrow galleries (Suchanek 1983; Posey 1986). Excavation rates of subsurface sediments are likely to depend at least on organism size, sediment organic carbon content (Cammen 1980) and seasonal temperature variation (Posey 1986). Many species of thalassinids, particularly those in the genus *Upogebia*, are presumably suspension feeders that pump surface waters through their deep burrow systems (Dworschak 1983; Suchanek 1983; Roberts et al. 1981). Burrow irrigation rates of about 7.5 l/hr have been calculated, resulting in significant fluxes of reduced pore-water chemicals into the water column (Waslenchuk et al. 1983). These shrimp also may cause significant oxygenation of deep sediments, which allows oxidation and mobilization of chemicals remaining in the solid phase under reducing conditions. Thus, thalassinids have distinct potential for transporting sediments and dissolved chemicals from depths of 1-2.5 m to the sediment surface. The quantitative importance of these advective activities will depend on the species present and the population densities.

The deep-feeding holothurian, *Molpadia*, will construct impermanent burrows with no apparent burrow wall. *Molpadia* feeds head-down, selectively processing fine particles at least as deep as 30 cm and depositing them at the surface uncompacted. The coarse particles remain at depth, forming pockets of sorted sediment. *Molpadia* densities may reach 9 individuals/m^2, with each holothurian transporting 2,250 cm^3/day from 30 cm depth to the surface (Rhoads and Young 1971). Irrigation rates are unknown. *Molpadia*, although often a smaller animal than the thalassinids, will transfer a substantial amount of sediment to the surface from a depth of at least 30 cm.

Polychaetes are also potential deep burrowers. *Heteromastus filiformis* (Capitellidae) and *Clymenella* (Maldanidae) construct irrigated mucus tubes from which they feed head-down to 30 cm on sedimentary particles and detritus (Mangum 1964; Aller and Yingst 1985). The ingested material is then processed into fecal pellets (0.5 mm long, *Heteromastus*) and deposited at the surface. *Heteromastus*, which often ingests anoxic mud, reworks 1.2 cm^3/day per individual at population densities up to 105/m^2 (Aller and Yingst 1985; Thayer 1983). *Clymenella* transports 0.75 cm^3/day per individual at densities up to 675/m^2 (Thayer 1983). While irrigation is unmeasured for *Heteromastus*, *Clymenella* oxidizes its burrow with 3 ml of water/hour (Mangum 1964). Thus, while each individual polychaete reworks relatively little sediment, at the high densities often found, *Heteromastus* populations (912 liters/m^2/year) and *Clymenella* populations (170 liters/m^2/year) transport a substantial amount of sediment from 30 cm depth to the surface.

In summary, deep bioturbation activities of macrofauna can transport substantial amounts of particles and dissolved chemicals from depths of 0.3-2.5 m in the sediment. Rates will depend on the species and population densities of the organisms and the characteristics of the environment (sediment-carbon content, temperature, etc.). These organisms alter the sediment fabric (affecting sorting, porosity, and permeability) and stimulate microbial production deep in the sediment column.

CONCLUSIONS

1. A normal assemblage of macrofauna (including the burrowing shrimp, *Axiopsis spinulicauda*) is present within the boundaries of the RADCAD site.

2. The present distribution of smaller, more abundant burrowing animals appears to be restricted to the upper 80 cm, suggesting that their burrowing activity is also restricted to this level. A strong statement cannot be made concerning the burrowing depth of the larger organisms, including *Axiopsis* and *Molpadia*. Active or recent burrows also appear above 80 cm.

3. Both large and small burrows were present in the sediments down to 2 m depth (the maximum depth sampled) but these burrows could have been relics of past burrows.

4. This project provided some direct evidence that the depth of bioturbation in the RADCAD site is less than 1 m under the present conditions. The potential for deeper burrowing activity following the addition of organically rich dredged materials is unknown and depends on the behavioral characteristics of the species present combined with the physical structure of the disposal mound.

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APPENDIX TABLES

Appendix Table 1. Box and Kasten core station locations sampled in March 1987 in Port Gardner. See Figure 1 for the radar range locations.

Station number	Radar range markers and distances (N.M.)	Depth in meters
1	0.85 SW Corner S. Pier / 0.80 Park Knob	103
2	1.02 SW Corner S. Pier / 0.80 Park Knob	109
3	1.15 SW Corner S. Pier / 0.42 Darlington Knob	112
4	1.15 SW Corner S. Pier / 0.53 Darlington Knob	120
5	1.09 SW Corner S. Pier / 0.65 Darlington Knob	116
6	1.15 SW Corner S. Pier / 0.75 Darlington Knob	115
7	1.18 SW Corner S. Pier / 0.90 Darlington Knob	114
8	1.20 SW Corner S. Pier / 1.00 Darlington Knob	114
9	1.22 SW Corner S. Pier / 1.09 Darlington Knob	111
10	1.15 SW Corner S. Pier / 0.70 Darlington Knob	115
11	1.25 SW Corner S. Pier / 0.80 Darlington Knob	115
12	0.50 SW Corner S. Pier / 0.91 Darlington Knob	128
13	1.75 SW Corner S. Pier / 0.90 Shore at Edgewater	135
14	2.13 SW Corner S. Pier / 1.50 Shore at Edgewater	132

Appendix Table 2. Approximate core depths, number of surface burrows observed, and number of macrofauna found from the *box cores* collected in Port Gardner during March 1987. All samples were screened through a basket with a mesh size of 10x10 mm.

Station number	Approx. core depth (cm)	Number of surface burrows	Macrofauna
5 March 1987			
10	35	1	1 Sipunculid, 1 polychaete, 1 *Travisia*
10	30	0	1 Brittle star, several small polychaetes
11	40	2	3 *Axiopsis*, several nereid polychaetes
11	30	3	1 *Axiopsis*, 2 *Molpadia*, 1 *Travisia*
11	20	1	1 *Axiopsis*, 1 *Travisia*, 1 brittle star
2	35	0	None
2	45	0	1 Nereid polychaete
9	40	0	1 Polychaete
6 March 1987			
3	20	0	1 Sipunculid, 1 echiuroid
3	20	0	1 Sipunculid, 1 *Travisia*

Appendix Table 2, cont'd

Station number	Approx. core depth (cm)	Number of surface burrows	Macrofauna
4	20	0	1 *Macoma*, several nereid polychaetes
4	15	0	1 *Molpadia*
5	15	0	1 *Molpadia*, 1 *Macoma*
5	25	0	1 *Molpadia*, 1 *Lucinoma*
6	30	0	1 Polychaete
6	30	1	1 *Molpadia*, 1 sipunculid, 1 scaleworm
7	30	1	None
7	40	1	1 *Axiopsis*, 1 *Solemya*
8	40	1	2 *Molpadia*
8	40	1	1 *Axiopsis*
7 March 1987			
1	45	1	1 *Molpadia*
1	35	0	1 *Axiopsis*, 2 *Molpadia*
2	40	0	1 *Yoldia*, 1 *Lucinoma*
2	35	0	1 *Travisia*, 1 *Lucinoma*, 1 nereid polychaete
12	30	1	1 *Molpadia*, 1 terebellid polychaete
12	25	1	1 *Axiopsis*, 1 *Molpadia*, 1 bamboo worm

Appendix Table 2, cont'd

Station number	Approx. core depth (cm)	Number of surface burrows	Macrofauna
13	45	0	1 *Molpadia*
13	30	0	1 *Travisia*, 2 brittle stars

Appendix Table 3. Measured core depths, estimated depths of the reduced organic layer, and macrofauna observed at various depths from the Kasten cores collected in Port Gardner during March 1987. Approximately half of the samples were screened (10-cm sections) with a 1.7-mm sieve.

Station number	Core depth (cm)	Approx. depth of reduced organic layer (cm)	Macrofauna
Unscreened samples			
5 March 1987			
10	146	90	1 Polychaete, 10 cm
10	182	80	None
10	163	80	1 Sipunculid, 40 cm
11	190	90	None
6 March 1987			
8	202	70	1 *Axiopsis* at surface, burrow extending to 43 cm in core; 1 small polychaete, 60 cm
8	188	85	Small polychaetes, 30 and 60 cm
8	192	70	Small polychaete, 25 cm
8	199	80	None
8	191	65	Small polychaete, 40 cm
7 March 1987			
1	198	80	Nereid polychaete at surface; small polychaetes, 0-20 cm

Appendix Table 3, cont'd

Station number	Core depth (cm)	Approx. depth of reduced organic layer (cm)	Macrofauna
1	191	Not Measured	1 *Lucinoma*, 10 cm; 1 brittle star, 30 cm
1	181	80	None
1	188	100	1 Small polychaete, 40 cm
1	184	110	None
1	181	100	1 Nereid polychaete, 20 cm
Samples screened at 1.7 mm			
9 March 1987			
11	182	50	*Pectinaria*, 0-15 cm; small polychaete, 25-35 cm; nematode, 25-35 cm
11	128	50	*Macoma*, polychaetes, nemertine, 0-10 cm; small polychaetes, 20-50 cm
11	184	Not Measured	Small polychaetes, 0-10 cm; small polychaetes, 30-70 cm
11	184	80	Small polychaetes, 0-60 cm
11	155	50	Several *Macoma*, polychaetes, 0-10 cm; polychaete, 20-30 cm
1	184	Not Measured	Small clams, 0-10 cm; tubeworms, 0-20 cm; polychaetes, 30-40 cm; *Molpadia*, 72 cm (in burrow)

Appendix Table 3, cont'd

Station number	Core depth (cm)	Approx. depth of reduced organic layer (cm)	Macrofauna
1	143	90	Small clams, tubeworms, 0-10 cm; *Molpadia*, 10 cm; *Travisia*, small polychaetes, 10-20 cm
1	197	80	Small clams, tubeworms, 0-10 cm
1	100	100	Small clams, tubeworms, 0-10 cm; *Yoldia*, polychaetes, 10-20 cm
1	124	80	Small clams, tubeworms, 0-10 cm; small polychaetes, 10-40 cm
10 March 1987			
14	176	120	Small clams, tubeworms, 0-10 cm; polychaete, 30-40 cm
13	169	120	Small clams, polychaetes, 0-10 cm; small polychaetes, 10-30 cm; small polychaetes, 50-60 cm
13	169	80	Small clams, nereid polychaete, 0-10 cm; small polychaete, 20-30 cm
13	141	Upper 120 cm archived in freezer at Univ. Washington	
11	155	" " " " " " "	
1	162	" " " " " " "	