Exxon Valdez Oil Spill
Restoration Project Annual Report

Herring Bay Monitoring and Restoration Studies

Restoration Project 94086
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Herring Bay Experimental and Monitoring Studies

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Study History: A comprehensive assessment of coastal habitat was initiated as Coastal Habitat Study No. 1 in 1989 following the *Exxon Valdez* oil spill. In 1990, experimental studies began in Herring Bay, Knight Island, Prince William Sound, which were designed to compliment the overall monitoring program by experimentally assessing intertidal community dynamics and mechanisms of recovery. This experimental approach went beyond basic species inventories, allowing a more comprehensive assessment of the oil spill impacts on physical and biological interactions mediating community structure. The manipulative experiments were designed to evaluate the strength of important species interactions and the role of physical factors in community structure.

Abstract: Intertidal studies established in 1990 in Herring Bay, Prince William Sound in response to the *Exxon Valdez* oil spill continued through the 1994 field season. Examination of the dominant intertidal alga, *Fucus gardneri*, showed that in the high intertidal, reproductive plants had fewer receptacles per plant and egg settlement rates were lower at oiled than control sites. *Fucus* germlings were negatively affected by herbivores and desiccation. Excluding plants which lost thallus material, plants grew faster at oiled than control sites. Experiments employing biodegradable erosion control fabric mats to act as a substrate for *Fucus* germlings were initiated in 1993 on a sheltered rocky site which had been heavily oiled. Dense populations of *Fucus* had developed on the surface of the mats by the summer 1994. Populations of intertidal grazing invertebrates, such as limpets and periwinkles continued to show reduced densities on oiled sites in 1994. Results of comparisons of mussel size-frequency, filamentous algae abundance and mussel recruitment in filamentous algae on oiled and control sites showed a higher abundance of smaller and recruiting mussels and filamentous algae on oiled sites. These patterns appear to be related to the detection of higher water motion on oiled sites based on calcium sulphate cylinder dissolution rates.

Key Words: Algae, barnacles, *Exxon Valdez* oil spill, *Fucus*, Herring Bay, intertidal, invertebrates, limpets, littorines, mussels, oil spill, pollution, Prince William Sound.

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EXECUTIVE SUMMARY

Intertidal studies established in 1990 in Herring Bay, Prince William Sound continued through the 1994 season. *Fucus* populations continue to show injury due to the oil spill. Plant densities were generally similar between oiled and control sites, but in the high intertidal reproductive plants at oiled sites had fewer receptacles per plant than at control sites. There were also more large and reproductive plants at oiled sites in the mid tidal zone, indicating that these plants just recently grew into the largest size class. As these plants continue to grow, they will become less dense due to mortality, and the populations should become more similar to those at control sites.

Settlement rates of *Fucus* eggs were much lower at oiled sites compared to control sites in the very high intertidal zones. Data on plant densities from the settlement experiments showed that oiled sites had lower densities than control sites in the very high zones, indicating that there may have been continued injury to the *Fucus* population in the very high zone which was not detected by our population dynamics study. Considering the short dispersal distance of *Fucus*, it seems likely that the lower settlement rates at oiled sites are due to lower densities of reproductive plants or fewer receptacles per plant or a combination of the two.

Germlings were negatively affected by herbivores and desiccation. There were more germlings in herbivore removal cages and these germlings were longer than in uncaged tiles. There were, however, also more and longer germlings in partially caged tiles, but not as many or as long as in fully caged tiles, indicating that the shading of cages also benefited germlings. Cracks and crevices in the substrate can provide refuges from herbivory and desiccation for *Fucus* germlings. Plants of all sizes were found growing in cracks and crevices more frequently than expected by the abundance of cracks and crevices. Germlings, however, were also found to prefer barnacles, but older plants were found less frequently on barnacles. Barnacles may initially provide an attractive habitat for *Fucus* plants, but mortality may be higher on barnacles compared to other substrates.

Excluding plants which lost thallus material, plants at oiled sites tended to grow faster than those at control sites. This may have been due to lower densities of plants at oiled sites. If all growth values, including negative values, were included in the analysis then there were few differences between oiled and control sites, indicating that oiled plants tended to lose plant material more readily than control plants.

Recovery of *Fucus* populations is nearing completion, but recovery in the high intertidal is hampered by high desiccation stress, low settlement rates, and short dispersal distances. Continued monitoring is necessary to evaluate full recovery from the spill/cleanup.

A survey performed in Prince William Sound in 1994 showed that the upper boundary of *Fucus* populations at the oiled sites was still an average of 0.5 m lower than the upper boundary at unoiled beaches. Restoration of severely damaged intertidal *Fucus* populations has been started on a small scale at a heavily oiled rocky intertidal site in Herring Bay, Prince William Sound. Experiments employed biodegradable erosion control fabric mats to act as a substrate for *Fucus* germlings and to protect germlings from heat and desiccation stress. A series of plots using mats made from a resilient coconut-fiber fabric was initiated in June 1993. Dense populations of *Fucus* developed on the surface of the mats by the summer of 1994. The natural rock surfaces adjacent to the mats were barren of macroscopic algal cover. By September 1994, the juvenile plants on the mats were approximately 2 cm in length. It is expected that the plants will become fertile during the 1995 season. These plants may serve as a source of embryos to enhance the recovery of new *Fucus* populations in this high intertidal area.

Invertebrate population dynamics sites established in 1990 were monitored through the 1994 field season. Populations of intertidal grazing invertebrates, such as limpets and periwinkles continued to show significantly reduced densities at all tidal levels on oiled sheltered rocky sites. On oiled coarse textured sites, significantly reduced densities were observed for *Tectura persona* and total limpets at MVDs 1 and 2 and for *L. sitkana* at MVD 3. Significantly higher densities were observed for *Lottia pelta* and total limpets at MVD 3 and for *Littorina sitkana* at MVD 1 on oiled coarse textured sites.

Barnacle recruitment patterns were assessed on three oiled sites. Adult *Chthamalus dalli* were more abundant than the other adults present on the sites, *Semibalanus balanoides* and *Balanus glandula*, and were generally in highest densities in lower quadrats. Recruits of *C. dalli* were also most abundant in lower quadrats and least abundant in the upper intertidal, the level of their highest abundance in undisturbed situations.

Mussel size-frequency distributions, shell growth and patterns of mussel recruitment in filamentous algae were also studied. Populations of mussels were similar at two of three matched oiled and control sites in terms of size-frequency distribution in 1993. For the third matched pair, the control site had fewer smaller individuals than the oiled site and a higher frequency of larger individuals. By September, fewer smaller mussels were present than in May, most likely reflecting a combination of growth and juvenile mortality. In 1994, for all three site pairs, smaller mussels were more common on oiled sites, and the mean length of mussels was less on oiled than non-oiled sites. No differences in growth rates of caged mussels were apparent after two years. Smaller mussels, however, exhibited a higher total growth rate than larger specimens. Summer growth rates were generally 2-3 times higher than winter rates for mussels.

Filamentous algae were more abundant in the lower intertidal on all sites than at MVD 1.0. Also, filamentous algae were encountered with more frequency on oiled sites than on controls, possibly due to a lowered abundance of the competitive dominant alga, *Fucus gardneri* or to differences in water movement between oiled and non-oiled shorelines.

Mussel abundance was higher in filamentous algae in July and September as compared to June.

Calcium sulphate dissolution cylinders were deployed on various locations within the Bay in order to determine the relative water motion adjacent to oiled and non-oiled shorelines. Decreased dissolution was observed for cylinders placed near the head of the Bay compared to those placed near the mouth. Most control sites in Herring Bay are located on the eastern side of the Bay near the head. Oiled sites are located either closer to the mouth of the Bay or in the western half of the Bay. Thus, oiled sites had a higher relative water motion compared to control sites based on cylinder dissolution rates. For cylinders placed on mussel study sites, dissolution rates were generally higher on the oiled site of a matched pair.

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CHAPTER 1. GENERAL INTRODUCTION AND SITE SELECTION

In March 1989, the *T/V Exxon Valdez* ran aground on Bligh reef in northeastern Prince William Sound, spilling 11 million gallons of North Slope crude oil. The spilled oil was transported by currents and prevailing winds to the south and west, impacting the shorelines of southwestern Prince William Sound. Prior to the oil spill, knowledge of intertidal communities in the spill region was restricted to either a few sites or to general characterizations of community structure over a wide area of Prince William Sound (Feder and Bryson-Schwafel 1988; Rosenthal *et al.* 1982).

The intertidal zone is a unique area of high productivity which supports a diverse array of organisms including many commercially and ecologically important species. This zone is particularly vulnerable to oil spills due to the grounding of oil, the persistence of oil in sediments, and the effects of associated cleanup activities. Oil may affect intertidal organisms directly by coating or ingestion, resulting in lower resource acquisition (i.e. food, light or nutrients), reproductive failure or death (Pople *et al.* 1990; Garrity and Levings 1990; Paine *et al.* 1988; Jackson *et al.* 1989; Shaw *et al.* 1986). Oil contamination may also affect commercially important fishes using intertidal habitats as breeding or nursery areas (Paine *et al.* 1988; Moles *et al.* 1987; Brule 1984). Indirectly, oiling may result in decreased productivity in prey species, accumulation of toxins through the food web and loss of microhabitat such as algal beds. Due to reductions in the abundances of some organisms, other organisms not directly affected by a spill, but which interact strongly with the damaged populations may also be influenced. Dispersants and emulsifiers can be highly toxic (Southward and Southward 1978; Farke *et al.* 1985) and hot water washing may be harmful or fatal to a variety of organisms (Ganning *et al.* 1983). The above effects can lead to long-term modifications of intertidal populations and communities (Dauvin and Gentil 1989; Southward and Southward 1978). Assessment of injuries to coastal resources and determination of rates of recovery require consideration of the various coastal geomorphologic types, the degree of oiling, the type and intensity of cleanup employed, the affected biota and trophic interactions.

Extensive cleanup operations were conducted throughout Prince William Sound to remove oil from impacted shorelines. Various treatments were used, such as hand cleaning, washing with varying water pressures and temperatures, repeated washings and wide scale use of bioremediation. These activities contributed to the death or removal of invertebrates and algae from oiled shorelines. Hot water, high pressure washing conducted from OMNI and MAXI barges was applied to many sites and clearly contributed to removal of organisms (Lees *et al.* 1993).

In late 1989, a monitoring program was initiated to document the effects of the oil spill on intertidal biota throughout the impacted area (Highsmith *et al.* 1994). The goal of the Coastal Habitat Injury Assessment (CHIA) program was to document effects of the spilled oil and subsequent cleanup on intertidal organisms. In 1990 studies commenced in Herring Bay, Knight Island, Prince William Sound, that were designed to compliment the

CHIA program by experimentally assessing intertidal community dynamics and mechanisms of recovery. This approach went beyond species inventories, allowing a more comprehensive assessment of the *Exxon Valdez* oil spill impacts on physical and biological interactions mediating community structure. The manipulative experiments and observations were designed to evaluate the role of species interactions and physical factors in community organization and recovery from the oil spill.

Site Selection

Sites for these studies were selected by pairing sites from oiled and unoiled areas in the Bay. The use of post-spill comparisons among control and impacted sites has been a common approach in assessing the effects of oil, and only in a few cases have pre-spill baseline data been available (Chan 1974; Crothers 1983; Jackson *et al.* 1989). A major assumption of any study where the sites are chosen after a perturbation is that the control sites represent pre-disturbance conditions. In the present case, the intertidal communities at the control sites were assumed to be similar to those at the oiled sites before the spill.

The southeast corner of Herring Bay retained ice until early April 1989, essentially excluding the oil slick. Therefore, control sites were restricted to the southeastern corner of the Bay. To minimize differences in exposure to wind and wave energy, most oiled study sites were established in the southwestern section of Herring Bay. Figure 1.1 shows the locations of all the oiled and control sites used in the population dynamics and algal studies presented here. Figure 1.2 shows locations for invertebrate-related studies. The general procedure for selecting sites was to identify a workable area in the control section of the Bay and then find an oiled area which resembled the control site as closely as possible. Site pairs were matched in as many physical characteristics as possible. The criteria used for matching sites included similarity in substrate composition, slope, directional and solar aspect, wave exposure, and, occasionally, the presence of patchily distributed organisms. Table 1.1 lists all sites utilized in the present study as well as habitat, specific studies conducted and level of oiling for each site.

Despite attempts to minimize physical differences between oiled and control sites, some differences remained. Control sites were more often subjected to fresh water influence because of large streams entering the southeast portion of the Bay (Fig. 1.1). Salinity and temperature measurements at the water surface and at 1 meter depth were recorded weekly at oiled and control sites in 1990 and 1991, and twice during 1992. Differences in water temperature were occasionally detected between oiled and control areas in the Bay (see Highsmith *et al.* 1993). Between-site differences, however, were small, within 1 degree, compared to seasonal and weekly fluctuations of up to 10 degrees. On 57 percent of the sampling dates, the surface salinity was significantly higher on the oiled side than the control side of the Bay. The salinity at 1 meter did not show as many differences as the surface salinity, and the differences between oiled and control areas were minor relative to seasonal and weekly fluctuations. The influence of fresh water in the intertidal tends to depress

species richness and reduce densities of some invertebrates and possibly algae, compared to areas where salinity is more constant (Barnes 1987).

Since our sites were not randomly selected, but rather hand picked, the generality of our results is limited to the specific sites we have studied. We do, however, compare our population dynamic results with those of the CHIA studies (Highsmith *et al.* 1994) to show generalities of our results. Compared with most other experimental ecological work, our studies are well replicated. Not only do we have adequate replication within site pairs, which is the equivalent of most good ecological studies, but we have replicated the experiments over space. This spatial replication is rarely performed by other studies, yet their results are often applied over much broader geographic areas with little or no evidence in support of the generalizations.

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Table 1.1. Characteristics of Herring Bay study sites (1994). PDX=Population Dynamics, ES=Egg Settlement, GGS=Germling Growth and Survival, GR=Growth of *Fucus*, SUB=Substrate, BR=Barnacle Recruitment, MSF=Mussel Size Frequency, FA=Filamentous Algae, CM=Caged Mussel, FM=*Fucus* Mat, SR=Sheltered Rocky, VW=Vertical Wall, CT=Coarse Textured, 0=no oil, 1=very light, 2=light, 3=moderate, 4=heavy.

Study	Habitat	Control Site	Oiling Level	Oiled Site	Oiling Level
PDX	SR	1231C	0	1231X	3,4
PDX	SR	1732C	1,2	1732X	3,4
PDX	SR (VW)	3811C	0	3811X	3
PDX	CT	2333C	1	2333X	3
PDX	CT	2834C	1	2834X	3
ES	SR	1221C	0	1221X	3,4
ES	SR	1222C	0	1322X	3,4
ES	SR	3C	1,2	3X	3,4
ES	SR	4C	1,2	4X	3,4
GGS	SR	1251C	2	1251X	3,4
GGS	SR	1411C	2	1311X	3,4
GGS	SR	1713C	0	1713X	2,3
GR	SR	1221C	0	1221X	3,4
GR	SR	1723C	1,2	1723X	3,4
SUB	SR	SUB1C	1,2	SUB1X	3,4
SUB	SR	SUB2C	1,2	SUB2X	3,4
SUB	SR	SUB3C	1,2	SUB3X	3,4
BR	SR (VW)	-	-	1522	3,4
BR	SR (VW)	-	-	KISKA	2
BR	SR (VW)	-	-	BARNACLE	3,4
MSF FA CM	SR	MB1C	2	MB1	3
MSF FA CM	SR	MB2C	2	MB2	3,4
MSF FA CM	SR	1522C	2	1522	3,4
FM	SR	-	-	WEASEL	3,4

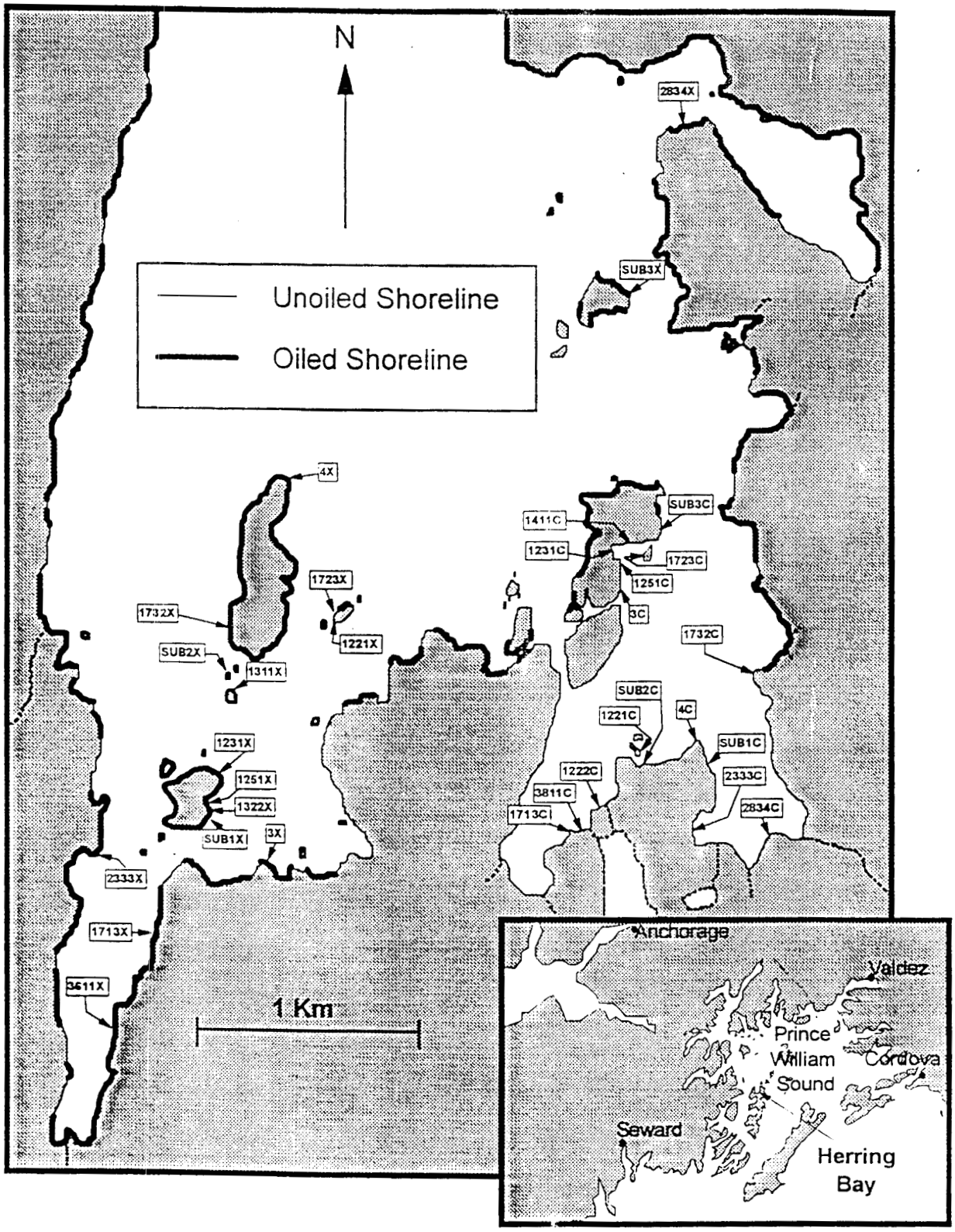

Figure 1.1. Map of the study area showing the locations of population dynamics and algal study sites.

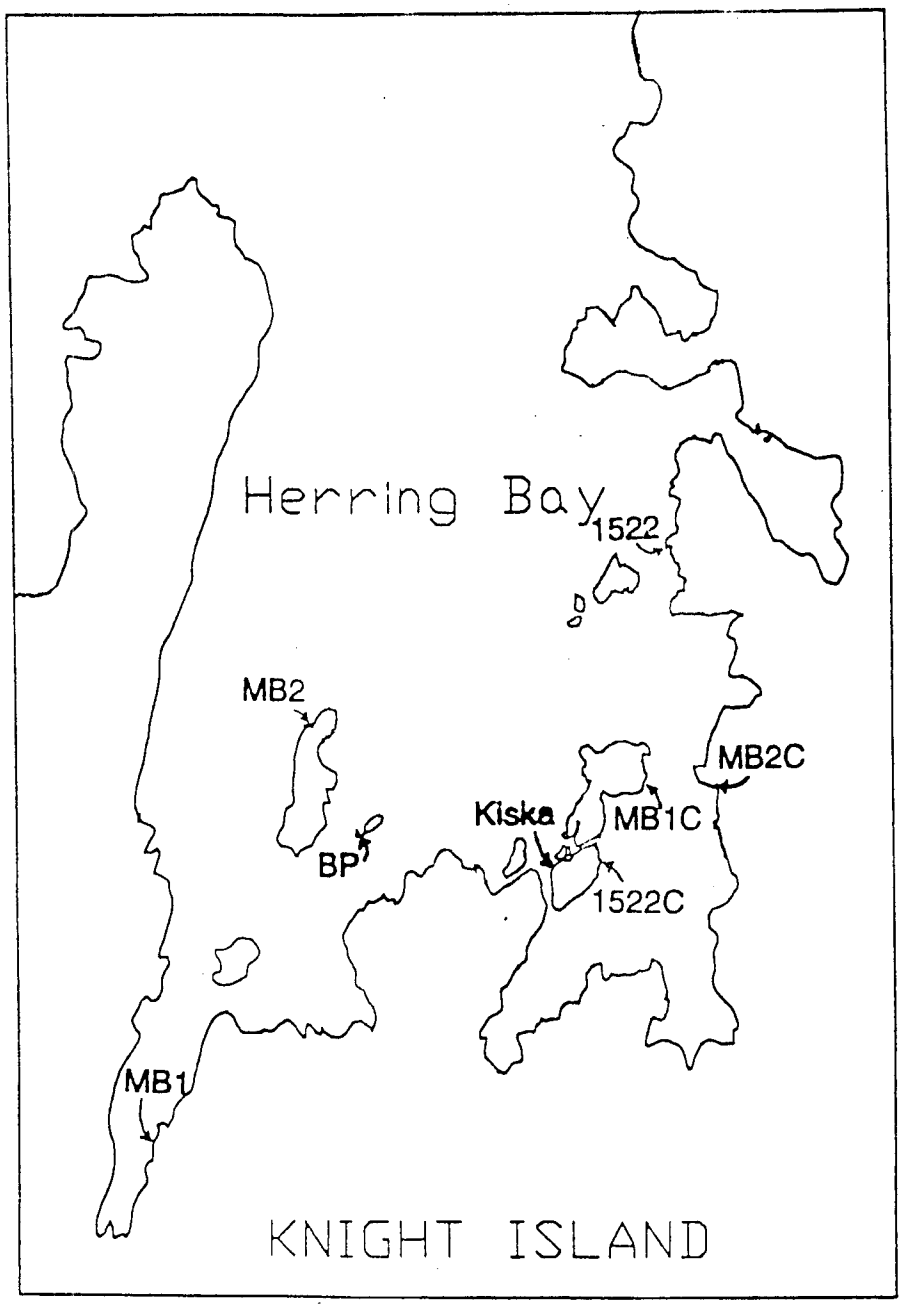

Figure 1.2. Map of the study area showing the locations of mussel and barnacle study sites.

CHAPTER 2. ALGAL STUDIES

INTRODUCTION

In Herring Bay, intertidal habitats are dominated by the alga, *Fucus gardneri* (Silva). This perennial brown alga was severely damaged by the oil spill and cleanup activities (Highsmith *et al.* 1995, van Tamelen and Stekoll 1995, Houghton *et al.* 1991). This plant occurs at all tidal levels and is well suited to study as all phases of its simple life cycle are easily observed in the field or lab. A single plant releases both eggs and sperm which fuse to form a zygote. Zygotes travel to the substrate in a thick mucus released from the receptacles of adult plants. After settling, zygotes begin dividing and grow into germlings and eventually adult plants. Because provides habitat for invertebrates and epiphytic plants and food for foragers, it plays a major role in the intertidal. Therefore, it is important to study the potential recovery of this dominant intertidal organism.

This study assessed recovery of *Fucus* populations and other algae from the *Exxon Valdez* oil spill and subsequent cleanup activities. The goal was to ascertain what is currently limiting the recovery of these seaweeds and to estimate the amount of time needed for full recovery. Many aspects of this study focused on the various life history stages of *Fucus* to understand how various environmental and biological factors affect all stages of *Fucus*. We monitored the population dynamics of *Fucus*, how environmental factors affect egg release, settlement rates of *Fucus* eggs, factors affecting germling growth and survival, growth rates of *Fucus* of various sizes, and the substrates upon which *Fucus* was found growing.

METHODS

Fucus Population Dynamics

As in previous studies (Highsmith *et al.* 1995, van Tamelen and Stekoll 1995), the population structure of *Fucus* was monitored at five pairs of control and oiled sites, including 3 sheltered rocky and 2 coarse textured site pairs (Figure 1.1, Table 1.1). Each site had 6 permanently marked, randomly placed quadrats (20x50 cm) in each of three tidal levels, giving a total of 18 quadrats per site. At each site, six transect heads were located along the base of the *Verrucaria* zone, approximately at mean higher high water. The length of the site was measured and divided by six, giving a segment length. The segment length was then multiplied by a random number (0-1.0) after subtracting the quadrat width (20 cm) from the segment length. Adding this number to quadrat width gave the distance from the edge of the segment to location of the first transect head. Each of the subsequent transect heads was located by adding the segment length to the location of the previous transect head. The upper right corner of each quadrat was located by measuring the length of the transect over

one meter of vertical drop (MVD), subtracting the length of the quadrat (50 cm), and multiplying by a random number. This was done for all three MVDs on each transect. The same random number was used for all MVDs on a given transect. A different number was generated for each transect.

The size-frequency distribution of *Fucus* was determined in each quadrat by measuring the length of all visible *Fucus* plants to the nearest 0.5 cm without removing plants from the substratum. Each plant was classified into one of six reproductive categories and one of five general condition categories. The six reproductive categories were 1) non-reproductive, 2) slightly swollen receptacles with evident conceptacles present, 3) swollen receptacles with light conceptacles present, 4) fully swollen receptacles with dark conceptacles and no mucus present, 5) fully swollen receptacles with dark conceptacles and mucus evident, and 6) receptacles depleted and decaying. The five condition classes were 1) plant with at least some undamaged blades, 2) stipe only with no blades and no regrowth, 3) stipe only with no normal blades but regrowth from damaged tissue evident, 4) holdfast only with no stipe or blades, and 5) holdfast only with regeneration evident. Also, the number of receptacles on each reproductive plant was recorded. Percent cover of all organisms was estimated by placing a 50-point grid over the quadrat. All drift algae were removed before assessment of percent cover or size distributions. The study plots were monitored during late May and early September 1994.

Desiccation Effects on *Fucus* Egg Release

The effects of direct sunlight and artificial shading on *Fucus* egg release were assessed on 22 July and 27 August 1994. For each trial, twenty fertile *Fucus* plants of similar size, health, and reproductive condition were collected from a shaded location in Auke Bay, 18 km North of Juneau, AK. All receptacles had abundant mucilage and well developed conceptacles. The plants were placed 0.5 m apart in two rows of ten with 1 m between rows. Ten plants were randomly chosen to receive shading. Artificial shading consisted of an inverted wire fish trap with a 40 X 40 X 2 cm wood platform on top of it. For all plants, one randomly chosen receptacle was secured over a plastic lid. Temperatures were measured every hour on the lid surfaces. Desiccation was estimated next to each plant by placing a wetted cotton ball in a petri dish and measuring weight loss over time.

After 5-6 hours, the chosen receptacles were clipped from the plants, placed with 20 ml sterile seawater in plastic containers, and sealed with the lids on which the receptacles were resting. The containers were put in a lighted (16:8 LD cycle in July and 24 h continuous illumination in August) incubator kept at 15°C. Samples were shaken initially and every 8 hours to prevent released eggs from attaching to the containers. After 24 hours, receptacles were removed from the containers. Samples were thoroughly mixed and 10 ml portions were transferred to grided 9 cm petri dishes with pipets. The number of eggs in 10 randomly chosen 1.27 square cm grid sections were counted with a dissecting microscope (10 X).

Fucus Egg Settlement

The number of *Fucus* eggs settling on oiled and control shores was estimated by deploying acrylic plates designed to catch *Fucus* eggs (Fig. 2.1). The plates were 5 X 10 cm and had nine grooves etched in them. The width of the grooves (125 um) was slightly larger than the width of an average *Fucus* egg (75 um). The plates were set out for one lunar day at a time for three days in a row. A plate was placed at each of three tidal levels (0.5, 1.0, 2.0 MVDs) along four transects, for a total of 12 plates per site. One transect was placed at either end of the site and the remaining two transects were spaced equidistant between them. This experiment was performed at two pairs of oiled and control sites in May and four site pairs in June, August, and September 1994. The distance and direction to the nearest fertile *Fucus* plant for each plate was recorded in all sampling months except June.

The effects of net water flow on egg settlement were investigated at the egg settlement sites in August and September. Net flows were estimated by measuring the dissolution rate of Plaster of Paris cylinders at each egg density site. The plaster was molded in plastic film canisters with 3 inch stainless steel screws placed through the center of each mold before hardening. Dissolution cylinders were oven-dried prior to recording initial and final weights at 40°C until there were no detectable changes in weight between consecutive days. The dissolution cylinders were screwed directly into plastic wall anchors in the rock surface at 1.0 MVD at the midpoint of each site. Any *Fucus* plants able to touch the cylinders were removed.

Germling Growth and Survival

The effects of substrate heterogeneity, tidal height, *Fucus* canopy, oiling level, and herbivores on *Fucus* germling survival and recruitment were assessed with a series of multi-factor experiments using tiles seeded with germlings. During the first two weeks of June 1992, tiles were seeded in the same manner as the petri dishes in the desiccation experiment. All of the following experiments were initiated on 4 July 1992. These experiments used ceramic tiles (6x8 cm) made with six grooves of three widths (0.80 mm, 0.50 mm, and 0.15 mm) and two depths (1.50 mm, 0.30 mm). The tiles were made with Pine Lake Red Stoneware clay and fired at cone 10 with no glazes or colorants. The six different sizes of grooves (3 widths x 2 depths) were randomly ordered horizontally on each tile (Fig. 2.2). The tiles were attached to the substratum with a screw through a central hole in the tile.

To evaluate the effects of adult *Fucus* canopy, tidal level, oiling history at the site, and prior seeding, eight plates were deployed at each of three control and their matched oiled sites. At both the 0.5 MVD and 1.0 MVD, two pairs of seeded and unseeded tiles were separated by one meter. One randomly chosen pair was designated as a *Fucus* canopy treatment and the other pair had no *Fucus* canopy. If a *Fucus* canopy was present in the no *Fucus* canopy treatment, the plants covering the tiles were removed. If there was no *Fucus* canopy in the *Fucus* canopy treatment, then *Fucus* plants, collected from the same tidal height, were transplanted just above the tiles by chipping off the rock with the plant attached

and using Z-Spar marine epoxy putty to secure the rock and plant in place. Each set of eight tiles was randomly located on the shoreline at each site. The temperature of each tile was recorded on one hot, sunny day in July 1992 by inserting a thermocouple into a small hole on the side of each tile.

The effect of herbivores on germling survival was investigated using additional seeded plates deployed at the same time as the *Fucus* canopy experiment described above. Herbivores were excluded by encasing tiles in Vexar mesh (about 3.5mm mesh size) and securing the tile and cage to the substratum with a screw (Fig. 2.2). To control for cage effects, tiles were also placed in a cage open at one end, allowing herbivores access. Uncaged control tiles were also used. All tiles were seeded and all *Fucus* canopy was removed from around the tiles. At each of the six sites, two sets of the three treatments were deployed, one at 1.0 MVD the other at 2.0 MVD. The 1 MVD set used the no *Fucus* canopy, seeded tile from the preceding experimental design as the control tile. The two caging treatments were placed next to this control tile. The 2 MVD treatments were placed directly below the 1 MVD caging treatments.

For all tiles, the number of germlings in each groove was counted, using a dissecting microscope, immediately before placement in the field. An area between the first and second grooves equal to the width of the widest groove was also counted to assess survival outside of grooves. After two months in the field, in early September 1992, the tiles were retrieved and the number of germlings were again counted using a dissecting microscope. After counting, the tiles were returned to the field. In June 1993 and September 1994, the number of plants visible with the naked eye in each groove were counted while the tiles were in the field. At the same time the length of the five largest plants in each groove was recorded. If there were fewer than five plants in a groove the length of each plant was recorded. We choose to evaluate recruitment density per linear length of groove and not the density per area of groove for two reasons. First, ultimately the density of plants per square meter of shoreline is the variable of interest. If the density of cracks in the rock surface were equal and only crack size varied, then the number of plants per length of crack, regardless of the surface area of the crack, would give a better representation of the density of plants at a larger scale. Second, as germlings grow they will decrease in density as they outgrow their grooves. After about six months of growth there will be a line of germlings about 0.5 cm long regardless of the area of the crack. For these reasons, we felt that density per length of groove was the appropriate variable to examine rather than density per area of groove.

Growth of Established *Fucus* Plants

To determine growth rates of *Fucus* plants in Herring Bay and estimate recovery time for these plants, individual plants were tagged and monitored for subsequent growth. Six randomly chosen plants in each of 3 size categories at each of three tidal levels were tagged by gluing a small uniquely labeled tag next to the plant with marine epoxy. The plants were chosen by finding the nearest plant in the specified tidal level to a randomly selected point on the shore. The randomly selected points were located using the same procedure to locate the

quadrats in the population dynamics study except that the quadrat length and width were not subtracted from the segment or transect lengths. The distance from each point to the chosen plant was recorded for each selected plant, giving an estimate of plant density of the various size categories at each site. Eighteen plants in each size category were marked at two pairs of control and oiled sites (1221C/1221X and 1723C/1723X). The size categories consisted of small plants (2-4.5 cm length), medium plants (5-10 cm), and large, reproductive plants (> 10cm). All plants were marked and measured between 16-19 May 1991. If plants were reproductive, the number of receptacles was counted for each plant. Plants were remeasured on 12-13 July and 22-23 August 1991, 6-7 June and 27-28 July 1992, 5-6 June and 30 August 1993, and 24-27 May and 4-5 September 1994.

If tags or plants were lost or the plants grew into a new size class, then new plants were located and tagged by selecting the nearest plant to the original, randomly located point. After each sampling period except in 1994, the number of plants in each size class at each tidal height was restored to at least six by this retagging procedure. Sample sizes can be greater than six if plants from a smaller size class grew into the next larger size class and there was no mortality in the larger size class. Growth was calculated in two ways. First, the overall growth rate of the population was estimated by including both negative and positive values of growth. This is termed the net growth rate. Second, the potential for growth of plants was estimated by including only positive values of growth. This is called the potential growth rate.

Substratum use by *Fucus*

Substratum use by *Fucus* was investigated by comparing the substrata of small (<2 cm), medium (2-10 cm) and large(> 10 cm) plants to total substratum availability. At 0.5 MVD, ten randomly located quadrats (25 X 25 cm) separated by at least one meter were examined at three pairs of oiled and control sheltered rocky sites. The 10 nearest plants to the upper left corner of the quadrat in each size category were found. If there was not a minimum of 10 small, 5 medium, and 2 large plants in the quadrat, another quadrat location was chosen. Each designated plant was removed and classified as growing on crevices, barnacles, smooth rock, or other substrata. Crevices were defined as having a width between 0.1 and 5 mm and a depth greater than width.

After determining substratum use by the plants, all algae were removed from the quadrat by scraping, leaving barnacles intact. A point contact method was used to measure the percent cover of crevices, smooth rock surface, and barnacles in the cleared plot. Quadrats were constructed using two sheets of clear plastic separated by 4 cm with a wood frame and supported approximately 10 cm above the substratum by two legs. In each sheet of plastic 50 holes were drilled such that each hole in the top sheet was directly over a hole in the bottom sheet. For each of the 50 pairs of holes a rod was pushed through both holes, and the substratum that was contacted by the rod was recorded. Littorine and limpet abundance was estimated by counting 5 randomly chosen 5 X 5 cm sections in each 25 X 25 cm quadrat.

Statistical Methods

The same basic statistical procedure was followed for both the population dynamics and egg settlement experiments. For any given type of data, comparisons were ultimately made for each pair of sites only, but, where appropriate, the pooled estimate of variance for all sites of a given habitat type was used. Raw data for all pairs of sites were checked for homogeneity of variances using Levene's test at the $p=0.10$ level. If variances were unequal, then the data were transformed using either an arcsin (percent cover data) or log transformation (all other data), and Levene's test was again applied on the transformed data. If either the raw or transformed variances were equal, then a one-way ANOVA was performed on all sites and contrasts between oiled and control sites within a pair were used to detect differences between oiled and control sites. If neither the raw nor the transformed variances were equal, then a regular t-test was used to compare each pair of sites. Before applying the t-test, however, raw data variances for each pair of sites were tested for homogeneity using the F-max test. If variances were not equal, then the raw data were transformed using either of the two transformations mentioned above and the F-max test was again applied. If the transformation failed to alleviate the heteroscedasticity, then a regular t-test with Satterthwaite's correction for non-homogeneous variances was applied to the raw data.

In other cases, simple t-tests were performed without attempting to use a pooled estimate of variance. When these simple t-tests were employed the procedure above was applied as if neither the raw nor transformed data had homogeneous variances for all sites. In a small number of cases involving multifactorial experiments, two- or three-way ANOVAs were used on the raw data if variances were judged to be homogeneous according to an F-max test. In cases where variances were not homogeneous, log transformations were used. The transformations did not always cure the heteroscedasticity, and in cases where variances remained non-homogeneous the ANOVA was carried out on the raw or transformed data, whichever had the more homogeneous variances. In cases where this was done, the fact that the assumptions of ANOVA were violated is indicated in the presentation of the data. All figures and tables represent raw means and one standard error of the mean. Statistical significance is indicated by one star ($p<0.05$), two stars ($p<0.01$), or three stars ($p<0.001$).

To perform overall statistical tests where pairs of sites were used and analyzed separately, for the population dynamics and egg density studies, Fishers procedure for combining probabilities of similar tests was employed (Sokal and Rohlf 1981). This procedure assumes that all the differences were in the same direction--that all control sites have higher means than oiled sites or vice versa. This was not always the case with the data presented here. If the direction of the difference varied between sites, the direction with the greater number of mean differences was chosen as the direction of the test. The site pairs in which the direction of the mean difference was opposite that of the test, were assigned a probability value equal to 1 minus their actual probability value.

RESULTS

Population Dynamics-Sheltered Rocky Sites

At site pair 1231C/1231X, a gently sloping sheltered rocky pair, there were significantly more large plants (>10 cm) at the oiled site in the second, at both times, and third, in May only, MVDs (Fig. 2.3). There were no other significant differences in the densities of plants in any of the size classes.

A more steeply sloped sheltered rocky pair, 1732C/1732X, had three significant differences in plant densities (Fig. 2.4). There were more germlings (<2.0 cm) at the oiled site in May in the second MVD. At the control site in the third MVD there were more medium (5.5-10 cm) plants in May and more large plants in September.

At the vertical wall sites, 3811C/3611X, there were only significant differences in the third MVD (Fig 2.5). There were more small plants (2.5-5 cm) at the control site in May and more germlings and medium plants in September.

At sites 1231C/1231X, there were more reproductive plants and receptacles at the oiled site in the second and third MVD in May (Figs. 2.6, 2.7). The other sites showed no differences in the number of reproductive plants or receptacles between oiled and control sites.

The percent cover of *Fucus* was greater in the second, both times, and third, in September, MVDs at the oiled site of the 1231C/1231X pair (Fig. 2.8). There were no differences in *Fucus* cover between oiled and control sites among the other site pairs. There was, however, more ephemeral algae at the oiled site in September in the third MVD at the 1732C/1732X site pair (Fig. 2.9).

Population Dynamics-Coarse Textured Sites

Because algae were sparse in the first two MVDs at the two coarse-textured site pairs, only third MVD results are reported. At the 2333C/2333X site pair there were more large plants at the oiled site at both times (Fig. 2.10). At the control site in May there were more germlings. In May at this pair there were both more reproductive plants and receptacles at the oiled site (Fig 2.11). There were no differences at the 2834C/2834X site pair between oiled and control sites.

The percent cover of *Fucus* was significantly higher at the oiled site at the 2333C/2333X site pair at both times (Fig. 2.11). There was no difference in the cover of ephemeral algae at either site pair.

Population Dynamics-Reproductive Plant Quality

Examination of reproductive plants at all sites, both sheltered rocky and coarse textured, revealed that at oiled sites reproductive plants were shorter than those at control sites in the third MVD in May (Fig. 2.12). Also, *Fucus* at control sites had more receptacles per plant in the first MVD at both times, but in the second MVD plants at oiled sites had more receptacles per plant in May. These data include all reproductive plants observed at all sites.

Population Dynamics-Overall Results

When site pairs were combined for overall tests differences between oiled and control areas were also detected (Table 2.1). At sheltered rocky sites in May there were more large plants and reproductive plants at the oiled sites in the 2 MVD. There was also a higher percent cover of *Fucus* and ephemeral algae at oiled sites at the 2 MVD. Also in May there were more medium plants in the 3 MVD at the control sites. In September oiled sites continued to have a higher cover of *Fucus* in the 2 MVD. At the control sites there were more germlings in the 3 MVD.

At coarse textured sites, there was also a higher cover of *Fucus* at oiled sites in both May and September (Table 2.1). Also in May there were more large plants at the oiled sites.

Desiccation Effects on *Fucus* Egg Release

The shade treatments were effective at reducing environmental stress. Shade treatments had significantly lower temperatures and desiccation rates than the sun treatments (Fig. 2.13). Also, there were significantly higher temperatures and desiccation rates in July compared to August trials.

The number of eggs released by receptacles receiving sun or shade treatments was inconsistent between July and August trials (Fig. 2.13). In July, shaded plants appeared to release more eggs than those kept in direct sunlight, while in August the opposite result was observed. This interpretation is supported by a significant date by treatment interaction. There were also significantly fewer eggs released in August than in July.

Fucus Egg Settlement

In every statistically significant case more eggs settled at the control sites than at the oiled sites (Fig. 2.14). Both the 1221C/1221X and 1222C/1322X site pairs showed differences only at the 0.5 MVD in which all cases were significant except May at 1221C/1221X. There were no other differences detected at these two sites. At the 0.5 MVD at both the 3C/3X and 4C/4X site pairs there were differences in all cases except in

August at 4C/4X. At the 1.0 MVD at the 3C/3X pair there differences in June and September. In June at the 4C/4X pair there were differences at both the 1.0 and 2.0 MVDs.

The distance to the nearest fertile *Fucus* plant at the 1221C/1221X site pair was greater at the oiled site on all sampling dates at 0.5 MVD, but it was greater at the control site in August at 1.0 MVD (Fig. 2.15). At the 1222C/1322X site pair this distance was greater at the oiled site in May and June at the 0.5 MVD but greater at the control site in May at the 2.0 MVD. The distance to the nearest fertile plant was greater at the oiled site of pair 3C/3X only in August at 2.0 MVD. No significant differences in distance to the nearest fertile plant were found between control and oiled sites of the 4C/4X pair.

Overall, there was always greater egg settlement at control sites at the 0.5 MVD (Table 2.2). In June egg settlement was greater at the control sites at the 1.0 MVD. There were no differences in egg settlement between oiled and control sites at the 2.0 MVD. The distance to the nearest fertile *Fucus* plant, which is inversely related to the density of reproductive plants, was always greater at oiled sites at 0.5 MVD. The distance to the nearest fertile plant was greater at control sites in August at the 1.0 MVD and in May at 2.0 MVD.

Egg settlement rate showed a significant negative relationship with net water flow when both oiled and control sites or just oiled sites were considered (Fig. 2.16). Control sites, however, showed no relationship between egg settlement and net flow. Average net flow was significantly greater at oiled sites than at control sites ($T=4.788$, $df=46$, $P<0.001$).

Fucus Recruitment

The initial seeding densities on the grooved tiles varied between groove widths but not depths (Fig. 2.17, Table 2.3). There were more germlings in wide grooves than in narrow or medium grooves. This was probably due to the increased surface area of wider grooves compared to narrower grooves. There were also more germlings in grooves than out of grooves. This can be attributed to the tendency for eggs to gather in grooves. Any slight movement of the tile immediately after seeding, before the eggs have attached to the substrate, would cause some of the eggs to fall into the grooves.

To account for the differences in initial seeding densities, the percent survival of germlings was calculated by dividing the number of germlings observed after being in the field by the initial number of germlings. Due to natural recruitment of germlings, it was possible for this value to be greater than 100 percent. A higher proportion of germlings survived in grooves than out of grooves (Fig. 2.17, Table 2.3). In September 1992, after two months, survival rate was higher in medium and narrow grooves than in wide grooves, especially in shallow grooves. In May 1993, after eleven months, survival was higher in

narrow grooves compared to wide grooves, and survival was slightly better in deep grooves compared to shallow grooves.

Natural recruitment was monitored on the unseeded tiles. Germlings never recruited naturally onto the tiles out of grooves. No significant differences were detected comparing the number of recruits in the different sized grooves in 1993 (Fig. 2.17, Table 2.3). In 1994, however, there were significantly more recruits in medium grooves compared to narrow grooves. Barnacles were significantly more abundant in wide grooves compared to other widths in 1994. No effect of depth was ever observed, but on both dates there was a significant tile effect indicating variation in recruitment success between tiles.

To examine the effects of *Fucus* canopy, tidal height, and oiling on germling survival, the number of germlings in all grooves were counted. Thus, the dependent variable is the number of germlings per plate regardless of groove size. A three-way ANOVA on the percent survival of germlings yielded three significant effects (Fig. 2.16, Table 2.4). First, there was an effect of site pair, indicating that there were differences in germling survival between site pairs. Second, germling survival was higher in control areas compared to oiled areas indicated by the significant oil effect. Finally, germling survival was greater under *Fucus* canopy compared to no canopy treatments. Natural recruitment of 1992 microscopic and 1993 macroscopic germlings after two and twelve months showed similar patterns to germling survival (Fig. 2.18, Table 2.4). First, there was a significant site pair effect for microscopic recruits, indicating differences in recruitment between site pairs. Second, natural recruitment of both micro- and macroscopic plants was higher at control sites compared to oiled sites. Finally, recruitment of macroscopic plants was greater under *Fucus* canopy.

The temperature of the tiles on a hot day was significantly greater at oiled sites compared to control sites, and tiles were significantly cooler under *Fucus* canopy than tiles with no canopy (Fig. 2.18, Table 2.4). The maximum tile temperature recorded was 43.6°C.

The effect of herbivores on germling recruitment was examined by evaluating the number of germlings per plate, ignoring groove size. The number of recruits in 1993 showed significantly fewer recruits on the uncaged tiles at 1 MVD. In 1994, there were also significantly fewer recruits on tiles with no cages, but there was no difference between cage controls and full caging treatments. This indicates that much of the variation in recruitment can be explained by cages and not herbivores. Once established, however, the growth of germlings was greater in full cages compared to no cage treatments. There was no difference in growth rate between cage controls and full cages or no cage treatments.

Growth of Established *Fucus* Plants

For growth rate data, because sample sizes were small due to loss of plants, tagged plants from both site pairs were grouped together, yielding a larger number of control and

oiled plants for comparison using simple t-tests. This, however, reduces the generality of the results.

There were few differences in the net growth rates, which include zero and negative values, between oiled and control plants (Figs. 2.19, 2.20, 2.21, Table 2.6). Small plants (2-5 cm) grew faster at oiled sites in the 1 MVD during the first two winters and over the 1992-1993 year (Table 2.6) and in the 3 MVD during the 1993-94 winter. During the winter of 1991-1992 medium plants (5-10 cm) also grew faster at the oiled sites. Large plants (> 10 cm) grew faster at control sites at 3 MVD over the 1994 year (Table 2.6) and 1993-94 winter (Figs. 2.19, 2.20, 2.21).

Potential growth rates, those with only positive values, were greater at oiled sites in the first MVD (Fig. 2.22). Small plants in the first MVD grew faster at oiled sites during the summer of 1991, both winters, in 1991-92, and in 1993-94 (Table 2.6). In the summer of 1993 small plants in the second MVD grew faster at the control sites. Small plants also grew faster at oiled sites at the 3 MVD during the 1993-94 winter, but these plants grew slower at oiled over the same time period at the 2 MVD. Growth rates of medium plants in the first MVD were faster at oiled sites during 1991-92 (Table 2.6), in both winters, and in the summers of 1992 and 1993. In the first and second MVDs large plants grew faster at oiled sites over the winter of 1991-92 (Figs. 2.22, 2.23). Over the 1993-94 year (Table 2.6) and winter large plants grew faster at control sites at the 3 MVD (Fig. 2.24).

Substratum Use by *Fucus*

Analyses of the proportion of small, medium, and large plants using different substrata compared to substratum availability were done using the Selectivity Indices:

$$\frac{\text{Puse-Pavailable}}{\text{Puse+Pavailable}}$$

where Puse = the proportion of plants of each size category using a substrate and Pavailable = the percent cover of that substrate.

The Selectivity Index (SI) results were examined using 95% confidence intervals to assess significant differences from zero. A positive SI indicates use greater than the availability of the substratum, and a negative value shows the opposite. The SIs for small plants showed were not significantly different from zero for either crevice or barnacle substratum types (Fig. 2.25). Small plants, however, did have an SI significantly less than zero for smooth rock substratum. Medium and large plants used crevices more than crevice availability at oiled sites but not at control sites. Both medium and large plants had SIs significantly less than zero for both barnacle and smooth rock substrata at all sites.

The percent cover of crevices and rock were significantly greater at control sites, whereas the percent cover of barnacles was significantly greater at oiled sites (Fig. 2.26).

The numbers of littorines and limpets did not differ significantly between oiled and control sites.

DISCUSSION

Previous studies have demonstrated that many larger plants were killed or removed by the oil spill and subsequent clean-up efforts (Highsmith *et al.* 1995, van Tamelen and Stekoll 1995). This result was concentrated in the first two meters of vertical drop at sheltered rocky sites. In general, however, during the 1994 field season few differences in plant density were found. There were, however, some important exceptions. At the 2 MVD at sheltered rocky sites, especially the 1231C/1231X pair, there were more large and reproductive plants at oiled sites which resulted in greater percent cover of *Fucus* at oiled sites. A similar pattern was seen in the data for coarse textured sites. In previous years there have been fewer large and reproductive plants at oiled sites, but the data from this study represents a reversal of this trend. This is due to the growth of those plants which recruited just after the oil spill into the largest size category. It is expected that these plants will continue to grow and become less dense to eventually show densities similar to control sites.

The length of reproductive plants is similar between oiled and control sites in the 1 and 2 MVDs, but at the 3 MVD reproductive plants were slightly longer at control sites. This result is consistent with previous results which showed that reproductive plants were initially shorter at oiled sites but had grown to equal their control site counterparts. The number of receptacles per plant at the 1 MVD, however, continues to show lower numbers at oiled sites, but at the 2 MVD there were more receptacles per plant at oiled sites. Reproductive plants in the high intertidal have still not recovered from the effects of the spill, but lower in the intertidal they are producing as many or more receptacles than plants at control sites. *Fucus* plants seem to recover initially by investing more energy into growth and then allocating resources to reproductive efforts.

In contrast to earlier studies (Highsmith *et al.* 1995, van Tamelen and Stekoll 1995), this study did not show any disparity of results from different site pairs. The fact that different sites pairs exhibited different results was explained by differences in cleanup technologies applied to the oiled sites. It seems that these differences between sites have mostly disappeared.

In order for *Fucus* to recover from the damages documented in the Herring Bay studies, plants must settle as eggs and develop into germlings, survive to adulthood and, because of the short dispersal distance of *Fucus* eggs, become reproductive to continue local recolonization of impacted areas. We have observed large variations in the production of eggs by individual *Fucus* plants (Highsmith *et al.* 1995). Some of this variation may be explained by weather patterns. In our experiments, exposure to sun inhibited egg release in July. The opposite result was obtained when the experiment was repeated in August. The weather in July was warmer and drier compared to August and this may have caused fewer

eggs to be released from plants exposed to terrestrial conditions. Superimposed on these data, there seems to be a decrease in egg production as the summer progressed. To predict recovery rates, we need to know what conditions can lead to reproductive failure in *Fucus*.

One possible result of the reduction of reproductive *Fucus* plants in oiled areas, was that fewer eggs were found to settle on oiled shorelines. The number of eggs settling on oiled shorelines in the high intertidal was much lower than on control sites even five years after the spill. In lower tidal levels there were fewer eggs settling at oiled sites in 1991 and 1992 (Highsmith *et al.* 1995). In the high intertidal, the density of reproductive plants at these sites was lower as shown by longer distances to the nearest fertile plants in most cases (Table 2.2). Because eggs rarely travel more than one meter from the parental plant and are much more abundant near the source plant (McConnaughey 1985, van Tamelen and Stekoll 1995), the lower settlement rates observed can be attributed to lower densities of reproductive plants. The negative relationship between net water flow and egg settlement rate suggests an alternative explanation of lower egg settlement at oiled sites since these areas had generally higher flow rates. Without further study, it can not be determined if egg settlement rate is affected by net water flow. It may be that oiled sites have lower settlement due to reduced reproductive plant densities and that they just coincidentally also have higher water flow.

After settling on rock surfaces, *Fucus* sporelings face a variety of challenges before reaching adulthood. In normal situations with a healthy canopy of *Fucus*, germlings are subjected to grazing pressures from molluscan herbivores such as limpets and snails. Germlings with herbivores present tended to be less abundant and shorter than where herbivores were excluded (Fig. 2.17, Table 2.5). There were, however, significant effects of the cages used to exclude herbivores. Tiles without cages in the high intertidal had fewer germlings than open caged tiles, indicating that there was a positive effect of cages on germling survival (Fig. 2.17, Table 2.5). This positive effect could be due to protection from desiccation and heating. Germling growth was also affected by cages, but growth was only significantly enhanced when cages were present and herbivores were removed (Table 2.5). After one summer in the field, germlings showed no trends or significant effects of herbivores, suggesting that herbivores only affect germlings longer than about 1 mm. As plants grow to greater than 1 mm, herbivores may become more important to germling survival due to higher plant attractiveness to herbivores because of increased energy per plant (Lubchenco and Gaines 1981).

Germlings may also be brushed off the rock surface by adult plants thrust back and forth by wave action (Highsmith *et al.* 1995). Cracks and crevices in the rock surfaces may provide a refuge from both herbivory and whiplash (Lubchenco 1983, Highsmith *et al.* 1995). Conversely, at oiled sites lacking a healthy canopy of adult *Fucus* and associated herbivores, germlings are not subjected to strong herbivory or the whiplash effect of adult plants, but they are subjected to increased heat and desiccation stress. In the *Fucus* canopy, desiccation is relatively low while outside of *Fucus* beds on exposed rock surfaces desiccation can be severe, especially in the high intertidal (Brawley and Johnson 1991). Germling survival was found to be higher where temperatures were lower under the *Fucus* canopy

(Highsmith *et al.* 1995). Germling survival was also lower at oiled sites lacking *Fucus* canopy and subjected to severe heat and desiccation stress. Temperatures exceeding 43°C have been recorded for tiles placed in the high intertidal zone at oiled sites in Herring Bay. Although it appears that cracks and crevices can provide some protection from heat and desiccation stress, cracks alone are not sufficient to allow survival of young *Fucus* germlings. Germling survival is lower without *Fucus* canopy regardless of the presence of cracks (Fig. 2.16). However, cracks do seem to provide protection from whiplash by adult plants and herbivory by allowing newly recruited germlings to grow to sizes (>0.5cm) more resistant to these mortality sources before being exposed to them (Lubchenco 1983). Although germlings recruiting under *Fucus* canopy may face survival challenges in the form of herbivory and whiplash, the alternative of recruiting in areas without *Fucus* canopy seems to present more severe threats to future survival by heating and desiccation stresses.

Potential growth rates of established *Fucus* plants during the 1991-1992 year were greater at oiled sites in the upper intertidal for all size classes of plants and in 1993 for small and medium sized plants (Fig. 2.22). This is probably a result of lower densities of *Fucus* plants, especially larger plants, at oiled sites resulting in reduced intraspecific competition for light, nutrients, or space (Kendziorek and Stekoll 1984). Once germlings become established at damaged sites, recovery can proceed rapidly due to growth rates ranging from 6 to 8 cm per year. Growth rates for plants at control sites ranged from 2 to 6 cm per year.

Despite the potential for plants to grow rapidly at oiled sites, population growth rates at oiled sites, measured by the net growth rates, generally were not significantly different from control sites (Figs. 2.19, 2.20, 2.21). There were only four significant differences for net growth rates versus 12 for potential growth rates. This disparity of results for potential and net growth rates indicate differences in overall growth dynamics. Although plants at oiled sites had the potential for growing rapidly, they also seemed to lose plant material more readily, resulting in net growth rates equivalent to plants at control sites.

Given that we only observed germlings to successfully recruit into cracks or crevices, *Fucus* should be seen more abundantly in cracks or crevices than the availability of heterogeneous substrata. This the case for medium and large plants at oiled sites, and there are similar trends for small plants at oiled sites and all plants at the control sites. Barnacles can provide refuge from molluscan grazers for newly recruited seaweeds (Lubchenco 1983, Dungan 1986, Farrell 1989). In our study we see that small *Fucus* plants are found on barnacles in proportions similar to barnacle availability. Larger plants, however, were found to utilize barnacle substrata less frequently than the abundance of barnacles. Germlings may settle and recruit onto barnacles, but they may have lower survival on barnacles, resulting in less barnacle use by larger plants. Thus, barnacles may initially enhance recovery by providing refuges from herbivory and desiccation for recruiting germlings, but subsequent recovery may be hampered by barnacles due to higher mortality rates for *Fucus* plants.

Recolonization will be greatly inhibited by exposure to the terrestrial environment in the upper intertidal where *Fucus* canopy has been removed by the oil spill or clean-up

activities. One method by which recovery may proceed in areas which have lost all *Fucus* plants in the high intertidal is expansion of *Fucus* beds from low in the intertidal and recruitment into cracks and crevices. As *Fucus* plants lower in the intertidal or in cracks grow to reproductive status, taking about 2-3 years at linear growth rates of 7.0 cm per year, they will provide both a source of eggs and protection from harsh terrestrial conditions for germlings. Desiccation will be reduced in areas immediately surrounding the *Fucus* canopy where adult plants cover the rock surface during low tides. The boundaries of *Fucus* beds can slowly expand as plants on the edges grow, become reproductive, release eggs, and provide shelter for newly settled germlings. The rate of expansion can be estimated by considering that eggs do not usually travel more than 0.5 meter from the source plant and that it takes about 3-4 years for a plant to fully mature. Thus the expansion rate would be about 0.5 m from the edge of the *Fucus* bed every 3-4 years. This rate, however, may be reduced as *Fucus* colonizes areas closer to the upper limit of growth due to increased exposure to harsh conditions.

For an area to be fully recovered not only must the densities, size distributions, and biomass of the components of the community be similar to control sites, but the settlement and recruitment rates should also be equivalent to rates at control sites. This study has documented continued lower *Fucus* settlement rates at oiled sites compared to controls. Recruitment rates at oiled sites also seemed to be reduced compared to control sites. These data suggest that full recovery has not yet occurred more than 5 years after the spill. Continued monitoring is necessary to evaluate full recovery from the *Exxon Valdez* oil spill.

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Table 2.1. Results of overall tests for *Fucus* population dynamics studies at sheltered rocky (SR) and coarse textured (CT) habitats (Hab). Each test combined all pairs of sites using Fisher's test for combined probabilities (Sokal and Rohlf 1981). Number of plants in four size classes (0-2, 2-5, 5-10, and >10 cm), number of reproductive plants (REP), number of receptacles per 0.10 m^2 (REC), and percent cover of *Fucus* (FUC) and ephemeral algae (EPH) were tested at 1, 2, and 3 MVD. "o" indicates the control site values are significantly greater ($p<0.05$) than values at oiled sites and " " indicates the reverse. "ns" indicates no significant difference.

Hab	MVD	DATE	0-2	2-5	5-10	>10	REP	REC	FUC	EPH
SR	1	24 May	ns	ns	ns	ns	ns	ns	ns	ns
		04 Sep	ns	ns	ns	ns	ns	ns	ns	ns
	2	24 May	ns	ns	ns			ns		
		04 Sep	ns	ns	ns	ns	ns	ns		ns
	3	24 May	ns	ns	o	ns	ns	ns	ns	ns
		04 Sep	o	ns	ns	ns	ns	ns	ns	ns
CT	3	24 May	ns	ns	ns		ns	ns		ns
		04 Sep	ns	ns	ns	ns	ns	ns		ns

Table 2.2. Results of overall tests for *Fucus* egg settlement and dispersal. Each test combined all four site pairs using Fisher's test for combined probabilities (Sokal and Rohlf, 1981). Average number of eggs per plate (EGGS) and average distance to nearest fertile plant (DIST) were tested at 0.5, 1 and 2 MVD. "o" indicates the control sites are significantly greater than the oiled sites and "•" indicates the reverse. "ns" indicates no significance and "-" indicates no data.

MVD	YEAR	MONTH	EGGS	DIST
0.5	1994	May	o	•
		June	o	-
		Aug	o	•
		Sep	o	•
1.0	1994	May	ns	ns
		June	o	-
		Aug	ns	o
		Sep	ns	ns
2.0	1994	May	ns	o
		June	ns	-
		Aug	ns	ns
		Sep	ns	ns

Table 2.3. F and p-values for the 2-way ANOVAs comparing different groove sizes. The dependent variables are the initial density of germlings in 1992, the percent survival of seeded germlings in 1992, the number of visible recruits in 1993 and 1994, and the number of barnacles 1994. Statistically significant results ($p<0.05$) are indicated by an asterisk. Data can be seen in Figure 2.17.

	Initial		Survival[a]		1993 Fucus		1994 Fucus[a]		1994 Barnacles	
	F	p	F	p	F	p	F	p	F	p
Tile	2.26	0.002*	16.65	<0.001*	2.58	0.001*	1.93	0.014*	4.00	<0.001*
Depth (D)	0.18	0.676	1.84	0.177	0.39	0.535	1.95	0.165	0.07	0.800
Width (W)	21.04	<0.001*	7.83	0.001*	0.51	0.602	4.47	0.014*	7.05	0.001*
D*W	2.01	0.138	4.04	0.020*	0.72	0.487	0.32	0.727	1.77	0.176

[a]These tests violate the assumption of homogeneity of variances.

Table 2.4. F and p-values for the three-way ANOVAs with oiling impact (control or oiled), tidal level (0.5 or 1.0 MVD), and presence or absence of Fucus canopy as the three factors tested. The tests were blocked by the three pairs of sites (pair) where the experiment was conducted. The dependent variables were the percent survival of seeded germlings and the number of microscopic recruits in 1992, the number of macroscopic recruits in 1993, and the temperture of the tiles. Statistically significant results ($p<0.05$) are indicated with an asterisk. Data can be seen in Figure 2.18.

	1992		1993		Tile			
	Survival		Recruits		Recruits		Temperature	
	F	p	F	p	F	p	F	p
Pair	9.18	0.003*	3.92	0.044*	1.01	0.376	41.93	<0.001*
Oil (O)	8.64	0.011*	7.39	0.017*	8.43	0.025*	6.43	0.015*
Level (L)	0.52	0.482	0.62	0.444	1.34	0.254	0.50	0.484
Canopy (C)	9.53	0.008*	2.69	0.123	8.74	0.005*	15.39	<0.001*
O*L	0.18	0.675	1.72	0.211	3.96	0.054	0.02	0.833
O*C	0.22	0.649	0.73	0.409	0.01	0.921	0.05	0.824
L*C	0.60	0.452	0.05	0.831	0.08	0.778	0.20	0.654
O*L*C	0.49	0.496	0.94	0.350	2.53	0.121	0.19	0.669

Table 2.5. The mean and standard error (in parentheses) of the number and size (mm) of germlings in the presence and absence of herbivores and on tiles with no cage. In each time period, statistically indistinguishable values have the same letter to the right.

Number in 1993	CAGED	CAGE CONTROL	NO CAGE
1 MVD	63.33(30.06)[a]	17.33(8.60)[a]	1.17 (1.17)[b]
2 MVD	46.83(24.39)[a]	18.00(7.68)[a]	20.17 (7.45)[a]
Number in 1994			
1 MVD	44.00(10.75)[a]	62.83(20.00)[b]	5.33 (2.31)[c]
2 MVD	33.83(19.68)[a]	94.83(37.11)[b]	33.83(12.96)[c]
Size in 1994			
1 MVD	22.18 (8.08)[a]	6.02(5.04)[a,b]	1.15 (0.42)[b]
2 MVD	9.70 (6.03)[a]	5.73(2.09)[a,b]	3.70 (1.74)[b]

Table 2.6. The mean (±SE) yearly net and potential growth rates of three sizes of Fucus plants. Dashes indicate either that one plant (in parentheses) or no plants were present. Asterisks indicate a significant difference between control and oiled values.

Net Growth		1991-1992		1992-1993		1993-1994	
	MVD	Control	Oiled	Control	Oiled	Control	Oiled
2-4.5cm	1	0.036(0.008)*	0.120(0.020)	0.068(-)	0.126(-)	0.038(0.011)	0.075(.0003)
	2	0.098(0.022)	0.105(0.036)	0.088(0.030)	--	0.059(0.015)	0.051(0.017)
	3	0.091(0.021)	0.083(0.018)	--	0.049(-)	0.047(0.015)*	0.160(0.062)
5-9.5cm	1	0.084(0.012)*	0.151(0.024)	0.015(0.047)	0.126(0.018)	0.121(0.029)	0.111(0.022)
	2	0.118(0.025)	0.137(0.014)	0.120(0.023)	0.198(0.087)	0.123(0.034)	0.098(-)
	3	0.146(0.031)	0.147(0.015)	0.097(0.097)	0.110(0.062)	0.080(0.017)	0.125(0.029)
>10cm	1	0.097(0.013)	0.105(0.058)	0.063(0.053)	0.143(0.026)	0.029(0.029)	0.080(0.041)
	2	0.145(0.039)	0.200(-)	0.135(0.036)	0.170(0.020)	0.130(0.034)	0.110(0.016)
	3	0.127(-)	0.100(0.009)	0.136(0.061)	0.193(0.043)	0.216(0.023)*	0.108(0.032)
Potential Growth							
	MVD	Control	Oiled	Control	Oiled	Control	Oiled
2-4.5cm	1	0.036(0.008)*	0.120(0.020)	0.068(-)	0.126(-)	0.047(0.007)*	0.075(0.003)
	2	0.098(0.022)	0.105(0.036)	0.088(0.030)	--	0.073(0.006)	0.051(0.017)
	3	0.091(0.021)	0.083(0.018)	0.107(0.107)	0.049(-)	0.057(0.014)	0.160(0.062)
5-9.5cm	1	0.084(0.012)*	0.151(0.024)	0.058(0.025)	0.126(0.018)	0.121(0.029)	0.111(0.022)
	2	0.118(0.025)	0.137(0.014)	0.120(0.023)	0.198(0.087)	0.123(0.034)	0.098(-)
	3	0.146(0.031)	0.147(0.015)	0.034(0.160)	0.110(0.062)	0.102(0.011)	0.125(0.029)
>10cm	1	0.097(0.013)	0.157(0.035)	0.063(0.053)	0.143(0.026)	0.059(-)	0.116(0.025)
	2	0.145(0.039)	0.200(-)	0.135(0.036)	0.170(0.020)	0.162(0.017)	0.110(0.016)
	3	0.127(-)	0.100(0.009)	0.188(0.038)	0.193(0.043)	0.216(0.023)*	0.108(0.032)

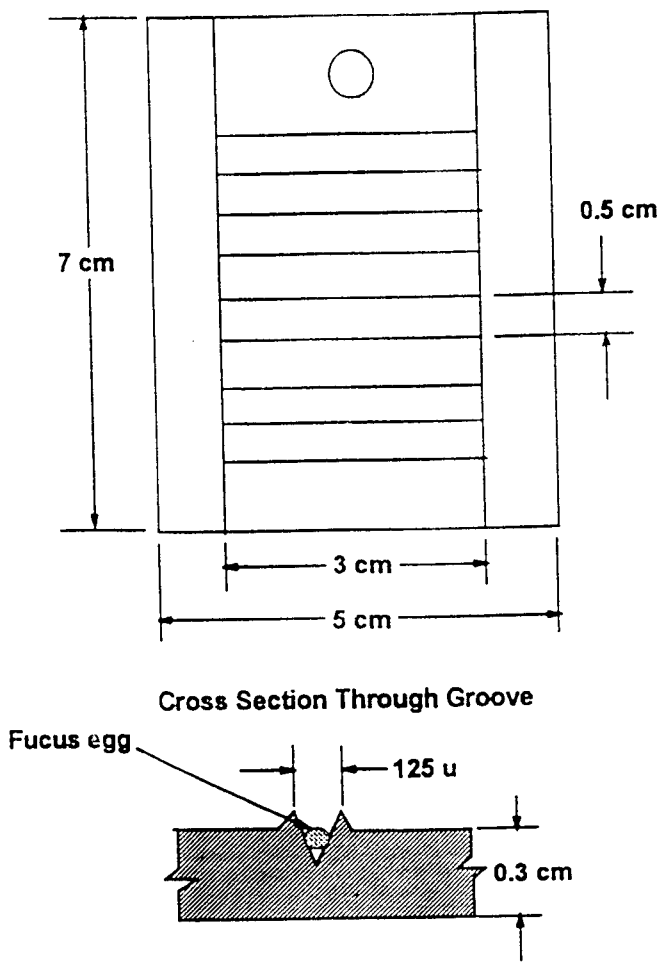
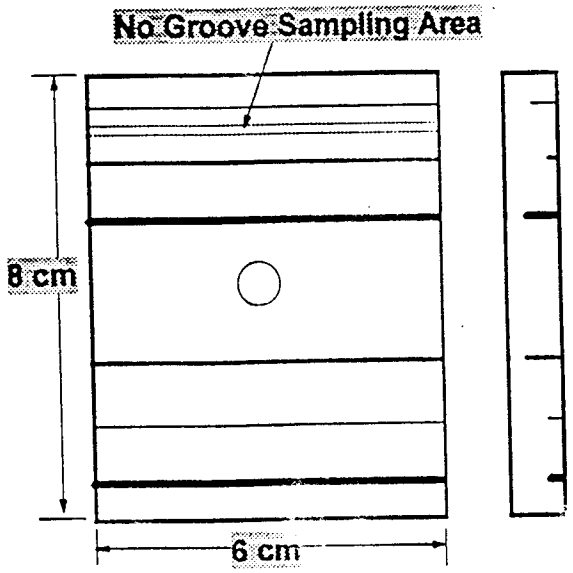


Figure 2.1. Schematic diagram of an acrylic *Fucus* egg catcher plate.



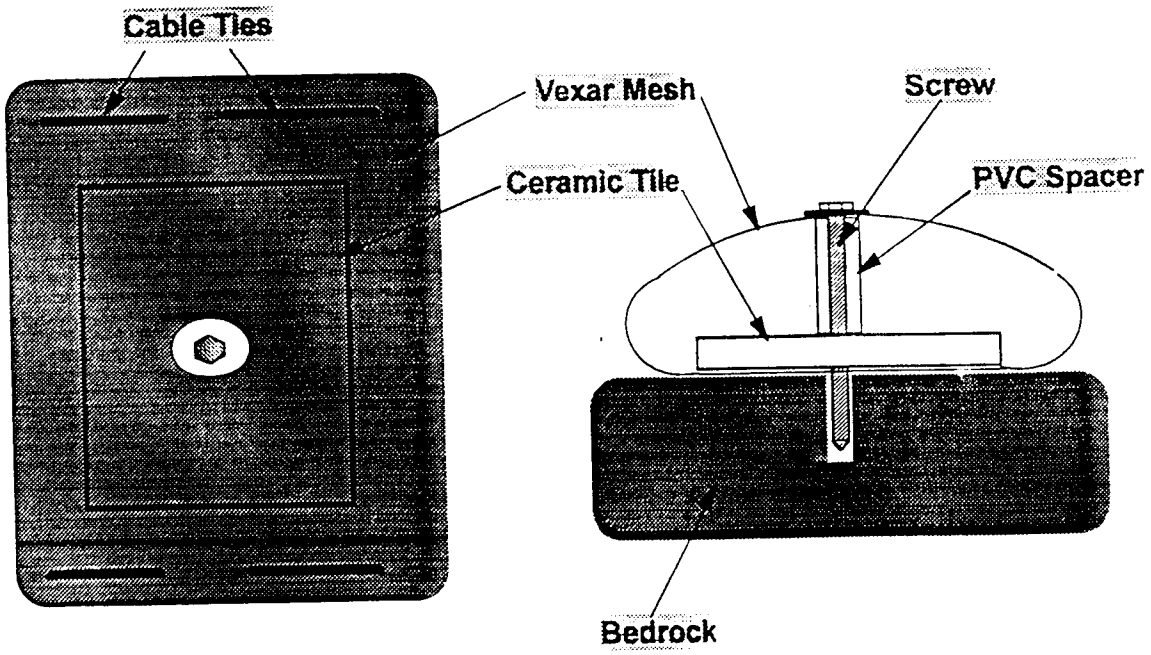


Figure 2.2. Schematic diagram of a ceramic *Fucus* recruitment tile and the vexar cage used to manipulate herbivores. To control for cage effects cable ties were left off one end of the vexar cage so that the cage was open to herbivores.

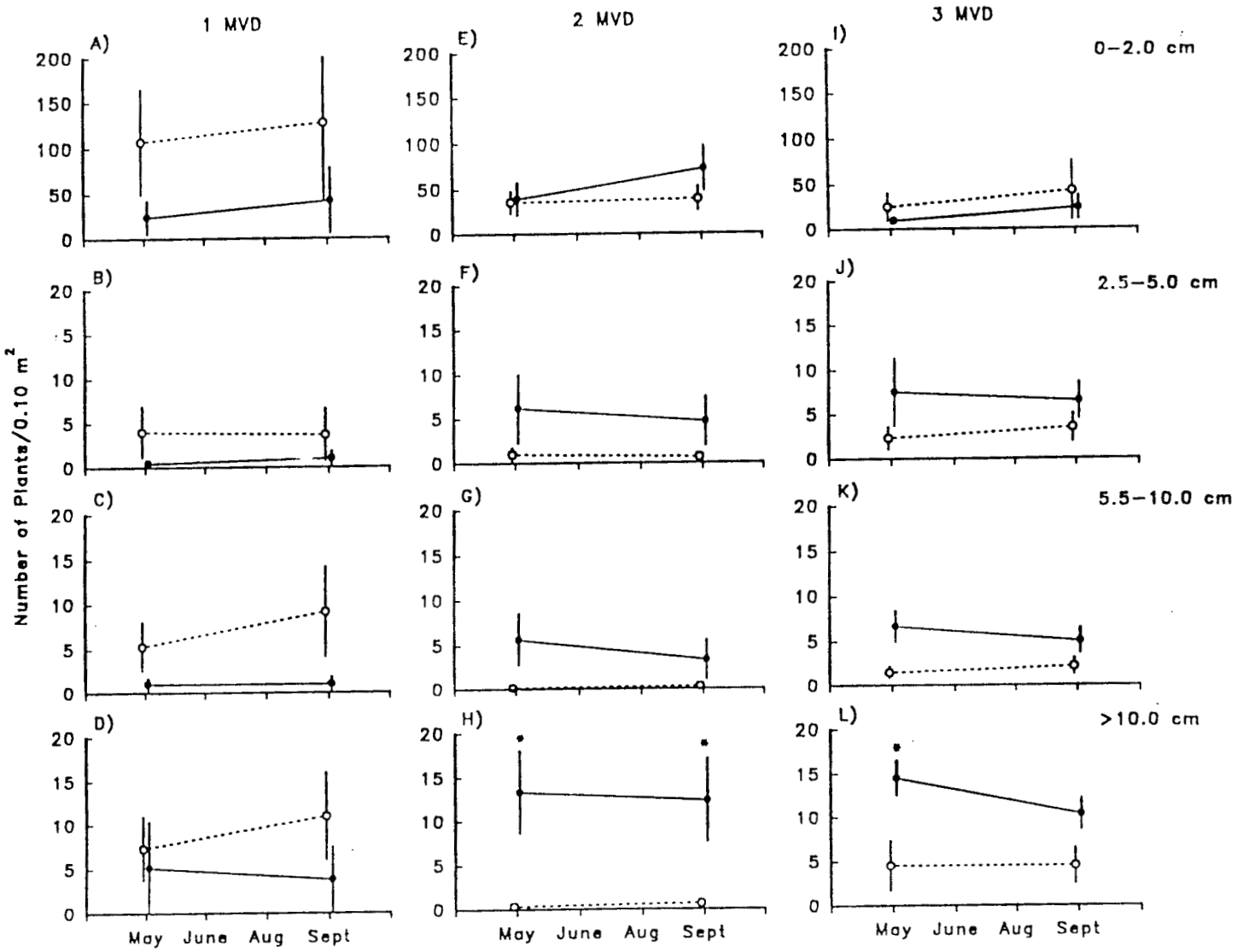


Figure 2.3. Mean number (± SE) of germling (0-2.0 cm), small (2.0-5.0 cm), medium (5.5-10 cm), and large (>10 cm) *Fucus* plants at the 1231C/1231X site pair. Each row of three graphs represents all MVDs for each of the four size classes. The oiled site is represented by solid circles and lines, and the control site is represented by open circles and dashed lines. Asterisks indicate statistically significant differences between oiled and control sites on the indicated sampling date (* P<0.05, ** P<0.01, *** P<0.001).

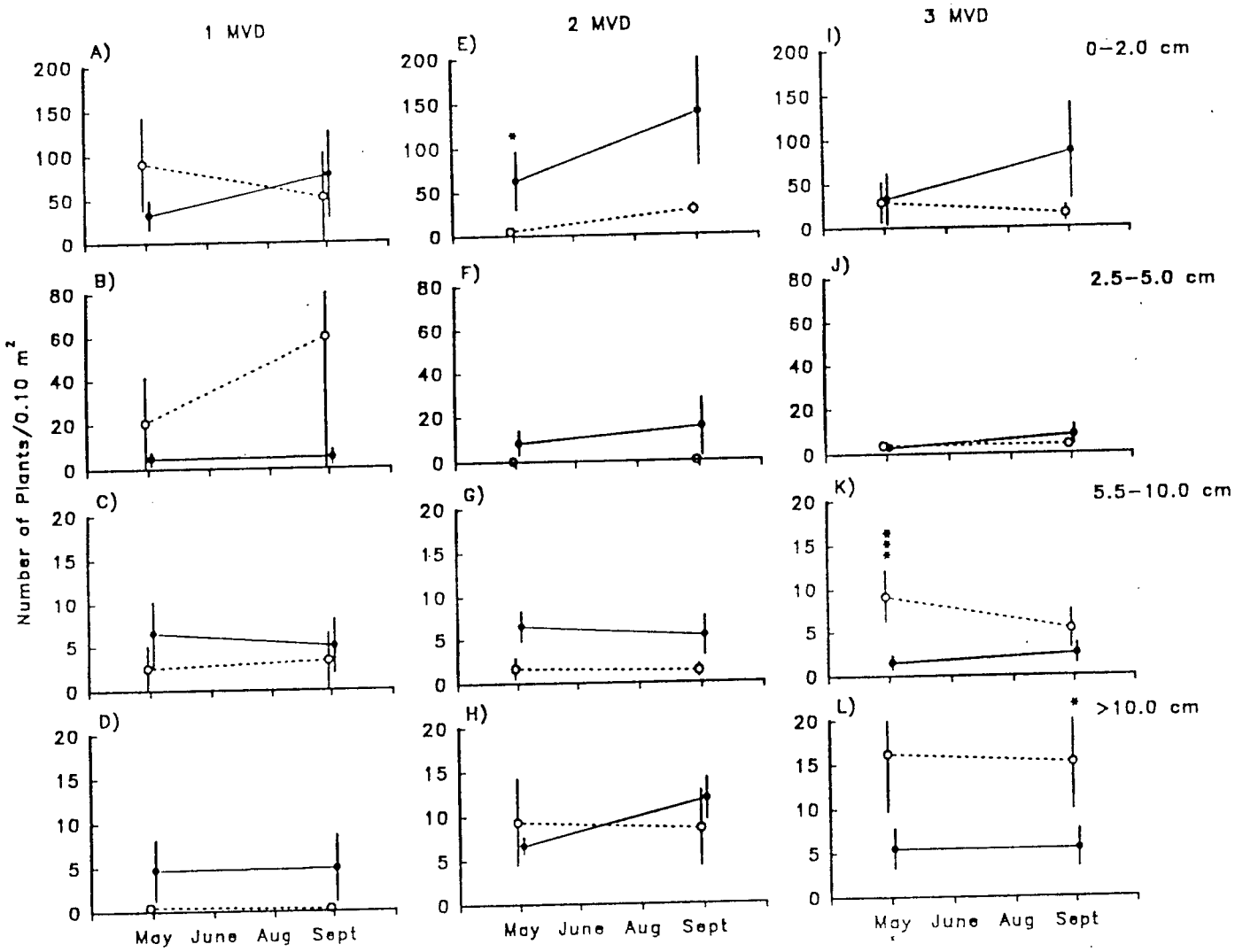


Figure 2.4. Mean number (± SE) of *Fucus* plants in four size classes at three tidal levels at site pair 1732C/1732X. Layout is the same as those in Figure 2.3.

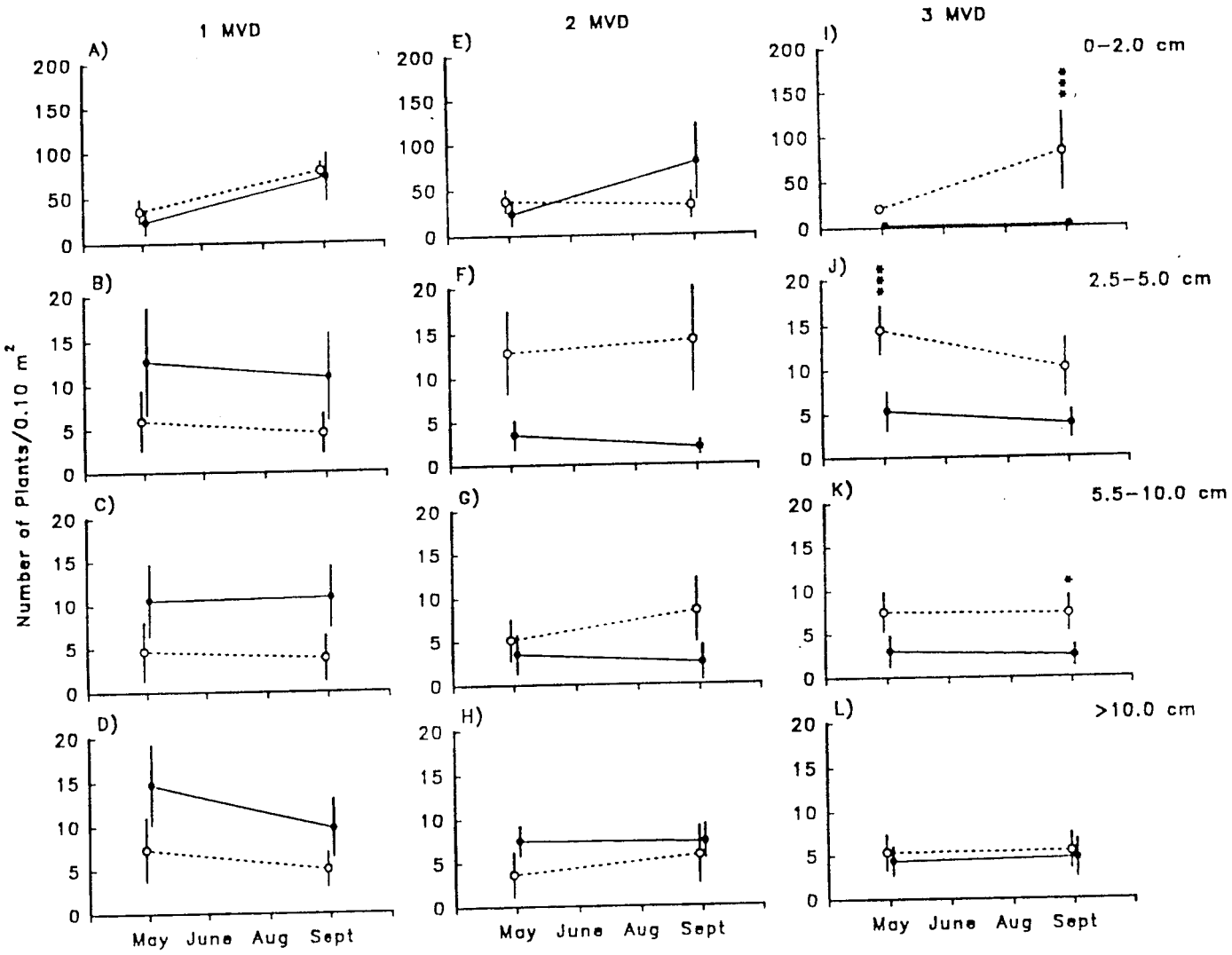


Figure 2.5. Mean number (± SE) of *Fucus* plants in four size classes at three tidal levels at site pair 3811C/3611X. Layout is the same as those in Figure 2.3.

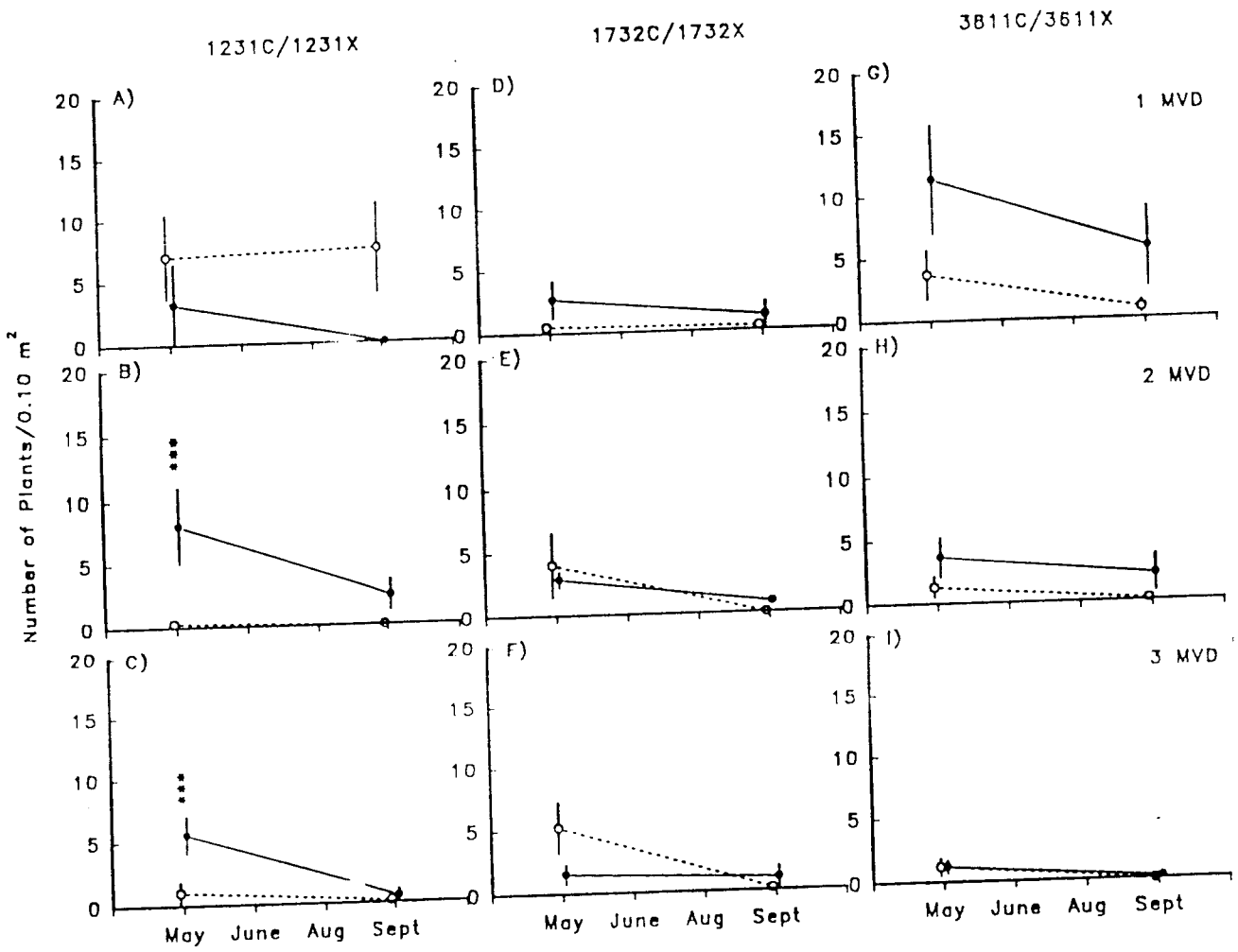


Figure 2.6. Mean number (± SE) of reproductive *Fucus* plants per quadrat at three tidal levels at the three sheltered rocky site pairs. Symbols and lines are the same as those in Figure 2.3.

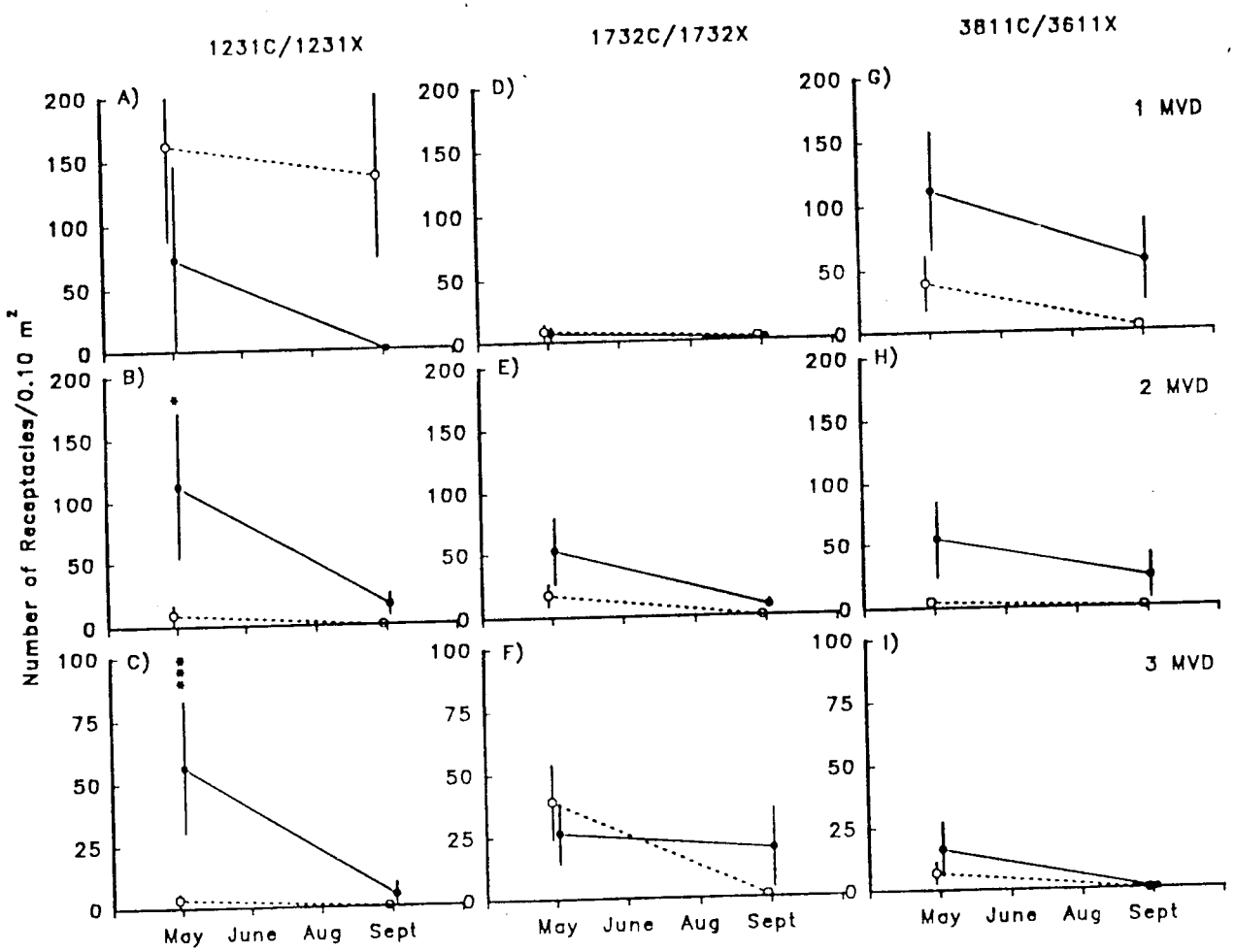


Figure 2.7. Mean number (± SE) of receptacles per quadrat at three tidal levels at the three sheltered rocky site pairs. Symbols and lines are the same as those in Figure 2.3.

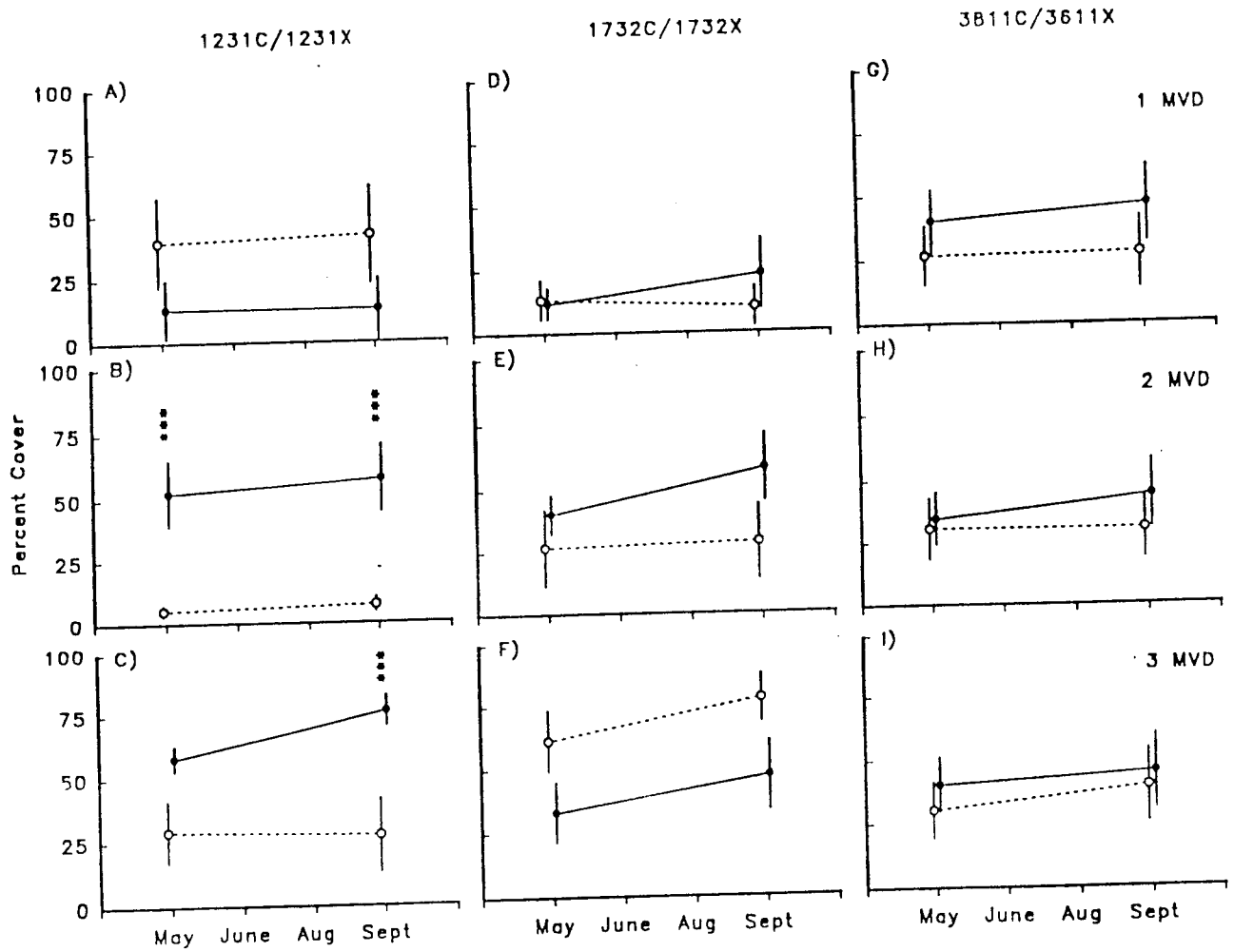


Figure 2.8. Mean percent cover (± SE) of *Fucus* at three tidal levels at the three sheltered rocky site pairs. Symbols and lines are the same as those in Figure 2.3.

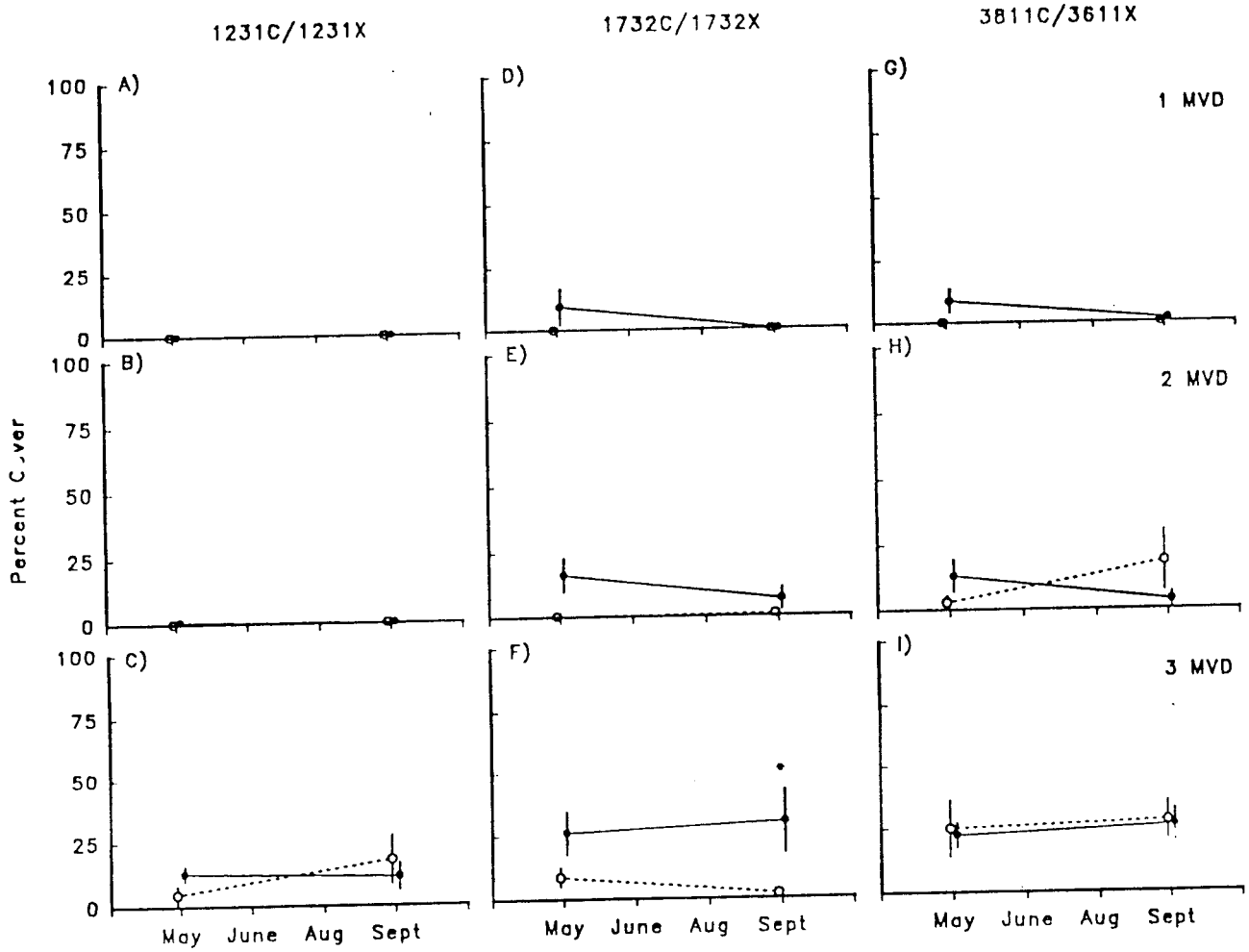


Figure 2.9. Mean percent cover (± SE) of ephemeral algae at three tidal levels at the three sheltered rocky site pairs. Symbols and lines are the same as those in Figure 2.3.

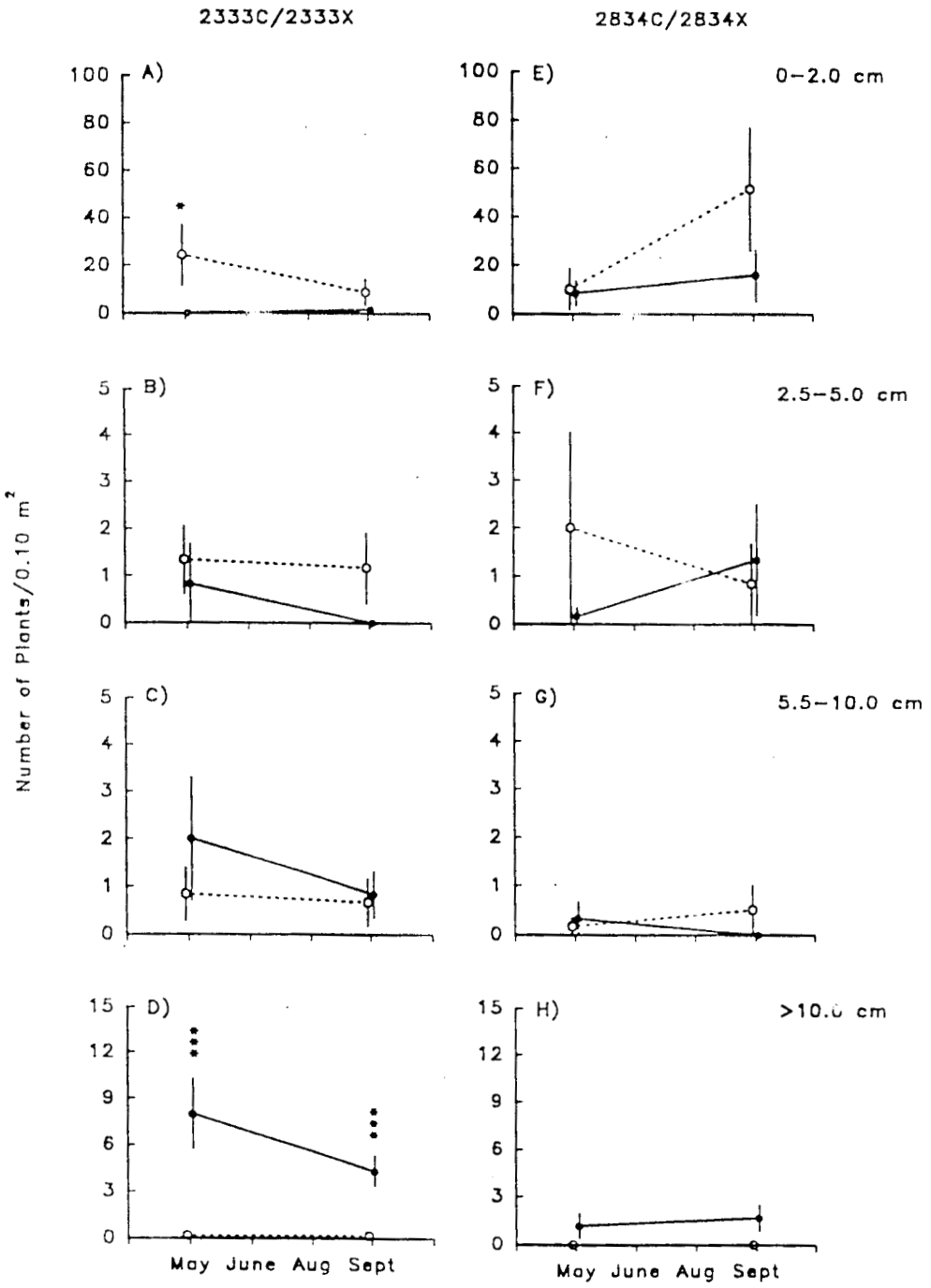


Figure 2.10. Mean number (± SE) of *Fucus* plants in four size classes at 3.0 MVD at the two coarse textured site pairs. Symbols and lines are the same as those in Figure 2.3.

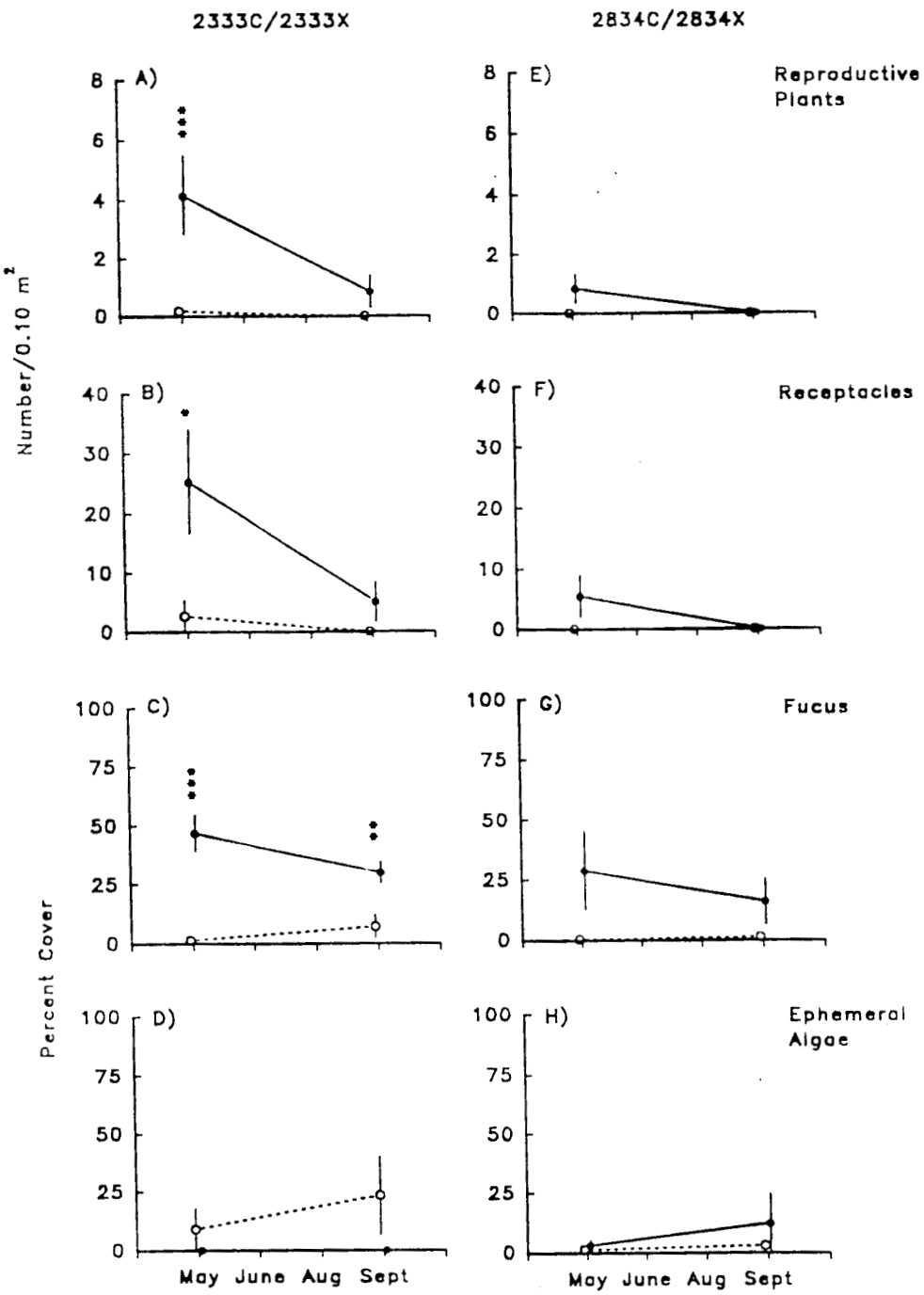


Figure 2.11. Mean number (± SE) of reproductive *Fucus* plants per quadrat, receptacles per quadrat, and percent cover of *Fucus* and ephemeral algae at 3.0 MVD at the two coarse textured site pairs. Symbols and lines are the same as those in Figure 2.3.

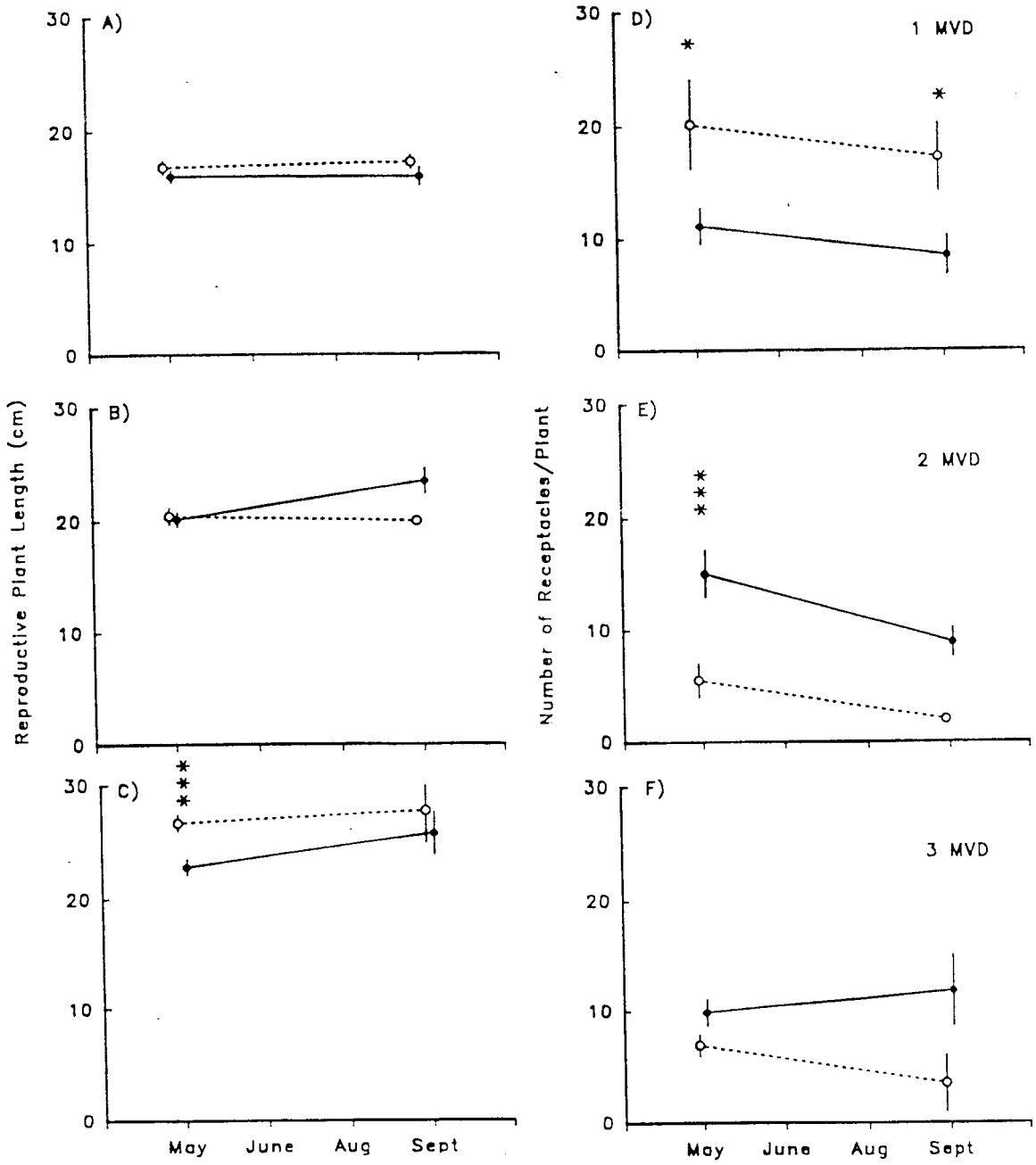
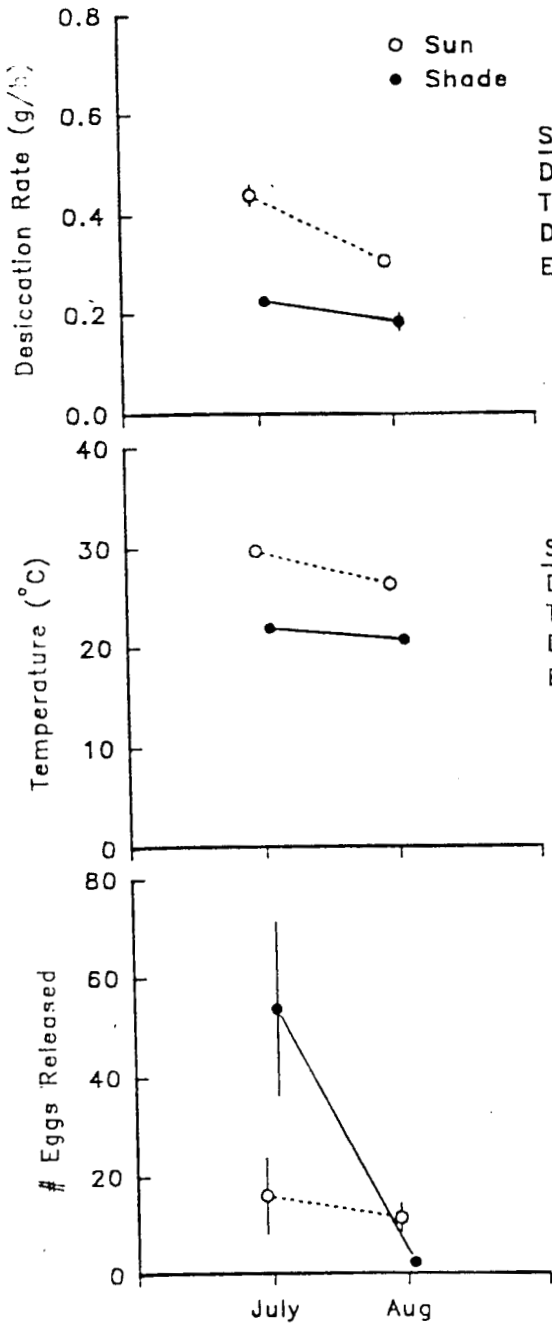


Figure 2.12. The average length and number of receptacles per plant for all reproductive *Fucus* plants at all five site pairs sampled. The top graphs are for the first MVD, the middle graphs for the second MVD, and the bottom graphs for the third MVD. Layout is the same as Figure 2.3.



Source	df	F/MSE	P
Date (D)	1	24.43	0.000 *
Treatment (T)	1	99.84	0.000 *
D*T	1	1.19	0.283
Error	36	0.03	

Source	df	F/MSE	P
Date (D)	1	15.92	0.000 *
Treatment (T)	1	140.29	0.000 *
D*T	1	3.63	0.065
Error	36	3.21	

Source	df	F/MSE	P
Date (D)	1	9.49	0.004 *
Treatment (T)	1	0.45	0.508
D*T	1	10.04	0.003 *
Error	36	6.49	

Figure 2.13. Mean (± SE) number of eggs released, temperature, and desiccation rate for sun and shade treatments. ANOVA results are given to the right of each graph. The F/MSE column contains the MS value for Error and the F ratios for all other sources.

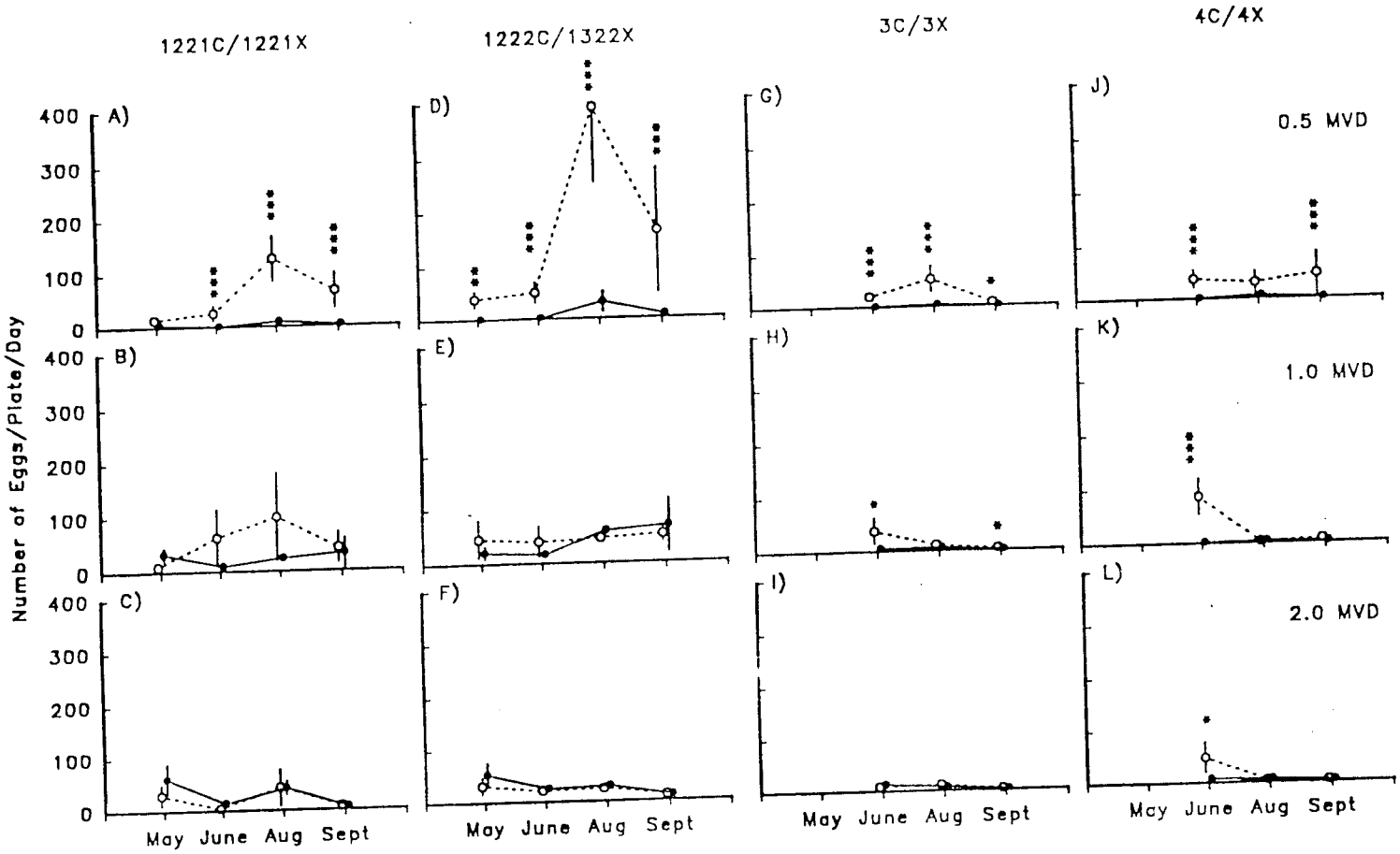


Figure 2.14. Mean number (± SE) of eggs settled per plate per day at three tidal levels at four site pairs. Symbols and lines are the same as those in Figure 2.3.

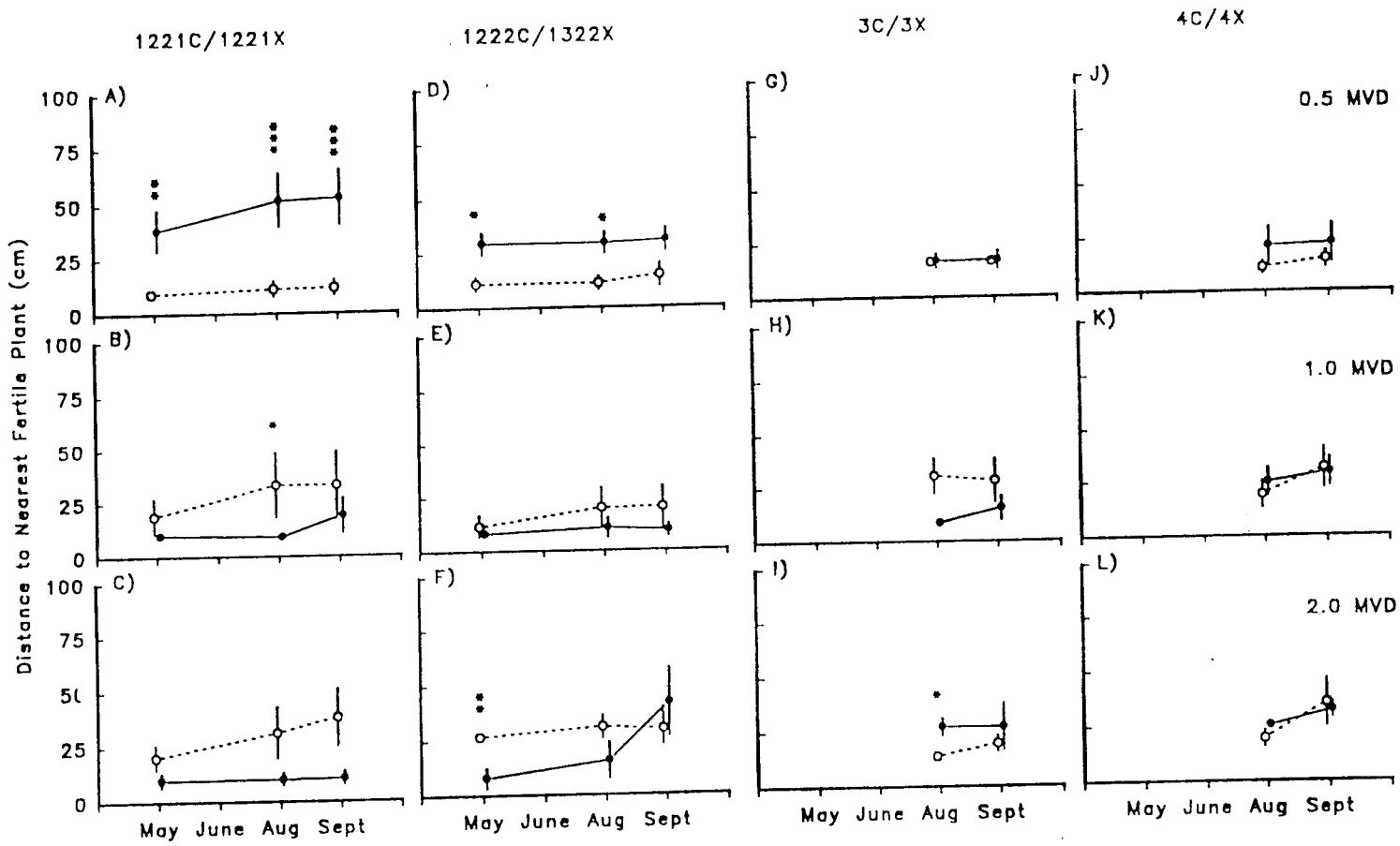


Figure 2.15. Mean distance (± SE) to the nearest fertile *Fucus* plant from settling plates at three tidal levels at four site pairs. Symbols and lines are the same as those in Figure 2.3.

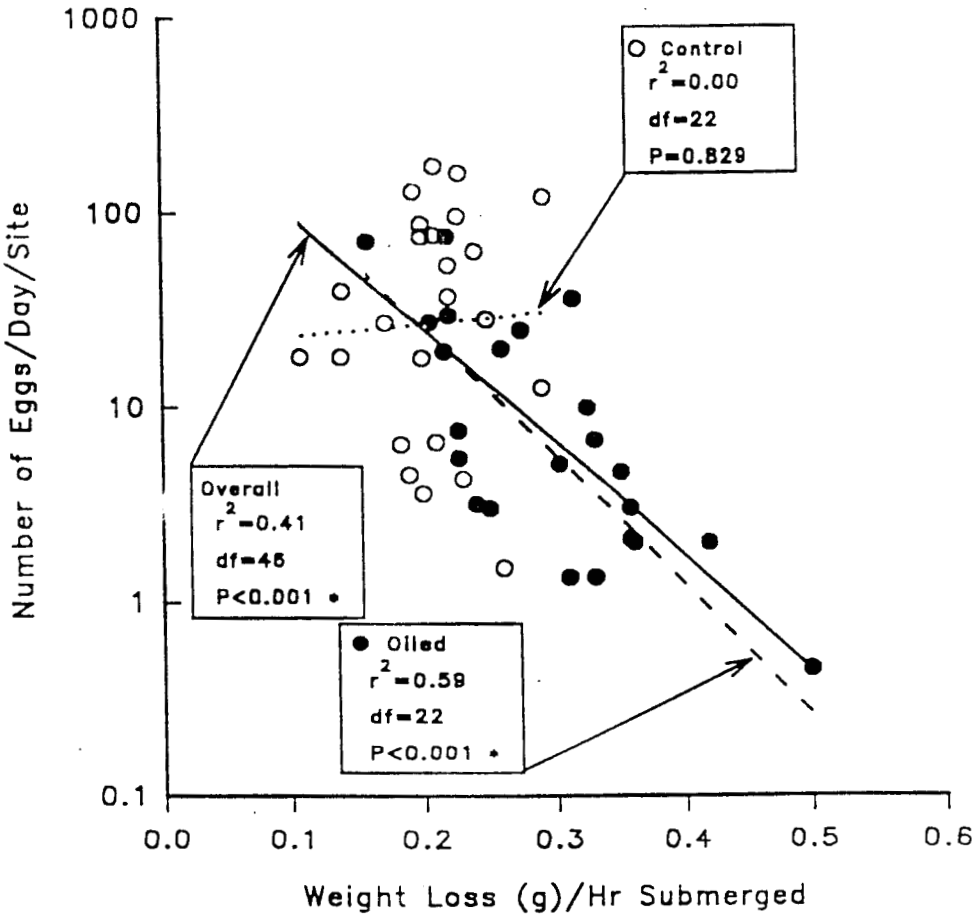


Figure 2.16. Net water flow versus egg settlement rate. The y-axis is in log scale.

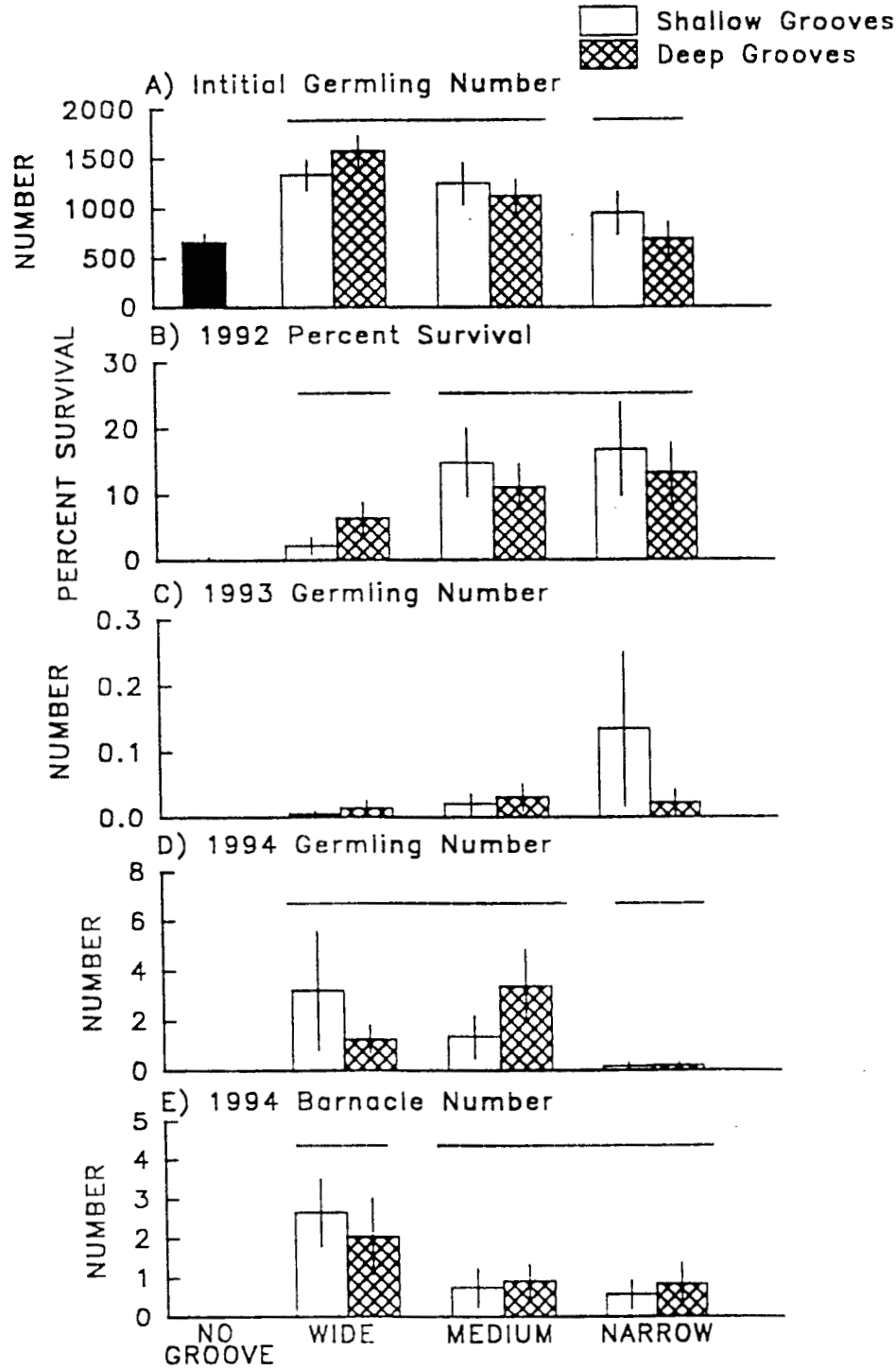


Figure 2.17. The effect of groove size on *Fucus* and barnacles. Initial seeding densities (A) and the percent survival (B) on seeded tiles of germlings in various sized grooves and out of grooves on tiles in 1992. The number of visible germlings in 1993 (C) and 1994 (D) and barancles (E) in and out of grooves. Error bars represent one standard error of the mean. Horizontal bars above graphs connect statistically indistinguishable groove widths. Results of statistical analyses are presented in Table 2.3.

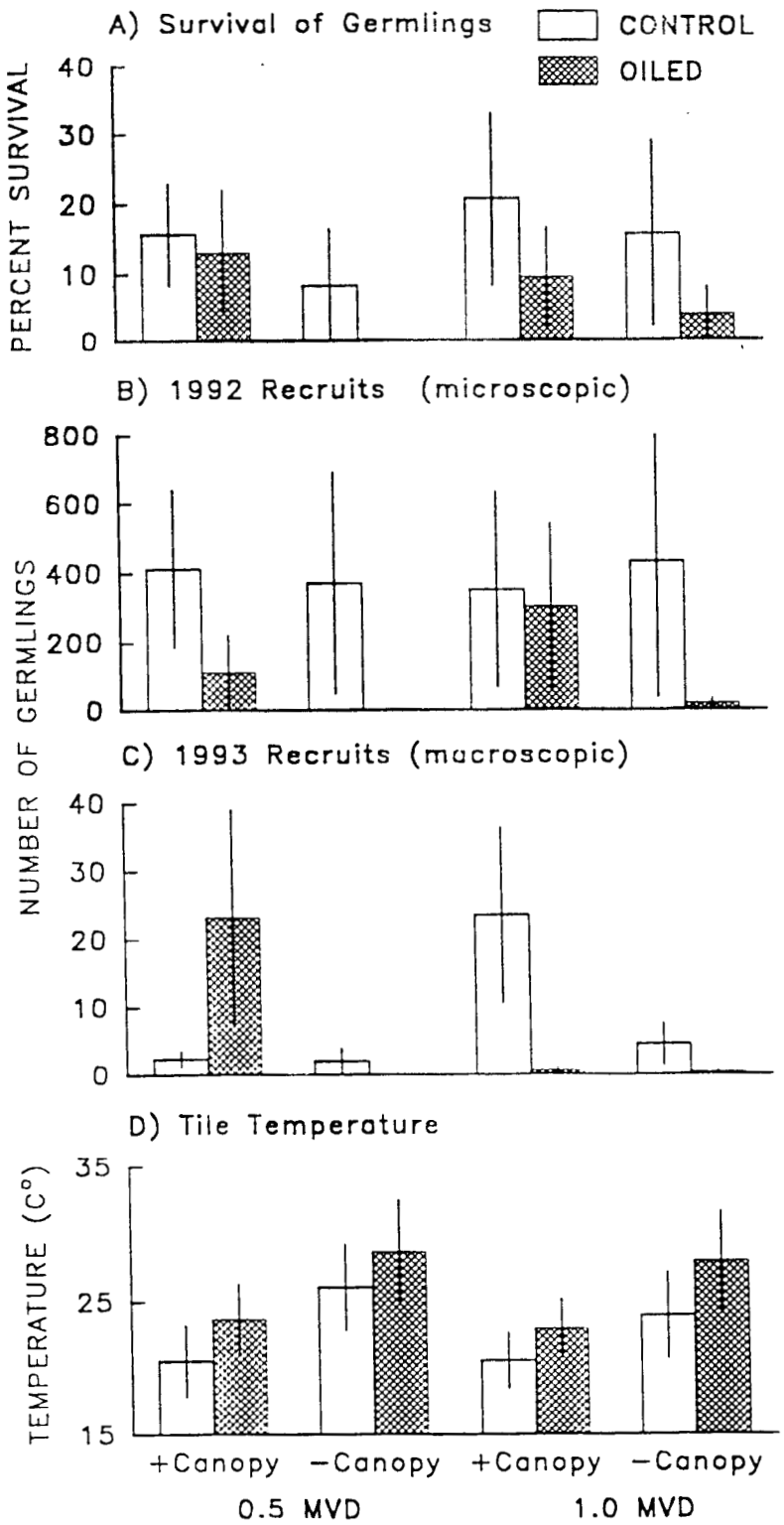


Figure 2.18. The percent survival (A) on seeded tiles, the number of new recruits (B and C) on unseeded tiles, and tile temperatures (C) with (+Canopy) and without (-Canopy) *Fucus* canopy, at the 0.5 MVD and 1.0 MVD tidal levels and at oiled and control sites. Error bars represent one standard error of the mean. Results of statistical analyses are presented in Table 2.4.

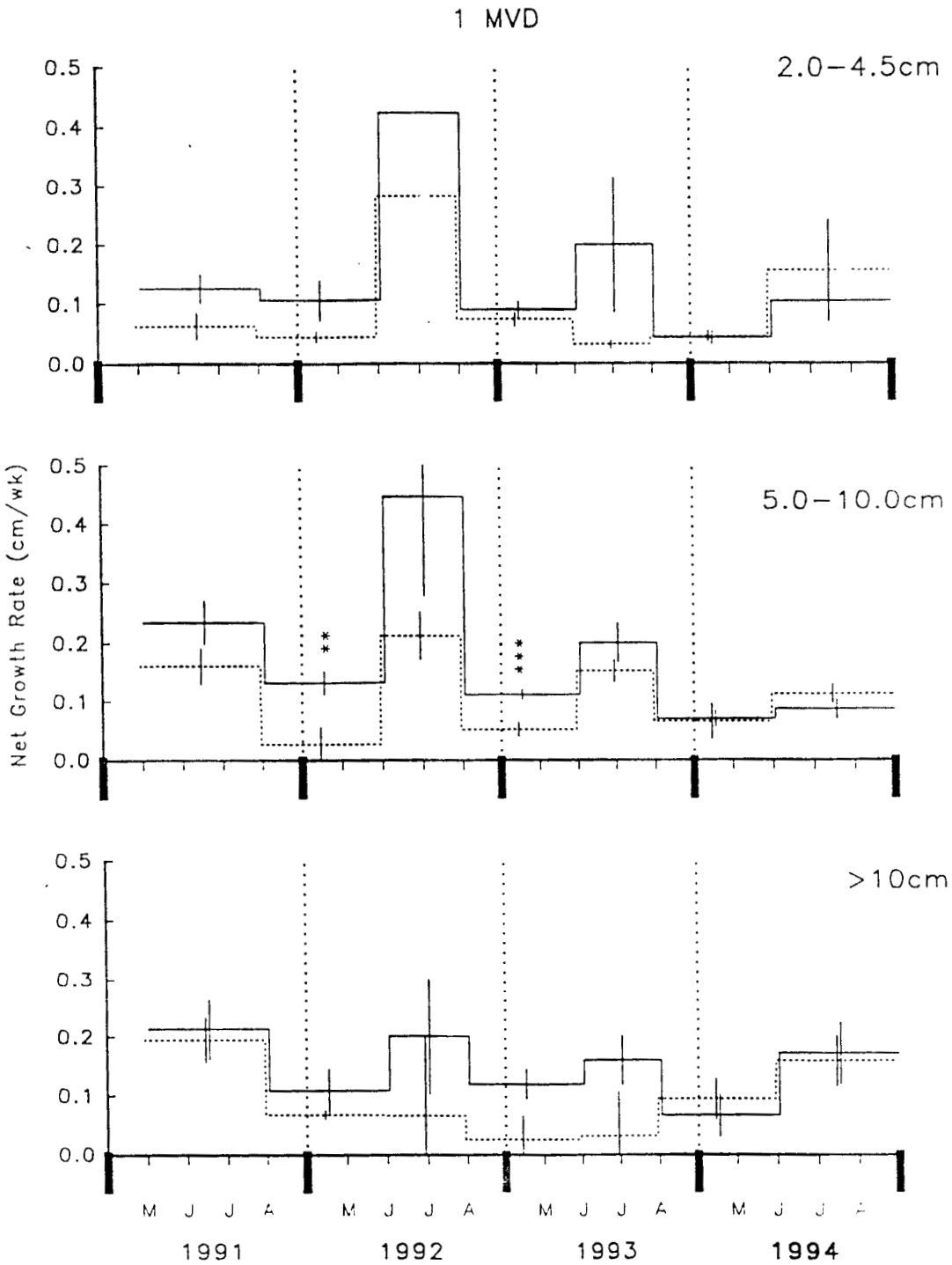


Figure 2.19. Nets growth rates of tagged plants in three size classes at 1 MVD from summer 1991 to summer 1994. Data were combined from the two control sites (1221C and 1723C) and the two oiled sites (1221X and 1723X). Dashed lines represent control sites and solid lines represent oiled sites. Error bars represent standard error of the mean. Stars indicate statistically significant differences between rates at oiled and control sites.

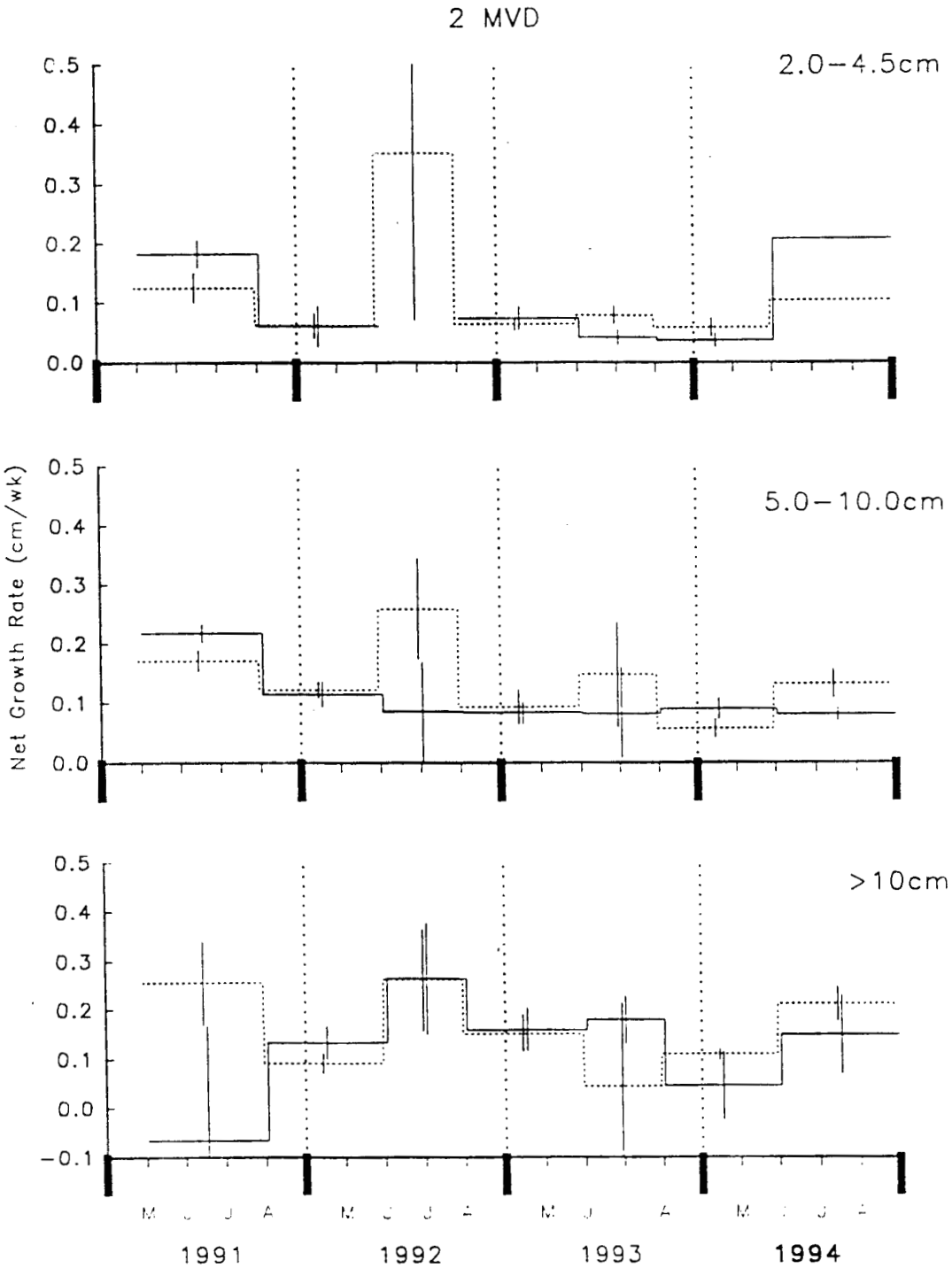


Figure 2.20. Net growth rates of tagged plants in three size classes at 2 MVD from summer 1991 to summer 1994. Layout is the same as Figure 2.19.

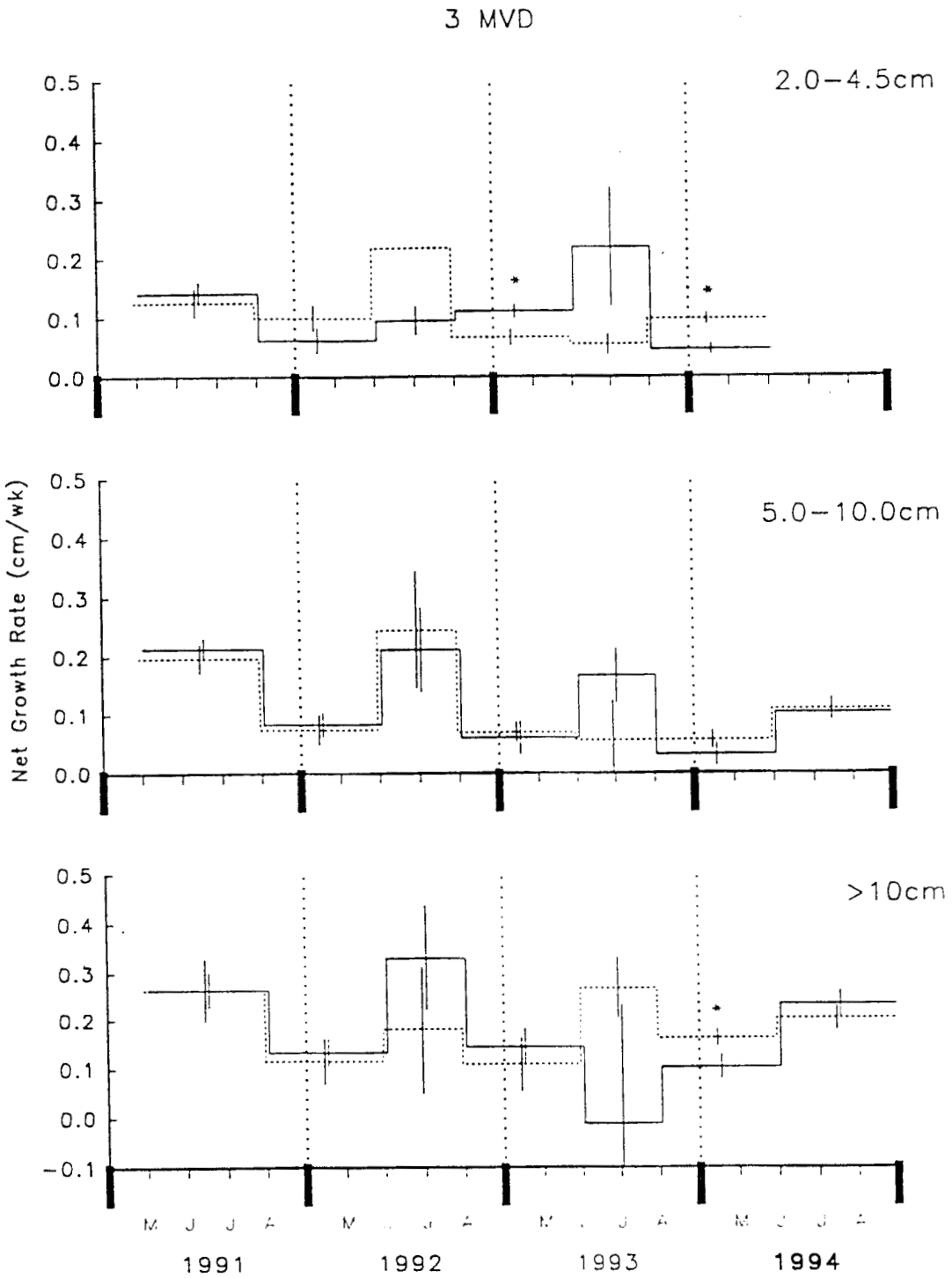


Figure 2.21. Net growth rates of tagged plants in three size classes at 3 MVD from summer 1991 to summer 1994. Layout is the same as Figure 2.19.

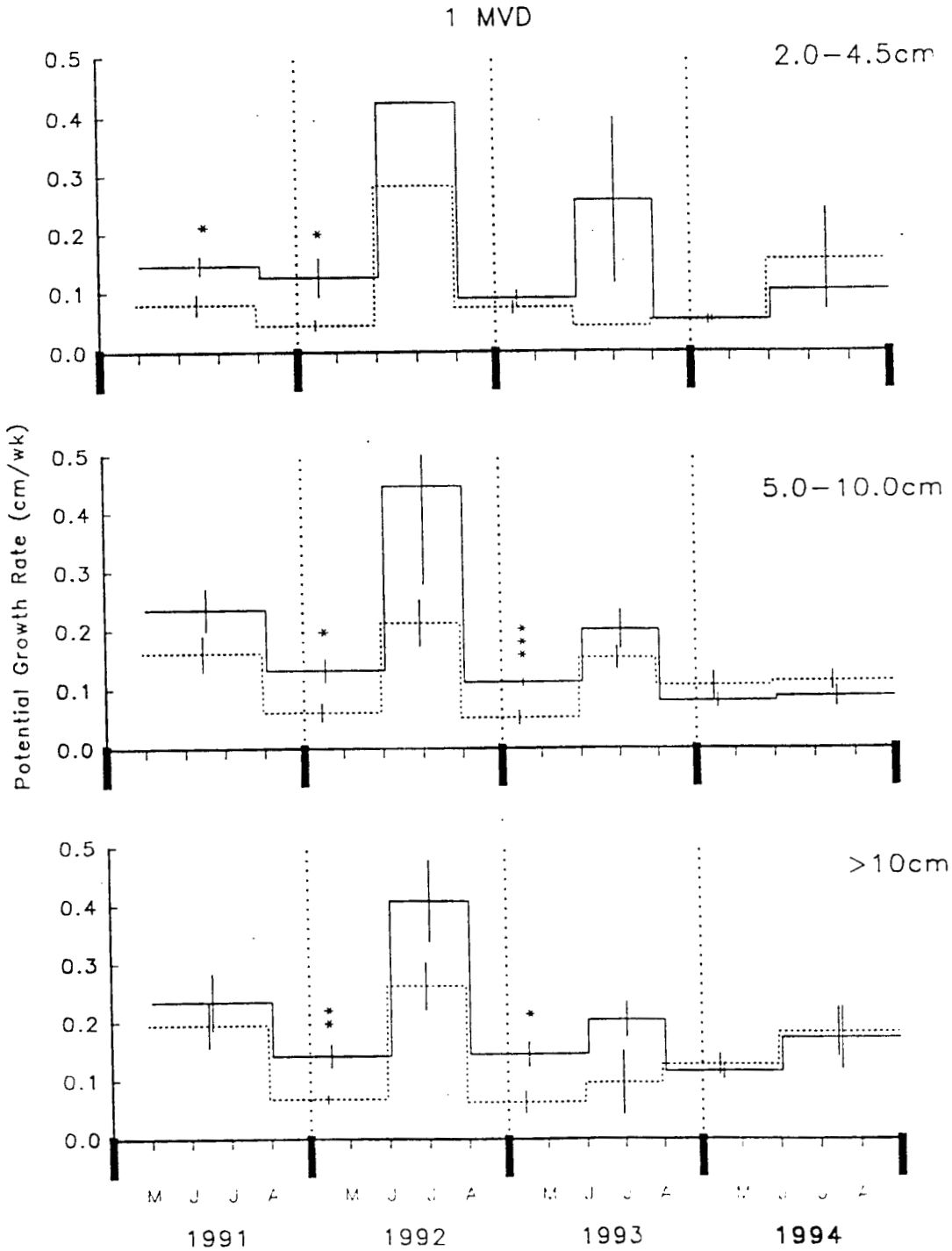


Figure 2.22. Potential growth rates of tagged plants in three size classes at 1 MVD from summer 1991 to summer 1994. Layout is the same as Figure 2.19.

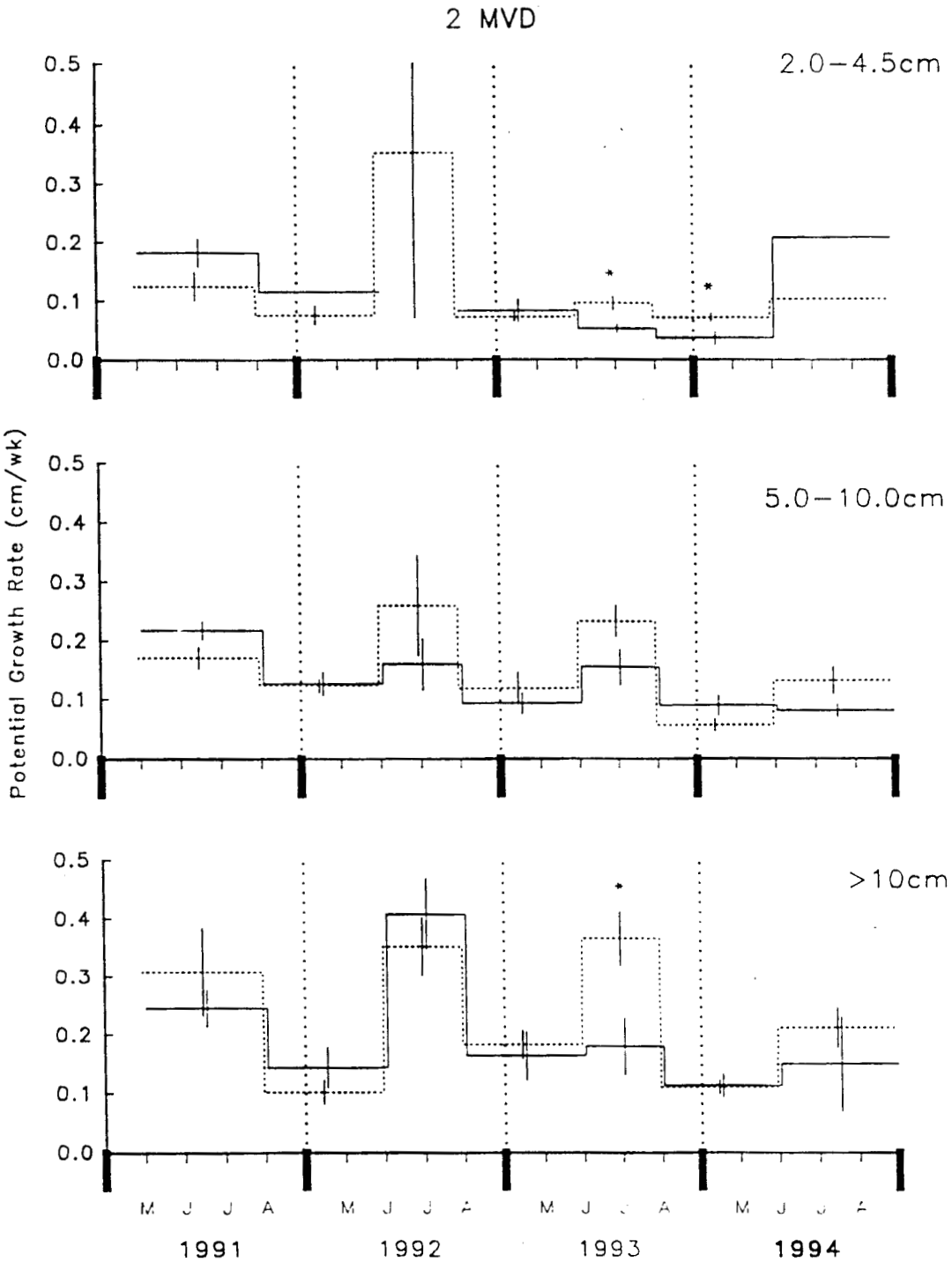


Figure 2.23. Potential growth rates of tagged plants in three size classes at 2 MVD from summer 1991 to summer 1994. Layout is the same as Figure 2.19.

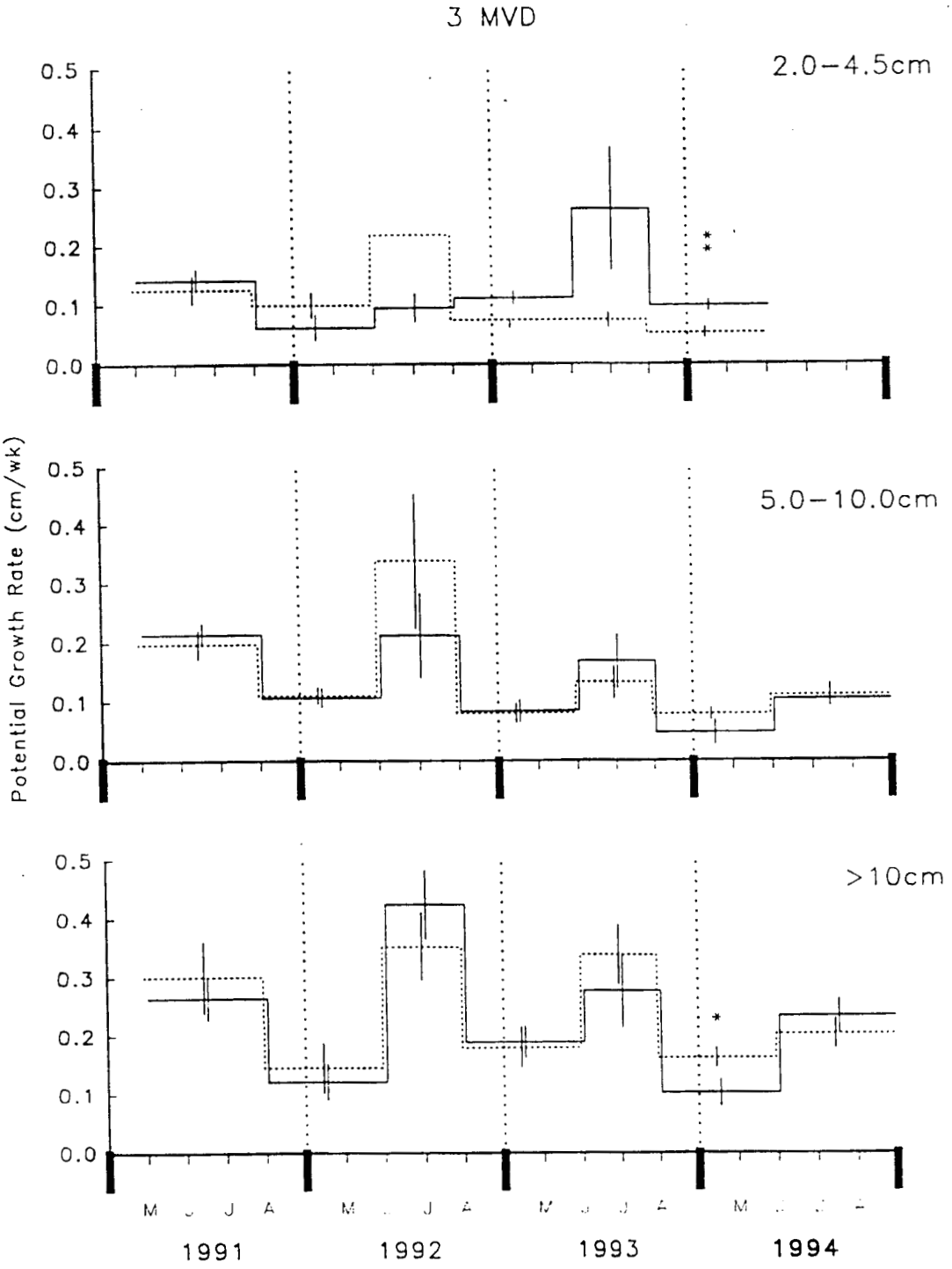


Figure 2.24. Potential growth rates of tagged plants in three size classes at 3 MVD from summer 1991 to summer 1994. Layout is the same as Figure 2.19.

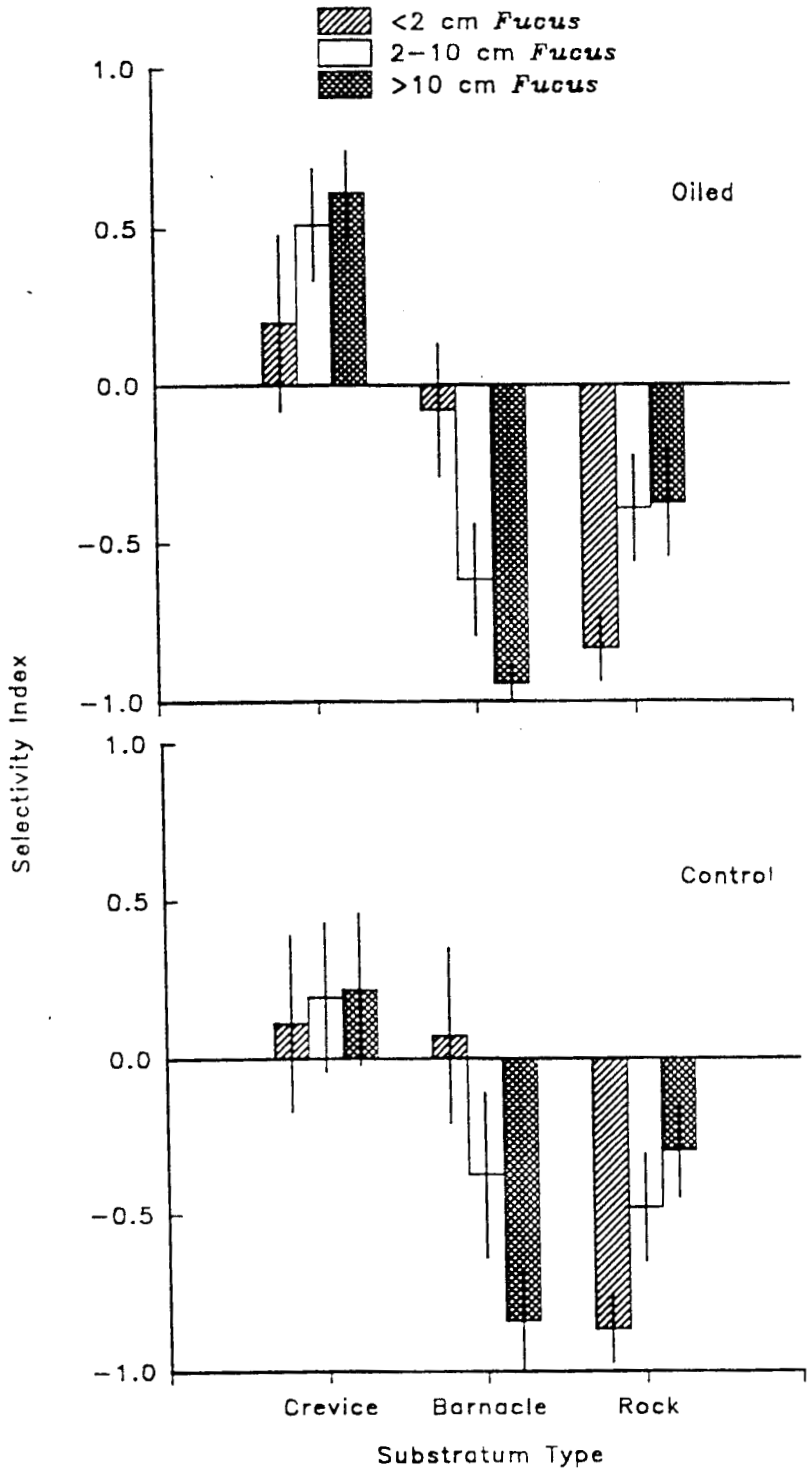


Figure 2.25. Mean selectivity index (± 95% Confidence Interval) of small (<2 cm), medium (2-10 cm) and large (>10 cm) *Fucus* plants on crevice, barnacle, and rock substratum types.

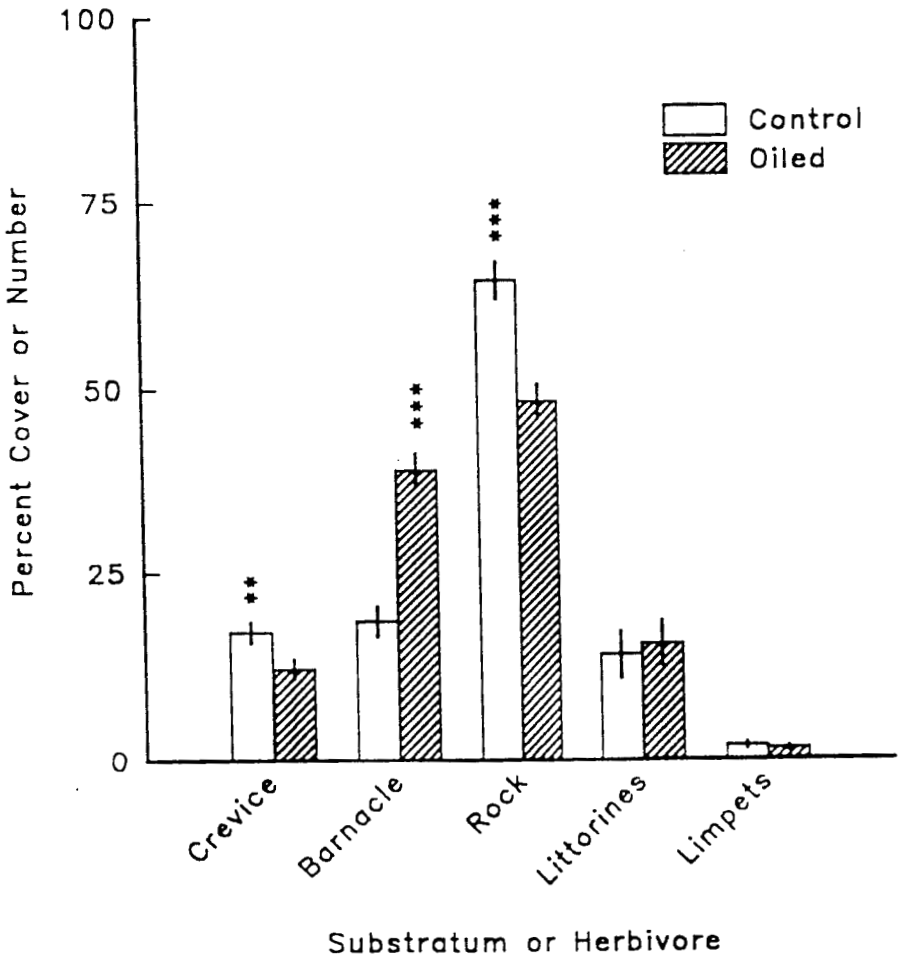


Figure 2.26. Mean (± SE) number of littorines and limpets and percent cover of the three substratum types. Asterisks over bars indicate significantly differences (* P<0.05, ** P<0.01, *** P<0.001).

CHAPTER 3. *FUCUS* RESTORATION

INTRODUCTION

The oil spill and subsequent cleanup activities from the *Exxon Valdez* accident in March 1989 caused considerable damage to the intertidal plant community, especially to *Fucus gardneri* (Silva), the dominant plant in this region. *Fucus* populations were shown to be damaged throughout the intertidal zone during the summer of 1990 (Houghton *et al.*, 1993a, 1993b; Stekoll *et al.*, 1993a, 1993b, 1995; van Tamelen & Stekoll, 1995a, 1995b). In the summer of 1992, populations in the low and mid-intertidal zones at many locations were showing signs of recovery. Surveys of mid and high intertidal zones with a south exposure in Herring Bay, however, showed almost no recovery by the third year after the spill. These habitats remained as bare rock with sparse barnacle and littorine populations.

The purposes of this study were to 1) determine the geographic extent of regions showing slow recovery, 2) determine the factors causing the slow recovery, and 3) determine if cost-effective methods can be developed to restore *Fucus* to regions where populations are not recovering.

METHODS

Study Sites

Our primary restoration study site ("Weasel Beach") is at the north end of Herring Bay in Prince William Sound, Alaska (Figure 1) where *Fucus* populations have been extensively documented since 1991. The site is a region of steep rocky shore subject to intense solar radiation during the summer months when it is exposed to the sun for the entire day. In addition, it is in a location protected from wave action so there is no wave spray to moisten and cool the rock surface.

We have identified other areas of this habitat type in Prince William Sound using the Oil Spill Geographical Information System (GIS) databases assembled by the Alaska Department of Natural Resources. The GIS was used to integrate information on the geographic distributions of factors important to defining these habitats such as oiling category, shoreline aspect, shoreline slope, and habitat type. We have conservatively estimated that there are about 20 km of coastline throughout Prince William Sound that fit the physical criteria of the unrecovered beaches we have seen in Herring Bay.

The Oil Spill GIS was also used to identify unoiled sites with physical characteristics, *i.e.* southern exposure, protected rocky habitat, and beach steepness, similar to the oiled sites that were not recovering. During the spring of 1994 we surveyed a sample of these control

sites on the west side of Knight Island in Lower Herring and Drier Bays. A matching set of oiled sites was sampled in Herring and Northwest Bays.

At each study site the height of the upper boundary of the *Fucus* band was determined relative to the MLLW tidal datum. The locations of the study site endpoints were determined with an autonomous GPS receiver. These study sites ranged from 200 to 2000 meters in length. Random sample points along the beach at each study site were chosen by dividing the beach length into 10 equal segments. A random starting point was chosen within the first segment and the remaining samples were taken at regular intervals of 1/10th the beach length. Sample points at study sites with the longest beach lengths were picked directly with the GPS receiver. Shorter beach segments or beach segments where GPS satellite reception was poor were divided into segments based on boat run times between the endpoints of the study site. The 30 to 100 m resolution of the GPS receiver was not sufficient to pick samples on short beach segments.

At each sample point we determined the vertical distance between the water line and the highest *Fucus* plant within a 1 meter swath centered on the randomly selected point on the beach. Vertical distances were determined with a transit and hand-held sight level. The time of the measurement was also noted to calculate the height relative to published (National Oceanic and Atmospheric Administration) tide heights.

Restoration Methods

A preliminary experiment to test the feasibility of fastening and maintaining erosion control fabrics in the rocky intertidal was initiated in May 1992 at Weasel Beach. The material tested was ANTIWASH/GEOJUTE fabric from Belton Industries of Atlanta, Georgia. This fabric was chosen because it had the highest water retention of the materials we tested (Table 1), it is completely biodegradable without any synthetic netting that can trap or injure wildlife, and the estimated life-span of this material in terrestrial applications is two years according to the manufacturer. We felt this life-span would be long enough to allow *Fucus* juveniles to become established in this region. In 1993 we used a more durable fabric made of coconut fiber (DeKoWe 900 fabric, Belton Industries). This fabric has a manufacturer's suggested life-span of five to ten years.

One meter wide strips (mats) of the jute fabric were fastened to the intertidal rocks with a combination of stainless steel screws and epoxy putty. The coconut fiber fabric mats, also 1 meter wide, were fastened totally with stainless steel screws. The screw fasteners permitted easier removal of the mats when censusing the plots.

The tops of the mats were placed at the Mean High Water mark (+3.4 m MLLW or 0 MVD, meter of vertical drop) as indicated by the lower boundary of the *Verrucaria* zone. The strips extended down the intertidal to cover the substrate to the level 1 meter vertically below Mean High Water (1 MVD). Altogether six mats were fastened at randomly located

positions along the length of Weasel Beach. Six areas of similar size were selected and monitored as uncovered control plots. Counts of *Fucus*, littorines, and limpets were made in 9, 100 cm^2 quadrats on the substrate covered by the fabric and on uncovered controls in both the 0.0-0.5 MVD and the 0.0-1.0 MVD tidal zones. In addition the total number of *Fucus* plants were counted in the treatment strips. In 1994, we also counted and mapped the *Fucus* plants on the surface of the coconut fiber fabric. All plants greater than 2 mm in length were counted between the Mean High Water level and the 1 MVD mark. A 100 cm^2 quadrat was used to guide the census to ensure that all the small plants were censused. The quadrat data also provided information on the spatial distribution of plants on the mat.

Reproductive *Fucus* plants were harvested from a number of locations throughout Herring Bay and transplanted to three of the experimental mats and to three of the control plots in both 1993 and 1994. Six plants were attached by plastic tie-wraps to each of the experimental strips where they were expected to release fertilized eggs over a period of a few weeks. The plastic ties were attached directly to the coconut fiber fabric in the fabric treatments and to the rock surface using epoxy putty in the nonfabric controls.

Reproductive *Fucus* plants were also harvested to provide fertilized eggs in an inoculation solution that was poured over the experimental plots. After collection, the fertile receptacles were cut from the plants, washed with fresh water and placed on toweling to dry. The dried receptacles were then placed overnight in clean seawater for release of the fertilized eggs. The concentration of eggs in the resulting egg solution was determined by placing 10 ml of the egg solution into a petri dish with a cm counting grid on the bottom. Eggs were counted in 10 of the cm grids. The egg solution was then diluted with seawater to produce a final inoculation solution for use in the field. This final inoculation solution was equally divided and sprinkled over each of the same inoculation plots listed above. During the Spring 1993 visit the egg concentrations, reported as a nominal egg density over the treatment area on the beach, ranged from 0.18 eggs mm^{-2} on June 9th to 0.007 eggs mm^{-2} on June 10th. During the late Summer visit the concentration was 0.02 eggs mm^{-2} on September 1. Plants collected in 1994 did not release sufficient embryos for the inoculation procedures.

Temperatures and desiccation

To assess the relative protection afforded by the fabric, air and rock temperatures were measured during periods of low water, both under and away from the fabric. Temperatures were measured with thermistors connected to a data logger which sampled every five minutes. Concurrently we estimated the rate of desiccation by measuring the weight loss of wetted cotton balls. For each desiccation measurement, three cotton balls of similar dry weight (2 g total) were set on a tared 9 cm plastic Petri dish. The cotton balls were wetted with a 10.0 grams of distilled water and the dishes were placed on the substrate. Cotton ball weights were monitored every 30 minutes until high water. Experiments were performed on May 28 and September 9.

RESULTS

Surveys of *Fucus* Upper Limits

The heights of the upper *Fucus* boundaries at the oiled and control sites throughout Prince William Sound are summarized in Table 2. The average height at the unoiled controls (+2.89 m MLLW) was significantly higher (t-test, $t=3.94$, $p<0.001$) than at the oiled sites (+2.48 m MLLW). The variability seen in these heights appears to be related to differences in wave exposure at the sites. Even though all of these sites were characterized as sheltered rocky habitat, some sites were closer to headlands and the openings of the bays. The more exposed sites had higher upper *Fucus* boundaries.

Restoration

Observations of the GEOJUTE fabric in September, 1992, showed that it was eroding and becoming detached from the substrate. On the initial visit of the 1993 field season only small remnants of the fabric remained at points were it was screwed to the rock substrate.

In contrast to the jute fabric, the coconut fiber mats persisted through the winter season and were only mildly abraded by September 1994 after fifteen months exposure in the intertidal. We expect that this fabric will remain in place for at least one more year.

By the end of the summer of 1994, dense populations of young *Fucus* plants with mean densities over 500 plants m^{-2} had grown on the surface of the coconut fiber mats (Figure 2). There was no significant difference between inoculation treatments in the overall density of juvenile plants on the mats. The inoculated mats, however, had patches of plants in the immediate vicinity of the plant attachment sites (Figure 3). The majority of plants on the mats, both inoculated and uninoculated controls , occurred on the bottom edges. This portion of the mat remained moist for the longest period of time and was also the closest to the band of fertile adult plants that would have provided a source of embryos.

Densities of the *Fucus* plants were much less on the rock substrate itself. These densities showed no differences between treatments, *i.e.* erosion control fabrics, egg inoculations, and controls (ANOVA, $F=1.59$ $p=0.27$), and the counts within the treatments were pooled to produce the overall means (Figure 4). The number of *Fucus* plants is still very low in the top 0.5 meter of the intertidal and increased only slightly during the two and a half year period of this study. Densities in the 0.5 to 1.0 MVD zone have fluctuated around 15 plants m^{-2} until the September 1994 sample when the density reached 34 plants m^{-2}.

The density of littorines in the restoration plots showed a general decrease in abundance from Spring 1993 to the last sampling period in September 1994 (Figure 5). No differences were found in limpet densities as a function of mat cover (ANOVA, $p>0.05$). Densities were significantly higher at the lower tidal level (ANOVA., $p=0.0007$), and were significantly different between sampling periods (ANOVA, $p<.0001$).

In contrast to the littorine populations, limpets showed a large increase in population size during the summer of 1993 at both tidal levels (Figure 6). Limpet densities increased in both the plots with the coconut fiber matting and the bare control plots. However, there were significantly more individuals under the coconut fiber matting at both the 0.5 MVD (Figure 7) and 1.0 MVD (Figure 8) levels (ANOVA, $p< 0.0001$).

Subsequent to the large population increase seen during the summer of 1993, populations under the coconut fiber matting at the 0.5 MVD showed a significant decline between the winter of 1994. These levels then persisted through September 1994. The populations on bare rock substrate at this tidal level remained fairly constant during this time period. At the 1.0 MVD, the populations under the coconut fiber matting showed a slight decline during 1994. The populations on bare substrate showed a slight increase in the spring of 1994, but then a very large decrease in the September sample. During the summer months, therefore, it appears that the coconut fiber matting was sheltering the limpets from desiccation.

Results from the temperature and desiccation experiments were similar in May and September. In May temperatures under the matting were cooler and the desiccation rate was less than away from the matting or even near to the edge of the matting (Figure 9)

We also have documented the *Fucus* distribution at the Herring Bay restoration site with an annual series of photographs started in 1990 (Figure 10). These photographs show that the *Fucus* populations colonized the lower intertidal zone fairly rapidly and reached the 2 MVD level by 1992. The upper boundary approached the 1.5 MVD mark by 1993 and remained at this level through the summer of 1994.

DISCUSSION

The upper intertidal zone is a very harsh environment for recruitment and survival of *Fucus* individuals. Experimental transplants of individual adult plants from lower tidal zones showed that these plants could not survive more than a few months (DeVogelaere & Foster 1994; Stekoll et al. 1993). Microscopic juvenile stages are even more susceptible to mortality from high temperatures and desiccation (Brawley & Johnson 1991). Our observations of *Fucus* egg dispersal and recruitment patterns (McConnaughey 1984, van Tamelen & Stekoll 1995a, 1995b) indicate that *Fucus* recruitment in the high intertidal requires a large population of adults to provide both a constant supply of eggs and a sheltered

environment for survival of the young plants. Colonization of new plants, therefore, progresses from the edges of existing natural beds.

At the experimental site in the northern portion of Herring Bay, the natural bed of adult *Fucus* is still approximately 0.5 m below the experimental restoration plots, and has not changed for the past two years. The dense recruitment of young plants onto the coconut fiber matting shows that the moist environment provided by the matting is the most important factor limiting the expansion of the *Fucus* population. The majority of these plants, however, have settled on the lower edges of the mats. This distribution pattern suggests that limited embryo dispersal from the nearby band of fertile adult plants is another critical factor regulating population increase in the high intertidal.

The new populations of young plants that have settled on the erosion control fabric will serve as an additional source of embryos in the high intertidal. The recruitment of plants on natural rock surfaces within the restoration plots shows that there is some suitable substrate available for recruitment in this region. This substrate is found in microhabitats behind rocks which shelter the substrate from the direct sun and near small tidal pools. The majority of these microhabitats, however, appear to be beyond the dispersal range of the present population of adult plants.

The development of these new *Fucus* populations into sources of embryos will require that the fabric persist long enough to allow these plants to become reproductive. We expect that the juvenile plants will become fertile during the spring and summer of 1995. The mats, even though abraded in some spots, appear sturdy enough to persist at least one more year.

The techniques for inoculating the mats and rock surfaces with *Fucus* embryos were not cost-effective for this type of restoration effort. The use of embryo inoculation solutions did not increase *Fucus* densities on the treated mats. The transplant of fertile adults appeared to provide a very localized increase in recruitment. This technique, however, is very time consuming and labor intensive. Most plants died fairly quickly after transplantation or were washed from the transplant site. Other techniques for more uniform seeding of the mats are under investigation.

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Table 3.1. Comparison of water retention ability of various erosion control fabrics.

Fabric Type	Dry Weight ($g\ cm^{-2}$)	Wet Weight ($g\ cm^{-2}$)	Water Retention (%)
GEOJUTE	0.058	0.347	601
DeKoWe 400	0.077	0.183	239
DeKoWe 900	0.096	0.244	255
BonTerra	0.065	0.173	267

Table 3.2. The height of the upper limit of the *Fucus gardneri* band at both oiled and control (unoiled) south facing, sheltered rocky sites in Prince William Sound. Weasel Beach is the restoration site in the northern section of Herring Bay.

Oiled Sites	Height (m MLLW)	Control Sites	Height (m MLLW)
Northwest Bay #3	2.58	Lower Herring Bay #24	3.05
Northwest Bay #6	2.49	Lower Herring Bay #26	3.10
Northwest Bay #7	2.74	Lower Herring Bay #29	2.79
Weasel Beach	1.88	Lower Herring Bay #30	2.84
Herring Bay #30	2.70	Lower Herring Bay #31	2.85
Herring Bay #33	2.38	Drier Bay #43	2.89
Herring Bay #34	2.16	Drier Bay #44	2.70
Herring Bay #35	2.73		
Herring Bay #40	2.62		
Herring Bay #43	2.57		
Mean	2.49		2.89

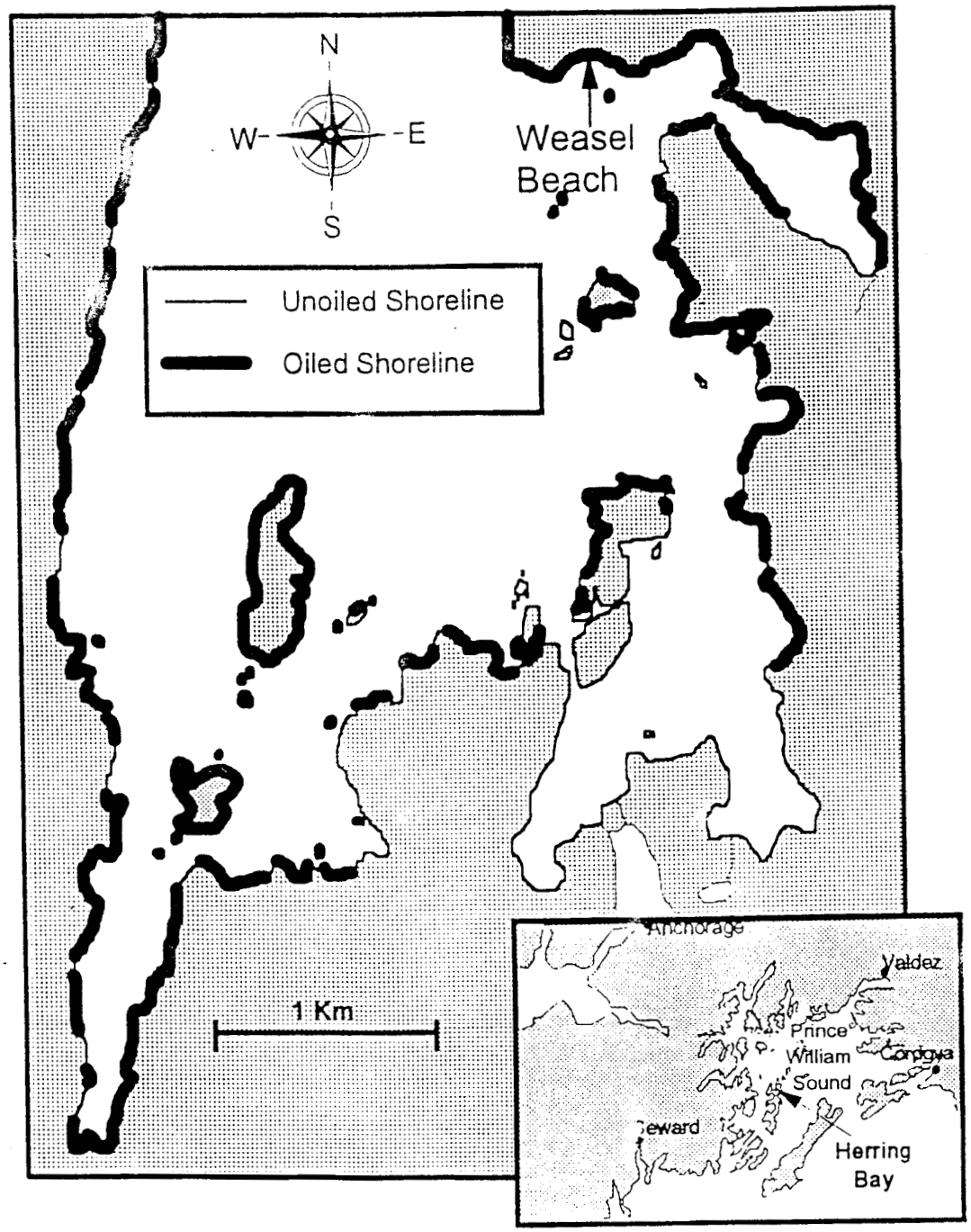

Figure 3.1. Location of the *Fucus* restoration site, Weasel Beach, at the north end of Herring Bay in Prince William Sound, Alaska.

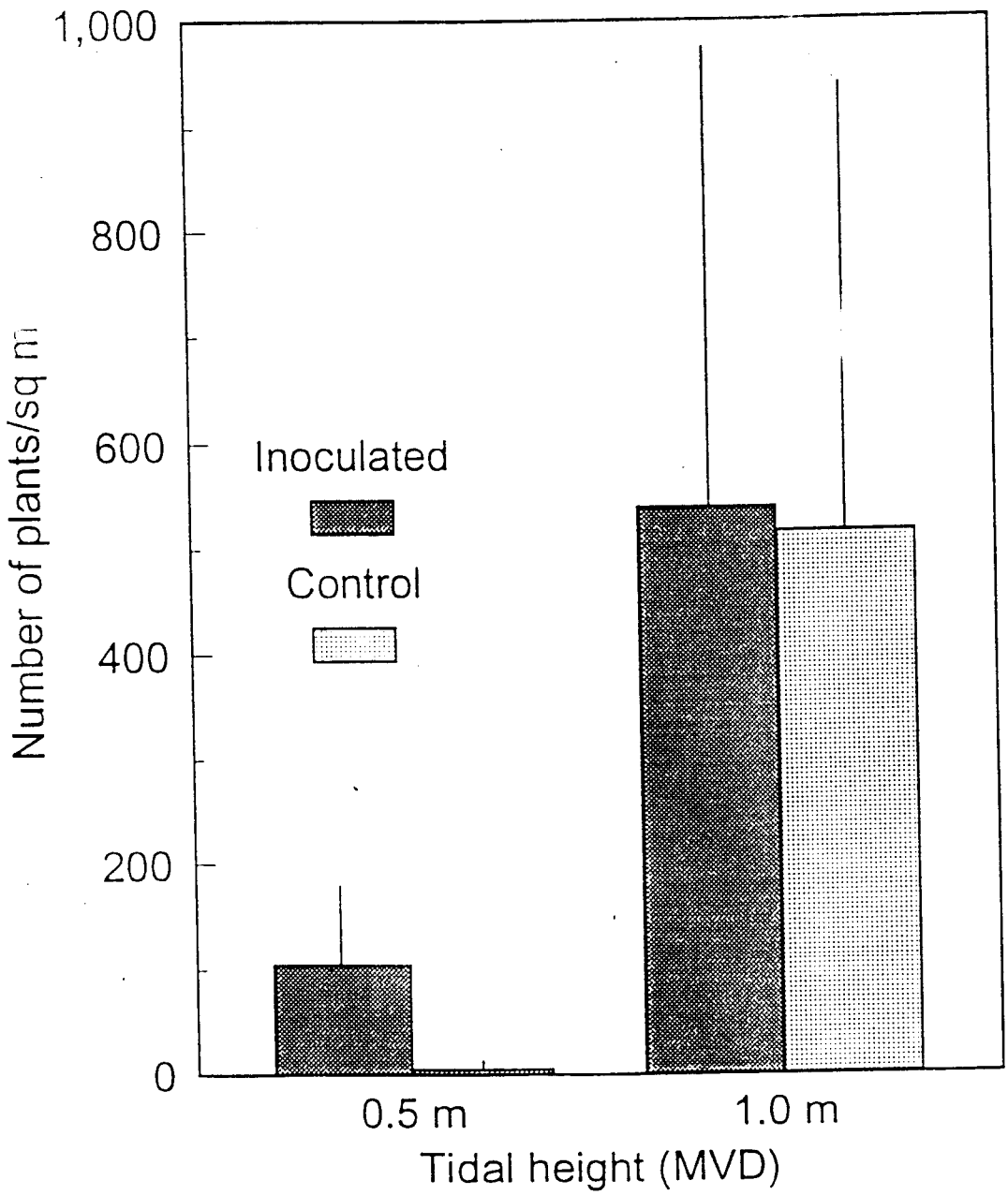

Figure 3.2. Density of *Fucus* plants on the surface of coconut fiber erosion control mats at Weasel Beach in September 1994. Mats were deployed in June 1993. Inoculated mats were seeded with transplanted fertile *Fucus* plants and sprinkled with *Fucus* embryo solutions in the summer of 1993. Controls were not inoculated. MVD = meters of vertical drop below the mean high water line. N = 3 for each treatment. Error bars represent one standard error of the mean.

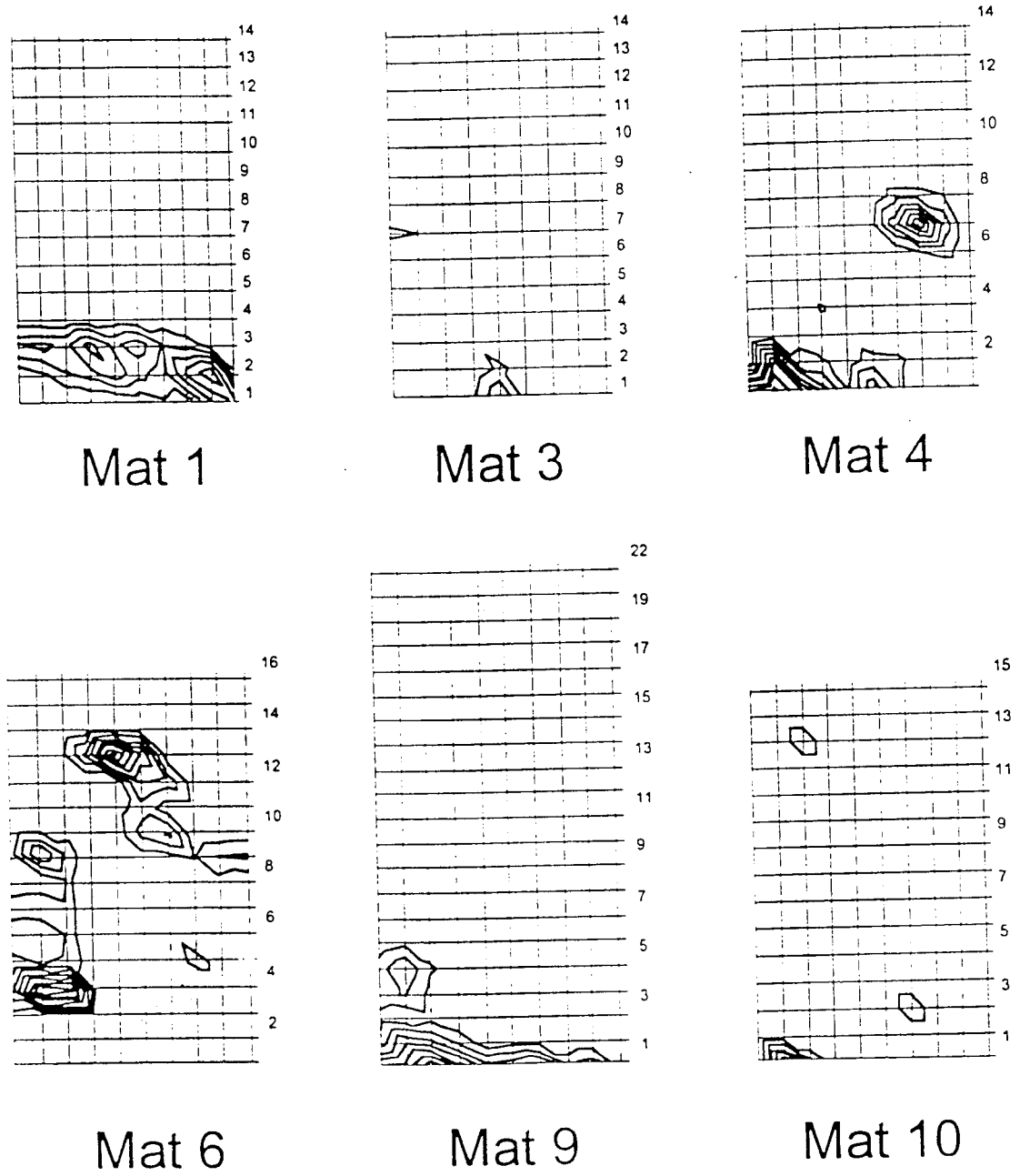

Figure 3.3. Density contour maps of *Fucus* germlings on the mat surfaces in September 1994. Each contour represents an increase of 10 plants per 100 square cm. Mats 4, 6 and 10 were inoculated in 1993 by tying fertile *Fucus* plants to them. Mats vary in length due to the differences in slope along the beach. The bottom of each mat is at 1.0 MVD and the top is at 0.0 MVD (MHW).

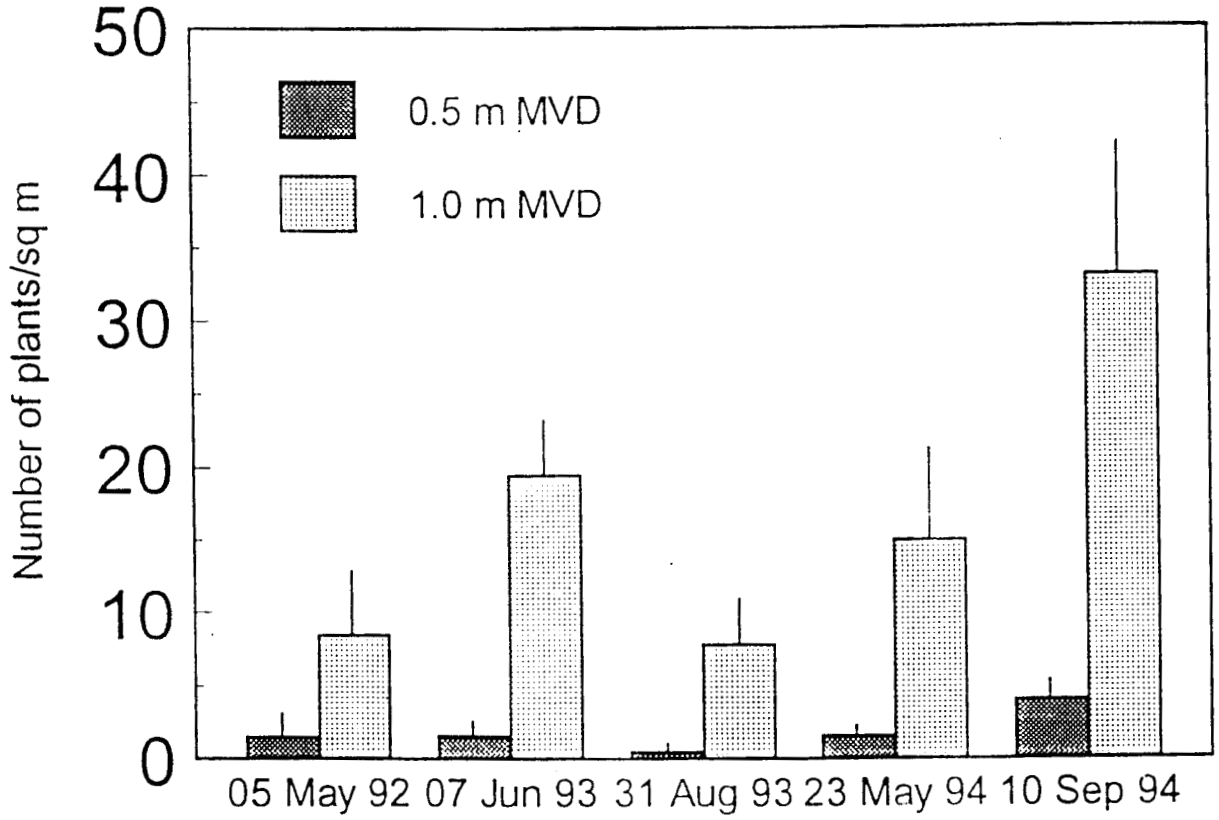

Figure 3.4. Density of *Fucus* plants at two tidal heights on the rock substrate over time. Values are the mean of density counts from control, inoculated, and mat covered sites. MVD = meters of vertical drop below the mean high water line. N = 12 for all times except in 1992 when N = 9. Error bars represent one standard error of the mean.

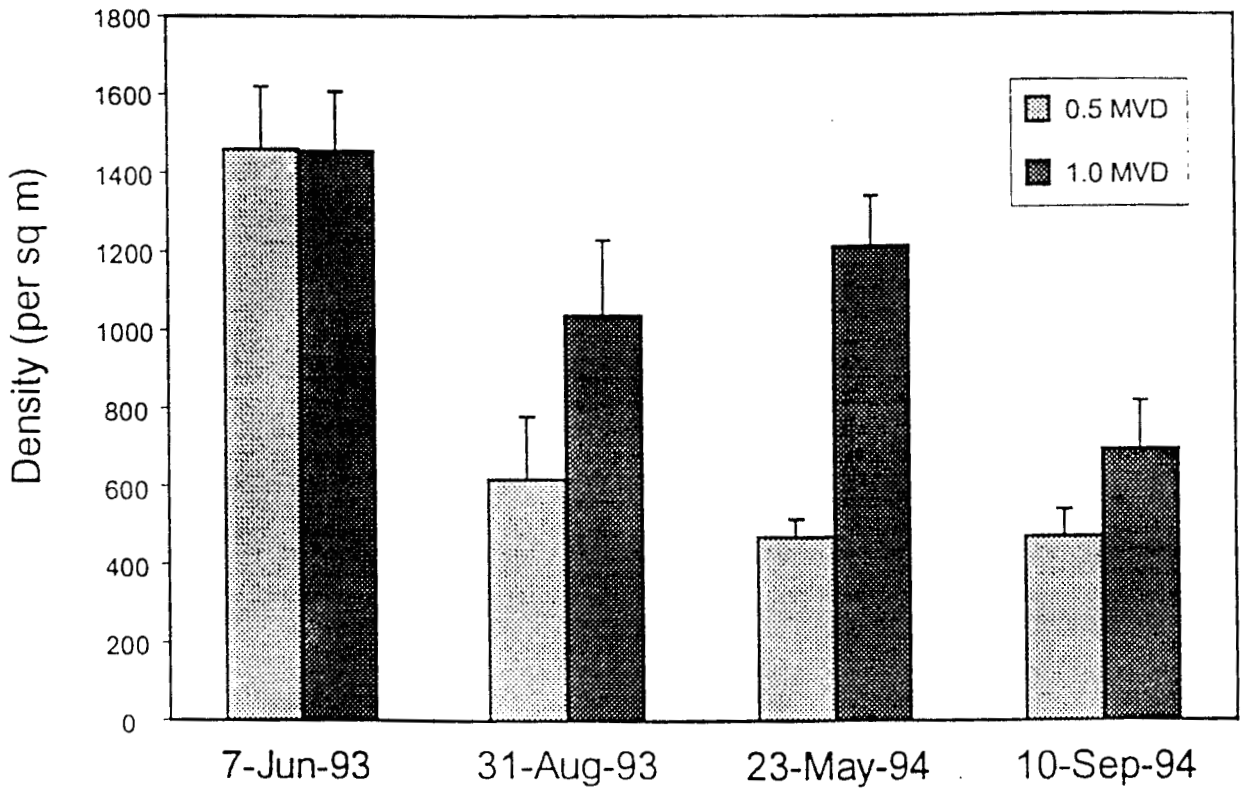

Figure 3.5. Densities of littorine snails at Weasel Beach pooled over all treatments. N = 12 for each sample.

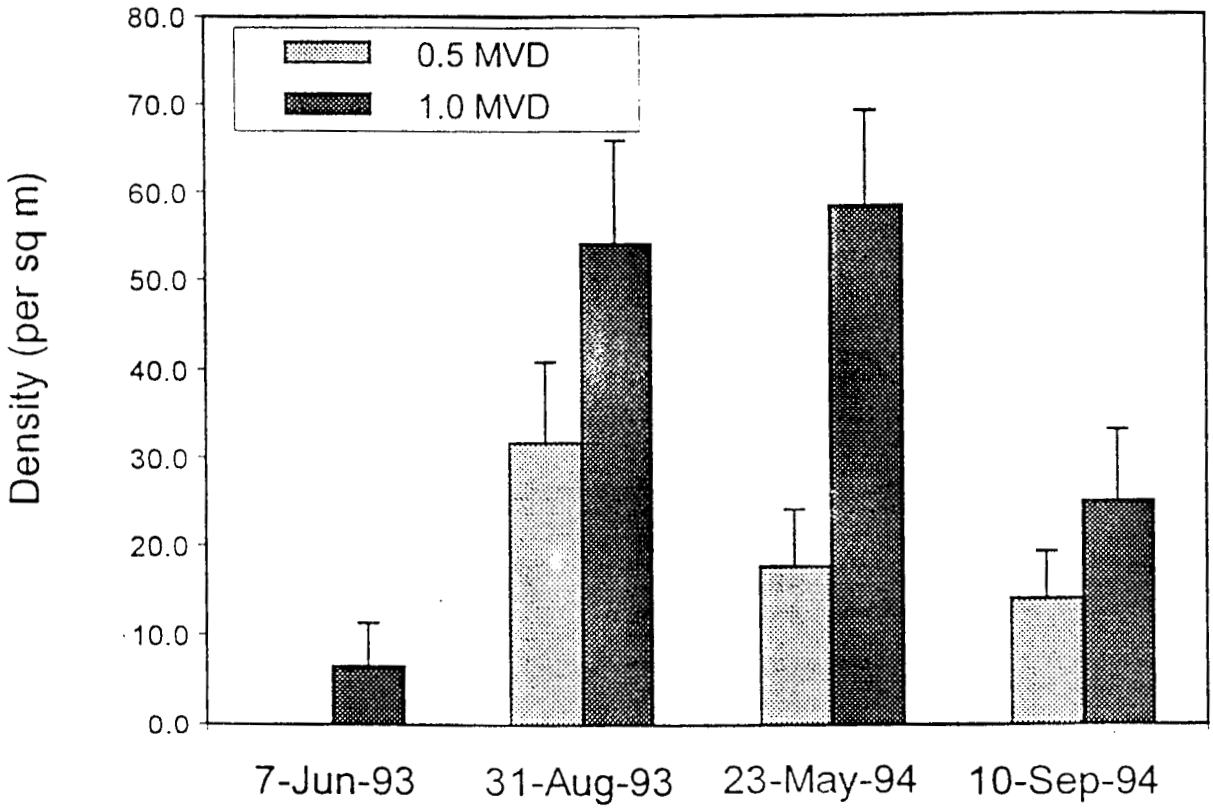

Figure 3.6. Densities of limpets pooled over all treatments. N = 12 for each sample.

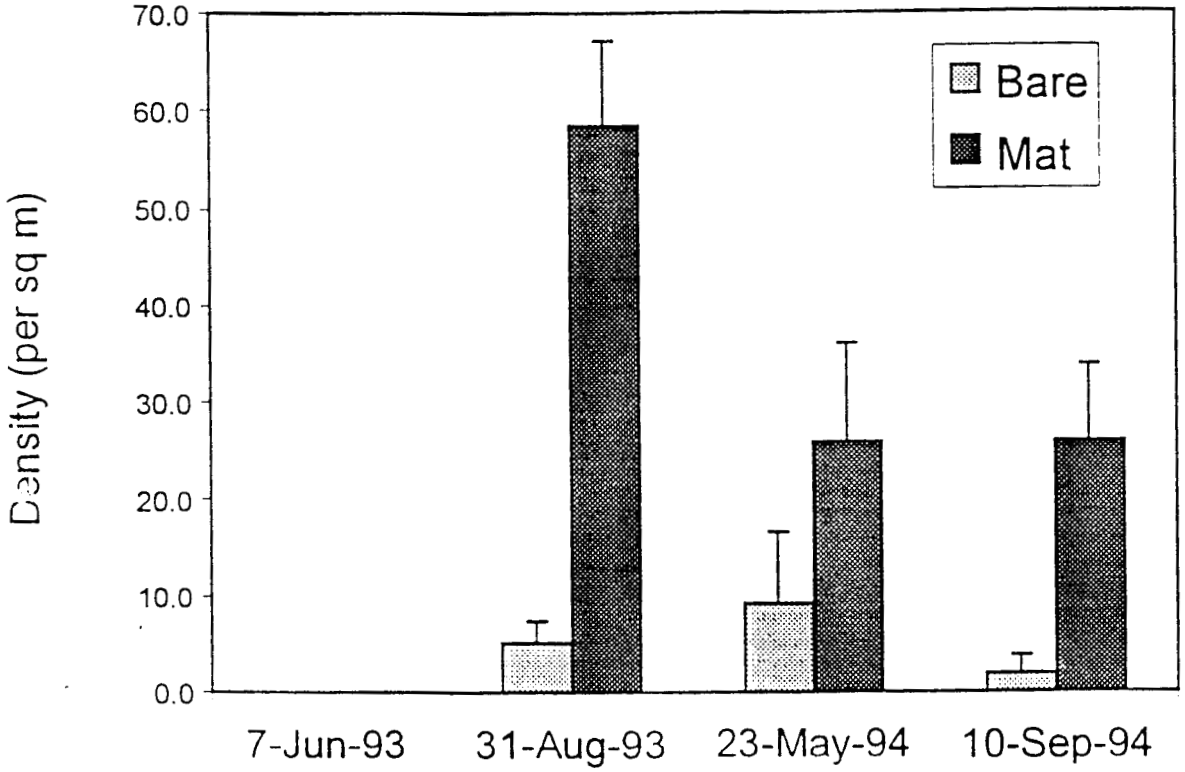

Figure 3.7. Densities of limpets on the rock surface at 0.5 MVD on bare substrate and on mat-covered plots. N = 6 for all treatments.

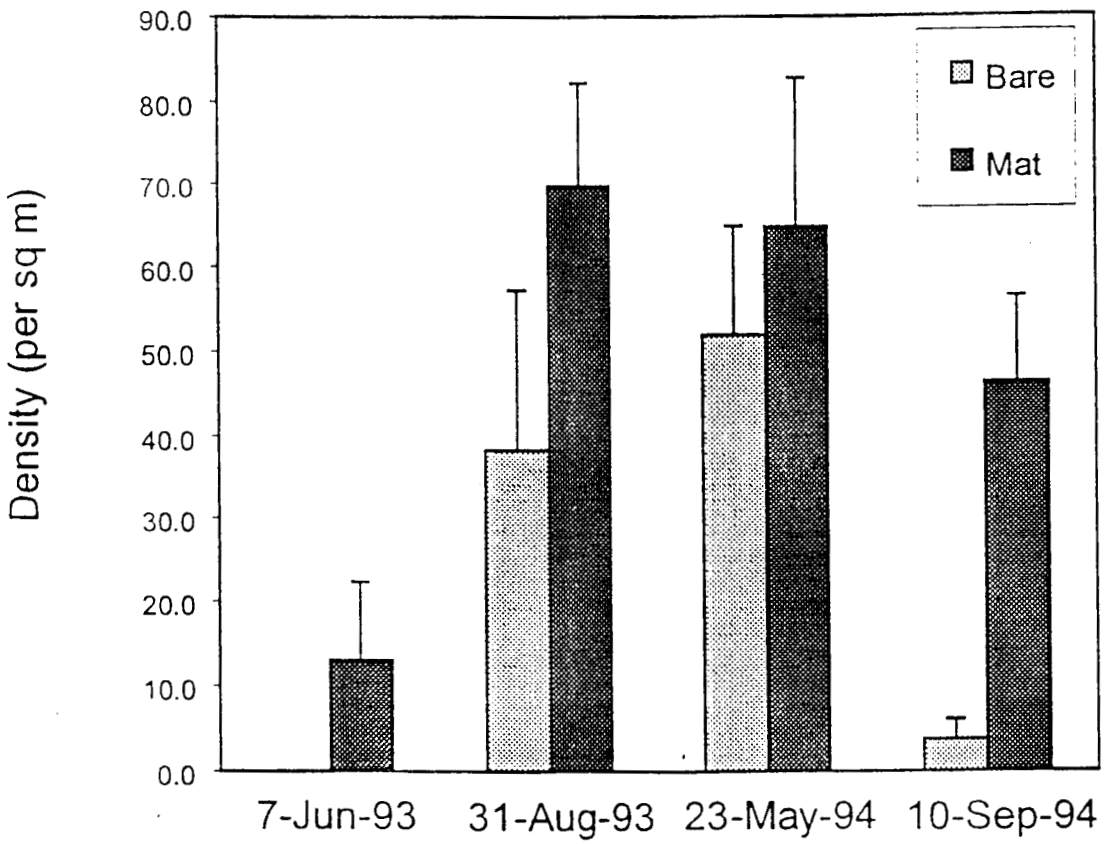

Figure 3.8. Densities of limpets on the rock surface at 1.0 MVD on bare substrate and on mat-covered plots. N = 6 for all treatments.

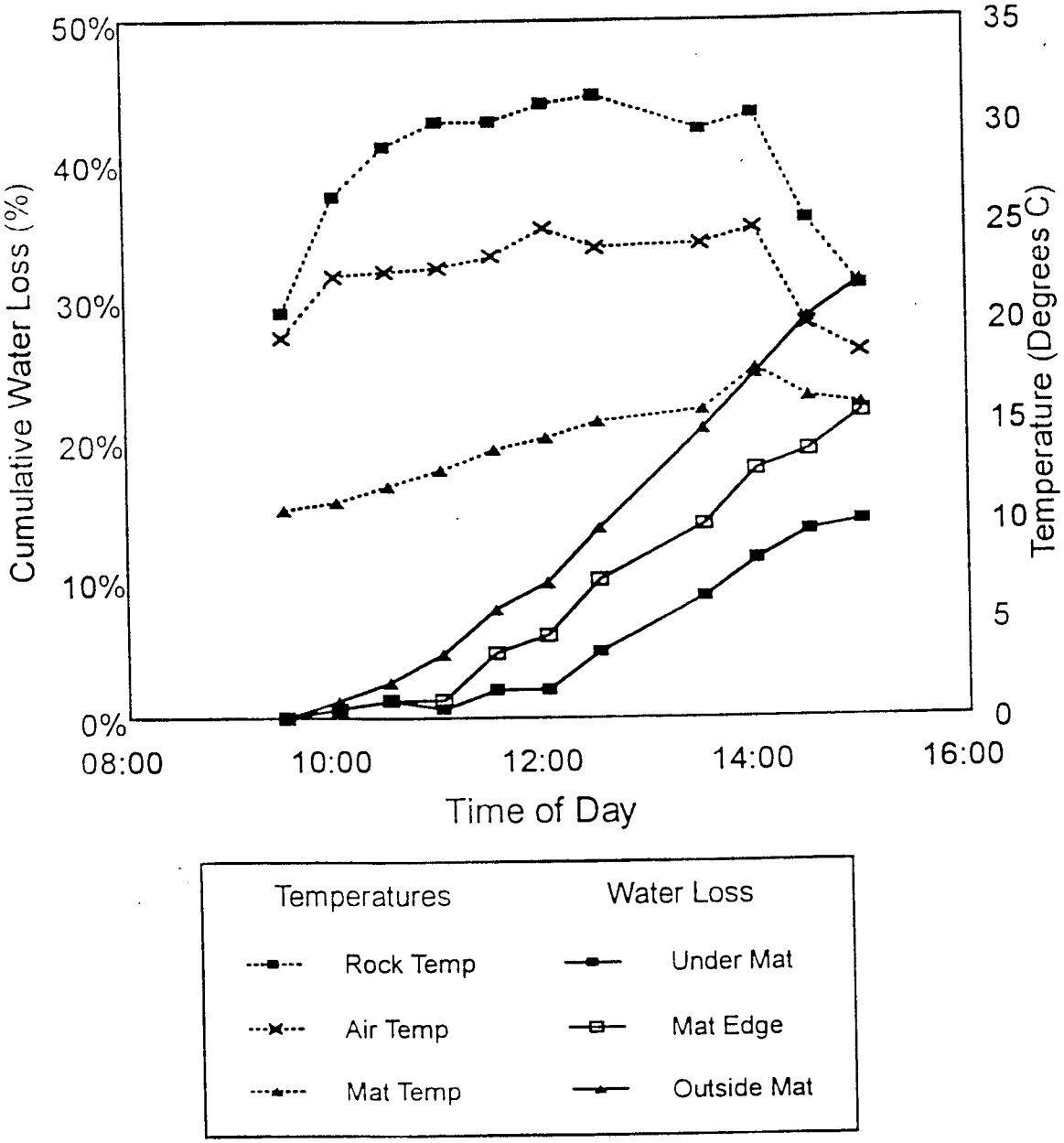

Figure 3.9. Desiccation (as percent water loss) and temperatures on May 28, 1994 at Weasel Beach in Prince William Sound.

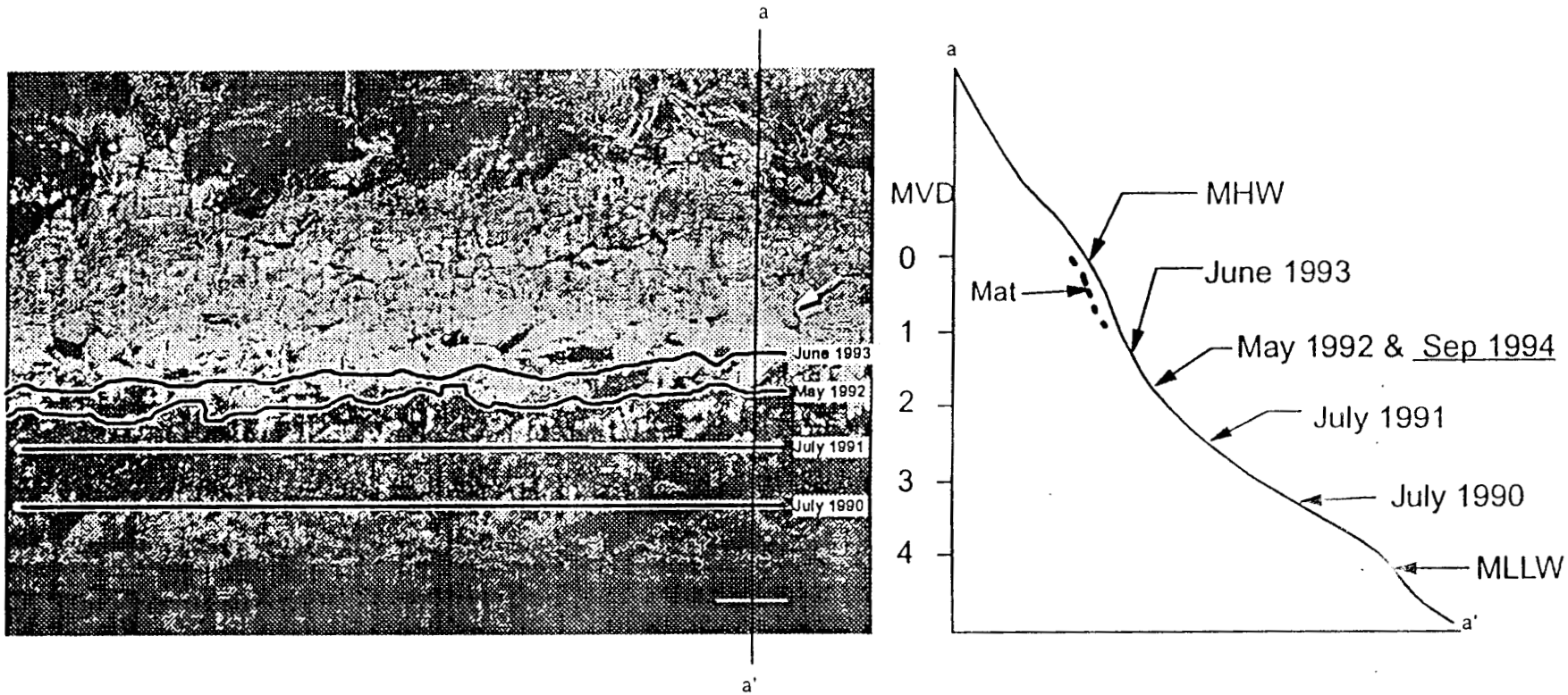

Figure 3.10. The upper limits of *Fucus* at Weasel Beach from 1990 to 1994. The figure is a computer image of the Weasel Beach restoration site based on a photograph taken in September 1994. The dotted lines indicate the maximum heights of the *Fucus* band at the years designated on the right edge of the picture. The lines were drawn using superimposed images. The figure on the right is a schematic representation of the section through the intertidal at line a-a'. The line is at the 1.5 MVD. Note that the upper limit for *Fucus* drops from 1993 to 1994. An erosion control mat can be seen at the right side of the photograph above the June 1993 mark (at arrow). The lower edge of the mat is at 1 MVD. The line at the lower right is a 1.0 m scale.

CHAPTER 4. INVERTEBRATE STUDIES

INTRODUCTION

Since 1990, several studies have been implemented which focus on key intertidal invertebrate species. A population dynamics study was designed to monitor densities of limpets, littorines and the dog whelk, *Nucella*, at three tidal heights on matched pairs of oiled and control sheltered rocky and coarse textured sites. This study continued through the 1994 field season.

Experiments were initiated in 1993 to examine the influence of water motion on growth rates, size-frequency distribution and recruitment of mussels in the intertidal at three matched site pairs. Mussel size and age data collected during the CHIA study (Highsmith *et al.* 1992) indicated that mussels of a given age tended to be larger on oiled sites relative to control sites. The data suggested that there may be inherent differences between oiled and control sites. Possibly the currents which transported oil to various shorelines are the prevailing currents in the region, and typically distribute larvae, phytoplankton and nutrients to the intertidal zone at higher rates than at non-oiled locations. The possibility that oiled sites are more productive than non-oiled sites needed to be investigated due to the extensive use of matched oiled and unoiled site pairs in damage assessment studies. In projecting recovery times and endpoints, any differences between oiled and control sites not related to oiling effects must be considered. Dissolution rates of gypsum cylinders were used as indicators of relative water motion (Muus 1968, Gerard 1982, Petticrew and Kalff 1991) at the mussel study sites.

Another study was initiated in 1993 to monitor the ratios of the barnacle *Chthamalus dalli* to *Balanus glandula* and *Semibalanus balanoides*. The CHIA study found significantly higher densities of *C. dalli* on oiled sites compared with control sites, especially in the mid- to lower- intertidal (Highsmith *et al.* 1994). In undisturbed systems, *Chthamalus* tends to be restricted to the high intertidal, due to competitive exclusion from lower levels by the superior space competitors, *B. glandula* and *S. balanoides* (Connell 1961, Wethey 1985). *C. dalli* was the first barnacle species to recruit into the free space created by the oil spill and subsequent cleanup. Monitoring the abundance of these barnacle species relative to their recruitment densities on oiled rock faces continued in 1994 in order to track recruitment dynamics relative to competitive interactions.

METHODS

Population Dynamics of Selected Invertebrates

The permanent quadrats used for the *Fucus* population studies (Chapter 2) were also used for measuring invertebrate densities, including limpets, *Littorina sitkana* and *Nucella*

spp.. The five site pairs, three sheltered rocky and two coarse textured, have been monitored since 1990 and include six quadrats at each MVD.

Data analysis

Quadrat data for all years were analyzed for each MVD on each sampling date. Raw data were tested for variance homogeneity using Levene's test at the $p=0.10$ level. Unequal variances were log transformed, and a t-test was conducted. If the data transformation also failed the test for variance homogeneity, then the non-parametric analog, Mann-Whitney test, was conducted. Species with low densities (i.e., *Nucella* spp. and *Tectura scutum*) were analyzed using a two sample randomization test (Manly 1991). Differences were considered statistically significant when $p<0.05$.

Fisher's method of combining p-values (Sokal and Rohlf 1981) was used to evaluate significant differences in abundance over all sites within a habitat for each visit and MVD ($p<0.05$). Analyses were separated by MVD at each sampling date.

Power and Power 50% approximations were presented when significant differences between oiled and control sites within a habitat were not detected using Fisher's method. Power is defined as the probability of obtaining a significant result when the null hypothesis being tested is not true (Manly 1991). Power 50% is based on the assumption that the effect of the spill was to decrease the value of a particular parameter on oiled sites by 50% relative to control sites. Monte Carlo methods (Manly 1991) were employed to generate the Power and Power 50% statistics.

Barnacle Recruitment

Barnacle populations at three oiled sites in Herring Bay were examined for recruitment and successional patterns. The sites were located at Barnacle Point, Kiska and Site 1522 (Figure 1.2). Each site was representative of typical barnacle habitat along a vertical rock wall. Four randomly placed transects were established at each site in June 1993. Along each transect, 10x20 cm quadrats were positioned and permanently marked at 0.5, 1.0 and 1.5 MVDs. One 10x10 cm section of each quadrat was scraped of all barnacles and the remaining 10x10 cm section left unscraped. Adult barnacles were counted in the entire 10x10 cm unscraped section and recorded as either *Balanus/Semibalanus* or *Chthamalus dalli*. Juveniles, unidentifiable to species, were counted only in the lower left quarter of the 10x10 cm section (5x5 cm). All counts were repeated a minimum of three times or until a variance less than 10% was reached. In subsequent visits, adult and juvenile counts were taken from both the unscraped and previously scraped quadrats. Sites were visited at least twice each in 1993 and 1994.

Mussel Size-Frequency Distributions

To determine if differences existed in the distribution of mussel size classes in mussel beds on oiled and control sites in Herring Bay, three pairs of matched oiled and control sites were established for size-frequency distribution studies. Oiled and control sites were matched based on beach characteristics such as site topography, slope, exposure and presence of comparable mussel bands or beds. The three oiled sites selected were Mussel Beach 1, Mussel Beach 2 (referred to hereafter as MB1 and MB2, respectively) and 1522; non-oiled matched sites were MB1C, MB2C and 1522C (Figure 1.2).

During the initial visit to each of the sites in June 1993, the total length of the mussel band was determined. Unworkable areas or areas devoid of mussels were excluded from the measurement. Four transects were randomly established in the mussel band. The position of the first transect was randomly located in the first quarter of the band. The other three transects were located by consecutively adding one-fourth of the total band length to the first transect location. The top of each transect was marked at Mean High High Water (MHHW) with anchored screws or marine epoxy.

A mussel collection quadrat was randomly established on each transect. The width of the mussel band along the transect was measured. Unworkable areas or areas devoid of mussels plus 0.5 m for the length of the sampling frame were subtracted from the width measurement. The remaining width was multiplied by a random number and the upper right corner of the quadrat was placed at this point along the transect line.

If mussels were sparsely distributed or in patches, all mussels in the quadrat were collected. The size of the collection quadrat differed between 1993 and 1994. In 1993, mussels were collected from a 20x50 cm quadrat. In 1994, the size of the collection quadrat was reduced to 10x20 cm in order to reduce the sample processing time in the laboratory. If mussels were densely packed and evenly distributed, a subsample was collected. In 1993, subsampling was achieved by placing a 3x50 cm subsampling frame in the middle of the underlying 20x50 cm frame. Only the mussels in the 3x50 subsampling frame were collected. In 1994, a subsample was collected by randomly selecting either the upper or lower half of the 10x20 cm frame. Samples were bagged separately, frozen and returned to the laboratory for sorting and analysis.

Sites were revisited in September 1993, May 1994 and September 1994 and the previously established transect and quadrat locations were utilized for the collection of mussels. Newly-established collection quadrats were placed 1 meter to the left of previously established quadrats unless the new location was unworkable, in which case the quadrat was moved to the left until a suitable location was reached.

In the laboratory, mussels were thawed and washed over a 0.5 mm sieve. Mussels were measured from the tip of the umbo to the widest portion of the posterior shell. Measurements were taken to the nearest 0.05 mm using dial calipers.

Data analysis

For the mussel size-frequency distribution study, a randomization procedure utilizing Kolmogorov-Smirnov statistics was performed. Mussels were grouped into 2 mm size categories and summed for all four quadrats within a site and divided by the total number of mussels from all four quadrats to obtain a percent frequency per size increment per site. Cumulative frequencies were then calculated for each successive size increment. The difference between the cumulative frequencies for the oiled and control sites was calculated for each size increment. The largest of these differences was recorded. A randomization program re-allocated the quadrats randomly to oiled or control categories (four in each category) without replacement. The cumulative frequencies were then recalculated. This was repeated 5000 times. A p-value was determined from the ranking of the differences obtained by the randomization process relative to the largest difference in cumulative frequencies from the real data.

Filamentous Algae

Mussels recruit either directly into existing mussel beds or by initially settling on filamentous algae and later migrating into the bed (McGrath *et al.* 1988). Thus, the amount of filamentous algae present on a shoreline may affect mussel recruitment success. To determine the number of juvenile mussels attached to filamentous algae at each mussel study site, percent filamentous algal cover was determined and algae were collected. Along each randomly established transect, filamentous algal percent cover was estimated using a 40-point grid system (40x50 cm). No effort was made to identify algae at each point beyond filamentous or non-filamentous. The quadrats were placed along each random transect line at the 1.0, 2.0, 3.0 and 3.5 MVD levels. The left side of the grid was placed along the stretched meter tape when facing the beach.

At each meter drop, filamentous algal samples were collected to the right of the point grid frame. In 1993, a 10x10 cm sample of algae was removed, if present, from an area with 100% filamentous algal cover using a razor blade. In 1994, methods were altered to reduce laboratory processing time; 5x10 cm algal samples were collected from areas with at least 50% filamentous algal cover. Percent cover was estimated and recorded. Samples were bagged separately, frozen and returned to the laboratory for analysis.

Filamentous algal samples were thawed and examined in the laboratory for the presence of mussel recruits. All juveniles found in the algae were removed and measured. Data were recorded for various size categories and specimens were stored in 50% isopropyl alcohol. Samples were collected in June, July and September 1993 and May, June, August and September 1994.

Data analysis

Filamentous algal percent cover data and data on the total numbers of mussels in filamentous algae were analyzed for significant differences between site pairs using 2-sample t-tests, or a one-sample t-test when variances were zero. Analyses were separated by MVD for each sampling date. Percent cover data less than 100% were normalized to 100%.

Tagged and Caged Mussels

The currents which transported the *Exxon Valdez* oil to shorelines in Herring Bay may also provide a more continual or greater rate of supply of fresh particulates to filter feeders at oiled sites relative to those areas where oil was not transported. An increased food supply should result in increased rates of growth for filter feeders. Mussels were marked for growth studies at each of the six mussel study sites described above. Initial mussel length measurements were taken in June 1993.

Thirty to fifty mussels were collected near the mussel collection quadrat from two of the four collection transects. The two transects utilized were randomly chosen. The mussels were bagged separately in sea water and returned to the research vessel where they were marked and their length measured to the nearest 0.05 mm using calipers. The marked mussels were returned to their respective transects. Two different methods were employed to mark the mussels. Super-glue gel was used to attach small (<4 mm) plastic fish tags to the outer shell or alternatively, an engraving tool was used to etch numbers directly into the shell. The mussels were placed inside wire mesh cages (20x20x7 cm) and the cages attached to the substrate with anchored screws. The mussels were collected again in August 1993, remeasured to determine summer growth and returned to their cages. In 1994, the mussels were again remeasured in May and August to determine respective winter and summer growth.

Water Circulation Studies

Dissolution rates of calcium sulphate cylinders were measured to determine if differences in volume of water movement existed between oiled and control sites and if there were detectable differences between areas of the Bay. Dissolution cylinders were constructed from commercially available calcined gypsum. Small and large PVC pipe molds were used to make cylinders for both short-term and long-term deployments, respectively. Gypsum powder was mixed with water and stirred to remove air bubbles, then poured into the molds. A length of plastic coated aluminum wire was embedded into one end of each cylinder. The molds were removed after the mixture had set (1 to 1.5 hours) and rough seams were smoothed with a razor blade. The cylinders were dried overnight at 40°C. Waterproof epoxy was applied to both ends of each cylinder to prevent dissolution from the ends and to allow for a radially symmetrical surface for dissolution. A numbered tag was embedded in

the epoxy on the bottom of each cylinder (the end from which the aluminum wire extended). The cylinders were then redried for 48 hours at 40°C, placed in a desiccator to cool and weighed to the nearest 0.001g. Length and diameter measurements were taken to the nearest 0.1 mm. Following exposure in the field, cylinders were removed from the deployment site, dried for 48 hours at 40°C, cooled in a desiccator, weighed and measured as before. Dissolution rates are reported as the change in weight of the cylinder divided by the total length of the cylinder (to correct for slight cylinder-length inconsistencies) and the time the cylinder was submerged. These "flux" calculations are the values reported.

Calcium sulphate dissolution cylinders were deployed on the mussel study sites and at 32 locations around the perimeter of Herring Bay (Fig. 4.34). Two methods were used to deploy the cylinders. For one method, two 4-inch lengths of PVC pipe were attached to rocks, 15-20 cm apart with marine epoxy. A one-hole rubber stopper was inserted into each pipe opening. The plastic coated wire at the end of each cylinder was then inserted into the rubber stopper. The rocks held the cylinders at the chosen location throughout deployment. The other method used metal brackets mounted in the bedrock to hold the cylinders on site. Four cylinders were placed on each mussel study site. At the 32 locations around the perimeter of Herring Bay, one calcium sulphate cylinder was deployed at 1 MVD below MHHW.

To determine whether dissolution from rainfall would be a significant factor in dissolution rates of the cylinders, two cylinders were placed on the top deck of the research vessel for a 48 hour period during which 5.3 cm of rain fell. Less than 0.04 gms dissolved from each cylinder. Typically, dissolution rate measurements for deployments in the intertidal were two orders of magnitude higher than measured during the period of heavy rain. Therefore, dissolution due to rain was ignored. Additionally, tests were conducted on the replication quality of the cylinders. Five sets of three cylinders, with each cylinder placed 10 cm from the other two in the set, were placed at varying tidal heights and locations within Herring Bay. For all five sets, the variability between the three cylinders within a set was less than 3% in all cases. Thus, due to the time-intensive nature of preparing each cylinder, a maximum of four cylinders was placed on each site, two on each of two transects at the mussel study sites and two each on the 18 sites chosen around the eastern perimeter of the Bay. A computer software program provided tidal height and time data for specific locations and was used to determine the total amount of time that each cylinder was submerged during the tidal cycles throughout the deployment.

RESULTS

Population Dynamics of Selected Invertebrates

Mean densities of invertebrates monitored for population dynamics in May and September 1994 are shown in Tables 4.1-4.14. Statistical results for comparisons between sites of a pair and the results of Fisher's test for combining p-values across all site pairs

within a habitat type are given. Results of power analyses conducted on the data when significant differences were not detected are included in Tables 4.1-4.14 in the rows labeled "Power" and "Power 50." The mean abundances for each organism across the two habitats, sheltered rocky and coarse textured, along with the statistical results for combining p-values within each habitat are illustrated in Figs. 4.1-4.8. Results from data collections made since the population dynamics study was started in 1990 are also included in Figs. 4.1-4.8 to show trends over time.

Sheltered Rocky Habitat-Individual Site Pairs

At sheltered rocky sites, *Tectura persona* densities were not significantly different between oiled and control sites in either May or September 1994 (Table 4.1). *Lottia pelta* had significantly higher densities at the control site of pair 3811C/3611X at MVD 3 in May and MVD 2 in September, and at the control site of pair 1231C/1231X at MVD 3 in September (Table 4.2). *L. pelta* densities were significantly higher at the oiled site of pair 1231C/1231X at MVD 2 in May. *Tectura scutum* occurred in very low densities at all sites and differences were not significant (Table 4.3). For all limpets combined, including juveniles, individual site pair statistical results showed significant differences between oiled and control sites for pair 3811C/3611X at MVD 3 in May and pair 1231C/1231X at MVD 3 in September (Table 4.4).

The periwinkle, *Littorina sitkana*, was significantly more abundant at the control site of pair 3811C/3611X at MVDs 2 and 3 in both May and September (Table 4.5). No other site pairs were significantly different. Like *Tectura scutum*, *Nucella lamellosa* occurred in low densities at most sites (Table 4.6) and significant differences were not observed between sites. *N. lima* did not occur in the sheltered rocky quadrats in 1994 (Table 4.7).

Sheltered Rocky Habitat-Overall Statistical Tests

Figures 4.1-4.4 show overall mean abundance of limpets and periwinkles for oiled and control sheltered rocky habitat from 1990 through 1994. *Tectura persona* (Fig. 4.1) had higher abundances on control sites for all sampling dates at MVDs 1 and 2 and for all but one sampling date at MVD 3, though not all are statistically significant. *Lottia pelta* (Fig. 4.2), showed significantly higher numbers on control sites at MVD 2 during most sampling dates in 1991, but not in 1992 or 1993. In September of 1994, however, significant differences were again detected. At MVD 3, significantly higher numbers of *L. pelta* were detected on control sites during at least one sampling date per year from 1990 through 1994. No statistical differences were detected for *T. scutum* when combining p-values (Table 4.3). For all limpets combined, including juveniles (Fig. 4.3), significantly higher abundances were detected on control sites at all MVDs for most sampling periods since 1990. However, at MVD 1, significant differences were not found in 1992 or 1994 and at MVD 2, significant differences have not been detected since 1991.

The periwinkle, *Littorina sitkana* (Fig. 4.4), had significantly higher numbers on control sites compared to oiled sites at MVD 1 in late summer of 1991, during both sampling dates in 1993, and in the fall of 1994 and at MVD 2 in all years sampled. Very few *L. sitkana* were found at MVD 3 on either oiled or control sites, but higher densities were found at control sites in 1994. At all three MVDs, the numbers of *L. sitkana* have generally increased from 1990 to 1994.

Coarse Textured Habitat-Individual Site Pairs

For coarse textured habitat, two site pairs were sampled: 2333C/2333X and 2834C/2834X. *Tectura persona* was significantly more abundant on control sites for MVD 1 in May and MVD 2 in September at pair 2333C/2333X and for MVD 1 in both May and September at pair 2834C/2834X. (Table 4.8). Higher densities at 2333C were nearly significant for MVD 2 and 3 in May and MVD 1 and 3 in September (Table 4.8). The lower intertidal limpet, *Lottia pelta*, was significantly more abundant on the oiled site of matched pair 2333C/2333X at MVD 3 in both May and September (Table 4.9). No significant differences occurred between oiled and control populations of *T. scutum* in May or September for either site pair (Table 4.10). For all limpets combined, including juveniles, significantly more limpets were found at MVD 1 on the control site of pair 2834C/2834X in both May and September and at the control site of pair 2333C/2333X at MVD 2 in September (Table 4.11).

Littorina sitkana density was higher at MVD 1 of the oiled site of pair 2333C/2333X in September (Table 4.12). The reverse was true at MVD 3, with higher numbers on the control site in September. No significant differences were detected between oiled and control populations of *Nucella lamellosa* and *N. lima* on either site pair in May or September (Tables 4.13 and 4.14, respectively).

Coarse Textured Habitat-Overall Statistical Tests

Figures 4.5-4.8 show abundances of limpets and periwinkles for oiled and control coarse textured habitat from 1990 through 1994. *Tectura persona* densities were higher on control sites in all years at MVD 1 and during at least one sampling period in each year at MVD 2 (Fig. 4.5). Though densities generally remained higher at control sites at MVD 3, no significant differences have been detected since early summer of 1991. For *Lottia pelta*, the highest abundances were found at MVD 3 and were significantly higher on oiled sites compared to control sites in 1991 and again during both sampling dates in 1994 (Fig. 4.6). Increased abundances of *L. pelta* have been found on both oiled and control sites several years after the oil spill than during the year immediately following the spill. For all limpets combined, at MVD 1, significantly higher numbers were found on control sites for all sampling dates in 1990, for at least one sampling date in 1991 and 1992, and for both sampling dates in 1994 (Fig. 4.7). At MVD 2, a similar trend was seen with at least one

sampling date in most years having higher numbers of limpets on control sites. In 1991, however, three sampling dates had higher numbers on oiled sites. At MVD 3, higher numbers of limpets have been detected on oiled sites compared to control sites on several sampling dates in each year sampled. The generally high densities of limpets found at MVD 3 are due to juvenile limpets recruiting onto algae in the low intertidal.

Since 1990, *Littorina sitkana* has increased on oiled sites at all three MVDs (Fig. 4.8). Higher densities were found at control sites for most sampling dates in 1990 at MVDs 1 and 2 and on two sampling dates in 1991 at MVDs 1 and 2. However, at MVD 1, higher numbers have been detected at oiled sites on one sampling date in both 1992 and 1994. Very few *L. sitkana* were found at MVD 3 until 1993.

Barnacle Recruitment

The total numbers of adult *Semibalanus balanoides* and *Balanus glandula* (*Semibalanus/Balanus*) were generally low compared to juveniles and to adult *Chthamalus dalli* on both scraped and unscraped plots (Figures 4.9-4.11). In order to discuss differences in *Semibalanus/Balanus* abundances between MVDs and across time, means and standard errors for these barnacles are presented in Table 4.15. Adult *Semibalanus/Balanus* tended to be somewhat more abundant in the higher intertidal (MVDs 0.5 and 1.0) than at MVD 1.5 at all three sites in both 1993 and 1994 in unscraped plots (Figures 4.9-4.11). On scraped plots, abundances of the *Semibalanus/Balanus* group were low in 1994, one year after removal of barnacles. Among the *Semibalanus/Balanus* that recruited into scraped plots in 1993 and survived until May 1994, up to 80% mortality had occurred by August 1994 (Table 4.15).

Juvenile barnacle abundances at most MVDs were generally lower in August 1993 in unscraped plots than during initial counts in June 1993 at all three sites (Figures 4.9-4.11), indicating post-settlement mortality. Higher densities occurred occasionally in August, indicating that some recruitment occurred after the initial spring settlement. On scraped plots, 1993 recruitment of *Semibalanus/Balanus* was very low and/or mortality was high, as juvenile abundances were zero in most cases in August. Some recruitment must have occurred on scraped plots after August, as higher numbers of adult *Semibalanus/Balanus* were found in May 1994 than juveniles in 1993. In 1994, densities of recruits on scraped and unscraped plots were generally highest at Barnacle Point (Figure 4.9) and Kiska (figure 4.10) had the lowest recruitment of the three sites in both years.

Settlement of *Chthamalus dalli* occurred subsequent to the barnacle counts in August 1993. Those *C. dalli* surviving the winter were counted as adults on both scraped and unscraped plots in May 1994. In most cases, some mortality had occurred by August 1994. *C. dalli* recruits were generally most abundant at MVDs 1.0 and 1.5 and least abundant at MVD 0.5, just the opposite of normal adult distribution. Recruitment levels were higher in 1994 than 1993. In 1993 and 1994, *C. dalli* dominated the adult barnacle population in the

lower barnacle zone (MVD 1.5, Figures 4.9-4.11). Table 4.16 lists ratios of *C. dalli* adults to *Semibalanus/Balanus* adults for each MVD at all three barnacle sites in 1993 and 1994. Ratios were higher at MVD 1.5 compared to MVD 0.5 for all dates and on both scraped and unscraped plots.

Mussel Size-Frequency Distributions

Mussel abundance in June 1993 decreased exponentially at site MB2 with increasing individual size while a bimodal distribution was found at control site MB2C (Figure 4.12). Randomization analysis revealed that the two size-frequency distributions were significantly different. The other two matched pairs, 1522/1522C and MB1/MB1C had very similar size-frequency distributions (Figs. 4.13-4.14), although the mean length of mussels was less on oiled sites compared to controls (Table 4.17). At oiled site MB2, half the population was 4 mm or less in length while the 50% point at the control site occurred at a length of 20 mm (Fig. 4.12). Mean individual length at MB2C was almost twice that at MB2 (19.05 mm vs. 10.14 mm, Table 4.17). The size-frequency histogram for the control site, with a recruitment peak and a second smaller peak of accumulated adults, is a common size-class distribution for animals with multi-year life spans. It is tempting to interpret the difference in the sites as a long-term impact of the oil spill, i.e. existing mussels were killed by the oil or recruitment was poor in the years following the spill. Data from the other two site pairs (Figs. 4.13 and 4.14), however, do not support such an interpretation.

In September 1993, there were fewer small mussels than in June at most sites (Figs.4.15-4.17). Sites MB2 and MB2C (Fig. 4.15) had significantly different cumulative frequency curves again in September, though the shape of the curves changed to reflect the shift to larger individuals. The major difference between the two curves, in contrast to the other site pairs (Figs. 4.16 and 4.17), is that the oiled site (MB2) had a higher percentage of small mussels than the control site (MB2C). Both MB2 and MB2C had a weakly bimodal distribution with the second size-frequency peaks at approximately 18 mm and 28 mm, respectively. The mean length of mussels on site MB2C was 22 mm, much larger than the 13.5 mm mean length of mussels on the oiled sites (Table 4.17). This differences decreases with time and will be discussed later. Although the differences between the cumulative frequency curves for matched pairs 1522/1522C (Fig. 4.16) and MB1/MB1C (Fig. 4.17) in September were not significant, the curves do not overlap as they did during the first visit in June. For both matched pairs, the cumulative frequency curve for the control site is above the curve for the oiled site, indicating that smaller mussels make up a larger proportion of the population at control sites in September. This difference is also seen in Table 4.17, where oiled site mussels had greater mean lengths than control site mussels. In September, all four sites had a weakly biomodal size-frequency distribution similar to MB2C (Fig. 4.15).

May 1994 mussel size-frequency comparisons reflect an increase in the proportion of small individuals, especially at oiled sites (Figs. 4.18-4.20). Differences in mussel size

distribution were highly significant for pair 1522/1522C (Fig. 4.19) and pair MB1/MB1C (Fig. 4.20). Mean mussel length was greater at control sites (Table 4.17).

Mussel size-frequency curves for September 1994 (Figs. 4.21-4.23) showed very high proportions of small, <4 mm, mussels on both oiled and control sites. However, the curves for the oiled and control sites were similar within each matched pair and no significant difference was detected between matched sites. As in May 1994, mussels were larger at control sites (Table 4.17), though differences have decreased over time. In 1994, bimodal length distributions did not occur for either collection sampled, as was observed in 1993.

Size-frequency distributions (Figs. 4.12-4.23) for each site were compared between dates. Major differences or similarities are presented, with p-values, in Table 4.18. The spring and fall size-frequency distrubutions in 1993 were significantly different at oiled sites 1522 and MB2 ($p=.01$ and $p=.03$, respectively), and nearly different at the other oiled site, MB1 ($p=0.08$). For the control sites, only MB2C ($p=0.03$) showed a significant difference between visits. For all six sites, the curve for the first visit started above that of the second visit, indicating high mortality of spring recruits and/or growth into larger size classes during the summer. For 1994, the spring and fall mussel size-frequencies were significantly different for three sites (1522C, MB1 and MB1C; Table 4.18). However, the trends were opposite to those in 1993, with a higher proportion of small mussels in fall than spring. May samples were evidently collected prior to spring recruitment. For five of the six sites, there were significantly more small mussels in fall 1994 than fall 1993 (Table 4.18). Spring-spring comparisons between 1993 and 1994 yielded non-significant results. Generally, small individuals were more frequent in spring 1994 than fall 1993, though only significantly so at MB2 and MB2C.

Filamentous Algae

At all six sites, the percent cover of filamentous algae was very low in the upper intertidal (MVD 1) for all visits in 1993 and 1994 (Tables 4.19-4.25). Figures 4.24 and 4.25 summarize the trends for filamentous algal cover on oiled and control sites at each MVD for 1993 and 1994, respectively. The highest average percent cover generally occurred at MVDs 3 and 3.5 during all visits to the sites in both years. The data at all MVDs are highly variable, emphasizing the patchy distribution of filamentous algae in the intertidal, and resulting in few statistically significant differences between matched oiled and control sites (Tables 4.19-4.25). The general trend observed at MVDs 2, 3, and 3.5 was toward higher percent cover of filamentous algae on the oiled site of each pair. In fact, during all visits in 1993 and 1994, all but one statistically significant difference was for higher percent cover of filamentous algae on the oiled site of the pair (Tables 4.19-4.25).

In an attempt to determine the number of mussels that had settled onto filamentous algae at each site, collections were made adjacent to each algal percent cover quadrat. Where the percent cover of filamentous algae was very low, such as in MVD 1 at most sites,

collections were not possible. Consequently, the numbers of collections were too few to perform statistical analyses in many instances (Tables 4.26-4.29). Due to high variability and low number of samples, few statistical differences between oiled and control sites occurred, although oiled sites had higher absolute numbers of mussels in a majority of cases (59% in 1993 and 75% in 1994). Figures 4.26 and 4.27 illustrate the trends for mussel densities in filamentous algae at each matched pair for all MVDs in 1993 and 1994, respectively. Higher numbers of mussels occurred on filamentous algae in September than in June 1993 and in August than May 1994 (note vertical scale changes in Figure 4.27).

Mussels on filamentous algae tended to be larger, > 1mm, in the spring collection in both 1993 and 1994 (Figs. 4.28-4.33). Later in the summer when mussels were more abundant, sizes were smaller, <1.0 mm, in September 1993 and August 1994, indicating a recruitment in the interval between visits.

Tagged/Caged Mussels

Mussel growth rates over the summer of 1993 were low or even slightly negative (Table 4.30), possibly due to handling stress during tagging. Growth rates over the winter months averaged approximately 0.3 mm/month and during the summer of 1994 were generally over 1 mm/month. Average total growth during the 14 month period ranged from 1mm to 10 mm with a median between 6 mm and 7 mm.

Over the entire time period of measurement, smaller mussels exhibited a larger total growth rate than larger specimens (data not shown). Mussels with an initial length of approximately 20 mm grew 0-15 mm, while mussels 35 mm in length averaged about 5 mm total growth. Growth data did not show any significant differences between oiled and non-oiled sites, despite differences in water motion indicated by the calcium sulphate cylinder dissolution study (next section).

Water Circulation Studies

For the calcium sulphate dissolution cylinders placed 1.0 MVD below MHHW at 32 locations within Herring Bay (Figure 4.34), dissolution rates tended to be highest near the mouth of Herring Bay and lowest near the head of the Bay (Figs. 4.35-4.37). Most of the control sites for the Herring Bay experimental studies are located on the eastern side of Herring Bay near the head, where oil did not penetrate. Oiled sites are located either toward the mouth of the Bay or on the western side of the Bay. Although the actual dissolution rates varied depending on the tidal series during which the calcium sulphate cylinders were deployed, the general trends were similar around Herring Bay in June, August and September.

Deployments were made several times throughout the 1993 and 1994 field seasons on the mussel study site pairs 1522/1522C, MB1/MB1C, and MB2/MB2C (Figs. 4.38 and 4.39). The first deployment on these sites was at the end of a spring tidal series in early June. The flux rates measured during this time period were the lowest measured for all deployments. Subsequent deployments were made closer to the mid-points of the tidal series.

In most cases, the dissolution rates were higher on the oiled site of a matched pair. Site MB1C, however, had higher flux rates than its matched oiled site on four occasions. Of the three oiled sites, MB1 is the most protected and is located slightly closer to the head of the Bay than the matched control, MB1C. This proximity to the head of the Bay may explain the slower cylinder dissolution rates.

DISCUSSION

The study sites in Herring Bay continued to show an oil/treatment effect for *Tectura persona* in the upper intertidal zone, especially on coarse textured sites. Overall statistics for combining p-values from site pairs supported this trend on both sheltered rocky and coarse textured habitats. *Littorina sitkana* also had reduced densities in the upper intertidal on sheltered rocky oiled sites. However, coarse textured sites showed either no significant differences or higher values on oiled sites. *Lottia pelta* continued to show increasing densities in the high intertidal at sheltered rocky sites, indicating that recovery for this species is underway in the upper intertidal. Overall, the upper intertidal on oiled shorelines in Herring Bay continues to show significantly lower densities of major grazers, especially in sheltered rocky habitat.

In the mid and lower intertidal, *Littorina sitkana* densities continued to be significantly lower on sheltered rocky oiled sites compared to control sites. In coarse textured habitat, the only significant difference for *L. sitkana* occurred in the low intertidal, in September 1994, with higher numbers on control sites. *Lottia pelta* were found in significantly higher densities at control sites in sheltered rocky habitat and at oiled sites in coarse textured habitat in both mid and lower intertidal levels. *Tectura persona* were not abundant in lower regions of sheltered rocky habitat and no significant differences were detected. In coarse textured habitat, *T. persona* continued to occur in higher densities on control sites and the difference was significant for mid intertidal limpets in September 1994.

The observation that *C. dalli* were more abundant on oiled, cleaned sites and occurred lower than expected in the intertidal originated from the CHIA study (Highsmith *et al.* 1994). The observation was significant, as *C. dalli* are generally restricted to the upper intertidal in undisturbed systems, being excluded from lower intertidal levels by the superior space competitors, *Semibalanus balanoides* and *Balanus glandula* (Connell 1961, Wethey 1985). High-pressure hot-water washing conducted in summer 1989 created large areas of free space. Settlement of *C. dalli* larvae coincided with this availability of space, thus,

giving them a six-month advantage over other barnacles. Upon settling, *C. dalli* recruits encountered little spatial competition, few, if any, predators and lack of a whiplash effect from movements of large *Fucus* plants in tidal currents. Whiplash effects of macroalgae on young barnacles can be fatal (Farrell 1989). In the absence of competitors and large *Fucus* plants, the small *C. dalli* is able to colonize areas where it generally cannot persist. *C. dalli* was also an initial colonizer in a community succession study in Oregon (Farrell 1991).

In Herring Bay, in 1993 and 1994, *C. dalli* spat were not present on beaches until late summer, whereas balanoid spat were observed in spring to early summer. *S. balanoides*, one of the early recruiting species, generally releases a single brood of eggs annually in the spring, to coincide with the spring phytoplankton bloom (Crisp 1954, Barnes and Barnes 1968, Rucker 1983). Conversely, *C. dalli* is capable of producing several broods annually, depending on prevailing environmental conditions (Southward and Southward 1967, Barnes 1989).

In 1993 and 1994, *C. dalli* still dominated the lower barnacle zone (MVDs 1.0-1.5). Balanoid recruits were most abundant at MVD 1.0 in 1993, although no pattern was evident in 1994. *C. dalli* recruits were generally most abundant at MVD 1.5 and found in lowest numbers at MVD 0.5, the level of their highest abundance in undisturbed situations.

Mussel size and age data for sites sampled during the Coastal Habitat Injury Assessment (CHIA) study (Highsmith *et al.* 1992) indicated that mussels of a given age tended to be larger on oiled sites relative to control sites. These data may indicate inherent differences between oiled and control sites. We posited that currents which delivered the oil to certain shorelines may also concentrate recruits and fresh particulates in the intertidal zone in the same areas. The possibility that oiled sites are more productive than non-oiled sites was investigated, due to the extensive use of matched oiled and non-oiled site pairs in damage assessment studies.

Experiments initiated in 1993 were designed to compare growth rates, size-distributions and recruitment of mussels into the intertidal at matched oiled and control sites. In 1993, five summers after the spill, size-frequency distributions of mussels were similar at two of three matched oiled and control sites. For the third matched pair, the control site had fewer smaller individuals than the oiled site and a higher frequency of larger individuals. For all three site pairs in 1994, smaller mussels were more common on oiled sites, and the mean length of mussels was less on oiled than non-oiled sites. Free space at oiled sites, made available by the spill/cleanup, may have facilitated recruitment of mussels. Most likely, the free space was initially colonized by barnacles, frequently the first organisms to occupy open space, followed by mussels which are known to settle among barnacles (Navarrete and Castilla 1990). Although dissolution rates from calcium sulphate cylinders measured higher water motion on oiled sites, based on preliminary results, no differences in mussel growth were apparent. Perhaps the concentration of particulates in the water column is above the saturation point of the filtering capacities of mussels on both oiled and non-oiled sites. Other, unforeseen factors, may override effects of flow rate, as well. Individual

mussel filtration rates can vary greatly, which may balance any effects due to differential current flow and food supply.

Mussel growth patterns from the caged mussel study did indicate that smaller mussels exhibited more total shell growth than larger mussels. An explanation for this difference may be that larger mussels allocate a greater proportion of their resources to reproduction than somatic growth, but linear measurements are not good indicators of relative biomass increase when comparing animals of different sizes. The difference may also be attributed to the reduced metabolic activity in larger mussels (Seed 1976) and a reduced rate of water transport (i.e. food uptake) in larger mussels (Jorgensen 1976). Growth was highest during the summer months for all mussel sizes, when food was most abundant.

Filamentous algae occurred most often in the lower intertidal (MVDs 3.0 and 3.5) and were more abundant on oiled than non-oiled sites. Juvenile mussels attached to filamentous algae were also more abundant at oiled sites. The increased presence of filamentous algae at oiled sites may have been a residual effect of the spill. Common ephemeral species such as *Cladophora* and *Pilayella*, onto which mussels recruit, were frequently observed in greater densities at oiled sites subsequent to the spill (Highsmith *et al.* 1994). Ephemerals are often viewed as indicators of recent environmental perturbation, increasing in abundance as a result of the elimination of competitive dominants (Lubchenco 1978, Sousa 1979). Another factor which may explain higher numbers of recruits at oiled sites is the lowered densities of herbivorous gastropods (limpets and littorines). Grazers could also mechanically remove newly settled mussels via bulldozing. Petraitis (1990) found that littorines play an important role in controlling mussel recruitment levels in New England. A final alternative is that the oiled sites, having higher water motion, may be able to support a more diverse algal community than the control sites.

Mussel abundance in filamentous algae increased from June to September. Juvenile mussels in filamentous algae were generally >1.0 mm in length by early summer, representing recruits from an early spring spawning. Similarly, mussel populations in the Pacific northwest may spawn and settle by late winter (Suchanek 1978). By mid summer, a second recruitment pulse was evident from the high number of small, <1.0 mm mussels in filamentous algae. Initial settlement of mussel larvae onto filamentous algae is termed primary settlement (Bayne 1964, Seed 1976). Secondary settlement occurs when, after a period of growth in the algae (1-2 mm, Seed 1969), the young mussels move upwards into the adult mussel bed through bysso-pelagic migration or byssus drifting (Sigurdsson *et al.* 1976, Lane *et al.* 1985). Mussels may undergo a protracted spawning period, lasting for several months (Jewett *et al.* 1992), or may even have two discrete spawning periods annually (Seed 1976; Lowe *et al.* 1982), which may explain the presence of larger recruits (>1.0 mm) in the first filamentous algae samples collected in early summer and high densities of <1.0 mm recruits observed in mid to late summer.

Other investigators have noted the presence of small, <1.0 mm mussels in the byssus matrix of adult mussel beds (Petersen 1984; McGrath *et al.* 1988), suggesting that the

primary-secondary settlement model is not the only method for mussel recruitment. In the present study, < 1.0 mm mussels were also present in adult mussel beds, indicating that mussels in Herring Bay utilize both direct settlement and primary-secondary settlement methods. Highest densities of < 1.0 mm recruits in adult beds were observed for the initial, late spring visit in both years.

Water currents are critical to the transport of mussel recruits from filamentous algae into adult mussel beds (Verwey 1952). Eyster and Pechenik (1987) in a laboratory study, reported that water agitation greatly enhanced larval attachment to filamentous substrata. Thus, water motion appears to be an essential factor in both phases of the recruitment process for young mussels. In the present study, filamentous algae and associated mussel recruits were more abundant at oiled sites, which usually had higher water motion based on cylinder dissolution rates. Calcium sulphate dissolution rates indicated the general pattern of water motion in the Bay and supported the hypothesis that oiled shorelines were historically the more productive (stronger currents, more nutrients and higher availability of larvae) than the control sites.

Although many intertidal invertebrates potentially affected by the *Exxon Valdez* oil spill/cleanup in 1989 have returned to levels comparable to undisturbed conditions, a few species, mostly grazers, still demonstrate altered distributional patterns. *Tectura persona* densities are lower at oiled sites, especially in the upper intertidal, for both sheltered rocky and coarse textured habitats. *Littorina sitkana* and *Lottia pelta* show lower densities at sheltered rocky oiled sites, as well. Continued observation of successional patterns in barnacle populations is of interest to determine the time required for barnacles to return to pre-spill distributions and abundances. Mussels have recolonized disturbed shorelines and size-frequency distributions at oiled sites are similar to those for matched control sites, although densities of small mussels were generally higher at the oiled sites. Differences in recruitment of mussels onto filamentous algae were rarely significant between oiled and non-oiled sites. Filamentous algae and associated mussel recruits, however, occurred more frequently at oiled than non-oiled sites.

Intertidal plants and animals provide food and shelter for a host of organisms in the nearshore ecosystem. Black oystercatchers, harlequin ducks, Barrow's and common goldeneyes, surf scoters, turnstones, surfbirds, northwestern crows, river and sea otters, brown and black bears, Sitka black-tailed deer and numerous fish species utilize the resources provided by the intertidal. Several species were negatively impacted by the spill, primarily due to ingestion of contaminated food items or decline of preferred prey (Patten 1993, Bowyer *et al.* 1993).

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Table 4.1. Mean abundance comparisons of the limpet *Tectura persona* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Tectura persona		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	75.00	30.30	8.33	4.77	+	0.0792	86.67	26.54	58.33	19.22	+	0.4075
1732C/1732X	1	96.67	34.03	33.33	25.65	+	0.1680	28.33	7.92	28.33	21.36	=	1.0000
3811C/3611X	1	13.33	9.89	1.67	1,67	+	0.2945	0.00	0.00	1.67	1.67	-	0.3632
OVERALL MEAN		61.67	24.74	14.44	10.70	+		38.33	11.49	29.44	14.08	-	
FISHERS TEST							0.0184						0.5117 (y)
POWER							---						0.006
POWER 50%							---						0.500
1231C/1231X	2	31.67	16.00	13.33	13.33	+	0.3994	41.67	17.97	1.67	1.67	+	0.0765
1732C/1732X	2	6.67	3.33	13.33	4.94	-	0.2897	16.67	11.74	1.67	1.67	+	0.2595
3811C/3611X	2	38.33	26.51	5.00	3.42	+	0.2659	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		25.56	15.28	10.55	7.23	+		19.45	9.90	1.11	1.11	+	
FISHERS TEST							0.2713						0.0620
POWER							0.378						---
POWER 50%							0.529						---
1231C/1231X	3	6.67	3.33	0.00	0.00	+	0.1019	5.00	5.00	0.00	0.00	+	0.3632
1732C/1732X	3	1.67	1.67	0.00	0.00	+	0.3632	0.00	0.00	0.00	0.00	=	1.0000
3811C/3611X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		2.78	1.67	0.00	0.00	+		1.67	1.67	0.00	0.00	+	
FISHERS TEST							0.0963						0.4028
POWER							---						---
POWER 50%							---						---

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.2. Mean abundance comparisons of the limpet *Lottia pelta* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Lottia pelta		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	13.33	4.22	76.67	50.64	-	0.8255	48.33	15.15	51.67	33.90	-	0.9302
1732C/1732X	1	16.67	9.89	90.00	67.43	-	0.7854	96.67	41.37	75.00	67.07	+	0.7889
3811C/3611X	1	18.33	10.14	60.00	32.35	-	0.2472	76.67	41.20	53.33	23.62	+	0.6338
OVERALL MEAN		16.11	8.08	75.56	50.14	-		73.89	32.57	60.00	41.53	+	
FISHERS TEST							0.2515						0.4924
POWER							0.374						0.198
POWER 50%							0.547						0.686
1231C/1231X	2	163.33	35.84	295.00	20.45	-	0.0096	235.00	46.96	133.33	40.72	+	0.1329
1732C/1732X	2	123.33	23.76	95.00	31.70	+	0.4908	85.00	49.45	116.67	6[illegible].33	-	0.7045
3811C/3611X	2	136.67	38.36	78.33	31.24	+	0.2656	90.00	31.83	0.00	0.00	+	0.0368
OVERALL MEAN		141.11	32.65	156.11	27.80	+		136.67	42.75	83.33	35.02	+	
FISHERS TEST							0.3343 (xy)						0.0266
POWER							0.141						----
POWER 50%							0.938						----
1231C/1231X	3	70.00	25.03	81.67	40.86	-	0.8126	148.33	49.22	26.67	16.87	+	0.0415
1732C/1732X	3	46.67	33.23	66.67	40.47	-	0.7105	35.00	26.30	10.00	5.16	+	0.7420
3811C/3611X	3	43.33	10.54	3.33	3.33	+	0.0047	23.33	9.19	0.00	0.00	+	0.0519
OVERALL MEAN		53.33	22.93	50.56	28.22	-		68.89	28.24	12.22	7.34	+	
FISHERS TEST							0.6935 (xy)						0.0091
POWER							0.010						----
POWER 50%							0.800						----

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.3. Mean abundance comparisons of the limpet *Tectura scutum* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Tectura scutum		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	0.00	0.00	0.00	0.00	=	1.0000	1.67	1.67	3.33	2.11	-	0.5490
1732C/1732X	1	1.67	1.67	3.33	3.33	-	0.6643	3.33	3.33	0.00	0.00	+	0.3632
3811C/3611X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.56	0.56	1.11	1.11	-		1.67	1.67	1.11	0.70	+	
FISHERS TEST							0.5468						0.4887
POWER							----						0.000
POWER 50%							----						----
1231C/1231X	2	1.67	1.67	5.00	5.00	-	0.5413	1.67	1.67	5.00	2.24	-	0.2596
1732C/1732X	2	0.00	0.00	0.00	0.00	=	1.0000	5.00	3.42	3.33	2.11	+	0.6367
3811C/3611X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.56	0.56	1.67	1.67	-		2.22	1.70	2.78	1.45	-	
FISHERS TEST							0.4953						0.3893
POWER							----						0.073
POWER 50%							----						0.062
1231C/1231X	3	10.00	10.00	0.00	0.00	+	0.3632	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	3	6.67	6.67	0.00	0.00	+	0.3632	6.67	6.67	0.00	0.00	+	0.3632
3811C/3611X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		5.56	5.56	0.00	0.00	+		2.22	2.22	0.00	0.00	+	
FISHERS TEST							0.2231						0.4028
POWER							----						----
POWER 50%							----						----

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.4. Mean abundance comparisons of total limpets between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Total Limpets		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	90.00	34.55	85.00	49.72	+	0.9358	136.67	23.90	120.00	31.31	+	0.6811
1732C/1732X	1	115.00	39.05	155.00	90.76	-	0.6941	128.33	46.86	108.33	65.55	+	0.8090
3811C/3611X	1	31.67	17.78	61.67	33.51	-	0.4474	80.00	42.35	83.33	36.03	-	0.9534
OVERALL MEAN		78.89	30.46	100.56	58.00	-		115.00	37.70	103.89	44.30	+	
FISHERS TEST							0.3827						0.5110
POWER							0.025						0.096
POWER 50%							0.574						0.491
1231C/1231X	2	233.33	43.72	328.33	26.51	-	0.0928	291.67	38.85	188.33	32.40	+	0.0683
1732C/1732X	2	135.00	22.91	130.00	40.42	+	0.9164	161.67	53.57	160.00	61.91	+	0.9842
3811C/3611X	2	215.00	46.96	91.67	31.98	+	0.0551	95.00	35.19	161.67	88.64	-	0.5004
OVERALL MEAN		194.44	37.86	183.33	32.97	+		182.78	42.54	170.00	60.98	+	
FISHERS TEST							0.1828 (x)						0.1883
POWER							0.260						0.092
POWER 50%							0.928						0.705
1231C/1231X	3	296.67	99.09	108.33	54.06	+	0.1262	296.67	66.52	100.00	47.26	+	0.0367
1732C/1732X	3	68.33	39.70	83.33	41.77	-	0.7999	103.33	52.89	118.33	60.36	-	0.8555
3811C/3611X	3	71.67	19.90	13.33	8.03	+	0.0216	275.00	111.89	111.67	36.19	+	0.1950
OVERALL MEAN		145.56	52.90	68.33	34.62	+		225.00	77.10	110.00	47.94	+	
FISHERS TEST							0.0160						0.0323
POWER							----						----
POWER 50%							----						----

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.5. Mean abundance comparisons of the periwinkle *Littorina sitkana* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Littorina sitkana		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	360.00	164.80	418.33	71.39	-	0.7520	333.33	139.80	100.00	33.67	+	0.2886
1732C/1732X	1	124.00	53.54	328.33	110.98	-	0.1557	321.67	205.92	111.67	57.00	+	0.3489
3811C/3611X	1	1088.33	351.54	128.33	77.61	+	0.0760	785.00	259.73	26.67	14.98	+	0.0224
OVERALL MEAN		524.11	189.96	291.66	86.66	-		480.00	201.82	79.45	35.22	+	
FISHERS TEST							0.3081 (xy)						0.0[illegible]
POWER							0.098						---
POWER 50%							0.271						---
1231C/1231X	2	143.33	30.73	116.67	71.31	+	0.7384	6.67	6.67	23.33	16.67	-	0.3750
1732C/1732X	2	353.33	229.10	100.00	42.58	+	0.9158	38.33	17.21	21.67	15.15	+	0.4839
3811C/3611X	2	690.00	191.83	35.00	17.08	+	0.0269	603.33	156.16	11.67	8.33	+	0.0066
OVERALL MEAN		395.55	150.55	83.89	43.66	+		216.11	60.01	18.89	13.38	+	
FISHERS TEST							0.0582						0.0229
POWER							---						---
POWER 50%							---						---
1231C/1231X	3	41.67	19.57	0.00	0.00	+	0.0864	13.33	13.33	0.00	0.00	+	0.3632
1732C/1732X	3	203.33	143.10	105.00	101.05	+	0.5869	1.67	1.67	26.67	26.67	-	0.8581
3811C/3611X	3	116.67	35.47	8.33	8.33	+	0.0028	213.33	49.44	0.00	0.00	+	0.0076
OVERALL MEAN		120.56	66.05	37.78	36.46	+		76.11	21.48	8.89	8.89	+	
FISHERS TEST							0.0013						0.0156
POWER							---						---
POWER 50%							---						---

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.6. Mean abundance comparisons of the dogwhelk *Nucella lamellosa* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Nucella lamellosa		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	1	0.00	0.00	3.33	2.11	-	0.1747	38.33	20.72	6.67	6.67	+	0.1764
3811C/3611X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	1.11	0.70	-		12.78	6.91	2.22	2.22	+	
FISHERS TEST							0.2650						0.2666
POWER							0.000						0.025
POWER 50%							----						0.025
1231C/1231X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	2	16.67	9.19	10.00	10.00	+	0.6341	6.67	3.33	18.33	16.42	-	0.6871
3811C/3611X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		5.56	3.06	3.33	3.33	+		2.22	1.11	6.11	5.47	-	
FISHERS TEST							0.5349						0.5555
POWER							0.008						0.001
POWER 50%							0.012						0.064
1231C/1231X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	3	5.00	3.42	0.00	0.00	+	0.2031	0.00	0.00	3.33	2.11	-	0.1747
3811C/3611X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		1.67	1.14	0.00	0.00	+		0.00	0.00	1.11	0.70	-	
FISHERS TEST							0.2899						0.2650
POWER							0.009						0.00
POWER 50%							0.010						----

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.7. Mean abundance comparisons of the dogwhelk *Nucella lima* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Nucella lima		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
1231C/1231X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
3811C/3611X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.6552						0.6552
POWER							---						---
POWER 50%							---						---
1231C/1231X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
3811C/3611X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.6552						0.6552
POWER							---						---
POWER 50%							---						---
1231C/1231X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
1732C/1732X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
3811C/3611X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.6552						0.6552
POWER							---						---
POWER 50%							---						---

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.8. Mean abundance comparisons of the limpet *Tectura persona* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Tectura persona		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	170.00	49.73	13.33	8.03	+	0.0248	85.00	29.07	26.67	4.22	+	0.1015
2834C/2834X	1	221.67	17.01	104.00	46.65	+	0.0311	195.00	25.00	103.33	28.36	+	0.0358
OVERALL MEAN		195.84	33.37	58.67	27.34	+		140.00	27.04	65.00	16.29	+	
FISHERS TEST							0.0018						0.0073
POWER							----						----
POWER 50%							----						----
2333C/2333X	2	118.33	40.61	18.33	9.10	+	0.0569	196.67	21.55	41.67	17.78	+	0.0002
2834C/2834X	2	121.67	27.25	196.67	41.45	-	0.1615	180.00	29.67	140.00	33.96	+	0.3959
OVERALL MEAN		120.00	33.93	107.50	25.28	+		188.34	25.61	90.84	25.87	+	
FISHERS TEST							0.1214						0.0002
POWER							----						----
POWER 50%							----						----
2333C/2333X	3	68.33	34.49	0.00	0.00	+	0.1044	106.67	34.42	20.00	15.49	+	0.0612
2834C/2834X	3	50.00	24.63	72.00	38.65	-	0.6310	38.33	29.03	30.00	13.78	+	0.8141
OVERALL MEAN		59.17	29.56	36.00	19.33	+		72.50	31.73	25.00	14.64	+	
FISHERS TEST							0.1548						0.0671
POWER							0.261						----
POWER 50%							0.347						----

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.

(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.9. Mean abundance comparisons of the limpet *Lottia pelta* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Lottia pelta		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	1.67	1.67	10.00	8.17	-	0.5067	0.00	0.00	1.67	1.67	-	0.3632
2834C/2834X	1	3.33	3.33	4.00	2.45	-	0.8801	1.67	1.67	3.33	2.11	-	0.5490
OVERALL MEAN		2.50	2.50	7.00	5.31	-		0.84	0.84	2.50	1.89	-	
FISHERS TEST							0.3561						0.1993
POWER							0.117						0.000
POWER 50%							----						----
2333C/2333X	2	18.33	12.49	35.00	9.22	-	0.3083	43.33	9.55	38.33	5.43	+	0.6586
2834C/2834X	2	30.00	7.30	70.00	58.14	-	[illegible]	41.67	12.23	63.33	38.44	-	0.6029
OVERALL MEAN		24.17	[illegible]	52.50	33.68	-		42.50	10.89	50.83	21.94	-	
FISHERS TEST							0.0918						0.5254
POWER							----						0.045
POWER 50%							----						0.747
2333C/2333X	3	66.67	20.28	305.00	70.75	-	0.0089	66.67	22.16	224.00	48.64	-	0.0121
2834C/2834X	3	81.67	39.36	196.00	81.89	-	0.2153	38.33	17.01	90.00	38.47	-	0.2232
OVERALL MEAN		74.17	29.82	250.50	76.32	-		52.50	19.59	157.00	43.56	-	
FISHERS TEST							0.0041						0.0056
POWER							----						---
POWER 50%							----						---

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.10. Mean abundance comparisons of the limpet *Tectura scutum* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Tectura scutum		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	3.33	3.33	-	0.3632
2834C/2834X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	1.67	1.67	-	
FISHERS TEST							0.5966						0.3086
POWER							----						----
POWER 50%							----						----
2333C/2333X	2	0.00	0.00	6.67	4.22	-	0.1747	3.33	3.33	3.33	3.33	=	1.0000
2834C/2834X	2	0.00	0.00	0.00	0.00	=	1.0000	6.67	4.22	3.33	3.33	+	0.5490
OVERALL MEAN		0.00	0.00	3.34	2.11	-		5.00	3.78	3.33	3.33	+	
FISHERS TEST							0.1804						0.4098
POWER							0.094						0.076
POWER 50%							----						0.360
2333C/2333X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	2.00	2.00	-	0.3739
2834C/2834X	3	0.00	0.00	0.00	0.00	=	1.0000	11.67	6.01	10.00	7.75	+	0.8666
OVERALL MEAN		0.00	0.00	0.00	0.00	=		5.84	3.01	6.00	4.88	-	
FISHERS TEST							0.5966						0.3438
POWER							----						---
POWER 50%							----						---

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.11. Mean abundance comparisons of total limpets between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Total limpets		May 1994.						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	171.67	50.89	23.33	9.55	+	0.3027	85.00	29.07	31.67	6.01	+	0.3740
2834C/2834X	1	225.00	18.03	108.00	47.48	+	0.0353	196.67	26.29	106.67	28.36	+	0.0422
OVERALL MEAN		198.34	34.46	65.67	28.52	+		140.84	27.68	69.17	17.19	+	
FISHERS TEST							0.0185						0.0258
POWER							---						---
POWER 50%							---						---
2333C/2333X	2	141.67	38.51	60.00	11.55	+	0.0696	246.67	24.59	83.33	16.87	+	0.0003
2834C/2834X	2	151.67	24.14	275.00	52.14	-	0.0574	235.00	32.02	215.00	27.30	+	0.6447
OVERALL MEAN		146.67	31.33	167.50	31.85	-		240.84	28.31	149.17	22.09	+	
FISHERS TEST							0.1270 (x)						0.0005
POWER							0.155						---
POWER 50%							0.867						---
2333C/2333X	3	185.00	68.93	313.33	69.94	-	0.2205	220.00	40.08	294.00	43.89	-	0.2446
2834C/2834X	3	171.67	35.35	326.00	86.41	-	0.1107	253.33	30.62	300.00	35.64	-	0.3438
OVERALL MEAN		178.34	52.14	319.67	78.18	-		236.67	35.35	297.00	39.77	-	
FISHERS TEST							0.0372						0.1022
POWER							---						0.394
POWER 50%							---						0.940

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.12. Mean abundance comparisons of the periwinkle *Littorina sitkana* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Littorina sitkana		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	101.67	43.93	105.00	24.05	-	0.9482	71.67	32.29	253.33	68.98	-	0.0383
2834C/2834X	1	85.00	32.33	128.00	42.00	-	0.4305	93.33	18.74	153.33	84.25	-	0.3641
OVERALL MEAN		93.34	38.13	116.50	33.03	-		82.50	25.52	203.33	76.62	-	
FISHERS TEST							0.3350						0.0232
POWER							0.130						---
POWER 50%							0.361						---
2333C/2333X	2	140.00	51.51	131.67	43.93	+	0.9045	71.67	23.86	45.00	22.62	+	0.4362
2834C/2834X	2	133.33	22.16	130.00	31.09	+	0.9322	148.33	50.23	138.33	63.69	+	0.9043
OVERALL MEAN		136.67	36.84	130.84	37.51	+		110.00	37.05	91.67	43.16	+	
FISHERS TEST							0.5390						0.3271
POWER							0.091						0.183
POWER 50%							0.673						0.504
2333C/2333X	3	158.33	58.05	161.67	52.75	-	0.9669	78.33	33.51	2.00	2.00	+	0.0216
2834C/2834X	3	133.33	34.42	164.00	115.61	-	0.7887	70.00	32.04	16.00	8.12	+	0.1697
OVERALL MEAN		145.83	46.24	162.84	84.18	-		74.17	32.78	9.00	5.06	+	
FISHERS TEST							0.5066						0.0073
POWER							0.011						---
POWER 50%							0.549						---

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.13. Mean abundance comparisons of the dogwhelk *Nucella lamellosa* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Nucella lamellosa		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
2834C/2834X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.5966						0.5966
POWER							----						----
POWER 50%							----						----
2333C/2333X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
2834C/2834X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.5966						0.5966
POWER							----						----
POWER 50%							----						----
2333C/2333X	3	0.00	0.00	3.33	3.33	-	0.3632	0.00	0.00	0.00	0.00	=	1.0000
2834C/2834X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	1.67	1.67	-		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.3086						0.5966
POWER							----						----
POWER 50%							----						----

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.14. Mean abundance comparisons of the dogwhelk *Nucella lima* between oiled and control population dynamics site pairs. MVD = meter vertical drop; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; Power = power to detect given difference; Power 50% = power to detect a 50% difference.

Nucella lima		May 1994						September 1994					
		no. m-2						no. m-2					
Site Pair	MVD	C	SE	O	SE	D	P-Value	C	SE	O	SE	D	P-Value
2333C/2333X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
2834C/2834X	1	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
OVERALL MEAN		0.00	0.00	0.00	0.00	=		0.00	0.00	0.00	0.00	=	
FISHERS TEST							0.5966						0.5966
POWER							---						---
POWER 50%							---						---
2333C/2333X	2	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
2834C/2834X	2	0.00	0.00	0.00	0.00	=	1.0000	6.67	4.94	0.00	0.00	+	0.2354
OVERALL MEAN		0.00	0.00	0.00	0.00	=		3.34	2.47	0.00	0.00	+	
FISHERS TEST							0.5966						0.2256
POWER							---						0.015
POWER 50%							---						0.014
2333C/2333X	3	0.00	0.00	0.00	0.00	=	1.0000	0.00	0.00	0.00	0.00	=	1.0000
2834C/2834X	3	13.33	6.67	8.00	8.00	+	0.6177	8.33	3.07	14.00	6.00	-	0.3985
OVERALL MEAN		6.67	3.34	4.00	4.00	+		4.17	1.54	7.00	3.00	-	
FISHERS TEST							0.4429						0.3294
POWER							0.070						0.105
POWER 50%							0.115						0.181

(x) = At least one site pair with a p-value <0.1000 in opposite direction of overall test.
(y) = Direction of difference between overall means in opposite direction of overall tests.

Table 4.15. Mean abundance of adult *Semibalanus balanoides Balanus glandula* on scraped and unscraped plots at three sites in 1993 and 1994. MVD = meter vertical drop; SE = standard error.

		June 1993				Aug 1993				May 1994				Aug 1994			
		Scraped		Unscraped		Scraped		Unscraped		Scraped		Unscraped		Scraped		Unscraped	
Site	MVD	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
1522	0.5	0.0	0.0	55.9	55.9	0.0	0.0	44.1	44.1	15.3	12.4	223.7	75.2	31.8	31.8	164.2	77.4
	1.0	0.0	0.0	65.0	65.0	0.0	0.0	45.2	45.2	80.7	39.8	288.4	61.8	3.3	2.9	188.5	36.0
	1.5	0.0	0.0	10.3	10.3	0.0	0.0	4.5	4.5	22.0	9.8	81.7	39.5	0.0	0.0	37.6	28.1
Barnacle pt.	0.5	0.0	0.0	95.1	95.1	0.0	0.0	60.4	60.4	28.4	9.6	194.6	60.0	5.8	2.4	59.5	21.4
	1.0	0.0	0.0	35.1	35.1	0.0	0.0	13.4	13.4	16.4	7.4	25.9	15.1	3.3	3.3	2.0	1.7
	1.5	0.0	0.0	9.0	9.0	0.0	0.0	1.0	1.0	16.7	3.5	9.7	4.1	0.0	0.0	0.3	0.3
Kiska	0.5	0.0	0.0	42.3	42.3	0.0	0.0	45.4	45.4	103.9	46.1	115.5	42.3	2.8	1.1	74.1	32.2
	1.0	0.0	0.0	13.8	13.8	0.0	0.0	8.0	8.0	29.4	6.0	87.1	41.4	5.0	2.0	24.9	18.0
	1.5	0.0	0.0	7.5	7.5	0.0	0.0	5.5	5.5	24.5	6.9	20.9	10.5	1.5	1.0	2.8	2.1

Table 4.16. Ratio of adult *Chthamalus* to *Semibalanus/Balanus* on plots sampled in 1993 and 1994. MVD = meter vertical drop. Note that only unscraped plot ratios are reported for 1993, since *Semibalanus/Balanus* adults were not present on scraped plots until 1994. (See also Table 4.15).

Site	MVD	Jun 1993	Aug 1993	May 1994		Aug 1994	
		Unscraped	Unscraped	Unscraped	Scraped	Unscraped	Scraped
1522	0.5	1.4	3.7	0.2	0.3	0.1	0.6
	1.0	2.0	3.1	0.2	0.4	0.2	8.0
	1.5	24.1	41.4	1.2	1.5	1.7	---
Barnacle Point	0.5	1.9	3.3	0.6	12.2	2.3	45.0
	1.0	3.6	16.1	24.4	42.3	232.5	297.7
	1.5	30.7	256.0	42.1	12.2	1303.3	---
Kiska	0.5	5.1	6.4	2.4	1.4	2.5	39.0
	1.0	3.3	9.3	5.6	21.6	8.8	76.2
	1.5	30.4	54.2	28.4	42.2	97.7	341.0

Table 4.17. Mean mussel length (mm) at six sites sampled in 1993 and 1994 for size-frequency distribution studies. SE = standard error. Mean lengths are for mussels > 1.0 mm only and do not include recent recruits.

	Jun 1993		Sep 1993		May 1994		Sep 1994	
Site	Mean	SE	Mean	SE	Mean	SE	Mean	SE
MB2	10.14	1.30	13.53	1.67	10.79	1.52	11.67	1.09
MB2C	19.05	1.56	21.98	2.36	14.60	1.59	13.67	2.33
1522	11.27	0.98	19.10	3.16	10.04	0.53	12.44	0.48
1522C	14.22	2.53	14.86	3.40	18.32	1.61	15.84	1.53
MB1	11.87	2.03	21.08	3.67	9.67	1.49	12.15	2.53
MB1C	12.64	1.82	14.87	2.09	15.59	1.79	13.58	1.30

Table 4.18. Statistical comparisons of size-frequency curves for individual mussel study sites, summarized as p-values. Comparisons are between various sampling dates. The sampling date with the higher percentage of smaller mussels is reported beneath the p-value for each comparison, if a significant difference occurred. "-" indicates no difference in curves.

Date Comparison	MB2	MB2C	1522	1522C	MB1	MB1C
Jun 93-Sep 93	0.03	0.03	0.01	0.77	0.08	0.28
	June	June	June	-	-	-
Jun 93-May 94	0.89	0.08	0.79	0.86	0.25	0.26
	-	-	-	-	-	-
Sep 93-May 94	0.03	0.03	0.06	0.68	0.10	0.97
	1994	1994	-	-	-	-
Sep 93-Sep 94	0.03	0.00	0.01	0.64	0.00	0.00
	1994	1994	1994	-	1994	1994
May 94-Sep 94	0.06	0.26	0.63	0.00	0.00	0.00
	-	-	-	September	September	September

Table 4.19. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in June 1993. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	4	4	0.0	0.0	0.0	0.0	
MB2C/MB2	1	4	4	0.0	0.0	3.1	1.9	
1522C/1522	1	4	4	0.0	0.0	10.0	10.0	
MB1C/MB1	2	4	4	9.4	9.4	16.3	16.3	
MB2C/MB2	2	4	4	1.3	0.7	21.9	2.4	***
1522C/1522	2	4	4	21.3	19.6	20.0	11.4	
MB1C/MB1	3	4	4	29.4	17.2	24.4	12.0	
MB2C/MB2	3	4	4	13.1	3.6	48.1	17.6	
1522C/1522	3	4	4	5.6	4.1	54.4	7.7	***
MB1C/MB1	3.5	3	3	39.2	26.8	34.2	16.7	
MB2C/MB2	3.7	4	2	55.0	22.6	88.8	1.3	
1522C/1522	3.5	3	0	32.5	13.8	---	---	

Table 4.20. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in July 1993. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	4	4	0.0	0.0	0.0	0.0	
MB2C/MB2	1	4	4	0.0	0.0	1.3	0.7	
1522C/1522	1	4	3	0.0	0.0	7.5	7.5	
MB1C/MB1	2	4	4	4.4	2.1	10.0	8.4	
MB2C/MB2	2	4	4	1.3	0.7	31.3	8.7	*
1522C/1522	2	4	3	7.5	5.3	40.0	10.2	**
MB1C/MB1	3	4	4	6.9	2.8	36.9	16.0	
MB2C/MB2	3	4	4	6.9	4.5	55.0	19.1	
1522C/1522	3	4	1	11.3	4.8	37.5	---	
MB1C/MB1	3.5	2	1	57.5	25.0	0.0	---	
MB2C/MB2	3.5	4	4	20.0	10.9	74.4	9.3	**
1522C/1522	3.5	2	1	40.0	2.5	50.0	---	

Table 4.21. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in September 1993. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	4	4	0.0	0.0	0.0	0.0	
MB2C/MB2	1	4	4	0.0	0.0	0.0	0.0	
1522C/1522	1	4	4	0.0	0.0	0.6	0.6	
MB1C/MB1	2	4	4	0.6	0.6	0.0	0.0	
MB2C/MB2	2	4	4	1.3	1.3	10.0	6.2	
1522C/1522	2	4	4	25.0	25.0	3.8	2.4	
MB1C/MB1	3	4	4	4.4	0.6	8.8	3.9	
MB2C/MB2	3	4	4	2.5	1.8	45.6	17.2	
1522C/1522	3	4	4	0.0	0.0	24.4	4.4	**
MB1C/MB1	3.5	4	2	27.5	9.6	63.8	28.8	
MB2C/MB2	3.5	4	2	18.8	7.3	0.0	0.0	
1522C/1522	3.5	4	2	1.3	1.3	10.0	0.0	***

Table 4.22. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in May 1994. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	6	6	0.0	0.0	1.7	1.2	
MB2C/MB2	1	6	6	0.8	0.5	1.3	0.9	
1522C/1522	1	6	6	0.0	0.0	3.8	1.7	
MB1C/MB1	2	6	6	4.6	3.6	3.8	1.9	
MB2C/MB2	2	6	6	2.5	2.0	16.7	9.4	
1522C/1522	2	6	6	10.0	9.5	25.3	10.2	
MB1C/MB1	3	6	6	14.6	4.6	25.8	10.5	
MB2C/MB2	3	6	6	49.6	13.3	54.2	15.0	
1522C/1522	3	6	6	15.8	5.4	58.3	4.3	***
MB1C/MB1	3.5	3	2	55.0	8.0	73.8	11.3	
MB2C/MB2	3.5	5	5	65.5	11.5	86.5	45.7	
1522C/1522	3.5	5	2	49.5	12.6	33.8	21.3	

Table 4.23. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in June 1994. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	4	4	0.0	0.0	2.6	1.8	
MB2C/MB2	1	4	4	0.0	0.0	0.0	0.0	
1522C/1522	1	4	4	0.0	0.0	0.0	0.0	
MB1C/MB1	2	4	4	2.5	2.5	11.9	4.5	
MB2C/MB2	2	4	4	0.6	0.6	2.5	1.0	
1522C/1522	2	4	4	0.6	0.6	13.1	13.1	
MB1C/MB1	3	4	4	1.9	1.2	33.1	4.8	***
MB2C/MB2	3	4	4	45.6	18.0	27.5	22.7	
1522C/1522	3	4	4	13.1	13.1	45.0	19.1	
MB1C/MB1	3.5	4	3	54.4	19.2	52.5	15.1	
MB2C/MB2	3.5	3	4	88.3	3.0	48.1	7.0	***
1522C/1522	3.5	4	4	30.0	10.1	30.6	17.6	

Table 4.24. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in August 1994. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	4	4	0.0	0.0	5.0	5.0	
MB2C/MB2	1	4	4	0.0	0.0	0.0	0.0	
1522C/1522	1	4	4	0.0	0.0	2.5	2.5	
MB1C/MB1	2	4	4	1.3	1.3	15.7	9.8	
MB2C/MB2	2	4	4	0.0	0.0	25.0	7.6	**
1522C/1522	2	4	4	0.6	0.6	24.5	13.1	
MB1C/MB1	3	4	4	2.5	1.4	42.5	9.1	**
MB2C/MB2	3	4	4	29.4	13.4	36.9	15.7	
1522C/1522	3	4	4	6.3	3.6	16.9	4.8	
MB1C/MB1	3.5	4	4	43.8	12.4	49.4	14.2	
MB2C/MB2	3.5	4	4	64.4	20.6	64.4	15.0	
1522C/1522	3.5	4	4	26.9	15.7	62.5	11.1	

Table 4.25. Means, standard errors and p-value significance of percent filamentous algal cover on three matched pairs of mussel study sites in September 1994. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. Statistical significance from t-tests between matched oiled and control sites are represented as follows: * = p<0.05, ** = p<0.025, *** = p<0.01.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	4	4	0.0	0.0	1.3	0.7	
MB2C/MB2	1	4	4	0.0	0.0	0.6	0.6	
1522C/1522	1	4	4	0.0	0.0	0.0	0.0	
MB1C/MB1	2	4	4	1.3	1.3	20.0	6.4	*
MB2C/MB2	2	4	4	0.6	0.6	14.4	7.9	*
1522C/1522	2	4	4	6.9	5.3	11.3	9.6	
MB1C/MB1	3	4	4	8.1	2.4	63.1	11.3	***
MB2C/MB2	3	4	4	25.0	8.2	38.8	22.9	
1522C/1522	3	4	4	14.4	7.9	6.9	2.6	
MB1C/MB1	3.5	4	3	51.9	11.6	63.3	2.2	
MB2C/MB2	3.5	4	3	45.6	15.6	12.5	12.5	
1522C/1522	3.5	4	4	20.6	11.1	19.6	4.9	

Table 4.26. Mean densities of *Mytilus trossulus* in 10 x 10 cm collections of filamentous algae from three matched pairs of mussel study sites in June 1993. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. No t-test between any matched pair was significant.

				Control		Oiled	
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE
MB1C/MB1	1	0	3	---	---	0.00	0.00
MB2C/MB2	1	0	0	---	---	---	---
1522C/1522	1	0	0	---	---	---	---
MB1C/MB1	2	2	3	186.00	150.00	7.33	5.90
MB2C/MB2	2	0	1	---	---	246.00	---
1522C/1522	2	1	3	174.00	---	9.67	7.22
MB1C/MB1	3	2	3	229.00	57.00	239.67	235.18
MB2C/MB2	3	3	3	74.33	18.44	78.67	12.71
1522C/1522	3	1	3	22.00	---	7.00	2.65
MB1C/MB1	3.5	3	4	164.67	67.27	282.00	97.13
MB2C/MB2	3.5	3	2	59.00	1.16	111.50	85.50
1522C/1522	3.5	3	0	59.33	14.33	---	---

Table 4.27. Mean densities of *Mytilus trossulus* in 10 x 10 cm collections of filamentous algae from three matched pairs of mussel study sites in September 1993. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error. No t-test between any matched pair was significant.

				Control		Oiled	
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE
MB1C/MB1	1	0	0	---	---	---	---
MB2C/MB2	1	0	0	---	---	---	---
1522C/1522	1	0	2	---	---	95.00	12.00
MB1C/MB1	2	0	0	---	---	---	---
MB2C/MB2	2	0	2	---	---	324.00	130.00
1522C/1522	2	2	2	474.50	344.50	418.00	14.00
MB1C/MB1	3	0	1	---	---	752.00	--
MB2C/MB2	3	0	2	---	---	451.00	136.00
1522C/1522	3	2	3	173.50	7.50	564.33	228.79
MB1C/MB1	3.5	4	2	650.00	67.02	482.50	35.50
MB2C/MB2	3.5	3	0	262.67	119.22	---	---
1522C/1522	3.5	2	1	583.00	66.00	941.00	---

Table 4.28. Mean densities of *Mytilus trossulus* in 10 x 10 cm collections of filamentous algae from three matched pairs of mussel study sites in May 1994. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	1	2	370.0	---	813.0	745.0	
MB2C/MB2	1	1	1	144.0	---	148.0	---	
1522C/1522	1	1	4	137.5	---	102.0	47.0	
MB1C/MB1	2	4	4	326.6	48.6	19.0	15.1	***
MB2C/MB2	2	4	4	136.6	55.2	137.0	83.5	
1522C/1522	2	4	4	167.0	41.8	166.5	43.0	
MB1C/MB1	3	4	4	72.5	40.8	293.5	169.8	
MB2C/MB2	3	4	4	100.5	56.9	135.5	26.3	
1522C/1522	3	4	4	50.5	15.3	185.5	19.1	***
MB1C/MB1	3.5	2	1	76.0	18.0	748.0	---	
MB2C/MB2	3.5	3	2	88.7	17.4	62.0	14.0	
1522C/1522	3.5	3	1	25.3	5.5	40.0	---	

Table 4.29. Mean densities of *Mytilus trossulus* in 10 x 10 cm collections of filamentous algae from three matched pairs of mussel study sites in August 1994. MVD = meter vertical drop; Nc = number of samples from control site; No = number of samples from oiled site; SE = standard error.

				Control		Oiled		
Site Pair	MVD	Nc	No	Mean	SE	Mean	SE	
MB1C/MB1	1	0	4	---	---	1478.0	157.7	
MB2C/MB2	1	0	3	---	---	573.3	431.3	
1522C/1522	1	0	2	---	---	662.0	122.0	
MB1C/MB1	2	3	4	1280.7	362.1	2734.5	677.1	
MB2C/MB2	2	1	4	1236.0	---	1077.0	186.4	
1522C/1522	2	3	4	516.7	147.7	2304.5	1119.2	
MB1C/MB1	3	4	4	2421.5	204.6	6373.0	2393.5	
MB2C/MB2	3	4	4	1715.5	628.6	1662.0	298.3	
1522C/1522	3	4	4	1860.5	897.4	2852.0	1158.5	
MB1C/MB1	3.5	4	4	2213.0	491.4	4043.5	939.2	
MB2C/MB2	3.5	4	4	450.5	185.9	1817.0	395.2	**
1522C/1522	3.5	4	4	1124.0	90.1	4093.5	3131.7	

Table 4.30. Seasonal growth rates and total growth for caged mussels on oiled and non-oiled sites in Herring Bay from June 1993 to August 1994. Tran = transect number; N = number of mussels measured; SE = standard error.

		GROWTH RATE (mm/month)									TOTAL GROWTH (mm)		
		06/93-08/93			08/93-05/94			05/94-08/94			06/93-08/94		
SITE	TRAN	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE
MB1	1	42	0.13	0.05	40	0.34	0.03	28	0.87	0.12	28	6.02	0.66
	3	28	0.88	0.13	26	0.33	0.04	23	1.78	0.17	23	10.41	0.74
MB1C	2	60	0.82	0.10	38	0.46	0.04	24	1.39	0.15	25	9.04	0.50
	3	52	0.39	0.07	35	0.21	0.02	19	1.10	0.12	19	5.96	0.64
MB2	2	20	-0.09	0.02	14	0.06	0.02	3	0.17	0.12	3	1.23	0.53
	3	52	0.06	0.05	43	0.58	0.04	35	1.23	0.10	35	9.03	0.53
MB2C	2	21	0.44	0.11	18	0.33	0.03	17	1.18	0.15	17	7.54	0.68
	4	33	-0.16	0.09	27	0.14	0.02	19	0.96	0.14	19	3.72	0.58
1522	2	34	0.11	0.05	24	0.31	0.03	20	0.85	0.09	20	5.38	0.60
	4	24	0.09	0.06	9	0.07	0.02	7	0.05	0.02	7	0.95	0.20
1522C	1	31	0.29	0.11	15	0.38	0.07	11	1.19	0.22	12	6.96	0.84
	4	36	0.31	0.06	29	0.29	0.03	26	1.36	0.15	26	7.27	0.62

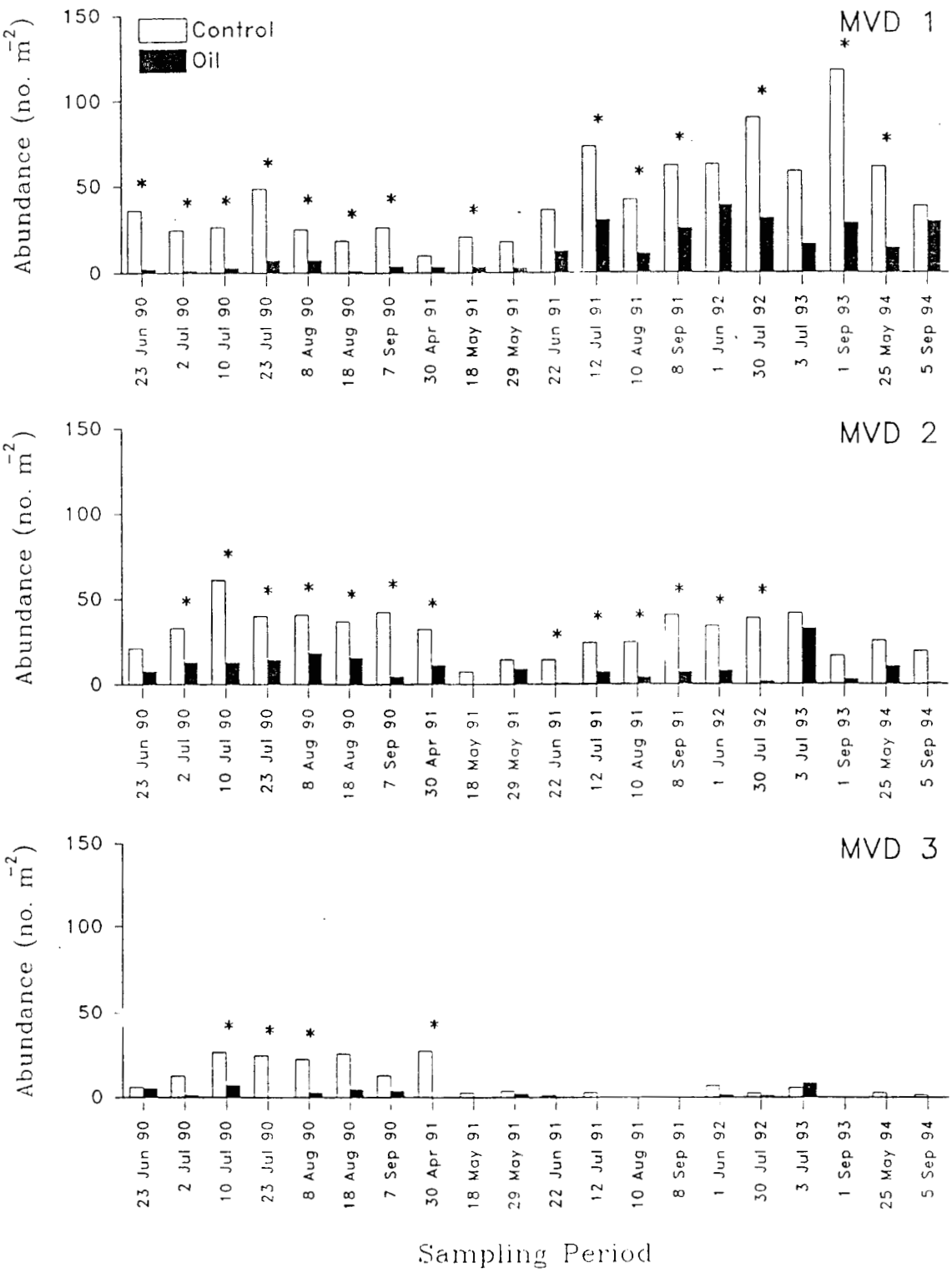

Figure 4.1. Density (No. m^{-2}) of *Tectura persona* at sheltered rocky sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

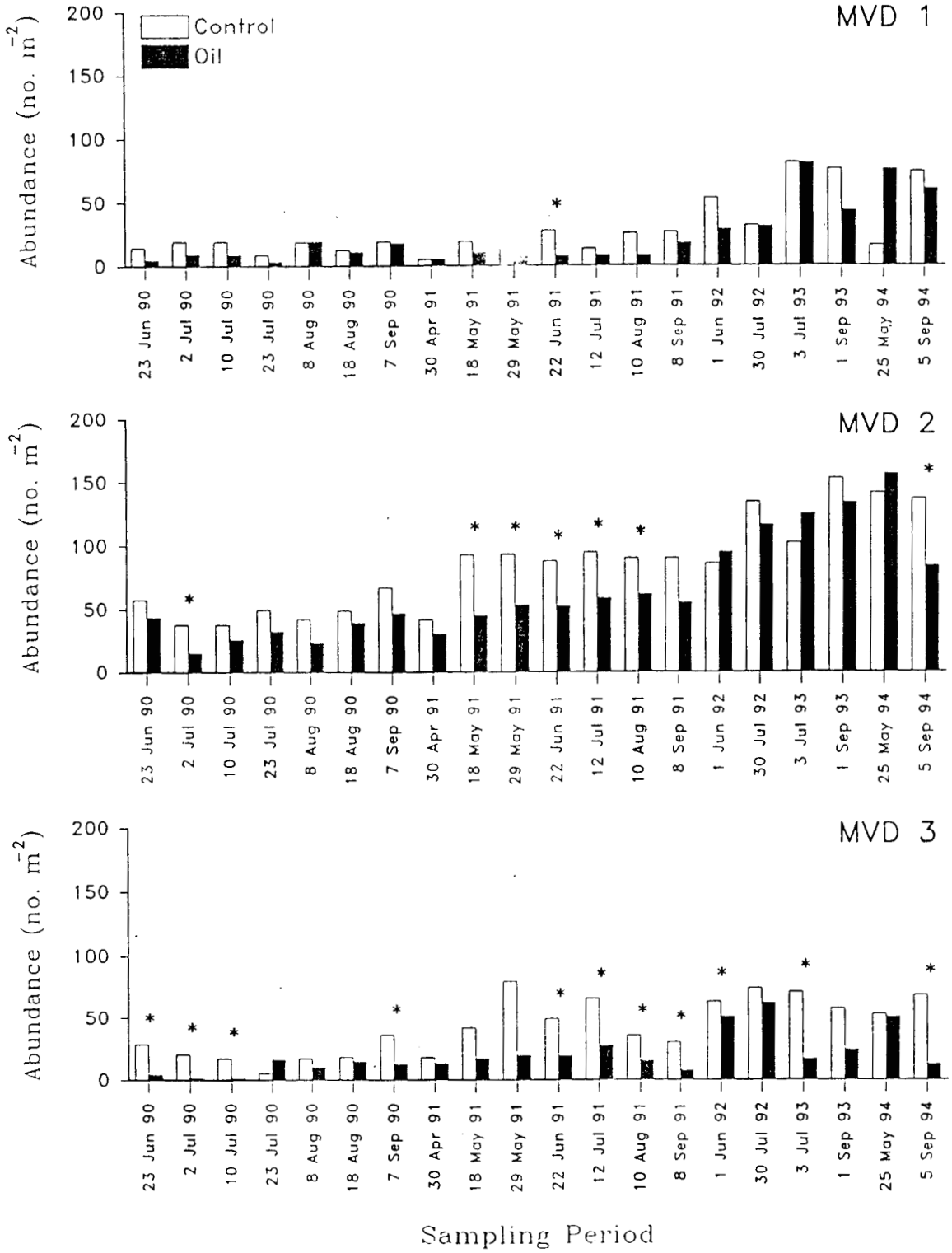

Figure 4.2. Density (No. m^{-2}) of *Lottia pelta* at sheltered rocky sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

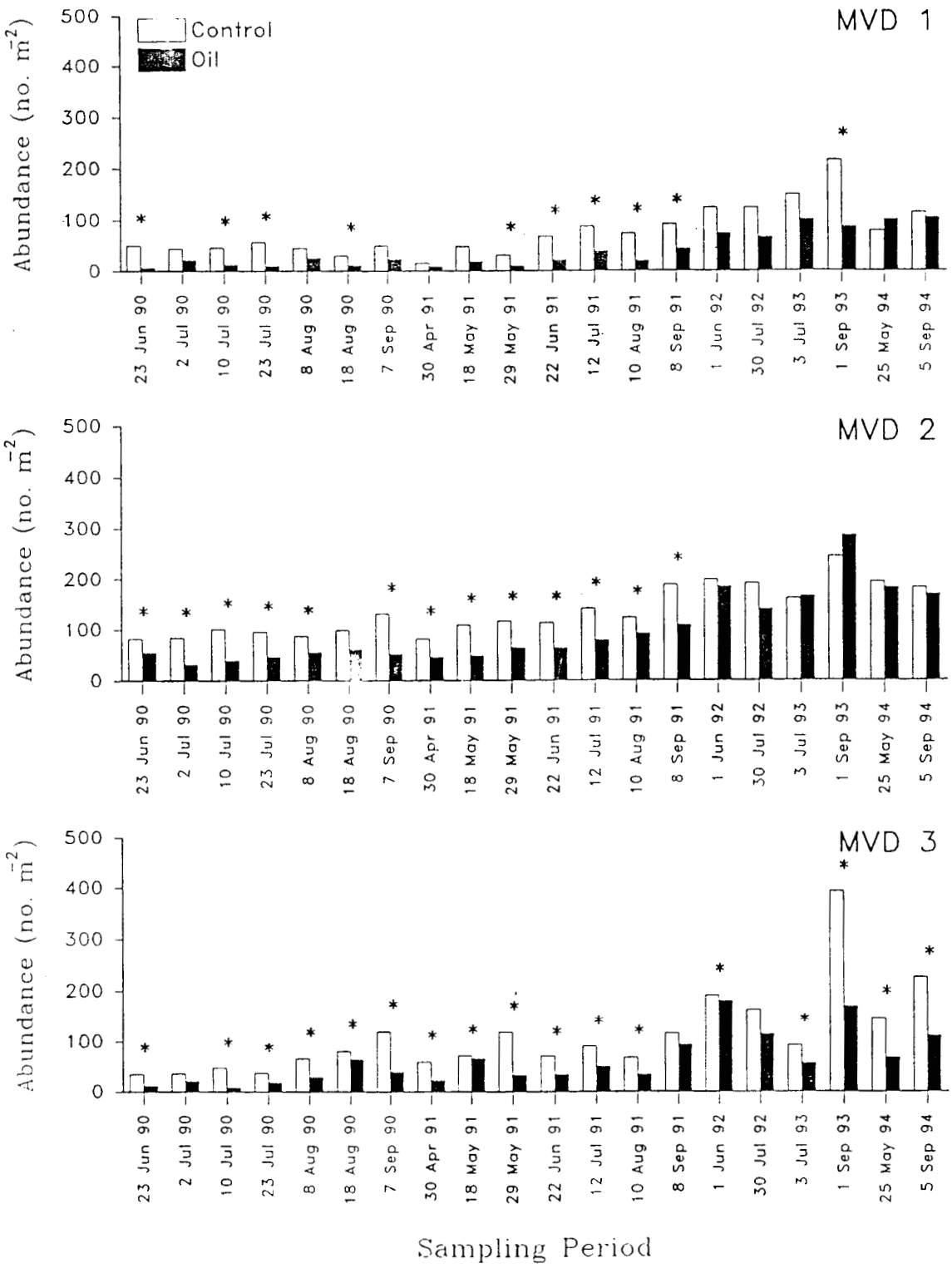

Figure 4.3. Density (No. m^{-2}) of all limpets at sheltered rocky sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

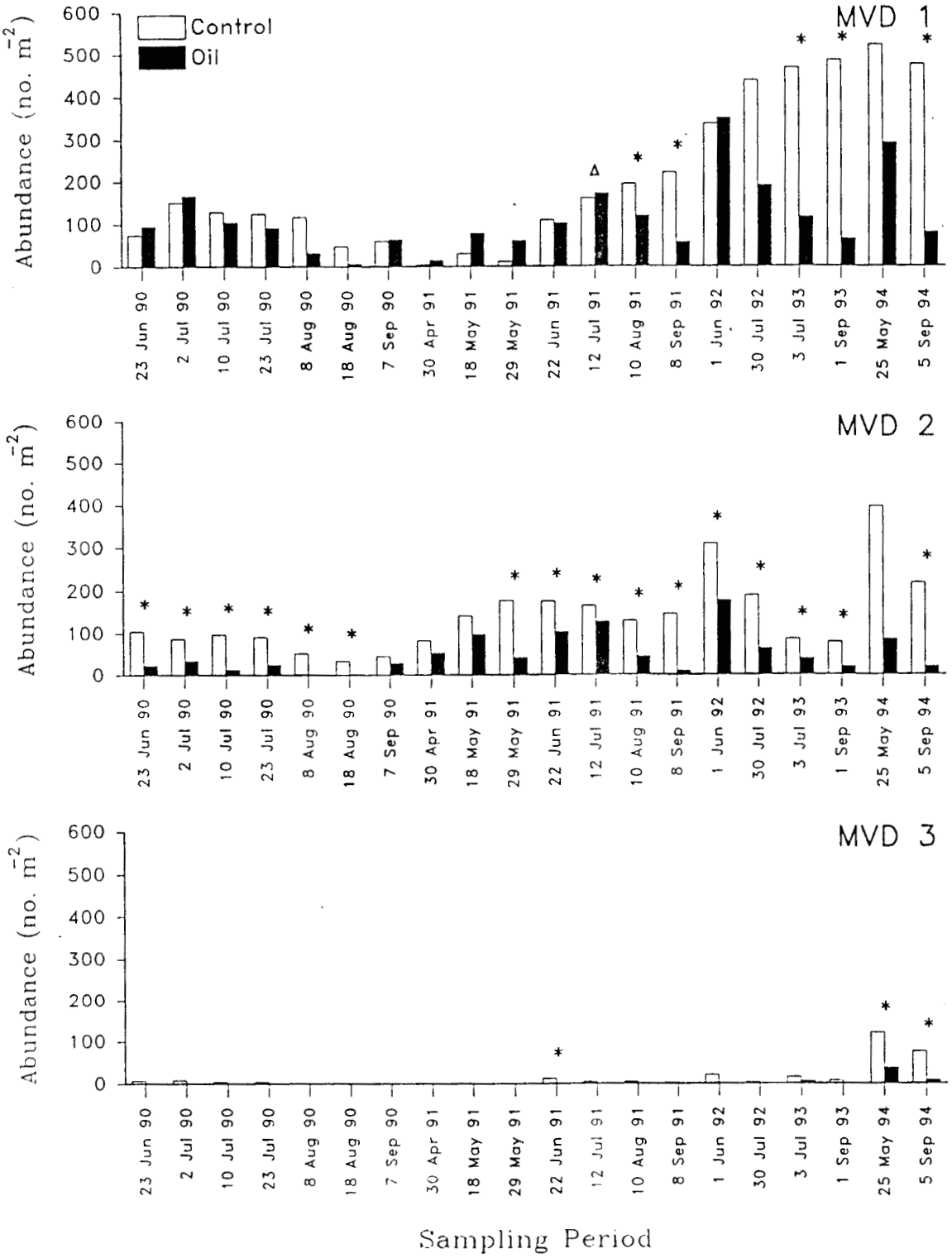

Figure 4.4. Density (No. m^{-2}) of *Littorina sitkana* at sheltered rocky sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

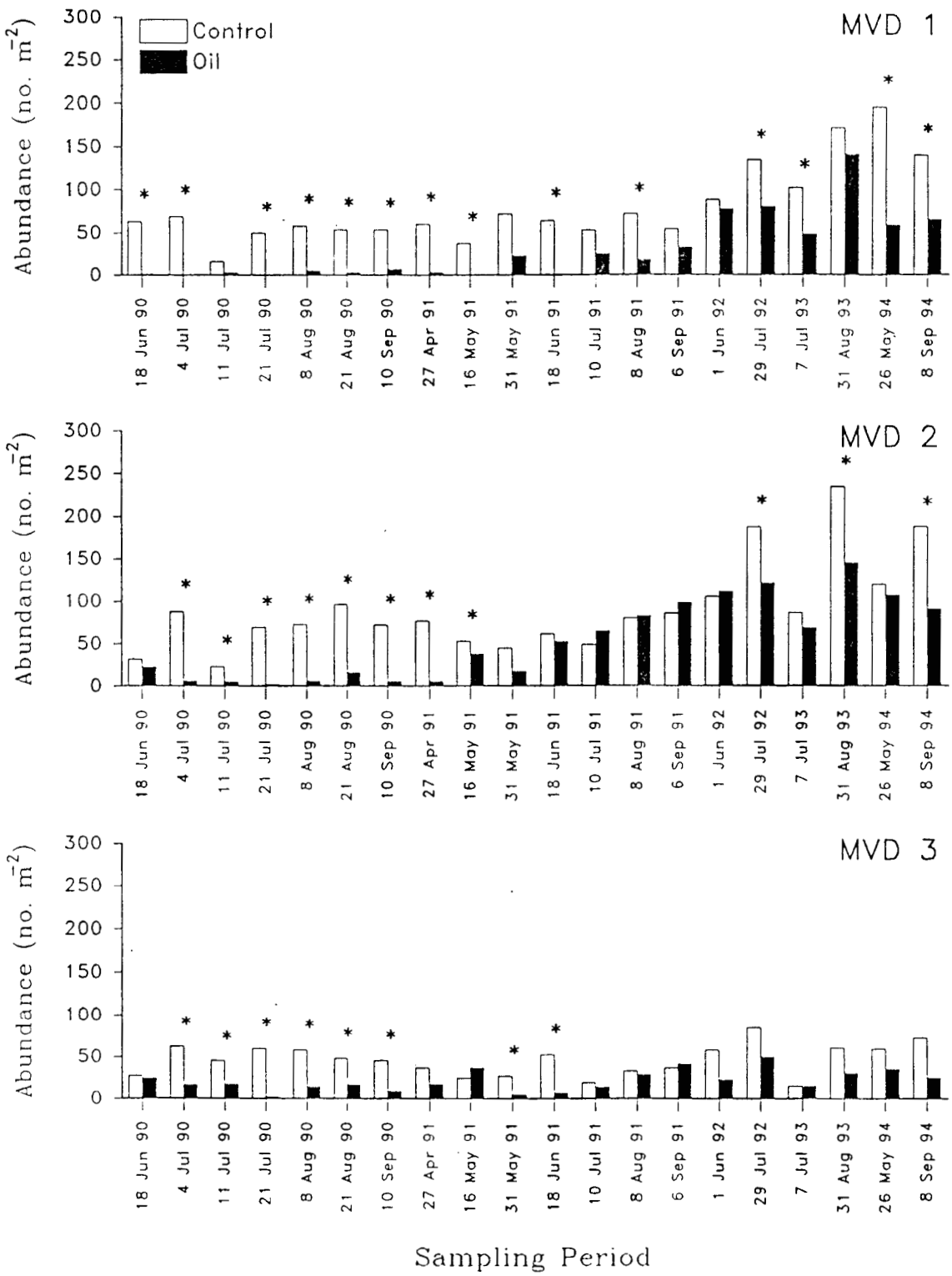

Figure 4.5. Density (No. m^{-2}) of *Tectura persona* at coarse textured sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

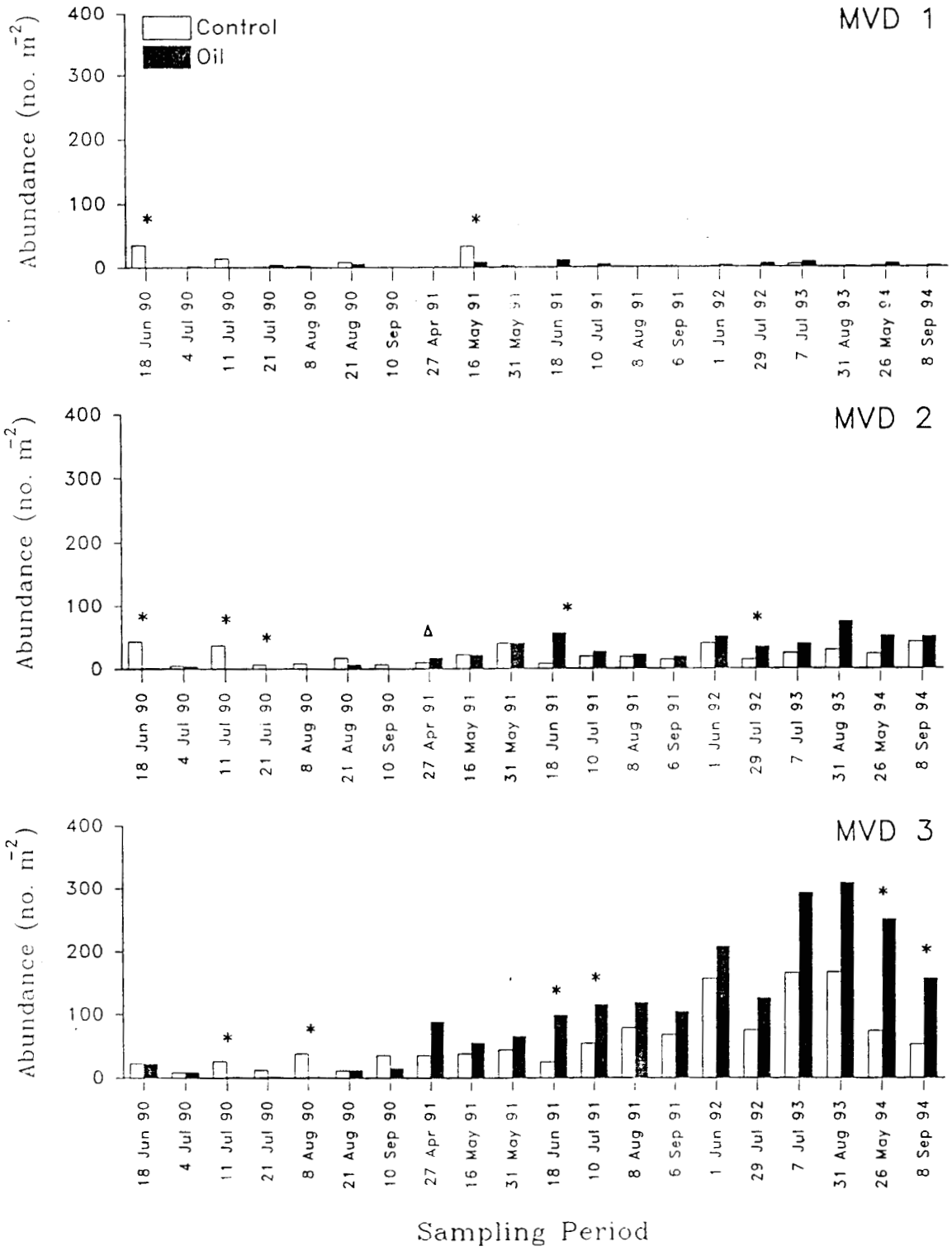

Figure 4.6. Density (No. m^{-2}) of *Lottia pelta* at coarse textured sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

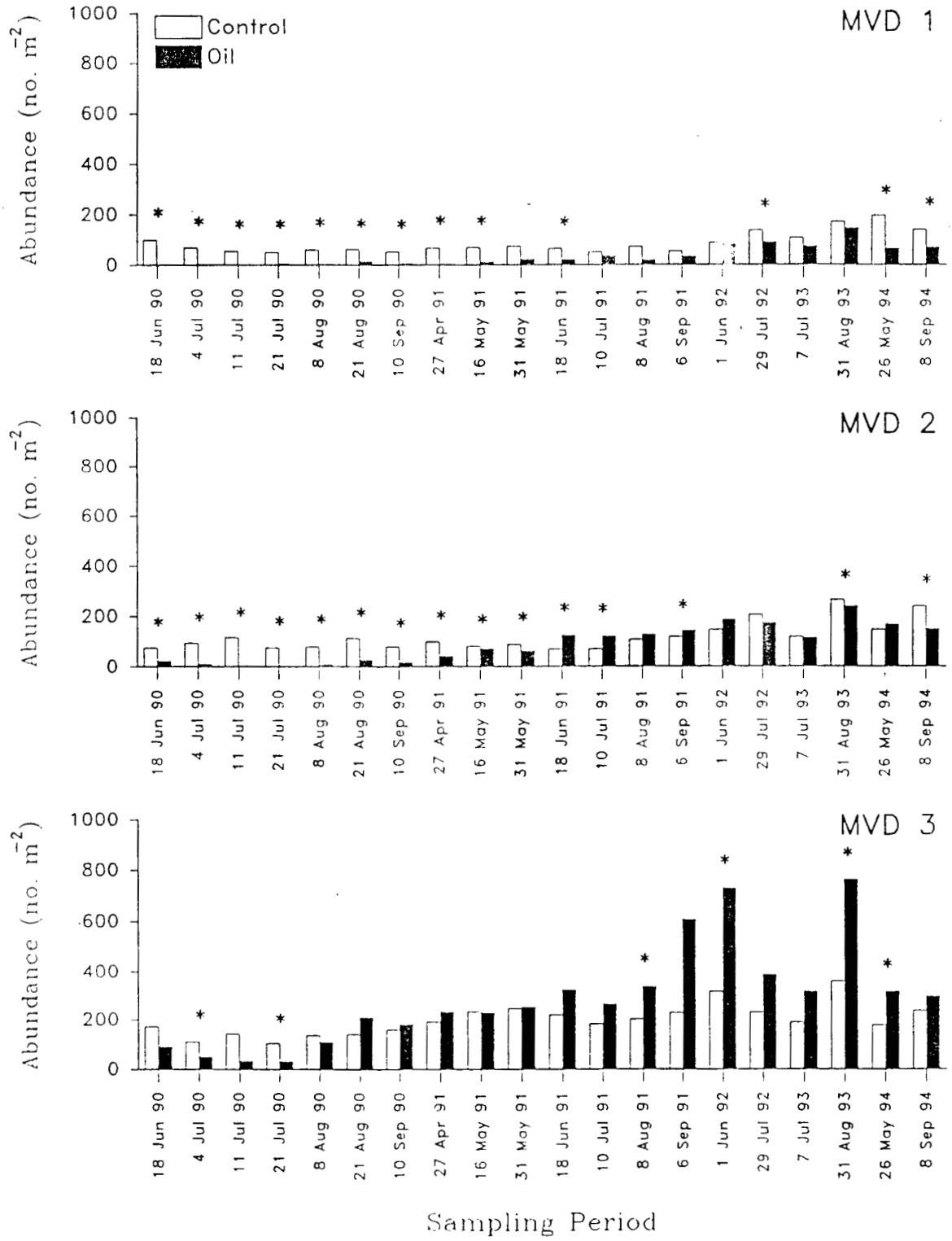

Figure 4.7. Density (No. :n^{-2}) of all limpets at coarse textured sites from 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

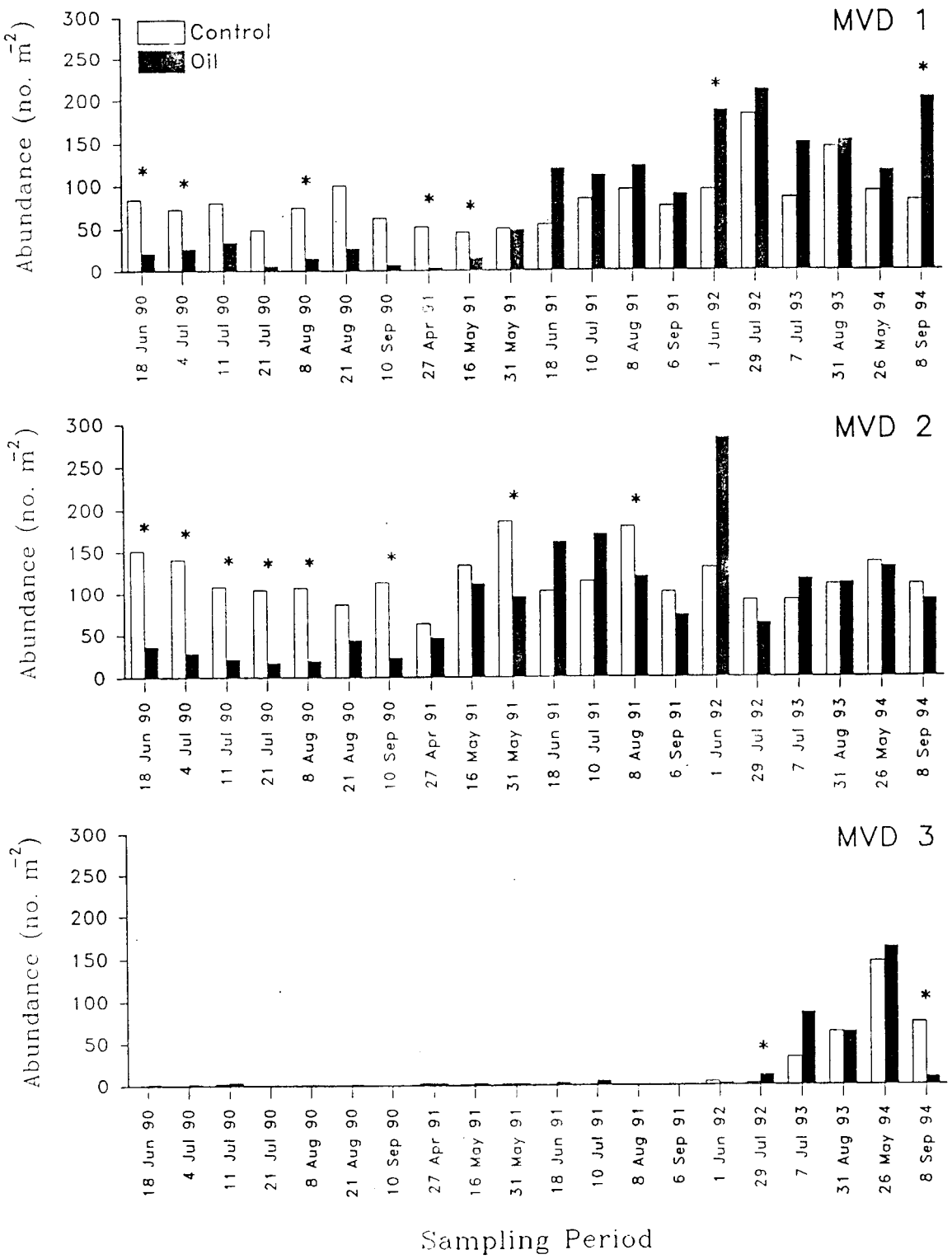

Figure 4.8. Density (No. m^{-2}) of *Littorina sitkana* at coarse textured sites fron. 1990 through 1994. MVD refers to the meter of vertical drop below mean high high water. Asterisks indicate statistically significant differences between oiled and control sites for Fisher's test for combining p-values across site pairs at the $p \leq 0.05$ level.

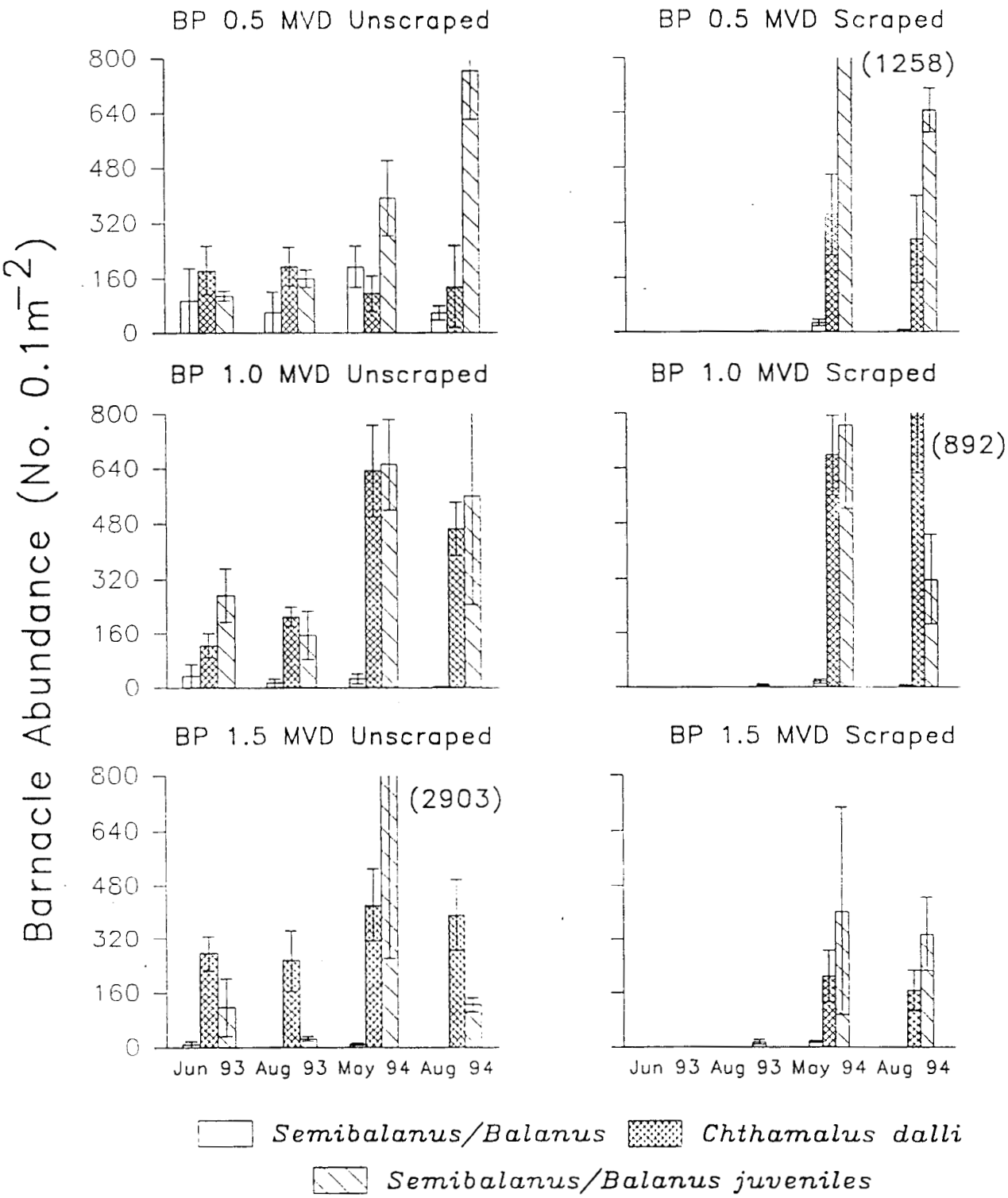

Figure 4.9. Barnacle abundances on 10 x 10 cm scraped and unscraped plots at Barnacle Point in 1993 and 1994. MVD refers to the meter of vertical drop below mean high high water. *Semibalanus/Balanus* refers to adult *S. balanoides* and *B. glandula* combined, *Chthamalus dalli* refers to adult *C. dalli*, and juveniles refers to combined *S. balanoides* and *B. glandula* spat.

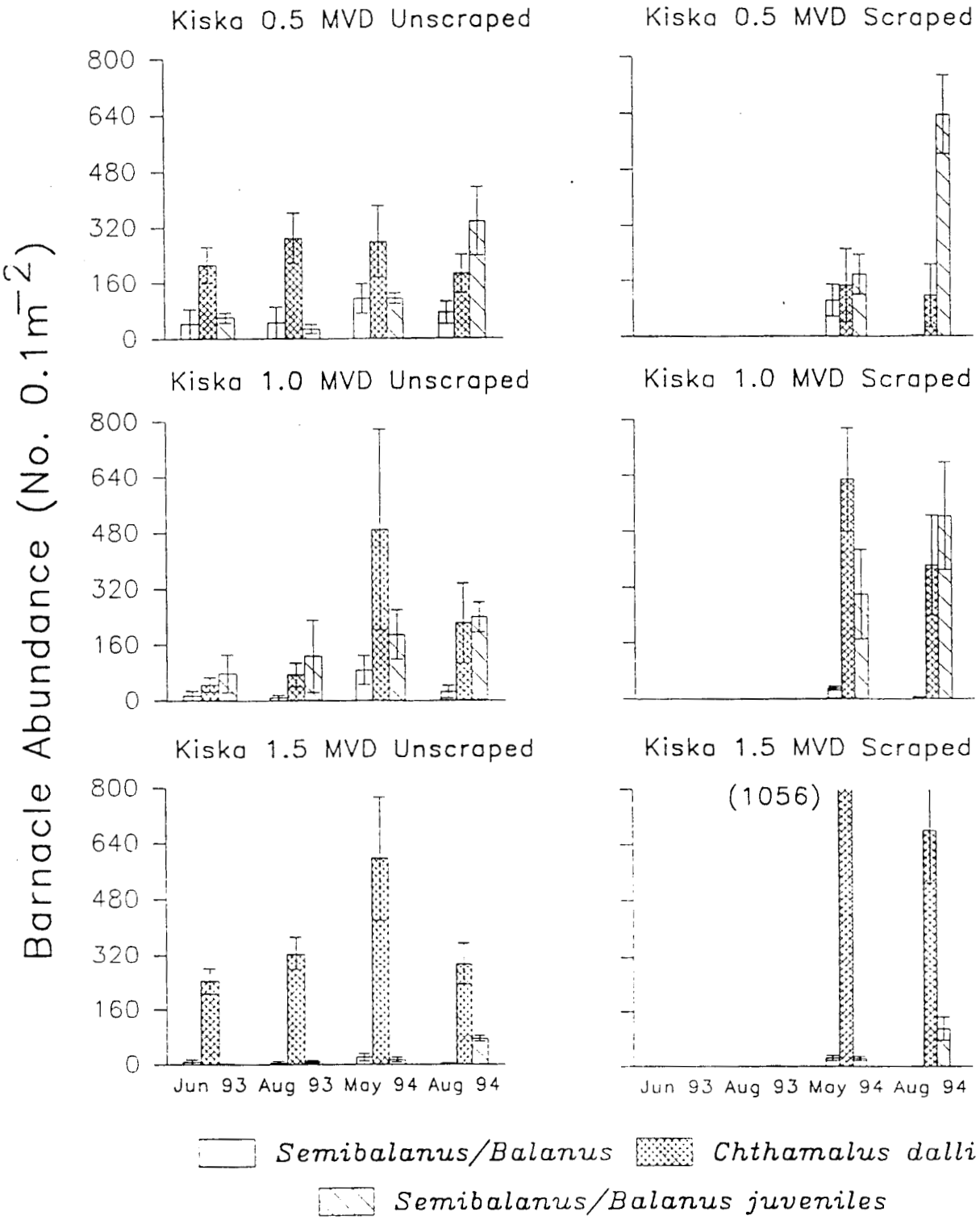

Figure 4.10. Barnacle abundances on 10 x 10 cm scraped and unscraped plots at Kiska in 1993 and 1994. MVD refers to the meter of vertical drop below mean high high water. *Semibalanus/Balanus* refers to adult *S. balanoides* and *B. glandula* combined, *Chthamalus dalli* refers to adult *C. dalli*, and juveniles refers to combined *S. balanoides* and *B. glandula* spat.

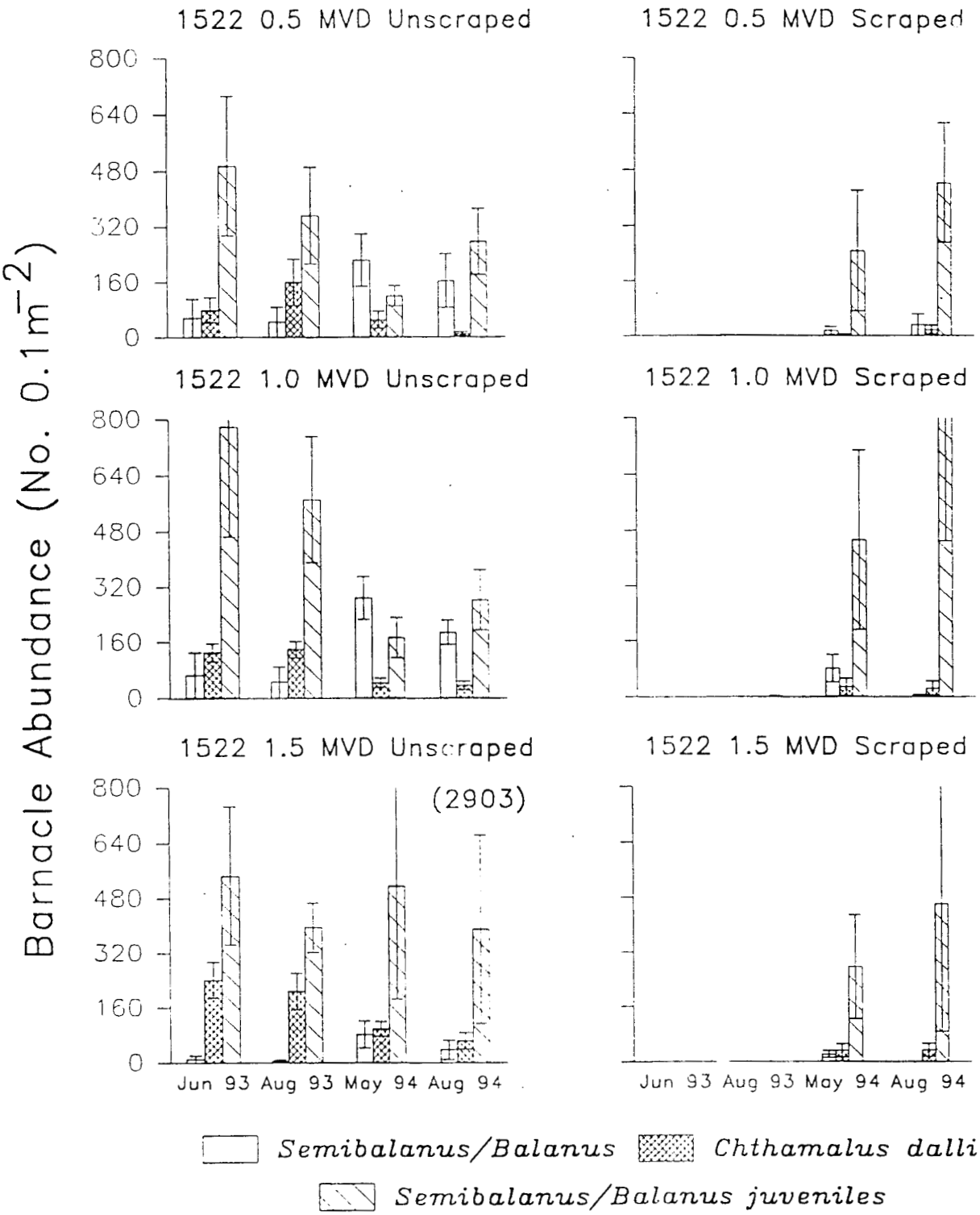

Figure 4.11. Barnacle abundances on 10 x 10 cm scraped and unscraped plots at Site 1522 in 1993 and 1994. MVD refers to the meter of vertical drop below mean high high water. *Semibalanus/Balanus* refers to adult *S. balanoides* and *B. glandula* combined, *Chthamalus dalli* refers to adult *C. dalli*, and juveniles refers to combined *S. balanoides* and *B. glandula* spat.

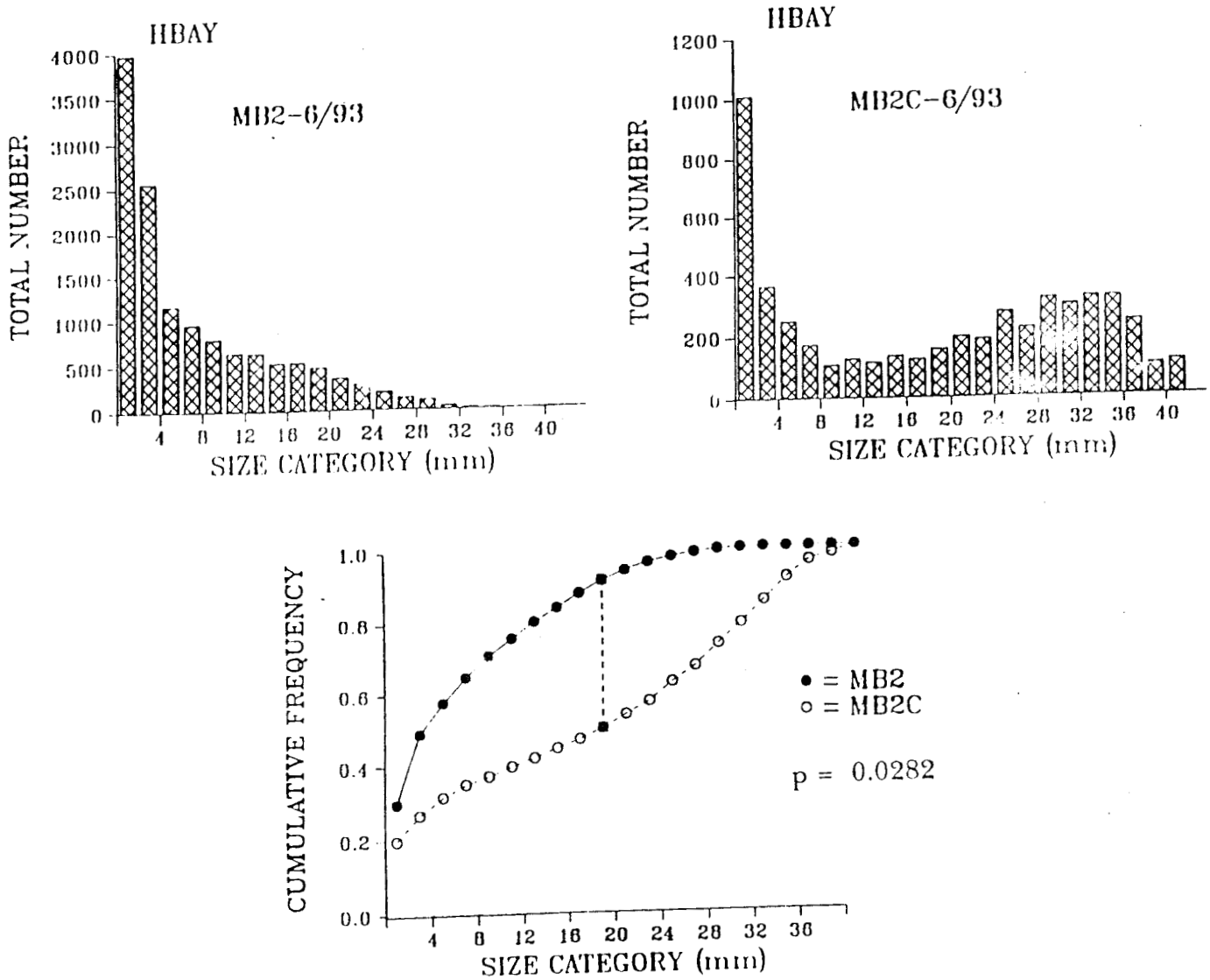

Figure 4.12. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB2/MB2C in June 1993. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves

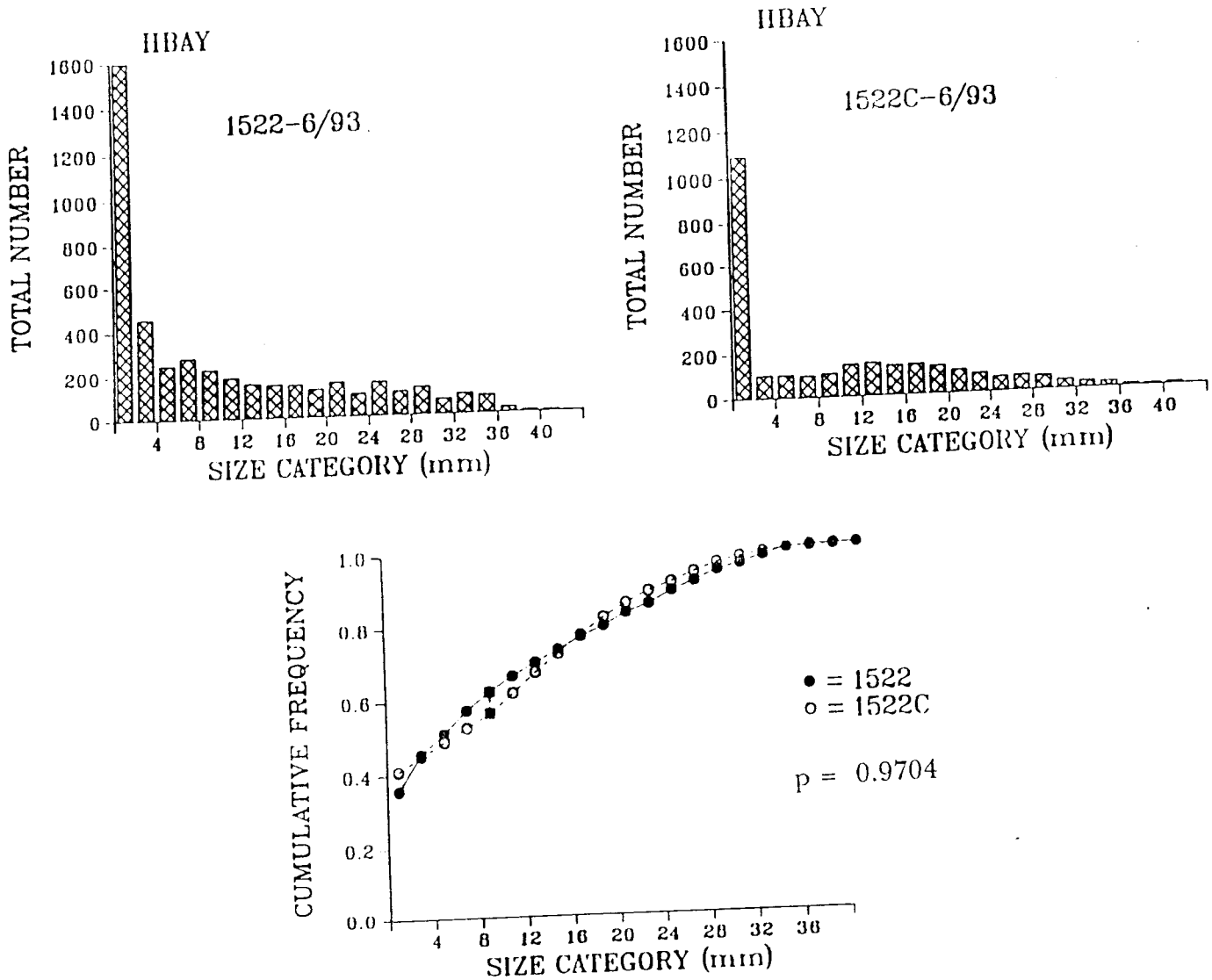

Figure 4.13. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair 1522/1522C in June 1993. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

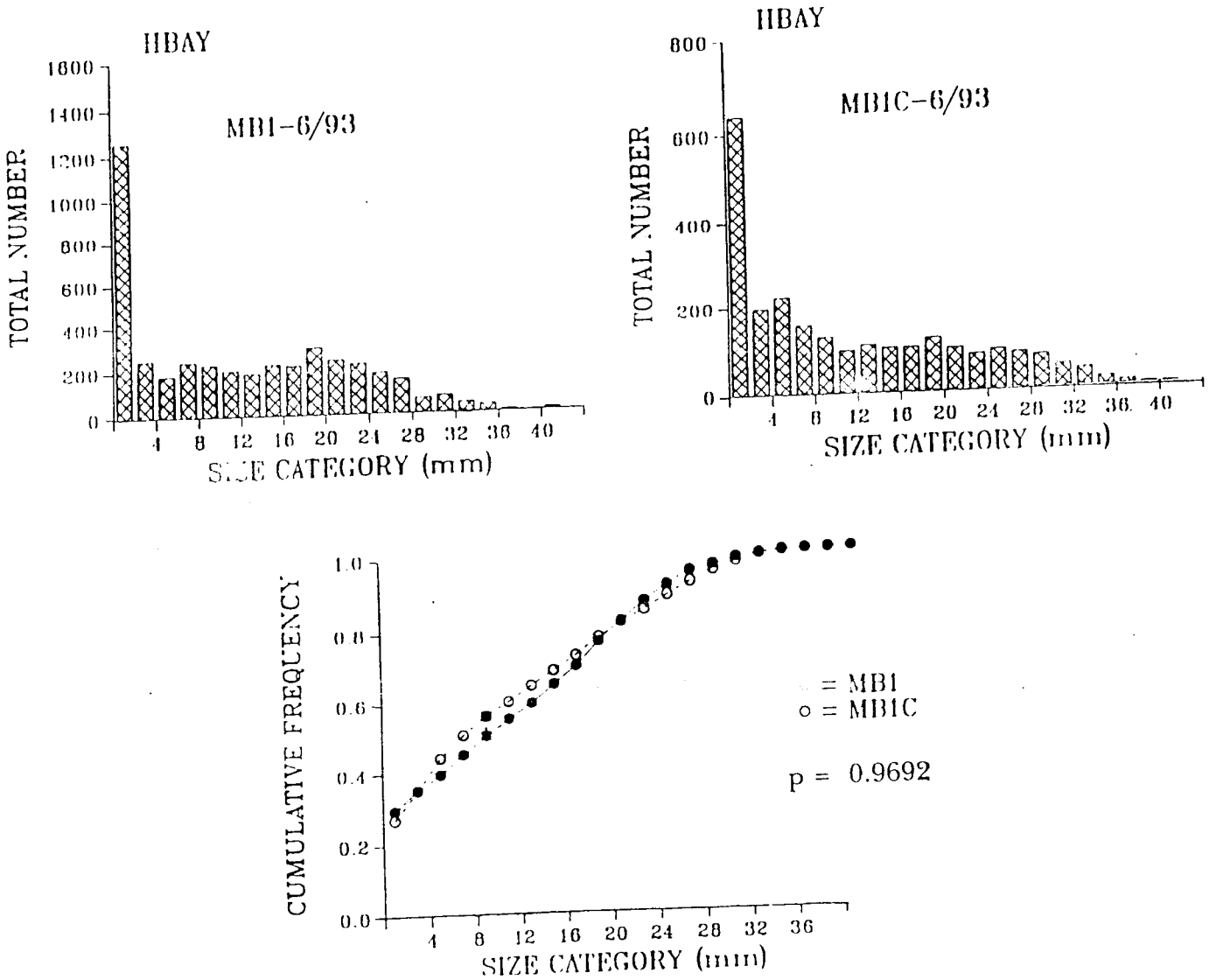

Figure 4.14. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB1/MB1C in June 1993. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

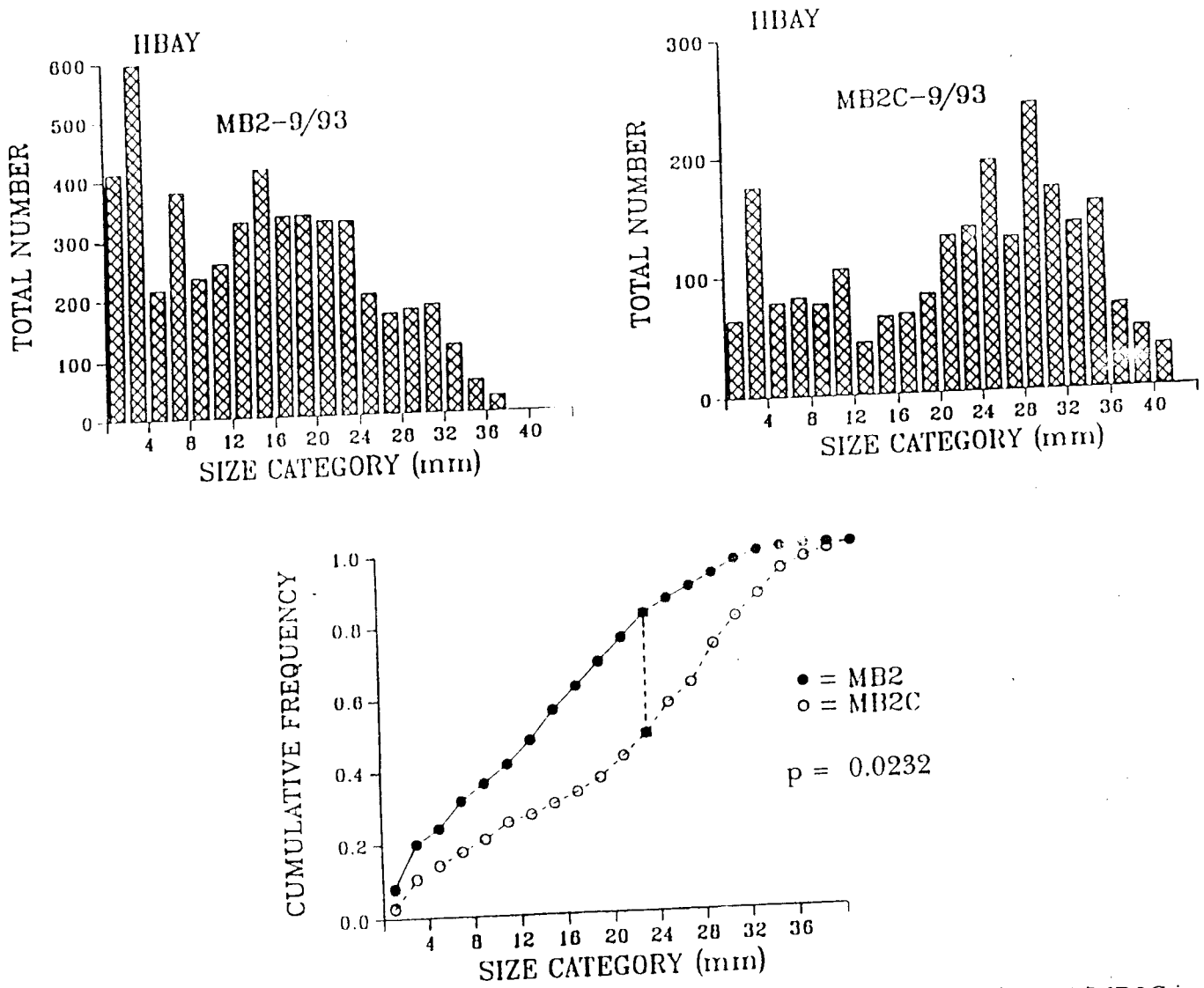

Figure 4.15. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB2/MB2C in September 1993. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

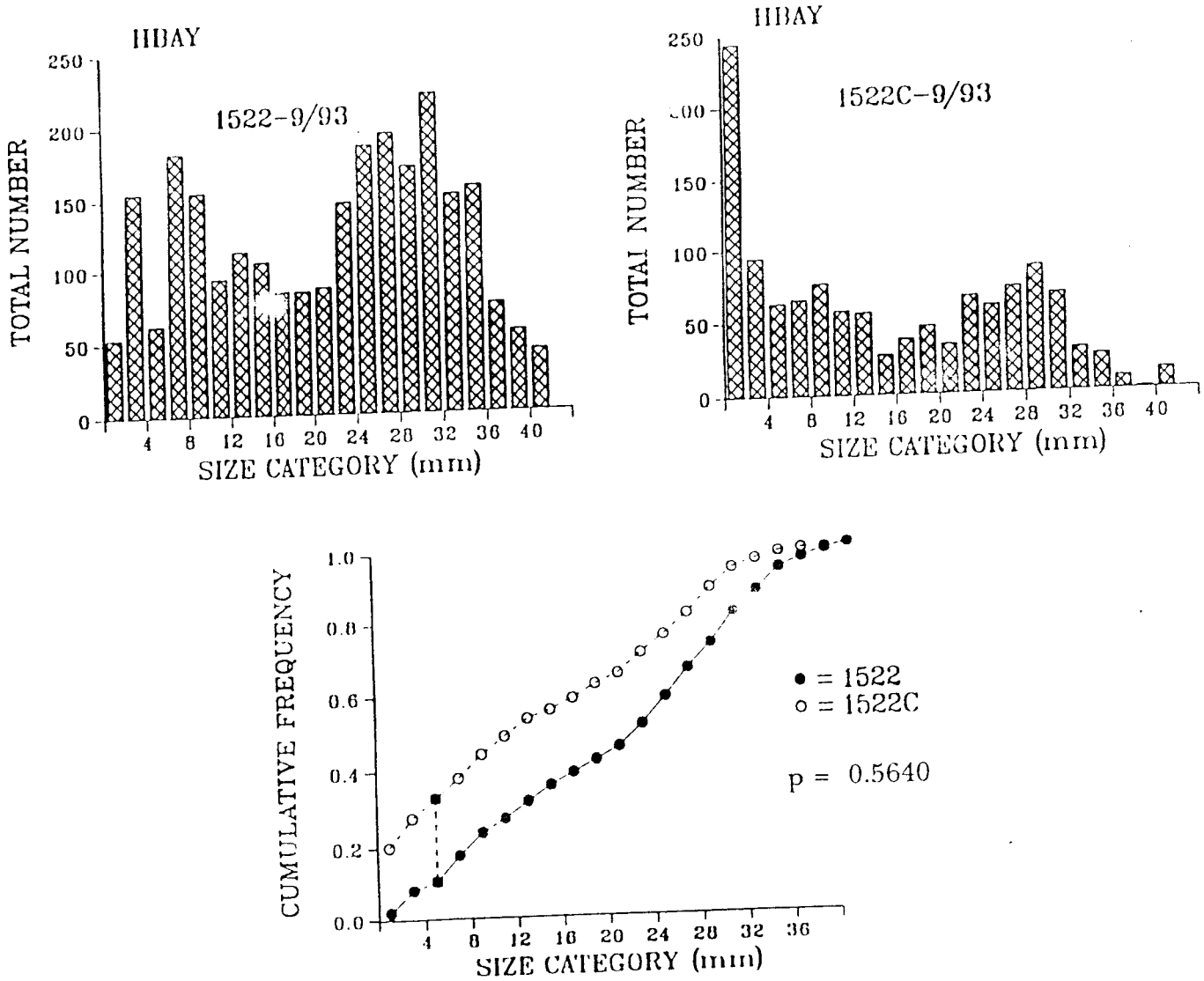

Figure 4.16. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair 1522/1522C in September 1993. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

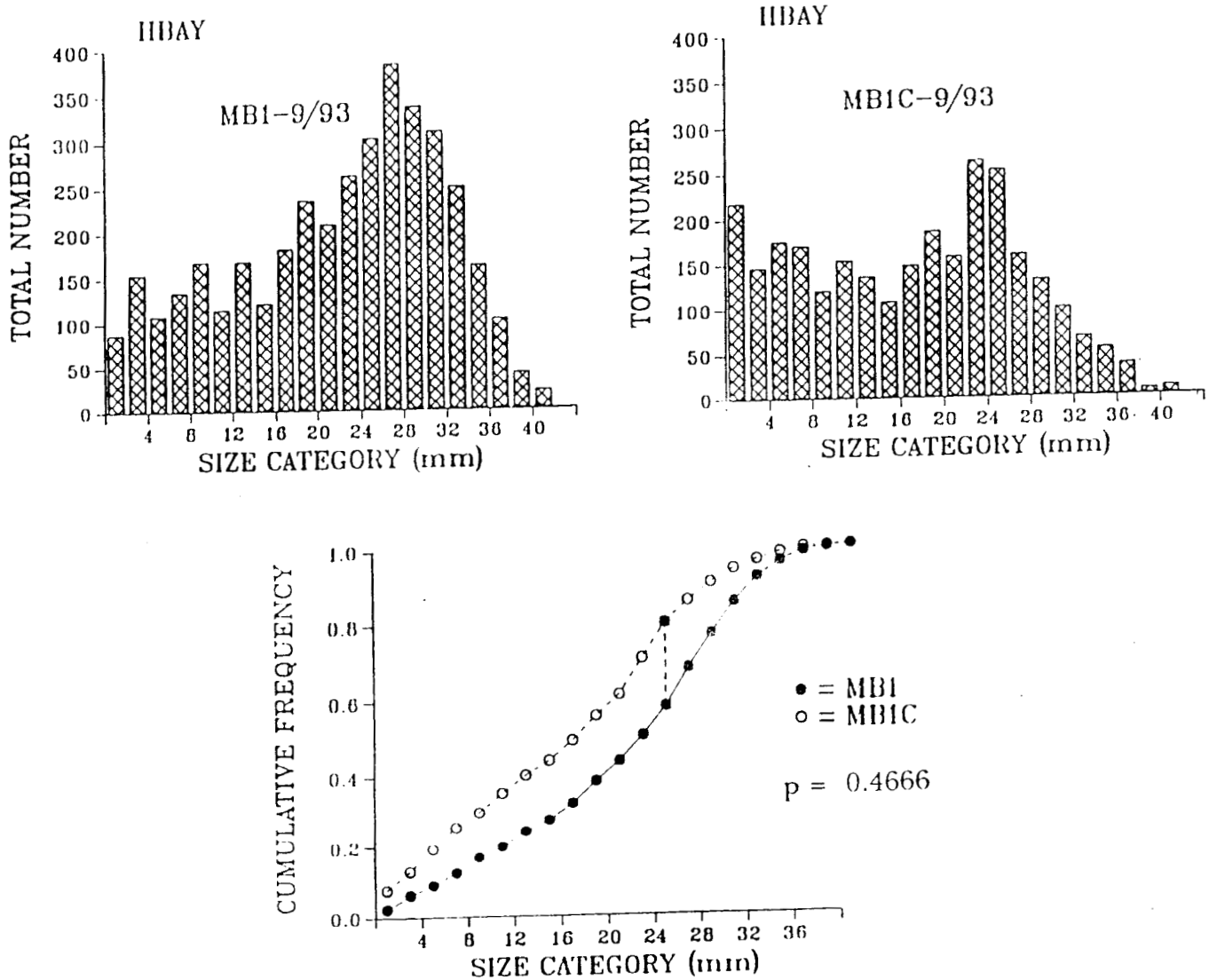

Figure 4.17. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair.MB1/MB1C in September 1993. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

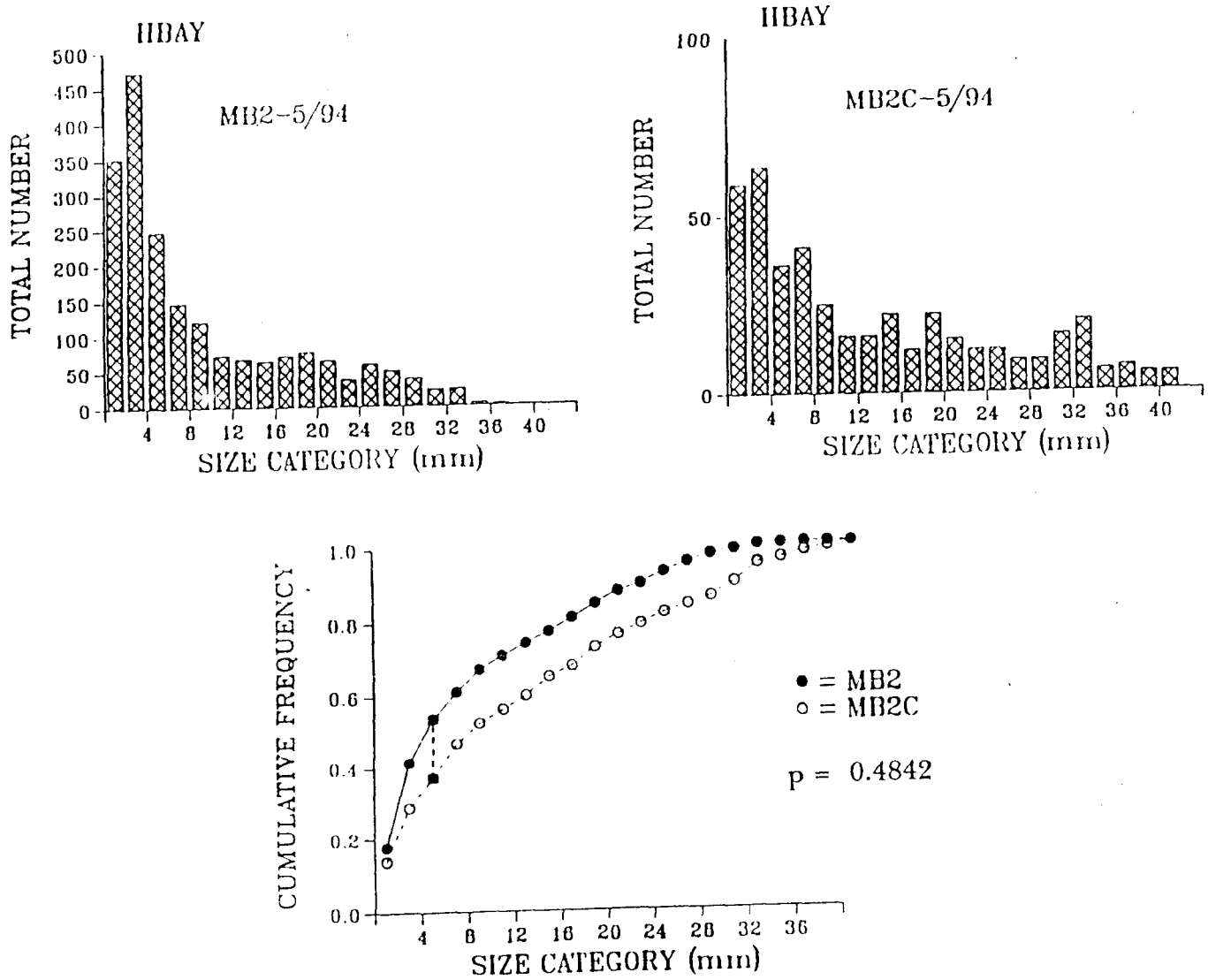

Figure 4.18. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB2/MB2C in May 1994. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

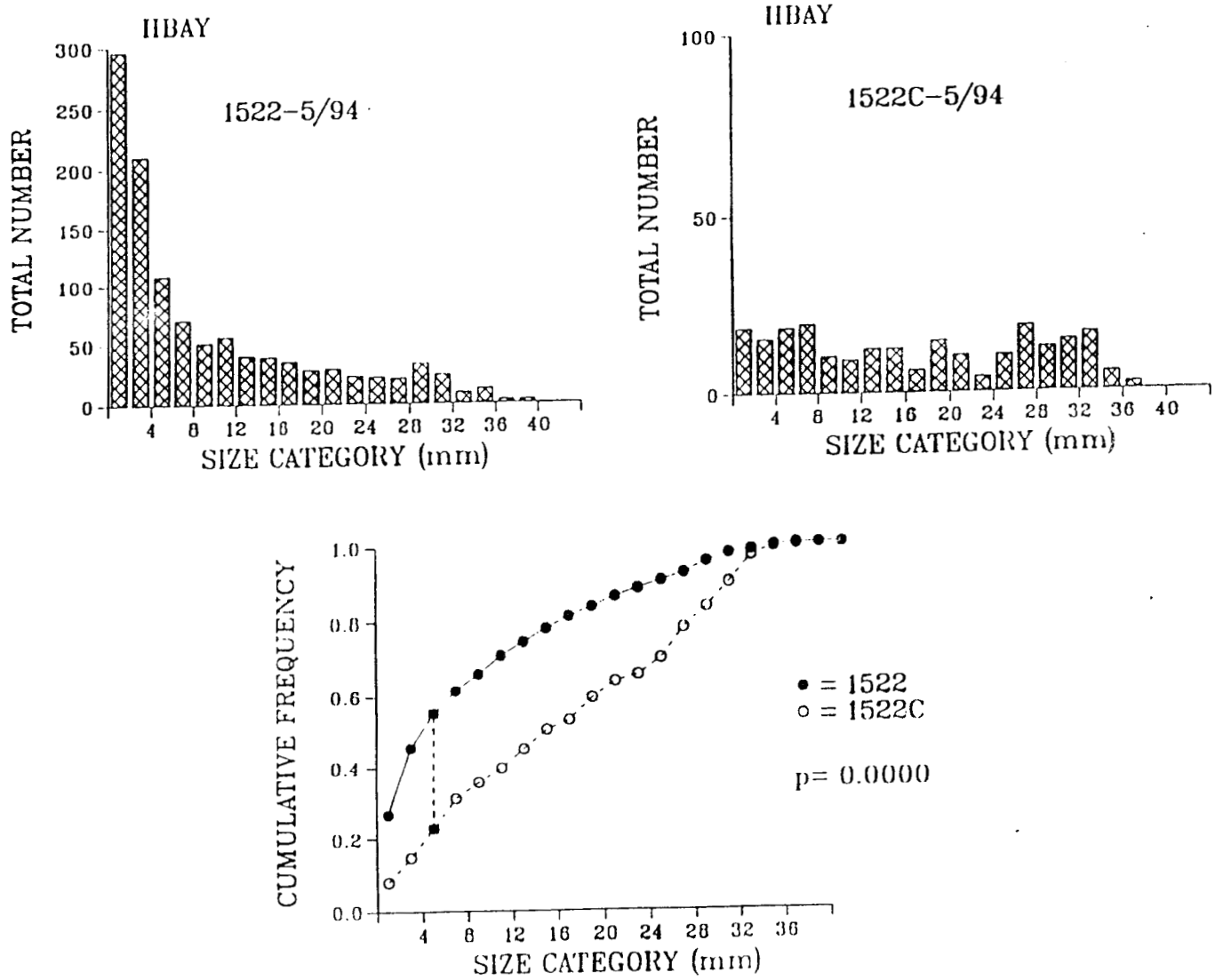

Figure 4.19. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair 1522/1522C in May 1994. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

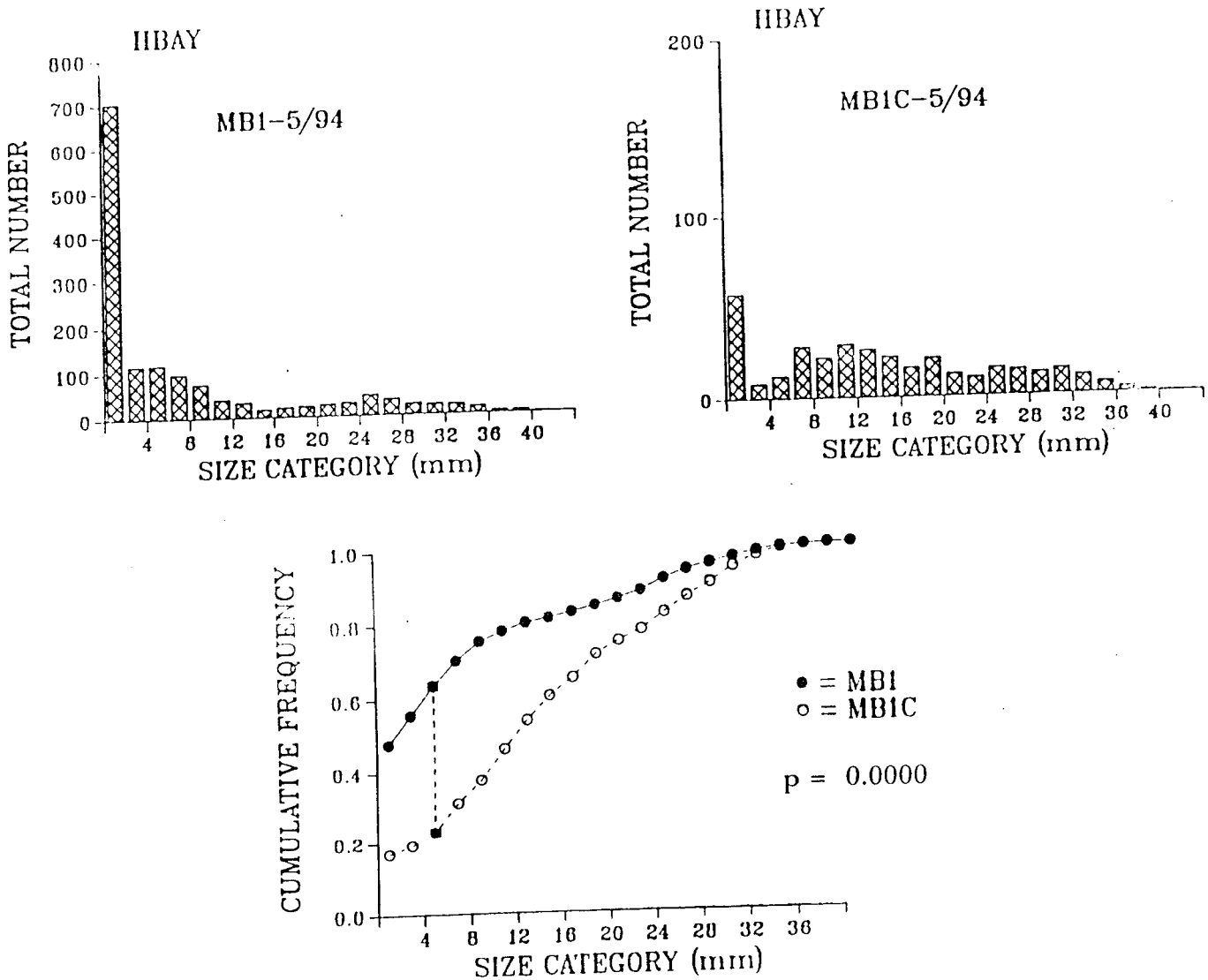

Figure 4.20. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB1/MB1C in May 1994. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

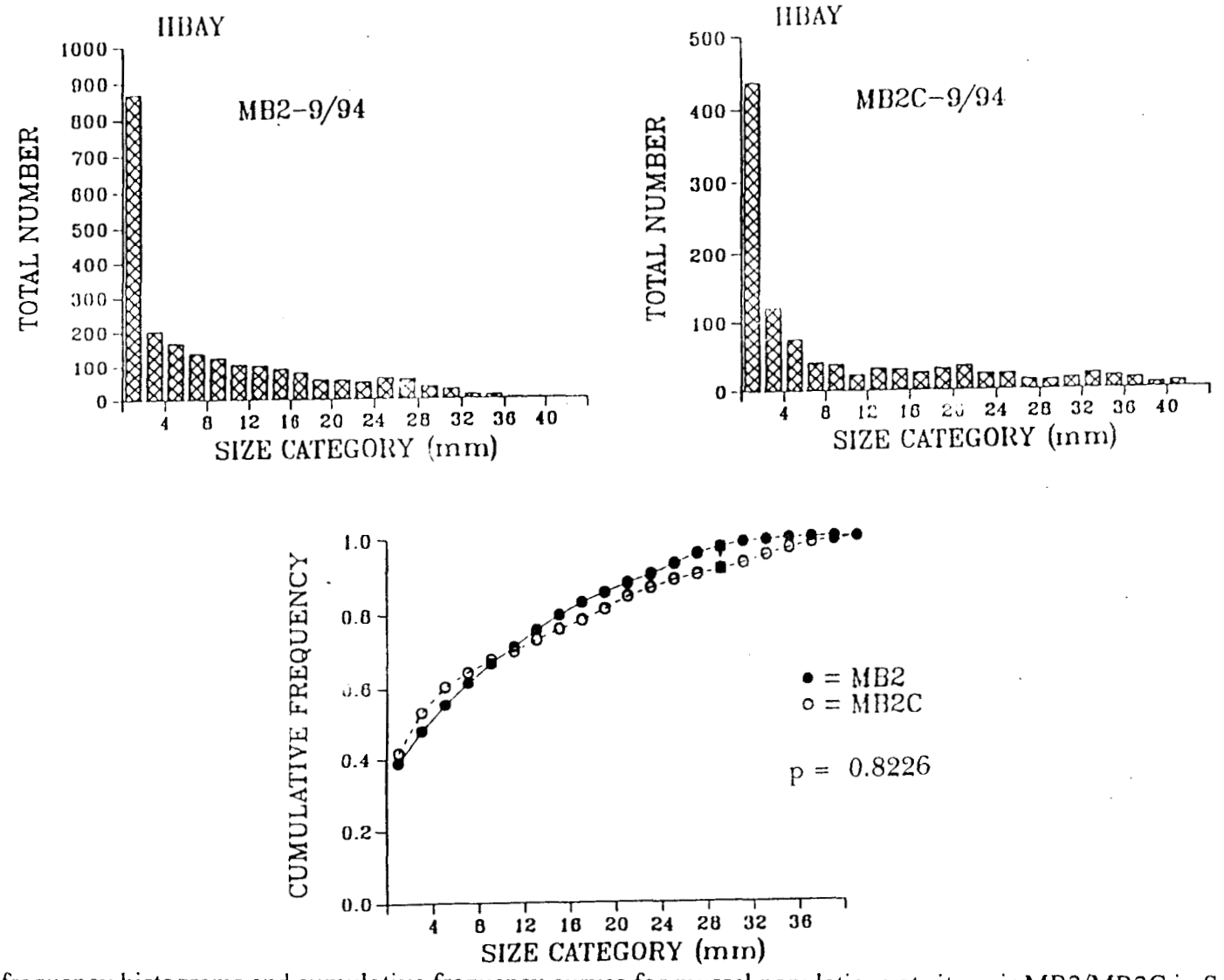

Figure 4.21. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB2/MB2C in September 1994. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

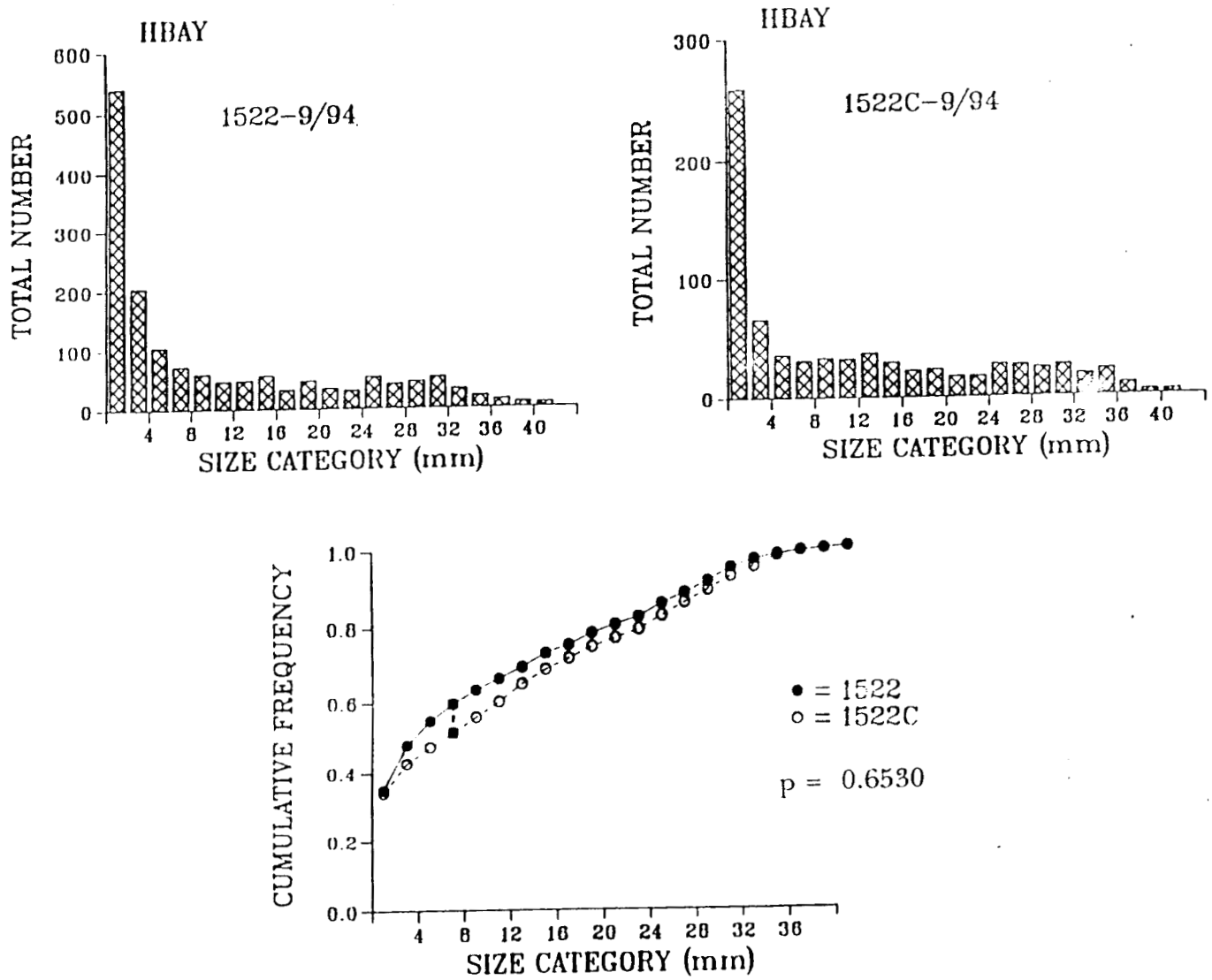

Figure 4.22. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair 1522/1522C in September 1994. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

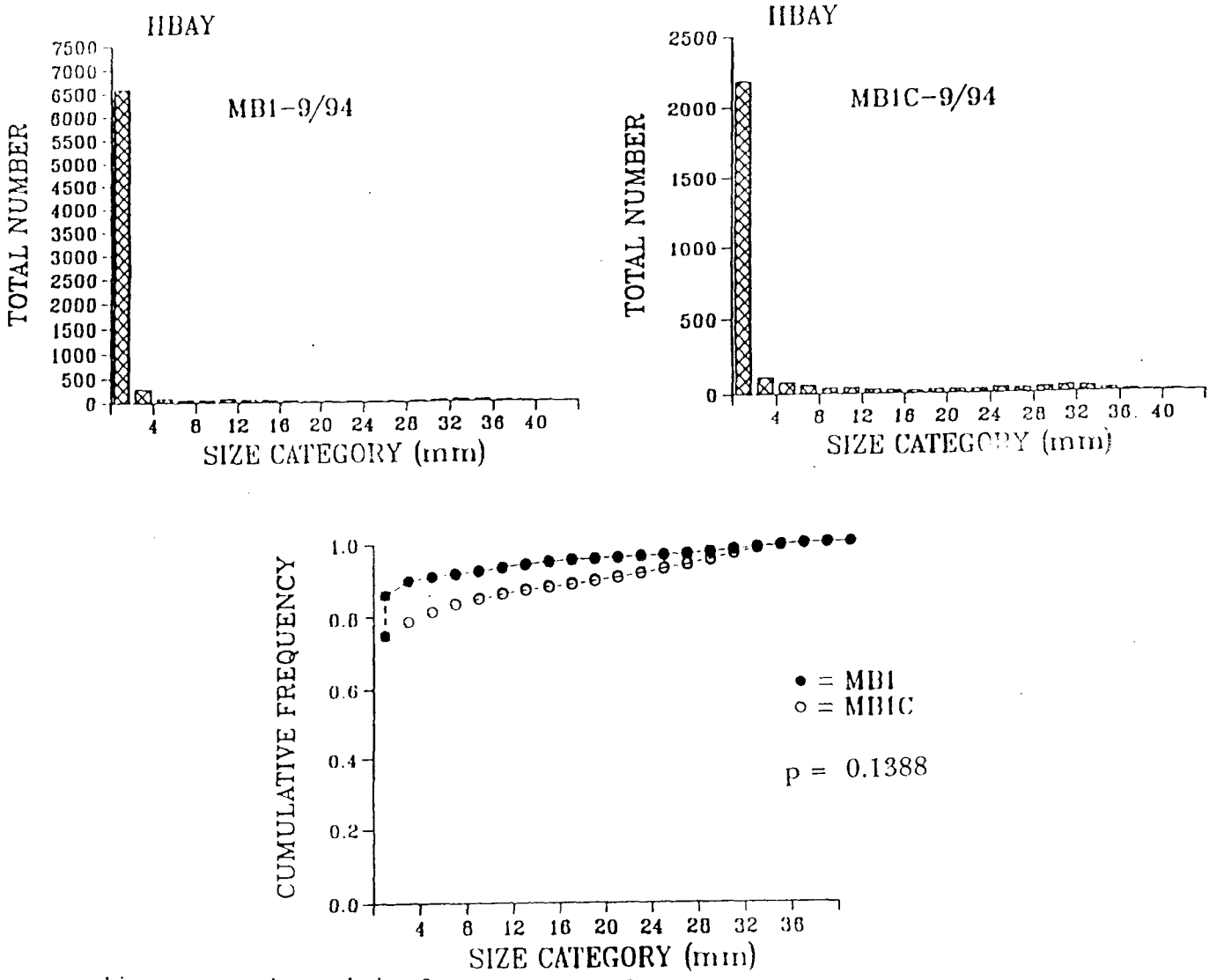

Figure 4.23. Size-frequency histograms and cumulative frequency curves for mussel populations at site pair MB1/MB1C in September 1994. The cumulative frequency curves illustrate the contribution of each successive size class to the population. The p-value was calculated using randomization procedures to compare the maximum difference between the oiled and control site curves. The vertical line connecting the two cumulative frequency curves is located at the point of maximum difference between the two curves.

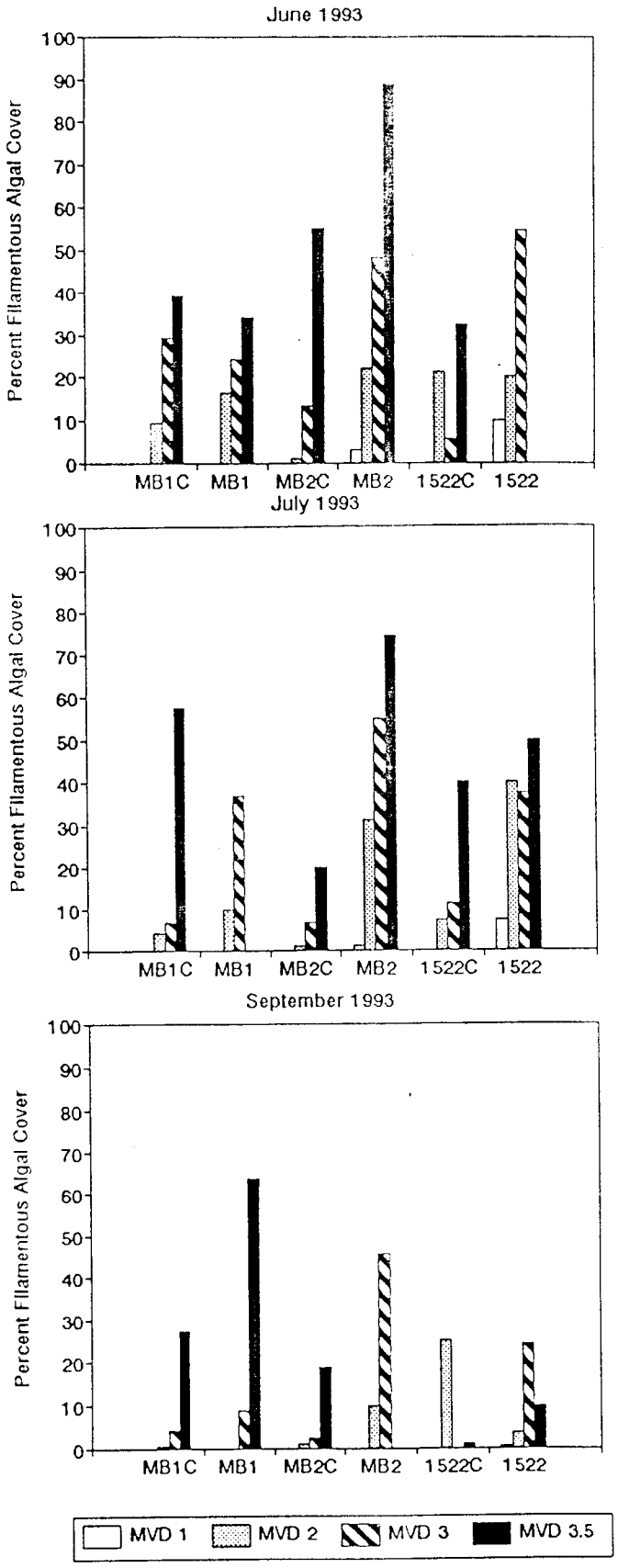

Figure 4.24. Percent filamentous algal cover on oiled and control mussel study sites during three visits in 1993. MVD=meter vertical drop. Data are from Tables 4.19-4.21.

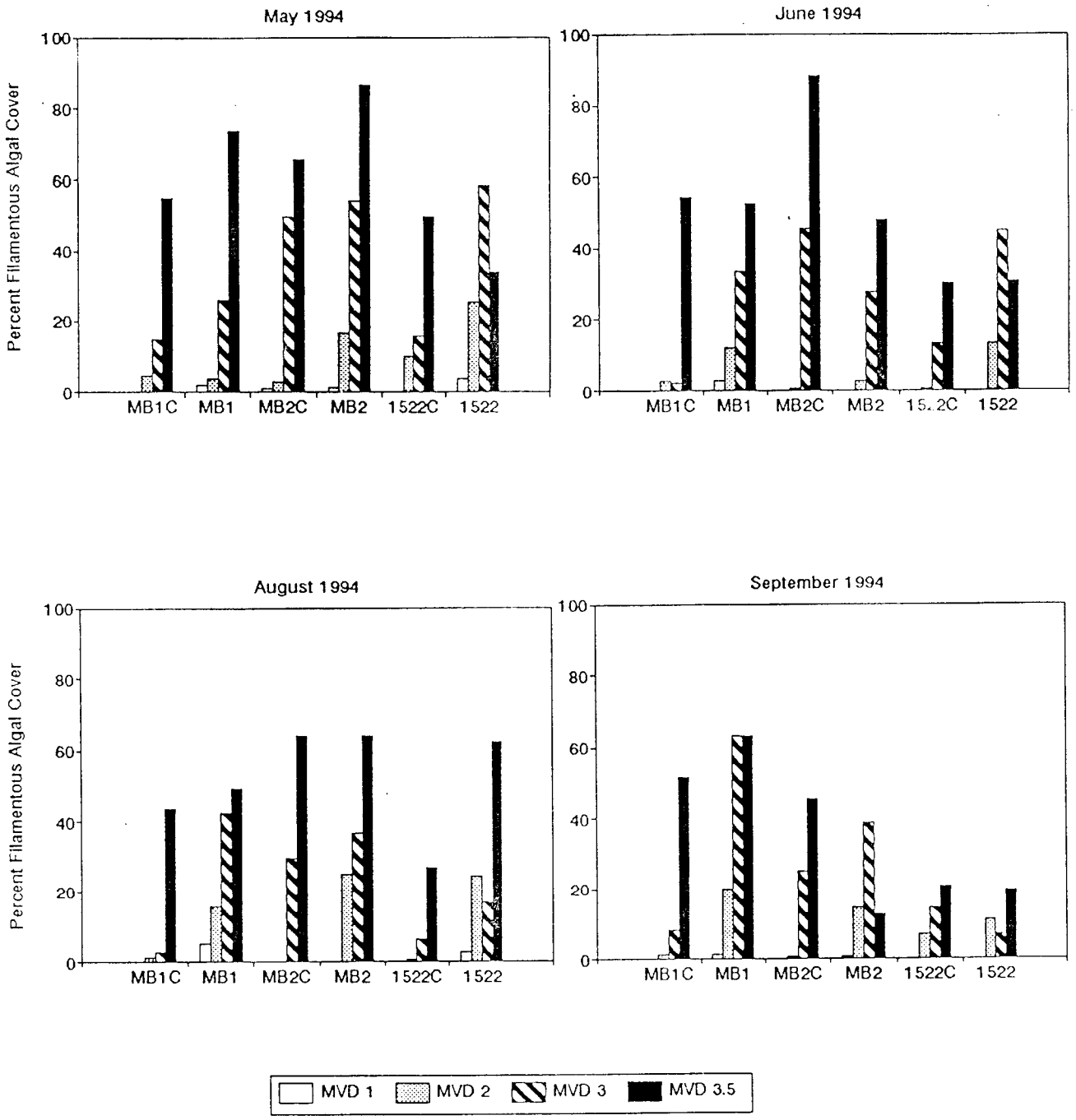

Figure 4.25. Percent filamentous algal cover on oiled and control mussel study sites during four visits in 1994. MVD=meter vertical drop. Data are from Tables 4.22-4.25.

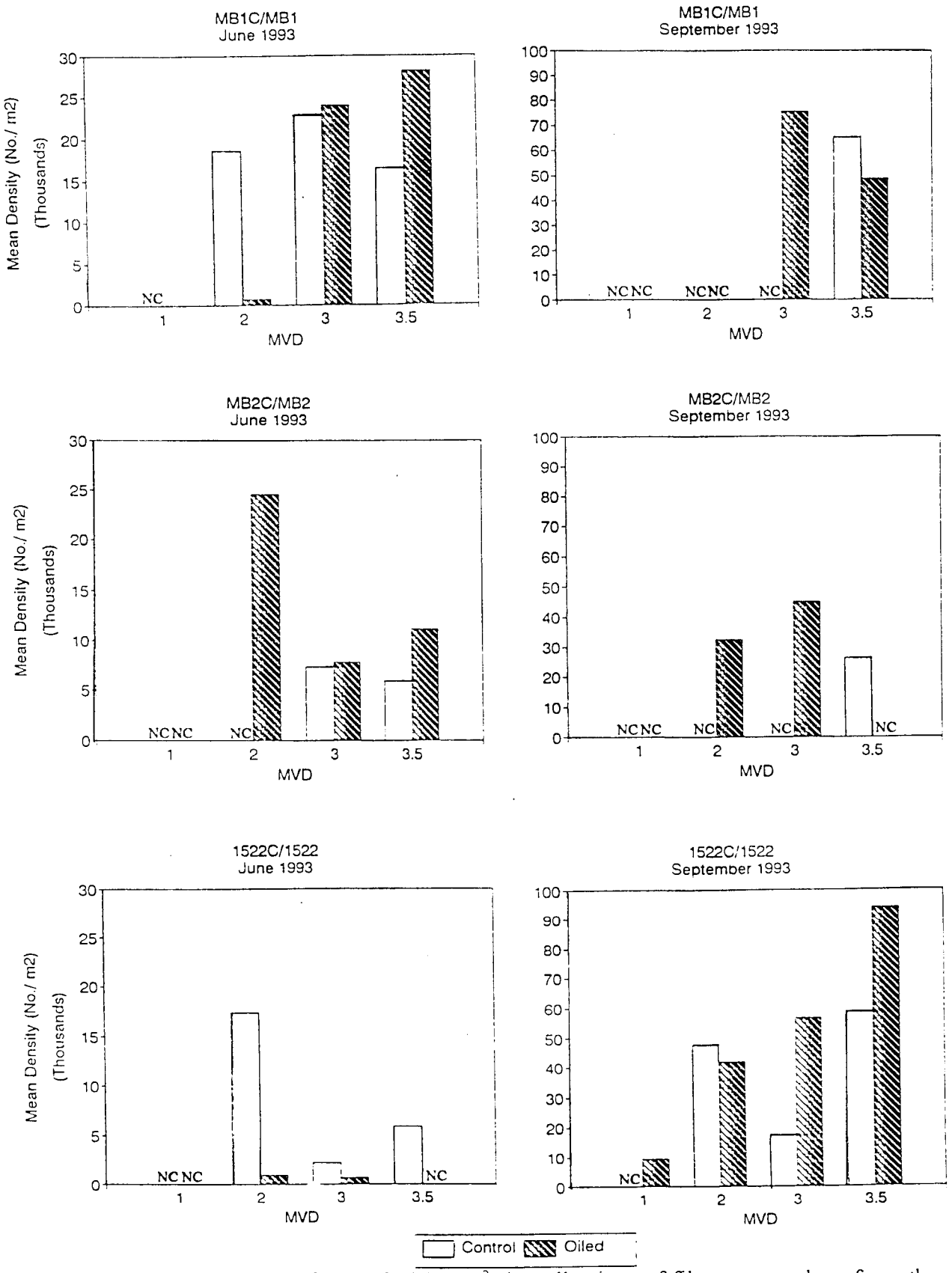

Figure 4.26. Mean densities of mussels (No. m^{-2}) in collections of filamentous algae from three matched pairs of oiled and control sites in 1993. MVD=meter vertical drop; NC=no algae to collect. Data are from Tables 4.26-4.27.

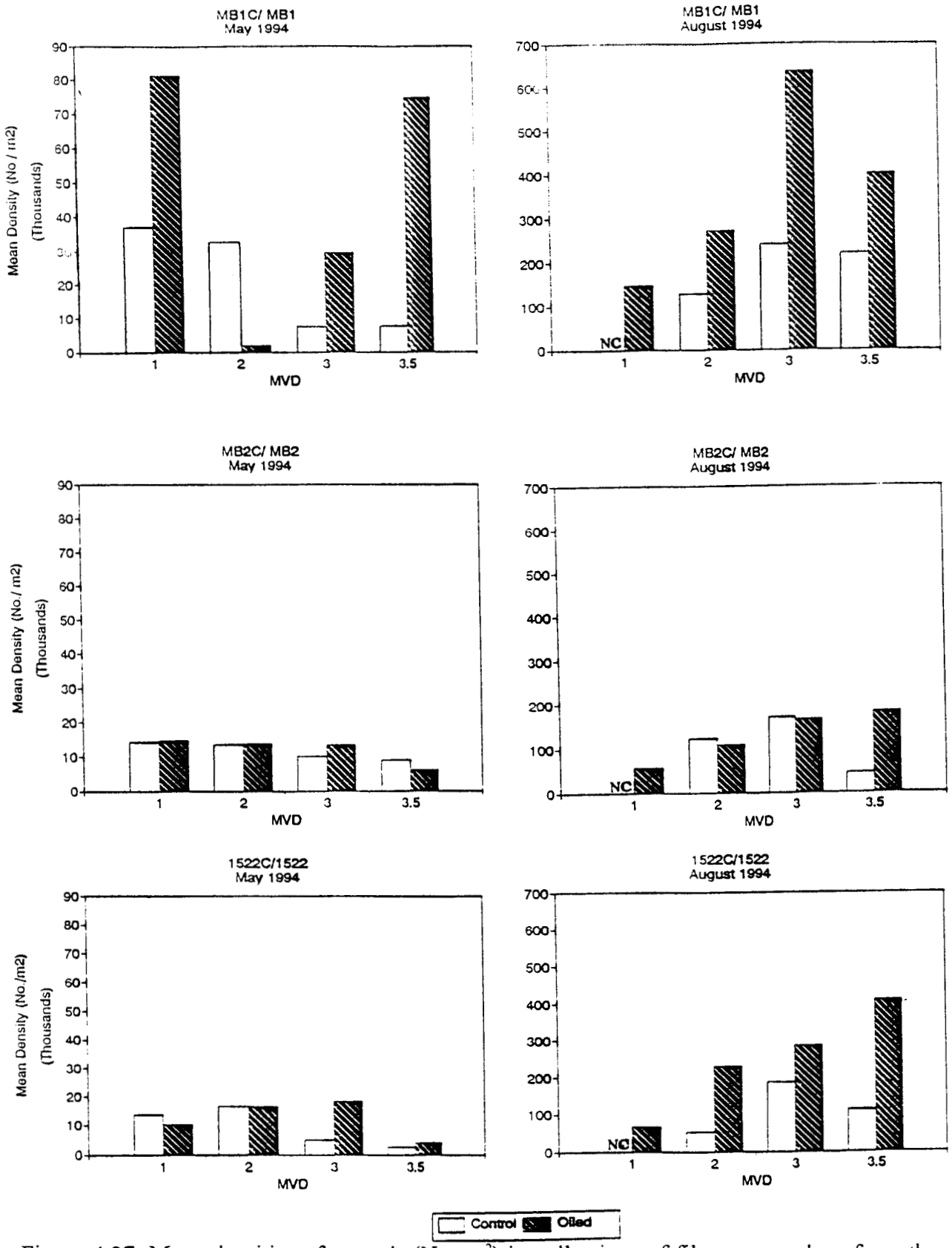

Figure 4.27. Mean densities of mussels (No. m^{-2}) in collections of filamentous algae from three matched pairs of oiled and control sites in 1994. MVD=meter vertical drop; NC=no algae to collect. Data are from Tables 4.28-4.29.

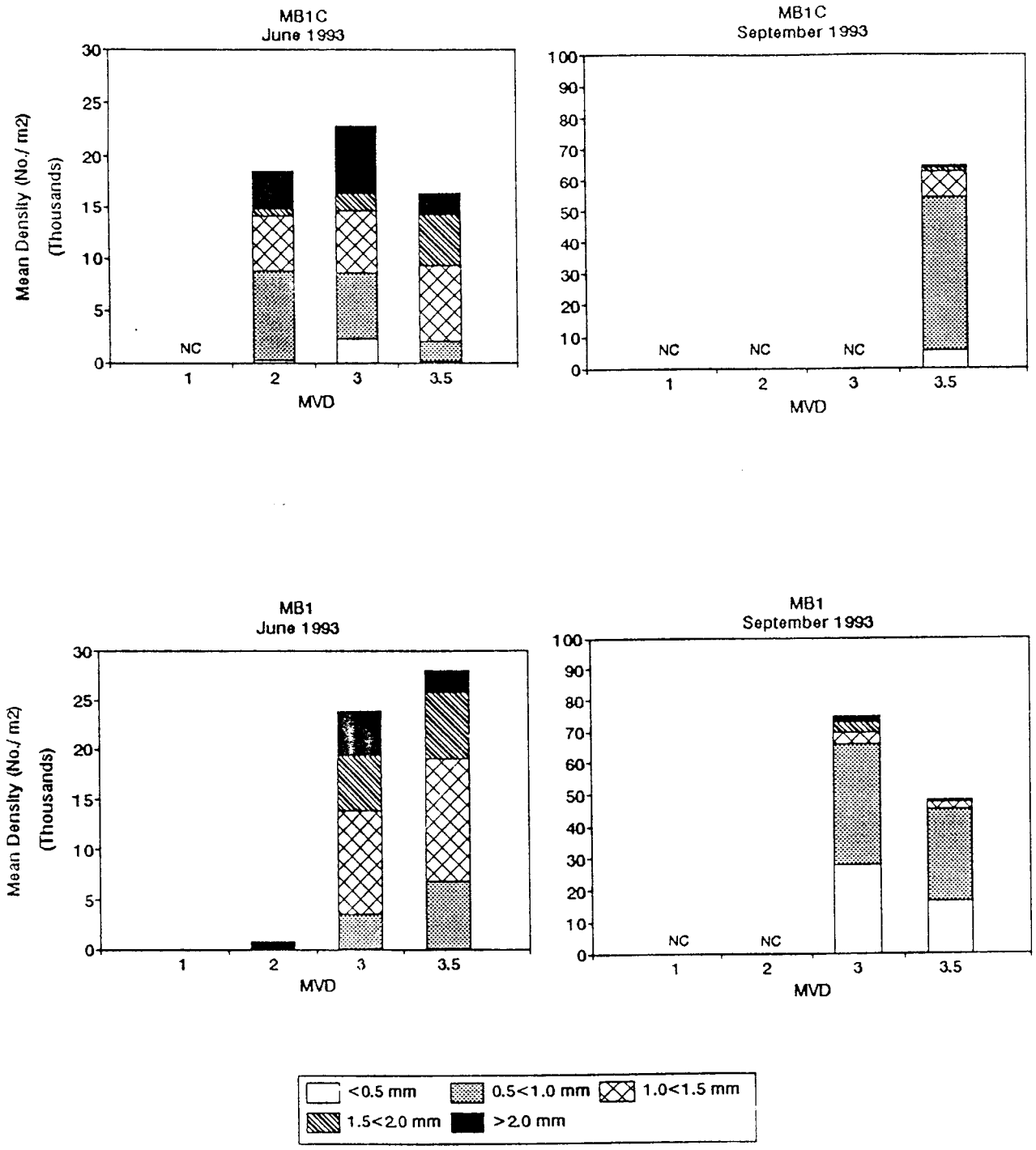

Figure 4.28. Number of mussels (1000 m^{-2}) of different size classes in filamentous algae collections from matched pair MB1/MB1C in 1993. MVD=meter vertical drop; NC=no algae to collect.

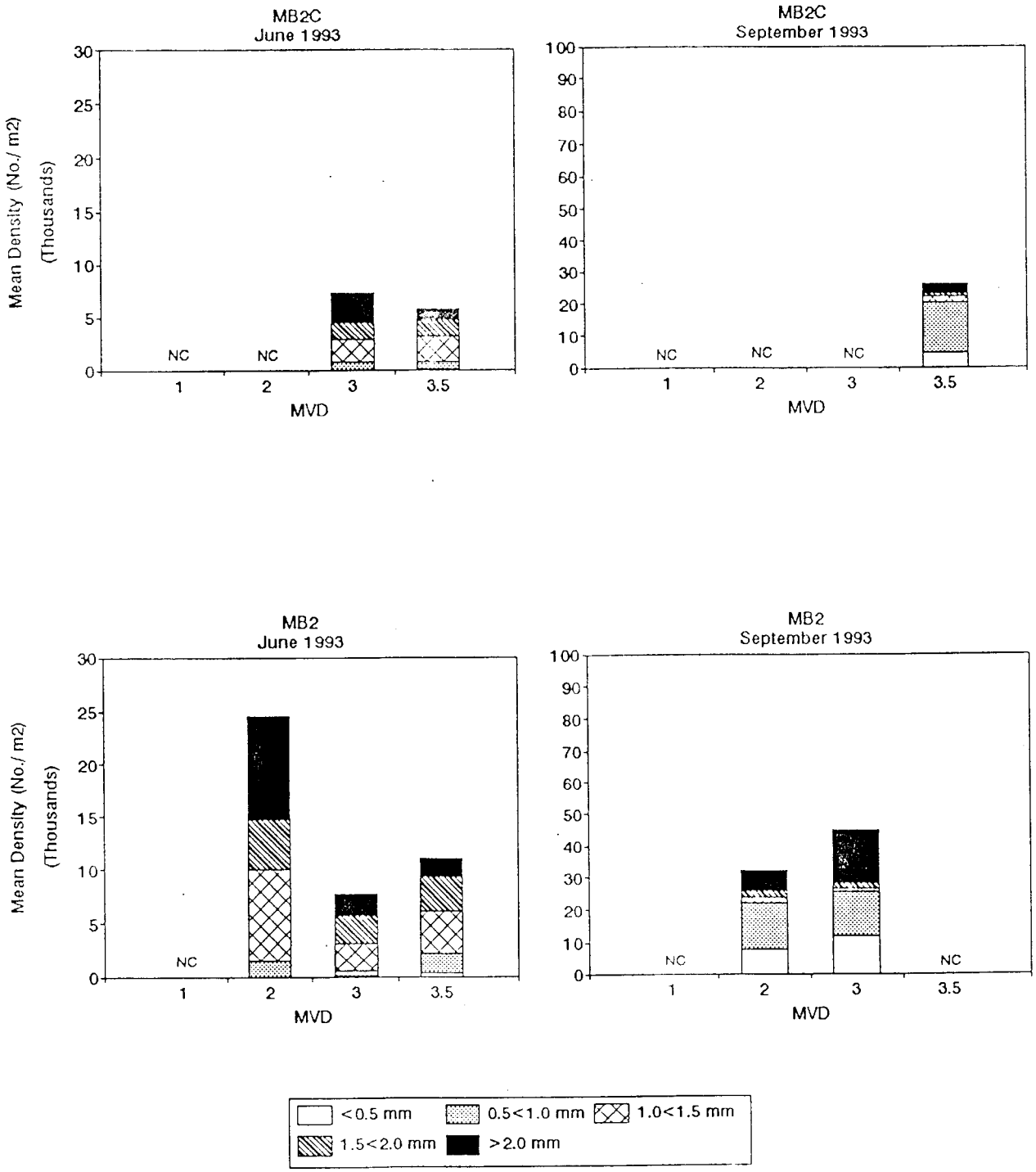

Figure 4.29. Number of mussels (1000 m^{-2}) of different size classes in filamentous algae collections from matched pair MB2/MB2C in 1993. MVD=meter vertical drop; NC=no algae to collect.

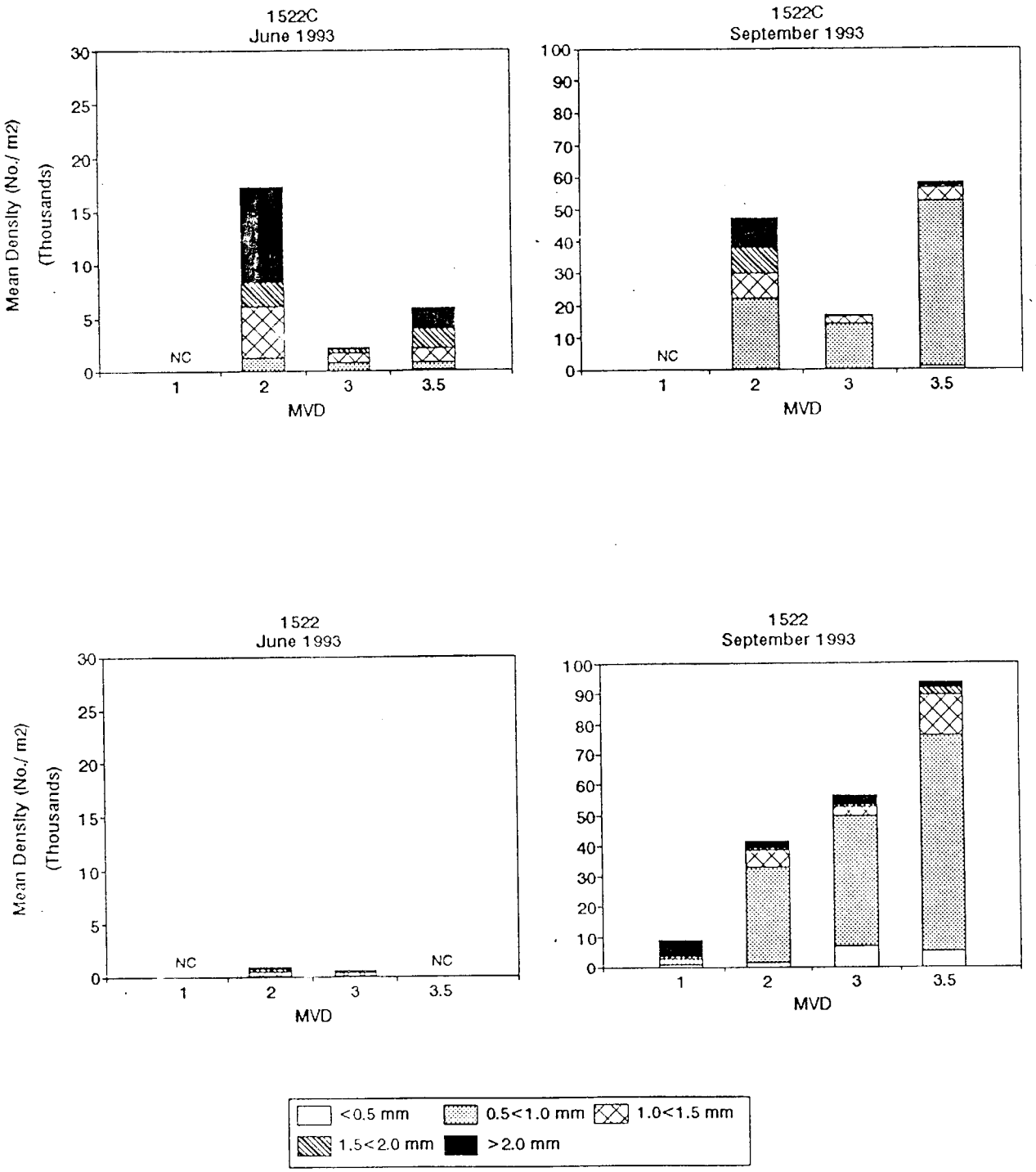

Figure 4.30. Number of mussels (1000 m^{-2}) of different size classes in filamentous algae collections from matched pair 1522/1522C in 1993. MVD=meter vertical drop; NC=no algae to collect.

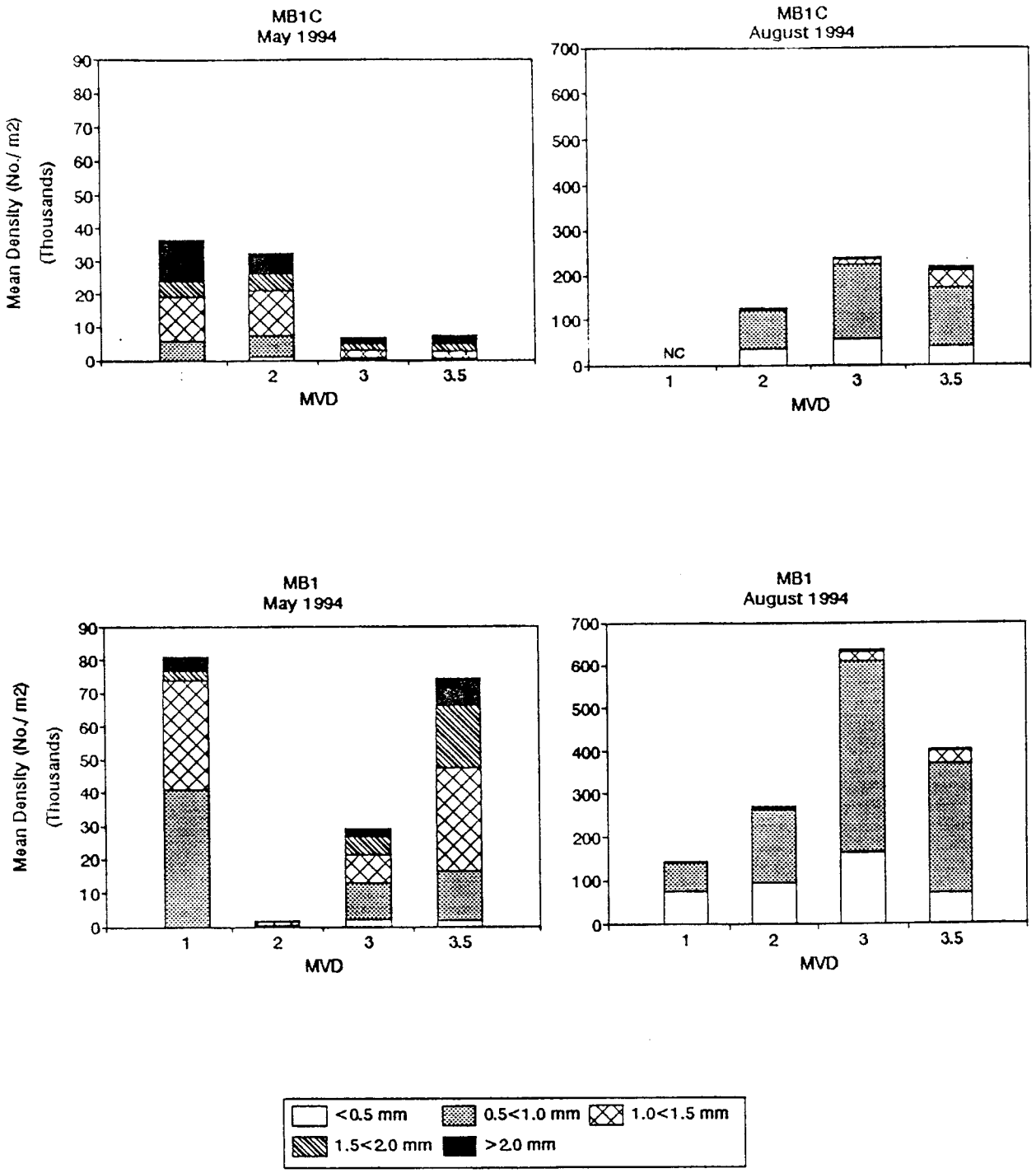

Figure 4.31. Number of mussels (1000 m^{-2}) of different size classes in filamentous algae collections from matched pair MB1/MB1C in 1994. MVD=meter vertical drop; NC=no algae to collect.

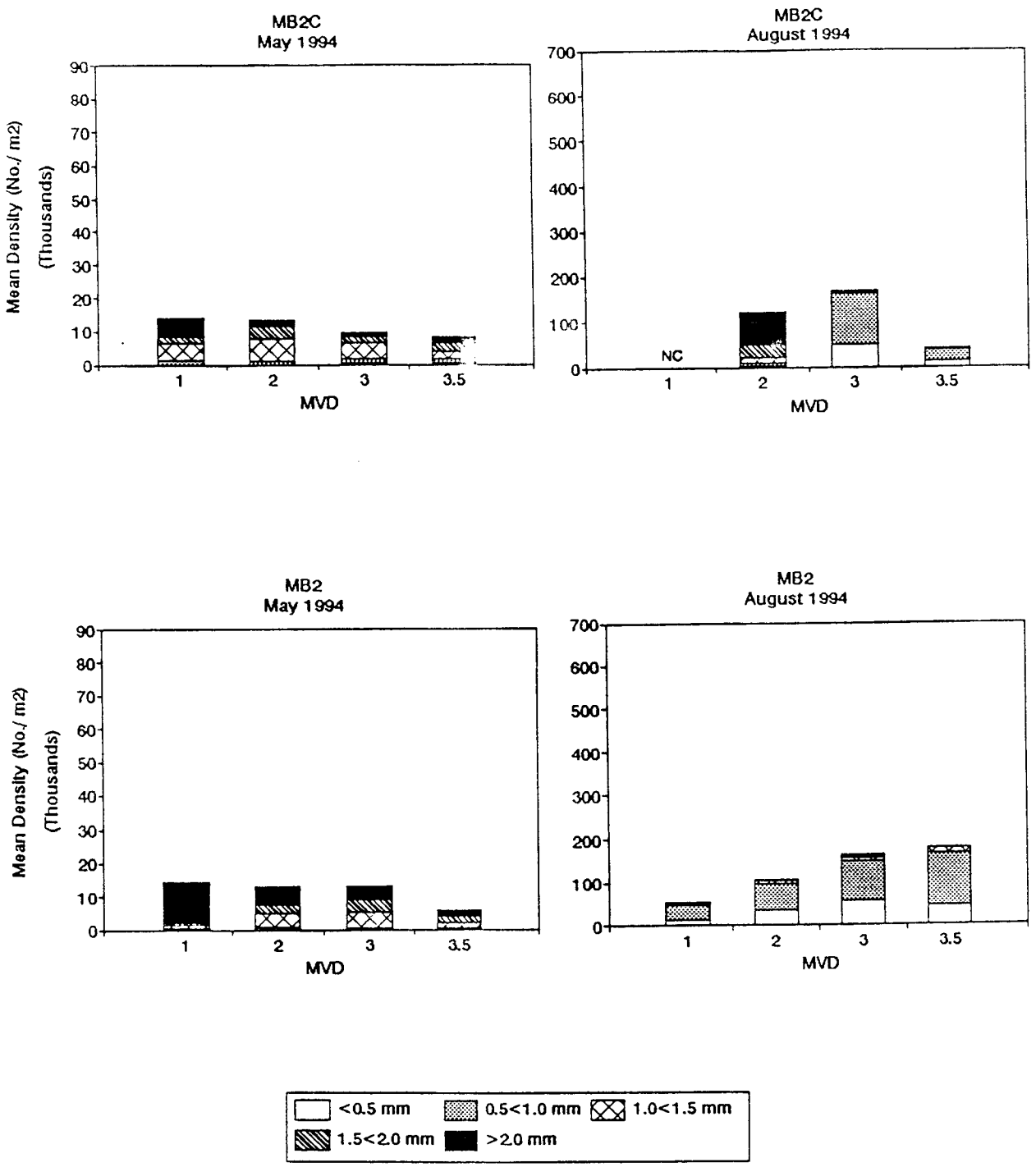

Figure 4.32. Number of mussels (1000 m^{-2}) of different size classes in filamentous algae collections from matched pair MB2/MB2C in 1994. MVD=meter vertical drop; NC=no algae to collect.

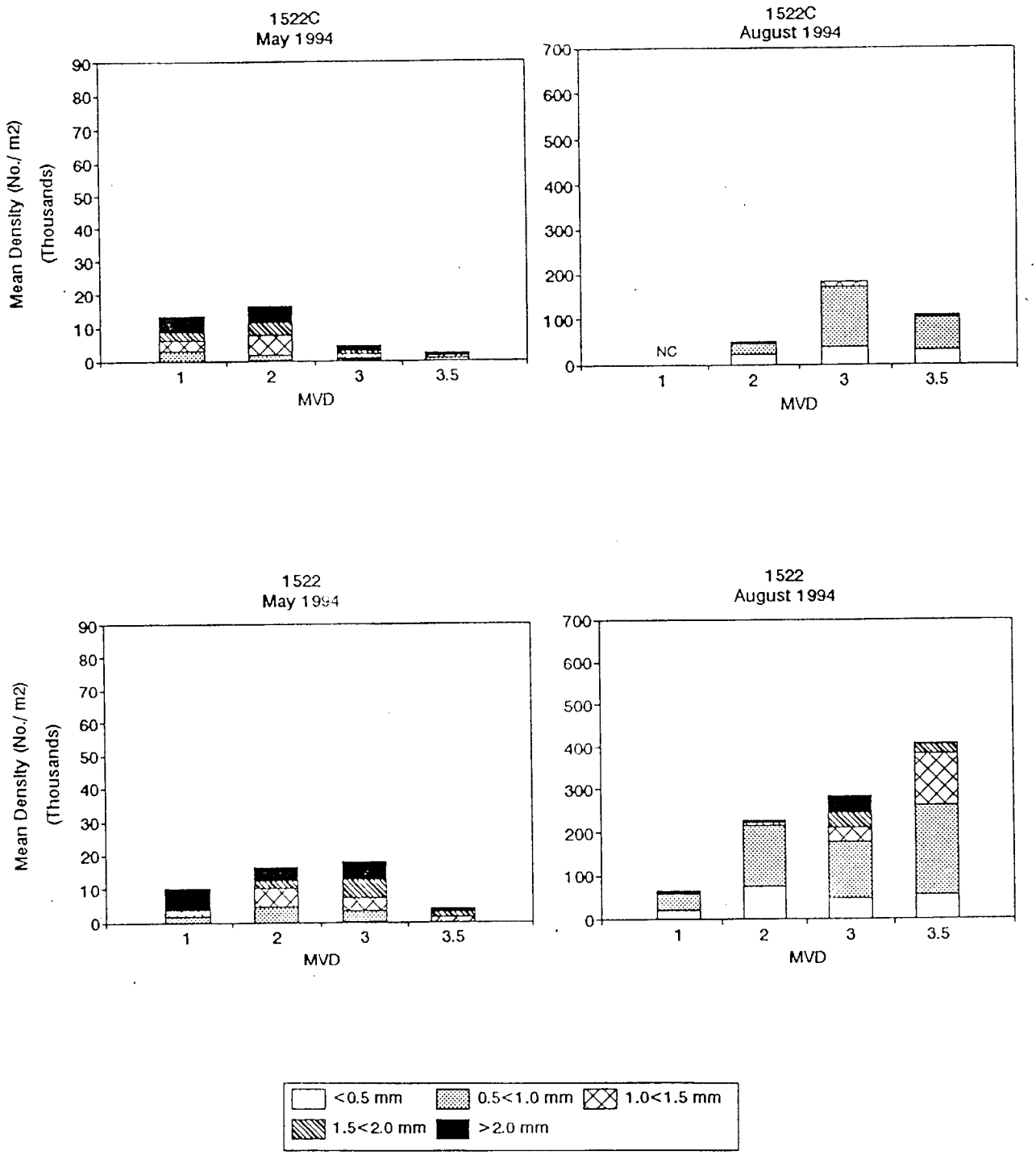

Figure 4.33. Number of mussels (1000 m^{-2}) of different size classes in filamentous algae collections from matched pair 1522/1522C in 1994. MVD=meter vertical drop; NC=no algae to collect.

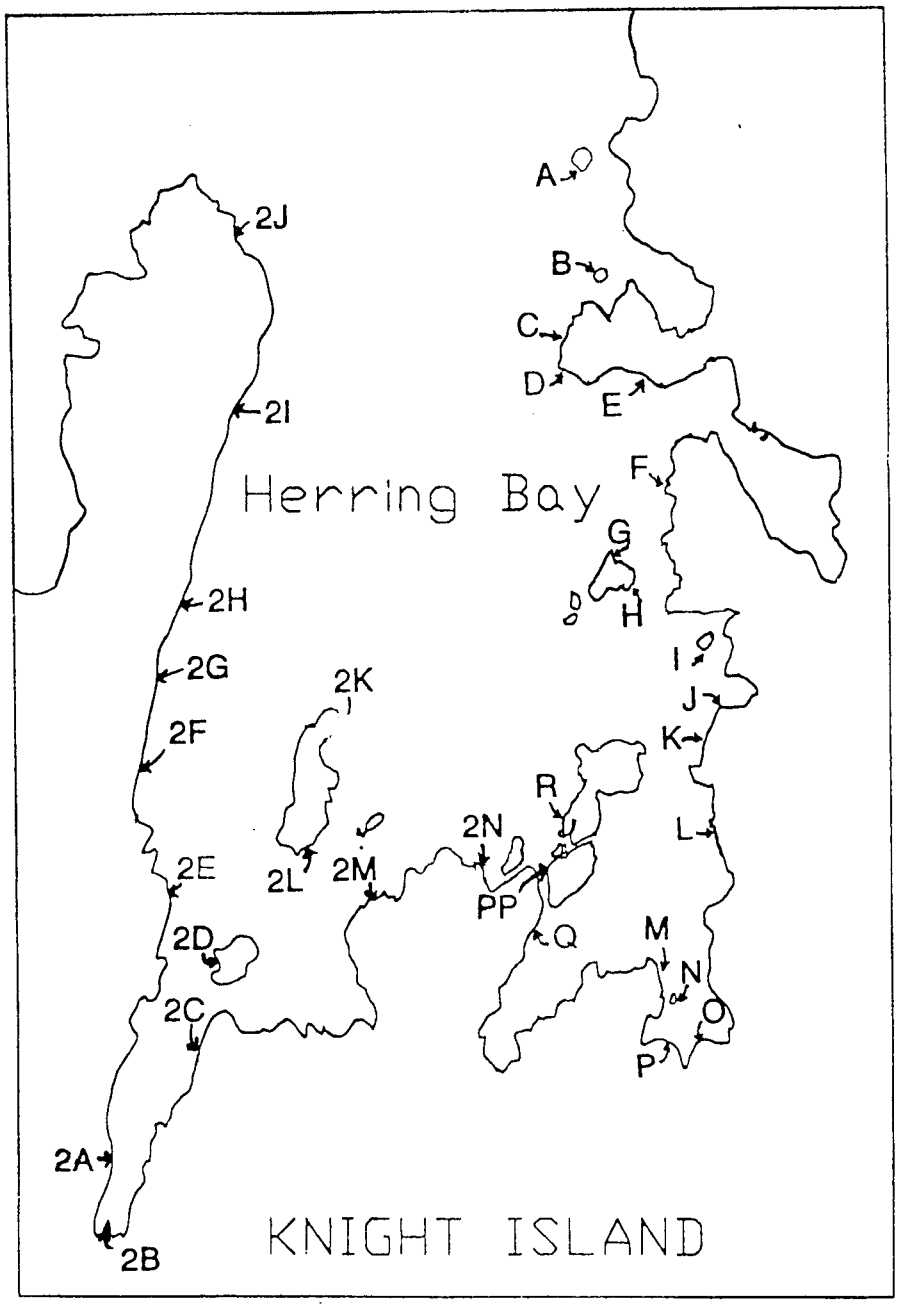

Figure 4.34. Location of calcium sulphate dissolution sites around the perimeter of Herring Bay.

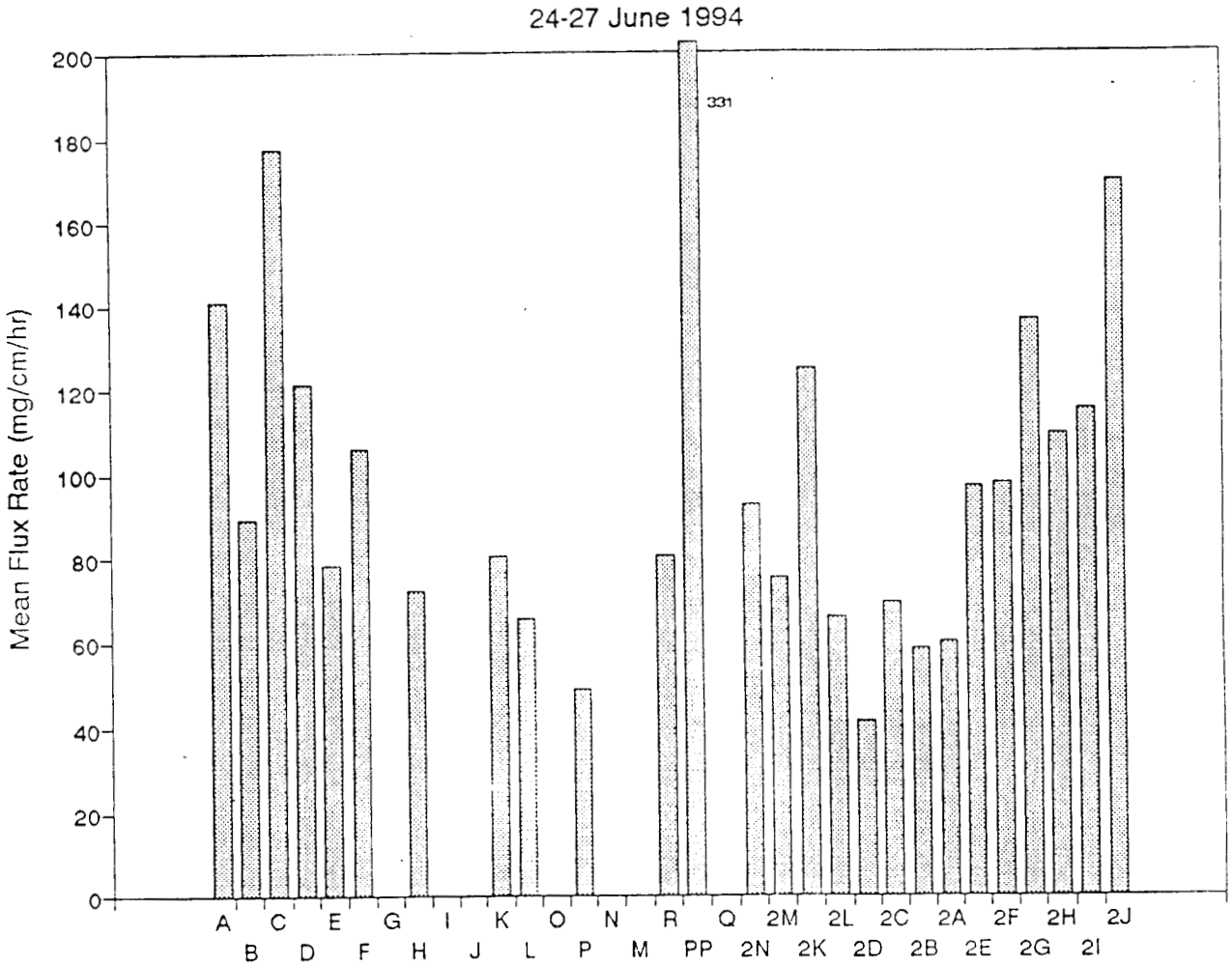

Figure 4.35. Dissolution rates of calcium sulphate cylinders deployed at sites within Herring Bay between 24-27 June 1994. The letters correspond to the locations shown on the map in Figure 4.34. One cylinder was deployed at each location.

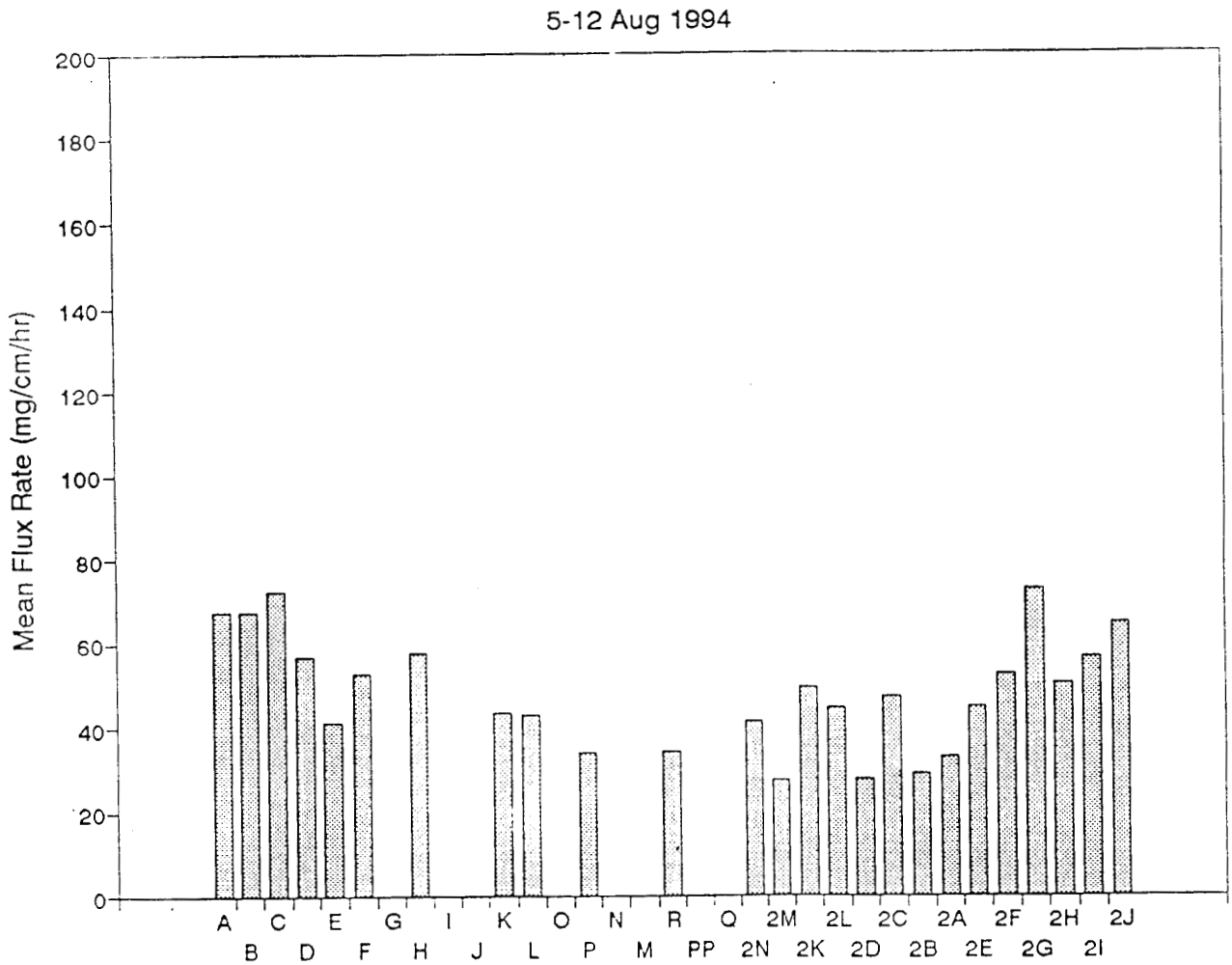

Figure 4.36. Dissolution rates of calcium sulphate cylinders deployed at sites within Herring Bay between 5-12 August 1994. The letters correspond to the locations shown on the map in Figure 4.34. One cylinder was deployed at each location.

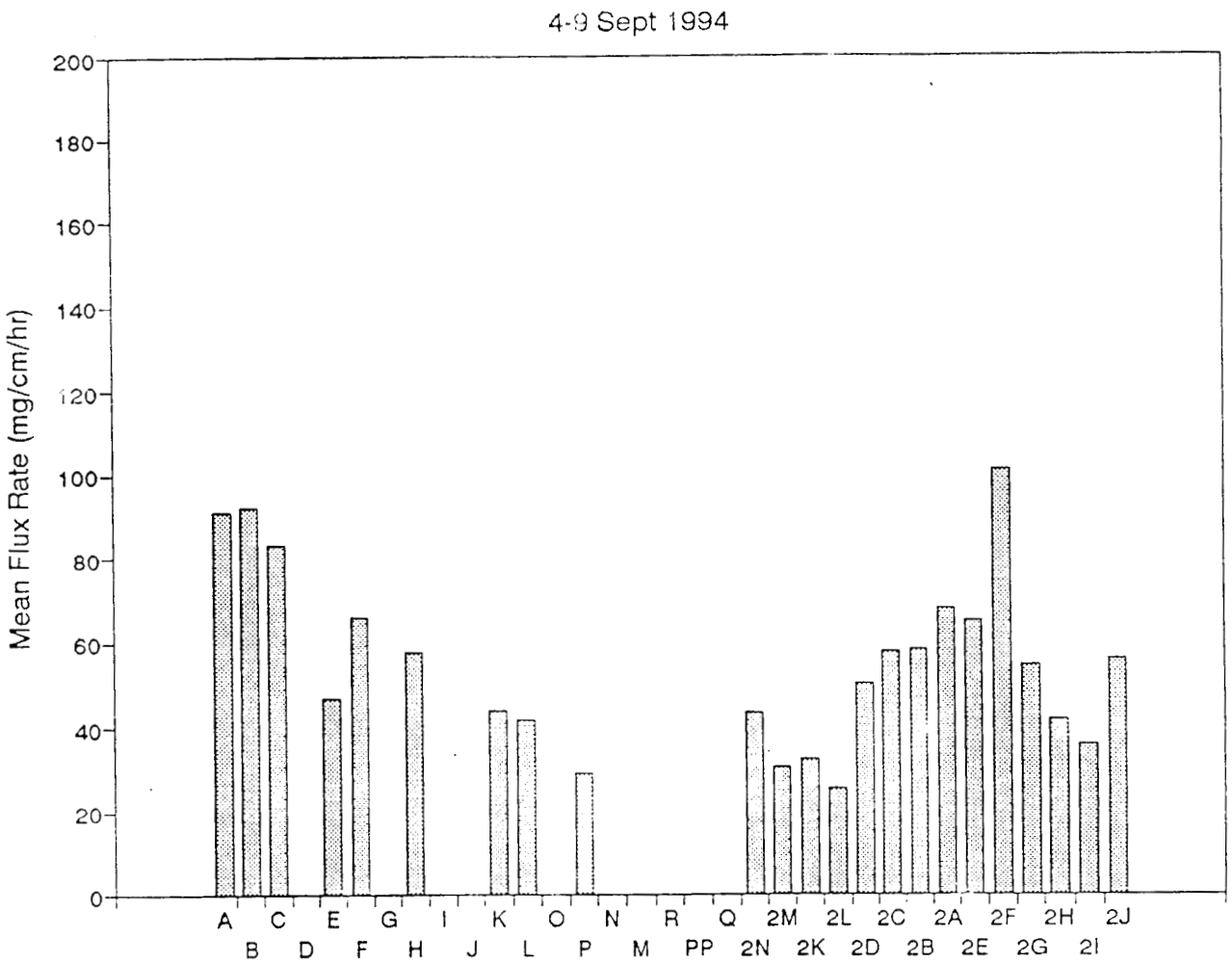

Figure 4.37. Dissolution rates of calcium sulphate cylinders deployed at sites within Herring Bay between 4-9 September 1994. The letters correspond to the locations shown on the map in Figure 4.34. One cylinder was deployed at each location.

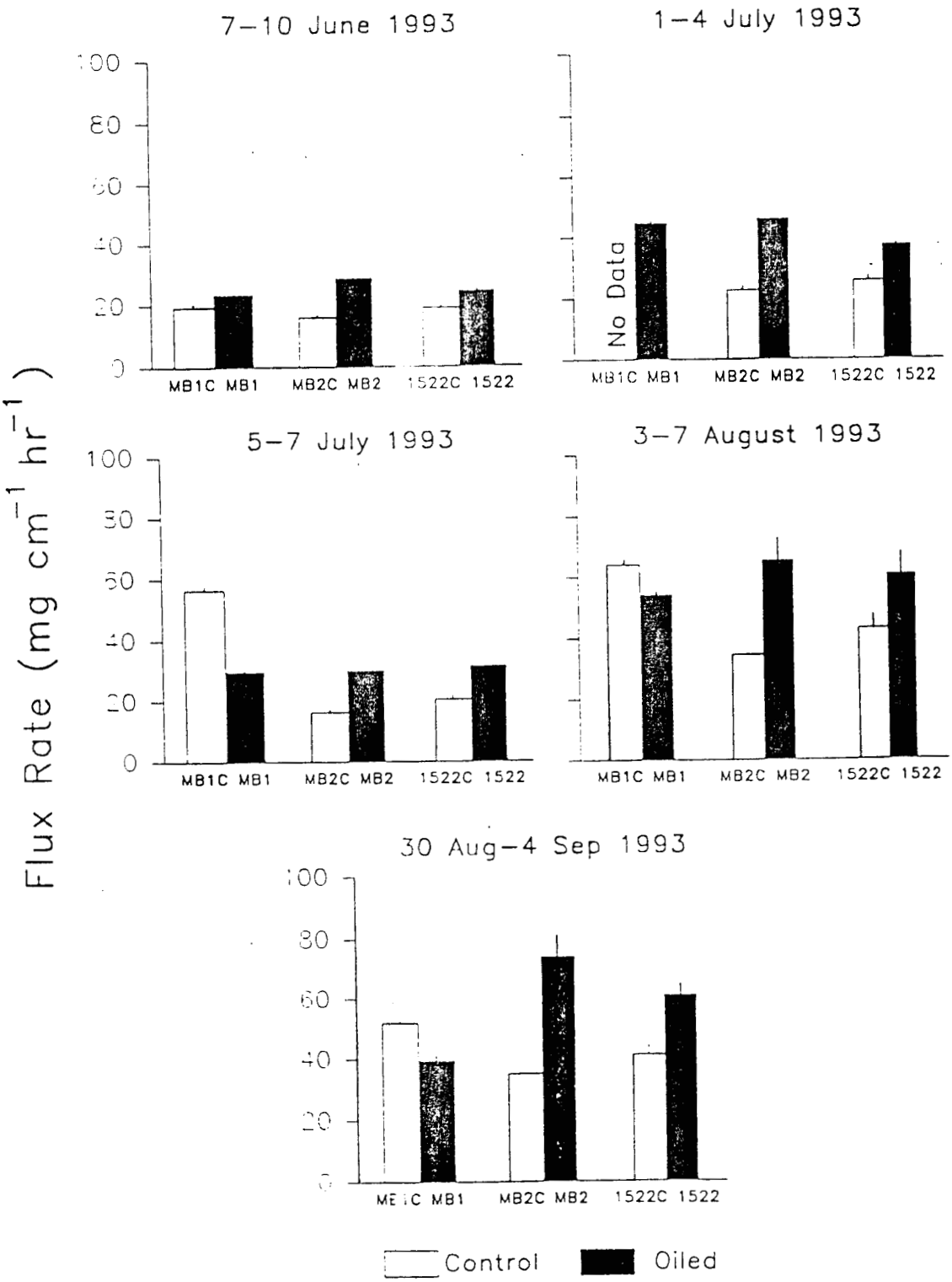

Figure 4.38. Mean dissolution rates of calcium sulphate cylinders deployed at three oiled and three control mussel study sites during low tide series in 1993. Flux rates are the weight change of each cylinder during deployment divided by the length of the cylinder and time submerged under water. Four cylinders were deployed on each site. Vertical bars are one standard error. Note than site MB1C has no data for the 1-4 July visit.

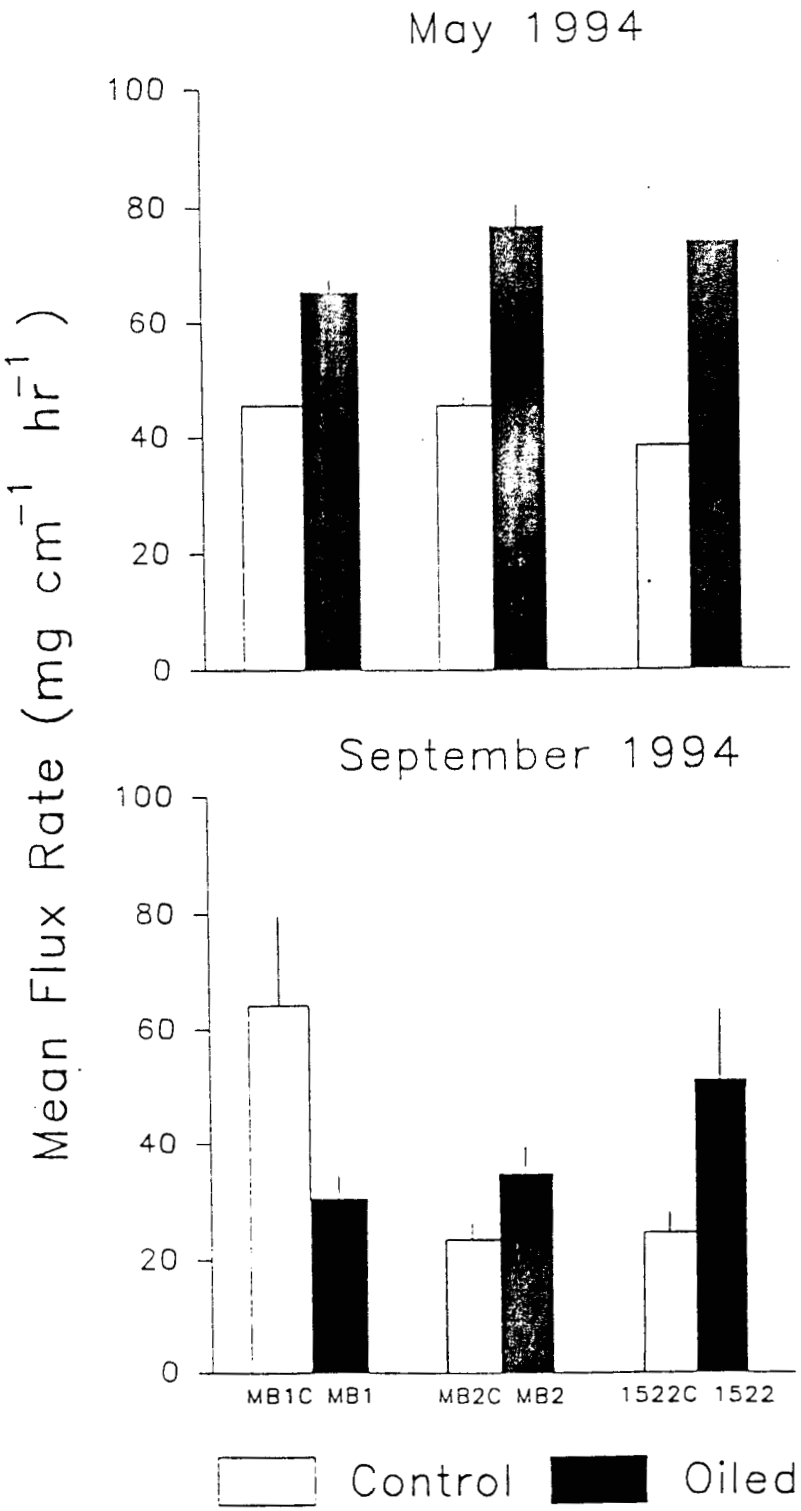

Figure 4.39. Mean dissolution rates of calcium sulphate cylinders deployed at three oiled and three control mussel study sites during low tide series in 1994. Flux rates are the weight change of each cylinder during deployment divided by the length of the cylinder and time submerged under water. Four cylinders were deployed on each site. Vertical bars are one standard error.