Exxon Valdez Oil Spill
Restoration Project Final Report

Herring Bay Monitoring and Restoration Studies

Restoration Project 95086C
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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 disaster. 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 *T/V Exxon Valdez* oil spill continued through the 1995 field season. Data were compared for matched oiled and control sites. For the dominant intertidal alga, *Fucus gardneri*, densities were lower, the reproductive plants had fewer receptacles per plant, and egg settlement rates were lower on oiled sites, especially in the higher intertidal. *Fucus* canopy enhanced recruitment of germlings. *Fucus* germlings were negatively affected by herbivores and desiccation, and substrate affected long-term survival. Excluding plants which lost thallus material, plants grew faster at oiled sites. Experiments employing biodegradable erosion control fabric mats to act as a substrate for *Fucus* germlings showed dense populations of *Fucus* one year after deployment, but deterioration of the fabric occurred in over winter in the second year. *Tectura persona* and *Littorina sitkana* continued to show reduced densities on oiled sites in 1995. Filamentous algal percent cover and mussel recruitment and growth were greater on oiled sites. These patterns may be related to the detection of greater water motion on oiled sites based on calcium sulfate 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

Over the six years that the Herring Bay studies were conducted, we were able to determine the major ecological forces acting on all of the life history stages of *Fucus gardneri* the dominant alga in Prince William Sound. This study represents the most thorough study of *Fucus* ecology on the Eastern Pacific shore. *Fucus* populations were altered by the oil spill and subsequent cleanup. After the oil spill, there were fewer large plants, reproductive plants, and lower settlement rates at oiled sites relative to unoiled sites. Ephemeral algae were more abundant at oiled sites, probably as a result of the removal of competitive dominants. Recovery of *Fucus* populations is obvious from the data which show a cohort of plants recruiting in 1990 and growing to adult sizes in 1995. The pace of recovery was slower in the high intertidal and varied between sites. By 1995, the original sampling design did not detect many differences between oiled and control sites, but when sampling was focused in the very high intertidal region, there were still fewer large plants and reproductive plants at oiled sites subjected to direct sunlight relative to unoiled sites.

To understand what factors have been limiting the recovery of *Fucus* populations in the high intertidal and on sunny shores, experiments were conducted involving all life history stages of *Fucus*. Egg production was not reduced for oiled plants relative to unoiled plants, but settlement rates were much lower on oiled shores relative to unoiled shores. In the high intertidal, lower settlement rates have persisted through 1995, showing little recovery. On the other hand, settlement rates have recovered in the mid intertidal zone. These low settlement rates at oiled sties may be due to reduced densities of reproductive plants. *Fucus* eggs travel very short distances from their parent plant, so local reductions in reproductive plant density could result in low settlement rates. One possible mechanism by which *Fucus* could inoculate shores with zygotes is by detached drifting plants washing up on the shore.

After settlement, *Fucus* zygotes rarely survived on flat rock and were confined to cracks and crevices. Cracks and crevices, appearing essential to *Fucus* recruitment, provided protection from desiccation, whiplash by adult plants and herbivory. The presence of adult *Fucus* canopy had conflicting effects on recruitment. Canopy removed germlings by whiplash when the canopy was thrust back and forth by waves, but canopy also greatly reduced desiccation stress and enhanced recruitment. In Herring Bay, the overall effect of canopy appeared to be positive for *Fucus* recruitment, since germlings could find refuge from whiplash in cracks. Herbivory had relatively few effects on *Fucus* recruitment density but caused a decreased growth of germlings. The most important factor affecting *Fucus* recruitment was desiccation, limiting recruitment in the high intertidal and on sunny shores.

Growth of established *Fucus* plants at oiled sites was slightly faster than at unoiled sites. The increased growth rates could be due to reduced intraspecific competition. Where *Fucus* was able to successfully recruit at denuded oiled sites, recovery was enhanced by higher growth rates. Growth rate was unrelated to water flow.

The substrate upon which *Fucus* was growing influenced the probability of future survival. Barnacles provided ideal cracks and crevices to encourage *Fucus* recruitment, but survival on barnacles was low relative to survival on rock surfaces. In Herring Bay, only plants growing directly on rocks were likely to survive to reproduce. Any initial pulse of barnacle recruitment following the oil spill may have encouraged *Fucus* recruitment, but survival of the *Fucus* germlings recruiting onto barnacles was low due to increased chances of dislodgment.

Surveys performed at various locations in western Prince William Sound in 1994 showed that the upper boundary of *Fucus* populations at the oiled sites (2.49 m MLLW) was an average of 0.5 m lower than the upper boundary at unoiled beaches (2.89 m). A resurvey of the restoration study site in Herring Bay ("Weasel Beach") in May and August 1995 showed that the upper *Fucus* boundary had increased from +1.9 m (MLLW) in 1994 to +2.8 m in 1995. The new 1995 level is nearly equal to the mean upper boundary for the control sites in the 1994 survey. In addition, *Fucus* densities at the Weasel Beach restoration site showed a large increase in 1995. These are encouraging signs that recovery was beginning in these high intertidal zones. The visual appearance of the upper 1 m of the *Fucus* zone at the oiled sites, however, remained quite barren compared to the control areas. The thalli in the oiled sites were very small and densities were relatively low. Full recovery should occur when these newly recruited thalli become reproductively mature and provide a source of embryos in this region. Reproductive maturity for these new thalli will be reached in approximately 2 years.

Restoration of severely damaged intertidal *Fucus* populations was tested on a small scale at a heavily oiled rocky intertidal site in Herring Bay, Prince William Sound. Experiments employed two types of 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 with jute fabric was initiated in 1992, and a more resilient coconut-fiber fabric was tested in June 1993. The jute fabric deteriorated within one year and therefore was not effective in enhancing *Fucus* recruitment. Dense populations of *Fucus* developed on the surface of the coconut-fiber 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 thalli on the mats were approximately 2 cm in length. This fabric deteriorated during the winter of 1995 and the thalli on the mat did not have an opportunity to become reproductive.

Transplantation of adult *Fucus* thalli and sporelings attached to erosion control fabric was also tested as a potential restoration technique. The adult thalli died within a few months of transplant and mortality rates were high in the sporeling populations transplanted to south-facing beaches.

The slow recovery of *Fucus* populations in the high intertidal appears to be due to a variety of factors. The primary factor is a low supply of embryos into this area. The patterns of juvenile recruitment on the inoculated mats show that embryo dispersal is very limited. Limited dispersal was also seen in experiments using egg settlement plates. However, even when thalli of various age classes are transplanted into this environment, the successful establishment of new populations is low. The harsh physical conditions of this habitat with temperatures on the rock surfaces recorded as high as 43.6 degrees C cause severe desiccation and heat stress. The significant relationship seen between aspect and the upper boundary of *Fucus* on two islands within Herring Bay shows that solar exposure is an important factor regulating *Fucus* distribution. A third factor potentially slowing the recovery of high intertidal *Fucus* was increased grazing pressure. Surveys at Weasel Beach showed very high densities of littorinid snails during 1993 and the spring of 1994 which subsequently decreased in the late summer of 1994 and in 1995 when *Fucus* populations were increasing. Caging studies in Herring Bay have also implicated grazers as a factor controlling the recruitment of young *Fucus* thalli.

Injury to limpet and littorine populations occurred as a result of the oil spill and cleanup efforts, with lower densities detected on oiled sites compared to control sites in 1990 and 1991. In sheltered rocky and coarse textured habitats, populations of the upper intertidal limpet, *Tectura persona*, continued to show lower densities on oiled sites in 1995. *Lottia pelta*, which occurs lower in the intertidal than does *T. persona*, had reduced densities on sheltered rocky sites at MVD 3 during at least one sampling date per year through 1995. In the upper and mid-intertidal, this limpet has recovered. In low intertidal coarse textured habitat, *L. pelta* has occurred in greater densities on oiled sites compared to control sites since 1992. The periwinkle, *Littorina sitkana* showed initial injury on both sheltered rocky and coarse textured sites. Significantly higher densities of *L. sitkana* were still detected on sheltered rocky habitat in 1994 in the high intertidal and in 1995 in the low intertidal. On coarse textured sites, *L. sitkana* periodically showed higher densities on oiled sites in the upper and mid-intertidal since 1992. Until 1993, *L. sitkana* were rarely found in the low intertidal of Herring Bay on either oiled or control sites.

Invertebrate densities were monitored on five matched pairs of sheltered rocky sites throughout western PWS during the CHIA study in 1990 and 1991. These sites were visited again in 1993, 1994, and 1995 and counts of *Tectura persona, Lottia pelta, Littorina sitkana*, and *Nucella* spp. were made. Comparisons between the two data sets reveal similarities and differences for invertebrate densities and recovery rates in Herring Bay and on the broader scale CHIA sites. Densities of *L. pelta* in Herring Bay reflect those seen for the larger CHIA study area. *L. pelta* densities increased over time in both data sets. In the high intertidal *T. persona* densities were similar on control sites from Herring Bay and the CHIA study sites. On oiled sites, *T. persona* numbers were low relative to control sites in both studies during 1990 and 1991. Oiled CHIA sites showed recovery of *T. persona* by 1993. Herring Bay *T. persona* population data indicated incomplete recovery by 1995. *L. sitkana* densities showed more variability between the two data sets. *L. sitkana* were more abundant on the CHIA sites than in Herring Bay in 1990 and 1991. In general, abundances decreased on CHIA sites by 1994 and 1995 and were similar to the numbers found in Herring Bay.

In response to the removal of *Fucus* canopy, *Littorina sitkana* living underneath the canopy declined significantly over a several day period and remained low through the two month length of this experiment. In contrast, numbers of *L. scutulata* declined over a several day period following *Fucus* removal, but increased to initial levels within one month. This recovery may be due to recruitment and growth of previously unidentifiable *L. scutulata* by the latter sampling dates.

In general, both *Lottia pelta* and *Tectura persona* declined immediately after the removal of *Fucus* canopy. For *T. persona*, the decline occurred at MVD 0.5 at the protected and intermediately exposed sites. On the exposed site, *T. persona* initially increased following *Fucus* removal. One month after *Fucus* removal, however, *T. persona* densities had declined to zero or very low numbers on all sites. *T. persona* had not recolonized the quadrats within the two month period of the study. *L. pelta* densities declined following *Fucus* removal in the upper and mid-intertidal. *L. pelta* densities had recovered to original levels within two months.

Mussel size-frequency distributions, shell growth and patterns of mussel recruitment in filamentous algae were also studied. In May 1993, size-frequency distributions of mussels on oiled and control sites were similar for two out of three matched pairs. 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 1993, fewer smaller mussels were present on all sites than in May, most likely reflecting a combination of growth and juvenile mortality. In May 1994, smaller mussels were more common on two of the oiled sites relative to their controls. In September 1994, no differences were detected for the size-frequency distribution of mussels in beds on oiled and control sites. The total numbers of small (<2 mm) mussels were higher in

September 1994 than any other sampling date, on oiled and control sites, indicating heavy recruitment into the beds over the summer. By May 1995, very few mussels larger than 10 mm were found on any site, indicating mortality of the older mussels, possibly due to predation by *Nucella* spp. or other predators.

Filamentous algae were more abundant in the lower intertidal of Herring Bay than in the upper intertidal and were more abundant on oiled sites than control sites. Mussels that had recruited into filamentous algae were generally more abundant on oiled sites. Mussels have both primary and secondary settlement. Primary settlement into filamentous algae is followed by secondary settlement into the mussel band. With more filamentous algae available for mussel settlement and generally higher numbers of mussels on filamentous algae, oiled sites have a larger supply of small mussels available for subsequent recruitment into the bed.

Mussels were collected, measured, tagged, caged, and redeployed on oiled and control sites in 1993. Subsequent shell-length measurements were taken each spring and fall over a three year period. Growth over the first summer was low on all sites, possibly a result of stress from the initial handling. Monthly growth was highest in summer compared to winter and highest on oiled sites compared to control sites. Many of the mussels died over the length of the study.

Calcium sulfate dissolution cylinders were deployed on various locations within Herring 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. For cylinders placed on mussel study sites, dissolution rates were higher on the oiled sites. As described above, these sites also had the highest recruitment of mussels and fastest mussel growth rates. This result indicates that water movement differences between sites may affect recovery rates of certain organisms, especially those with pelagic larvae.

Barnacle recruitment patterns were assessed on three oiled sites. In undisturbed quadrats, 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. Quadrats were scraped in June 1993. Convergence of data on scraped and unscraped quadrats for *C. dalli* and adult *S. balanoides* + *B. glandula* occurred within two years. The timing and densities of recruitment varied from year to year and mortality between juvenile and adult stages was high for *C. dalli* and *S. balanoides* + *B. glandula.*

Oil spills have deleterious effects on the nearshore biota due to both physical and chemical (toxic) effects. The *Exxon Valdez* oil spill initially may have been toxic to intertidal organisms but the physical coating of the shore was responsible for smothering many organisms. The design used in the Herring Bay studies did not permit clear, unambiguous testing of the effects of oil toxicity free from other confounding mechanisms by which the oil spill may have affected intertidal organisms, including beach treatment. But we found no direct evidence that the oil itself was toxic to *Fucus*. The results of our work at Herring Bay are consistent with the hypothesis that cleanup activities, especially the hot water, high pressure wash, caused the most damage. The oil spill/cleanup acted essentially to create large patches of bare rock and beach. Damage was related to physical disturbance. Recovery is dependent upon the ability of key organisms to recolonize bare space.

There is some evidence that indicates that the effect of the oil spill/cleanup on invertebrates was not direct but may have been a result of the loss of *Fucus*. Bare rock was created by removing *Fucus*, barnacles, mussels and associated fauna, especially in the upper intertidal. Bare space created by removing *Fucus* would afford more opportunity for settlement of species with pelagic, widely dispersed larvae such as barnacles and mussels. The bare space would also expose the limpets and snails to increased stress from desiccation and predation. Bare space would allow settlement and recruitment by *Fucus*, but because *Fucus* has a very limited dispersal range, this species would be slower to recruit than barnacles or ephemeral algae. Thus, we can explain the oil spill/cleanup effects by just the removal of the overstory plants.

Recolonization of the created bare space proceeds as a function of recruitment and not of competition in Herring Bay. Even in small cleared patches there was no predictable succession seen. It is unlikely that herbivory plays a major role in keeping large bare patches uncolonized. Rather it is more likely that patchy recruitment combined with the effects of desiccation are the major factors controlling the rates of recolonization of the mid- to upper intertidal.

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 prevaling 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; Pain *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 geomorpholigic 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 (CHIQA) 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 intractions 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 (Figure 1.1). 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. A set of sites was selected from long-term monitoring of Fucus and several key invertebrate species, including three matched pairs of sheltered rocky sites and two matched pairs of coarse textured sites (Table 1.1). The locations of these sites are shown in individual chapters of this report. Other sites selected for specific *Fucus* or invertebrate studies are described in individual chapters also. 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, and wave exposure.

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 Bya. 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 the variations of up to 10 degrees seen over a field season. 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 studies. 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. Our statistical power was not always high for all organisms. However, we were able to demonstrate long-term trends over time that strengthened the individual statistical tests. 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 Population Dynamics study sites. SR=Sheltered Rocky, CT=Coarse Textured, O=no oil, 1=very light, 2=light, 3=moderate, 4=heavy.

Habitat	Control Site	Oiling Level	Oiled Site	Oiling Level
SR	1231C	0	1231X	3, 4
SR	1732C	1, 2	1732X	3, 4
SR	3811C	0	3811X	3
CT	2834C	1	2834X	3
CT	2333C	1	2333X	3

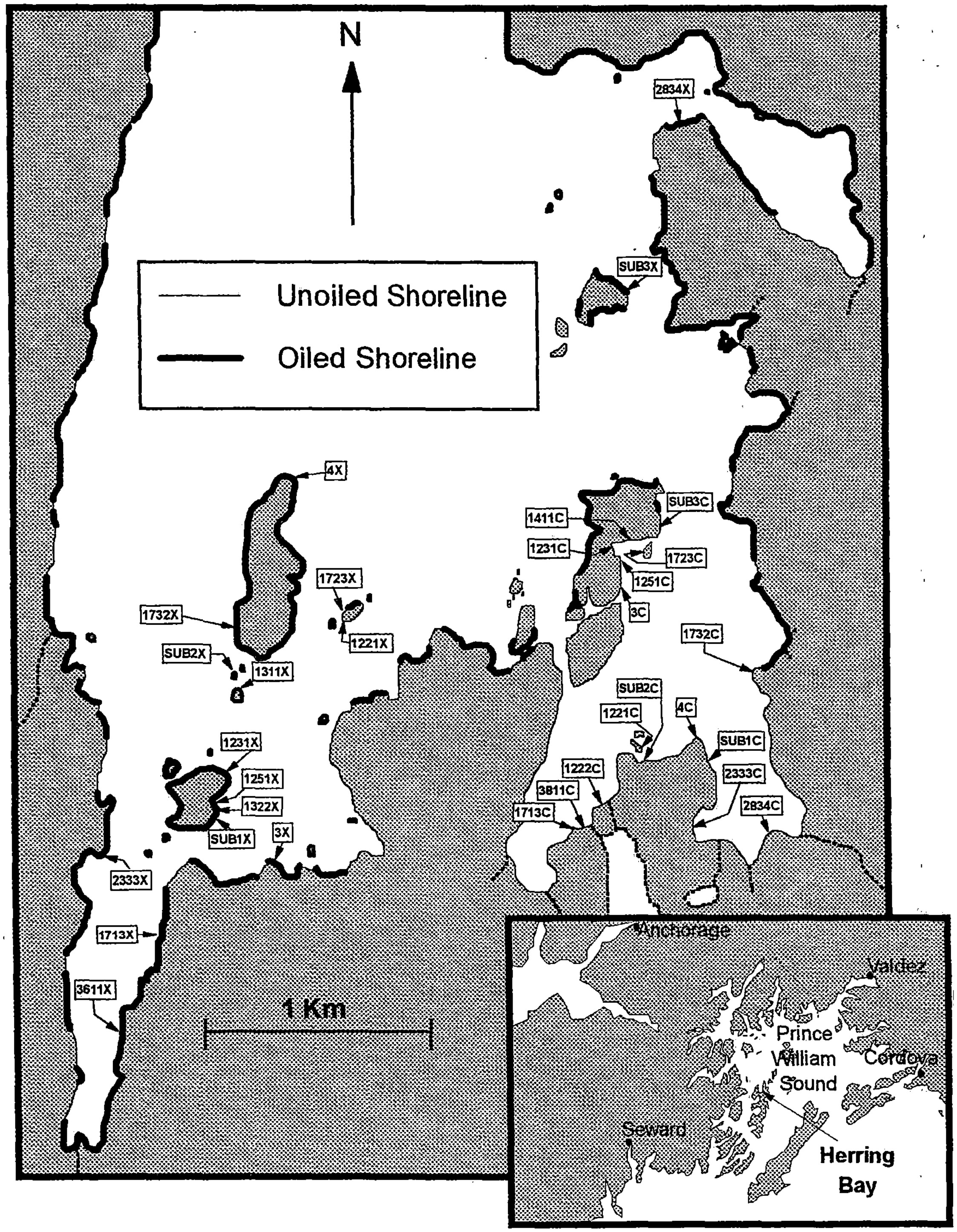

Figure 1.1. Oiled and unoiled shorelines in Herring Bay, Prince William Sound, Alaska after the *Exxon Valdez* oil spill. Boxed numbers indicate location of experimental sites used in this study. A "C" after a site number designates a control or unoiled site. An "X" indicates an oiled site.

CHAPTER 2. ALGAL STUDIES

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INTRODUCTION

Seaweeds are often the most conspicuous members of intertidal communities, especially in the wave-protected shores of northern boreal habitats where fucoid algae dominate. Following the *Exxon Valdez* oil spill, the abundance of the only fucoid alga in this region, *Fucus gardneri* Silva, was less at oiled sites compared to reference sites (DeVogelaere and Foster 1994, Highsmith *et al.* 1996, Stekoll *et al.* 1996, Houghton *et al.* 1996). Fucoid algae have been affected in a number of other oil spills. Southward and Southward (1978) documented lower abundances of several species of fucoid algae following the *Torrey Canyon* oil spill. Similar reductions have also been observed for the *Arrow* oil spill (Thomas 1973, 1977, 1978), the *Amoco Cadiz* oil spill (Floc'h and Diouris 1980), and the *Esso Bernicia* oil spill (Rolan and Gallagher (1991).

Most of the reductions in *Fucus* and other seaweed populations were due to clean-up effects rather than direct damage from oiling. The wisdom of using severe clean-up technologies to try to remove oil from shorelines has been questioned (Foster *et al.* 1990). Lees *et al.* (1996) found that severe cleaning of shorelines was much more detrimental to *Fucus* and other intertidal organisms than leaving the oil in place. Rolan and Gallagher (1991) also found that cleaning by bulldozing oiled shorelines resulted in longer recovery times compared to oiled but unbulldozed shores following the *Esso Bernicia* spill.

After the *Torrey Canyon* spill, Southward and Southward (1978) observed that weedy, ephemeral algae colonized shores rapidly, resulting in a distinctive "greening" of the intertidal, but recovery of fucoids was somewhat dependent upon the presence or absence of herbivores. Kendziorek and Stekoll (1984) observed the recovery of *Fucus* populations after harvesting for the herring-roe-on-kelp fishery. They found that when large *Fucus* plants are removed from a large area, the small plants which are left behind quickly grow in densely packed stands which eventually thin out to resemble the pre-disturbance population. After the initial growth of young individuals, there were higher densities of large plants and higher percent cover of *Fucus* in disturbed plots compared to undisturbed plots. McCook and Chapman (1991) and Keser and Larson (1984) found similar patterns of higher densities following massive ice-scour or artificial clearing.

If shores are completely denuded with the removal of small as well as large plants, then recovery must occur via the production of spores, dispersal, recruitment, and growth. Little is known about the cues that induce *Fucus* to initiate receptacle formation or release eggs. Connell (1985) defined settlement as the process of propagules in the water column landing and attaching to the substrate and specified that settlement can only be observed within 24 hours of the actual settlement event. According to this definition, only two studies have observed settlement in fucoid algae in the field. McConnaughy (1985) collected eggs on specially designed acrylic plates, but some of his trials lasted longer than one day, confusing settlement with post-settlement mortality. Kendrick and Walker (1991) stained propagules of *Sargassum* and used a venturi vacuum to retrieve the dispersed propagules. They found that the dispersal distance of *Sargassum* is generally less than 1 m from parent plants. Other studies have suggested that dispersal distance is short based on observations of early recruits (Deysher and Norton 1982, Sousa 1984, Arrontes 1993). In the laboratory, Norton and Fetter (1981) suggested that *Sargassum* settlement was inversely related to water velocity, but they did not correct for the time available to settle at different water velocities.

DeVogelaere and Foster (1994) suggested that *Fucus* may need cracks and crevices for recovery since recruits seem to be found more frequently in crevices. Lubchenco (1983) also showed that recruitment of fucoids was enhanced by substrate heterogeneity. There are at least two reasons for the enhancement of recruitment by cracks or crevices. First, cracks and crevices in the substrate may decrease desiccation stress (Jernakoff 1983). Second, germlings may escape herbivory in cracks or crevices (Lubchenco 1983). Several studies have shown that herbivores inhibit fucoid recruitment (Hartnoll and Hawkins 1985, Barker and Chapman 1990, Chapman and Johnson 1990, Benedetti-Cecchi and Cinelli 1992), but few have examined the role of desiccation in germling survival (Brawley and Johnson 1991, 1993). An additional factor that can influence fucoid recruitment is the presence of adult canopy. Some studies have shown that canopy decreases recruitment (Lubchenco 1986, Benedetti-Cecchi and Cinelli 1992, Vadas *et al.* 1992) but others have suggested that canopy can enhance recruitment (Brawley and Johnson 1991). These conflicting results may result from different mechanisms of interaction between canopy and recruits. Canopy may inhibit recruitment by removing germlings when large fronds are thrust back and forth by waves (whiplash effect) or by attracting grazers which eat new recruits. On the other hand, canopy may decrease desiccation and heat stress for germlings, enhancing survival.

After recruitment, *Fucus* plants grow to mature sizes before producing receptacles. Growth is usually positively correlated with plant size (Edelstein and McLachlan 1975, Ang 1991, 1992), and seasonal differences in growth rates are quite pronounced (Edelstein and McLachlan 1975, Mathieson *et al.* 1976, Niemeck and Mathieson 1976, Sideman and Mathieson 1983, Thom 1983, Keser and Larson 1984, Ang 1991). Populations higher in the intertidal zone usually grow slower, are less dense, and have higher mortality rates than *Fucus* in lower intertidal zones (Niemeck and Mathieson 1976, Keser and Larson 1984). Highest mortality occurs during the winter and is related to the age of the plant and physical factors such as winter storms and ice scouring (Neimeck and Mathieson 1976, Keser and Larson 1984).

The overall goal of the studies presented here was to determine the patterns of recovery of *Fucus* from the effects of the *Exxon Valdez* oil spill and to ascertain which factors may limit recovery for *Fucus* in areas which have been slow to recover. The basic approach was to monitor recovery from damaged sites and to assess factors, including oiling, which may have affected each stage of the life history of *Fucus*. The initial step was to set up a monitoring program to assess recovery of *Fucus* populations at various tidal levels. Egg production and fertilization success may have been adversely affected by the oil spill, so the capacity of individual receptacles to produce viable eggs was assessed and compared between oiled and control sites. Settlement was monitored at oiled and control sites and potential dispersal distances were evaluated. Factors that potentially affect recruitment of *Fucus* were manipulated in a variety of experiments that were mostly performed at both oiled and control sites. These factors consisted of desiccation, herbivory, substrate heterogeneity, and whiplash from canopy. Growth of individually marked *Fucus* plants of various sizes was monitored at both oiled and control sites and at different tidal levels.

METHODS

Study Sites

Most sites for these studies consisted of matched control and oiled shorelines. Matched sites were determined by first locating a workable area in the unoiled southeastern section of the bay and then matching the selected site with an oiled shoreline in the southwestern section of the bay. The criteria used for matching sites included similarity in substrate composition, slope, directional and solar aspect, and wave exposure. The sites are listed in Table 2.1 along with the studies that were performed at each site. The site locations are given in Fig. 2.1.

Fucus Population Dynamics

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 (Fig. 2.1, Table 2.1). 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 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), giving the distance from the edge of the segment to the location of the first transect head. Each of the subsequent transect heads were 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. The number of receptacles on each reproductive plant was recorded and only living plants were counted. 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 once every two weeks from 20 June to 15 September in 1990 for a total of six visits. In 1991, the plots were visited in April, June, and August. The quadrats were monitored in May and August in 1992, 1993, and 1994 and in May 1995.

High Zone Population Dynamics

An additional study was conducted in 1995 to assess the recovery of *Fucus* and two species of invertebrates in the very high intertidal zone (0.0-0.5 MVD). Three pairs of oiled and control sites that varied in their compass orientation were sampled in May 1995. At each site twelve transects with one quadrat (20x50 cm) each were positioned in a manner similar to the population dynamics study above. The vertical height of the quadrats varied uniformly from 0.0 to 0.5 MVD, but they were randomly assigned to transects. Thus, at each site there was one and only one quadrat at each of twelve tidal levels ranging from 0.0 to 0.5 MVD. This avoided the problem of getting a high proportion of high or low quadrats at a site using random vertical placement of quadrats.

The percent cover of *Fucus*, number of large (>10 cm) *Fucus* plants, number of reproductive *Fucus* plants, number of *Tectura persona*, and number of *Littorina sitkana* were recorded for each quadrat. This sampling focused on the species and sizes which showed the greatest damage and least recovery from the *Exxon Valdez* oil spill.

Fucus Reproductive Potential and Egg Viability

In 1991, the relative fertility of *Fucus* at oiled and control sites was assessed by measuring the rate of egg release from randomly selected receptacles. In addition, the viability of the released eggs was determined. Plants for this study were collected from the same sites as those used for the population dynamics study (see above). The nearest plants with undamaged receptacles to the origin of 0.5 m radius semicircular areas on either side of each quadrat were collected. Plants were collected three times during the summer and within two days of population dynamics monitoring. Plants at paired oiled and control sites were collected on the same day. For each plant collected, one randomly chosen receptacle was cut from the plant, rinsed in fresh water for about ten seconds, blotted dry, and placed between two paper towels in the dark at 8-10°C for 24 hours. The receptacles were then weighed and placed in resealable plastic vials with 20 ml of sterile seawater and placed in an incubator at 8-10°C with a photoperiod of 16:8 (L:D) at 50-80 $\mu E/m^2/s$ light. During the 48 hour incubation period the samples were shaken every 8 hours to prevent released eggs from attaching to the walls of the vials. After the incubation period the receptacles were removed from the vials and 2.0 ml of 0.1% Calcoflour stain was added and allowed to be absorbed by any living cells for 30 minutes. Then 7.0 ml of 20% formalin was added to each bottle.

The total number of eggs released by each receptacle was determined by estimating the number of eggs in each vial. Each sample was thoroughly mixed and transferred to a 9 cm petri dish. The number of eggs in 10 randomly chosen fields of view of a dissecting microscope (25X) was counted. These ten counts were then extrapolated to obtain an estimate of the total number of eggs in each vial.

The viability of the eggs produced by each receptacle was also evaluated. After the number of eggs was determined, the egg solutions were transferred to centrifuge tubes and centrifuged for less than 10 seconds or allowed to settle for at least 16 hours. Four drops of concentrated samples were transferred to a microscope slide and examined under a fluorescent microscope. The number of unfertilized (non-fluorescent) and fertilized (fluorescent) eggs were counted until 100 eggs were examined. If fewer than 100 eggs were examined then up to 5 additional slides were prepared until 100 eggs had been examined. If after examination of six slides there were still fewer than 100 eggs examined, the numbers of counted for all slides were recorded.

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. Since there was limited time in Prince William Sound and the species of *Fucus* is the same, these studies were carried out in Juneau. All receptacles had well developed conceptacles and were releasing mucus. 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).

Fertility of Floating *Fucus*

Fucus gardneri is monoecious with both male and female structures in each conceptacle, therefore it is potentially possible for a single plant or plant part to produce fertilized eggs at distant locations. To assess the possibility of recolonization of denuded shorelines by egg release from drift *Fucus* plants, the reproductive potential of drift plants was determined. To obtain drift plants, a skiff was driven at about 1.5-2.0 m/s, and any plants within 1 m of the bow of the skiff were collected. Collections were made along three transects on each sampling date. Each transect originated from one of three sites in the southwest finger of Herring Bay. The sites were 2333X, 3611X, and 1852X (Fig. 2.1). Starting as close as was safe to the shoreline, the skiff was driven in a random compass direction until the shore was encountered at which time the skiff was driven in a new random compass direction. Each transect was run until 10 plants had been collected. The three sampling dates were 22 May, 3 June, and 8 August 1991.

After collection, the plants were treated exactly the same as the plants collected in the *Fucus* reproductive potential and egg viability study above.

Short Range Dispersal Patterns

Short range dispersal patterns of *Fucus* eggs were investigated by monitoring egg settlement rates at various distances and directions from fertile plants. Two to four fertile plants releasing mucus were collected, rinsed in fresh water, and dried in the dark for 12 hours to encourage egg release. These plants were then attached to the center of two perpendicular 4 m sections of 0.5 inch diameter PVC pipe joined in the middle. The pipes were placed with one pipe parallel to the water line in areas of Herring Bay where no other fertile *Fucus* plants were located within 10 m of the center of the pipes. Seven egg settlement plates were secured to the pipes with stainless steel screws in all four directions at 0, 10, 20, 40, 80, 120, and 200 cm from the source plants. The plates were 5x7 cm with 9 grooves etched in a central area of 3x4 cm (Fig. 2.2). The width of the grooves (125 μm) was slightly larger than the width of an average *Fucus* egg (75 μm) so that eggs falling on the plates were likely to be caught in the grooves.

The pipe apparatus was retrieved after 24 hours in the field and the number of eggs on each plate was counted. This procedure was repeated five times from 6-10 July, 1993 and eight times from 1-7 August, 1993. Because of very low egg abundance on plates in some trials, only those five trials in which more than 100 eggs were found on all of the plates combined were used for analyses.

Fucus Egg Settlement

The number of *Fucus* eggs settling on oiled and control shores was estimated from 1991 through 1993 by deploying acrylic plates identical to those used for the short range dispersal experiments. The plates were set out for one day at a time for three (1992-1995) or four (1991) days in a row. Plates were placed at each of three tidal levels (0.5, 1.0, and 2.0 MVDs) along four transects perpendicular to the shore for a total of 12 plates per site. One transect was placed at either end of the site and the remaining two transects were equally spaced between them. This procedure was performed at four pairs of oiled and control sites in May, June, and August of 1991 and 1992, in July and August 1993, in May, June, July, and August of 1994 and 1995. Only two pairs of sites were sampled in May of 1994. Since only four pairs of sites could be sampled during a sampling period, a method of rotating sites pairs was devised to assess both yearly variation and to sample a large number of sites. Two pairs of sites were used in all five years, but each year two new site pairs were added and two old site pairs were dropped. In August 1991 and on all sampling dates in successive years except in June 1994, the distance to the nearest fertile *Fucus* plant for each plate was recorded.

The effects of net water flow on egg settlement were investigated at the egg settlement sites in August and September 1994. 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 plants able to touch the cylinders were removed.

Fucus Recruitment: Desiccation

The effect of desiccation on *Fucus* germling survival was investigated by monitoring germling survival in areas of varying desiccation rates. On 3 May 1991, plastic petri dishes (9x60 mm) were seeded with approximately equal densities, about 144 eggs/cm^2, of *Fucus* eggs in the lab at Juneau and incubated until 30 May 1991. Seeding consisted of inducing fertile receptacles to release eggs in a vial with seawater and the dishes were seeded in plastic containers using the inoculation produced from the released eggs. After seeding the dishes were incubated at 8-10°C with a 8:16 light dark cycle with 50-100 μE/m^2/sec of light intensity. The seeded dishes were kept on ice during shipment to Herring Bay. On 1 June 1991 four seeded dishes were bolted to random locations on rock surfaces at 1 MVD at each of six sites. At this time all germlings were about 0.5mm in length. The initial percent cover of germlings on each dish was 20%, and the percent cover of *Fucus* germlings was estimated on each dish after 11 days in the field. All visual estimates of percent cover were made by a single observer, reducing the chance of bias in the results (Dethier *et al.* 1993). Percent cover was used rather than density because the former could be estimated in the field while density could only be accurately ascertained using a microscope. Growth of germlings was minimal during this time period, so changes in percent cover reflect mortality of germlings.

In an attempt to account for some of the variation in germling mortality we measured desiccation rates on 20 June 1991 by placing wetted cotton balls on freezer container lids in the field and measuring the loss of water from the cotton balls over time. One lid with one cotton ball was placed near each dish at all sites as the tide receded and exposed the plates. The weight of the wetted cotton ball was about 5 g. The lids and cotton balls were collected just before being covered again by the rising tide. Due to limited periods of hot, sunny weather, these observations were carried out only once. During the time the dishes were monitored in the field, the weather was mostly hot and dry, but just after monitoring of the dishes a storm developed, forcing us to measure desiccation 9 days after germling mortality was assessed. We assume that conditions during the mortality study were similar to conditions during the desiccation studies.

Fucus Recruitment: Whiplash

Observations of the petri dishes after the desiccation trials described above while the dishes were still in the field indicated that germlings were only surviving in the corners of the petri dishes, suggesting that whiplash from adult plants may be removing germlings. To experimentally show that adult *Fucus* plants have the potential to remove germlings from seeded petri dishes, petri dishes with germlings on them were mounted on a plywood board and suspended just under the water surface in an area subjected to slight wave action. The bottom of the board was weighted to keep the board vertical. Adult *Fucus* plants were attached to the board above the petri dishes in such a way as allow the fronds to brush against the surface of the dishes as a result of the slight water motion at the site. Observations in the field of these attached plants confirmed that the apparatus was a fair mimic of the wave action effects of attached plants on the shore. Molluscan herbivores were excluded from the board since it was suspended in open water by ropes attached above the tideline. Desiccation was also eliminated as a source of mortality since the dishes were continuously submerged. Thus, this experiment isolated the effects of canopy without the confounding effects of herbivores and desiccation. *Fucus* plants were suspended above four of the dishes, and three other dishes served as controls with no adult *Fucus* plants. After 10 days in the field the density of germlings was measured on each dish under a dissecting microscope.

Fucus Recruitment: Canopy, Substrate Heterogeneity, and Herbivory

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. 2.3). 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 tiles were deployed at each of three control and matched oiled sites. At both the 0.5 MVD and 1.0 MVD, two pairs of seeded and unseeded tiles were separated by a horizontal distance of 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 another set of seeded tiles 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. 2.3). 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 shared the seeded tile with no *Fucus* canopy 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 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. After counting, which took about 10 hours, the tiles were returned to the field. In June 1993 and September 1994, the number of plants in each groove visible with the naked eye was 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 was equal and only crack size varied, 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 regardless of the area of the crack. For these reasons, we felt that number per length of groove was the appropriate variable to examine rather than density or number per area of groove.

Growth and Mortality of Established Plants

To determine growth rates, we monitored individually tagged *Fucus* plants for four years. At all sites, six plants in each of three tidal levels (0-1, 1-2, and 2-3 MVDs) were chosen in each of three size classes. The size classes were small (2.0-4.5 cm in length), medium (5.0-10.0 cm), and large (>10 cm) plants. Six transect heads were randomly located at mean higher high water. Along each transect, one point was randomly located in each tidal level and marked with a stainless steel screw. The plants were chosen by finding the nearest plant in each size class to the randomly selected point. Plants were tagged by using marine epoxy to affix a small labelled tag to the substrate with markings pointing directly to the holdfast.

Eighteen plants in each size category were marked at each site for a total of 216 plants. In 1991, only reproductive plants were chosen in the large size category. All plants were initially marked and measured between 16-19 May 1991 and remeasured on 22-23 August 1991, 6-7 June 1992, 27-28 July 1992, 5-6 June 1993, 30-31 August 1993, 24-27 May 1994, and 4-5

September 1994. Besides measurements of plant length, the distance from each plant to the random point was recorded during summer 1991, giving an estimate of plant density for the different size categories at each site.

If plants were lost or 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, the number of plants at each site in each size class at each tidal level was restored to at least six by this retagging procedure. Sample sizes may be greater than six if plants from a smaller size class grew into a larger size class. Growth rates were calculated for each plant by dividing the change in length by the number of weeks since the last measurement.

To determine the effects of water flow on *Fucus* growth rates, plants were individually marked at 26 sites varying in exposure to waves and currents. Site locations are given in Figure 3.2. Plants were tagged at the 1.25-1.75 MVD tide level. Substrate type, plant densities, and slope were similar at all sites. At each site six plants were marked by attaching a numbered tag to the stipe with a cable tie. Plants were initially tagged and measured between 23 June 1994 and remeasured on 3 September 1994 and 18 May 1995. Between 9-13 August 1994 two calcium sulphate dissolution sticks were deployed at all of the sites at the same tidal level. The methods for flow measurement are described in detail in Chapter 3.

At the 18 sites (sites A through R in Fig. 3.2) measuring *Fucus* growth in relation to water flow on the eastern shore of Herring Bay the effect of surrounding *Fucus* canopy on adult *Fucus* plants was tested. At each site two adult plants (>10 cm) were marked with epoxy putty tags on the substrate near the holdfast (see above), and the plant locations were recorded by triangulation from marked points in the high intertidal. All of the surrounding plants able to touch one of the marked plants, randomly determined, were removed and the canopy around the second plant was left intact. This experiment was initiated on 8 July 1993. The next three weeks were exceptionally warm and sunny for Prince William Sound. On 4 September 1993 the sites were revisited and plant mortality was noted. Since plant locations were triangulated, mortality could not have been due to tag loss.

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 each site, ten randomly located quadrats (25 X 25 cm) at 0.5 MVD were examined. 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 (only for 1994), 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 (1994 only), smooth rock surface, and barnacles in the cleared plot. Quadrat frames 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 pointed rod (2.5 mm diameter) was pushed through both holes, and the substratum that was contacted by the rod was recorded.

In 1994, these observations were carried out at three pairs of oiled and control sheltered rocky sites protected from waves (Fig. 2.1, Table 2.1). Identifying crevices and determining crevice use by *Fucus* proved time consuming, so in 1995 plants were classed either growing on rock or on barnacles. In 1995, sampling was carried out at two tidal levels, 0.5 MVD and 1.5 MVD, at both exposed (site A) and protected (site R) sites (Fig. 3.2).

Breaking Strengths and Mortality of *Fucus* on Barnacles and Rock

The ability of *Fucus* plants to attach to different substrates was investigated by measuring the breaking strength of plants growing on barnacles and bare rock. At each site 20 (40 at one site) plants were haphazardly chosen based on size, substrate, and health. All plants tested at each site visually varied only in substrate and mostly ranged from 5-10 cm since large plants were rare growing on barnacles and smaller plants were rare growing on rock. For each plant, a loop of string (3 mm diameter) was secured around the stipe of the plant and attached to a spring scale with a maximum reading indicator. The plant was then slowly and evenly pulled via the string and spring scale at an angle of about 30 degrees above horizontal until the plant failed. Almost all failures were at the holdfast with only 17 out of 120 plants failing at the stipe and 5 of the 120 failed due to substrate (all barnacles) failure. The force required for the plant to be removed was recorded. After failure, the plant was retrieved, and the largest and smallest diameters of the failure location were measured with calipers. Dividing the force required for failure (Newtons) by the surface area (m^2) of the failure site, assuming an elliptical shape, gave the breaking strength (Pascals) of the plant. This was performed at protected and exposed sites and, at the exposed site, for both *Balanus glandula/Semibalanus balanoides* and *Semibalanus cariosus* as barnacle substrates. All sampling was performed from 29-30 July 1995.

To investigate the chance of surviving for *Fucus* plants growing on rock or on barnacles, plants were marked and their survival over one summer was monitored. At each of eight sites, ten plants growing on rock and ten plants growing on barnacles were marked by tying colored fishing line to the stipes of plants, using different colors for the different substrates. Plants were selected the same as in the tenacity experiments described above. All plant locations were recorded by triangulation from screws in the high intertidal. All plants were initially marked in May 1995 and the number of plants left was recorded six and 14 weeks later.

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.

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. A site pair in which the direction of the mean difference was opposite that of the test, was assigned a probability value equal to 1, minus their actual probability value.

For other experiments either simple t-tests or ANOVAS were performed. When t-tests were employed the procedure above was applied as if neither the raw nor transformed data had homogeneous variances for all sites. For two- or three-way ANOVAs the raw data were used 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. Tukey's post-hoc test was used to separate means of factors with more than two levels. All figures and tables represent raw means and one standard error of the mean except where indicated. Statistical significance is indicated by one star ($p<0.05$), two stars ($p<0.01$), or three stars ($p<0.001$).

RESULTS

Population Dynamics-Sheltered Rocky

In the high intertidal (1 MVD) there were more small (2.5-5.0 cm), medium (5.5-10.0 cm), and large (>10 cm) *Fucus* plants at control sites in 1990 and 1991 except for the first in date both years for small plants and the first date in 1990 for medium plants (Fig. 2.4). In 1992, in June for medium plants and in August for small plants, there were more plants at oiled sites. At oiled sites, the peak abundances of germlings occurred in 1990, of small plants in 1991 and 1992, of medium plants in 1992 and 1993, and of large plants in 1993 and 1994, indicating that a cohort of plants recruited to oiled sites in 1989 or 1990 and grew to adult plants by 1994.

In the mid intertidal (2 MVD) at control sites there were more medium plants on half of the dates in 1990 and more large plants on all dates in 1990 and 1991 (Fig. 2.5). Similar to the results for the high intertidal, there was a cohort of plants recruiting in 1989 or 1990 and growing to adult size in 1993 and 1994. In contrast to the high zone, there were significantly more germlings at oiled sites on 5 of 6 dates in 1990 and on the first date in 1991, more small plants on all dates in 1991 and on one date in 1992, more medium and large plants on all dates in 1992, and on the first dates in 1993, 1994, and 1995. There were also more germlings at control sites on one date in both 1992 and 1993 and more small plants at oiled sites on the last two sampling dates (1994 and 1995), but the difference between the overall means was slight.

In the low zone, at oiled sites there also appears to be a cohort of plants recruiting in 1989 and 1990 and growing to large plants in 1992 and 1993 (Fig. 2.6). There also appears to be a similar pattern occurring among plants at control sites. The timing of these cohorts seems to be slightly different with the control site plants lagging slightly behind the oiled sites plants. At control sites, there were significantly more small plants in 1992 and on one date in both 1993 and 1994, more medium plants on the second date in 1993 and in 1994, and more large plants in 1995. There were more medium plants at oiled sites on all dates of 1991. Finally, there were more germlings at control sites on all but three sampling dates, but overall mean differences were slight for all dates except for 1991 and 1992.

The density of reproductive plants was greater at control sites on all dates in 1990 and 1991 in the high and mid zones, and on the first date in 1992, there were still more reproductive plants at control sites in the high zone (Fig. 2.7). On the first date in 1993 and both dates in 1994 in the mid zone there were more reproductive plants at oiled sites, corresponding with the greater abundance of plants at that time and tidal level. In the low zone, the were more reproductive plants at control sites on the first date of both 1990 and 1991. Reproductive plants tend to be more abundant early in the summer compared to later, especially at oiled sites.

The density of receptacles per quadrat paralleled the density of reproductive plants in the high and mid zones in 1990 and 1991 (Fig. 2.8). In the high zone this difference persisted through the first date in 1993. In 1994 there were more receptacles per quadrat at oiled sites in the mid (both dates) and low (first date) zones.

In 1990 the percent cover of *Fucus* was greater at control sites at all levels for all dates except for two in the low zone (Fig. 2.9). In the high zone this difference persisted until the second date in 1992 when the cover at oiled sites had increased to levels not distinguishable from those at control sites. In the mid zone, the percent cover of *Fucus* was greater at oiled sites in 1992, 1993, and 1994. In the low zone, there was greater *Fucus* cover at oiled sites on the second date in 1994, but the overall mean difference was minimal.

There was significantly more ephemeral algae (opportunistic species that can recruit at any time of the season and die off over winter) at oiled sites on all dates in 1990 and on the first one (mid zone) or two (high and low zones) dates in 1991 (Fig. 2.10). The abundance of ephemeral algae was generally greater early in the season and was significantly higher at oiled sites on the first dates in 1992 and 1995 for the high zone, in 1993, 1994, and 1995 for the mid zone, and in 1995 for the low zone.

The results from the three site pairs studied were not uniform. The overall results discussed above were typical of two site pairs (1231C/1231X and 3811C/3611X), but the remaining site pair (1732C/1732X) showed few significant differences (Appendix A gives results for each site).

Population Dynamics-Coarse Textured

Algae were sparse in the first two MVDs on coarse textured sites, so data will only be presented for the third MVD. Similar to sheltered rocky sites, at oiled sites a cohort of plants recruited in 1989 or 1990 and grew to the largest size category by 1992 and 1993 (Fig. 2.11). There were significantly more germlings at oiled sites in 1991. Small plants were more abundant at oiled sites on all dates in 1991 and 1992 and on the first date in 1993. Medium and large plants were more abundant at oiled sites on all dates in 1992 and 1993, and large plants continued to be more abundant at oiled sites in 1994. At control sites, germlings were more abundant on the first date in both 1994 and 1995.

Both the density of reproductive plants and receptacles per quadrat were greater at control sites on the first one (receptacles) or two (reproductive plants) dates in 1991 (Fig. 2.12). On the first dates of both 1993 and 1994 there more reproductive plants and receptacles per quadrat at oiled sites.

In 1990 the percent cover of *Fucus* was greater at control sites but in 1992, 1993, and 1994 there was a higher cover of *Fucus* at oiled sites (Fig. 2.12). The higher percent cover at oiled sites corresponds to the greater abundances of large plants at oiled sites at those times. There were no differences in the abundance of ephemeral algae at coarse textured sites (Fig. 2.12).

As with the sheltered rocky sites the overall results presented here were not consistent between the two site pairs. One site pair (2834C/2834X) had few significant differences, thus the other site pair (2333C/2333X) had even more pronounced patterns than those presented here (Appendix A).

Population Dynamics-Reproductive Plant Quality

Generally, the length of reproductive plants was greater for plants at all control sites combined (Fig. 2.13). This was true in the high zone on all dates in 1991 and 1992 and on the second date in 1993, in the mid zone for half of the dates in 1990, on the first date in 1991, and on both dates in 1992, and in the low zone on the first two dates in 1990, on the first dates in both 1992 and 1994, and on all dates in 1993 and 1995. Reproductive plant length was greater at oiled sites on only one date for each zone, in 1990 for the high zone, in 1994 for the mid zone, and in 1991 for the low zone.

In the high zone, the number of receptacles per plant was greater for control plants from 1990 through 1994 except for the second date in 1993 (Fig. 2.14). In the mid zone, there were more receptacles per plant at control sites on the first date in 1992, but on the second date in 1994 and in 1995 there were more receptacles per plant at oiled sites. In the low zone, there were more receptacles per plant at oiled sites on the last date in 1991 and on the first date in 1994.

High Zone Population Dynamics

At the two sites not facing north (121.5 and 76.5 degrees from north) there were lower covers of *Fucus* and lower abundances of large plants, reproductive plants, and the limpet *Tectura persona* at oiled sites (Fig. 2.15). There were no differences in the abundance of *Littorina sitkana* at all sites or of any of the other measured abundances at the north facing site. Using Fisher's test for combining probabilities over all site pairs, there was a lower cover of *Fucus* and abundances of large plants, reproductive plants, and *Tectura persona* .

Reproductive Potential and Egg Viability

At all times and at all levels in 1991, the average number of reproductive plants, out of 12 possible, collected at the three pairs of sheltered rocky sites was greater at control sites than at oiled sites (Table 2.2). Differences were only significant in the first MVD in July and August and in the third MVD in August. This result indicates that there were fewer reproductive plants at oiled sites and is consistent with the reproductive plant densities observed in the population dynamics study (Fig. 2.7).

The average wet weight per receptacle was significantly greater at control sites relative to oiled sites in the third MVD during the second sampling period and in the second MVD during the third sampling period (Table 2.2).

There were two significant differences in the total number of eggs produced per receptacle from oiled and control areas (Table 2.2). In the second MVD during the first sampling period more eggs were produced by oiled receptacles. In the first MVD during the second sampling period more eggs were produced by receptacles from control sites.

The proportion of eggs which were viable was significantly greater at oiled sites during the first sampling period in the second and third MVDs (Table 2.2). During the second sampling period, however, in the second MVD the proportion of viable eggs was greater at the control sites. Late in the season, all released eggs were viable.

Desiccation Effects on *Fucus* Egg Release

Shading was effective at reducing environmental stress. Shade treatments produced significantly lower temperatures and desiccation rates than the sun treatments (Fig. 2.16). 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. 2.16). In July, shaded plants released more eggs than those kept in direct sunlight, while in August the shaded plants released almost no eggs. It is likely that few of the plants collected in August were fertile due to the lateness of the season. This idea is supported by the fact that there were significantly fewer eggs released in August than in July. However, this experiment should be repeated in order to further test the effect of shading on egg release in *Fucus*.

Floating *Fucus* Fertility

The number of eggs released did not differ between drifting and attached plants (Fig. 2.17). There were, however, more eggs released during the third sampling period compared to the earlier dates. For attached plants, a greater proportion of eggs were fertilized in the third sampling period compared to both earlier dates (Fig. 2.17). Fertilization rates remained constant for drifting plants and were lower than for attached plants in July and August. Receptacles of drifting plants were heavier than those on attached plants at all times, and receptacle size peaked in July (Fig. 2.17).

The average density of drifting plants ranged from 0.034 to 0.002 plant per square meter, and all drifting plants found were fertile. Although these open water densities seem low, plants were often observed aggregated near shorelines, resulting in a much higher plant density. Thus, drifting plants can be locally abundant.

Short Range Dispersal Patterns

There was a greater proportion of eggs settling closer to source plants compared to further away, but there were no differences in the percent of eggs settling at different directions from the source plants (Fig. 2.18). Dispersal distances were very limited with 95% of the observed eggs settling on plates 20 cm or closer to the source plants. The two-way ANOVA yielded a significant main effect of distance ($F=45.190$; $p<0.001$), no effect of direction ($F=0.891$; $p=0.448$), and no interaction ($F=0.948$; $p=0.524$). Post-hoc analysis indicated that more eggs settled 0, 10, and 20 cm from the source plants compared to 40, 80, 120, and 200 cm. Also, the percent of eggs settled at 40 cm was greater than percentages at 120 and 200 cm.

Fucus Egg Settlement

There were always significantly more eggs at control sites at the 0.5 MVD (Fig. 2.19). At the 1 and 2 MVDs there were significantly more eggs at control sites at all times in 1991 and 1992 except in May 1991 at 2 MVD. In the upper two tidal levels virtually no eggs settled at oiled sites in 1991 and 1992 while the control sites had average settlement rates of up to about 250 eggs per plate per day, corresponding to over 200,000 eggs per square meter per day. At control sites, settlement rates were lower at the 2 MVD than at the 0.5 MVD level with a maximum of about 100 eggs per plate per day. By 1993 at the 2.0 MVD level settlement rates had increased to converge with those observed at control sites indicating that there may be some recovery from the effects of the oil spill and clean-up efforts. Recovery can also be seen at the 1 MVD level from 1993 onward where settlement rates at oiled sites increased from 1991 and 1992 levels to converge with control levels, but occasionally (4 of 10 dates) there were more eggs found at control sites. In August of 1995 there were more eggs at oiled sites in both the 1 and 2 MVDs. Egg settlement rates at oiled sites in the 0.5 MVD increased slightly since 1992 but had not converged with control site rates by 1995. These differences were generally consistent at all sites examined (Appendix B).

In general, the distance to the nearest fertile *Fucus* plant, which is inversely related to the density of reproductive plants, was greater at oiled sites compared to control sites (Fig. 2.20). At the 0.5 MVD the distance to the nearest fertile *Fucus* plant was significantly greater at oiled sites on all dates although convergence of means began in 1993. At the 1 MVD the distance to the nearest fertile plant was also greater at oiled sites in 1991 and 1992, but in July 1993 and 1994 the reverse is true. At the 2 MVD fertile plants were further away at oiled sites in 1991, but in June and August 1993 and May and July 1995 they were slightly further away at control sites. On the last sampling date at 2 MVD the distance was again greater for oiled sites. At all levels, the distance to the nearest fertile plant remained relatively constant at control sites, but at oiled sites the distance decreases over time to converge with control levels. The differences averaged over all site pairs were also seen at individual site pairs (Appendix B).

In 1994, 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. 2.21). 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: Desiccation and Whiplash

Wetted cotton balls lost 10-20% of their total mass during the five hours of the field desiccation trial. The percent cover of germlings after 11 days in the field was negatively correlated with drying rate and there seems to be a threshold effect (Fig. 2.22). In areas where the desiccation rate exceeded about 0.2 g/hr few germlings survived, while in areas with desiccation rates of less than about 0.15 g/hr most of the germlings survived. Only four areas had intermediate survival rates; most areas had either high or low survival of germlings.

Germlings growing on dishes subjected to whiplash from large plants showed significantly higher mortality than germlings without large plants present. The density of germlings on dishes subjected to whiplash was 0.73 ($\pm$0.32 SE) per field of view under a dissecting microscope at 25x power. In contrast, on control dishes germling density remained at the original level of 77.45 ($\pm$7.90 SE) per field of view ($p<0.010$, $df=5$). Germlings on dishes subjected to whiplash were found only in the corners between the side and bottom of the dishes where adult fronds could not touch, suggesting that physical contact with the adult plants was necessary to remove germlings. If shading, or chemical release from adult plants caused germling mortality, then surviving germlings would be evenly dispersed over the petri dish.

Fucus Recruitment: Substrate Heterogeneity

The size of the tile grooves spanned the size range of most cracks seen in the rock surface (Fig. 2.23). The initial seeding densities on the grooved tiles varied between groove widths but not depths (Fig. 2.24A, Table 2.3). There were fewer germlings in narrow grooves than in wide 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 or to increase over time. After one summer almost no germlings survived out of grooves and after one year none survived (Fig. 2.24B, C). In grooves, however, about 10% of the germlings survived. After two months, survival rate was higher in medium and narrow grooves than in wide grooves, especially in shallow grooves (Fig. 2.24B, Table 2.3). After one year, survival was greater in narrow relative to wide grooves, and in deep compared to shallow grooves (Fig. 2.24C, Table 2.3).

Natural recruitment was monitored on the unseeded tiles for the first year. In July 1993 there was no difference in the number of visible germlings per tile (t-test, $df=45$, $p=0.282$), so seeded and unseeded tiles were lumped for analyses after this date. Germlings never recruited naturally onto the tiles out of grooves. No significant differences were detected comparing the number of microrecruits in the different sized grooves in August 1992 (Fig. 2.25A, Table 2.4). In June 1993, however, there were significantly more microrecruits in medium and narrow grooves compared to wide grooves (Fig. 2.25B, Table 2.4). There were significantly more visible recruits in deep grooves than in shallow grooves in 1993 and 1994 (Fig. 2.25C,D,E, Table 2.4). On both sampling dates in 1994 there were more recruits in medium grooves compared to either wide or narrow grooves (Fig. 2.25D,E, Table 2.4). In contrast to *Fucus*, barnacles were significantly more abundant in wide grooves compared to other widths in both 1993 and 1994 (Fig. 2.24D,E, Table 2.3).

Fucus Recruitment: Canopy, Tidal Height, and Oiling

To examine the effects of *Fucus* canopy, tidal height, and oiling on germling survival, the number of germlings in all grooves were counted. The dependent variable is the percent survival or number of germlings per tile regardless of groove size. Both percent survival in August 1992 and number of recruits in July 1993 were greater under *Fucus* canopy and at unoiled sites (Fig. 2.26, Table 2.5). There were no other main treatment effects on any of the other dates sampled.

The temperature of the tiles on a hot day was significantly greater at oiled sites compared to unoiled sites, and tiles were significantly cooler under *Fucus* canopy than tiles with no canopy (Table 2.6). The maximum tile temperature recorded was 43.6°C.

Fucus Recruitment: Caging Study

The effect of cages and herbivores on germling recruitment was examined by evaluating the number of germlings per plate, ignoring groove size. If there were differences between fully caged tiles and tiles with open cages, then this was considered as an herbivore effect since the only difference between the two treatments was the presence or absence of herbivores. If there were differences between uncaged tiles and open cages, this indicated that there was an effect of the cages.

There were no significant effects of caging or tidal zone on the survival of germlings (Fig. 2.27, Table 2.7). In the high zone, however, there tended to be higher survival in open and full cages than on uncaged tiles, suggesting an effect of the cages.

The number of recruits in 1993 showed significantly more recruits on the fully caged tiles (Fig. 2.28A, Table 2.7), indicating an herbivore effect. By September 1994, the number of germlings on tiles with open cages had increased to equal the number on fully caged tiles, but the germling number on uncaged tiles remained significantly lower than either cage treatment. Thus, at the end of the experiment there was a significant cage effect. Germlings were longer in the absence of herbivores. The length of germlings was always greater on fully caged tiles compared to either open caged or uncaged tiles (Fig. 2.28B, Table 2.8).

Growth and Mortality

In the high zone there was a lower density of plants of all size classes at oiled sites in 1991. The mean distance to the nearest plant in all size classes was significantly greater at oiled sites than at control sites in the high zone (Fig. 2.29). There was also a significantly greater distance for large plants in the mid zone at oiled sites.

The growth rate of the population as a whole, indicated by the net growth rate including both positive and negative values, was generally not significantly different between oiled and control sites. Net growth rates were generally greater at oiled sites than at control sites in the high zone for all size classes on all dates (Fig. 2.30), but significant differences were detected only for medium plants during the 1991 and 1992 winters. In the mid zone, these were no differences between oiled and control sites in net growth rate (Fig. 2.31). In the low zone, growth rates were significantly greater at the oiled sites compared to control sites for small plants only during the 1992-93 winter, but this pattern was reversed in the next winter (Fig. 2.32). Large plants also grew faster at control sites in the low zone in the 1993 winter.

Yearly net growth rates at the oiled sites were almost always greater than at control sites from 1991 until 1993. Significant differences were detected in the high zone for small and medium plants from 1991 to 1992 (Table 2.9). At control sites plants in all size classes lower in the intertidal grew faster than plants in higher zones (Table 2.10). These growth differences were significant in both winters and in the summer of 1993 (Table 2.10). At oiled sites, however, there were no growth patterns related to tidal level.

Absolute growth rate did not vary with the length of the plant; all plants grew at the same absolute rate regardless of initial size. Of the 14 regressions (7 time periods for both oiled and control sites) only five showed a significant relationship between growth rate and initial size (Table 2.11). In all five cases the slope of the regression line was quite small ranging from 0.002 to 0.006. The proportional growth rate, measured by the percent change in length, did vary with initial size of plant (Table 2.11). All 14 regressions yielded a negative slope indicating that shorter plants grew relatively faster than longer plants. All but two of the regressions showed a significant relationship between initial length and percent change in length. There were no significant effects of net flow rate on the growth of *Fucus* (Fig. 2.33). However, the fact that the power of the experiment was low and a p-value of 0.075 was obtained for the summer data, suggest that the trend of lower growth at higher flow rates should be re-examined.

There were no differences in the mortality rate (% mortality/week) among tidal heights, plant size, or oiling (Table 2.12). Mortality, however, was almost twice as high during the summer compared to winter. Surrounding canopy affected the survival of marked plants. Almost half of the plants (44%) that had the surrounding canopy removed had died after eight weeks. This mortality rate (5.5%/week) is about twice that of any naturally observed mortality during the growth studies. At the same time, only one of 18 (5.5%) plants that had the surrounding canopy left intact had died. Thus, the mortality rate (0.7%/week) of control plants was about one eighth of that for canopy removal plants (p=0.018, Fisher's exact test).

Substratum Use by *Fucus*

Analyses of the proportion of small, medium, and large plants using different substrates compared to substrate availability were done using the Selectivity Indices (Krebs 1989):

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

where **Puse** = the proportion of plants of each size category using a substrate and **Pavailable** = the percent cover of that substrate. A positive SI indicates use greater than the availability of the substratum, and a negative value shows the opposite. The Selectivity Index (SI) results were plotted with 95% confidence intervals so that values significantly different from zero could be visually identified.

In 1994, all plant sizes had SIs significantly less than zero for smooth rock (Fig. 2.34). Generally, the SIs for all plant sizes were positive for crevices but were significantly different from zero only for medium and large plants at oiled sites. For barnacle substrates, medium and large plants had significantly lower SIs than zero, but small plant SIs were near zero.

In 1995 for rock substrates including both smooth rock and crevices, small and medium plants at protected sites had SIs less than zero but large plants had SIs greater than zero (Fig. 2.35). At exposed sites small plants also had significantly negative SIs, but the SIs for medium and large plants did not differ significantly from zero. For barnacle substrates the situation was reversed. At protected sites small and medium plants had significantly positive SIs, but large plants had negative SIs. At exposed sites, none of the SIs differed significantly from zero.

The SIs also varied between plant sizes for all substrate types in 1994 (Fig. 2.34, Table 2.13). For smooth rock surfaces, small plants had significantly lower SIs than either medium or large plants. Small plants also had lower SIs than large plants for crevices. All plant sizes differed significantly for barnacle substrate with small plants having the highest SIs and large plants the lowest. In 1995, the three plant sizes differed significantly for rock substrates with small plants having the lowest SIs and large plants the highest (Fig. 2.35, Table 2.14). For barnacle substrates, large plants had lower SIs than either small or medium plants.

There were also differences among sites in the value of SIs for the different substrate types. In 1994, oiled sites had higher SIs for crevices and lower SIs for barnacles (Fig. 2.34, Table 2.13). There was also a pair effect for each substrate type, indicating differences between matched pairs of oil and control sites. In 1995, there was a significant exposure by size interaction term for both rock and barnacle substrates (Fig. 2.35, Table 2.14). For rock substrates, there were generally higher SIs at exposed sites compared to protected sites, but this was not true for large plants. For barnacle substrates, the SIs were higher for both small and large plants at the exposed site compared to protected sites. There were not any significant tidal level effects in 1995, so data from the two tidal levels were pooled for presentation.

Breaking Strengths and Mortality of *Fucus* on Barnacles and Rocks

At both the exposed and protected sites, the breaking strength of *Fucus* was almost three times greater for *Fucus* growing on rock compared to plants growing on barnacles of all species (Fig. 2.36). There was no difference in the breaking strength of *Fucus* between sites.

Mortality was higher for *Fucus* growing on barnacles compared to plants growing on rock (Fig. 2.37). After both six and 14 weeks, a significantly higher proportion of plants survived when they were growing on rock compared to barnacles.

DISCUSSION

Population Dynamics

The information gathered on *Fucus* size indicates that in some areas many larger plants were killed or removed by the oil spill and subsequent cleanup efforts. The removal of large plants at oiled sites resulted in fewer reproductive plants as well as less receptacles per quadrat. These results occurred mostly in the first two meters of vertical drop at sheltered rocky sites, showing that the effects of the spill on *Fucus* were concentrated in the upper portion of the intertidal zone in this habitat. Ephemeral algae, however, were more abundant in the third MVD, demonstrating that the effects of the spill were not limited to the upper intertidal. Also, at coarse textured sites where algae were only abundant in the low intertidal, lower abundances of large plants were observed in the third MVD at oiled sites.

In addition to differences in plant densities, the condition of reproductive plants at all sites showed differences between oiled and control sites. At oiled sites, plants were shorter and had fewer receptacles than at control sites, possibly due to a larger proportion of relatively young reproductive plants at oiled sites. Convergence was seen in 1994 and 1995 for both length and number of receptacles per plant, indicating relatively slow recovery due to low growth rates, rapid loss of plant fronds, limited production of receptacles, or a combination of these processes. The fact that the number of receptacles per plant was lower at oiled sites indicates a significant problem for recolonization. *Fucus* eggs tend to travel less than 0.5 meters from their source plant (McConnaughey 1985, van Tamelen and Stekoll 1995, see below), therefore reductions in receptacle number have contributed to reductions in egg settlement rate, leading to increased recovery times.

Lower percent coverage of *Fucus* at oiled sites in 1990 and 1991 was a result of the removal of large and reproductive plants. *Fucus* cover was lower at the same oiled sites and tidal levels where the density of large plants was reduced. The loss of the dominant alga also may have led to increases in the cover of weedy, ephemeral algal species such as *Cladophora*, *Scytosiphon,* and *Enteromorpha*. In many habitats, ephemeral species are indicative of recently disturbed areas where the competitive dominant has been removed (Lubchenco 1978, Sousa 1979). There is, however, an alternative explanation to the observed increase in ephemeral algae. These types of algae are typically more susceptible to grazing by molluscan herbivores.

Since post spill decreases in the abundance of these herbivores have been demonstrated in Herring Bay and other spill affected regions (Houghton *et al.* 1996, Lees *et al.* 1996) the lack of herbivory may have allowed ephemeral algae to flourish.

The general results described above were not uniform at all sites. Only two, the gently sloping pair 1231C/1231X and the vertical wall pair 3811C/3611X, of the sheltered rocky site pairs sampled showed patterns indicative of major disturbance. The remaining site pair, the intermediately sloped pair 1732C/1732X, showed little or no effect of the oil spill even though oiling was heavy at this site. The variability among sites may be due, in part, to different cleanup treatments applied to the sites. Based on information provided by the Alaska Department of Natural Resources and on field observations in the spring of 1990 we determined that site 1732X probably was not treated to remove oil, but sites 1231X and 3611X were treated. Where *Fucus* canopy was removed, the rock was mostly free of oil except for small amounts in cracks and crevices in the rock in 1990. There were often holdfasts still attached to the rock indicating that *Fucus* was once abundant. These observations suggest that these sites were treated with high pressure, hot water in 1989.

Recovery Processes

Recovery of *Fucus* has proceeded at varying rates between sites and tidal heights. For example, at site pair 1231C/1231X in the second MVD there were more germlings (0-2.0 cm) in 1990 at the oiled site. Later in 1990 and early in 1991 there were more small plants (2.5-5.0 cm), in 1991 there were more medium plants (5.5-10 cm), and in 1992 and 1993 there was an increase of large plants at the oiled site. Thus, over time the plants grew into successively larger size classes.

Similar patterns were found at the vertical wall sites, 3811C/3611X, and the coarse textured pair, 2333C/2333X. The rate, magnitude, and variation of recovery, however, varies slightly among site pairs. Much of this variation could be explained by variations in environmental conditions and starting points. For example, recovery at the vertical site 3611X was faster, had a higher magnitude, actually increasing above control densities, and had less variation compared to the gently sloping site 1231X. The vertical walls faced northwest and rarely had direct sun at low tide, leading to lower desiccation stress. Lower stress would have the effect of enhancing recolonization as recruitment may be limited by desiccation and heat stress (Brawley and Johnson 1991, see below).

Recovery in the upper intertidal at sheltered rocky sites has proceeded more slowly than in lower zones. The number of 5-10 cm and >10 cm plants increased in 1991 (5-10 cm) and in 1992 (>10 cm) at oiled sites in the first MVD to levels similar to those at control sites (Figs. 2.4-2.7). These increases occurred earlier in lower tidal levels. A similar pattern of recovery was seen in Bristol Bay when larger numbers of small plants were observed in plots cleared of *Fucus* (Kendziorek and Stekoll 1984). Predictably, as the number of plants at oiled sites increased, the percent cover of *Fucus* also increased, especially as the plants grew to larger sizes.

At the end of the 1992 season in the mid intertidal, there were dense beds of young *Fucus* plants just starting to become reproductive. These plants were found in higher densities than the plants in control areas due to their smaller size, but by 1994 the density of *Fucus* plants fell to values similar to the control sites. In the mid intertidal, *Fucus* seems to have fully recovered by 1994. In the upper intertidal, where desiccation stress is high, recovery of *Fucus* has proceeded more slowly, and significant differences for some of the variates were still detected in 1995.

Egg Production and Dispersal Mechanisms

Both egg production and dispersal can have great influences on recovery. If the production of viable propagules or dispersal is limited, then recovery of denuded shores will be retarded. There were no consistent and biologically meaningful differences detected between oiled and control sites in the egg release rate of receptacles, the wet weight of receptacles, or the viability of released eggs. It appears that the oil spill either had no effect upon *Fucus* egg production and viability or *Fucus* plants had recovered from any oiling effect by 1991.

Many seaweeds have been shown to have short distances between new recruits and parent plants (Anderson and North 1966, Dayton 1973, Deysher and Norton 1982, Paine 1979, Sousa 1984, Vandermeulen and DeWreede 1986, Chapman 1986, Reed *et al.* 1988, Norton 1992). All of these studies, however, examined recruitment at various distances from source plants. There are many factors that vary with distance from source plants, especially those that form canopies, such as desiccation and herbivory (Brawley and Johnson 1991). Both of these factors have been shown to increase mortality among new recruits (Lubchenco 1983, Chapman 1990, Brawley and Johnson 1991, see Chapman 1995 for a review). It is possible that initial dispersal distances are longer than those observed for recruits but that mortality further from canopy forming adults is rapid and severe. Kendrick and Walker (1991), however, found short dispersal distances of settling *Sargassum muticum* propagules that were dyed and vacuumed up using a venturi pump. This is the only study that has investigated dispersal distance at the settlement stage of an alga. In our experiments 96% of observed eggs settled within 20 cm of the source plants, indicating short dispersal distances for *Fucus gardneri.*

There are a variety of mechanisms that could lead to short dispersal distances in *Fucus*. *Fucus* eggs are either released at low tide (Brawley and Johnson 1992) or in the water column after reimmersion as the tide floods (Pollock 1970, Müller and Gassmann 1985). Short dispersal distances should occur if eggs are released at the start of low tide with large quantities of mucus (Brawley and Johnson 1992), and these eggs would have enough time to begin adhering to the substrate (Vreeland *et al.* 1993), reducing the likelihood that the eggs would be swept away by water currents. On the other hand, eggs released into the water column may maintain short dispersal distances by having relatively large, spherical eggs (75 μm) which would decrease frictional resistance and increase sinking rates (Coon *et al.* 1972, Okuda and Neushul 1981). If the eggs are released with mucus, as they are when released during low tide (Brawley 1990), then their effective diameter would be increased resulting in even faster sinking rates (Norton 1992). Mucus could also serve to temporally bind eggs together producing a large mass of eggs which would rapidly fall to the substrate (Brawley, 1990, Norton, 1992). McConnaughey (1985) found that the distribution of settled eggs was leptokurtic, suggestive of dispersal mechanisms similar to pollen in the wind.

The idea that long distance dispersal in seaweeds can be accomplished by drifting plants is not new (Russell 1967, Dayton 1973, John 1974, Norton 1977a, b, Deysher and Norton 1982, Norton and Mathieson 1983, van den Hoek 1987, Paine 1988, Norton 1992). No studies so far have actually ascertained that drift plants are fertile and able to release viable propagules. Indeed, Norton and Mathieson (1983) have suggested that drift plants have lower reproductive abilities compared to attached plants due to lower nutrient fluxes. Norton (1992) suggests that seaweeds likely to be good drift dispersers are those that are both monoecious and self-fertile. *Fucus gardneri* satisfies both of these requirements and has been shown in this study to release many, viable propagules.

Fucus may have evolved morphological features which enable it to utilize drift plants as mechanism to colonize new areas. For example, the inflated receptacles of *Fucus* may serve to keep unattached plants near the surface of the water so that when they encounter a shoreline, they will release eggs into a suitable intertidal habitat. Also, the propensity to release eggs either during or after desiccation may also serve to increase the chances of eggs released by drift plants encountering favorable habitats, since drifting plants will only be dried when they are washed up on shorelines. Thus, *Fucus* is similar to vascular plants which have seeds adapted for both long and short range dispersal although the mechanisms are very different the result is the same. Some propagules land in areas close to where the parent plant grew and survived to reproduce while others land in novel areas.

Settlement Patterns

In general, the number of eggs settling on oiled shorelines in the high intertidal was much lower than on control sites even six years after the spill (Fig. 2.19). In lower tidal levels the settlement rate was lower at oiled sites in 1991 and 1992, but by 1993 there is little or no difference in settlement rates at control and oiled sites. This pattern was spatially consistent, being observed at all 12 site pairs studied. Also, at the two pairs examined over the three years of the study, the pattern was temporally consistent, showing recovery of settlement rates in lower zones and little or no recovery in the highest zones.

The density of reproductive plants at oiled sites was lower as shown by longer distances to the nearest fertile plants in most cases (Fig. 2.20). This result was also consistent spatially and temporally, showing faster recovery in lower zones and less recovery in high zones. In other experiments this study has also documented lower abundances of reproductive *Fucus* plants at sites impacted by oil spills. Because eggs rarely travel more than one half meter from the parental plant and are much more abundant near the source plant (McConnaughey 1985, van Tamelen and Stekoll 1995, Fig. 2.18), the lower settlement rates observed can be attributed to lower densities of reproductive plants. At the 2 MVD level in 1992, however, the distance to the nearest reproductive plant converged between oiled and control sites, but the settlement rate at oiled sites remained low. Van Tamelen and Stekoll (1996) observed fewer receptacles per reproductive plant at oiled sites than at control sites in Herring Bay, which may contribute to lower settlement rates at oiled sites.

Norton and Fetter (1981) presented evidence from the lab that *Sargassum* propagules settle in higher densities at higher flow rates. Their study, however, did not correct for the shorter amount of time propagules have to settle at higher flows; propagules travelling at 0.5 m/s will have half as long to settle compared to propagules travelling at 0.25 m/s over the same surface area. Thus, their study may not be applicable to field situations because it was done in the lab making extrapolation to the field difficult and there was no time correction for different water velocities. By measuring settlement rates and net water flow simultaneously in the field, this study documented a negative relationship between water velocity and settlement rate. This relationship may be confounded, however, by the fact that control sites that had higher settlement rates also had lower water velocities. Therefore, the negative relationship between water velocity and settlement rate may be due to either water velocity differences or the effects of oiling and the removal of reproductive plants.

Recolonization will be greatly inhibited by exposure to the rigorous environment in the upper intertidal where *Fucus* canopy has been removed by the oil spill or clean-up activities. Where reproductive *Fucus* plants are sparse or have fewer receptacles, settlement of *Fucus* eggs can be greatly reduced. Low settlement rates can impede recolonization where *Fucus* has been removed by an oil spill or other disturbance.

Recruitment

After settling on rock surfaces, *Fucus* sporelings face a variety of challenges before reaching adulthood. Cracks and crevices in the substrate 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). In this study, germlings survived poorly out of grooves (Fig. 2.24B) and never recruited naturally out of grooves (Fig. 2.25). Since the recruits visible after one year were evenly dispersed among the groove widths, settlement appears to be unbiased toward groove width. After an initial even settlement, the chance of survival was greatest in narrow and medium width grooves. In contrast, recruitment to larger sizes was greatest in both deep and narrow grooves. Wide grooves may be wide enough to allow grazing by small littorinid snails and limpets while narrow grooves may not allow germlings to grow larger since zygotes were only slightly smaller than the grooves. There may also be competition for wide grooves since barnacles recruited most abundantly to these grooves, often forming a line of new recruits only in the wide grooves. This heavy recruitment of barnacles may have prevented the establishment of some *Fucus* germlings.

Although cracks and crevices increased survival and recruitment, cracks alone were not sufficient to allow survival of young *Fucus* germlings. Germling survival and recruitment was lower without *Fucus* canopy regardless of the presence of cracks, indicating that *Fucus* canopy had a positive effect on recruitment in Herring Bay (Fig. 2.26). The lack of significant canopy effects in 1994 may have been due to the loss of canopy plants over and near some tiles that were supposed to be in canopy. Other studies have shown that *Fucus* canopy can have both positive and negative effects on germling recruitment (Menge 1976, Lubchenco 1986, Vadas et al. 1992, Brawley & Johnson 1991, Chapman 1995). Germlings may be brushed off the rock surface by adult plants, that were abundant at unoiled sites, as they are thrust back and forth by wave action (Dayton 1971, Vadas et al. 1992). Conversely, at oiled sites lacking a healthy canopy of adult *Fucus* germlings 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 & Johnson 1991). In Herring Bay, germling survival was found to be higher where desiccation stress was lower (Fig. 2.22), as well as under the *Fucus* canopy (Fig. 2.26). Germling survival was also lower at oiled sites lacking *Fucus* canopy and thus subjected to more severe heat and desiccation stress. Tile temperatures were lower under *Fucus* canopy and higher at oiled sites, with a maximum of 43.6°C, showing that temperatures can be severe in this region. It appears that the positive effects of *Fucus* canopy of reducing heat and desiccation stress are more important in Herring Bay than the negative effects of whiplash by the canopy. 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 in higher intertidal zones.

In normal situations with a healthy canopy of *Fucus* germlings are subjected to grazing pressures from molluscan herbivores such as limpets and snails. In this study, the results of the caging study were not always easy to interpret. There may have been an effect of cages in the high zone on germling survival since tiles with either open or full cages tended to have higher survival rates than tiles without cages (Fig. 2.27). Since the cage effect was only seen in the high zone, and because germling survival was less where desiccation was high (Fig. 2.22) and in the absence of *Fucus* canopy (Fig. 2.26), this potential cage effect can be attributed to the reduction of heat and desiccation stress by the cages. The number of recruits was greater in full cages in 1993, indicating that herbivores had a negative effect on recruitment (Fig. 2.28). In September 1994, however, the number of germlings on tiles in open cages had increased to equal the number on tiles in full cages, indicating that there was a cage effect. Thus, both the absence of herbivores and shading by cages promotes recruitment with the former acting faster than the latter. Herbivores also affected germling net growth; germlings on tiles with full cages averaged 7-8 times longer than germlings on other tiles. Longer germlings may be a consequence of reduced herbivory pressure. But the lack of evidence of extensive grazing marks on the germlings outside of cages suggests that growth of the germlings inside cages may have been enhanced. Such enhanced growth rates in fully caged tiles without herbivores may be due to less energy being allocated to anti-herbivore compounds, allowing more energy to be devoted to growth (Yates & Peckol 1993).

Recolonization will be greatly inhibited by exposure to the rigorous environment in the upper intertidal where *Fucus* canopy has been removed by the oil spill or clean-up activities. Where reproductive *Fucus* plants are sparse or have fewer receptacles, settlement of *Fucus* eggs can be greatly reduced. Low settlement rates can impede recolonization where *Fucus* has been removed on a large scale by an oil spill or other disturbance.

Once eggs have settled on a denuded shoreline, they may face additional barriers to recolonization. At denuded sites, since there is no protective *Fucus* canopy, germlings face much greater desiccation and heat stress, leading to lower growth and survival rates. Lower growth rates as germlings will increase the time spent in a stage more vulnerable to herbivory, whiplash, heat, and desiccation, further decreasing their chances of survival to adulthood. On the other hand, denuded sites tended to have fewer herbivores (Highsmith et al. 1996) so germling survival, recruitment, and growth may be greater in highly disturbed sites such as the oiled and cleaned sites.

Growth and Mortality

An unexpected result of the oil spill and clean-up was that newly recruited *Fucus* plants grew faster at oiled sites compared to control sites. These enhanced growth rates may have been due to reduced herbivory pressure or to reductions in plant densities at the oiled sites leading to less intraspecific competition for light, nutrients, or space (Kendziorek and Stekoll 1984). The effect of increased water motion at oiled sites tended to lead to decreased growth rates (Figure 2.33) which is the opposite of the observed pattern.

Growth rates reported here are similar to rates reported in other studies of fucoid algae on the west coast, but lower than those reported on the east coast. The maximum growth rate was 0.45 cm/wk in summer 1992 (Fig. 2.32), which is close to the maximum rate reported for *F. distichus* ssp. *edentatus* (approx. 0.47 cm/wk) in central Puget Sound (Thom 1983). The maximum growth rate at control sites, however, was only 0.36 cm/wk. These maximum rates are lower than those reported for *F. distichus* ssp. *edentatus* (1.0 cm/wk) in Maine (Keser and Larson 1984) and for *F. vesiculosus* (0.88 cm/wk) along the New England coast (Mathieson *et al.* 1976). Other studies of fucoid algae have reported average yearly growth rates of 0.63 cm/wk for *F. distichus* ssp. *edentatus* in New England (Sideman and Mathieson 1983) and 0.30 cm/wk for *F. spiralis* in New Hampshire (Niemeck and Mathieson 1976). The maximum yearly growth rate reported in this study was 0.20 cm/wk.

These differences in growth rates may be due not only to species differences, but also to latitudinal differences (Mathieson *et al.* 1976). Light and temperature seem to be key environmental factors controlling fucoid growth (Mathieson *et al.* 1976, Niemeck and Mathieson 1976). At high latitudes, such as Alaska, seasonal fluctuations in light and temperature are more extreme than in temperate areas. Because of these extreme differences, growth dynamics might also be quite different. Additionally, most studies of fucoid growth show rapid growth during spring-summer, when light and temperatures are increasing. In our study, winter growth rates were sometimes greater than summer rates. We measured plants only from May to August. Due to this limited sampling regime, rates reported for winter include early spring growth, which might have been quite rapid, thus inflating the winter growth rates.

Small amounts (200 ppb) of oil have been shown to stimulate *Fucus* growth, especially in juvenile plants (Steele 1977), possibly due to nutritional benefits from the hydrocarbons (Stebbings 1970). Steele (1977) found that above this level, however, there is an adverse effect of oil on growth. Stebbings (1970) found that the adherence of thick layers of oil inhibits gas exchange with the air. Other studies have shown that adult *Fucus* plants are fairly resistant to oil (Thomas 1973, Nelson 1982, Crothers 1983), unless tarry masses adhere to the fronds (Thomas 1973, Nelson 1982). This resistance is perhaps because of a mucilage layer that protects the algae (Thomas 1973). Oil was never observed adhering to any of the plants in this study. Any direct effects of oil would be due to hydrocarbons found in the water column.

Greater observed growth rates at oiled sites in the upper intertidal for all size classes during 1991-1992 may be due to either indirect effects of the oil spill (*e.g.* herbivory, density effects, substrate availability) or to site differences not related to oiling. For example, there was greater ice scour in the southeastern portion of the bay where control sites were located (van Tamelen and Stekoll 1996). Ice scour may have caused breakage of plant stipes, resulting in lower or negative growth at these sites.

Growth rates in this study varied with tidal height (Table 2.10). Other studies have found higher growth rates in the low intertidal (Schonbeck and Norton 1978, 1979, Keser and Larson 1984). In the upper intertidal, slower growth rates may be related to a decrease in photosynthesis since the plants spend more time out of water each day. In addition tissue damage due to desiccation (Schonbeck and Norton 1978) or nutrient shortage (Schonbeck and Norton 1979) are possible factors. We observed such growth patterns at control sites, but at oiled sites we failed to detect any relationship of growth to tidal height. At oiled sites, plant density was reduced more in the upper intertidal compared to lower zones (van Tamelen and Stekoll 1996, this study), thus intraspecific competition was least in the upper zones, allowing plants in the high zone to grow as fast as plants lower down.

Our data show that large plants grew faster than small plants (Table 2.11). Although larger plants had higher absolute growth rates, smaller plants grew proportionately faster (i.e. greater percent change in length). Ang (1991) suggested that growth is size-dependent and reported highest growth rates for plants that were between 4.5 and 9.5 cm in length. Some plants larger than 9.5 cm had similarly high growth rates, but others had negative growth rates due to attrition, resulting in lower overall growth rates. Niemeck and Mathieson (1976), however, showed no relationship between initial size of plant and growth rates, but they did not distinguish between potential and net growth rates.

Percent mortality varied with season (Table 2.12). Paradoxically, the highest mortality rates were in the summers when growth rates were highest. Others have found that mortality is greatest during winter when storms, and freezing, and ice scour can kill plants (Thom 1983, Keser and Larson 1984, Ang 1991). The reasons for the high summer mortality rates are unclear, but may be related to the high summer temperatures and desiccation stress.

Habitat Use

Few studies have examined the use of barnacles by fucoids relative to the availability of barnacles. Farrell (1991) mentions that *Pelvetiopsis* and *Fucus* are almost always growing on barnacles except where herbivores have been removed. His study areas consist of almost 100% barnacle cover and are subjected to heavy barnacle recruitment. There are few bare spaces to be colonized by fucoids, and those that do become available are quickly covered by spat. DeVogelaere and Foster (1994) examined the proportion of *Fucus* recruits on cracks, smooth rock, barnacles, and tar relative to the availability of those substrate types. They found that *Fucus* use differed from availability, but did not statistically compare the use of a particular substrate to its availability. Even though DeVogelaere and Foster (1994) worked in the same location as this study, they obtained much higher estimates of the cover of cracks in the substrate (about 47% for their study compared to about 20% in this study). This discrepancy probably results from the techniques used to estimate the coverage of cracks. DeVogelaere and Foster (1994) counted the proportion of 10x10 cm squares dominated by cracks and failed to define what constitutes a crack. From our experience, cracks may seem visually abundant even when the actual abundance is relatively low, thus DeVogelaere and Foster (1994) may have over estimated the abundance of cracks by using visual techniques (see Dethier *et al.* 1993 for a review of percent cover techniques). They may also have used a less stringent definition of cracks than we did here.

This is the only study to examine the selectivities of different sized fucoids on various kinds of substrate. DeVogelaere and Foster (1994) compared only percent cover of substrates and proportion of plants using the substrates, and they only looked at plants less 2.5 cm in length. Generally, small plants (<2.5 cm) either show a positive or no relationship to barnacles or crevices in the substrate, and small plants tend to avoid smooth rock (DeVogelaere and Foster 1994, Figs. 2.34-2.35). Large plants (>10 cm), on the other hand, were consistently negatively associated with barnacles and medium sized plants (2-10 cm) were intermediate between small and large plants. Since *Fucus* plants are not mobile, this shift in substrate use indicates that there is higher mortality on barnacles compared to plants growing on either smooth or creviced rock (Fig. 2.37). Indeed, over the summer of 1995, we observed nearly double the mortality rate of *Fucus* plants growing on barnacles compared to those individuals growing on rock. The mechanism for this mortality seems to be dislodgement. Plants growing on rock had breaking strengths almost three times of those growing on barnacles regardless of barnacle species (Fig. 2.36).

It is interesting that we found no effects of exposure on either substrate use or breaking strengths of *Fucus*. *Fucus* is known to vary in many morphological characteristics as a function of wave exposure, but it appears that breaking strength is unaffected by exposure. The adhesive strength of plants is the same in wave-protected and exposed locations. The breaking strength of the stipe of *Fucus* stipes may vary with wave exposure (Blanchette, unpublished data), but this was not assessed in this study, since most plants failed at the interface between the holdfast and the substrate.

Recruiting onto barnacles may seem to be a good strategy for young fucoid plants. The barnacle, *Chthamalus dali,* recruited into bare patches created by the oil spill/cleanup, displacing the larger *Balanus* species. Thus, it was possible that these barnacles would accelerate recovery of fucoids at oiled sites by providing substrate heterogeneity. Over longer time scales, however, plants which recruit onto barnacles may have higher mortality rates due to dislodgement as they grow larger. In Herring Bay virtually all large plants are found attached to rock and almost none are found on barnacles. Even though recruitment is much more successful on barnacles, the chances of surviving to reproductive age (>10 cm) are very slim for those plants which recruit onto barnacles. Our study of recruitment of *Fucus* onto barnacles did not differentiate with respect to barnacle species, so it is unknown whether survival of *Fucus* germlings would be a function of the species of barnacle. The best strategy for *Fucus* re-population seems to be to recruit into cracks and crevices in the substrate and not on barnacles. Cracks and crevices in the rock surface can often enhance fucoid recruitment in the same manner as barnacles by decreasing desiccation stress (Jernokoff 1985) and decreasing herbivory (Lubchenco 1983). We did not do a study of the interactions of *Fucus* and barnacles and, therefore, can say nothing about how *Fucus* may affect barnacle recruitment at oiled sites.

OVERALL DISCUSSION

It has been extremely difficult to ascertain the cleanup history of our particular sites due to incomplete records and the geographic scale of the record keeping. All of the oiled sites are in shoreline segments in which some part, but not necessarily all, of the segment received high pressure, hot water treatments, but we can not be certain of the treatment applied to individual sites. There is good evidence that cleanup efforts caused much of the decrease in *Fucus* canopy (Bromen *et al.* 1983, Foster *et al.* 1990, Rolan and Gallagher 1991, Lees *et al.* 1996, Houghton *et al.* 1996). Photographs of an OMNI boom in action show large amounts of floating *Fucus* within the containment boom during and after cleaning (Foster *et al.* 1990, Noerager and Goodman 1991). These plants probably came from the rock being cleaned since the density of floating *Fucus* was visually much lower in surrounding areas.

One of the consequences of the difficulties in determining oiling and clean-up histories was that all control sites were in the east half of the bay while most of the oiled sites were in the west half of the bay. Since the oiled and control sites were spatially segregated, it could be argued that the observed differences between oiled and control sites could just be an effect of location in the bay. If the southeastern (control) portion of the bay had inherently different *Fucus* populations, biology , and ecology, then no convergence in measured attributes should be observed. In this study, however, we observed convergence in all of the attributes measured between control and oiled sites, suggesting that the differences between oiled and control sites were caused by an event occurring before sampling began. The most obvious event that could have led to the observed results was the oil spill. Not only did we observe convergence, suggestive of recovery from the oil spill, we have also identified plausible mechanisms for how the oil spill or clean-up could have led to the observed differences between control and oiled sites.

The oil spill, especially with regard to intertidal plants, was basically a broad scale disturbance similar to other disturbances such as ice scour and logs that clear organisms from rocky shores (Dayton 1971, Paine and Levin 1981, McCook and Chapman 1991, 1993). The results presented here do not require the oil spill to be the agent of disturbance; they have elucidated the mechanisms by which *Fucus* has and continues to recover from a broad scale disturbance. These studies have also ascertained the factors which may limit recovery for *Fucus* populations following disturbance. In the lower tidal levels recovery occurred rapidly, taking about four years in the mid zone. In the low zone, however, relatively little damage was observed so recovery was faster than in higher zones. In contrast, recovery is not yet complete in the high zone.

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Table 2.1. List of studies and the sites used for each study. Site locations in Herring Bay are given in Fig. 2.1. All sites are sheltered rocky habitats except 2333C/2333X and 2834C/2834X which are coarse-textured sites.

Study		Control Sites	Oiled Sites
Population Dynamics		1231C	1231X
		1732C	1732X
		3811C	3611X
		2333C	2333X
		2834C	2834X
High Zone Population Dynamics		1231C	1231X
		1411C	1311X
		1852C	1852X
Egg Settlement	All Years	1221C	1221X
		1222C	1322X
	1991	1231C	1231X
		1723C	1723X
	1992	1312C	1312X
		1411C	1311X
	1993	1732C	1732X
		1713C	1713X
	1994	3C	3X
		4C	4X
	1995	5C	5X
		6C	6X
Recruitment Tiles		1251C	1251X
		1411C	1311X
		1713C	1713X
Growth and Mortality		1221C	1221X
		1723C	1723X
Substrate Use		SUB1C	SUB1X
		SUB2C	SUB2X
		SUB3C	SUB3X

Table 2.2. The mean and standard error (in parentheses) of the number of plants collected, wet weight of receptacles, number of eggs released, and percent of eggs viable for the *Fucus* reproductive potential and egg viability study in 1991. Asterisks indicate a statistical difference ($p<0.05$) between oiled and control sites.

MVD	Oiling	June		July		August	
Number of Plants Collected at Sheltered Rocky Sites (N=3)							
1	Control	8.0	(2.0)	11.3	(0.3)*	11.3	(0.3)*
	Oiled	4.0	(2.5)	2.7	(0.7)	2.7	(1.2)
2	Control	11.7	(0.3)	11.7	(0.3)	9.7	(0.9)
	Oiled	5.7	(2.9)	5.0	(2.5)	3.7	(1.7)
3	Control	9.3	(0.3)	10.0	(1.5)	6.7	(0.7)*
	Oiled	8.0	(1.5)	6.3	(0.9)	3.0	(1.2)
Wet Weight of Receptacle (g)							
1	Control	0.34	(0.06)	0.63	(0.09)	0.83	(0.09)
	Oiled	0.33	(0.13)	0.70	(0.20)	0.79	(0.40)
2	Control	0.36	(0.05)	0.99	(0.11)	0.96	(0.13)*
	Oiled	0.41	(0.07)	0.61	(0.17)	0.38	(0.08)
3	Control	0.54	(0.08)	1.02	(0.14)*	1.02	(0.17)
	Oiled	0.43	(0.05)	0.59	(0.08)	0.54	(0.21)
Number of Eggs Released per Receptacle							
1	Control	1202.88	(1182.11)	1292.24	(1169.87)*	2761.82	(1047.51)
	Oiled	36.60	(25.34)	286.17	(134.89)	331.09	(256.28)
2	Control	235.02	(134.82)*	2775.72	(1239.04)	1178.16	(775.85)
	Oiled	2494.44	(1375.55)	703.66	(570.41)	591.69	(442.48)
3	Control	293.30	(88.18)	380.67	(121.52)	137.76	(29.70)
	Oiled	1420.00	(719.60)	892.48	(272.33)	72.47	(33.65)
Percent of Released Eggs That Were Viable							
1	Control	15.9	(6.7)	42.9	(8.5)	100.0	(0.0)
	Oiled	10.6	(8.3)	36.9	(17.1)	100.0	(0.0)
2	Control	18.1	(6.3)*	51.3	(7.7)*	100.0	(0.0)
	Oiled	42.0	(10.0)	22.6	(9.9)	100.0	(0.0)
3	Control	33.4	(7.3)*	28.9	(7.7)	100.0	(0.0)
	Oiled	67.8	(7.6)	21.4	(6.1)	100.0	(0.0)

Table 2.3. Results of ANOVAs comparing the number and survival of *Fucus* germlings and barnacles in different groove widths and depths. The test were blocked by tiles, and in all cases blocking explained significant amounts of variation, reducing the effects of between tile variation due to differences in germling density. The degrees of freedom (df), F ratios (F), mean square error (MSE), and p values (p) are given for each variable tested. The F/MSE column contains F ratios for all tested terms and the mean square error term in the last row of the column. The information provided is sufficient to reconstruct a regular ANOVA table. Data can be seen in Fig. 2.24.

	Initial Number			1992 Survival[1]			1993 Survival			1993 Barnacles			1994 Barnacles		
Source	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p
Tile	23	2.264	<0.001	23	16.620	<0.001	23	9.328	<0.001	46	1.842	0.002	46	2.793	<0.001
Depth(D)	1	0.175	0.676	1	1.854	0.176	1	6.030	0.016	1	0.039	0.844	1	3.019	0.084
Width(W)	2	21.034	<0.001	2	7.841	0.001	2	6.214	0.003	2	16.897	<0.001	2	4.358	0.014
DxW	2	2.013	0.138	2	4.047	0.020	2	0.318	0.728	2	0.023	0.977	2	0.538	0.584
Error	115	0.430		115	3.342		115	4.385		230	5.416		230	9.096	

[1]Indicates that the test violated the assumption of homogeneity of variances.

Table 2.4. Results of ANOVAs comparing the number of *Fucus* microrecruits and recruits visible with the unaided eye in different groove widths and depths. The test were blocked by tiles, and in all cases blocking explained significant amounts of variation, reducing the effects of between tile variation due to treatments imposed upon whole tiles. The format of the table is the same as in Table 2.3. Data can be seen in Fig. 2.25.

	1992 Microrecruits			1993 Microrecruits[1]			1993 Recruits			May 1994 Recruits[1]			August 1994 Recruits[1]		
Source	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p
Tile	23	11.724	<0.001	23	14.090	<0.001	46	3.780	<0.001	46	3.701	<0.001	46	2.127	<0.001
Depth(D)	1	0.148	0.701	1	1.662	0.200	1	5.280	0.022	1	8.968	0.003	1	15.630	<0.001
Width(W)	2	1.139	0.324	2	8.638	<0.001	2	2.432	0.090	2	5.979	0.003	2	10.073	<0.001
DxW	2	0.110	0.896	2	0.472	0.625	2	1.069	0.342	2	0.410	0.664	2	1.636	0.197
Error	115	6.027		112	5.285		230	3.171		230	5.287		230	5.017	

[1]Indicates that the test violated the assumption of homogeneity of variances.

Table 2.5. Results of ANOVAs comparing the survival of seeded *Fucus* germlings and the number of recruits on tiles for the experiment testing canopy (canopy), oiling (oil), and tidal level (level). The tests were blocked by the three pairs of sites (pair) where the experiment was conducted. The format of the table is the same as in Table 2.3. Data can be seen in Fig. 2.26.

	1992 Survival			1993 Survival			1993 Recruits			May 1994 Recruits			August 1994 Recruits		
Source	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p
Pair	2	8.720	0.003	2	1.793	0.203	2	0.006	0.376	2	0.093	0.911	2	0.795	0.459
Oil(O)	1	7.404	0.017	1	0.151	0.704	1	5.423	0.025	1	0.513	0.478	1	0.423	0.520
Level(L)	1	0.504	0.489	1	1.097	0.313	1	1.339	0.255	1	2.341	0.135	1	0.403	0.529
Canopy(C)	1	10.509	0.006	1	0.029	0.867	1	8.736	0.005	1	0.076	0.784	1	0.127	0.723
OxL	1	0.276	0.607	1	0.064	0.803	1	3.958	0.054	1	0.263	0.611	1	0.019	0.891
OxC	1	0.129	0.725	1	0.156	0.699	1	0.010	0.921	1	0.953	0.335	1	0.069	0.794
LxC	1	0.670	0.427	1	0.025	0.877	1	0.080	0.779	1	0.068	0.796	1	0.882	0.354
OxLxC	1	0.553	0.469	1	1.560	0.232	1	2.524	0.121	1	6.205	0.017	1	3.193	0.082
Error	14	4.598		14	63.417		37	8.451		37	16.099		37	14.382	

Table 2.6. Tile temperatures at oiled and unoiled sites and with and without *Fucus* canopy. A three way ANOVA with oil, tidal level, and canopy yielded significant effects of both oil and canopy treatments; there was no effect of tidal height and no significant interactions. Numbers in parentheses are standard errors.

	+Canopy	-Canopy
Unoiled	20.55 (1.64)	25.02 (2.18)
Oiled	23.34 (1.63)	28.35 (2.49)

Table 2.7. Results of ANOVAs comparing the survival of seeded *Fucus* germlings and the number of recruits on tiles for the experiment testing caging (cage), oiling (oil), and tidal level (level). The tests were blocked by the three pairs of sites (pair) where the experiment was conducted. The format of the table is the same as in Table 2.3. Data can be seen in Figs. 2.27 and 2.28A.

		1992 Survival		1993 Survival		1993 Recruits		May 1994 Recruits		August 1994 Recruits	
Source	df	F/MSE	p	F/MSE	p	F/MSE	p	F/MSE	p	F/MSE	p
Pair	2	1.773	0.193	8.797	0.002	0.518	0.603	1.572	0.230	1.600	0.225
Oil (O)	1	3.424	0.078	0.295	0.593	1.719	0.203	8.130	0.722	2.105	0.161
Level(L)	1	1.048	0.317	1.675	0.209	0.001	0.970	0.043	0.837	1.279	0.270
Cage(C)	2	3.061	0.067	3.309	0.055	5.791	0.010	2.397	0.114	4.121	0.030
OxL	1	0.263	0.613	0.043	0.837	2.621	0.120	0.004	0.952	0.072	0.791
OxC	2	0.443	0.648	0.246	0.784	0.225	0.800	0.069	0.934	1.041	0.370
LxC	2	5.373	0.013	1.813	0.187	1.081	0.357	0.194	0.825	1.991	0.160
OxLxC	2	0.234	0.793	0.101	0.904	0.579	0.569	0.376	0.691	3.745	0.040
Error	22	3.517		2.891		1603.5		2974.3		2006.7	

Table 2.8. Results of ANOVAs comparing the sizes of *Fucus* germlings on tiles for the experiment testing caging (cage), oiling (oil), and tidal level (level). The tests were blocked by the three pairs of sites (pair) where the experiment was conducted. The format of the table is the same as in Table 2.3. Tidal level was omitted as a factor in July 1993 since most tiles in the high zone were lacking germlings. Data can be seen in Fig. 2.28B.

	July 1993			May 1994			August 1994		
Source	df	F/MSE	p	df	F/MSE	p	df	F/MSE	p
Pair	2	0.630	0.542	2	0.234	0.794	2	0.788	0.469
Oil (O)	1	0.296	0.592	1	0.007	0.933	1	0.008	0.930
Level(L)	--	--	--	1	0.653	0.429	1	0.986	0.333
Cage(C)	2	3.864	0.037	2	6.434	0.008	2	7.388	0.004
OxL	--	--	--	1	1.748	0.203	1	2.496	0.131
OxC	2	0.239	0.789	2	0.029	0.971	2	0.046	0.955
LxC	--	--	--	2	1.669	0.216	2	3.165	0.065
OxLxC	--	--	--	2	1.120	0.348	2	1.458	0.258
Error	21	44.490		18	87.223		18	112.33	

Table 2.9. The mean (±SE) yearly net 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	(0.003)
	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)

Table 2.10. Growth rates (cm/wk) *Fucus* plants at 1, 2, and 3 MVDs averaged over all size classes at control (C) and oiled (O) sites in Herring Bay from summer 1991 to summer 1993. Asterisks indicate significant differences from the other two numbers in that column based on the results of Tukey's post-hoc tests.

	Summer 1991		Winter 1991		Summer 1992		Winter 1992		Summer 1993	
MVD	C	O	C	O	C	O	C	O	C	O
1	0.16	0.21	0.06*	0.13	0.24	0.42	0.07*	0.12	0.09*	0.21
2	0.19	0.21	0.10	0.13	0.32	0.35	0.13	0.11	0.21	0.11
3	0.20	0.20	0.16	0.10	0.35	0.32	0.11	0.13	0.16	0.20

Table 2.11. Results from regressions of percent change in *Fucus* length vs. initial plant length for each sampling period. Number of samples (n), slope of the regression line, r^2, and the p-value (p) are given for control sites and oiled sites.

		Absolute Growth			Proportional Growth		
Control Sites	N	Slope	r^2	p	Slope	r^2	p
Summer 1991	77	0.006	0.239	0.000	-1.188	0.228	0.000
Winter 1991	61	0.001	0.014	0.364	-2.076	0.176	0.001
Summer 1992	55	-0.001	0.001	0.793	-0.999	0.168	0.002
Winter 1992	74	0.002	0.030	0.138	-3.078	0.191	0.000
Summer 1993	84	0.003	0.012	0.328	-0.553	0.042	0.061
Winter 1993	69	0.006	0.456	0.000	-1.163	0.097	0.009
Summer 1994	44	0.002	0.217	0.001	-0.631	0.227	0.001
Oiled Sites							
Summer 1991	79	-0.005	0.033	0.108	-2.945	0.504	0.000
Winter 1991	64	0.004	0.054	0.044	-2.567	0.098	0.012
Summer 1992	59	-0.003	0.003	0.693	-1.073	0.105	0.012
Winter 1992	81	0.002	0.044	0.060	-4.845	0.304	0.000
Summer 1993	81	0.001	0.000	0.864	-1.958	0.059	0.029
Winter 1993	49	-0.001	0.010	0.505	-2.798	0.286	0.000
Summer 1994	18	0.003	0.449	0.002	-0.795	0.158	0.102

Table 2.12. Mortality (%/week) of small (2.0-4.5 cm), medium (5.0-10.0 cm), and large (>10 cm) *Fucus* plants averaged over all 3 MVDs and of *Fucus* plants at 1, 2, and 3 MVDs averaged over all size classes at control and oiled sites in Herring Bay from summer 1991 to summer 1993. Averages for summer and winter are also given.

	Control		Oiled	
Size (cm)	Mean	S.E.	Mean	S.E.
2.0-4.5	2.11	0.65	2.35	0.64
5.0-9.5	1.78	0.35	2.07	0.68
>10.0	1.59	0.24	2.11	0.97
MVD				
1	2.06	0.42	1.79	0.60
2	1.70	0.27	2.55	0.60
3	1.29	0.28	2.07	0.49
Summer	2.24	0.15	2.91	0.53
Winter	0.99	0.09	1.16	0.21

Table 2.13. Two-way ANOVA results from 1994 comparing the selectivity indices of *Fucus* for the three substrate types. Size and oil were the factors in the ANOVA, and Pair was used as a blocking factor. The F and p values are given for all tested effects. The mean square error term is also given as the last value in the F/MSE column so that the regular ANOVA table can be reconstructed. Data are presented in Fig. 2.36.

		Smooth Rock		Crevice[1]		Barnacle[1]	
Source	df	F/MSE	p	F/MSE	p	F/MSE	p
Pair	2	18.888	<0.001	7.963	<0.001	3.922	0.022
Size (S)	2	33.598	<0.001	3.148	0.046	43.267	<0.001
Oil (O)	1	0.021	0.885	9.382	0.003	4.452	0.036
S*O	2	1.442	0.239	1.060	0.349	0.562	0.571
Error	166	0.125		0.347		0.277	

[1]Indicates that the test violated the assumption of homogeneity of variances

Table 2.14. Three-way ANOVA results from 1995 comparing selectivity indices of *Fucus* for the two substrate types. The F and p values are given for all tested effects. The mean square error term is also given as the last value in the F/MSE column so that the regular ANOVA table can be reconstructed. Data are presented in Fig. 2.35.

		Rock		Barnacle[1]	
Source	df	F/MSE	p	F/MSE	p
Exposure(E)	1	5.766	0.018	1.508	0.222
Level(L)	1	0.811	0.370	0.356	0.552
Size(S)	2	39.045	<0.001	25.214	<0.001
E*L	1	0.143	0.706	0.394	0.532
E*S	2	5.357	0.006	3.740	0.027
L*S	2	0.582	0.560	2.185	0.118
E*L*S	2	0.749	0.475	0.502	0.607
Error	105	0.182		0.261	

[1]Indicates that the test violated the assumption of homogeneity of variances

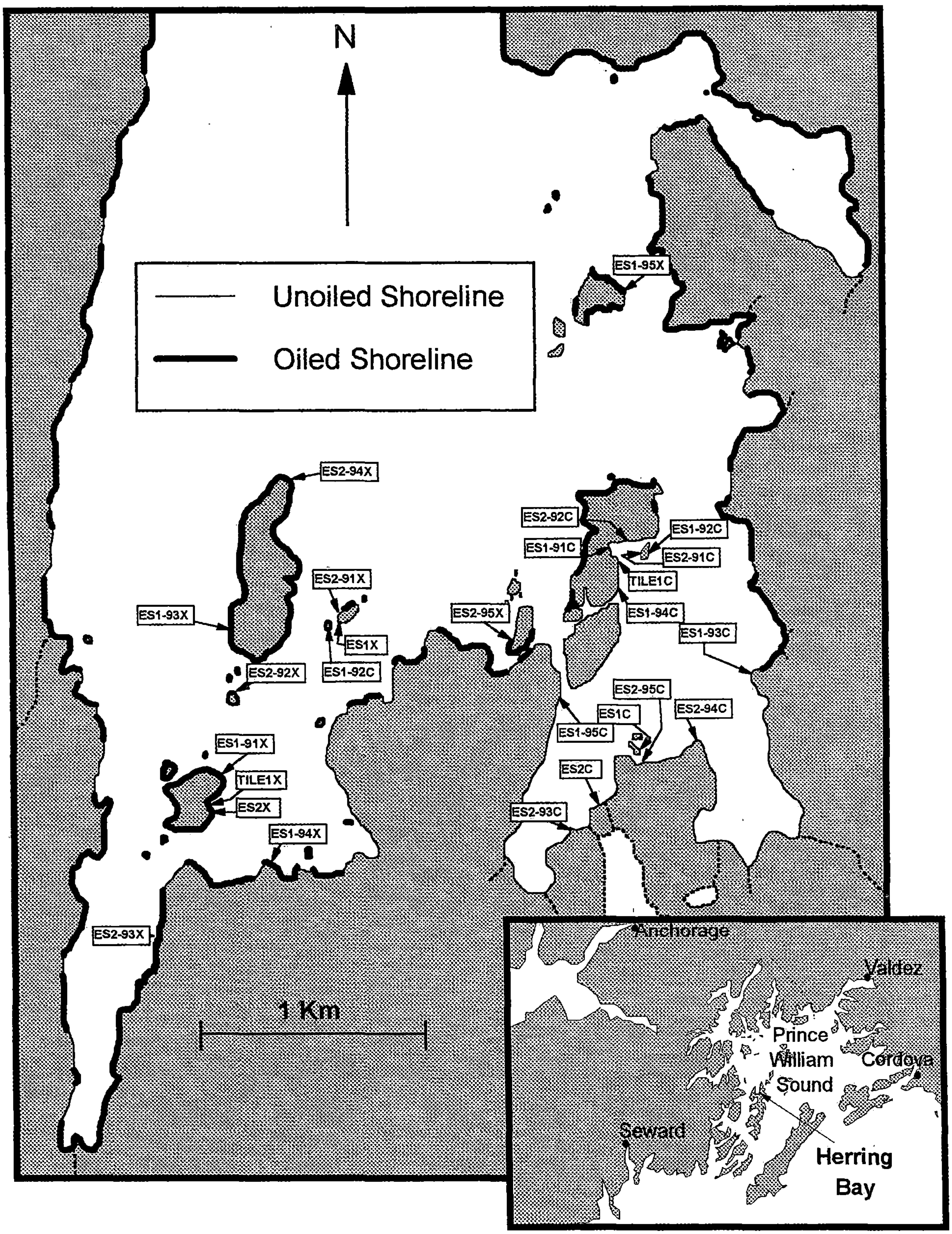


Figure 2.1. Map of Herring Bay showing the location of study sites used in studies described in Chapter 2. Experiments performed at each site are given in Table 2.1.

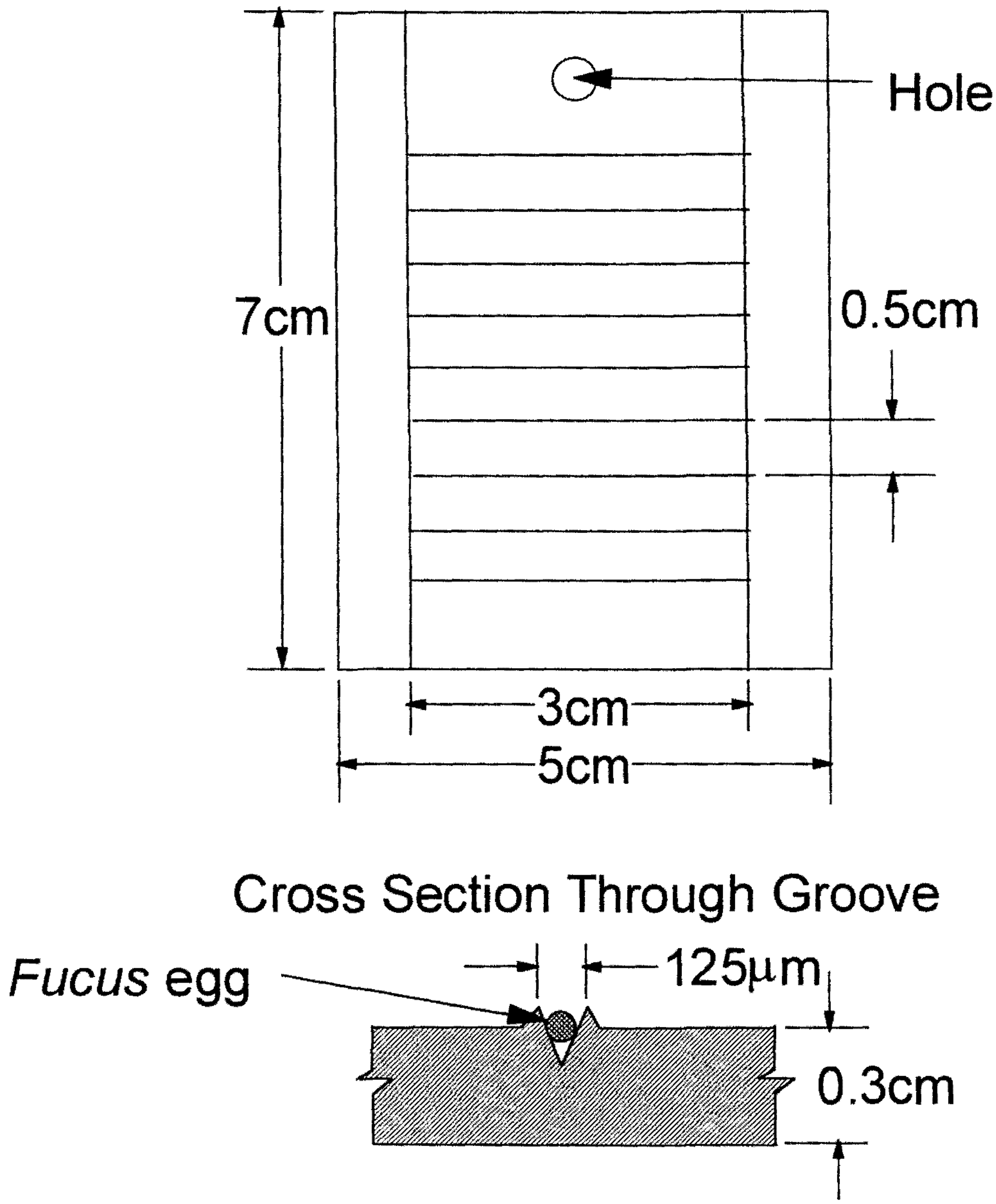


Figure 2.2. Schematic diagram of an acrylic *Fucus* egg catcher plate.

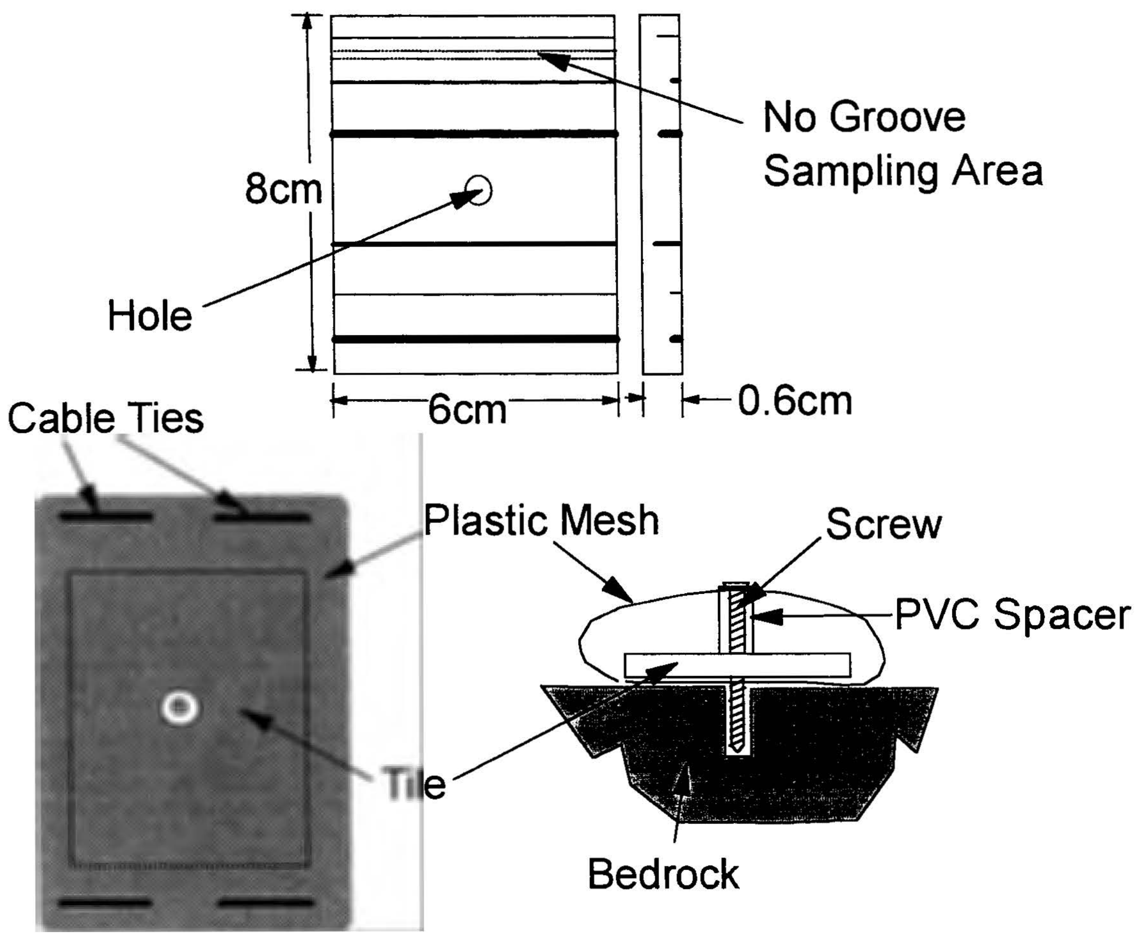


Figure 2.3. Schematic diagram of a ceramic *Fucus* recruitment tile and the Vexar cage used to manipulate herbivores. To control for cage effects cable ties were left off one end of the Vexar cage so that the cage was open to herbivores.

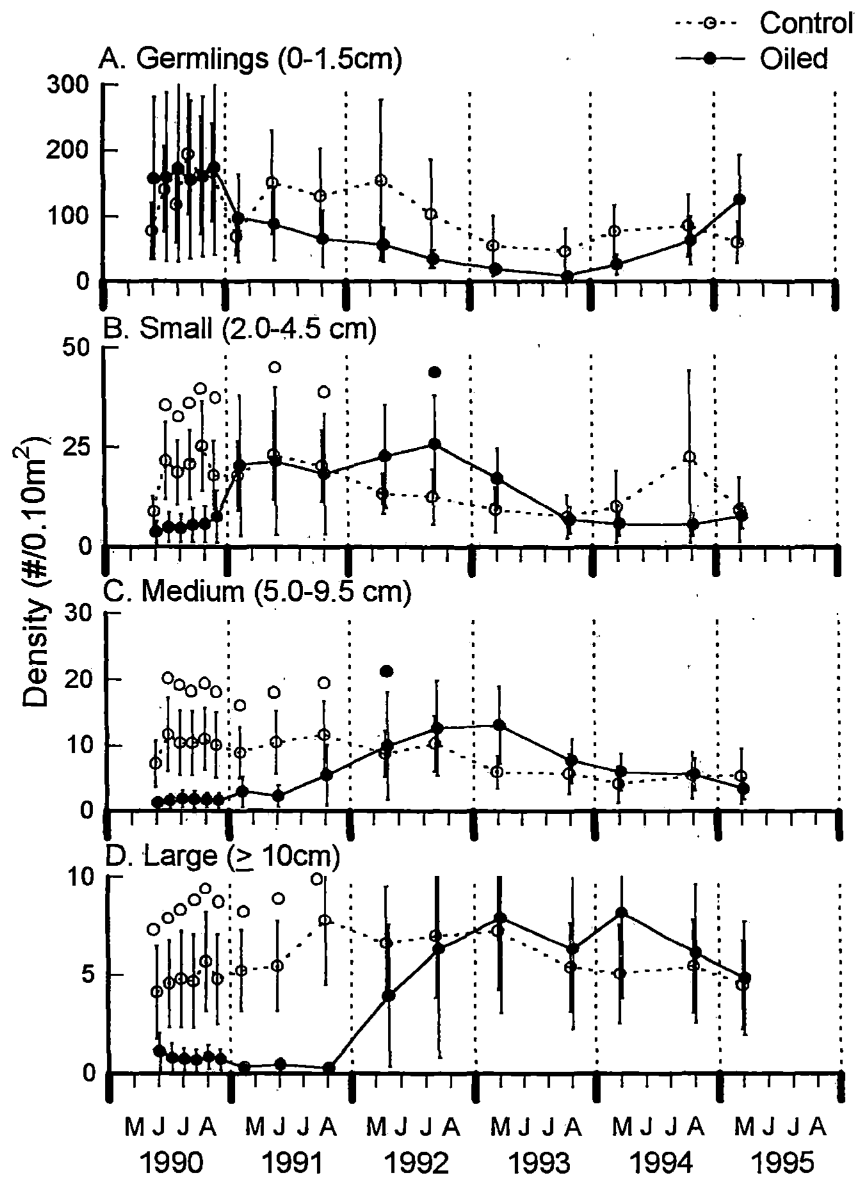


Figure 2.4. Mean number (± SE) of germling (0-2.0 cm), small (2.0-5.0 cm), medium (5.5-10 cm), and large (>10 cm) *Fucus* plants in the first MVD at sheltered rocky sites in Herring Bay, Prince William Sound. Symbols above lines indicate that oiled (filled circles) or control (open circles) sites are significantly greater on the indicated sampling date. Y-axis scales may be different

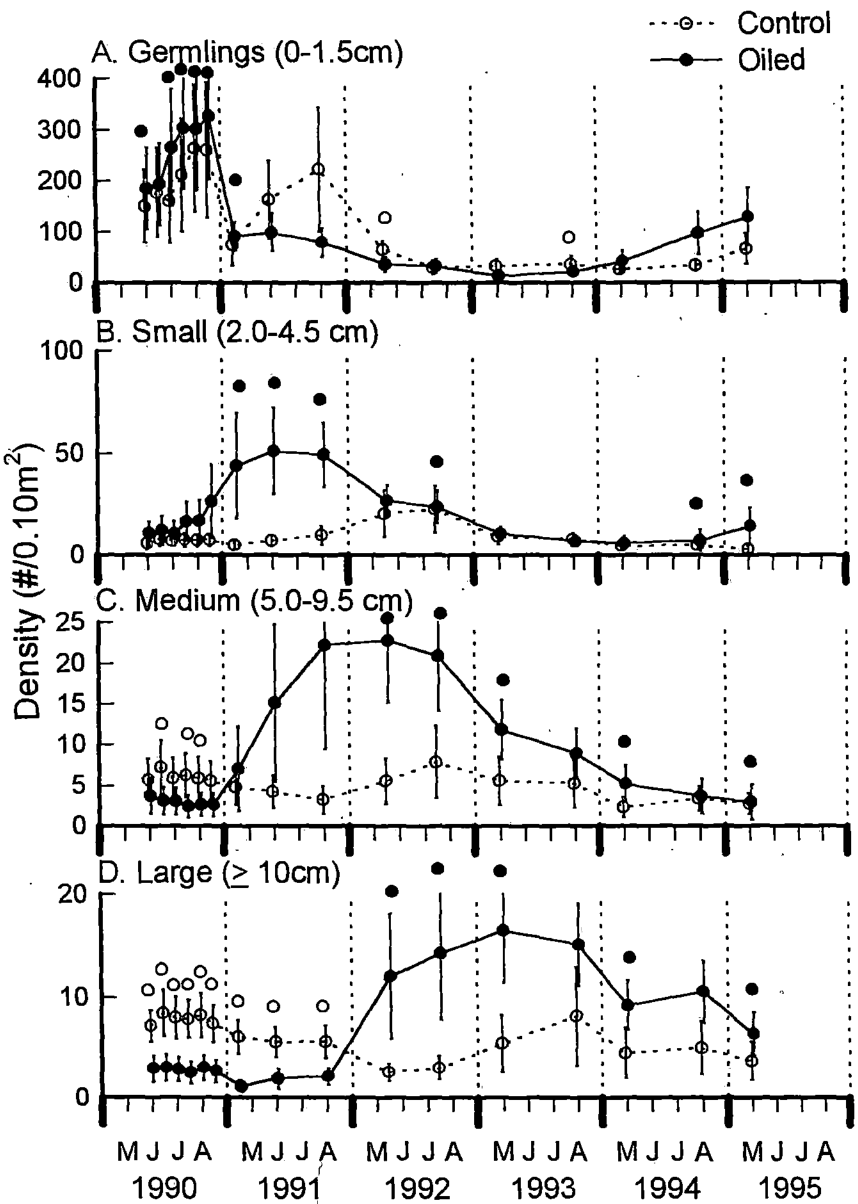


Figure 2.5. Mean number (± SE) of *Fucus* plants in four size classes in the second MVD at sheltered rocky sites. Layout is the same as those in Figure 2.4.

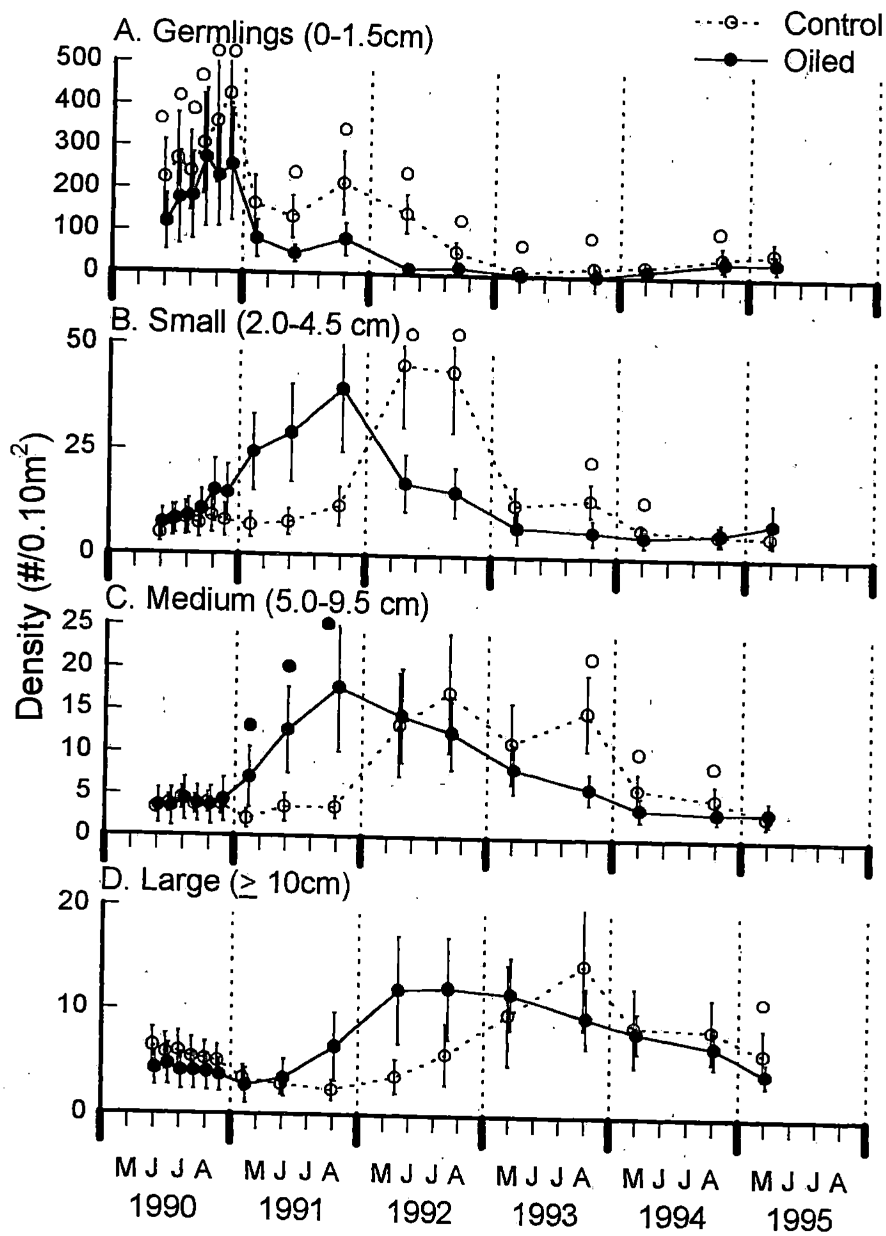


Figure 2.6. Mean number (± SE) of *Fucus* plants in four size classes in the third MVD at sheltered rocky sites. Layout is the same as those in Figure 2.4.

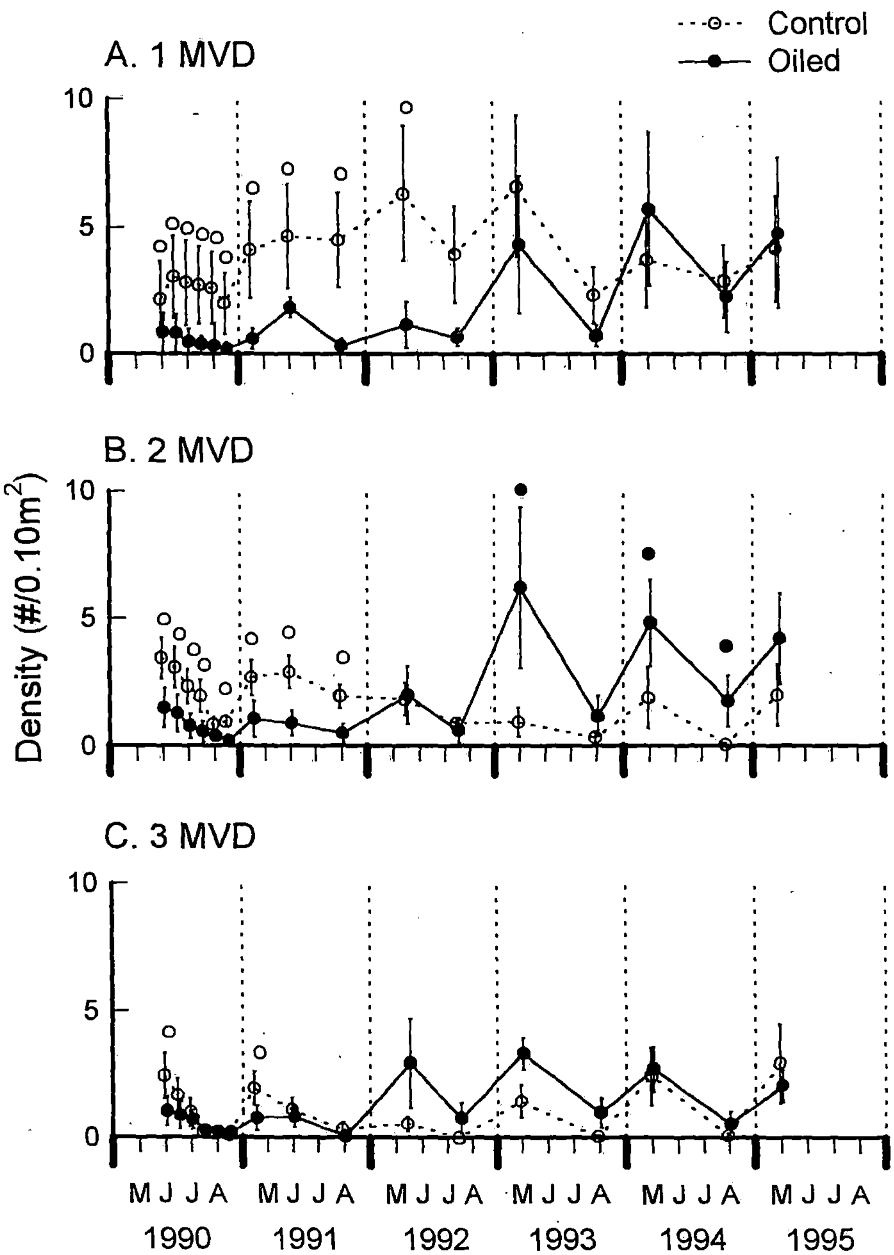


Figure 2.7. Mean number (± SE) of reproductive *Fucus* plants per quadrat at three tidal levels at sheltered rocky sites. Symbols and lines are the same as those in Figure 2.4.

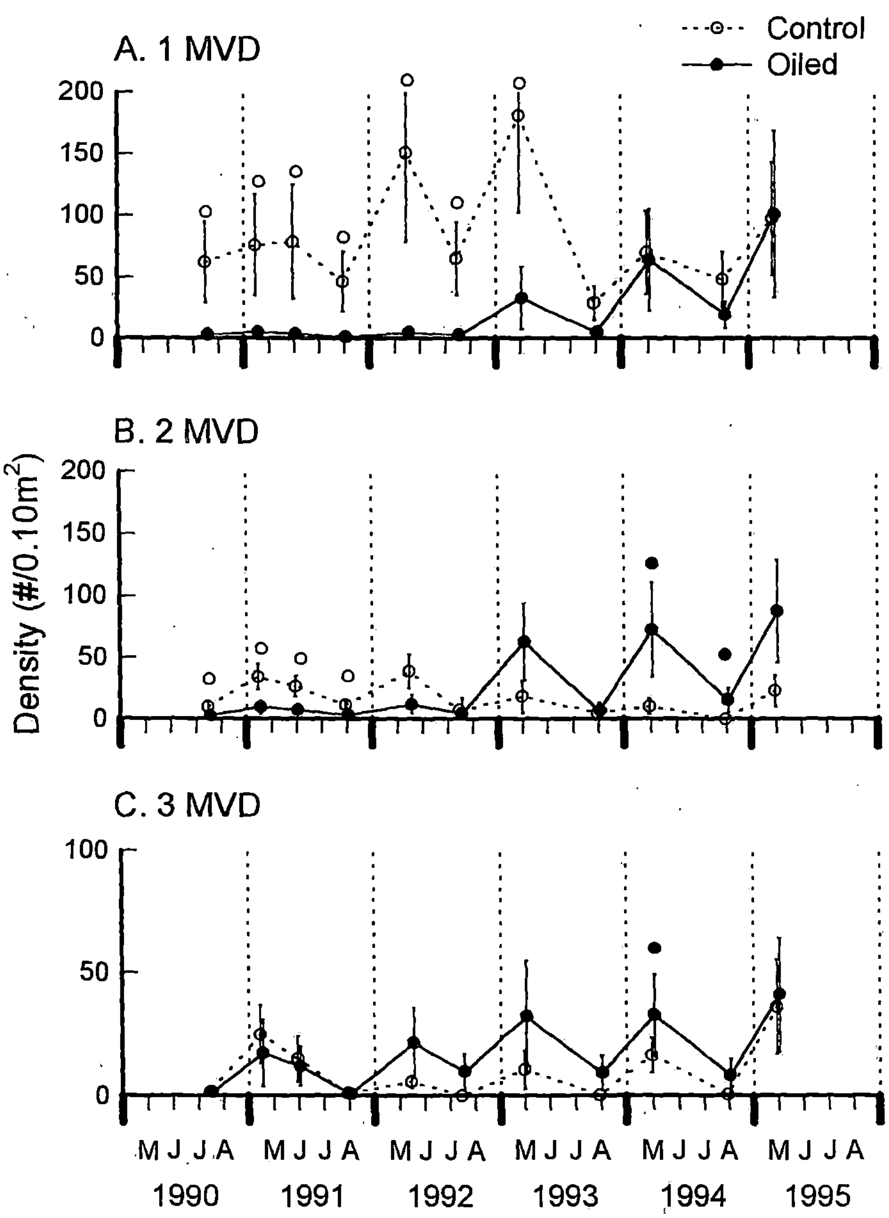


Figure 2.8. Mean number (± SE) of *Fucus* receptacles per quadrat at three tidal levels at sheltered rocky sites. Symbols and lines are the same as those in Figure 2.4.

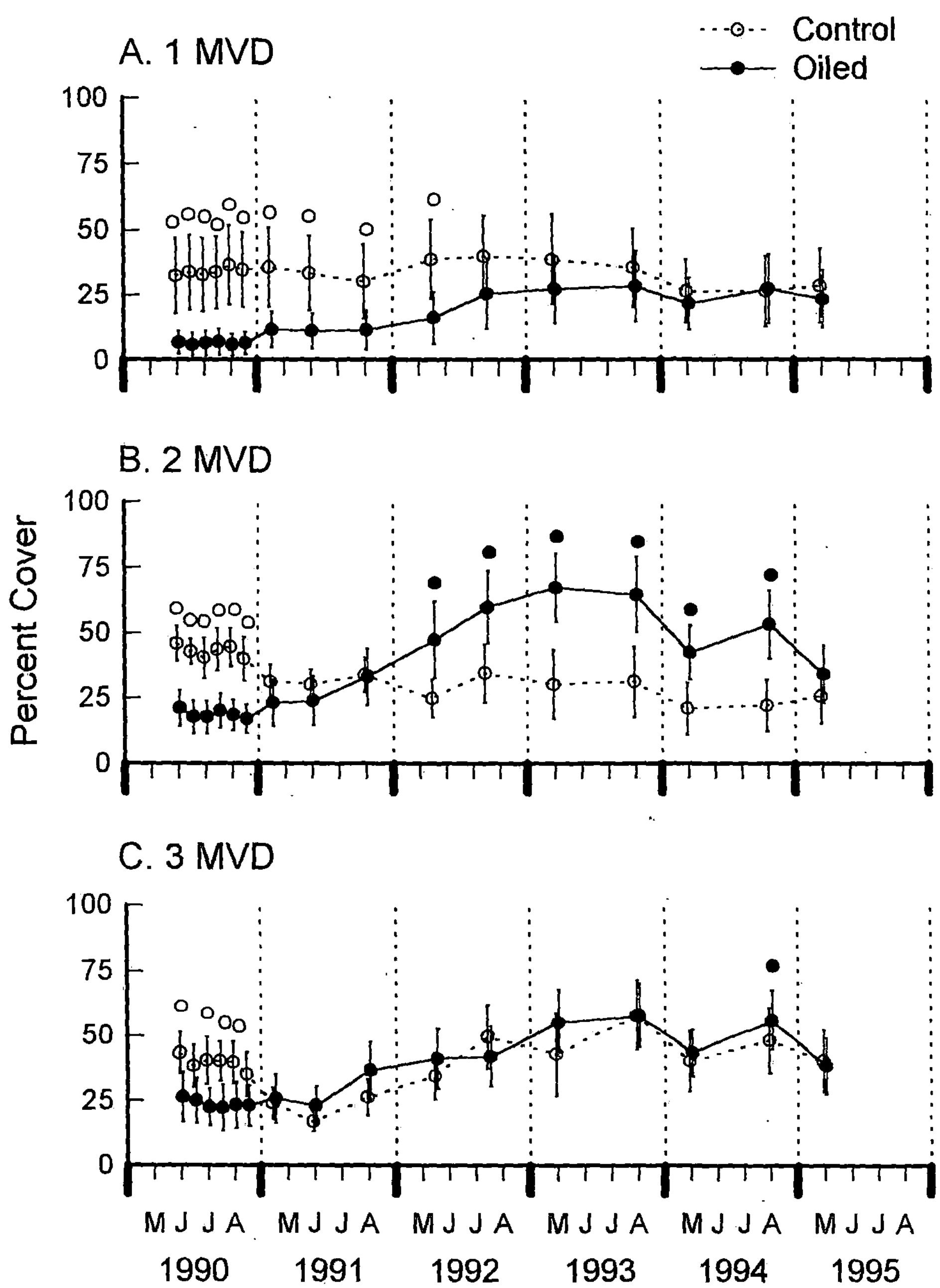


Figure 2.9. Mean percent cover (± SE) of *Fucus* at three tidal levels at sheltered rocky sites. Symbols and lines are the same as those in Figure 2.4.

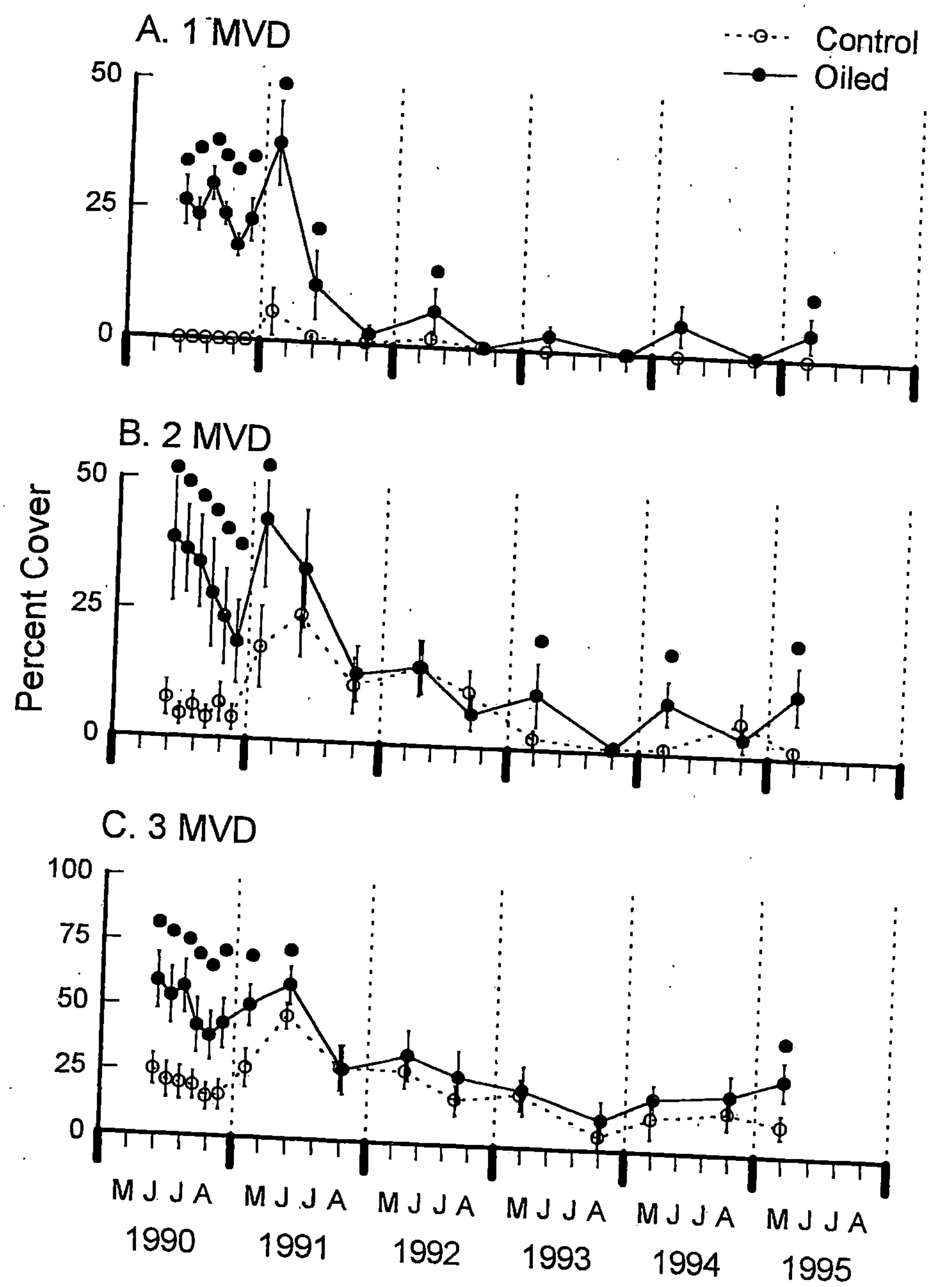


Figure 2.10. Mean percent cover (± SE) of ephemeral algae at three tidal levels at sheltered rocky sites. Symbols and lines are the same as those in Figure 2.4.

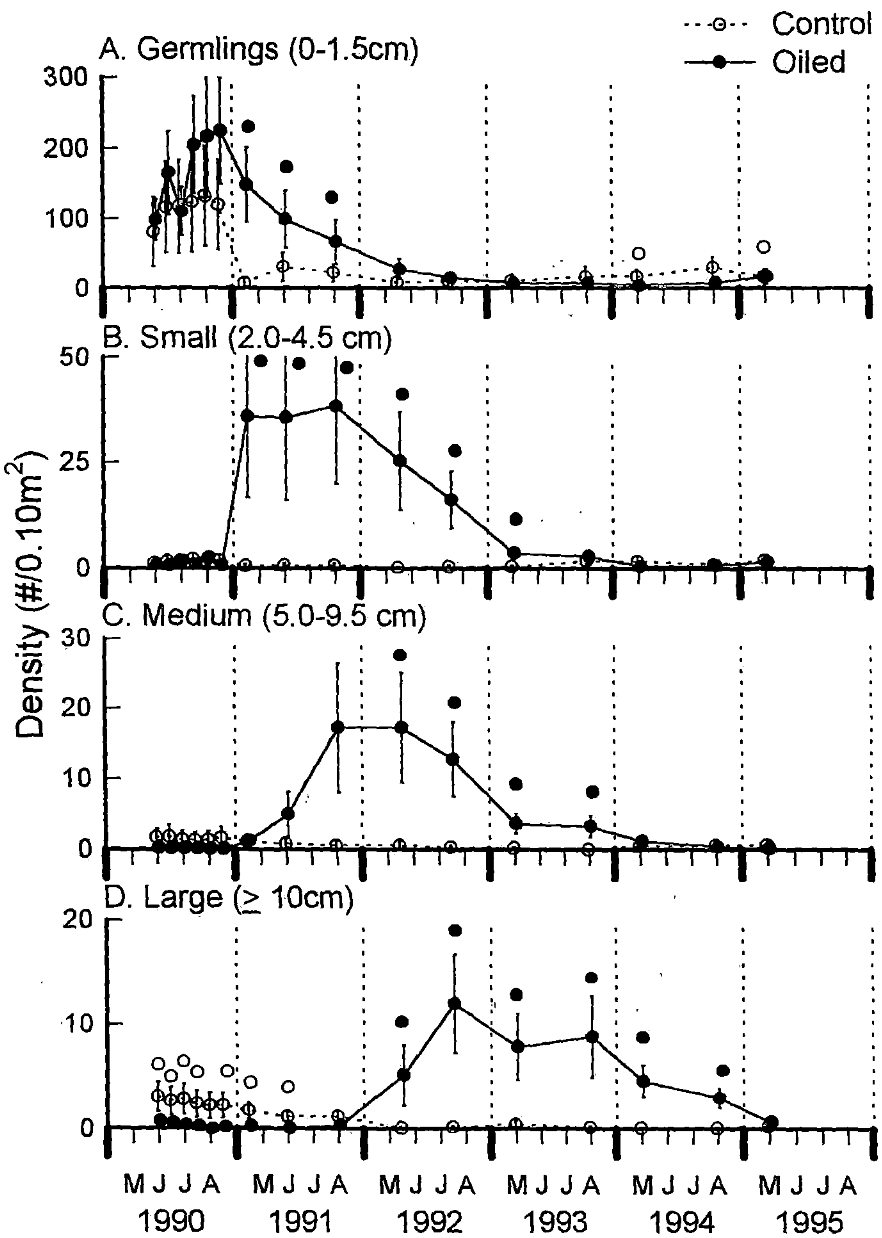


Figure 2.11. Mean number (± SE) of *Fucus* plants in four size classes at the third MVD at coarse textured sites. Symbols and lines are the same as those in Figure 2.4.

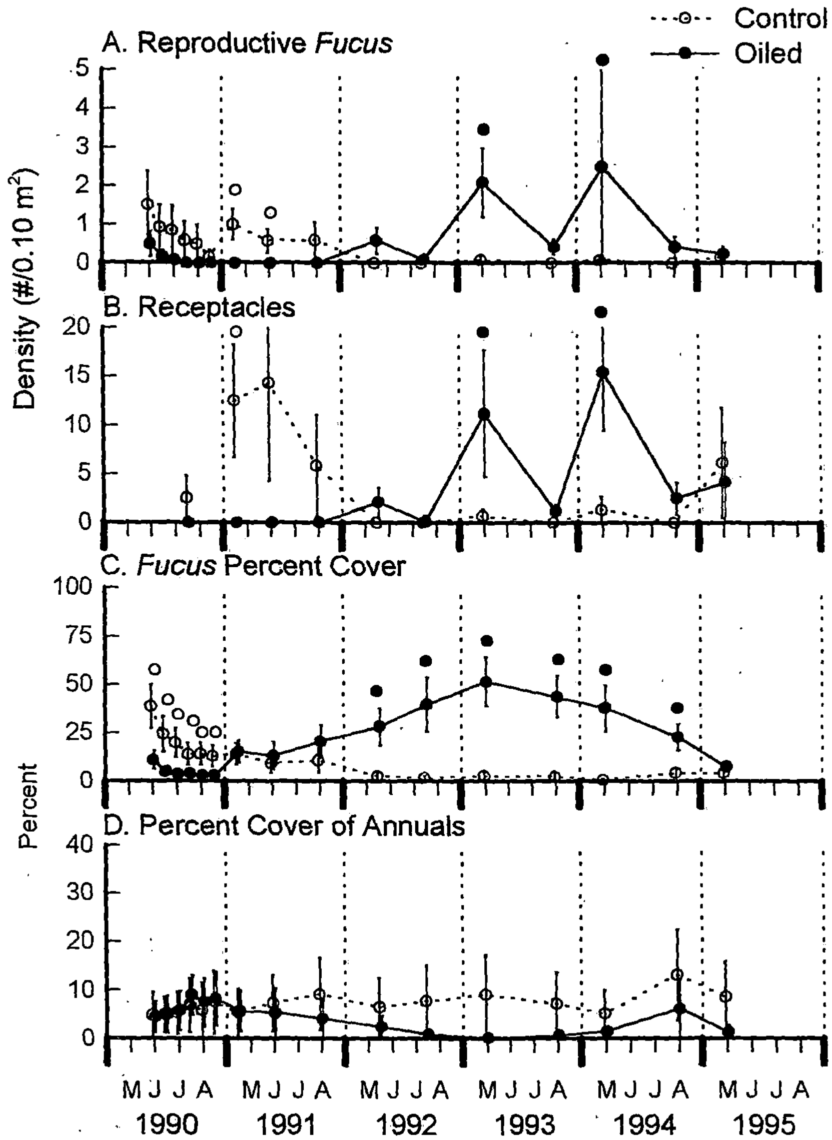


Figure 2.12. Mean number (± SE) of reproductive *Fucus* plants per quadrat, receptacles per quadrat, and percent cover of *Fucus* and ephemeral algae at the third MVD at course textured sites. Symbols and lines are the same as those in Figure 2.4.

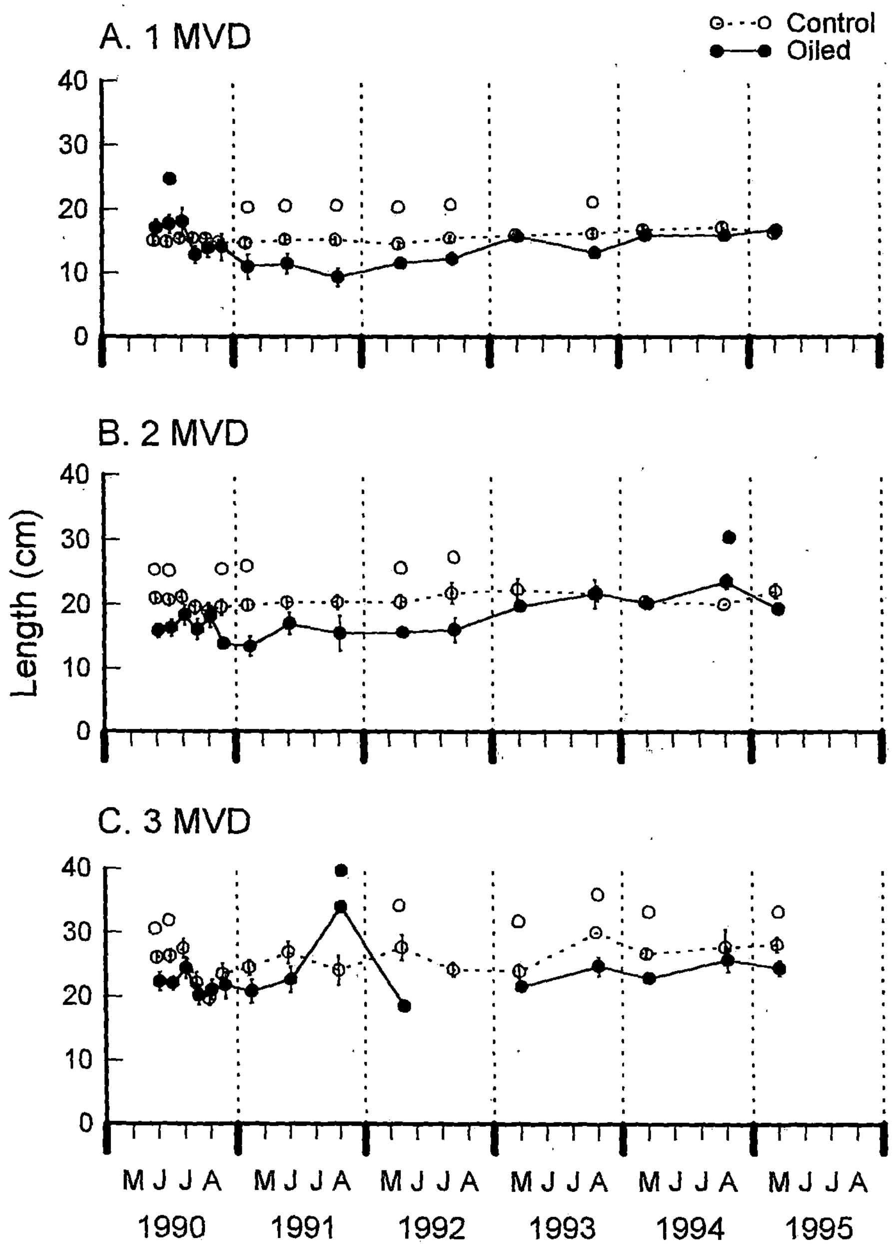


Figure 2.13. The average length for all reproductive *Fucus* plants at all five site pairs sampled. Layout is the same as Figure 2.4.

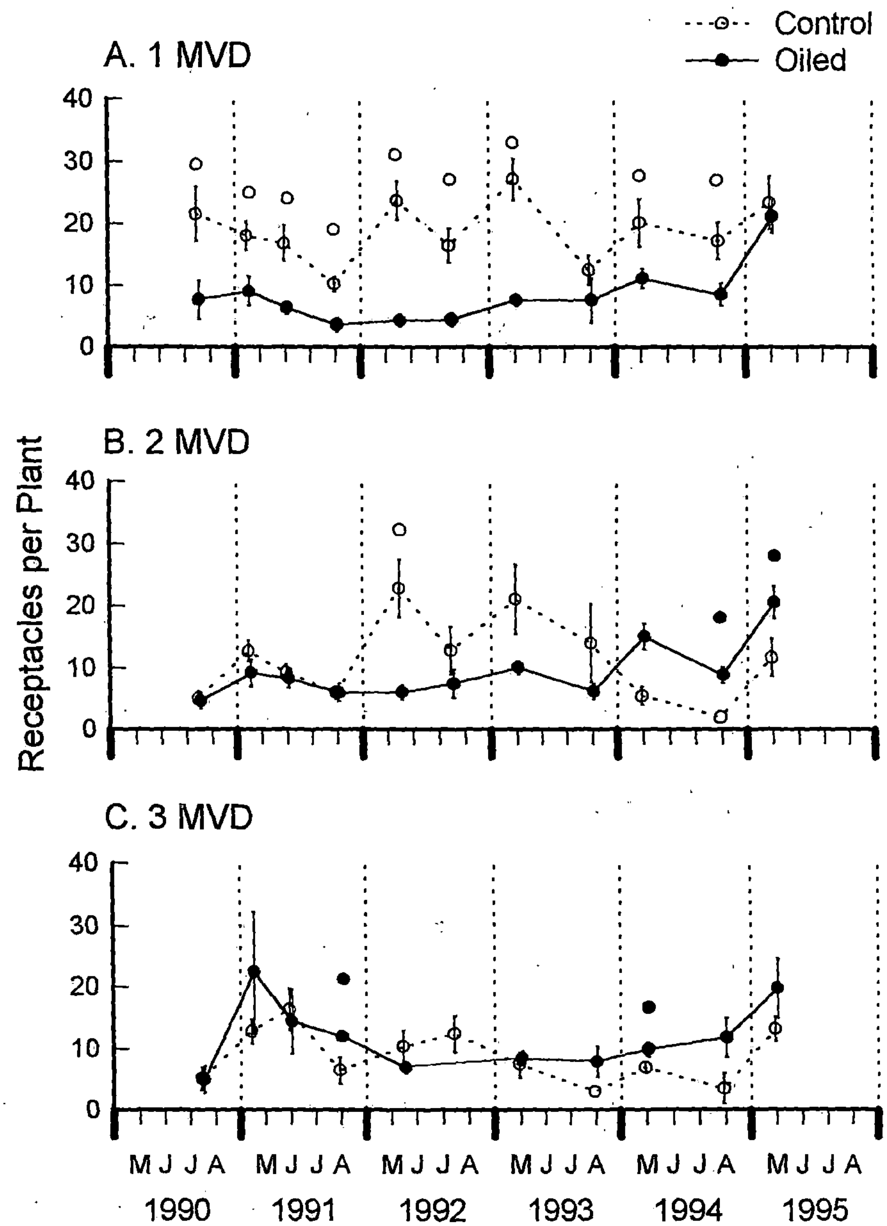


Figure 2.14. The average number of receptacles per reproductive *Fucus* plant at all five site pairs sampled. Layout is the same as Figure 2.4.

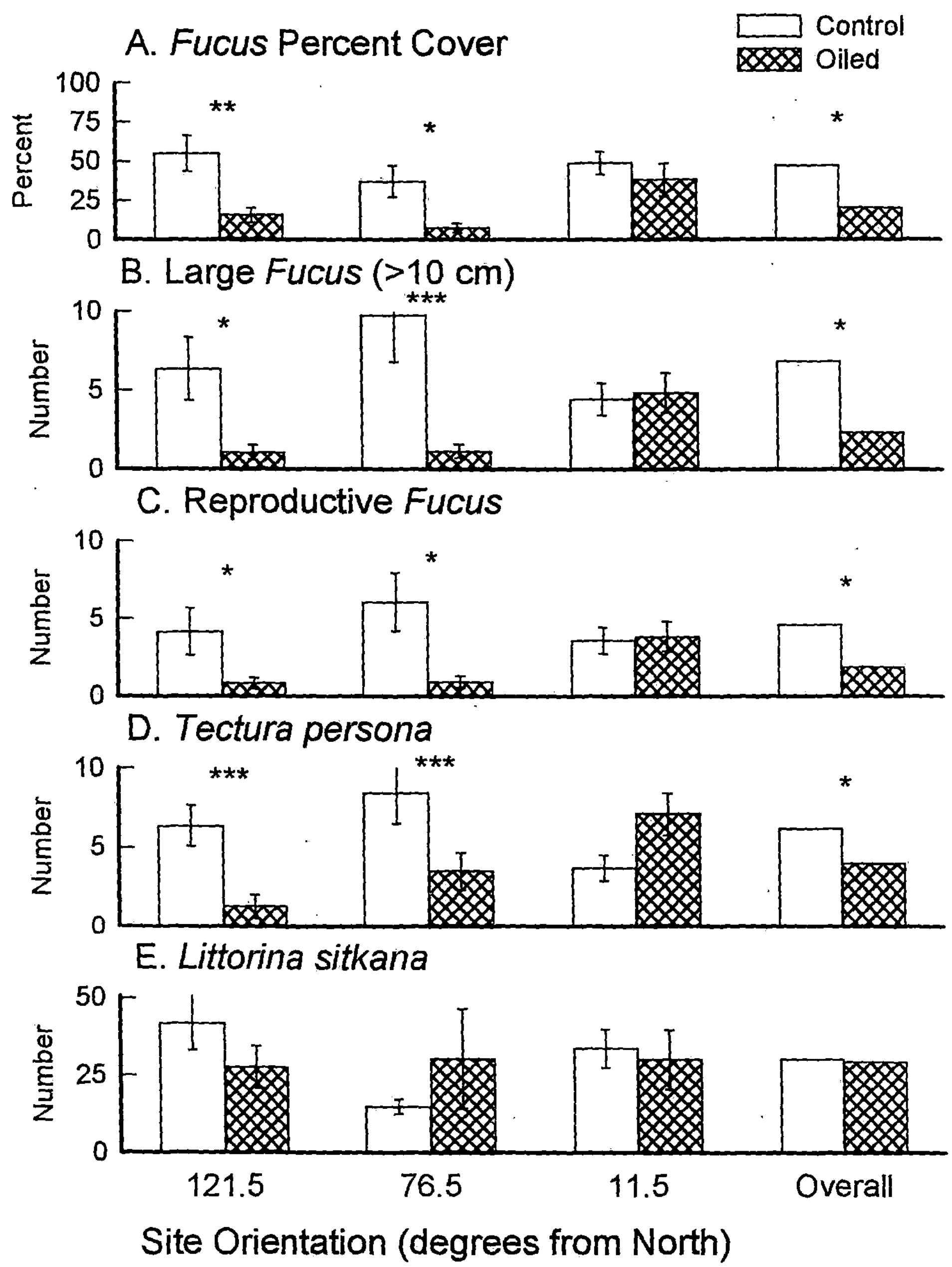
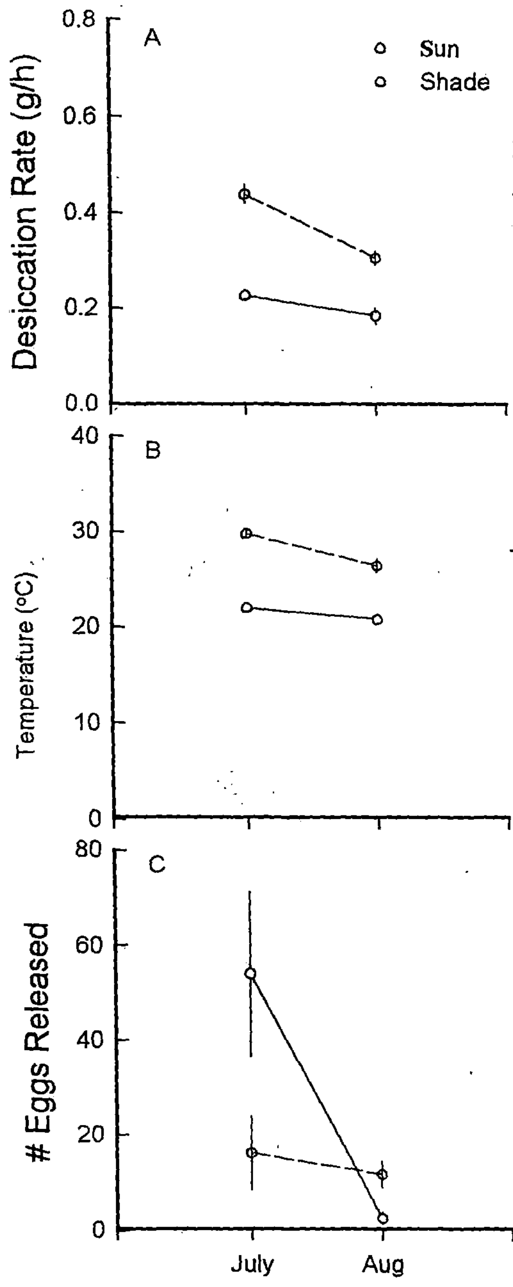


Figure 2.15. Abundances (± SE) of various organisms in the very high zone (0.0-0.5 MVD) at three pairs of control and oiled sites which vary in their solar aspect. Asterisks indicate statistical differences (*=p<0.05, **=p<0.01, ***=p<0.001 for site pairs). Solar aspect is given by degrees from north so that a south facing shore would have a value of 180 and east or west shores would each have a value of 90.



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 2.16. Mean (± SE) number of *Fucus* 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.

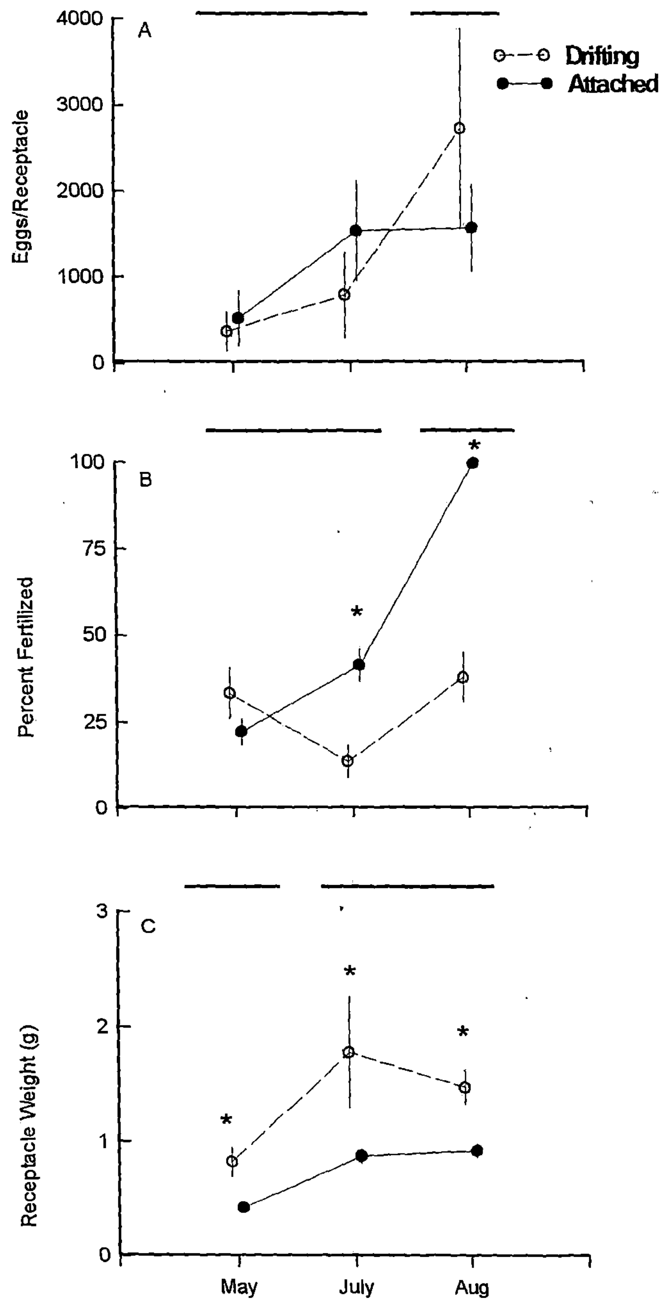


Figure 2.17. The average (± SE) number of *Fucus* eggs released per receptacle, percent of fertilized eggs, and wet weight of receptacles of attached and drifting *Fucus* for the three sampling dates in 1991. Dates connected by bars are not significantly different ($p<0.05$). July includes attached plants that were collected at the end of June.

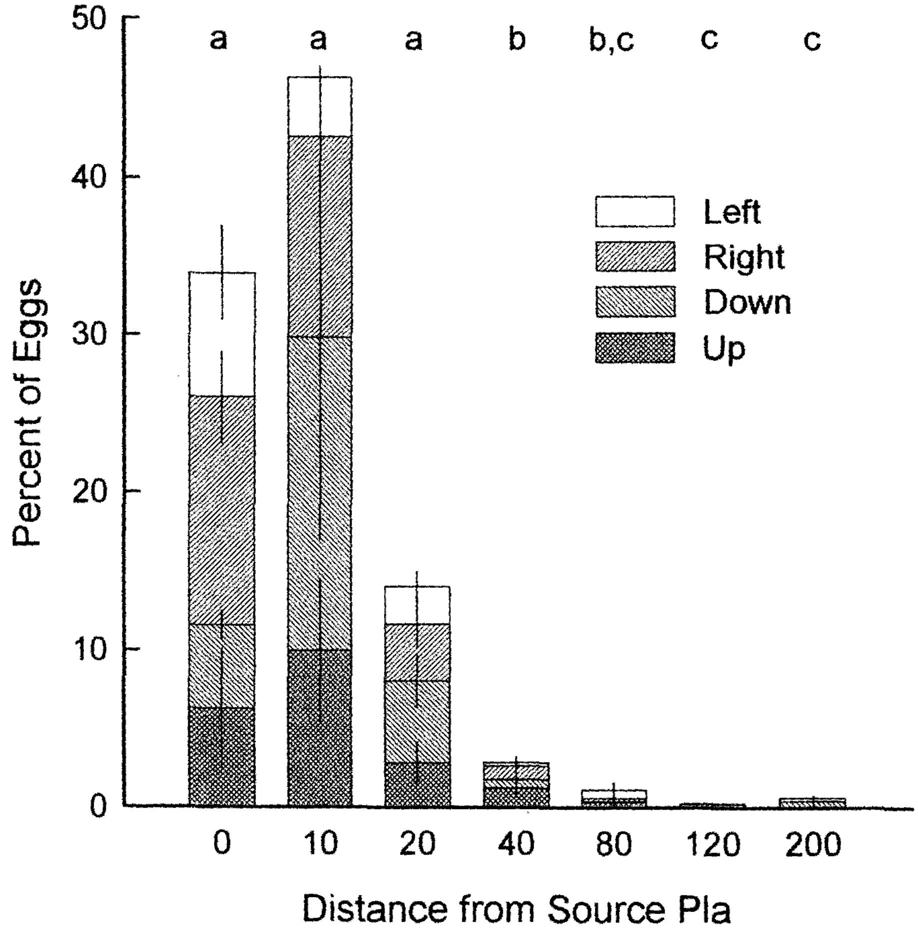


Figure 2.18. The average (± SE) percent of *Fucus* eggs settled at different distances and directions from source plants. Statistically indistinguishable distances (all directions combined) are indicated by the same letter above the bars.

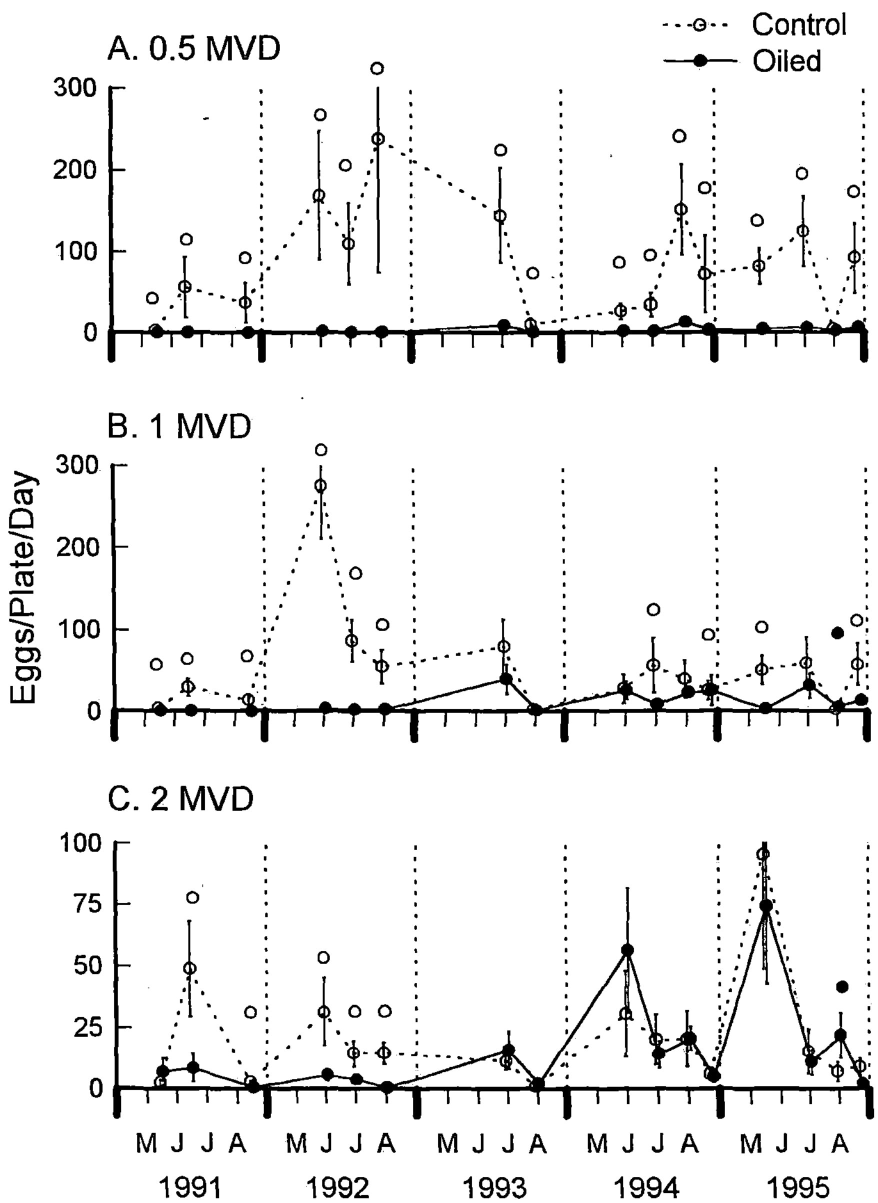


Figure 2.19. Mean number (± SE) of *Fucus* eggs settled per plate per day at three tidal levels. Symbols and lines are the same as those in Figure 2.4.

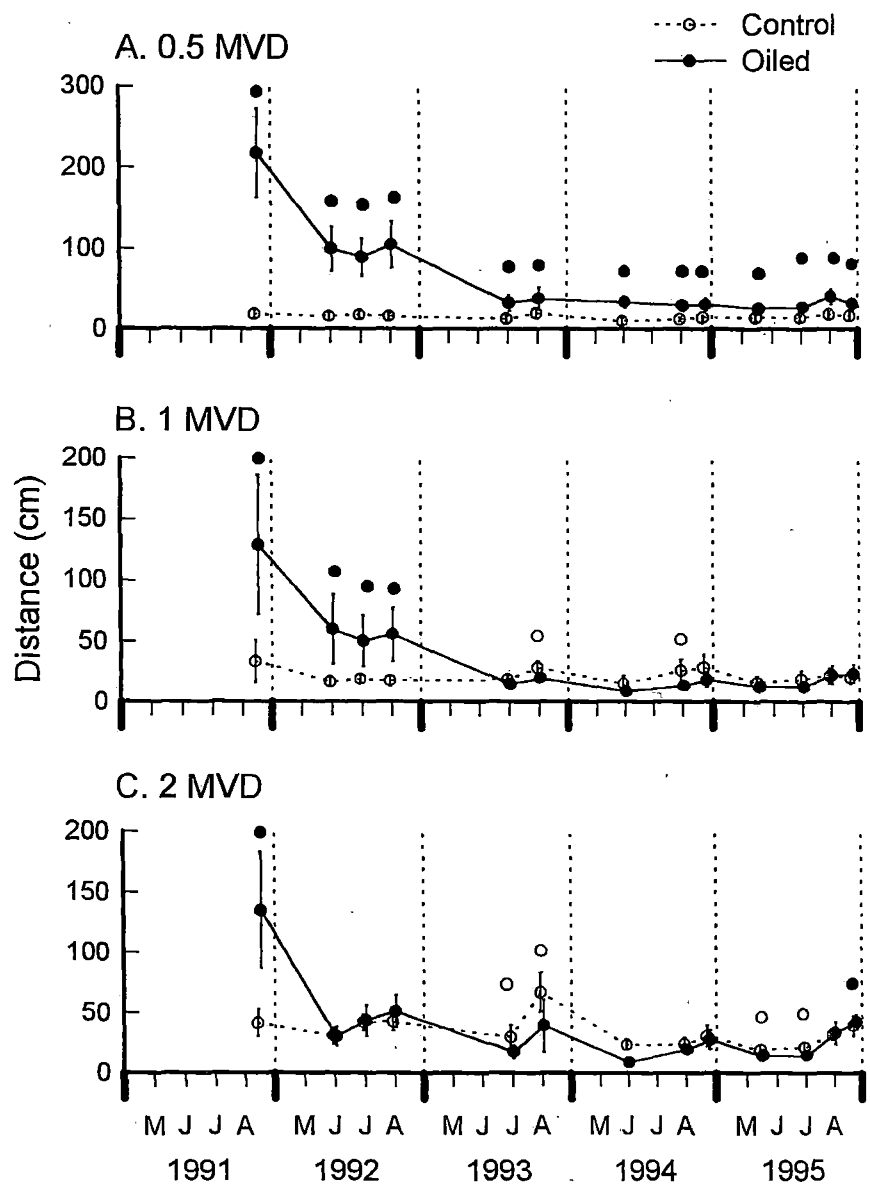


Figure 2.20. Mean distance (± SE) to the nearest fertile *Fucus* plant from settling plates at three tidal levels. Symbols and lines are the same as those in Figure 2.4.

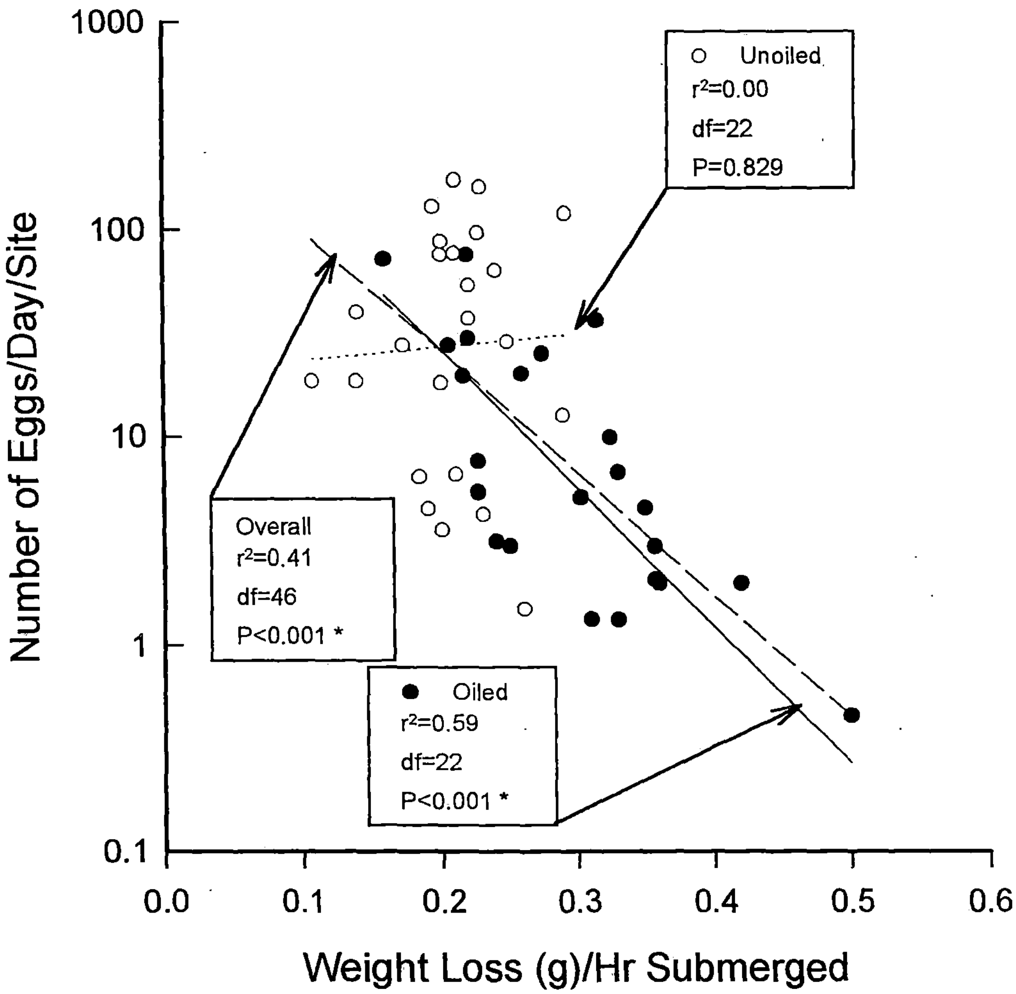


Figure 2.21. Net water flow versus *Fucus* egg settlement rate in 1994. The y-axis is in log scale.

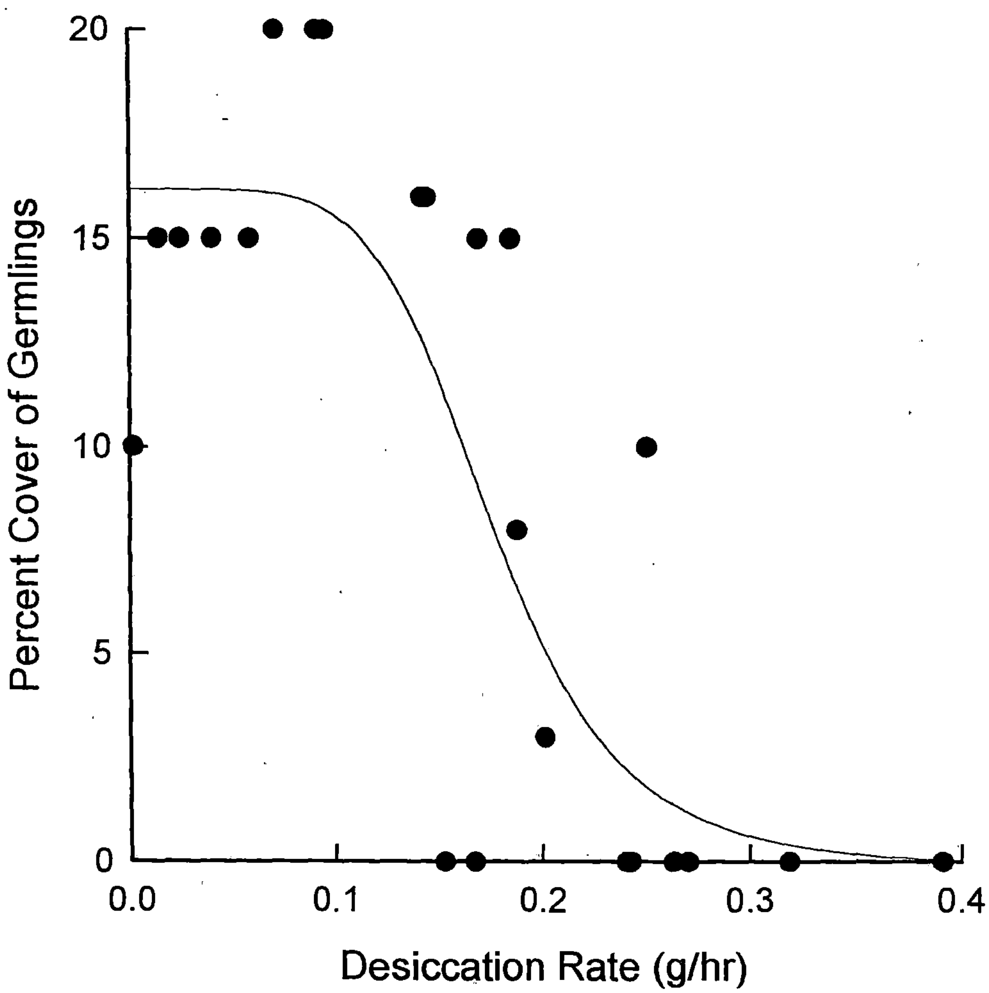


Figure 2.22. The relationship between the measured desiccation rate and the estimated percent cover of *Fucus* on petri dishes after being in the field for 11 days. There is a significant regression ($r^2=0.524$, $df=22$, $F=24.178$, $p<0.001$), but the regression line is not shown. The sigmoid curve shown was generated by SigmaPlot (Version 5.0) using the curve fitting function.

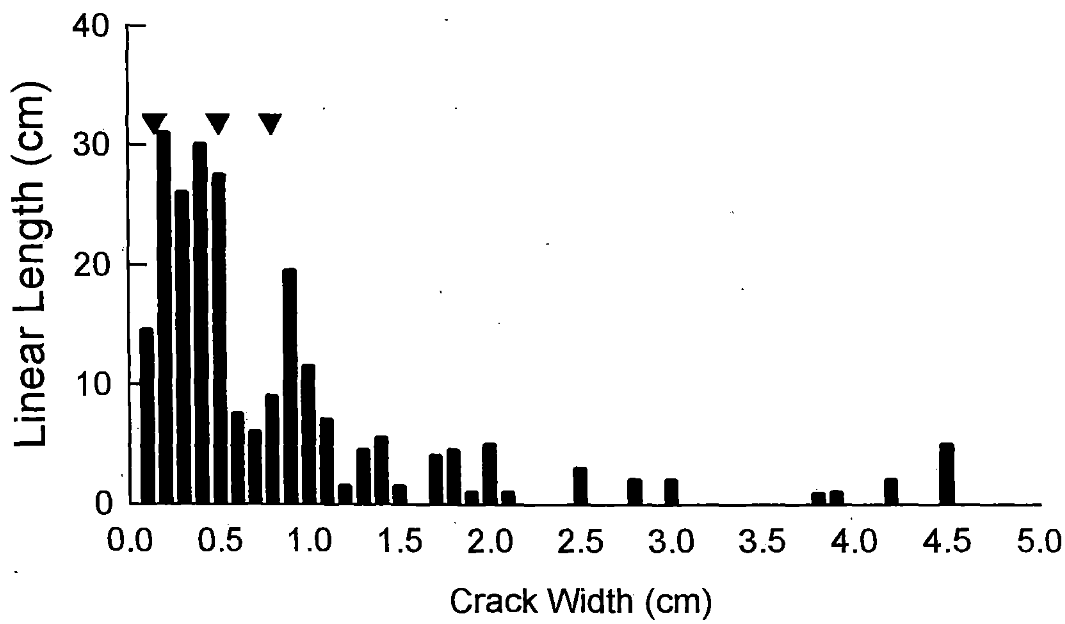
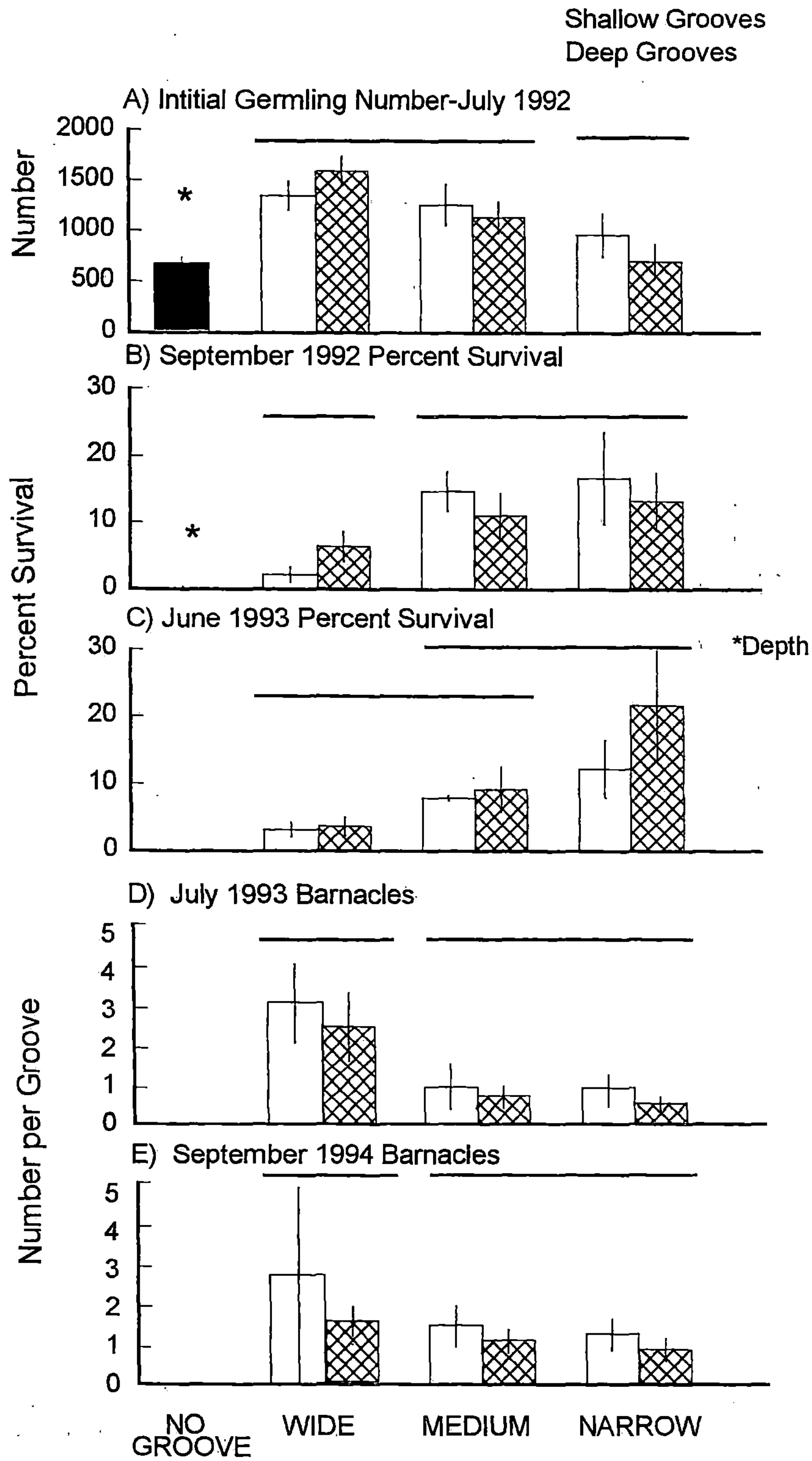


Figure 2.23. The width frequency distribution of cracks in Herring Bay. The proportion of linear length of cracks is given for different crack widths, and the width of the grooves used on the ceramic tiles are indicated by the inverted triangles.



Fgure 2.24. Initial *Fucus* seeding density, survival of seeded germlings, and recruitment of barnacles in grooves of various sizes. Lines above graphs connect statistically indistinguishable groove widths. The asterisk and depth symbol indicate that there was a significant effect of depth. Error bars represent one standard error of the mean. Results of statistical analyses are given in Table 2.3.

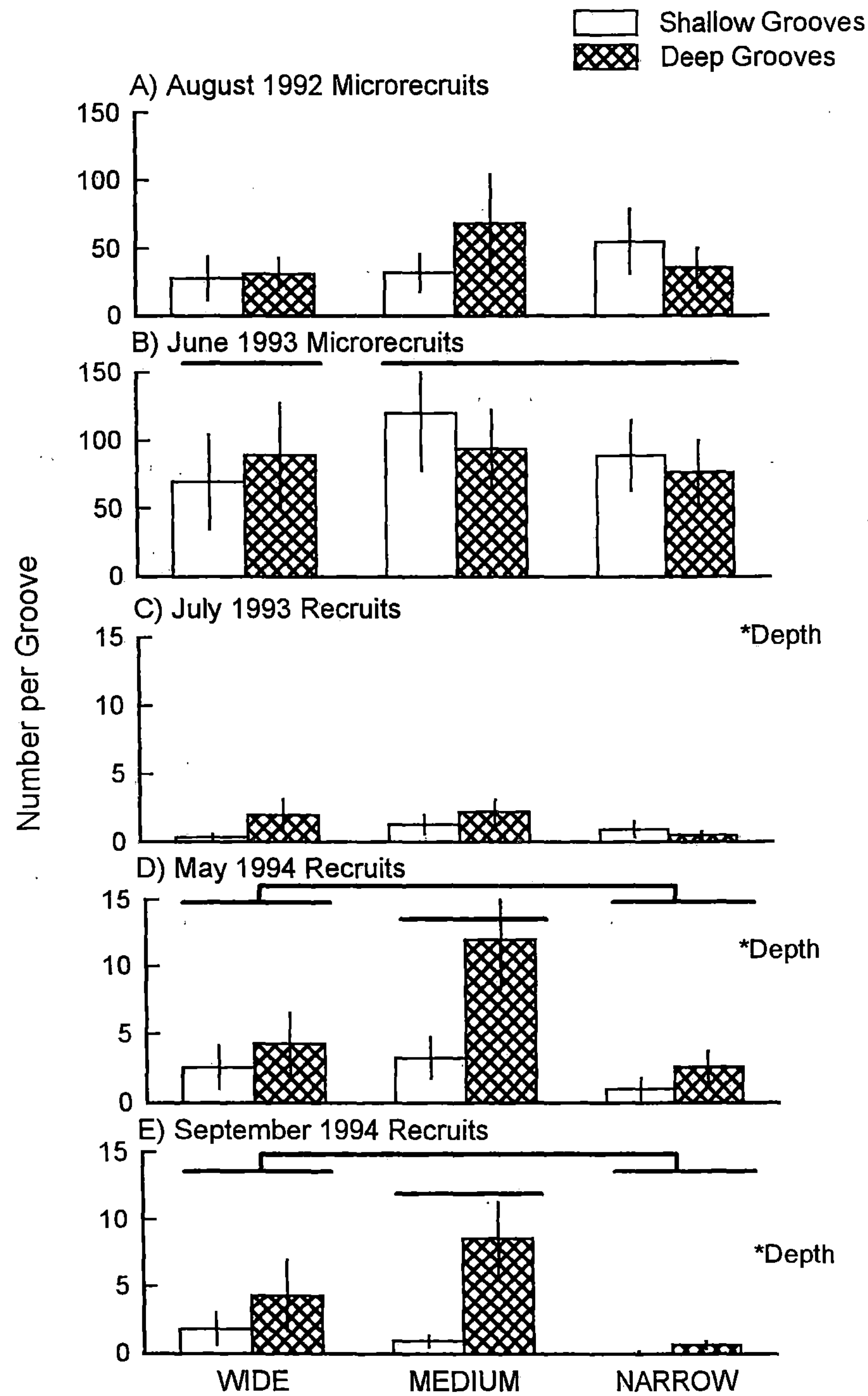


Figure 2.25. The number of *Fucus* micro- and macrorecruits in grooves of various sizes. Microrecruits were counted only on unseeded tiles while macrorecruits included both seeded andx unseeded tiles. Layout is the same as in Figure 2.24. Results of statistical analyses are given in Table 2.4.

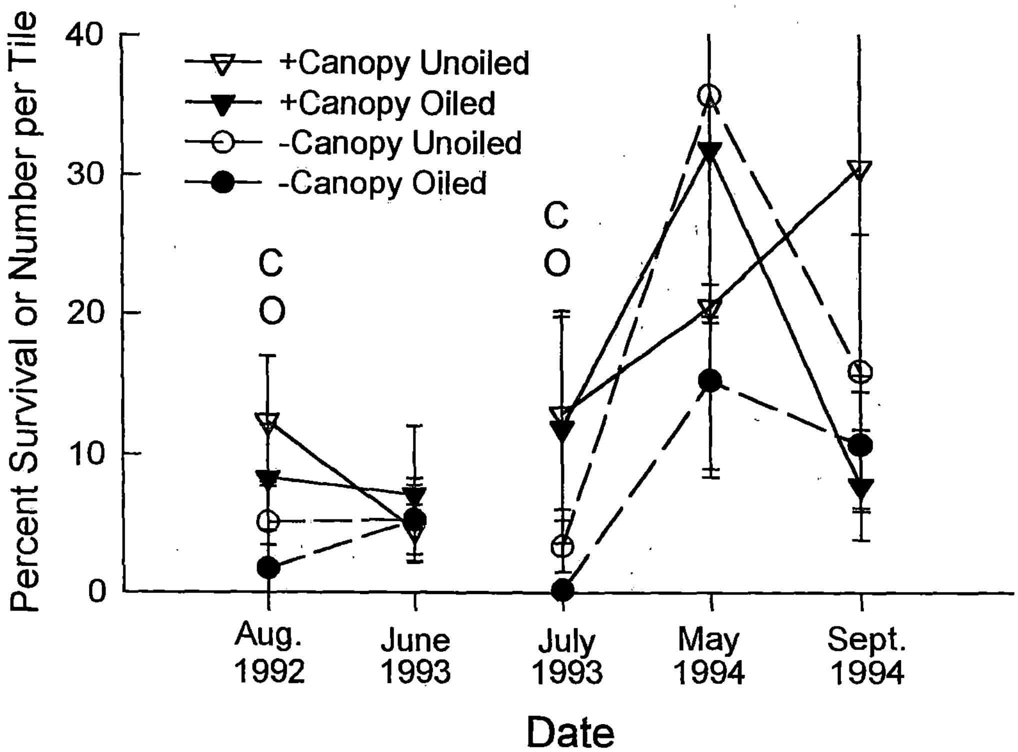


Figure 2.26. The percent survival or number of *Fucus* macrorecruits on tiles at unoiled and oiled sites and with and without canopy. Percent survival is given for the August 1992 and June 1993 dates, and the number of visible recruits is given for the remaining three dates. Letters above a sampling date show the significant effects from 3-way ANOVAs (Table 2.5).

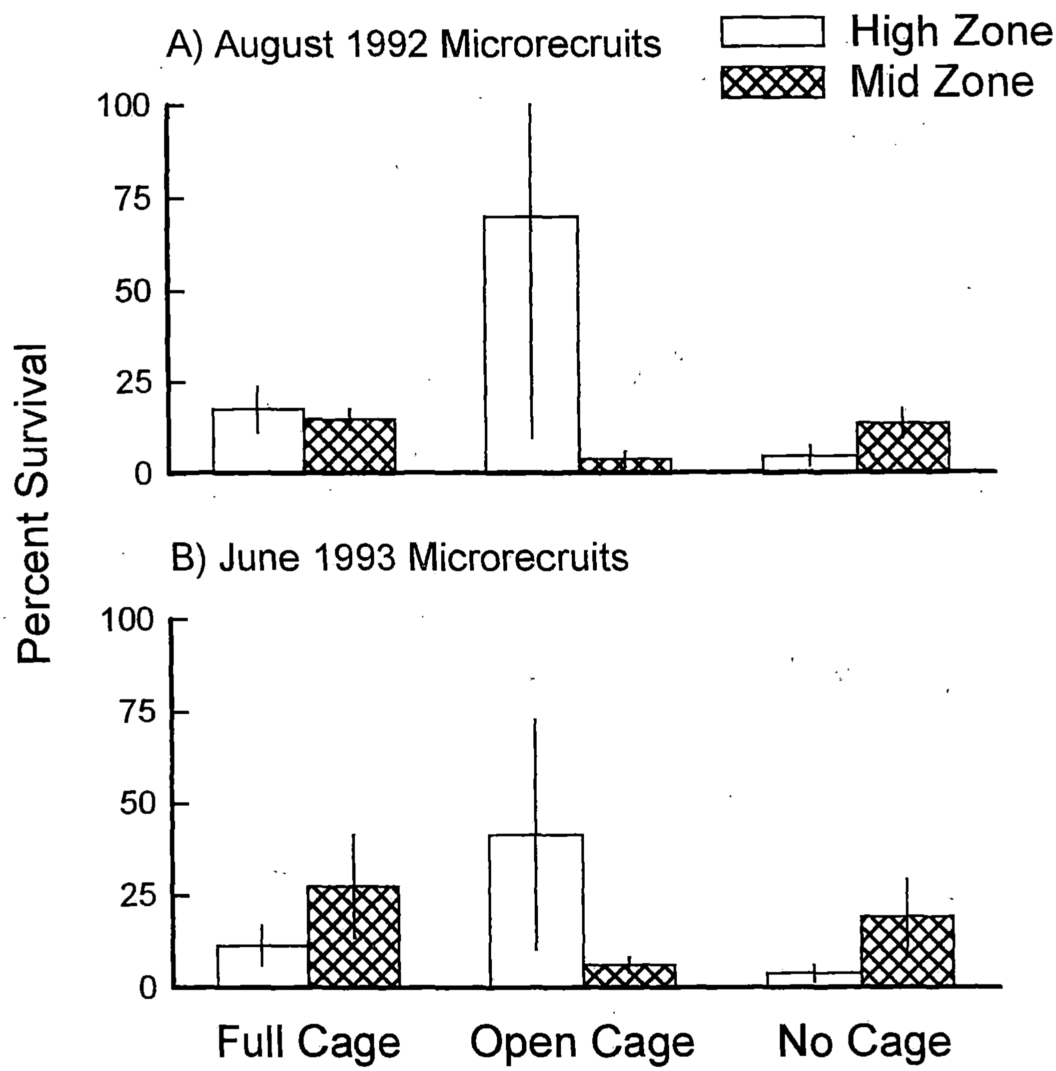


Figure 2.27. The percent survival of seeded *Fucus* germlings at two tidal levels and in the different caging treatments for two sampling dates. Statistical results are given in Table 2.7.

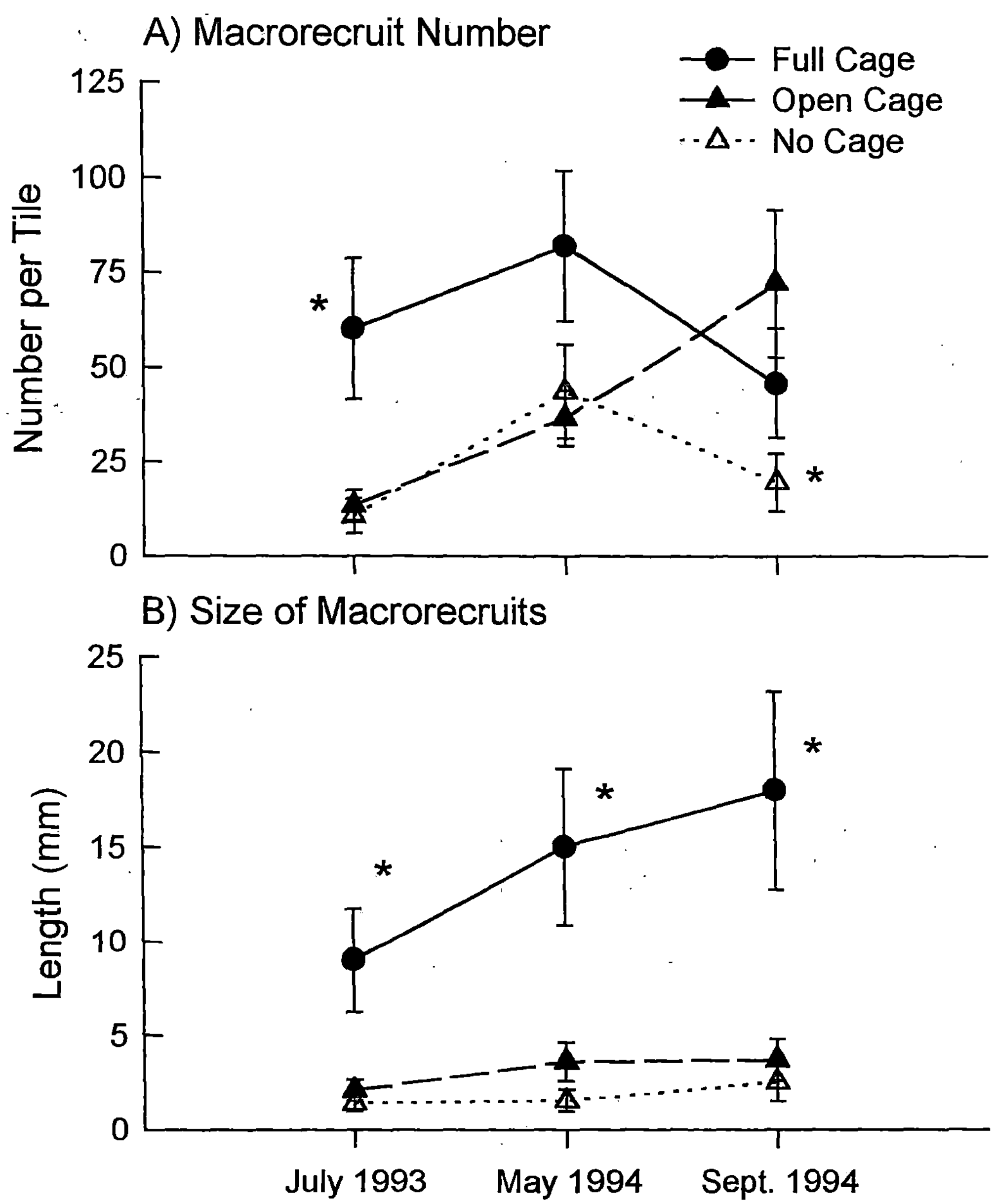


Figure 2.28. The number and size of *Fucus* macrorecruits on tiles with different caging treatments. Asterisks next to symbols indicate that the treatment was significantly different from the other two treatments ($p<0.05$). Statistical results are given in Tables 2.7 and 2.8.

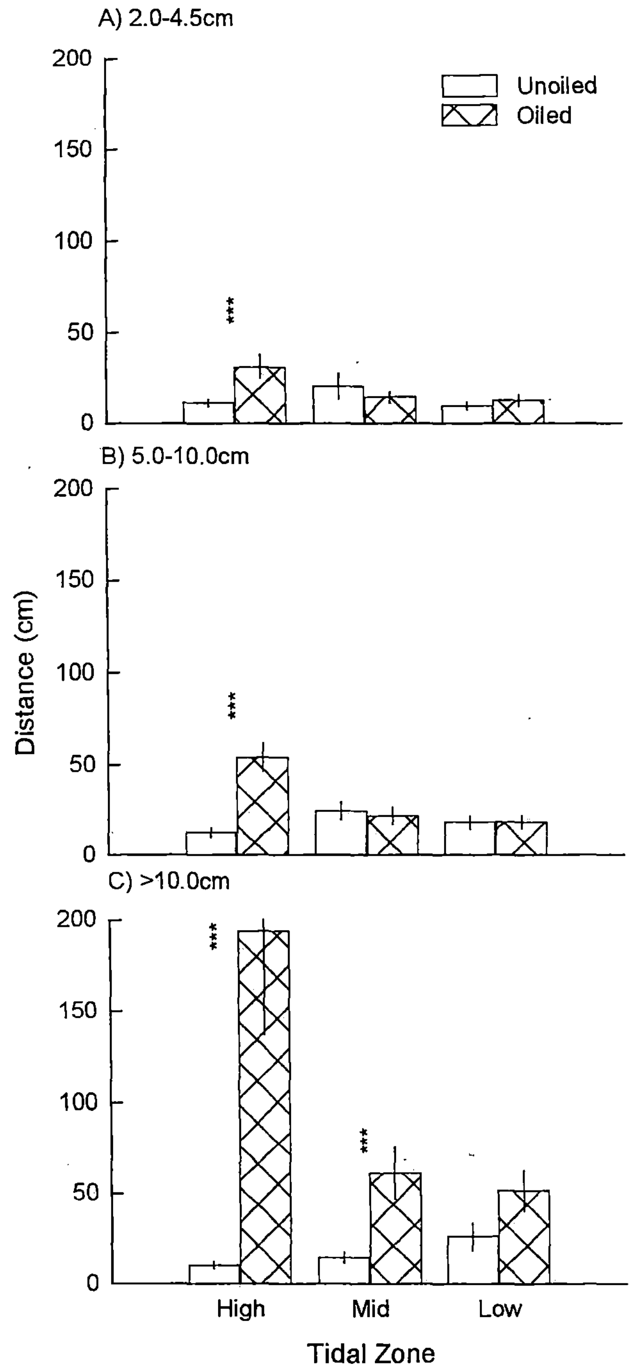


Figure 2.29. Distance from a random point to the nearest *Fucus* plant in each size class at 1, 2, and 3 MVDs in 1991. Stars indicate significance: one star ($p<0.05$), two stars ($p<0.01$), and three stars ($p<0.001$).

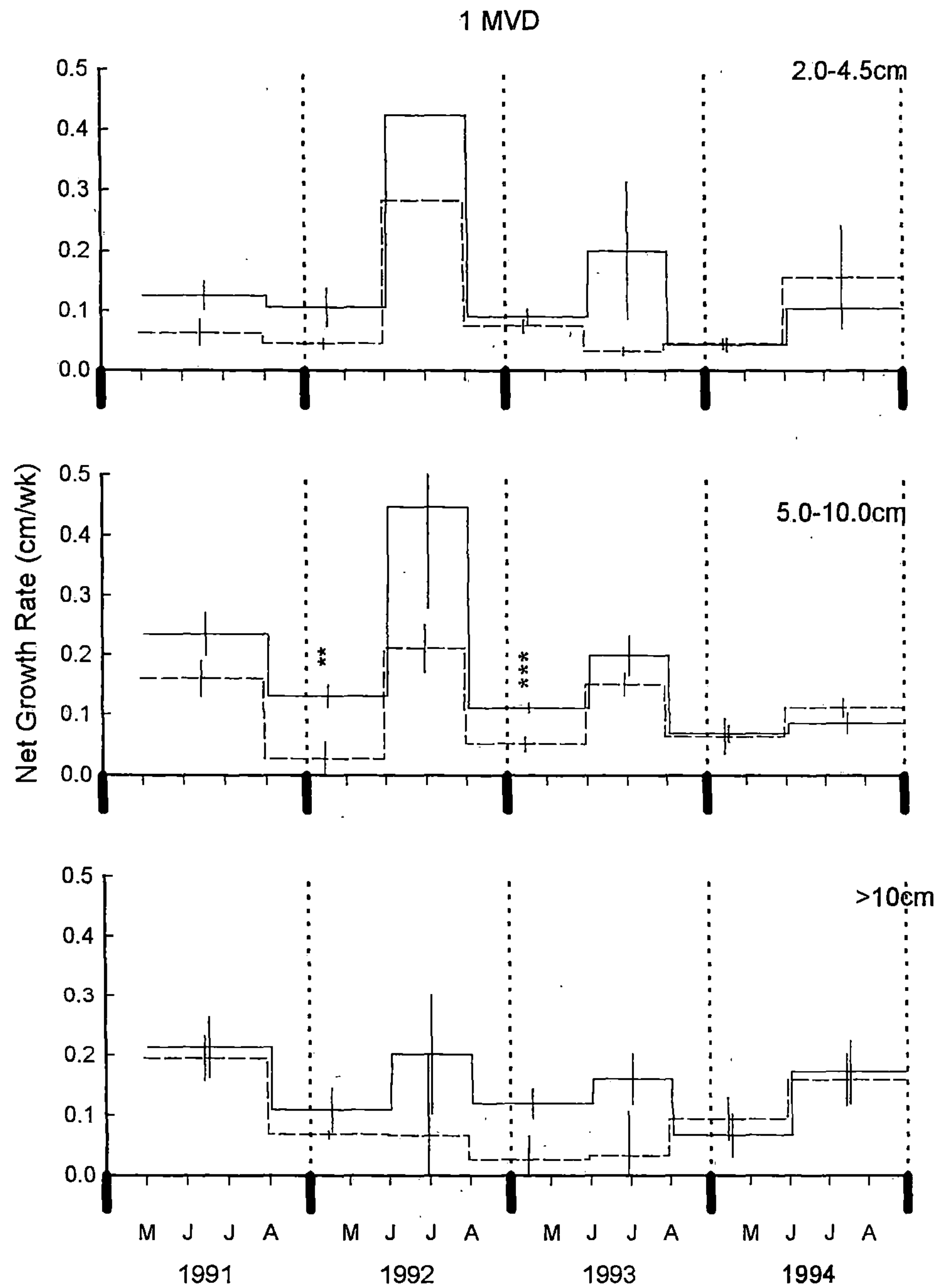


Figure 2.30. Mean net growth rates of *Fucus* at 1 MVD for small (2.0-4.5cm), medium (5.0-10.0cm), and large (>10.0cm) *Fucus* plants. Dashed lines represent plants at control sites and solid lines represent plants at oiled sites. The endpoints of each horizontal portion of a line represent sampling dates. Error bars represent one standard error of the mean. Stars represent statistical significance: one star ($p<0.05$), two stars ($p<0.01$), and three stars ($p<0.001$). If an error bar or horizontal line is missing it indicates that there were one or no plants for that time.

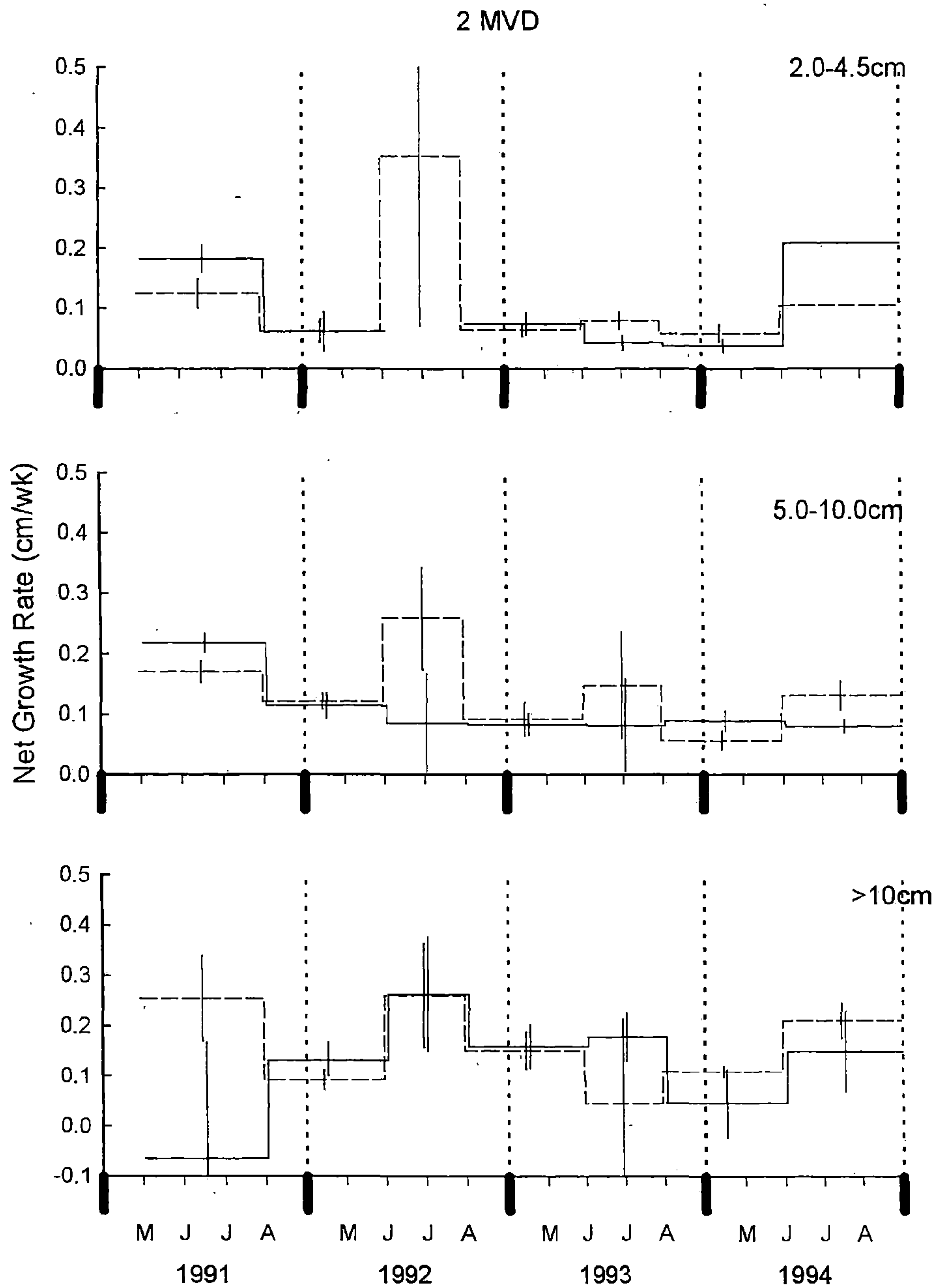


Figure 2.31. Mean net growth rates of *Fucus* at 2 MVD for small (2.0-4.5cm), medium (5.0-10.0cm), and large (>10.0cm) *Fucus* plants. Layout is the same as Figure 2.30.

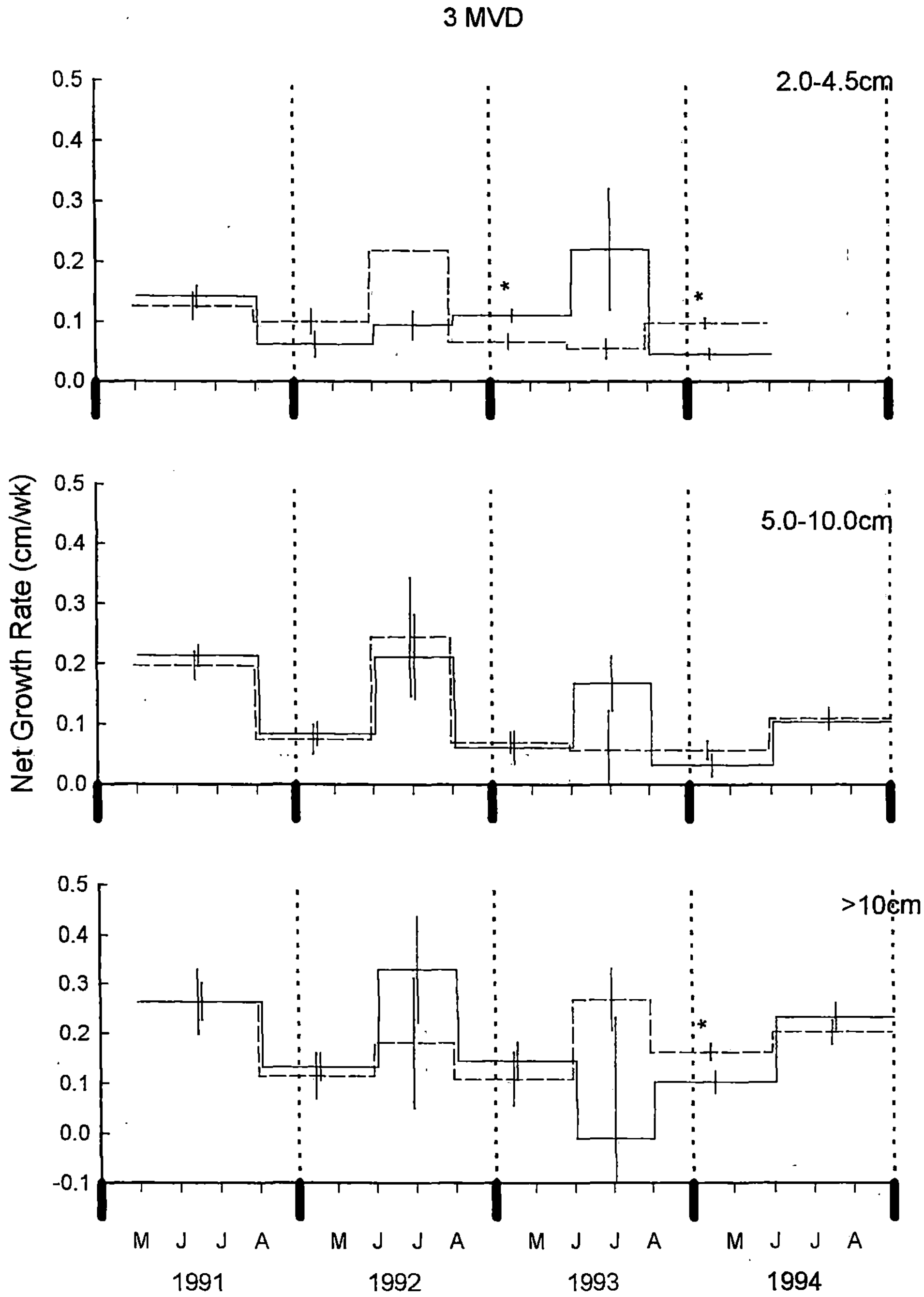


Figure 2.32. Mean net growth rates of *Fucus* at 3 MVD for small (2.0-4.5cm), medium (5.0-10.0cm), and large (>10.0cm) *Fucus* plants. Layout is the same as Figure 2.30.

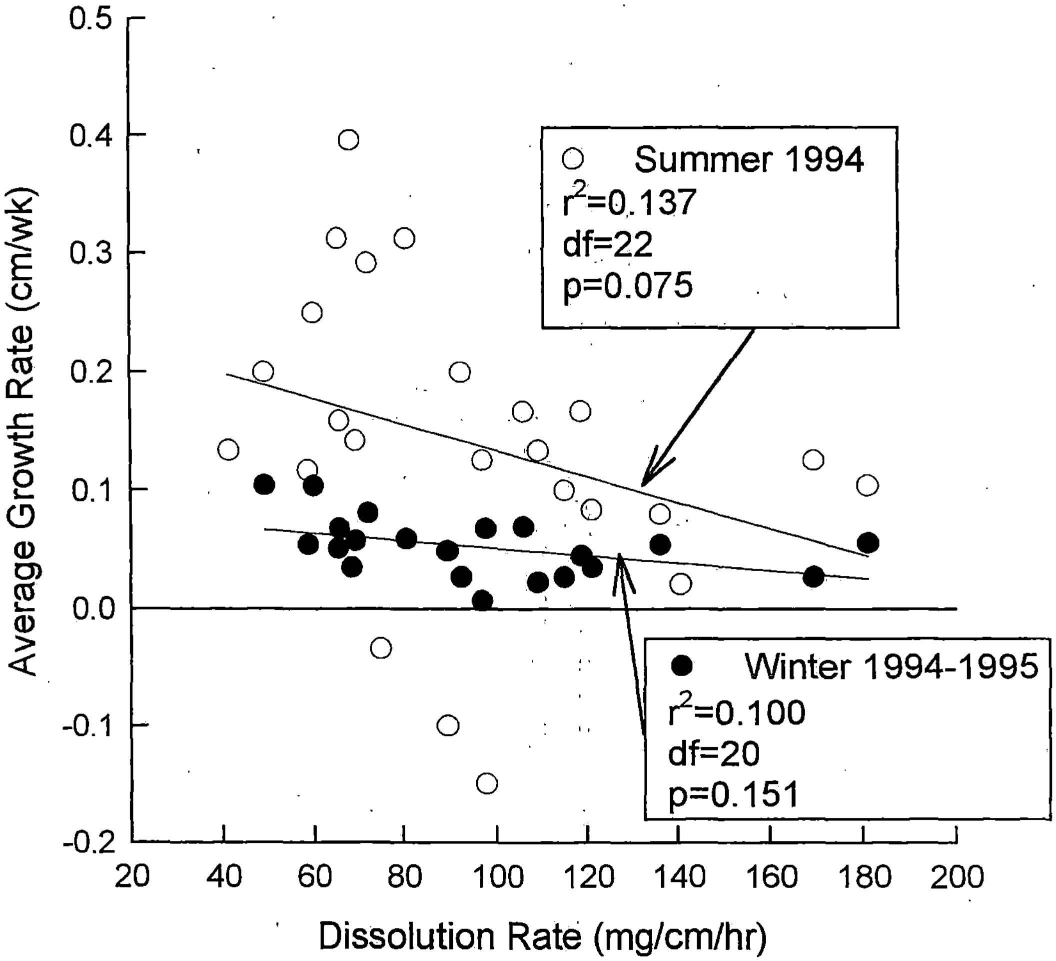


Figure 2.33. Average growth rate of *Fucus* for each of 18 sites versus net water flow measured by dissolution rate of calcium sulfate dissolution cylinders for both summer and winter periods.

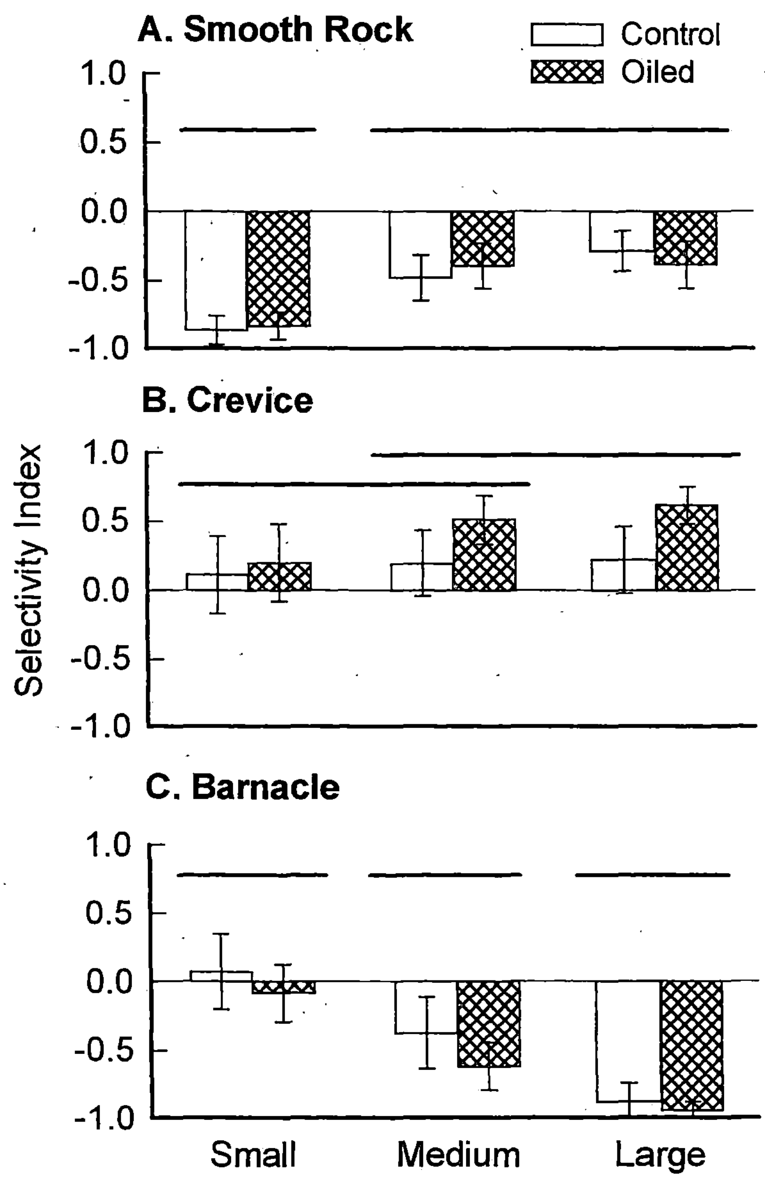


Figure 2.34. Selectivity indices of *Fucus* for three substrate types in 1994 for small (<2 cm), medium (2-10 cm), and large (>10 cm) plants at both control and oiled sites. Error bars represent 95% confidence intervals. Lines above the graphs connect statistically indistinguishable values for plant sizes. Statistical results are given in Table 2.13.

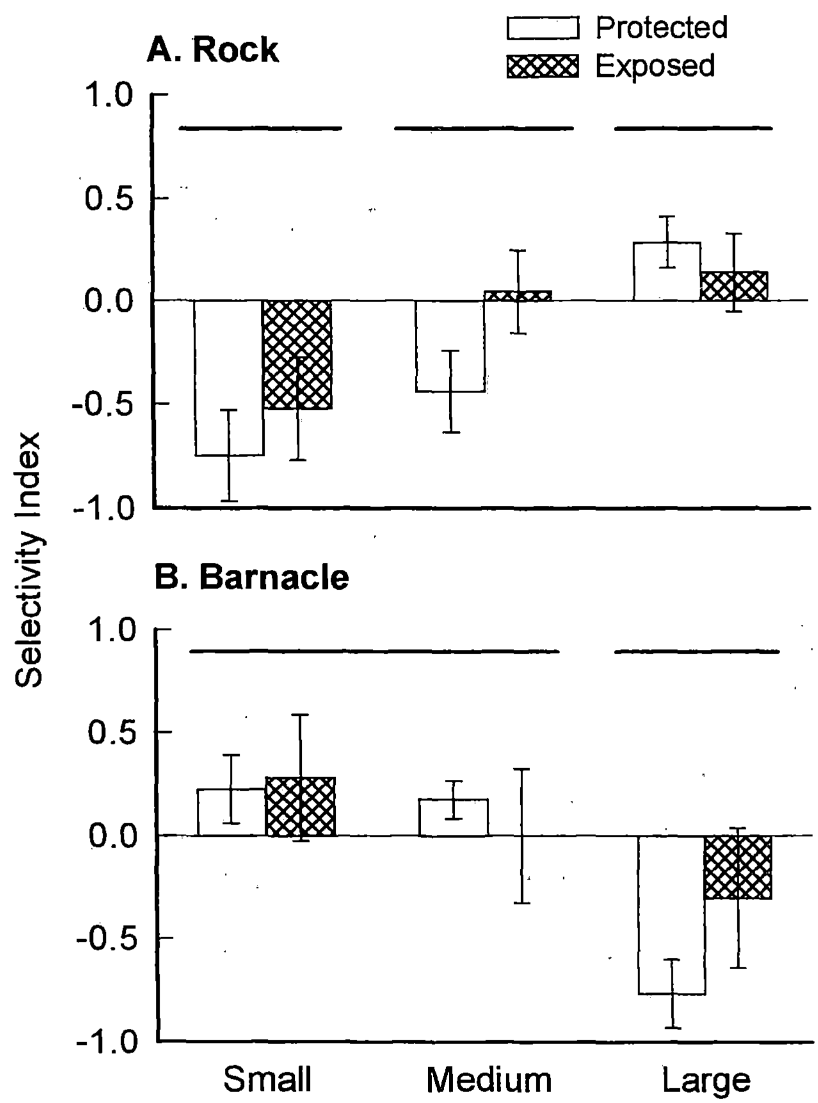


Figure 2.35. Selectivity indices of *Fucus* for two substrate types in 1995 for small (<2 cm), medium (2-10 cm), and large (>10 cm) plants at both control and oiled sites. Error bars represent 95% confidence intervals. Lines above the graphs connect statistically indistinguishable values for plant sizes. Statistical results are given in Table 2.14.

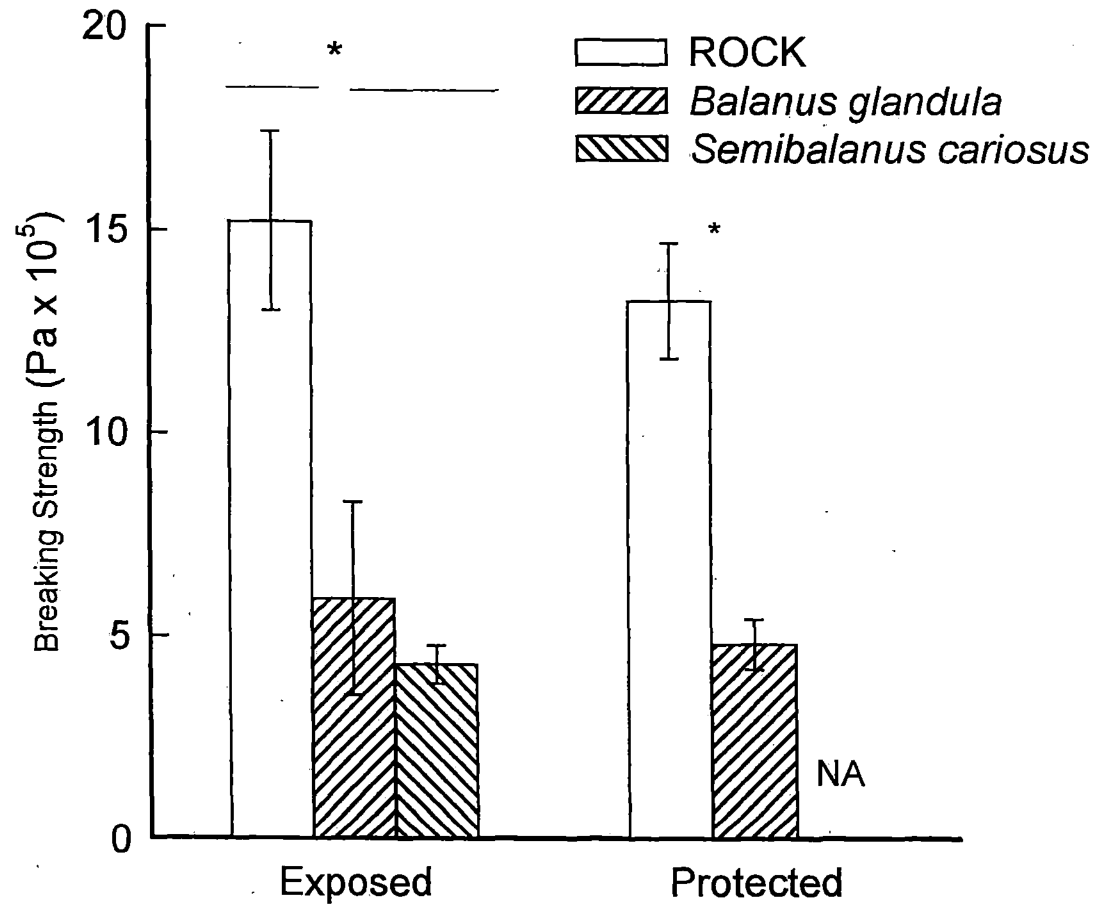


Figure 2.36. Mean breaking strength of *Fucus* attached to rock or either of two species of barnacle at exposed and protected sites. Error bars represent one standard error of the mean. Asterisks indicate that there was a statistical difference among substrate types, and the lines below the asterisks connect statistically indistinguishable substrate types when more than two substrates are compared. There was no difference between exposed and protected sites.

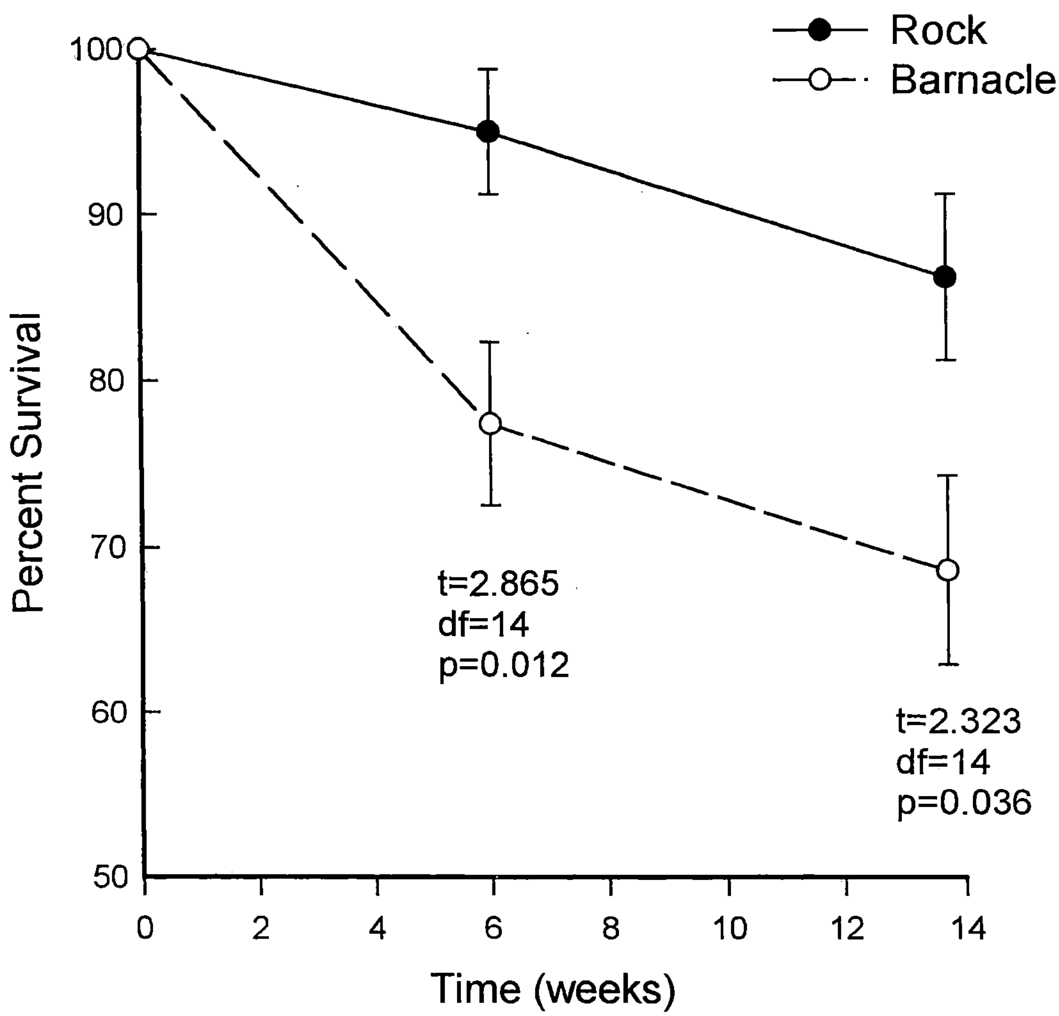


Figure 2.37. Percent survival of *Fucus* plants growing on rock and barnacles over the summer. Plants were initially marked on 20 May 1995. Error bars represent one standard error of the mean.

CHAPTER 3. INVERTEBRATE STUDIES

INTRODUCTION

The Coastal Habitat Injury Assessment (CHIA) project was designed to determine the effects of oil and subsequent cleanup activities on intertidal invertebrates and algae in areas impacted by the Exxon Valdez oil spill (Highsmith et al. 1994). The study encompassed the entire spill area, including shorelines outside of Prince William Sound, and examined several habitat types. In spring 1990, a field station was established in Herring Bay, Knight Island in Prince William Sound (Figure 3.1), with studies concentrating on coarse textured and sheltered rocky habitat. The Herring Bay study was established as a result of a Natural Resource Damage Assessment (NRDA) Management Team recommendation to complement the CHIA studies by providing a research platform for determining rates of recovery and potential factors limiting or enhancing recovery. This chapter presents the results of monitoring and experimental studies on several key invertebrate species.

The CHIA study found differences between oiled and control sites for the limpet *Tectura persona*, the barnacles *Chthamalus dalli*, *Balanus glandula* and *Semibalanus balanoides*, the mussel *Mytilus trossulus*, two species of periwinkle, *Littorina sitkana* and *L. scutulata*, and oligochaetes (Highsmith et al. 1994). Studies of other oil spills in temperate or subarctic regions have also shown reduced densities of invertebrates, particularly barnacles and intertidal grazers, such as limpets and littorines (Southward and Southward 1978, Mann and Clark 1978). In addition, other studies following the Exxon Valdez oil spill and cleanup operations showed decreased invertebrate populations on oiled coarse textured and sheltered rocky shorelines with varying rates of recovery seen over time (Gilfillan et al. 1995, Houghton et al. 1993, DeVogelaere and Foster 1994).

In Herring Bay, studies were implemented in 1990 which focused on several of these key intertidal invertebrate species. A population dynamics study was designed to monitor densities of limpets, littorines, the dog whelk, *Nucella* spp., and the seastar, *Leptasterias hexactis* at three tidal heights on matched pairs of oiled and control sheltered rocky and coarse textured sites. The species chosen for long-term monitoring represented intertidal organisms with two very different reproductive strategies. *L. sitkana*, *Nucella* spp., and *L. hexactis* lack a dispersal phase in their life history (Kozloff 1983). The limpet species studied use a dispersal strategy in which the larvae have a pelagic phase before settling into the intertidal. Thus, they can recruit onto oiled shorelines from a greater distance than can the organisms with non-dispersal phases. From 1990 through 1993, the study found that populations of intertidal grazing invertebrates (limpets and littorines) continued to show reduced densities at oiled sites, especially in the upper intertidal zone. By 1993, recovery was underway in the mid and lower intertidal zones, with few statistical differences in invertebrate densities remaining between oiled and control sites. The population dynamics study continued through the summer of 1995 to determine when and if recovery had occurred.

Injury to and recovery of *Fucus gardneri*, the major structural component of the intertidal in Herring Bay and most of the oil spill region, was discussed earlier in this report. As of 1995, *Fucus* cover remained low in the high intertidal oiled shorelines. Due to its importance to the intertidal community in terms of biomass and interactions, general recovery of the intertidal community relies heavily on the recovery of *Fucus*, especially in the high intertidal where desiccation stress is greatest. In Herring Bay we have correlated *Fucus* percent cover with the abundance of various invertebrates.

In addition, the removal of *Fucus* cover and the resulting effects on mobile invertebrate abundances was studied in 1995.

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 environmental 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. Intertidal habitats with solid substrate that are more exposed to waves are generally more productive and diverse (Leigh et al. 1987). This may be a result of increased food availability for filter feeders, increased nutrient renewal, enhanced competitive ability of productive organisms, and protection of intertidal organisms from predation. Results from community level multi-dimensional scaling analyses of data from the CHIA study showed that sheltered rocky site data tended to cluster relative to wave exposure (Highsmith et al. 1994). The possibility that oiled sites have more water motion over the substrate, and thus 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 calcium sulphate cylinders were used in Herring Bay as indicators of relative water motion (Muus 1968, Gerard 1982, Petticrew and Kalff 1991) at the mussel study sites.

Barnacle studies conducted in Herring Bay during the initial damage assessment phase in 1990 through 1993 showed higher abundances of *Chthamalus dalli* on oiled sites compared to matched controls. *C. dalli* also had higher recruitment in cleared spaces. In addition, 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). A study was initiated in 1993 to monitor abundances and recruitment of *C. dalli*, *Balanus glandula*, and *Semibalanus balanoides*. This monitoring continued in 1994 and 1995 in order to track recruitment dynamics relative to competitive interactions.

METHODS

POPULATION DYNAMICS OF SELECTED INVERTEBRATES

Three site pairs from sheltered rocky habitat and two site pairs from coarse textured habitat in Herring Bay have been monitored for invertebrate densities from 1990 to 1995. These sites are listed in Table 1.1 and Figure 3.1. *Fucus* (Chapter 2) and several invertebrates were monitored at least twice per year to determine changes over time on oiled and control sites. All sites include six 0.1 m^2 quadrats randomly placed within each of the first three meter vertical drops (MVD) from Mean High High Water (MHHW). All quadrats were permanently marked. During each collection of data, all limpets, *Littorina sitkana*, *Nucella* spp., and *Leptasterias hexactis* were counted. In addition to the Herring Bay population dynamics sites, the sheltered rocky sites from the Coastal

Habitat Injury Assessment project (CHIA, Highsmith et al. 1994) were visited, opportunistically in 1993, 1994, and 1995, once each summer. On these sites, invertebrates in six non-disturbed 0.1 m^2 quadrats were counted at each of the three MVDs.

Data Analysis

Invertebrate density 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 and unequal variances were log transformed. T-tests were conducted between site pairs for raw or log transformed data.

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 calculated 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.

RECRUITMENT ON OILED AND NON-OILED SURFACES

Table 3.1 lists study sites used for recruitment studies on oiled and non-oiled surfaces. One study monitored recruitment and succession on tarred (oiled) and untarred (unoiled) rocky substrate. To determine if algal and invertebrate recruitment patterns and/or grazing rates were affected by the presence of tar, caged and uncaged plots were monitored that had been scraped to remove tar or left tarred (unscraped). Another study monitored recruitment and succession onto ceramic tiles. This study occurred on six sites. Oiled and unoiled tiles were placed directly in the intertidal or caged. More detailed information is given below for each study.

Recruitment on Vertical Rock Faces

Since 1990, four study sites have been monitored for barnacle recruitment (Table 3.2). An additional six sites were added to the study in 1991. The oiled sites for this study were selected from rock walls where tar bands had established within the barnacle zone in the upper intertidal. Control sites were selected to match as many physical characteristics as possible with the oiled sites, except the control sites lacked a tar band. At each site, a series of paired 10 X 10 cm plots was established on a vertical rock face at MVD 0.5. The location of the first pair of plots was randomly established from the left end of the site and subsequent paired plots were placed 0.5 m apart. To evaluate the possible impact of weathered oil on barnacle recruitment at oiled sites, one member of each pair was scraped and brushed to remove all visible tar. The adjoining 10 x 10 cm plot was not disturbed. To control for scraping and brushing affects, one member of each plot pair at control sites was scraped and brushed to remove any algae or invertebrates present. The sites were periodically monitored for recruitment of barnacles, *Fucus* germlings and grazers. Grazers, defined here as limpets and the two species of littorines (*Littorina sitkana* and *L. scutulata*), were not quantified during 1992, but counts resumed at each plot in 1993. In 1991, the experiment was modified by randomly assigning grazer exclusion cages to half of the study plots. The cages excluded most limpets and littorines, with the exception of juveniles less than 4 mm in length, which were removed by hand during each site visit throughout the study period. This study was closed out after the 1993 field season due to the loss of most of the cages by 1994.

Recruitment on Oiled and Non-oiled Tile Pairs

In 1991, nine unglazed, red clay tile pairs were placed in the intertidal at each of three oiled and control site pairs (Table 3.1). Each tile was 53 cm^2 in area and each pair was placed side by side in the intertidal. Six of the tile pairs consisted of a tile treated with North Slope crude oil, taken from the T/V Exxon Valdez in 1989, and a non-oiled tile. Of these tiles pairs, half were enclosed by a 4 mm mesh stainless steel cage to exclude grazers. The remaining three pairs consisted of a clean tile and a tile painted black (rather than oiled) as a control for dark coloration and possible temperature differences. However, the paint may have introduced artifacts such as chemical and texture differences that could affect recruitment. The tile pairs were placed 50 cm apart along the MVD 2 contour, with the location of the first tile pair randomly determined from the left end of the site. During subsequent visits, tiles were sampled for barnacle recruits, *Fucus* germlings, percent filamentous algal cover and grazers. In 1992, cover was further subdivided into barnacle adults, *Chthamalus dalli*, and *Fucus* adults (plants 2.0 cm). Again, this study was closed out after the 1993 field season due to the loss of most of the cages and many tiles by 1994.

Data analysis

Recruitment data were analyzed using a paired t-Test between plots within the sites. Analysis of variance was used to compare like treatments between oiled and control sites as well as the effects of caging. Data were log transformed if normality tests (Kolmogrov-Smirnov) and variance homogeneity tests (Levene's) failed. If the transformed data also failed the tests, then the non-parametric Wilcoxon Signed Rank Test or Kruskal-Wallis ANOVA on ranks was performed. All relevant information pertaining to the type of analysis performed is indicated in the presentation of data.

FUCUS AS INFRASTRUCTURE AND PROTECTION FOR INVERTEBRATES

As indicated in the introduction, increased water motion may result in higher recruitment, growth and survival rates of intertidal organisms due to such factors as increased nutrient, propagule or food supply,. To investigate this possibility, we determined the abundance of epiphyte grazers (*Littorina sitkana*, *L. scutulata*, *Lottia pelta*) and a filter feeder (*Mytilus trossulus*) on *Fucus* plants per unit weight at locations where calcium sulphate cylinders were utilized to estimate relative water motion. On 25 of the sites shown in Figure 3.2, *Fucus* plants were collected from the 0.5, 1.5, and 2.5 MVDs. These sites were originally selected for a study on calcium dissolution rates which is described in a later section. The sites were selected at MHHW and a marker was set in marine epoxy at the waterline. At low tide, a transect line was run perpendicular from MHHW to the waterline. At each of the three MVDs listed above, the nearest *Fucus* plant (> 10 cm in length) to the right of the tape was collected. Collections were carefully made such that all invertebrates within the plant were also collected. The plants were returned to the boat, all invertebrates were collected and counted, and each *Fucus* plant was weighed.

To determine the extent that invertebrates rely on *Fucus* canopy for cover, an experiment was conducted to compare invertebrate densities over time after the removal of *Fucus* canopy. Three sites were chosen to represent a variety of wave exposures in Herring Bay based on calcium sulphate dissolution measurements (See Water Circulation section, this chapter). The sites selected were sites A, G, and M (Figure 3.2), representing "exposed", "moderate", and "protected" shorelines, respectively. The exposed site was subjected to waves about 1 m in height during storms while at the protected site, waves did not reach above 0.25 m (personal observations between April and September during six field seasons). At site G, maximum wave heights were greater than 0.25 m but less than 1 m. At each site, four 25 x 25 cm quadrats were permanently marked at each of three tidal levels (0.5, 1.5, and 2.5 MVDs). At each tidal level, quadrat locations were spaced 2 m apart along the site. All *Fucus* plants with holdfasts in the quadrat and within a 10 cm border around the quadrat were removed. and placed in plastic bags. Any plants outside of the border that were large enough to "flop" into the quadrat were also removed. All limpets and littorines remaining in each quadrat after *Fucus* removal were counted for five consecutive days starting with the day of *Fucus* removal. Counts were also taken 33 and 64 days after *Fucus* removal.

Data Analysis

To determine if water current rates affect invertebrate densities on *Fucus* plants, correlations were made between *Littorina sitkana*, *L. scutulata*, *Lottia pelta*, and *Mytilus trossulus* densities on *Fucus* plants and calcium dissolution rates (described below). Densities for each invertebrate species were normalized to the weight of the *Fucus* plant.

To test the effects of *Fucus* removal on invertebrates, data were analyzed with repeated measures 2-way ANOVAs with site and tidal level as factors. The repeated measures ANOVAs were weighted to account for the different time intervals of the last two sampling days. Tidal level was not used as a factor for *Littorina scutulata*, because this species was essentially absent at the lower tidal levels, resulting in little to no variance at these levels.

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 (40 x 50 cm). No effort was made to identify algae at each point beyond filamentous or non-filamentous. The quadrats were randomly placed along each transect line within the 1.0, 2.0, 3.0 and 3.5 MVD levels. This was done by multiplying the tape distance within each MVD by a random number and using the resultant tape distance as the upper edge of the quadrat frame.

To determine mussel density in filamentous algae, it was necessary to collect samples for microscopic identification in the laboratory. Samples were randomly collected within a 2 m horizontal distance from the right side of the point grid frame at each transect and MVD. In 1993, a 10 x 10 cm sample of algae was removed, with a razor blade, from an area with 100% filamentous algal cover within the sampling frame. If no 10 x 10 cm areas with 100 % filamentous algal cover were found within the 2 m sampling distance, no collection was made. In 1994, methods were altered to increase the number of samples collected per site but reduce the laboratory processing time. Algal samples of 5 x 10 cm were collected from the nearest location to the quadrat frame that had at least 50% filamentous algal cover. Percent cover within the sampling frame was estimated and recorded so that the total number of mussels on filamentous algae could be normalized to a standard 10 x 10 cm area. Thus, algal percent cover within the sampling frame ranged from 50% to 100% and the assumption was made that mussel recruit density found in frames with less than 100% algal cover was representative of mussel density had there been 100% cover. This methodology probably increased variability of the data but no more so for oiled sites than control sites and the increased number of samples due to this procedure should help to balance overestimates and underestimates within control and oiled data sets for 1994. 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. Because of budget reductions, no samples were collected in 1995.

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. The percent filamentous algal cover data were arcsine root transformed before statistics were performed. Analyses were separated by MVD for each sampling date. For the filamentous algal collections, samples from less than 100% cover within the 5 x 10 cm sampling frame were normalized to 100 %. Also, the 5 x 10 cm quadrat collections made in 1994 were normalized to a standard 10 x 10 cm sample area.

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

MUSSEL SIZE-FREQUENCY DISTRIBUTIONS

This experiment is part of the overall investigation of the potential positive relationship between water flow and the abundance and sizes of organisms present as a site (see Introduction, para. 5). Earlier Herring Bay reports referred to the mussel present as *Mytilus edulis*. Recent taxonomic works indicate the species is actually *M. trossulus* (McDonald and Koehn 1988, Geller et al. 1994). Three pairs of matched oiled and control sites were established for size-frequency distribution studies to determine if differences existed in the distribution of mussel size classes in mussel beds on matched oiled and control sites. 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 3.1), respectively. These six sites represented most of the coastline in Herring Bay that could be considered having a mussel "band" or bed.

During the initial visit to each of the sites in June 1993, the total length of the mussel band was determined. This study was designed to study size frequencies of mussel populations. Thus, to insure that mussel collections were made, to increase N, areas devoid of mussels were excluded from the measurement. Four vertical transects, set perpendicular to the shoreline, 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 mussel band length to the first transect location. The top of each transect was marked at MHHW with anchor screws or marine epoxy.

The width of the mussel band along the transect was measured and multiplied by a random number. The upper right corner of the quadrat frame was placed at this tape distance 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, September 1994, and May 1995. Newly-established collection quadrats were placed one 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 in a 0.5 mm sieve. Length measurements were taken to the nearest 0.05 mm using dial calipers except for mussels less than one mm in length which were classified as < 1 mm.

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 and the largest of these differences for all size classes 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 and the largest difference recorded. This was repeated 5000 times. A p-value was determined from the ranking of the "largest differences" obtained by the randomization process relative to the "largest difference" in cumulative frequencies from the real data.

TAGGED AND CAGED MUSSELS

Mussels were tagged and caged at each of the six mussel study sites described above to determine if growth rate differences existed for mussels on the oiled study sites compared to the control sites. Initial mussel collection, tagging, and length measurements were taken in June 1993. Thirty to sixty mussels were collected near the mussel collection quadrats, described under Mussel Size-Frequency above, from two randomly selected existing transects. The mussels were bagged separately in sea water and returned to the research vessel where each mussel was tagged or marked and it's length measured to the nearest 0.05 mm using dial calipers. 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 tagged or marked mussels were stored in a flowing seawater tank until the next low tide, then were returned to their respective transects. The mussels were placed inside wire mesh cages (20x20x7 cm) and the cages attached to the substrate within the bed with anchor screws. The mussels were collected again in August 1993, May 1994, August 1994, May 1995, and August 1995, remeasured to determine growth, and returned to their cages.

Data Analysis

Annual and total growth rates were analyzed using two-sample t-tests for comparisons of oiled sites with control sites. Means and standard errors are reported for seasonal (summer or winter) 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 Herring Bay. Dissolution cylinders were constructed from commercially available calcined gypsum, or calcium sulphate. 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. For all deployments, cylinders were placed on the set of sites for the same period of time. Thus, dissolution measurements are good indicators of relative differences in water motion and "integrate" dissolution over the same time period.

Calcium sulphate dissolution cylinders were deployed on the mussel study sites and at 33 locations around the perimeter of Herring Bay (Fig. 3.2). 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 throughout deployment. The other method used metal brackets mounted in the bedrock to hold the cylinders on site. In both cases the cylinder was attached by the metal wire at the bottom so that the cylinder protruded above the holder into the water column so any mounting effect was minimal. Four cylinders were placed on each mussel study site. At the 33 locations around the perimeter of Herring Bay, one calcium sulphate cylinder was deployed at 1 MVD below MHHW. The dissolution cylinders were placed on large rocks and sufficiently above or away from sediments that erosion due to sediment scour was unlikely. Pitting was not observed and the cylindrical shape was retained in all cases.

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 to test for replication between 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, selected randomly from several different batches, the variability among 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 during each deployment, two on each of two transects at the mussel study sites and one each (except for a few instances where two cylinders were deployed to check replicability) on the 33 sites chosen around the 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.

To determine if the tidal computer software program was reasonably accurate for Herring Bay, a site in mid-Herring Bay was selected. On May 26, 1994, starting one half hour before the time listed for high tide, pieces of marine epoxy were placed at the water level every five minutes until the time of high tide listed in the program. The markers were monitored relative to the water level to determine if the water level peaked before or lagged behind the program time. No measurable difference was detected. In addition, a tag was embedded in marine epoxy at the high water level (as determined from the tidal program) during one tidal cycle in May 1994. Periodically, measurements were made using a surveyor's sight level to determine the vertical difference between the water level and the marine epoxy marker throughout the roughly 12 hour tidal cycles (between high tides) during a several day period. The exact time of each measurement was recorded and the measured vertical differences were compared to those shown in the tidal program for each given time. Six different measurements were taken on six different dates and tidal levels. The differences between the measured and tide program vertical distances ranged from 4 to 32 cm (for total vertical distances of 51 to 444 cm). For purposes of this project, we utilized the numbers obtained from the tide program to calculate our submergence times given that slight differences obtained for different tidal cycles would be the same for both oiled and control sites.

Data Analysis

Dissolution (flux) rates were calculated using the difference in weight before and after deployment. Due to slight inconsistencies in the length of each cylinder (but not the diameter), the weight difference was divided by the cylinder length to normalize all samples to the same starting surface area. This number was then divided by total time under water over the deployment period to determine a rate of weight loss per cm of cylinder length. This is the number that is reported as flux rate in figures and tables. Calcium sulphate dissolution rates were analyzed for significant differences between site pairs using 2-sample t-tests. Fisher's method of combining p-values (Sokal and Rohlf 1981) was used to evaluate significant differences in flux rate over all sites for each visit ($p < 0.05$).

BARNACLE RECRUITMENT

Barnacle populations at three oiled sites in Herring Bay were examined for recruitment and successional patterns at three MVDs. Because some oil removal methods essentially created bare rock, a portion of each study plot was scraped to see if recruitment dynamics and ultimate community composition would be different. The sites were located at Barnacle Point (BP), Kiska and 1522 (Figure 3.1). A randomized method of selecting sites from total available shoreline was not used; however, care was taken to choose sites that seemed to represent typical Herring Bay 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 glandula* + *Semibalanus balanoides*" or *Chthamalus dalli*. Juveniles, or spat, were counted only in the lower left quarter of the 10x10 cm section (5x5 cm). In subsequent visits, adult and juvenile counts were taken from both the unscraped and previously scraped quadrats. In August 1994, a sudden influx of small (<0.5 mm) spat was observed in the quadrats. These spat were identified as *C. dalli*. Using a magnifying glass, the spat were counted in each quadrat in August and September 1994. There was no subsequent settlement of these spat observed in 1995. Sites were visited at least twice each year in 1993, 1994, and 1995. During each visit, all quadrat counts were repeated a minimum of three times or until a variance in repeated counts was less than 10%. The average of the individual counts in each quadrat was used as the abundance for that quadrat in further data analyses.

Data Analysis

Barnacle juveniles, adults (*Semibalanus glandula* and *Balanus glandula*), and *Chthamalus dalli* were analyzed using two-sample t-tests for comparisons of scraped plots with unscraped plots.

RESULTS

POPULATION DYNAMICS OF SELECTED INVERTEBRATES

Mean densities of the invertebrates *Littorina sitkana, Lottia pelta, Tectura persona, T. scutum, Nucella lamellosa, N. lima*, total *Nucella* spp., *Leptasterias hexactis*, total limpets, and unidentifiable limpets (usually limpets < 6-8 mm) from population dynamics sites are presented for both sheltered rocky and coarse textured habitats in figures and appendix tables as described below. Statistical results comparing matched oiled and control sites and the results of Fisher's test for combining p-values across all site pairs within a habitat type are given in Appendices C.1-C.44. Results of power analyses conducted on the data (only when significant differences were not detected) are included in the appendix tables in the rows labeled "Power" and "Power 50." The mean abundances for each organism across each habitat, sheltered rocky or coarse textured, along with the statistical results for combining p-values within each habitat are illustrated in Figs. 3.3-3.11. It should be noted that the means presented in the figures are habitat means, or means of site means. There is no variance reported for these because the statistical results presented for a habitat are from combining the p-values from each site pair comparison. This can be confusing when the mean of means for abundances are or are not very different as illustrated in a figure but the combined p-values from the site pairs show non-significance or significance, respectively. However, results are considered statistically significant based on the results of the Fisher's test for combining p-values.

Sheltered Rocky Habitat

At all MVDs, whenever statistical significance was detected, *Tectura persona* occurred in higher numbers on control sites than on oiled sites. In addition, even when no statistical significance was detected, habitat means were higher on control sites during every sampling date except one. At sheltered rocky sites, *T. persona* abundances were significantly higher on control sites at MVD 1 compared to oiled sites on at least one sampling date each summer from 1990 through 1995 (Figure 3.3). This limpet occurs mainly in the upper intertidal and is usually not found in high abundances in the lower intertidal. At MVD 2, no significant differences were detected after mid-summer in 1992 and at MVD 3 after May 1991. At MVD 1, the numbers of *T. persona* occurring on both oiled and control sites has increased since 1990.

The lower intertidal limpet, Tectura scutum, showed very low densities at MVDs 1 and 2 (Figure 3.4). Statistical significance occurred only once out of all 22 sampling dates at MVD 1, with higher densities on control sites in September 1993. At MVD 2, statistical significance occurred on only two of 22 sampling dates, in late summer of 1990 and in June of 1993, with higher densities on control sites. At MVD 3, densities were slightly higher than at MVDs 1 and 2. However, only one date showed statistically significant differences, in August 1990, with higher densities on oiled sites.

The limpet *Lottia pelta*, which is more evenly distributed throughout the three MVDs than the two Tectura species, showed statistically significant differences at MVD 1, on only one sampling date, in mid-summer 1991 (Figure 3.5). At MVD 2, statistically significant differences occurred in 1990, 1991, and 1994 with higher densities on control sites. At MVD 3, statistical differences were detected as late as 1995 and occurred on at least one sampling date in each year from 1990 through 1995, with all differences showing higher densities on control sites.

Another intertidal grazer, the periwinkle *Littorina sitkana*, showed significantly higher numbers on control sites on many sampling dates for all three MVDs from 1990 to 1995 (Figure 3.6). In no case was *L. sitkana* density significantly higher at an oiled site. For MVD 1, significant differences occurred at least once in 1991, 1993 and 1994. For MVD 1 at oiled sites, there is a pattern of high densities in early summer and lower densities in late summer. This pattern is also somewhat evident for oiled sites at the other MVDs and for control sites, suggesting summer mortality rather than migration. At MVD 2, significant differences occurred on almost all sampling dates through 1994 with higher numbers on control sites. MVD 3 showed significantly higher numbers on control sites on only one sampling date before 1994, but were significantly higher on control sites during both sampling dates in 1994 and the last sampling date in 1995. Densities appear to have increased after 1990, especially on control sites at MVD1.

Nucella lamellosa and *N. lima* occurred in low numbers on all sites and very few sampling dates showed statistically significant differences between oiled and control sites (Appendices C.1-C.44). Results for *N. lamellosa* on sheltered rocky habitat are shown in Figure 3.7. Statistically significant differences occurred only once over all MVDs and sampling dates, with higher densities on oiled sites at MVD 2 in 1990. Results for *Nucella lima* for sheltered rocky sites are not shown for sheltered rocky sites because they occurred in such low numbers and were never significant at any MVD or sampling date.

The other categories of invertebrates that are presented in the appendix tables, total limpets, unidentifiable limpets, total *Nucella* spp., and *Leptasterias hexactis* are not presented in figures. Total limpets tend to follow the trends for whichever limpet is dominant at that MVD, although the results from other limpets may increase or decrease significance levels. For instance, at MVD 1 where *Tectura persona* was significantly higher on control sites compared to oiled sites across time and where *Lottia pelta* showed few significant differences, total limpets were generally higher on control sites but were statistically significantly higher on fewer sampling dates than *T. persona* alone. The trend for total limpets at MVD 2 closely tracked that of *T. persona* with higher numbers on control sites, especially in 1990 and 1991. At MVD 3, total limpets closely followed the trend for *Lottia pelta*, however, the statistically significant trend for higher numbers on control sites was strengthened. Unidentifiable limpets, or small limpets (usually less than 6-8 mm) that could not be speciated in the field, showed no significant differences between oiled and control sites at MVDs 1 and 2 during any of the 22 sampling dates. However, at MVD 3, there were four sampling dates where higher numbers were detected on control sites, which is probably what contributed to the strong statistical trend seen for total limpets at MVD 3.

Trends for total *Nucella* spp. mirrored those of *N. lamellosa* almost completely due to the extremely low numbers of *N. lima* found on any site during all 22 sampling dates. *Leptasterias hexactis* were found in only a few quadrats and had densities of zero on both oiled and control sites over 80% of the time. Significant differences were not detected between oiled and control site densities for this species.

Coarse Textured Habitat

Figures 3.8-3.11 show abundances of limpets and littorines for oiled and control coarse textured habitat from 1990 through 1995. *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 (Figure 3.8). Though densities generally remained higher at control sites at MVD 3, no significant differences have been detected since early summer of 1991. Again, these invertebrates appear to have increased in density over time on both oiled and control sites since the first year after the oil spill.

The lower intertidal species of Tectura, *T. scutum*, showed very low densities at MVD 1 and was never significantly different between oiled and control sites from 1990 through 1995 (Figure 3.9). At MVD 2, except for a relatively high density measured on control sites during the third visit in the summer of 1990, significant differences occurred with higher numbers on oiled sites. Overall densities were low compared to other limpets. At MVD 3, abundances were higher on both oiled and control sites compared to upper 2 MVDs. There were several sampling dates where greater numbers were found on oiled sites, however significant differences only occurred in June of both 1991 and 1992.

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 and the last sampling date in 1995 (Fig 3.10). At MVDs 2 and 3, higher densities of *L. pelta* have been found on both oiled and control sites several years after the oil spill compared to the year immediately following the spill. At MVD 1, densities were very low but significantly higher densities of *L. pelta* were found on control sites in June 1990 and May 1991.

Since 1990, *Littorina sitkana* densities increased from less than 5/o.1 m^2 to about 15/0.1 m^2on oiled sites at all three MVDs (Figure 3.11). At MVD 1, densities were significantly higher at control sites on three of seven sampling dates in 1990 and in May 1991. Thereafter, densities at oiled sites increased and were significantly higher than at control sites in May 1992, and in September 1994 and 1995. Again, at MVD 2, higher densities were detected on control sites in 1990 and August 1991. In 1995, higher densities were found on oiled sites, with May being significantly higher. At MVD 3, almost no *L. sitkana* were found on either oiled or control sites until August 1992 when higher densities were detected on oiled sites. Thereafter, densities generally increased through 1995 on both control and oiled sites. However, only one significant difference occurred, with higher numbers found on control sites in September 1994.

As on sheltered rocky habitat, trends for total limpets tended to follow those for whichever limpet species dominated at that MVD. At MVD 1, total limpets followed the trend seen for *Tectura persona*, with higher densities on control sites across time. In 1990, the data for total limpets showed higher numbers on control sites compared to oiled, as seen for *T. persona*. However, in mid- to late-summer in 1991, there were three sampling dates with statistically higher densities on oiled sites, strengthening a trend seen for *L. pelta* and *T. scutum*. At MVD 3, total limpets showed trends similar to *L. pelta*, with higher numbers on oiled sites. Unidentifiable limpets showed only one statistically significant difference out of all 22 sampling dates at MVD 1 and 2, with higher numbers on oiled sites in September 1990. However, at MVD 3, higher numbers were detected on oiled sites on at least one sampling date in 1991, 1992, and 1993, which is probably what contributed to that same trend seen for total limpets.

Both *Nucella lamellosa* and *N. lima* occurred in very low numbers on coarse textured sites, with none found on any site during any sampling date at MVD 1. At MVD 2, no *N. lamellosa* were found, very few *N. lima* were found, and in no instance were significant differences detected between oiled and control sites. At MVD 3, zero or low densities were found during most sampling dates, except in September 1993 when higher, though non-significant, numbers occurred on oiled sites than on control sites (1.83 per quadrat vs. 0.22).

No *Leptasterias hexactis* were found at MVD 1 or 2 on coarse textured sites and on only three sampling dates at MVD 3. They were found only on control sites with densities less than 0.2 per quadrat in all three instances.

Coastal Habitat Sheltered Rocky Sites

Sheltered rocky sites monitored during the Coastal Habitat Injury Assessment (CHIA) project in 1990 and 1991 were revisited in 1993, 1994, and 1995. These sites were visited opportunistically during the Herring Bay field season and we couldn't duplicate the sampling methods used during the CHIA study where all invertebrates were collected from within each quadrat and sorted in the laboratory. Instead, we counted major invertebrates in the CHIA control quadrats. Due to time and personnel constraints, a number of quadrats were lost to rising tides. Thus, the number of quadrats sampled per site was decreased compared to those quadrats sampled for population dynamics studies in Herring Bay and the power of the statistical tests is reduced. Appendix tables C.45-C.47 list these power values and results of statistical tests between each matched pair and for overall tests for sheltered rocky habitat for *Tectura persona*, *Lottia pelta*, *Littorina sitkana*, *Nucella lamellosa*, and *N. lima*. As described below, Figures 3.12-3.16 show comparisons of Herring Bay and CHIA "mean of site means" abundance data for these invertebrates on sheltered rocky oiled and control habitat. Also included in the figures are data for CHIA sites in 1990 and 1991 (Highsmith et al. 1994).

Table 3.2 shows the results of Fisher's test for combing p-values comparing matched oiled and control values on Herring Bay and CHIA sheltered rocky sites. This table was produced to illustrate whether trends were similar between the two sets of data. Because of the matched pair design, no statistics were done between the control data on CHIA sites and on Herring Bay sites. For those organisms studied, fewer significant differences were detected on the CHIA sites than in Herring Bay. Although the significant differences between oiled and control sites did not always occur at the same MVDs or during the same dates, the patterns were generally similar between the Herring Bay and CHIA data sets. For *Littorina sitkana*, total limpets, and *Tectura persona*, significant differences were for higher densities on control sites than oiled sites in both Herring Bay and for the set of CHIA sites. For *Lottia pelta*, significant differences in Herring Bay were for higher densities on control sites , especially in the lower mid- and lower intertidal. On CHIA sites, densities were significantly higher on oiled sites at MVD 2 in 1990 and 1991. By 1993, however, densities were higher on control sites.

Figure 3.12 illustrates the data comparison for *Tectura persona* at MVDs 1, 2, and 3. *T. persona* has increased over time since May 1991 on the CHIA sites. On control sites the two data sets track fairly closely at MVD 1. However, on oiled sites the abundance of *T. persona* appears to have increased much more on CHIA sites than on Herring Bay sites. In general, at MVDs 2 and 3, CHIA sites show higher abundances than Herring Bay sites. At MVD 3, the numbers found on Herring Bay sites were very low. On CHIA sites, however, abundances varied from visit to visit, with the highest densities for both oiled and control sites found in May 1995.

For *Lottia pelta*, the CHIA and Herring Bay data tracked each other fairly closely for both abundance and trends across time (Figure 3.13). The exceptions were between control sites at MVD 1 in 1993 and 1994, and on most dates at MVD 2 where Herring Bay densities are higher than CHIA densities. Again, densities in both areas have increased since 1990 on oiled and control sites at all MVDs.

Littorina sitkana abundance data show bigger differences between the two data sets than for *Lottia pelta* and *Tectura persona* (Figure 3.14). Much of the variability between the two data sets occurred for data collected in 1990 and 1991. It is impossible to tell whether these differences are real or whether the differing sampling methods used in 1990 and 1991 are the cause. *L. sitkana* are often found within algal canopy and can be difficult to see in the field, especially newly recruited juveniles. The 1990 and 1991 CHIA data were obtained by collecting everything from a quadrat and sorting out the invertebrate species in the laboratory whereas subsequent CHIA samples and all Herring Bay population dynamics samples were collected in the field.

Nucella lamellosa and *N. lima* were found in low abundance on both CHIA and Herring Bay sites. Although the magnitudes of trends for *N. lamellosa* may differ, the general patterns across time are similar for both data sets (Figure 3.15). *N. lima* data show higher abundances on CHIA sites than Herring Bay sites for almost all MVDs and sampling dates (Figure 3.16). The abundances, though, are usually less than one organism per quadrat. Abundances measured on both oiled and control CHIA sites tended to decrease after 1991. Again, this may be due to the sampling method change after 1991. However, *Nucella* are easy to spot, especially on bedrock substrate where they can't hide under small rocks or gravel.

RECRUITMENT ON OILED AND NON-OILED SUBSTRATES

Recruitment on Vertical Rock Faces

Recruitment and density data were analyzed using a paired t-test between plots within each site for barnacle juveniles (Appendix Figures C.1-C.11), barnacle adults (Appendix Figures C-12-C.15), and *Chthamalus dalli* (Appendix Figures C.16-C.19). Figures 3.17-3.24 show the results of ANOVAs to compare like treatments between oiled and control sites as well as the effects of caging.

Barnacle juveniles, of all species combined, counted on each plot were defined as those that had not yet overwintered. Changes in coloration near the test base and relative size were used to subjectively determine which barnacles were counted as "recruits" and which were counted as "adults". For uncaged treatments, barnacle recruit densities were significantly higher on scraped plots at control sites compared to oiled sites until late June in 1990 and for a brief period that summer on unscraped plots (Figure 3.17). In 1991 and 1992, higher numbers were found on the oiled sites in late summer for both scraped and unscraped plots. Low numbers of recruits were seen in early and mid-summer in 1990, 1991, and 1992. In 1993, in contrast to previous years, a large settlement pulse of *Semibalanus balanoides* and *Balanus glandula* occurred in early spring in the general area of the control sites which resulted in significantly higher densities at control sites compared to oiled sites for all treatments ($p<0.05$, ANOVA; Figs. 3.17 and 3.18). This was seen for caged, uncaged, scraped, and unscraped treatments. The only exception was for data from the caged scraped plots, sampled in August 1993, for which no difference in density was observed (Fig. 3.18). Densities on control sites in 1993 were generally much higher, and often an order of magnitude higher, than observed in previous years. The only significant differences between unscraped caged and uncaged plots or between scraped caged and uncaged plots in occurred on two dates in 1991 (scraped plots, Fig. 3.18).

For barnacle adults (not including *Chthamalus dalli*), which included mainly *Balanus glandula* and *Semibalanus balanoides*, densities were generally higher on oiled sites for all treatments in 1992 and on caged plots in 1993 (Figure 3.19). Adults are defined as those barnacles that were not the current year's recruits and that had survived within the quadrats to be counted. No significant differences were detected between unscraped caged and uncaged plots. The caged, scraped plots had significantly greater densities than the uncaged, scraped plots in both 1992 and 1993 ($p<0.05$, Figure 3.19).

Densities of adult *Chthamalus dalli* at control sites were generally low for all treatments (Figure 3.20). On uncaged plots, oiled site densities were significantly higher than on control sites for both scraped and unscraped plots on all sampling dates in 1992 and 1993. Significant differences were detected on scraped and unscraped caged plots in 1993 only. No significant differences were observed between caged treatments for either scraped or unscraped plots.

On uncaged plots, *Fucus* germling densities were significantly higher on control scraped and unscraped plots compared to oiled plots during most sampling dates in 1990. In fact, during most sampling dates in 1990, 1991, 1992, and 1993, *Fucus* germling densities were higher on control sites than on oiled sites for all treatments, and significantly so on many sampling dates (Figures 3.21 and 3.22). Significant differences occurred between unscraped caged and uncaged plots in 1991 and between scraped caged and uncaged plots in 1992 (Figure 3.22).

Grazer densities were generally higher on unscraped plots compared to scraped plots through 1991, except for caged treatments (Figure 3.23). No significance was detected for any of the treatments in 1993. Grazer densities were significantly higher on control sites compared to oiled sites for all treatments during most sampling dates (Figure 3.24).

Recruitment on Oiled and Non-oiled Tile Pairs

Table 3.3 lists means and standard deviations of barnacle recruits on oiled (or painted) and unoiled (or not painted) tile pairs at three oiled and three control sites in 1991, 1992, and 1993. Recruitment data were analyzed using a paired t-test between oiled and unoiled plots within each site and treatment and significance levels are reported as "p-val". There was sparse settlement on the tile pairs placed at control sites in 1991. The oiled sites 1322X and 1723X showed a recruitment pulse by mid-summer, although high variability resulted in only three significant differences between oiled and unoiled tiles in 1991 for any treatments. Although all three instances were for higher numbers of recruits on unoiled tiles compared to oiled tiles, two of the significant differences were between only a few recruits on unoiled tiles versus zero on oiled tiles. In 1992 and 1993, no significant differences were detected between oiled and unoiled tiles for any treatment (Table 3.3).

Mean abundances and standard deviations for adult barnacles (*Semibalanus balanoides* and *Balanus glandula*) resulting from recruitment in caged, uncaged, and paint treatments are given in Table 3.4, as well as results of t-tests between oiled and unoiled tiles. Low numbers of adult barnacles on the tiles indicate that very few recruits reach adult sizes. The caged treatment had only one significant difference, with higher numbers of adults on the oiled tiles at site 1222C compared to unoiled tiles. No significant differences between oiled and unoiled tiles were detected on any date in 1992 or 1993 for the uncaged treatment. For the painted treatments, site 1322X had higher numbers of adults on painted tiles versus unpainted tiles in early June 1993. This difference was between only 2.3 and 0.7 individuals and they had all died on the painted tiles by August.

Chthamalus dalli barnacle densities are shown in Table 3.5 for 1992 and 1993. *C. dalli* densities were low on control quadrats in 1992 and were absent from most tiles in 1993. Site 1322X was the only site to show significant differences between oiled and unoiled tiles for any treatment. Three of the four instances were for caged treatments, with higher numbers on oiled tiles compared to unoiled tiles. On uncaged tiles, site 1322X showed higher numbers on unoiled tiles during one sampling date. No significant differences were detected between oiled and unoiled tiles from the paint treatment.

Very few *Fucus* germlings were detected on most site tiles for any treatment in 1991 (Table 3.6). The exception was on caged tiles on sites 1221X, 1723X, and 1723C in late August. The only significant difference between unoiled and oiled tiles in 1991 was for higher densities of *Fucus* germlings on unoiled caged tiles on site 1723C in August. Again, in 1992 and 1993 there were very few *Fucus* germling recruits onto uncaged or painted tiles on any site. There were recruits onto both oiled and unoiled caged tiles. For caged treatments, there were significantly more *Fucus* germlings on unoiled tiles on sites 1723C in June 1992, 1723X in early July 1992, and 1221C in August 1992. All other t-tests in 1992 and all t-tests in 1993 between unoiled and oiled tiles revealed no significant differences with $p < 0.05$. Overall, *Fucus* germlings occurred in significantly greater densities in caged than uncaged treatments (p 0.05, Kruskal-Wallis ANOVA).

Fucus plants that were germlings in previous years and had survived to adult sizes (>2 cm) by 1993, were analyzed as *Fucus* adults (Table 3.7). Except for a few plants, *Fucus* adults were only detected on unoiled caged tiles. Densities were higher on caged unoiled tiles compared to oiled tiles on five of six sites, although none were statistically significant at $p < 0.05$. For all sites combined, there were significantly more *Fucus* plants on caged than uncaged, clean tiles (Mann-Whitney U-test, $p = .001$). Caging effects were not tested for oiled tiles because there were essentially no plants on the oiled tiles. As higher densities of *Fucus* germlings and adults occurred on caged, unoiled tiles, the cages either facilitated recruitment and survival or were effective at excluding grazers.

Percent algal cover was significantly different between unoiled and oiled tiles only once for any treatment or any site in 1992 or 1993 (Table 3.8). However, in contrast to *Fucus* germlings and adults, percent algal cover was significantly higher on uncaged than caged unoiled tiles in 1992 ($p < 0.05$, ANOVA). By 1993, percent cover on uncaged tiles had fallen substantially compared to 1992.

To look at differences in *Fucus* and invertebrate recruitment and density between oiled and unoiled tiles across all sites, ANOVAs were performed and mean densities are plotted in Figures 3.25-3.29 for invertebrates and *Fucus*. To increase N for a given treatment, all sites were combined for these analyses. Figure 3.25 shows a settlement of barnacles in late summer 1991 and low recruitment in 1992 and 1993 on both oiled and unoiled tiles. The settlement of barnacles that occurred in 1993 on control sites from the vertical rock face study described above was not seen on tiles from any treatment. Few of the barnacles that settled onto tiles in 1991 survived to adulthood (Figure 3.26). No significant differences were found between adult barnacle densities on unoiled tiles versus oiled tiles on any date. There were significantly more barnacles on caged than uncaged, oiled tiles (Mann-Whitney U-test, $p = .001$). This difference did not occur on unoiled tiles (Mann-Whitney U-test, $p = .17$). Similarly, *Chthamalus dalli* showed significant differences only twice, with higher numbers on caged oiled tiles compared to caged unoiled tiles in 1992 (Figure 3.27). For caging effects, there were significantly more *C. dalli* on uncaged than caged, clean tiles (Mann-Whitney U-test, $p = .001$) but there was no difference between oiled tiles in caged and uncaged treatments (Mann-Whitney U-test, $p = .15$). Caging resulted in higher *S. balanoides* and *B. glandula* densities on oiled tiles and lower *C. dalli* densities on clean tiles and no differences for the other two treatment combinations. Therefore, the role of grazers in determining barnacle densities, if any, is not differentiated in this experiment. The fact that most recruitment and highest adult barnacle densities occurred at two of the oiled sites (Tables 3.3-3.5) supports the need to evaluate currents at oiled and control sites.

Fucus germling densities were higher in 1992 than in 1991 and 1993 (Figure 3.28). Densities were significantly higher on unoiled tiles compared to oiled tiles for uncaged treatments in late summer of 1991 and 1992 and for caged treatments in late summer 1991 and mid-summer in 1992. *Fucus* germling densities were low in 1993 on all treatments and no significant differences were detected between oiled and unoiled tiles. Percent algal cover was also highest for most treatments in 1992 compared to 1991 and 1993, especially on unoiled tiles (Figure 3.29). For uncaged tiles, percent algal cover was significantly higher on unoiled tiles in June of 1992 and both sampling dates in 1993. For caged treatments, algal cover was significantly greater in June and July 1992 and June 1993. Additionally, unpainted tiles had higher percent algal cover than painted tiles on one date each in 1991 and 1992 (Fig. 3.29).

The densities of grazers (limpets and the periwinkles *Littorina sitkana* and *L. scutulata*) were significantly higher on unoiled, uncaged tiles in late summer of 1991 and throughout the summer of 1992 compared to oiled, uncaged tiles (Figure 3.30). Caged tiles showed higher densities of grazers on unoiled tiles throughout the summer of 1992. No significant differences were detected between oiled and unoiled tiles in 1993 for either caged or uncaged treatments. For the paint treatment, grazer densities were higher on unpainted tiles in 1993. No significant differences were detected in 1991 and 1992. Caging effects were not detected. Grazer densities increased over time and stabilized at about three per tile. Given limpet foraging requirements, tile size may have been limiting and both *Fucus* germlings and percent algal cover declined in 1993.

CORRELATIONS BETWEEN GRAZERS AND *FUCUS* PERCENT COVER

Total limpets, *Lottia pelta*, *Tectura persona*, and *Littorina sitkana* abundances from the Population Dynamics site quadrats were regressed on *Fucus* percent cover (Chapter 2: Tables 3.9, 3.10). Sheltered rocky and coarse textured habitat data for control sites only were analyzed (Table 3.9) to obtain results not confounded by any oiling effects. Control- and oiled-site data were then combined (Table 3.10) to increase the sample size for the analyses. The data used were from 1993, 1994, and 1995 because they were entered into the database by quadrat number, not just MVD.

For both habitat types at control sites only (Table 3.9), *L. sitkana* abundances at MVDs 1 and 2 were positively correlated with *Fucus* cover. Conversely, *L. pelta* was negatively correlated with *Fucus* cover at MVD 3 in sheltered rocky habitat. For both oiled- and control-quadrat data combined (Table 3.10), total limpets, *L. pelta* and *L. sitkana* were correlated with *Fucus* cover at MVD 1 of sheltered rocky habitat. *L. pelta* remained negatively correlated with *Fucus* at MVD 3. For coarse textured habitat, the only significant relationships were at MVD 3, where *L. pelta* was positively correlated with *Fucus* and *T. persona* was negatively correlated with *Fucus*. With the possible exception of MVD 1 in sheltered rocky habitat, the contradictory results and low R^2 values do not provide convincing evidence that the distribution of selected invertebrate grazers is strongly dependent upon *Fucus* cover.

FUCUS AS INFRASTRUCTURE AND PROTECTION FOR INVERTEBRATES

Figures 3.31-3.34 show correlations between invertebrate densities per *Fucus* plant weight and calcium sulphate dissolution rates. Plants were collected in May 1995 from most sites (unoiled) shown in Figure 3.2 where calcium dissolution rate measurements were made (described in a later section). *Littorina sitkana* density was negatively correlated with calcium sulphate dissolution rate at MVD 1.5 (Figure 3.31). At MVDs 0.5 and 2.5, the negative slope was not significantly different from a slope of zero. For two other grazing invertebrates, *L. scutulata* and *Lottia pelta*, there was no significant correlation between density and dissolution rate (Figures 3.32 and 3.33, respectively). However, at all MVDs for both organisms, the regression lines had negative slopes. For *Mytilus trossulus*, which attaches byssal threads directly to *Fucus* plants, the regression slopes were positive but not significantly different from zero (Figure 3.34). Though only one regression was significant for the gastropods, the uniformly negative slopes raise the possibility that this group can only attach weakly to *Fucus* plants and would therefore be less abundant on plants in areas of higher water motion.

In response to the removal of *Fucus* canopy, *L. sitkana* living underneath the *Fucus* canopy declined significantly in abundance over time ($p = 0.000$, Table 3.11), and this effect was most obvious at the protected site where this snail was most abundant (Figure 3.35). Statistical differences were detected between sites (Table 3.11) but not between tidal levels. *L. sitkana* densities remained much lower than initial densities through the last sampling date two months after *Fucus* removal. In contrast, *L. scutulata* densities tended to decline initially when *Fucus* was removed ($p < 0.05$) but recovered at MVD 0.5 to near initial densities at the protected site within two months (Fig. 3.36).

Recovery at the exposed site occurred within one month at MVD 0.5 and within two months at MVD 2.5. The increases for this species may be due to recruitment and growth occurring over the summer months.

In general, both *Lottia pelta* and *Tectura persona* declined immediately after the removal of *Fucus* canopy (Figures 3.37 and 3.38). After one month, *L. pelta* densities had returned to original levels. *L. pelta* was most abundant in the mid zone but hardly present in the low zone for all three degrees of exposure. In most instances, densities increased again after one month. For *T. persona*, after an initial increase in density at MVD 1.5 at exposed and protected sites, densities for all categories declined and did not recover during the experimental period.

FILAMENTOUS ALGAE

Appendix tables C.48 and C.49 list site means and statistical results for matched pair comparisons of filamentous algal percent cover and for combined p-values across all site pairs. Figures 3.39 and 3.40 summarize the trends for filamentous algal cover on individual site pairs at each MVD for 1993 and 1994, respectively. 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. The highest average percent cover generally occurred at MVDs 3 and 3.5. The data at all MVDs are highly variable, emphasizing the patchy distribution of filamentous algae in the intertidal. 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. During all visits in 1993 and 1994, all but one statistically significant difference indicated higher percent cover of filamentous algae on the oiled site of the pair.

Table 3.12 shows the statistical results of Fisher's test for combining p-values across all three site pairs. Statistical significance for the combined p-values are shown by an open circle when percent cover is higher on control sites and with a black circle when higher on oiled sites ($p < 0.05$). At MVD 1, statistical significance was detected on only one date, with higher percent cover on oiled sites in May 1994. At MVD 2, statistical significance was detected for four of seven sampling dates with percent cover higher on oiled sites. At MVD 3, statistical significance was detected on six of seven sampling dates with percent cover higher on oiled sites in all cases. At MVD 3.5, percent cover was significantly higher on oiled sites in July and September 1993 but, conversely, was significantly higher on control sites in June 1994.

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 (Appendix tables C.50-C.51). Due to high variability and low sample numbers, few statistical differences between oiled and control sites occurred, although oiled sites had higher absolute numbers of mussels in the majority of site pair comparisons. Figures 3.41 and 3.42 illustrate the trends for mussel densities in filamentous algae at each matched site pair for all MVDs in 1993 and 1994, respectively. Higher numbers of mussels occurred later in the summer compared to the first visit each year (note vertical scale changes in Figures 3.41 and 3.42).

When individual p-values from each site pair are combined using Fisher's method for combining p-values (Table 3.12), statistical significance occurred only twice at MVD 2. In May

1994, mussel densities were higher at control sites but in September 1994, densities were higher at oiled sites. For MVD 3, mussel densities were higher at oiled sites on only one date, May 1994. For MVD 3.5, mussel densities were higher on oiled sites on two occasions, June and August, 1994.

Mussels were less dense and tended to be larger (> 1 mm) during the earliest sampling date in each year compared to later in the summer (Figures 3.43-3.48). Note the change in the y-axis scales for each sampling date. In 1993 (Figures 3.43, 3.45, 3.47), a settlement of mussels occurred between the June and July sampling dates, with higher total mussel density and more small (< 0.5 mm) mussels occurring on the later date. In 1994 (Figures 3.44, 3.46, 3.48), strong settlement occurred between the May and late June sampling dates, with higher densities and a higher percentage of < 0.5 mm mussels occurring in the June sample. The recruits grew into larger size classes by August and September.

Parametric statistical comparisons were not made between years because of somewhat different collecting methods and the low number of samples in 1993. However, the mean densities per MVD per year were greater at each oiled site in 1994 than 1993 (Mann-Whitney U-test, p=0.014 for all three sites). Mussel densities at control sites were not significantly greater in 1994 than 1993 (Mann-Whitney U-test, p=0.057 for sites MB1 and MB2, p=0.10 for site 1522). The increased recruitment at oiled sites could be taken as evidence of recovery but it cannot be distinguished from interannual variability. Unfortunately, data are not available for 1995 because this experiment was terminated due to budget constraints.

MUSSEL SIZE-FREQUENCY DISTRIBUTIONS

Mussel abundances and size frequency distributions varied over time within sites and in some cases were significantly different between matched sites. Mussel size frequency distributions, plotted in 2 mm incremental size categories for mussels collected within the mussel band on three oiled and three control sites between June 1993 and May 1995, are shown in Figures 3.49-3.54. The data plotted are those analyzed with K-S statistics for cumulative frequency discussed below (Figures 3.55-3.57). For those analyses, the sum of all mussels in each size class across the site quadrats were used so the data presented in Figures 3.49-3.54 are for 0.4 m^2 (sum of four 0.1 m^2 quadrats). High variability in mussel densities between sampling dates made it difficult to keep the y-axes consistent for all graphs on a page. An attempt was made to at least keep the range similar within a calendar year, although detail is lost in some graphs.

At site MB1, mussel recruitment is indicated by high abundances of small (< 2 mm) mussels in the spring off all three years (Figure 3.49). Small mussels were found in very high numbers in fall 1994, indicating that a settlement had occurred after the spring sampling period. A similar pattern occurred for the matched, site MB1C (Figure 3.50), although the abundances of small mussels were lower. By May 1995, on both sites, very few mussels larger than 8 to 10 mm were found, indicating mortality of older mussels. At site MB2, high numbers of small mussels were found spring 1993 and 1994 but not 1995 (Figure 3.51). Again the highest density of small mussels was found in the fall of 1994. Like site MB2, site MB2C showed high proportions of < 2 mm mussels in the spring censuses (Figure 3.52). Although densities were low in spring 1994, subsequent recruitment occurred with a high density of < 2 mm individuals present in September. Again, by May 1995 at both MB2 and MB2C, very few mussels > 8 to 10 mm were found. Sites 1522 and 1522C had size-frequency distributions similar to the other site pairs except very weak recruitment in spring 1994 but, again, late recruitment resulted in high numbers of < 2 mm individuals by September (Figs. 3.53 and 3.54, respectively). Sites 1522 and 1522C both showed a more even distribution of mussel sizes in May 1995 than any of the other four sites.

Mussel size-frequency distribution data from four quadrats combined per site (Figures 3.49-3.54) were converted to percentages and replotted as cumulative curves in Figures 3.55-3.57 with comparisons between oiled and control sites shown as p-values based on non-parametric K-S comparison of the cumulative frequency data with maximum difference from randomized distributions repeated 5000 times (See Methods). Combining quadrats may reduce independence of the data so conversion to percentages and a randomization process were used. For site pair MB1/MB1C, statistically significant differences between the oiled and control sites occurred only during the May 1994 sampling date, where the oiled site had a much higher proportion of small mussels (Figure 3.55). The curves for September 1994 and May 1995 illustrate the high percentage of small mussels relative to the rest of the size categories on both the oiled and control sites.

For site pair MB2/MB2C, statistically significant differences were shown on three sampling dates, in June and September 1993 and in May 1995 (Figure 3.56). For the 1993 sample dates, there were higher proportions of smaller mussels on the oiled site compared to the control site (the oiled site curve tended towards a cumulative frequency of 1.0 at smaller lengths). While the curve for MB2 in May 1995 also approached 1 at a smaller mussel length than MB2C, the four smallest size categories accounted for over 80% of the sample so that the control curve initially overlies the oiled curve.

Site pair 1522/1522C had very similar cumulative frequency curves on the oiled and control sites on three of the five sampling dates (Fig. 3.57). The only statistically significant difference occurred in May 1994, with a higher proportion of small mussels on the oiled site.

Many of the differences in size distributions of mussels, whether comparing oiled and control sites or a given site on different dates, can be attributed to differences in recruitment. Figure 3.58 displays the mean size of mussels for each site pair across time. This figure more easily illustrates the differences in the cumulative size frequency diagrams (Figures 3.55-3.57), in which the oiled site curve overlies the control site curve in most cases, indicating smaller mussels at the oiled site. As stated in the methods section, mussels < 1.0 mm length were not measured but were categorized as "< 1 mm." This creates a problem for calculating average length on a site. One solution would be to give a length to all of these mussels, such as 1.0 mm, and calculate mean length for each site based on this assumption. However, we decided to calculate mean length without these very young mussels to give a better indication of mussel size of the mature bed. The exclusion of mussels < 1 mm reduces the differences shown for oiled versus control sites in most cases, because there were higher numbers of small mussels on the oiled sites. The most obvious exceptions are for sites 1522 and MB1 in September 1993 (Figures 3.55, 3.57, 3.58), in which mean length was higher on the oiled site. Mussels were significantly larger at MB2C than MB2 on both sampling dates in 1993 and again in May 1995. The only significant differences for the other two site pairs occurred in May 1994. One explanation of the tendency for oiled sites to have smaller mussels is that the oiled sites are still in the recovery phase and that many of the mussels present have either recruited recently or have not yet grown to a size expected at an undisturbed site. An alternative explanation is that there is higher water flow at the oiled sites and they, therefore, have higher mussel recruitment rates and a younger average age than mussels at control sites.

Mean densities and standard errors are shown for each site in Figure 3.59, including all mussels and only those mussels > 2 mm. One-way ANOVA's on > 2 mm mussels for each site across all five sampling dates indicate statistically significant ($p < 0.05$) differences between sampling dates for sites 1522, 1522C, and MB1C. T-tests (a posteriori) performed between each sampling date showed that the ANOVA results for site 1522 were due to differences between September 1993 and September 1994 and between September 1994 and May 1995. For site 1522C, statistical differences occurred between May 1995 and all other sampling dates except for May 1994. At site MB1C, significant differences occurred between September 1994 and all other sampling dates, and between May 1995 and all sampling dates except September 1993. In all three cases where the one-way ANOVA for a site across time was significant, the density for the May 1995 sampling date accounted for some of that difference. Although the one-way ANOVA was not significant for all sites across time, the May 1995 sampling date always had the smallest mean density of > 2 mm mussels compared to all other dates. When all mussels, including those < 2 mm, are included, every site except MB1 had the lowest density in May 1995 compared to all earlier dates. By including the mussels < 2 mm in the one-way ANOVAs for each site across time, site MB1 also has significant differences between sample dates.

The mean mussel densities over the five sampling dates for the oiled sites MB1, MB2 and 1522 were approximately 10,000, 30,000 and 19,000, respectively, whereas the means for control sites MB1C, MB2C and 1522C were approximately 4,000, 10,000 and 7,000, respectively. Mussel densities were significantly greater at MB1 than MB1C (Mann-Whitney U-test, $p < .05$) but densities were not higher at MB2 or 1522 than MB2C or 1522C, $p = .075$ and $p = .111$, respectively. However, it appears that the May 1995 collections preceded mussel recruitment activity that year. If May 1995 samples are excluded from the analyses, then mussel densities are significantly greater at oiled sites MB1 ($p < .03$), MB2 ($p = .014$) and 1522 ($p < .03$) than their matched control sites.

The mussel recruitment and density data, taken as a whole, support our hypothesis that there is greater water flow and, hence, greater recruitment potential at oiled sites than control sites.

TAGGED/CAGED MUSSELS

To further explore the similarities and differences between matched oiled and control sites, growth rates of mussels were compared. Table 3.13 presents seasonal growth in length for each summer and winter from spring 1993 to fall 1995. Stress from the initial handling necessary in tagging the mussels may account for the low growth rates of mussels in the summer of 1993. Growth over the third summer was also low compared to the second summer and to winter growth in most cases. Winter growth incorporates a longer period of time (8 to 9 months) compared to summer growth (3 to 4 months) due to the timing of our sampling trips. This study was not designed to compare growth rates of mussels over a wide size range. During a similar study in Kachemak Bay (Highsmith and Saupe 1996), it was noted that mid-sized mussels (10 to 20 mm) grew faster than small mussels or large mussels, although small mussels had higher growth rates relative to their body length. Increased mussel sizes over the length of the experiment may account for the slowed growth rates by fall 1994 and continuing through the final summer of the experiment. There was often high mortality of mussels between visits as indicated by the decreasing number of mussels measured from each site. The stress from repeated collections may account for some of the mortality. To reduce handling stress, direct tagging of mussels within the mussel bed was attempted. In most cases, it was not possible to obtain accurate length measurements, because the mussels were too tightly packed to allow use of calipers. Consequently, we tagged mussels along the edges of beds, resulting in extremely low recovery rates, even with just one month between data collection visits.

Mussel growth rates from spring 1993 to spring 1994 were generally lower than growth rates from spring 1994 to spring 1995 (Table 3.14), a result of the low growth rates in the summer of 1993 (Table 3.13). Growth rates were higher in winter 1993-94 than winter 1994-95 which counteracts the summer difference somewhat. Statistical differences in year one were detected only between the oiled and control sites of matched pair MB2/MB2C, with higher growth rates detected on the oiled site. Again in year two, higher growth rates were detected at MB2 but higher growth rates occurred at control site 1522C than 1522 . The same results were obtained for total growth over the entire length of the study, from June 1993 until August 1995. Note that the number of mussels available for measurement and statistical analyses decreased over time due to mortality.

To test for caging effects, calcium sulphate dissolution cylinders were placed adjacent to each other in the intertidal in areas representing a wide range of flow rates. One cylinder was caged and the other uncaged. Results revealed 4.94 ± 2.71 % ($n = 6$) less dissolution for caged cylinders. The reduced dissolutions for cylinders in cages occurred for both oiled and control sites and may have slightly reduced the volume of water, and thus particulates, that flowed past each mussel.

WATER CIRCULATION STUDIES

For the calcium sulphate dissolution cylinders placed 1.0 MVD below MHHW at 33 locations within Herring Bay (Figure 3.2), dissolution rates tended to be highest near the mouth of Herring Bay and lowest near the head of the bay except for site PP where tidal currents passing through a narrow passage are accelerated (Figure 3.60). These data were used for correlations of *Fucus* growth data presented in Chapter 2 and for selecting sites for the *Fucus* canopy removal experiment (this chapter). 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 August 1993 and June and September 1994.

Deployments were made several times throughout the 1993, 1994, and 1995 field seasons on the site pairs MB1/MB1C, MB2/MB2C, and 1522/1522C (Figures 3.61 and 3.62). Appendix tables C.52 and C.53 include mean dissolution data for each site and for overall sites within the oil and control categories along with statistical results. The first deployment on these sites was at the end of a spring tide series in early June 1993. The flux rates measured during this time period were the lowest measured for all deployments. Most subsequent deployments were made closer to the mid-points of the tidal series and had higher dissolution rates. In general, flux was higher on oiled sites with the exception of site pair MB1/MB1C. When all site pair p-values are combined for a given data set, dissolution was significantly higher on oiled sites compared to control sites on all eight sampling dates from 1993 through 1995 (Appendix Tables C.52 and C.53).

The differences in dissolution rates were probably underestimated. Surface area available for dissolution is a function of the radius of the cylinder, which decreases as calcium sulphate mass decreases. Thus, on sites where dissolution rates are greatest, the radius is decreasing at a faster rate than on sites with lower dissolution rates. This results in a smaller surface area from which dissolution can occur and a decreasing rate of weight loss. The higher dissolution rates at oiled sites and near the mouth of the bay are probably due to differences in tidal currents and possibly some limited difference in wave action.

BARNACLE RECRUITMENT

T-tests performed on the data collected for barnacle recruitment and succession on three oiled sites showed few statistical differences across time within a treatment or between treatments. However, presented here are the trends found for adult *Chthamalus dalli*, adult *Semibalanus balanoides* + *Balanus glandula*, and juveniles across time. Statistical significance is noted as asterisks in Figures 3.63-3.71.

Means and standard errors for *Chthamalus dalli* abundances in 10 x 10 cm plots for sites 1522, BP, and Kiska (Figure 3.1) are included in Figures 3.63-3.65, respectively. On all three sites and most MVDs, the scraped plots show increases from zero adult *C. dalli* to numbers equaling those on unscraped plots by the end of the sampling period in 1995. After the first summer, the curves for scraped and unscraped plots tended to follow the same general trends. In other words, the major decreases or increases from visit to visit occur on both scraped and unscraped plots, although the magnitudes may vary. A major increase in adult *C. dalli* appeared on sites BP and Kiska in 1995 and will be discussed below. Site 1522 shows a general decrease in *C. dalli* populations of the unscraped plots over time. However, the other two sites do not mirror this trend. T-tests performed between scraped and unscraped *C. dalli* data revealed no statistically significant differences on any MVD, date, or site.

The total numbers of adult *Semibalanus balanoides* and *Balanus glandula* (*S. balanoides* + *B. glandula*) were generally low compared to adult *Chthamalus dalli* on both scraped and unscraped plots (Figures 3.66-3.68), with the exception of site 1522. Adult *S. balanoides* + *B. glandula* 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 1993, 1994, and 1995 in unscraped plots. On scraped plots, abundances of the *S. balanoides* + *B. glandula* group were low in 1994, one year after removal of barnacles. The plots were initially scraped in June 1993 and very few recruits arrived over the summer (data discussed below). Thus, by May 1994 there were few adults in the scraped plots. However, a few adults were counted on scraped plots on each site in May 1994 and may have represented late-settling spat that grew enough over the winter to be excluded as juveniles in the subsequent count. By 1995, *S. balanoides* + *B. glandula* densities on scraped plots were very similar to those on unscraped plots.

Juvenile *S. balanoides* + *B. glandula* (referred to subsequently as juveniles) abundance values are shown for each sampling date for sites 1522, BP, and Kiska in Figures 3.69-3.71, respectively. There was a wide time frame in which barnacle spat settled into the intertidal, depending on the year examined. In 1993, high numbers of juveniles occurred only on site 1522 and were more abundant during the June sampling date, indicating that settlement had occurred prior to June. Personal observations made during the summer of 1993 failed to detect the usual "whitewash" of barnacle spat that was noted in previous years on the rocky shorelines. The data suggest that, except for site 1522, relatively poor recruitment success or high mortality occurred immediately following settlement in 1993. Recruitment apparently occurred on scraped plots after August, as higher numbers of adult *S. balanoides* + *B. glandula* were found in May 1994 than juveniles in 1993 on corresponding plots. In 1994, juveniles generally increased in abundance between the June and August visits on sites 1522 and Kiska, especially on the scraped plots where space availability was greater. However, at MVD 0.5 on site BP, barnacles decreased in abundance over the summer on the scraped plots. Conversely, abundance increased on the unscraped plots at MVD 0.5. Juvenile densities also decreased on the unscraped plots at MVD 1.5, although the numbers can be attributed to high recruitment on only one out of four plots (as evidenced by the high variability, Figure 3.70). There may be both extended recruitment and continual mortality occurring throughout the summer. In 1995, juvenile densities were fairly high in June on all sites and most MVDs. However, mortality had occurred over the summer reducing densities by late August.

In August 1994, recruitment of very small *C. dalli* juveniles was observed and they were counted separately from other barnacle juveniles in August and again in September 1994 (Fig. 372). Many spat were barely visible to the eye and so were counted using a magnifying glass. Site BP had the highest spat density and site 1522 had the least settlement. Mortality was observed in most cases between August and September. In view of the very high numbers of *C. dalli* adults counted in May 1995 on sites BP and Kiska (Figures 3.63-3.65), the barnacle juveniles were significantly undercounted or additional recruitment occurred after the first week in September.

DISCUSSION

The patterns of injury and recovery from the Exxon Valdez oil spill for the various invertebrates monitored during the Herring Bay studies varied with habitat type (sheltered rocky or coarse textured), tidal height and time. Although the effects on invertebrates in Herring Bay were variable, there are patterns in the data demonstrating that some populations have been reduced and recovery remains incomplete.

The oiled study sites in Herring Bay continued to show an oil/treatment effect for *Tectura persona* in the upper intertidal zone. Reduced *T. persona* densities were found at oiled sites relative to unoiled sites in the high intertidal as late as 1995 at sheltered rocky sites and in both the high and mid-intertidal at coarse textured sites. *T. persona* is a high intertidal grazer, utilizing thin films of microalgae and diatoms (Castenholz 1961; Nicotri 1977). The oiling and subsequent clean-up were especially damaging to upper regions of the intertidal, reducing or eliminating most species. In addition, with the loss of *Fucus* canopy immediately following the spill, any *T. persona* moving or recruiting into the upper intertidal may have been susceptible to desiccation stress or predation. Although no significant correlation was detected between *Fucus* percent cover and *T. persona* abundance for the sheltered rocky population dynamics quadrats, *T. persona* densities in the high intertidal declined immediately following the removal of *Fucus* canopy during the *Fucus* removal experiment. Repopulation of the quadrats had not occurred by the last sampling period, two months after *Fucus* removal. As discussed In Chapter 2, a high zone population dynamics study was conducted to determine if shoreline aspect affected the recovery rates of *Fucus*, especially in the high intertidal. *T. persona* densities were also determined. Significant differences in *Fucus* percent cover and in *T. persona* abundances were detected in the high intertidal (<0.5 MVD) on east and southeast facing shorelines, with higher abundances found on the control shorelines.

Lottia pelta, another intertidal limpet which tends to be more abundant at lower tide levels than *T. persona*, also continued to show statistically higher densities in the low intertidal at control sites in sheltered rocky habitat as late as 1995. On coarse textured sites, higher numbers were found on oiled sites in the lower intertidal. Gilfillan et al. (1993) reported that *L. pelta* was significantly more abundant in the upper intertidal at reference sites compared to lightly oiled shorelines in sheltered and exposed bedrock habitats immediately following the oil spill, but results varied on more heavily oiled sites. They reported no statistical differences among oiling levels.

L. pelta has shown increases in densities over time at both oiled and control sites within Herring Bay, and at CHIA sites. Correlations showed significant relationships between *L. pelta* densities and *Fucus* percent cover at oiled and control sites in sheltered rocky and coarse textured habitat, although results were mixed for different tidal heights. At sheltered rocky habitats, *L. pelta* densities correlated positively with *Fucus* percent cover in the upper intertidal but the relationship was negative at lower MVDs. In the upper intertidal, *L. pelta* is likely to rely heavily on *Fucus* for shelter from desiccation and avian predation than at lower tidal levels where other algal species are more abundant and exposure times are less. At coarse textured sites, conversely, *L. pelta* densities correlated significantly with *Fucus* cover at MVD 3. Percent cover of *Fucus* was low in the upper intertidal at coarse textured sites.

One focus of the population dynamics studies was the hypothesis that invertebrates lacking dispersal phases in their life histories, such as *Littorina sitkana*, *Nucella* spp., and *Leptasterias hexactis* would take longer to recover on oiled sites because of reduced adult densities at these sites. Of the four species investigated, only *L. sitkana* occurred in sufficiently high numbers for statistical analyses of differences between oiled and control sites. This intertidal grazer was significantly more abundant at control sites than oiled sites as late as 1995 in sheltered rocky locations. For coarse textured habitat, however, higher numbers of *L. sitkana* were detected at oiled sites on several sampling dates after 1991. Although significant differences were found between oiled and control sites, *L. sitkana* densities appeared to increase over time at both sheltered rocky and coarse textured habitats.

Several studies have shown immediate declines in Littorina spp. densities following oil spills and various cleanup actions (Chasse 1978, Southward and Southward 1978, Nelson 1982, Houghton et. al. 1993, De Vogelaere and Foster 1994, Highsmith et. al. 1994), while others have found no apparent effects (Thomas 1978, Clark et. al. 1978, Rolan and Gallagher 1991, Gilfillan et. al. 1993). For most studies in which no injury to Littorina spp. was detected, species having planktonic larvae and direct development with crawl-away juveniles were lumped, e.g. *L. scutulata* and *L. sitkana*, respectively. Studies in which species having different reproductive strategies were monitored separately showed that the littorines with planktonic dispersal recovered more quickly than did direct developers (Southward and Southward 1978, Houghton et al. 1993, De Vogelaere and Foster 1994, Highsmith et al. 1994). *L. sitkana*, which is more spherical and less streamlined than *L. scutulata*, is more abundant at wave-protected than exposed areas (Behrens 1972, Behrens-Yamada 1989, this study). This habitat preference would constrain gradual, non-swimming dispersal from a point source.

Population dynamics of mussels were compared between oiled and control sites in conjunction with water-flow estimators to evaluate potential habitat quality differences between site pairs as explained in the Introduction. The mean length of mussels was lower at oiled than non-oiled sites. Individual year-classes were not evident in the size-frequency distribution curves. High mortality after initial settlement, prolonged recruitment, or differential growth among individuals in a year-class induced by crowding and overgrowing have made separation by year-class impossible in other studies (Seed 1969b, Bayne and Worrall 1980, Wallace 1980, Kautsky 1982). The present study found high densities of small, < 2 mm, mussels in both spring and fall collections indicating that either direct settlement into the mussel band is occurring more than once per year (Suchanek 1978), spring settlement is from over-wintering stocks on filamentous algae (Seed 1969a), or many of the newly settled mussels form a pool of competitively suppressed non-growing individuals that remain small until the death of already established mussels (Kautsky 1982). Overall, the mussel recruitment and density data support the contention that higher recruitment potential, probably due to higher water flow, exists at the oiled study sites.

In May 1995, the total numbers of mussels on each site were generally the lowest found across all sampling dates indicating high mortality rates for the large numbers of mussels counted in September 1994. Site notes made by the sampling crews in May 1995 describe a dramatic difference in the appearance of the mussel beds compared to all prior visits. Where there had previously been dense bands of mussels composed of a wide range of shell sizes, there was bare space with mussels restricted mainly to cracks in the substrate. In addition, nearby pocket beaches and depressions in the bedrock were filled with empty mussel shells. Although high numbers of *Nucella* were not observed on the study sites in May 1995, many of the empty shells had *Nucella* drill holes in them. At nearby sites and in other areas of Herring Bay, highly-aggregated populations of *Nucella lamellosa* were observed feeding on mussels and barnacles (Sam Stoker, pers. comm., our unpubl. obs.). Houghton et. al. (1993) reported that localized populations of *Nucella* had increased dramatically on some sites from year to year, with one site increasing in density from 2.4 to 58.4 individuals m-2 in a one year period. With larger mussels having disappeared from the study beds by 1995, new recruitment may not be successful due to predation, temperature stress or dessication. Thus, the establishment of new mussel beds or bands may depend on the recruitment and succession of other species first. Barnacles are often the first macrospecies to colonize open space, followed by mussels which are known to settle among barnacles (Navarrete and Castilla 1990). Although the population dynamics study reported here lacked the power to detect significant differences in *Nucella* densities between oiled and control sites, Houghton et al. (1993) reported lower densities at oiled and treated sites than at controls following the spill. We cannot be sure of the cause of mortality between sampling dates at our sites but the drilled shells and *Nucella* observations made by us and other workers suggest the possibility that local aggregations of *Nucella* moved through our study sites between September 1994 and May 1995. However, given the breadth of the decline, winter mortality due to physical factors must have been high.

Filamentous algae occurred most often in the lower intertidal (MVDs 3.0 and 3.5) and were more abundant at oiled sites during most sampling dates. Juvenile mussels attached to filamentous algae were also more abundant at oiled sites though differences were not often statistically significant due to high within site variability. 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 a recent 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 filamentous algal recruits at oiled sites was 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.

Mussel abundances in filamentous algae increased seasonally from June to September. Juvenile mussels 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 (Seed 1969a), 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 or more discrete spawning periods annually (Seed 1976; Lowe et al. 1982), which may explain the presence of larger recruits (>1.0 mm) in the algal 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 mode of mussel recruitment. As described above, <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.

The timing and abundance of newly recruited mussels onto filamentous algae and into the mussel beds differed from year to year. A dramatic increase in juvenile densities occurred between late May and late June 1994, when mussel densities in filamentous algae increased from a few hundred to several thousand per 10 x 10 cm collection (Figures 3.41-3.48). The very high numbers of small mussels that recruited onto filamentous algae during the summer of 1994 were also seen in the mussel beds in September, indicating that young had either recruited directly or had started to migrate from the filamentous algae. Houghton et al. (1993) also reported large fluctuations in mussel abundance at their sites and patchy, interannually variable recruitment of mussels.

Agitation by water movement induces spawning in *Mytilus edulis* and settlement ensues after a planktonic developmental period (Seed 1969a, Suchanek 1978). 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 all phases of the mussel recruitment process. In the present study, filamentous algae and associated mussel recruits were more abundant at oiled sites, which usually had significantly greater water motion based upon cylinder dissolution rates (Figures 3.61 and 3.62).

Adult densities and recruitment rates of barnacles were monitored at MVDs 0.5, 1.0, and 1.5 over three summers on three oiled sites in Herring Bay. Throughout the study, *Chthamalus dalli* densities were higher on unscraped plots than *Semibalanus balanoides* and *Balanus glandula* densities combined. Recovery of both *C. dalli* and the *S. balanoides* + *B. glandula* combination occurred by spring 1995, with the data for scraped and unscraped plots often plotted on top of each other (Figures 3.63-3.68).

Assessment of barnacle interactions, specifically between *C. dalli* and *S. balanoides* + *B. glandula*, was difficult due to the patchy or aggregated settlement of the different barnacle species. When barnacle cyprids settle, they seek to attach near another individual of the same species, resulting in species and age classes concentrating around each other in areas available for settlement. In our study, high variability between quadrats and sites resulted in low power and the inability to detect statistical differences between scraped and unscraped plots. Even within our small quadrats (10 x 10 cm), extreme patchiness was often evident with hundreds of individuals concentrated in a two or three cm2 area and either very few individuals in the rest of the quadrat or another dense patch of a different species occurring elsewhere in the same quadrat (personal observations).

In studies conducted in 1991-1993 in the upper intertidal (MVD 0.5) of Herring Bay, oil had an initial effect on barnacle recruitment, but differences between oiled and control sites were mainly nonexistent by 1993. Barnacles had successfully colonized both oiled and non-oiled substrates so that by 1992 there were no differences in abundance of surviving adults between treatments. *Chthamalus dalli*, however, occurred in much higher densities on oiled sites than control sites throughout the study. However, it was not determined whether the low densities of *C. dalli* at control sites was a result of inherent differences between the sites, such as lower salinity at the surface near control sites, or due to the presence of superior space competitors. The high-pressure, hot-water washing conducted on many oiled shores created large areas of free space in the summers of 1989 and 1990. The high numbers of *C. dalli* observed on oiled sites relative to non-oiled sites (Houghton et. al. 1993; Highsmith et al. 1994) was most likely a result of high *C. dalli* larval abundance coinciding with this new availability of settlement space. Connell (1961) and Wethey (1985) reported that the congener, C. stellatus, is normally excluded from lower intertidal levels by the superior space competitors, *Semibalanus balanoides* and *Balanus glandula*, thus restricting adult Chthamalus to upper intertidal areas. *C. dalli* is also out competed for space by other barnacles, notably *B. glandula*, and therefore only occurs in the high intertidal (Dayton 1971, Kozloff 1983). *C. dalli* is capable of producing several broods annually, depending on prevailing environmental conditions (Southward and Southward 1967, Barnes 1989). *S. balanoides* generally releases a single brood each spring, to coincide with the spring phytoplankton bloom (Crisp 1954, Barnes and Barnes 1968, Rucker 1983). Thus, the major release and settlement of *B. glandula* larvae takes place in the spring with only sporadic larval release into the early summer (Barnes and Barnes 1956). Upon settling into the free space provided by the hot-water washing, many of the normal sources of mortality for *C. dalli* would be absent, e.g. superior competitors, predatory snails, bulldozing limpets and macroalgae. Whiplash effects of macroalgae on young barnacles can be fatal (Grant 1977, Farrell 1989). Whiplash from adult *Fucus* plants would be lower on oiled sites than on control sites, due to reduced percent cover of this alga following the spill.

In summary, seven summers after the oil spill, the intertidal communities of Herring Bay have not fully recovered, although recovery of some species has occurred. Damage from oil and cleaning was minimal in the low intertidal in most cases, so recovery has been rapid in that area. Reduced densities of the limpet *Tectura persona* persist in the high intertidal on both sheltered rocky and coarse textured sites. Another limpet, *Lottia pelta* continued to have higher densities in the low intertidal at control sites compared to oiled sites in sheltered rocky habitat, but the reverse was true at coarse textured sites. Similarly, the periwinkle *Littorina sitkana* had reduced densities at oiled sheltered rocky sites but higher densities on coarse textured sites. Recovery of gastropods in the upper intertidal may depend on full recovery of *Fucus* for protection from predation and desiccation.

The main driving force behind differences between oiled and control sites throughout the spill region was the creation of bare substrata due to oiling and clean-up activities (Gilfillan et al. 1995, Highsmith et al. 1996). Initial recruits into the bare space included ephemeral algae, especially filamentous greens, and the barnacle *Chthamalus dalli*. The lower densities of limpets and littorines at oiled sites resulted in reduced grazing pressure on the ephemeral algae. The Herring Bay studies have shown that in the absence of heavy tar, barnacles will recruit into the available bare space. The presence of the initial barnacle recruits enhances recruitment of mussels, *Fucus* and additional barnacles. Low numbers of predatory gastropods, such as *Nucella* spp., increase survival rates of both barnacles and mussels. The presence of higher filamentous algal cover may also enhance recruitment of mussels onto oiled sites. As *Fucus* cover increases, gastropod densities also increase. Finally, with the recovery of predators such as *Nucella* spp., barnacle and mussel populations may decrease in patches where intense predation occurs.

The successional patterns that occurred after the oil spill are similar to those reported for other oil spill studies on rocky shores. Southward and Southward (1978) report almost complete disappearance of limpets, littorines, and dogwhelks as well as most barnacles, following oiling and treatment with dispersants after the Torrey Canyon spill. They also reported that most damage occurred in the high intertidal.

Generally, higher dissolution rates of calcium sulphate cylinders were measured at oiled sites than control sites. The higher water movement past the oiled sites may account for the higher mussel recruitment and growth rates at oiled sites. Significantly higher filamentous algal cover was also recorded at oiled sites, making the total mussel population much greater at oiled sites. Wave action can suppress feeding rates of intertidal mollusks (Brown and Quinn 1988). In Herring Bay, mussel growth rates were highest at the oiled sites, supporting the hypothesis that current flow is typically greater at oiled sites, resulting in differences in food supply and recruitment rates.

Injury and recovery trends for several key invertebrates, e.g. *Tectura persona*, *Lottia pelta*, *Littorina sitkana*, and *Nucella* spp. were similar for the Herring Bay and CHIA sheltered rocky sites. However, the differences found between oiled and control sites for recruitment and growth rates relative to water motion within Herring Bay may not necessarily reflect differences across the entire spill region. Although "intra-bay" differences have been measured for some parameters, Herring Bay is relatively wave-protected and homogeneous compared to the entire spill region. Differences in wave exposure between sheltered rocky sites were much greater in the CHIA study than occur in Herring Bay. Differences in mussel recruitment and growth rates may be even greater between oiled and control shorelines throughout the entire spill region than was shown within Herring Bay. Unfortunately, no measurements of water motion were made during the CHIA study. However, based on the fetch and site aspect relative to the direction of predominant storms, sites were assigned an "exposure" rating. When community data were analyzed using multi-dimensional scaling methods, the sheltered rocky CHIA site data were grouped according to exposure (Highsmith et al. 1994). If water circulation differences occur between oiled sites and control sites throughout the spill region as they did for the study sites in Herring Bay, estimates of spill-wide injury may have actually been underestimated for some species. For this reason, the collection of baseline data in areas potentially impacted by an oil spill would be preferable to post-oil spill paired-site studies.

The discussions above and in Chapter 2 describe injury to several key intertidal invertebrates and their interactions with *Fucus*, the major intertidal algal species in Herring Bay. In addition, recruitment and growth rates for *Mytilus trossulus*, a species damaged by the oil spill and cleanup activities, were shown to vary with water motion. These differences impact recovery processes on oiled sites and may indicate inherent differences between oiled and control sites in a post-impact matched pair design. An understanding of the interactions and recovery processes of the intertidal region is necessary for determining impacts to higher-order consumers as intertidal plants and animals provide food and shelter for a host of organisms in the nearshore ecosystem. Fish, such as sculpins, pricklebacks, and gunnels, and juvenile pollock utilize the intertidal zone (Highsmith et al. 1994). Intertidal algae are also used as substratum for egg deposition by herring in spring and for foraging and protection by some species of salmon fry. Many bird species forage in the intertidal, e.g. black oystercatchers, harlequin ducks, Barrow's goldeneye, common goldeneye, surf scoters, pigeon guillemots and gulls all feed in the intertidal to some extent. Black oystercatchers feed on mussels, limpets, chitons, and crabs (Hartwick 1978, Frank 1982, Marsh 1986a, b, Sharp and Cody 1993). Harlequin ducks feed on clams, chitons, limpets, hermit crabs, and mussels and the Barrow's and common goldeneyes and surf scoters feed on mussels and snails (Patten 1993). Pigeon guillemots feed on benthic fishes commonly found in the intertidal, such as gunnels, pricklebacks and sculpins, and on invertebrates such as crabs and shrimps (Oakley and Kuletz 1993). Most of the above bird species suffered injury from the oil spill (Laing and Klosiewski 1993) with loss of harlequin ducks in Prince William Sound estimated at 25% of the population (Patten 1993). Day et al. (1993) reported that the bird species that failed to show clear evidence of recovery by 1993 tended to be intertidal feeders. Intertidal mussels also contribute to the diet of river otters (Bowyer et al. 1993) and sea otters (Burn 1993). Bowyer et al (1993) found that otters in oiled regions had lower body masses, larger home ranges, and a less diverse diet than otters in unoiled areas of Prince William Sound in the year following the oil spill. Burn (1993) reported that sea otter densities declined in both oiled and non-oiled regions following the oil spill and that the spill's long-term effects on otters will depend on the densities and contamination levels of their major prey, clams and mussels. Many other higher-order consumers periodically inhabit the intertidal, either scavenging for food or utilizing the intertidal structure for protection. Brown and black bears have been observed feeding on amphipods when the invertebrates occur in high concentrations on drift algae; Sitka black-tailed deer feed on drift algae; Northwestern crows feed on *Nucella* by dropping and cracking the shells on bedrock; ducks have been observed clearing sections of a beach of littorines; and the fingerlings of several species of salmon and trout can be observed at high tide hiding among *Fucus* fronds.

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CHAPTER 4. *FUCUS* RESTORATION

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EXECUTIVE SUMMARY

Fucus populations in Herring Bay were severely damaged by the oil spill and subsequent clean up activities. By 1993, populations in the low and mid intertidal regions showed significant signs of recovery. Populations in the high intertidal, especially at sites with a southern exposure, showed little to no recovery at that time. Surveys performed at various locations in western Prince William Sound in 1994 showed that the upper boundary of *Fucus* populations at the oiled sites (2.49 m MLLW) was an average of 0.5 m lower than the upper boundary at unoiled beaches (2.89 m). A resurvey of the restoration study site in Herring Bay ("Weasel Beach") in May and August 1995 showed that the upper *Fucus* boundary had increased from +1.9 m (MLLW) in 1994 to +2.8 m in 1995. The new 1995 level is nearly equal to the mean upper boundary for the control sites in the 1994 survey. In addition, *Fucus* densities at the Weasel Beach restoration site showed a large increase in 1995. These are encouraging signs that recovery is beginning in these high intertidal zones. The visual appearance of the upper 1 m of the *Fucus* zone at the oiled sites, however, remains quite barren compared to the control areas. The thalli in the oiled sites are very small and densities are relatively low. Full recovery should occur when these newly recruited thalli become reproductively mature and provide a source of embryos in this region. Reproductive maturity for these new thalli will be reached in approximately 2 years.

Restoration of severely damaged intertidal *Fucus* populations was tested on a small scale at a heavily oiled rocky intertidal site in Herring Bay, Prince William Sound. Experiments employed two types of 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 with jute fabric was initiated in 1992, and a more resilient coconut-fiber fabric was tested in June 1993. The jute fabric deteriorated within one year and therefore was not effective in enhancing *Fucus* recruitment. Dense populations of *Fucus* developed on the surface of the coconut-fiber 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 thalli on the mats were approximately 2 cm in length. This fabric deteriorated during the winter of 1995 and the thalli on the mat did not have an opportunity to become reproductive.

Transplantation of adult *Fucus* thalli and sporelings attached to erosion control fabric was also tested as a potential restoration technique. The adult thalli died within a few months of transplant and mortality rates were high in the sporeling populations transplanted to south-facing beaches.

The slow recovery of *Fucus* populations in the high intertidal appears to be due to a variety of factors. The primary factor appears to be a low supply of embryos into this area. The patterns of juvenile recruitment on the inoculated mats show that embryo dispersal is very limited. Limited dispersal was also seen in experiments using egg settlement plates. However, even when thalli of various age classes are transplanted into this environment, the successful establishment of new populations is low. The harsh physical conditions of this habitat with

temperatures on the rock surface recorded as high as 43.6° C cause severe desiccation and heat stress. The significant relationship seen between aspect and the upper boundary of *Fucus* on two islands within Herring Bay shows that solar exposure is an important factor regulating *Fucus* distribution. A third factor potentially slowing the recovery of high intertidal *Fucus* was increased grazing pressure. Surveys at Weasel Beach showed very high densities of littorinid snails during 1993 and the spring of 1994 which subsequently decreased in the late summer of 1994 and in 1995 when *Fucus* populations were increasing. Cage studies in Herring Bay have also implicated grazers as a significant factor controlling the recruitment of young *Fucus* thalli.

INTRODUCTION

The oil spill and subsequent clean-up 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 in studies conducted during the summer of 1990 (Houghton *et al.*, 1993a, 1993b; Stekoll *et al.,* 1993a, 1993b, 1996; van Tamelen & Stekoll, 1995, 1996). 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 4.1) 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 beaches that have been slow to recover 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* thallus greater than 2 cm in length 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.

In 1995, the upper boundary of *Fucus* populations was surveyed on two small islands in Herring Bay. These surveys were designed to investigate the influence of beach aspect on the distribution of *Fucus* populations. These two small, circular islands were chosen because they allowed us to isolate beach aspect from other physical factors, such as wave exposure, that could influence the distribution of *Fucus* populations. Random sampling sites around the circumference of the islands were chosen using a methodology similar to that used above for segmenting the linear beach segments. At each site we determined the upper limit of the highest *Fucus* thallus and fertile *Fucus* in 1 meter swaths centered on the randomly chosen starting points. Tidal heights were determined using a hand sight level and stadia rods. We measured the aspect of the beach relative to true north with a compass and the slope of the beach with an inclinometer.

Restoration

Biodegradable Fabric

A preliminary experiment to test the feasibility of fastening and maintaining mats of erosion control fabric in the rocky intertidal was initiated in May 1992 at "Weasel Beach". These fabrics are routinely used to control erosion on exposed banks that are associated with construction activities. The material tested initially was ANTIWASH/GEOJUTE fabric (Belton Industries of Atlanta, Georgia). This fabric was chosen because it had the highest water retention of the materials we tested (Table 4.1), 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. One meter wide mats of the jute fabric were fastened in the upper intertidal to the rocks with a combination of stainless steel screws and epoxy putty. But this fabric did not last for the summer season, and 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.

The final experimental design involved creating 12, 1 m wide plots placed perpendicular to the shoreline with the top of the plots at the Mean High Water mark (+3.4 m above MLLW or 0 MVD, meter of vertical drop) as indicated by the lower boundary of the *Verrucaria* zone. The bottom of each of the plots was placed at +2.4 m above MLLW (1 MVD). The coconut fiber mats, also 1 meter wide, were fastened to the substratum with stainless steel screws within the plots. The screw fasteners permitted easier removal of the mats when enumerating the plots. Six plots were covered with the mats and six were left uncovered as controls.

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* thalli were counted in the treatment strips. In 1994, we also counted and mapped the *Fucus* thalli on the surface of the coconut fiber fabric. All thalli greater than 2 mm in length were counted between the Mean High Water level and the 1 MVD mark. A 100 cm2 quadrat was used to guide the census to ensure that all the small thalli were censused. The quadrat data also provided information on the spatial distribution of thalli on the mat.

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 of 1994.

Substrate Inoculation

Inoculation of the experimental plots with *Fucus* embryos was accomplished with two methods: 1) transplanting fertile adults and 2) the direct seeding of substrates with embryos. Reproductive *Fucus* thalli 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 thalli 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* thalli 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 thalli, 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^2 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. Thalli collected in 1994 did not release sufficient embryos for the inoculation procedures.

Transplantation of juvenile *Fucus*

The transplantation of juvenile thalli on pieces of coconut fiber matting was also tested as a potential restoration method. These transplant mats were also used to investigate the influence of beach aspect on recruitment processes in the high intertidal. Two strips of coconut fiber matting were naturally seeded with *Fucus* embryos by fastened them among dense populations of adults in the low intertidal at approximately +0.5 m MLLW. The mats were put into place on 25 May 1994. An inspection of these mats on 7 September 1994 showed that the mats were covered by microscopic (0.2 to 0.5 mm) sporelings. On 19 May 1995, the mats had a uniform cover of 0.2 to 0.5 cm *Fucus* along with a dense cover of *Scytosiphon*, *Pilayella*, and *Enteromorpha*. The mats were cut into 15x15 cm pieces for transplanting to high intertidal sites with north, south, east, and west aspects on a small island just offshore of Weasel Beach. Three pieces of matting were fastened at 0.5 MVD (+2.8 m MLLW) at each site using epoxy putty. The pieces were randomly assigned to each of the transplant locations. The numbers of visible *Fucus* thalli on the transplanted pieces of matting were counted on 26 August 1995.

Transplantation of Adult *Fucus*

On 31 May 1992 several adult (> 8 cm) *Fucus* were transplanted to "Weasel Beach" to determine the survival of adult *Fucus* in the upper intertidal. Thalli were taken from both the "Weasel Beach" area and a beach about 2 km directly south of "Weasel Beach". Thalli along with a piece of the rock substrate to which they were attached were removed from the mid intertidal with a chisel . The thalli were transplanted to "Weasel Beach" by gluing the rock to the new location with marine epoxy. Six to 8 plants were transplanted to each of four different tidal elevations at the east end of "Weasel Beach". The four tidal elevations were 0.0, 0.2, 0.4, and 0.7 MVD. *Fucus* thalli were counted and measured for total length after transplantation and again on 8 June and 31 August 1993.

RESULTS

Surveys of *Fucus* Upper Boundaries

The heights of the upper *Fucus* boundaries at the oiled and control sites throughout Prince William Sound in the summer of 1994 are summarized in Table 2. The average upper limit 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 upper limits 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.

A comparison of the upper boundary of *Fucus* populations at Weasel Beach in 1994 and 1995 (Figure 4.2) shows a dramatic increase between these two years. The thalli at the upper boundary in 1995 were generally small (~2 cm) and were not visible in the general site photographs. This upward migration of the upper boundary coincided with a large increase in *Fucus* density observed on rock substrate in the experimental restoration plots (both controls and fabric covered plots. See "Restoration" section below) (Figure 4.3).

We also documented the *Fucus* distribution at the Herring Bay restoration site with an annual series of photographs started in 1990 (Figure 4.4). 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 but dropped below this level by September of 1994. The visible boundary then moved slightly higher during the summer of 1995. As mentioned earlier, the smaller plants (< 2-3) cm were not visible in these photographs, and therefore the results determined using this method may miss the smaller plants that were detected in the other upper boundary surveys.

The distribution of *Fucus* upper limits around the two islands in Herring Bay is presented in Figure 4.5. The distribution of *Fucus* upper limits with respect to aspect was fit to a polynomial regression with an R^2 of 0.72. The south facing sites had lower *Fucus* upper limits than those with a north aspect. The mean upper limit of the south facing sites (135 to 225 degrees) was significantly lower (ANOVA, $F=6.27$, $p= 0.003$) then the north facing sites (0 to 45 and 325 to 360 degrees) (Figure 4.6).

The *Fucus* upper limits on the islands showed a weak, but significant negative regression ($t=-2.49$, $p=0.021$) with beach slope (Figure 4.7). This relationship may be due to a number of factors including the period of time the rock surface of the different sites remains moist and the vertical dispersal ability of the *Fucus* embryos.

Restoration Techniques

Biodegradable Fabrics

Observations of the GEOJUTE fabric in September, 1992, only 4 months after installation, 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 had expected that this fabric would remain in place for three years until the settled *Fucus* thalli had became reproductive. Unfortunately, on the May survey in 1995 these mats had deteriorated to the point that only a few small sections were left on the rocks. These remnants were removed at this time.

These substrates, however, were useful in documenting some of the processes influencing the population dynamics of *Fucus* in the upper intertidal. By the end of the summer of 1994, dense populations of young *Fucus* thalli with mean densities over 500 thalli m^{-2} had grown on the surface of the coconut fiber mats (Figure 4.8). There was no significant difference between inoculation treatments in the overall density of juvenile thalli on the mats. The inoculated mats, however, had patches of thalli in the immediate vicinity of the thallus attachment sites (Figure 4.9). The majority of thalli on the mats, both inoculated and uninoculated controls , occurred along 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 thalli that would have provided a source of embryos.

Densities of the *Fucus* thalli were much lower 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 shown in Figure 4.3. The number of *Fucus* thalli in the top 0.5 meter of the intertidal was very low during the first three years of the project and increased slightly in 1995. Densities in the 0.5 to 1.0 MVD zone increased dramatically during 1995 and reached a density of nearly 300 thalli m^{-2} by the end of the summer. These thalli were generally smaller than 2 cm in length so the visual appearance of this zone still appears very barren (Figure 4.4). These thalli should grow rapidly during the winter and spring of 1996, producing a significant amount of biomass and becoming visible in site survey photographs by the end of the summer of 1996.

The density of littorines in the restoration plots showed a general decrease in abundance from Spring 1993 to the last sampling period in August 1995 (Figure 4.10). No differences were found in littorine densities as a function of mat cover (ANOVA, $p=0.4282$) (Figure 4.11). Densities were significantly higher at the lower tidal level (ANOVA., $p=0.0007$), and were significantly different between sampling periods (ANOVA, $p<0.0001$) (Figure 4.10).

Limpet populations, in contrast to the littorine populations, showed a large increase in population size during the summer of 1993 at both tidal levels (Figure 4.12) with a subsequent decline in the late summer of 1994 and 1995. Limpet densities during 1993 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 4.13) and 1.0 MVD (Figure 4.14) 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 during the winter of 1994. These levels then persisted through August 1995. 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 1994 sample (Figure 4.14). 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 1994. 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 4.15)

Transplantation of juvenile and adult *Fucus*

The transplantation of newly settled juveniles on the coconut fiber matting showed that relatively few individuals survived at sites with either a south or west exposure (Figure 4.16). Survival was relatively good at the north and east facing sites.

The transplanted adults at "Weasel Beach" did not survive in the upper tidal elevations (Table 4.3). Only one thallus survived at the 0.4 MVD elevation for more than and year, and this plant disappeared by 31 August 1993. Two of eight plants survived at the lowest transplant level of 0.7 M. These transplants grew and were reproductive in the second year subsequent to transplantation.

DISCUSSION

The upper intertidal zone is a very harsh environment for recruitment and survival of *Fucus* individuals. Experimental transplants of individual adult thalli and juveniles from lower tidal zones showed that these thalli could not survive more than a few months (DeVogelaere & Foster 1993; Stekoll et al. 1993a, this study). 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 1995, 1996) indicate that *Fucus* egg dispersal is limited to less than 1m, and 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 thalli. Colonization of new thalli, 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. The recruitment of juvenile thalli into the restoration plots increased during 1995. If these thalli survive they should become fertile during 1996 and 1997. The dense recruitment of young thalli onto the coconut fiber matting in the vicinity of fertile adult thalli in 1994 showed that the moist environment provided by the matting is a critical factor limiting the expansion of the *Fucus* population. The majority of these thalli, 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 thalli is another critical factor regulating population increase in the high intertidal.

The recruitment of thalli 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 thalli.

The techniques for inoculating the mats and rock surfaces with *Fucus* embryos and the transplantation of juvenile and adult *Fucus* 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 thalli died fairly quickly after transplantation or were washed from the transplant site. The seeding of mats and the subsequent transplantation of juvenile thalli appeared to work well for north facing beaches. For south facing beaches, where restoration activities are most needed, the observed survival rate of the juveniles may be too low to produce a large population of fertile adult thalli. It would be interesting to test this technique on a larger scale.

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Table 4.1. 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 4.2. The height of the upper limit of the *Fucus gardneri* band at oiled and control (unoiled) south-facing, sheltered rocky sites in Prince William Sound. "Weasel Beach" is the restoration site in the northern end of Herring Bay.

Oiled Sites	Height (m above MLLW)	Control Sites	Height (m above 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

Table 4.3. Fate of adult *Fucus* thalli transplanted to "Weasel Beach" on 31 May 1992.

Tidal Level (MVD)	Date	N	Mean Length (cm ±SE)	% Survival
0.0	31 May 1992	6	10.6 ±1.9	100
	8 June 1993	0	0	0
	31 August 1993	0	0	0
0.2	31 May 1992	7	8.6 ±1.1	100
	8 June 1993	0	0	0
	31 August 1993	0	0	0
0.4	31 May 1992	8	9.3 ±0.6	100
	8 June 1993	1	6.0 ±0.0	12
	31 August 1993	0	0	0
0.7	31 May 1992	8	9.9 ±1.1	100
	8 June 1993	2	17.5 ±5.8	25
	31 August 1993	2	17.5 ±5.8	25

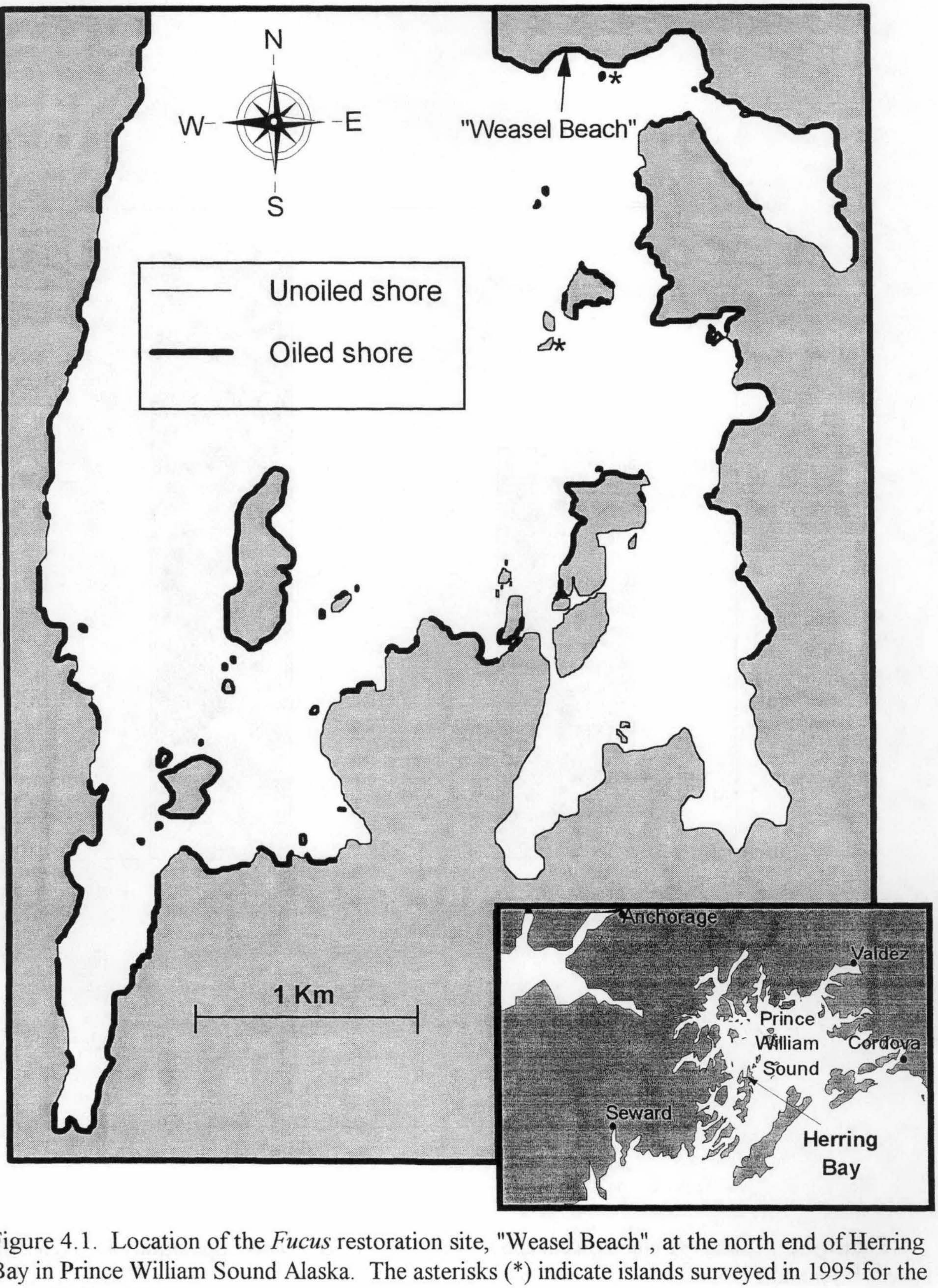

Figure 4.1. Location of the *Fucus* restoration site, "Weasel Beach", at the north end of Herring Bay in Prince William Sound Alaska. The asterisks (*) indicate islands surveyed in 1995 for the upper limits of *Fucus*.

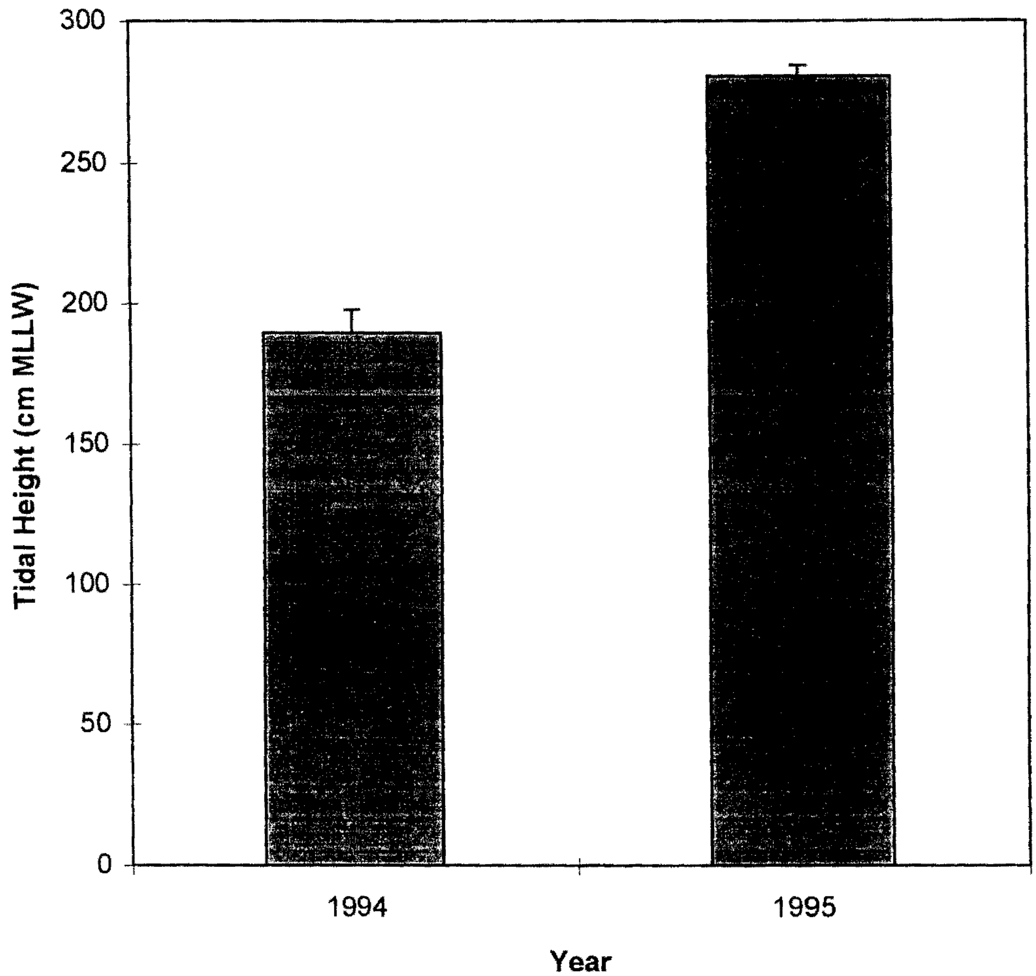

Figure 4.2. The upper limits (in cm above MLLW +SE) of *Fucus* populations at "Weasel Beach" in 1994 and 1995.

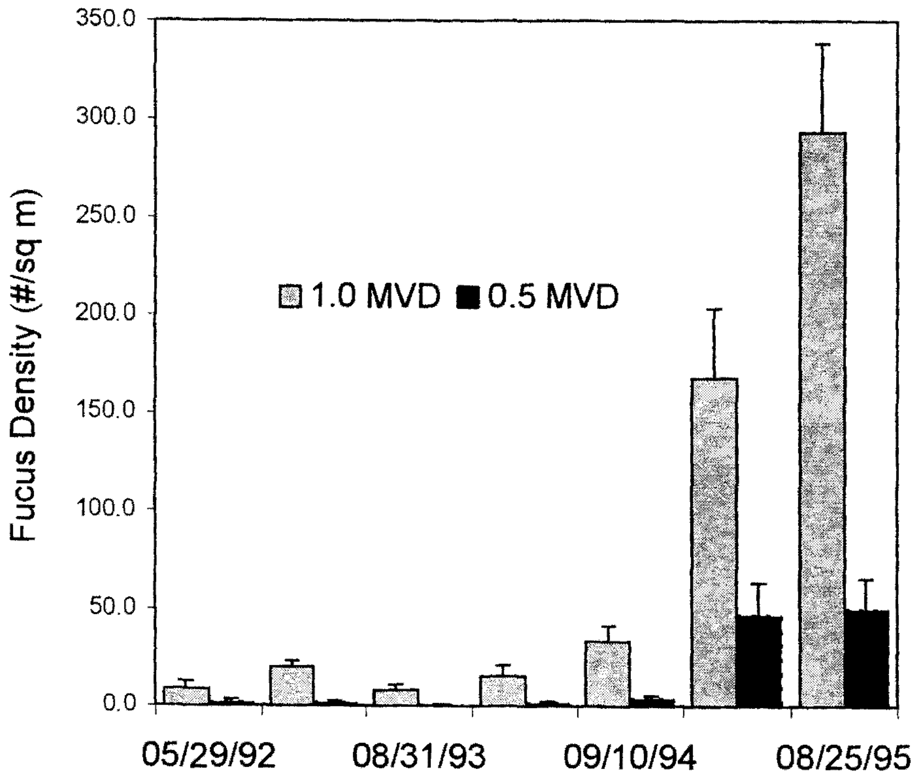

Figure 4.3. The density of *Fucus* thalli (+SE) in experimental restoration plots (controls and fabric covered plots) at "Weasel Beach" in 1995 at both the 0.5 and 1.0 MVDs.

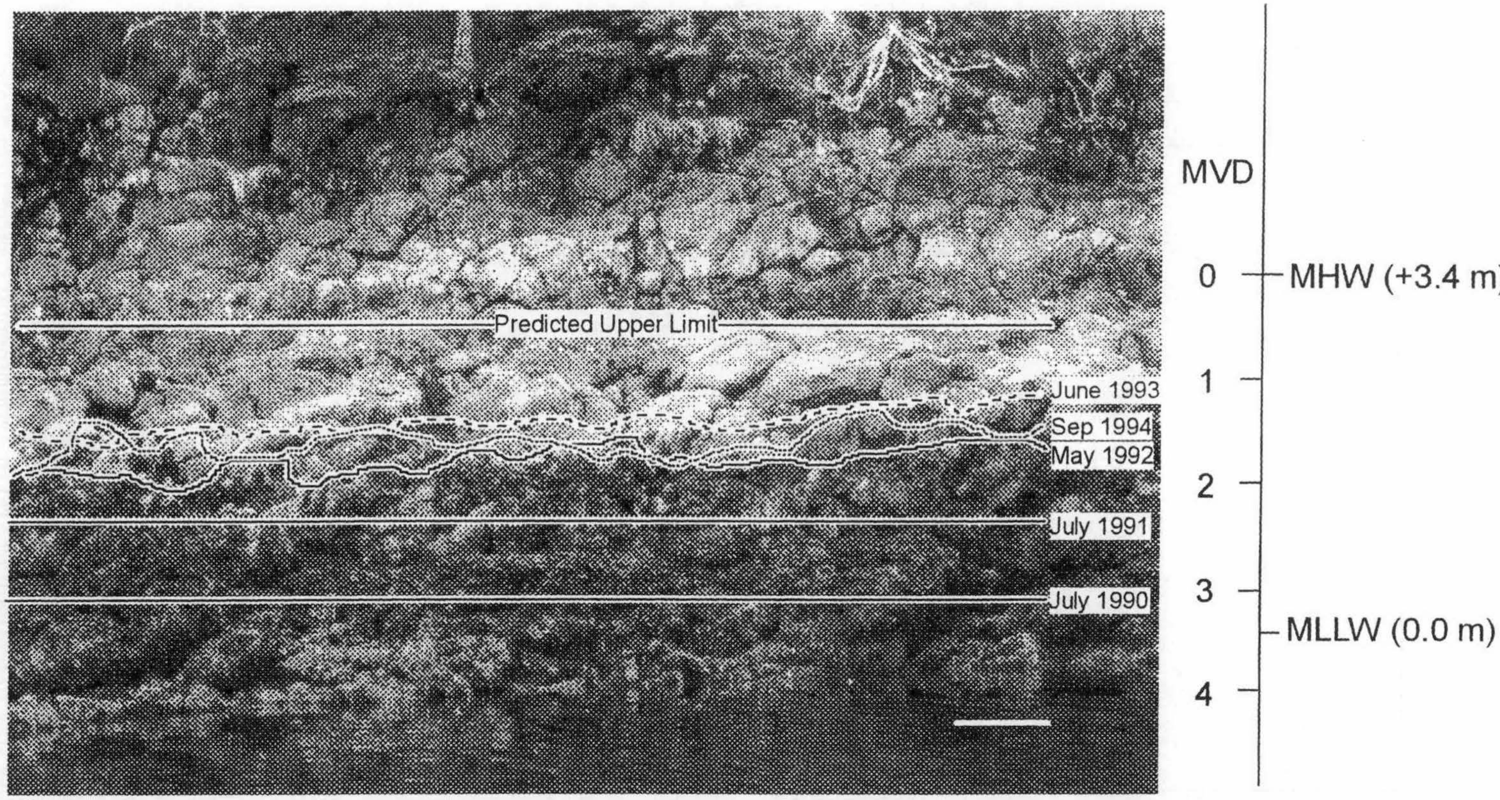

Figure 4.4. The upper limits of *Fucus* at "Weasel Beach" from 1990 to 1995. The figure is a computer image of the "Weasel Beach" restoration site in Herring Bay and is scanned from a photograph taken in the summer of 1995. The horizontal lines indicate the maximum heights of the visible *Fucus* band at the years indicated on the right edge of the picture. These lines were drawn using superimposed images. *Fucus* thalli less than ca. 3 cm in length were not detectable using this method. Note that the upper limit for *Fucus* dropped from 1993 to 1994. The upper limit in 1995 is similar to that in 1994. The Predicted Upper Limit is based on the mean values from south facing unoiled sites (see Table 2). A scale bar at the lower right represents 1.0 m in length.

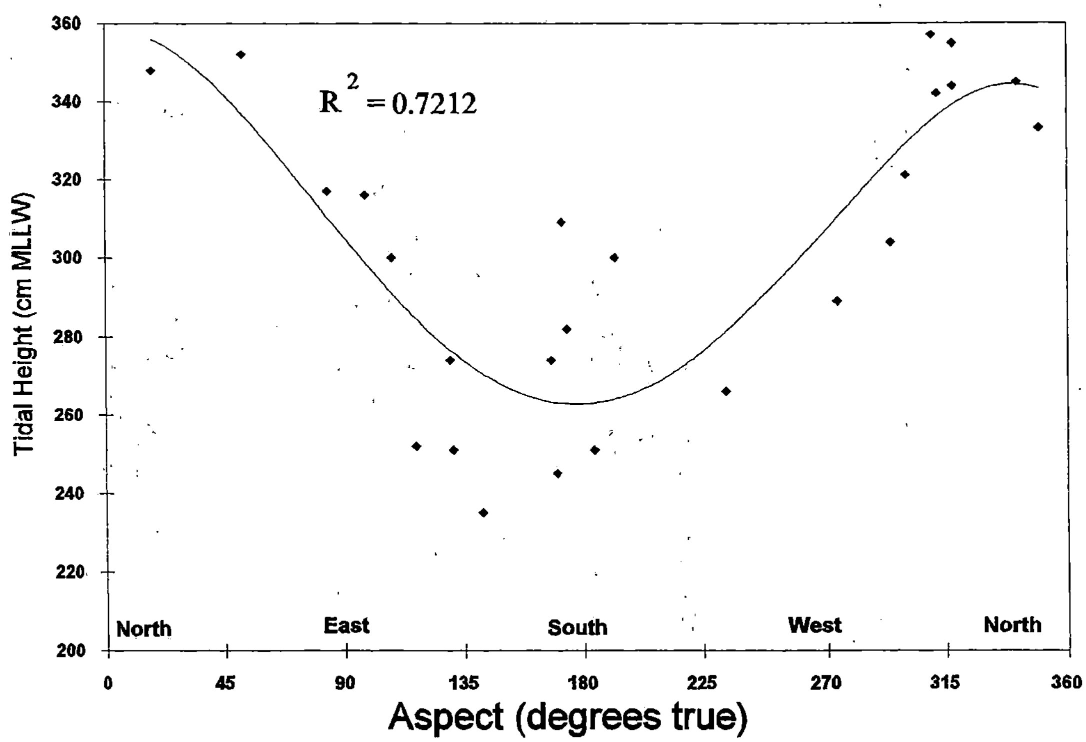

Figure 4.5. The distribution of *Fucus* upper limits around two islands in Herring Bay, Knight Island during the summer of 1995. The line is a best fit fourth-order polynomial regression.

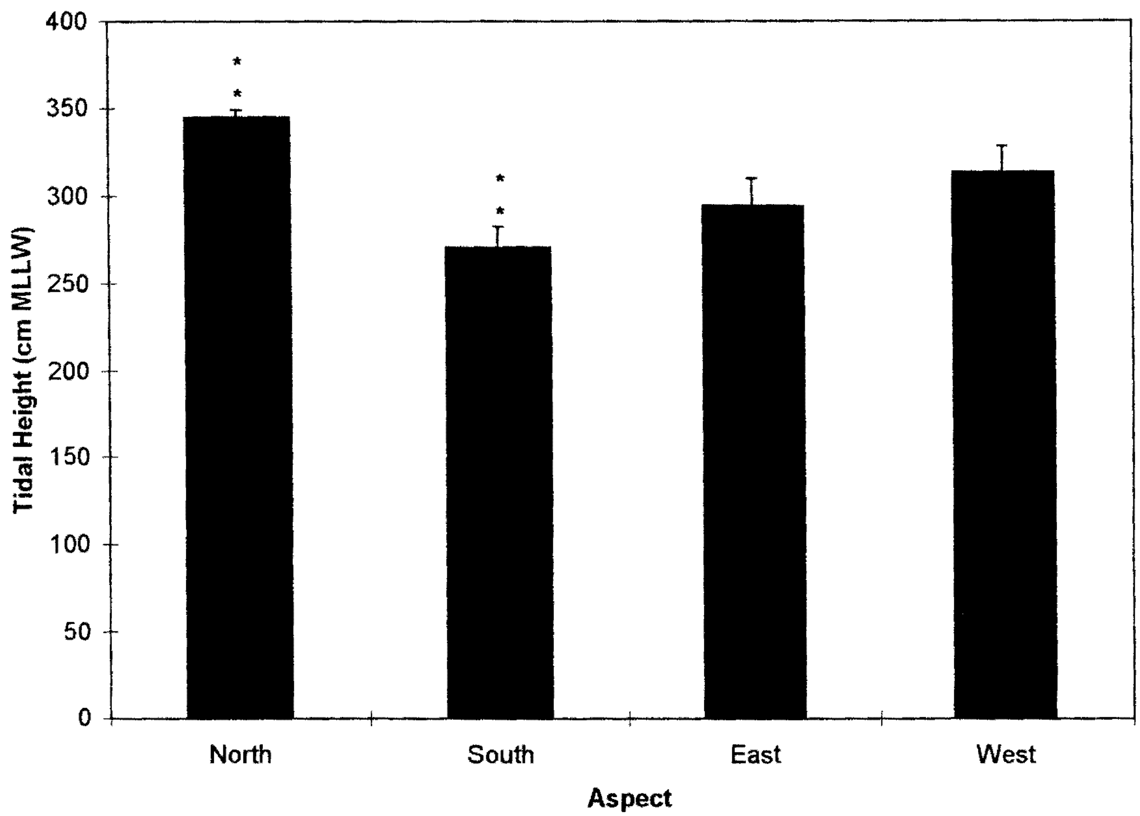

Figure 4.6. Mean upper limits of *Fucus* as a function of aspect at two islands in Herring Bay, Knight Island. The upper limits were measured relative to Mean Lower Low Water (0.0 m). Error bars represent 1 SE. The mean upper limit at the North was significantly different from the South facing aspect.

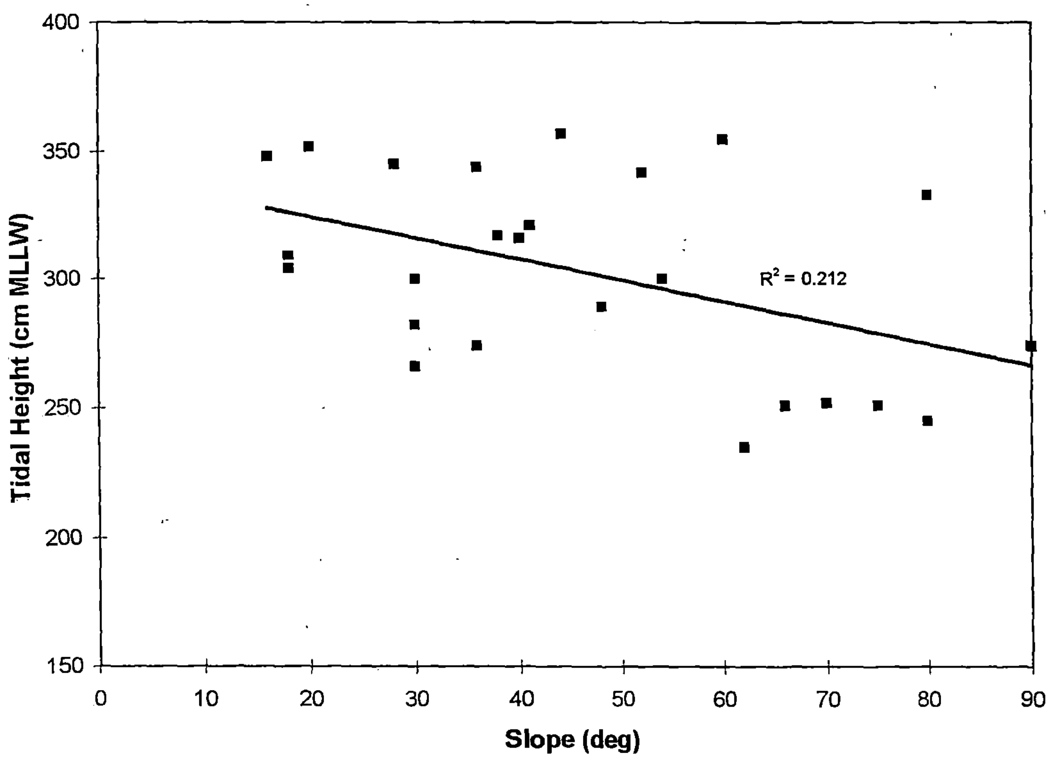

Figure 4.7. The upper limits of *Fucus* as a function of beach slope at two islands in Herring Bay, Knight Island.

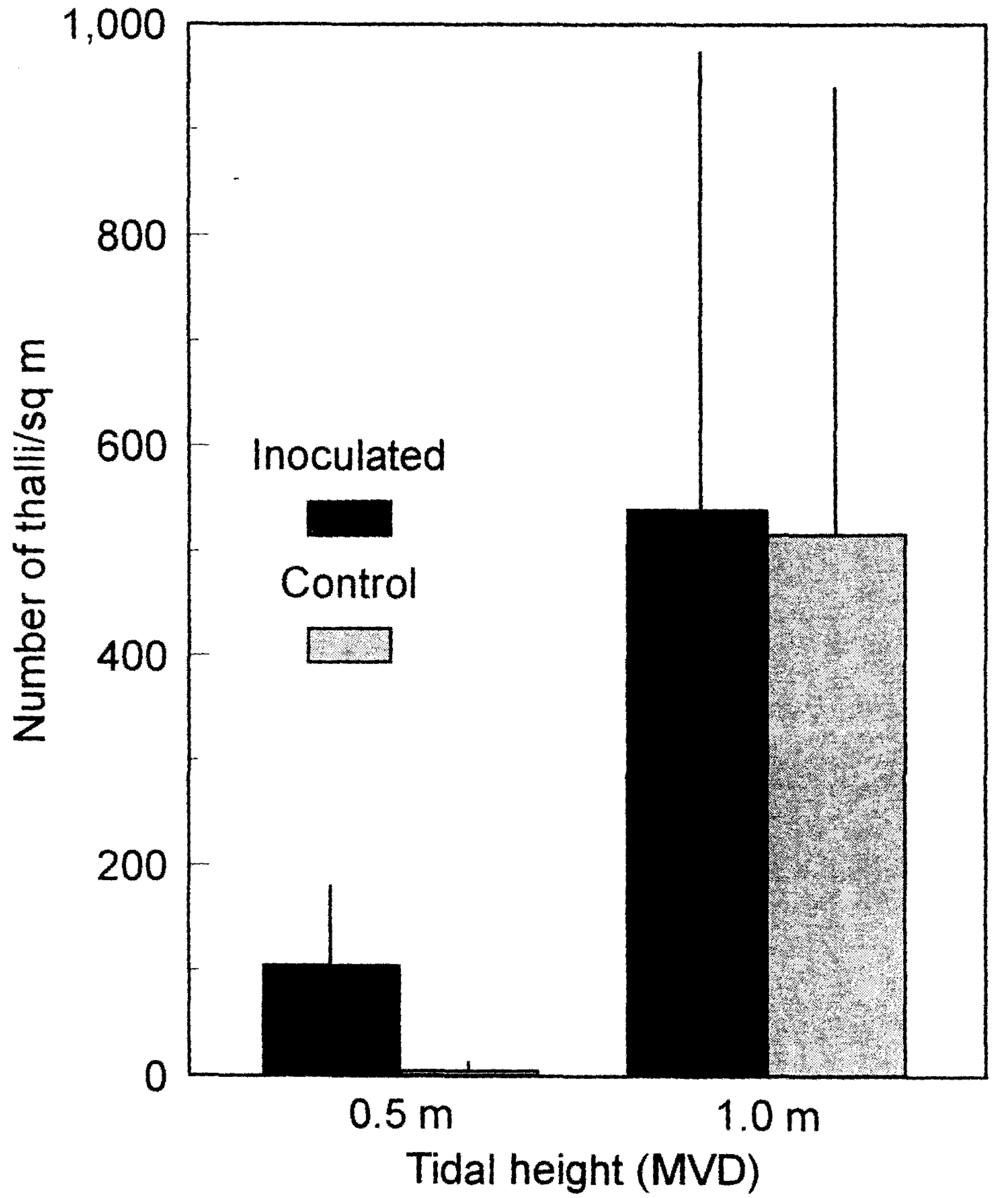

Figure 4.8. Density of *Fucus* thalli on the surface of coconut fiber erosion control mats at "Weasel Beach" in September 1994. Mats were deployed in June 1993. Inoculated mats were seeded with transplanted fertile *Fucus* thalli and sprinkled with *Fucus* embryo solutions in the summer of 1993. Controls 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.

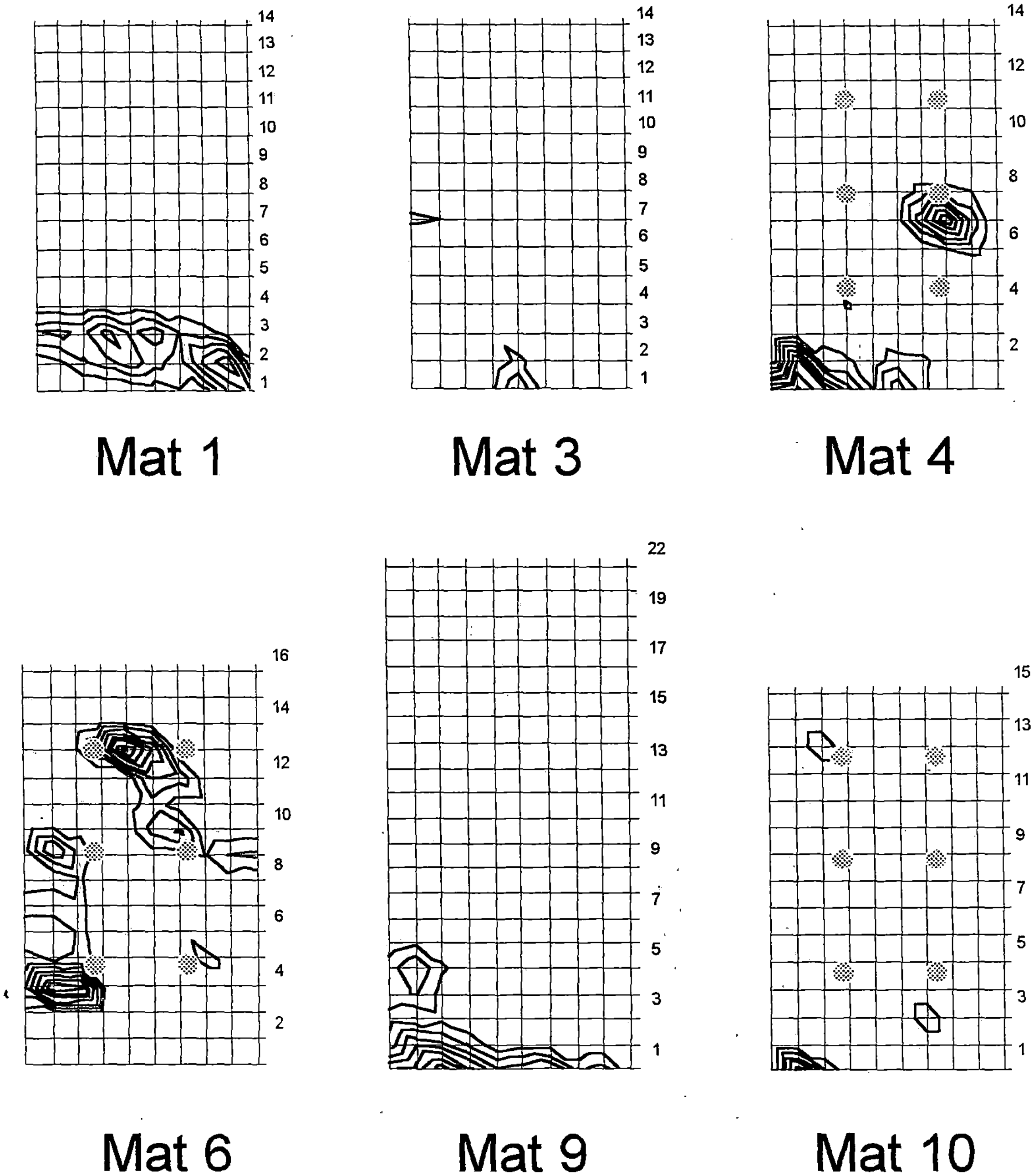

Figure 4.9. Density contour maps of *Fucus* germlings on the mat surfaces in September 1994. Each contour represents an increase of 10 plants per 100 square cm. Mats 4, 6 and 10 were inoculated in 1993 by tying fertile *Fucus* plants to them (grey circles). Mats vary in length due to the differences in slope along the beach. The bottom of each mat is at 1.0 MVD and the top is at 0.0 MVD (MHW).

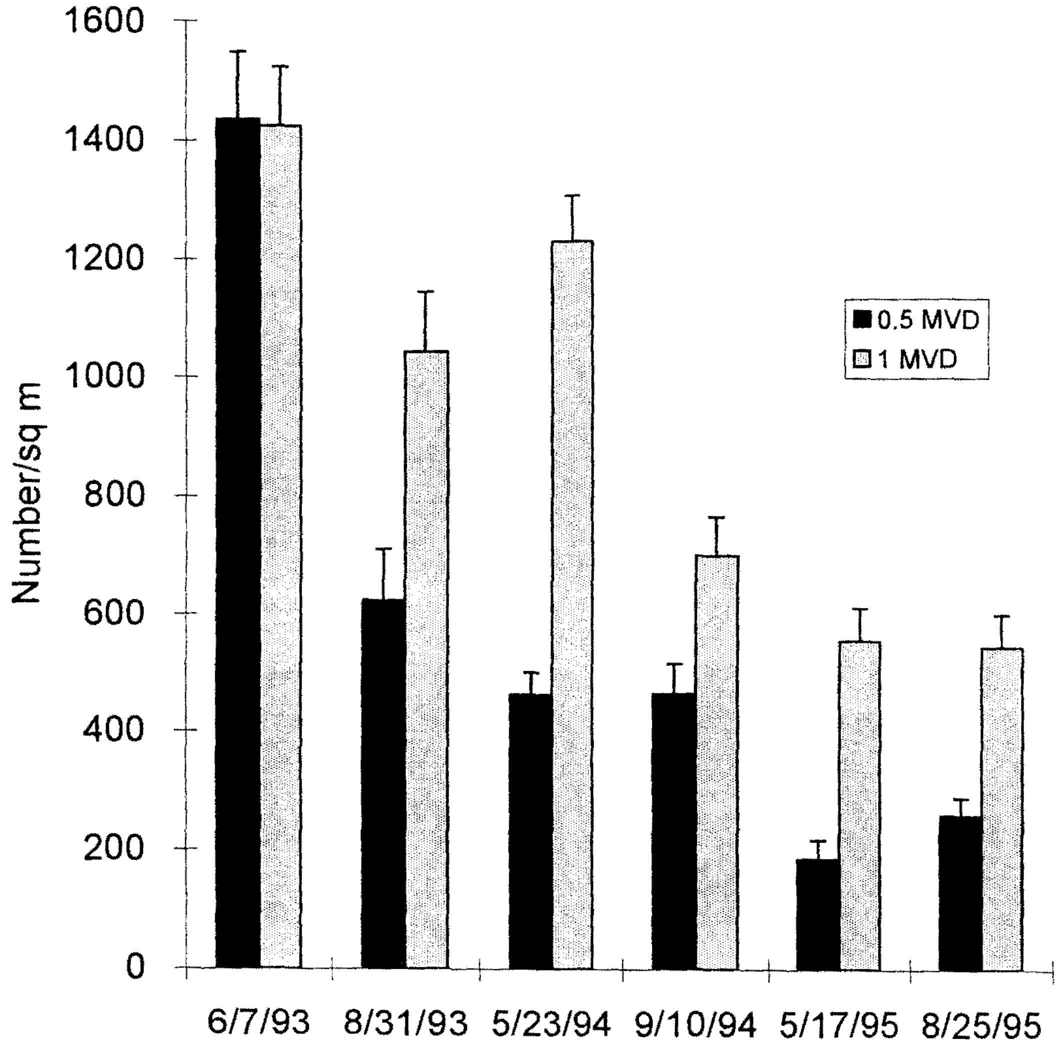

Figure 4.10. Density of littorine snails on the rock surface in the restoration plots at "Weasel Beach".

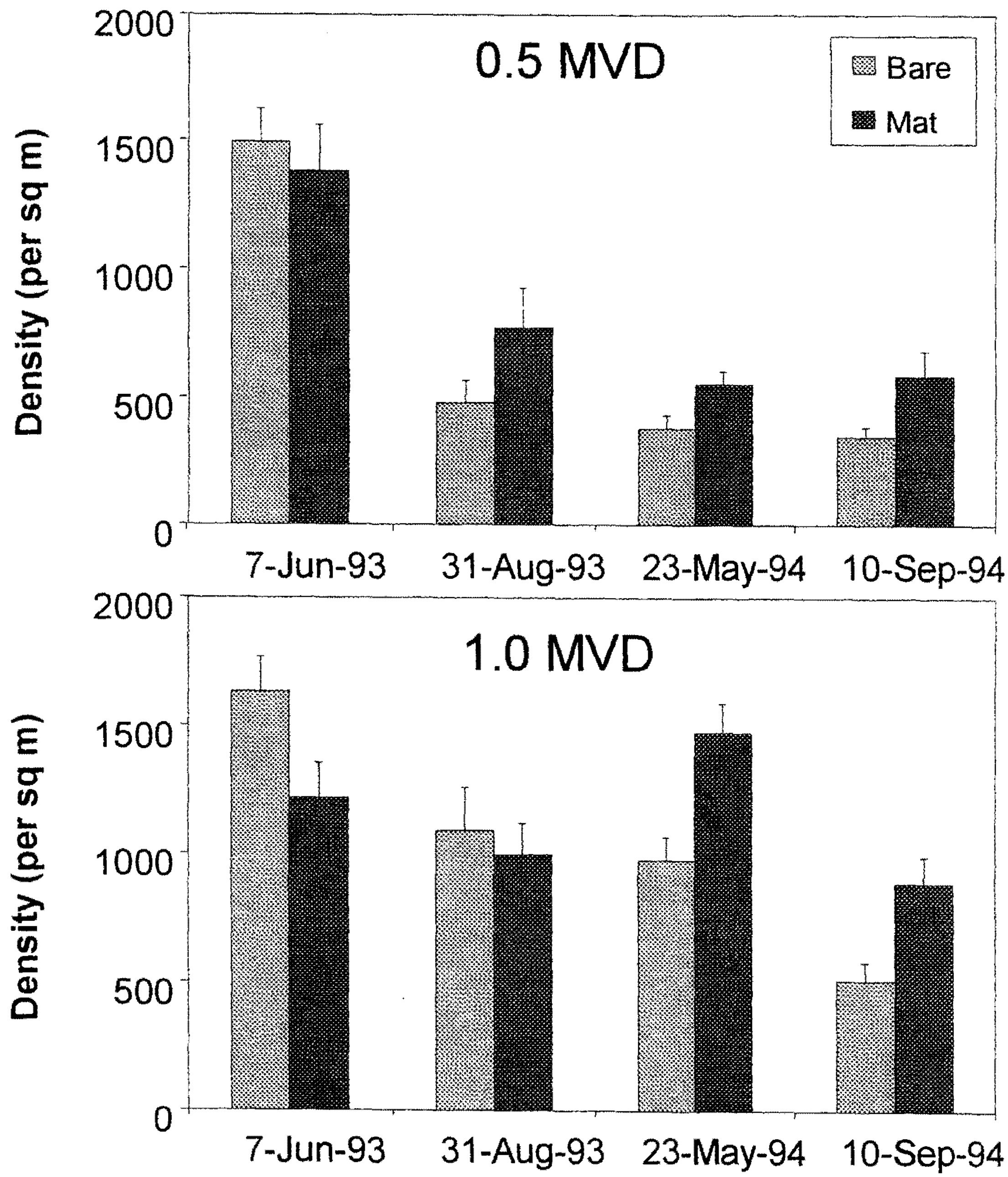

Figure 4.11. Density of littorine snails on the rock surface without mat cover (bare) and on the rock surface with mat cover (mat) in the restoration plots at "Weasel Beach".

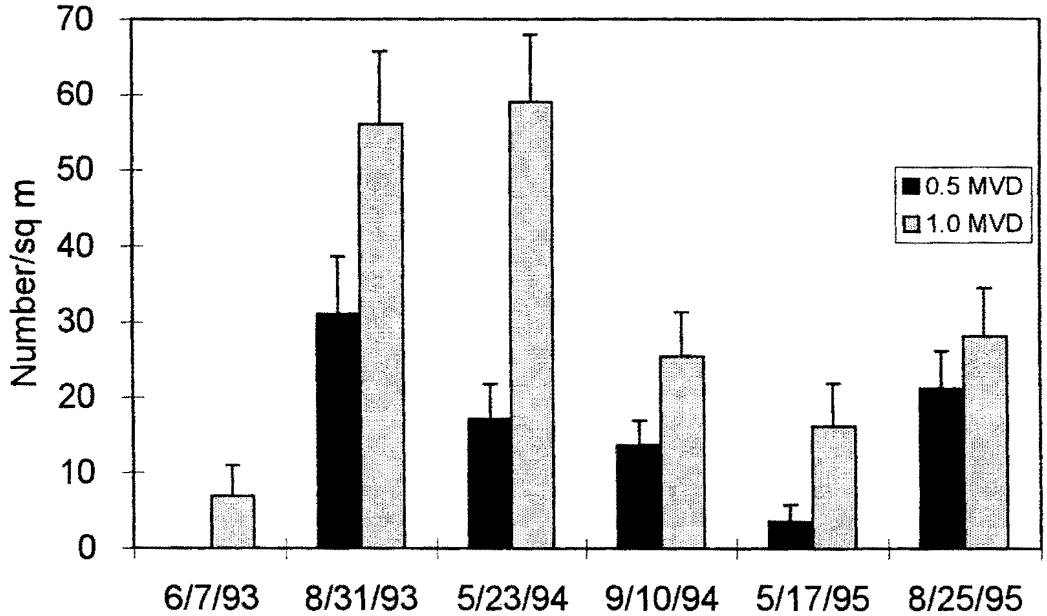

Figure 4.12. Density of limpets on the rock surface in the restoration plots at "Weasel Beach".

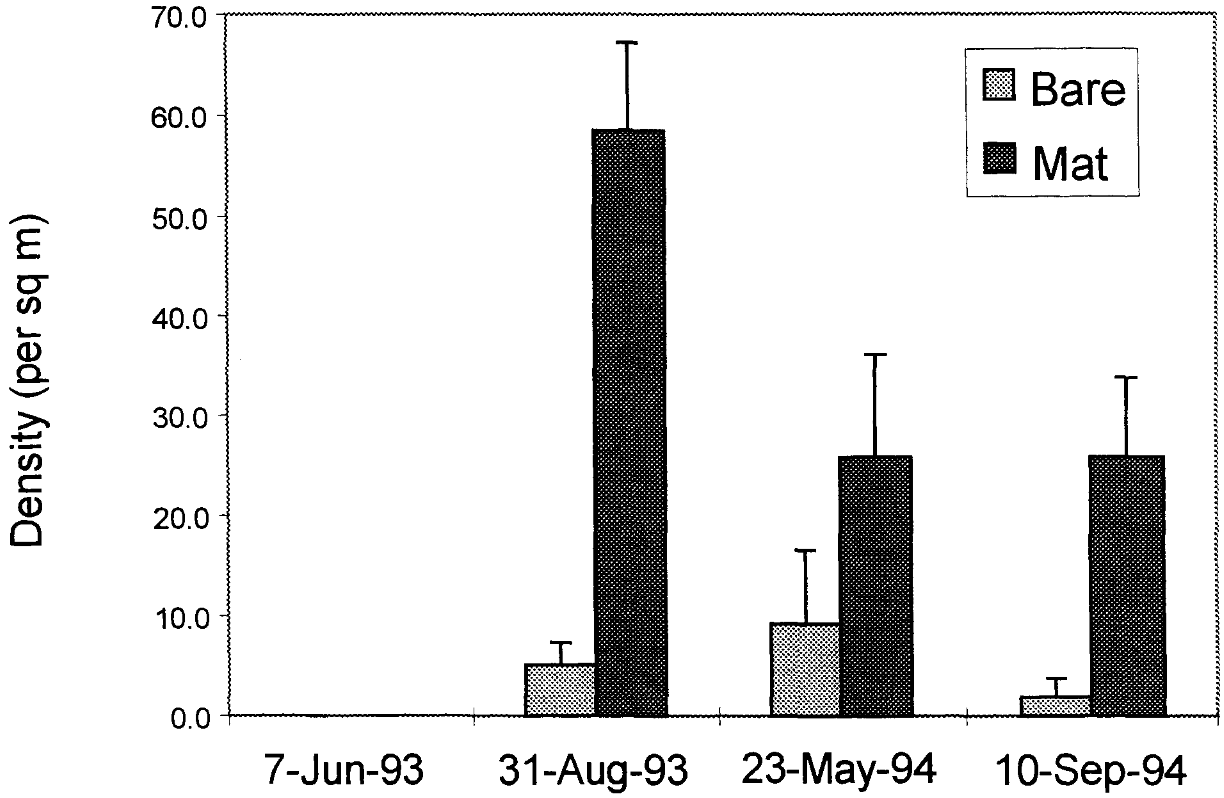

Figure 4.13. Densities of limpets on the rock surface at 0.5 MVD on bare plots and on mat-covered plots at "Weasel Beach " restoration plots. N = 6 for all treatments.

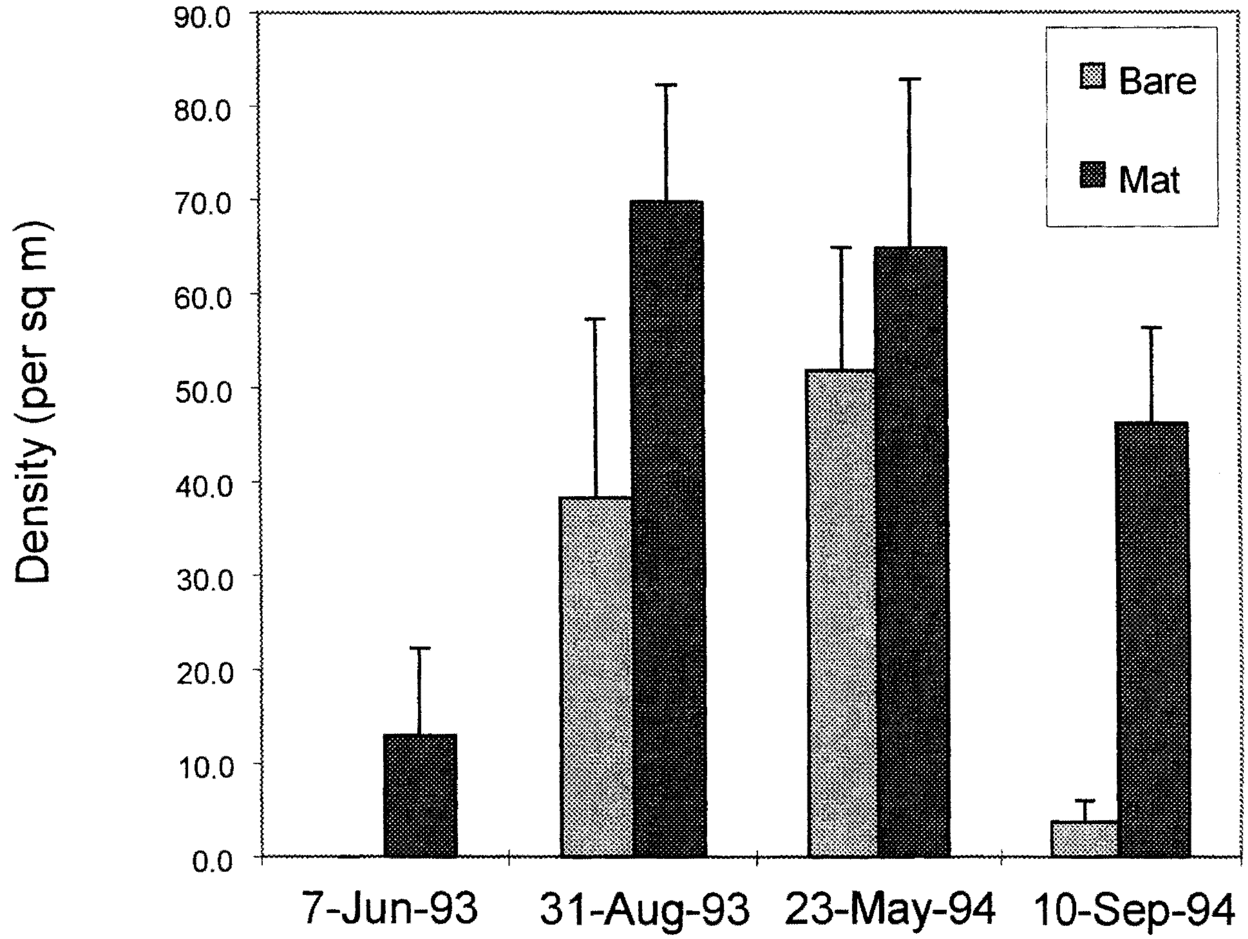

Figure 4.14. Densities of limpets on the rock surface at 1.0 MVD on bare plots and on mat-covered plots at "Weasel Beach" restoration plots. N = 6 for all treatments.

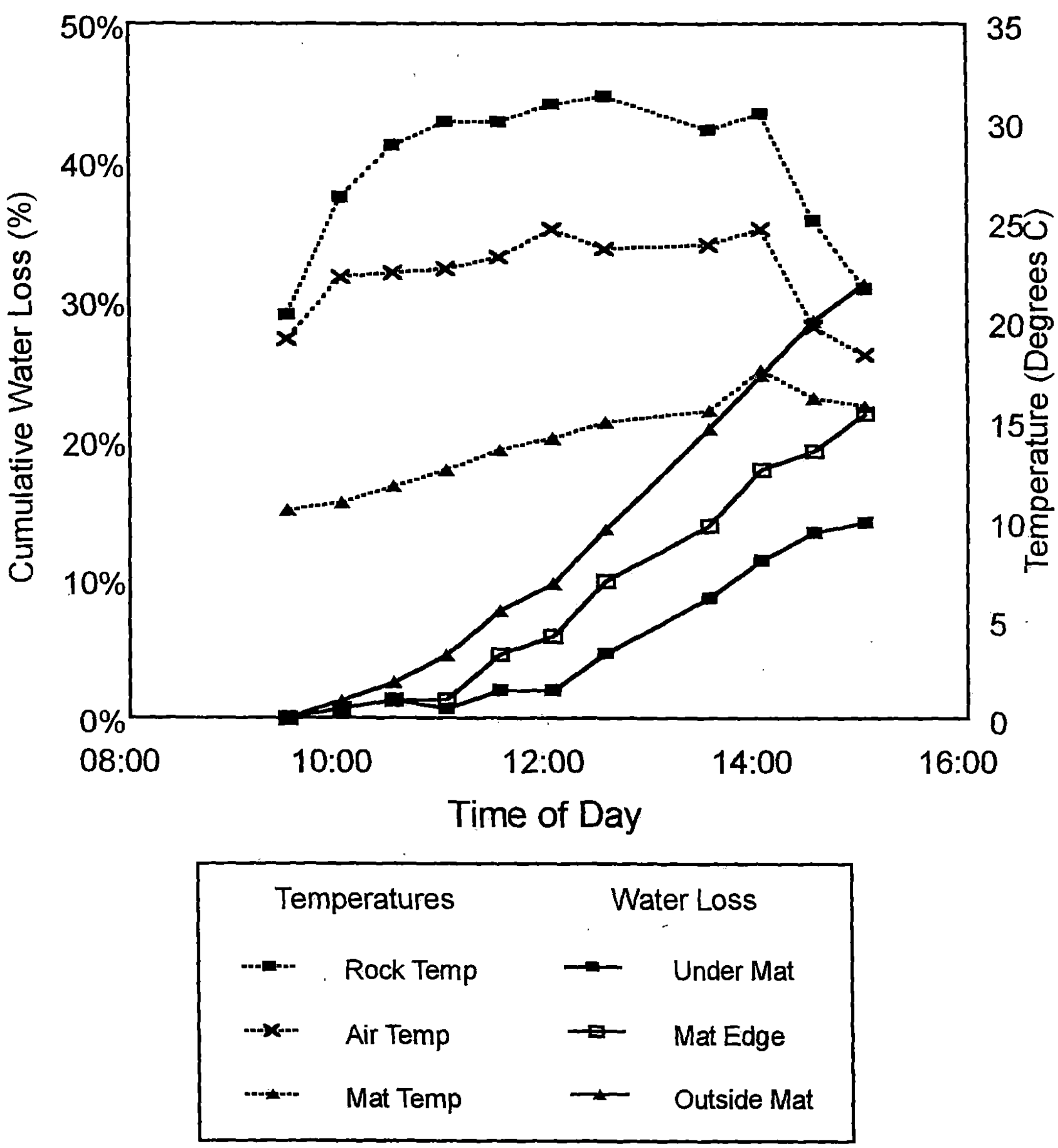

Figure 4.15. Desiccation (as percent water loss) and temperatures on 28 May 1994 at the "Weasel Beach" restoration plots in Knight Island, Prince William Sound.

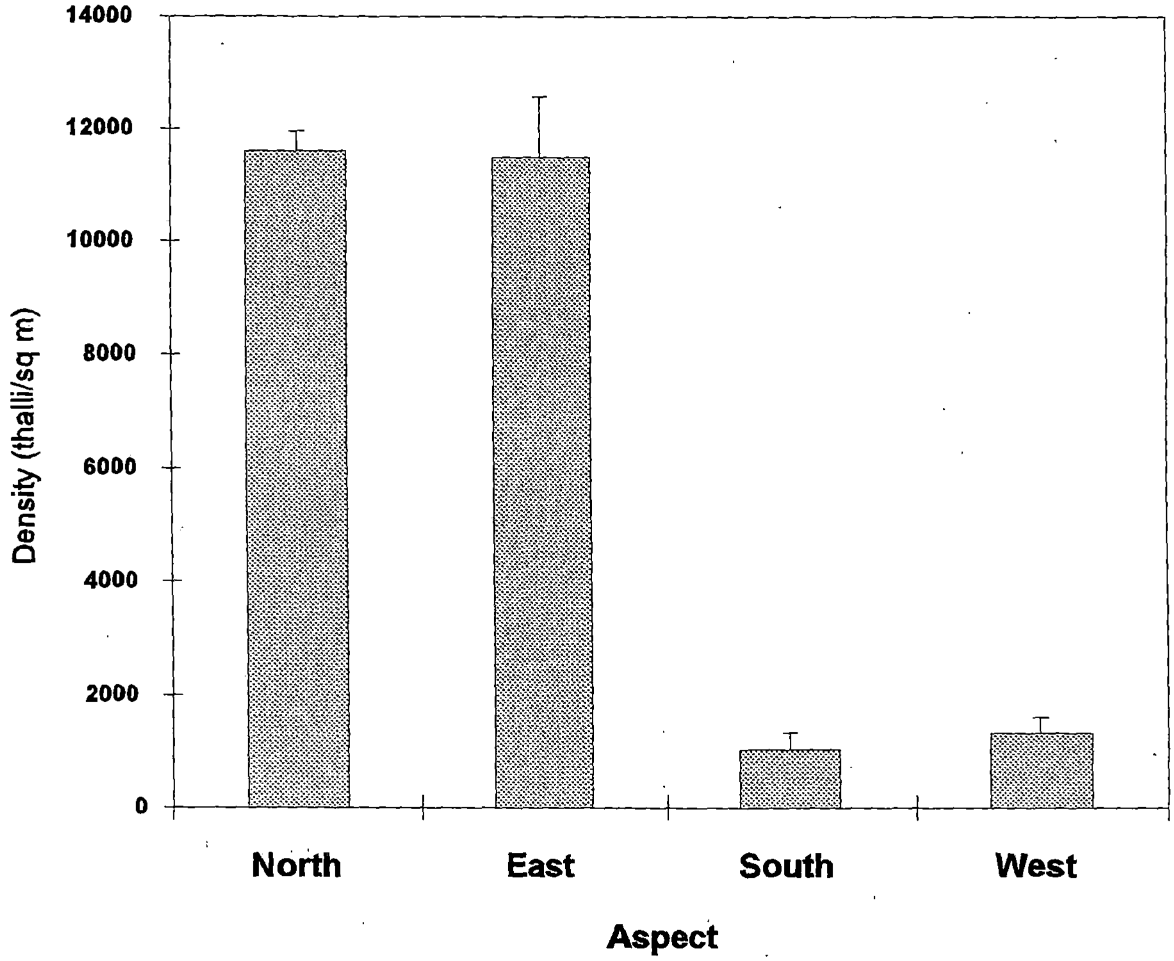

Figure 4.16. Density of transplanted *Fucus* thalli around a small island in the northern part of Herring Bay, Prince William Sound. Small pieces of pre-seeded coconut fiber erosion control mats were placed at four different aspects in September 1994. Thalli densities were measured in September 1995.

CHAPTER 5. SUMMARY AND SYNTHESIS OF OBSERVATIONS AT HERRING BAY

The Intertidal at Herring Bay

Herring Bay was chosen as a representative site in Prince William Sound (PWS) for sheltered rocky and coarse textured habits. The Bay was selected because there were a number of potential sites for experimentally comparing oiled and non-oiled habitats. In addition, there were supposed to be two "set aside" sites in Herring Bay which would allow comparisons of cleaned versus untreated oiled sites. However, the "set asides" had actually been treated and most of the sites in Herring Bay are more protected than sites on the periphery of the islands of PWS. This fact is reflected in the less diverse intertidal biota in Herring Bay. Extrapolations of the conclusions drawn from our experiments at Herring Bay are probably only valid for other sites in PWS that have similar exposures.

The rocky intertidal at Herring Bay is dominated by the brown seaweed *Fucus gardneri* Silva. This species has also been identified previously as *Fucus distichus* L. emend. Powell or *Fucus evanescens* C. Agardh (O'Clair *et al.* 1996). The prevailing opinion of algal systematists is that *Fucus gardneri* is the predominant fucoid found growing in the mid- to high intertidal along the coast of Alaska from Ketchikan to Nome. In Herring Bay there is one other *Fucus* species that grows in the very high intertidal in estuarine areas. This plant is the diminutive *Fucus cottonii* and has no major role in Herring Bay ecology. *Fucus gardneri* (hereafter referred to as *Fucus*) occurs in Herring Bay from MLLW to near MHHW. Other algae in this area are annual greens such as *Ulva, Monostroma* and *Chaetomorpha/Rhizoclonium*, annual browns such as *Myelophycus/Scytosiphon, Pilayella, Ectocarpus, Soranthera, Dictyosiphon, Elachista,* and *Leathesia,* annual reds such as *Dumontia, Gloiopeltis, Halosaccion, Palmaria* and *Porphyra,* and perennial reds such as *Neorhodomela, Rhodomela, Endocladia, Ptilota* and species in the Gigartinaceae family.

Associated with *Fucus* is a comparatively limited community of macro-invertebrates. These include the littorine snails, *Littorina sitkana* and *Littorina scutulata*, the limpets *Lottia pelta, Tectura persona* and *Tectura scutum,* and species of amphipods and isopods. Other species that do not necessarily associate with *Fucus* directly but are found in the sheltered rocky sites are barnacles (*Balanomorpha* spp., *Chthamalus dalli, Balanus glandula, Semibalanus balanoides*) and other crustaceans (*Pagurus* spp.), bivalves (*Mytilus trossulus, Turtonia minuta*), and whelks (*Nucella* spp.). In soft bottom areas, annelids such as errant polychaetes, sedentary polychaetes and Oligochaeta species are common. Littorines and limpets are grazers and may eat *Fucus* plants directly or feed on diatom or bacteria films found on the *Fucus* thallus or surrounding rocks. Isopods and amphipods are detritavores and are likely to feed on microscopic flora associated with *Fucus* (Lubchenco 1983), although this interaction was not assessed in the present study.

Fucus makes up the majority of the floral biomass and percent cover in the intertidal: 99%, 95% and 65% of the algal biomass in the high, mid and low zones, respectively, during the late spring and summer at Herring Bay (Highsmith *et al.* 1994). These numbers are higher in the fall and winter when annuals are not abundant. The *Fucus* thalli provide a source of primary productivity to the nearshore, but this carbon source is directly available to grazers only when the plants are very small or when they have died and been dislodged from the substrate. Live, adult *Fucus* thalli are more important as structure in the intertidal. The fronds provide both shelter and an indirect food source for the associated invertebrate community. The shelter provided serves multiple functions: protection from predation by fish and birds, protection from the desiccation effects of the receding tide (McCook and Chapman 1991) and a surface on which to deposit eggs. *Fucus* can provide an indirect food source by acting as a surface on which microalgal and bacterial films can grow (Viejo and Arrontes 1992.). *Fucus* also plays the role of antagonist by competing for space with other attached biota such as barnacles and mussels, and by sweeping areas bare due to the whiplash effect of its fronds (Jernakoff 1983, 1985, van Tamelen *et al.* 1997). *Fucus,* because of its abundance and ecological functions, is the defining species for the sheltered rocky sites in Herring Bay and Prince William Sound in general.

Fucus makes its living by photosynthesis. Its growth season extends from spring through summer. Growth is not only a function of available light but also of nutrient concentration in the seawater. Specifically, growth is usually limited in the summer by the decline in nitrogen and phosphorus levels. Intraspecific competition is important for this species (Kendziorek and Stekoll 1984) perhaps through the mechanism of shading or whiplash effect. *Fucus* becomes fertile in the summer and is able to release millions of eggs/zygotes per thallus per season. Because *Fucus gardneri* is monoecious, most of the released eggs are fertilized zygotes. These zygotes are not motile and usually are released with copious mucilage secretions from the *Fucus* receptacles. Hence, zygotes disperse very close to the parent plant with over 95% remaining within 20 cm of the adult. Survival of *Fucus* germlings in Herring Bay (and probably throughout its range) depends on protection from desiccation and adult whiplash and to a lesser extent from herbivores. Small cracks and crevices in the substrate afford this protection. The ideal width (500 μ) for these cracks is about 4-5 times the diameter of the zygote. The ideal depth of the cracks is greater than 0.5 mm. If these cracks are near the parent plant, the parent plant can provide some protection from desiccation, but as the germlings emerge from the cracks they are susceptible to whiplash from the nearby adults. *Fucus* plants in Herring Bay need two to three years of growth before becoming fertile. Individual fronds can live up to several years.

Oil Spill Effects

Oil spills have deleterious effects on the nearshore biota due to both physical and chemical (toxic) effects. Laboratory studies have shown that oil is toxic to organisms, especially at the larval and juvenile stages. *Fucus* fertilization is inhibited by oil at low concentrations in seawater (Steele 1977). Mussels have been used extensively in toxicity testing (e.g. Smith 1968, Kanter 1974, Rice *et al.* 1979) . Most toxic effects are over relatively long term exposures and high concentrations (*e.g.* Stekoll *et al.* 1980). The *Exxon Valdez* oil spill initially may have been toxic to intertidal organisms but the physical coating of the shore was responsible for smothering many organisms. Work done on sites that were oiled and not cleaned (Houghton *et al.* 1996) indicated that toxic/smothering effects of oil on the intertidal community were minimal compared to the effects of the cleanup activities. The results of our work at Herring Bay are consistent with the hypothesis that cleanup activities, especially the hot water, high pressure wash, caused the most damage. Therefore, it is our view that the oil spill/cleanup acted essentially to create large patches of bare rock and beach. Damage was related to physical disturbance. Recovery is dependent upon the ability of key organisms to recolonize bare space.

The assumption of physical disturbance is borne out by the data collected by the Herring Bay study. The percent cover of bare rock in 1990 was much greater at oiled sites. Obviously bare rock was created by removing *Fucus*, barnacles, mussels and associated fauna, especially in the upper intertidal. All of the following measures are consistent with the scenario that bare space was created by the spill/cleanup. There were fewer *Fucus* plants, reproductive plants, receptacles and eggs released per square meter at the oiled sites. The reproductive plants that were at oiled sites were shorter and had fewer receptacles than plants at control sites. Receptacle weight was lower for the plants at oiled sites. A cohort of juvenile *Fucus* plants appeared in the intertidal at oiled sites in 1990 and reached adult size in 1994. No such cohort or pulse of numbers was seen in the unoiled sites.

The design used in the Herring Bay studies did not permit clear, unambiguous testing of the effects of oil toxicity free from other confounding mechanisms by which the oil spill may have affected intertidal organisms, including beach treatment. But we found no direct evidence that the oil itself was toxic to *Fucus*. For example, the growth rates of *Fucus* were greater at oiled sites, perhaps due to the lack of intraspecific competition. We found no effects of oiling on *Fucus* mortality. And the egg release rate and egg viability were not different between plants at the control and oiled sites.

In addition, there is some evidence that indicates that the effect of the oil spill/cleanup on invertebrates was not direct but may have been a result of the loss of *Fucus*. Our studies showed that when *Fucus* thalli were removed from an area, there was an immediate decline in the densities of littorines and limpets. Subsequent to the oil spill/cleanup, densities of these organisms correlated with densities of *Fucus*. Densities of the limpet *Tectura persona* and the snail *Littorina sitkana* were lower at oiled sites through 1995 at both sheltered rocky and coarse textured sites. On the other hand there appeared to be an increase in the density of the barnacle *Chthamalus* at oiled sites, probably due to lack of dominant competitors (other barnacle species), bulldozing grazers (limpets and littorines) and predatory snails (*Nucella*). Bare space created by removing *Fucus* would afford more opportunity for settlement of species with pelagic, widely dispersed larvae such as barnacles and mussels, though only barnacles typically colonize bare rock surfaces. The bare space would also expose the limpets and snails to increased stress from desiccation and predation. Bare space would allow settlement and recruitment by *Fucus*, but because *Fucus* has a very limited dispersal range, this species would be slower to recruit than barnacles or ephemeral algae. Thus, we can explain the oil spill/cleanup effects by just the removal of the overstory plants. Recolonization of the created bare space proceeds as a function of recruitment and not of competition in Herring Bay. In some spills, it has been reported that there is a "greening" of the intertidal (Southward and Southward 1978, Rolan and Gallagher 1991) caused by rapid recolonization of the bare space by ephemeral algae. To some extent such recolonization was observed in Herring Bay, but its occurrence was very irregular and patchy. Even in small cleared patches there was no predictable succession seen. In many cases, the bare patches remained bare, or *Fucus* or barnacles were the primary invader. Our studies with clearings and cages indicate it is unlikely that herbivory plays a major role in keeping large bare patches uncolonized. Rather it is more likely that patchy recruitment combined with the effects of desiccation are the major factors controlling the rates of recolonization of the mid- to upper intertidal.

Here is a typical scenario from our data. Recolonization occurs from the lower intertidal upward due to the fact that the source of zygotes is from fertile *Fucus* plants in the lower intertidal and typical dispersal range is a few cm. Zygotes that attach on rocks away from the parent plant may survive herbivory but will die of desiccation in a short time. However, there may be small patches of plants that survive in cracks. Greatest survival will be near the periphery of an existing *Fucus* bed where the juveniles are in cracks, partially shaded by adults, but out of range of the whiplash effect. Barnacles may initially aide in the settlement of *Fucus* juveniles, but *Fucus* plants subsequently have higher mortality when attached to barnacles. The newly settled *Fucus* plants provide food and shelter for the limpets and littorines, whose numbers will begin to increase. As the *Fucus* plants grow their whiplash effect reduces barnacle recruitment. Ephemeral algae may come in for a few months and cover a bare patch. This situation may delay *Fucus* recovery by shading recruits and promoting a higher herbivore density. But ephemerals are ephemeral and once they die out, the *Fucus* germlings are ready to begin growing again. Mussels may appear in sporadic settlement patterns, and be attracted to filamentous algae. There may be some space competition of mussels and *Fucus* but we have no data on this interaction. *Fucus* will move up the intertidal at a rate determined by the exposure and aspect of the site. At "Weasel Beach" *Fucus* beds expanded up the intertidal at about 1 vertical meter per year through 1992 (Stekoll and Deysher 1996). After that, the expansion declined and even reversed, with about 1 vertical meter left to reach the probable upper limits of its distribution in 1995. So, recolonization will slow asymptotically as the plants near their upper limits. The time to final recolonization will be a factor of the weather conditions each year. But once the *Fucus* population has recovered, it is likely that the invertebrate population will have, or will soon recover. Possible exceptions would be direct-developing species, e.g. *Littorina sitkana* or *Nucella* spp., at locations where adults did not survive the spill/cleanup. In general, it may be possible to monitor the recovery of an oil spill in this region at coarse textured and rocky sites by using *Fucus* as a surrogate for the intertidal community.

Comparison to Other Systems

The Coastal Habitat Injury Assessment (CHIA) study (Highsmith *et al.* 1994) found that throughout the entire area of the *Exxon Valdez* oil spill there were 19 algal taxa injured in at least one habitat. Taxa that showed impaired recovery were *Fucus gardneri, Myelophycus/Scytosiphon, Gloiopeltis furcata,* and filamentous brown algae. Most of the taxa affected were located in sheltered rocky sites. In PWS, members of the brown algae were affected the most. *Fucus* was by far the most severely affected alga throughout the area of the spill.

Some researchers have reported a "greening" (Southward and Southward 1978) or a presence of a "green algal stain" (Rolan and Gallagher 1991) subsequent to a cold water oil spill. After the grounding of the *Torrey Canyon* (Arabian crude oil) the green ephemeral alga *Enteromorpha* was found to be dominant in the mid to upper intertidal (Southward and Southward 1978). Floc'h and Diouris (1980) reported that the *Amoco Cadiz* spill of Kuwaiti crude oil caused little greening due to the limited use of dispersants in the cleanup. After the *Esso Bernicia* accident near Sullum Voe in 1978 (Bunker C oil), Rolan and Gallagher (1991) found an increase in filamentous greens and *Enteromorpha* in areas that had been mechanically cleaned. No greening, however, has been reported for some other spills, such as the *General M. C. Meigs* (Navy special fuel oil, Clark *et al.* 1978) or the *Arrow* spill (Bunker C oil, Thomas 1978). Fifteen months after the *Exxon Valdez* oil spill, Houghten *et al.* (1991a, 1991b) did not document greening in the upper intertidal, but did report an increase in filamentous greens and filamentous and encrusting browns in the lower tide zone at protected rocky sites. Later, in May

1991, Houghton *et al.* (1996) reported an increase in filamentous greens, mainly *Ulothrix*, in the upper intertidal at Category 3 sites which had been heavily oiled and extensively cleaned. Gilfillan *et al.* (1995) did not find any greening at sheltered rocky sites in PWS but did find an increase in *Fucus* in exposed rocky sites in 1990 at the mid tide level. Data from the CHIA study also failed to show any increases in specific green algae in the upper intertidal. However, specific taxa that were enhanced at oiled sites were *Pilayella* in PWS, *Fucus gardneri* in the lower intertidal on the Kenai Peninsula, *Gloiopeltis furcata* at Cook Inlet-Kenai sites and *Halosaccion glandiforme, Palmaria* spp. and *Porphyra* spp. in the Kodiak Island area. Plants in the Gigartinaceae group were enhanced at certain sites throughout the area of the spill (Highsmith *et al.* 1994). Most of these enhancements occurred in the lower intertidal zone. A few of the taxa listed above are perennials which makes it difficult to call these increases at oiled sites a rapid colonization by ephemerals. The CHIA study did find oiled habitats that had more annuals and ephemerals as a group in 1990 and 91 in the lower intertidal (Highsmith *et al.*1994). Additionally, all of the species listed above had biomass or percent cover values that were significantly lower in oiled sites at other levels in the intertidal and at other habitat types.

After the grounding of the *Torrey Canyon* there was an interesting successional series in the mid to upper intertidal (Southward and Southward 1978). Initially, *Enteromorpha* grew rapidly and provided a refuge for germinating *Fucus,* which recruited heavily. Then the limpet population exploded, creating limpet "fronts" that decimated the brown algae, creating space for a large settlement of barnacles. Recovery took nine or more years. Most of the injury was attributed to the heavy use of dispersants on this spill. In our study the sampling periods were too far apart to discern rapid successional patterns with any confidence. But limited succession was seen at some of the CHIA study sites (Highsmith *et al.* 1994). At sheltered rocky sites along the Kenai Peninsula *Fucus* invaded the space normally occupied by *Alaria* in the low intertidal. The situation with *Fucus* and *Alaria* is similar to that reported by Lubchenco and Menge (1978) who found an interaction with the red alga *Chondrus* and ephemeral algae. In their study, it was found that herbivores caused the differences. In the present case the explanation for a higher percent cover in the oiled sites is related to the loss of *Alaria* plants at these sites relative to controls. It appears that the oil spill and cleanup affected the *Alaria* population which allowed *Fucus* to invade the lower tidal level. The reason for the decline in the *Alaria* population may be related to an increase in grazing pressure, mostly from littorines, but could also be due to toxic effects of the spilled oil on embryonic plants (Steele and Hanisak 1979). This *Alaria* effect was not seen in PWS or Herring Bay because there were no *Alaria* plants in PWS sheltered rocky sites.

Local extinctions of some species, especially those in the high intertidal, shortly after an oil spill have been reported. Such extinctions can play an important role in the recovery of an area, especially in coarse textured and estuarine habitats where diversity is very low. After the *Arrow* spill the high intertidal species *Fucus spiralis* disappeared and had not begun to recover six years later (Thomas 1978). Other taxa that occurred only at control sites were *Elachista, Punctaria*, *Petalonia*, and *Polysiphonia*. *Fucus spiralis* also disappeared after the *Amoco Cadiz* spill (Floc'h and Diouris 1980). The high intertidal species *Pelvetia canaliculata* was also eradicated. One and a half years later only 2 mm germlings of this species were visible at oiled sites. *Pelvetia* was also slow to recover in Sullum Voe after the *Esso Bernicia* spill (Rolan and Gallagher 1991). In the CHIA study, the fucoid alga *Fucus cottoni*, a high intertidal species similar to *Pelvetia* but occurring in soft substrate, was found only at control sites in three habitats (Highsmith *et al.* 1994). The CHIA study also found several other species that were locally extinct at oiled sites of certain habitats. Of these there were three taxa in the Chlorophyta, six in the Phaeophyta, and only two in the Rhodophyta. There were also several taxa that showed "extinctions" in some habitats and enhancements in others (Highsmith *et al.* 1994). For example, *Littorina sitkana* was significantly more abundant at control sites in Herring Bay as late as 1995 in sheltered rocky habitat but was more abundant at some oiled sites in coarse textured habitat. More generally, several studies have reported littorine declines following oil spills/cleanup (Chasse 1978, Southward and Soutward 1978, Nelson 1982, Houghton *et. al.* 1993, DeVogelaere and Foster 1994, Highsmith *et. al.* 1994, Hooten and Highsmith 1996), and others have reported no impacts (Thomas 1978, Clark *et. al.* 1978, Rolan and Gallagher 1991, Gilfillan *et. al.* 1993). In the latter cases, free-spawning and direct-developing species were lumped. When investigated separately, the planktonic dispersers recovered more quickly than the direct developing species.

Several studies have reported a change in species zonation following an oil spill. *Fucus vesiculosus* decreased in the upper zone after the *Arrow* spill (Thomas 1978). The upper limits for the kelp *Laminaria* and for *Himanthalia* were raised by two meters following the *Torrey Canyon* spill (Southward and Southward 1978). *Hedophyllum* became dominant in the mid intertidal after the *General M. C. Meigs* spill (Clark *et al.* 1978). After the *Amoco Cadiz* spill *Fucus vesiculosus* extended into the lower tide zones. The CHIA results show many instances of a species becoming relatively more abundant at a higher or lower zone. Examples include *Chthamalus dalli* invading the lower intertidal at oiled/cleaned sites, presumably due to release from competition and predation (Highsmith *et. al.* 1996), and *Fucus gardneri* becoming more abundant in the low intertidal at sheltered rocky sites along the Kenai Peninsula, but the study found no instance of a species occupying a different zone in an oiled site (Highsmith *et. al.* 1994).

The time required for recovery to a prespill condition will vary with the type of oil spilled, the intensity of the cleanup and the sensitivity of the plants and animals in a particular habitat. Further, our Herring Bay work suggests that shore sites exposed to moderate to strong currents have higher recruitment and growth rate potential than sites with less water motion. Also, heavy recruitment of grazers (Southward and Southward 1978) or predators (*Nucella*, this study) may result in setbacks in recovery processes and rates. Mann and Clark (1978) have estimated that recovery will take from 5 to more than 10 years, depending on some of the above factors. Clark *et. al.* (1978) found that the normal algal taxa had returned after 2.5 years and recovery was complete 5 years after the grounding of the *General M. C. Meigs*. Southward and Southward (1978) estimated recovery to take more than 9 years after the *Torrey Canyon* spill. By contrast Gilfillan *et. al.* (1995) state that the oiled shoreline in PWS was 73-91% recovered from the effects of the oil spill in the summer of 1990. This conclusion was based on the assumption that the oil spill caused 100% injury in 1989. Houghton *et. al.* (1993) indicated that there were few statistically significant differences between oiled and control beaches in PWS in the summer of 1991, but stated that full recovery was still several years away in many areas. The intertidal zone impacted by the EVOS, except for extensive outer coast sand beaches, is really a mosaic of habitat types and within each habitat there is considerable patchiness due to various combinations of physical and biological factors. The degree of oiling on shores, even over distances of a few meters, was also quite patchy. There is no single recovery rate for the intertidal community and it is not a straight line phenomenon. The CHIA results indicated that the number of taxa differences were actually increasing for the algae in the summer of 1991 (Highsmith *et. al.* 1994) and many differences were apparent in 1994 from percent cover data (Stekoll *et. al.* 1996). Similarly, various invertebrates had not recovered by the last CHIA census in 1991 (Highsmith *et. al.* 1994, 1996) and mussel densities in 1995 were the lowest for the entire Herring Bay study (this report). For these reasons, we cannot estimate a time to full recovery for those shorelines impacted by the oil spill.

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Table A-1. Fucus Attributes. Herring Bay. Sheltered Rocky. June 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	1123.333	880.695	6	2966.667	2797.135	-	0.5437	6	123.333	45.510	6	28.333	28.333	+	0.1068
1732C/1732X	1	6	955.000	231.153	6	668.333	301.412	+	0.4678	6	55.000	31.278	6	41.667	14.240	+	0.7062
3811C/3611X	1	6	251.667	176.284	6	1081.667	630.859	-	0.2338	6	88.333	39.023	6	40.000	40.000	+	0.4074
1231C/1231X	2	6	168.333	66.303	6	3436.667	1440.434	-	0.0176	6	18.333	10.138	6	231.667	122.459	-	0.3004
1732C/1732X	2	6	3703.333	1709.465	6	735.000	373.066	+	0.3751	6	103.333	50.772	6	80.000	50.596	+	0.7515
3811C/3611X	2	6	638.333	361.298	6	1408.333	589.075	-	0.2912	6	60.000	24.495	6	13.333	7.149	+	0.0974
1231C/1231X	3	6	643.333	245.203	6	873.333	294.434	-	0.5617	6	55.000	35.285	6	63.333	23.333	-	0.8478
1732C/1732X	3	6	4886.667	2050.827	6	2678.333	1669.374	+	0.4232	6	43.333	9.189	6	133.333	65.047	-	0.2317
3811C/3611X	3	6	1208.333	389.251	6	50.000	21.603	+	0.0055	6	50.000	15.275	6	25.000	14.318	+	0.2600

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	80.000	39.833	6	0.000	0.000	+	0.1009	6	43.333	27.162	6	21.667	21.667	+	0.5469
1732C/1732X	1	6	60.000	35.777	6	28.333	15.581	+	0.4360	6	23.333	16.667	6	10.000	4.472	+	0.4576
3811C/3611X	1	6	76.667	30.405	6	10.000	10.000	+	0.0639	6	56.667	26.791	6	1.667	1.667	+	0.0098
1231C/1231X	2	6	75.000	34.521	6	40.000	28.636	+	0.4533	6	143.333	13.333	6	20.000	12.910	+	0.0001
1732C/1732X	2	6	36.667	15.847	6	58.333	26.760	-	0.5019	6	55.000	25.658	6	65.000	26.173	-	0.7905
3811C/3611X	2	6	61.667	27.254	6	15.000	9.574	+	0.1373	6	16.667	7.601	6	3.333	2.108	+	0.1218
1231C/1231X	3	6	30.000	8.944	6	48.333	24.141	-	0.4927	6	40.000	15.056	6	53.333	21.239	-	0.6197
1732C/1732X	3	6	40.000	7.746	6	45.000	27.417	-	0.8642	6	100.000	23.944	6	60.000	19.833	+	0.2272
3811C/3611X	3	6	30.000	3.652	6	15.000	11.475	+	0.2413	6	53.333	14.530	6	16.667	8.028	+	0.0517

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	43.333	21.705	6	16.667	16.667	+	0.3528	0	--	--	0	--	--		----
1732C/1732X	1	6	11.667	11.667	6	8.333	4.014	+	0.7925	0	--	--	0	--	--		----
3811C/3611X	1	6	25.000	11.475	6	1.667	1.667	+	0.0641	0	--	--	0	--	--		----
1231C/1231X	2	6	63.333	9.545	6	6.667	4.216	+	0.0003	0	--	--	0	--	--		----
1732C/1732X	2	6	31.667	11.667	6	36.667	17.448	-	0.8165	0	--	--	0	--	--		----
3811C/3611X	2	6	8.333	3.073	6	1.667	1.667	+	0.0856	0	--	--	0	--	--		----
1231C/1231X	3	6	10.000	3.652	6	10.000	6.325	o	1.0000	0	--	--	0	--	--		----
1732C/1732X	3	6	41.667	16.617	6	21.667	11.081	+	0.3403	0	--	--	0	--	--		----
3811C/3611X	3	6	21.667	6.541	6	0.000	0.000	+	0.0212	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.007	0.004	-	0.1747	6	0.467	0.204	6	0.080	0.076	+	0.0959
1732C/1732X	1	6	0.000	0.000	6	0.093	0.064	-	0.1857	6	0.167	0.091	6	0.070	0.027	+	0.5331
3811C/3611X	1	6	0.000	0.000	6	0.690	0.072	-	0.0001	6	0.340	0.144	6	0.050	0.026	+	0.0722
1231C/1231X	2	6	0.000	0.000	6	0.217	0.107	-	0.0416	6	0.800	0.054	6	0.217	0.074	+	0.0004
1732C/1732X	2	6	0.130	0.059	6	0.367	0.135	-	0.2486	6	0.383	0.101	6	0.360	0.103	+	0.8080
3811C/3611X	2	6	0.100	0.045	6	0.573	0.123	-	0.0065	6	0.193	0.047	6	0.057	0.029	+	0.0215
1231C/1231X	3	6	0.243	0.071	6	0.597	0.079	-	0.0119	6	0.387	0.063	6	0.280	0.092	+	0.2795
1732C/1732X	3	6	0.263	0.053	6	0.503	0.092	-	0.0495	6	0.500	0.094	6	0.370	0.101	+	0.3576
3811C/3611X	3	6	0.247	0.059	6	0.683	0.154	-	0.0249	6	0.413	0.085	6	0.140	0.092	+	0.0301

Table A-2. Fucus Attributes. Herring Bay. Sheltered Rocky. July 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	2626.667	1302.602	6	2656.667	2656.667	-	0.9921	6	406.667	182.586	6	61.667	61.667	+	0.1037
1732C/1732X	1	6	876.667	217.726	6	735.000	299.753	+	0.7102	6	58.333	30.267	6	50.000	19.833	+	0.8225
3811C/3611X	1	6	721.667	435.694	6	1386.667	918.592	-	0.5278	6	183.333	78.599	6	35.000	33.040	+	0.1125
1231C/1231X	2	6	291.667	74.673	6	3636.667	1484.686	-	0.0275	6	70.000	36.240	6	263.333	146.189	-	0.6747
1732C/1732X	2	6	4366.667	2256.094	6	678.333	361.270	+	0.2819	6	86.667	39.129	6	83.333	54.324	+	0.9613
3811C/3611X	2	6	650.000	312.506	6	1486.667	590.698	-	0.2391	6	80.000	26.204	6	21.667	12.225	+	0.0713
1231C/1231X	3	6	1543.333	699.246	6	826.667	301.813	+	0.3689	6	140.000	82.341	6	71.667	26.635	+	0.4481
1732C/1732X	3	6	4940.000	2100.151	6	4423.333	2970.075	+	0.8899	6	51.667	11.377	6	153.333	61.192	-	0.2173
3811C/3611X	3	6	1563.333	500.877	6	68.333	17.591	+	0.0005	6	48.333	16.210	6	25.000	14.549	+	0.3092

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	150.000	69.905	6	0.000	0.000	+	0.0847	6	60.000	27.689	6	15.000	15.000	+	0.1835
1732C/1732X	1	6	70.000	38.987	6	25.000	10.567	+	0.2913	6	31.667	19.221	6	5.000	3.416	+	0.4487
3811C/3611X	1	6	130.000	59.777	6	21.667	21.667	+	0.1192	6	45.000	19.791	6	3.333	3.333	+	0.0149
1231C/1231X	2	6	116.667	55.237	6	31.667	19.394	+	0.1772	6	175.000	28.607	6	21.667	14.240	+	0.0007
1732C/1732X	2	6	46.667	20.111	6	48.333	23.154	-	0.9577	6	56.667	30.295	6	61.667	23.154	-	0.8983
3811C/3611X	2	6	53.333	26.416	6	13.333	8.819	+	0.1814	6	20.000	8.944	6	6.667	4.216	+	0.2073
1231C/1231X	3	6	48.333	16.617	6	41.667	25.353	+	0.8304	6	38.333	15.366	6	60.000	25.691	-	0.4858
1732C/1732X	3	6	38.333	7.923	6	48.333	30.921	-	0.3524	6	85.000	20.616	6	63.333	23.758	+	0.5066
3811C/3611X	3	6	28.333	6.541	6	13.333	11.450	+	0.2818	6	53.333	16.056	6	18.333	9.098	+	0.0871

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	53.333	24.450	6	16.667	16.667	+	0.2436	0	--	--	0	--	--		----
1732C/1732X	1	6	16.667	16.667	6	6.667	4.216	+	0.7090	0	--	--	0	--	--		----
3811C/3611X	1	6	21.667	7.923	6	1.667	1.667	+	0.0596	0	--	--	0	--	--		----
1231C/1231X	2	6	55.000	10.567	6	3.333	3.333	+	0.0009	0	--	--	0	--	--		----
1732C/1732X	2	6	26.667	9.545	6	35.000	18.028	-	0.6915	0	--	--	0	--	--		----
3811C/3611X	2	6	10.000	3.652	6	0.000	0.000	+	0.0409	0	--	--	0	--	--		----
1231C/1231X	3	6	6.667	4.944	6	10.000	6.325	-	0.6867	0	--	--	0	--	--		----
1732C/1732X	3	6	25.000	9.916	6	16.667	9.888	+	0.5650	0	--	--	0	--	--		----
3811C/3611X	3	6	18.333	5.426	6	0.000	0.000	+	0.0197	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.003	0.003	-	0.3632	6	0.473	0.198	6	0.073	0.073	+	0.0626
1732C/1732X	1	6	0.000	0.000	6	0.057	0.038	-	0.1814	6	0.160	0.086	6	0.063	0.029	+	0.4666
3811C/3611X	1	6	0.000	0.000	6	0.647	0.052	-	0.0001	6	0.383	0.149	6	0.040	0.029	+	0.0371
1231C/1231X	2	6	0.003	0.003	6	0.123	0.054	-	0.0273	6	0.780	0.022	6	0.203	0.066	+	0.0021
1732C/1732X	2	6	0.067	0.027	6	0.320	0.117	-	0.1365	6	0.387	0.095	6	0.290	0.103	+	0.4145
3811C/3611X	2	6	0.063	0.034	6	0.650	0.080	-	0.0001	6	0.117	0.030	6	0.037	0.021	+	0.0279
1231C/1231X	3	6	0.227	0.091	6	0.553	0.107	-	0.0468	6	0.437	0.070	6	0.313	0.126	+	0.3553
1732C/1732X	3	6	0.207	0.043	6	0.410	0.058	-	0.0228	6	0.383	0.102	6	0.313	0.072	+	0.6148
3811C/3611X	3	6	0.193	0.076	6	0.647	0.159	-	0.0236	6	0.330	0.073	6	0.123	0.060	+	0.0410

Table A-3. Fucus Attributes. Herring Bay. Sheltered Rocky. July 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	2373.333	1314.934	6	2968.333	2962.337	-	0.8580	6	373.333	155.192	6	45.000	45.000	+	0.0696
1732C/1732X	1	6	765.000	204.886	6	998.333	473.367	-	0.6607	6	55.000	24.597	6	43.333	14.757	+	0.6928
3811C/3611X	1	6	395.000	234.617	6	1201.667	807.037	-	0.3598	6	133.333	65.507	6	50.000	48.028	+	0.3291
1231C/1231X	2	6	308.333	162.017	6	4278.333	1794.099	-	0.0276	6	56.667	27.406	6	216.667	122.574	-	0.5306
1732C/1732X	2	6	3798.333	1858.719	6	875.000	573.409	+	0.1638	6	85.000	36.309	6	88.333	50.161	-	0.9581
3811C/3611X	2	6	695.000	438.214	6	2808.333	1071.807	-	0.0980	6	76.667	26.289	6	16.667	9.545	+	0.0575
1231C/1231X	3	6	1178.333	497.972	6	1016.667	258.929	+	0.7792	6	133.333	83.971	6	68.333	24.279	+	0.4742
1732C/1732X	3	6	4641.667	1802.769	6	4393.333	2796.378	+	0.9420	6	60.000	18.619	6	181.667	89.122	-	0.4272
3811C/3611X	3	6	1383.333	488.840	6	73.333	18.197	+	0.0014	6	63.333	18.559	6	23.333	14.757	+	0.1225

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	165.000	72.790	6	0.000	0.000	+	0.0727	6	55.000	26.677	6	11.667	11.667	+	0.1675
1732C/1732X	1	6	53.333	37.565	6	30.000	14.142	+	0.5739	6	30.000	22.361	6	8.333	4.014	+	0.8100
3811C/3611X	1	6	93.333	37.208	6	25.000	25.000	+	0.1584	6	58.333	24.822	6	1.667	1.667	+	0.0085
1231C/1231X	2	6	98.333	47.358	6	31.667	17.780	+	0.2169	6	170.000	29.889	6	23.333	14.757	+	0.0013
1732C/1732X	2	6	35.000	14.776	6	51.667	25.615	-	0.5854	6	48.333	24.141	6	56.667	18.915	-	0.7914
3811C/3611X	2	6	43.333	14.298	6	8.333	6.541	+	0.0502	6	20.000	7.303	6	5.000	3.416	+	0.0924
1231C/1231X	3	6	56.667	27.162	6	46.667	22.755	+	0.7835	6	46.667	22.161	6	43.333	18.197	+	0.9098
1732C/1732X	3	6	38.333	9.098	6	66.667	39.044	-	0.3179	6	78.333	16.415	6	63.333	26.416	+	0.6400
3811C/3611X	3	6	40.000	5.164	6	18.333	14.701	+	0.1945	6	55.000	16.882	6	16.667	7.601	+	0.0652

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	48.333	23.010	6	10.000	10.000	+	0.1575	0	--	--	0	--	--		----
1732C/1732X	1	6	18.333	18.333	6	3.333	3.333	+	0.8504	0	--	--	0	--	--		----
3811C/3611X	1	6	18.333	7.491	6	1.667	1.667	+	0.0644	0	--	--	0	--	--		----
1231C/1231X	2	6	48.333	8.724	6	5.000	3.416	+	0.0009	0	--	--	0	--	--		----
1732C/1732X	2	6	16.667	9.189	6	18.333	11.081	-	0.9101	0	--	--	0	--	--		----
3811C/3611X	2	6	5.000	2.236	6	0.000	0.000	+	0.0756	0	--	--	0	--	--		----
1231C/1231X	3	6	10.000	6.831	6	5.000	3.416	+	0.5275	0	--	--	0	--	--		----
1732C/1732X	3	6	15.000	7.638	6	16.667	8.028	-	0.8834	0	--	--	0	--	--		----
3811C/3611X	3	6	5.000	2.236	6	0.000	0.000	+	0.0756	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.003	0.003	-	0.3632	6	0.440	0.184	6	0.087	0.087	+	0.0625
1732C/1732X	1	6	0.000	0.000	6	0.073	0.062	-	0.2262	6	0.167	0.094	6	0.067	0.028	+	0.5056
3811C/3611X	1	6	0.000	0.000	6	0.817	0.031	-	0.0001	6	0.377	0.148	6	0.040	0.032	+	0.0398
1231C/1231X	2	6	0.003	0.003	6	0.113	0.056	-	0.0389	6	0.693	0.075	6	0.213	0.076	+	0.0034
1732C/1732X	2	6	0.067	0.029	6	0.337	0.123	-	0.1267	6	0.320	0.108	6	0.280	0.101	+	0.6935
3811C/3611X	2	6	0.117	0.049	6	0.570	0.087	-	0.0016	6	0.200	0.052	6	0.040	0.014	+	0.0085
1231C/1231X	3	6	0.173	0.056	6	0.547	0.090	-	0.0074	6	0.450	0.054	6	0.280	0.098	+	0.1379
1732C/1732X	3	6	0.210	0.055	6	0.453	0.084	-	0.0327	6	0.403	0.113	6	0.330	0.082	+	0.5482
3811C/3611X	3	6	0.210	0.066	6	0.670	0.147	-	0.0179	6	0.340	0.092	6	0.077	0.035	+	0.0450

Table A-4. Fucus Attributes. Herring Bay. Sheltered Rocky. August 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	3951.667	2029.807	6	2400.000	2392.005	+	0.6316	6	390.000	173.801	6	68.333	68.333	+	0.1157
1732C/1732X	1	6	1273.333	331.559	6	1361.667	595.015	-	0.8994	6	65.000	28.255	6	48.333	17.780	+	0.6284
3811C/3611X	1	6	621.667	383.522	6	916.667	633.902	-	0.6989	6	166.667	60.259	6	46.667	42.714	+	0.1353
1231C/1231X	2	6	425.000	124.760	6	4608.333	1660.332	-	0.0068	6	76.667	36.938	6	398.333	230.989	-	0.6211
1732C/1732X	2	6	5056.667	2795.596	6	948.333	574.563	+	0.2652	6	86.667	42.635	6	61.667	39.616	+	0.6766
3811C/3611X	2	6	858.333	404.981	6	3553.333	1326.333	-	0.0806	6	66.667	22.755	6	41.667	19.047	+	0.4192
1231C/1231X	3	6	1368.333	601.866	6	1305.000	429.851	+	0.9334	6	116.667	74.863	6	96.667	20.763	+	0.8021
1732C/1732X	3	6	6460.000	2463.150	6	6786.667	4445.196	-	0.9500	6	58.333	15.366	6	206.667	108.526	-	0.4472
3811C/3611X	3	6	1343.333	490.555	6	81.667	27.498	+	0.0166	6	48.333	14.926	6	20.000	10.328	+	0.1496

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	153.333	71.864	6	0.000	0.000	+	0.0860	6	51.667	24.002	6	11.667	11.667	+	0.1648
1732C/1732X	1	6	58.333	34.777	6	26.667	11.738	+	0.4085	6	30.000	22.211	6	6.667	3.333	+	0.4758
3811C/3611X	1	6	100.000	40.579	6	26.667	26.667	+	0.1619	6	58.333	25.221	6	1.667	1.667	+	0.0088
1231C/1231X	2	6	108.333	50.360	6	26.667	17.448	+	0.1565	6	173.333	30.623	6	21.667	15.147	+	0.0013
1732C/1732X	2	6	31.667	13.017	6	40.000	17.512	-	0.7105	6	38.333	17.401	6	48.333	16.004	-	0.6812
3811C/3611X	2	6	48.333	18.333	6	8.333	6.541	+	0.0669	6	23.333	8.028	6	5.000	3.416	+	0.0619
1231C/1231X	3	6	45.000	17.078	6	40.000	24.900	+	0.8718	6	33.333	14.982	6	50.000	21.135	-	0.5345
1732C/1732X	3	6	35.000	9.574	6	61.667	31.981	-	0.4430	6	78.333	23.298	6	56.667	24.450	+	0.5356
3811C/3611X	3	6	31.667	7.032	6	13.333	8.028	+	0.1166	6	51.667	14.926	6	16.667	7.601	+	0.0632

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	45.000	22.023	6	5.000	5.000	+	0.2043	6	1343.333	619.907	6	53.333	53.333	+	0.1872
1732C/1732X	1	6	16.667	16.667	6	5.000	3.416	+	0.7541	6	328.333	328.333	6	35.000	31.172	+	0.8231
3811C/3611X	1	6	20.000	6.831	6	1.667	1.667	+	0.0605	6	93.333	36.301	6	1.667	1.667	+	0.0404
1231C/1231X	2	6	48.333	10.462	6	3.333	2.108	+	0.0049	6	286.667	94.857	6	8.333	6.541	+	0.0005
1732C/1732X	2	6	6.667	4.944	6	13.333	9.888	-	0.5599	6	8.333	6.541	6	70.000	51.251	-	0.7130
3811C/3611X	2	6	3.333	3.333	6	0.000	0.000	+	0.3632	6	5.000	5.000	6	0.000	0.000	+	0.3632
1231C/1231X	3	6	6.667	6.667	6	5.000	3.416	+	0.8284	6	43.333	43.333	6	11.667	8.333	+	0.7407
1732C/1732X	3	6	0.000	0.000	6	3.333	2.108	-	0.1747	6	0.000	0.000	6	30.000	21.603	-	0.2236
3811C/3611X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.000	0.000	6	0.000	0.000	o	1.0000

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.467	0.192	6	0.087	0.087	+	0.0729
1732C/1732X	1	6	0.000	0.000	6	0.040	0.033	-	0.2138	6	0.167	0.082	6	0.090	0.044	+	0.4593
3811C/3611X	1	6	0.000	0.000	6	0.680	0.031	-	0.0001	6	0.380	0.144	6	0.033	0.022	+	0.0321
1231C/1231X	2	6	0.030	0.021	6	0.180	0.119	-	0.1993	6	0.763	0.064	6	0.253	0.085	+	0.0028
1732C/1732X	2	6	0.050	0.029	6	0.237	0.083	-	0.1208	6	0.340	0.116	6	0.317	0.101	+	0.7997
3811C/3611X	2	6	0.040	0.019	6	0.427	0.108	-	0.0042	6	0.207	0.064	6	0.033	0.010	+	0.0118
1231C/1231X	3	6	0.263	0.068	6	0.390	0.081	-	0.2783	6	0.410	0.066	6	0.290	0.121	+	0.3211
1732C/1732X	3	6	0.157	0.048	6	0.303	0.056	-	0.0754	6	0.460	0.096	6	0.287	0.104	+	0.2192
3811C/3611X	3	6	0.153	0.054	6	0.577	0.176	-	0.0383	6	0.357	0.073	6	0.090	0.043	+	0.0091

Table A-5. Fucus Attributes. Herring Bay. Sheltered Rocky. August 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	3141.667	2021.622	6	2188.333	2184.336	+	0.7553	6	530.000	236.136	6	81.667	81.667	+	0.1030
1732C/1732X	1	6	1215.000	360.682	6	1203.333	494.440	+	0.9852	6	50.000	19.664	6	51.667	20.883	-	0.9548
3811C/3611X	1	6	515.000	310.813	6	1421.667	991.257	-	0.4033	6	178.333	80.681	6	38.333	36.370	+	0.1447
1231C/1231X	2	6	238.333	137.123	6	4060.000	1873.795	-	0.0191	6	53.333	23.046	6	366.667	229.575	-	0.4166
1732C/1732X	2	6	6841.667	3597.045	6	1340.000	501.558	+	0.4188	6	78.333	35.536	6	118.333	68.625	-	0.6160
3811C/3611X	2	6	851.667	426.813	6	3671.667	1288.993	-	0.0645	6	90.000	33.466	6	21.667	10.138	+	0.0792
1231C/1231X	3	6	1530.000	702.742	6	1203.333	414.171	+	0.6972	6	153.333	89.691	6	83.333	22.311	+	0.3593
1732C/1732X	3	6	7063.333	2936.800	6	5556.667	3080.079	+	0.7307	6	50.000	14.376	6	351.667	187.482	-	0.2138
3811C/3611X	3	6	2158.333	751.831	6	121.667	65.900	+	0.0002	6	76.667	18.915	6	25.000	13.602	+	0.0509

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	173.333	78.895	6	0.000	0.000	+	0.0794	6	66.667	29.174	6	11.667	11.667	+	0.1106
1732C/1732X	1	6	33.333	19.607	6	28.333	11.377	+	0.8299	6	30.000	17.512	6	11.667	5.426	+	0.3409
3811C/3611X	1	6	123.333	44.171	6	21.667	21.667	+	0.0657	6	73.333	29.059	6	1.667	1.667	+	0.0079
1231C/1231X	2	6	80.000	37.506	6	21.667	14.240	+	0.1766	6	170.000	30.876	6	21.667	15.147	+	0.0015
1732C/1732X	2	6	33.333	14.530	6	53.333	24.989	-	0.5047	6	48.333	26.130	6	61.667	19.903	-	0.6933
3811C/3611X	2	6	63.333	26.916	6	5.000	3.416	+	0.0453	6	26.667	8.819	6	6.667	4.216	+	0.0680
1231C/1231X	3	6	41.667	17.208	6	38.333	20.235	+	0.9026	6	43.333	14.982	6	48.333	22.718	-	0.8579
1732C/1732X	3	6	38.333	9.098	6	58.333	37.896	-	0.2661	6	68.333	19.734	6	53.333	20.923	+	0.6134
3811C/3611X	3	6	40.000	9.310	6	13.333	9.888	+	0.0780	6	46.667	13.824	6	18.333	8.333	+	0.1097

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	45.000	21.253	6	5.000	5.000	+	0.2037	0	--	--	0	--	--		----
1732C/1732X	1	6	15.000	15.000	6	3.333	2.108	+	0.7921	0	--	--	0	--	--		----
3811C/3611X	1	6	18.333	6.541	6	1.667	1.667	+	0.0628	0	--	--	0	--	--		----
1231C/1231X	2	6	23.333	7.601	6	0.000	0.000	+	0.0278	0	--	--	0	--	--		----
1732C/1732X	2	6	0.000	0.000	6	11.667	6.541	-	0.1345	0	--	--	0	--	--		----
3811C/3611X	2	6	1.667	1.667	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----
1231C/1231X	3	6	5.000	5.000	6	3.333	2.108	+	0.7650	0	--	--	0	--	--		----
1732C/1732X	3	6	0.000	0.000	6	3.333	2.108	-	0.1747	0	--	--	0	--	--		----
3811C/3611X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.003	0.003	-	0.3632	6	0.467	0.196	6	0.077	0.077	+	0.0708
1732C/1732X	1	6	0.000	0.000	6	0.043	0.029	-	0.1787	6	0.217	0.111	6	0.060	0.027	+	0.3268
3811C/3611X	1	6	0.103	0.071	6	0.607	0.040	-	0.0004	6	0.413	0.152	6	0.040	0.024	+	0.0339
1231C/1231X	2	6	0.000	0.000	6	0.137	0.091	-	0.0877	6	0.760	0.051	6	0.240	0.083	+	0.0018
1732C/1732X	2	6	0.033	0.021	6	0.277	0.094	-	0.0560	6	0.380	0.100	6	0.277	0.079	+	0.4021
3811C/3611X	2	6	0.177	0.091	6	0.293	0.091	-	0.2742	6	0.200	0.068	6	0.037	0.012	+	0.0402
1231C/1231X	3	6	0.103	0.064	6	0.303	0.070	-	0.0376	6	0.410	0.067	6	0.263	0.102	+	0.1952
1732C/1732X	3	6	0.150	0.032	6	0.310	0.054	-	0.0372	6	0.493	0.098	6	0.307	0.113	+	0.1958
3811C/3611X	3	6	0.197	0.055	6	0.590	0.177	-	0.0678	6	0.290	0.079	6	0.120	0.064	+	0.0972

Table A-6. Fucus Attributes. Herring Bay. Sheltered Rocky. September 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	3198.333	1604.395	6	2668.333	2638.402	+	0.8671	6	365.000	166.228	6	141.667	141.667	+	0.3306
1732C/1732X	1	6	1380.000	396.493	6	1563.333	727.758	-	0.8294	6	68.333	34.295	6	45.000	18.930	+	0.5646
3811C/3611X	1	6	436.667	225.665	6	991.667	627.574	-	0.4247	6	106.667	57.310	6	40.000	36.056	+	0.3480
1231C/1231X	2	6	370.000	78.867	6	4015.000	1775.764	-	0.0050	6	60.000	26.077	6	690.000	490.245	-	0.1619
1732C/1732X	2	6	6661.667	3483.704	6	945.000	331.358	+	0.0768	6	96.667	39.805	6	60.000	30.332	+	0.4806
3811C/3611X	2	6	770.000	406.858	6	4848.333	1635.450	-	0.0176	6	66.667	25.647	6	45.000	18.212	+	0.5066
1231C/1231X	3	6	1845.000	799.078	6	1440.000	536.134	+	0.6827	6	110.000	79.331	6	98.333	20.562	+	0.8896
1732C/1732X	3	6	8731.667	3295.794	6	6091.667	3368.546	+	0.5877	6	70.000	20.331	6	311.667	164.771	-	0.4884
3811C/3611X	3	6	2156.667	845.970	6	145.000	64.226	+	0.0016	6	60.000	15.492	6	31.667	16.210	+	0.2350

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	155.000	69.077	6	0.000	0.000	+	0.0749	6	55.000	23.770	6	8.333	8.333	+	0.0936
1732C/1732X	1	6	65.000	41.613	6	23.333	9.888	+	0.5437	6	28.333	20.069	6	11.667	6.541	+	0.4481
3811C/3611X	1	6	83.333	39.553	6	25.000	25.000	+	0.2409	6	60.000	24.766	6	1.667	1.667	+	0.0086
1231C/1231X	2	6	90.000	41.633	6	26.667	14.757	+	0.1821	6	150.000	23.094	6	23.333	15.635	+	0.0011
1732C/1732X	2	6	35.000	14.776	6	48.333	24.141	-	0.6477	6	46.667	22.755	6	50.000	14.376	-	0.9039
3811C/3611X	2	6	41.667	16.617	6	5.000	3.416	+	0.0570	6	25.000	8.851	6	6.667	4.216	+	0.0910
1231C/1231X	3	6	40.000	17.701	6	43.333	22.311	-	0.9091	6	38.333	13.017	6	46.667	21.551	-	0.7475
1732C/1732X	3	6	38.333	10.776	6	70.000	43.050	-	0.3174	6	68.333	17.966	6	48.333	17.591	+	0.4448
3811C/3611X	3	6	33.333	6.146	6	16.667	13.081	+	0.2757	6	45.000	14.549	6	16.667	7.601	+	0.1150

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	40.000	20.166	6	5.000	5.000	+	0.2106	0	--	--	0	--	--		----
1732C/1732X	1	6	11.667	11.667	6	1.667	1.667	+	0.8139	0	--	--	0	--	--		----
3811C/3611X	1	6	8.333	4.014	6	0.000	0.000	+	0.0925	0	--	--	0	--	--		----
1231C/1231X	2	6	26.667	4.216	6	0.000	0.000	+	0.0015	0	--	--	0	--	--		----
1732C/1732X	2	6	0.000	0.000	6	6.667	6.667	-	0.3632	0	--	--	0	--	--		----
3811C/3611X	2	6	1.667	1.667	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----
1231C/1231X	3	6	1.667	1.667	6	5.000	2.236	-	0.2596	0	--	--	0	--	--		----
1732C/1732X	3	6	0.000	0.000	6	1.667	1.667	-	0.3632	0	--	--	0	--	--		----
3811C/3611X	3	6	1.667	1.667	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.437	0.181	6	0.070	0.070	+	0.0636
1732C/1732X	1	6	0.000	0.000	6	0.043	0.036	-	0.2180	6	0.203	0.111	6	0.077	0.032	+	0.4505
3811C/3611X	1	6	0.000	0.000	6	0.647	0.086	-	0.0002	6	0.403	0.141	6	0.047	0.026	+	0.0339
1231C/1231X	2	6	0.000	0.000	6	0.123	0.082	-	0.1263	6	0.667	0.074	6	0.193	0.071	+	0.0027
1732C/1732X	2	6	0.053	0.029	6	0.273	0.098	-	0.1114	6	0.327	0.119	6	0.277	0.082	+	0.7324
3811C/3611X	2	6	0.070	0.044	6	0.170	0.059	-	0.0952	6	0.207	0.061	6	0.043	0.014	+	0.0173
1231C/1231X	3	6	0.153	0.069	6	0.443	0.069	-	0.0173	6	0.320	0.079	6	0.267	0.105	+	0.6673
1732C/1732X	3	6	0.143	0.045	6	0.247	0.086	-	0.2852	6	0.443	0.103	6	0.293	0.082	+	0.2690
3811C/3611X	3	6	0.180	0.056	6	0.670	0.140	-	0.0106	6	0.293	0.070	6	0.127	0.054	+	0.1003

Table A-7. Fucus Attributes. Herring Bay. Sheltered Rocky. April 1991.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	1440.000	616.036	6	918.333	896.513	+	0.6418	6	391.667	176.888	6	430.000	430.000	-	0.9359
1732C/1732X	1	6	345.000	116.326	6	1226.667	584.007	-	0.8213	6	30.000	13.166	6	118.333	58.219	-	0.5757
3811C/3611X	1	6	290.000	115.557	6	773.333	529.954	-	0.8737	6	116.667	69.362	6	66.667	40.634	+	0.5479
1231C/1231X	2	6	38.333	25.353	6	840.000	416.973	-	0.0075	6	10.000	4.472	6	855.000	600.065	-	0.0045
1732C/1732X	2	6	1398.333	613.745	6	535.000	128.809	+	0.3946	6	61.667	25.745	6	118.333	46.218	-	0.3093
3811C/3611X	2	6	786.667	553.309	6	1350.000	277.357	-	0.3841	6	75.000	22.323	6	346.667	130.094	-	0.0559
1231C/1231X	3	6	1191.667	577.174	6	573.333	196.293	+	0.3344	6	121.667	66.704	6	218.333	68.089	-	0.3344
1732C/1732X	3	6	2128.333	832.304	6	1756.667	1053.368	+	0.7875	6	68.333	15.366	6	480.000	197.518	-	0.8977
3811C/3611X	3	6	1626.667	555.714	6	126.667	49.374	+	0.0044	6	23.333	7.601	6	35.000	8.466	-	0.3293

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	160.000	70.427	6	46.667	46.667	+	0.2094	6	65.000	27.659	6	3.333	3.333	+	0.0668
1732C/1732X	1	6	35.000	24.324	6	33.333	15.847	+	0.9553	6	23.333	13.081	6	5.000	3.416	+	0.2049
3811C/3611X	1	6	73.333	24.450	6	10.000	8.165	+	0.0339	6	68.333	21.200	6	1.667	1.667	+	0.0061
1231C/1231X	2	6	63.333	36.209	6	155.000	127.874	-	0.5061	6	135.000	25.133	6	8.333	5.426	+	0.0057
1732C/1732X	2	6	28.333	15.581	6	41.667	21.512	-	0.6266	6	35.000	18.394	6	21.667	7.923	+	0.5206
3811C/3611X	2	6	38.333	16.617	6	13.333	6.667	+	0.1928	6	11.667	6.009	6	3.333	3.333	+	0.2531
1231C/1231X	3	6	25.000	19.279	6	58.333	26.130	-	0.3288	6	33.333	12.019	6	33.333	22.311	o	1.0000
1732C/1732X	3	6	26.667	12.293	6	136.667	71.259	-	0.1048	6	43.333	9.545	6	38.333	17.966	+	0.8108
3811C/3611X	3	6	11.667	1.667	6	16.667	11.156	-	0.1748	6	26.667	14.982	6	11.667	9.804	+	0.4217

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	55.000	25.133	6	5.000	5.000	+	0.1946	6	958.333	484.496	6	36.667	36.667	+	0.1856
1732C/1732X	1	6	28.333	17.966	6	11.667	5.426	+	0.3954	6	915.000	589.993	6	120.000	74.342	+	0.8916
3811C/3611X	1	6	40.000	14.376	6	1.667	1.667	+	0.0088	6	406.667	154.352	6	8.333	8.333	+	0.0082
1231C/1231X	2	6	56.667	10.220	6	11.667	6.541	+	0.0040	6	626.667	129.992	6	81.667	56.416	+	0.0032
1732C/1732X	2	6	23.333	10.541	6	18.333	12.758	+	0.7687	6	408.333	181.593	6	205.000	102.136	+	0.3521
3811C/3611X	2	6	0.000	0.000	6	1.667	1.667	-	0.3632	6	0.000	0.000	6	3.333	3.333	-	0.3632
1231C/1231X	3	6	10.000	3.652	6	11.667	7.923	-	0.8523	6	70.000	41.312	6	206.667	166.847	-	0.7819
1732C/1732X	3	6	31.667	10.462	6	10.000	5.164	+	0.0929	6	565.000	292.333	6	298.333	224.268	+	0.4858
3811C/3611X	3	6	16.667	5.578	6	1.667	1.667	+	0.0276	6	115.000	28.137	6	16.667	16.667	+	0.0132

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.063	0.029	-	0.0432	6	0.457	0.198	6	0.113	0.113	+	0.1034
1732C/1732X	1	6	0.003	0.003	6	0.110	0.070	-	0.1094	6	0.263	0.131	6	0.140	0.048	+	0.5378
3811C/3611X	1	6	0.000	0.000	6	0.320	0.138	-	0.0284	6	0.350	0.128	6	0.097	0.046	+	0.1071
1231C/1231X	2	6	0.003	0.003	6	0.217	0.118	-	0.0798	6	0.583	0.081	6	0.307	0.114	+	0.0782
1732C/1732X	2	6	0.303	0.074	6	0.463	0.122	-	0.4559	6	0.237	0.077	6	0.243	0.090	-	0.9973
3811C/3611X	2	6	0.047	0.018	6	0.467	0.154	-	0.0120	6	0.117	0.040	6	0.143	0.059	-	0.6201
1231C/1231X	3	6	0.143	0.057	6	0.473	0.087	-	0.0095	6	0.280	0.063	6	0.287	0.087	-	0.9935
1732C/1732X	3	6	0.467	0.099	6	0.507	0.134	-	0.8184	6	0.260	0.085	6	0.403	0.130	-	0.3950
3811C/3611X	3	6	0.130	0.053	6	0.783	0.119	-	0.0008	6	0.177	0.032	6	0.083	0.064	+	0.1047

Table A-8. Fucus Attributes. Herring Bay. Sheltered Rocky. June 1991.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	1843.333	818.061	6	476.667	419.306	+	0.1679	6	476.667	219.722	6	416.667	416.667	+	0.9012
1732C/1732X	1	6	2265.000	1336.505	6	1038.333	450.869	+	0.4049	6	61.667	26.257	6	86.667	47.235	-	0.6536
3811C/3611X	1	6	435.000	228.163	6	1128.333	802.053	-	0.4251	6	153.333	88.154	6	143.333	92.039	+	0.9390
1231C/1231X	2	6	370.000	160.333	6	1103.333	587.915	-	0.2565	6	13.333	6.146	6	810.000	382.065	-	0.0033
1732C/1732X	2	6	3305.000	1497.515	6	868.333	308.614	+	0.4886	6	115.000	56.965	6	163.333	49.035	-	0.5347
3811C/3611X	2	6	1215.000	650.993	6	990.000	222.815	+	0.7504	6	86.667	25.254	6	560.000	206.527	-	0.0260
1231C/1231X	3	6	691.667	273.866	6	793.333	293.106	-	0.8051	6	108.333	63.056	6	393.333	124.168	-	0.0679
1732C/1732X	3	6	1775.000	786.676	6	530.000	254.650	+	0.1631	6	85.000	25.133	6	436.667	203.743	-	0.9595
3811C/3611X	3	6	1583.333	453.907	6	105.000	63.232	+	0.0188	6	43.333	4.944	6	43.333	21.551	o	0.3476

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	195.000	87.474	6	10.000	10.000	+	0.0175	6	55.000	25.133	6	3.333	3.333	+	0.1766
1732C/1732X	1	6	48.333	36.186	6	38.333	22.571	+	0.8193	6	38.333	21.357	6	6.667	3.333	+	0.6764
3811C/3611X	1	6	71.667	21.667	6	20.000	18.074	+	0.0970	6	70.000	22.061	6	3.333	3.333	+	0.0110
1231C/1231X	2	6	61.667	28.097	6	335.000	234.460	-	0.1950	6	116.667	18.559	6	25.000	15.653	+	0.0036
1732C/1732X	2	6	36.667	17.826	6	66.667	20.111	-	0.2904	6	35.000	17.842	6	30.000	12.910	+	0.8250
3811C/3611X	2	6	28.333	14.926	6	51.667	36.644	-	0.5685	6	15.000	7.638	6	1.667	1.667	+	0.0759
1231C/1231X	3	6	48.333	30.267	6	123.333	37.387	-	0.1500	6	28.333	12.494	6	48.333	24.279	-	0.4807
1732C/1732X	3	6	45.000	15.864	6	231.667	103.872	-	0.2040	6	43.333	10.541	6	46.667	20.276	-	0.8869
3811C/3611X	3	6	13.333	4.216	6	25.000	11.475	-	0.3624	6	15.000	6.708	6	10.000	8.165	+	0.6463

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	58.333	26.257	6	3.333	3.333	+	0.1743	6	1045.000	497.619	6	33.333	33.333	+	0.1793
1732C/1732X	1	6	31.667	20.069	6	13.333	6.667	+	0.4063	6	945.000	745.376	6	73.333	32.830	+	0.9115
3811C/3611X	1	6	50.000	15.275	6	1.667	1.667	+	0.0080	6	363.333	148.541	6	10.000	10.000	+	0.0091
1231C/1231X	2	6	63.333	6.667	6	5.000	3.416	+	0.0001	6	523.333	96.217	6	45.000	35.940	+	0.0009
1732C/1732X	2	6	21.667	10.776	6	21.667	11.377	o	1.0000	6	271.667	152.914	6	175.000	84.725	+	0.5924
3811C/3611X	2	6	1.667	1.667	6	0.000	0.000	+	0.3632	6	3.333	3.333	6	0.000	0.000	+	0.3632
1231C/1231X	3	6	3.333	2.108	6	10.000	6.325	-	0.3409	6	3.333	2.108	6	178.333	133.027	-	0.2932
1732C/1732X	3	6	25.000	8.466	6	13.333	4.944	+	0.2615	6	373.333	218.398	6	168.333	93.074	+	0.4081
3811C/3611X	3	6	5.000	3.416	6	1.667	1.667	+	0.4010	6	71.667	54.186	6	13.333	13.333	+	0.4912

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.013	0.008	-	0.1747	6	0.450	0.194	6	0.120	0.120	+	0.1065
1732C/1732X	1	6	0.017	0.008	6	0.087	0.087	-	0.7632	6	0.233	0.112	6	0.100	0.037	+	0.4900
3811C/3611X	1	6	0.013	0.010	6	0.120	0.059	-	0.1603	6	0.323	0.129	6	0.113	0.046	+	0.2291
1231C/1231X	2	6	0.000	0.000	6	0.260	0.110	-	0.0216	6	0.657	0.047	6	0.270	0.114	+	0.0176
1732C/1732X	2	6	0.370	0.115	6	0.473	0.144	-	0.6885	6	0.170	0.077	6	0.190	0.069	-	0.6818
3811C/3611X	2	6	0.333	0.127	6	0.237	0.100	+	0.5464	6	0.083	0.048	6	0.257	0.097	-	0.0887
1231C/1231X	3	6	0.290	0.044	6	0.557	0.064	-	0.0067	6	0.283	0.059	6	0.277	0.062	+	0.9433
1732C/1732X	3	6	0.660	0.112	6	0.540	0.099	+	0.4708	6	0.147	0.032	6	0.357	0.130	-	0.1973
3811C/3611X	3	6	0.380	0.086	6	0.880	0.059	-	0.0012	6	0.077	0.020	6	0.057	0.031	+	0.4516

Table A-9. Fucus Attributes. Herring Bay. Sheltered Rocky. August 1991.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	1746.667	861.877	6	351.667	307.727	+	0.1584	6	381.667	164.771	6	348.333	348.333	+	0.9328
1732C/1732X	1	6	1815.000	1181.431	6	995.000	587.434	+	0.5482	6	88.333	43.773	6	90.000	47.610	-	0.9799
3811C/3611X	1	6	385.000	123.309	6	625.000	400.006	-	0.5791	6	141.667	60.851	6	115.000	58.238	+	0.7581
1231C/1231X	2	6	1253.333	481.308	6	635.000	395.616	+	0.3444	6	10.000	5.164	6	521.667	203.362	-	0.0025
1732C/1732X	2	6	4358.333	2768.987	6	733.333	127.506	+	0.5583	6	146.667	72.373	6	211.667	40.859	-	0.4523
3811C/3611X	2	6	1075.000	424.490	6	1026.667	310.265	+	0.9286	6	140.000	59.273	6	748.333	229.585	-	0.0257
1231C/1231X	3	6	755.000	255.444	6	740.000	318.852	+	0.9714	6	155.000	74.106	6	306.667	76.797	-	0.1857
1732C/1732X	3	6	2966.667	1222.388	6	1605.000	765.096	+	0.3673	6	145.000	54.022	6	820.000	347.515	-	0.3872
3811C/3611X	3	6	2758.333	788.989	6	151.667	66.303	+	0.0007	6	53.333	11.738	6	65.000	27.417	-	0.7039

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	208.333	93.110	6	91.667	91.667	+	0.3929	6	61.667	28.684	6	1.667	1.667	+	0.1464
1732C/1732X	1	6	31.667	22.571	6	38.333	24.956	-	0.8469	6	45.000	28.018	6	5.000	2.236	+	0.6474
3811C/3611X	1	6	110.000	39.158	6	35.000	22.174	+	0.1265	6	126.667	42.085	6	1.667	1.667	+	0.0053
1231C/1231X	2	6	33.333	19.944	6	376.667	247.126	-	0.3628	6	110.000	19.833	6	35.000	15.221	+	0.0133
1732C/1732X	2	6	40.000	21.756	6	68.333	23.440	-	0.3965	6	38.333	19.903	6	21.667	7.032	+	0.4481
3811C/3611X	2	6	25.000	9.916	6	223.333	113.891	-	0.3854	6	20.000	7.303	6	6.667	3.333	+	0.1277
1231C/1231X	3	6	40.000	22.657	6	138.333	33.706	-	0.0360	6	28.333	12.758	6	45.000	28.137	-	0.6014
1732C/1732X	3	6	51.667	13.520	6	363.333	179.605	-	0.9879	6	28.333	10.462	6	133.333	58.119	-	0.1276
3811C/3611X	3	6	15.000	2.236	6	31.667	13.520	-	0.4717	6	15.000	6.191	6	16.667	11.156	-	0.8987

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	51.667	23.863	6	0.000	0.000	+	0.0826	6	720.000	343.113	6	0.000	0.000	+	0.0899
1732C/1732X	1	6	26.667	17.638	6	8.333	6.541	+	0.3528	6	336.667	274.344	6	21.667	17.966	+	0.6966
3811C/3611X	1	6	56.667	14.757	6	1.667	1.667	+	0.0062	6	323.333	115.200	6	15.000	15.000	+	0.0102
1231C/1231X	2	6	51.667	8.724	6	3.333	2.108	+	0.0046	6	330.000	65.777	6	16.667	14.757	+	0.0040
1732C/1732X	2	6	5.000	3.416	6	11.667	8.333	-	0.4762	6	13.333	9.888	6	73.333	47.023	-	0.7705
3811C/3611X	2	6	1.667	1.667	6	0.000	0.000	+	0.3632	6	5.000	5.000	6	0.000	0.000	+	0.3632
1231C/1231X	3	6	3.333	3.333	6	1.667	1.667	+	0.6643	6	6.667	6.667	6	20.000	20.000	-	0.5413
1732C/1732X	3	6	1.667	1.667	6	0.000	0.000	+	0.3632	6	5.000	5.000	6	0.000	0.000	+	0.3632
3811C/3611X	3	6	5.000	3.416	6	0.000	0.000	+	0.2031	6	11.667	9.804	6	0.000	0.000	+	0.2875

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.303	0.188	6	0.150	0.142	+	0.4592
1732C/1732X	1	6	0.017	0.010	6	0.053	0.046	-	0.7165	6	0.150	0.090	6	0.113	0.045	+	0.8823
3811C/3611X	1	6	0.010	0.007	6	0.080	0.039	-	0.1763	6	0.453	0.150	6	0.083	0.039	+	0.0455
1231C/1231X	2	6	0.017	0.010	6	0.153	0.102	-	0.2693	6	0.610	0.053	6	0.373	0.146	+	0.1918
1732C/1732X	2	6	0.147	0.054	6	0.420	0.133	-	0.1802	6	0.287	0.098	6	0.247	0.057	+	0.9251
3811C/3611X	2	6	0.180	0.101	6	0.063	0.048	+	0.2761	6	0.117	0.047	6	0.377	0.124	-	0.0682
1231C/1231X	3	6	0.263	0.074	6	0.380	0.100	-	0.3686	6	0.330	0.081	6	0.467	0.122	-	0.3669
1732C/1732X	3	6	0.267	0.082	6	0.333	0.145	-	0.9211	6	0.347	0.098	6	0.543	0.171	-	0.3295
3811C/3611X	3	6	0.347	0.120	6	0.727	0.095	-	0.0304	6	0.113	0.028	6	0.090	0.042	+	0.4786

Table A-10. Fucus Attributes. Herring Bay. Sheltered-Rocky. June 1992.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	588.333	244.314	6	153.333	64.842	+	0.1160	6	281.667	99.446	6	168.333	162.407	+	0.5650
1732C/1732X	1	6	3551.667	3174.753	6	870.000	393.921	+	0.8383	6	51.667	24.687	6	245.000	94.048	-	0.0748
3811C/3611X	1	6	506.667	251.259	6	678.333	324.863	-	0.6848	6	66.667	26.667	6	270.000	130.945	-	0.5046
1231C/1231X	2	6	96.667	71.024	6	295.000	112.982	-	0.1681	6	18.333	16.415	6	290.000	123.153	-	0.0333
1732C/1732X	2	6	1051.667	245.865	6	393.333	146.166	+	0.0441	6	388.333	207.837	6	223.333	47.093	+	0.2849
3811C/3611X	2	6	820.000	175.157	6	393.333	186.148	+	0.1260	6	205.000	116.154	6	286.667	61.950	-	0.5489
1231C/1231X	3	6	550.000	217.516	6	281.667	92.571	+	0.2828	6	186.667	65.405	6	271.667	79.390	-	0.4279
1732C/1732X	3	6	2306.667	858.016	6	115.000	67.268	+	0.0163	6	843.333	278.384	6	235.000	115.203	+	0.0711
3811C/3611X	3	6	1508.333	281.465	6	21.667	12.494	+	0.0037	6	331.667	99.446	6	15.000	7.638	+	0.0041

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	160.000	72.710	6	175.000	175.000	-	0.9385	6	90.000	43.665	6	85.000	85.000	+	0.9593
1732C/1732X	1	6	35.000	11.475	6	48.333	23.582	-	0.6222	6	30.000	17.889	6	10.000	6.325	+	0.3166
3811C/3611X	1	6	68.333	22.123	6	75.000	48.080	-	0.9023	6	78.333	26.130	6	23.333	16.667	+	0.1064
1231C/1231X	2	6	11.667	5.426	6	311.667	122.975	-	0.0102	6	51.667	12.225	6	195.000	105.728	-	0.8343
1732C/1732X	2	6	91.667	49.694	6	135.000	32.838	-	0.4836	6	16.667	6.146	6	56.667	20.440	-	0.0904
3811C/3611X	2	6	63.333	29.174	6	238.333	74.718	-	0.0541	6	8.333	8.333	6	108.333	58.047	-	0.0873
1231C/1231X	3	6	91.667	58.845	6	163.333	31.588	-	0.3085	6	43.333	28.829	6	110.000	36.878	-	0.1848
1732C/1732X	3	6	266.667	106.823	6	253.333	126.271	+	0.9373	6	58.333	14.472	6	223.333	101.412	-	0.9310
3811C/3611X	3	6	43.333	18.197	6	18.333	8.724	+	0.2437	6	10.000	4.472	6	26.667	14.982	-	0.3115

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	83.333	37.298	6	8.333	8.333	+	0.0871	6	2461.667	1163.585	6	18.333	18.333	+	0.0577
1732C/1732X	1	6	25.000	13.602	6	18.333	10.462	+	0.7058	6	778.333	489.547	6	85.000	58.694	+	0.6910
3811C/3611X	1	6	81.667	27.978	6	8.333	8.333	+	0.0308	6	1296.667	512.495	6	48.333	48.333	+	0.0106
1231C/1231X	2	6	41.667	8.724	6	40.000	21.448	+	0.9440	6	970.000	274.372	6	175.000	110.204	+	0.0227
1732C/1732X	2	6	8.333	5.426	6	15.000	9.220	-	0.5471	6	135.000	85.625	6	156.667	90.836	-	0.8657
3811C/3611X	2	6	5.000	5.000	6	5.000	3.416	o	1.0000	6	60.000	60.000	6	31.667	23.154	+	0.6689
1231C/1231X	3	6	3.333	2.108	6	13.333	8.028	-	0.2560	6	31.667	24.552	6	151.667	85.573	-	0.2074
1732C/1732X	3	6	11.667	4.773	6	73.333	43.333	-	0.6026	6	138.333	49.961	6	473.333	317.781	-	0.9022
3811C/3611X	3	6	1.667	1.667	6	1.667	1.667	o	1.0000	6	1.667	1.667	6	23.333	23.333	-	0.7658

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.013	0.010	-	0.1938	6	0.500	0.209	6	0.170	0.166	+	0.2049
1732C/1732X	1	6	0.037	0.029	6	0.083	0.083	-	0.8747	6	0.253	0.096	6	0.157	0.080	+	0.4860
3811C/3611X	1	6	0.013	0.013	6	0.123	0.049	-	0.0566	6	0.410	0.154	6	0.163	0.054	+	0.1591
1231C/1231X	2	6	0.007	0.007	6	0.040	0.017	-	0.0359	6	0.330	0.045	6	0.567	0.171	-	0.3230
1732C/1732X	2	6	0.183	0.067	6	0.143	0.046	+	0.8689	6	0.290	0.115	6	0.487	0.119	-	0.2177
3811C/3611X	2	6	0.267	0.088	6	0.320	0.093	-	0.6730	6	0.127	0.056	6	0.367	0.153	-	0.1438
1231C/1231X	3	6	0.090	0.051	6	0.213	0.080	-	0.1908	6	0.300	0.150	6	0.583	0.130	-	0.1335
1732C/1732X	3	6	0.247	0.093	6	0.297	0.110	-	0.8593	6	0.603	0.091	6	0.563	0.172	+	0.9301
3811C/3611X	3	6	0.503	0.054	6	0.663	0.134	-	0.2287	6	0.133	0.029	6	0.090	0.043	+	0.2888

Table A-11. Fucus Attributes. Herring Bay. Sheltered Rocky. August 1992.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	200.000	79.162	6	90.000	57.850	+	0.2881	6	205.000	104.011	6	36.667	32.830	+	0.1538
1732C/1732X	1	6	2593.333	2257.042	6	506.667	204.070	+	0.7002	6	60.000	40.906	6	340.000	168.780	-	0.3827
3811C/3611X	1	6	323.333	148.653	6	461.667	134.075	-	0.5053	6	113.333	62.964	6	400.000	167.412	-	0.1401
1231C/1231X	2	6	55.000	51.039	6	276.667	126.798	-	0.1359	6	6.667	4.216	6	210.000	97.365	-	0.0020
1732C/1732X	2	6	385.000	141.910	6	386.667	144.353	-	0.9936	6	436.667	218.139	6	148.333	34.585	+	0.4319
3811C/3611X	2	6	463.333	233.633	6	328.333	152.193	+	0.6387	6	236.667	124.088	6	353.333	110.594	-	0.4988
1231C/1231X	3	6	321.667	120.649	6	283.333	119.043	+	0.8256	6	196.667	53.521	6	226.667	58.348	-	0.7127
1732C/1732X	3	6	773.333	424.261	6	25.000	16.279	+	0.0057	6	733.333	249.862	6	88.333	50.755	+	0.0378
3811C/3611X	3	6	580.000	166.853	6	146.667	66.767	+	0.0366	6	390.000	128.478	6	71.667	27.254	+	0.0796

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	225.000	95.315	6	83.333	81.350	+	0.2846	6	106.667	50.706	6	105.000	105.000	+	0.9889
1732C/1732X	1	6	30.000	13.663	6	120.000	54.894	-	0.3553	6	21.667	15.147	6	20.000	12.649	+	0.9344
3811C/3611X	1	6	55.000	18.212	6	176.667	80.609	-	0.4183	6	81.667	28.684	6	65.000	47.871	+	0.7713
1231C/1231X	2	6	3.333	2.108	6	230.000	108.965	-	0.0008	6	43.333	13.824	6	180.000	85.596	-	0.8432
1732C/1732X	2	6	161.667	83.523	6	171.667	55.403	-	0.9225	6	23.333	8.028	6	78.333	28.097	-	0.0892
3811C/3611X	2	6	71.667	46.434	6	225.000	37.837	-	0.0284	6	23.333	14.757	6	170.000	81.199	-	0.0392
1231C/1231X	3	6	91.667	61.178	6	158.333	23.298	-	0.3325	6	76.667	54.447	6	175.000	46.673	-	0.2003
1732C/1732X	3	6	335.000	107.819	6	128.333	68.625	+	0.1369	6	78.333	25.221	6	1796.667	1640.209	-	0.9402
3811C/3611X	3	6	90.000	41.713	6	40.000	17.512	+	0.2949	6	21.667	8.333	6	33.333	14.530	-	0.5020

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	81.667	44.827	6	0.000	0.000	+	0.1281	6	1713.333	784.770	6	0.000	0.000	+	0.0808
1732C/1732X	1	6	3.333	2.108	6	10.000	5.164	-	0.2596	6	50.000	39.243	6	40.000	25.430	+	0.8350
3811C/3611X	1	6	33.333	10.853	6	10.000	5.164	+	0.0809	6	188.333	70.589	6	50.000	25.033	+	0.0945
1231C/1231X	2	6	25.000	5.627	6	3.333	3.333	+	0.0078	6	206.667	75.660	6	23.333	23.333	+	0.0431
1732C/1732X	2	6	0.000	0.000	6	10.000	8.165	-	0.2752	6	0.000	0.000	6	88.333	86.349	-	0.3532
3811C/3611X	2	6	1.667	1.667	6	5.000	3.416	-	0.4010	6	3.333	3.333	6	25.000	16.279	-	0.4433
1231C/1231X	3	6	0.000	0.000	6	15.000	13.102	-	0.3041	6	0.000	0.000	6	263.333	204.559	-	0.2543
1732C/1732X	3	6	0.000	0.000	6	6.667	4.216	-	0.1747	6	0.000	0.000	6	23.333	18.012	-	0.2518
3811C/3611X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.000	0.000	6	0.000	0.000	o	1.0000

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.007	0.007	-	0.3632	6	0.507	0.204	6	0.167	0.167	+	0.1607
1732C/1732X	1	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.277	0.113	6	0.283	0.123	-	0.9343
3811C/3611X	1	6	0.007	0.007	6	0.003	0.003	+	0.8140	6	0.413	0.155	6	0.317	0.115	+	0.6374
1231C/1231X	2	6	0.027	0.016	6	0.000	0.000	+	0.0996	6	0.340	0.067	6	0.650	0.152	-	0.1009
1732C/1732X	2	6	0.010	0.007	6	0.087	0.043	-	0.1058	6	0.447	0.161	6	0.570	0.125	-	0.4505
3811C/3611X	2	6	0.293	0.105	6	0.137	0.065	+	0.2224	6	0.250	0.107	6	0.577	0.142	-	0.0702
1231C/1231X	3	6	0.083	0.057	6	0.063	0.063	+	0.5861	6	0.407	0.157	6	0.707	0.124	-	0.1850
1732C/1732X	3	6	0.070	0.035	5	0.404	0.180	-	0.1151	6	0.733	0.088	5	0.500	0.208	+	0.3340
3811C/3611X	3	6	0.403	0.098	6	0.600	0.091	-	0.1635	6	0.353	0.127	6	0.137	0.036	+	0.1510

Table A-12. Fucus Attributes. Herring Bay. Sheltered Rocky. June 1993.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	271.667	170.576	5	86.000	56.533	+	0.3667	6	110.000	56.155	5	12.000	12.000	+	0.0371
1732C/1732X	1	6	1231.667	1156.303	6	246.667	79.568	+	0.3913	6	88.333	74.718	6	221.667	115.106	-	0.3542
3811C/3611X	1	6	156.667	58.519	6	265.000	116.068	-	0.4241	6	85.000	38.275	6	283.333	100.022	-	0.0937
1231C/1231X	2	6	610.000	235.599	6	108.333	49.086	+	0.5513	6	11.667	6.009	6	105.000	45.074	-	0.2392
1732C/1732X	2	6	76.667	43.869	6	228.333	103.615	-	0.2074	6	91.667	37.543	6	148.333	29.031	-	0.2600
3811C/3611X	2	6	295.000	154.375	6	58.333	37.365	+	0.1085	6	165.000	64.795	6	70.000	29.777	+	0.2123
1231C/1231X	3	6	128.333	72.729	6	48.333	19.565	+	0.3131	6	78.333	21.972	6	93.333	24.037	-	0.6549
1732C/1732X	3	6	96.667	54.934	6	21.667	17.966	+	0.2235	6	181.667	89.756	6	43.333	28.008	+	0.1720
3811C/3611X	3	6	83.333	21.858	6	25.000	16.279	+	0.0580	6	113.333	21.082	6	78.333	59.072	+	0.5891

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	123.333	49.239	5	4.000	4.000	+	0.0016	6	140.000	60.718	5	2.000	2.000	+	0.0693
1732C/1732X	1	6	23.333	14.063	6	160.000	68.459	-	0.4850	6	30.000	11.255	6	35.000	17.272	-	0.8133
3811C/3611X	1	6	31.667	10.462	6	205.000	84.014	-	0.3685	6	46.667	17.448	6	115.000	42.170	-	0.1652
1231C/1231X	2	6	1.667	1.667	6	121.667	65.085	-	0.0002	6	15.000	6.708	6	173.333	55.718	-	0.1383
1732C/1732X	2	6	103.333	44.547	6	125.000	18.212	-	0.6622	6	106.667	54.386	6	141.667	26.130	-	0.5747
3811C/3611X	2	6	61.667	42.223	6	108.333	25.484	-	0.3663	6	40.000	23.805	6	180.000	71.740	-	0.0937
1231C/1231X	3	6	71.667	17.013	6	143.333	29.852	-	0.0636	6	35.000	20.616	6	180.000	40.988	-	0.0102
1732C/1732X	3	6	206.667	98.376	6	63.333	27.889	+	0.1913	6	195.000	88.722	6	130.000	48.990	+	0.5357
3811C/3611X	3	6	100.000	28.048	6	43.333	28.597	+	0.1875	6	61.667	34.100	6	41.667	14.004	+	0.5993

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	123.333	54.934	5	0.000	0.000	+	0.0747	6	4063.333	1789.394	5	0.000	0.000	+	0.0724
1732C/1732X	1	6	28.333	10.138	6	28.333	11.377	o	1.0000	6	580.000	291.571	6	180.000	110.030	+	0.2283
3811C/3611X	1	6	46.667	17.448	6	50.000	17.889	-	0.8965	6	805.000	298.248	6	285.000	121.044	+	0.1373
1231C/1231X	2	6	15.000	6.708	6	80.000	35.777	-	0.2870	6	313.333	229.269	6	795.000	353.466	-	0.2796
1732C/1732X	2	6	3.333	2.108	6	50.000	18.074	-	0.0345	6	190.000	127.070	6	470.000	149.287	-	0.1837
3811C/3611X	2	6	10.000	8.165	6	56.667	41.446	-	0.4474	6	51.667	42.459	6	633.333	438.662	-	0.4273
1231C/1231X	3	6	8.333	6.541	6	41.667	18.151	-	0.1147	6	193.333	191.340	6	351.667	292.705	-	0.6604
1732C/1732X	3	6	23.333	8.433	6	58.333	29.145	-	0.2755	6	90.000	29.439	6	620.000	382.527	-	0.7505
3811C/3611X	3	6	11.667	4.014	6	0.000	0.000	+	0.0335	6	36.667	17.448	6	0.000	0.000	+	0.0896

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.017	0.013	-	0.2039	6	0.523	0.210	6	0.173	0.162	+	0.1473
1732C/1732X	1	6	0.000	0.000	6	0.007	0.007	-	0.3632	6	0.223	0.128	6	0.243	0.105	-	0.8242
3811C/3611X	1	6	0.000	0.000	6	0.083	0.051	-	0.1013	6	0.417	0.177	6	0.407	0.128	+	0.9449
1231C/1231X	2	6	0.003	0.003	6	0.070	0.062	-	0.3251	6	0.220	0.103	6	0.683	0.142	-	0.0295
1732C/1732X	2	6	0.003	0.003	6	0.117	0.059	-	0.0780	6	0.453	0.161	6	0.647	0.104	-	0.2883
3811C/3611X	2	6	0.063	0.042	6	0.157	0.078	-	0.2718	6	0.237	0.131	6	0.693	0.148	-	0.0417
1231C/1231X	3	6	0.023	0.017	6	0.123	0.055	-	0.1195	6	0.320	0.142	6	0.780	0.112	-	0.0228
1732C/1732X	3	5	0.036	0.010	6	0.393	0.154	-	0.1050	5	0.748	0.158	6	0.513	0.162	+	0.2788
3811C/3611X	3	6	0.550	0.147	6	0.277	0.079	+	0.1467	6	0.350	0.163	6	0.367	0.113	-	0.8032

Table A-13. Fucus Attributes. Herring Bay. Sheltered Rocky. September 1993.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	185.000	110.717	5	100.000	75.565	+	0.5591	6	50.000	28.636	5	24.000	24.000	+	0.5150
1732C/1732X	1	6	975.000	859.635	6	73.333	42.164	+	0.8174	6	110.000	104.115	6	63.333	33.032	+	0.6783
3811C/3611X	1	6	265.000	105.917	6	126.667	41.687	+	0.2522	6	71.667	30.267	6	120.000	45.240	-	0.3954
1231C/1231X	2	6	438.333	218.776	6	151.667	33.508	+	0.5396	6	13.333	6.146	6	80.000	26.583	-	0.0223
1732C/1732X	2	6	18.333	11.377	6	433.333	223.751	-	0.0089	6	43.333	19.777	6	58.333	13.017	-	0.5406
3811C/3611X	2	6	646.667	272.515	6	63.333	34.416	+	0.0141	6	181.667	66.604	6	71.667	30.705	+	0.1645
1231C/1231X	3	6	106.667	65.912	6	38.333	16.210	+	0.8390	6	70.000	26.833	6	85.000	26.045	-	0.6968
1732C/1732X	3	6	331.667	299.771	6	15.000	8.062	+	0.1480	6	168.333	56.239	6	28.333	14.240	+	0.0351
3811C/3611X	3	6	200.000	46.476	6	25.000	14.318	+	0.0049	6	180.000	37.327	6	75.000	48.080	+	0.1152

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	85.000	37.483	5	4.000	4.000	+	0.0942	6	80.000	33.566	5	0.000	0.000	+	0.0629
1732C/1732X	1	6	30.000	24.221	6	91.667	43.773	-	0.2459	6	16.667	8.433	6	43.333	27.162	-	0.3705
3811C/3611X	1	6	58.333	27.978	6	111.667	32.395	-	0.2412	6	65.000	25.133	6	83.333	31.376	-	0.6581
1231C/1231X	2	6	1.667	1.667	6	101.667	45.783	-	0.0001	6	10.000	6.831	6	163.333	60.974	-	0.1374
1732C/1732X	2	6	53.333	25.517	6	110.000	20.331	-	0.1131	6	146.667	68.686	6	125.000	17.654	+	0.2004
3811C/3611X	2	6	103.333	61.626	6	56.667	24.175	+	0.4969	6	86.667	69.122	6	165.000	42.876	-	0.3582
1231C/1231X	3	6	53.333	16.056	6	105.000	21.253	-	0.0811	6	68.333	42.850	6	155.000	36.309	-	0.1538
1732C/1732X	3	6	225.000	78.262	6	31.667	14.926	+	0.2186	6	263.333	93.047	6	86.667	31.376	+	0.1022
3811C/3611X	3	6	175.000	40.229	6	45.000	19.451	+	0.0156	6	103.333	49.441	6	43.333	18.197	+	0.2813

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	50.000	22.804	5	0.000	0.000	+	0.0798	6	738.333	337.979	5	0.000	0.000	+	0.0806
1732C/1732X	1	6	8.333	4.773	6	3.333	3.333	+	0.4105	6	50.000	28.752	6	15.000	15.000	+	0.3058
3811C/3611X	1	6	11.667	5.426	6	18.333	9.098	-	0.5433	6	85.000	55.603	6	150.000	108.167	-	0.6047
1231C/1231X	2	6	5.000	3.416	6	8.333	6.541	-	0.6611	6	136.667	114.358	6	35.000	27.779	+	0.8540
1732C/1732X	2	6	3.333	2.108	6	10.000	4.472	-	0.2073	6	20.000	16.330	6	66.667	44.247	-	0.3458
3811C/3611X	2	6	1.667	1.667	6	16.667	13.081	-	0.4288	6	3.333	3.333	6	115.000	109.110	-	0.4168
1231C/1231X	3	6	0.000	0.000	6	16.667	8.028	-	0.0925	6	0.000	0.000	6	193.333	142.634	-	0.2333
1732C/1732X	3	6	1.667	1.667	6	11.667	7.491	-	0.4356	6	5.000	5.000	6	81.667	68.625	-	0.4272
3811C/3611X	3	6	0.000	0.000	6	1.667	1.667	-	0.3632	6	0.000	0.000	6	3.333	3.333	-	0.3632

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	0	--	--	0	--	--		----	0	--	--	0	--	--		----
1732C/1732X	1	0	--	--	0	--	--		----	0	--	--	0	--	--		----
3811C/3611X	1	0	--	--	0	--	--		----	0	--	--	0	--	--		----
1231C/1231X	2	0	--	--	0	--	--		----	0	--	--	0	--	--		----
1732C/1732X	2	0	--	--	0	--	--		----	0	--	--	0	--	--		----
3811C/3611X	2	0	--	--	0	--	--		----	0	--	--	0	--	--		----
1231C/1231X	3	0	--	--	0	--	--		----	0	--	--	0	--	--		----
1732C/1732X	3	0	--	--	0	--	--		----	0	--	--	0	--	--		----
3811C/3611X	3	0	--	--	0	--	--		----	0	--	--	0	--	--		----

Table A-14. Fucus Attributes. Herring Bay. Sheltered Rocky. May 1994.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	1068.333	575.288	6	236.667	183.896	+	0.1985	6	40.000	28.402	6	5.000	3.416	+	0.7160
1732C/1732X	1	6	905.000	518.683	6	325.000	157.284	+	0.3097	6	206.667	206.667	6	46.667	28.245	+	0.4744
3811C/3611X	1	6	355.000	122.604	6	236.667	126.166	+	0.5164	6	60.000	33.961	6	126.667	59.703	-	0.3546
1231C/1231X	2	6	353.333	118.397	6	390.000	178.680	-	0.8676	6	10.000	6.831	6	61.667	38.420	-	0.0834
1732C/1732X	2	6	53.333	40.470	6	628.333	321.252	-	0.0984	6	1.667	1.667	6	83.333	52.578	-	0.0093
3811C/3611X	2	6	376.667	116.667	6	238.333	124.242	+	0.4359	6	128.333	45.929	6	35.000	15.864	+	0.0837
1231C/1231X	3	6	246.667	153.094	6	96.667	47.866	+	0.3717	6	23.333	12.293	6	75.000	37.837	-	0.2232
1732C/1732X	3	6	296.667	222.975	6	335.000	284.262	-	0.9176	6	38.333	6.009	6	30.000	12.649	+	0.5650
3811C/3611X	3	6	210.000	52.662	6	28.333	15.147	+	0.0078	6	145.000	26.677	6	53.333	21.396	+	0.0231

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	53.333	27.039	6	10.000	6.325	+	0.4509	6	73.333	35.932	6	51.667	51.667	+	0.7378
1732C/1732X	1	6	25.000	25.000	6	65.000	37.216	-	0.3932	6	5.000	3.416	6	46.667	33.632	-	0.4114
3811C/3611X	1	6	46.667	33.533	6	105.000	41.130	-	0.2974	6	73.333	35.746	6	146.667	45.142	-	0.2316
1231C/1231X	2	6	1.667	1.667	6	56.667	28.363	-	0.0003	6	3.333	2.108	6	133.333	47.023	-	0.0235
1732C/1732X	2	6	16.667	11.156	6	65.000	17.272	-	0.0406	6	93.333	48.143	6	66.667	8.819	+	0.1641
3811C/3611X	2	6	51.667	23.723	6	35.000	22.323	+	0.6200	6	36.667	25.122	6	75.000	16.882	-	0.2340
1231C/1231X	3	6	15.000	6.708	6	66.667	17.062	-	0.0182	6	45.000	27.659	6	145.000	19.621	-	0.0146
1732C/1732X	3	6	91.667	29.373	6	15.000	7.188	+	0.0221	6	161.667	64.829	6	55.000	22.174	+	0.1506
3811C/3611X	3	6	75.000	22.323	6	30.000	17.127	+	0.1408	6	53.333	19.777	6	43.333	15.847	+	0.7014

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	70.000	34.059	6	31.667	31.667	+	0.4290	6	1613.333	735.960	6	728.333	728.333	+	0.4127
1732C/1732X	1	6	5.000	3.416	6	26.667	14.530	-	0.4298	6	88.333	57.644	6	71.667	47.918	+	0.8285
3811C/3611X	1	6	36.667	19.090	6	113.333	44.020	-	0.1412	6	393.333	213.599	6	1115.000	454.480	-	0.1812
1231C/1231X	2	6	3.333	2.108	6	80.000	29.552	-	0.0278	6	88.333	73.504	6	1120.000	587.157	-	0.0509
1732C/1732X	2	6	40.000	25.430	6	28.333	6.009	+	0.1757	6	175.000	84.449	6	525.000	262.980	-	0.2338
3811C/3611X	2	6	13.333	8.028	6	36.667	15.635	-	0.2138	6	48.333	35.253	6	541.667	302.946	-	0.1295
1231C/1231X	3	6	10.000	8.165	6	55.000	14.549	-	0.0224	6	33.333	23.476	6	561.667	260.428	-	0.0037
1732C/1732X	3	6	51.667	19.903	6	15.000	7.188	+	0.1138	6	390.000	148.212	6	263.333	119.015	+	0.5202
3811C/3611X	3	6	11.667	6.541	6	11.667	4.773	o	1.0000	6	68.333	42.772	6	163.333	106.134	-	0.4258

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.003	0.003	-	0.3632	6	0.393	0.176	6	0.130	0.115	+	0.2832
1732C/1732X	1	6	0.000	0.000	6	0.093	0.072	-	0.2049	6	0.133	0.077	6	0.117	0.060	+	0.9364
3811C/3611X	1	6	0.000	0.000	6	0.087	0.045	-	0.0881	6	0.267	0.113	6	0.400	0.124	-	0.5014
1231C/1231X	2	6	0.000	0.000	6	0.007	0.004	-	0.1747	6	0.053	0.023	6	0.523	0.128	-	0.0050
1732C/1732X	2	6	0.003	0.003	6	0.173	0.067	-	0.0406	6	0.267	0.154	6	0.403	0.077	-	0.2429
3811C/3611X	2	6	0.030	0.026	6	0.147	0.065	-	0.0788	6	0.307	0.123	6	0.347	0.105	-	0.7285
1231C/1231X	3	6	0.047	0.033	6	0.203	0.057	-	0.0140	6	0.290	0.121	6	0.577	0.048	-	0.0559
1732C/1732X	3	6	0.103	0.046	6	0.323	0.090	-	0.0947	6	0.613	0.121	6	0.330	0.118	+	0.1006
3811C/3611X	3	6	0.260	0.110	6	0.307	0.065	-	0.6591	6	0.303	0.108	6	0.403	0.107	-	0.5216

Table A-15. Fucus Attributes. Herring Bay. Sheltered Rocky. September 1994.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	1270.000	847.034	6	420.000	361.478	+	0.3778	6	36.667	29.401	6	10.000	8.165	+	0.4027
1732C/1732X	1	6	518.333	492.547	6	768.333	483.690	-	0.7248	6	598.333	598.333	6	51.667	30.487	+	0.1536
3811C/3611X	1	6	786.667	85.544	6	711.667	255.948	+	0.7867	6	45.000	22.174	6	108.333	48.540	-	0.2627
1231C/1231X	2	6	388.333	128.281	6	721.667	245.376	-	0.2564	6	6.667	4.944	6	46.667	27.649	-	0.0722
1732C/1732X	2	6	288.333	60.079	6	1390.000	597.818	-	0.6317	6	3.333	2.108	6	151.667	126.133	-	0.1323
3811C/3611X	2	6	323.333	136.813	6	798.333	414.338	-	0.3019	6	141.667	57.932	6	20.000	7.746	+	0.2312
1231C/1231X	3	6	425.000	324.127	6	233.333	130.248	+	0.5953	6	35.000	15.653	6	65.000	20.453	-	0.2711
1732C/1732X	3	6	160.000	83.347	6	860.000	534.359	-	0.7208	6	40.000	20.817	6	81.667	41.184	-	0.3878
3811C/3611X	3	6	823.333	430.455	6	23.333	12.293	+	0.0102	6	101.667	32.804	6	38.333	15.581	+	0.1118

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	91.667	49.961	6	10.000	8.165	+	0.3740	6	110.000	49.666	6	38.333	36.370	+	0.2714
1732C/1732X	1	6	33.333	31.376	6	50.000	30.551	-	0.7115	6	3.333	2.108	6	48.333	37.186	-	0.3918
3811C/3611X	1	6	38.333	25.484	6	108.333	34.681	-	0.1349	6	50.000	19.149	6	96.667	32.931	-	0.2486
1231C/1231X	2	6	3.333	2.108	6	33.333	22.161	-	0.1938	6	6.667	3.333	6	123.333	47.656	-	0.0766
1732C/1732X	2	6	13.333	6.667	6	53.333	22.460	-	0.1186	6	85.000	42.012	6	118.333	23.582	-	0.5048
3811C/3611X	2	6	85.000	35.940	6	25.000	19.621	+	0.1736	6	58.333	32.292	6	73.333	19.437	-	0.6990
1231C/1231X	3	6	21.667	9.098	6	50.000	13.904	-	0.1190	6	45.000	19.958	6	103.333	17.448	-	0.0524
1732C/1732X	3	6	53.333	21.858	6	25.000	10.567	+	0.2703	6	151.667	52.499	6	55.000	20.777	+	0.1177
3811C/3611X	3	6	73.333	20.111	6	25.000	11.762	+	0.0648	6	55.000	19.621	6	46.667	20.763	+	0.7765

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	75.000	36.125	6	0.000	0.000	+	0.0925	6	1363.333	634.847	6	0.000	0.000	+	0.0845
1732C/1732X	1	6	3.333	2.108	6	11.667	9.804	-	0.8501	6	33.333	21.239	6	18.333	16.415	+	0.5886
3811C/3611X	1	6	8.333	4.773	6	56.667	31.798	-	0.1391	6	40.000	21.135	6	560.000	311.598	-	0.1427
1231C/1231X	2	6	0.000	0.000	6	23.333	11.738	-	0.1035	6	0.000	0.000	6	158.333	83.603	-	0.1168
1732C/1732X	2	6	0.000	0.000	6	8.333	4.014	-	0.0925	6	0.000	0.000	6	80.000	42.190	-	0.1164
3811C/3611X	2	6	1.667	1.667	6	21.667	14.240	-	0.1922	6	3.333	3.333	6	236.667	170.346	-	0.1512
1231C/1231X	3	6	1.667	1.667	6	5.000	5.000	-	0.5413	6	1.667	1.667	6	46.667	46.667	-	0.7250
1732C/1732X	3	6	1.667	1.667	6	10.000	8.165	-	0.4738	6	10.000	10.000	6	196.667	156.837	-	0.4216
3811C/3611X	3	6	0.000	0.000	6	1.667	1.667	-	0.3632	6	0.000	0.000	6	1.667	1.667	-	0.3632

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.010	0.010	-	0.3632	6	0.420	0.190	6	0.130	0.118	+	0.2539
1732C/1732X	1	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.100	0.076	6	0.227	0.136	-	0.4516
3811C/3611X	1	6	0.000	0.000	6	0.013	0.013	-	0.3632	6	0.277	0.138	6	0.467	0.148	-	0.3852
1231C/1231X	2	6	0.003	0.003	6	0.003	0.003	o	1.0000	6	0.073	0.029	6	0.577	0.129	-	0.0030
1732C/1732X	2	6	0.010	0.007	6	0.067	0.043	-	0.2751	6	0.287	0.150	6	0.580	0.129	-	0.1197
3811C/3611X	2	6	0.187	0.113	6	0.037	0.027	+	0.1635	6	0.307	0.120	6	0.443	0.136	-	0.3677
1231C/1231X	3	6	0.150	0.098	6	0.117	0.053	+	0.9174	6	0.273	0.143	6	0.763	0.059	-	0.0158
1732C/1732X	3	6	0.020	0.013	6	0.300	0.125	-	0.0152	6	0.777	0.096	6	0.470	0.136	+	0.0827
3811C/3611X	3	6	0.280	0.074	6	0.267	0.067	+	0.8123	6	0.397	0.143	6	0.453	0.146	-	0.8479

Table A-16. Fucus Attributes. Herring Bay. Sheltered Rocky. May 1995.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	89.500	59.227	6	118.500	106.441	-	0.8166	6	5.167	3.468	6	3.667	2.552	+	0.7348
1732C/1732X	1	6	44.833	15.859	6	99.500	44.831	-	0.2771	6	17.000	17.000	6	6.000	3.821	+	0.5155
3811C/3611X	1	6	47.333	20.659	6	161.167	51.057	-	0.0656	6	6.000	3.924	6	14.000	3.055	-	0.1388
1231C/1231X	2	6	64.667	22.003	6	168.667	67.490	-	0.1736	6	0.833	0.654	6	16.333	10.154	-	0.0040
1732C/1732X	2	6	109.833	58.446	6	80.000	34.043	+	0.6685	6	0.833	0.654	6	14.000	8.079	-	0.1094
3811C/3611X	2	6	25.167	11.940	6	138.833	66.166	-	0.5131	6	7.333	3.739	6	12.667	8.724	-	0.5866
1231C/1231X	3	6	36.000	17.957	6	38.333	23.802	-	0.9392	6	5.333	2.472	6	10.833	4.542	-	0.3125
1732C/1732X	3	6	54.667	23.170	6	67.833	36.991	-	0.7691	6	2.167	0.703	6	13.833	10.499	-	0.3597
3811C/3611X	3	6	85.167	46.325	6	4.000	4.000	+	0.0005	6	9.000	2.191	6	1.000	0.365	+	0.0040

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	6.167	3.885	6	0.667	0.667	+	0.2413	6	10.333	4.794	6	2.667	2.667	+	0.1924
1732C/1732X	1	6	7.000	7.000	6	3.167	1.869	+	0.6083	6	0.333	0.333	6	3.167	2.120	-	0.2158
3811C/3611X	1	6	2.833	1.815	6	6.500	2.291	-	0.2382	6	2.833	1.701	6	8.667	3.870	-	0.1977
1231C/1231X	2	6	0.167	0.167	6	2.000	1.613	-	0.2099	6	0.167	0.167	6	9.167	3.745	-	0.0003
1732C/1732X	2	6	0.333	0.333	6	4.833	3.655	-	0.0336	6	6.000	3.502	6	6.167	1.078	-	0.9646
3811C/3611X	2	6	7.833	3.301	6	2.000	1.265	+	0.1299	6	4.833	2.056	6	3.667	1.520	+	0.6580
1231C/1231X	3	6	2.167	1.249	6	5.000	2.381	-	0.3167	6	2.500	1.586	6	7.500	0.764	-	0.0176
1732C/1732X	3	6	2.667	0.882	6	4.167	1.537	-	0.4170	6	9.167	3.439	6	2.833	1.642	+	0.1275
3811C/3611X	3	6	3.833	1.352	6	1.167	0.307	+	0.0720	6	7.000	2.191	6	2.500	1.025	+	0.0924

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	9.667	4.514	6	2.667	2.667	+	0.2114	6	272.500	125.644	6	120.833	120.833	+	0.4047
1732C/1732X	1	6	0.500	0.500	6	4.000	2.408	-	0.2338	6	2.333	2.333	6	26.000	16.492	-	0.2103
3811C/3611X	1	6	2.333	1.229	6	7.667	3.801	-	0.2114	6	17.833	11.244	6	157.000	65.869	-	0.4154
1231C/1231X	2	6	0.000	0.000	6	7.833	3.701	-	0.0879	6	0.000	0.000	6	163.500	83.919	-	0.1089
1732C/1732X	2	6	3.333	2.390	6	2.667	0.760	+	0.7958	6	55.833	29.670	6	33.667	17.039	+	0.5317
3811C/3611X	2	6	2.667	1.202	6	2.167	0.910	+	0.7470	6	14.000	8.140	6	66.500	23.528	-	0.0612
1231C/1231X	3	6	1.500	0.957	6	4.333	0.615	-	0.0320	6	20.333	15.515	6	87.500	37.523	-	0.1291
1732C/1732X	3	6	5.000	2.556	6	0.667	0.494	+	0.0535	6	71.333	34.144	6	3.500	2.500	+	0.0256
3811C/3611X	3	6	2.333	1.174	6	1.167	0.792	+	0.4293	6	16.667	8.245	6	32.167	30.387	-	0.6331

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
1231C/1231X	1	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.433	0.195	6	0.160	0.145	+	0.3184
1732C/1732X	1	6	0.000	0.000	6	0.087	0.079	-	0.2547	6	0.100	0.100	6	0.140	0.061	-	0.4404
3811C/3611X	1	6	0.000	0.000	6	0.067	0.022	-	0.0108	6	0.323	0.134	6	0.403	0.129	-	0.6630
1231C/1231X	2	6	0.000	0.000	6	0.067	0.040	-	0.0577	6	0.063	0.030	6	0.293	0.094	-	0.0202
1732C/1732X	2	6	0.013	0.013	6	0.243	0.096	-	0.0163	6	0.367	0.150	6	0.367	0.111	o	0.7842
3811C/3611X	2	6	0.033	0.022	6	0.063	0.029	-	0.5005	6	0.343	0.132	6	0.363	0.125	-	0.9659
1231C/1231X	3	6	0.107	0.058	6	0.287	0.057	-	0.0320	6	0.290	0.128	6	0.383	0.052	-	0.3886
1732C/1732X	3	6	0.093	0.040	6	0.307	0.094	-	0.0543	6	0.580	0.133	6	0.417	0.144	+	0.3350
3811C/3611X	3	6	0.147	0.038	6	0.273	0.071	-	0.1404	6	0.343	0.105	6	0.353	0.134	-	0.9785

Table A-17. Fucus Attributes. Herring Bay. Coarse Textured. June 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1451.667	918.928	6	1803.333	531.135	-	0.7472	6	10.000	8.165	6	1.667	1.667	+	0.4738
2834C/2834X	3	6	171.667	80.350	6	161.667	62.526	+	0.9237	6	13.333	9.545	6	16.667	9.189	-	0.8065

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	13.333	6.146	6	0.000	0.000	+	0.0822	6	23.333	8.433	6	1.667	1.667	+	0.0110
2834C/2834X	3	6	21.667	17.966	6	5.000	3.416	+	0.8178	6	38.333	19.394	6	13.333	7.149	+	0.2543

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	13.333	7.601	6	1.667	1.667	+	0.0820	0	--	--	0	--	--		----
2834C/2834X	3	6	16.667	9.888	6	8.333	4.773	+	0.4654	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.060	0.060	6	0.003	0.003	+	1.0000	6	0.390	0.107	6	0.063	0.023	+	0.0090
2834C/2834X	3	6	0.037	0.033	6	0.087	0.061	-	0.6788	6	0.383	0.119	6	0.157	0.070	+	0.1690

Table A-18. Fucus Attributes. Herring Bay. Coarse Textured. July 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1478.333	932.007	6	3048.333	1060.199	-	0.2921	6	13.333	13.333	6	3.333	3.333	+	0.8745
2834C/2834X	3	6	853.333	372.967	6	248.333	123.408	+	0.1546	6	20.000	18.074	6	10.000	5.164	+	0.6063

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	11.667	7.923	6	0.000	0.000	+	0.2009	6	16.667	9.189	6	1.667	1.667	+	0.0754
2834C/2834X	3	6	25.000	25.000	6	3.333	2.108	+	0.8418	6	36.667	17.256	6	10.000	6.325	+	0.1774

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	3.333	2.108	6	1.667	1.667	+	0.5490	0	--	--	0	--	--		----
2834C/2834X	3	6	15.000	9.574	6	1.667	1.667	+	0.2105	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.060	0.060	6	0.003	0.003	+	1.0000	6	0.243	0.100	6	0.050	0.018	+	0.0984
2834C/2834X	3	6	0.040	0.015	6	0.097	0.074	-	0.8550	6	0.247	0.083	6	0.050	0.021	+	0.0468

Table A-19. Fucus Attributes. Herring Bay. Coarse Textured. July 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1525.000	985.365	6	1841.667	591.560	-	0.7885	6	10.000	10.000	6	6.667	6.667	+	0.7872
2834C/2834X	3	6	813.333	351.754	6	356.667	107.197	+	0.2426	6	23.333	21.396	6	26.667	12.561	-	0.8958

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	10.000	6.325	6	0.000	0.000	+	0.1747	6	18.333	9.098	6	0.000	0.000	+	0.1000
2834C/2834X	3	6	18.333	18.333	6	3.333	2.108	+	0.8120	6	38.333	19.734	6	6.667	3.333	+	0.3877

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	0	--	--	0	--	--		----
2834C/2834X	3	6	16.667	12.824	6	1.667	1.667	+	0.2223	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.083	0.079	6	0.007	0.004	+	0.8776	6	0.223	0.084	6	0.040	0.014	+	0.0694
2834C/2834X	3	6	0.023	0.008	6	0.107	0.077	-	0.6038	6	0.177	0.066	6	0.030	0.015	+	0.1218

Table A-20. Fucus Attributes. Herring Bay. Coarse Textured. August 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1551.667	1040.806	6	3541.667	1126.926	-	0.2237	6	10.000	10.000	6	6.667	6.667	+	0.7872
2834C/2834X	3	6	925.000	386.857	6	545.000	243.047	+	0.4250	6	33.333	19.607	6	13.333	7.149	+	0.3605

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	8.333	4.773	6	0.000	0.000	+	0.1412	6	18.333	9.098	6	0.000	0.000	+	0.1000
2834C/2834X	3	6	18.333	18.333	6	3.333	2.108	+	0.8120	6	30.000	16.330	6	5.000	3.416	+	0.4257

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1.667	1.667	6	0.000	0.000	+	0.3632	6	20.000	20.000	6	0.000	0.000	+	0.3632
2834C/2834X	3	6	10.000	8.165	6	0.000	0.000	+	0.2752	6	30.000	26.204	6	0.000	0.000	+	0.3041

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.127	0.105	6	0.160	0.069	-	0.5812	6	0.153	0.053	6	0.050	0.015	+	0.1608
2834C/2834X	3	6	0.010	0.007	6	0.020	0.014	-	0.8210	6	0.127	0.061	6	0.030	0.019	+	0.2306

Table A-21. Fucus Attributes. Herring Bay. Coarse Textured. August 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1665.000	1026.264	6	2860.000	1147.969	-	0.4557	6	8.333	8.333	6	20.000	16.330	-	0.5388
2834C/2834X	3	6	986.667	386.089	6	1480.000	586.299	-	0.4982	6	25.000	17.272	6	31.667	14.472	-	0.7734

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	10.000	6.325	6	0.000	0.000	+	0.1747	6	15.000	7.638	6	0.000	0.000	+	0.1067
2834C/2834X	3	6	18.333	18.333	6	1.667	1.667	+	0.7816	6	30.000	17.512	6	0.000	0.000	+	0.1474

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1.667	1.667	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----
2834C/2834X	3	6	8.333	8.333	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.110	0.110	6	0.067	0.039	+	0.9254	6	0.167	0.072	6	0.047	0.016	+	0.2444
2834C/2834X	3	6	0.007	0.004	6	0.083	0.060	-	0.4616	6	0.120	0.046	6	0.013	0.008	+	0.0672

Table A-22. Fucus Attributes. Herring Bay. Coarse Textured. September 1990.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1423.333	900.732	6	3495.000	1151.251	-	0.1868	6	6.667	6.667	6	5.000	5.000	+	0.8455
2834C/2834X	3	6	965.000	390.100	6	990.000	349.657	-	0.9629	6	30.000	18.439	6	10.000	6.325	+	0.3291

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	13.333	9.545	6	0.000	0.000	+	0.2213	6	16.667	7.601	6	0.000	0.000	+	0.0798
2834C/2834X	3	6	20.000	20.000	6	1.667	1.667	+	0.7758	6	28.333	16.617	6	3.333	2.108	+	0.4073

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1.667	1.667	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----
2834C/2834X	3	6	1.667	1.667	6	0.000	0.000	+	0.3632	0	--	--	0	--	--		----

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.150	0.131	6	0.057	0.049	+	0.6884	6	0.120	0.050	6	0.037	0.014	+	0.2068
2834C/2834X	3	6	0.000	0.000	6	0.107	0.061	-	0.0106	6	0.137	0.063	6	0.020	0.010	+	0.1418

Table A-23. Fucus Attributes. Herring Bay. Coarse Textured. April 1991.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	41.667	41.667	6	2610.000	858.468	-	0.0001	6	3.333	2.108	6	698.333	366.255	-	0.0002
2834C/2834X	3	6	118.333	71.387	6	346.667	203.939	-	0.3155	6	8.333	6.541	6	20.000	16.125	-	0.5177

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	8.333	6.541	6	21.667	12.225	-	0.3589	6	11.667	6.009	6	1.667	1.667	+	0.1399
2834C/2834X	3	6	13.333	13.333	6	3.333	2.108	+	0.7802	6	23.333	9.189	6	3.333	2.108	+	0.1702

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	8.333	4.014	6	0.000	0.000	+	0.0925	6	86.667	50.310	6	0.000	0.000	+	0.1456
2834C/2834X	3	6	11.667	4.014	6	0.000	0.000	+	0.0335	6	163.333	64.842	6	0.000	0.000	+	0.0532

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.107	0.092	6	0.057	0.046	+	0.6210	6	0.150	0.063	6	0.277	0.104	-	0.2720
2834C/2834X	3	6	0.003	0.003	6	0.050	0.036	-	0.4616	6	0.133	0.049	6	0.030	0.010	+	0.1122

Table A-24. Fucus Attributes. Herring Bay. Coarse Textured. June 1991.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	265.000	241.230	6	1108.333	373.385	-	0.0870	6	5.000	3.416	6	620.000	343.540	-	0.0008
2834C/2834X	3	6	351.667	166.582	6	868.333	438.044	-	0.2961	6	10.000	8.165	6	93.333	51.489	-	0.0693

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1.667	1.667	6	85.000	52.773	-	0.1465	6	6.667	2.108	6	0.000	0.000	+	0.0250
2834C/2834X	3	6	15.000	10.247	6	15.000	10.247	o	1.0000	6	16.667	6.667	6	1.667	1.667	+	0.0684

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	3.333	2.108	6	0.000	0.000	+	0.1747	6	128.333	99.814	6	0.000	0.000	+	0.2549
2834C/2834X	3	6	8.333	4.014	6	0.000	0.000	+	0.0925	6	158.333	101.207	6	0.000	0.000	+	0.1785

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.147	0.114	6	0.030	0.030	+	0.4118	6	0.120	0.060	6	0.223	0.118	-	0.5596
2834C/2834X	3	6	0.003	0.003	6	0.097	0.089	-	0.4222	6	0.063	0.037	6	0.043	0.022	+	0.8516

Table A-25. Fucus Attributes. Herring Bay. Coarse Textured. August 1991.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	126.667	112.891	6	950.000	469.879	-	0.0149	6	8.333	6.541	6	668.333	313.671	-	0.0178
2834C/2834X	3	6	326.667	131.825	6	383.333	166.166	-	0.7948	6	6.667	4.944	6	100.000	55.678	-	0.1482

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	326.667	173.890	-	0.1191	6	10.000	4.472	6	1.667	1.667	+	0.1114
2834C/2834X	3	6	11.667	11.667	6	18.333	10.462	-	0.6795	6	13.333	8.819	6	5.000	3.416	+	0.3989

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	5.000	5.000	6	0.000	0.000	+	0.3632	6	76.667	76.667	6	0.000	0.000	+	0.3632
2834C/2834X	3	6	6.667	4.216	6	0.000	0.000	+	0.1747	6	40.000	27.325	6	0.000	0.000	+	0.2031

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.157	0.134	6	0.000	0.000	+	0.4642	6	0.143	0.089	6	0.340	0.131	-	0.2292
2834C/2834X	3	6	0.027	0.016	6	0.083	0.083	-	0.9236	6	0.073	0.038	6	0.073	0.037	o	0.9314

Table A-26. Fucus Attributes. Herring Bay. Coarse Textured. June 1992.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	146.667	121.537	6	353.333	176.667	-	0.3579	6	3.333	3.333	6	406.667	156.539	-	0.0052
2834C/2834X	3	6	21.667	10.776	6	198.333	118.277	-	0.5237	6	0.000	0.000	6	101.667	74.584	-	0.2310

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	10.000	8.165	6	281.667	109.100	-	0.0262	6	0.000	0.000	6	76.667	43.333	-	0.1371
2834C/2834X	3	6	1.667	1.667	6	63.333	47.796	-	0.0616	6	1.667	1.667	6	26.667	14.063	-	0.0647

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	5.000	3.416	-	0.2031	6	0.000	0.000	6	5.000	3.416	-	0.2031
2834C/2834X	3	6	0.000	0.000	6	6.667	3.333	-	0.1019	6	0.000	0.000	6	36.667	27.162	-	0.2349

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.133	0.110	6	0.000	0.000	+	0.0322	6	0.033	0.022	6	0.457	0.137	-	0.0312
2834C/2834X	3	6	0.023	0.010	6	0.047	0.047	-	0.8504	6	0.020	0.013	6	0.110	0.057	-	0.1964

Table A-27. Fucus Attributes. Herring Bay. Coarse Textured. August 1992.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	158.333	125.709	6	208.333	86.387	-	0.7498	6	8.333	8.333	6	291.667	109.496	-	0.0004
2834C/2834X	3	6	51.667	36.002	6	96.667	42.479	-	0.4378	6	0.000	0.000	6	33.333	25.647	-	0.2504

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	6.667	6.667	6	205.000	68.544	-	0.0084	6	1.667	1.667	6	193.333	71.539	-	0.0054
2834C/2834X	3	6	0.000	0.000	6	50.000	36.788	-	0.2322	6	1.667	1.667	6	46.667	23.476	-	0.0554

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.000	0.000	6	0.000	0.000	o	1.0000
2834C/2834X	3	6	0.000	0.000	6	1.667	1.667	-	0.3632	6	0.000	0.000	6	1.667	1.667	-	0.3632

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.153	0.149	6	0.000	0.000	+	0.3632	6	0.017	0.017	6	0.600	0.146	-	0.0024
2834C/2834X	3	6	0.000	0.000	6	0.017	0.017	-	0.8300	6	0.013	0.013	6	0.193	0.131	-	0.0682

Table A-28. Fucus Attributes. Herring Bay. Coarse Textured. June 1993.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	21.667	4.773	6	65.000	44.628	-	0.4601	6	5.000	3.416	6	63.333	24.450	-	0.1376
2834C/2834X	3	6	186.667	184.674	6	81.667	55.222	+	0.5979	6	3.333	3.333	6	10.000	4.472	-	0.2596

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	3.333	3.333	6	58.333	17.013	-	0.0002	6	8.333	6.541	6	118.333	40.531	-	0.0031
2834C/2834X	3	6	0.000	0.000	6	15.000	10.247	-	0.2031	6	0.000	0.000	6	38.333	23.298	-	0.1608

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1.667	1.667	6	33.333	11.450	-	0.0096	6	13.333	13.333	6	141.667	56.179	-	0.0170
2834C/2834X	3	6	0.000	0.000	6	8.333	6.541	-	0.2586	6	0.000	0.000	6	81.667	73.956	-	0.3198

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.163	0.148	6	0.007	0.007	+	0.4250	6	0.050	0.032	6	0.753	0.134	-	0.0030
2834C/2834X	3	6	0.040	0.013	6	0.007	0.004	+	0.0240	6	0.003	0.003	6	0.277	0.119	-	0.0516

Table A-29. Fucus Attributes. Herring Bay. Coarse Textured. September 1993.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	90.000	49.261	6	93.333	93.333	-	0.9754	6	10.000	8.165	6	41.667	24.141	-	0.2424
2834C/2834X	3	6	246.667	234.800	6	56.667	48.831	+	0.8952	6	25.000	25.000	6	15.000	8.062	+	0.7114

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	46.667	16.262	-	0.0350	6	3.333	3.333	6	130.000	41.633	-	0.0001
2834C/2834X	3	6	0.000	0.000	6	20.000	13.663	-	0.2031	6	0.000	0.000	6	46.667	37.208	-	0.2652

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	8.333	4.014	-	0.0925	6	0.000	0.000	6	23.333	13.333	-	0.1405
2834C/2834X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.000	0.000	6	0.000	0.000	o	1.0000

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	0	--	--	0	--	--		----	0	--	--	0	--	--		----
2834C/2834X	3	0	--	--	0	--	--		----	0	--	--	0	--	--		----

Table A-30. Fucus Attributes. Herring Bay. Coarse Textured. May 1994.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

Size Class One (<= 2 cm) density (#/m^2)

Site Pair	MVD	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	243.333	125.928	6	1.667	1.667	+	0.0376
2834C/2834X	3	6	101.667	84.238	6	85.000	49.041	+	0.8676

Size Class Two (2.5-5 cm) density (#/m^2)

Site Pair	N	C	SE	N	O	SE	D	P
2333C/2333X	6	13.333	7.149	6	8.333	8.333	+	0.6586
2834C/2834X	6	20.000	20.000	6	1.667	1.667	+	0.7758

Size Class Three (5.5-10 cm) density (#/m^2)

Site Pair	MVD	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	8.333	5.426	6	20.000	12.910	-	0.4242
2834C/2834X	3	6	1.667	1.667	6	3.333	3.333	-	0.6643

Size Class Four (> 10 cm) density (#/m^2)

Site Pair	N	C	SE	N	O	SE	D	P
2333C/2333X	6	1.667	1.667	6	80.000	22.509	-	0.0001
2834C/2834X	6	0.000	0.000	6	11.667	7.923	-	0.2009

Reproductive plant density (#/m^2)

Site Pair	MVD	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	1.667	1.667	6	41.667	13.017	-	0.0001
2834C/2834X	3	6	0.000	0.000	6	8.333	4.773	-	0.1412

Receptacle density (#/m^2)

Site Pair	N	C	SE	N	O	SE	D	P
2333C/2333X	6	26.667	26.667	6	253.333	86.204	-	0.0308
2834C/2834X	6	0.000	0.000	6	55.000	33.838	-	0.1650

Ephemeral Percent Cover

Site Pair	MVD	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.090	0.086	6	0.000	0.000	+	0.4478
2834C/2834X	3	6	0.013	0.013	5	0.036	0.027	-	0.5678

Fucus Percent Cover

Site Pair	N	C	SE	N	O	SE	D	P
2333C/2333X	6	0.013	0.010	6	0.470	0.075	-	0.0010
2834C/2834X	6	0.003	0.003	5	0.348	0.186	-	0.0132

Table A-31. Fucus Attributes. Herring Bay. Coarse Textured. September 1994.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	90.000	53.166	6	16.667	10.853	+	0.4681	6	11.667	7.491	6	0.000	0.000	+	0.1801
2834C/2834X	3	6	515.000	253.150	6	158.333	105.623	+	0.2227	6	8.333	8.333	6	13.333	11.450	-	0.7314

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	6.667	4.944	6	8.333	4.773	-	0.8133	6	1.667	1.667	6	43.333	9.888	-	0.0001
2834C/2834X	3	6	5.000	5.000	6	0.000	0.000	+	0.3632	6	0.000	0.000	6	16.667	8.028	-	0.0925

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.000	0.000	6	8.333	5.426	-	0.1852	6	0.000	0.000	6	50.000	33.267	-	0.1932
2834C/2834X	3	6	0.000	0.000	6	0.000	0.000	o	1.0000	6	0.000	0.000	6	0.000	0.000	o	1.0000

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.233	0.167	6	0.000	0.000	+	0.0942	6	0.070	0.048	6	0.300	0.044	-	0.0110
2834C/2834X	3	6	0.020	0.016	5	0.148	0.148	-	0.8762	6	0.013	0.013	5	0.192	0.107	-	0.0422

Table A-32. Fucus Attributes. Herring Bay. Coarse Textured. May 1995.
Results of statistical differences between means of oiled and control site pairs. MVD = meter vertical drop; N = sample size; C = control mean; O = oiled mean; SE = standard error; D = direction of difference; + = control > oiled; - = control < oiled; o = control = oiled; P = probability value; dashes = no data.

		Size Class One (<= 2 cm) density (#/m^2)								Size Class Two (2.5-5 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	10.667	5.897	6	0.167	0.167	+	0.0017	6	2.333	1.229	6	0.167	0.167	+	0.1489
2834C/2834X	3	6	22.667	17.183	6	34.500	21.039	-	0.6724	6	1.667	1.476	6	3.000	1.693	-	0.5659

		Size Class Three (5.5-10 cm) density (#/m^2)								Size Class Four (> 10 cm) density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.500	0.500	6	0.167	0.167	+	0.5413	6	0.333	0.211	6	1.000	0.683	-	0.3730
2834C/2834X	3	6	0.833	0.833	6	0.167	0.167	+	0.7460	6	0.167	0.167	6	0.333	0.333	-	0.6643

		Reproductive plant density (#/m^2)								Receptacle density (#/m^2)							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.333	0.211	6	0.333	0.211	o	1.0000	6	12.333	11.363	6	0.833	0.654	+	0.5975
2834C/2834X	3	6	0.000	0.000	6	0.167	0.167	-	0.3632	6	0.000	0.000	6	7.500	7.500	-	0.3632

		Ephemeral Percent Cover								Fucus Percent Cover							
Site Pair	MVD	N	C	SE	N	O	SE	D	P	N	C	SE	N	O	SE	D	P
2333C/2333X	3	6	0.160	0.137	6	0.000	0.000	+	0.2040	6	0.073	0.058	6	0.137	0.042	-	0.1724
2834C/2834X	3	6	0.013	0.008	5	0.028	0.028	-	0.9112	6	0.013	0.013	5	0.016	0.012	-	0.6768

Appendix B-1. Mean (± standard error) number of *Fucus* eggs per plate at all site pairs and all MVDs during summer months from 1991 to 1995. Significance (Sig) is indicated by asterisks: 1 asterisk=p<0.05; 2 asterisks=p<0.01; and 3 asterisks=p<0.001.

			0.5 MVD			1.0 MVD			2.0 MVD		
Site Pair	Year	Month	Control	Oiled	Sig	Control	Oiled	Sig	Control	Oiled	Sig
1221C 1221X	1991	May	4.38 (0.60)	1.00 (0.18)	**	9.94 (3.53)	2.13 (0.46)		4.88 (3.11)	10.81 (6.60)	
		June	54.06 (18.96)	1.00 (0.53)	***	27.38 (6.77)	0.50 (0.42)	***	91.75 (44.78)	13.88 (7.43)	*
		July	25.06 (8.33)	0.06 (0.06)	***	4.81 (2.11)	0.13 (0.07)	***	0.88 (0.13)	0.13 (0.07)	
	1992	May	19.92 (14.11)	0.08 (0.08)	***	63.42 (22.57)	0.75 (0.32)	***	12.75 (5.89)	3.25 (1.34)	
		June	106.75 (38.43)	1.58 (1.26)	***	56.83 (13.54)	0.58 (0.25)	***	19.83 (10.77)	1.00 (0.43)	*
		July	63.92 (31.25)	0.17 (0.17)	***	48.25 (17.77)	0.08 (0.08)	**	37.42 (11.00)	0.00 (0.00)	***
	1993	June	83.50 (44.97)	8.67 (2.67)	***	23.50 (22.51)	8.00 (2.92)		5.00 (1.14)	5.75 (1.76)	
		July	3.08 (2.35)	0.25 (0.14)		1.50 (1.01)	0.00 (0.00)		0.92 (0.70)	0.50 (0.35)	
	1994	May	14.08 (4.86)	3.58 (1.11)		9.83 (1.69)	32.17 (10.24)		29.58 (19.28)	60.42 (27.98)	
		June	26.25 (14.69)	0.83 (0.29)	***	61.92 (52.14)	9.58 (3.68)		4.00 (2.45)	12.83 (5.58)	
		Aug.	128.58 (41.55)	9.92 (2.86)	***	99.50 (80.54)	23.25 (7.03)		42.58 (34.30)	41.42 (12.80)	
		Sept.	67.83 (32.83)	2.75 (0.73)	***	41.67 (28.07)	32.33 (25.47)		7.08 (2.48)	5.83 (1.46)	
	1995	May	0.17 (0.10)	0.17 (0.17)		0.08 (0.08)	0.08 (0.08)		10.00 (3.59)	1.00 (0.59)	*
		June	1.75 (0.55)	17.17 (13.19)		22.67 (7.78)	9.92 (2.70)		28.25 (19.67)	3.42 (1.44)	*
		July	4.83 (2.58)	0.00 (0.00)		6.92 (2.71)	0.92 (0.81)		19.67 (7.51)	0.33 (0.24)	***
		Aug.	2.75 (0.73)	0.42 (0.32)	*	9.17 (4.88)	0.17 (0.17)	***	0.42 (0.21)	0.17 (0.10)	

Appendix B-1. Cont.

Site Pair	Year	Month	0.5 MVD Control	0.5 MVD Oiled	0.5 MVD Sig	1.0 MVD Control	1.0 MVD Oiled	1.0 MVD Sig	2.0 MVD Control	2.0 MVD Oiled	2.0 MVD Sig
1222C 1322X	1991	May	1.63 (1.18)	0.38 (0.30)		4.50 (2.18)	0.88 (0.88)		4.06 (1.12)	16.06 (14.99)	
		June	16.31 (5.04)	0.25 (0.18)	***	27.06 (7.32)	0.63 (0.16)	***	86.25 (23.39)	4.63 (4.05)	***
		July	18.75 (3.41)	0.06 (0.06)	***	5.69 (1.02)	0.06 (0.06)	***	3.56 (0.72)	0.69 (0.31)	***
	1992	May	9.00 (3.12)	0.17 (0.17)	*	22.33 (9.25)	0.50 (0.32)	***	1.83 (0.10)	6.58 (1.94)	
		June	22.92 (6.77)	0.58 (0.21)	***	23.00 (6.43)	0.58 (0.34)	**	5.50 (1.21)	3.58 (3.05)	
		July	14.08 (4.79)	0.08 (0.08)	***	16.17 (9.90)	1.92 (1.27)		0.83 (0.52)	0.58 (0.21)	
	1993	June	257.17 (58.04)	26.42 (13.31)	***	59.17 (30.58)	21.08 (7.01)		11.50 (0.91)	30.83 (13.07)	
		July	8.50 (7.51)	0.25 (0.25)	*	1.00 (0.27)	0.00 (0.00)		1.00 (0.33)	2.00 (1.08)	
	1994	May	38.92 (14.73)	1.08 (0.37)	**	46.08 (33.85)	20.25 (11.51)		31.67 (15.29)	52.25 (22.88)	
		June	50.92 (19.21)	1.83 (0.10)	***	39.83 (27.64)	16.92 (7.73)		20.67 (9.34)	24.38 (8.35)	
		Aug.	391.92 (137.42)	31.25 (19.38)	***	45.67 (8.54)	59.25 (6.92)		24.17 (6.65)	28.33 (2.06)	
		Sept.	163.67 (115.02)	6.67 (3.24)	***	51.75 (13.77)	67.83 (48.44)		11.17 (2.85)	10.58 (5.97)	
	1995	May	0.58 (0.29)	0.83 (0.22)		0.75 (0.21)	0.67 (0.30)		23.83 (7.98)	33.83 (15.39)	
		June	94.25 (24.69)	2.00 (0.49)	***	39.75 (11.69)	18.75 (5.11)		11.42 (6.64)	6.92 (2.84)	
		July	2.83 (2.01)	5.33 (3.62)		0.25 (0.16)	7.58 (5.07)		0.25 (0.16)	4.33 (3.46)	
		Aug.	12.17 (3.49)	10.08 (2.51)		0.92 (0.58)	18.83 (10.03)	***	0.75 (0.34)	3.25 (1.07)	

Appendix B-1. Cont.

Site Pair	Year	Month	0.5 MVD Control	0.5 MVD Oiled	0.5 MVD Sig	1.0 MVD Control	1.0 MVD Oiled	1.0 MVD Sig	2.0 MVD Control	2.0 MVD Oiled	2.0 MVD Sig
1231C 1231X	1991	May	3.94 (2.89)	0.00 (0.00)		2.19 (1.04)	0.00 (0.00)		0.50 (0.18)	0.25 (0.10)	
		June	132.63 (118.20)	0.13 (0.07)	***	29.19 (15.74)	0.88 (0.48)	***	9.19 (6.20)	0.75 (0.32)	*
		July	80.56 (72.05)	0.13 (0.07)	***	31.06 (15.04)	0.06 (0.06)	***	2.31 (0.45)	0.31 (0.06)	***
1312C 1312X	1992	May	93.25 (33.81)	4.75 (1.32)		247.25 (58.71)	3.00 (0.59)	***	17.67 (7.79)	3.58 (2.63)	*
		June	181.25 (75.54)	0.83 (0.22)	***	135.75 (52.95)	4.17 (2.06)	**	19.75 (6.70)	6.42 (2.05)	
		July	262.42 (108.47)	0.08 (0.08)	***	93.50 (32.04)	2.33 (1.80)	**	11.08 (3.36)	0.42 (0.21)	***
1732C 1732X	1993	June	141.08 (67.73)	0.75 (0.29)	***	162.92 (55.64)	14.08 (6.01)	*	11.17 (3.59)	10.75 (3.19)	
		July	17.25 (16.25)	0.50 (0.29)		5.75 (4.32)	1.17 (0.95)		0.92 (0.21)	4.92 (2.13)	
3C 3X	1994	June	20.42 (7.81)	1.67 (0.54)	***	38.17 (23.53)	6.25 (3.98)	*	8.33 (1.01)	11.75 (6.49)	
		Aug.	53.08 (23.32)	4.67 (1.93)	***	12.33 (0.81)	6.92 (0.90)		10.92 (2.58)	7.17 (1.84)	
		Sept.	7.50 (2.74)	1.50 (1.28)	*	4.00 (0.90)	0.75 (0.37)	*	2.92 (0.88)	1.17 (0.48)	
5C 5X	1995	May	17.50 (14.99)	12.50 (5.48)		27.92 (19.12)	6.75 (2.88)		21.17 (11.45)	4.92 (1.72)	
		June	43.33 (20.14)	5.25 (1.98)	*	110.50 (83.19)	53.67 (16.00)		13.08 (7.47)	25.33 (11.21)	
		July	1.25 (0.58)	3.50 (2.37)		1.00 (0.36)	11.83 (6.44)	*	0.67 (0.36)	82.58 (32.45)	***
		Aug.	47.33 (21.34)	0.42 (0.25)	**	47.08 (30.36)	2.42 (2.20)	***	0.83 (0.32)	1.25 (0.55)	

Appendix B-1. Cont.

Site Pair	Year	Month	0.5 MVD Control	0.5 MVD Oiled	0.5 MVD Sig	1.0 MVD Control	1.0 MVD Oiled	1.0 MVD Sig	2.0 MVD Control	2.0 MVD Oiled	2.0 MVD Sig
1723C 1723X	1991	May	0.25 (0.18)	0.06 (0.06)		0.00 (0.00)	0.06 (0.06)		0.19 (0.12)	0.63 (0.38)	
		June	21.44 (6.26)	0.50 (0.18)	***	35.25 (12.15)	1.94 (1.20)	***	7.88 (3.03)	14.69 (11.31)	
		July	22.44 (13.02)	0.13 (0.07)	***	14.50 (6.49)	0.38 (0.07)	***	3.63 (0.87)	0.38 (0.38)	***
1411C 1311X	1992	May	554.92 (265.50)	3.17 (2.73)	***	768.83 (168.43)	10.08 (7.77)	***	93.08 (40.27)	9.58 (3.93)	*
		June	126.83 (80.33)	0.25 (0.16)	***	131.17 (28.61)	4.00 (2.09)	**	12.42 (2.77)	3.75 (1.98)	
		July	612.33 (514.84)	0.67 (0.30)	***	62.00 (23.16)	4.83 (2.54)	**	8.83 (2.86)	0.75 (0.29)	***
1713C 1713X	1993	June	96.08 (63.54)	0.75 (0.08)	***	74.33 (22.89)	116.58 (58.51)		17.50 (7.18)	16.25 (12.94)	
		July	11.50 (5.32)	0.08 (0.08)	***	2.75 (0.69)	5.08 (2.36)		1.08 (0.44)	1.67 (1.67)	
4C 4X	1994	June	38.00 (15.88)	0.58 (0.25)	***	86.00 (32.20)	1.33 (0.49)	***	48.25 (28.16)	7.67 (2.45)	*
		Aug.	31.33 (19.74)	6.67 (1.89)		2.50 (0.67)	3.50 (1.00)		4.42 (1.32)	6.00 (2.82)	
		Sept.	46.58 (39.30)	1.29 (0.61)	***	6.08 (2.89)	1.25 (0.50)		3.83 (0.95)	2.25 (1.40)	
6C 6X	1995	May	309.08 (72.20)	2.83 (1.85)	***	175.17 (51.98)	5.58 (3.40)	***	326.75 (162.98)	257.21 (108.00)	
		June	359.17 (126.29)	1.33 (0.45)	***	65.08 (23.47)	46.00 (37.41)		9.00 (2.27)	8.58 (4.94)	
		July	9.33 (5.54)	0.00 (0.00)		2.17 (1.42)	1.67 (1.05)		8.08 (6.88)	0.58 (0.48)	*
		Aug.	302.83 (147.35)	12.08 (6.81)	*	172.25 (67.84)	31.33 (10.06)		34.25 (13.06)	4.08 (1.11)	*

Appendix B-2. Mean distance (± standard error) from the egg catcher plate to the nearest fertile *Fucus* plant at all site pairs and all MVDs during summer months from 1991 to 1993. Significance (Sig) is indicated by asterisks: 1 asterisk=$p<0.05$; 2 asterisks=$p<0.01$; and 3 asterisks=$p<0.001$. Distances are in centimeters.

			0.5 MVD			1.0 MVD			2.0 MVD		
Site Pair	Year	Month	Control	Oiled	Sig	Control	Oiled	Sig	Control	Oiled	Sig
1221C 1221X	1991	July	7.38 (0.90)	141.25 (50.43)	***	35.00 (15.24)	74.25 (30.54)		24.50 (8.03)	35.00 (16.58)	
	1992	May	20.50 (7.71)	49.50 (14.56)		21.50 (4.72)	23.75 (6.26)		21.25 (1.97)	19.00 (2.94)	
		June	21.75 (7.43)	47.00 (13.45)	*	23.50 (4.25)	19.75 (2.69)		28.25 (5.66)	24.50 (7.90)	
		July	18.75 (7.08)	57.25 (19.09)	*	23.75 (5.56)	19.75 (3.42)		30.50 (6.08)	54.50 (17.59)	
	1993	June	12.00 (0.91)	23.25 (17.26)		27.50 (4.77)	18.25 (3.57)		21.75 (6.91)	30.00 (11.80)	
		July	14.00 (2.48)	25.50 (16.66)		35.25 (11.36)	21.50 (4.92)		58.50 (7.51)	76.00 (46.47)	
	1994	May	9.25 (1.76)	38.30 (9.30)	**	18.88 (8.08)	9.88 (1.97)		20.13 (5.61)	9.75 (3.13)	
		Aug.	11.13 (3.32)	51.88 (12.23)	***	33.25 (15.14)	9.25 (2.39)	*	31.25 (11.67)	10.13 (2.78)	
		Sept.	11.63 (3.47)	53.00 (12.42)	***	33.38 (15.64)	19.00 (8.16)		38.25 (13.00)	10.63 (2.98)	
	1995	May	22.25 (6.61)	19.00 (6.73)		10.75 (0.85)	15.00 (7.25)		15.75 (4.39)	25.25 (6.61)	
		June	22.00 (6.61)	12.75 (4.21)		10.50 (1.32)	15.25 (7.18)		14.00 (1.58)	31.00 (5.29)	*
		July	23.75 (6.51)	17.50 (3.78)		11.00 (1.29)	35.50 (18.18)		27.50 (1.19)	43.00 (11.15)	
		Aug.	23.00 (7.31)	16.50 (4.94)		9.75 (1.25)	36.50 (17.31)	*	23.75 (2.10)	72.00 (6.36)	**

Appendix B-2. Cont.

Site Pair	Year	Month	0.5 MVD Control	0.5 MVD Oiled	0.5 MVD Sig	1.0 MVD Control	1.0 MVD Oiled	1.0 MVD Sig	2.0 MVD Control	2.0 MVD Oiled	2.0 MVD Sig
1222C 1322X	1991	July	13.50 (1.44)	308.75 (96.19)	***	11.25 (3.64)	203.50 (119.04)	***	9.50 (2.10)	219.25 (103.63)	***
	1992	May	8.50 (2.33)	109.75 (34.26)	**	13.00 (2.27)	75.25 (44.88)	*	32.00 (5.11)	31.75 (17.21)	
		June	9.50 (1.32)	124.00 (46.14)	***	18.75 (3.47)	72.50 (48.07)		44.75 (6.54)	65.50 (23.56)	
		July	8.50 (0.29)	115.00 (34.22)	***	15.75 (4.97)	64.25 (33.89)	*	44.00 (7.27)	38.75 (10.62)	
	1993	June	8.38 (3.87)	24.25 (6.24)		17.50 (5.14)	11.50 (2.53)		43.00 (13.82)	11.00 (2.74)	*
		July	26.50 (8.91)	30.75 (11.50)		49.25 (8.29)	11.00 (2.08)	***	120.25 (22.66)	31.00 (20.13)	***
	1994	May	11.00 (3.16)	29.50 (4.87)	*	11.75 (4.97)	8.25 (2.50)		26.63 (1.28)	7.75 (4.34)	**
		Aug.	11.00 (3.16)	29.50 (4.87)	*	20.00 (9.12)	10.63 (4.53)		30.88 (5.14)	15.63 (8.25)	
		Sept.	14.63 (5.38)	30.75 (5.31)		20.38 (9.42)	9.50 (2.94)		29.75 (7.00)	41.88 (15.48)	
	1995	May	12.00 (2.35)	19.25 (7.38)		8.50 (2.40)	15.25 (3.59)		11.00 (3.94)	14.00 (4.26)	
		June	12.00 (2.35)	25.00 (7.20)		8.75 (2.43)	15.75 (3.77)		19.75 (3.68)	8.50 (2.78)	
		July	20.50 (3.30)	30.50 (6.85)		16.50 (1.44)	25.75 (4.05)		43.00 (4.88)	35.75 (8.89)	
		Aug.	17.00 (4.30)	29.00 (7.08)		13.00 (0.71)	23.25 (2.43)		67.50 (16.49)	38.50 (4.57)	

Appendix B-2. Cont.

Site Pair	Year	Month	0.5 MVD Control	0.5 MVD Oiled	0.5 MVD Sig	1.0 MVD Control	1.0 MVD Oiled	1.0 MVD Sig	2.0 MVD Control	2.0 MVD Oiled	2.0 MVD Sig
1231C 1231X	1991	July	25.75 (10.77)	216.50 (58.47)	***	67.00 (41.01)	149.75 (51.79)		73.00 (18.66)	167.50 (54.52)	
1312C 1312X	1992	May	8.13 (1.74)	108.50 (41.21)	**	14.75 (3.82)	74.25 (47.52)	*	40.38 (6.79)	37.75 (2.59)	
		June	9.00 (1.73)	68.00 (8.09)	***	15.75 (3.50)	44.00 (17.29)		50.00 (3.14)	35.25 (3.57)	
		July	10.25 (1.25)	105.50 (35.97)	***	13.50 (3.88)	68.25 (29.48)	**	36.00 (6.75)	55.00 (6.36)	
1732C 1732X	1993	June	7.50 (2.06)	45.75 (6.86)	***	13.25 (0.25)	16.50 (1.85)		36.50 (16.46)	8.75 (3.47)	*
		July	9.25 (1.97)	52.50 (20.53)	*	13.00 (0.58)	33.25 (4.50)	***	43.25 (16.90)	23.00 (13.98)	
3C 3X	1994	Aug.	16.38 (1.70)	16.75 (3.22)		30.38 (8.22)	8.63 (1.93)		13.63 (2.25)	27.00 (3.76)	*
		Sept.	16.50 (1.77)	17.13 (4.05)		28.25 (10.05)	15.38 (5.48)		19.38 (3.65)	27.00 (10.41)	
5C 5X	1995	May	11.00 (3.34)	42.00 (5.58)	***	33.00 (15.12)	13.00 (4.02)	*	28.00 (9.26)	10.00 (3.03)	*
		June	10.00 (3.39)	46.25 (10.06)	***	36.50 (17.45)	12.00 (2.97)	*	25.75 (10.26)	9.75 (2.56)	*
		July	12.25 (5.76)	49.75 (10.08)	***	40.50 (13.38)	15.50 (4.41)		31.00 (8.44)	19.50 (5.55)	
		Aug.	12.75 (5.44)	58.75 (10.91)	???	39.75 (12.64)	22.25 (5.47)		39.00 (12.06)	19.50 (7.35)	

Appendix B-2. Cont.

Site Pair	Year	Month	0.5 MVD Control	0.5 MVD Oiled	0.5 MVD Sig	1.0 MVD Control	1.0 MVD Oiled	1.0 MVD Sig	2.0 MVD Control	2.0 MVD Oiled	2.0 MVD Sig
1723C 1723X	1991	July	27.75 (6.34)	204.75 (13.77)	***	20.50 (9.85)	88.50 (26.33)		59.50 (15.24)	118.75 (15.96)	
1411C 1311X	1992	May	25.50 (6.95)	131.50 (19.89)	**	16.25 (3.33)	66.50 (15.63)	*	29.50 (12.18)	34.00 (9.41)	
		June	31.25 (7.33)	117.50 (25.07)	**	16.75 (2.50)	65.75 (16.46)	*	45.25 (10.96)	49.50 (16.80)	
		July	27.00 (7.29)	142.00 (25.73)	***	17.25 (2.29)	71.00 (21.95)	*	60.00 (9.50)	57.00 (19.82)	
1713C 1713X	1993	June	23.50 (10.88)	37.00 (10.64)		15.00 (3.54)	13.25 (1.70)		18.75 (2.66)	20.75 (3.64)	
		July	28.50 (12.91)	42.75 (6.98)		14.75 (3.77)	13.25 (3.15)		46.00 (18.55)	27.00 (6.77)	
4C 4X	1994	Aug.	11.00 (2.88)	21.13 (8.60)		19.38 (6.23)	25.00 (6.44)		19.38 (3.72)	25.38 (2.19)	
		Sept.	14.75 (3.72)	22.13 (8.79)		31.63 (9.33)	29.75 (6.65)		35.63 (10.79)	32.25 (3.54)	
6C 6X	1995	May	13.25 (3.50)	22.50 (6.24)		12.00 (4.56)	6.75 (2.43)		23.00 (2.38)	8.00 (4.71)	
		June	12.25 (2.81)	26.25 (6.93)		19.75 (7.76)	7.00 (3.03)		25.50 (1.44)	9.50 (5.85)	*
		July	17.25 (1.80)	66.00 (16.97)	***	22.00 (8.73)	12.75 (4.46)		26.75 (0.75)	35.50 (11.75)	
		Aug.	15.75 (3.90)	23.25 (7.98)	???	19.25 (7.50)	10.75 (3.95)		27.25 (1.60)	40.25 (7.87)	