Exxon Valdez Oil Spill
Restoration Project Final Report

The Effects of the *Exxon Valdez* Oil Spill on Shallow Subtidal Communities in Prince William Sound, Alaska, 1989-93

Restoration Project 93047
(Subtidal Study Number 2A)
Final Report

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Study History: Restoration Project 93047 was initiated in 1989 as Coastal Habitat Study Number 1 through the U.S.D.A. Forest Service (Comprehensive Assessment of Injury to Coastal Habitats), continued in 1990 as Air/Water Study Number 2 through Alaska Department of Fish and Game (Petroleum Hydrocarbon-Induced Injury to Subtidal Sediment Resources), and was reclassified in 1991 as Subtidal Study Number 2 (Injury to Benthic Communities), which had distinct shallow tidal and subtidal project objectives. In 1992, the two elements were split into separate projects numbers 2A (Injury to Shallow Benthic Communities) and 2B (Deep Water Benthos). In 1993, the project effort continued under Restoration Project 93047 (Subtidal Monitoring: Recovery of Sediments, Hydrocarbon-degrading Microorganisms, and Eelgrass Communities in the Shallow Subtidal Environment). The final report included herein presents a comprehensive analysis of results from 1989-93 with emphasis on the eelgrass community. No field activities were conducted in 1992 and 1994. Additional sampling of eelgrass habitat will occur under Restoration Projects 95106 and 96106. Scientific manuscripts that have emerged thus far from this study include: (1) Dean, T.A., L. McDonald, M.S. Stekoll, and R.R. Rosenthal. 1993. Damage Assessment in Coastal Habitats: Lessons Learned from *Exxon Valdez*. pp. 695-697. Proc. of 1993 Int. Oil Spill Conf., Mar. 29-Apr. 1, 1993. Am. Petrol. Inst., Washington , D. C.; (2) Dean, T.A., S.C. Jewett, D.R. Laur, and R.O. Smith. In press. Injury of Epibenthic Invertebrates Resulting from the *Exxon Valdez* Oil Spill. *Exxon Valdez* Oil Spill Symp. Proc., Am. Fish. Soc. Symp. Ser.; (3) Dean, T.A., M.S. Stekoll, R.O. Smith. In press. Kelps and Oil: The Effects of the *Exxon Valdez* Oil Spill on Subtidal Algae. *Exxon Valdez* Oil Spill Symp. Proc., Am. Fish. Soc. Symp. Ser.; (4) Dean, T.A., M.S. Stekoll, S.C. Jewett, R.O. Smith, and J.E. Hose. In Submission. Eelgrass (Zostera marina) in Prince William Sound, Alaska: Effects of the *Exxon Valdez* Oil Spill. Mar. Ecol. Prog. Ser.; (5) Jewett, S.C. 1993. Biological Effects of the *Exxon Valdez* Oil Spill: Coastal Habitat: Shallow Subtidal Regions. Alaska's Wildl. 25(1):22-23; and (6) Jewett, S.C., T.A. Dean, and D.R. Laur. In press. The Effects of the *Exxon Valdez* Oil Spill on Benthic Invertebrates in an Oxygen-Deficient Embayment in Prince William Sound, Alaska. *Exxon Valdez* Oil Spill Symp. Proc., Am. Fish. Soc. Symp. Ser.; (7) Laur, D.R. and L. Haldorson. In press. Coastal Habitat Studies: The Effects of the *Exxon Valdez* Oil Spill on Shallow Subtidal Fishes in Prince William Sound. *Exxon Valdez* Oil Spill Symp. Proc., Am. Fish. Soc. Symp. Ser.

Abstract: Injuries to several of the dominant taxa in the nearshore subtidal community were observed in the heavily oiled portions of western Prince William Sound following the *Exxon Valdez* oil spill of March 1989. The initial effects were most pronounced in more protected eelgrass and silled fjord habitats, where PAH (polycyclic aromatic hydrocarbon) concentrations in sediments exceeded 1000 ng g-1 in 1990. The taxa impacted most included eelgrass, infaunal amphipods, several infaunal mollusks, helmet crabs, and leather stars. All were more abundant at unoiled control sites than at oiled sites in 1990. Several opportunistic or stress-tolerant infaunal species, several of the dominant suspension-feeding epifaunal taxa, and several fish species that feed on these epifauna were more prevalent in oiled areas. By 1993, PAH concentrations in sediments declined to less than 100 ng g-1, and there were far fewer differences between oiled and control sites with respect to the abundance of dominant plant, invertebrate, and fish taxa. However, not all taxa had recovered fully. Within eelgrass beds, there was still evidence of organic enrichment of sediments as indicated by greater infaunal abundance at oiled sites, and some large epibenthic invertebrates were still more abundant at control sites.

Key Words: Eelgrass, epifauna, *Exxon Valdez*, infauna, oil spill, Prince William Sound, subtidal.

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PREFACE

This report is a complete presentation of all subtidal invertebrate and plant studies conducted by the University of Alaska since 1989. As such, much of the material has been presented previously. In the interest of those persons that have read and reviewed earlier documents, we herein offer a guide to the new or updated material that is included since our last report of December 1993.

The following are sections of the report that present new information or are substantially revised from the previous reports:

3.0 Methods

- 3.9 Hemosiderosis of Fishes
- 3.10 Experimental Studies with *Musculus*

4.0 Results

- 4.1 Effects on Plants
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- 4.2 Infaunal and Epifaunal invertebrates
- 4.3 Large Epibenthic Invertebrates
- 4.4 Fishes (pages 63 and 64 only)
- 4.5 Experimental Studies with *Musculus*
- 4.6 Results from Hydrocarbon Analyses

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- 5.4 Hydrocarbon Levels and their Relation to Observed Effects
- 5.5 Causes for Observed Effects
- 5.7 Recovery of Subtidal Communities

EXECUTIVE SUMMARY

This report examined injury to, and recovery of, shallow (< 20 m) subtidal communities within Prince William Sound following the *Exxon Valdez* oil spill. Injury was assessed primarily by examining differences in population parameters (eg. abundance, biomass) of dominant taxa within several subtidal habitats.

In 1990, we noted significant differences between oiled and control sites with respect to a number of taxa. Effects were especially evident in more sheltered bays where either laminarian algae (on hard substrates) or eelgrass (on soft substrates) dominated. Among the differences noted were greater densities of eelgrass flowers and shoots, greater densities of amphipods and trochid snails, and greater densities of crabs (*Telemessus*) and some sea stars (*Dermasterias*), at the control sites. Other taxa, including small epifaunal mussels (*Musculus*) and spirorbid worms, a variety of infaunal polychaetes, and juvenile cod were more abundant at oiled sites.

The infaunal benthic community within the deeper portion (3 to 20 m) of the eelgrass habitat appeared especially affected by the spill, as there was a decline in diversity as well as reductions in a number of dominant taxa. On the other hand, the benthic community in shallower portions of the habitat, within the eelgrass bed, showed a general enhancement of both diversity and abundance of several dominant taxa. The notable exception was for amphipods, which declined in all habitats.

We also noted an abundance of dead animals within a fjord in Herring Bay in 1989. By 1990, the community at this site was reduced from the over 20 taxa observed in 1989 to 6 taxa in 1990, and the system was almost totally dominated by one polychaete (*Nephtys cornuta*). The benthic community within the fjord recovered in 1991, but then declined again in 1993. The decline observed in 1993 was associated with low oxygen levels. This brings into question whether the decline in 1990 within this habitat was due to oil, naturally occurring low oxygen levels, or a combination of these factors.

Polycyclic aromatic hydrocarbon (PAH) levels were generally higher at oiled than control sites. The highest PAH levels observed were greater than 1000 ng g-1 in the Herring Bay fjord and at several eelgrass sites in 1990. PAH levels declined to less than 100 ng g^{-1} in 1993, but were still somewhat higher at oiled sites.

Many of the observed effects appeared related to the effects of oil. The reduction in the abundance of amphipods may have been due to the acute toxicity of oil. However, most other declines in population density were probably related to either the sublethal effects of oil or to indirect effects such as increased predation. Increased abundance of most taxa at oiled sites appeared related, either directly or indirectly, to organic enrichment from either oil or from bioremediation.

primarily small epifauna (eg. *Musculus*) and a number of infaunal polychaete families. Most of the taxa that continued to be more abundant at oiled sites are either opportunistic or tolerant taxa that respond favorably to organic enrichment.

The Effects of the *Exxon Valdez* Oil Spill on Shallow Subtidal Communities in Prince William Sound, Alaska 1989-1993

1.0 INTRODUCTION

1.1 Background

The shallow subtidal habitat of Prince William Sound, from the intertidal zone to depths of approximately 20 m, typically has dense macrophyte (algal) assemblages, and is a critical habitat for many commercially and ecologically important animals (Rosenthal *et al.*, 1977; Rosenthal, 1980; Feder and Jewett, 1987). The region is most noted as a nursery for salmon, king crab, Dungeness crab, and some pandalid shrimps, the spawning grounds for Pacific herring, and the feeding grounds for sea otters, river otters and many marine birds. As primary producers, the benthic marine macrophytes are probably at least as important as the transient phytoplankton blooms. Seaweeds are a main source of food for several marine invertebrates, including sea urchins and crabs, and provide a food source for detrital-based food webs in the deeper subtidal zone. Subtidal eelgrass and algal beds are extremely important feeding grounds for migratory waterfowl (McConnaughey and McRoy, 1979) and pigeon guillemots (Kuletz, 1983). These shallow subtidal regions typically contain numerous polychaete worms, small snails and clams, amphipods, copepods, isopods, sea urchins, and sea stars, many of which serve as food for coastal-feeding otters, birds, fishes, crabs and shrimps (see review in Feder and Jewett, 1981, 1987; Hogan and Irons, 1988; McRoy, 1988).

It was expected that a certain proportion of oil from the spill (either the original oil from surface waters, oil leached from contaminated shorelines, and/or oil dispersed into receiving waters via shoreline remediation procedures) would reach the bottom by physical and biological processes. Shallow subtidal data collected in polluted waters elsewhere indicate that changes in species number, abundance, biomass, and diversity occur if sizable quantities of oil flow to the bottom (e.g., Cabioch *et al.*, 1978; Kineman *et al.*, 1980; and Sanders *et al.*, 1980). Changes in composition of benthic fauna and flora can have serious trophic implications. Further, the larvae of most benthic organisms in Prince William Sound move into the water column (March through June) and are utilized as food by large zooplankters and larval and juvenile stages of pelagic fishes, salmon fry, and herring. Thus, damage to the benthic system by hydrocarbon contamination could affect feeding interactions of important species in the water column, as well as on the bottom.

1.2 History of the Project

The subtidal Coastal Habitat Program was initiated in late summer 1989. Shortly after approval of the project by the Management Team, logistic arrangements were made, and a shakedown/training cruise was conducted. An initial subtidal survey was conducted in Prince William Sound in October, 1989. Effects on plants, invertebrates, and fishes were evaluated in sheltered rocky habitats at 5 sites (a subset of those visited by Coastal Habitat intertidal sampling team).

The October 1989 sampling program indicated that, in general, the sampling design and the site selection process used in the initial surveys were not adequate to detect statistically significant effects on subtidal organisms. A major problem was the variance among sites, especially as related to fresh water input at sites (all controls) on the mainland portion of the Sound. As a result, changes were made to the study plan for 1990. Sampling continued in the spring and summer of 1991 and 1993, at a subset of sites visited in 1990. No sampling occurred in 1992 and 1994.

1.3 Overview of the Study Design

In 1990, we concentrated our sampling and experimental efforts on selected habitat types, chosen based on the relative ecological importance of these habitats, their risk to damage from oil, and on their proportion of total habitat in the oiled area. All studies were conducted at oiled sites and control sites that were matched to the oiled sites with regard to geomorphology, degree of freshwater input, substrate type, and general circulation and wave exposure regimes. A similar design was used in 1991 and 1993, except that only a subset of those sites sampled in 1990 was visited in 1991 and 1993.

All studies were conducted within Prince William Sound (PWS). We excluded other areas (Kenai and Kodiak/Alaska Peninsula regions) because we anticipated that effects were greatest within PWS and because of the logistical and monetary constraints.

1.4 Report Organization

This report summarizes the subtidal data collected in 1989, 1990, 1991, and 1993. Emphasis is on the latter three years. The results section of the report is organized around different taxonomic groupings (plants, epibenthic invertebrates, infaunal invertebrates, and fishes) and further subdivided according to habitat (eelgrass, *Laminaria/Agarum* habitats in island bays, *Laminaria/Agarum* habitats on island points, and in *Nereocystis* habitats along relatively exposed coastlines).

2.0 OBJECTIVES

This study examined injury to, and recovery of shallow (< 20 m) subtidal communities of plants, invertebrates, and fishes, within Prince William Sound, Alaska that resulted from the *Exxon Valdez* oil spill.

3.0 METHODS

3.1 Sampling Design

3.1.1 Stratified Random Sampling at Oiled and Control Sites

Rationale

For most of our studies on the subtidal communities, we used a stratified random sampling design in order to determine the effects of the spill. We measured population parameters (e.g. abundance, biomass, diversity, reproductive success) for the dominant plant, invertebrate, and fish species at both oiled and control sites within 4 specified habitats: Eelgrass (*Zostera marina*) beds, *Laminaria/Agarum* beds (areas where either *Laminaria saccharina* or *Agarum cribrosum* dominate) both in bays and on points within the Knight Island archipelago, and *Nereocystis* beds. These strata were defined with respect to dominant plants, physiography, and location within the Sound in order to insure that variance due to factors other than oil was minimized, thereby increasing the power to detect differences among oiled and control sites.

We selected habitat types primarily based on the dominant vegetation type. The dominant vegetation at a particular site is generally determined by a suite of important environmental factors (e.g., substrate type, salinity, water motion). Therefore, we could indirectly assess the physical environment by assessing vegetation type. Classification by the dominant vegetation also offered an advantage in that we could generally determine the vegetation type (and indirectly the substrate type and other physical factors) by observing the habitat from the surface (either from a boat or plane), thereby eliminating the need for preliminary dive surveys. Both eelgrass and *Nereocystis* habitats have vegetation that grows from the bottom to near the water's surface and can be observed from the surface. Most of the remainder of the shallow subtidal within Prince William Sound is dominated by *Laminaria/Agarum*.

Within each habitat, we selected oiled sites and then located and sampled at a control site that matched, as closely as possible, the selected oiled site with respect to non-biological factors other than oiling. The procedures used for the selection of sampling strata and selection of sites within sampling strata follow.

Selection of Sampling Strata

The first order of stratification used in our sampling plan was based on vegetation type. The shallow subtidal communities within Prince William Sound are structurally dominated by 3 vegetation types: Eelgrass, *Laminaria/Agarum*, and *Nereocystis*. Eelgrass dominates in areas of soft substrate that generally occur in back bays at the mouths of streams. It often forms extensive beds that cover large areas in these back bays. Eelgrass also occurs in scattered patches throughout much of the rocky subtidal zone, but we have restricted our definition of eelgrass habitat to the larger beds on soft substrate.

Nereocystis (bull kelp) dominates on points in more exposed areas with strong currents. *Nereocystis* forms a floating canopy and the subcanopy algal community is dominated by a suite of algae generally associated with strong water motion. While *Nereocystis* habitats are relatively rare in PWS, they represent habitats of special significance. *Nereocystis* beds have high diversities of algae, epifaunal invertebrates, and non-demersal fishes. It also represents the one habitat for which there were pre-spill data available.

By far the most widely represented habitat in PWS is the *Laminaria/Agarum* habitat. Generally, if a habitat is not dominated by eelgrass or *Nereocystis*, it is dominated by *Laminaria saccharina*, *Agarum cribrosum*, or a combination of these species. *Laminaria/Agarum* beds occur on rocky substrate throughout the Sound in all but the most exposed points.

For the *Laminaria/Agarum* habitat, we further stratified into three oceanographic regions (islands, mainland, and outer Sound) and into three physiographic types (bays, points, and straight shore line) per region. This stratification scheme resulted in 9 potential strata within the *Laminaria/Agarum* habitat, 1 within the *Nereocystis* habitat, and 1 within the eelgrass habitat, for a total of 11 potential strata in all.

In order to remain within budgetary constraints and yet sample a sufficient number of sites within each habitat, we limited our sampling effort in 1990 to only 4 of these 11 potential strata: eelgrass, *Laminaria/Agarum* in island bays, *Laminaria/Agarum* on island points, and *Nereocystis*. The strata sampled were selected based on ecological importance, potential for impact, and extent of the habitat within the oiled region.

We elected not to sample *Laminaria/Agarum* habitats on the mainland or in the outer Sound because there were relatively few of these habitats that were oiled. We also elected not to sample runs (sections of straight shoreline) on the islands because these represented habitats that were intermediate between points and bays, and we felt that we could extrapolate from results obtained in bays and on points in order to estimate effects on runs.

Locations of the different vegetation types were initially identified, based on information obtained in our 1989 survey, and by polling knowledgeable biologists familiar with Prince William Sound as to the location of eelgrass beds and *Nereocystis* beds. These were later verified in surveys conducted by plane or boat (see site selection below).

Selection of Sites within Habitats

An initial selection of oiled sites was conducted in the laboratory in winter 1990. We identified strata based on our experience in the fall of 1989, and on anecdotal evidence from biologists familiar with the Sound. Sites were initially chosen based on an overlay of oil information and habitat information on navigation charts. Oiled areas were identified, based on the summer 1989 oil maps and the September 1989 "walkathon" data. Areas that were moderately to heavily oiled in both surveys were marked as oiled areas. From those oiled areas for each stratum (e.g. eelgrass beds or *Laminaria/Agarum* habitats in island bays), we selected a 200 m section of shoreline to be sampled. The selection of the sampling locations was based on the following hierarchy for order of preference: sites for which there were pre-spill biological data, sites previously sampled in NMFS or DEC hydrocarbon surveys, sites sampled by Coastal Habitat intertidal crews, and randomly selected sites within the habitat. Details of the initial site selection process are described in Appendix A.

Control sites were selected that were indicated as not oiled in both the summer oil survey and the September walkathon. Controls were matched with selected oiled sites, as closely as possible, with regard to aspect, proximity to sources of freshwater input, slope, wave exposure, and water circulation. We randomly selected a matched control site if more than one existed.

Alternate oiled and control site locations were chosen according to the above criteria, in the event that our initially produced maps proved inaccurate with respect to habitat type, or if controls did not match the oiled sites with respect to aspect, wave exposure, etc.

In spring 1990, we conducted a site confirmation cruise to insure that our preliminary selections of oiled sites were appropriate with regard to habitat type, and that the control sites matched these oiled sites with regard to habitat and to physiographic aspects. In several instances, our preliminary identification of habitat type was incorrect, and alternate sites were substituted for those chosen initially. For the oiled sites, all final selections were from our initial list of chosen or alternate sites. For the control sites, we occasionally had to deviate from the initial list and search the western portion of the Sound for appropriate controls that matched the oiled sites as closely as possible, but were not oiled (based on shoreline oiling maps). A total of 3 alternate control sites that were not on our initial list of selected or alternate sites were selected as controls (Moose Lips Bay, Puffin Bay, and Naked Island). The final locations of sites selected within each habitat are given in Figure 1 and Appendix B.

Selection of Depth Strata Within Each Habitat Type

Within each habitat, we further stratified our sampling effort, primarily by depth. In eelgrass habitats, we elected to sample within 3 strata: 3 to 6 m, 6 to 20 m, and at the mid point of the eelgrass bed (generally < 3m) (Figure 2). In the *Laminaria/Agarum* habitats we sampled at 2 depth strata: 2 to 11 m and 11 to 20 m. Within the *Nereocystis* habitat we sampled within the *Nereocystis* bed, (within a depth range of 2 to 8 m). We elected to sample only in the deeper portions of the subtidal (> 2 m) because preliminary data collected in 1989 suggested that at the shallower depths, the variability within a site was extremely large. As a result, the sampling effort was concentrated in the more homogeneous portions of the habitat where the power to detect differences was largest.

3.1.2 Sampling in Fjords

In October 1989 sampling, one of our sampling sites was within a fjord in northeastern Herring Bay that was heavily oiled (Figure 3). This small embayment (hereafter referred to as Herring Bay fjord) is located along the northwestern side of Knight Island. It covers approximately 0.5 km^2 and has a maximum depth of 35 m. The depth of a sill, that stretches along the mouth of the bay, is only 4 m. At depths greater than 10 m, the substrate in the bay is composed primarily of fine flocculent silt.

Sampling in 1989 indicated that sediments at depths greater than 13 m were hypoxic or anoxic, and many animals were either dead or dying. Similar fjords within the Knight Island area were sampled in 1990 to determine the extent of such "dead zones" and to better establish a possible relationship between the existence of dead zones and oiling.

Three fjords were sampled in the Spring 1990: Herring Bay fjord (the same site as sampled in 1989), inner Lucky Bay (control) and inner Bay of Isles (oiled) (Figure 1). A more extensive survey of these and 2 additional sites (Disk Lagoon - oiled, and Humpback Cove - control) was conducted in fall 1990 (Figure 1). All of these sites had sills and restricted entrances similar to that observed at Herring Bay fjord in 1989.

In 1991, the fjords in Herring Bay and inner Lucky Bay were the only fjord sites sampled, and in 1993, only the Herring Bay site was sampled. The sampling effort was reduced because this habitat was relatively rare within PWS, and because there was a potential confounding effect of natural disturbances (seasonally low oxygen) and the effects of oil within these sites.

The oiled sites chosen for the silled fjord studies represented all of the oiled silled fjords that were in the PWS region. Control sites were selected that matched these sites as closely as possible with regard to size and depth. However, the number of potential controls was small, and in reality, the oil and control pairs were often very different from one another. As a result, we will primarily rely on comparisons of temporal patterns within the Herring Bay fjord to examine the potential effects of oil.

3.2 Biological Sampling Methods

3.2.1. Sampling within the Eelgrass Habitat

1990 Sampling

At each eelgrass site, we established three 30 m long transects, within the eelgrass bed (Figure 2). These were placed in the middle of the depth range of eelgrass, and at randomly selected locations along the 200 m section of shoreline selected for sampling.

Large motile invertebrates and fishes were counted along each 30 m transect. Divers swam the transect and counted fishes, by species, within a 1 m swath to either side of the transect center line and within 3 m of the bottom. These surveys were made prior to other sampling efforts on the transect in order to avoid disturbance to the fish community and to achieve accurate counts of fishes. Larger sessile invertebrates, non-cryptic specimens of echinoderms and crustaceans larger than 10 cm, and newly recruited juvenile sea stars were also counted in this 2 m by 30 m band.

Along each transect, we harvested all eelgrass from 4 randomly placed 0.25 m^2 quadrats. The turions (above-sediment portions of the plant arising from the rhizome, usually with 4 or 5 leaves attached) of the plants were cut approximately 1 cm above the sediment surface. The plants were bagged underwater and returned to the boat. There, the number of turions and total number of leaves per quadrat were counted, and all turions in each quadrat were weighed. In addition, we noted the number of flowering stalks per quadrat.

Densities of infaunal invertebrates were estimated from two 0.1 m^2 suction dredge samples taken along each of the three transects within the eelgrass bed. One 0.1 m^2 quadrat was sampled from each of the first two quadrats on each transect. The dredge samples were taken from the upper left hand corner of each quadrat (determined while facing the shore) after the eelgrass had been collected. Similar dredge samples were taken from 3 additional transects in each of two strata (3 to 6 m and 6 to 20 m) that were established independent of the distribution of eelgrass. These transects were placed at random positions within the sampling site and at random depths within the stratum.

Eelgrass seeds were collected from 4 randomly placed 0.25 m^2 quadrats on each of 3 transects in the eelgrass bed at each site. The sediment in each quadrat was collected to a depth of approximately 5 cm using an airlift. The sediments were sieved through a 1 mm mesh screen and the seeds within each sample counted.

Epibenthic invertebrates within the eelgrass bed were sampled using a dropnet. A 0.5 m diameter (0.196 m^2 area) circular steel frame, with a 1 mm mesh net attached, was dropped from a small boat near (<3 m horizontally) the 2 random points where infauna were collected. After the net was dropped, it was pursed and retrieved aboard the boat. The contents of the net were washed into a jar and preserved with formalin.

We sampled at 8 eelgrass sites between 3 July and 11 August 1990. Four oiled sites (Bay of Isles, Herring Bay, Sleepy Bay, and Clammy Bay) and four paired control sites (Drier Bay, Lower Herring Bay, Moose Lips Bay, and Puffin Bay) were visited (Figure 1 and Appendix B).

1991 Sampling

In 1991, sampling continued in the eelgrass habitat as described above, except for the following modifications. All sampling was conducted between 10 and 28 July. For sampling of eelgrass, we counted the number of turions within each 0.25 m^2 quadrat without harvesting plants and counted the number of flowering stalks of eelgrass within a 1 m band on one side of the 30 m transect. Larger epibenthic invertebrates were sampled as in 1990, except that newly recruited sea stars were counted in a 2 m by 30 m band.

Infaunal invertebrates were sampled as in 1990, except that no sampling was conducted at the shallow (3 to 6 m) depth stratum and dropnet sampling was discontinued.

Small mussels (*Musculus* spp.) were sampled by collecting four randomly selected eelgrass turions from next to each epibenthic sampling quadrat. The turions were placed into sampling bags underwater, placed in containers with formalin aboard ship, and later examined to determine the density and size distribution of mussels. A maximum of 40 randomly selected mussels were measured from each site.

Two additional eelgrass sites were sampled in 1991. These were in the Short Arm portion of Bay of Isles (an oiled site), and in the Mallard Bay (a control site in Drier Bay) (Figure 1 and Appendix B). Only the eelgrass stratum was sampled at these sites.

1993 Sampling

Sampling in 1993 was conducted between 13 and 25 July. Sampling of infaunal and epifaunal invertebrates was conducted as in 1991, except that only three pairs of oiled and control sites were visited: Sleepy Bay and Mooselips Bay, Bay of Isles and Drier Bay, and Herring Bay and Lower Herring Bay.

3.2.2 Sampling in the *Laminaria/Agarum* Habitat in Island Bays

1990 Sampling

Three transects were randomly placed within each of two depth strata, 2 to 11 and 11 to 20 m, within the *Laminaria/Agarum* bay habitat. The percent cover by understory algae was determined in four 0.25 m^2 quadrats placed at random positions along each transect. All algae greater than 10 cm in height were collected from these quadrats and returned to the boat where each individual was identified, weighed, and measured.

Infaunal invertebrates associated with pockets of soft sediment along the transects were sampled using a suction dredge. These samples were taken from the first two quadrats on each transect when possible. If there was no soft sediment within the quadrat, then the sample was taken from the first available patch while traveling toward the next quadrat. There were no dropnet samples taken at the *Laminaria/Agarum* habitats.

Large (> 10 cm) motile invertebrates and fishes were counted in a 2 m swath along each transect as described in 3.2.1 above. These counts were made prior to the clearing of algae from quadrats.

We sampled at 6 sites within the *Laminaria/Agarum* bay habitat in 1990. Three oiled sites (Northwest Bay, Herring Bay, and Bay of Isles) and three paired control sites (Cabin Bay, Lower Herring Bay, and Mummy Bay) were visited (Figure 1 and Appendix B). All sites were sampled as described above between 22 May and 12 June 1990. A second visit was made to the sites between 21 July and 29 July, 1990 and fish abundances were determined within shallow depth stratum.

1991 Sampling

The sampling in *Laminaria/Agarum* bay habitats in 1991 was restricted to infaunal invertebrates, large epibenthic invertebrates, and fishes. All sampling was conducted between 29 July and 5 August. Fishes and large epibenthic invertebrates were sampled only in the shallow (2 to 11 m) depth stratum. Sampling methods were the same as in 1990.

1993 Sampling

The sampling in *Laminaria/Agarum* bay habitats in 1993 was restricted to large epibenthic invertebrates. All sampling was conducted between 16 and 24 July. Large epibenthic invertebrates were sampled only in the shallow (2 to 11 m) depth stratum at two pairs of sites: Herring Bay and Lower Herring Bay, and Bay of Isles and Mummy Bay. Sampling methods were the same as in 1990.

3.2.3 Sampling in *Laminaria/Agarum* Habitats at Island Points.

1990 Sampling

Sampling in the *Laminaria/Agarum* habitats at island points was identical to that described for island bays. We sampled at 6 sites within the *Laminaria/Agarum* point habitat in 1990. Three oiled sites (Outer Herring Bay, Ingot Point, and Discovery Point) and three paired control sites (Outer Lower Herring Bay, Peak Point, and Lucky Point) were visited (Figure 1 and Appendix B). Sampling was conducted between 18 July and 7 August, 1990. Dredge samples used to determine the abundance of infaunal invertebrates were not processed, due to budgetary constraints. These samples were archived for possible future processing.

1991 and 1993 Sampling

There was no sampling conducted within this habitat in 1991 or 1993.

3.2.4 Sampling in *Nereocystis* habitats

1990 Sampling

Sampling in the *Nereocystis* habitat was conducted within the depth stratum in which *Nereocystis* was observed at all sites (2 to 8 m). Sampling was conducted between 14 June and 2 July 1990. Within the *Nereocystis* zone, sampling of smaller stipate kelps (*Agarum, Laminaria spp., Pleurophycus*), large epibenthic invertebrates, and fishes was as described for *Laminaria/Agarum* habitats in Island bays (see section 3.2.2 above) except that at 2 of the sites, (Little Smith Island and Naked Island) we sampled along 5 and 6 transects, respectively. *Nereocystis* density was determined by counting all plants greater than 2 m in height within a 4 m swath along the transects.

The size distribution of *Nereocystis* was determined by measuring the diameter of the stipe, at a distance 1 m above the bottom, for the first 20 plants observed along each transect. Fewer than 20 were measured in cases where there were fewer than 20 individuals present on a particular transect. The relationship between stipe diameter and total wet weight was determined by weighing, and measuring the stipe diameter of each plant from 20 to 40 plants collected from each site. The plants were collected from near the transects and were selected in order to obtain as wide a range in sizes as possible. An analysis of these data indicated that stipe diameter was an excellent predictor of weight. The equation for the regression of stipe diameter *vs.* the log of the weight was:

$$\text{Log}_e \text{ weight (Kg)} = [0.457 \text{ X Stipe diameter (mm)}] - 2.68$$

The regression coefficient for this equation was = 0.85, with N = 147..

We sampled at 5 sites within the *Nereocystis* habitat in 1990 (Figure 1 and Appendix B); two oiled sites (Latouche Point and Little Smith Island) and three control sites (Procession Rocks, Naked Island, and Zaikof Pt.). We did not sample from an oiled site that matched the Zaikof site, and as a result, data from Zaikof are not presented here.

1991 and 1993 Sampling

There was no sampling conducted within this habitat in 1991 or 1993.

3.2.5 Sampling in Silled Fjords

1989 Sampling

At the Herring Bay silled fjord in 1989, dredge samples were taken from two randomly placed stations that ran from shore to 20 m. The stations were positioned at randomly selected locations directly offshore of a 200 m section of shoreline that was chosen for sampling by the intertidal sampling team. Along each station a 30 m long transect was established within each of three depth strata: 0 to 2 m, 2 to 8 m, and 8 to 20 m. The sampling depth within each depth stratum was also selected at random. Dredge samples were taken from a 0.25 m^2 quadrat randomly placed along each transect within each depth stratum. We also made a video of each transect and prepared a bathymetric chart of the bay using a fathometer aboard a small boat. Additional videos were taken along transects through the deeper portions of the bay in order to document the presence of large numbers of dead organisms.

1990 Sampling

In 1990, estimates of density of infaunal invertebrates were obtained from 3 sites in the spring and 5 sites in the fall. At each site we first conducted a bathymetric survey as described above. Stations were then established at random positions along the 20 m depth contour at each site. At each station, divers collected duplicate 0.1 m^2 suction dredge samples of sediment for analysis of benthic infauna.

Temperature, salinity, and dissolved oxygen were measured at the bottom (depth = 20 m) and the surface at each sampling site in 1990.

1991 and 1993 Sampling

We sampled at Herring Bay and at Lucky Bay in 1991, and at Herring Bay in 1993, using the same methods as described for 1990.

3.3 Germination of Eelgrass Seeds and Genetic Analysis of Seedlings

An experiment was conducted to examine the effect of oil on the potential germination of eelgrass seeds. Seeds were collected from the sediments at oiled and control sites and were germinated in filtered seawater in the laboratory.

Approximately 150 eelgrass seeds were collected from each of 4 stations (Herring Bay, Lower Herring Bay, Bay of Isles, and Drier Bay) between 11 and 19 July 1990. Sediments were collected from a depth of approximately 2 m at each site using a suction dredge. The sediments were sieved through a 1 mm mesh screen and the seeds were collected and placed into vials of filtered seawater. The vials were placed on ice and returned to the Seward Marine Laboratory.

There the seeds were removed and placed into randomly numbered plastic Petri dishes containing 30 ml of 9 ppt filtered seawater. Salinities of 4.5 to 9 ppt are optimal for germination (Phillips, 1974). A total of 15 dishes was used for each site. Ten haphazardly selected seeds were placed into each dish, with one exception. Only 2 seeds were placed in one of the dishes from Herring Bay because too few seeds were available from this site.

The dishes were kept in a controlled temperature cold room at 9oC and a 10:14 hour light dark cycle. The number of seeds germinated was monitored daily for approximately 10 weeks. Any germinated seeds were removed and preserved in 10% formalin. These were placed in a vial labelled with the number of the Petri dish from which the seedling was removed.

A subset of seedlings that were germinated in the laboratory was collected and was subjected to microscopic examination to determine the proportion of mitotic figures that were normal. Preserved seedlings were selected haphazardly from the vials with germinated seeds. A total of 30 seedlings was examined; 11 from Herring Bay, 6 from Lower Herring Bay, 10 from Bay of Isles, and 5 from Drier Bay.

Meristematic regions of eelgrass seeds were dissected from formalin-fixed seedlings by making two cuts across the shoot. The resulting tissue was approximately 2 mm in length. The cotyledon sheath enclosing the meristematic tissue was scored longitudinally using a scalpel and a small cut was made into the area above each emerging root. The tissue was stored in a cellulase solution (pH 5.0) for two days at room temperature, then rinsed in distilled water. Tissue was post-fixed for 15 minutes in acid alcohol (3 parts 100% ethanol: 1 part glacial acetic acid) then rinsed again in distilled water. Mitotic figures were stained using the Feulgen squash technique developed for terrestrial plant root tips (Kihlman, 1971). The tissue was hydrolyzed in 1 N HCl for 10 min, then stained for 1 hr at 20oC using leucobasic fuchsin (Feulgen stain). The tissue was placed on a microscope slide and squashed in a drop of 45% acetic acid beneath a cover slip.

Approximately 2 hours later, the tissue was examined at 1000 X for aberrant anaphase/telophase mitotic figures (AT) (Hose, 1985). From each seedling, 20 AT were scored as normal or aberrant. Aberrant AT had at least one chromosome or chromatid aberration (translocation bridge, attached fragment, acentric fragment, stray chromosome, or lagging chromosome) or spindle abnormality (Multipolar spindle). Any pycnotic nuclei present in the meristematic regions were recorded.

3.4 Determining Growth Rates of *Agarum cribrosum*

The growth rate of *Agarum cribrosum* was determined at 2 pairs of oiled and control sites between 05 June and 29 July 1990: at Herring Bay (oiled) and Lower Herring Bay (control); and at Bay of Isles (oiled) and Mummy Bay (Control). At a depth of 8 m at each site, 20 plants between 50 and 100 cm in height were selected. The plants were all within 2, 2 m x 30 m swaths and were separated by 1 to 2 m. Each plant was marked by driving a steel spike, with a numbered plastic tag attached, into the sea floor next to each plant. A small piece of plastic surveyors flashing was placed through a hole near the midrib at a height approximately 10 cm above the juncture of the holdfast and the blade. We then measured and recorded this distance. Surrounding plants within a radius of about 1 m, were removed in order to eliminate potential competition.

After a period of 41 to 57 days, the stations were revisited and the distance from the bottom of the blades to the tag were remeasured and recorded. The growth of each plant was calculated as the change in distance from the base of the blade to the tag over the 41 to 57 days. All measurements were standardized to the growth (in cm) per 30 days.

3.5 Sampling and Analysis of Sediments for Hydrocarbon Content, Grain Size, and Carbon Isotope Ratios

Sediments were collected from each depth stratum at each study site visited in each year. All samples were taken from the second of three sampling stations, located approximately in the middle of each sampling site. SCUBA divers collected the sediment samples in pre-cleaned, wide-mouth 4 oz. jars. Divers took two sample jars into the water, cracked the jars' lid just below the water surface, and proceeded to the bottom at each sampling site. There, the jar's lid was removed and the jar was used to scoop sediment to a depth of approximately 5 cm. A 10 to 100 g sample of sediment was obtained at each sampling location. The samples were taken from within 3 m of the buoy anchor marking each sampling station when possible. If the sediment could not be collected near the buoy, samples were taken at the closest adjacent patch of loose sediment.

One of the collected samples was used to determine hydrocarbon levels and the other to determine sediment composition and carbon isotope ratios. All hydrocarbon sediment samples were numbered sequentially, labelled, sealed with evidence tape, signed, and frozen on board. At the end of the field season, all hydrocarbon sediment samples were sent to the Technical Services Task Force, Analytical Chemistry Group (TSTF-ACG), NOAA/NMFS, Auke Bay, Alaska for processing. Hydrocarbons were extracted from the sediment samples and the extracted samples were analyzed for the concentration of various hydrocarbon fractions (Appendix E) using gas chromatography combined with a mass spectrometer detector (GC-MS). The samples were prioritized for analysis, with highest priority given to samples collected from eelgrass and silled fjord habitats. Analyses were completed for all samples collected from eelgrass habitats in 1990, 1991, and 1993; from Herring Bay fjord in 1989, 1990, 1991, and 1993; and from *Laminaria/Agarum* bays in 1990. A few additional samples (1 or 2 per site) have also been analyzed for samples collected from *Laminaria/Agarum* point and *Nereocystis* habitats in 1990. Remaining samples have been archived for possible future analyses.

The samples to be used for the determination of grain size and carbon isotope ratios were also numbered, labelled, and frozen aboard the ship. These were then shipped to the University of Alaska Fairbanks for analysis. Only samples from eelgrass and silled fjord habitats were processed. In the laboratory each of these samples was split into two subsamples. One fraction was used for analyses of grain size and the other for the analysis of organic carbon stable isotope ratios.

Sediments were analyzed for their grain sizes by the usual pipette-sieve method, and the sediment types and grain size distributions defined statistically following the conventional grain size parameters stated in Folk (1980).

Organic carbon, organic nitrogen, and stable carbon isotope ratios were also determined for sediments sampled within the eelgrass habitats and silled fjords in 1990 and 1991. The methods, results, and discussion of stable carbon isotope ratios are given in Appendix C.

3.6 Sorting and Identification of Infaunal and Small Epifaunal Invertebrates

Samples of infaunal and small epifaunal invertebrates were returned to the University of Alaska, Fairbanks laboratory for sorting, counting, weighing, and identification. All samples were sieved through a 1 mm sieve. The methods are detailed in the Standard Operating Procedure for laboratory processing of the benthic samples (Appendix D).

An attempt was made to identify organisms to at least the family level, but there were a few instances when only higher taxonomic levels were assigned to an individual. Many of the more common organisms were identified to the genus and species.

3.7 Experiments Evaluating Reproductive Success of *Dermasterias*

We conducted a series of experiments to examine the effect of the spill on reproductive success in the sea star, *Dermasterias imbricata*. We collected stars from oiled and control sites and examined gonad weight, and spawning success. Animals used to determine gonad index were collected from Herring Bay and Lower Herring Bay. Spawning success was determined for animals collected from 2 oiled sites (Herring Bay and Northwest Bay) and 2 control sites (Lower Herring Bay and Cabin Bay).

At each site, divers swam along the bottom and collected organisms as they were encountered. No attempt was made to obtain a random sample within each site. We selected only those individuals that were presumably of reproductive size (greater than approximately 8 cm diameter from ray to ray).

In all experiments, animals were taken from the field to the Seward Marine Laboratory for these tests. Each animal was placed into a sealed plastic bag, and filled about 3/4 full with sea water. The remaining head space was filled with oxygen by placing a tube from cylinder of compressed O_2 into the partially sealed bag, and then opening the cylinder's valve. The bags were then placed on ice in a cooler for transport. Separate coolers were used for animals from oiled and control sites. Animals were delivered to the laboratory on the day of collection.

In our first experiment conducted on 5 May 1990, 140 animals were collected; 70 from an oiled site (Herring Bay) and 70 from a control site (Lower Herring Bay). Once in the laboratory, a subset of 24 animals from each site was selected at random, and each individual selected was placed into a Pyrex baking dish with filtered seawater. Each animal was injected with 3 to 5 ml of 1 Molar -1-Methyladanine to induce spawning (Strathmann, 1987). We noted whether the animals spawned and then dissected all animals to determine their sex (for those animals that did not spawn) and condition of the gonads. The remaining animals were dissected to determine gonad index.

In dissecting animals collected from Herring and Lower Herring Bay for their gonads, we noted a relatively high proportion of animals were parasitized by an undescribed species of barnacle, *Dendrogaster* sp. (Grygier, 1982; Kozloff, 1987). In order to examine the possible effects of oil on the level of infection by these parasites, and the effects of the parasite on spawning success, we noted the presence of parasites in the animals used in spawning experiments.

A second experiment was conducted on 25 May 1990. A total of 89 *Dermasterias* was collected from the field; 43 from an oiled site (Northwest Bay) and 46 from a control site (Cabin Bay). The animals were transported to Seward as described above. All animals were injected with methyladanine and the spawning success noted. All animals were then dissected and the number of rays parasitized was recorded.

More animals were collected in June 1990 and July 1991 and 1993 to provide additional information on the possible effects of oil on the rate of parasitism. On 7 June 1990, 42 *Dermasterias* were collected from Mummy Bay (a control site) and on 12 June 1990, 53 animals were collected from Bay of Isles (an oiled site). In 1991, *Dermasterias* were collected from 2 control sites (Lower Herring Bay and Mummy Bay), and from 2 oiled sites (Sleepy Bay and Bay of Isles) between 24 July and 30 July. A total of 52 animals was collected. In July 1993, 106 animals were collected from 2 oiled (Herring Bay and Bay of Isles) and 2 control sites (Lower Herring Bay and Mummy Bay). All animals were dissected aboard ship immediately after collection and the presence or absence of parasites in each ray was noted.

3.8 Sampling and Analysis of Fish Gut Contents

Young-of-year (YOY) Pacific Cod were collected from 3 oiled (Herring Bay, Bay of Isles, and Clammy Bay) and 3 control (Lower Herring Bay, Drier Bay, and Puffin Bay) eelgrass sites for gut content analysis. Collections were made at Herring Bay, Lower Herring Bay, Drier Bay, and Bay of Isles between 4 July and 15 July, 1990. Clammy and Puffin Bay samples were collected 9 August to 11 August, 1990. Divers collected fish from within the study site by spearing fish with small pole spears. Twelve to eighteen fish were collected per site ranging in size from 48 to 78 mm (standard length). The fish were then frozen and transported to the University of Alaska, Juneau for analysis.

In the laboratory, each fish was weighed and measured. The fish were dissected and a visual estimate of the proportion of the gut that was filled was obtained. The contents of the gut were removed, sorted, identified (generally to order), counted, and the volume for each taxon was determined.

3.9 Hemosiderosis of Fishes

Fishes were examined in 1993 for the presence of hemosiderosis, an indicator of exposure to pollutants, including petroleum (Khan and Nag, 1993). Hemosiderin, which results after excessive destruction of erythrocytes, in fish concentrates in discrete areas in liver and spleen called melanomacrophage centers. It can be demonstrated by a monospecific stain, Perl's Prussian Blue. Fishes were collected in the intertidal and shallow (< 6 m) subtidal region of the eelgrass beds in Herring Bay (oiled) and Lower Herring Bay (control) in July 1993. Approximately 30 specimens of pricklebacks (*Anoplarchus* spp.) and 30 crescent gunnel (*Pholis laeta*) were collected by hand, dipnet, and pots, preserved in 10% buffered formalin, and sent to Dr. R.A. Khan, Memorial University of Newfoundland, for analysis.

3.10 Experimental Studies with *Musculus*

Experiments were conducted in Herring Bay in 1993 to examine the effects of *Musculus* spp. on eelgrass, and to examine the effects of predation on the distribution and abundance of *Musculus*. Studies (see sections 4.2) demonstrated that, in 1990, *Musculus* spp. was more abundant at oiled sites, eelgrass was more abundant at control sites, and that potential predators of *Musculus* spp. were abundant at control sites. We hypothesized that densities of *Musculus* were lower at oiled sites because abundances of predators (especially the crab *Telmessus cheriagonus* and the sea star *Dermasterias imbricata*) were lower there, and that higher densities of *Musculus* spp. at oiled sites led to a reduction in eelgrass density.

The first experiment was designed to test the hypothesis that *Musculus* inhibited the growth of eelgrass. Ten 1 m^2 plots were established within the eelgrass bed at Herring Bay, where densities of *Musculus* averaged about 40,000 m^{-2}. The plots were placed about 2 m apart along two 20 m long lines laid within the eelgrass bed. All *Musculus* were removed from 5 randomly selected plots. Divers gently rubbed the blades of the eelgrass and then collected the mussels using an airlift. The remaining 5 plots served as unmanipulated controls.

The initial removal was conducted on 17 and 18 July 1993. Approximately two months later, on 25 September 1993, we revisited the site and collected all of the eelgrass blades within a 0.25 m^2 area within each plot. After collection, we counted the number of eelgrass turions and the number of *Musculus* on the eelgrass.

A second experiment was conducted to test the hypothesis that the abundance of *Musculus* spp. could be locally limited by predation, especially predation from the crab, *Telmessus cheriagonus*, and from the sea star, *Dermasterias imbricata*. Two 30 m long transect lines were established within the eelgrass bed at Herring Bay. A total of 10, 1 m diameter plots were established at equal distances along each line. The plots were randomly assigned one of five treatments: Predator exclusion (caged), *Dermasterias* inclusion (caged with a *Dermasterias* enclosed), *Telmessus* inclusion (caged with a *Telmessus* enclosed), Cage Control (a partial cage), and a control (no cage). The cages used were 1 m in diameter hoop nets that were approximately 1 m tall and were constructed with 2.5 cm mesh nylon netting. The bottom hoop of each cage was secured to the bottom using U-shaped steel reenforcement bar "staples". The net was maintained in an upright position by placing small fish-net floats on the upper two rings of the hoop net. The cage control consisted of a cage, but with one half of the netting of the hoop cut out. The netting was removed such that there were two panels of netting separated by two areas where the netting was removed.

Telmessus and *Dermasterias* were collected by hand from the surrounding areas within Herring Bay and one animal each was placed in their respective cages. The *Telmessus* were approximate 8 cm in carapace width and the *Dermasterias* were about 15 cm from ray tip to ray tip. The animals were placed into cages on 18 July 1993. Approximately two months later, on 26

September 1993, the site was revisited and all the eelgrass within each cage was sampled by divers and placed into a small mesh bag underwater. Care was taken to place the eelgrass blades into the bags without dislodging any *Musculus* that may have been attached. The samples were preserved in formalin and later the number of eelgrass blades and *Musculus* in each sample were counted.

3.11 Data Analysis

3.11.1 Analysis of Data from Stratified Sampling

Analysis of Percent Cover, Abundance, Biomass, Diversity, and Hydrocarbon Data

For the percent cover, abundance, and biomass estimates for each of the dominant infaunal and small epifaunal taxa, and for diversity measures for benthic infauna, we tested the null hypothesis of no significant difference among oiled and control sites using a randomization procedure (Manly, 1991). In most instances, separate analyses were performed for each depth stratum within each habitat and year. We tested for oil category (oil or control) as the main effect, with pair (arbitrarily assigned as 1 through 4) as a blocking factor. For those taxa that occurred in several habitats, we also examined the effect of oil over all habitat types using a similar procedure. In cases where we had data from 1990, 1991, and 1993, we performed a 2-factor randomization procedure, and tested for significant effects due to oil, to year, and to the interaction of oil and year.

Replicate stations were sampled within each site, and in some cases, replicate quadrats were sampled within each station. In all cases we used station rather than quadrat means as replicates in our analyses.

The randomization procedure can be briefly summarized as follows. 1) A blocked analysis of variance (ANOVA) was performed, and a sum of squares produced. 2) Next, using the original data set, we randomly reassigned values for oil code to each station value. The ANOVA was then rerun on this new data set. 3) Step 2 was repeated 1000 times. 4) The sums of squares from the ANOVA of the original data set was compared with sums of squares of the 1000 randomly drawn data sets.

The proportion of instances in which the sums of squares for the randomly drawn data exceeded the sums of squares for the original data was recorded. This value is the significance level of the test as described by Fisher (1935). The significance level is interpreted in the same manner as for parametric procedures. If the randomly drawn sums of squares exceeded the sums of squares for the original data less than 10 % of the time, then this is equivalent to $P = 0.10$ for an ANOVA, and there is some evidence of an effect of oiling. If the value is 1% (equivalent to $P = 0.01$), then there is very strong evidence that oiling had an effect.

Analysis of Size Frequency Data for Algae and Mussels

Size (wet weight, length, or stipe diameter) frequency distributions were established for the dominant algal species in each habitat in 1990. We compared the distributions at oiled sites *vs.*

control sites, within each habitat and depth stratum, using a randomization procedure similar to that described above, but using a Komolgorov-Smirnoff (KS) D value (Siegel, 1956) as the test statistic. We performed a KS test on the original data set, randomly reassigned oil and control categories to plants found on particular quadrats (for *Agarum*), or transect (for *Nereocystis*), and reran the KS test. We randomized with regard to groups of plants from quadrats and transects rather than each individual plant because we felt that the sizes of plants in close proximity to one another may have been correlated in some way and were not truly independent samples. The randomization process was repeated 1000 times, and the D statistic from the randomized data sets was compared with the D statistic from the initial data set.

Selection of Taxa

In the data sets for infauna and smaller epifauna, there was a large number of taxa represented. Many of these taxa were rare, occurring in only a few samples. We omitted the rare species from our analyses of abundance and biomass for individual taxa in order to reduce analysis time. There was generally little power to detect differences among sites for these taxa.

In most benthic biological studies, as well as the study reported here, organisms collected and subsequently used in analyses, include infaunal macrofauna, slow-moving macrofaunal surface dwellers, and small, sessile epifauna. Large motile epifauna such as shrimps, crabs, and sea stars are typically not adequately sampled and therefore are not included in the analyses. However, since only small representatives of these larger motile epifauna were collected with the dredge sampler that we have employed, these epifauna were included in the analyses.

The mesh size of the collection bag was 1 mm, and as a result, organisms smaller than 1 mm (meiofauna) were generally not sampled. Those few individuals smaller than 1 mm that remained in the samples were excluded from the analyses. Also excluded from the analyses were organisms that are considered highly motile and non-benthic, such as calanoid copepods, mysids, euphausiids, chaetognaths, and fishes.

All analyses were conducted for groups of organisms identified to the family level (or order in cases where individuals could not be identified to family). We eliminated all taxa that occurred in fewer than one-sixth of the samples for a particular habitat, depth stratum, and year, and then ranked the remaining taxa. This eliminated species that occurred at only a few of the sampling sites, and thereby eliminated species for which there was extremely little power to detect effects. The 15 highest ranking taxa in each year were then selected for analysis. Generally, the 15 highest ranking taxa for one year were also the highest ranking for another. However, occasionally a taxon was ranked in the top 15 one year but not another. As a result the number of taxa for which analyses were performed was generally between 15 and 25. Separate rankings were made for abundance (number of individuals per sample) and biomass within each habitat, depth stratum, and year. A list of the rankings for each habitat, depth stratum, and year is given in Table 1.

The Use of Covariates in Analysis of Benthic Infaunal Data

Previous studies of infauna and preliminary analyses of our data indicate that the faunal composition and the abundance of infaunal species is determined to a degree by sediment grain size. While our paired design was generally successful in controlling for grain size, sediment types differed among some pairs. Because of our inability to completely control for this factor, and because it was anticipated that grain size would be unaffected by oiling, we felt it appropriate to use grain size as a covariate in analysis of infaunal organisms. For individual taxa from the eelgrass habitats that were considered predominantly infaunal, we used the percent mud (% silt plus % clay) as a covariate in our analyses.

Some species collected in our dredge samples were epifaunal (e.g., spirorbid worms and mussels), rather than infaunal. We did not use grain size as a covariate in our analysis of epifaunal taxa. Assigned designations of "infauna" or "epifauna" were based on a review of the literature for each taxon.

We did not collect grain size data for *Laminaria/Agarum* habitats, and no covariates were used in the analyses of these data.

Computation of Diversity Measures

Species diversity can be thought of as a measurable attribute of a collection or a natural assemblage of species and consists of two components: the number of species or "species richness" and the relative abundance of each species or "evenness". We have elected to characterize communities of benthic infauna and smaller epifauna using several common measures of diversity: The "species richness" component was measured using the total number of taxa per sample, and Margalef's species richness index (Green, 1979) which scales the total number of taxa with respect to the total number of individuals. The species richness index, SR, was computed as:

$$SR = \frac{S - 1}{\log_e N}$$

Where S = the number of species [taxa]

N = the total number of individuals.

We used Simpson's index (Simpson, 1949) as a measure of dominance. The Simpson dominance index, D, was calculated as:

$$D = \frac{\Sigma\, n_i(n_i - 1)}{N(N-1)}$$

Where n_i = number of individuals of i^{th} species

N = total number of individuals.

The maximum value for the Simpson dominance index (1.0) is obtained when there is a single species [taxon] (i.e., complete dominance). Simpson's dominance values approaching 0 are obtained when there are numerous species [taxa], each comprising a small fraction of the total (i.e. no dominance).

We also measured diversity using the Shannon index (Shannon and Weaver, 1963). This is one of the most widely used measures of diversity and incorporates both species richness and evenness components. The Shannon index, H', was calculated as:

$$H' = -\Sigma_i P_i \log_e P_i, N$$

Where n_i = number of individuals in the i^{th} spies

N = total number of individuals.

In all of the above indices, we have used taxa identified to family (or above) as opposed to species. While diversity indices are normally applied to species, the overall diversity of a community is comprised of hierarchical components (e.g. family, genus, and species) and the concept can be applied to any of these components (Pielou, 1974). Diversity values computed using taxon identifications higher than species have been reported by Lloyd *et al.* (1968), Valentine (1973) and Ferraro and Cole (1990, 1992). Better resolution of multivariate data is also possible when taxonomic levels higher than species are used (Warwick, 1988; Rosenberg, 1972; Heip *et al.*, 1988).

For the analyses of community parameters (diversity, dominance, etc.) all taxa sampled were used, including both infauna and small epifauna. No covariate was used in these analyses.

Analysis of Fish Abundance

In our analysis of abundance of fish species, we have eliminated all schooling fishes (e.g. herring). These fish were observed only in a few of our samples, but when observed they were found in extremely high numbers. This distribution pattern precluded us from obtaining reasonable estimates of abundance for these species using the diver survey techniques we employed.

We grouped some species of fish into higher order functional groups prior to analysis. These groups generally correspond to families, or subgroups of families. For example, we grouped all species of greenlings into a single family grouping of "Hexagrammidae" for purposes of the analysis. Groupings were made among species that were behaviorally and functionally similar in order to increase sample sizes and to increase our power to detect differences among sites.

3.11.2 Analysis of Data from Fjords

A visual examination of the trends in diversity and relative abundance of species was used to detect changes in these measures over time. The trends were so obvious that no statistical analyses were performed.

3.11.3 Analysis of Data from Experiments with Sea Star Fertility

The effect of the spill on spawning success was examined by comparing the proportion of animals spawning at oiled *vs.* control sites using a chi-square test (Siegel, 1956). Chi-square tests were also used to examine the effect of oil on the proportion of sea stars that were parasitized, and on the effect of parasitism on spawning success. The effect of oil on gonad development was examined by comparing mean gonad indices for animals from oiled and control sites using a Student's t-test (Sokal and Rohlf, 1969).

3.11.4 Gut Content Analysis

We tested for differences in the diets of young-of-year Pacific cod at oiled and control sites using a blocked analysis of variance, with oil code (oiled or control) as the main effect and sites as blocks. We examined differences in total volume, and in the proportion of the gut that was filled with the two principal food items, molluscan larvae and microcrustaceans.

3.11.5 Analysis of Data From Experiments with *Musculus*

Mean *Musculus* densities in cleared and control plots were compared using a t-test. Mean densities of *Musculus* in the different treatments (caged with *Dermasterias*, caged with *Telmessus*, caged, cage control, and control) were compared using a one-way ANOVA, followed by Bonferoni's multiple range test.

3.11.6 Analysis of Sediment Data

Randomization tests, similar to those described in Section 3.11.1 above, were conducted to test for differences in sediment parameters at oiled *vs.* control sites or among years. Separate analyses were conducted for each of 2 sediment parameters (proportions of mud and sand). All data were arcsin transformed prior to analyses.

3.11.7 Analysis of Hydrocarbon Data

Chemical analysis of the sediments collected yielded values for several component hydrocarbon analytes. We report the concentrations of summed polycyclic aromatic hydrocarbon fractions (Appendix E) as indicators of the contribution of oil spilled by the *Exxon Valdez*. These values also include some PAHs from non-anthropogenic sources and from sources other than the spill. However, these represent relative values of oil from the spill that allow us to compare concentrations of oil at oiled vs. control sites.

Statistical analyses were performed to test the hypothesis of no significant differences among oiled *vs.* control sites or among years with respect to PAH concentrations. Randomization ANOVA procedures similar to those described above for biological variates were used as the statistical test.

3.11.8 Interpretation of Statistical Results

The statistical inference for randomization test results is with respect to the sites that were sampled, and not the population of all possible sites of a similar type within Prince William Sound. The extrapolation required to apply the results of the statistical analyses to the population within the entire Sound is a deductive rather than an inductive process, and relies partly on the professional judgment using the weight of all evidence available. However, we feel that it is reasonable to deduce that in cases where there is relatively strong evidence for an effect of oil at the sites sampled (i.e. if $P < 0.10$ in the randomization tests), that this is indicative of the effects of oil as expressed within that particular habitat over the entire Sound.

4.0 RESULTS

4.1 Effects on Plants

4.1.1 Eelgrass

The dominant plant in the eelgrass habitat was eelgrass (*Zostera marina*). This is an aquatic angiosperm with true roots, leaves, and seeds. The density of eelgrass turions (uprights protruding from the substrate) was higher at the control sites relative to oiled sites in 1990 (Figure 4 and Table 2). The mean densities of turions were higher at control sites in 3 of the 4 pairs of sites sampled, and averaged over 200 m^2 at control sites compared to approximately 150 m^2 at oiled sites. Mean values for turion density in 1990 differed at P = 0.08 (Appendix F).

Mean densities of flowering stalks were also higher at control sites (P = 0.06, Table 2 and Figure 4). Means densities of flowers were higher at control than at oiled sites in all four pairs of sites sampled, and the average density of flowers was 7 m^{-2} at control sites compared with 3 m^{-2} at oiled sites. Most surprising was the total lack of flowers at Herring Bay. We found no flowering stalks in the quadrats sampled and more extensive swims of the eelgrass bed at this site revealed no flowers.

We found no differences among oiled and control sites with respect to biomass of eelgrass (P = 0.63, Figure 4).

The average number of seed pods per flowering stalk was similar among oiled and control sites (mean = 9.2 per stalk at oiled sites and 9.8 per stalk at controls, P = 0.99). As a result, the lack of flowers at oiled sites translated directly to a lack of seeds produced, and the differences in the density of seed pods also differed among oiled and control sites (P = 0.08).

We also sampled the density of seeds in the sediments at each site, but found no difference among oiled and control sites (P = 0.74). Average densities were 102 and 134 seeds m^{-2} at oiled and control sites respectively. Presumably, many of the seeds in the sediments were predominantly from seed crops produced in prior years, since most seed pods were still immature at the time of sampling in 1990. The seed density varied considerably both among and within sites. Average densities per site ranged from 1.3 m^{-2} to 472 m^{-2}, and the number of seeds collected within each 0.10 m^2 quadrat within a site often ranged from 0 to over 100. Seed densities in sediments were presumably a product of several factors including the number of seeds produced, their dispersal distance, their retention rate at a particular site, and the germination rate of seeds. As a result, the density of seeds in sediments probably did not accurately reflect the reproductive potential of plants at a given site for this or prior years.

We examined both the potential germination rate and the number of mitotic aberrations in seedlings produced from germinated seeds collected from each of 4 sites (Herring Bay, Bay of Isles, Lower Herring Bay, and Drier Bay). Seeds from Herring Bay had a higher germination rate than seeds from its paired control site (Lower Herring Bay), but the seedlings produced from these seeds also had higher rates of genetic abnormalities (Table 3). The germination rates and rates of abnormal mitoses were similar for Bay of Isles and Drier Bay. We suspect that the higher germination rates and concomitant higher rates of genetic abnormalities at Herring Bay were related to the older average age of seeds at this site. Since there were no flowers present at Herring Bay in 1990, all seeds found in sediments must have been at least 1 year old. Unpublished data from eelgrass beds in Southern California (T.A. Dean, unpublished) suggest that germination rates of newly produced seeds are lower than for seeds that have remained in the sediment for several months.

We continued to examine densities of eelgrass shoots in 1991 and 1993. In 1990, the average density of shoots at oiled sites was 76% of the control density. In 1991, the difference was greatly reduced (the mean at oiled sites was 95% of the control), but increased again in 1993 (mean at oiled sites was 83% of the control). The average density of flowering shoots at oiled sites relative to controls was 39% in 1990, 87% in 1991, and 41% in 1993.

There were significantly greater densities of both shoots and flowering shoots at control sites when data from the three sites visited in all years were analyzed together in a two-way analysis ($P < 0.01$, Figure 5 and Table 2). Neither the differences among years nor the interaction of year and oiling category were insignificant for both flower and turion density (Table 2). In contrast, there were no significant differences among sites, with respect to either the density of shoots or flowering shoots, when data from either 1991 or 1993 were analyzed in a one-way analysis (Table 2).

4.1.2 Algae

The dominant plants in bay habitats are the stipate kelps *Agarum cribrosum* and *Laminaria saccharina*. (A listing of algal species is given in Appendix G). The density, biomass and percent cover of *Laminaria* spp. (the vast majority of which was *L. saccharina*) were greater at the oiled sites relative to the control sites in the deeper stratum, and both density and percent cover were greater at oiled sites in the shallow stratum in 1990 (Figure 6, Table 4, and Appendix G). *Laminaria* represented about 45%, on average of the total algal cover at oiled sites, but only 13% of the total cover at control sites.

The density and biomass of *Agarum* did not differ among sites (for density, $P = 0.40$ shallow and $P = 0.70$ deep; for biomass, $P = 0.16$ shallow and $P = 0.28$ deep; Appendix H). However, there were observable differences with regard to size distributions of *Agarum*. There tended to be proportionally more small plants, and proportionally fewer large plants at the oiled sites, especially in the shallower depth strata (Figure 7). These differences in size distribution was significant in shallow bays ($P < 0.01$), but not in deeper parts of bays or on points (Figure 7).

The total biomass of all algae tended to be greater at control than at oiled sites. The biomass in the shallow stratum averaged 1,132 g m^{-2} at the oiled sites and 1,766 g m^{-2} at the control sites. In the deeper stratum, mean biomass values were 387 and 529 g m^{-2} at oiled and control sites respectively. However, mean biomass did not differ significantly among oiled and control sites in either depth stratum ($P = 0.15$ shallow, and $P = 0.53$ deep).

Points around the islands of the Knight Island group tended to have slightly higher algal diversity than the Bays, but were still dominated by *Agarum cribrosum* and *Laminaria saccharina*. The density of *Agarum* was more than twice as great at oiled sites than at control sites ($P = 0.02$ deep and $P = 0.06$ shallow, Table 4 and Figure 8). This difference was largely due to the significantly higher density of small *Agarum* (< 10 cm in height) at the oiled sites, especially in the deeper stratum (Figure 8 and Table 4). Also, the size distributions of *Agarum* (for plants larger than 10 cm) revealed a pattern similar to that observed in the Bays, with proportionally fewer large individuals and more smaller plants at the oiled sites, especially in the shallower depth stratum (Figure 8). There were no differences among oil and control sites with respect to density, biomass, or cover by *Laminaria* (deep, $P = 0.26$, 0.92, and 0.87; shallow, $P = 0.43$, 0.37, and 0.64 respectively), or biomass of all algae (deep, $P = 0.79$; shallow $P = 0.22$; Appendix H).

Nereocystis habitats had a canopy of *Nereocystis leutkeana* with a diverse understory consisting primarily of *Agarum cribrosum*, *Pleurophycus gardneri*, and 3 *Laminaria* species (*L. saccharina*, *L. groenlandica*, and *L. yezoensis*). *Nereocystis* density was significantly greater at the oiled sites relative to the control ($P < 0.01$, Table 4 and Figure 9). Also, there were proportionally more small plants and fewer large plants at the oiled sites (Figure 9).

The biomass of *Agarum* was significantly greater at the oiled sites relative to the control sites within the *Nereocystis* habitat ($P < 0.01$). Mean biomass of *Agarum* was 284 g m^{-2} at oiled sites and only 32 g m^{-2} at the control sites. However, this was largely the result of a relatively high biomass of *Agarum* at 1 of the oiled sites (554 g m^{-2} at Little Smith Island). There were no other significant differences among oiled and control sites with regard to the percent cover, density, or biomass of any of the understory algae.

The total biomass of all understory kelps (all kelps excluding *Nereocystis*) tended to be greater at control than at oiled sites. The biomass averaged 3,699 g m^{-2} at the oiled sites and 6,240 g m^{-2} at the control sites, but did not differ significantly among oiled and control sites ($P = 0.16$).

We measured the growth rate of *Agarum* at 2 oiled and 2 control sites for a period of between one and two months in the summer of 1990. The growth rate of the plants was relatively low, ranging from 3.8 to 9.4 cm per 30 days, and there was no consistent pattern with respect to the differences among oiled and control sites (Table 5). At one of the two pairs of oiled and control sites examined (Herring Bay and Lower Herring Bay) growth was better at the oiled than at the control. The pattern was the opposite at the other pair (Bay of Isles and Mummy Bay).

4.2 Infaunal and Epifaunal Invertebrates

4.2.1 Sediment Grain Size

The sediments within the eelgrass habitat were composed mostly of sand and mud (Figure 10 and Appendix I). There were no significant differences ($P > 0.10$, randomization ANOVA) in mud or sand between pairs in any of the three sampling years. The two-way test on the three common site pairs over the three years revealed that percent mud was significantly greater ($P = 0.03$) at control eelgrass bed (< 3 m) sites ($\bar{X} = 43.8\%$) than at oiled bed sites ($\bar{X} = 32.6\%$). Also, there was a significant decrease ($P = 0.02$) in mud content at the eelgrass bed sites over the three years; 1990 had the greatest mud content. There were no significant differences among oilcodes or years with respect to percent sand.

Within the fjordic portion of Herring Bay, the sediments were comprised mostly of muds (Appendix I). The mean proportion of the sediments at 20 m that was mud varied from 98% in 1990, to 43% in 1991, and 49% in 1993.

4.2.2 Infauna and Small Epifauna in Stratified Sampling

Eelgrass Habitats

The benthic community in soft sediments within and adjacent to eelgrass beds consisted of a diverse assemblage of invertebrates dominated by polychaetes, bivalve and gastropod mollusks, and crustaceans (Table 1 and Appendix J). We examined differences among oiled and control sites with respect to community parameters for both infaunal and epifaunal taxa. These parameters included Shannon diversity [H'], Simpson's dominance [D], species richness (SR), total number of taxa (T), total abundance (A), and total biomass (B), as well as the abundance and biomass of dominant taxa.

1990 - Dredge sampling of the benthic community within the four pairs of eelgrass bed (< 3 m) sites revealed significant differences between oiled and control sites relative to total abundance and biomass. Both parameters were greater ($P < 0.01$) at oiled sites (Table 6, Figure 11, and Appendix K). The greater abundance and biomass at oiled sites was mainly attributable to epifaunal organisms, in particular, spirorbid polychaetes, mytilid mussels (*Musculus* spp.), and lacunid snails (*Lacuna vincta*). Dominant infaunal organisms that also had greater abundance and/or biomass at oiled sites were spionid polychaetes (Table 7, Figure 12, and Appendix L). Epifaunal trochid snails and phoxocephalid amphipods and infaunal crustaceans were the only dominant groups that displayed greater abundance or biomass at control sites.

Additional analyses performed on the data collected by dropnet in the eelgrass bed also revealed that onchidorid nudibranchs were more abundant and had greater biomass at oiled sites, while species richness, the abundance of syllid and nereid polychaetes, and amphipods were greater at control sites (Table 1, Figures 13-14, and Appendices M-N).

At the shallow (3-6 m) depth stratum sampled by suction dredge, species richness was greater at control sites and five taxa (rissoid snails, venerid and tellinid clams, phoxocephalid amphipods, and all amphipods) were significantly ($P \leq 0.1$) more abundant or had greater biomass at control sites. Only one family (opheliid polychaetes) was more abundant ($P \leq 0.05$) at oiled sites (Figures 15-16).

The pattern displayed offshore of the beds (6-20 m) was very different from within the eelgrass bed. Analyses conducted for taxa collected by suction dredge revealed that dominance was lower and total abundance was greater at control sites (Table 6, Figure 17, and Appendix K). Furthermore, five dominant taxa (sigalionid polychaetes, caecid and lepetid snails, venerid clams, and all amphipods) were more abundant and/or had greater biomass at control sites, while only maldanid polychaetes and infaunal gastropods were more abundant at the oiled sites (Table 8, Figure 18, and Appendix L).

1991 - Fewer differences were observed between oiled and control sites in 1991 than in 1990. There were no differences ($P > 0.1$) among oiled and control sites (both eelgrass bed and deep strata) with respect to any of the six community parameters (Table 6, Figures 11 and 17, and Appendix K). Dredge sampling at five pairs of eelgrass bed sites revealed that four of the dominant infaunal taxa (lumbrinerid polychaetes, Rhynchocoela ribbon worms, and lacunid and trochid snails) had greater abundance or biomass at control sites, while total infauna, nereid polychaetes and venerid clams had greater biomass at oiled sites (Table 7, Figure 12, and Appendix L). The higher abundance of epifaunal taxa observed at oiled sites in 1990 was not statistically discernible in 1991.

We did not sample with dropnets in 1991. However, an independent estimate of mytilid mussel abundance was obtained by sampling individual blades of eelgrass and counting the number of mussels attached. For these samples, the abundance of *Musculus* spp. (the only mytilid genus present) was significantly greater at oiled sites ($P = 0.06$, Figure 19).

We also examined the size distribution of *Musculus* spp. at one oiled site (Clammy Bay, Site #25) and one control site (Puffin Bay, Site #26) twice in 1991 to estimate the growth rate of these mussels, and to determine if there were differences in growth between oiled and control sites. The size distributions of the mussels were similar ($P > 0.1$) at the oiled and control sites, and increased from a mean of approximately 3 mm in length in July to about 6 mm in August (Figure 20).

Offshore (6-20 m) of the eelgrass bed, there were relatively few differences with respect to the abundance and biomass of dominant taxa. Only one infaunal family (orbiniid polychaetes) and epifaunal group (crustaceans) had greater biomass at control sites. Two infaunal polychaete families (Maldanidae and Spionidae) had greater biomass or were more abundant at oiled sites (Table 8, Figure 18, and Appendix L).

1993 - Dredge sampling of the benthic community at the three pairs of eelgrass bed sites (< 3 m) revealed significant differences between oiled and control sites relative to species richness, total taxa, abundance and biomass. All were greater ($P \leq 0.1$) at oiled sites (Table 6, Figure 11, and Appendix K). These greater values at oiled sites were mainly attributed to infaunal and epifaunal polychaetes (infauna: Amphictenidae, Nereidae, Opheliidae, and Spionidae; epifauna: Spirorbidae) and mytilid mussels (*Musculus* spp.) (Table 7). Dominant taxa more prevalent at control eelgrass beds were infaunal polychaetes (Lumbrineridae and Polynoidae), infaunal bivalves (Lucinidae and Tellinidae), and epifaunal amphipods (Phoxocephalidae) (Table 7, Figure 12, and Appendix L).

Offshore of the eelgrass bed, at 6-20 m depths, none of the community parameters (H', D, SR, T, A, B) exhibited significant differences between oiled and control sites (Table 6, Figure 17, and Appendix K). More of the dominant taxa displayed greater abundance or biomass at oiled sites. These included syllid polychaetes, caecid snails, mytilid mussels, and amphipods (Table 8, Figure 18, and Appendix L). This was the first time that amphipods were more prevalent at oiled sites.

1990, 1991, 1993 - In the two-way analyses, in which data from all three years were compared in a single analysis, comparisons between oiled and control sites indicated that there were no significant differences ($P > 0.1$) relative to diversity, dominance, or species richness in either depth strata (bed or deep) (Table 6, Appendix O). However, total taxa, abundance, and biomass in the bed were significantly greater at oiled sites ($P \leq 0.05$). Total biomass in the deep stratum was greater at control sites ($P \leq 0.05$).

Two-way analyses on the dominant taxa within the bed revealed that most taxa had greater abundance or biomass at oiled sites (Table 7, Appendix P). Notable exceptions were lumbrinerid polychaetes (biomass), tellinid clams and amphipods (abundance) which were more abundant at control sites. Similar analyses within the 6-20 m stratum also revealed that most taxa had greater abundance or biomass at oiled sites (Table 8, Appendix P). Total infaunal abundance, two polychaete families, and two clam families had greater abundance or biomass at control sites.

The two-way analyses also revealed that diversity and dominance were not significantly different over the three years in either depth stratum (Table 6, Appendix O). Within the bed, the analyses showed differences between years for species richness, total taxa and total abundance. Within the deep stratum, differences between years were apparent for total taxa, total abundance and total biomass (Table 6, Appendix O). In all two-way analyses involving significant differences of community parameters between years, the parameters were lowest in 1990 and highest in 1993.

Two-way analyses were used to examine the differences in the quantities of dominant taxa between years. There were few differences between years within the bed stratum (Table 7, Appendix P). However, total abundance and abundance or biomass of several taxa in the deep stratum revealed differences over the three-year period (Table 8, Appendix P). In most instances, the lowest values were in 1990 and the highest values were in 1993. Notable exceptions were lumbrinerid polychaetes and venerid clams in the 6-20 m stratum which had highest biomass values in 1990 and lowest values in 1993.

There was a significant interaction between oiling and year for total abundance in the eelgrass bed ($P < 0.10$) Table 6. Total abundance was greater at oiled sites in 1990 and 1993, but not in 1991 (Figure 11). Significant interactions were also noted for several of the dominant taxa within the eelgrass habitat (Tables 7 and 8). Most notable were significant interactions for amphipod abundance in both the eelgrass bed ($P < 0.05$ Table 7) and in the deep stratum ($P < 0.01$, Table 8). Amphipods were more abundant at control sites in 1990, and more abundant at oiled sites in 1993 (Appendix P).

Laminaria/Agarum Bay Habitat

1990 - The benthic community, inclusive of infauna and small epifauna, within three pairs of *Laminaria/Agarum* bay sites was dominated by polychaetes, bivalves, gastropods and crustaceans (Table 1 and Appendix J). Within the shallow (2-11 m) depth stratum in 1990, species richness, total taxa and total biomass were significantly greater at oiled sites (Table 9, Figure 21, and Appendix Q). Comparisons on the dominant taxa revealed that eight families had greater abundance or biomass at oiled sites, while none were greater at the control sites. Families greater at oiled sites included five polychaetes (Amphictenidae, Capitellidae, Lumbrineridae, Polynoidae, and Serpulidae), two snails (Cylichnidae and Nassariidae) and one clam (Lucinidae) (Table 10, Figure 22, and Appendix R).

Within the deep stratum (11-20 m), Shannon diversity was significantly higher and Simpson dominance was significantly lower at oiled sites than at control sites (Table 9, Figure 23). Two families (cirratulid polychaetes and mytilid mussels) had greater abundance or biomass at oiled sites, while four families (spionid and serpulid polychaetes, tellinid clams, and caecid snails) had greater abundance or biomass at control sites (Table 11, Figure 24, and Appendix R).

1991 - Fewer differences among oiled and control sites were noted in 1991. Within the shallow depth zone (2-11 m) there were no differences with respect to community parameters between oiled and control sites in 1991 (Table 9, Figure 21, and Appendix Q). Furthermore, only two taxa (dorvilleid polychaetes and small, unidentified gastropods) were more abundant at oiled sites, compared with eight taxa in 1990. Spionid polychaetes were more prevalent at control sites in 1991 (Table 10, Figure 22, and Appendix R).

At the deeper stratum (11-20 m), diversity was still higher and dominance lower at oiled sites, but the differences were not as great as observed in 1990 (Table 9, Figure 23, and Appendix Q). Comparisons for the dominant taxa from the deep stratum indicated that lumbrinerid and opheliid polychaetes had greater abundance in oiled sites, while serpulid polychaetes were more prevalent at control sites (Table 11, Figure 24, and Appendix R).

1990 and 1991 - In the two-way analyses, in which data from both years were examined in a single analysis, comparisons indicated that there were no significant differences in community parameters (H', D, SR, T, A, B) between oiled and control sites at the shallow stratum (Table 9, Appendix S). However, the abundance or biomass of four dominant infaunal taxa were greater at the oiled sites (Table 10, Appendix T).

Within the deep stratum (11-20 m), diversity and species richness were significantly greater and dominance was less at the oiled sites (Table 9, Appendix S). Four families had greater abundance or biomass at control sites, while two had greater abundance at oiled sites (Table 11, Appendix T).

There were dramatic increases in diversity, species richness, total taxa, total abundance, and total biomass at both oiled and control sites from 1990 and 1991, within the shallow depth stratum (Table 9, Appendix S). Five community parameters (Table 9, Appendix S), as well as the abundance or biomass of 16 of the dominant taxa all increased from 1990 to 1991 (Table 10, Appendix T). The taxa included six polychaetes, four snails, three bivalves, two amphipods, and one brittle star. No taxa were more prevalent in 1990.

In the deep stratum, total abundance for all organisms increased significantly from 1990 to 1991 (Table 9, Appendix S), as did the abundance or biomass of eight of the dominant taxa (Table 11, Appendix T). These included five polychaetes and three bivalves. Only one family, serpulid polychaetes, was greater in 1990. In addition, a significant interaction was noted between oil code and year with respect to dominance (Table 9, Appendix S). In the deep stratum, dominance increased at the oiled sites relative to control sites, while the opposite pattern was observed in the shallow depth stratum.

4.2.3 Infauna in Fjords

During the initial visit to Herring Bay fjord in October 1989, we noted a number of dead and dying organisms on the bottom, primarily in the deeper portions (> 11 m) of the fjord (See Section 4.3.2 below). In addition to the dead organisms, the mud substrate had a patchy, cobweb-like layer of the bacterium, *Beggiatoa.* This colorless, sulfur-dependent, hemolithotrophic bacteria is associated with enrichment of labile organic matter and low dissolved oxygen (Jorgensen, 1980).

The benthic community in Herring Bay fjord in 1989 was characterized not only by the presence of dead animals, but also a moderately low Shannon diversity (H') (1.7), a moderately high Simpson dominance index (0.4), and a near absence of sensitive burrowing amphipods (Amphithoidae: 16 individuals m^{-2}). The high dominance was mainly attributed to an abundance of stress-resistant taxa such as the bivalves *Lucina tenuisculpta* (Lucinidae) and *Mysella tumida* (Montacutidae) and the polychaetes *Nephtys cornuta* (Nephtyidae) and *Polydora socialis* (Spionidae) (Table 12, Figure 25). In spite of this, the community still maintained a relatively rich assemblage of infauna (i.e., 24 taxa at the family level or higher) (Table 12).

Similar surveys at Herring Bay fjord in 1990 revealed that the diversity and number of taxa were extremely low in both spring and fall surveys (Table 12). The H' diversity was less than 0.1 and there were only 6 taxa present by the fall. Furthermore, several taxa that were abundant in the Fall of 1989, including *Lucina*, *Mysella*, and *Polydora* were absent, and the community was almost totally dominated by *Nephtys cornuta* (Table 12). Dissolved oxygen values 0.5 m above the bottom averaged 3.6 mg l^{-1} in May, but were near zero in October.

By mid August 1991, the community in Herring Bay fjord demonstrated dramatic signs of recovery. Diver surveys revealed no dead organisms, although *Beggiatoa* was still evident on the bottom. Almost all infaunal community parameters had recovered to or near levels observed in 1989 (Table 12). *Nephtys cornuta* still dominated; however, *Lucina* and *Polydora* were now present again, but in low density. Many of the more sensitive species began to appear in moderate densities. These included burrowing amphipods (132 individuals m^{-2}) of the families Ischyroceridae, Isaeidae, Dexaminidae, Phoxocephalidae, and Lysianassidae. The dissolved oxygen during the August sampling (more than one month earlier than 1989 and 1990 fall samplings) averaged 9.7 mg l^{-1} at 0.5 m above the bottom.

The results from sampling in the fjordic embayment of Herring Bay in late September 1993 reversed the trend toward recovery; it tended to resemble the sampling in October 1990, i. e., there were few taxa (4), low H' (0.02), high D (0.99), and no dissolved oxygen in the bottom waters. Nephtyid polycfhaetes, in particular *Nephtys cornuta*, still dominated the fauna (2352 individuals m^{-2}; 99.8% of all infaunal abundance) (Table 12, Figure 25).

Four other fjords were examined during late September 1990. These included one heavily oiled (Inner Bay of Isles), one moderately to lightly oiled site (Disk Lagoon) and two control sites (Inner Lucky Bay and Humpback Cove). All of these sites had low bottom-water dissolved oxygen values of < 1 mg l^{-1} and the sulfur-dependent bacteria, *Beggiatoa* present. All sites had relatively low diversity and high dominance, and were dominated by *Nephtys cornuta* (Table 12).

Only one of the four other fjords, Inner Lucky Bay, was visited again in August 1991. As was the case in Herring Bay fjord, there were dramatic changes that took place since the sampling in Fall of 1990. *Nephtys* abundance was drastically reduced and diversity (both H' and the total number of taxa) increased.

4.3 Large Epibenthic Invertebrates

4.3.1 Patterns of Abundance at Oiled and Control Pairs

The dominant subtidal macroinvertebrates on hard substrata in bays, on points, and in *Nereocystis* habitats were five species of sea stars (*Dermasterias imbricata*, *Evasterias troschelii*, *Pycnopodia helianthoides*, *Orthasterias koehleri*, and *Henricia leviuscula*) and one crab (*Telmessus cheiragonus*) (Appendix U). In 1990, in the deeper stratum of the bays and in both shallow and deep strata on the points, *Telmessus* abundance was significantly greater at the control sites than at the oiled sites (Table 13, Figure 26). Average abundances were 1.1 per 100 m^2 at control sites and less than 0.2 per 100 m^2 at the oiled sites. In addition, 2 sea star species were generally more abundant at control sites. *Dermasterias* density was significantly greater at controls in the shallower stratum of both bay and point habitats (Figure 27), and *Evasterias* was more abundant at controls in the shallow stratum at points and in *Nereocystis* habitats (Figure 28). None of the other species showed significant reductions at any of the other oiled sites in 1990 (Appendix V).

Within the eelgrass beds, only *Pycnopodia*, *Dermasterias*, and *Telmessus* were abundant. *Telmessus* was significantly more abundant at the control sites than at oiled sites in 1990 (Figure 26, Table 13). Average densities were more than 3 per 100 m^2 at control sites, but only 0.4 per 100 m^2 at oiled sites, and in each of the four site pairs, average abundance was greater at the controls. There were no significant differences for the sea star species within the eelgrass bed in 1990 (Table 13). However, average abundances of *Dermasterias* were about twice as high at control sites than at oiled sites (Figure 27).

Telmessus and *Dermasterias* were common to most or all habitats. Therefore, we were able to examine effects of oiling on these species over all habitats combined. It is clear from these results that the densities of *Telmessus* and *Dermasterias* were lower at heavily oiled sites than at control sites in 1990 throughout the western portion of Prince William Sound (Table 13, Figures 26 and 27). Of the 12 pairs of sites in which *Telmessus* was present in at least one of the sites in the pair, 11 of these had higher *Telmessus* abundance at the control site, and the overall average abundance of *Telmessus* was about 4 times greater at the controls. *Dermasterias* abundance was greater at the control in 10, and greater at the oiled in 3 pairs of sites, and average abundance was almost twice as great at control sites.

Within the bay habitat, populations of both *Telmessus* and *Dermasterias* appeared to have recovered fully by 1993 (Figure 29 and Appendix W). In 1991, mean abundances of both species were only slightly greater at control sites, and only *Dermasterias* densities differed significantly among sites. By 1993, mean abundances of both species were slightly higher at the oiled sites.

However, within the eelgrass bed, there were still indications of a possible effect of oil as of July 1993. The pattern of higher mean abundance at the control sites persisted, as densities of both *Telmessus* and *Dermasterias* were nearly 3 times greater at control sites than at oiled sites in 1993 (Figure 29). While the differences in densities in 1993 were not significant (Table 13), when data from all years were considered together, there were still highly significant differences observed among oiled and control sites (Table 14 and Figure 29).

Also apparent was a significant decline in the population density of *Telmessus* within the eelgrass beds between 1990 and 1993, especially at control sites (Figure 29). We do not know if this was related to the effects of oil, or to natural fluctuations in population density.

The patterns of abundance for *Pycnopodia* were quite different than for other sea stars, and were quite different among habitats (Figure 30). In 1990, densities of *Pycnopodia* were generally greater at oiled sites within bay and point habitats, and differences in density were marginally significant ($0.05 < P < 0.10$) in the shallow portions of these habitats (Table 13 and Figure 30). The differences persisted to a large extent through 1993 (Figure 31). In 1990 there were 2.2 times as many adult *Pycnopodia* at oiled than control sites in the shallow bay habitat, and in 1993, there were 1.7 times more of these sea stars at oiled sites. The differences among sites remained significant ($P < 0.05$) when all three year's data were considered together (Table 14 and Figure 31).

In contrast, there was no significant difference in the densities of adult *Pycnopodia* at oiled *vs.* control sites within the eelgrass habitat in 1990 (Table 13 and Figure 30), and in 1991, densities were significantly greater at control sites ($P < 0.05$, Table 13 and Figure 31). There was also a significant interaction with respect to the effects of oiling and year (Table 14 and Figure 31), as mean densities were higher at control sites in 1990 and 1991, and higher at oiled sites in 1993. These data suggest possible injury to populations of *Pycnopodia* in the eelgrass habitat, and recovery by 1993.

One striking result was the extremely large number of juvenile (young-of-year) *Pycnopodia* present in 1991 and 1993, and the significant increase in juvenile *Pycnopodia* over time (Figure 31). There were highly significant ($P < 0.01$) increases in the density of juvenile *Pycnopodia* between 1990 and 1993 in both eelgrass and bay habitats (Table 14 and Figure 31). In 1991, newly settled *Pycnopodia* were observed in moderate abundance (greater than 0.05 m^{-2}) in the bay habitat, and in high abundance (greater than 0.5 m^{-2}) in the eelgrass habitat. By 1993, the densities had more than doubled in each of the habitats.

In 1991, the density of these newly settled individuals of *Pycnopodia* was twice as high at oiled sites in the bay habitats, and was 2.7 times higher at oiled sites in the eelgrass habitat. Differences among oiled and control sites were significant in the shallow bay habitat ($P < 0.01$) but not in the deeper bay or eelgrass habitats (Table 13 and Figure 31). Most of the individuals observed were attached to the blades of either algae or eelgrass, and were apparently feeding on epifauna attached to the plants. Epifauna of eelgrass, including small mytilids (*Musculus* spp.), were more abundant at oiled than at control sites in 1991 (Section 4.2) and the differences in densities of small *Pycnopodia* may have been related to differences in prey availability. There were no significant differences among oiled and control sites in 1993 (Table 13 and Figure 31).

Sea urchins (*Strongylocentrotus droebachiensis*) were generally rare, and few were observed within our sampling transects (Table 15). Within the shallow depth stratum in four *Laminaria/Agarum* bay sites sampled in each of three years (1990, 1991, and 1993), we observed only 7 urchins in 1990, 0 in 1991, and 11 in 1993. However, while turning over cobbles in the lower intertidal in search of intertidal fishes, and while swimming over larger areas in the shallow subtidal, we noted a general increase in the density of urchins in 1993. At some sites, we noted densities of about 10 m^{-2} under intertidal cobbles, and occasionally saw patches of similar density within eelgrass beds. Most of the urchins observed were small (test diameters of less than approximately 2 cm). These anecdotal observations suggest that, while still relatively rare, aggregations of small urchins appeared more common in 1993, and densities of urchins may be increasing.

4.3.2 Large Epifauna in Fjords

In 1989, we observed numerous dead animals in deeper portions (> 11 m) of the Herring Bay fjord. In one area surveyed (approximately 70 m^2) at Herring Bay, we observed over 40 dead animals laying on the bottom including 23 polychaete worms and 11 *Pycnopodia*. Also encountered were dead fish (cod), shrimp, squid, naticid snails, and brittle stars. These were in varying states of decay and were not enumerated.

Similar surveys at this site in 1990 and 1991 revealed fewer dead animals. In video transect surveys conducted in the spring 1990 we saw only one dead *Pycnopodia* over a 90 m^2 area. In fall 1990 only one dead cod and 3 dead worms were observed over an equal 90 m^2 survey area. More extensive visual searches in fall 1990 revealed some dead fish, but there were no concentrated pockets of dead organisms as observed in 1989.

Similar surveys and searches at 4 other fjords in Prince William Sound in 1990 and 1991 found some dead organisms in both oiled and control sites. These organisms included one Pacific herring, and several unidentified worms. However, none of these surveys found the concentration of dead organisms that we observed in Herring Bay Fjord in 1989.

4.3.3 Reproductive success in *Dermasterias*

Nearly one third (29%) of the *Dermestarias imbricata* collected in 1990 were infected with *Dendrogaster* sp. (Table 16). The incidence of infection ranged from 17% at Lower Herring Bay to 39% at Cabin Bay. In 1991, the average proportion of sea stars infected with the parasite was about 10%, but the infection rate increased again to 32% in 1993 (Table 16). For the three sites from which animals were collected in all three years, there were significant differences among years and among sites, and a significant interaction between sites and years (In all cases $P < 0.05$, G-test). However, there were no significant differences in the proportion of sea stars infected at oiled *vs.* control sites in 1990 (Table 17).

Experiments conducted in 1990 indicated that the presence of *Dendrogaster* sp. clearly impaired the reproductive potential of *Dermasterias imbricata*. Eighty-one percent of the animals that were not infected with *Dendrogaster* spawned successfully while an average 47% of the infected individuals spawned (Table 18). Spawning success was inversely related with the level of infection. Only 28% of the sea stars that had *Dendrogaster* present in more than one ray spawned successfully. The effect of *Dendrogaster* sp. on reproductive potential was also evident based on the density of eggs in the gonads. Parasitized females had significantly fewer eggs per mg of gonad than females that were not parasitized ($P < 0.01$, chi-square test).

4.4 Fishes

Over fifteen species of fish were found in eelgrass habitat in 1990. Pacific cod (especially young-of-year) were by far the most abundant species, comprising over 90% of the total number of fishes. A variety of demersal species made up the remainder of the fish community within this habitat (Appendix X).

In 1990, the abundance of both adult and young-of-year cod was greater at oiled than at control sites ($P < 0.01$ for both, Table 19, Figure 32, and Appendix Y). There was an average of 4 times as many young-of-year cod at oiled sites as controls, and adults were about 5 times as abundant at the oiled sites. The abundance of all other fishes in the eelgrass beds was very similar at oiled and control sites, and did not differ significantly.

The guts of young-of-year Pacific cod were examined to determine their diets. Diets were comprised primarily of molluscan larvae and small crustaceans (harpacticoid copepods, calanoid copepods, and amphipods). The diets of fish differed at the oiled and control sites. Fish at the oiled sites generally had fuller guts (Figure 33). Young-of-year cod from oiled sites also had generally higher proportions of molluscan larvae, although differences among all pairs of sites did not differ significantly (Figure 33). Young-of-year cod at the control sites had significantly more crustaceans ($P = 0.02$) in their guts.

The fish community in *Laminaria/Agarum* habitats in bays and on points was dominated by Arctic shanny and a mixed group of sculpins. For the purposes of our analysis, we have divided the sculpins into 2 functional groups: smaller sculpin species and larger sculpin species. Other fishes found within these sites included various greenlings and ronquils. The point habitats tended to have somewhat greater abundances and a higher diversity of fishes than the bays, but the fish assemblages in these two habitats were otherwise similar.

Within the shallow bay habitat in 1990, greenlings (Hexagrammidae) were more abundant at oiled sites (Table 19, Figure 34 and Appendix Y). There were no differences in fish abundance at deeper bay sites in 1990.

In the point habitats, a relatively diverse group of fishes including small sculpins and searchers (Bathymasteridae) (in shallow waters); and greenlings, ronquils, and young-of-year Arctic shanny (in deeper waters) were found in greater abundance at oiled sites (Table 19 and Appendix Y). Juvenile cod were more abundant at control sites in both the deep and shallow strata (Table 19). However, these differences were due to one large school of fish noted at one of the control sites, and may not be representative of the more general pattern for this species. Pholids were also noted to be more abundant at deeper control sites.

Because of the similarity of the fish assemblages in bay and point habitats, we were also able to test for differences among control and oiled sites within the combined depths and habitats. In these analyses, both greenlings (Hexagrammidae, Figure 34) and small sculpins (Small Cottidae, Figure 35) were found to be more abundant at oiled sites ($P = 0.03$ and $P = 0.07$ respectively; Table 19 and Appendix Y).

The fish community within the *Nereocystis* habitat was dominated by schooling fishes (eg. herring and sand lance). The schools were uncommon, but there were large numbers of fish within each school. Because of this high spatial and temporal variability, we were unable to adequately sample densities of these schooling fish and have not analyzed these data statistically. Other species of non-schooling fish were found in relatively low density, and the only significant difference observed was a greater abundance of greenlings (Hexagrammidae) at oiled sites ($P = 0.08$ Appendix Y).

Only a limited number of fish species were counted in our 1991 and 1993 surveys. These included cod (both young-of-year and adults) in eelgrass habitats in 1991 and 1993, and Arctic shanny and small sculpins in shallow bay habitats in 1991. Within the eelgrass habitat, there were greater numbers (not significant; $P = 0.19$) of young-of-year cod at the oiled sites in all years (Table 19, Figure 20 and Appendix Y).

This trend is further emphasized in the two-way analyses for effects of oiling and year, that also indicated that there were significantly more juvenile cod at oiled sites (Table 20, Figure 36, and Appendix Y). In addition, the density of both young-of-year cod and adult cod differed significantly among years ($P < 0.01$ and $P < 0.05$ respectively, Table 18, and Appendix Y). Densities increased from 1990 to 1991, and then decreased again in 1993.

Within the shallow bay habitats in 1991, there were significantly greater numbers of adult Arctic shanny and small sculpins at control sites relative to oiled sites ($P = 0.06$ and $P = 0.02$ respectively, Table 19 and Appendix Y). This is in contrast to 1990, when no significant differences were observed for these taxa. In the two-way analyses for shallow bays, there was a significant decrease in the density of adult Arctic shanny from 1990 to 1991, but there were no significant differences among oiled and control sites (Table 20, Figure 36, and Appendix F).

In addition to the comparisons of dominant fishes at oiled and control subtidal habitats, limited histological information was compiled on selected fishes in 1993. Examination of formalin-fixed sections of liver from ten pricklebacks and spleens from ten crescent gunnels revealed multifocal centers of hemosiderin in all specimens examined from the oiled Herring Bay site. No pigment centers were observed in prickleback and crescent gunnel tissues taken from the reference site (R.A. Khan, pers. commun. 1993). Storage product (lipid and/or glycogen) depletion was observed in 11 of 15 pricklebacks from Herring Bay, and none of 15 pricklebacks from Lower Herring Bay.

4.5 Experimental Studies with *Musculus*

In experiments conducted to examine the effects of *Musculus* spp. on eelgrass, we noted no significant effect of the removal of *Musculus* on eelgrass density (Table 21). However, the removal of *Musculus* proved to be an ineffective treatment. Several days after removing *Musculus*, we found it difficult to distinguish the cleared from the control plots because of immigration of *Musculus* onto the cleaned eelgrass blades. After returning to the site several months later, we could not distinguish cleared from control areas without examining plot markers.

In our predator exclusion experiment, there were no significant differences among any of the treatments (Table 22). However, we could not find any *Telmessus* or *Dermasterias* inside our inclusion cages after the approximate two month experimental period, and we doubt the effectiveness of cages in either including or excluding predators. This was clearly the case for the crabs and stars that we attempted to cage in, as well as juvenile Pacific cod (a known predator of *Musculus*) that were observed swimming in and out of cages.

4.6 Results from Hydrocarbon Analyses

Three sediment samples were collected from each depth stratum within each habitat for the evaluation of hydrocarbon concentrations. However, only samples collected from the eelgrass habitat, the *Laminaria/Agarum* bay habitat, and one silled fjord site were analyzed in total. Only one or two samples were analyzed for other habitats (*Laminaria/Agarum* points, *Nereocystis*, and other fjords). We rely on the mean concentration sum of the PAHs (summed PAH) from these samples to indicate the degree of oiling. Analytes that comprise the summed PAHs, inclusive of analytes that resemble weathered *Exxon Valdez* crude oil, are given in Appendix E. Mean concentrations are given in Appendix AA. It was determined that some of the samples sent to the Technical Services Task Force, Analytical Chemistry Group, NOAA/NMFS were improperly analyzed. Therefore, a total six samples collected in 1990 (Catalog 6546: one from Herring Bay silled fjord and five from deep eelgrass habitat) were not included in the statistical analyses.

Eelgrass Habitat

1990 - The average concentration of summed PAHs in the eelgrass bed sediment was more than twice as high at oiled sites (538 ng g^{-1}) than at control sites (236 ng g^{-1}). This difference was significant ($P < 0.035$, Table 23, Figure 37, and Appendix AA).

Offshore of the eelgrass bed, at 6-20 m, there were relatively high concentrations of PAHs present at some control sites that were adjacent to unoiled shorelines. Two of four control sites had PAH concentration higher than 600 ng g^{-1} sediment. This resulted in no statistical difference ($P = 0.71$) between average summed PAHs at oiled (550 ng g^{-1}) and control sites (388 ng g^{-1}) (Table 23, Figure 37, and Appendix AA).

1991 - The concentration of summed PAHs within sediment from the eelgrass bed in 1991 were still significantly greater at oiled sites ($P = 0.08$; Table 23, Figure 37 and Appendix AA). The average concentrations at oiled and control sites were 134 and 94 ng g^{-1}, respectively.

The concentration of summed PAHs within sediment offshore (6-20 m) of the eelgrass bed were also significantly greater at oiled sites in 1991 ($P = 0.02$; Table 23, Figure 37, and Appendix AA). The average concentrations at oiled and control sites were 159 and 87 ng g^{-1}, respectively.

1993 - Four years after the spill, differences in oil concentrations in sediments were not significant ($P > 0.1$) within the eelgrass bed, although the average PAH was greater at oiled (27 ng g^{-1}) than at control sites (16 ng g-1). The concentrations of summed PAHs within sediments offshore (6-20 m depth stratum) of the eelgrass bed were greater at oiled sites in 1993 ($P = 0.01$; Table 23, Figure 37, and Appendix AA). The average concentrations at oiled and control sites were 72 and 29 ng g-1, respectively.

1990-93 - In the two-way analyses, in which oil data from all three years were compared in a single analysis, comparisons between treatment (oiled and control) sites indicated that there were no significant differences ($P > 0.1$) relative to summed PAH concentrations in either depth stratum (bed or deep), although the decision relative to the eelgrass bed was close ($P = 0.101$; Table 23). This analysis also revealed that summed PAHs significantly decreased over the three years in both depth strata (Table 23). The concentration was highest in 1990 and lowest in 1993 in both depth strata. There were no significant interactions between the effects of oil and year in either depth stratum (Table 23).

Laminaria/Agarum Bay Habitat

1990 - At the sites sampled in *Laminaria/Agarum* bay habitats, there were also striking differences among oiled and control sites with respect to concentrations of oil (summed PAHs). In general, oil concentrations were greater at the shallower depth. Concentrations were nearly three times higher at oiled than control sites in the shallow portions of the habitat, and nearly four times higher at oiled than control sites in the deeper stratum. Statistically significant differences ($P \leq 0.1$) were noted in both strata (Table 23, Figure 38, and Appendix AA).

Sediment samples collected in the *Laminaria/Agarum* bay habitat in 1991 were not analyzed for hydrocarbon concentrations.

Island Point and *Nereocystis* Habitats

1990 - There are little hydrocarbon data available for Island Point or *Nereocystis* habitats (Figure 38, Appendix AA) and no statistical analyses were performed for these habitats. The general trend of somewhat higher concentrations of oil at oiled sites, with occasionally high concentrations of oil at some control sites, was also evident from these data.

5.0 DISCUSSION

5.1 Interpretation of Statistical Tests and the Assessment of Injury

In assessing the injury to subtidal populations of plants and animals caused by the spill, we rely primarily on the comparison of population parameters in oiled *vs.* control sites in 1990, 1991, and 1993. There are few pre-spill data available, and we were unable to make pre- *vs.* post - spill comparisons except in a very broad sense. Also, we have not attempted to link changes in biological variates with hydrocarbon concentrations in any statistical sense. Given the high degree of spatial variability in both hydrocarbon concentrations and biological variates, the relatively high degree of error in the measurement of hydrocarbon concentrations and biological variates, and the relatively small sample sizes for both, such an analysis would probably not be very enlightening.

Our comparison of oiled and control sites in the three years suggest that the spill resulted in changes to at least some species within each of the components (plants, infaunal invertebrate, epibenthic invertebrate and fish) of the shallow subtidal ecosystem in Prince William Sound. The following provides a brief discussion of the differences between pre- and post-spill surveys as well as a summary of the statistical differences observed between oiled and control sites in 1990, 1991, and 1993, and our interpretation of the statistical tests with respect to the effects of the spill.

As with all assessments of the effects of a disturbance on ecological systems, the final decision as to whether an impact has occurred generally rests on "weight of evidence". When one examines a host of biological variates as we have done, it is anticipated, both from statistical and biological perspectives, that one would find some significant differences among oiled and control sites even in the absence of an effect of the spill. However, the evidence for an effect becomes stronger when one finds repeated patterns of effects over a variety of habitats that can be supported by our knowledge of the effects of oil and of biological interactions among species. Therefore, we will focus our discussion on consistent patterns that emerge from the statistical tests, and on hypotheses as to how the spill may have acted to cause these changes.

5.2 Comparisons with Pre-Spill Surveys

Surveys of subtidal algae, invertebrates, and fish were conducted at selected sites throughout Prince William Sound in the mid 1970's (Rosenthal *et al.*, 1977, Rosenthal 1980). The general description of the subtidal community given by Rosenthal *et al.* agrees with our observations in 1989, 1990, 1991, and 1993. There did not appear to be any radical changes in the relative abundances of dominant subtidal algae, macrobenthic invertebrates, or fish as a result of the spill. That is, there were no dominant taxa present in the mid 1970's that were absent from the community in 1990.

There is very little quantitative information on the subtidal communities from surveys conducted in the mid 1970's that can be used to assess changes as a result of the spill. Only one of the sites surveyed by Rosenthal *et al.*, Latouche Point, was heavily oiled in the spill. Communities at Latouche Point were similar before and after the spill. A comparison of mean abundances of dominant algae at comparable depths and times of year in 1976 and 1990 are given in Table 24. In 1990, the mean density of *Ncreocystis* was lower and the density of *L. groenlandica* was higher than in 1976. However, these differences are not out of the range with what one might expect from inter-annual variation in the absence of a spill (Rosenthal *et al.*, 1977; Rosenthal, 1980). The increased abundance of longer lived species such as *L. groenlandica*, and a decrease in abundance of fugitive species such as *Nereocystis* is what one would expect with an increase in sea otter population density as occurred over the period from 1976 to 1989. The same pattern has been observed following an increase in otter populations elsewhere in Alaska (Duggins, 1980).

None of the fish surveys conducted prior to the spill were at sites that were oiled in 1989. However, based on surveys from other sites in Prince William Sound during the mid 1970's (Rosenthal, 1980), the fish assemblages we recorded were similar to those observed prior to the spill.

We noted that the numbers of fish species and the numbers of individuals of fish varied seasonally within Prince William Sound. Juvenile and transitory species were absent from the nearshore zone from late fall through spring, and increased beginning in late May through summer. Arctic shanny young-of-year (YOY) recruited into island point habitats as our survey progressed. We observed few YOY in our surveys in May, but noted relatively high abundances in July. Similar seasonal trends in fish abundance were noted by Rosenthal (1980). Other workers have reported similar seasonal shifts in distributional patterns of North Pacific fishes (Simenstad *et al.*, 1976; Moulton, 1977; Cross *et al.*, 1978).

In 1967, McRoy (1970) examined populations of eelgrass at three sites within Prince William Sound (Redhead Bay, Sawmill Bay, and Stockdale Harbor) that were not oiled following the spill. His estimates of mean shoot density at these sites ranged from approximately 200 to 700 m^{-2}, and estimates for mean flowering shoot density ranged from approximately 3.5 to 10 m^{-2}. These are comparable to what we observed at control sites and higher than we observed at oiled sites in 1990. In 1991, both our oiled and control sites had lower values than reported by McRoy. It is difficult to draw conclusions from these comparisons with respect impacts of the spill, especially since there were no common sites between McRoy's study and ours.

5.3 Effects of the Spill Based on Comparisons of Oiled and Control Sites

5.3.1 Effects on Eelgrass

The comparisons of various parameters at oiled *vs.* control sites in 1990 indicate that the density of shoots and flowering shoots of eelgrass were lower at oiled than at control sites, and that these differences were marginally significant. In the subsequent years, differences among oiled and control sites persisted to an extent, but when analyzed on a year by year basis, were no longer significant. These data lead to alternative interpretations regarding the possible effect of oil:

1. Based on observations of significant differences in 1990, but not in the following years, one could propose that there was a significant effect of oiling on density of both shoots and flowering shoots, and that recovery had occurred by 1991.

2. Based on the highly significant effect of oiling category in the analysis of data from the 3 pairs of sites sampled in all years, and on the relative persistence in the proportional differences among

oiled and control means at these sites, one could argue that there was a significant effect of oiling, and that the effect persisted through 1993.

3. On the same basis as indicated for argument 2 above, one could suggest that there were no effects of oil, and that differences observed among oiled and control sites were unrelated to oiling, but were rather due to inherent differences among sites.

At present, we have no way of unequivocally rejecting any of these arguments. Unfortunately, there are no pre-spill data available for sites that were oiled during the spill. As a result, any argument suggesting an effect of oil is predicated upon the assumption that shoot and flowering shoot densities would have been similar at the oiled and control sites in the absence of a spill. Longer-term observations at the sites can help to resolve this conflict. Continued persistent differences among the sites would suggest that, in fact, differences observed in 1990 through 1993 were the result of inherent site differences. Convergence among oiled and control sites would support arguments for an initial effect of oiling.

Our opinion is that there was an effect of oil and that there has been some, if not complete, recovery of eelgrass. Support for this comes from a second set of independent evaluations of the effects of the spill on eelgrass populations in Prince William Sound (Houghton *et al.* 1991, 1993). In 1990, Houghton *et al.* conducted surveys at six oiled and three control sites. While three of the oiled sites were common to the ones used in our study, three other oiled sites and the 3 control sites were different than the sites we sampled. These investigators found, as we did, that flowering was less common at oiled than at control sites. Mean values reported by Houghton *et al.* (1991) were very similar to those we reported. In 1990, we estimated mean flowering shoot densities of 2.8 and 7.3 m^{-2} at oiled and control sites respectively compared to values of 1.7 and 8.4 m^{-2} reported by them.

The 1990 surveys conducted by Houghton and his co-workers (Houghton *et al.* 1991) failed to demonstrate any statistically significant differences among oiled and control sites with respect to density of shoots. However, they found that mean densities were generally higher at control sites (316 m^{-2} at control sites *vs.* 240 m^{-2} at oiled sties in July 1990) and the proportional differences among oiled and control sites were almost identical to those we observed (75% *vs.* 76%). Also, in keeping with our results, Houghton *et al.* (1991) found no significant differences with respect to biomass or seed germination among oiled and control sites.

Both our studies and those conducted by Houghton *et al.* suggest that the differences in shoot density and flowering that we observed were related to the impacts of oiling or cleanup activities, and were not the result of inherent site differences. However, these data, and comparisons of these with pre-spill data provided by McRoy (1970), also suggest that the effects of oiling on eelgrass were slight. The oiled sites that we examined represented some of the most heavily oiled regions within Prince William Sound, yet there were no signs the elimination of eelgrass beds or drastic reductions in the structure or functions that eelgrass provides. While there were possible reductions in eelgrass density, we observed no significant reduction in biomass, and substantial populations of eelgrass persisted at all oiled sites. Similarly, a reduction in flowering at oiled sites in 1990 had no apparent effect on population densities in 1991 or 1993, as differences in the density of shoots among oiled and control sites decreased between 1990 and 1993. Also, there were no apparent effects of oil on the density of seeds in the sediment in 1990, on their germination rate, or on the extent of chromosomal aberrations in seedlings.

It was somewhat surprising that seed densities did not differ among oiled and control sites, even though there were large differences with respect to the numbers of flowers. Even more surprising was the relatively poor correlation between density of seeds in the sediments and the density of flowers, and the relatively high seed density in sediments at Herring Bay in spite of the lack of flowers there. We suspect that seed densities in sediments probably represented a mix of seed sets from 1989 and 1990, dominated by seeds set in 1989. Seeds generally overwinter in the sediments before germinating (Taylor, 1957), and only a few of the flowering shoots observed in 1990 had mature seeds. The density of seeds in the sediments was presumably a product of several factors including the number of seeds produced, their dispersal distance, their retention rate at a particular site, and the germination rate of seeds. As a result, the density of seeds in sediments did not necessarily reflect the reproductive potential of plants at a given site in 1990 or in prior years.

We observed higher rates of germination of seeds collected from Herring Bay (an oiled site) compared with its unoiled control (Lower Herring Bay), but the seedlings produced from the Herring Bay seeds had higher rates of genetic abnormalities. We suspect that both the higher germination rates and concomitant higher percentages of genetic abnormalities at Herring Bay were related to the older average age of seeds at this site. Since there were no flowers present at Herring Bay in 1990, all seeds found in sediments must have been at least 1 year old. Unpublished data from eelgrass beds in southern California (T.A. Dean, unpublished) suggest that germination rates of newly produced seeds are lower than for seeds that have remained in the sediment for several months.

5.3.2 Effects on Algae

There were no radical changes in the relative abundance of algae as a result of the spill. However, our data present a consistent picture of disturbance to the algal communities followed by the beginning of recovery. Among the dominant kelps within each habitat, there was a consistent pattern of more small plants (recruits) at the oiled sites relative to the controls. There are two reasonable explanations for the above observations. The first is that plants at the oiled sites were damaged and/or removed in 1989 by some disturbance event. The population structure in 1990 reflected this disturbance with high numbers of smaller plants that presumably recruited in the winter or spring of that year. A second explanation is that growth of the plants at the oiled sites was reduced for some reason in 1989 (possibly nutrient or light limitation) resulting in a population of smaller plants at oiled sites in 1990.

The first explanation appears more probable. The greater population densities of *Laminaria saccharina* in oiled bays, and the higher density of small *Agarum cribrosum* at oiled points suggest recent recruitment by these species at oiled sites, but not at the control sites. Furthermore, the size distribution of the *Agarum cribrosum* in both bays and points indicates that there were more recruits of this species at oiled sites. Small plants that were less than 100 g wet weight were more abundant at oiled sites, and growth data gathered for *A. cribrosum* populations in Puget Sound (Vadas, 1968) suggest that plants less than 100 g are less than 1 year old. Also, we suspect that slow growth caused by limited nutrients or light at oiled sites in 1989 would have resulted in a relative increase of middle sized plants rather than a relative increase of small plants. Finally, *Nereocystis* communities had a higher density of the smaller plants. A logical conclusion is that some event or events caused a reduction in the density of mature kelps in the nearshore subtidal habitats in 1989.

The differences in size distribution may have been the result of slower growth of plants at oiled sites, or loss of larger plants coupled with recent recruitment at the oiled sites. The existing growth information indicates that there was no consistent difference in growth rate at oiled and control sites. However, we measured growth at only 2 pairs of sites, and only during a time of year when growth is expected to be slow (Vadas, 1968).

5.3.3 Effects on Infaunal and Small Epifaunal Invertebrates

The response of the benthos within eelgrass habitats to oiling in 1990 differed among depth strata and among taxa within a given strata. Within the eelgrass bed, there were notable reductions in the abundance of phoxocephalid amphipods and trochid gastropods. Of the seven other large taxonomic groups (order/phylum) that showed significant differences among oiled and control sites, abundances and biomass were always greater at the oiled sites. This was primarily as a result of increased abundance of epifaunal taxa, especially mytilid clams and spirorbid worms, and several families of suspension/deposit feeding polychaetes. In contrast, most of the taxa in the deeper strata outside of the eelgrass bed had greater abundances at control sites in 1990. Among those taxa that were more commonly found at control sites were amphipods and venerid clams.

Responses within the shallow portions of *Laminaria/Agarum* bay habitats were essentially the same as noted within the eelgrass bed. That is, there was generally greater abundance and biomass at oiled sites. In 1990, we noted 8 taxa that were more abundant or had greater biomass at oiled sites, while none were more abundant at control sites. In deeper parts of the *Laminaria/Agarum* bay habitat, the results were much less consistent, with 2 taxa showing greater abundance or biomass at oiled sites, and 4 greater abundance or biomass at control sites.

Only the deeper strata within the eelgrass bed displayed the classic characteristics of disturbed communities, with low diversity and high dominance (Pielou, 1974; Pearson and Rosenberg, 1978). In contrast, oiled sites within the deeper strata within the eelgrass habitat, as well as the shallower *Laminaria/Agarum* bay sites, displayed some enhancement of diversity and abundance, characteristics generally associated with moderate organic enrichment (Pearson and Rosenberg, 1978).

The pattern of reductions in the abundance of amphipods at oiled eelgrass sites (both within the bed and in deeper strata) is similar to effects observed following other oil spills. Massive declines in benthic amphipods were observed following the *Amoco Cadiz* oil spill, and five amphipod species almost totally disappeared from heavily oiled areas subsequent to the spill (Cabioch *et al.*, 1978; Chassé, 1978; den Hartog and Jacobs, 1980; Dauvin, 1982).

The reductions in biomass of venerid clams and other bivalves that we noted at oiled sites in deeper eelgrass strata were similar to the effects noted in intertidal populations following the spill, and were comparable to reductions in clam abundance noted in subtidal populations following the *Amoco Cadiz* spill. Houghton *et al.* (1993) found that stocks of *Saxidomus* and *Protothaca* were decimated following oiling and subsequent shoreline cleanup activities along many western Prince William Sound beaches. Chassé (1978) observed that subtidal population of burrowing macrofauna, like bivalves, were severely damaged following the *Amoco Cadiz* spill.

The differences among oiled and control sites within the eelgrass beds generally persisted through 1993. Relatively few significant differences were noted among oiled and control sites in 1991. Differences were evident again in 1993 when we sampled at only a three of the most heavily oiled eelgrass beds and their paired control sites. On the other hand patterns at the deeper sites within the eelgrass habitat, and within the shallow strata of the *Laminaria/Agarum* habitat showed signs of almost complete recovery. By 1991, there were few differences observed among oiled and control sites, and by 1993 (at deeper eelgrass sites), and there were generally greater abundance and biomass at oiled sites. There was also a general increase in the abundance of dominant taxa between 1990 and 1993 at the deeper eelgrass sites.

Our evaluation of the effects of oil on benthic fauna in fjords was largely dependent on a time series within one heavily oiled fjordic environment in Herring Bay. Observations there in 1989 through 1993 suggest that there was a marked decline in infaunal abundance between fall 1989 and fall 1990, a recovery the following year, and a decline to 1990 levels again in 1993. The initial decline was associated with high sediment PAH concentrations as well as extremely low oxygen levels. Recovery in 1991 was associated with lower PAH concentrations and higher dissolved oxygen levels. The 1993 decline occurred when oxygen was low, as were PAH concentrations. Mean PAH concentrations were 1214 ng g^{-1} in October 1989, 336 ng g^{-1} in May 1990, 65 ng g^{-1} in August 1991, and 56 ng g^{-1} in September 1993. These data suggest that declines in abundance between 1989 and 1990 may have been caused, in part, by oiling, but that comparable declines can occur as natural phenomenon as the result of restricted water flow and seasonally low oxygen levels.

Among the taxa that showed significant declines in the Herring Bay Fjord were amphipods. This is in keeping with comparable declines noted in the eelgrass habitat, and observed following other oil spills.

Many of the taxa that dominated in the fjordic habitats, including Lucinidae, Nephtyidae, and Spionidae, were opportunists characteristic of low oxygen environments. *Lucina* and presumably other lucinid clams appear to be able to live where conditions are extreme and oxygen and food limited (Yonge and Thompson, 1976). *Lucina* is in the same order as the stress-tolerant *Thyasira* genus, and several species of *Thyasira* (*T. flexuosa, T. sarsi, T. mtokanagai, T. miyadii*) have been reported from organically enriched and polluted substrates (see Table 1 in Pearson and Rosenberg, 1978).

Lizarraga-Partida (1974) reported *Nephtys cornuta* in semi-polluted substrates in Ensenada Bay, Mexico, in areas enriched with organic material derived from sewage-fish waste. Pearson and Rosenberg (1978) gave several other examples of *Nephtys* (*N. incisa, N. hombergi, N. ciliata, N. longosetosa, and N. faneiscona*) appearing in organically enriched and polluted areas, often low in dissolved oxygen. Although *Nephtys* is mainly a predator, it also deposit feeds and thus can utilize the high organic loads associated with the decay of dead organisms.

Pearson and Rosenberg (1978) reported that several species of *Polydora* (Spionidae) occur in organically enriched and polluted substrates, i. e., *P. ciliata, P. ligni, P. kempi, P. paucibranchiata, P. quadrilobata,* and *P. nuchalis.* Members of this family are often observed as initial colonizers of disturbed substrates. *Polydora* is able to colonize empty (defaunated) substrates rapidly and in high numbers, but they are also described as being poor competitors (Grassle and Grassle, 1974).

The disappearance of amphipods from the fjordic portion of Herring Bay is also consistent with observations made in low oxygen environments (Pavella *et al.*, 1983; Harper *et al.*, 1991). Benthic crustaceans, like amphipods, generally emigrate when dissolved oxygen is below 2.8 mg l^{-1} or are killed once values reach 0.4 - 0.7 mg l^{-1} (converted from ml l^{-1} as cited in Tyson and Pearson, 1991).

Silled embayments like Herring Bay often have a depauperate benthic community since the sill restricts exchange between inside and outside waters, and seasonal density stratification limit exchange between bottom and surface waters. In many Scandinavian and Scottish fjords, a seasonal cycle of oxygen depletion and natural cycles of organic enrichment are brought about by these restrictions, resulting in a dominance of stress-tolerant benthic taxa and low diversity (Jørgensen, 1980; Rosenberg, 1980; Josefson and Rosenberg, 1988; also see review by Pearson, 1980) such as observed in the fjordic portion of Herring Bay. These organisms (e. g., Lucinidae, Nephtyidae, and Spionidae) are periodically subjected to stress caused by, or confounded by, hypoxic ($O_2 < 2$ mg l^{-1}) or anoxic ($O_2 = 0$ mg l^{-1}) conditions on the seafloor. This periodic phenomenon of low dissolved oxygen has also been documented in estuaries (Rosenberg, 1977; Rhoads and Germano, 1982) as well as along the open coast (e. g., Boesch and Rabalais, 1991; Harper *et al.*, 1991; Rabalais and Harper, 1991), and has been called the "August Effect" in a New England estuary (Rhoads and Germano, 1982).

Of the four periods when oxygen concentrations were measured, only the two earliest seasonal samplings, May 1990 and August 1991, had appreciable values (2.2 - 11.2 mg l^{-1}). Although our data are meager, we speculate that the oxygen concentrations rise in spring when the stratification breaks down and drop again in the fall (September or October) when stratification reforms, as documented for other regions (e.g., Rosenberg, 1977; Stachowitsch, 1991). The conditions prevalent during the summer are conducive to colonization from adjacent shallow depths as well as outside the embayment. Only the stress-tolerant taxa can apparently withstand the hypoxic/anoxic conditions that often arise in late fall. The community's recovery from disturbance tends to be rapid, because the community is kept in an early successional state by the annual recurring hypoxia/anoxia (Boesch and Rosenberg, 1981; Boesch and Rabalais, 1991).

5.3.4 Effects on Larger Epibenthic Invertebrates

There was strong evidence of an adverse effect of the spill on populations of two numerically dominant epibenthic invertebrates within Prince William Sound; the helmet crab, *Telmessus cheiragonus* and the leather star, *Dermasterias imbricata*. *Telmessus* was consistently found in lower abundance at oiled sites in each of the 3 habitats in which it occurred (eelgrass, bays, and points). *Dermasterias* abundance was lower at oiled sites, especially in shallower portions of the habitats.

The evidence for possible effects on sea stars other than *Dermasterias* was less convincing. *Evasterias* were more abundant at control sites in shallow bays and in the *Nereocystis* habitat, but this pattern was not evident in any of the other habitats or depths. Similarly, there were no significant differences among oiled and control sites with respect to densities of either *Orthasterias* or *Henricia*. Patterns of abundance suggested possible adverse impacts of oiling on adult *Pycnopodia* in eelgrass beds. However, adult *Pycnopodia* were generally more abundant at oiled sites in shallow portions of bay and point habitats, and in 1991, young-of-year *Pycnopodia* were much more abundant at oiled sites in shallow bays.

A surprising result of our studies with *Dermasterias* was the extremely high incidence of internal barnacle parasites. In 1990, approximately 30% of the *Dermasterias* population was infected with this parasite that impairs reproductive effort by castrating its host. In summer 1991, the rate of infection by the parasite had declined markedly, but increased again in 1993. However, there were no differences in the incidence of parasitism among oiled and control sites, and we do not know if the high rate of parasitism in 1990 was the result of the spill.

There was also direct evidence of injury to larger epibenthic invertebrates within the Herring Bay Fjord. Several dead or dying shrimp were observed in the fjord in fall 1989. However, as with benthic infauna, it is unclear whether mortality was the result of oiling, naturally occurring low oxygen levels, or a combination of these factors.

5.3.5 Effects on Fishes

Increased abundances in young-of-year fishes were noted at oiled sites in both eelgrass and in *Laminaria/Agarum* habitats. In the eelgrass habitat, we noted a greater abundance of young-of-year Pacific cod, and in the *Laminaria/Agarum* habitats, we noted greater abundances of juvenile Arctic shanny at the oiled sites in 1990. Ebeling *et al.* (1972) also found greater numbers of larval and young-of-year fishes in oiled sites relative to control sites in the Santa Barbara Channel immediately following the very large oil spill there in 1969.

5.4 Hydrocarbon Levels and Their Relation to Observed Biological Results

Our analyses of hydrocarbon data indicated that PAH concentrations were generally higher at oiled than at control sites, were generally higher in protected bays than on more exposed coasts, and tended to increase with water depth and decrease over time. Similar trends were observed by O'Clair *et al.* (1994). In 1989, they found the highest average PAH concentrations of 810 to 852 ng g^{-1} (88,412 - 123,581 ng total hydrocarbon g^{-1}), in Sleepy Bay, Herring Bay and Bay of Isles. In 1990, PAH concentrations of greater than 800 ng g^{-1} were observed at only two locations (Bay of Isles and Drier Bay).

O'Clair *et al.* (1994) also found that hydrocarbon concentrations tended to move from the intertidal to shallow (generally less than 20 m) depths over time. In 1990 and 1991, there were generally greater concentrations of hydrocarbons at 20 m than at 3 and 6 m. At 20 m depth, the highest average PAH concentration of 965 ng g^{-1} (78,545 ng total HC g^{-1}) was observed in June 1991 in Bay of Isles.

While PAH concentrations were generally higher at oiled sites, relatively high concentrations of PAHs were also observed at some control sites where there was little or no oil along the shoreline. This suggests that oil had reached subtidal sediments even at sites relatively far removed from heavily oiled beaches. Our control sites were in bays or along relatively long stretches of coastline that had little or no oil on their shores. This also suggests that inferences made, with respect to effects of oil at subtidal sites adjacent to moderately to heavily oiled shorelines, are perhaps conservative estimates of injury. We would expect larger differences among oiled and control sites than we observed if, in fact, our control sites had been totally free of oil.

There is some evidence that high PAH concentrations at some control sites were due to contamination from sources other than the spill. For example, the average concentration of PAHs at 20 m depth at the Lower Herring Bay eelgrass site in 1990 was 687 ng g^{-1}. Further investigation revealed that none of the samples from the Lower Herring Bay deep site contained patterns of PAHs that were characteristic of weathered *Exxon Valdez* crude oil, based on the ratios of alkyl-dibenzothiophenes and alkyl-phenanthrenes, and on ratios of alkyl-chrysenes and alkyl-phenanthrenes. The PAH patterns were more evident of gasoline (possibly contaminated during collection), diesel oil (possibly from clean-up activities) and of submarine oil seeps (S. Rice and J. Short, NMFS/NOAA, personal communication, 1994).

There are insufficient data to make direct statistical correlations between PAH concentrations and biological effects. It is important to understand that our hydrocarbon data serve only as indicators of exposure. Relatively few hydrocarbon samples were collected and analyzed, and the bulk of our samples were not collected until summer 1990, more than a year after the spill. Furthermore, samples that were analyzed for hydrocarbons were not taken from exactly the same location as our biological samples. Given the degree of spatial and temporal variability in sediment hydrocarbon levels, and given that higher levels were observed in 1989, prior to the bulk of our sampling effort, it is likely that at least portions of the populations of plants and animals that we sampled were exposed to much higher levels of hydrocarbons than we have measured in the sediments. This is especially true for moderately mobile organisms such as sea stars that were probably too slow to completely escape from oiled waters, and may at times have been exposed to very high concentrations of oil in the intertidal zone.

However, we can state that, in a general sense, there was a correspondence between PAH concentrations and biological impacts, both on temporal and spatial scales. We generally observed greater impacts in areas where there was more oil. Impacts were most severe, and PAH concentrations were highest in eelgrass beds and in shallow parts of bays and points. Our observations also indicate that biological effects generally ameliorated over time as concentrations of PAHs decreased.

5.5 Causes for Observed Effects

5.5.1 Possible Causative Agents and Classifications of Effects

The biological effects summarized above can largely be attributed to the spill. The available evidence suggests that there were differences among oiled and control sites for a given taxon within each component of the subtidal ecosystem in Prince William Sound (plants, infaunal invertebrates, epibenthic invertebrates, and fish) and that oil was present within the sediments at our oiled sites. Furthermore, our findings largely agree with historical evidence of the effects of oil.

The differences that we observed among oiled and control sites may have occurred as the result of the direct (first order) effects of oiling, or as an indirect (second or higher order) effects. The direct effects include chemical toxicity of aromatic derivatives; asphyxiation or entanglement due to direct physical coating; and a variety of reproductive, behavioral, and other sublethal disorders that ultimately may lead to long-term population changes. They may also include the effects of cleanup activities such as physical cleaning methods, bioremediation, and increased boating activity relating to the cleanup effort. Second order effects include changes in a prey species abundance as the result of the direct effect of oil on its predator, changes in predator abundance as the result of direct effects of oil on prey abundance, changes in the abundance of competitors, or changes in habitat abundance as the result of direct effects of oil.

Both first and second order effects can have a positive or a negative influence on a given taxa. For example, toxicity of oil (a direct effect) and reduction in prey availability (a second order effect) can both lead to a reduction in the abundance of a particular taxa. On the other hand, increases in nutrients associated with bioremediation activities (a first order effect) or reduction in predator densities (a second order effect) may lead to increases in abundance. Both increases and reductions in abundance are herein classified as impacts of the spill, since they represent deviations from the normal state.

Many of the differences that we observed were probably attributable to the direct effects of oil. However, it is likely that many of these changes were the result of factors other than acute toxicity. In a treatise on the biological effects of petroleum hydrocarbons in the sea, Spies (1987) reasoned that there are toxic effects on benthic organisms when hydrocarbon levels in interstitial water are in the range of 500-1000 ppb (ng g^{-1}). Stimulation through enhancement of microbial activity occurs in the range of 20-100 ppb, and no measurable benthic effects occur below 10 ppb. While these values for hydrocarbons in interstitial water are not directly comparable to our measurements of PAHs in sediments, they suggest that we should expect relatively few toxic effects based on our measured PAH levels. The mean PAH concentrations that we observed at oiled sites in 1990 ranged from a maximum of 1,664 ng g^{-1} in the deep strata of eelgrass beds in Bay of Isles, to a minimum of 23 ng g^{-1} at Smith Island. The vast majority of the sediment hydrocarbon values that we obtained were in the range expected to result in enhancement of benthic fauna (between 20 and 500 ng g^{-1}). In 1991 and 1993, PAH levels declined, but were still generally in the range in which one might expect slight enhancement.

Other studies conducted in Prince William Sound following the spill also suggest that oil was seldom present at toxic levels in subtidal sediments. O'Clair *et al.* (1994) indicated that concentrations of PAHs in subtidal sediments were too low to be considered acutely toxic to most animals. Direct measures of toxicity of sediments (Wolfe *et al.* 1993) found significant mortality of amphipods or oyster larvae in subtidal sediments collected at depths of 6 to 20 m at six of seven oiled sites in 1991. However, there were no significant differences in survival in subtidal sediments collected from oiled sites compared to those from reference sites. While it is possible that the reductions in abundance or biomass that we observed were, in part, due to acute toxicity of oil, it seems more likely that reductions were the result of chronic exposure to hydrocarbons, to sublethal effects such as changes in behavior that may have resulted in increased predation, or mortality resulting from cleanup activities. Increases in abundance or biomass were probably related to organic enrichment or a reduction in predation or competition. Hypotheses as to causes for changes in specific populations are given in Sections 5.5.2 through 5.5.5 below.

Studies of the effects of oiling and cleanup conducted in the intertidal zone have indicated that cleanup activities, and especially the use of hot-water, high-pressure washing of oiled shorelines, was detrimental to intertidal communities, and often slowed recovery of intertidal populations (eg. Houghton *et al.*, 1991, 1993; De Vogelaere and Foster, 1994). It is extremely difficult to make similar statements that discriminate among the effects of oiling, subsequent shoreline cleanup, or collateral damage associated with cleanup and monitoring efforts on subtidal communities. While cleanup was often localized on a particular shoreline segment, the effects, including mobilization of oiled sediments and increased boat traffic, were often dispersed over a broader subtidal area. However, we suspect that cleanup efforts in many cases had a significant detrimental effect on subtidal populations.

An alternative hypothesis for the differences in species abundances at oiled and control sites is that these sites were inherently different, regardless of the effects of oil. It may be, for example, that predominant current patterns that resulted in the oiling of certain sites were also responsible for the concentration of planktonic larvae and food sources at those oiled sites. Such a hypothesis may explain why certain species, e.g., larval fishes, were more abundant at the oiled sites. However, this hypothesis relies on the unlikely assumption that current patterns are not variable. Furthermore, such a hypothesis cannot easily explain why we observed lower abundances of many of the species at oiled sites in 1990.

Dissolution rates of calcium sulfate cylinders were measured in 1993 by Highsmith *et al.* (1995) to determine if differences in extent of water movement existed between intertidal oiled and control sites in Herring Bay, Prince William Sound. In most cases, the dissolution rates were higher on the oiled site of a matched pair, indicative of greater water movement. This tends to support the notion that some oiled sites may be greater concentrating sites, i.e., they received oil as well as higher densities of selected fauna simply because of greater water transport.

5.5.2 Causes of Effects on Eelgrass

Lower densities of shoots and inflorescences at oiled sites in 1990 were clearly correlated with higher levels of hydrocarbons in the sediments. However, it is unlikely that these levels were sufficient to cause the observed effects. Laboratory studies suggest that some hydrocarbons (toluene and diesel fuel) can retard photosynthesis and growth in eelgrass (McRoy and Williams, 1977), but prior field experiments have failed to demonstrate an effect of oil on seagrass density or growth (Ballou *et al.*, 1987). Possible toxicological effects of oil on flowering have not been examined, but can not be ruled out.

We suspect that impacts on shoot and flower density more likely resulted from "collateral" damage from cleanup and monitoring activities. On several occasions, we observed bare patches in the eelgrass bed that were the direct result of plants being uprooted by boat anchors, in a manner similar to that described by Walker *et al.* (1989). We suspect that this may have been a contributing factor to lower shoot density at oiled sites. Cleanup and monitoring efforts were intense at all of our oiled sites, and small boats associated with these efforts often anchored in the eelgrass beds. There is no documentation available that describes the amount and type of vessel activity that occurred just offshore of oiled coastlines; however, all shores adjacent to our selected oiled sites had been subjected to intense cleaning activities that required extensive vessel support.

The reduction in shoot and flower density may also have been the result of lower irradiance levels. Shoreline cleanup efforts (especially high-pressure washing) led to high levels of suspended sediments in the nearshore zone (A.J. Mearns, personal communication), and presumably reduced light available to eelgrass. Experiments performed elsewhere (Backman and Barilotti, 1976, Dennison and Alberte, 1982, 1986; Dennison, 1982) clearly demonstrate that shading can reduce density of eelgrass, and reductions in seagrass density in Chesapeake Bay and Australia have been attributed to a general degradation in water clarity (Orth and Moore, 1983; Walker and McComb, 1992).

It is also possible that shoot density and flowering at oiled sites was reduced as a result of higher densities of the small mussel, *Musculus* sp. *Musculus* were significantly more abundant at oiled sites, and at some sites (Herring Bay, Clammy Bay, and Sleepy Bay) were at times so dense that they almost completely covered the eelgrass blades and caused the plants to lie along the bottom. The weighing down of eelgrass blades by epiphytes can remove plants from more optimal light regimes that are present higher in the water column (Phillips, 1984), and perhaps more importantly in the case of fouling by *Musculus*, can directly inhibit light penetration to blades. Moderate fouling of eelgrass blades can reduce light penetration by up to 65% (Silberstein *et al.*, 1986) and can reduce photosynthesis by 31%.(Sand-Jansen, 1977). An increase in fouling of eelgrass has been blamed for reduction in the density of seagrasses in Australia (Walker and McComb, 1988; Larkum and West, 1990).

5.5.3 Causes for Effects on Seaweeds

Our results suggest that there were possible reductions in some kelp species immediately following the spill. However, it is unlikely that the oil in the water column or sediments directly killed the kelp plants. Except in cases of chronic exposure (Clark *et al.*, 1978), oil has been shown to have little direct adverse impact on adult kelps (North *et al.*, 1964; Foster *et al.*, 1971, Guzman and Campodonico, 1981; Peckol *et al.*, 1990). However, the anchoring of vessels and the creation of plumes of suspended sediments associated with shoreline cleanup efforts (See Section 5.5.2 above) may have contributed to the mortality of kelps. In the calm bays of Prince William Sound, sediment can persist on the plants for long periods (T. Dean, personal observation), possibly causing damage by shading and abrasion, leading to the weakening and death of the plants during winter storms.

The transport of oil and oiled sediments to the nearshore subtidal could also have indirectly contributed to an increase in kelp recruitment by reducing the abundance of a grazer. There were few large invertebrate grazers in the subtidal in Prince William Sound. Sea urchins, that can graze germlings and effectively prevent kelp recruitment (Dean *et al.* 1989) were rare, presumably due to the presence of sea otters and other predators. Other smaller grazers, such as chitons, limpets, and top snails were common, but we have no data on subtidal populations of these grazers or their potential impacts on kelp recruitment. The only suggestion of a possible impact was that the sea star, *Dermasterias imbricata*, a potential grazer of kelp germlings which has been reported to consume surface films of bacteria and diatoms (A.J. Paul, personal communication), was less abundant at oiled than at control sites. A decrease in grazing pressure by sea stars or small gastropods at oiled sites could conceivably have led to an increase in the number of germlings.

5.5.4 Causes for Effects on Small Benthic Invertebrates

There is convincing evidence that populations of amphipods declined at oiled sites. Amphipod abundance was about twice as high at control than at oiled sites, in all depth strata within the eelgrass habitat, and in the shallow depth stratum within the *Laminaria/Agarum* bay habitat. We suspect that the lower abundance at oiled sites was, at least in part, the result of acute toxicity of oil. However, studies of the toxicity of Prince William Sound sediments, as well as prior studies from elsewhere, have produced somewhat ambiguous results.

Wolfe *et al.* (1993) tested for toxicity of sediments to amphipods using standard laboratory toxicity tests in both 1990 and 1991. In 1990, there was significant toxicity observed in most intertidal sediment samples collected from oiled beaches, and mean mortalities were significantly greater in sediments from oiled than from reference sites. However, there was no indication of toxicity in subtidal sediments. In 1991, significant toxicity was observed at several subtidal sites, including three of our oiled eelgrass sites (Sleepy Bay, Herring Bay, and Bay of Isles). However, there was also significant toxicity observed at several reference sites, including our Drier Bay site, and there were no significant differences in amphipod mortality at oiled *vs.* reference sites. Busdosh (1981) reported 50% mortality in the arctic amphipod *Boeckosimus (Onisimus) affinis* exposed for 10 weeks to mechanically dispersed oil in concentrations (total hydrocarbons) as low as 200 ppb (ng g^{-1}). However, it is unclear whether oil, the dispersent, or a combination of these were toxic. Lee *et al.* (1977) estimated that the amphipods *Gammarus mucronatus* and *Amphithoe valida* began to show toxic effects such as mortality from aqueous extracts of fuel oil at 800 ppb total hydrocarbons, but toxic effects of crude oil were not observed until concentrations reached 2,400 ppb. Amphipod abundance in experimental ecosystems decreased by 98% during a 25 week exposure to sediments that contained 109,000 ppb hydrocarbons (Grassle *et al.*, 1981; Elmgren and Frithsen, 1982). For relatively short-term exposure, Foy (1982) reported 50% mortality in arctic amphipods after 96 hour exposure to dispersed crude oil in measured concentrations of 45,000-162,000 ppb. The amphipod *Anonyx laticoxae* survived an 18 day exposure to sediment containing 292,000 ppb of hydrocarbons (Anderson *et al.*, 1979). Massive declines in benthic amphipods were observed following the *Amoco Cadiz* oil spill when total hydrocarbons in the shallow subtidal sediments approximated 515,000 ng g^{-1}. Within two years, when sediment oil concentrations had decreased to 31,000 ng g^{-1}, three of the five species had returned in low numbers (Dauvin 1982).

It is difficult to make quantitative evaluations of the potential toxic effects of exposure to *Exxon Valdez* oil on amphipod populations based on these prior studies, in part because of the different measures of exposure that were used. However, we can state that PAH concentrations in subtidal sediments in protected bay, following the spill were in the range of 500 to 1000 ng g^{-1}, and that total hydrocarbon levels averaged from 50,000 to 100,000 ng g^{-1}. At least some of the literature suggests that these may be high enough to cause mortality in amphipods.

It is less likely that the reduction in bivalves that we noted in deeper portions of the oiled eelgrass habitat were due to the acute toxicity of oil. The principal members of these families are the suspension- or deposit-feeding clams, *Saxidomus, Protothaca, Macoma, and Tellina.* After the *Tsesis* fuel oil spill, Elmgren *et al.* (1983) found that subtidal *Macoma balthica* (Tellinidae) were found to be highly contaminated with oil (tissue concentrations of 2,000,000 ng g^{-1}) but there were no indications of reductions in population abundance. Abundance and biomass of *M. balthica* increased for three years after that spill. Studies (in vitro and in situ) have shown that intertidal *M. balthica* were adversely affected by exposure to Prudhoe Bay crude oil, but only at much higher concentrations (> 500,000 ng g^{-1}) than we observed (Feder *et al.*, 1976; Shaw *et al.*, 1976; Taylor and Karinen, 1977; Stekoll *et al.*, 1980).

By far the more prevalent response among benthic taxa was an increase in abundance or biomass at oiled sites. We suspect that increases were because many of the taxa were tolerant of oil, and were able to take advantage of increased carbon sources made available from the degradation of oil and bioremediation.

Several polychaete families that had greater concentrations in the oiled eelgrass habitat sites, including amphictenids, maldanids, nereids, and spionids, have been typically characterized as either opportunistic or stress-tolerant. The amphictenids in the oiled eelgrass habitat were dominated by the subsurface deposit feeders *Pectinaria* spp. Gray (1979) lists *P. koreni* as one that increases in abundance under slight pollution.

The subsurface deposit feeding maldanid polychaetes were one of three families that made a rapid recovery in an eelgrass bed oiled by the *Amoco Cadiz* spill (Jacobs, 1980). Spies and DesMarais (1983) showed that petroleum was utilized by the maldanid *Praxillella* as a carbon source in a natural petroleum seep in the Santa Barbara Channel. They suggested the petroleum was used in sufficient amounts to account for greater density of organisms observed in the seep than in a similar nonseep environment.

Two species of nereids, *N. diversicolor* and *N. succinea*, are known to increase in abundance under slight pollution (Gray, 1979). *Nereis diversicolor* are highly tolerant to crude oil (Kasymov and Aliev, 1973) and to low oxygen concentration (Henricksson, 1969). *Nereis succinea* from an oiled marsh has been characterized as a resistant species with stimulated population growth (Hyland *et al.*, 1985) and as an opportunist (Boesch, 1977). Presumably other nereid representatives, particularly those in our study (i.e., *Micronereis* sp. and *Platynereis bicanalicata)* behave similarly. Since nereids vary greatly in their feeding modes (i.e., predator, surface deposit feeder, suspension feeder, and mixed feeder, Fauchald and Jumars, 1979) they have an adaptive advantage in disturbed areas such as the oiled portion of Prince William Sound.

Spionid polychaetes have been observed in numerous investigations as classic secondary opportunists in polluted regions (e.g., Sanders *et al.*, 1972; Grassle and Grassle, 1974; Pearson and Rosenberg, 1978; Gray, 1979). This family has the unique ability to utilize different life-history strategies. Their feeding mode is transitional between indirect deposit feeders and filter feeders (Jacobs, 1980) and both benthic and pelagic larvae are represented (Gray, 1979). A member of this family, *Polydora*, flourished in shallow waters immediately following the spill of #2 fuel oil (Sander *et al.*, 1980). There were at least eight species of spionids, including the genus *Polydora*, that dominated the oiled eelgrass sites in Prince William Sound.

Opheliid polychaetes (mainly the subsurface deposit feeder *Armandia brevis*) that were also more abundant at oiled eelgrass sites are not considered to be opportunists, but intertidal representatives of this family were observed to be very resistant to oil from the *Amoco Cadiz* oil spill (Chassé, 1978).

Some of the faunal increases in oiled habitats were attributable to the small epifaunal, suspension-feeding spirorbid polychaetes and *Musculus* spp. mussels. Little information is available on the response of these organisms to oil, although considerable information is available on the response of another mytilid mussel, *Mytilus edulis*. The mytilids *Mytilus edulis* and *Modiolus demissus* have been observed to increase respiration and decrease feeding and assimilation when exposed to crude concentrations of 1000 ppb (Table 3 in Hyland and Schneider, 1976). However, *M. edulis* has generally been shown to be extremely hardy and resistant to pollutants, including oil (e.g., Lee *et al.*, 1972; Farrington *et al.*, 1982; Ganning *et al.*, 1983; Viarengo and Canesi, 1991).

We suspect that many of the tolerant species were able to utilize an increased food supply provided by hydrocarbon-utilizing bacteria, or by bacteria stimulated by chemical fertilizers sprayed on adjacent beaches in 1989 and 1990 for the purpose of bioremediation. Significantly higher numbers of hydrocarbon-degrading microorganisms were found at oiled intertidal and shallow (< 20 m) subtidal sediments relative to reference sites in Prince William Sound following the spill (Braddock and Richter, 1994; Braddock *et al.*, in press a,b). Six of the sites sampled by Braddock and others were the same general sites that we sampled i.e., Herring Bay, Lower Herring Bay, Bay of Isles, Drier Bay, Sleepy Bay, and Moose Lips Bay.

The same general pattern of increased microbial activity has been observed following other oil spills (Colwell *et al.*, 1978; Roubal and Atlas, 1978; Ward *et al.*, 1980; Lizarraga-Partida *et al.*, 1991). Elevated heterotrophic bacterial populations were observed in oil-contaminated beach sand two years after the *Metula* spill in 1974 in the Straits of Magellan (Colwell *et al.*, 1978). An enrichment of the numbers of hydrocarbon-utilizing bacteria relative to total bacteria was observed in sediments collected one year after the *Amoco Cadiz* spill off the coast of France in 1978 (Ward *et al.*, 1980).

The measurement of various naturally-occurring isotopes in infaunal invertebrates has suggested that petroleum degradation as well as chemoautotrophy are tightly coupled processes in sediments and have a key role in passing petroleum carbon and energy into the food chain (Spies and

DesMarais, 1983; Spies, 1987). Additionally, heterotrophically derived carbon (e.g., hydrocarbon-utilizing forms) is presumably more labile to meiofauna. Harpacticoid copepods ingest heterotrophically derived carbon at a rate about nine times faster than autotrophically derived carbon (Brown and Sibert, 1977). This is presumably due to the smaller size of heterotrophs. Fleeger and Chandler (1983) and Feder *et al.* (1990) determined that increases in meiofaunal density in experimentally oiled intertidal regions were most likely due to increases in microbial production by oil-degrading bacteria, or oil-induced inhibition of predation.

Over the four-year period (1989-93) that oil-degrading bacteria were investigated in oiled sediments in Prince William Sound, quantities were greatest in 1990 and steadily declined thereafter (Braddock and Richter,1994). Although declines were evident, greater concentrations were generally greater in oiled sediments than in reference sediments, even in 1993. The highest bacterial concentrations in 1993 were in subsurface beach sediments. Their findings tend to agree with our sediment hydrocarbon concentrations which declined from 1990 to 1993, but were still greater (albeit not significantly so) at most oiled sites in 1993.

The increases in the abundance of some smaller benthic invertebrate taxa, and especially the epifauna, may also have resulted from an indirect affect of oiling or cleanup on their predators. Significant reductions of both the crab *Telmessus*, and the sea star *Dermasterias* were noted at oiled sites in 1990. These species feed on a variety of invertebrates including spirorbids and *Musculus* (Personal Observations by S.C. Jewett and T.A. Dean). However, experiments conducted in 1993 suggest that predation by crabs and sea stars may not be a major determinant of the distribution and abundance of *Musculus*.

It is also possible that some of the increases in abundance were due to a reduction in competition, especially with amphipods. Elmgren *et al.* (1983) noted there was an unusually heavy recruitment of *Macoma balthica* in areas where subtidal amphipods were virtually eliminated following the *Tsesis* spill, and they attributed the increases in *Macoma* to a reduction in competition with the amphipods. Similarly, Van Bernem (1982) attributed a substantial increase in the abundance of oligochaetes on an oiled mudflat to a reduction of corophid amphipod competitors.

Causes for declines in infaunal abundance in Herring Bay fjord may have been the result of naturally occurring anoxia, toxicity to oil, or by a combination of these factors. It is probable that oiling of the fjord led to a much sharper decline in oxygen content that would have occurred otherwise, leading to what we suspect was abnormally high mortality. This was suggested by several lines of evidence. First, *Lucina* that dominated at Herring Bay in 1989 (61% of faunal abundance) were mainly older than one year; many were more than three years old. Therefore, the habitat in the Herring Bay site prior to the spill must have been conducive to support *Lucina*, even though the region is periodically subjected to low oxygen concentrations. Second, *Nephtys*, which dominated the site after 1990 has been shown to prefer oiled to clean sediments (Busdosh, 1978). Finally, in fall 1989, we observed a number of highly mobile fuana in the Herring Bay fjord that were dead or dying. These species are normally capable of emigrating from sites as oxygen levels decline, and their demise suggests possible toxic effects of oil.

5.5.4 Causes for Effects on Large Epibenthic Invertebrates

We suspect that the reduction in population densities of *Telmessus* at oiled sites was due to the avoidance of oiled sites by adult crabs and the acute toxicity of oil on larvae. While oiling can be acutely toxic to adult crabs (Rice *et al.* 1977, 1979), crabs seldom venture into the intertidal zone, and adult crabs probably were not exposed to lethal concentrations of oil (or to the rigors of shoreline treatment). Furthermore, crabs can detect oil in relatively low concentrations (Pearson *et al.*, 1980, 1981), are highly mobile, and may have effectively avoided heavily oiled sites. Oiling can also lead to behavioral modifications such as a poor righting response which may in turn lead to higher rates of predation (Burger *et al.*, 1991).

The observed longer term decline in the abundance of *Telmessus* was possibly the result of the effects of oil on recruitment of crabs. Larvae of crabs are particularly sensitive to oil relative to adult crabs and to other invertebrate larvae (see review in Rice 1978) and concentrations of hydrocarbons that were not lethal to adults may have impaired recruitment. Krebs and Burns (1978) noted similar long-term declines in population density and a general failure of recruitment of fiddler crabs for several years following the west Falmouth oil spill.

In contrast, we suspect that the lower population density of *Dermasterias* at oiled sites was the result of mortality caused by either oil toxicity or cleanup activities. Sea stars are sensitive to oil (O'Clair and Rice, 1985) and narcosis of sea stars has been observed following oiling both in the laboratory (O'Clair and Rice, 1985) and following an experimental spill in the field (Cross *et al.*, 1987). Unlike many of the species that are common in the subtidal, *Dermasterias* also can be found intertidally and were likely exposed to much higher concentrations of oil than we measured in subtidal sediments. These sea stars migrate into the lower intertidal areas as the tide rises, become exposed on steeper rock faces as the tide falls, and then release themselves from the rocks falling into deeper water as the tide recedes further. As a result of this behavior, *Dermasterias* were probably exposed to oil slicks at the waters surface as well as to harm from cleanup activities (especially high pressure hot water cleaning).

5.5.5 Causes for Effects on Fishes

The increase in the abundance of Pacific cod at oiled sites within the eelgrass habitat was likely a direct result of the increase in mussels that we observed at those sites. The fish at the oiled sites had fuller guts with proportionally more mollusk larvae than those at the control sites.

Gut content analyses of young-of-year Pacific cod in the eelgrass habitat also indicated that fewer crustaceans were being taken as food in the oiled sites relative to the controls. The lack of crustaceans in the guts of fish from oiled sites may have been because there were fewer crustaceans at the oiled sites. Evidence from dredge and dropnet samples in the eelgrass sites suggest that amphipods were less abundant at the oiled sites, and these as well as other crustaceans may have been negatively impacted by oil.

The general pattern of higher abundances of fish at oiled sites was also observed in other habitats. We do not know the cause for this, but suspect that it too may be the result of increased availability of food.

5.6 Possible Implications of Effects on Higher Trophic Levels

We have little direct evidence of the effects of observed changes in the subtidal organisms that we have studied on higher trophic levels. However, in a general sense, we know that changes in composition of benthic fauna can have serious trophic implications. Many of the species affected in Prince William Sound were of special significance to higher trophic levels. For example, significant declines in the biomass of the bivalve families, including Veneridae and Tellinidae, were noted in soft sediments outside of eelgrass beds. These families include the suspension and deposit-feeding clams, *Saxidomus, Protothaca, Macoma,* and *Tellina.* All are important prey to the large sea otter population within Alaska (Calkins, 1978; Green and Brueggeman, 1991). In addition, *Telmessus* were adversely impacted by the spill, and these also serve as valuable food for otters (Green and Brueggeman, 1991).

There is also the possibility that subtidal species, especially infaunal and epibenthic invertebrates, may be contaminated with hydrocarbons, and may serve as a pathway of contamination for their predators. Many subtidal benthic invertebrates and small fish are important food resources for bottom-feeding species such as pandalid shrimps, crabs, larger bottom fishes such as halibut, sea ducks, and sea otters (see review in Feder and Jewett, 1981, 1987; Hogan and Irons, 1988; McRoy, 1988; Koehl *et al.*, 1984). Furthermore, the larvae of most benthic organisms in Prince William Sound are released into the water column and are utilized as food by large zooplankters and juvenile stages of pelagic fishes such as salmon and herring.

Possible contamination via invertebrate prey has been suggested for several fish species. Wertheimer *et al.* (1993) reported that juvenile pink and chum salmon in the nearshore waters of Prince William Sound were contaminated by exposure to the spill crude oil in 1989, but not in 1990. Although there were no observable negative effects to chum salmon, pink salmon grew significantly slower and were significantly smaller in oiled areas than in non-oiled areas in 1989. While they found no evidence of a reduction in available prey organisms of these juvenile salmon, they determined that epibenthic prey biomass, which was primarily harpacticoid copepods, was higher in oiled locations than non-oiled locations in 1989.

Dolly Varden from the littoral zone in western Prince William Sound showed some of the highest concentration of exposure to oil (as measured by concentrations of fluorescent aromatic compounds (FACs) in bile) of any fish sampled in 1989 (Collier *et al.*, 1993). There was little evidence of reproductive impairment. By 1990, FAC concentrations had dropped markedly at heavily oiled sites.

Dolly Varden and cutthroat trout that emigrated to the sea through oil-contaminated waters had lower growth and survival rates than those emigrating through uncontaminated waters (Hepler *et al.* 1993). Bioaccumulation of petrogenic hydrocarbons in the food chain or chronic starvation were hypothesized as the pathways that spilled crude oil had slowed growth and accelerated mortality of these two species. Oil concentration of benthic infauna and epifauna is a possible source of this contamination.

There was substantial evidence of exposure to petroleum in yellowfin sole, rock sole, and flathead sole from PWS oiled sites at depths less than 30 m in 1989 and 1990, as to a lesser extent in 1991

(Collier *et al.*, 1993). All species had increased levels of biliary FACs and induced hepatic P450 activities. Pacific halibut, mainly captured deeper than 30 m, showed some evidence of increased oil exposure in 1989 (based on elevated biliary FACs), but less than the other flatfish at shallower depths. By 1990 the levels of FACs in halibut had dropped considerably.

Walleye pollock first sampled in PWS in the late winter of 1990 revealed exposure to oil through increased levels of FACs; levels of FACs dropped substantially by 1991 (Collier *et al.*, 1993). There was even evidence of petroleum exposure to pollock in 1990 near Kodiak Island more than 400 miles from the grounding site.

5.7 Recovery of the Subtidal Communities in Prince William Sound

Rates of recovery for oil-impacted benthic communities have ranged from weeks on rocky shores at Santa Barbara (Straughan, 1971) to a decade in muddy fine sand of the Bay of Morlaix (N. France) (Ibanez and Dauvin, 1988). Teal and Howarth (1984) suggested that a century may be needed in salt marshes.

The recovery rate of the subtidal community in Prince William Sound seems dependent on the component in question, and on the degree of exposure to waves. Subtidal algae in protected bays, and almost all components of the shallow subtidal benthic community on exposed points or in *Nereocystis* beds, either were unaffected by the spill or recovered nearly completely by 1990. Some components of the benthic infaunal community, especially amphipods, apparently recovered within three to four years after the spill. However, there were some larger epibenthic invertebrates (some sea stars and crabs) that had not fully recovered by 1993. Furthermore, many infaunal taxa were still more abundant at oiled sites in 1993, indicating possible continued effects of organic enrichment. Based on the lengthy recovery in fine sediments (low-energy areas) after the *Amoco Cadiz* spill (Ibanez and Dauvin, 1988), we suspect it may take as long as a decade to see normality return to the oiled eelgrass benthic community of Prince William Sound.

One problem in predicting recovery within this community is that we do not have a very good picture of what the pre-spill conditions were like. As a result, full evaluation of recovery will depend on several more years of post-spill monitoring.

The recovery process that we observed within benthic infaunal communities is fairly typical of what has been observed in benthic infaunal communities following other oil spills. The general sequence of events after a catastrophic oil spill is 1) a toxic effect with considerable mortality; 2) an organically enriched period in which opportunistic taxa become extremely abundant; and 3) a period in which opportunists decrease in importance and fauna begin to return to conditions similar to adjacent unoiled areas and/or to a community characteristic of relatively undisturbed conditions (Pearson and Rosenberg, 1978; Glémarec and Hily, 1981; Glémarec and Hussenot, 1981, 1982; Spies *et al.*, 1988). It is difficult to categorize any of the shallow subtidal habitats we studied in Prince William Sound as simply resembling one or more of the successional stages noted above. While the community as a whole may not reflect a particular stage, a disruptive response and later recovery was evident in some faunal groups, especially amphipods in eelgrass habitats. Other groups, especially many benthic polychaetes, increased in abundance, a characteristic of organic enrichment.

In 1993, hemosiderosis was observed in crescent gunnels collected from an oiled site in Herring Bay, but was not observed in fishes collected from an unoiled reference site in Lower Herring Bay, suggesting that some fish species were still being exposed to oil as late as four years after the spill. This, in spite of the relatively low PAH levels observed in 1993. Mean concentration of PAH's were relatively low in 1993 in sediments from subtidal eelgrass beds in Herring Bay and Lower Herring Bay; in July 1993 it had diminished to 21 (5,436 ng total HC g^{-1}) and 4 (839 ng total HC g^{-1}), respectively. Hemosiderin was reported in yellowfin sole *Pleuronectes aspera*, quillback rockfish, *Sebastes maliger*, and kelp greenling, *Hexagrammos decagrammus*, following the spill (Khan and Nag, 1993) and in plaice, *Pleuronectes platessa*, following the *Amoco Cadiz* oil spill off the coast of France (Haensly *et al.*, 1982). Exposure of fish to petroleum hydrocarbons is known to induce hemosiderosis (Khan and Nag, 1993). While other stressors can also cause hemosiderosis, there were no other known pollutants at the Herring Bay site. Hemosiderin in tissues disappears within approximately six weeks after removal from the pollutant (R.A. Khan, Pers. Commun. 1993) suggesting recent exposure of the fish.

We do not know if the presence of hemosiderosis has led to declines in population of crescent gunnels. There were no apparent effects on gunnel densities in eelgrass beds in 1990, but we have not made quantitative observations on gunnel population densities since then. However, the presence of this bioindicator of oil suggests that some contamination of fishes, and potentially other taxa, persisted as of summer 1993.

These findings are corroborated, in part, by the finding of Collier *et al.* (1993) in which nearshore (< 30 m) benthic flatfishes showed continuing exposure through the first two field seasons after the spill, and even after more than two years there was still some evidence of increased exposure of fishes from these habitats.

6.0 CONCLUSIONS

There was apparent injury to several subtidal populations of plants and invertebrates within the most heavily oiled areas of western Prince William Sound as a result of the spill. These are based primarily on comparisons of population parameters (e.g. abundance, biomass) at oiled and unoiled (control) sites in 1990, and are summarized as follows.

- There were injuries to eelgrass populations. Densities of shoots and flowering shoots of eelgrass were lower at oiled than at control sites in 1990. A separate independent study supported these findings and attribute the reductions to the spill.

- There were only minor injuries to benthic macro-algae. There were no consistent differences in biomass of algae between oiled and control sites. However, there were higher densities of several kelp species at oiled sites, and there were generally more small plants at the oiled sites. This suggests possible disturbance to algae at oiled sites followed by recruitment.

- There were differences in the abundance of infauna and small epifaunal invertebrates at oiled and control sites that were likely related to the oil spill. The effects varied with depth, but there were generally fewer amphipods, but greater abundances of opportunistic species at oiled sites. Within the oiled eelgrass bed, there were notably higher abundances of dominant epifaunal that live attached to eelgrass

- Effects on larger epibenthic invertebrates varied among species and habitats. There was injury to two dominant epifaunal taxa, leather stars and helmet crabs, that were notably less abundant at oiled sites.

- There were generally greater abundances of fish species at oiled sites. This was most notable in eelgrass beds. There were many more young of the year cod within oiled compared with unoiled eelgrass beds.

There were insufficient data to make direct statistical correlations between PAH concentrations and all biological effects. However, there was a correspondence between PAH concentrations and biological impacts, both on temporal and spatial scales. We generally observed greater impacts in areas where there was more oil. Impacts were most severe, and PAH concentrations were highest in eelgrass beds and in shallow parts of bays and points. Our observations also indicate that biological effects generally ameliorated over time as concentrations of PAHs decreased.

The recovery rate of the subtidal community in Prince William Sound was dependent on the component in question and on the degree of exposure to waves. Algae and smaller invertebrate taxa appeared to recover quickly, within several years. Several of the larger epibenthic invertebrates showed continued signs of injury, even 4 years after the spill. Recovery was slower in more protected habitats, especially eelgrass beds. The recovery process that was observed within the benthic infaunal community is fairly typical of what has been observed in benthic infaunal communities following other oil spills. Generally, there is an initial toxic response with high mortality of some sensitive species such as amphipods. This is followed by an organic enrichment period, and ultimately a return to the period when conditions are similar to adjacent unoiled areas or to pre-spill conditions. Although the concentration of PAHs in sediments were relatively low in 1993, there were still some larger epibenthic invertebrates that were more abundant at control sites, and the infaunal community at oiled sites appeared enhanced. These data suggest that while injuries were much less evident in 1993 than in 1990, nearshore subtidal communities had not yet returned to an undisturbed state.

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TABLES

Table 1. List of the 15 dominant infaunal and epifaunal taxa sampled by suction dredge and by dropnet within each habitat, depth stratum, and year. Separate rankings are given for abundance and biomass. Taxa present in 1990 or 1991 were analyzed in all years regardless of rank.

Dredge Samples - Eelgrass - Abundance - 1990

RANK	Deep (6-20m) TAXA NAME	Shallow (3-6m) TAXA NAME	Bed (<3m) TAXA NAME
1	SPIONIDAE	SPIONIDAE	SPIONIDAE
2	LUCINIDAE	OPHELIIDAE	SPIRORBIDAE
3	TELLINIDAE	SPIRORBIDAE	MYTILIDAE
4	OPHELIIDAE	MONTACUTIDAE	GASTROPODA
5	THYASIRIDAE	MYTILIDAE	CAPRELLIDEA
6	NEPHTYIDAE	GASTROPODA	OPHELIIDAE
7	MYTILIDAE	LACUNIDAE	LACUNIDAE
8	SPIRORBIDAE	LUCUNIDAE	TELLINIDAE
9	SYLLIDAE	TELLINIDAE	MONTACUTIDAE
10	BIVALVIA	BIVALVIA	AMPHICTENIDAE
11	AMPHICTENIDAE	AMPHICTENIDAE	BIVALVIA
12	CAPITELLIDAE	CAPRELLIDEA	CAPITELLIDAE
13	CAECIDAE	RISSOIDAE	SYLLIDAE
14	MALDANIDAE	BALANIDAE	PHOXOCEPHALIDAE
15	OPHIUROIDEA	SYLLIDAE	POLYNOIDAE

Dredge Samples - Eelgrass - Abundance - 1991

RANK	Deep (6-20m) TAXA NAME	Shallow (3-6m) TAXA NAME	Bed (<3m) TAXA NAME
1	SPIONIDAE		MYTILIDAE
2	OPHELIIDAE		OPHELIIDAE
3	LUCINIDAE		CAPRELLIDEA
4	SYLLIDAE		SPIRORBIDAE
5	SPIRORBIDAE		SPIONIDAE
6	THYASIRIDAE	NO	GASTROPODA
7	TELLINIDAE	DATA	MONTACUTIDAE
8	CAPITELLIDAE		SYLLIDAE
9	AMPHICTENIDAE		LACUNIDAE
10	SIGALIONIDAE		BIVALVIA
11	RISSOIDAE		CAPITELLIDAE
12	CAECIDAE		RISSOIDAE
13	AMPHARETIDAE		POLYNOIDAE
14	NEPHTYIDAE		TELLINIDAE
15	BIVALVIA		TROCHIDAE

Dredge Samples - Eelgrass - Abundance - 1993

RANK	Deep (6-20m) TAXA NAME	Shallow (3-6m) TAXA NAME	Bed (<3m) TAXA NAME
1	OPHELIIDAE		CAPRELLIDEA
2	SPIONIDAE		SPIRORBIDAE
3	LUCINIDAE		MYTILIDAE
4	THYASIRIDAE		OPHELIIDAE
5	MYTILIDAE		MONTACUTIDAE
6	SYLLIDAE	NO	GASTROPODA
7	CAPITELLIDAE	DATA	BIVALVIA
8	MONTACUTIDAE		SYLLIDAE
9	SIGALIONIDAE		POLYNOIDAE
10	AMPHARETIDAE		SIGALIONIDAE
11	AMPHICTENIDAE		SPIONIDAE
12	NEPHTYIDAE		TELLINIDAE
13	SPIRORBIDAE		ISCHYROCERIDAE
14	TELLINIDAE		CAPITELLIDAE
15	OEDICEROTIDAE		NEREIDAE

Table 1. (Continued)

Dredge Samples - Eelgrass - Biomass - 1990

RANK	Deep (6-20m) TAXA NAME	Shallow (3-6m) TAXA NAME	Bed (<3m) TAXA NAME
1	LUCINIDAE	LUCINIDAE	VENERIDAE
2	VENERIDAE	CHAETOPTERIDAE	MYTILIDAE
3	OLIVIDAE	ECHINARACHNIDAE	TELLINIDAE
4	BIVALVIA	TELLINIDAE	MYIDAE
5	TELLINIDAE	RHYNCHOCOELA	LUCINIDAE
6	RHYNCHOCOELA	MYTILIDAE	NEREIDAE
7	LUMBRINERIDAE	VENERIDAE	PHYLLODOCIDAE
8	CARDIIDAE	OLIVIDAE	SPIONIDAE
9	MYTILIDAE	OPHELIIDAE	ATELECYCLIDAE
10	THYASIRIDAE	OPHIUROIDEA	GLYCERIDAE
11	GLYCERIDAE	ORBINIIDAE	GONIADIDAE
12	CAECIDAE	OWENIIDAE	OPHELIIDAE
13	OPHIUROIDEA	NEPHTYIDAE	LACUNIDAE
14	ORBINIIDAE	LYONSIIDAE	LUMBRINERIDAE
15	SPIONIDAE	SPIONIDAE	AMPHICTENIDAE

Dredge Samples - Eelgrass - Biomass - 1991

RANK	Deep (6-20m) TAXA NAME	Shallow (3-6m) TAXA NAME	Bed (<3m) TAXA NAME
1	TELLINIDAE		MYTILIDAE
2	LUCINIDAE		VENERIDAE
3	OLIVIDAE		TELLINIDAE
4	BIVALVIA		ATELECYCLIDAE
5	NEPHTYIDAE		MYIDAE
6	MYTILIDAE	NO	RHYNCHOCOELA
7	RHYNCHOCOELA	DATA	LUCINIDAE
8	CARDIIDAE		SPIONIDAE
9	THYASIRIDAE		OPHELIIDAE
10	UNGULINIDAE		ORBINIIDAE
11	AMPHICTENIDAE		POLYNOIDAE
12	CAECIDAE		NEREIDAE
13	CHAETOPTERIDAE		LUMBRINERIDAE
14	LEPETIDAE		BIVALVIA
15	GLYCYMERIDAE		MONTACUTIDAE

Dredge Samples - Eelgrass - Biomass - 1993

RANK	Deep (6-20m) TAXA NAME	Shallow (3-6m) TAXA NAME	Bed (<3m) TAXA NAME
1	LUCINIDAE		MYTILIDAE
2	TELLINIDAE		BRYOZOA
3	CARDIIDAE		TELLINIDAE
4	MYTILIDAE		OLIVIDAE
5	THYASIRIDAE		LUMBRINERIDAE
6	OLIVIDAE	NO	NEREIDAE
7	OPHIUROIDEA	DATA	RHYNCHOCOELA
8	ISCHNOCHITONIDAE		GASTROPODA
9	AMPHICTENIDAE		ATELECYCLIEAE
10	CRYPTOBRANCHIA		POLYNOIDAE
11	BRYOZOAN		MONTACUTIDAE
12	SPIONIDAE		CAPRELLIDEA
13	NASSARIIDAE		OPHELIIDAE
14	AMPHARETIDAE		BIVALVIA
15	NEPHTYIDAE		ORBINIIDAE

Table 1. (Continued)

Dredge Samples - Island Bay - Abundance

	Deep (11-20m)		Shallow (2-11m)	
	1990	1991	1990	1991
RANK	TAXA NAME	TAXA NAME	TAXA NAME	TAXA NAME
1	CAECIDAE	SPIONIDAE	SPIONIDAE	SPIONIDAE
2	SPIONIDAE	CAECIDAE	LUCINIDAE	OPHELIIDAE
3	LUCINIDAE	SIGALIONIDAE	SPIRORBIDAE	RISSOIDAE
4	OPHIUROIDEA	OPHIUROIDEA	CAPITELLIDAE	SPIRORBIDAE
5	SIGALIONIDAE	AMPHARETIDAE	RISSOIDAE	AMPHICTENIDAE
6	DORVILLEIDAE	LUCINIDAE	CAECIDAE	AMPHARETIDAE
7	LEPIDOPLEURIDAE	OPHELIIDAE	MONTACUTIDAE	LUCINIDAE
8	POLYODONTIDAE	LEPIDOPLEURIDAE	SIGALIONIDAE	SIGALIONIDAE
9	SPIRORBIDAE	DORVILLEIDAE	GASTROPODA	HIATELLIDAE
10	ISAEIDAE	SYLLIDAE	POLYNOIDAE	CAPITELLIDAE
11	SYLLIDAE	SPIRORBIDAE	OPHELIIDAE	GASTROPODA
12	CAPITELLIDAE	AMPHICTENIDAE	OPHIUROIDEA	CAECIDAE
13	CIRRATULIDAE	POLYODONTIDAE	DORVILLEIDAE	SYLLIDAE
14	SERPULIDAE	CAPITELLIDAE	BIVALVIA	MONTACUTIDAE
15	LUMBRINERIDAE	ISAEIDAE	SYLLIDAE	AORIDAE

Dredge Samples - Island Bay - Biomass

	Deep (11-20m)		Shallow (2-11m)	
	1990	1991	1990	1991
RANK	TAXA NAME	TAXA NAME	TAXA NAME	TAXA NAME
1	LUCINIDAE	CAECIDAE	LUCINIDAE	LUCINIDAE
2	CAECIDAE	LUCINIDAE	VENERIDAE	RHYNCHOCOELA
3	GLYCERIDAE	MYIDAE	SPIONIDAE	CANCRIDAE
4	ISCHNOCHITONIDAE	HIATELLIDAE	GLYCERIDAE	SPIONIDAE
5	LUMBRINERIDAE	LUMBRINERIDAE	CAECIDAE	CAECIDAE
6	OPHIUROIDEA	OPHIUROIDEA	RHYNCHOCOELA	CAPITELLIDAE
7	SERPULIDAE	ISCHNOCHITONIDAE	ORBINIIDAE	RISSOIDAE
8	MYTILIDAE	CARDIIDAE	LUMBRINERIDAE	OPHELIIDAE
9	RHYNCHOCOELA	SPIONIDAE	NEREIDAE	ANOMIIDAE
10	ONUPHIDAE	MYTILIDAE	OPHELIIDAE	NASSARIIDAE
11	LEPIDOPLEURIDAE	RHYNCHOCOELA	ISCHNOCHITONIDAE	ISCHNOCHITONIDAE
12	LEPETIDAE	LEPIDOPLEURIDAE	OPHIUROIDEA	LYONSIIDAE
13	POLYODONTIDAE	CYLICHNIDAE	SERPULIDAE	AMPHICTENIDAE
14	AMPHICTENIDAE	TELLINIDAE	MONTACUTIDAE	OPHIUROIDEA
15	SPIONIDAE	NUCULANIDAE	SCALIBREGMIDAE	CARDIIDAE

Dropnet Samples - Eelgrass

	Abundance	Biomass
	1990	1990
RANK	TAXA NAME	TAXA NAME
1	MYTILIDAE	MYTILIDAE
2	LACUNIDAE	LACUNIDAE
3	SPIRORBIDAE	HIPPOLYTIDAE
4	TROCHIDAE	TROCHIDAE
5	CAPRELLIDEA	PLEUSTIDAE
6	POLYNOIDAE	BRYOZOAN
7	MONTACUTIDAE	MONTACUTIDAE
8	BIVALVIA	POLYNOIDAE
9	GASTROPODA	NEREIDAE
10	ISCHYROCERIDAE	SPIRORBIDAE
11	ONCHIDORIDIDAE	CAPRELLIDEA
12	RISSOIDAE	ONCHIDORIDIDAE
13	HIPPOLYTIDAE	RISSOIDAE
14	NEREIDAE	GASTROPODA
15	SYLLIDAE	ISCHYROCERIDAE

Table 2. Test results for eelgrass population parameters in paired (oiled *vs.* control) site comparisons for 1990, 1991, and 1993; and for a two-way analysis examining the effects of oil, year, and their interaction. For the analyses by years, 000 = P<0.01; 00 = P<0.05; 0 = <0.1; 0 = > at control sites; X = > at oiled sites. For the Two-way analysis, 000 or XXX = P<0.01; 00 or XX = P<0.05; 0 or X = <0.1; 0 = > at control sites; X = > at oiled sites. NM = Not measured.

Eelgrass Bed - 1990, 1991, and 1993

	1990	1991	1993
Turion Density	0	-	-
Flower Density	0	-	-
Blade Density	0	NM	NM
Seed Pod Density	-	NM	NM
Seed Density	-	NM	NM
Biomass	-	NM	NM

Eelgrass Bed - Two-way analysis

	Oil	Year	Int.
Eelgrass - Turion Density	000	-	-
Eelgrass - Flowering Density	000	0	-

Table 3. Percent germination of eelgrass seeds, and the proportion of normal mitoses in seedlings from germinated seeds that were collected from oiled and control sites in Prince William Sound in 1990.

Seeds Germinated

Herring Bay (Oiled) and Lower Herring Bay (Control)

Site	Yes	No	%
Oiled	52	92	36.1%
Control	22	128	14.7%
Total	74	220	Mean=25.4%

$\chi^2 = 18.2$, df=1, $P<0.01$

Bay of Isles (Oiled)) and Drier Bay (Control)

Site	Yes	No	%
Oiled	22	128	14.7%
Control	18	132	12.0%
Total	40	260	Mean=13.4%

$\chi^2 = 0.41$, df=1, $P>0.30$

Normal Mitoses

Herring Bay (Oiled) and Lower Herring Bay (Control)

Site	Normal	Abnormal	% Normal
Oiled	106	114	48.2%
Control	100	20	83.3%
Total	206	134	Mean=65.8%

$\chi^2 = 39.4$, df=1, $P<0.01$

Bay of Isles(Oiled) and Drier Bay (Control)

Site	Normal	Abnormal	% Normal
Oiled	105	55	65.6%
Control	61	39	61.0%
Total	166	94	Mean=63.3%

$\chi^2 = 1.25$, df=1, $P>0.20$

Table 4. Test results for algal population parameters in paired (oiled *vs.* control) site comparisons for 1990. XXX = P<0.01; XX = P<0.05; X = <0.1; 0 = > at control sites; X = > at oiled sites.

Laminaria/Agarum Bays

		Deep 11-20 m	Shallow 2-11 m
Laminaria spp.	Percent cover	XX	XX
Laminaria spp.	Density	XXX	XX
Laminaria spp.	Biomass	XXX	-

Laminaria/Agarum Points

		Deep 11-20 m	Shallow 2-11 m
Agarum cribrosum	Density	XX	X
A. cribrosum (>10 cm)	Density	X	-
A. cribrosum (<10 cm)	Density	XXX	XX

Nereocystis

		Bed
Nereocystis luetkaena	Density	XXX
Agarum cribrosum	Biomass	XXX

Table 5. Differences in growth rate of *Agarum cribrosum* at oiled and control sites as measured from June through July 1990. Growth rates are given as the increase in length (cm) per 30 days.

Site Name	Oil Code	N	Mean	SD	t	df	P
Herring Bay	Oil	28	5.17	1.96	2.74	53	<0.01
Lower Herring Bay	Control	27	3.85	1.58			
Bay of Isles	Oil	30	4.59	1.63	7.84	45	<0.01
Mummy Bay	Control	30	9.40	2.95			

Table 6. Summary of ANOVA randomization test results on benthic invertebrate community parameters in paired (oiled vs. control) eelgrass habitat site comparisons, 1990, 1991, and 1993. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \leq 0.01$; ●●, OO and XX = $0.01 < P \leq 0.05$; ●, O and X = $0.05 < P \leq 0.1$; - = $P > 0.1$.

	1-Way Test					
	1990	1990	1991	1991	1993	1993
	Bed (< 3 m)	Deep (6-20 m)	Bed	Deep	Bed	Deep
Shannon Diversity (H')	-	-	-	-	-	-
Simpson Dominance (D)	-	●●	-	-	-	-
Species Richness (SR)	-	-	-	-	●	-
Total Taxa (T)	-	-	-	-	●●	-
Total Abundance (A)	●●●	O	-	-	●●	-
Total Biomass (B)	●●●	-	-	-	●	-

	2-Way Test					
	Bed (< 3 m)			Deep (6-20 m)		
	Treatment	Year	Interaction	Treatment	Year	Interaction
Shannon Diversity (H')	-	-	-	-	-	-
Simpson Dominance (D)	-	-	-	-	-	-
Species Richness (SR)	-	X	-	-	-	-
Total Taxa (T)	●●	XX	-	-	XXX	-
Total Abundance (A)	●●●	XX	X	-	XXX	-
Total Biomass (B)	●●	-	-	OO	X	-

Table 7. Summary of ANOVA randomization test results on benthic invertebrate abundance (A) and biomass (B) of dominant taxa in paired (oiled vs. control) eelgrass bed (< 3 m) site comparisons, 1990, 1991, and 1993. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \le 0.01$; ●●, OO and XX = $0.01 < P \le 0.05$; ●, O and X = $0.05 < P \le 0.1$; - = $P > 0.1$.

INFAUNA @ < 3 M

	1-Way Test						2-Way Test					
	1990		1991		1993		Treatment		Year		Interaction	
	A	B	A	B	A	B	A	B	A	B	A	B
Total	-	●●	-	●	●●	-	●●	-	-	-	X	-
Polychaeta	●	-	-	-	●●●	-	●●●	●	-	-	-	-
Amphictenidae	-	-	-	-	-	●●	●●	-	-	-	-	-
Lumbrineridae	-	-	-	OO	-	O	-	OO	-	-	-	-
Nereidae	-	-	-	●●	●●	-	●●●	-	-	-	-	-
Opheliidae	-	-	-	-	●●●	●	●●	●●	-	XX	-	-
Polynoidae	-	-	-	-	O	OO	-	-	-	-	-	-
Spionidae	●	●●●	-	-	●●●	●	●●	●●●	-	-	-	-
Rhynchocoela	-	-	-	OO	-	-	-	-	-	-	-	-
Bivalvia	-	●	-	-	-	-	-	-	-	-	-	-
Lucinidae	-	-	-	-	-	O	-	-	-	-	-	-
Tellinidae	-	-	-	-	O	-	OOO	-	-	-	-	-
Veneridae	-	●	-	●●	-	-	-	-	-	-	-	-
Gastropoda	●	●●	-	-	●	-	●●	-	-	X	-	-
Crustacea	-	O	-	-	●●	-	-	-	-	-	-	-

EPIFAUNA @ < 3 M

	1990 A	1990 B	1991 A	1991 B	1993 A	1993 B	Treatment A	Treatment B	Year A	Year B	Interaction A	Interaction B
Total	●●●	-	-	-	●●●	-	●●●	-	-	XX	-	-
Polychaeta	●●	●●●	-	-	●●	●●●	●●●	●●●	-	-	XX	-
Spirorbidae	●●	-	-	-	●●●	-	●●●	-	-	-	X	-
Bivalvia	●●●	●●●	-	-	●●●	●●●	●●●	●●●	-	-	-	-
Mytilidae	●●●	●●●	-	-	●●●	●●●	●●●	●●●	-	-	-	-
Gastropoda	●●	-	-	-	●●	-	●●●	●●	-	-	-	-
Lacunidae	-	●●	-	O	-	-	-	-	-	-	-	-
Trochidae	OOO	-	OOO	-	-	-	-	-	-	-	-	-
Crustacea	-	-	-	-	-	-	-	●	-	-	-	-
Amphipoda	-	-	-	-	-	-	OO	-	-	-	XX	-
Phoxocephalidae	OOO	-	-	-	OO	-	OOO	-	-	-	-	-
Echinodermata	●●	-	-	-	-	-	-	●	-	-	-	-

Table 8. Summary of ANOVA randomization test results on benthic invertebrate abundance (A) and biomass (B) of dominant taxa in paired (oiled vs. control) deep (6-20 m) eelgrass site comparisons, 1990, 1991, and 1993. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \leq 0.01$; ●●, OO and XX = $0.01 < P \leq 0.05$; ●, O and X = $0.05 < P \leq 0.1$; - = $P > 0.1$.

INFAUNA @ 6-20 M

	1-Way Test						2-Way Test					
	1990		1991		1993		Treatment		Year		Interaction	
	A	B	A	B	A	B	A	B	A	B	A	B
Total	-	-	-	-	-	-	○	-	XXX	-	-	-
Polychaeta	-	-	-	-	○	○○	-	-	XX	-	-	-
Ampharetidae	-	-	-	-	-	-	-	-	XX	-	-	-
Amphictenidae	-	-	-	-	-	○	-	-	-	-	-	-
Capitellidae	-	-	-	-	○	-	-	-	-	-	-	-
Goniadidae	-	-	-	-	-	-	-	○○	-	-	-	XX
Lumbrineridae	-	-	-	-	-	-	-	-	-	XXX	-	X
Maldanidae	●●	-	●	-	-	-	●	-	-	-	-	-
Nephtyidae	-	-	-	-	-	-	●	-	-	-	-	-
Orbiniidae	-	-	-	○	-	-	-	○○	-	-	-	-
Sigalionidae	○	-	-	-	-	-	-	-	-	-	-	-
Spionidae	-	-	●	●	-	-	●●	●	-	-	-	-
Syllidae	-	-	-	-	●	-	●●●	-	-	-	-	-
Rhynchocoela	-	-	-	-	-	-	-	●●	-	-	-	-
Bivalvia	-	○○○	-	-	-	-	-	-	-	-	-	-
Lucinidae	-	-	-	-	-	-	-	-	XX	-	-	-
Montacutidae	-	-	-	-	-	-	○○○	-	-	-	-	-
Veneridae	-	○○	-	-	-	-	-	○○	-	XX	-	XX
Gastropoda	●●	-	-	-	-	-	●●	-	XX	-	-	-
Caecidae	○○	○○	-	-	●	●●	●●	●●	-	-	-	-
Nassariidae	-	-	-	-	-	-	-	-	-	X	-	-
Rissoidae	-	-	-	-	-	-	-	-	XXX	-	-	-
Crustacea	○	-	-	-	-	-	-	-	-	-	-	-

EPIFAUNA @ 6-20 M

	1990 A	1990 B	1991 A	1991 B	1993 A	1993 B	Treatment A	Treatment B	Year A	Year B	Interaction A	Interaction B
Total	-	-	-	-	●	-	●●	-	-	-	-	-
Polychaeta	-	-	-	-	-	-	-	-	-	-	-	-
Bivalvia	-	-	-	-	●●●	●●	●●●	●●●	-	-	-	-
Mytilidae	-	-	-	-	●●●	●●	●●●	●●●	-	-	-	-
Gastropoda	-	-	-	-	-	-	-	-	XX	-	-	-
Lepetidae	-	○○○	-	-	-	-	-	-	-	-	-	-
Crustacea	-	-	-	○○	-	-	-	-	-	-	-	-
Amphipoda	○○○	-	-	-	●●●	●	-	●	-	-	XXX	-
Oedicerotidae	-	-	-	-	-	-	●●	-	-	-	-	-
Echinodermata	-	-	-	-	-	-	-	-	XX	XXX	-	XX

Table 9. *Summary of ANOVA randomization test results on benthic invertebrate community parameters in paired (oiled vs. control) Laminaria/Agarum* Bay habitat site comparisons, 1990 and 1991. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \leq 0.01$; ●●, OO and XX = $0.01 < P \leq 0.05$; ●, O and X = $0.05 < P \leq 0.1$; - = $P > 0.1$.

	1-Way Test			
	1990	1990	1991	1991
	Shallow 2-11 m	Deep 11-20 m	Shallow 2-11 m	Deep 11-20 m
Shannon Diversity (H')	-	●●	-	●
Simpson Dominance (D)	-	OOO	-	O
Species Richness (SR)	●●	-	-	-
Total Taxa (T)	●●	-	-	-
Total Abundance (A)	-	-	-	-
Total Biomass (B)	●●	-	-	-

	2-Way Test					
	Shallow (2-11 m)			Deep (11-20 m)		
	Treatment	Year	Interaction	Treatment	Year	Interaction
Shannon Diversity (H')	-	XXX	-	●●●	-	-
Simpson Dominance (D)	-	-	X	OOO	-	X
Species Richness (SR)	-	XXX	-	●	-	-
Total Taxa (T)	-	XXX	-	-	-	-
Total Abundance (A)	-	XXX	-	-	XXX	-
Total Biomass (B)	-	XXX	-	-	-	-

Table 10. Summary of ANOVA randomization test results on benthic invertebrate abundance (A) and biomass (B) of dominant taxa in paired (oiled vs. control) shallow (2-11 m) *Laminaria/Agarum* Bay site comparisons, 1990 and 1991. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \leq 0.01$; ●●, OO and XX = $0.01 < P \leq 0.05$; ●, O and X = $0.05 < P \leq 0.1$; - = $P > 0.1$.

INFAUNA @ 2-11 M

	1-Way Test				2-Way Test					
	1990		1991		Treatment		Year		Interaction	
	A	B	A	B	A	B	A	B	A	B
Ampharetidae	-		-	-	-	-	XXX	-	-	-
Amphictenidae	●	-	-	-	-	-	XXX	-	-	-
Capitellidae	-	●●	-	-	-	●	-	-	-	-
Dorvillidae	-	-	●	-	●●	-	-	-	-	-
Lumbrineridae	-	●	-	-	-	-	-	-	-	-
Opheliidae	-	-	-	-	-	-	XXX	XXX	-	-
Polynoidae	●	-	-	-	●	-	-	-	-	-
Sigalionidae		-	-	-	-	-	X	-	-	-
Spionidae	-	-	O	O	-	-	-	-	XX	X
Syllidae	-		-	-	-	-	XX	-	-	-
Lyonsiidae	-	-	-	-	-	-	-	X	-	-
Lucinidae	-	●●	-	-	-	-	-	-	-	-
Cylichnidae	-	●●	-	-	-	-	-	XX	-	-
Nassaridae	-	●●●	-	-	-	-	-	XXX	-	-
Rissoidae	-	-	-	-	-	-	XXX	XXX	-	-
Unid. Gastropoda	-	-	●	-	●	-	X	-	-	-

EPIFAUNA @ 2-11 M

	1990 A	1990 B	1991 A	1991 B	Treatment A	Treatment B	Year A	Year B	Interaction A	Interaction B
Serpulidae	-	●●	-	-	-	-	-	-	-	XX
Spirorbidae	-	-	-	-	-	-	XXX	-	-	-
Anomiidae	-	-	-	-	-	-	-	XX	-	-
Hiatellidae	-	-	-	-	-	-	XXX	-	-	-
Aoridae	-	-	-	-	-	-	XX	-	-	-
Amphipoda	-	-	-	-	-	-	XXX	XX	-	-
Ophiuroidea	-	-	-	-	-	-	-	XX	-	-

Table 11. Summary of ANOVA randomization test results on benthic invertebrate abundance (A) and biomass (B) of dominant taxa in paired (oiled vs. control) deep (11-20 m) *Laminaria/Agarum* Bay site comparisons, 1990 and 1991. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \leq 0.01$; ●●, OO and XX = $0.01 < P \leq 0.05$; ●, O and X = $0.05 < P \leq 0.1$; – = $P > 0.1$.

INFAUNA @ 11-20 M

	1-Way Test				2-Way Test					
	1990		1991		Treatment		Year		Interaction	
	A	B	A	B	A	B	A	B	A	B
Ampharetidae	-	-	-	-	-	-	XXX	-	-	-
Amphictenidae	-	-	-	-	-	-	XXX	-	-	-
Cirratulidae	●	-	-	-	●●	-	-	-	-	-
Lumbrineridae	-	-	●	-	-	-	-	-	-	-
Opheliidae	-	-	●●	-	●	-	XXX	-	-	-
Sigalionidae	-	-	-	-	-	-	XX	-	-	-
Spionidae	O	-	-	-	-	-	XX	XXX	-	-
Rhynchocoela	-	-	-	-	-	-	-	-	-	X
Lucinidae	-	-	-	-	-	OO	-	-	-	-
Myidae	-	-	-	-	-	-	-	XXX	-	-
Tellinidae	-	OOO	-	-	-	O	-	XX	-	-
Caecidae	O	-	-	-	O	-	-	-	-	-

EPIFAUNA @ 11-20 M

	1990 A	1990 B	1991 A	1991 B	Treatment A	Treatment B	Year A	Year B	Interaction A	Interaction B
Serpulidae	OO	-	O	O	OOO	-	-	X	-	-
Hiatellidae	-	-	-	-	-	-	-	XX	-	-
Mytilidae	-	●	-	-	-	-	-	-	-	XX

Table 12. Population parameters for benthic invertebrates, dominant (in terms of abundance) invertebrate taxa, bottom oxygen, and SUMMED PAHs in oiled (Herring Bay, inner Bay of Isles, and Disk Lagoon) and unoiled silled fjords (inner Lucky Bay and Humpback Cove) in Prince William Sound.

HERRING BAY EMBAYMENT	10/18/89	5/28/90	10/1/90	8/14/91	9/25/93
Area Sampled (m^2):	0.50	0.60	0.60	0.60	0.60
Total Abundance (indiv m^{-2}):	4192.00	4863.00	3487.00	4393.00	2357.00
Total Biomass (g m^{-2}):	79.44	19.02	16.20	17.80	12.67
Total Taxa Family Level & Higher:	24.00	8.00	6.00	32.00	4.00
Shannon Diversity (H'):	1.66	0.03	0.10	1.64	0.02
Simpson Dominance (D):	0.39	0.99	0.97	0.41	0.99
Species Richness (SR):	2.76	0.82	0.61	3.70	0.39
Bottom Oxygen (mg l^{-1}):	-	2.2-5.0	0.0-0.1	8.7-11.2	0.00
$\overline{X}$ % Mud:	-	-	98.90	42.60	48.80
$\overline{X}$ SUMMED PAH (ng g^{-1}):	1213.77	336.20	-	65.17	55.72

10/18/89

Taxon	# m^{-2}	Cumul.%
Lucinidae	2544	60.69
Spionidae	368	69.47
Nephtyidae	336	77.48
Montacutidae	256	83.59
Rissoidae	80	85.50
Ampharetidae	64	87.02
Gastropoda (unid.)	64	88.55
Myidae	48	89.69
Goniadidae	48	90.84
Polyodontidae	48	91.98
Hiatellidae	32	92.75
Phyllodocidae	32	93.51
Balanidae	32	94.27
Caecidae	32	95.04
Sigalionidae	32	95.80
Pyrenidae	32	96.56
Thyasiridae	32	97.33
Ampithoidae	16	97.71

8/14/91

Taxon	# m^{-2}	Cumul.%
Nephtyidae	2737	62.30
Capitellidae	442	72.37
Diastylidae	238	77.78
Ampharetidae	145	81.08
Opheliidae	133	84.11
Spirorbidae	133	87.14
Bivalvia (unid.)	82	89.01
Munnidae	80	90.83
Caprellidea	67	92.35
Amphipoda (unid.)	55	93.60
Syllidae	40	94.51
Hesionidae	27	95.13
Ischyroceridae	23	95.65
Isaeidae	13	95.95
Dexaminidae	13	96.24
Spionidae	13	96.54
Phoxocephalidae	13	96.84
Lucinidae	13	97.13

5/28/90

Taxon	# m^{-2}	Cumul.%
Nephtyidae	4848	99.69

9/25/93

Taxon	# m^{-2}	Cumul.%
Nephtyidae	2352	99.79
Diastylidae	2	99.87

10/1/90

Taxon	# m^{-2}	Cumul.%
Nephtyidae	3432	98.42
Corambidae	22	99.05
Dorvilleidae	7	99.25
Hesionidae	7	99.46
Spirorbidae	7	99.66

Table 12. Continued.

INNER LUCKY BAY	6/6/90	9/28/90
Area Sampled (m^2):	0.20	0.20
Total Abundance (indiv m^{-2}):	740.00	725.00
Total Biomass (g m^{-2}):	1.11	2.98
Total Taxa Family Level & Higher:	4.00	2.00
Shannon Diversity (H'):	0.85	0.04
Simpson Dominance (D):	0.46	0.99
Species Richness (SR):	0.45	0.15
Bottom Oxygen (mg l^{-1}):	0.40	0.1-0.9
$\bar{X}$ SUMMED PAHs (ng g^{-1})	534.00	-

6/6/90			9/28/90		
Taxon	# m^{-2}	Cumul.%	Taxon	# m^{-2}	Cumul.%
Decapoda (unid.)	370	50.00	Nephtyidae	720	99.31
Nephtyidae	340	95.95			
Amphipoda (unid.)	25	99.33			

INNER BAY OF ISLES	6/10/90	9/29/90
Area Sampled (m^2):	0.20	0.40
Total Abundance (indiv m^{-2}):	2800.00	3667.00
Total Biomass (g m^{-2}):	22.82	19.89
Total Taxa Family Level & Higher:	18.00	10.00
Shannon Diversity (H'):	2.11	1.34
Simpson Dominance (D):	0.17	0.34
Species Richness (SR):	2.14	1.10
Bottom Oxygen (mg l^{-1}):	11.80	0.30-0.40
$\bar{X}$ SUMMED PAHs (ng g^{-1}):	503.00	-

6/10/90			9/29/90		
Taxon	# m^{-2}	Cumul.%	Taxon	# m^{-2}	Cumul.%
Nephtyidae	725	25.89	Montacutidae	1692	46.14
Gastropoda (unid.)	700	50.89	Nephtyidae	1255	80.37
Decapoda (unid.)	360	63.75	Haminoeidae	292	88.33
Lucinidae	325	75.36	Rissoidae	182	93.29
Opheliidae	160	81.07	Bivalvia (unid.)	115	96.43
Bivalvia (unid.)	12	85.36			
Ascidiacea	85	88.40			
Polynoidae	85	91.44			
Balanidae	45	93.05			
Montacutidae	40	94.48			
Caprellidea	40	95.91			
Goniadidae	30	96.98			

Table 12. Continued.

	DISK LAGOON 9/26/90	HUMPBACK COVE 9/30/90
Area Sampled (m^2):	0.60	0.60
Total Abundance (indiv m^{-2}):	3735.00	1668.33
Total Biomass (g m^{-2}):	121.98	11.12
Total Taxa Family Level & Higher:	13.00	5.00
Shannon Diversity (H'):	1.10	0.11
Simpson Dominance (D):	0.56	0.96
Species Richness (SR):	1.46	0.54
Bottom Oxygen (mg l^{-1}):	0.3-1.0	<0.10
$\overline{X}$ SUMMED PAHs (ng g^{-1})	-	-

DISK LAGOON 9/26190			HUMPBACK COVE 9/30/90		
Taxon	# m^{-2}	Cumul.%	Taxon	# m^{-2}	Cumul.%
Nephtyidae	2777	74.35	Nephtyidae	1638	98.20
Balanidae	208	79.92			
Lucinidae	165	84.34			
Balanomorpha	153	88.44			
Tellinidae	133	92.00			
Bivalvia (unid.)	105	94.81			
Ampharetidae	92	97.27			

Table 13. Summary of results for tests of differences in abundance of large epibenthic invertebrates at oiled *vs.* control sites. 000 or XXX = P<0.01; 00 or XX = P<0.05; 0 or X = <0.1; 0 = > at control sites; X = > at oiled sites. ND = no data, habitat not sampled.

Eelgrass Bed

	Bed 90	Bed 91	Bed 93
Telmessus cheiragonus	000	-	-
Dermasterias imbricata	-	00	-
P. helianthoides - adult	-	00	-

Laminaria/Agarum Bays

	Deep 11-20 m 90	Deep 11-20 m 91	Deep 11-20 m 93	Shallow 2-11 m 90	Shallow 2-11 m 91	Shallow 2-11 m 93
Telmessus cheiragonus	000	ND	ND	-	-	-
Dermasterias imbricata	-	ND	ND	00	-	-
Pycnopodia helianthoides	-	ND	ND	XX	X	-
P. helianthoides - adult	-	ND	ND	X	-	-
P. helianthoides - juvenile	-	ND	ND	-	XXX	-

Laminaria/Agarum Points

	Deep 11-20 m 90	Deep 11-20 m 91	Deep 11-20 m 93	Shallow 2-11 m 90	Shallow 2-11 m 91	Shallow 2-11 m 93
Telmessus cheiragonus	000	ND	ND	00	ND	ND
Dermasterias imbricata	-	ND	ND	0	ND	ND
Evasterias troschelii	-	ND	ND	0	ND	ND
Pycnopodia helianthoides	-	ND	ND	-	ND	ND
P. helianthoides - adult	-	ND	ND	X	ND	ND
P. helianthoides - juvenile	-	ND	ND	-	ND	ND

Nereocystis

	Bed 1990
Evasterias troschelii	0

All Habitats Combined

	All Depths Combined 1990
Telmessus cheiragonus	000
Dermasterias imbricata	00

Table 14. Test results for the density of large benthic invertebrates in two-way analyses of the effects of oil (oiled *vs*. control), year (1990, 1991, and 1993), and their interaction in eelgrass and shallow *Laminaria/Agarum* bay habitats. 000 or XXX = P<0.01; 00 or XX = P<0.05; 0 or X = <0.1; 0 = > at control sites or > in 1990.; X = > at oiled sites or > in 1993. For the interaction, 0 indicates a decline at control sites relative to oiled sites between 1990 and 1993, while X indicates the opposite.

	Eelgrass Bed			Bays 2-11 m		
	Oil	Year	Int.	Oil	Year	Int.
Telmessus cheiragonus	00	00	-	-	-	-
Dermasterias imbricata	000	-	-	00	-	-
Evasterias troschelii	-	-	-	-	-	-
P. helianthoides adult	-	-	00	XX	XXX	-
P. helianthoides juvenile	-	00	-	-	XXX	-

Table 15. Number of *Strongylocentrotus droebachiensis* observed in 180 m^2 areas sampled in each year at *Laminaria/Agarum* bay sites.

	90	91	93
Herring Bay (oiled)	1	0	4
Bay of Isles (oiled)	2	0	0
Mummy Bay (control)	4	0	6
Lower Herring Bay (control)	0	0	1
Total	7	0	11

_ole 16. Results of a Chi-square test examining differences in the proportion of *Dermasterias imbricata* parasitized by the barnacle, *Dendrogaster* sp., in 1990, 1991 and 1993.

Site	1990			1991			1993		
	With	W/out	% With	With	W/out	% With	With	W/out	% With
Northwest Bay	12	31	28%	-	-	-	-	-	-
Cabin Bay	18	28	39%	-	-	-	-	-	-
Herring Bay	8	18	31%	-	-	-	5	19	21%
Lower Herring Bay	4	20	17%	2	14	13%	1	31	3%
Bay of Isles	10	34	23%	0	5	0%	12	13	48%
Mummy Bay	14	28	28%	3	17	15%	16	9	64%
Sleepy Bay	-	-	-	0	11	0%	-	-	-
Total	66	159	29%	5	47	10%	34	72	32%

Table 17. Results of a Chi-square test examining differences in the infection rate of *Dermasterias imbricata* by the barnacle *Dendrogaster* sp. at oiled *vs*. control sites in 1990.

Herring Bay (Oiled) and Lower Herring Bay (Control)

Site	Parasitized Yes	No	%
Oiled	5	18	22%
Control	3	20	13%
Total	8	38	Mean=17%

χ^2 = 1.36, df=1, P=0.24

Northwest Bay (Oiled) and Cabin Bay (Control)

Site	Parasitized Yes	No	%
Oiled	12	31	28%
Control	18	28	39%
Total	30	59	Mean=34%

χ^2 = 1.25, df=1, P=0.26

Bay of Isles(Oiled) and Mummy Bay (Control)

Site	Parasitized Yes	No	%
Oiled	10	34	22.7%
Control	14	28	33.3%
Total	24	62	Mean=28.0%

χ^2 = 1.20, df=1, P=0.27

Table 18. Results of a Chi-square test examining differences in the spawning success of *Dermasterias imbricata* parasitized by the barnacle *Dendrogaster* sp. The starfish were collected from Northwest and Cabin Bays in 1990.

No. of Rays Parasitized	Spawn	No Spawn	% Spawn
0	48	11	81
1	9	3	75
2	2	3	40
3	0	4	0
4	1	1	50
5	2	5	29

$\chi^2 = 21.2$, df=5, $P<0.01$

Table 19. Summary of results for tests of differences in the abundance of fishes at oiled *vs.* control sites. 000 or XXX = P<0.01; 00 or XX = P<0.05; 0 or X = <0.1; 0 = > at control sites; X = > at oiled sites. ND = No data.

Eelgrass Bed

	Bed 90	Bed 91	Bed 93
Juvenile Cod	XXX	XX	XX
Adult Cod	XXX	-	-

Laminaria/Agarum Bays

	Deep 11-20 m		Shallow 2-11 m	
	90	91	90	91
Greenlings	-	ND	X	-
Adult Arctic Shanny	-	ND	-	0
Small Sculpins	-	ND	-	0

Laminaria/Agarum Points

	Deep 11-20 m		Shallow 2-11 m	
	90	91	90	91
Greenlings	X	ND	-	ND
Ronquils	X	ND	-	ND
Juvenile Arctic Shanny	X	ND	-	ND
Juvenile Cod	00	ND	00	ND
Pholids	0	ND	-	ND
Small Sculpins	-	ND	XXX	ND
Searchers	-	ND	X	ND

Nereocystis

	Bed 1990
Greenlings	X

Bays and Points Combined

	All Depths Combined 1990
Greenlings	XX
Small sculpins	X

Table 20. Test results for the density of fishes in two-way analyses of the effects of oil (oiled *vs.* control), year (1990, 1991, 1993), and their interaction in eelgrass and shallow *Laminaria/Agarum* habitats. 000 or XXX = P<0.01; 00 or XX = P<0.05; 0 or X = <0.1; 0 = > at control sites; X = > at oiled sites. Tests for juvenile and cod in eelgrass habitats include data for 1990, 1991, and 1993. All other tests are for 1990 and 1991 only.

	Eelgrass Bed			Bays 2-11 m		
	Oil	Year	Int.	Oil	Year	Int.
Adult Arctic Shanny	ND	ND	ND	-	X	-
Juvenile Cod	XX	XX	-	ND	ND	ND
Adult Cod	-	XXX	-	ND	ND	ND

Table 21. Mean densities of eelgrass blades (number 0.25 m^{-2}) and densities of *Musculus* (number per blade of eelgrass) in which *Musculus* had been removed approximately 10 weeks prior, and to control plots.

Eelgrass Blade Density

	Cleared	Control
Replicate 1	39	61
Replicate 2	35	31
Replicate 3	56	37
Replicate 4	40	39
Replicate 5	57	--
Mean	42.0	45.4

(t = 0.44, P = 0.68)

Musculus Density

	Cleared	Control
Replicate 1	103.4	72.0
Replicate 2	195.7	136.6
Replicate 3	36.1	154.8
Replicate 4	83.0	166.26
Replicate 5	183.7	--
Mean	120.4	132.4

(t = 0.31, P = 0.77)

Table 22. Mean density of *Musculus* (number per blade of eelgrass) within different treatments at Herring Bay in 1993.

Treatment	Mean density (#/blade)
Control	22.3
Cage Control	33.1
Cage	25.6
Cage with *Dermasterias*	33.1
Cage with *Telmessus*	26.2

(df = 5, F = 0.62, P = 0.66)

Table 23. Summary of ANOVA randomization test results on concentrations of hydrocarbons (SUMMED PAHs) at oiled vs. control sites. Results of both one-way analyses (testing for differences among oiled and control sites within a given year) and two-way analyses (testing for the effects of oil, year, and their interaction) are presented. ● = greater at oiled sites; O = greater at control sites; X = significant difference exists. ●●●, OOO and XXX = $P \leq 0.01$; ●●, OO and XX = $0.01 < P \leq 0.05$; ●, O and X = $0.05 < P \leq 0.1$; - = $P > 0.1$; ND = no data, habitat not sampled in 1991 and 1993.

		1-Way Test		
		1990	1991	1993
Eelgrass Habitat	Deep (6-20 m)	-	●●	●●
	Eelgrass Bed (<3 m)	●●	●	-
Laminaria/Agarum Bay Habitat	Deep (11-20 m)	●●	ND	ND
	Shallow (2-11 m)	●	ND	ND

		2-Way Test		
		Treatment	Year	Interaction
Eelgrass Habitat	Deep (6-20 m)	-	XXX	-
	Eelgrass Bed (<3 m)	-	XXX	-

Table 24. Comparison of mean densities of dominant macroalgae at Latouche Point prior to (June 1976) and after (July 1990) the EXXON VALDEZ oil spill. Data from 1976 are from Rosenthal et al., 1977. The 1976 data are means from depths of 3.5 to 6 m. The 1990 data are from depths of 3 m to 6 m.

Taxa	Mean Density ($No.m^2$)	
	1975	1990
Nereocystis luetkaena	1.2	0.3
Laminaria groenlandica(1)	6.8	38.0
Laminaria yezoensis	1.5	0.3
Agarum cribrosum	0.3	0.3
Pleurophycus gardneri	3.1	3.3

1 Rosenthal et al. (1977) identified this species as *L. dentigera*.

Table 25. Shallow subtidal study sites within ADEC shoreline segments, Prince William Sound, 1990. EVOS cleanup activity. Note the EVOS cleanup activity that occurred adjacent to many of the oiled study sites.

Site Name	Site #	Oil Code[1]	Habitat Code[2]	Lat.	Long.	ADEC Segment #	EVOS Cleanup Activity[3]	Survey Date
Cabin Bay	1	9	1	60°39.5	147°27.0	NA024	No Activity	
Northwest Bay	2	1	1	60 33.3	147 34.6	EL056-D	Manual removal; Bioremediation	Summer 1990
Herring Bay	3	1	1	60 26.8	147 47.1	KN0132A	Manual removal	5/29/90
L. Herring Bay	4	9	1	60 26.8	147 48.4	KN0551-A	No Activity	
Mummy Bay	5	9	1	60 13.8	147 49.0	KN0601	No Activity	
Bay of Isles	6	1	1	60 23.1	147 42.6	KN0136-A;KN0004-A	No Activity	
Bay of Isles	13	1	3	60 23.2	147 44.5	KN0202-A	No Activity	
Drier Bay	14	9	3	60 19.2	147 44.2	KN0575-A	No Activity	
L. Herring Bay	15	9	3	60 24.2	147 48.1	KN0551-A	No Activity	
Herring Bay	16	1	3	60 26.7	147 47.2	KN0132B	Rake/till; manual removal; Bioremed.; mechanical treat.	Summer 90-91
Sleepy Bay	17	1	3	60 04.0	147 50.1	LA017-A - LA018-A	Rake/till; manual removal; Bioremed.; mechanical treat.	Summer 90-91
Moose Lips Bay	18	9	3	60 12.7	147 18.5	No Segment #	No Activity	
Clammy Bay	25	1	3	60 39.1	147 22.5	NA006-B	No Activity	
Puffin Bay	26	9	3	60 44.0	147 25.0	ST001	No Activity	
Lucky Bay	27	9	5	60 13.7	147 52.0	KN0600-A	No Activity	
Herring Bay	28	1	5	60 28.1	147 42.4	KN0118-A	Manual removal; bioremed.	5/6/90
Bay of Isles	30	1	5	60 23.0	147 45.3	KN0200-A - KN0201-A	Rake/till; manual removal;	5/14/90
Lucky Bay	29	9	5	60 13.9	147 51.5	KN0600-A	No Activity	
Bay of Isles	31	1	5	60 23.2	147 39.6	KN0202-3-A;KN0009-A	Manual removal; bioremed.	6/7-9/91
Disk Lagoon	32	9	5	60 39.6	147 39.6	DI065-A	No Activity	
Humpback Cove	33	9	5	60 12.5	148 17.5	WH504	No Activity	

[1]Oil Codes 1 = Oiled
9 = Control

[2]Habitat Codes 1 = *Laminaria/Agarum* - Island Bays
3 = *Zostera* (eelgrass)
5 = Silled Fjords

[3]EVOS cleanup activity: information provided by ADEC Oil Spill Response Center, Anchorage, AK.

FIGURES

Figure 1. Locations of subtidal study sites in Prince William Sound. Lettered boxes represent inset maps A through N that detail study site locations. Number and letter codes represent the site number and indicate the habitat type. For example, in Map A, 33F is site #33, a silled fjord.

Habitat code: B = *Laminaria/Agarum* - Island Bay
P = *Laminaria/Agarum* - Island Points
E = Eelgrass
N = *Nereocystis*
F = Silled Fjord

The key below indicates site numbers, site names, and inset map locations.

Habitat Type	Site #	Name	Oil Code	Inset Map Location
Eelgrass	13	Bay of Isles	O	H
	14	Drier Bay	C	F
	15	Lower Herring Bay	C	G
	16	Herring Bay	O	I
	17	Sleepy Bay	O	D
	18	Moose Lips Bay	C	M
	25	Clammy Bay	O	K
	26	Puffin Bay	C	K
	24	Short Arm	O	H
	25	Mallard Bay	C	F
Laminaria/Agarum Island Bays	01	Cabin Bay	C	K
	02	Northwest Bay	O	J
	03	Herring Bay	O	I
	04	Lower Herring Bay	C	G
	05	Mummy Bay	C	E
	06	Bay of Isles	O	H
Laminaria/Agarum Island Points	19	Disk Lagoon	O	E
	20	Lucky Bay	C	E
	21	Outer L.H. Bay	C	G
	22	Outer Herring Bay	O	I
	23	Ingot Point	O	J
	24	Peak Point	C	K
Nereocystis	07	Latouche Point	O	C
	08	Procession Rocks	C	B
	11	Naked Island	C	K
	12	Little Smith Is.	O	L
	09	Zaikof Point	C	N
Silled Fjords	27	Outer Lucky Bay	C	E
	28	Herring Bay	O	I
	29	Inner Lucky Bay	C	E
	30	Inner Bay of Isles	O	H
	31	Outer Bay of Isles	O	H
	32	Disk Lagoon	C	J
	33	Humpback Cove	C	A

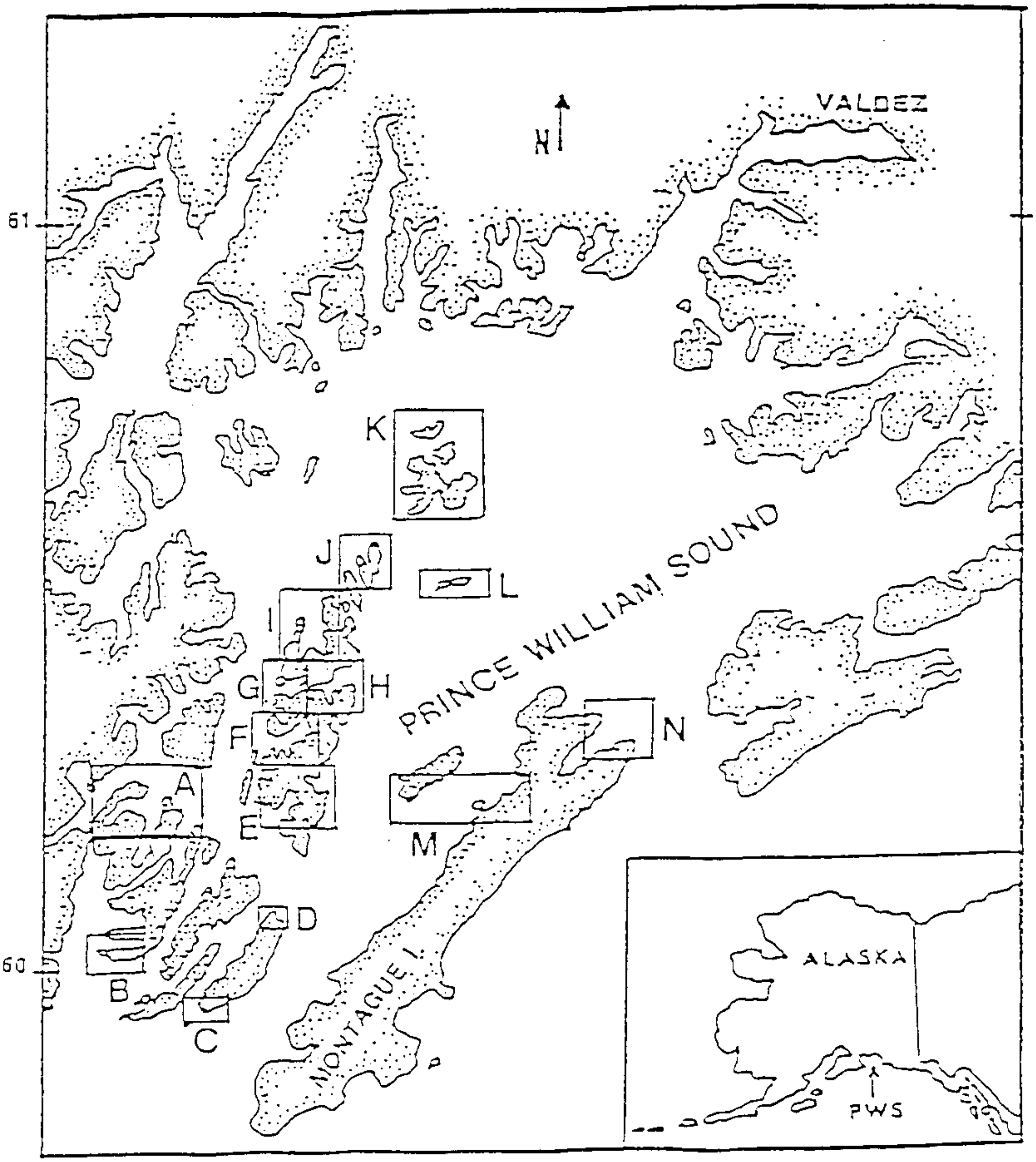


Figure 1. (continued)

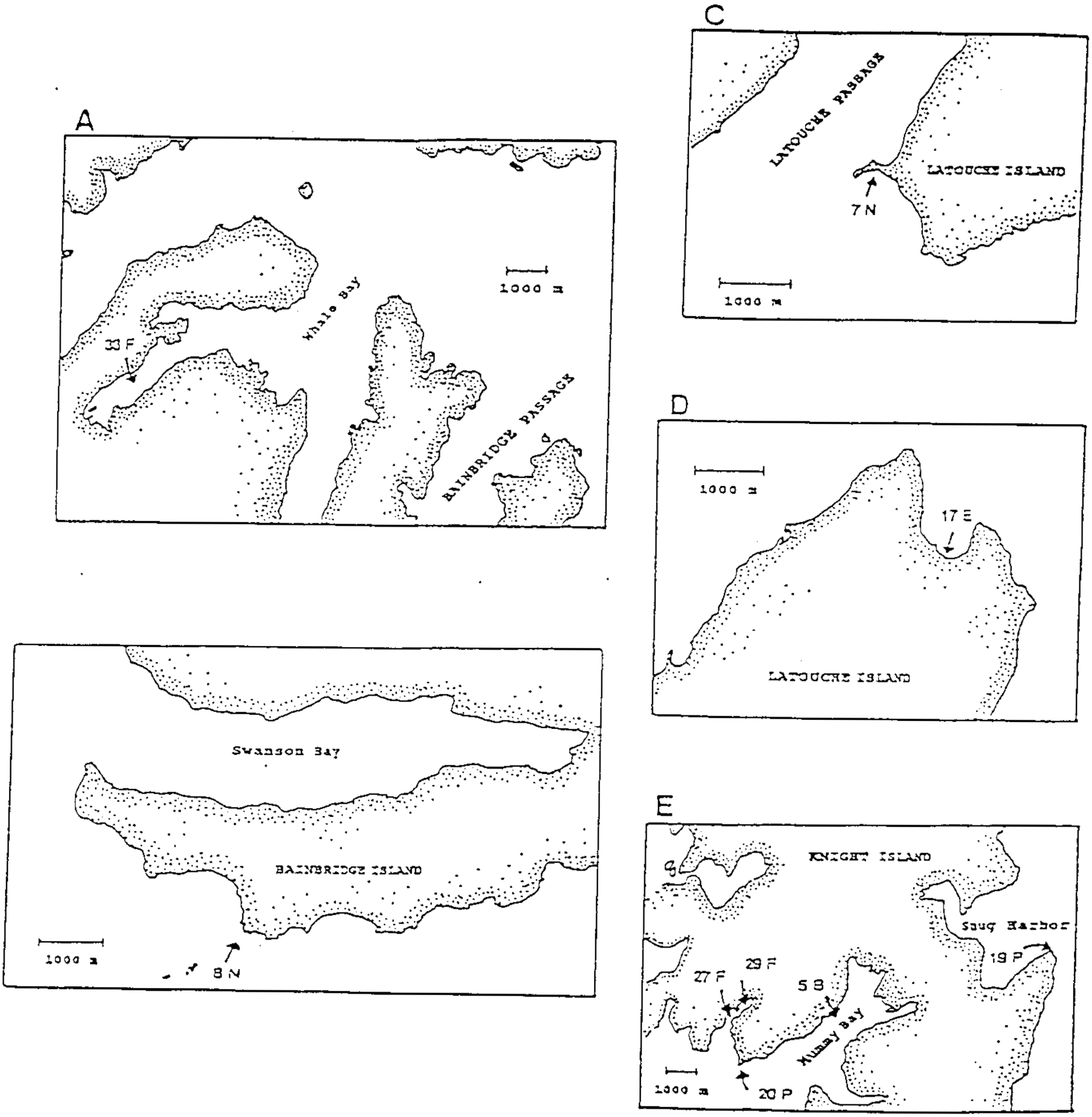


Figure 1. (continued)

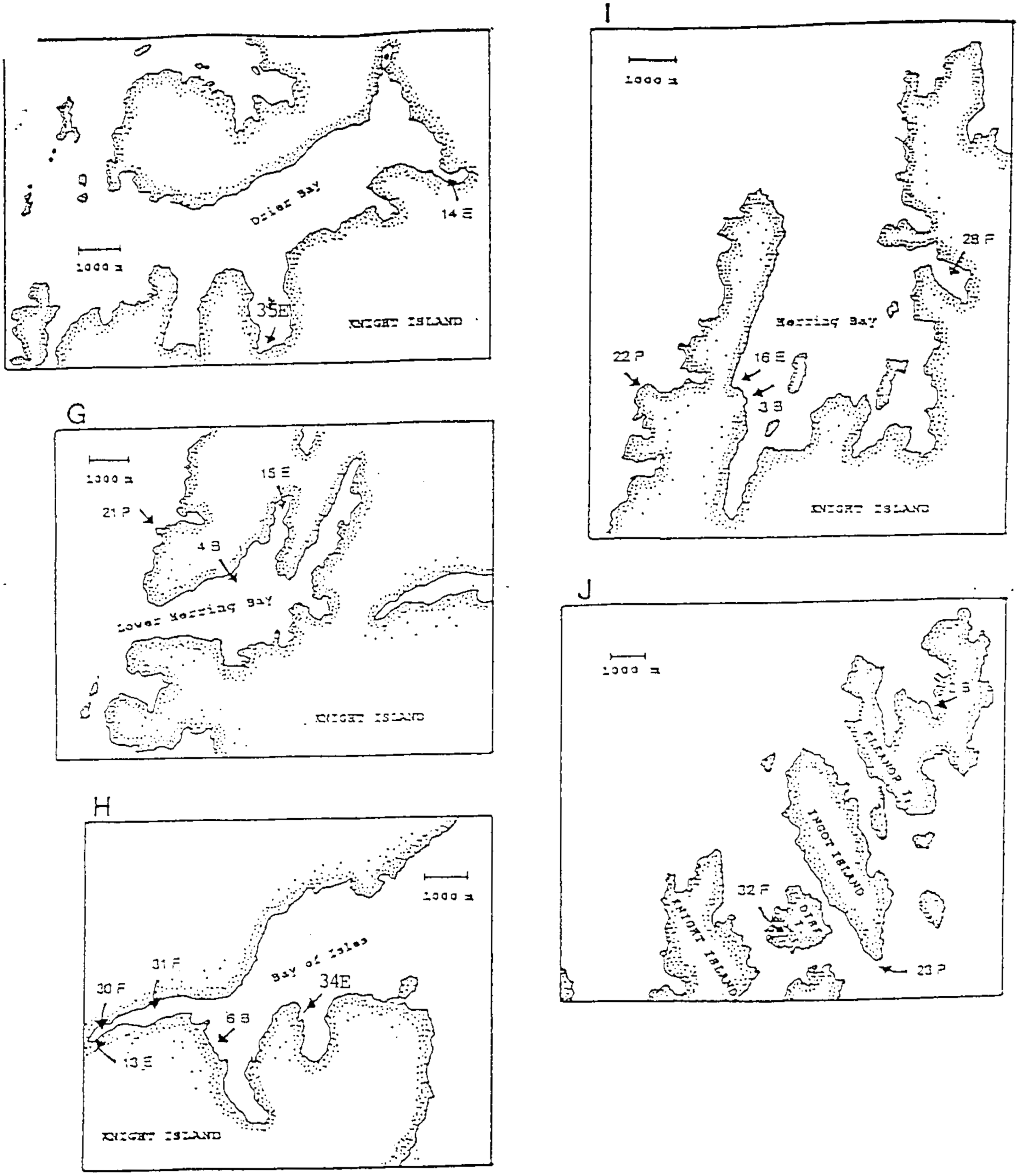


Figure 1. (continued)

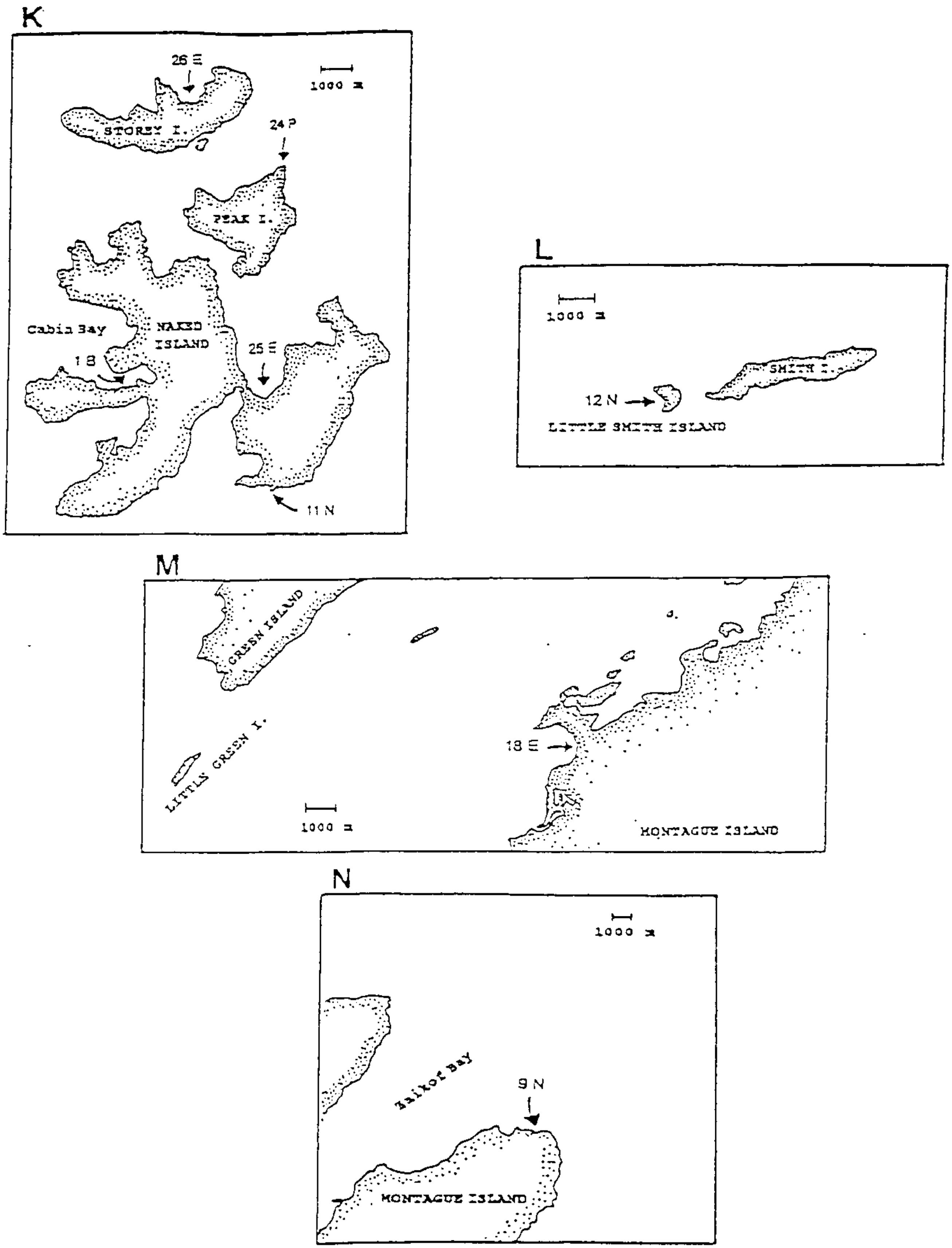


Figure 1. (continued)

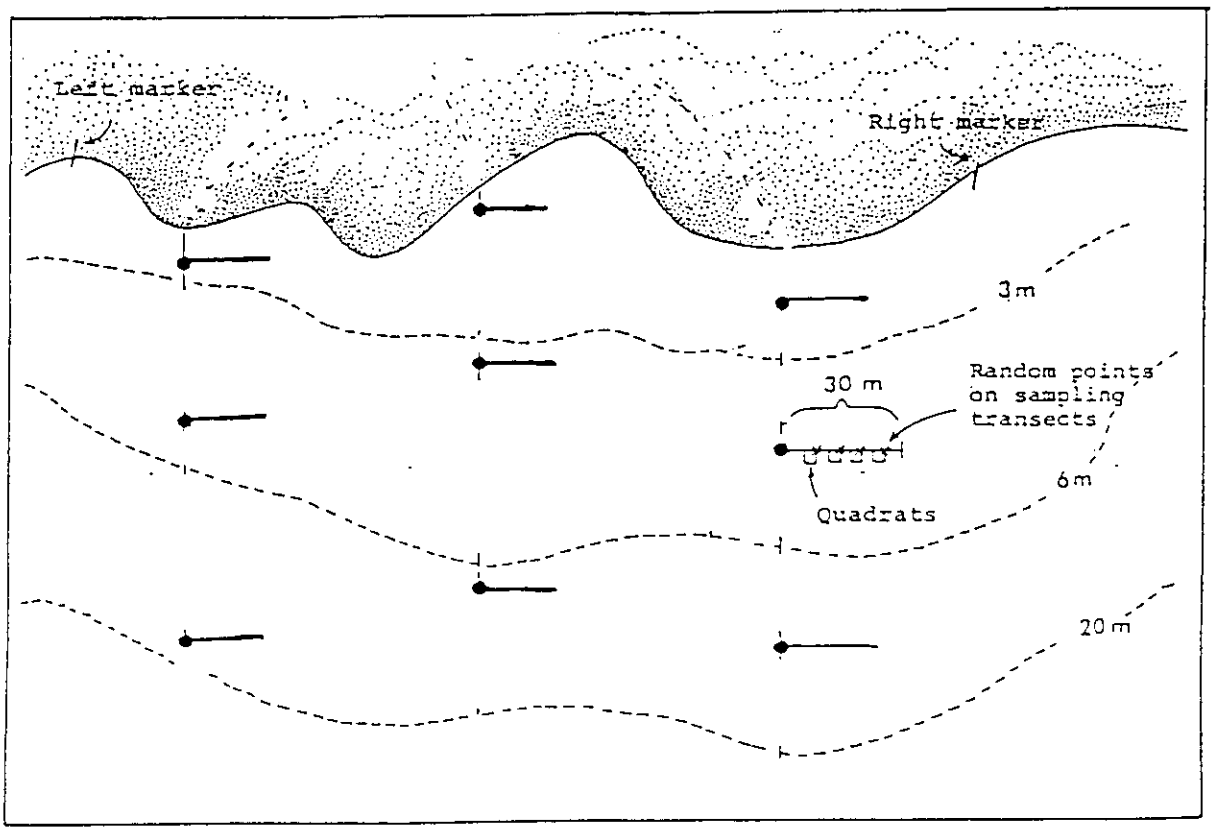


Figure 2. Schematic showing the layout of sampling stations and quadrat locations at eelgrass sampling sites. Samples within the eelgrass bed were selected independent of depth, but are shown here at depths less than 2 meters. Samples taken in other habitats (*Laminaria/Agarum* and *Nereocystis*) used a similar site layout, but with differing depth strata.

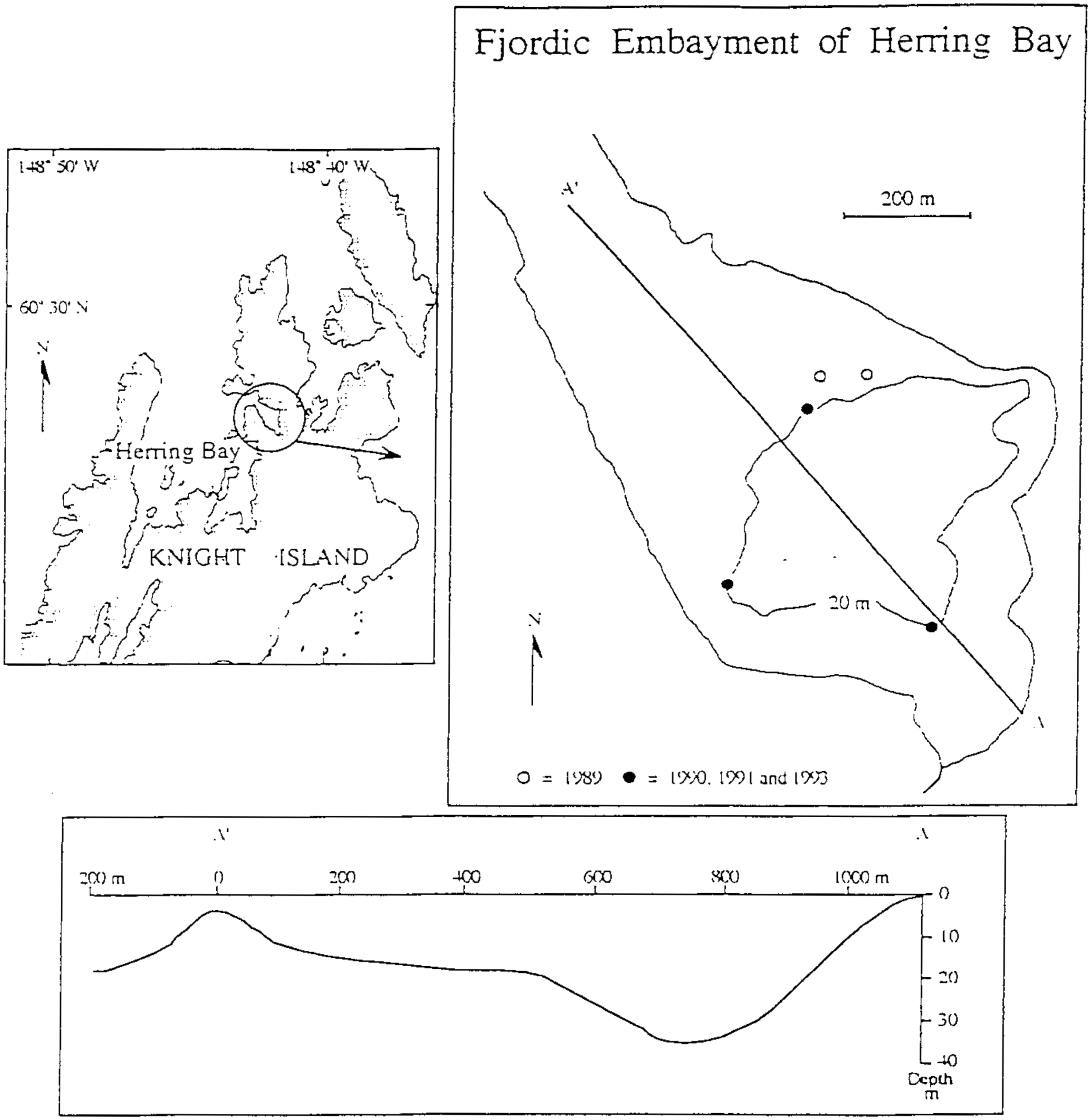


Figure 3. Detail showing the approximate sampling locations of sampling sites within the Herring Bay silled fjord in 1989, 1990, 1991 and 1993.

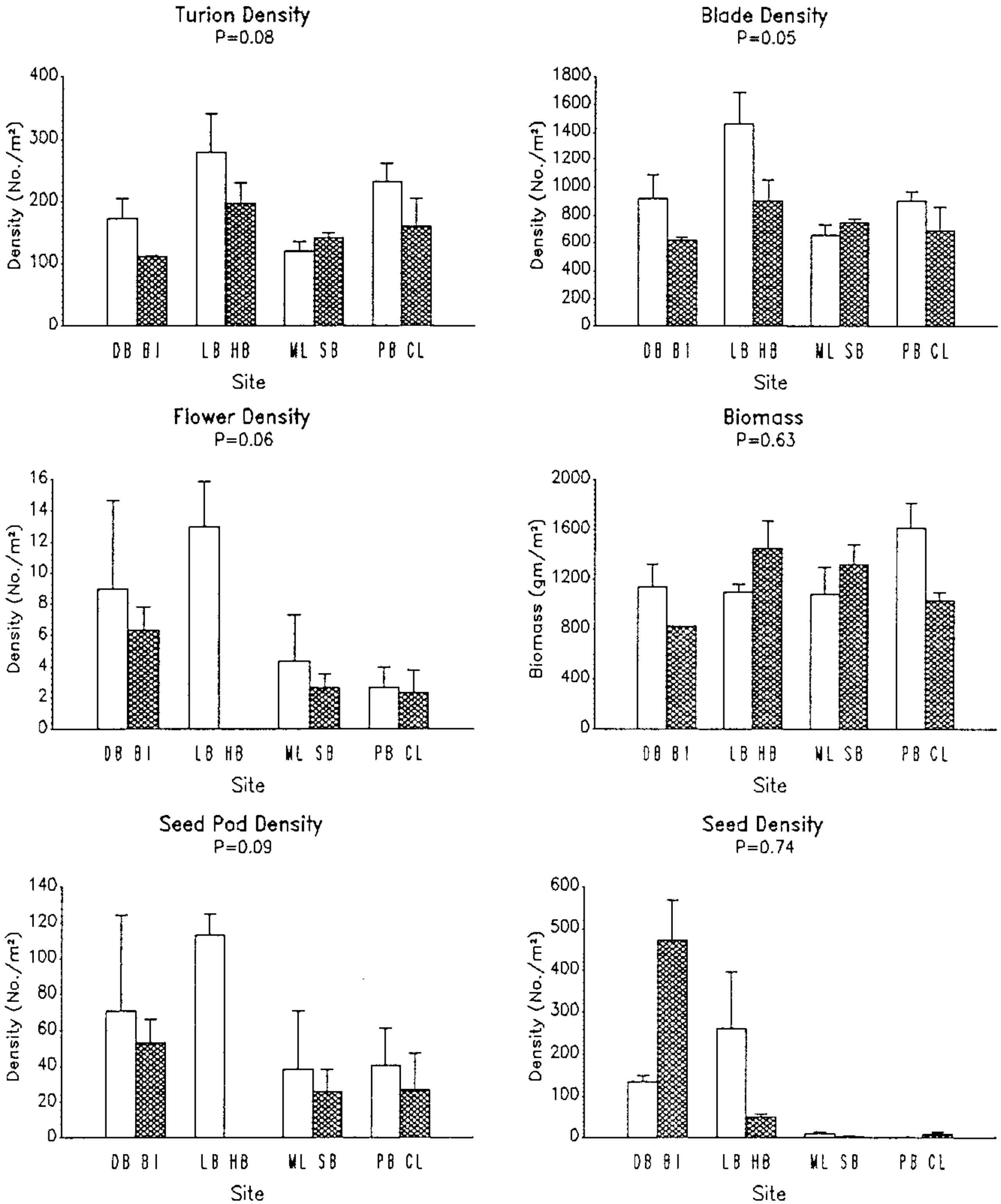


Figure 4. Mean densities (number m^{-2} +/- 1 standard error) of shoots, flowering shoots, blades, inforescences, and seeds; and biomass (g wet weight m^{-2} +/- 1 standard error) of eelgrass, *Zostera marina*, at oiled (shaded bars) and control sites (open bars) in 1990. Abbreviations for site names are as follows: DB - Drier Bay, BI - Bay of Isles, LB - Lower Herring Bay, HB - Herring Bay, ML - Mooselips Bay, SB - Sleepy Bay, PB - Puffin Bay, CL - Clammy Bay.

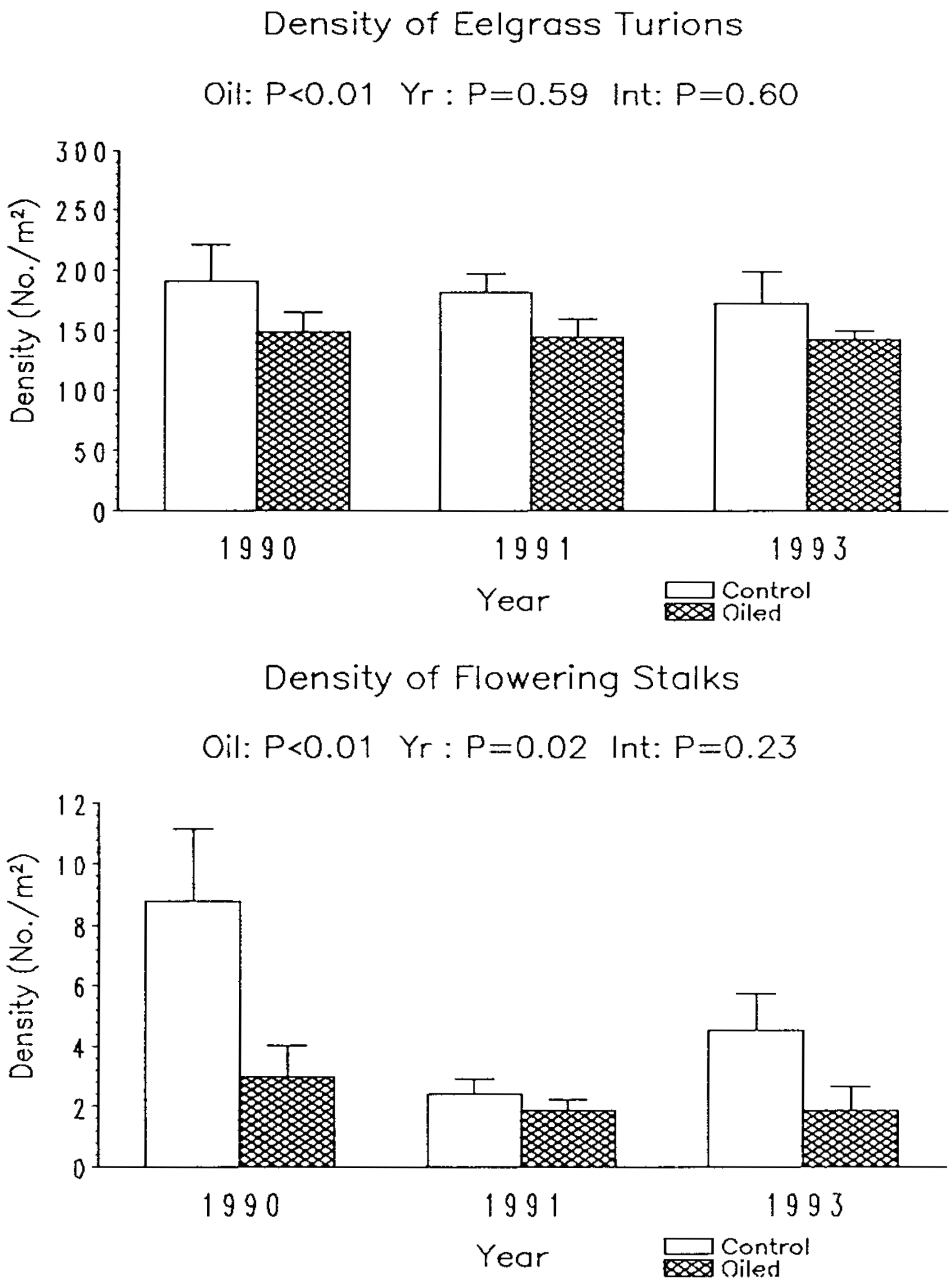


Figure 5. Mean densities (number m^{-2} +/- 1 standard error) of shoots and flowering shoots of eelgrass, *Zostera marina*, from three pairs of oiled (shaded bars) and control sites (open bars) in 1990, 1991, and 1993.

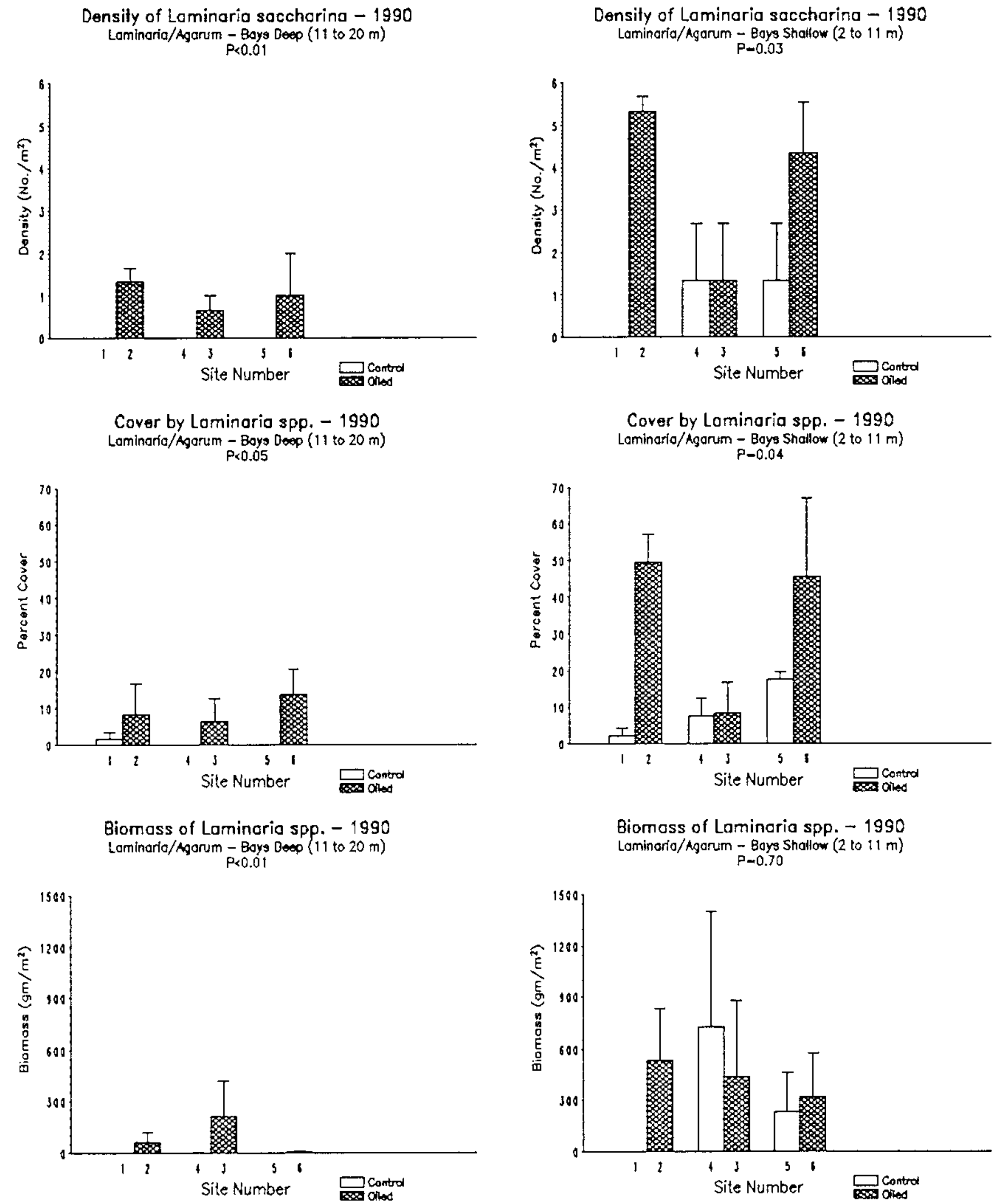


Figure 6. Density, percent cover, and biomass of *Laminaria spp.* at oiled and control sites at *Laminaria/Agarum* habitats in island bays. Error bars are +/- 1 standard error.

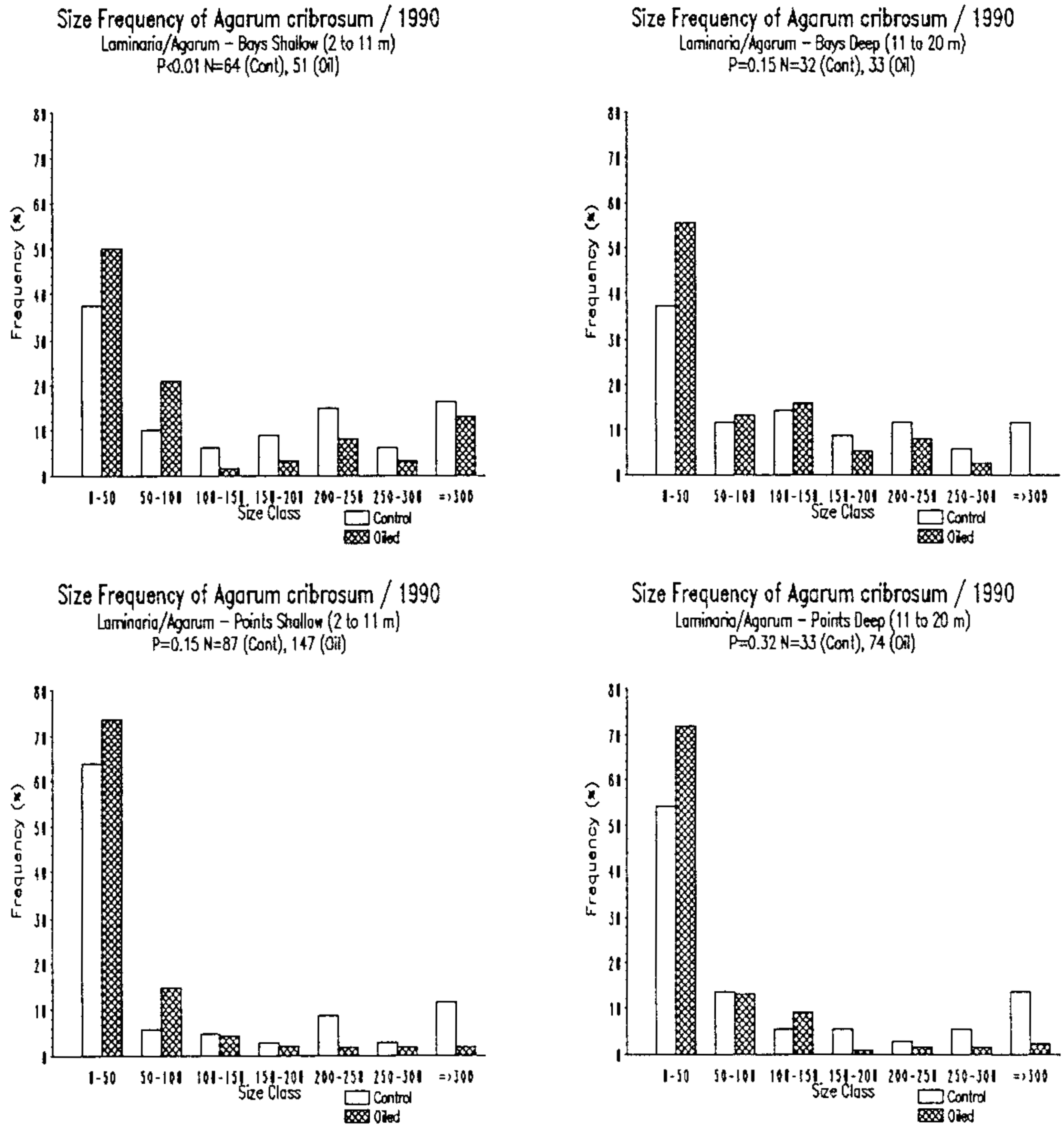


Figure 7. Size frequency of *Agarum cribrosum* at oiled and control sites in *Laminaria/Agarum* habitats in Prince William Sound in 1990. Size classes are given as wet weights (gms).

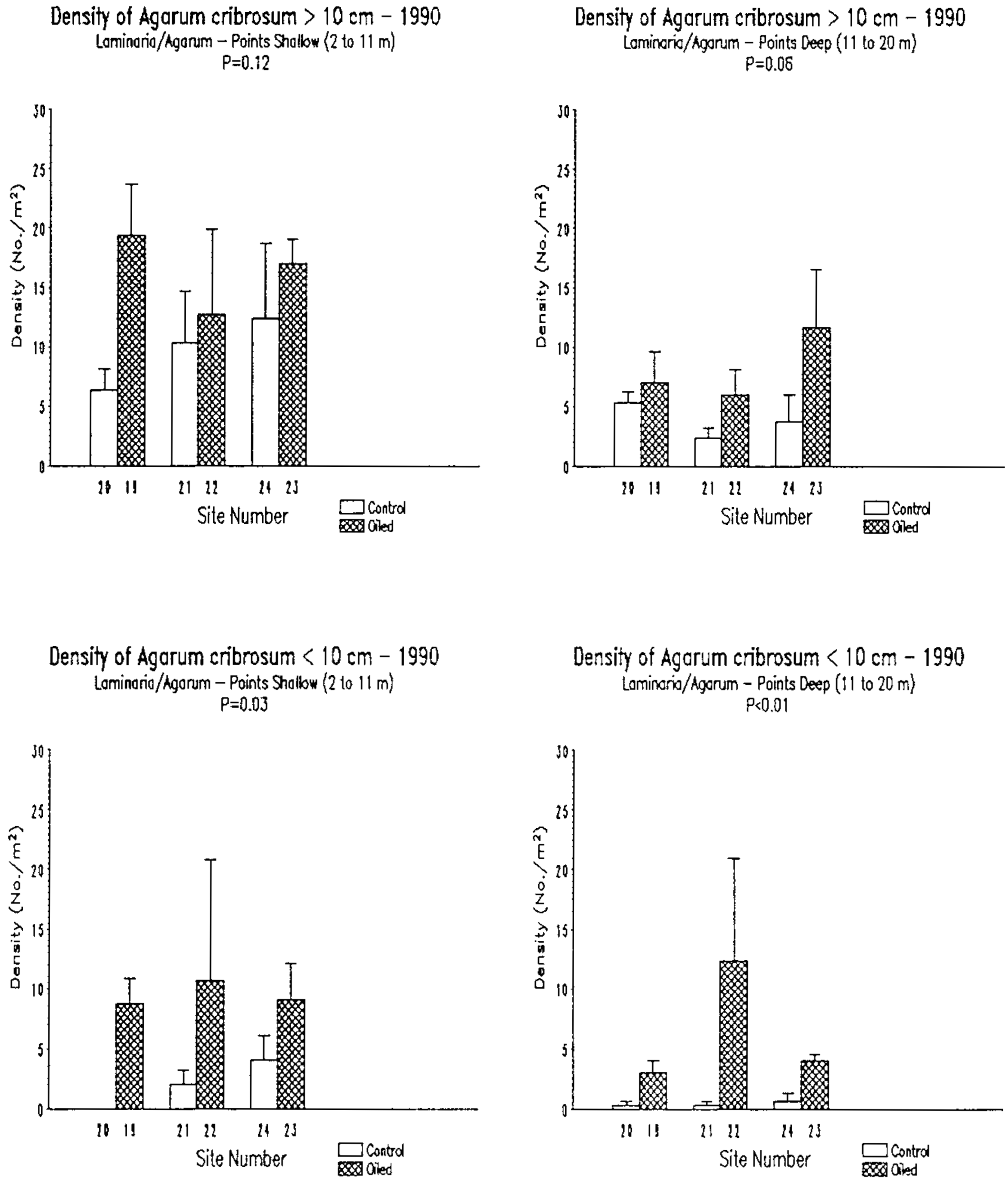


Figure 8. Density of large (>=10 cm) and small (< 10cm) *Agarum cribrosum* at oiled and control sites in *Laminaria/Agarum* habitats on island points in Prince William Sound. Error bars are +/- 1 standard error.

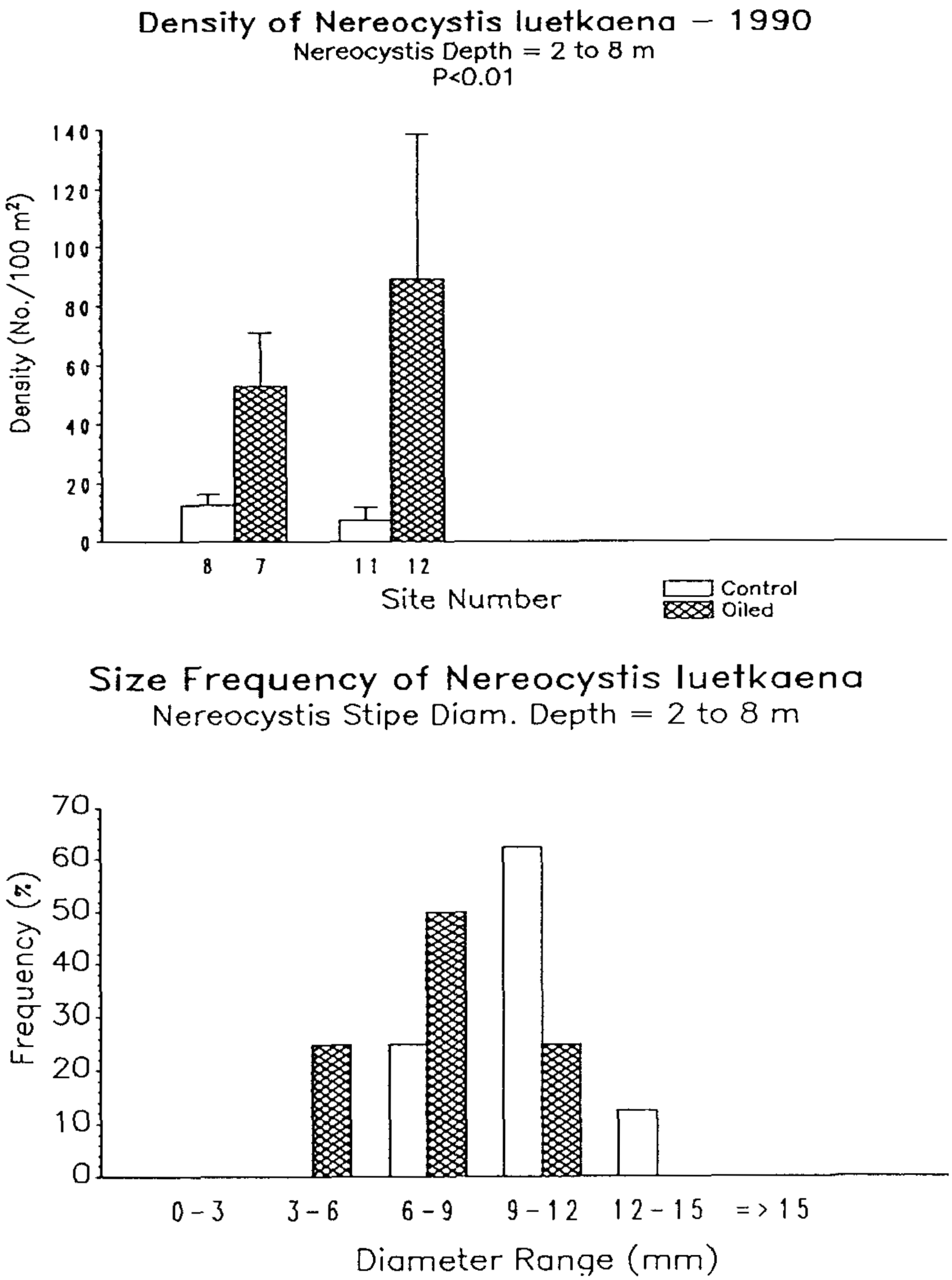


Figure 9. Density and size frequency of *Nereocystis luetkeana* at oiled and control sites in Prince William Sound. Error bars are +/- 1 standard error.

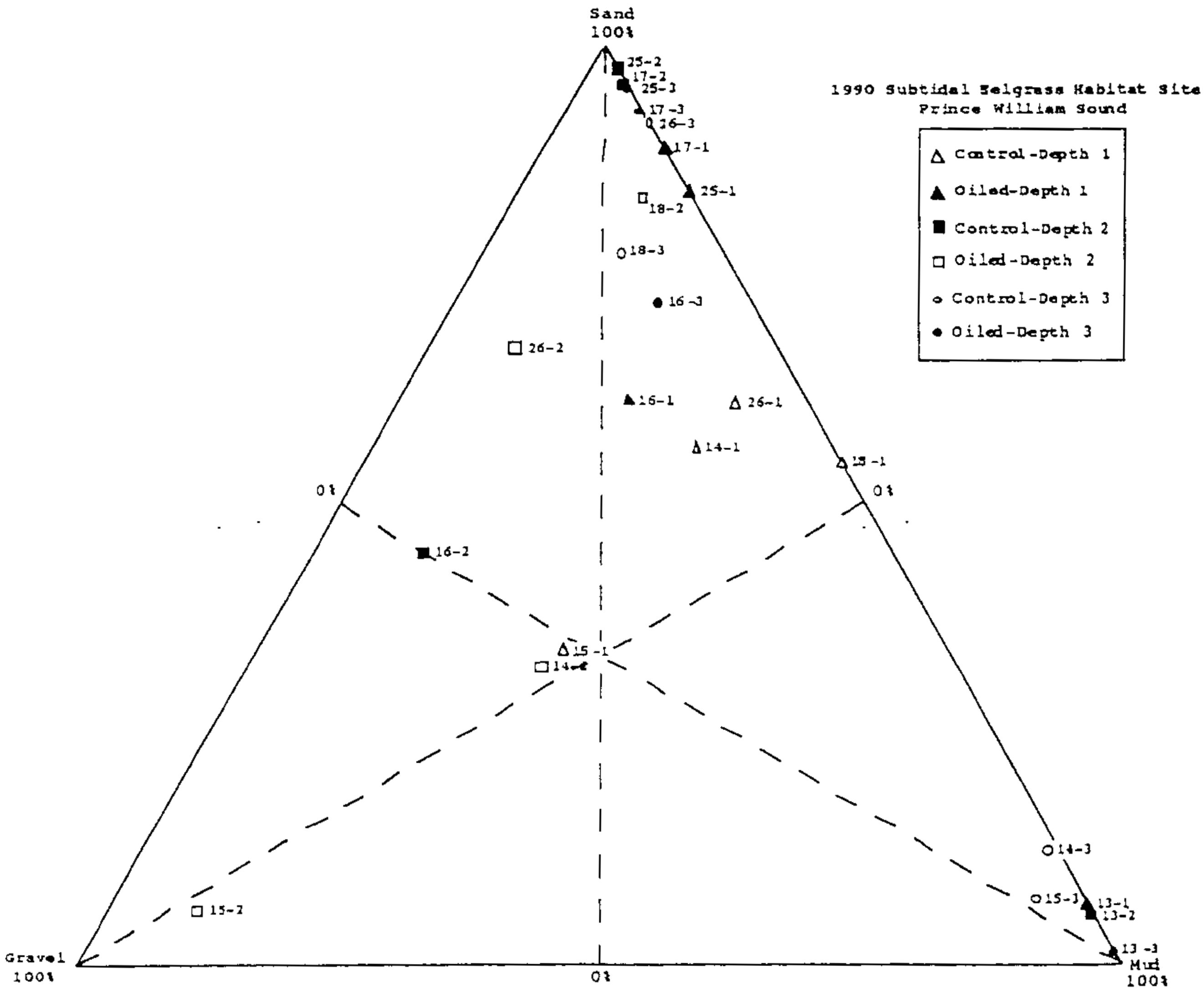


Figure 10. Ternary diagrams of granlometric composition of sediments at sites within eelgrass habitats in Prince William Sound in 1990, 1991 and 1993. Paired oiled and control sites and corresponding site numbers are: Bay of Isles (13) - Drier Bay (14); Herring Bay (16) - Lower Herring Bay (15); Sleepy Bay (17) - Moose Lips Bay (18); Clammy Bay (25) - Puffin Bay (26); and Short Arm of Bay of Isles (35) - Mallard Bay (34). Depths indicated are: Depth 1 - Deep (6-20 m); Depth 2 - Shallow (3-6 m); and Depth 3 - Bed (generally less than 3 m).

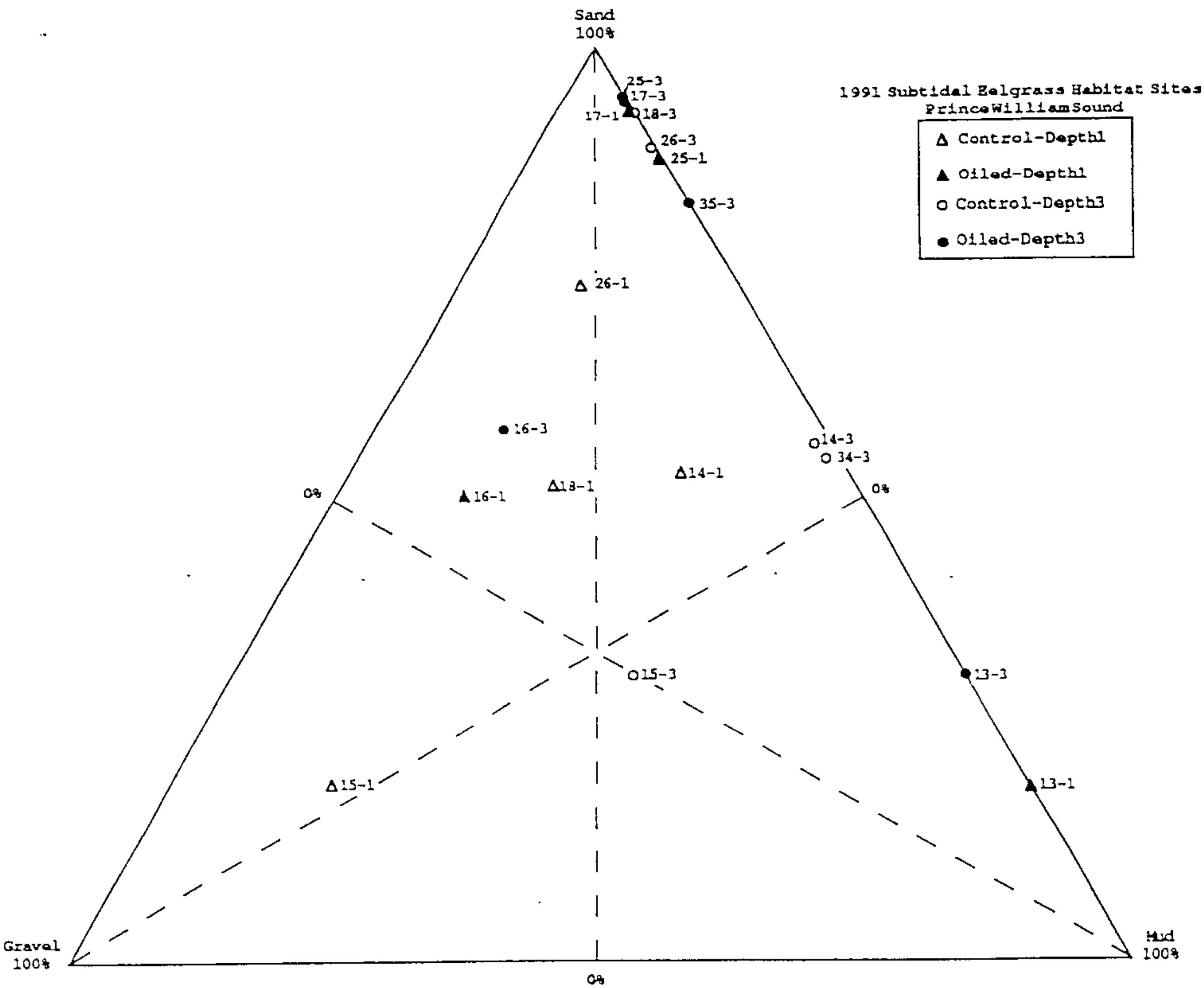


Figure 10. (Continued)

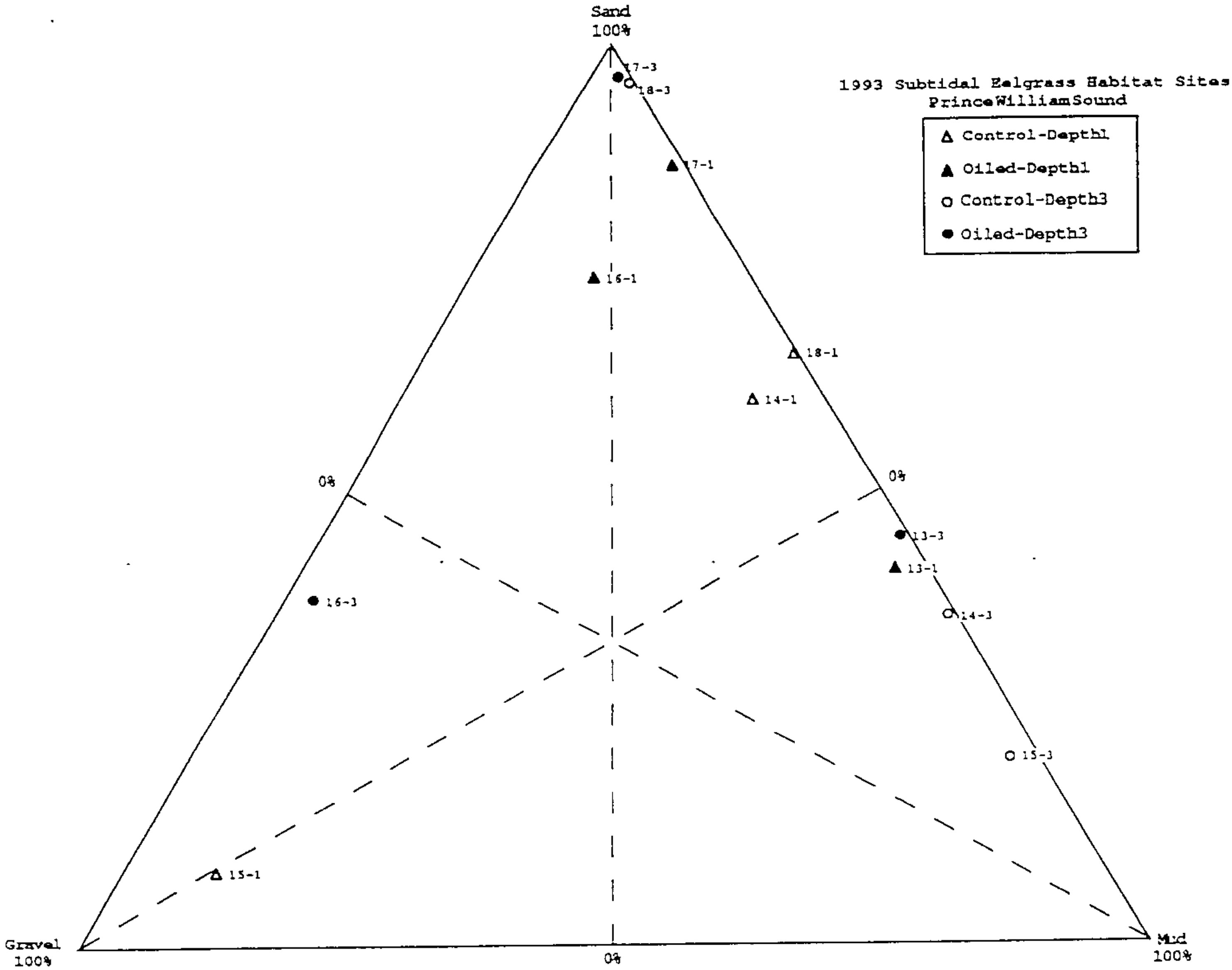


Figure 10. (Continued)

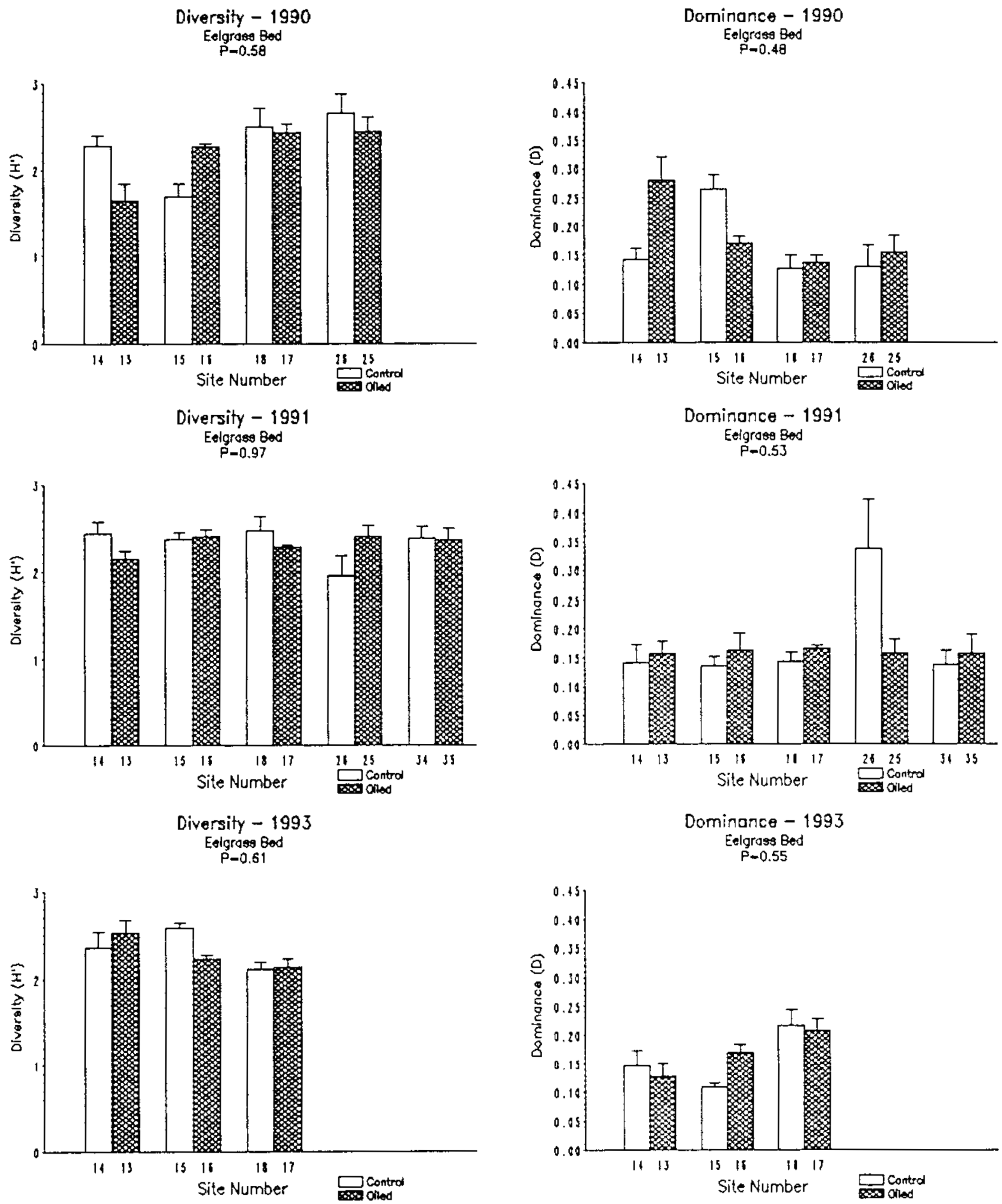


Figure 11. Diversity, dominance, species richness, total abundance, total biomass, and number of taxa for infaunal invertebrates from dredge samples in the eelgrass bed within eelgrass habitats in Prince William Sound in 1990, 1991 and 1993.

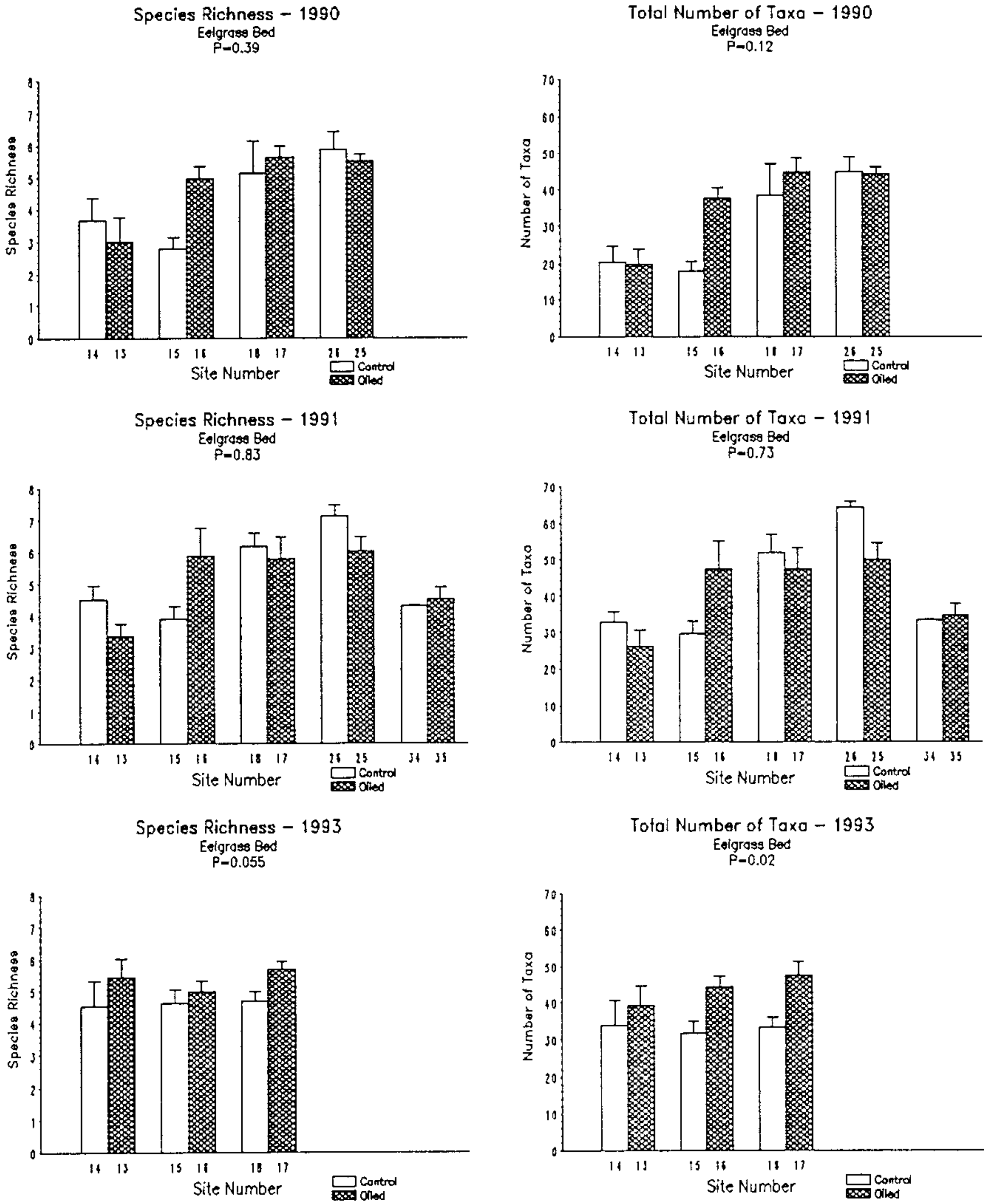


Figure 11. (Continued).

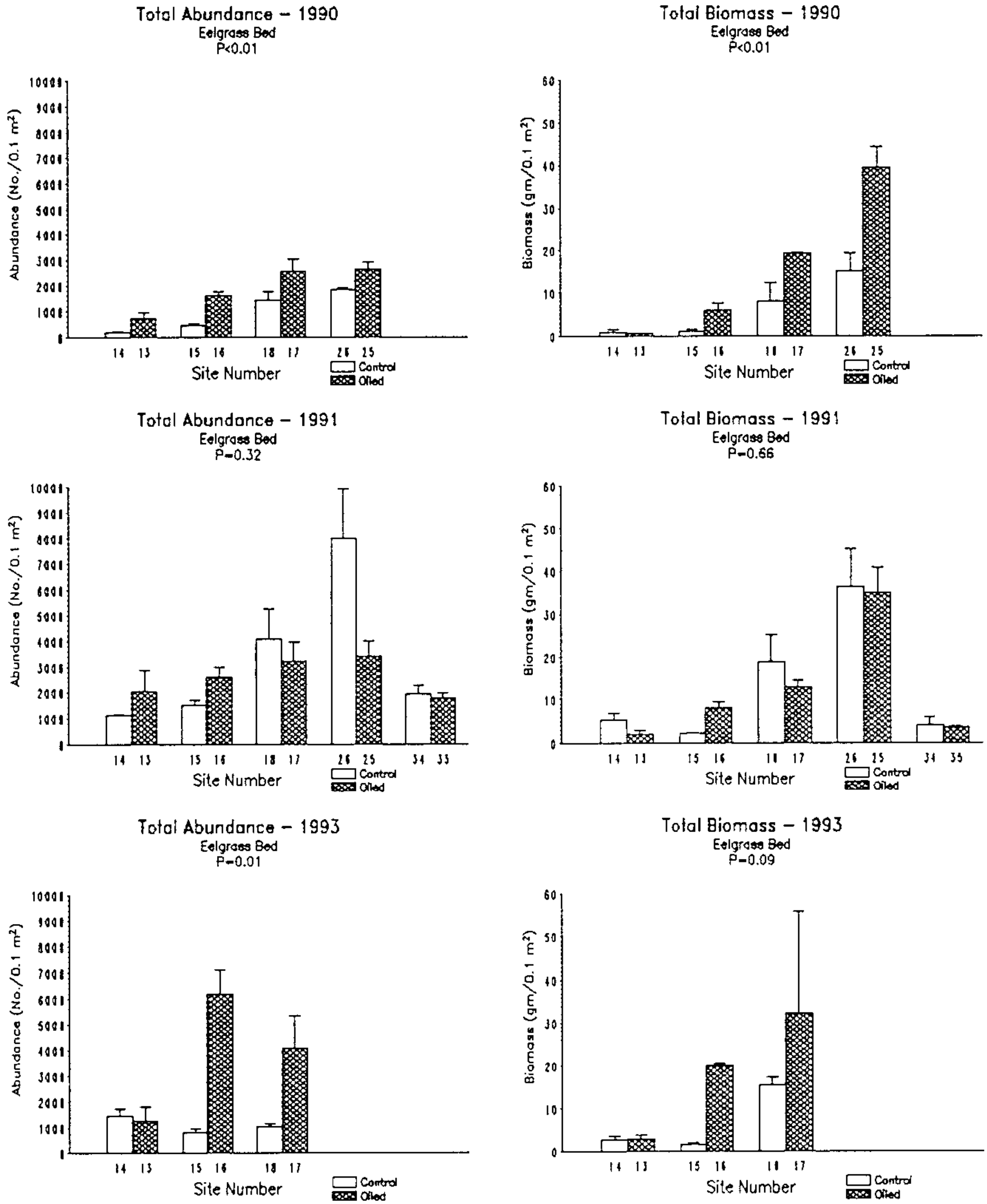


Figure 11. (Continued).

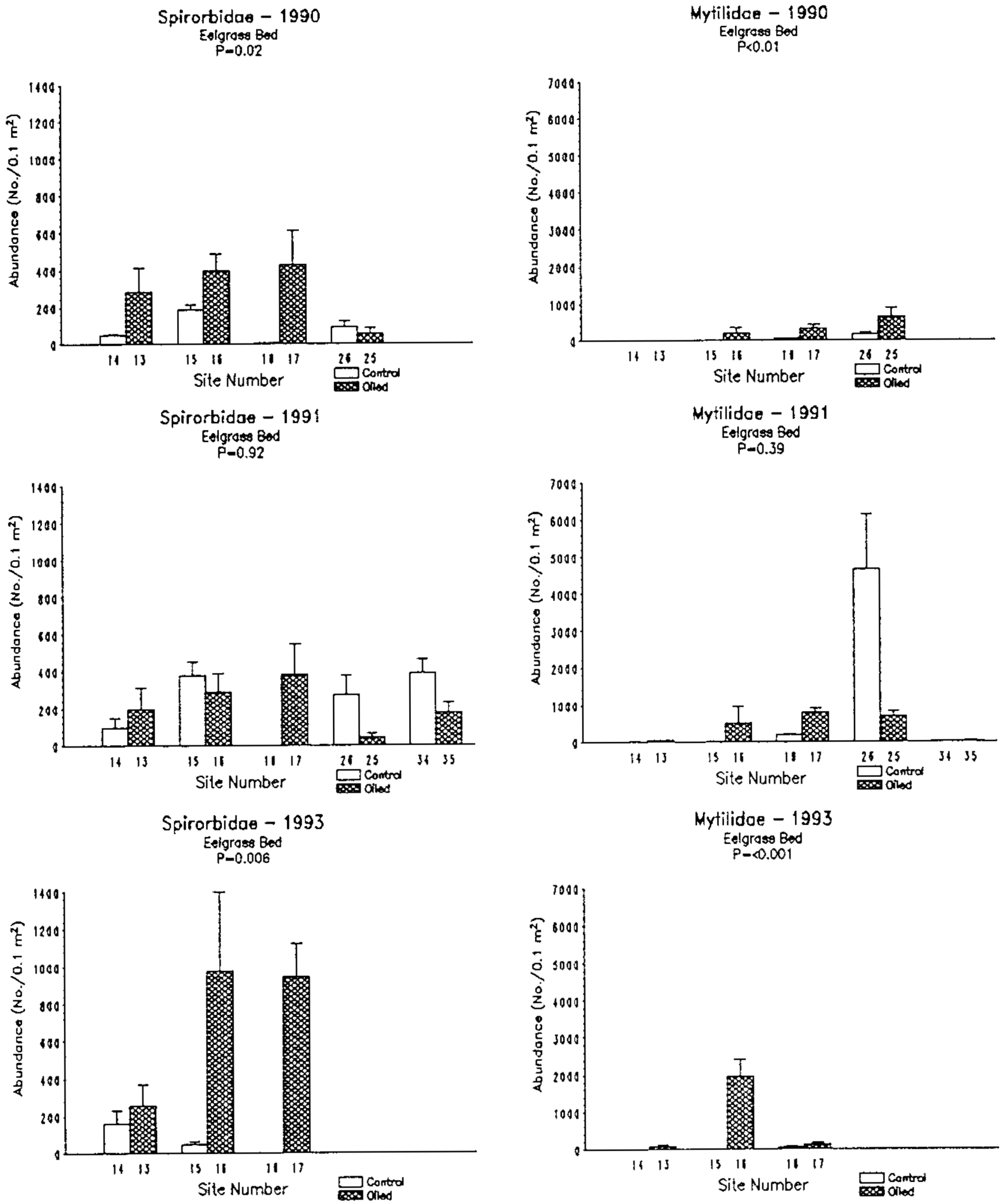
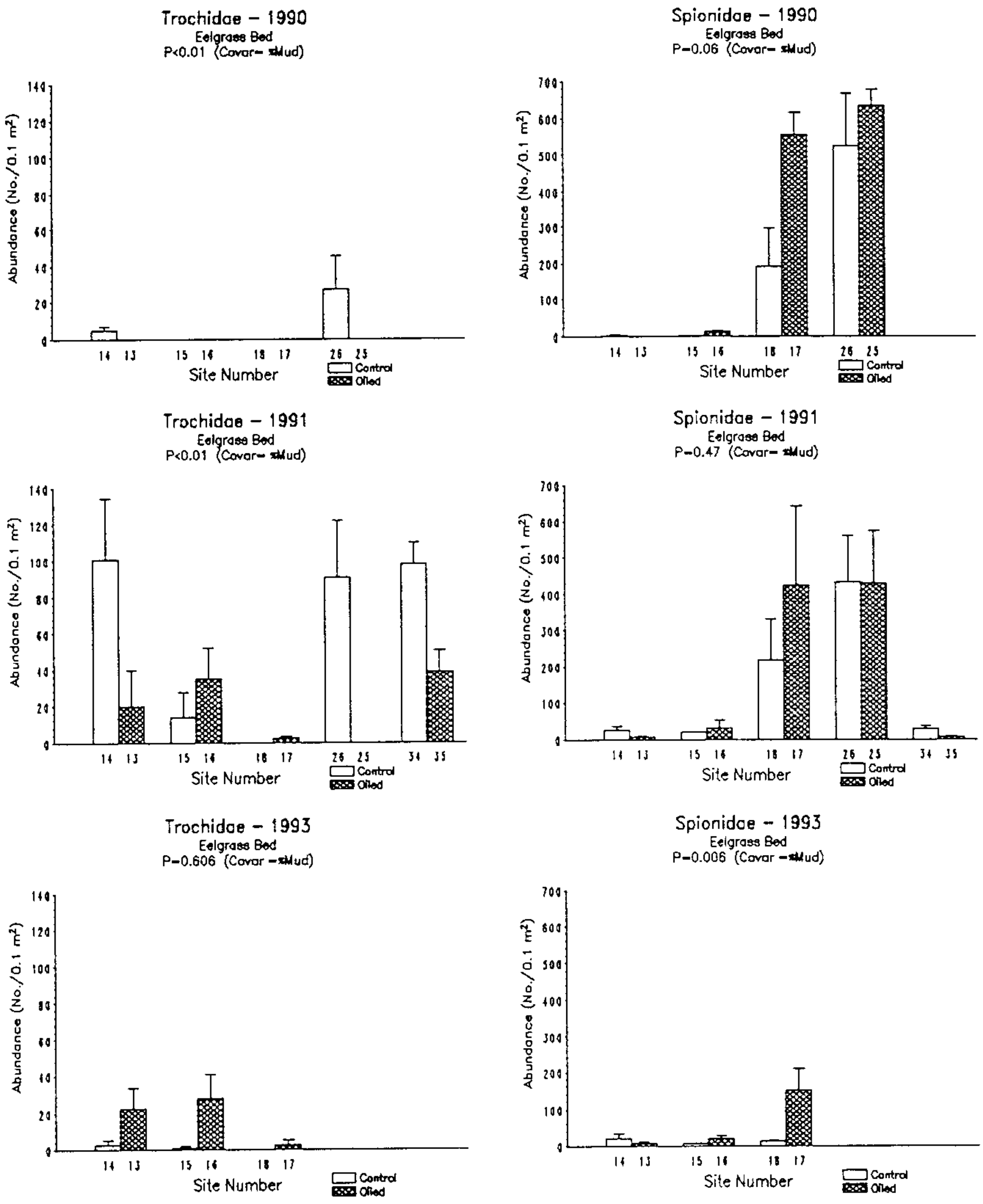


Figure 12. Abundance and/or biomass of dominant taxa in dredge samples that differed significantly at oiled and control sites in the eelgrass bed within the eelgrass habitats in Prince William Sound in 1990, 1991 and 1993.



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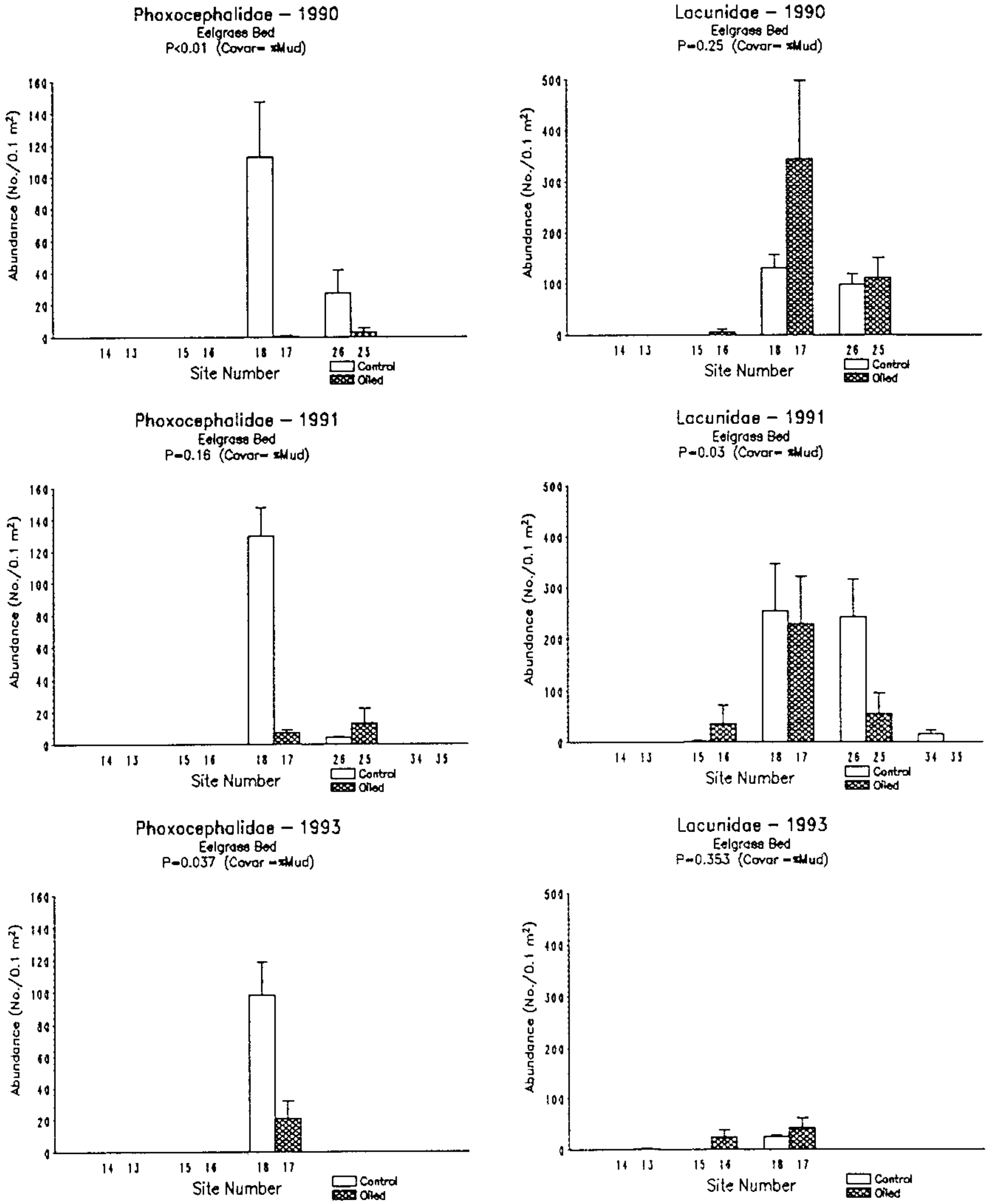

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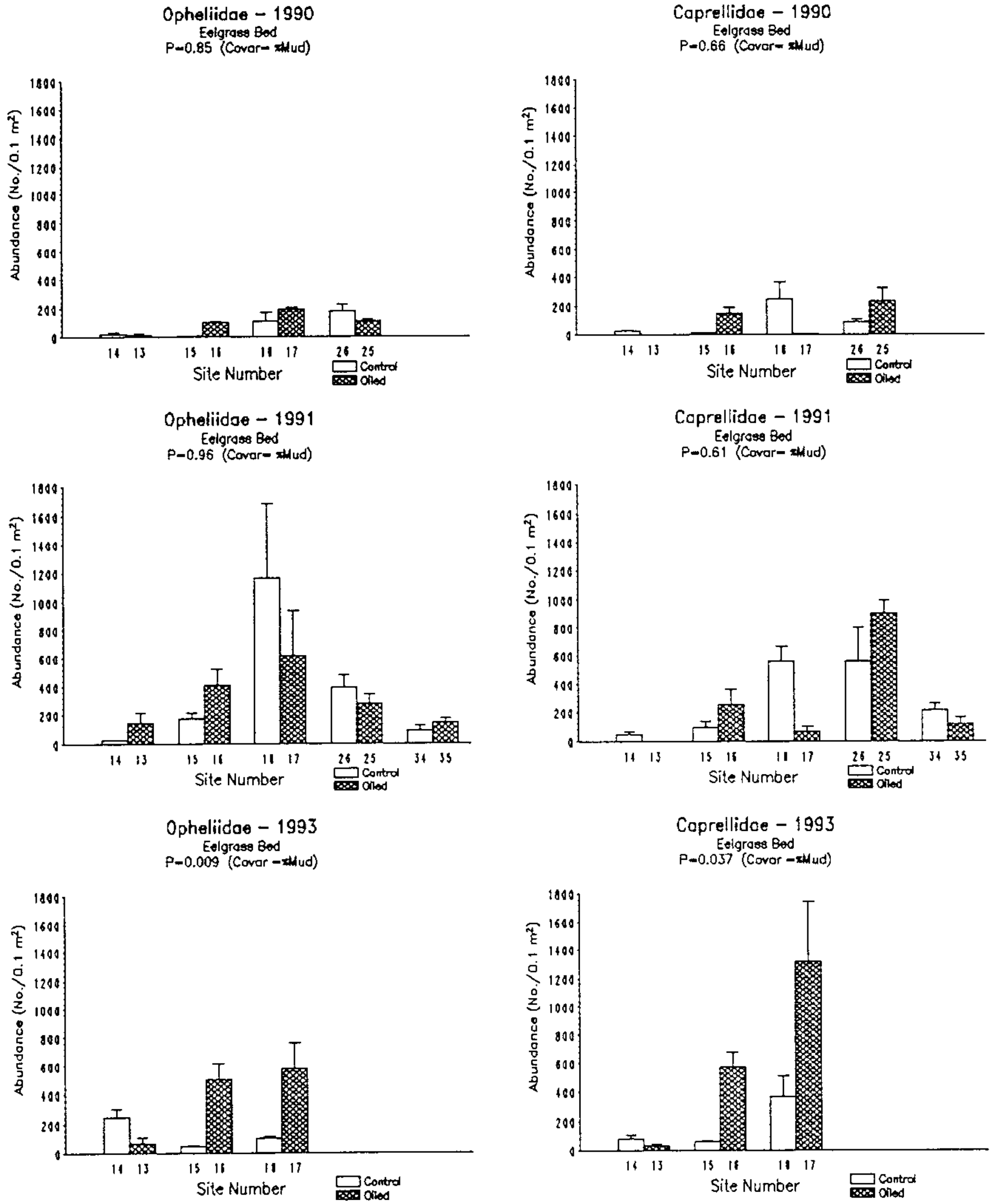

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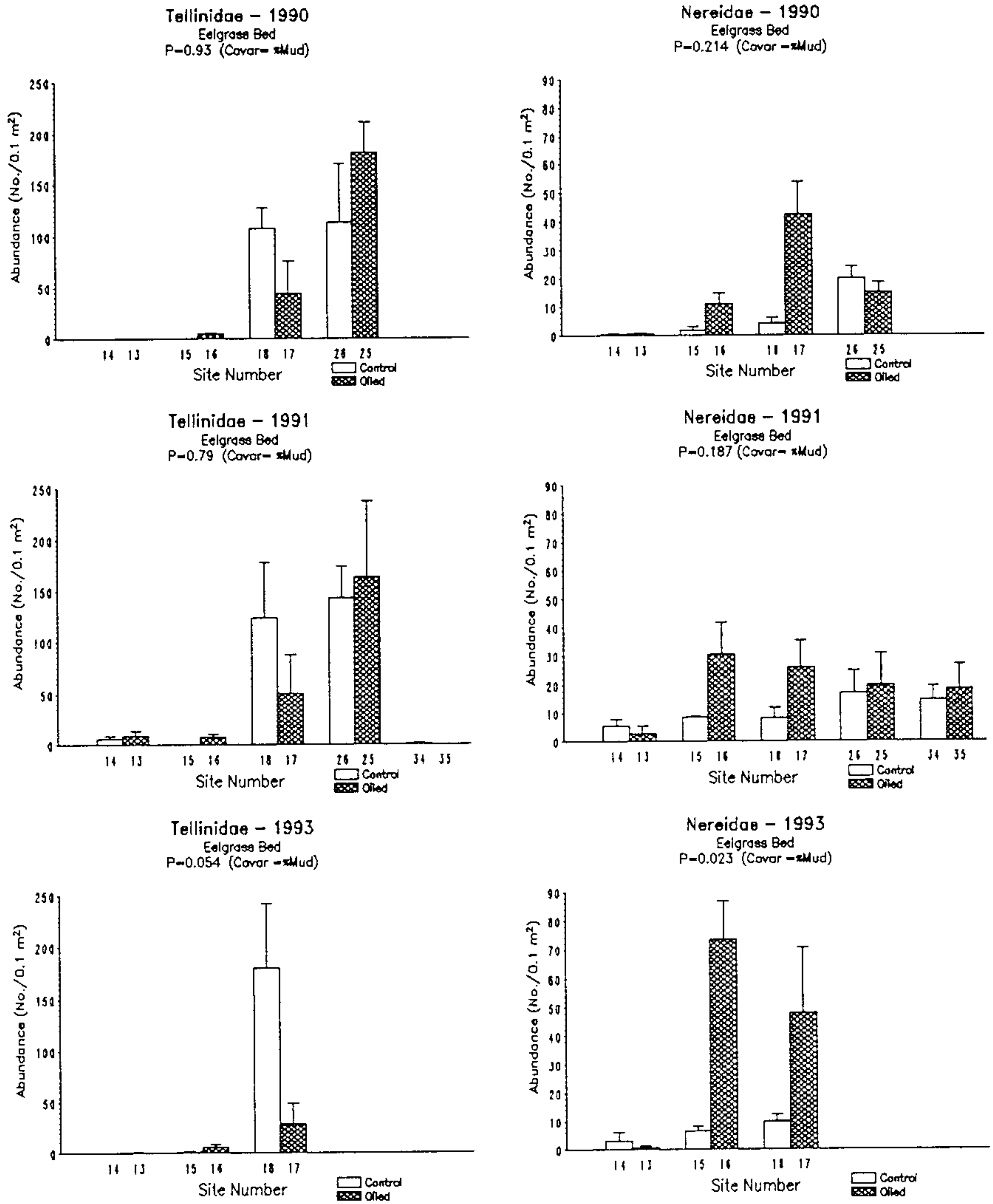

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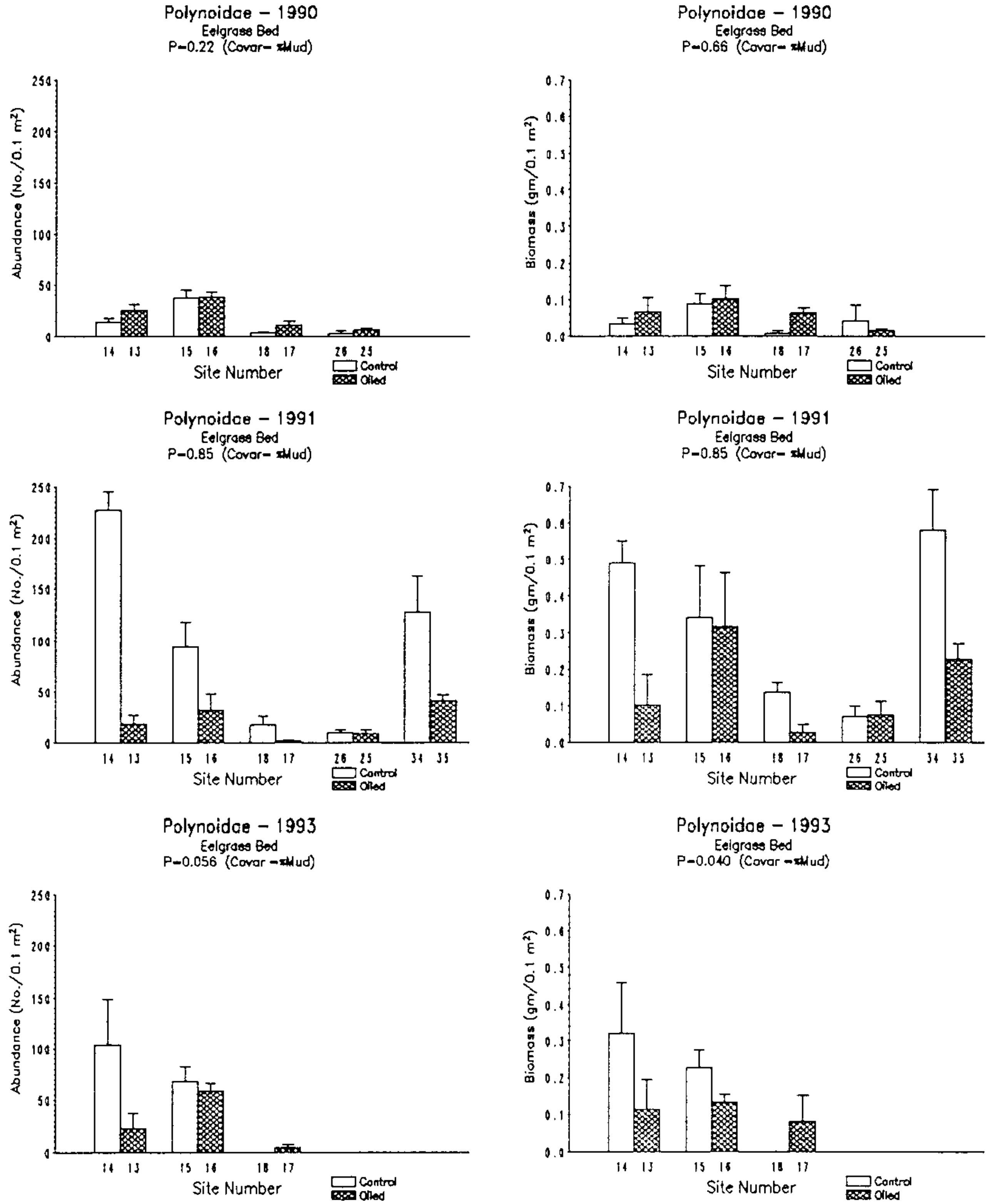

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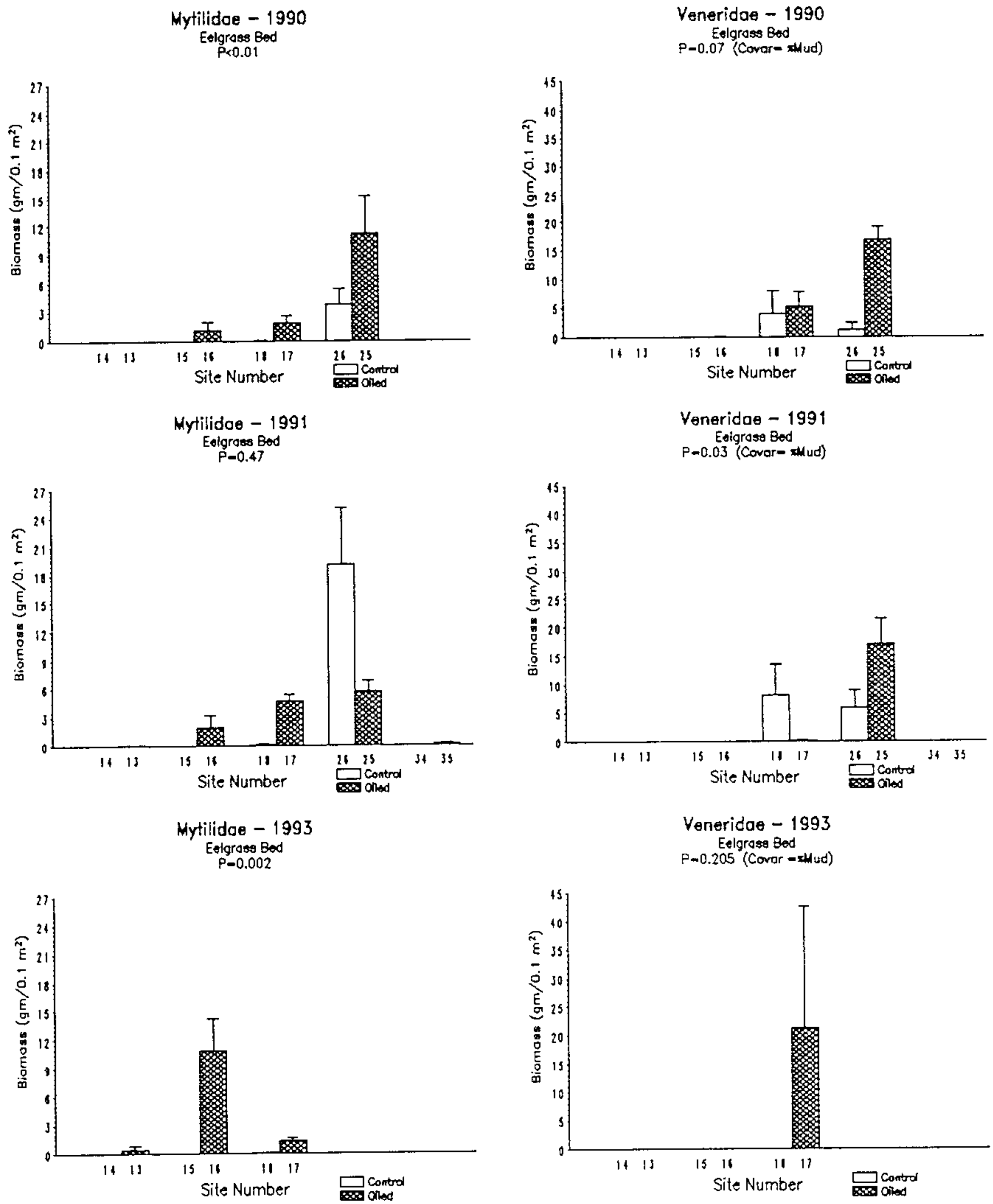

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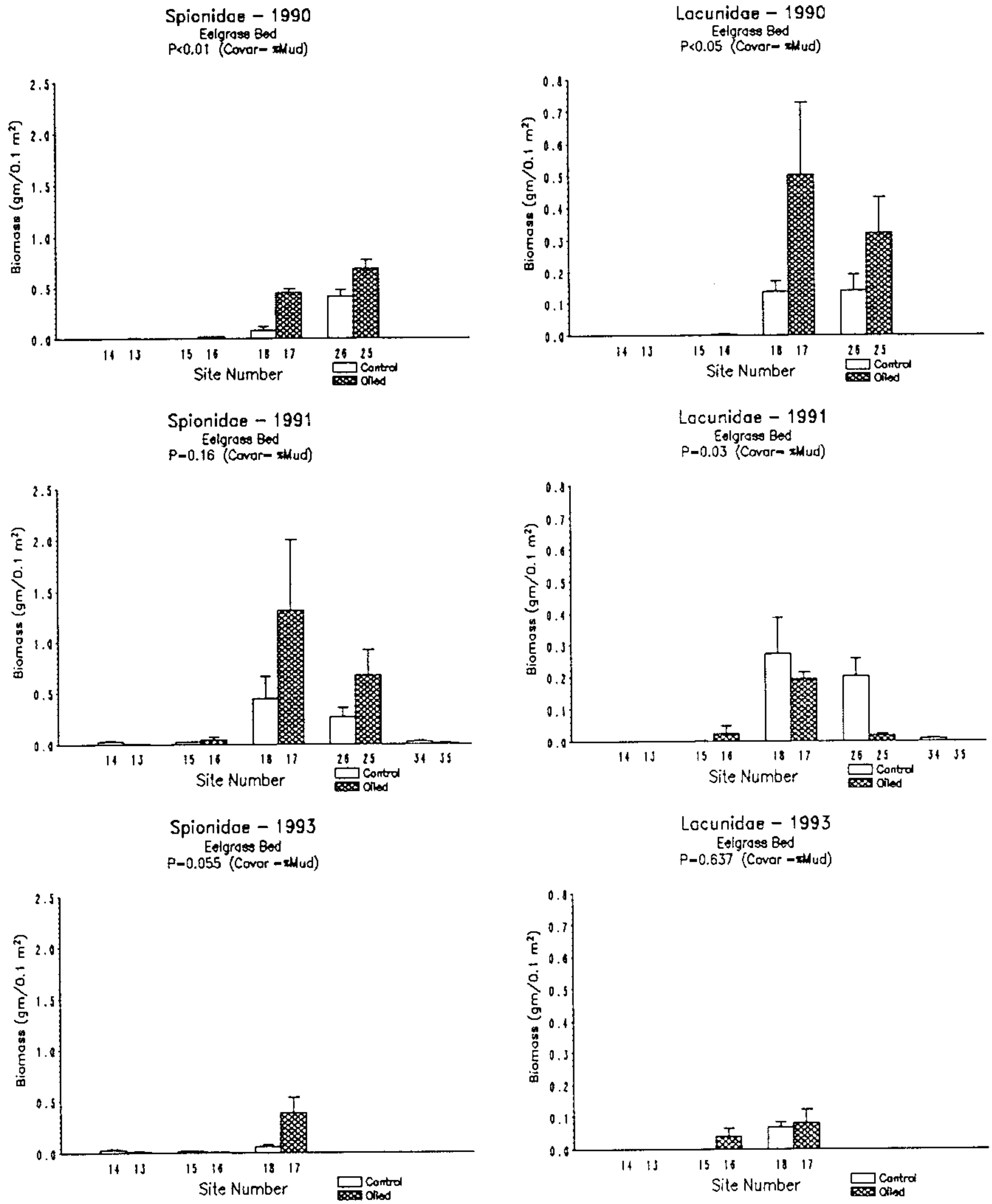

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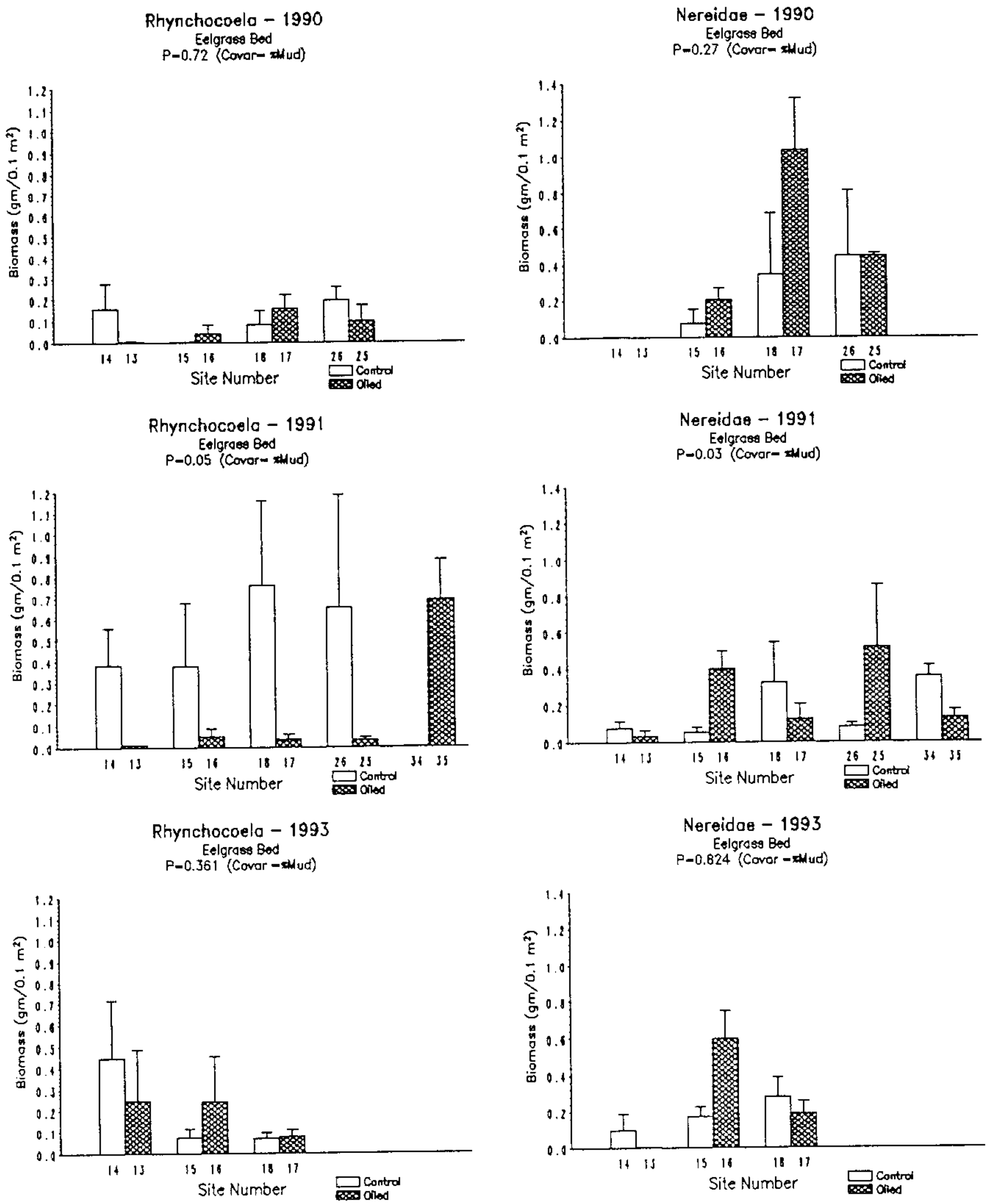

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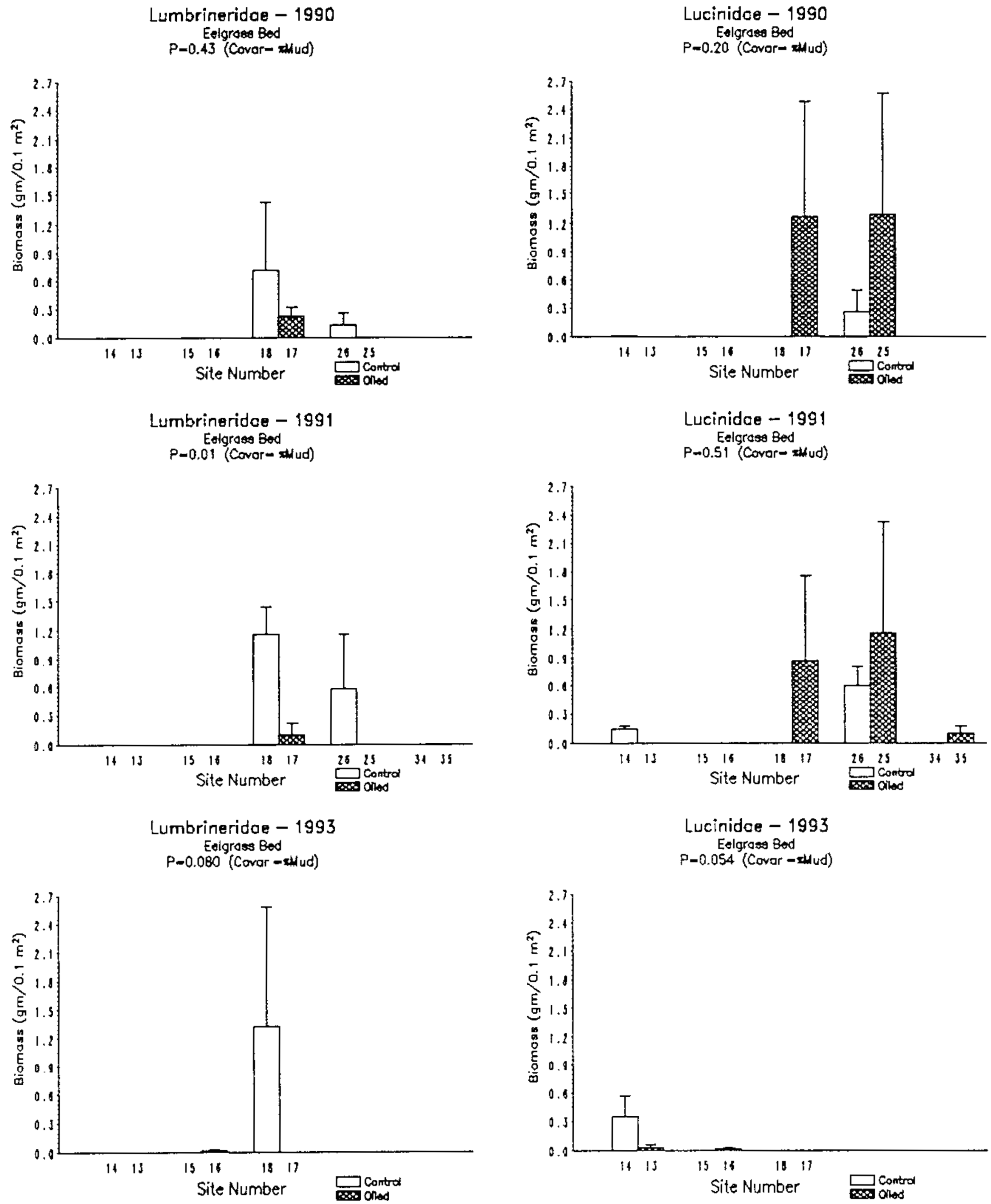

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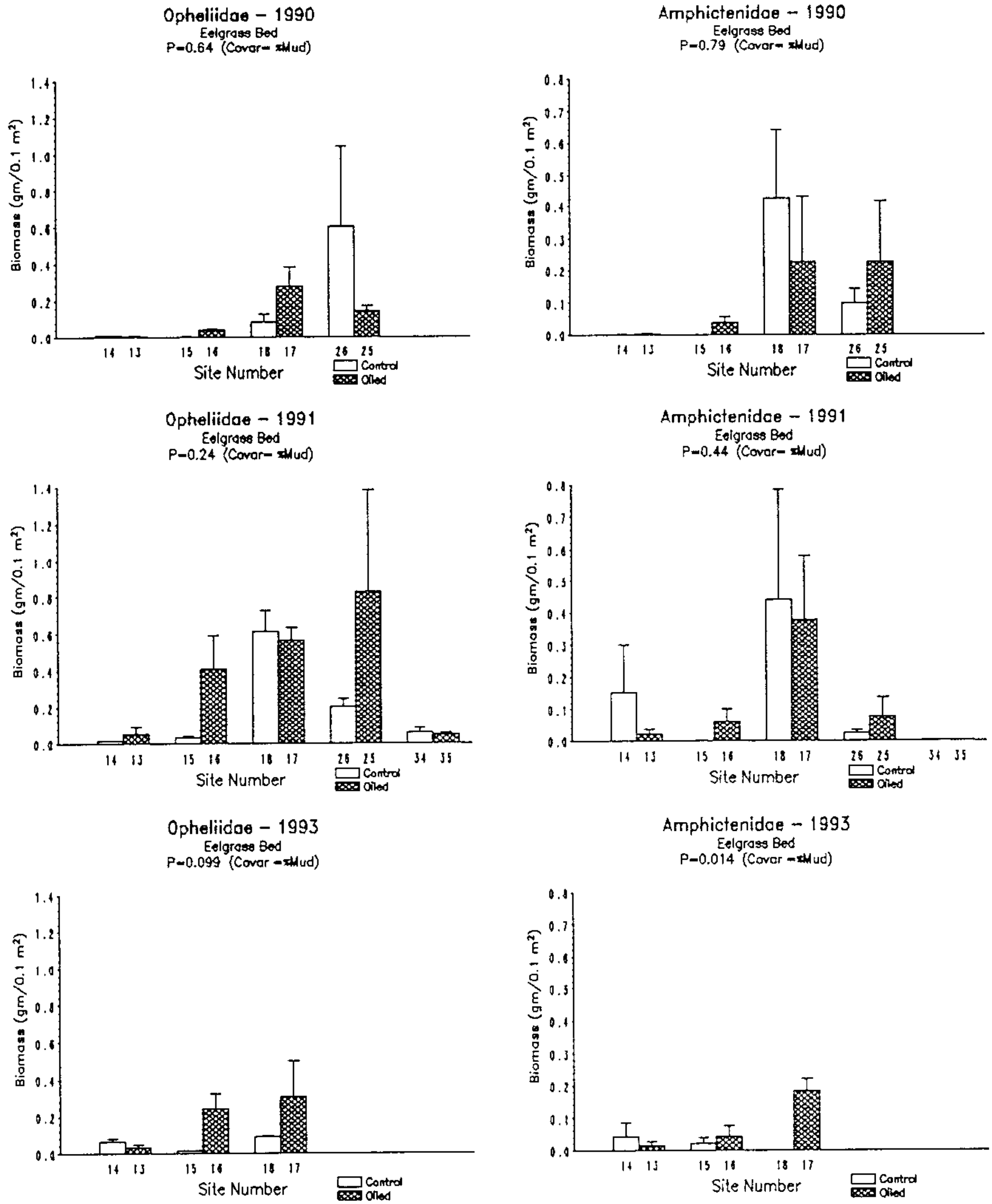

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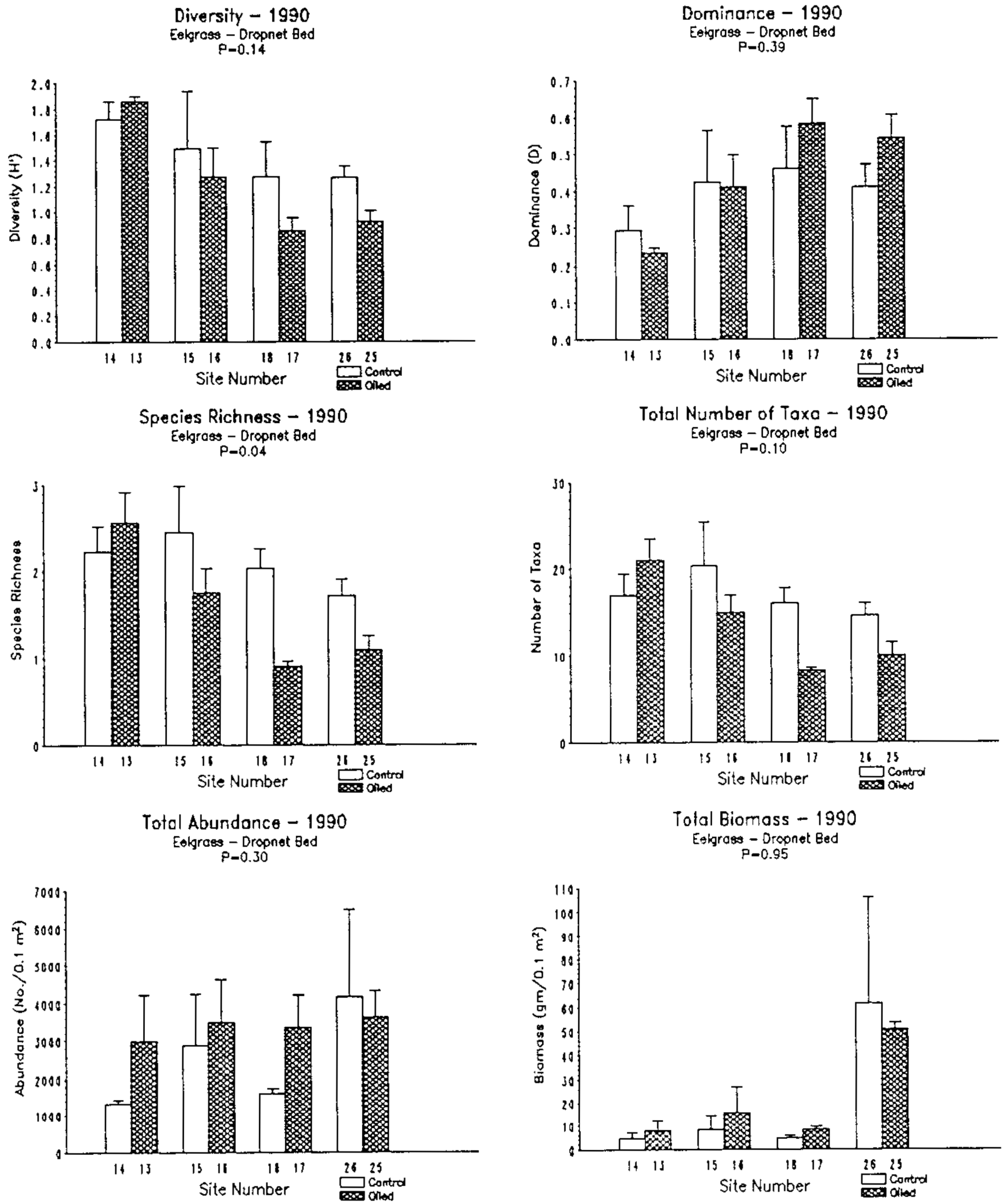


Figure 13. Diversity, dominance, species richness, total number of taxa, total abundance, and total biomass for infaunal invertebrates from dropnet samples in eelgrass beds within the eelgrass habitat in Prince William Sound.

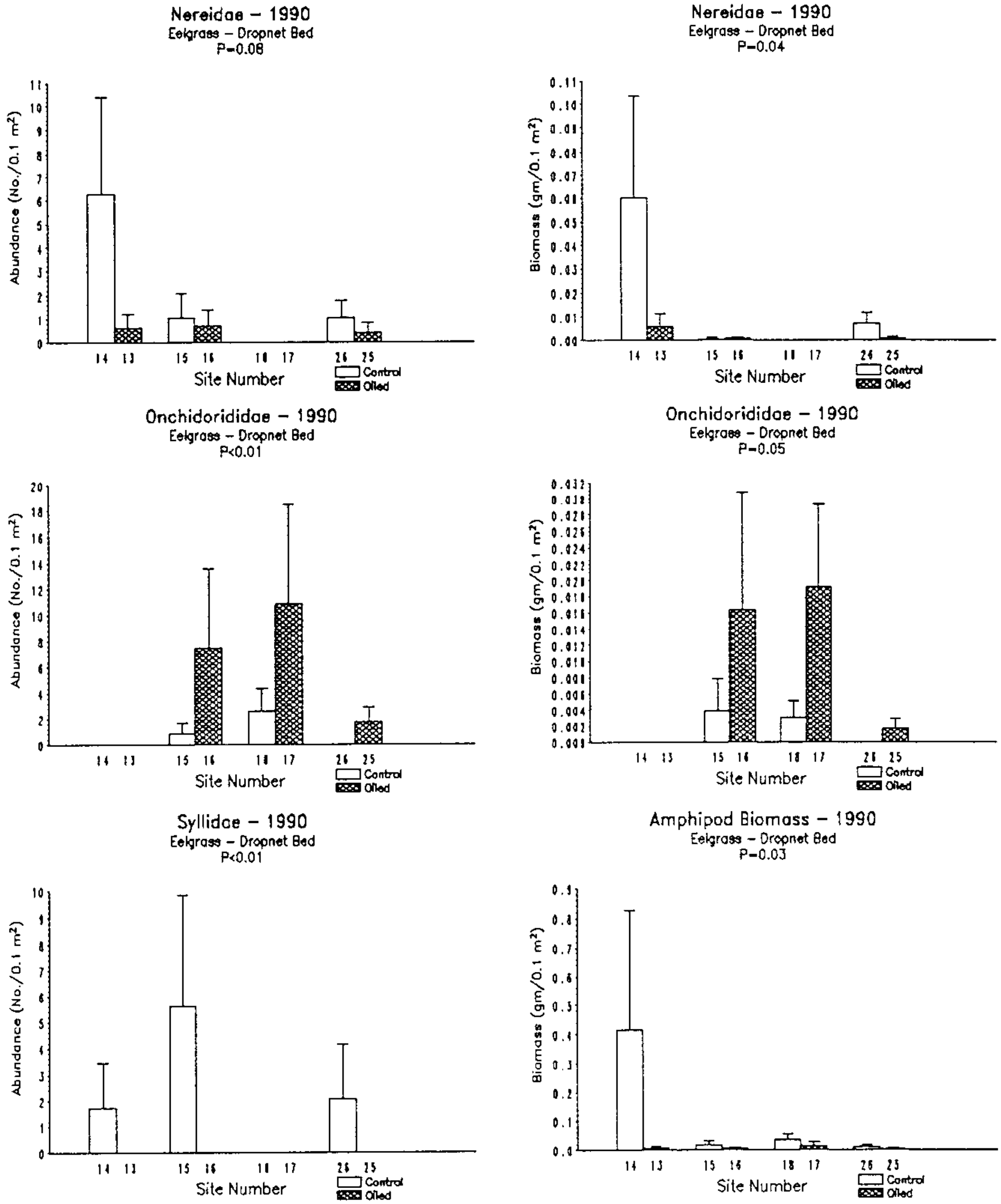


Figure 14. Abundance and biomass of dominant taxa in dropnet samples that differed significantly at oiled and control sites in the eelgrass bed within the eelgrass habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

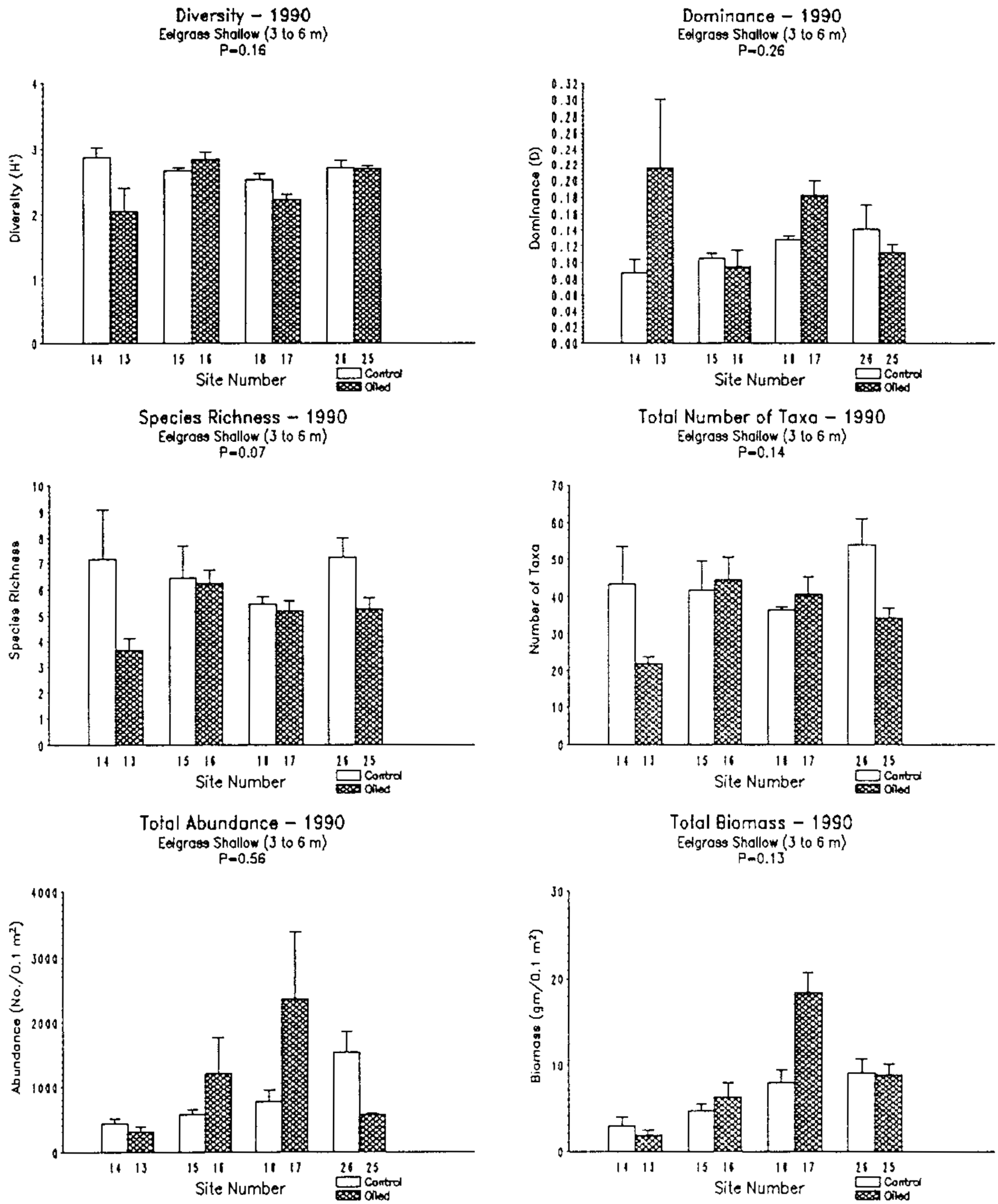


Figure 15. Diversity, dominance, species richness, total abundance, total biomass, and number of taxa for infaunal invertebrates from dredge samples in shallow stratum within eelgrass habitats in Prince William Sound in 1990.

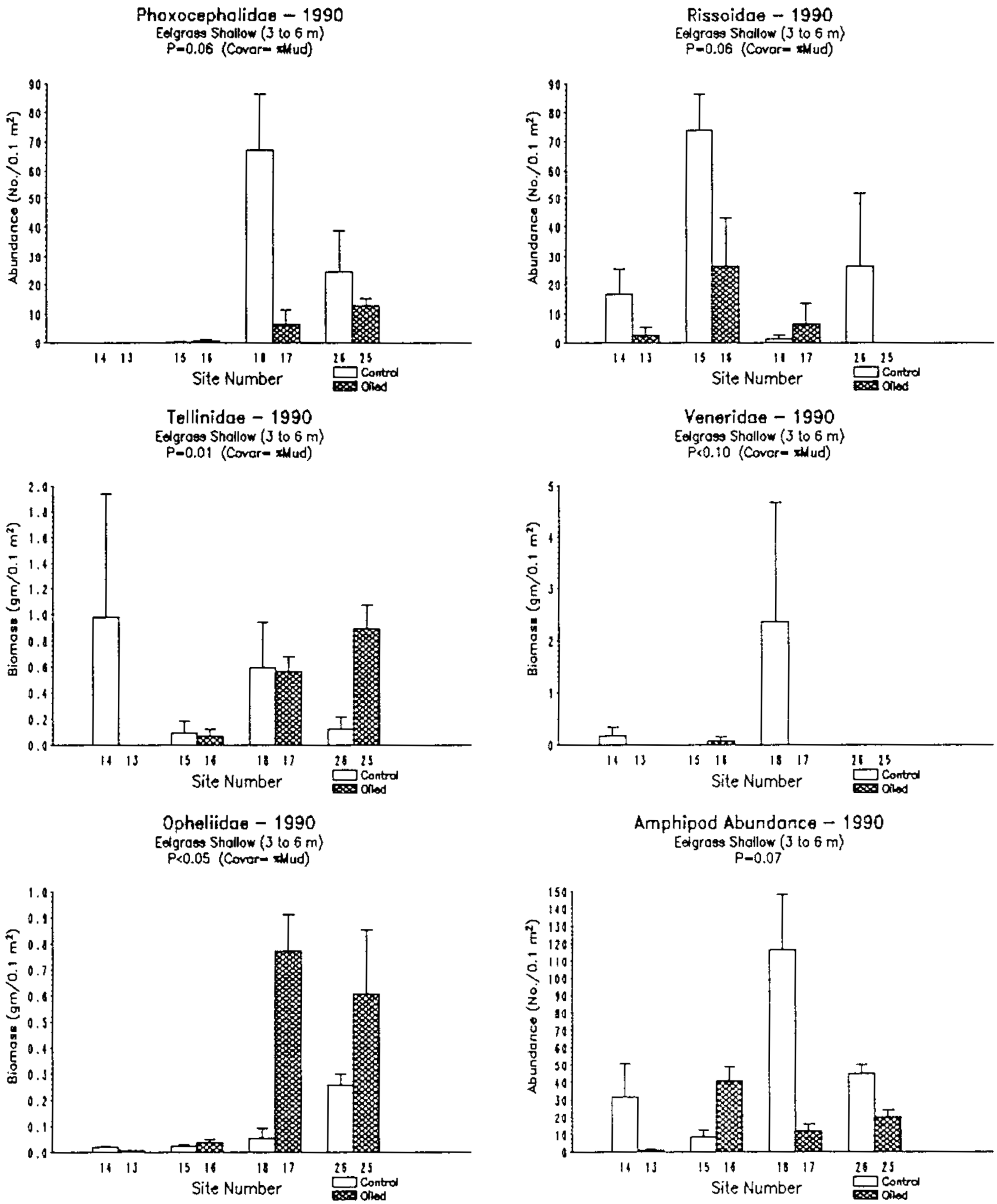


Figure 16. Abundance and biomass of dominant taxa in dredge samples that differed significantly at oiled and control sites in shallow stratum within the eelgrass habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

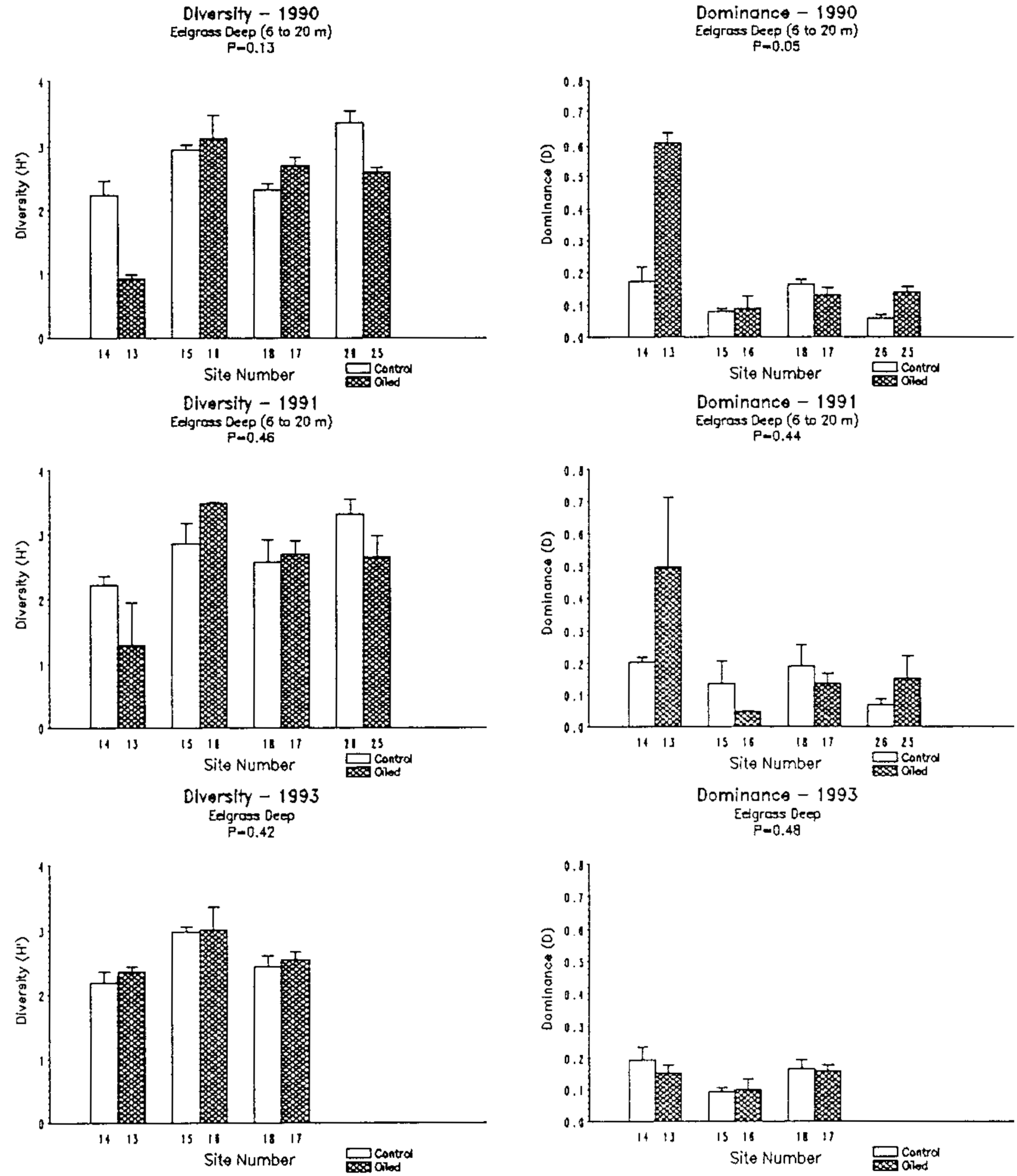


Figure 17. Diversity, dominance, species richness, total abundance, total biomass, and number of taxa for infaunal invertebrates from dredge samples in deep stratum within eelgrass habitats in Prince William Sound in 1990, 1991 and 1993. Error bars are +/- 1 standard error.

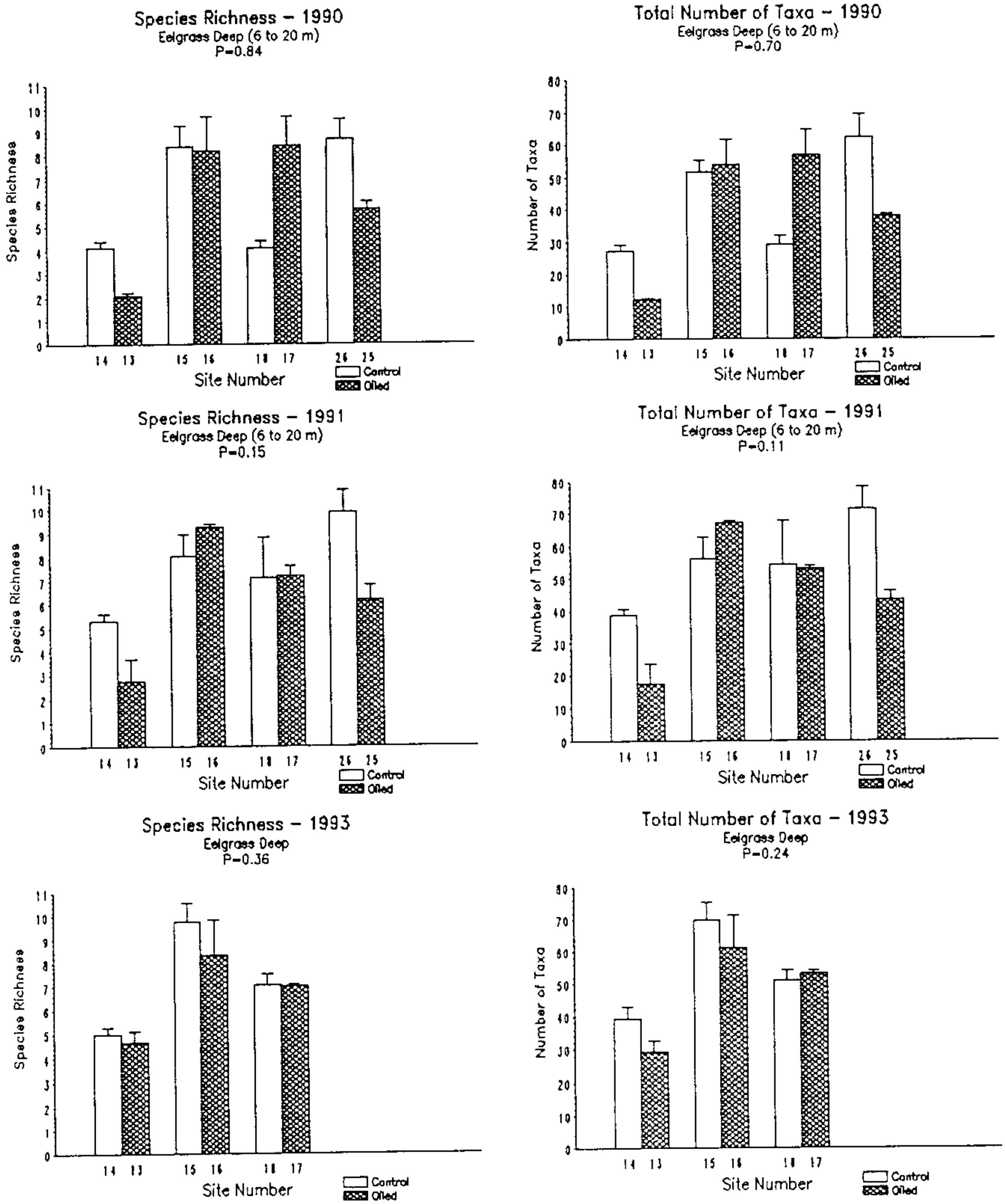
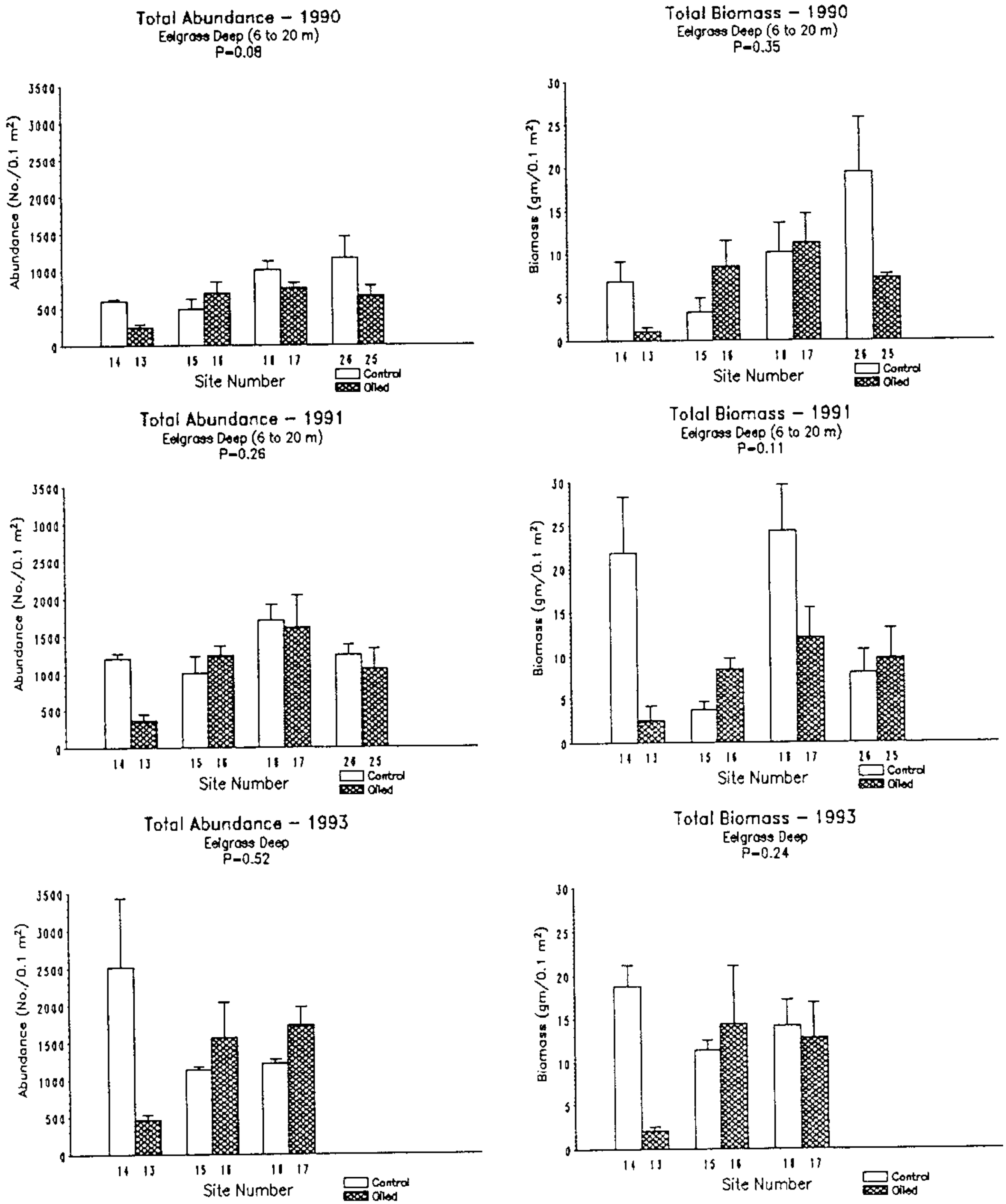


Figure 17. (Continued).



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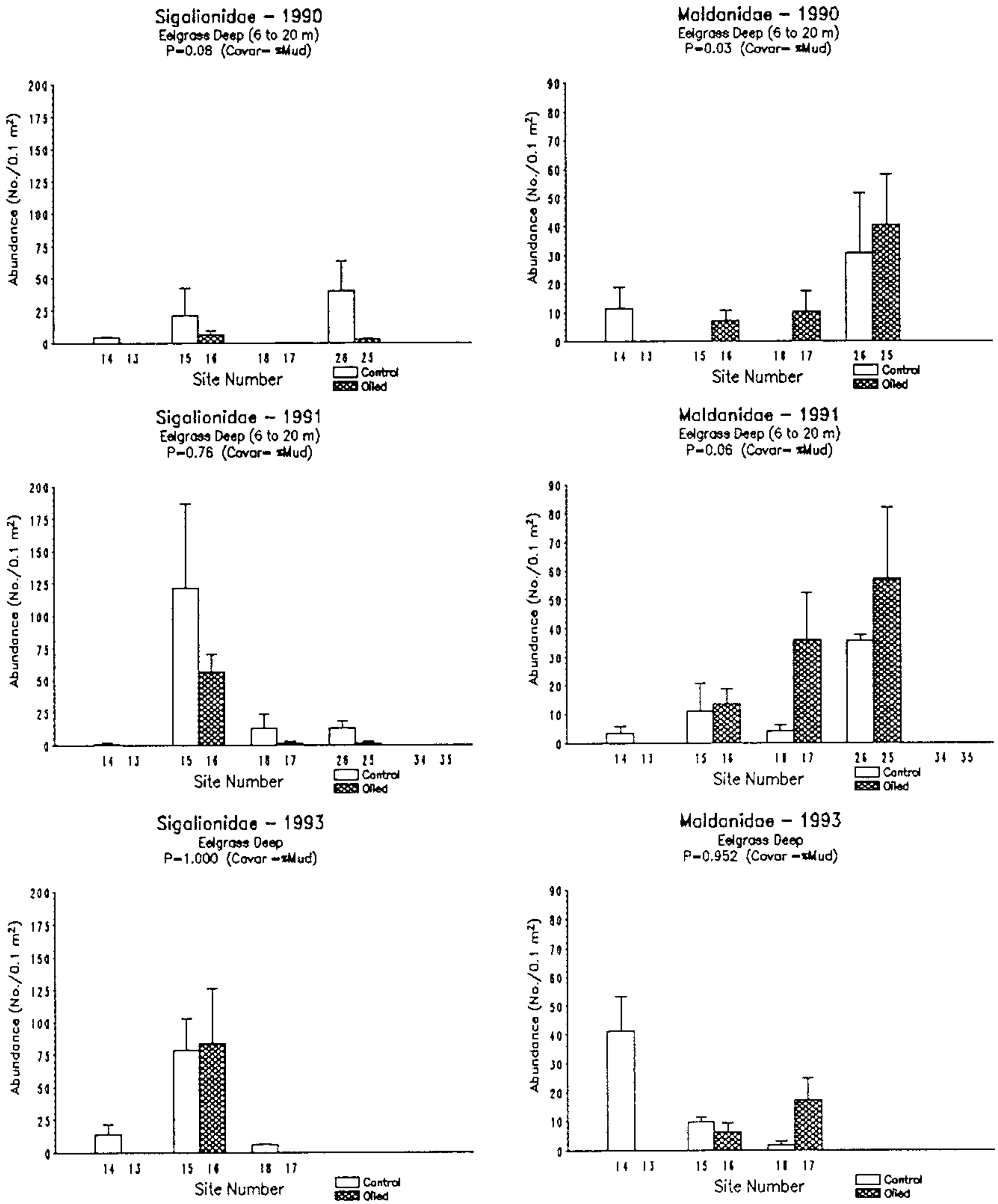
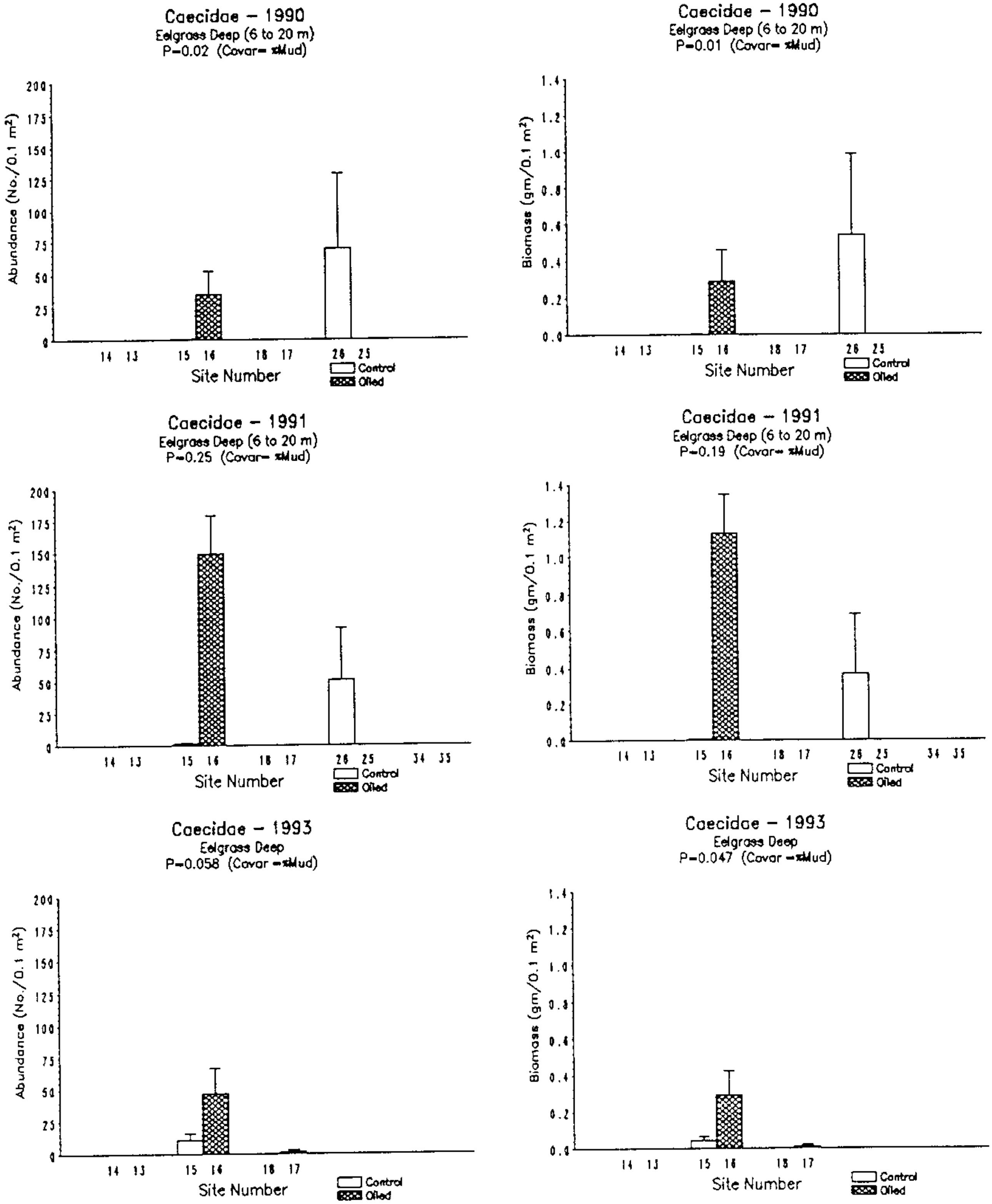


Figure 18. Abundance and/or biomass of dominant taxa in dredge samples that differed significantly at oiled and control sites in deep stratum within the eelgrass habitats in Prince William Sound in 1990, 1991 and 1993. Error bars are +/- 1 standard error.



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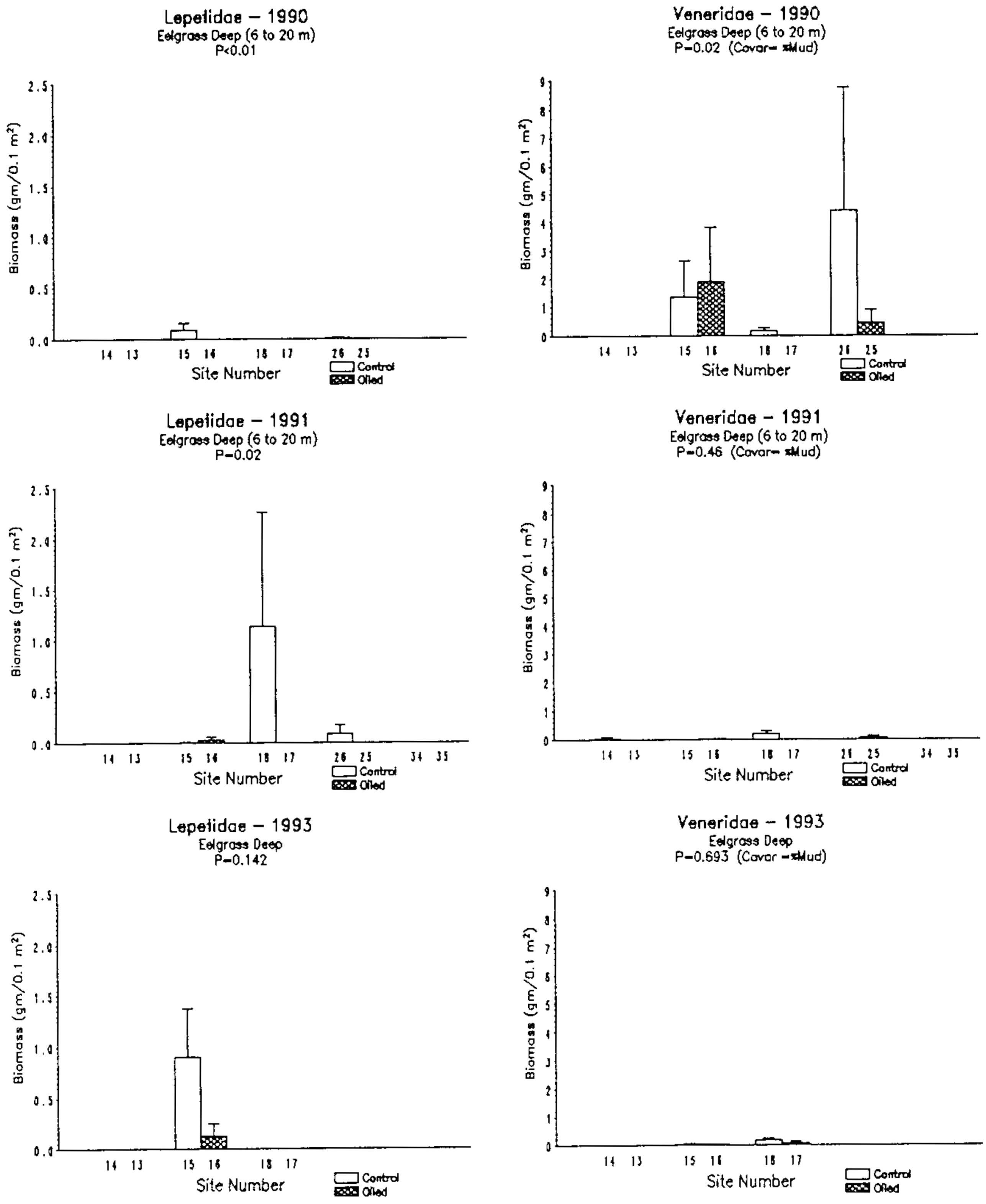

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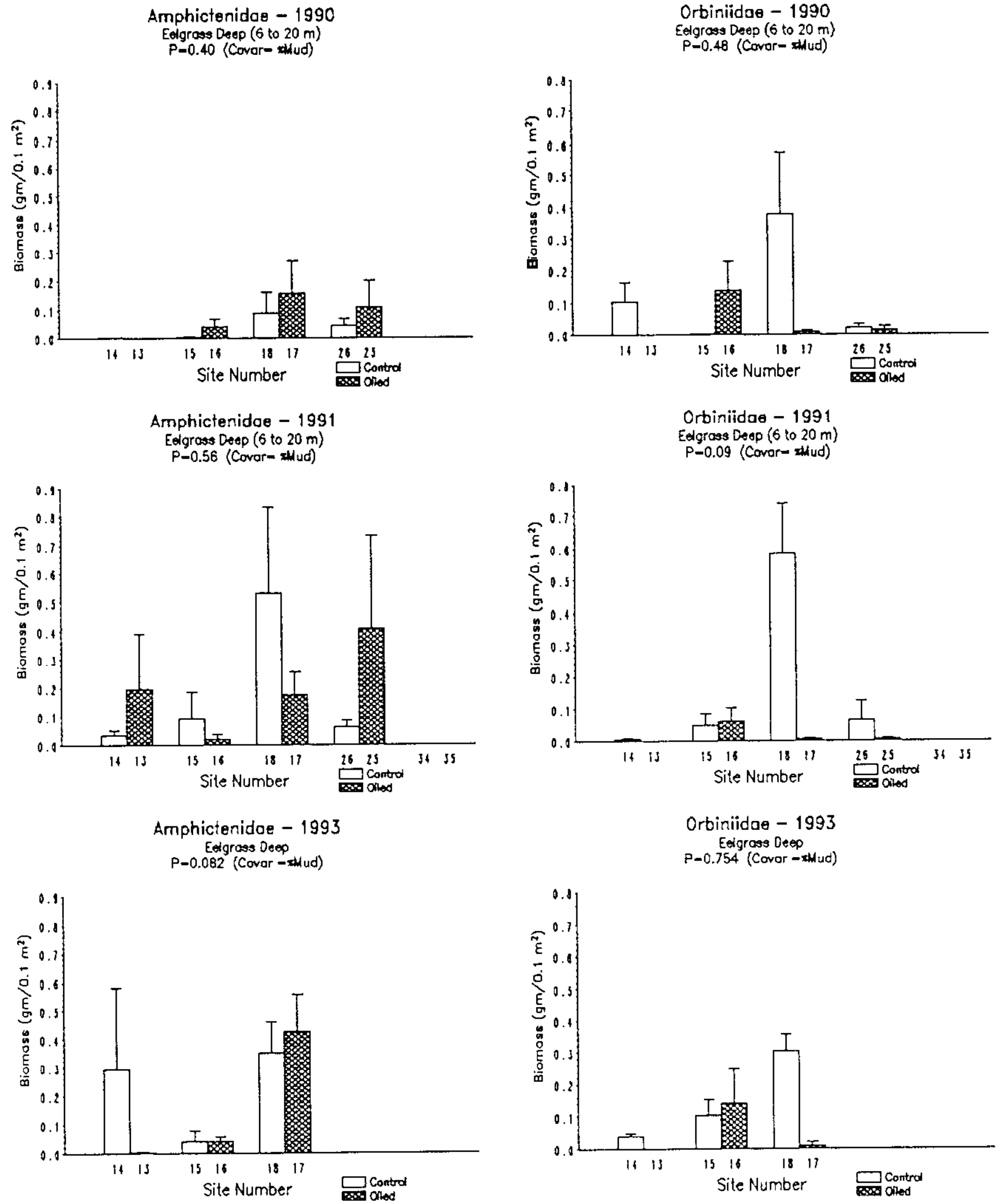

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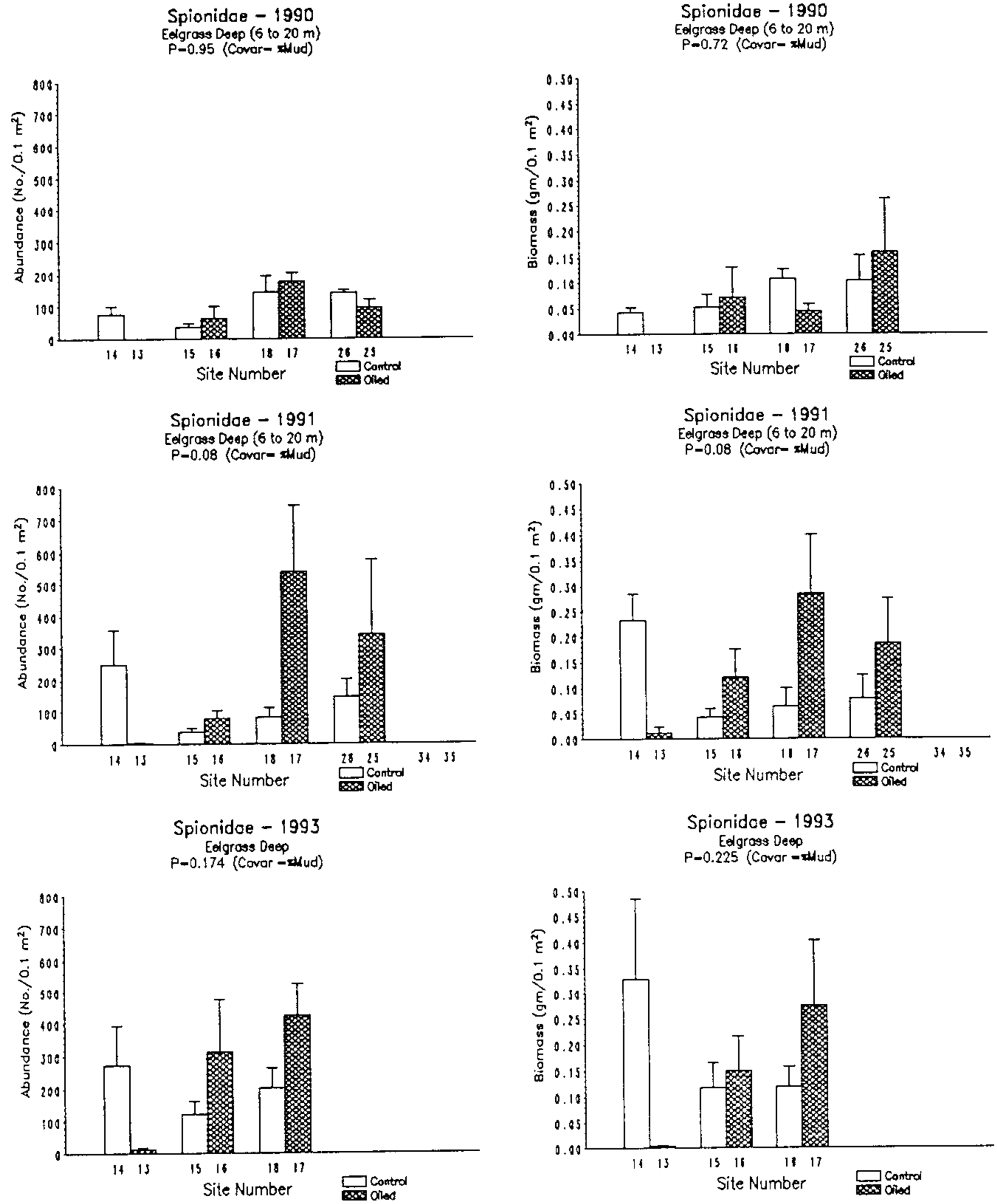

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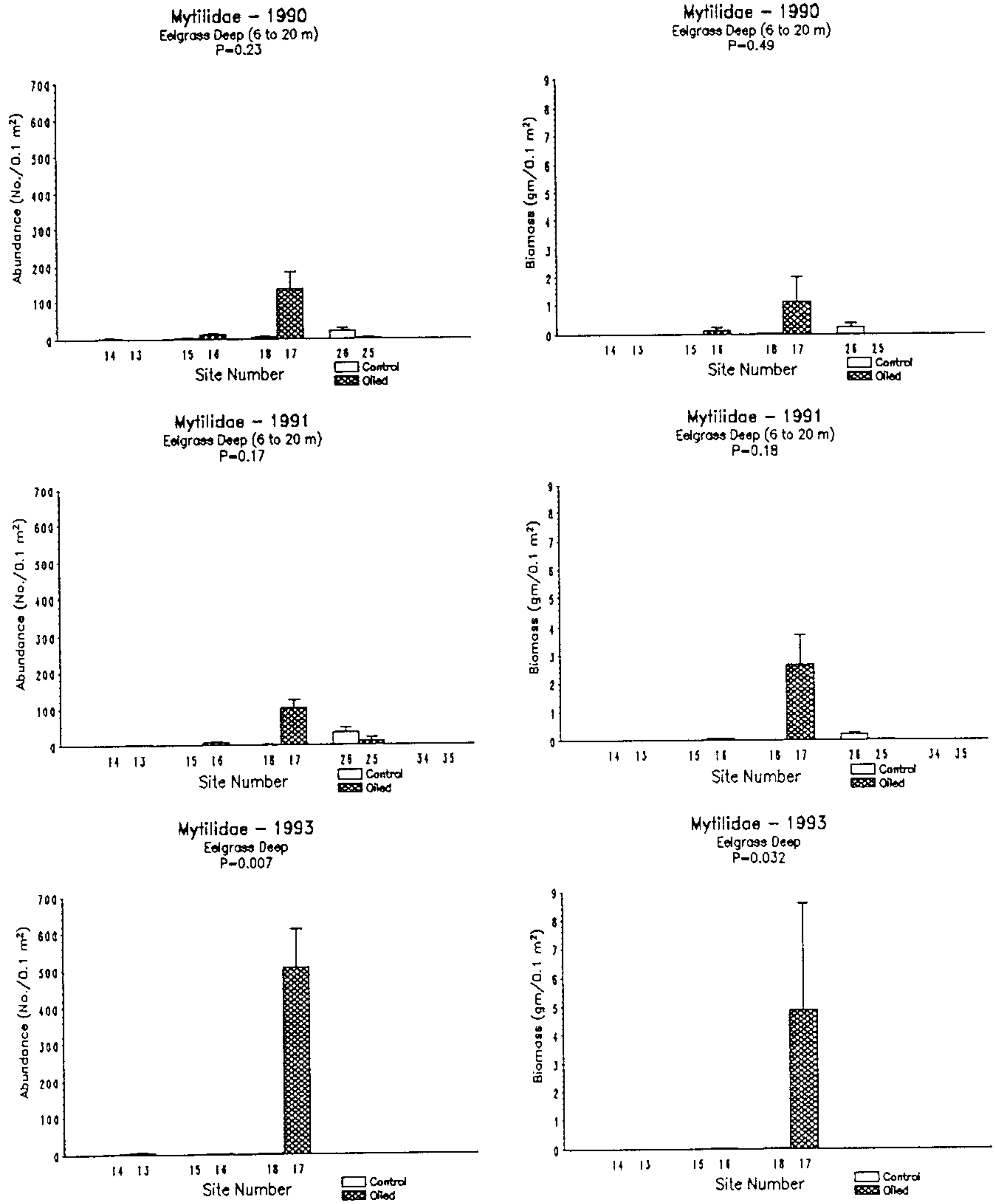

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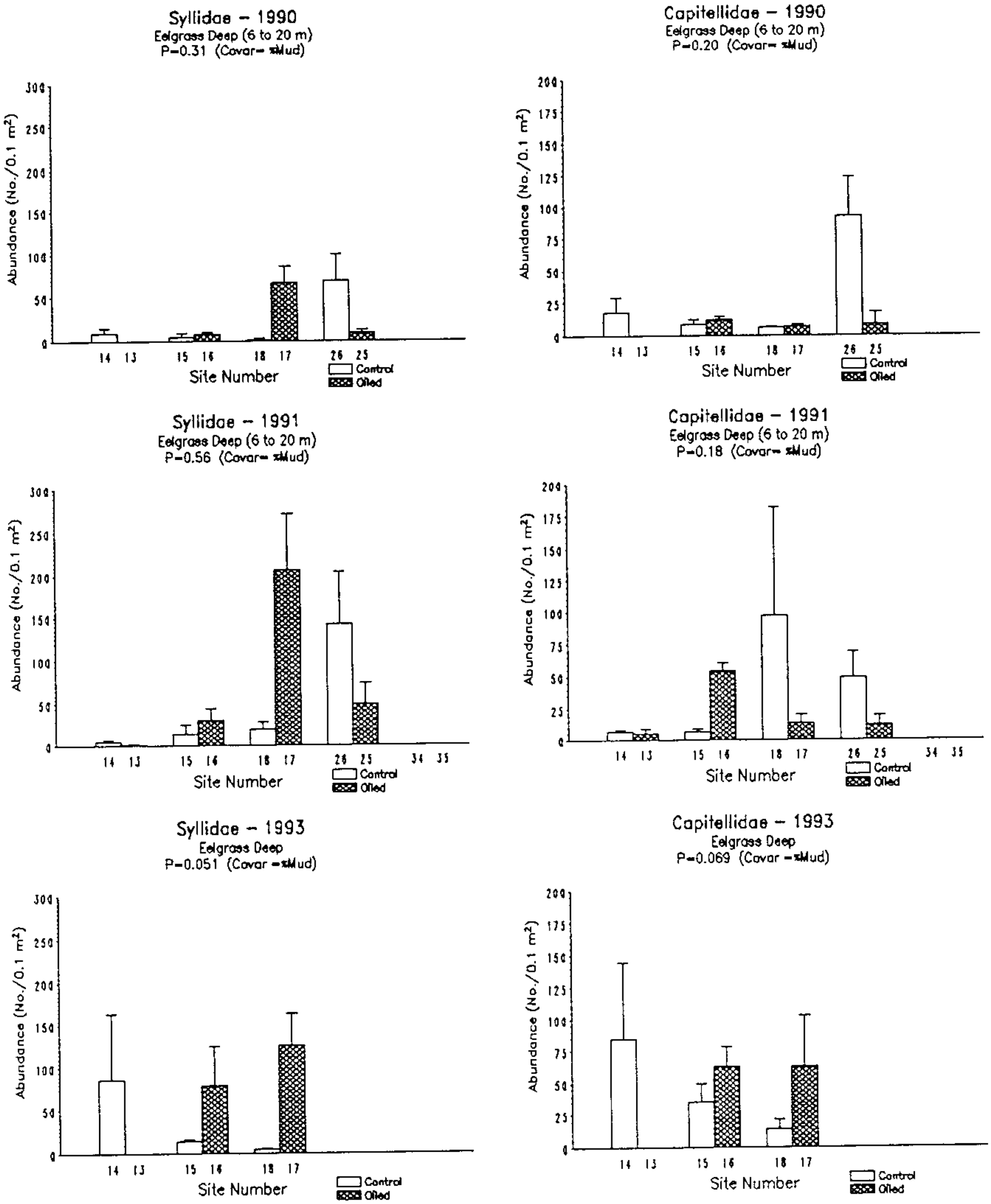

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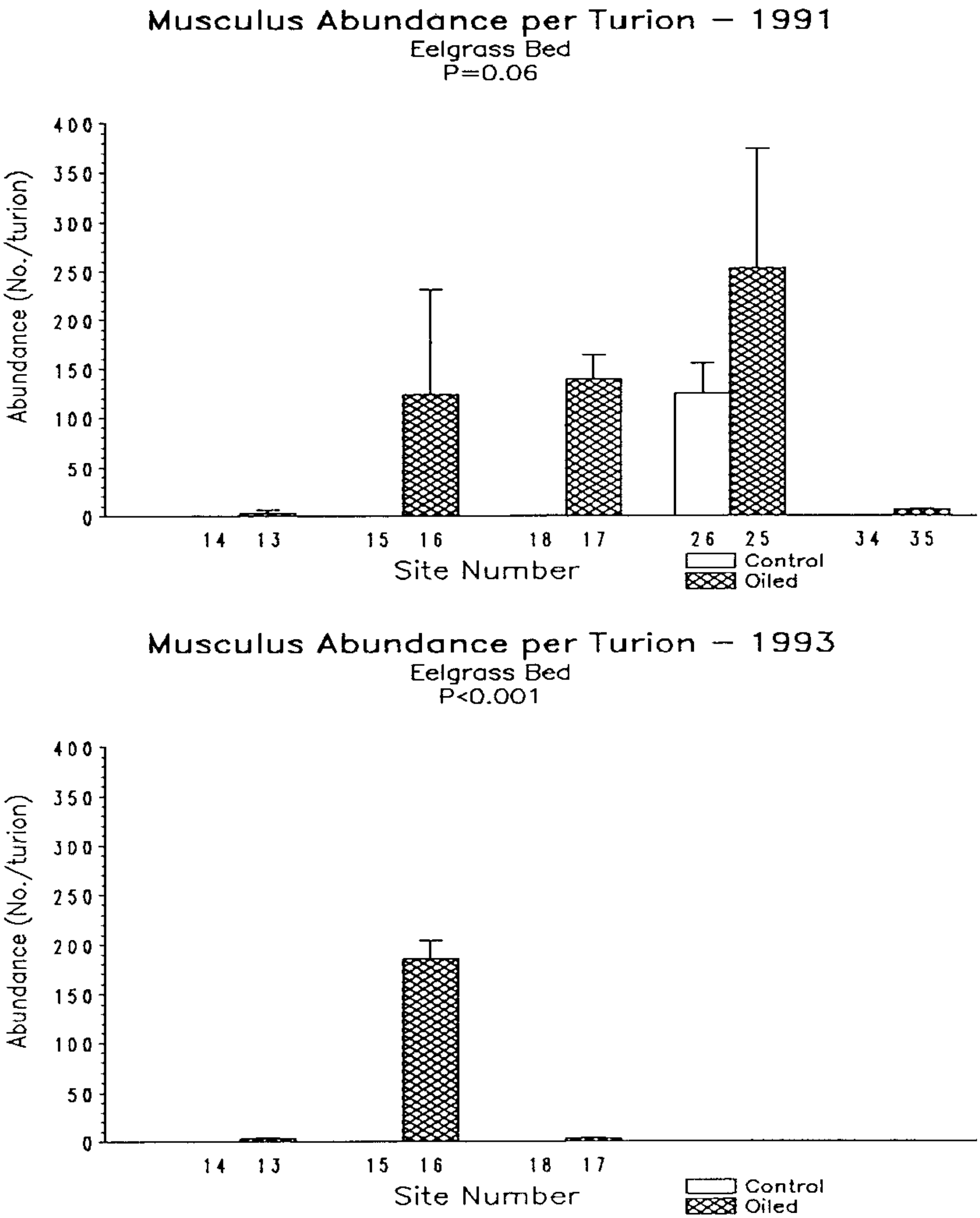


Figure 19. Abundance of *Musculus* spp. per eelgrass turion at oiled and control sites in eelgrass habitats in Prince William Sound in 1991 and 1993. Error bars are +/- 1 standard error.

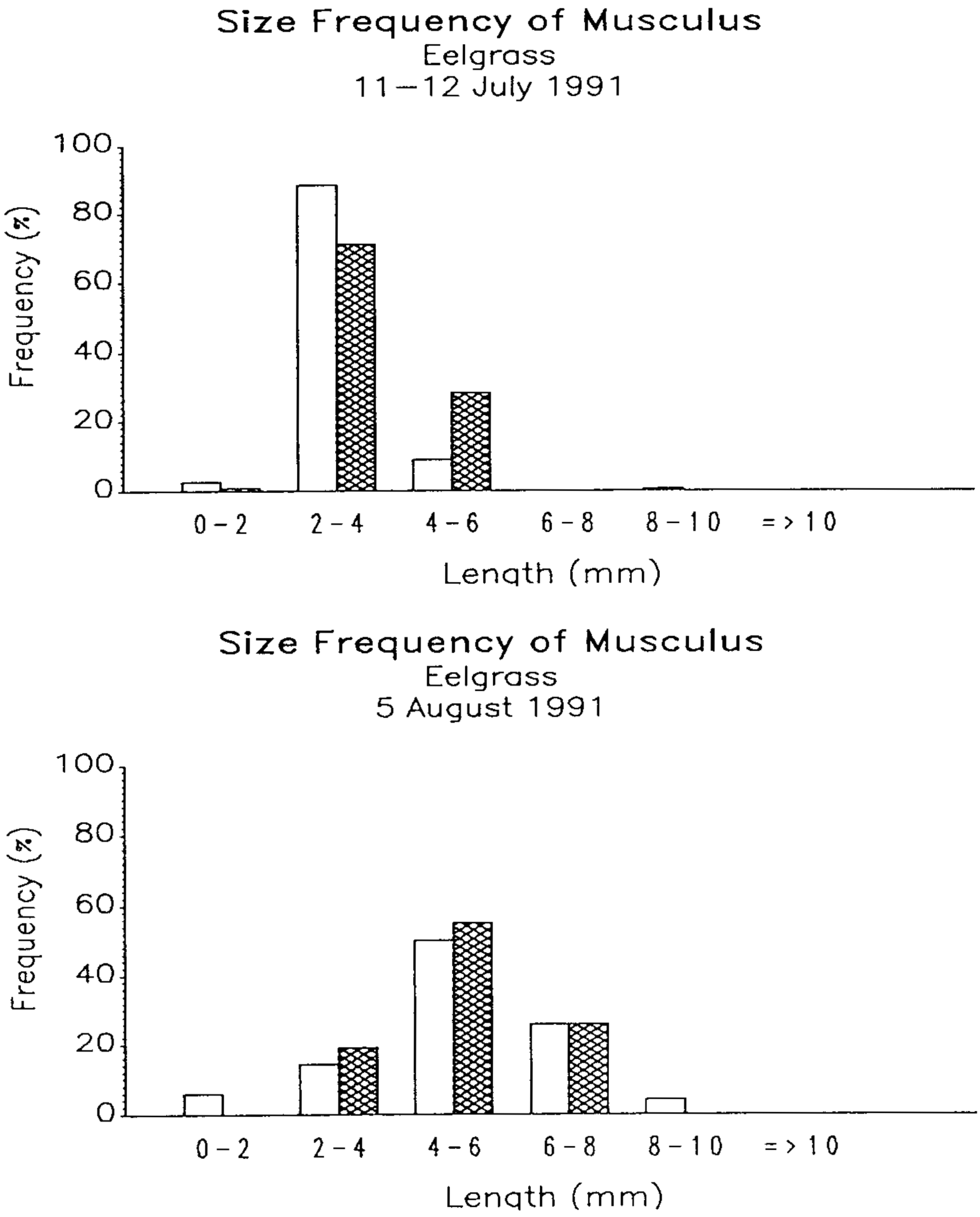


Figure 20. Size frequency of *Musculus* spp. at oiled and control sites in Eelgrass habitats in Prince William Sound during two visits in 1991. The data are from a single oiled site (Clammy Bay) and a single control site (Puffin Bay).

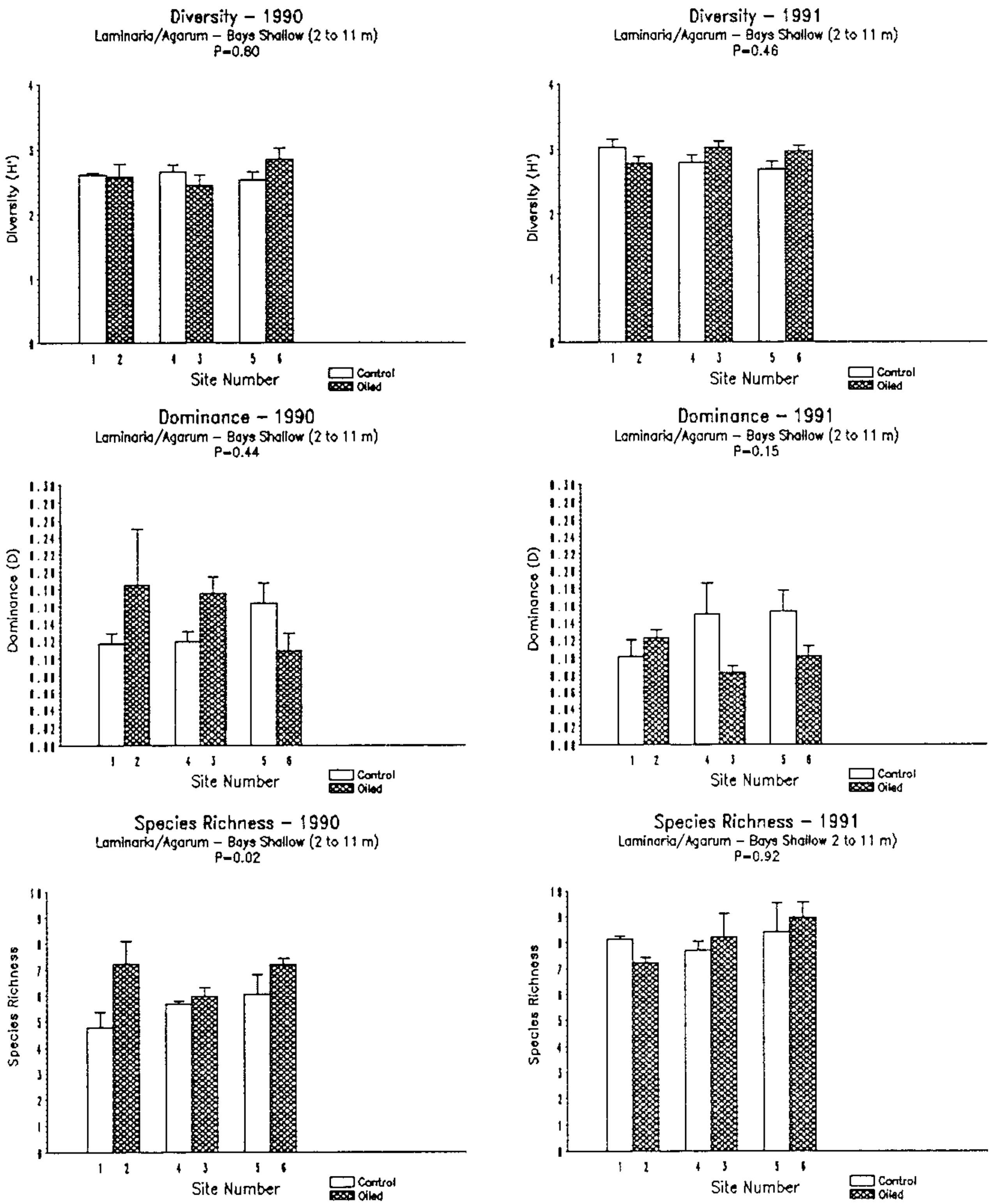
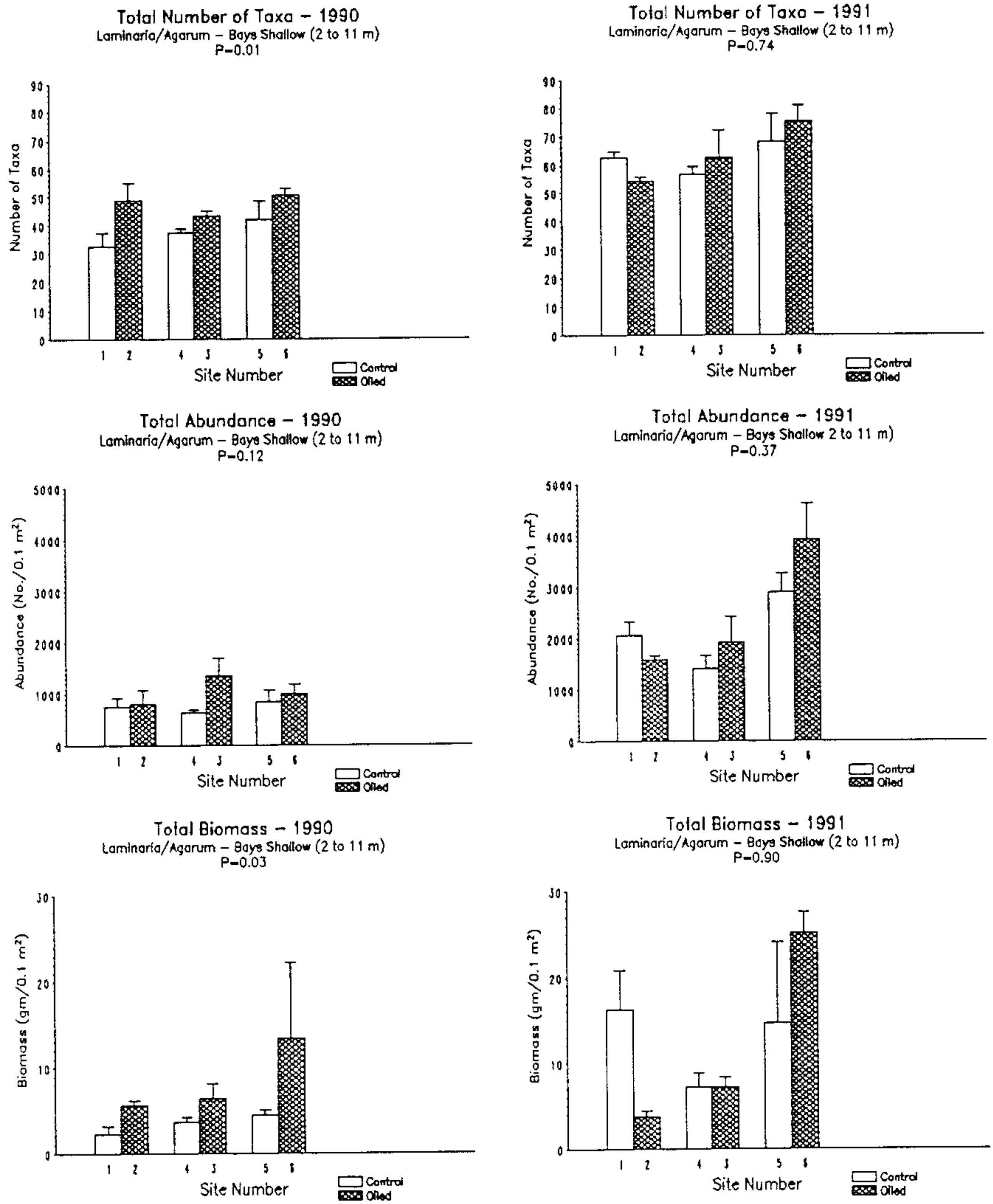


Figure 21. Diversity, dominance, species richness, total taxa, total abundance, and total biomass for infaunal invertebrates from dredge samples in shallow stratum within *Laminaria/Agarum* Bay habitats in Prince William Sound in 1990 and 1991.



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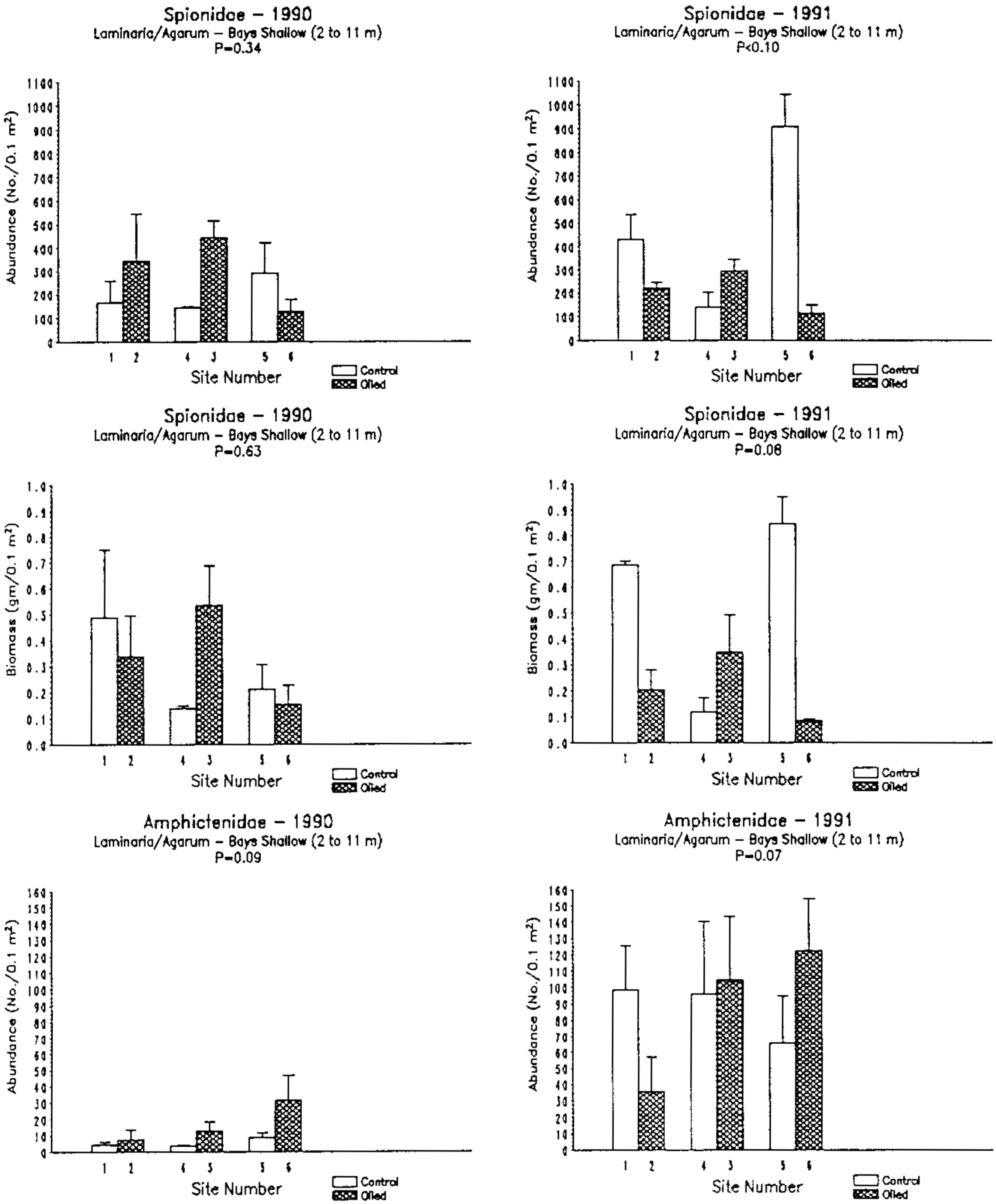


Figure 22. Abundance and biomass of dominant taxa in dredge samples that differed significantly at oiled and control sites in shallow stratum *Laminaria/Agarum* Bay habitats in Prince William Sound in 1990 and 1991. Error bars are +/- 1 standard error.

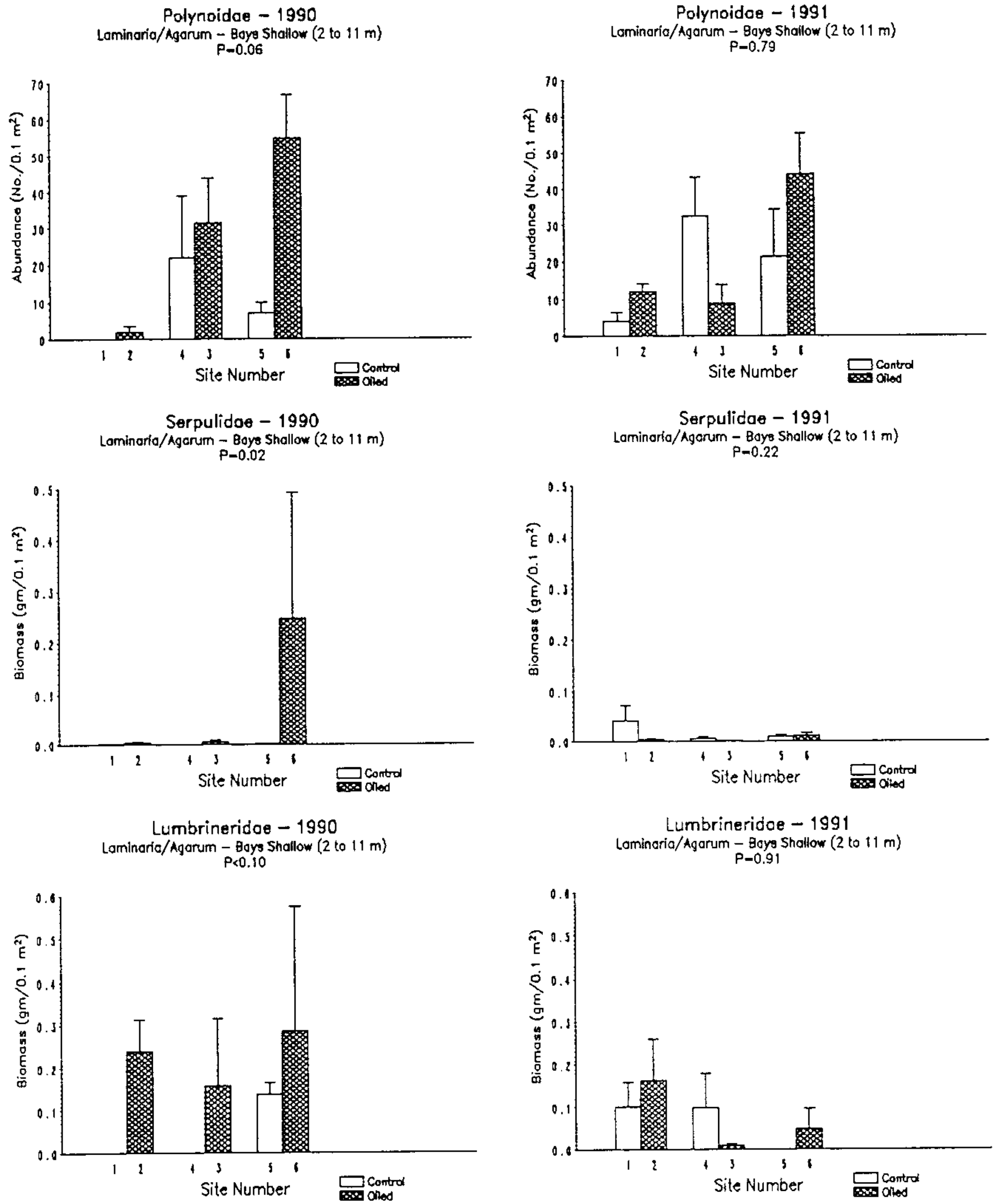
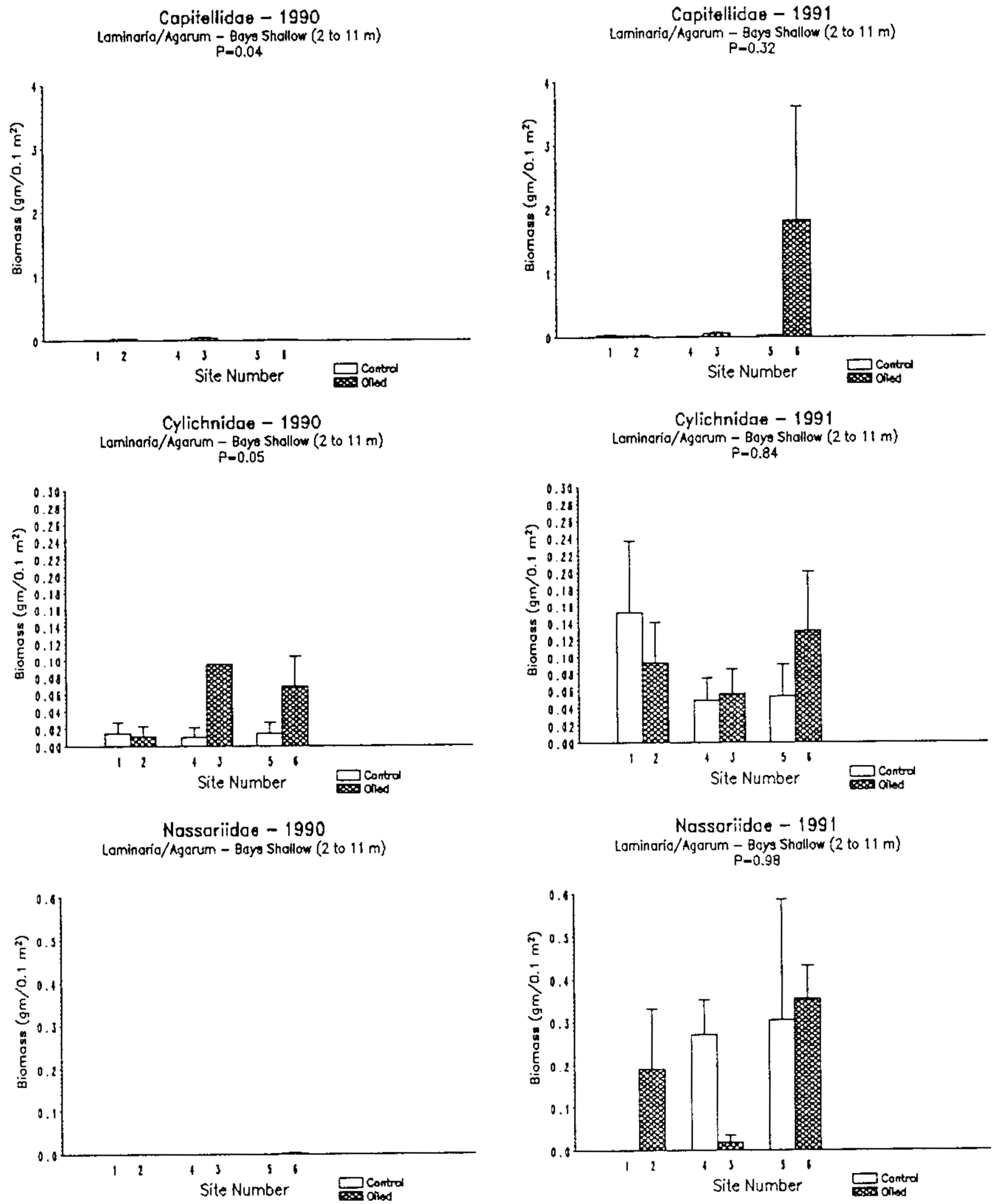


Figure 22. (Continued)



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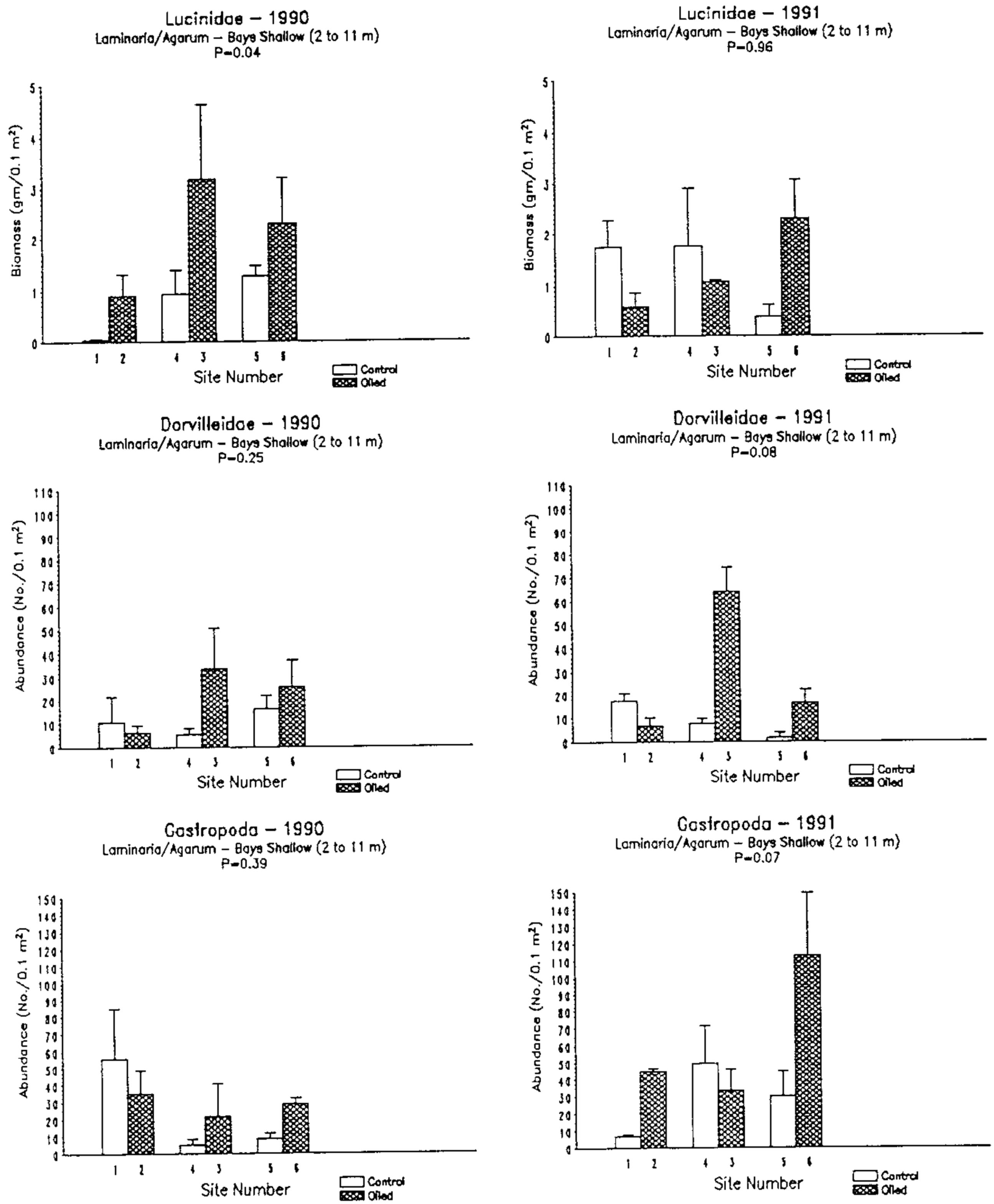

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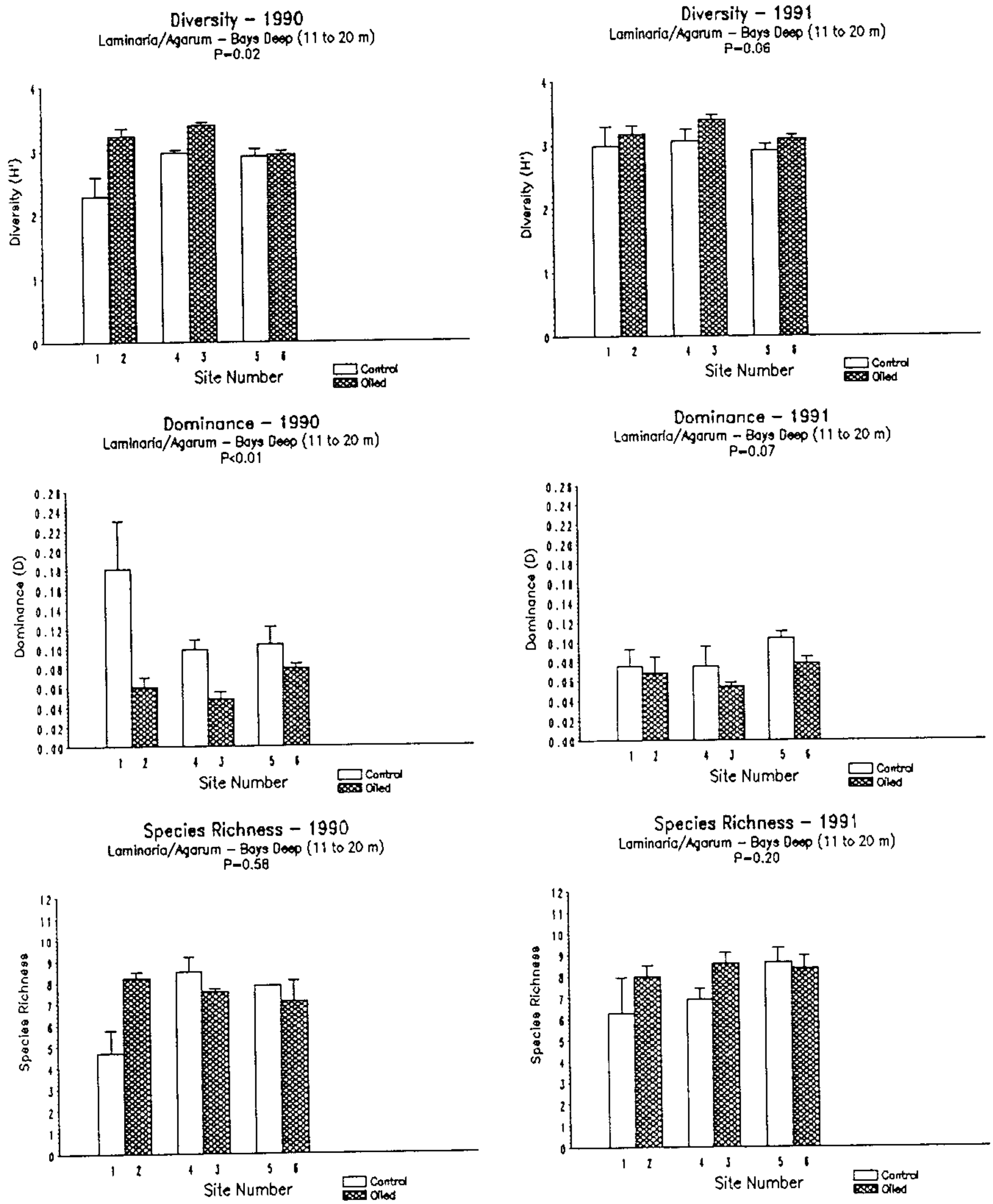
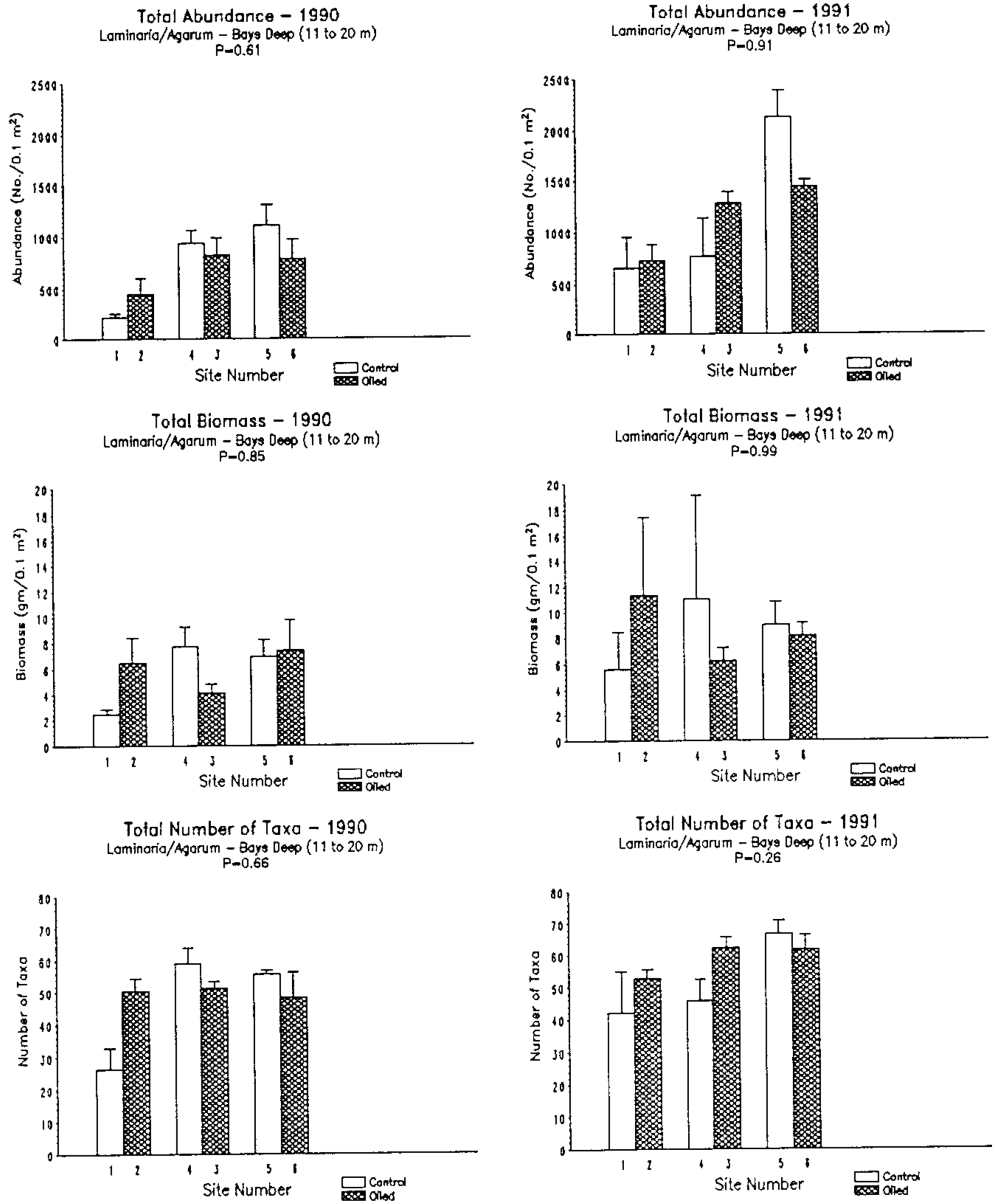


Figure 23. Diversity, dominance, species richness, total abundance, total biomass, and number of taxa for infaunal invertebrates from dredge samples in deep stratum within *Laminaria/Agarum* Bay habitats in Prince William Sound in 1990 and 1991. Error bars are +/- 1 standard error.



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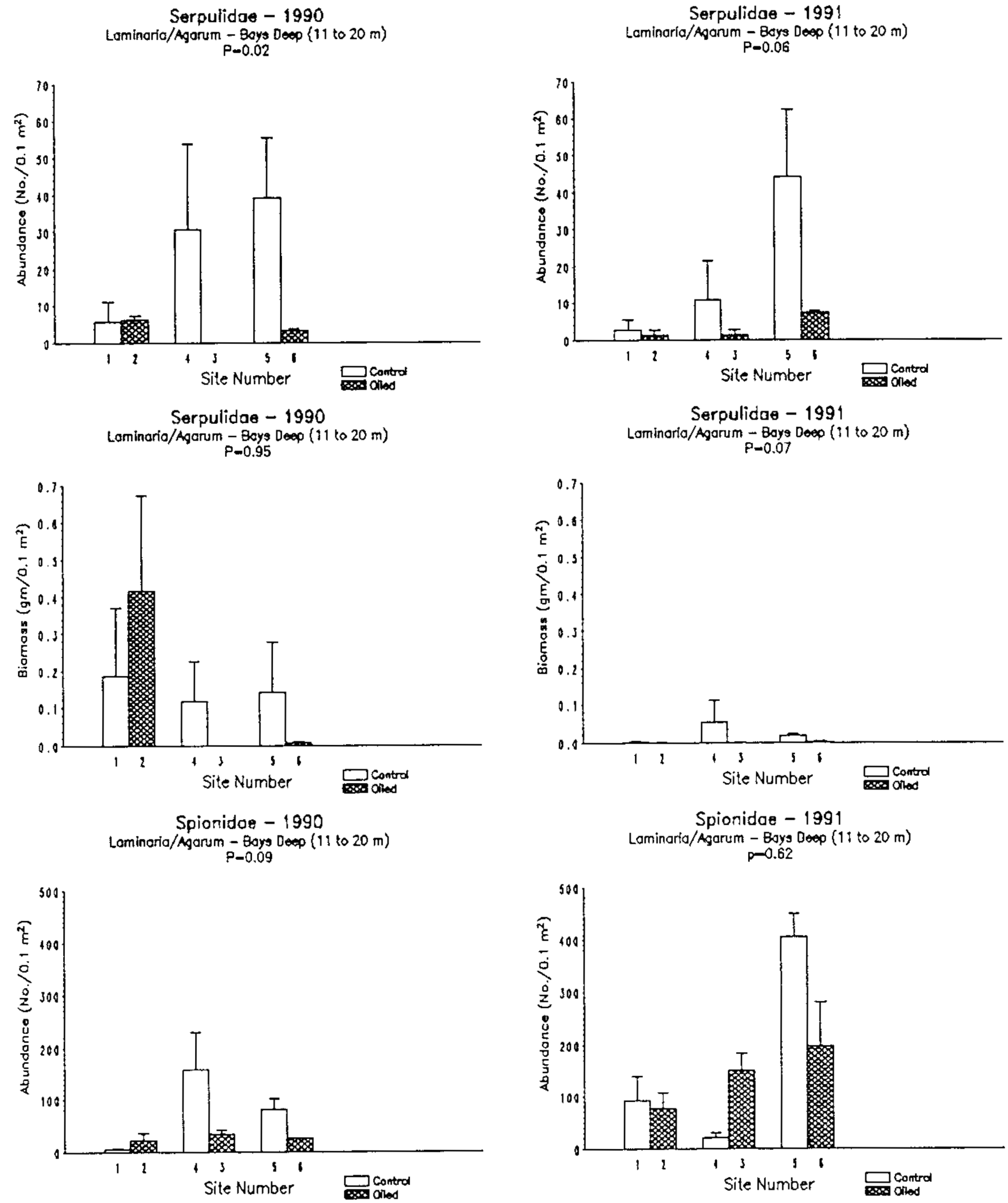
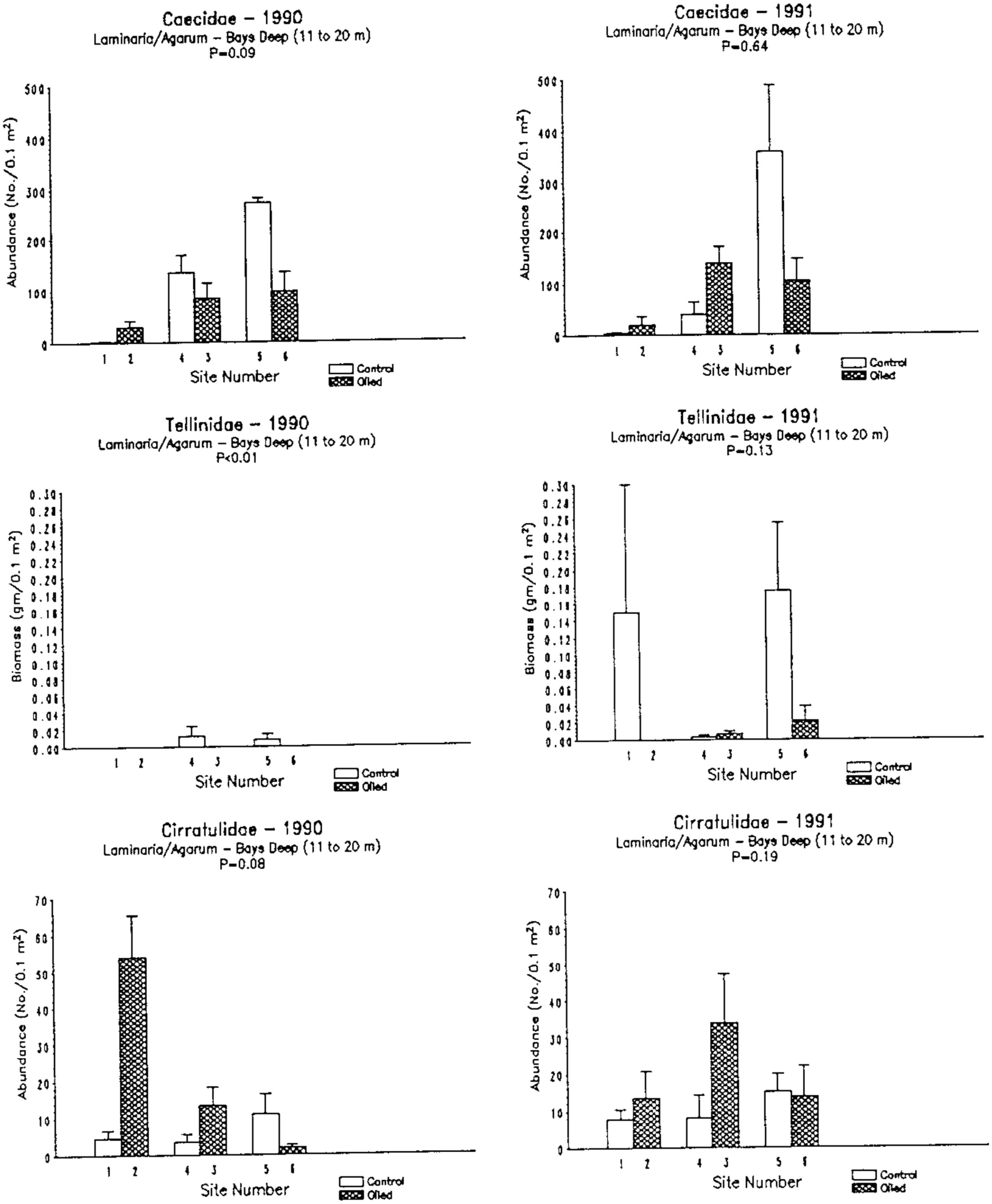


Figure 24. Abundance and biomass of dominant taxa in dredge samples that differed significantly at oiled and control sites in deep stratum *Laminaria/Agarum* Bay habitats in Prince William Sound in 1990 and 1991. Error bars are +/- 1 standard error.



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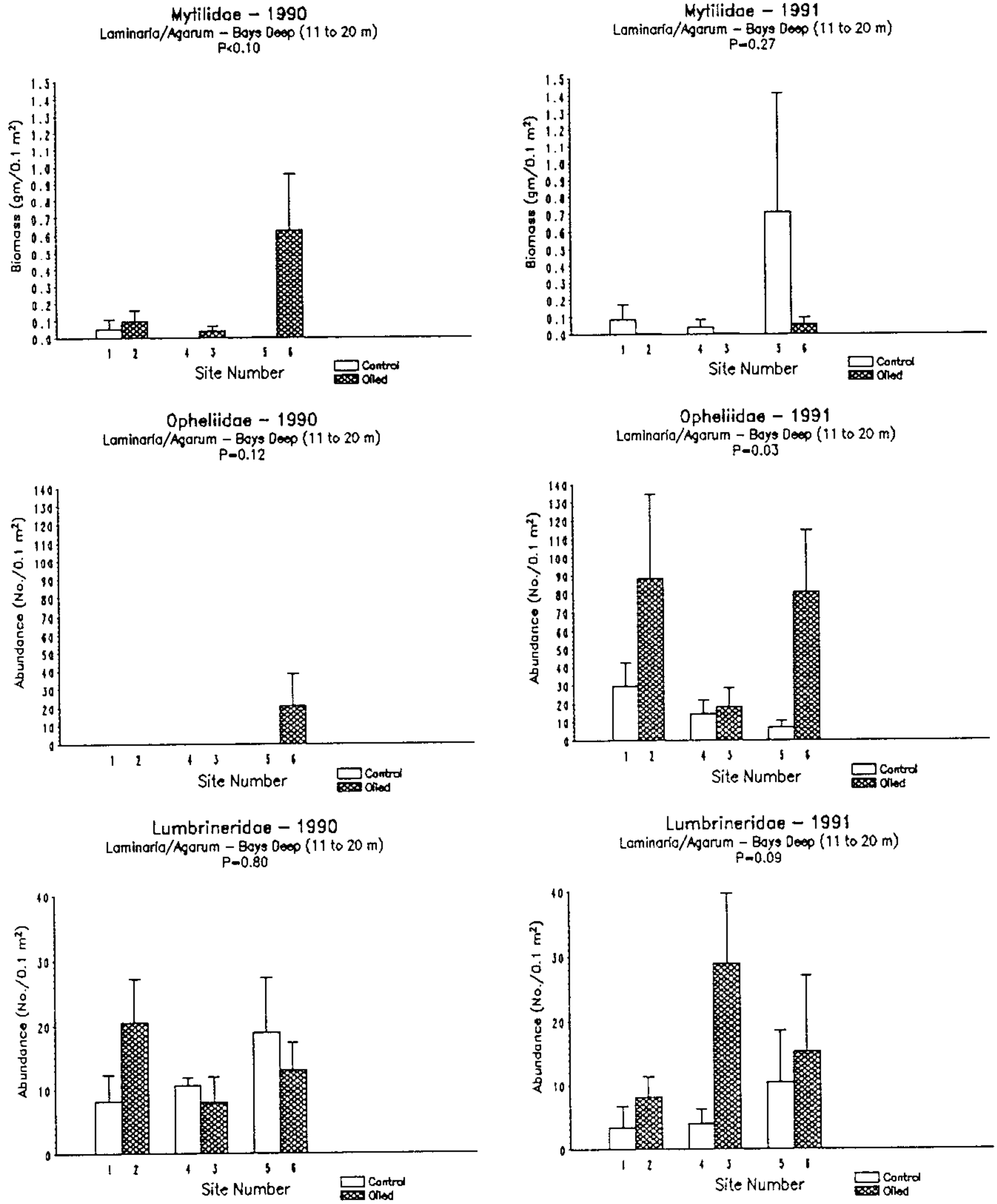

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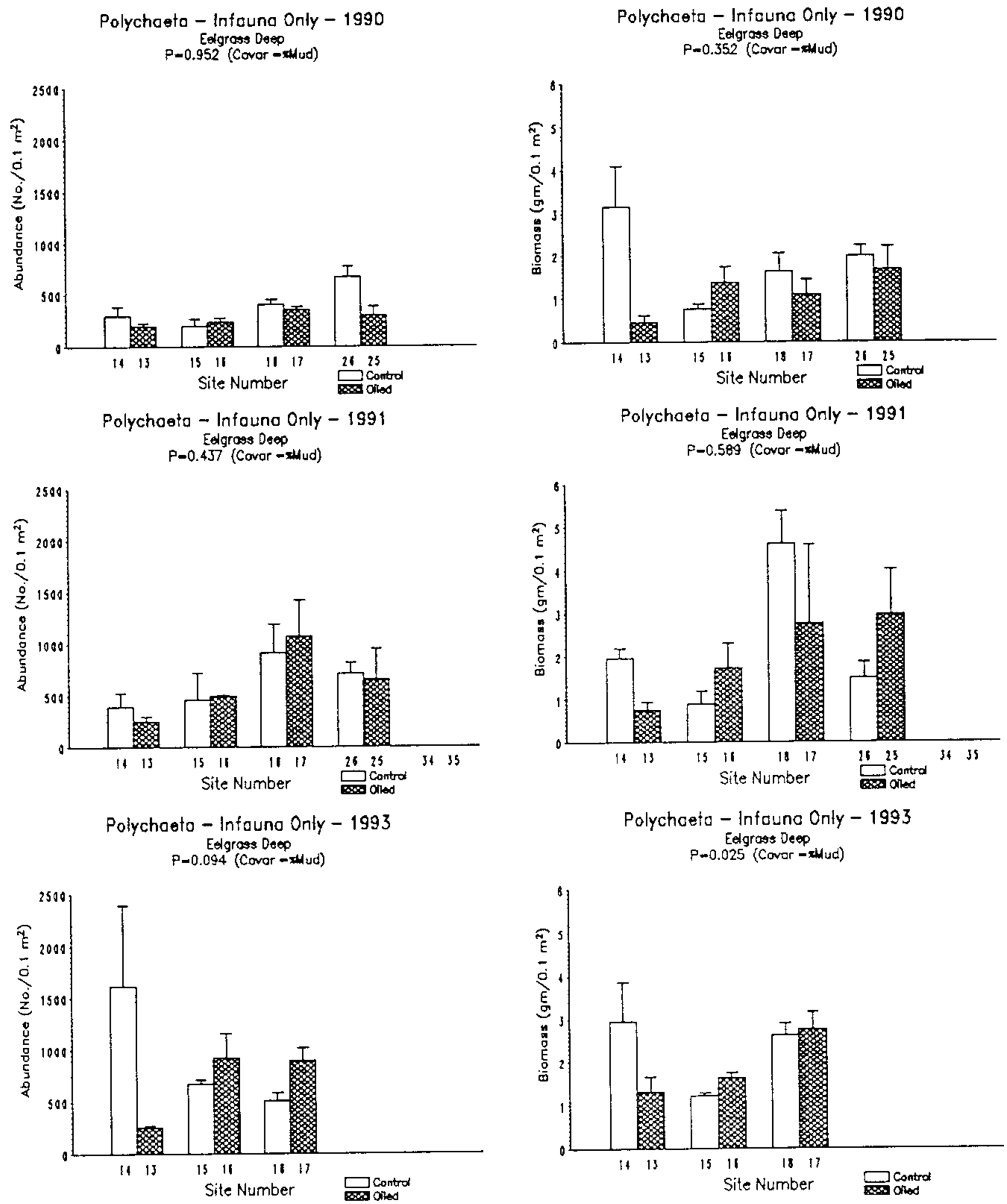

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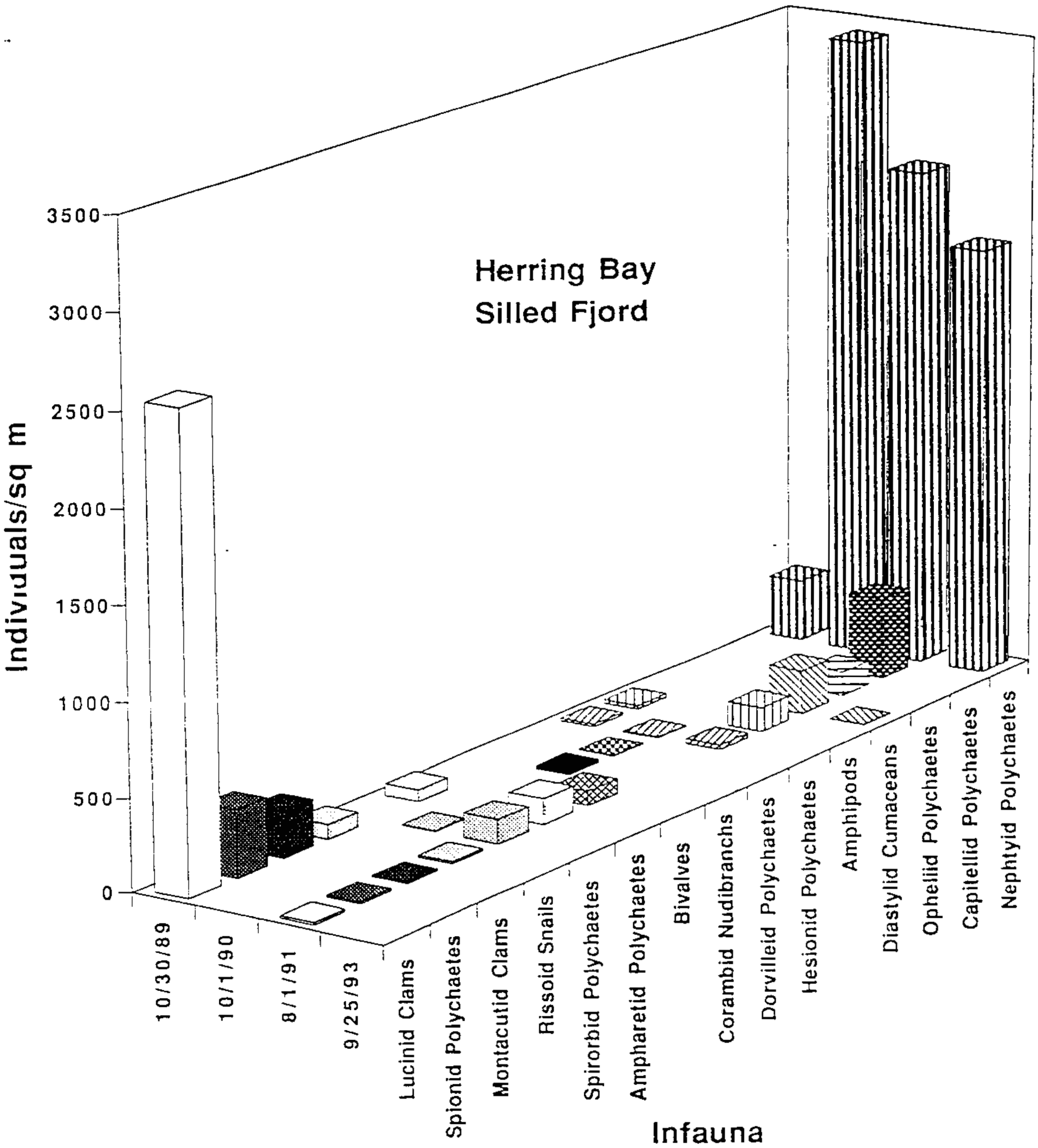


Figure 25. Abundances (individuals m^{-2}) of benthic invertebrate taxa collected by suction dredge from Herring Bay silled fjord, 1989-1991, and 1993.

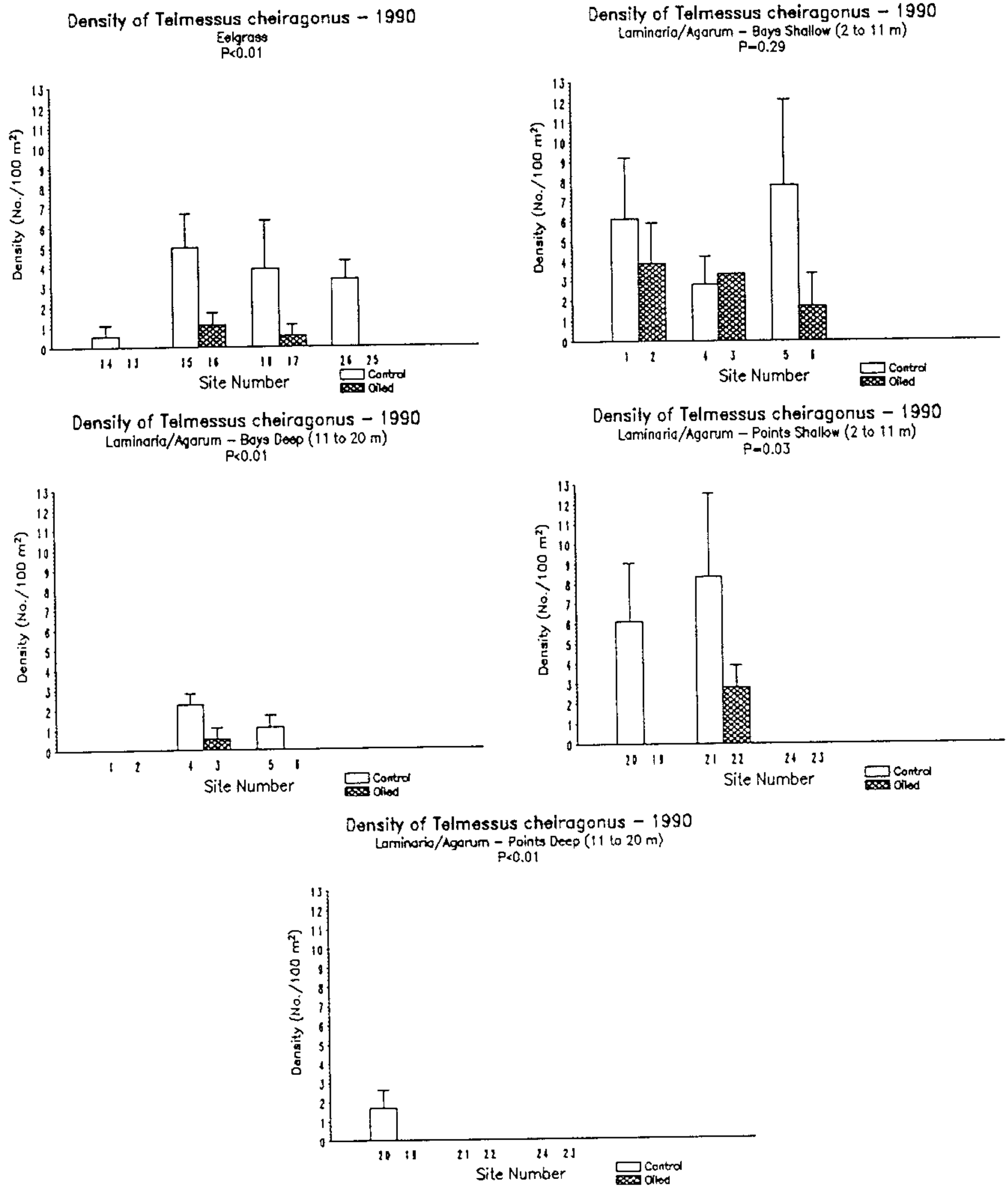


Figure 26. The abundance of *Telmessus cheiragonus* at oiled and control sites within eelgrass and *Laminaria/Agarum* habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

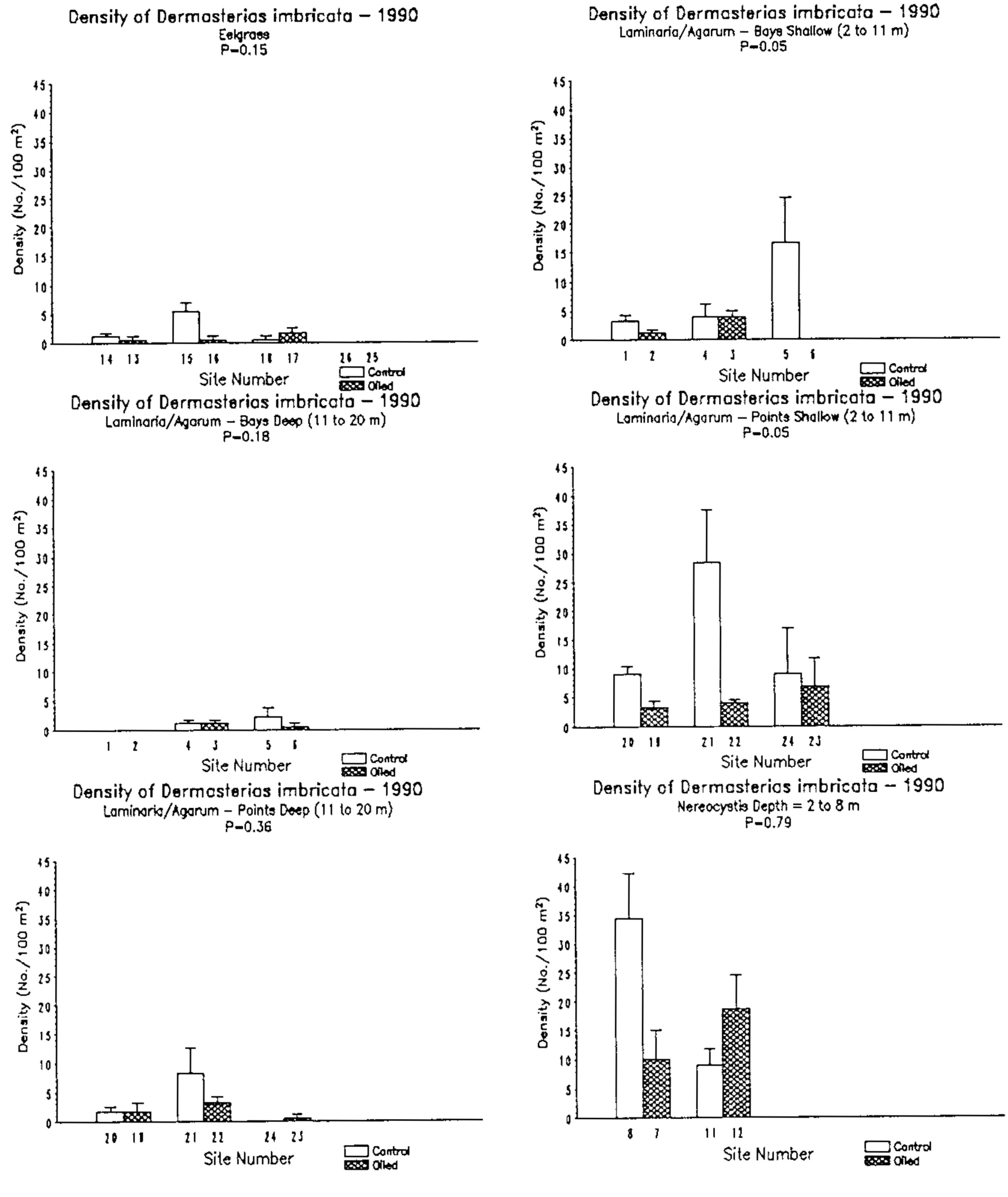


Figure 27. The abundance of *Dermasterias imbricata* at oiled and control sites within eelgrass, *Laminaria/Agarum*, and *Nereocystis* habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

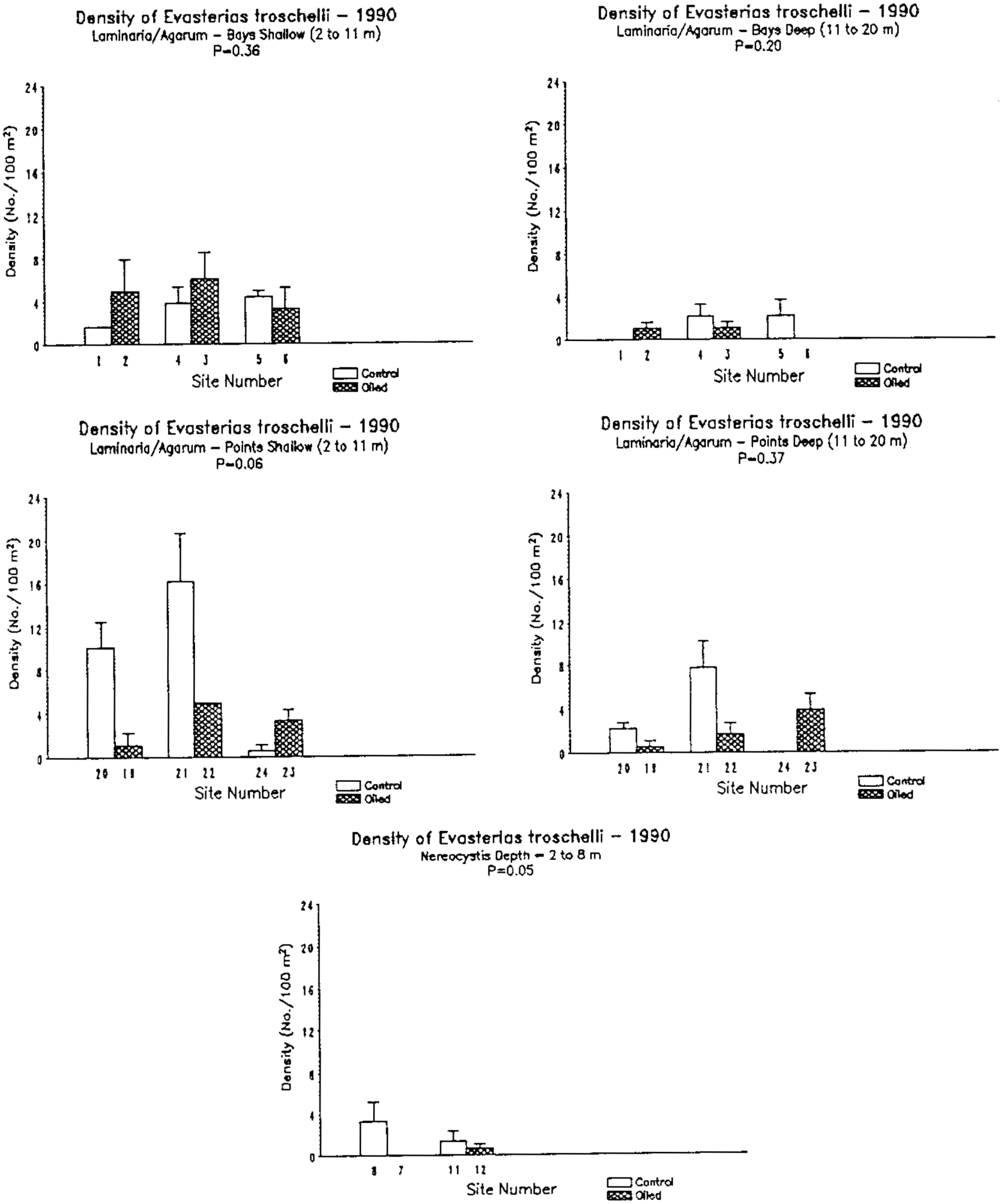


Figure 28. The abundance of *Evasterias troschelii* at oiled and control sites within eelgrass and *Laminaria/Agarum* habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

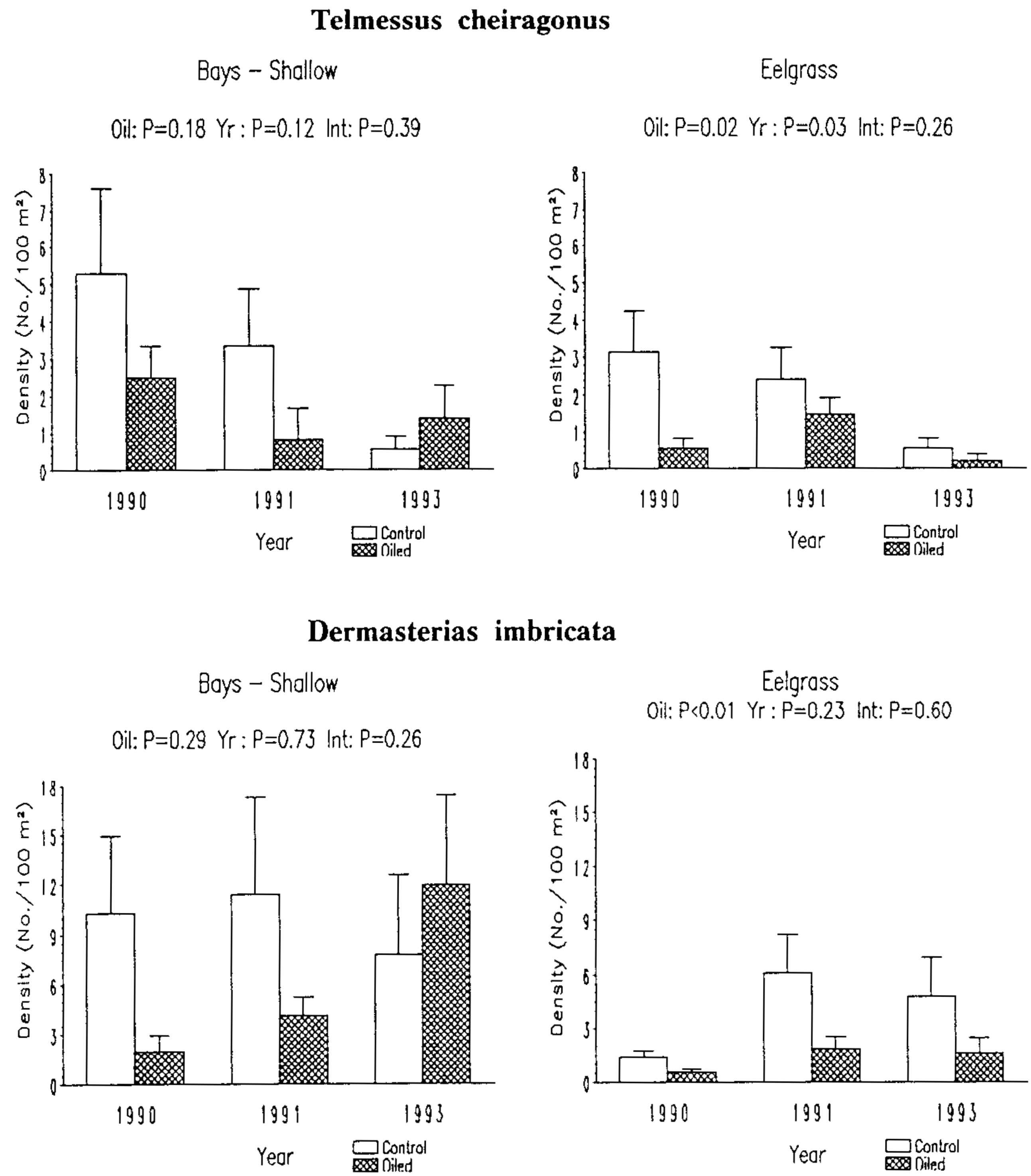


Figure 29. Mean densities (number 100 m^{-2} +/-1SE) of *Telmessus cheiragonus* and *Dermasterias imbricata* at oiled (shaded bars) and control sites (open bars) in 1990, 1991, and 1993.

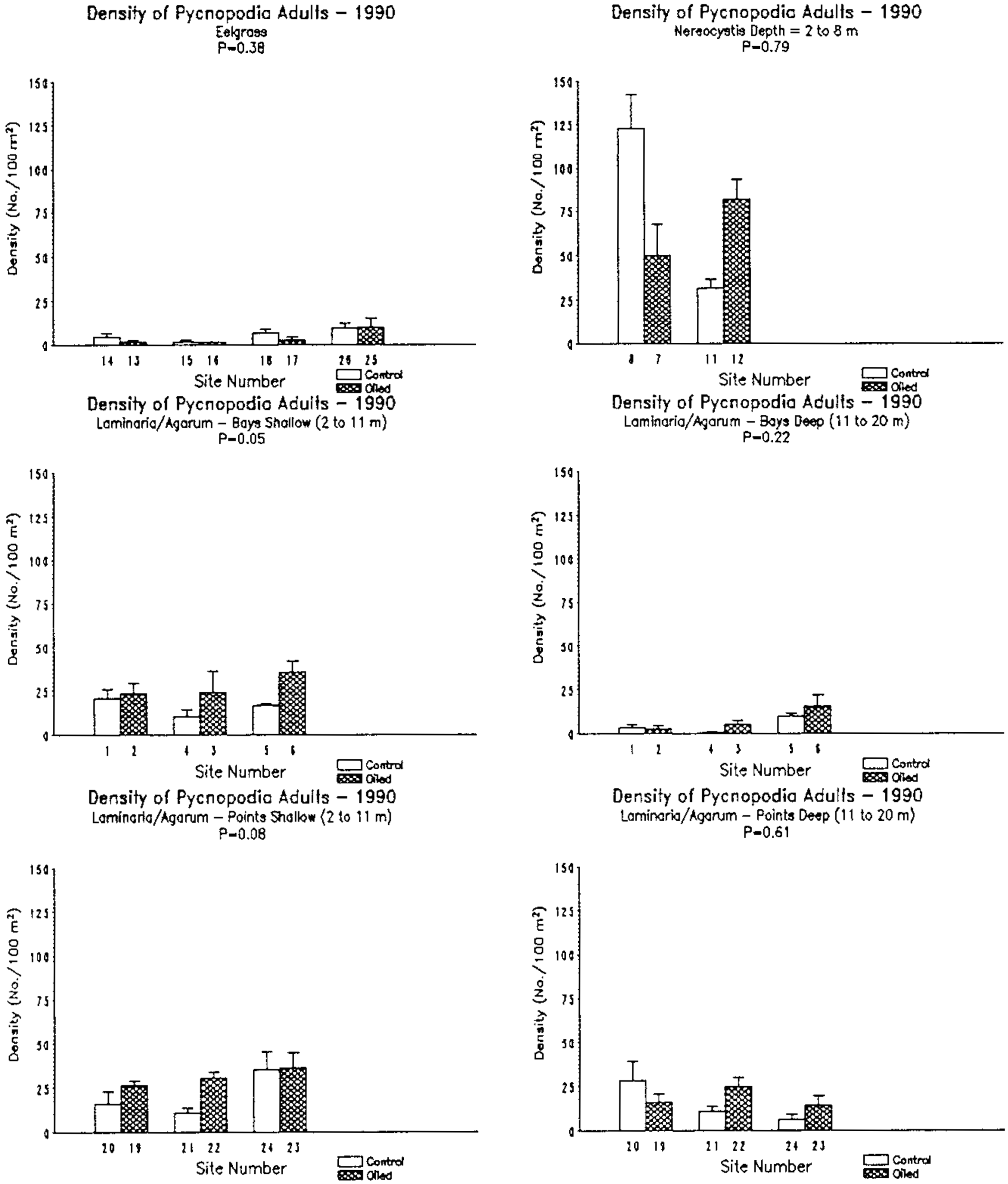


Figure 30. The abundance of adult *Pycnopodia helianthoides* at oiled and control sites within eelgrass, *Nereocystis*, and *Laminaria/Agarum* habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

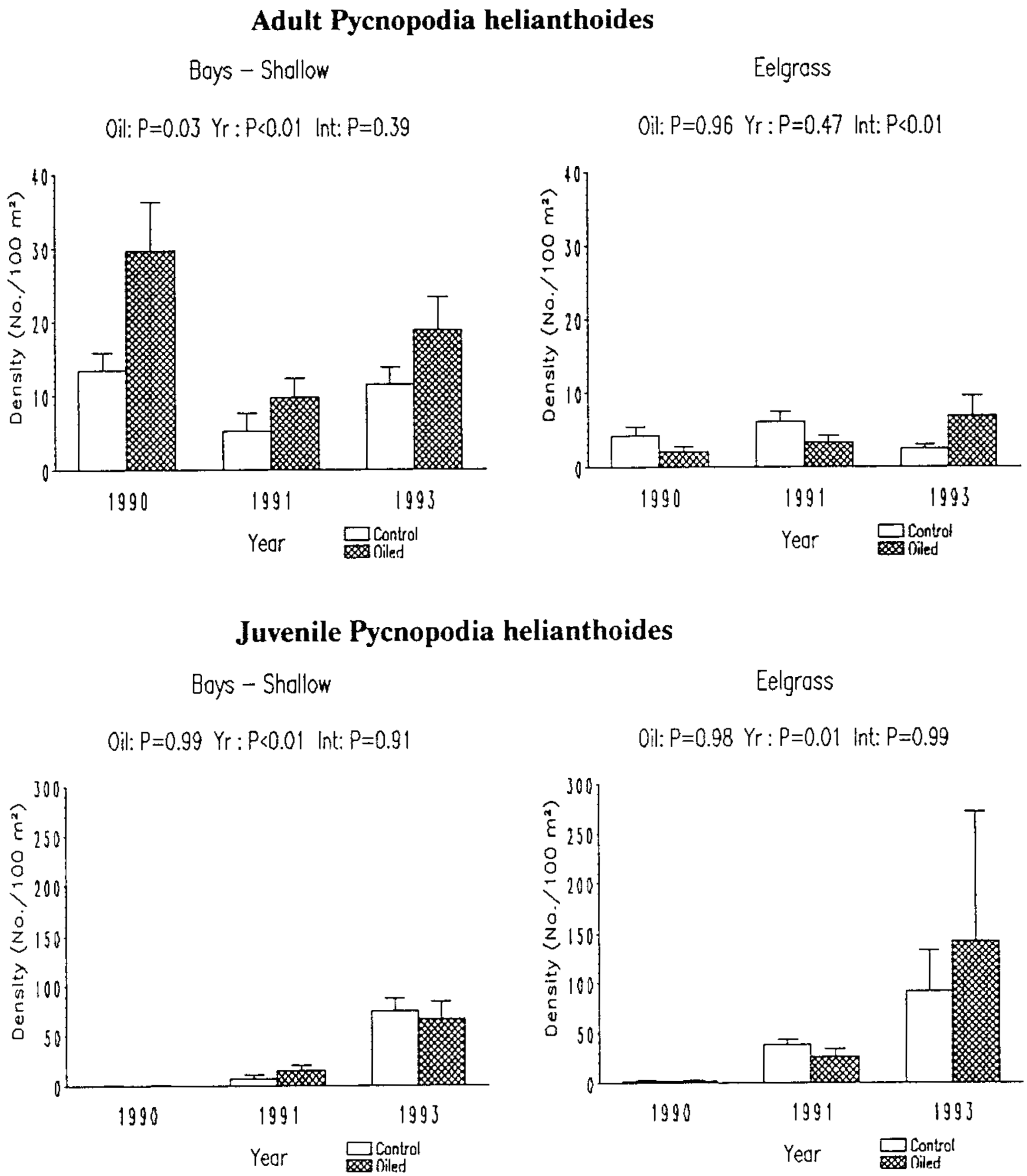


Figure 31. Mean densities (number 100 m^{-2} +/-1SE) of adult and juvenile *Pycnopodia helianthoides* at oiled (shaded bars) and control sites (open bars) in 1990, 1991, and 1993.

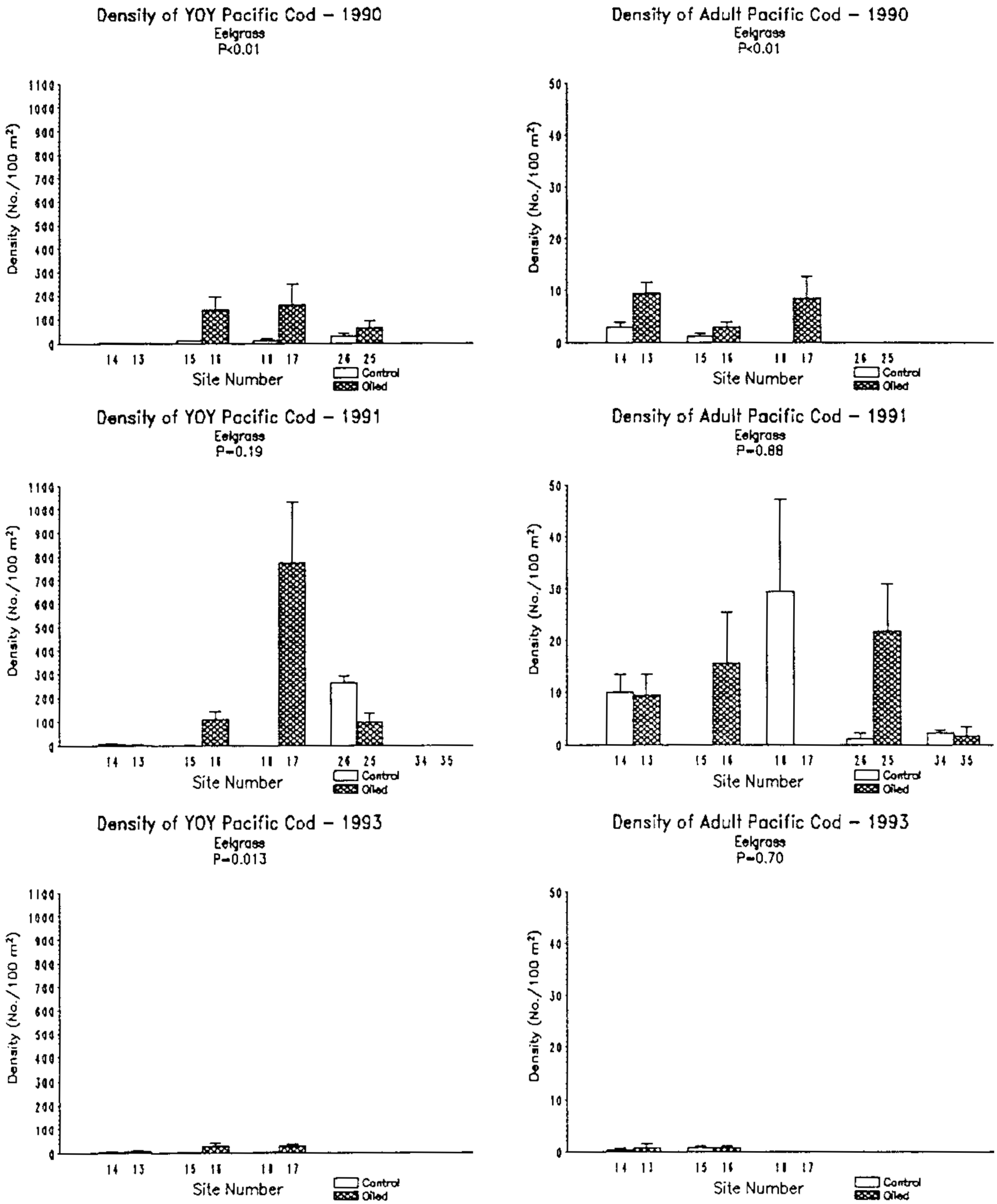


Figure 32. The abundance of young of year and adult Pacific Cod at oiled and control sites within the eelgrass habitat in Prince William Sound in 1990, 1991 and 1993. Error bars are +/- 1 standard error.

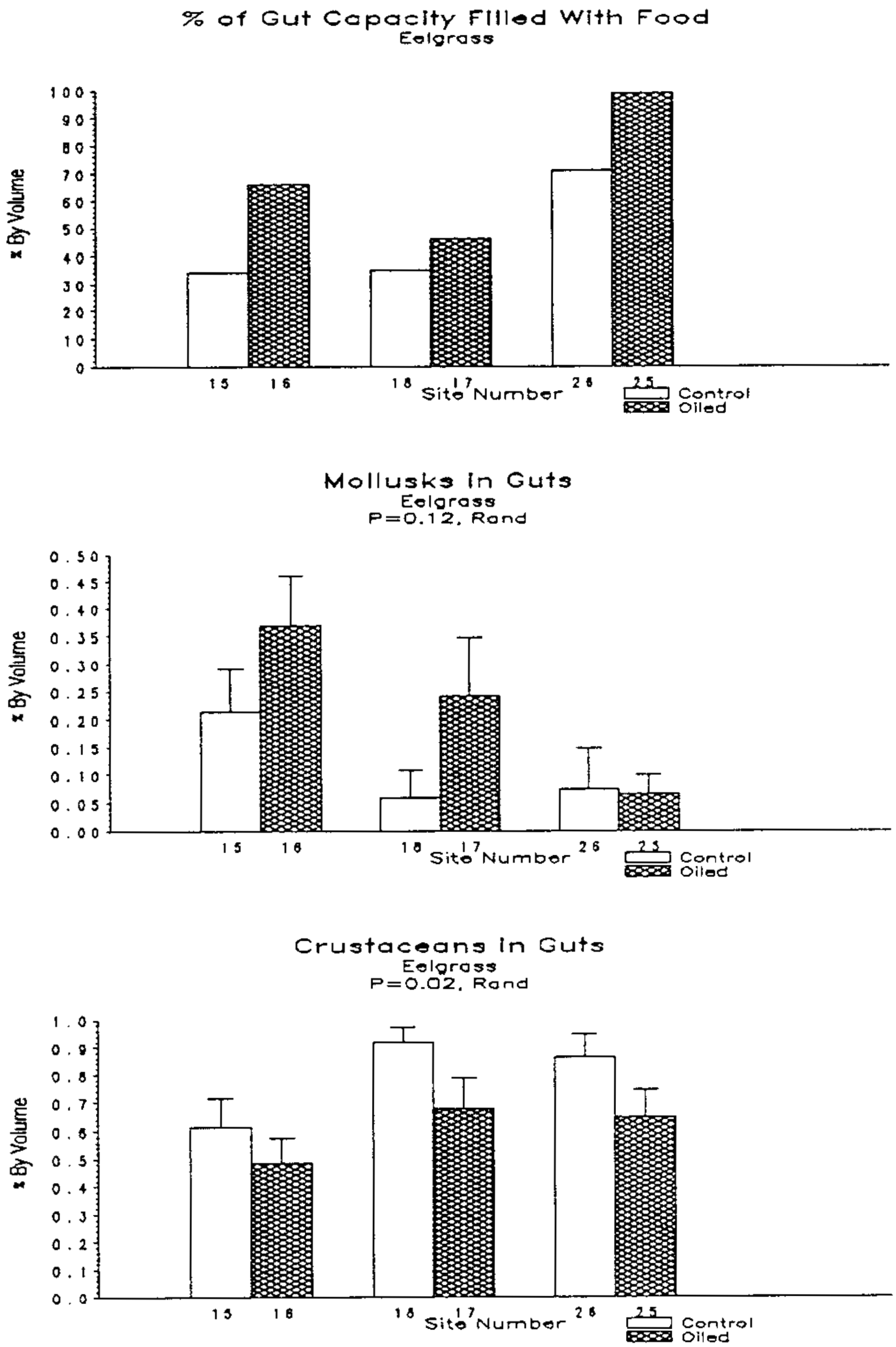


Figure 33. Percent fullness, and the percent occurrence of mollusks and crustaceans in the guts of young of year Pacific Cod from oiled and control sites at eelgrass habitats in Prince William Sound in 1990.

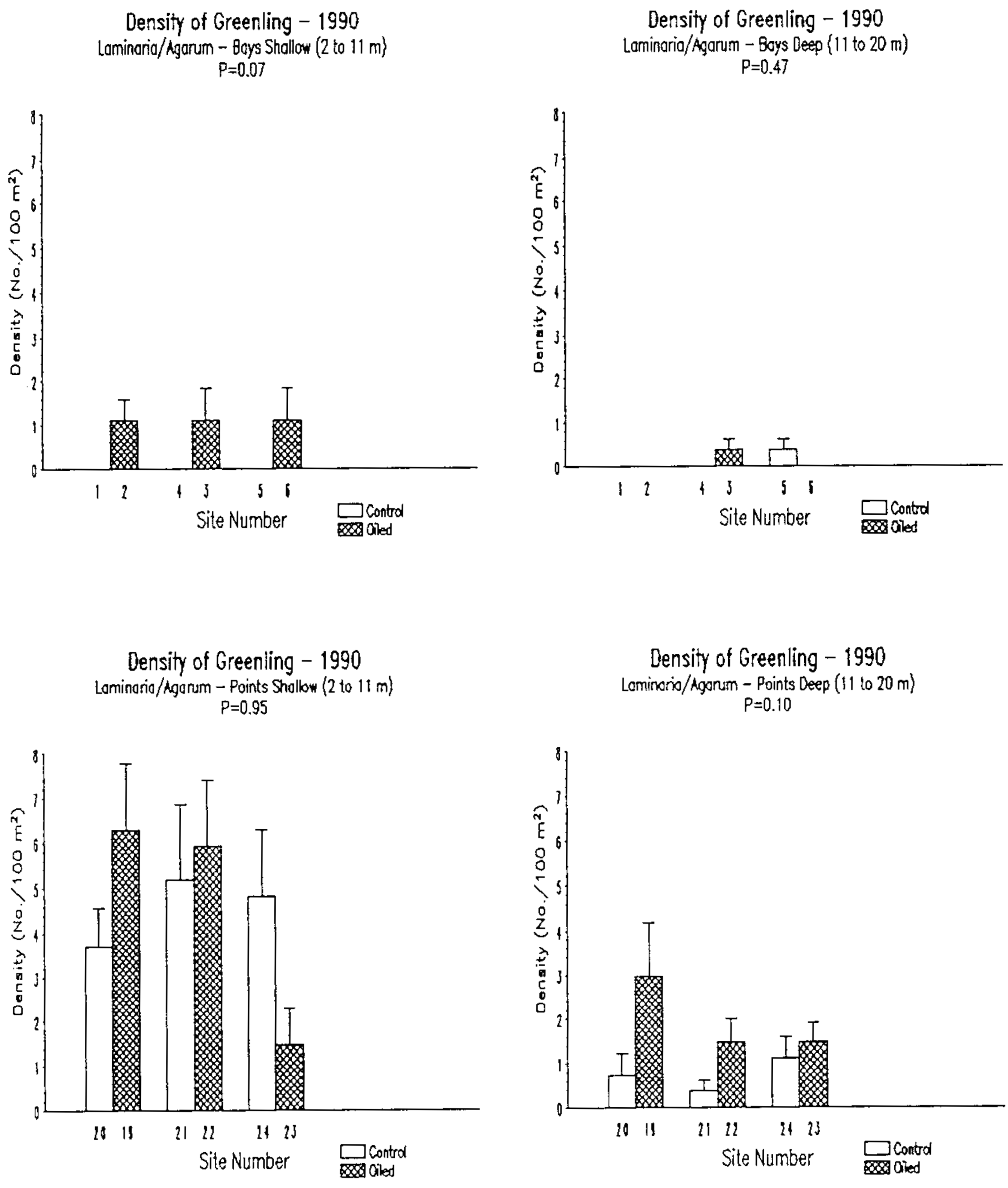


Figure 34. Abundance of Hexagrammidae (Greenlings) at oiled and control sites in *Laminaria/Agarum* habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.

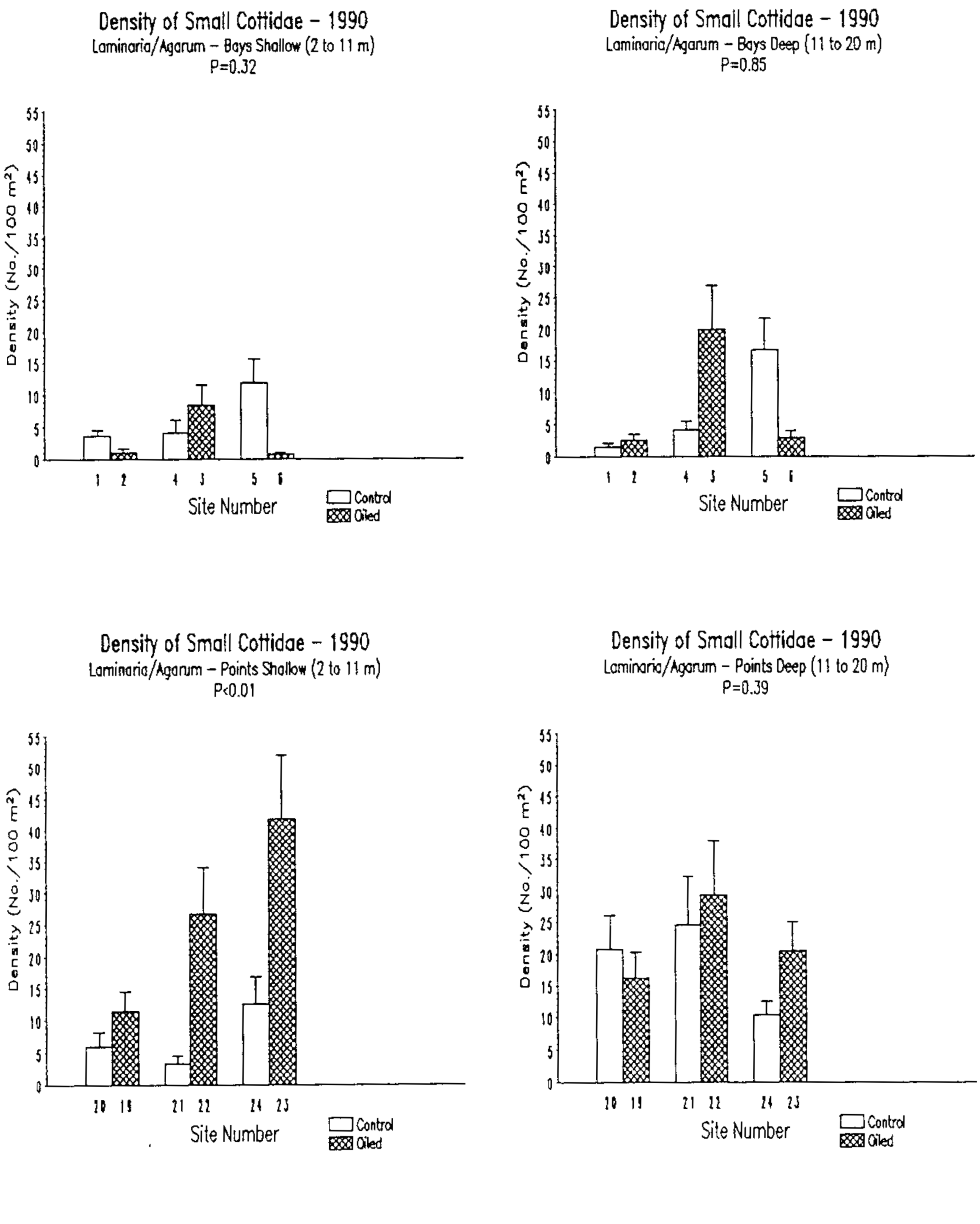
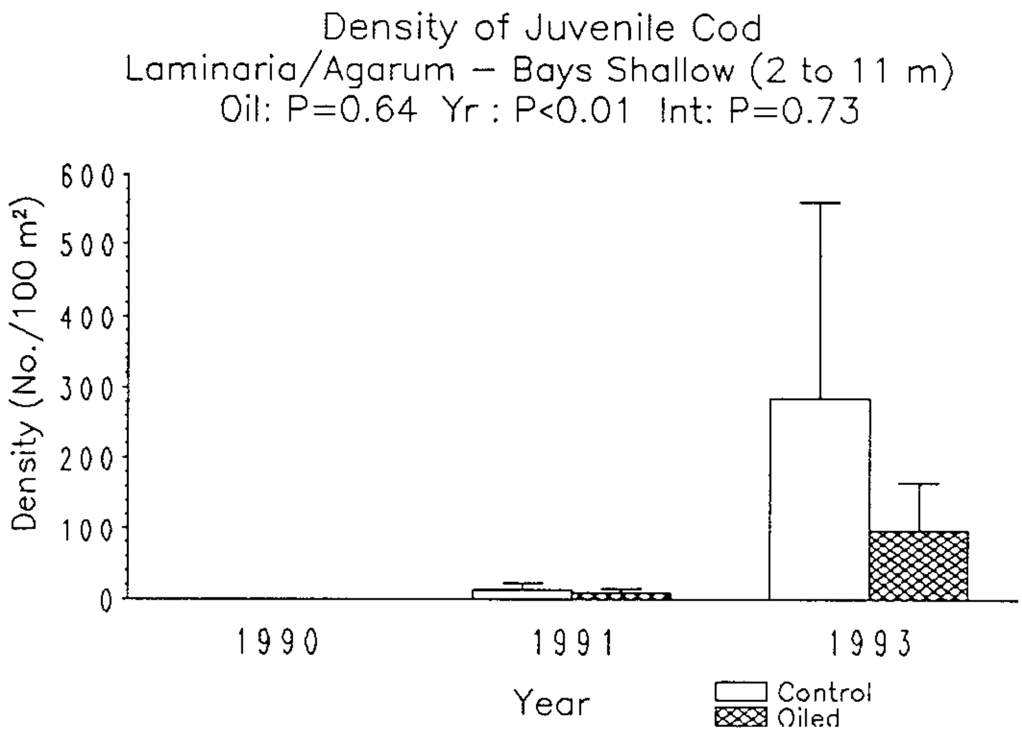


Figure 35. Abundance of small sculpins (cottidae) at oiled and control sites in *Laminaria/Agarum* habitats in Prince William Sound in 1990. Error bars are +/- 1 standard error.



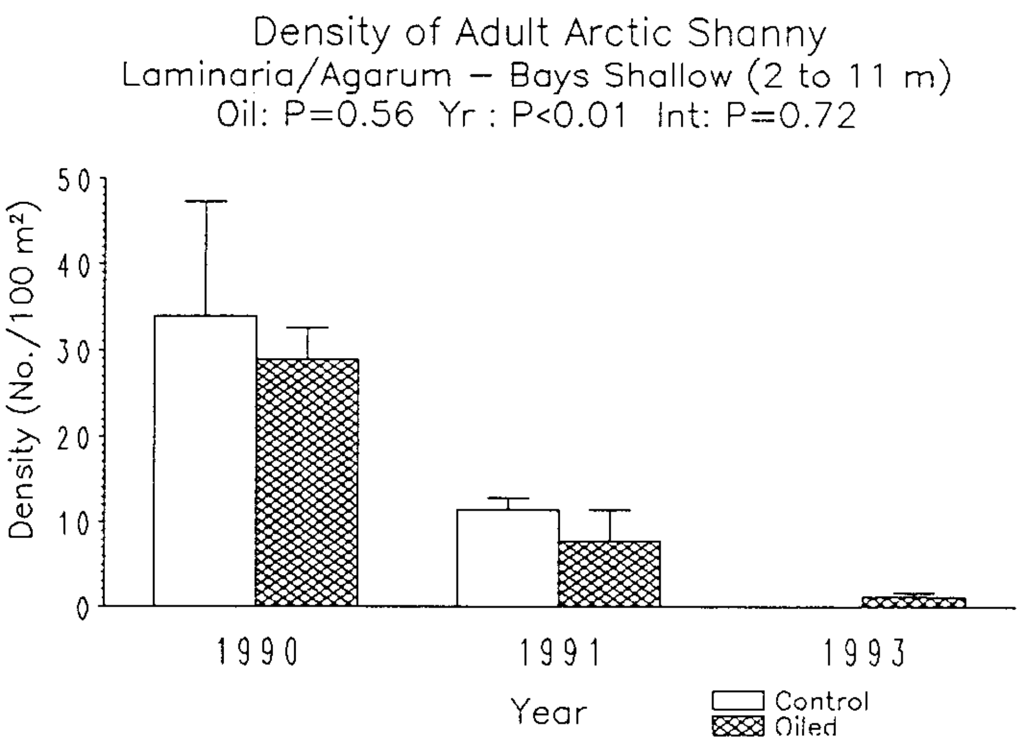


Figure 36. Abundance of juvenile cod and adult *Stichaeus* (arctic shanny) at oiled and control sites in *Laminaria/Agarum* habitats in Prince William Sound in 1990, 1991 and 1993. Error bars are +/- 1 standard error.

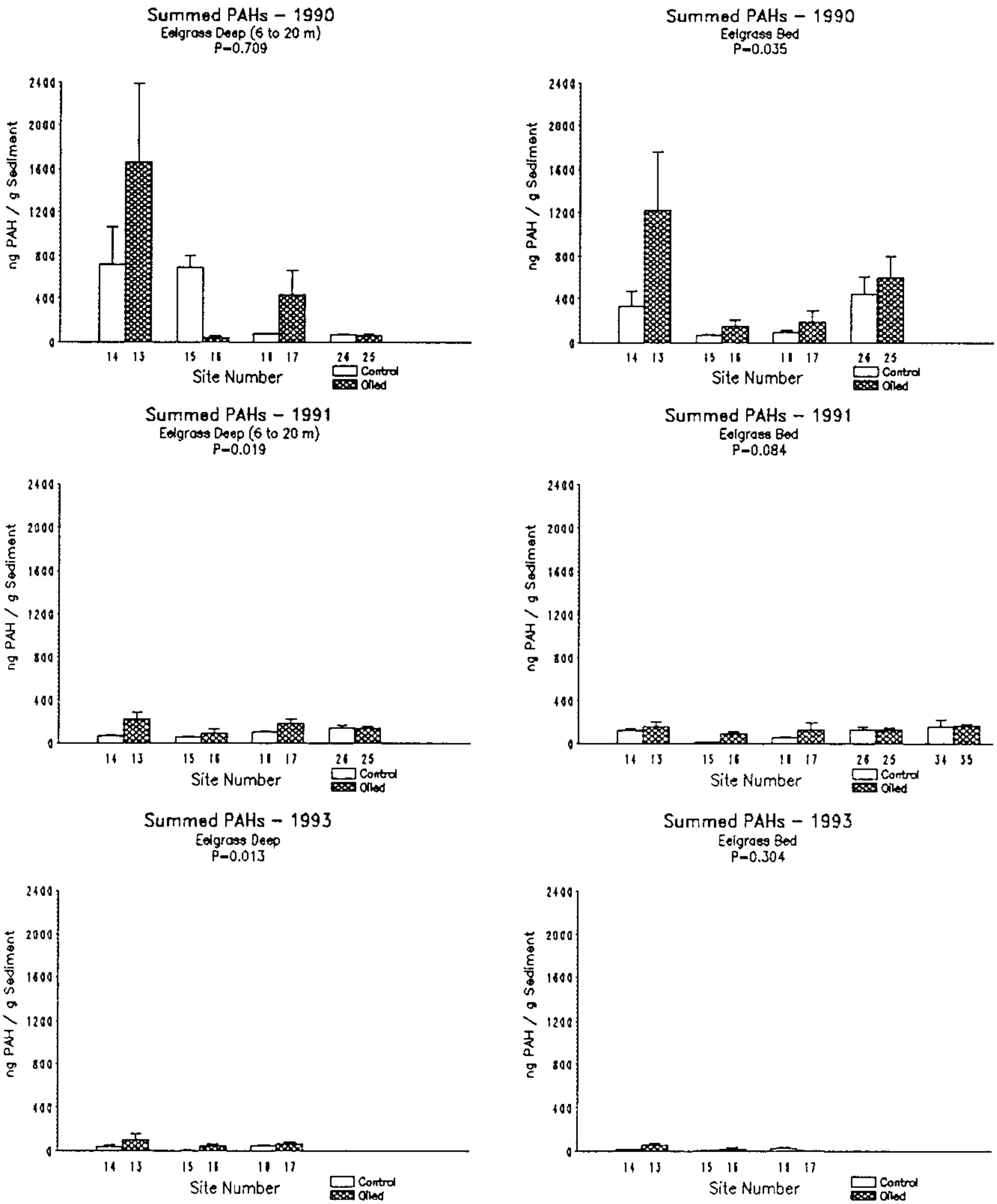


Figure 37. Concentrations of Summed PAHs in the eelgrass habitat in Prince William Sound in 1990, 1991 and 1993.

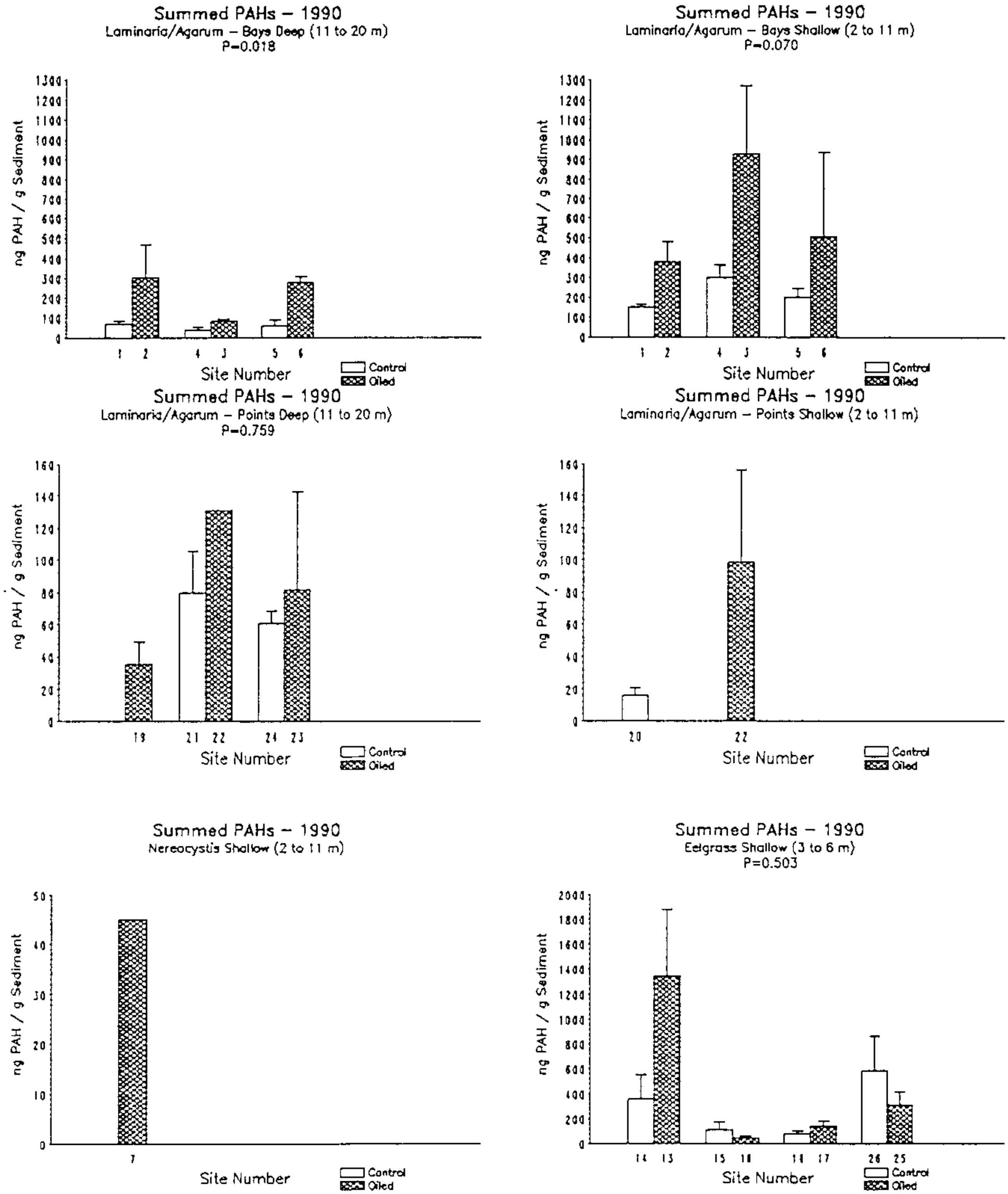


Figure 38. Concentrations of Summed PAHs in the *Laminaria /Agarum*, *Nereocystis*, and shallow eelgrass habitats in Prince William Sound in 1990, 1991 and 1993.

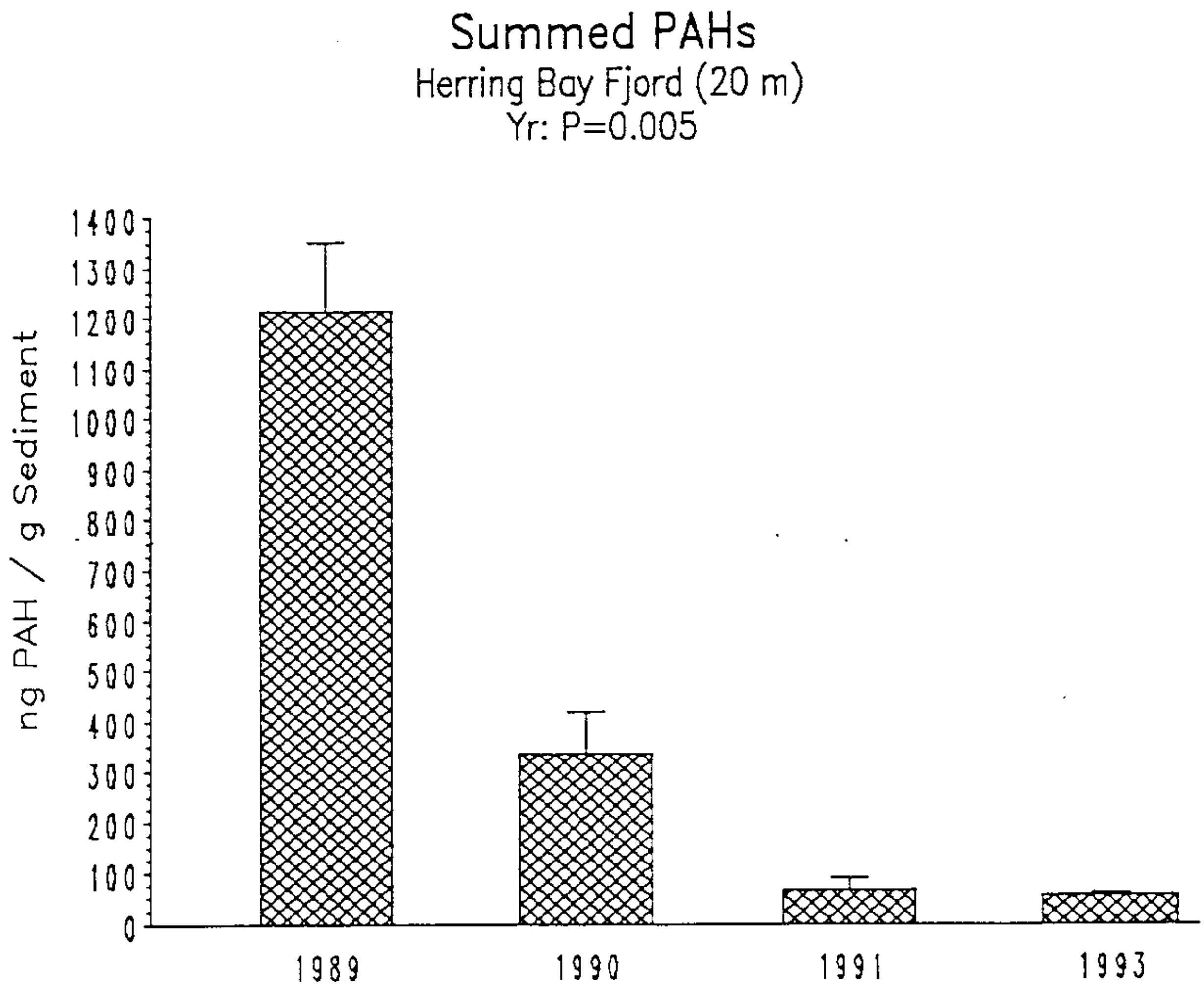


Figure 39. Concentrations of Summed PAHs in Herring Bay fjord in 1989, 1990, 1991 and 1993. Error bars are +/- 1 standard error.

APPENDIX A.

Standard operating procedure for field activities in shallow subtidal habitats in Prince William Sound, Alaska, 1990.

APPENDIX A. Standard operating procedure for field activities in shallow subtidal habitats in Prince William Sound, Alaska, 1990.

1.0. Definitions

Habitat type - One of the four habitat types mainly defined by the dominant plants present: *Laminaria/Agarum*, *Nereocystis*, or *Zostera*. The *Laminaria/Agarum* habitat is further subdivided in Island Bays and Island Points. The fourth habitat, silled fjord, was not characterized by plants but by the presence of a shallow sill at the fjord entrance.

Study site - An area of coastline to be sampled; within each habitat type study sites may be defined as moderate-heavily oiled, unoiled (control).

Site baseline - A line connecting the endpoints of the study site, approximately 200 m long.

Station transect - A line perpendicular to the site baseline extending from the 0 tide depth out to a depth of 20 m, at locations selected randomly within a study site. There are three station transects along a site baseline.

Depth strata - Subsets of the site in various depth ranges.

Sampling depth - Randomly selected points in the depth strata on a station transect.

Sampling transect - A 30-m line following the contour to the right of a station transect along which subtidal sampling is conducted.

Quadrat - A 0.25 m^2 (0.5 m by 0.5 m) plot for photography and plant studies randomly located along a sampling transect; also, a 0.1 m^2 plot for infaunal studies randomly located along a sampling transect.

2.0. Preliminary Study Site Selection

Silled Fjords - A total of eight potential study sites were initially selected: 2 heavily oiled sites (Arm of Herring Bay and the West arm of the Bay of Isles), 2 moderately oiled sites (Disk Lagoon and Marsha Bay), one lightly oiled site (Louis Bay) and 3 control sites (Northwest arm of Lower Herring Bay, Johnson Bay, and Copper Bay). Additional sites considered in the field were Lucky Bay and Humpback Cove in Whale Bay. We choose most sites within the Knight Island group that were similar in geomorphology to the Herring Bay site where we observed a "Dead Zone" in 1989. All had restricted entrances with an apparent sill, based on examination of hydrographic charts Heavily oiled sites had over 50% of their shoreline classified as moderately to heavily oiled on the map indicating cumulative impact of oiling through July 2, 1989 (the July map) and had at least 10% of the shoreline moderately to heavily oiled in September, as per the September "walkathon" data (the

September map). The control sites had no oil indicated on either map. We anticipated sampling at all sites over a two week period.

Island Points - Island Points were selected according to the following process. All potential sites were marked on a map. We first drew an outside polygon around the island groups, one around Naked, Storey, and Peak Islands and another around the islands from the northern tip of Eleanor Island to the southern tip of Knight Island. (Smith, Little Smith, Green, Montague, and Latouche Islands were considered part of the outer sound group because of the strong influence of oceanic currents). The polygons were drawn such that any two interior points that were separated by less than 4 km were contained within the polygon. Islands less than 1/2 km in the longest dimension were not considered. The verticies of the polygon were considered as points if the angle formed by lines drawn along the shoreline to 1/2 km in either direction from the vertex was less than 60#.

Points were classified as oiled if there was moderate to heavy oil present within 100 m to either side of the point as indicated in both the cumulative oiling map as of July and the September map. There were 11 such oiled points identified.

We selected 3 oiled sampling sites from these 11 sites. The sites were placed into three groups based on location: Four sites in the northwestern quadrant (1, 2, 3, and 4), four sites in the southeastern (6,7,8, and 9), and three miscellaneous sites (site 5 on the southwestern side of Knight Island and sites 10 and 11 in the northeastern quadrant).

We then examined the September walkathon data in more detail and gave preference to sites with heavy to moderate oil within 100 m to either side of the point. On this basis, Point # 10 was the selected over points 11 and 5. The remaining sites within each group were ranked using a random process. Final ranking are as follows:

Area	Selected	Alter. 1	Alter. 2	Alter. 3.
NW	4	2	3	1
SE	7	9	6	8
Other	10	11	5	-

Control sites were selected that were not oiled on both the July and September oil map, and that most closely matched the oiled sites with regard to location.

Island Bays - All bays were examined within the island group from Storey Island south to Knight Island. A bay was defined as a body that was longer (distance from the mouth to the uppermost reaches) than the mouth was wide and that had a length greater than or equal to 2 km. Bays were classified as oiled if at least half of their shorelines were moderately to heavily oiled on the July map and at least 20 % was heavily to moderately oiled on the September map. Five potential oiled bays were identified: Northwest Bay, Herring Bay, Horn Bay, Snug Harbor, and Bay of Isles. We selected Herring Bay as one of our sites to be sampled because it is being used as a base for intertidal and subtidal experiments. We then selected two other sites from a simple random sample of the remaining 4. The 2 selected sites were Northwest Bay and Snug Harbor. Alternate sites , in order of preference, as chosen through a random process, were Bay of Isles and Horn Bay.

Sites within bays were selected based on the presence of moderate to heavy oil in the September walkathon (along at least 1/2 km of shoreline), and on the existence of previously established NOAA/DEC sampling sites, at which samples were collected for hydrocarbon analysis in 1989. These generally represent shoreline segments of approximately 500 to 1000 m. Actual sites within these segments will be selected based on physical characteristics of substratum type and slope in a reconnaissance cruise in April, 1990.

Control bays were selected that most closely resembled the oiled bays and that were not oiled in both the July and September oil maps. These were as follows:

Oiled Site	Control	Alter. 1
Herring Bay	Lower Herring Bay	Drier Bay
Snug Harbor	Mummy Bay	
Northwest Bay	Cabin Bay	
Bay of Isles	Mummy Bay	
Horn Bay	Mummy Bay	

Eelgrass - Sites where eelgrass is present within the PWS area were identified by Kim Sundberg, Rick Rosenthal, and the NOAA staff of Chuck O'Clair and Stanley Rice. Oiled eelgrass beds were selected that were indicated as moderately to heavily oiled on both July and September oil maps. This resulted in 9 potential sites. One of these (Perry Island) was eliminated from consideration because there was no adequate control. The other 8 were placed into 3 groups: Group 1 are bowls on the eastern side of the islands, with mouths facing North (site # 2 on Naked Island, site # 3 on Latouche Island, and site # 7 in Snug Harbor). Group 2 is in the northwest quadrant of the Knight Island group (#3 on Disk Island and #'s 4 and 5 in Herring Bay). Group 3 are sites within Bay of Isles (8 and 9). Order of preference for sampling of sites within groups was determined based on the presence of DEC/NOAA sampling sites used in 1989. If hydrocarbon samples were taken at all sites within a group, then sites were selected at random. These were as follows:

Area	Selected	Alter. 1	Alter. 2
Bowls	6	7	2
NW	5	3	4
Bay of Isles	9	8	

Control sites were selected that were not oiled on both the July and September oil maps, that were in the same geographic region, and were of similar aspect and exposure. The control site for Herring Bay (#5) was within Lower Herring Bay, for the Latouche Island site was in Sawmill Bay on Evans Island, and for the Bay of Isles site was in Drier Bay.

Nereocystis - Sites where *Nereocystis* is present within the PWS area were identified by Kim Sundberg and Rick Rosenthal. Oiled *Nereocystis* beds were selected that were indicated as moderately to heavily oiled in both July and

September oil maps. This resulted in 5 potential sites: Danger Island, Latouche Pt., Green Island, Smith Island, and Little Smith Island. The sites were placed into 3 groups based on location: Group 1 is Danger and Latouche, group 2 is Green Island, and group 3 is Smith and Little Smith. Danger Island and Smith Island sites were randomly selected as priority sites among groups 1 and 3.

Control sites were selected that were not oiled on both the July and September oil maps, that were in the same geographic region, and were of similar aspect and exposure. The control site for Danger Island was Pt. Elrington, for Smith Island was Zaikof Pt., and for Smith Island was Pt. Montague.

3.0. Study Site Confirmation and Site Descriptions

Site confirmation - An aerial and ship based survey of all potential study sites was made in April, 1990. Tom Dean, Rick Rosenthal, and Dave Laur flew the Sound, examined each site from the air to insure that habitat types were correctly defined and that control sites resemble oiled sites with regard to geomorphology. Sites accessible by float plane were visited. Some study sites were marked with a pink paint mark on the shore line. Other sites have distinguishing features that allow sites to be identified. Photographs and/or videos were taken of each site. Those sites inaccessible by plane were visited by Tom Dean and Troy Tirrell aboard a boat.

Sites Selected - The sites selected in the confirmatory survey, and their site codes are given in Table 1. The site numbers used here were reassigned after site conformation visits and do not necessarily correspond to numbers assigned to sites during the preliminary selection phase as described in section 2.0.

Silled Fjords - Several of the potential silled fjord sampling sites were visited in April 1990. Most were found to be inadequate because they were too large and did not have sills. The only sites found to fit the prescribed characteristics were the previously sampled site in Herring Bay and the western arm of Bay of Isles. An additional control site was located in Port Audrey Cove, Drier Bay. The uppermost part of Lucky Bay may also be an adequate control.

Several sites and their alternatives were not adequate and new sites were selected. For example, the *Nereocystis* sites at Green Island and Pt. Elrington were deleted because of a lack of *Nereocystis* (on Green Island) or because the site was more exposed than the oiled site (Pt. Elrington). New sites were selected based on previously established criteria.

Site Descriptions - A description of each site follows.

Site # 01 - Cabin Bay - Naked Island. This is a *Laminaria/Agarum* control site. It is located within ADEC segment # NA024. Site is on northern shore of the southern arm, near the point between the northern and southern arms of the bay. A paint mark was placed on a rock above the high tide mark. The substrate is large cobble and boulder. (Note - there is a cobble beach to the east that may be a good collecting spot for clams.)

Site # 02 - Northwest Bay - Eleanor Island. This is a *Laminaria/Agarum* oiled site. It is located within ADEC segment # EL056-D. Site is on the eastern shore of the eastern arm, near a stream in the southern most portion of the bay. A paint mark was placed on a rock above the high tide mark. The substrate is large cobble and boulder. (Note - The site may need to be moved toward the mouth of the bay in order to match the Cabin Bay site better).

Site # 03. - Herring Bay. This is a *Laminaria/Agarum* oiled site. It is located within ADEC segment # KN0132A. Site is on the western shore, about 2/3 down the bay, just south of a salmon stream. The site is marked by a regulatory stream marker, 2 points south of the stream. The middle of the site is to be in the middle of the run just south of the 3rd point south of the stream. The substrate is rock outcrop with some boulders.

Site # 04. - Lower Herring Bay. This is a *Laminaria/Agarum* control site. It is located within ADEC segment # KN0551-A. Site is on the western shore near the start of the western arm of the Bay. The site is marked with a paint mark just to the south of a waterfall. Our site is to be centered 2 points (about 300 m) to the south of the mark. The substrate is rock outcrop.

Site # 05 - Mummy Bay - This is a *Laminaria/Agarum* control site. It is located within ADEC segment # KN0601. Site is on the northwestern shore of Mummy Bay, about 2/3 up the bay. The site is centered in the middle of a plateau that sticks out into the bay, with water falls on either side. The substrate is mostly cobble and boulder. No marks were made.

Site # 06 - Bay of Isles. This is a *Laminaria/Agarum* oiled site. It is located within ADEC segment #'s KN0136-A and KN0004-A. Site is on the southern shore of the bay, near the juncture of the western and southern arms. Center of site is on an outcropping of the eastern most of 2 points, just to the east of a small (30 m long) cobble beach. The substrate at the site is rock bluffs with boulder and cobble. No site marks were made.

Site # 07 - Latouche Pt. This is an oiled *Nereocystis* site. Site is on the southwestern tip of Latouche Island. Site center is about 100 m to the west of a small hooked tip off this point. No site mark was made.

Site # 08 - Procession Rocks, Bainbridge Island. This is a control *Nereocystis* site. Site is near the southern most tip of Bainbridge Island, between the island and Procession rocks. No site mark was made. An on site evaluation and determination of the best match for Latouche needs to be made.

Site # 09 - Zaikof Bay, Montague island. This is a control *Nereocystis* site. Site is on a Pt. on the southern shore of Zaikof Bay, about 2 km from Zaikof Pt. Site center is on the middle of 3 reefs that run offshore about 200 m southeast of a regulatory stream marker next to a large white rock on the bluff. No site mark was made. Substrate at the site is reef outcrop with large boulders.

Site # 10 - Montague Pt., Montague Island. This is an oiled *Nereocystis* site. Site is on the northwest shore of Montague Island near Pt. Montague. The site is directly offshore of a high bluff, just where the bluff falls off the west into a wooded meadow. The site is marked with pink paint on the roots of a spruce tree that appears to be falling from the bluff into the meadow. The site center is 100 m to the west of a razor back reef directly offshore of the mark. Substrate at the site is reef outcrop.

Site # 11 - Dubois Pt., Naked Island. This is a control *Nereocystis* site. Site is a small southerly projection on the southeast shore of Naked Island. There are 2 small islands off the tip of the point. The site center is on the southern tip of the eastern most island. No site mark was made.

Site # 12 - Little Smith Point. This is an oiled *Nereocystis* site. Site is at the southern most tip of Little Smith Island. Site center is a western tip of a small island off the point. No site mark was made.

Site # 13 - Bay of Isles. This is an oiled *Zostera* (eelgrass) site. It is located within ADEC segment # KN0202-A. Site center is 100 m east of a salmon stream, along the southern shore of the western arm of the bay. The substrate is small cobble and silt. No site marks were made.

Site # 14 - Drier Bay (Northeast cove). This is a control *Zostera* (eelgrass) site. It is located within ADEC segment # KN0575-A. Site center is 100 m west of the western most of 2 salmon streams along the southern shore of the cove. Substrate is mixed cobble with softer silt sediment. No site marks were made.

Site # 15 - Lower Herring Bay. This is a control *Zostera* (eelgrass) site. It is located within ADEC segment # KN0551-A. Site is at the mouth of a salmon stream near the northern extreme of the western arm of the bay. No site mark was made. Site center is the salmon stream. The substrate is cobble with silt.

Site # 16 - Herring Bay. This is an oiled *Zostera* (eelgrass) site. It is located within ADEC segment # KN0132B. Site is at the mouth of a salmon stream about 2/3 of the way into the bay on the western shore. Rebar that are painted pink mark an ADEC underwater transect. A site marker (flashing) was placed on a fallen tree just to the north of the site. The substrate at the site is cobble with silt.

Site # 17 - Sleepy Bay, Latouche Island. This is an oiled *Zostera* (eelgrass) site. It is located within ADEC segment #'s LA017-A - LA018-A. Site is in the southern most part of the bay, at the mouth of a salmon stream. The site center is the mouth of the salmon stream. Rebar that are painted pink mark an ADEC underwater transect. No site marks were made.

Site # 18 - Moose Lips Bay - Northeast Montague Island. This is a control *Zostera* (eelgrass) site. Site is in a small embayment due east of the Northern tip of Little Green Island. There are 2 salmon streams at this site. The southern most is an active stream. The northern most dead ends in a marsh behind the cobble berm. The site center is marked with a small buoy placed off the northern most stream, about 200 m from shore. The substrate is mostly silt and sand with some cobble.

Site # 25 - Clammy Bay (Northeastern Naked Island). This is an oiled *Zostera* (eelgrass) site. It is located within ADEC segment # NA006-B."Clammy Bay" is the unofficial name given to this eelgrass site by the field crew. The site is located on the southeastern side of McPherson Passage. The shoreline is covered with unconsolidated cobble and boulders. No streams are in the vicinity, but there is much freshwater from the adjacent steep hillside. Bottom substrate is fine sand to black silt.

Site # 26 - Puffin Bay (Northeastern Storey Island). This is a control *Zostera* (eelgrass). It is located within ADEC segment # ST001."Puffin Bay" is the unofficial name given to this eelgrass site by the field crew. The site is bisected by a small rocky pinnacle outcropping. A cobble beach is present. The substrate is grey compact sand.

Site # 19 - Discovery Point This is an oiled *Laminaria/Agarum* island point site. Site is on the southern entrance to Snug harbor. Site center is on the northern most extension of the point. No site marks were made.

Site # 20 - Lucky Point (What's it called Pt.) This is a control *Laminaria/Agarum* island point site. The site is at the western side of the mouth of Lucky Bay. The island is identified by 2 spruce trees. The site center is on the northwestern most point on the island. No site marks were made.

Site # 21 - Outside Lower Herring Bay (Pt Lyman control). This is a control *Laminaria/Agarum* island point site. Site is centered on the southernmost island off the point. The site center is on the northwestern most point on the island. No site marks were made.

Site # 22 - Outside Herring Bay (Pt. Lyman). This is an oiled *Laminaria/Agarum* island point site. Site is on the western most island off the point, with the site center at the western point of the island. No site marks were made.

Site # 23 - Ingot Pt. This is an oiled *Laminaria/Agarum* island point site. Site is on the southern most point of Ingot Island. Site center is at the middle of the largest island off the point, just west of three smaller islands. No site marks were made.

Site # 24 - Peak Pt. This is a control *Laminaria/Agarum* island point site. Site is on the northern most point of Peak Island. Site center is at the center of the long axis of the largest of three island off the point. No site marks were made.

Site # 27 - Outer Lucky Bay (SW Knight Island). This is a control silled fjord site. It is located within ADEC segment # KN0600-A. This site is located west of Mummy Bay and south of the inner fjord. Rock outcroppings at the south end and submerged rocks at the north end delineate the outer fjord. The substrate is gray silt. The beaches are composed of cobble.

Site # 28 - Herring Bay (NW Knight Island). This is an oiled silled fjord site. It is located within ADEC segment # KN0118-A. This site is located on the east side of Herring Bay; nearly surrounded by high peaks. The substrate is a flocculant gray-black material over silt. The veach is composed of cobble and talus rock.

Site # 29 - Inner Lucky Bay (SW Knight Island). This is a control silled fjord site. It is located within ADEC segment # KN0600-A. This site is located north of Site 27 and only accessible at high tide due to the presence of exposed rocks and rapids at low tide. The substrate is gray silt. The beach is composed of talus from the surrounding peaks. Freshwater enters the fjord from a stream and waterfall.

Site # 30 - Inner Bay of Isles (east Knight Island). This is an oiled silled fjord site. It is located within ADEC segment #'s KN0200-A - KN0201-A. This site is located west of Site 31. The substrate is an admixture of coarse gravel and gray silt. The narrow slate shingle beach is surrounded by a stand of alder. A fresh water stream drains into the fjord from the west.

Site # 31 - Outer Bay of Isles (east Knight Island). This is an oiled silled fjord site. It is located within ADEC segment #'s KN0202-3-A; KN0009-A. The site is located east of Site 30 and separated from the remainder of the bay by a shallow sill and 17 m deep channel. The substrate is a mixture of coarse gravel and gray silt. The beach is composed of cobble and gravel.

Site # 32 - Disk Lagoon (west Disk Island). This is an oiled silled fjord site. It is located within ADEC segment # DI065-A. The site is a small embayment on the west side of Disk Island, connected by three narrow passages to Lower Passage.

Site # 33 - Humpback Cove (western Whale Bay on the mainland of SW Prince William Sound). This is a control silled fjord site. It is located within ADEC segment # WH504. The site is at the western extension of Whale Bay. The substrate is a flocculant dark brown material over silt-clay. "Humpback Cove" is the unofficial name given to the site by the field crew.

Site # 34 - Mallard Bay (southern side of Drier Bay on the western side of Knight Island). This is a control *Zostera* (eelgrass) site. It is located within ADEC segment # KN0575-A. Site center is at the head end of the bay. Substrate is mixed cobble with softer silt sediment. No site marks were made.

Site # 35 - Short Arm (first bay on the south side entering the Bay of Isles). This is an oiled *Zostera* (eelgrass) site. It is located within ADEC segment # KN0206. Site center is at the head end of the bay. Substrate is mixed cobble with softer silt sediment. No site marks were made.

4.0 Sampling in Silled Fjords

An abbreviated survey of silled fjords will be conducted in May and June, 1990. Four sites will be visited and sampled (Herring Bay, Port Audrey Cove, Lucky Bay, and Bay of Isles). Estimates of density of infaunal invertebrates will be obtained from 6 benthic airlift samples (0.1 m^2) taken by divers at random positions along the 20 m depth contour in each of the 4 bays. A small boat with a fathometer will cruise the bay along three transects. The first will extend from the mouth of the bay, along its axis and to the uppermost reaches. A second will be run perpendicular to the first, and a third will be run that bisects the first two. A buoy will be placed at the first and last sounding of 20 m experienced on the transect. A diver will then go to the bottom and place a circular 0.1 m^2 frame 3 m from the buoy anchor in a predetermined random compass direction from anchor. The frame is pushed into the substrate until the frame handles are flush with the seafloor (i.e., 10 cm deep). The sediment within the frame is then vacuumed into a collecting bag attached to the suction device. The vacuum force needed for collection is obtained from a 70 GPM water pump and a 3.8 cm diameter Venturi jet dredge nozzle. The influent side of the dredge nozzle is connected to the pump and the effluent side to a 1.8 m length of 7.6 cm diameter flexible discharge hose, terminating in a 1.0 mm mesh collecting bag. A ball valve is used on the influent line to operate the suction system while the water pump is run at a constant rpm. The sample is considered complete when the sediment is removed to the lower lip of the collecting frame.

A second diver will characterize the bottom using a video. A 20 m transect will be videoed at each sampling site.

Two sediment samples will be taken at each station: one for hydrocarbon analysis and the other for grain size analysis. Each sample will be collected from within 3 m of the buoy anchor. A sample for hydrocarbons will be collected in a wide mouth jar (precleaned ICHEM) by scraping the top 5 cm from the surface of the substrate until the jar is half to three quarters filled. A sample for grain size analysis will taken in the same manner. In addition, at the second sampling station, a sample of the water 0.5 m above the bottom will be taken for hydrocarbon analysis.

A sample of any dead animals will be made (within the limits of safe diving - <20 meters) at each infaunal sampling station within the bay. An attempt will be made to sample at least 5 worms and 1 starfish (the most abundant dead organisms observed in 1989), and any dead fish observed at each sampling station. The invertebrates will be collected and frozen for hydrocarbon analysis. Fish will be dissected and preserved for histological/hydrocarbon analysis.

Upon return to the ship, lids to the hydrocarbon sample jars will be loosened and some water poured off, leaving a 2 cm headspace in order to prevent breakage upon freezing. A water sample will also be collected and analyzed for salinity.

A temperature, salinity, and dissolved oxygen profile will be made in each bay by lowering a temperature/dissolved oxygen probe into the water at the deepest part of the bay and measuring oxygen and salinity at every 1 m interval.

In the Fall, a more extensive survey will be conducted at these, and possibly

2 other sites. Upon arrival at the study site, a bathymetric survey of the bay will be made using a portable fathometer aboard a small inflatable boat and radar aboard the mother ship. Three survey lines will be run. The first will extend from the mouth of the bay, along its axisand to the uppermost reaches. A second will be run perpendicular to the first, and a third will be run that bisects the first two. Depth measurements will be made every 20 m along each line.

We will characterize the bottom using a diver held video camera. Three video transects will be made: One along the long axis of the bay, one along the short axis and through the deepest part of the bay, and one that bisects the short and long axis. The diver will swim along a compass course.

Sampling of sediments and infauna will be the same as in the Spring survey.

5.0. Stratified Sampling in *Laminaria* Habitats in Island Bays and on Island Points

5.1 Station setup

A. Locate the center of the study site. Drop buoys approximately 100 m to either side of the marker. (In cases where the habitat does not extend for 100 m on either side of the center, the distance may be reduced to 50 m). Drop the buoys so that a line connecting them is parallel to the site baseline. Start the skiff approximately 25 m to the right of right buoy and approach the buoy at a constant rate of speed. (Determine left versus right when facing the site from the sea). Record the time required to cover the distance from approximately 30 m from the right buoy to the left buoy. Do not vary the speed of the boat during this operation and maintain a constant distance from shore.

B. Divide the time by 3 (e.g., 7.2/3 = 2.4 Min). Select a random number on the calculator and multiply the two values (e.g., 2.4 X 0.8978 = 2.15 min). Add (Total Time)/3 to the result and 2 (Total Time)/3 to the result. For example, 2.15 min, 2.15+2.4 = 4.55 min, and 4.55+2.4 = 6.95 min are the random starting points at which to start the station transects when measured from the left hand side and traveling at the same speed. Buoys to mark the starting point of each station transect will be dropped at 2.15 min, 4.55 min, and 6.95 min when measured from the left hand side of the site.

C. At each station, a small boat will be driven seaward from nearshore along a course perpendicular to the site baseline, dropping marker buoys at randomly preselected depths in each of the depth strata. The original buoy marking the station transect will be retrieved after the marker buoy is dropped in the first depth stratum. The protocol for random selection of positions for the buoys is: (1) for each station transect select a random number (proportion) between 0.0 and 1.0, (2) multiply the range of depth in each strata by the proportion. For example, if the random proportion is 0.35, the depth (D) in the two depth strata would be:

2-11 m D = 0.35 x 9 m + 2 m = 5.2 m

11-20 m D = 0.35 x 9 m + 11 m = 16.2 m

All depths should be corrected to mean low low water using output from TIDE1 software for the region closest to the sampling site. A schematic of a hypothetical site layout is presented in Appendix Figure A-1.

5.2. Censusing Fish Populations

Two divers swim to the bottom at the deepest of the two marker buoys. Diver # 1 attaches a 30 m fiberglass transect tape to the anchor and swims a 30 m isobathyal sampling transect to the right (facing shore). The diver visually counts fish, by species, within 2 m of the transect line and within 3 m of the bottom. Non-cryptic specimens of echinoderms and crustaceans larger than 10 cm will also be counted in this 2 m by 30 m band.

Diver # 2 swims along the sampling transect from the buoy anchor recording a 2 m by 30 m video transect pointing the camera down toward the substrate.

After a 2 minute wait 3 m off the end of the transect, the divers swim side by side with the transect line between them, each diver counting the number of benthic fishes within a 1 m band on their side of the transect tape. An attempt will be made to count all individuals of length 5 cm or larger.

Following completion of the deepest transect the two divers will move up to the next shallowest marker buoy and repeat the procedure. Identical procedures as described above for the deepest sample transect will be followed at the sample stations in the shallower depth strata.

5.3. Sampling Plant and Epifaunal Invertebrate Populations

Following the fish subsampling at a sampling transect, two divers (#'s 3 and 4) swim down to the marker buoy anchor. At randomly preselected locations on the sampling transect, diver #3 places four large (0.25 m^2) quadrat frames, with the upper left hand corner of the frame on the specified random points.

The quadrats are place on the shoreward side of the sampling transect.

The random positions for the upper left corner of the large quadrats are determined by the following protocol. Multiple 7 m by a random number between 0.0 and 1.0 (proportion) to find the point for the upper left hand corner of the quadrat in the 7.5 m segments with the zero end of each section being closest to the marker buoy. The segment length is reduced from 7.5 m to 7 m before multiplying by the random proportion it insure that the resulting quadrats do not extend off the 30 m sampling transect. For example, if the random proportion is 0.26, the four quadrat locations on the 30 m sample transect would be 1.82, 9.32, 16.82, and 24.32 m.

Diver #3 estimates the amount of algal cover in each of the large quadrats. Diver #3 then clears all macroalgae from each large quadrat, placing the cut pieces in labeled mesh bags. The algae are to be clipped 5 cm above the substrate. *Laminarian* algae smaller than 5 cm are counted. The smaller algae (including small *Laminarians*, leafy reds, and encrusting forms) are to be collected from 1 quadrat at each sampling transect (see invertebrate sampling procedures below). Diver #4 photographs each quadrat using a camera with a 28 mm lens. Six frames are required in order to photograph the entire 50 by 50 cm area in each quadrat. The sequence of photographs in each quadrat is as reading a book, i.e. starting in the upper left hand corner and moving from left to right, when facing the 30 m end of the transect.

Aboard ship, algal samples are separated by species, counted, patted dry. Each plant is weighed individually and its weight recorded. The reproductive condition (either with or without evident sori) of each *Laminarian* species is noted.

Samples of representatives of each canopy species are preserved by placing them in labeled jars with 5% formalin.

5.4. Estimation of Population Parameters for Infaunal Invertebrates

Following completion of the photographic quadrats and algal sampling, two divers (#5 and 6) will go to the sampling transect which still has the 30 m tape and the four large quadrat frames in place. Diver #5 swims the tape until reaching the first quadrat frame and continues to swim until reaching a patch of soft substrate (silt, sand, or small gravel with depth greater than 5 cm.) larger than 0.1 m^2. Diver #5 then vacuums all material within a 0.1 m^2 frame placed in the center of the patch, to a depth of 10 cm, using an airlift sampler. Diver #5 then swims to the second quadrat and repeats the procedure. (Only 2 small quadrats are sampled for benthic infauna at each station transect). Diver #6 collects sediment samples for hydrocarbon and grain size analyses and then rolles up the tape and collects the quadrats on the return swim. At one station per site (#2) Diver #6 also collects a water sample from 0.5 m above the bottom for hydrocarbon and salinity measurement. On board ship all airlift samples will be preserved in 10% buffered (sea water) formalin.

5.5. Physical Measurements

Salinity and temperature will be measured at the middle sampling transect within each depth stratum. Measurements will be made at depths of 0.5 m below the surface, 2 m below the surface, and 0.5 m above the bottom using a YSI temperature/salinity meter.

6.0. Stratified Sampling in *Nereocystis* Habitat

6.1 Station Setup

All *Nereocystis* sampling sites will be marked with a single paint mark on the shore at the center of the site. Set sampling locations as follows: Locate the center marker of the study site. Drop buoys approximately 100 m to either side of the marker. Drop the buoys so that an imaginary line connecting them is parallel to the site baseline, just offshore of any visible kelp canopy. Start the skiff approximately 25 m to the right of the right buoy and approach the buoy at a constant rate of speed. (Determine left versus right when facing the site from the sea). Record the time required to cover the distance from approximately 30 m from the right buoy to the left buoy. Do not vary the speed of the boat during this operation and maintain a constant distance from shore.

Repeat steps B and C as described in 5.1 above to establish 3 stations at each of 2 depth strata. See Appendix Figure A-1 for a hypothetical site layout.

Divers #1 and 2 enter at the buoy on the outer margin of the kelp canopy and drop to the buoy anchor. They then swim a tape from the buoy on a compass course perpendicular to shore until no more canopy forming kelps (*Nereocystis*) are observed. The distance from the buoy to the inner margin of distribution for kelp canopy species is recorded. The divers then swim back the tape to 1/2 the distance to the buoy and mark the station with a pop float. This process is repeated for each transect station, establishing 3 stations per site in the center of the distribution of *Nereocystis*.

6.2 Sampling Fish, Plants, and Invertebrates

Fish, plants, invertebrates, and sediments are sampled at each station as described for *Laminaria* habitats with the following additions.

Along the three station transects within the center of distribution of *Nereocystis*, divers #2 and 3 will count all *Nereocystis* within a 2 m wide band on either side of the transect, and will measure diameters of the stipes of the first 20 *Nereocystis* encountered on each transect. All plants will be measured at a height of 1 m above the bottom. Divers #5 and 6 will obtain an independent sample of 40 *Nereocystis* (at 1 oiled and 1 control site only), and these plants will be weighed and measured to establish a regression between stipe diameter, length, and weight of the plants. These are to be collected outside of the sampling transects, but within 100 m and at the same depths as the sampling transects.

Also, on each of the 3 sampling transects within the *Nereocystis* canopy, canopy fishes will be counted along a 2m x 30 m band at a depth of 2 m. An attempt will be made to count all fish in a 2 m by 3 m column parallel to the surface. Sampling for fishes will be conducted at least 1 hr. after all other survey work has been completed.

7.0 Stratified Sampling in Eelgrass Habitat

7.1 Station Setup

All eelgrass sampling sites will be marked with a single paint mark on the shore at the center of the site. Set sampling locations as follows: Locate the center marker of the study site. Drop buoys approximately 100 m to either side of the marker. Drop the buoys so that an imaginary line connecting them is parallel to the site baseline, just offshore of any visible eelgrass. Snorkeling may be required to identify the outer margin of the eelgrass bed. Start the skiff approximately 30 m to the right of the right buoy and approach the buoy at a constant rate of speed. (Determine left versus right when facing the site from the sea). Record the time required to cover the distance from approximately 30 m from the right buoy to the left buoy. Do not vary the speed of the boat during this operation and maintain a constant distance from shore.

Repeat steps B and C as described in 5.1 above to establish 3 stations at each of 2 depth strata, 3 to 6 m and 6 to 20 m. See Appendix Figure A-2 for a layout of a hypothetical eelgrass site.

Divers #1 and 2 enter at the buoy on the outer margin of the eelgrass bed and drop to the buoy anchor. They then swim a tape from the buoy on a compass course perpendicular to shore until no more eelgrass is observed. The distance from the buoy to the inner margin of distribution eelgrass is recorded. The divers then swim back the tape to 1/2 the distance to the buoy and mark the station with a pop float. This process is repeated for each transect station, establishing 3 stations per site in the center of the distribution of eelgrass.

7.2 Sampling Fish

Within each of the 3 strata on each transect, divers will establish three 30 m long transects running parallel to shore. Divers #1 and 2 enter the water, lay out the tape, and sample fish and large motile invertebrates as described in section 5.2. (Note - A video may be required only on transects within the eelgrass bed).

7.3 Sampling Epifaunal Invertebrate Populations

Epifaunal invertebrates associated with eelgrass will be sampled only along the three sampling transects that lie within the eelgrass zone. Two samples are taken along each of the sampling transects; therefore, six epifaunal samples are collected at each eelgrass site. A 0.5 m^2 drop net will be dropped from a small boat within three meters adjacent to the two random points where infauna is to be collected (see Section 7.5). Once the net is dropped it is pursed and retrieved to the boat. The contents of the net are rinsed into a sample jar, preserved with buffered formalin, and labeled.

7.4 Sampling Eelgrass

Eelgrass will be sampled only along the sampling transect that lies within the eelgrass zone. Divers #3 and 4 will harvest all eelgrass from each of the 4 quadrats per depth stratum. The turions of the plants will be cut approximately 1 cm above the sediment surface. The plants will be bagged underwater and returned to the boat. There, the number of turions per quadrat will be counted, and all turions in each quadrat weighed. In addition, we will note the number of flowering stalks per quadrat, and count the number of seeds per stalk in the first 10 seed stalks encountered per quadrat. (Note - no photographs will be required in the eelgrass habitat.

7.5. Sampling Infaunal Invertebrates

Infaunal invertebrates will be sampled in a 0.1 m^2 airlift sample from each of first two quadrats per station transect. Station transects to be sampled include both those within the eelgrass zone and those outside of the eelgrass. Two sediment samples will be taken to a depth of 5 cm at each sampling transect. One will be used to determine grain size and the other to determine hydrocarbon concentrations.

8.0. Special Notes on Sample Collection for Sediments, Water, and Fish

8.1. Collecting Fishes for Food Habits, Condition Factor and Hydrocarbon Concentration Studies

Following completion of the above sampling, a collection of fishes will be made to assess diets, condition factor, and maximize collection of two species: (1) a commonly occurring benthic feeding species (kelp or whitespotted greenling if possible) and (2) a commonly occurring midwater feeding species (dusky=planktivore or black=piscivore if possible). Twenty to 25 individuals of each species are desired from each site. Fish will be collected at sites at least 50 m from the nearest sampling transect if possible.

Techniques including diver spearing, hook and line fishing, and diver operated hand nets will be used in an attempt to collect fish.

Collected fishes will be measured (fork length) and weighed. Selected tissues and/or organs will be removed and treated as specified in the documents detailing collection and handling of samples for hydrocarbon analyses (State/Federal damage assessment plan, analytical chemistry, collection and handling of samples, August 9, 1989, Auk Bay Lab Attorney Work Product). Tissue samples and organ samples should consist of 1 g per fish for 15 fish. Their stomachs will then be excised and fixed in 10% formalin.

8.2. Collecting Sediment and Bottom Water Samples

Two samples of sediment will be collected at each station transect, 3 m to the right of the buoy anchor. One sample will be used to determine hydrocarbon levels and the other to determine grain size. The following protocol will be followed: Collect sediment by scooping directly into the opened sample container. Scoop to a 5 cm depth to obtain 10- 100 g of sediment (equivalently 4 oz. jars will be filled to just below the shoulder). If sediment is not readily available at the point then collect the closest available material, including small rocks and organic material, along the sampling transect avoiding the locations of study quadrats for plant and animal collections. After returning the jar to the surface, loosen the lid and pour off approximately 2 cm of water to allow room for expansion of the sample upon freezing.

A water sample will be taken at a depth of 0.5 m above the surface at the middle sampling transect within each depth stratum.

All sediment and water samples are to be numbered sequentially, tagged, logged, sealed with evidence tape, and frozen.

All samples collected in the procedures described above will be handled and documented as specified in the protocols for sample accountability and chain of custody.

9.0 Experiments Evaluating Reproductive Success

9.1. Site Selection

All experiments will be conducted at 1 oiled and 1 control site. These will be either in the *Laminaria* habitat within island bays or within eelgrass habitat. The oiled sites will be selected at random from the 3 oiled sites used in the stratified sampling program. The control site will be the location matched with that site.

9.2. Design

- Species and collection sites

Experiments will be conducted with 3 invertebrate species (The blue mussel, Mytilus edulis, one of two clam species, Protothaca, and the starfish Dermasterias) and two plant species (a kelp, *Laminaria* saccharina or Agarum cribrosum, and eelgrass, *Zostera* marina). Mussels, starfish, and kelp will be collected from sites used in stratified sampling for *Laminaria/Agarum* habitat in island bays. Clams and eelgrass will be collected from eelgrass habitat.

- Invertebrate experiments

Twenty individuals of each species will be collected from each of 3 stations per site. We will collect individuals of approximately equal size. Mussels and clams will be collected from 1 m below mean low low water and starfish from 10 m below mean low low water. All samples will be returned to the University of Alaska Marine Laboratory in Seward for analysis. Samples will be collected from oiled and control sites on the same day and flown immediately to the laboratory.

One randomly selected individual per station (3 per site) will be sampled for hydrocarbons. Six individuals per station (18 per site) will be dissected, their body weight determined, and their gonads weighed. The ovaries from 3 females per station (9 per site) will then be fixed, stained, and sectioned for histological analysis. We will determine the developmental stage and the diameter of 100 oocytes per individual.

The remaining 13 individuals from each station will be spawned into individual containers. The eggs from 3 randomly selected females per station (9 per site) will be fertilized with the pooled sperm of 3 randomly selected males per station. Fertilization will take place in containers with filtered seawater placed in a controlled temperature room held at 10 °C. For starfish, 100 eggs will be sampled after 1 hour and the proportion of fertilized eggs noted, as evidenced by the presence of a fertilization membrane. For both starfish and bivalves, 100 individuals per container will be sampled after 48 hours and the proportion of normal larvae noted. A sample of 10 individuals per container will be preserved for later cytogenetic analysis. The cytogenetic analysis will consist of scoring 10 embryos per individual for chromosomal aberrations or the formation of micronuclei.

- *Laminaria/Agarum* experiments

Ten individuals of approximately equal size will be collected from a depth of 10 m at each station (30 individuals per site). The plants will be returned to the laboratory in Seward where the area of the blade and the area of the sorus will be measured. The plants will then be placed into 1 liter jars with filtered seawater and after 1 hour, the number of spores released per plant will be determined. Spores from 3 randomly selected plants per station (9 per site) will be used to make inoculation solutions of known spore density. A separate solution will be made for each plant. The solution will be added to petri dishes (one dish per plant) containing a glass slide. The dishes will be placed in an incubator and held at 10 °C and 451E/m^2/sec of light (continuous exposure). After 48 hours, the slides will be removed and 100 spores examined for germination success.

- Eelgrass experiments

Fifty eelgrass seeds will be sieved from the sediment at each of 3 stations per site. Quantitative airlift samples will be used for seed collection, if possible, in order to obtain an estimate of the density of seeds in the sediments. The seeds will be returned to the laboratory (in Seward) and placed into Petri dishes with filtered seawater (10 ppt) and held in a temperature controlled room at 10 °C. After 1 week, and at daily intervals for the next two weeks, we will determine the number of seeds germinating. All germinated seedlings will be preserved for possible examination of cytogenetic effects.

- Sampling frequency

All organisms used in these studies will be sampled once in 1990. The exact timing of experiments will depend on the reproductive condition of animals and plants. Animals will be checked at the beginning of the study period until sexually mature individuals are present. Based on existing literature, we anticipate that the invertebrates will be at a reproductive peak in late April or early May, that eelgrass will have its peak seed set in late July, and that *Laminaria/Agarum* will be at its peak in August.

10.0 Experiments Evaluating Germination Success of Eelgrass Seeds in Oiled and Unoiled Sediments

10.1. Site Selection

All experiments will be conducted using sediments collected from 1 oiled and 1 control site within the eelgrass habitat. The oiled site will be selected at random from the 3 oiled sites used in the stratified sampling program. The control site will be the location matched with that site.

10.2. Design

Twenty-one sediment cores (7 per station) will be collected from each site. These will be immediately transported (on ice) to the laboratory in Seward. Twelve of the sediments cores will be placed undisturbed into petri dishes (one dish per core) and placed into a flowing seawater bath. Nine cores will be sieved and placed into Petri dishes.

Four hundred fifty eelgrass seeds will be collected from a control site. The seeds will be taken to the laboratory and placed into petri dishes containing sediments. Twenty-five seeds will be placed in each of 18 dishes per site. The remaining three petri dishes (containing unsieved sediments) per site will be used as germination controls to evaluate the presence of naturally occurring seeds. The presence of germinating seeds will be noted daily for a period of 21 days. Any germinating seeds will be removed three days after germination and preserved for possible cytogenetic analysis. There have been no previous attempts to evaluate cytogenetic effects in eelgrass seedlings, so an initial screening of samples will be performed prior to full analysis. At the end of three weeks, a sediment sample will be taken from each dish and preserved for possible hydrocarbon analysis. All sediments in the previously unsieved sediments will be sieved and the number of ungerminated seeds determined.

11.0 Settling Experiments

11.1. Site Selection

All experiments will be conducted at 3 oiled and 3 control sites. These will be in *Laminaria/Agarum* habitat within island bays. The sites will be the same as those used for the stratified sampling program.

11.2. Design

Nine settling surfaces (tiles) will be placed at a depth of 7 m within each site. The tiles will be attached to rebar driven into the bottom and held in a vertical position, with faces parallel to shore, at a depth approximately 10 cm above the bottom. The rebar are to be laid along a line running parallel to shore with rebar spaced at 2 m intervals or greater. The site will be located in the approximate center of the sampling site. The location of the tiles is marked with a small surface float and with 3 subsurface floats spaced at 10 m intervals. The position of the buoy is triangulated using shoreline features and markings (if necessary) and these features are photographed to facilitate relocation of the site if the surface buoy is lost.

After 3 months, the tiles will be photographed and the number of algal sporelings and large benthic invertebrates will be counted. The tiles will be collected and preserved for latter quantification of the number species, and number of individuals (or percent cover) of each species.

12.0. *Agarum* Growth Experiment

12.1. Site Selection

All experiments will be conducted at 3 oiled, 3 control sites. These will be in the *Laminaria/Agarum* habitat within island bays. The sites will be the same as those selected in the stratified sampling program.

12.2. Design

At each island bay site, divers #3 and 4 will enter the water on the temporary buoy used to mark site for settling substrates. Diver #3 will tag 30 *Agarum* plants at each station. The plants will be the first 30 plants observed past the 3 m mark along the transect tape that are between 70 and 90 cm in length. The tape is laid from the buoy to the right (facing shore) and runs parallel to shore. If there are other *Agarum* or *Laminaria* of 70 cm or larger within 25 cm of the selected individual, the surrounding plant(s) will be removed (in order to eliminate potential confounding effects of competition) and additional plants will be selected. Plants will be double tagged by tying numbered surveyors flashing around the stipe of each individual and by placing a numbered tag on a steel spike next to each plant.

Diver #4 will follow Diver # 3 and measure the total length of each tagged plant and will place a small piece of flashing in a hole in the blade of each plant at a distance of 10 cm from the base of the blade.

After the plants are tagged and measured, an additional 30 plants will be collected, measured and weighed to obtain a regression of length vs. weight. After 2 months, the tagged plants will be collected, weighed, and measured. The distance from the base of the blade to the whole will also be measured. Differences in initial weight (estimated by a length weight regression) and final weight will be used to estimate net production (total growth - tissue lost to sloughing/grazing). The differences in distance of the hole from the base of the blade during initial and final measurements will be used to estimate relative gross production.

13.0 Data Analysis

All data will be entered and stored in an "INGRESS" database at the University of Alaska, Fairbanks. Data analyses will be supervised by Dr. Lyman McDonald.

The generic form of analysis for all data gathered will be a comparison of oiled vs control sites using t-tests or nested analyses of variance. In studies where more than one site is sampled, sites will be the primary sampling unit, with various degrees of subsampling within a site. For some experimental studies, there will be no replication of sites, and the primary sampling unit will be stations within sites.

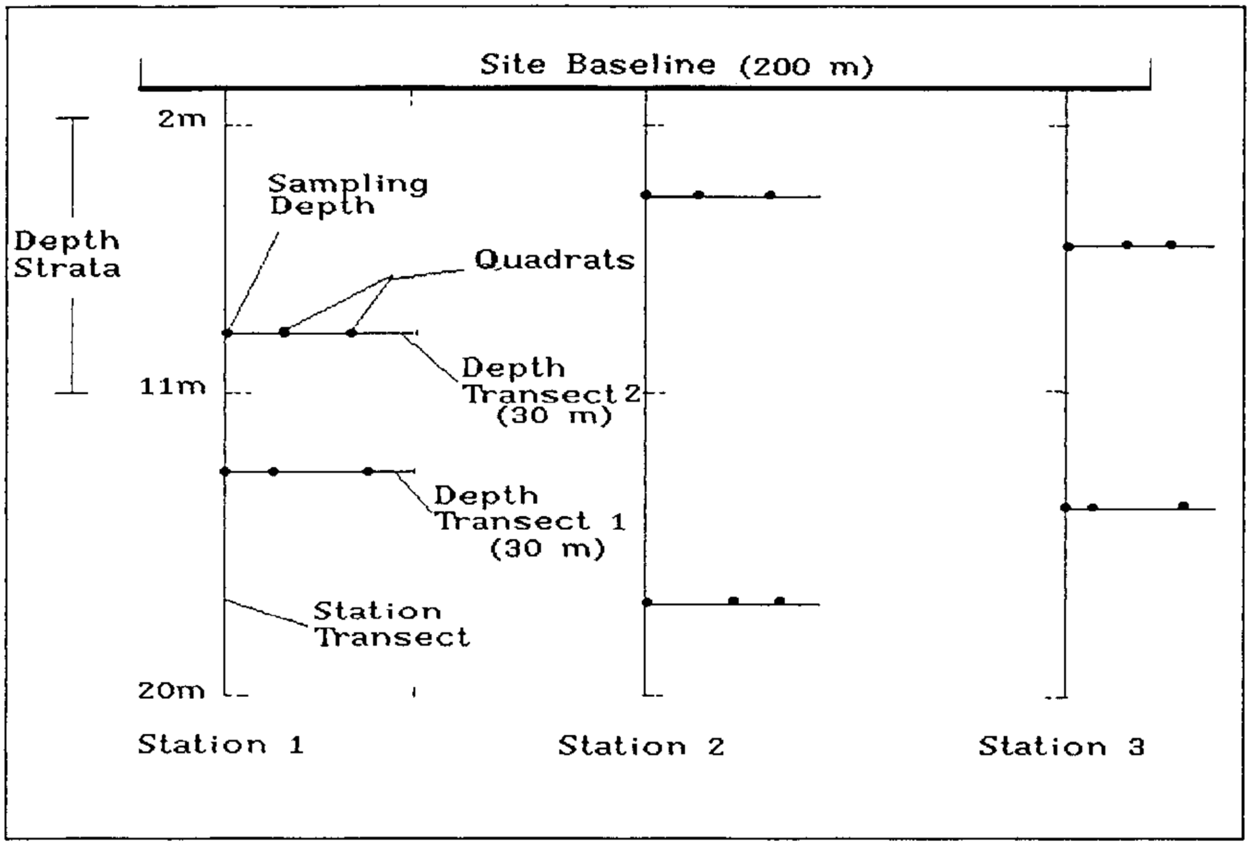
14.0 Schedule

The 1990 field schedule for the subtidal studies is given below.
Sampling schedule for 1990 subtidal studies in Prince William Sound.

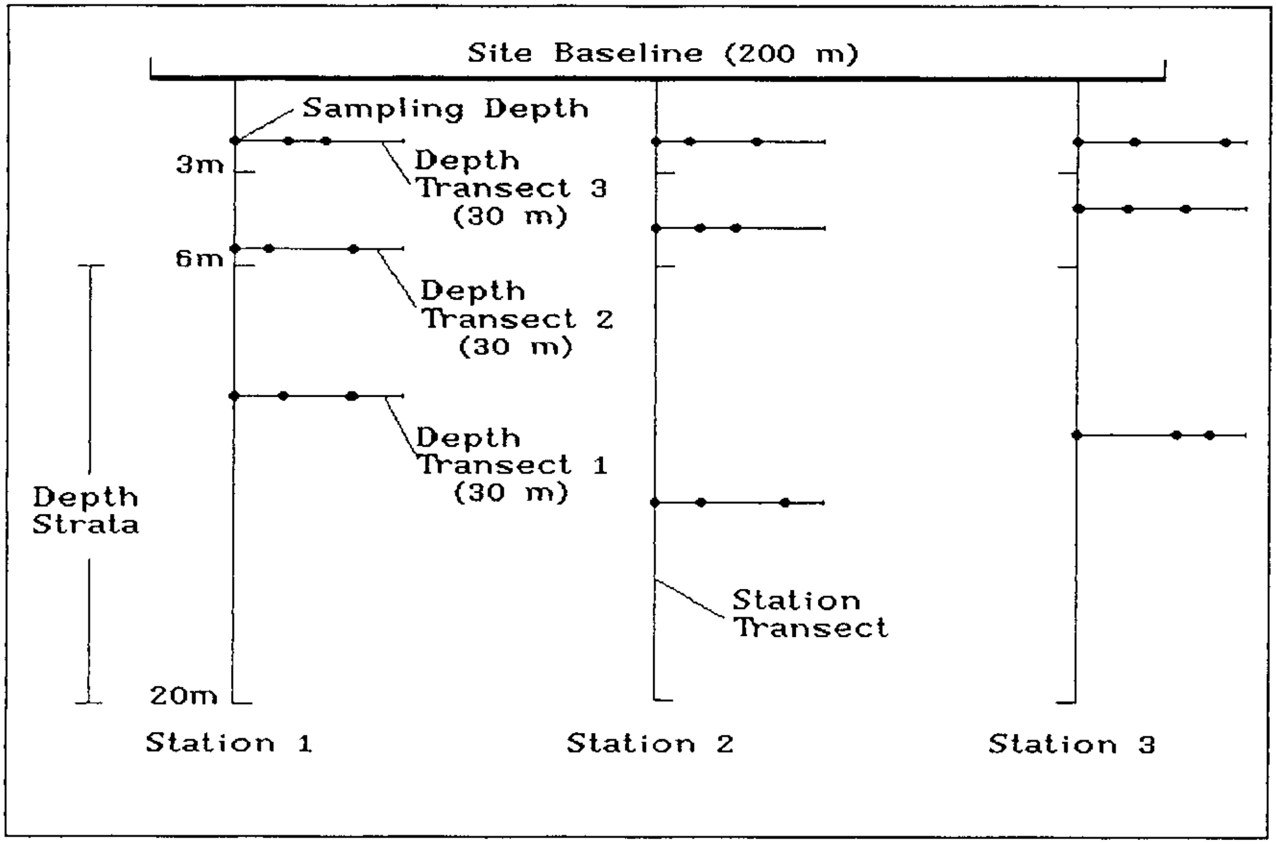
```
l   Apr  l   May   l   Jun   l   Jul   l  Aug  l  Sep  l  Oct  l

    Recon.
    l----l
                   Stratified Sampling
                   I.B.  Ner   Eel  I.P.
                  l-----l-----l----l----l
                                                              Silled Fjords
                                                                l---l
Invert. Experiments.
  l-----------l
                                            Eelgrass Experiments
                                               l------l
                                                   Laminaria Experiments
                                                           l--l
```

I.B. = Island Bays
Eel = Eelgrass
Ner = *Nereocystis*
I.P. = Island Points



Appendix Figure A-1. Hypothetical site layout for sampling in the *Laminaria/Agarum* bay habitat.



Appendix Figure A-2. Hypothetical site layout for sampling in the eelgrass (*Zostera*) habitat.

APPENDIX B.

Paired shallow subtidal study sites in western Prince William Sound, 1990, 1991, and 1993.

APPENDIX B. Paired shallow subtidal study sites in western Prince William Sound, 1990, 1991, and 1993. Study sites within silled fjords are from 1989-91, and 1993; they are not paired.

SITE NAME	SITE NUMBER	OILING STATUS	LATITUDE	LONGITUDE
***LAMINARIA/AGARUM* - ISLAND BAYS**				
Cabin Bay	1	Control	60^{0} 39.5	147^{0} 27.0
Northwest Bay	2	Oiled	60^{0} 33.4	147^{0} 34.6
Lower Herring Bay	4	Control	60^{0} 23.8	147^{0} 48.7
Herring Bay	3	Oiled	60^{0} 26.8	147^{0} 47.1
Mummy Bay	5	Control	60^{0} 13.8	147^{0} 49.0
Bay of Isles	6	Oiled	60^{0} 23.0	147^{0} 42.6
NEREOCYSTIS				
Procession Rocks	8	Control	60^{0} 00.8	148^{0} 16.0
Latouche Point	7	Oiled	59^{0} 57.0	148^{0} 03.3
Zaikof Point	9	Control	60^{0} 18.3	147^{0} 55.0
Montague Point	10	Oiled	60^{0} 22.5	147^{0} 04.8
Naked Island	11	Control	60^{0} 37.5	147^{0} 22.2
Little Smith Island	12	Oiled	60^{0} 31.3	147^{0} 26.0
***ZOSTERA* (EELGRASS)**				
Drier Bay	14	Control	60^{0} 19.2	147^{0} 44.2
Bay of Isles	13	Oiled	60^{0} 23.2	147^{0} 44.5
Lower Herring Bay	15	Control	60^{0} 24.2	147^{0} 48.0
Herring Bay	16	Oiled	60^{0} 26.7	147^{0} 47.2
Moose Lips Bay	18	Control	60^{0} 12.7	147^{0} 18.5
Sleepy Bay	17	Oiled	60^{0} 04.0	147^{0} 50.1
Puffin Bay	26	Control	60^{0} 44.0	147^{0} 25.0
Clammy Bay	25	Oiled	60^{0} 39.1	147^{0} 22.5
Mallard Bay	34	Control	60^{0} 17.2	147^{0} 48.5
Short Arm-Bay of Isles	35	Oiled	60^{0} 22.6	147^{0} 40.0
***LAMINARIA/AGARUM* - ISLAND POINTS**				
Lucky Point	20	Control	60^{0} 13.2	147^{0} 52.7
Discovery Point	19	Oiled	60^{0} 14.9	147^{0} 41.9
Lower Herring Bay	21	Control	60^{0} 24.0	147^{0} 51.0
Herring Bay	22	Oiled	60^{0} 26.6	147^{0} 49.4
Peak Point	24	Control	60^{0} 42.9	147^{0} 21.8
Ingot Point	23	Oiled	60^{0} 28.9	147^{0} 36.5

APPENDIX B. Continued.

SITE NAME	SITE NUMBER	OILING STATUS	LATITUDE	LONGITUDE
SILLED FJORDS				
Herring Bay	28-601	Oiled	60^0 28.1	147^0 42.4
Inner Lucky Bay	29	Control	60^0 13.9	147^0 51.5
Inner Bay of Isles	30	Oiled	60^0 23.0	147^0 45.3
Disk Lagoon	32	Oiled	60^0 29.6	147^0 39.7
Humpback Cove	33	Control	60^0 12.5	148^0 17.5

APPENDIX C.

Stable carbon isotope ratios ($\delta^{13}C$) of Prince William Sound subtidal sediments, subsequent to the EXXON VALDEZ oil spill.

APPENDIX C. Stable carbon isotope ratios ($\delta^{13}C$) of Prince William Sound subtidal sediments, subsequent to the EXXON VALDEZ oil spill.

Introduction

Numerous investigations have demonstrated the usefulness of stable carbon isotope ratios ($\delta^{13}C$) of organics in sediments and waters in identifying marine regions contaminated with petroleum (e.g., Calder and Parker, 1968; Spies and DesMarais, 1983; Anderson *et al.*, 1983; Eganhouse and Kaplan, 1988). The premise in these investigations was that carbon derived from various organic pools has a characteristic $\delta^{13}C$ value, e.g., the $\delta^{13}C$ of terrigenous C3 plants = -25 ‰ (Hong, 1986; Naidu *et al.*, 1992), marine phytodetritus = -21 ‰ (Fry and Sherr, 1984), seagrasses = -10 ‰ (McConnaughey and McRoy, 1979), and Prudhoe Bay crude oil = -30 ‰ (Magoon and Claypool, 1981). In principle, therefore, the $\delta^{13}C$ of marine sediments could, based on an isotope mixing equation (Calder and Parker, 1968; Eganhouse and Kaplan, 1988), help to estimate the proportion in the sediment of organic matter derived from various natural or anthropogenic pools. Based on the above premise, we have attempted to examine the possibility of subtidal sediment contamination by EXXON VALDEZ crude oil in Prince William Sound.

Methods

Organic carbon and nitrogen in bottom sediments were estimated on dry carbonate-free sample powders using the CHN analyzer. All OC/N rations is this report are computed on a weight to weight basis of OC and N. The $\delta^{13}C$ analysis was made by Coastal Science Laboratories, Inc. (Austin, Texas) on carbonate-free sediments, using a VG 602E mass spectrometer. The results are expressed relative to the PDB Standard, with a precison of 0.2 ‰. The mean $\delta^{13}C$ values of the oiled and unoiled samples were statistically compared using the nonparametric Mann-Whitney U Test. Differences between means at $p>0.05$ were considered insignificant.

Results

Analysis of the OC/N ratios indicated that the ratios were significantly greater ($p < 0.05$, t-test) at the oiled sites in two out of four pairs. Both Herring Bay (Site 16) and Sleepy Bay (Site 17) had higher values than their respective controls.

Stable carbon isotope values ($\delta^{13}C$) from 1990 sediments within the eelgrass bed (Appendix I-1) revealed a difference in only one of the four site-depth transect pairs. The values at oiled Herring Bay (16-3) were significantly more negative ($p = 0.01$; Mann-Whitney U Test) than at unoiled Lower Herring Bay (15-3). An insufficient number of samples precluded making the same comparisons for 1991.

Using pooled treatment data, no significant differences ($p > 0.05$) were detected between $\delta^{13}C$ values from oiled and control eelgrass sites in 1990. However, in 1991, the $\delta^{13}C$ values of oiled sediments (-22.2 ‰) were significantly lower ($p = 0.03$) than that of the unoiled sediments (-20.4 ‰).

Discussion

The finding of similar $\delta^{13}C$ values in 1990 sites, was contrary to our expectations. Initially, we postulated that the $\delta^{13}C$ of unoiled sediments in the Sound would be relatively higher (less negative values) than the values for the oiled sediments. We assumed that any marked contamination of sediments from the Sound with Prudhoe Bay crude oil would shift the $\delta^{13}C$ of the oiled sediments to more negative values. The discrepancy between our postulation and the analyzed $\delta^{13}C$ values for unoiled and oiled sediments suggests that oiled sediments were not markedly contaminated with oil. Alternatively, it is possible that petroleum intercalated into the sediments was overwhelmingly diluted by natural organic material (e.g., eelgrass debris). As noted previously, lower $\delta^{13}C$ values were determined for the 1991 oiled sediments, in comparison with unoiled sediments. It is possible that the source of the lower $\delta^{13}C$ values in the 1991 sediments is petroleum from the adjacent heavily-oiled beaches. Perhaps sufficient oil had accumulated in the subtidal region by 1991 so that an isotopic signature of oil could finally be detected there. Thus, it appears that at least some oil reworked from the beaches, either by storm waves or tides, is carried offshore and may accumulate in the subtidal region.

In conclusion, we believe that in Prince William Sound sediments, unless heavily contaminated with petroleum, $\delta^{13}C$ values are of limited use to assess the extent of sediment contamination by crude oil. It is suggested that additional $\delta^{13}C$ analysis, using GC-IRMS, on the methanol and benzene soluble material (e.g., saturated and aromatic hydrocarbons) of oiled and unoiled sediments (Anderson *et al.*, 1983), could provide a more useful index of detecting petroleum contamination of the Prince William Sound sediments than $\delta^{13}C$ analysis on gross organics of sediments.

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APPENDIX D.

Standard operating procedure for laboratory treatment of benthic invertebrate samples from shallow subtidal habitats in Prince William Sound, Alaska, 1990-91, and 1993.

APPENDIX D. Standard operating procedure for laboratory treatment of benthic invertebrate samples from shallow subtidal habitats in Prince William Sound, Alaska, 1990-91, and 1993.

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1. Chain-of-custody forms containing information on all samples received from the field operations are to be stored in a locked file cabinet in Room 118 O'Neill Building, UAF.

2. Preservative for all 0.1 m^2 airlift samples are immediately changed from formalin to 50 % isopropyl alcohol upon arrival in Fairbanks. Samples are then placed in a secure storage area at UAF. Samples are stored in white, air-tight, liquid-tight 5-gallon buckets appropriately labeled for contents. The samples, chain-of-custody forms and field notes containing additional sample-specific information must be retrieved from the locked file cabinet. These notes should be referred to when working up samples.

3. While working under the fume hood, rinse each sample with running water for a few minutes to remove alcohol. Samples should be washed onto a 1 mm-mesh screen and then placed on a sorting tray with sufficient water to cover the sample.

4. All rare, large (>1 cm) organisms are removed from the sample for processing later. The Laboratory Supervisor examines the remaining biota and associated material to determine if subsampling is warranted. If the amount of material to sort is more than one liter or if several thousand organisms are estimated to be present, necessitating numerous hours of processing, then a decision to subsample will be made.

5. Subsampling: Remove all large pieces of debris. Agitate the sample to insure that all animals are randomly dispersed in the pan. Evenly distribute (by spooning) debris among 16 jars (each jar is 6.25% of the whole). Between each spoonful, gently mix the debris to insure random distribution of organisms. To determine the appropriate number of subsamples, randomly select subsamples, count all organisms in each one and calculate the coefficient of variations for two subsamples, three subsamples, etc., through all sixteen subsamples if necessary. The least number of quadrats necessary to give a coefficient of variation 12.5% or less is an appropriate number of subsamples. The coefficient of variation expresses sample variability relative to the mean of the sample. This procedure will be carried out on all samples requiring subsampling. Subsample size (%) will be included on the Benthic Analysis Form for each taxon. For those rare, large organisms removed prior to subsampling the percent subsampled would be 100%.

6. For each sample or subsample, sort all animals to the family level of identification (except for organisms whose identity is known and those that dominate in density or biomass). Place each type into a petri dish of 50% isopropyl alcohol. Counts (see item 7) and blotted-dry wet weights (see item 9) are determined for each taxon and recorded on the laboratory Benthic Analysis Form. This form is filled out in the UAF laboratory during the processing of the 0.1 m^2 airlift samples. A new form is necessary for each

sample and new pages added as needed. Instructions for each field on the sheet follows:

Page:	Begin each sample with page 1.
Date:	The date the sample is analyzed.
Recorder:	The initials of the person filling out the form.
Reviewer:	The initials of the person reviewing the form and the date reviewed.
Site No.:	The number designated to each study site. Copy from sample label. Left justify.
Date:	Date sample was taken (year, month, day).
Station:	One of three randomly-selected lines perpendicular to the site baseline extending from the 0 tide depth out to a depth of 20 m.
Transect:	One of two randomly-selected lines following the depth contour to the right of a station transect.
Depth:	The randomly-selected depths in the two or three depth ranges (<3, 3-6 and 6-20 m) where samples were taken.
Quadrat:	One of two randomly-selected 0.1 m^2 plots along a transect (only quad 1 for 1989 data).
Taxon:	Lowest practical taxonomic level for each organism.
Taxon Code:	A numeric code for each taxon; established by the National Oceanographic Data Center. Left justify.
% Sampled:	The percentage of the sample that was examined for taxonomy, counts and weights. Right justify.
Count:	Total count of taxon group in the sample.
Wet Weight:	Total blotted-dry wet weight in grams (with three places to the right of the decimal) of the taxon.
Individual Length:	Currently not needed, leave blank.

7. Counting of Sample Organisms:

A. Counts whole organisms where possible; fragmented organisms follow the procedures below.

B. Amphipods may be in two parts (head plus pereon, abdomen plus telson). The sum of the numbers of whole amphipods and anterior parts will constitute the total number.

C. The total number of isopods will equal the number of whole organisms plus the number of separate heads.

D. The total number of polychaetes will equal the number of whole organisms plus the number of anterior parts will constitute the total number.

E. The number of whole bivalves plus the number of partial shells (greater than one-half of whole shell) will constitute the total number of bivalves.

F. Since bryozoans and hydroids are colonial forms and are typically fragmented their presence in a sample only receives a count of one.

8. Calibration: The Mettler PM200 electronic balance will be calibrated by a Mettler serviceman within 60 days prior to the initiation of weighing samples. Calibration checks will be made monthly by the Laboratory Supervisor using standard NBS traceable weights.

9. The wet weight of each taxonomic group and/or species is determined using a Mettler PM200 (0.001-200 g) balance. Working with one taxonomic group and/or species at a time, organisms are first transferred onto absorbent, bibulous paper and blotted until the paper fails to absorb more moisture (approximately 1-2 minutes), and then weighed. The weights are entered onto the data sheets. Taxon weighing <0.001 g will be recorded as 0.0005 g.

10. A collection of voucher specimens is made as a reference for all identifications to the genus and/or species. These specimens will be maintained by UAF.

11. In order to assure accuracy and consistency in processing the samples, systematic quality control checks are performed by the project's Laboratory Supervisor. Quality control checks will not be performed by the same individual who originally processed the sample. Approximately five percent of the samples will be rechecked. Discrepancies in the categories of identification, weight, and count shall not exceed three percent in each category. If they do, another one percent will be checked. If these are also out of compliance, then all samples to date will be reanalyzed.

12. After lab analyses are completed, each group and/or species is put into a vial with an appropriate label. All vials are put together by sites with the field tag. These samples are securely stored at UAF.

APPENDIX E.

Polycyclic aromatic hydrocarbons (SUMMED PAH) analyzed from sediments of shallow subtidal Prince William Sound study sites.

APPENDIX E. Polycyclic aromatic hydrocarbons (SUMMED PAH) analyzed from sediments of shallow subtidal Prince William Sound study sites. These represent PAHs from various sources, including EXXON VALDEZ crude oil, other petroleum products, and biogenic sources. The list of EV PAH represents PAHs most characteristic of weathered EXXON VALDEZ crude oil (source: TSTF/ACG, NOAA/NMFS, Auke Bay, Alaska).

SUMMED PAH	EV PAH
Naphthalene	Naphthalene
1-methylnaphthalene	1-methylnaphthalene
2-methylnaphthalene	2-methylnaphthalene
C-2 naphthalenes	C-2 naphthalenes
C-3 naphthalenes	C-3 naphthalenes
C-4 naphthalenes	C-4 naphthalenes
Fluorene	Fluorene
C-1 fluorenes	C-1 fluorenes
C-2 fluorenes	C-2 fluorenes
C-3 fluorenes	C-3 fluorenes
Phenanthrene	Phenanthrene
C-1 phenanthrenes	C-1 phenanthrenes
C-2 phenanthrenes	C-2 phenanthrenes
C-3 phenanthrenes	C-3 phenanthrenes
C-4 phenanthrenes	C-4 phenanthrenes
Dibenzo(b,d)thiophene	Dibenzo(b,d)thiophene
C-1 dibenzo(b,d)thiophenes	C-1 dibenzo(b,d)thiophenes
C-2 dibenzo(b,d)thiophenes	C-2 dibenzo(b,d)thiophenes
C-3 dibenzo(b,d)thiophenes	C-3 dibenzo(b,d)thiophenes
Chrysene	Chrysene
C-1 chrysenes	C-1 chrysenes
C-2 chrysenes	C-2 chrysenes
C-3 chrysenes	
C-4 chrysenes	
C-1 fluoranthenes	C-1 fluoranthenes
Biphenyl	Biphenyl
Acenaphthylene	
Anthracene	
Acenaphthene	
Fluoranthene	
Pyrene	
Benzo (a) anthracene	
Benzo (b) fluoranthene	
Benzo (k) fluoranthene	
Benzo (e) pyrene	
Benzo (a) pyrene	
Perylene*	
Indeno (1,2,3-c,d) pyrene	
Dibenzo (a,h) anthracene	
Benzo (g,h,i) perylene	

* Perylene is derived from biogenic sources.

APPENDIX F.

Mean values for different eelgrass attributes at oiled and control sites, and probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix F. Mean values for different eelgrass attributes at oiled and control sites, and probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Eelgrass Bed - 1990 Depth = Bed

Pair	Site#	Oil Code	Plant Density (#/m^2)	Blade Density (#/m^2)	Biomass (gm/m^2)	Flower Density (#/m^2)	Seed Pods/ Flower	Seed Pod Density (#/m^2)	Seed Density (#/m^{2}sed)
1	13	O	110.00	618.00	821.33	6.33	9.66	53.33	472.00
1	14	C	172.67	921.67	1136.00	9.00	6.09	70.67	136.00
2	16	O	197.67	910.67	1450.67	0.00	.	0.00	50.67
2	15	C	279.00	1461.00	1096.00	13.00	9.93	113.33	261.33
3	17	O	140.33	748.00	1321.33	2.67	7.33	25.67	2.67
3	18	C	119.33	658.33	1084.67	4.33	6.94	38.33	9.33
4	25	O	160.00	690.67	1031.00	2.33	10.56	27.00	10.67
4	26	C	230.33	904.67	1613.00	2.67	16.42	40.67	1.33
	mean	O	152.00	741.83	1156.08	2.83	9.18	26.50	134.00
	mean	C	200.33	986.42	1232.42	7.25	9.84	65.75	102.00
	P		0.08	0.051	0.63	0.055	0.99	0.09	0.74

Eelgrass Bed - 1991 Depth = Bed

Pair	Site#	Oilcode	Plant Density (#/m^2)	Flower Density (#/m^2)
1	13	O	137.33	1.50
1	14	C	141.33	1.12
2	16	O	183.67	1.11
2	15	C	229.00	4.40
3	17	O	112.67	2.97
3	18	C	173.33	1.68
4	25	O	189.33	1.63
4	26	C	141.67	1.77
5	35	O	126.33	1.37
5	34	C	107.67	0.93
	mean	O	149.87	1.72
	mean	C	158.60	1.98
	P		0.52	0.60

APPENDIX G.

Macroalgal species collected in shallow subtidal habitats in Prince William Sound, 1990.

APPENDIX G. Macroalgal species collected in shallow subtidal habitats in Prince William Sound, 1990.

Species	Collection Site	ID Status
CHLOROPHYTA		
Acrosiphonia sp.	Little Smith Island	Confident
Cladophora seriacea	Lower Herring Bay	Tentative
Cladophora sp.	Ingot Pt.	Tentative
Derbesia marina	Bay of Isles	Positive
Enteromorpha sp.	Bay of Isles	Tentative
Monostroma sp.	Bay of Isles	Tentative
Ulva fenestrata	Peak Pt.	Tentative
Ulva sp.	Lower Herring Bay	Confident
Ulvaria obscura	Little Smith Island	Tentative
PHAEOPHYTA		
Agarum cribosum	Peak Pt.	Positive
Alaria marginata	Peak Pt.	Positive
Alaria sp.	Little Smith Island	Positive
Chordaria flagelliformis	Sleepy Bay	Positive
Costaria costata	Peak Pt.	Positive
Cymathere triplicata	Northwest Bay	Positive
Cystoseira geminata	Peak Pt.	Positive
Desmarestia aculeata	Little Smith Island	Positive
Desmarestia ligulata	Peak Pt.	Positive
Desmarestia viridis	Peak Pt.	Positive
Dictysiphon foeniculaceus	Sleepy Bay	Positive
Eudesme virescens	Sleepy Bay	Positive
Laminaria dentigera	Zaikof Pt.	Tentative
Laminaria groenlandica	Zaikof Pt.	Positive
Laminaria saccharina	Bay of Isles	Positive
Laminaria yezoensis	Peak Pt.	Positive
Macrocystis sp.	Northwest Bay	Positive
Nereocystis luetkeana	Zaikof Pt.	Positive
Omphallophyllum ulvaceum	Peak Pt.	Positive
Omphallophyllum ulvoideum	Herring Bay	Positive
Pilayella littoralis	Herring Bay	Positive
Pleurophycus gardneri	Little Smith Island	Positive
Punctaria lobata	Sleepy Bay	Positive
Ralfsia fungiformis	Cabin Bay	Positive
Soranthera ulvoidea	Ingot Pt.	Confident
Sphacelaria rigidula	Peak Pt.	Positive

RHODOPHYTA

Ahnfeltia fastigiata	Peak Pt.	Positive
Callophyllis sp.	Mummy Bay	Positive
Callophyllis violacea	Herring Bay	Tentative
Chondrus sp.	Peak Pt.	Positive
Clathromorphum sp.	Peak Pt.	Positive
Constantinea simplex	Latouche Pt.	Tentative
Constantinea subulifera	Discovery Pt.	Positive
Corallina officinalis	Latouche Pt.	Positive
Cryptopleura ruprechtiana	Latouche Pt.	Positive
Euthora cristata	Peak Pt.	Positive
Halosaccion americanum	Lower Herring Bay	Positive
Membranopotera dimorpha	Latouche Pt.	Positive
Mikamiella ruprechtiana	Latouche Pt.	Positive
Neoptilota aspleniodes	Latouche Pt.	Positive
Neorhodomela aculeata	Peak Pt.	Positive
Neorhodomela oregona	Latouche Pt.	Positive
Neorhodomela sp.	Lower Herring Bay	Confident
Odonthalia floccosa	Little Smith Island	Positive
Odonthalia setacea	Little Smith Island	Positive
Odonthalia sp.	Peak Pt.	Positive
Opuntiella californica	Latouche Pt.	Positive
Phyllophora truncata	Lower Herring Bay	Confident
Platythamnion pectinatum	Lucky Bay	Positive
Polysiphonia pacifica	Peak Pt.	Positive
Porphyra nereocystis	Little Smith Island	Tentative
Pterosiphonia hamata	Peak Pt.	Tentative
Ptilota filicina	Herring Bay	Confident
Ptilota sp.	Peak Pt.	Positive
Pugetia fragilissima	Lower Herring Bay	Positive
Rhodymenia pertusa	Latouche Pt.	Positive
Scagelia pylaisaei	Peak Pt.	Positive
Stenogramma interrupta	Lower Herring Bay	Confident
Tayloriella sp.	Peak Pt.	Tentative
Thuretellopsis peggiana	Discovery Pt.	Positive
Weeksia coccinea	Herring Bay	Positive

APPENDIX H.

Mean values for percent cover, density, biomass of dominant macroalgal species at oiled and control sites in *Laminaria/Agarum* bay, *Laminaria/Agarum* point, and *Nereocystis* habitats in 1990 and 1991. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix H. Mean values for percent cover, density, and biomass of dominant macroalgal species at oiled and control sites in *Laminaria/Agarum* bay, *Laminaria/Agarum* point, and *Nereocystis* habitats in 1990. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Island Bay - 1990 Depth = Deep

Pair	Site#	Oilcode	*Agarum* DENSITY (#/m^2)	*Agarum* % COVER	*Agarum* BIOMASS (gm/m^2)	*L. sac.* DENSITY (#/m^2)	*L. sac.* % COVER	*L. sac.* BIOMASS (gm/m^2)
1	2	O	3.33	24.58	217.33	1.33	8.33	64.67
1	1	C	2.67	17.50	519.67	0.00	1.67	0.00
2	3	O	5.67	21.08	228.00	0.67	6.42	210.00
2	4	C	5.67	27.33	410.00	0.00	0.00	1.33
3	6	O	4.67	20.50	435.00	1.00	13.75	4.67
3	5	C	3.33	51.25	657.33	0.00	0.00	0.00
	mean	O	4.56	22.06	293.44	1.00	9.50	93.11
	mean	C	3.89	32.03	529.00	0.00	0.56	0.44
	P		0.69	0.31	0.26	0.00	0.04	0.00

Island Bay - 1990 Depth = Shallow

Pair	Site#	Oilcode	*Agarum* DENSITY (#/m^2)	*Agarum* % COVER	*Agarum* BIOMASS (gm/m^2)	*L. sac.* DENSITY (#/m^2)	*L. sac.* % COVER	*L. sac.* BIOMASS (gm/m^2)
1	2	O	2.00	10.00	148.00	5.33	49.58	533.00
1	1	C	11.33	66.08	1877.33	0.00	2.08	0.00
2	3	O	10.33	64.75	1437.67	1.33	8.33	437.67
2	4	C	9.67	37.92	1071.33	1.33	7.50	728.33
3	6	O	8.33	17.92	523.00	4.33	45.50	317.00
3	5	C	5.67	51.25	1389.00	1.33	17.50	230.67
	mean	O	6.89	30.89	702.89	3.67	34.47	429.22
	mean	C	8.89	51.75	1445.89	0.89	9.03	319.67
	P		0.48	0.25	0.16	0.03	0.04	0.71

Island Point - 1990 Depth = Deep

Pair	Site#	Oilcode	*Agarum* DENSITY (#/m²)	*Agarum* % COVER	*L. sac.* DENSITY (#/m²)	*L. sac.* % COVER	*L. groen.* DENSITY (#/m²)	*L. groen.* % COVER	*L. yez.* >=10cm DENSITY (#/m²)
1	19	O	10.00	31.25	2.67	8.42	0.00	0.00	0.00
1	20	C	5.67	43.00	0.33	18.00	0.00	0.00	0.00
2	22	O	18.33	30.58	2.33	22.58	0.67	0.00	0.00
2	21	C	2.67	44.67	2.00	5.25	0.00	0.00	0.00
3	23	O	15.67	31.00	0.67	1.92	0.33	0.42	0.00
3	24	C	4.33	16.42	12.00	7.50	0.00	0.00	0.33
	mean	O	14.67	30.94	1.89	10.97	0.33	0.14	0.00
	mean	C	4.22	34.69	4.78	10.25	0.00	0.00	0.11
	P		0.02	0.72	0.26	0.90	.	.	.

Island Point - 1990 Depth = Deep (continued)

Pair	Site#	Oilcode	*Agarum* BIOMASS (gm/m²)	*L. sac.* BIOMASS (gm/m²)	*L. groen.* BIOMASS (gm/m²)	*L. yez.* BIOMASS (gm/m²)
1	19	O	295.33	17.33	0.00	0.00
1	20	C	792.33	599.00	0.00	0.00
2	22	O	849.33	293.33	31.33	0.00
2	21	C	366.67	4.67	0.00	0.00
3	23	O	797.33	3.33	144.33	0.00
3	24	C	176.33	79.00	0.00	11.00
	mean	O	647.33	104.67	58.56	0.00
	mean	C	445.11	227.56	0.00	3.67
	P		0.45	0.80	0.00	.

Island Point - 1990 Depth = Shallow

Pair	Site#	Oilcode	*Agarum* DENSITY (#/m²)	*Agarum* % COVER	*L. sac.* DENSITY (#/m²)	*L. sac.* % COVER	*L. groen.* DENSITY (#/m²)	*L. groen.* % COVER	*L. yez.* >=10cm DENSITY (#/m²)
1	19	O	28.00	46.33	42.00	21.00	1.67	4.42	0.33
1	20	C	6.33	67.08	0.67	10.42	0.00	0.00	0.00
2	22	O	23.33	35.83	3.33	55.33	0.00	0.00	0.00
2	21	C	12.33	38.83	9.33	34.58	1.67	3.33	0.33
3	23	O	26.00	47.08	1.67	7.92	8.33	15.42	1.33
3	24	C	16.33	17.25	145.67	8.67	21.00	31.42	5.00
	mean	O	25.78	43.08	15.67	28.08	3.33	6.61	0.56
	mean	C	11.67	41.06	51.89	17.89	7.56	11.58	1.78
	P		0.06	0.85	0.49	0.22	0.24	0.59	0.07

Island Point - 1990 Depth = Shallow (continued)

Pair	Site#	Oilcode	*Agarum* BIOMASS (gm/m^2)	*L. sac.* BIOMASS (gm/m^2)	*L. groen.* BIOMASS (gm/m^2)	*L. yez.* BIOMASS (gm/m^2)
1	19	O	866.33	465.33	245.33	0.67
1	20	C	1694.67	52.33	0.00	0.00
2	22	O	1098.00	928.33	0.00	0.00
2	21	C	1097.33	1413.33	186.33	7.67
3	23	O	985.00	330.67	707.33	64.67
3	24	C	467.33	9.33	2557.67	257.67
	mean	O	983.11	574.78	317.56	21.78
	mean	C	1086.44	491.67	914.67	88.44
	P		0.80	0.75	0.28	0.13

Nereocystis Bed - 1990 Algae Density (#/m^2) Depth = Shallow

Pair	Site#	Oilcode	*Agarum*	*L. gro.*	*L. sac.*	*L. yez.*	*Pleuro*
1	7	O	0.33	39.00	0.00	0.33	3.33
1	8	C	0.00	131.00	0.00	0.67	12.00
2	12	O	8.80	252.40	0.00	8.80	0.80
2	11	C	5.83	46.83	0.83	13.50	1.33
	mean	O	4.57	145.70	0.00	4.57	2.07
	mean	C	2.92	88.92	0.42	7.08	6.67
	P		0.19	0.14	0.17	0.74	0.44

Nereocystis Bed - 1990 Algae Percent Cover Depth = Shallow

Pair	Site#	Oilcode	*Agarum*	*L. gro.*	*L. sac.*	*L. yez.*	*Pleuro*
1	7	O	0.00	81.67	0.00	0.17	1.75
1	8	C	0.00	33.17	0.00	0.00	22.17
2	12	O	19.80	31.45	0.00	7.95	1.30
2	11	C	0.00	66.21	0.21	13.33	0.00
	mean	O	9.90	56.56	0.00	4.06	1.52
	mean	C	0.00	49.69	0.10	6.67	11.08
	P		.	0.78	0.39	0.69	0.26

Nereocystis Bed - 1990 Algae Biomass (gm/m^2) Depth = Shallow

Pair	Site#	Oilcode	*Agarum*	*L. gro.*	*L. sac.*	*L. yez.*	*Pleuro*
1	7	O	14.67	3191.33	0.00	0.00	279.44
1	8	C	0.00	1825.67	0.00	55.33	1225.67
2	12	O	554.40	2279.20	0.00	406.20	20.60
2	11	C	63.67	4483.17	23.83	1496.83	21.67
	mean	O	284.53	2735.27	0.00	203.10	150.02
	mean	C	31.83	3154.42	11.92	776.08	623.67
	P		0.00	0.39	0.17	0.40	0.15

Nereocystis Stipe Density & Diameter
Nereocystis Bed - 1990 Depth = Shallow

Pair	Site#	Oilcode	DENSITY (#/100m^2)	STIPE DIAMETER (mm)
1	7	O	53.06	7.25
1	8	C	12.78	11.52
2	12	O	89.33	7.24
2	11	C	7.36	9.12
	mean	O	71.19	7.24
	mean	C	10.07	10.32
	P		0.007	0.096

APPENDIX I.

Granulometric composition of surficial sediments from subtidal habitats in western Prince William Sound, Alaska, Summer 1990, 1991, and 1993.

Appendix I-1. Granulometric composition, organic carbon (OC), nitrogen (N), OC/N ratios and stable carbon isotope ratios ($\delta^{13}C$) of surficial sediments from *Zostera* (eelgrass) habitats in western Prince William Sound, Alaska, Summer 1990.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz Mean	δ Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Bay of Isles Site (13)	Oiled	1	1	gs16	0.00	13.62	44.79	41.59	86.38	7.52	2.82	51.63	7.92	6.50	
		2	1	gs17	0.00	2.05	48.51	49.44	97.95	8.25	2.33	58.08	9.05	6.40	-22.10
		3	1	gs18	0.00	3.44	41.68	54.89	96.57	9.07	2.39	59.93	9.46	6.30	
				Mean	0.00	6.37	44.99	48.64	93.63	8.28	2.51	56.55	8.81	6.40	
		1	2	gs19	0.00	4.96	43.28	51.77	95.05	8.33	2.46	57.16	7.73	7.40	
		2	2	gs20	0.00	3.46	38.13	58.41	96.54	8.80	2.44	63.08	7.46	8.50	
		3	2	gs21	0.00	7.02	45.28	47.70	92.98	8.03	2.57	50.26	6.90	7.30	
				Mean	0.00	5.15	42.23	52.63	94.86	8.39	2.49	56.83	7.36	7.73	
		1	3	gs22	0.00	2.51	19.15	78.34	97.49	9.42	2.37	63.45	10.61	6.00	-18.20
		2	3	gs23	0.00	2.52	24.00	73.49	97.49	9.37	2.66	86.07	5.73	15.00	-24.10
		3	3	gs24	0.00	0.31	47.08	52.62	99.70	7.50	2.43	48.60	7.50	6.50	-22.30
				Mean	0.00	1.78	30.08	68.15	98.23	8.76	2.49	66.04	7.95	9.17	-21.53
Drier Bay Site (14)	Control	1	1	gs25	0.00	67.49	27.00	5.51	32.51	3.87	1.44	34.29	3.26	10.50	
		2	1	gs26	38.86	33.87	19.44	7.83	27.27	1.83	3.56	22.72	2.96	7.70	-21.90
		3	1	gs27	0.00	68.18	22.32	9.50	31.82	3.63	3.19	13.43	2.13	6.30	
				Mean	12.95	56.61	22.92	7.61	30.53	3.11	2.73	23.48	2.78	8.17	
		1	2	gs28	0.00	38.84	43.51	17.65	61.16	5.83	3.25	17.02	2.50	6.80	
		2	2	gs29	79.54	17.54	1.53	1.67	3.20	-3.80	3.49	1.94	0.28	6.90	
		3	2	gs30	40.17	41.92	8.33	9.58	17.91	0.13	4.35	8.31	0.98	8.50	
				Mean	39.90	32.77	17.79	9.63	27.42	0.72	3.70	9.09	1.25	7.40	
		1	3	gs31	0.00	18.18	36.53	45.30	81.82	7.45	3.13	40.43	4.65	8.70	-20.40
		2	3	gs32	3.27	16.25	55.67	25.82	80.49	6.50	3.39	35.08	5.67	6.20	-20.40
		3	3	gs33	0.00	3.93	39.80	56.27	96.08	8.93	2.82	51.93	8.31	6.20	-17.90
				Mean	1.09	12.79	44.00	42.46	86.13	7.63	3.11	42.48	6.21	7.03	-19.57

[1]Depth Transects 1 = 6-20 m, 2 = 3-6 m, 3 = < 3 m [2]Silt and clay

Appendix I-1. *Continued.*

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz Mean	δ Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Herring Bay Site (16)	Oiled	1	1	gs61	22.53	46.65	20.37	10.45	30.82	2.43	3.59	7.69	0.81	9.50	-23.00
		2	1	gs63[3]								6.22	0.56	11.10	
		3	1	gs65	11.39	76.24	7.38	5.00	12.38	0.18	2.59	10.01	0.83	12.10	
				Mean	16.69	61.45	14.19	7.73	21.60	1.31	3.09	7.97	0.73	10.90	
		1	2	gs62	0.00	86.42	5.53	8.06	13.59	2.72	2.07	7.43	0.69	10.70	
		2	2	gs64	58.64	33.38	1.38	6.60	7.98	-1.92	4.91	5.45	0.48	11.40	
		3	2	gs66	74.62	15.13	4.36	5.90	10.26	-3.53	4.63	0.91	0.15	6.00	
				Mean	44.42	44.98	3.76	6.85	10.61	-0.91	3.87	4.60	0.44	9.37	
		1	3	gs67	23.62	60.09	7.70	8.59	16.28	1.10	4.94	9.12	0.77	11.80	-20.70
		2	3	gs68	3.35	86.60	2.34	7.72	10.06	2.03	2.06	4.35	0.45	9.70	-21.40
		3	3	gs69	0.00	69.28	13.38	17.34	30.72	5.20	3.35	19.92	1.93	10.30	-21.00
				Mean	8.99	71.99	7.81	11.22	19.02	2.78	3.45	11.13	1.05	10.60	-21.03
Lower Herring Bay Site (15)	Control	1	1	gs52	57.45	34.86	3.34	4.34	7.68	-1.87	4.26	13.06	1.31	10.00	
		2	1	gs53	0.00	41.39	27.46	31.15	58.61	6.08	3.34	52.38	5.21	10.10	-23.00
		3	1	gs54	52.06	26.34	7.03	14.58	21.61	0.98	3.91	9.50	1.02	9.30	
				Mean	36.50	34.20	12.61	16.69	29.30	1.73	3.84	24.98	2.51	9.80	
		3	2	gs55	94.11	0.71	5.18	0.00	5.18	-1.88	1.29	0.52	0.11	4.70	
		2	2	gs56	69.22	16.84	3.08	10.87	13.95	-0.23	3.37	5.54	0.56	9.90	
		1	2	gs57	93.65	0.52	1.66	4.16	5.82	-1.88	1.62	12.11	1.97	6.11	
				Mean	85.66	6.02	3.31	5.01	8.32	-1.33	2.09	6.06	0.88	6.90	
		1	3	gs58	4.87	6.23	30.73	58.17	88.90	8.67	3.42	77.49	11.73	6.60	-16.20
		2	3	gs59	9.76	10.79	46.70	32.74	79.44	5.97	4.62	62.81	7.39	8.50	-18.90
		3	3	gs60	0.00	5.00	14.10	80.40	94.50	9.63	2.38	108.92	11.51	9.50	-17.50
				Mean	4.88	7.34	30.51	57.10	87.61	8.09	3.47	83.07	10.21	8.20	-17.53

[1]Depth Transects 1 = 6-20 m, 2 = 3-6 m, 3 = < 3 m [2]*Silt and clay* [3]Insufficient quantity for complete analyses.

Appendix I-1. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz Mean	δ Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Sleepy Bay	Oiled	1	1	gs34	0.00	83.03	12.66	4.31	16.97	3.17	1.29	7.65	1.18	6.50	
Site (17)		2	1	gs35	0.00	90.97	3.24	5.80	9.04	2.52	1.89	8.76	1.15	7.60	-23.60
		3	1	gs36	0.00	92.19	3.51	4.29	7.81	2.47	1.39	5.90	0.76	7.80	
				Mean	0.00	88.73	6.47	4.80	11.27	2.72	1.52	7.44	1.03	7.30	
		1	2	gs37	0.14	90.39	5.30	4.18	9.48	2.85	1.08	7.60	0.79	9.60	
		2	2	gs38	0.00	99.21	0.74	0.00	0.74	2.32	0.62	4.55	0.60	7.60	
		3	2	gs39	0.00	97.69	2.31	0.00	2.31	2.65	0.81	4.40	0.64	6.90	
				Mean	0.05	95.76	2.78	1.39	4.18	2.61	0.84	5.52	0.68	8.03	
		1	3	gs40	0.44	86.23	9.68	3.64	13.33	2.78	1.08	5.03	0.94	5.40	-21.10
		2	3	gs41	0.18	94.12	2.19	3.50	5.69	2.32	0.88	3.94	0.67	5.80	-22.80
		3	3	gs42	0.28	98.80	0.93	0.00	0.93	1.88	0.72	5.11	0.60	8.50	-23.00
				Mean	0.30	93.05	4.27	2.38	6.65	2.33	0.89	4.69	0.74	6.57	-22.30
Moose Lips	Control	1	1	gs43	0.00	62.86	33.03	4.10	37.14	4.07	1.05	5.81	0.85	6.80	
Bay		2	1	gs44	0.00	40.99	40.88	18.13	59.01	5.85	3.30	5.30	1.00	5.30	-22.10
Site (18)		3	1	gs45	0.00	60.14	34.47	5.39	39.86	4.03	1.42	3.76	0.55	6.80	
				Mean	0.00	54.66	36.13	9.21	45.34	4.65	1.92	4.96	0.80	6.30	
		1	2	gs46	0.00	85.00	15.00	0.00	15.00	3.42	0.68	3.36	0.49	6.90	
		2	2	gs47	0.00	85.34	11.11	3.55	14.66	3.10	0.93	3.55	0.58	6.10	
		3	2	gs48	14.12	78.45	4.86	2.57	7.43	1.80	2.65	2.56	0.44	5.80	
				Mean	4.71	82.93	10.32	2.04	12.36	2.77	1.42	3.16	0.50	6.27	
		1	3	gs49	0.00	90.01	5.93	4.07	10.00	3.20	0.69	2.59	0.41	6.30	-23.00
		2	3	gs50	0.00	83.35	8.24	8.41	16.65	3.18	2.20	3.19	0.52	6.10	-21.80
		3	3	gs51	29.36	59.89	4.96	5.79	10.75	0.23	5.01	3.33	0.50	6.70	-22.30
				Mean	9.79	77.75	6.38	6.09	12.47	2.20	2.63	3.04	0.48	6.37	-22.37

[1]Depth Transects 1 = 6-20 m, 2 = 3-6 m, 3 = < 3 m   [2]Silt and clay

Appendix I-1. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz Mean	δ Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Clammy Bay Site (25)	Oiled	1	1	gs70	0.00	77.16	14.37	8.47	22.84	3.58	2.19	7.89	0.82	9.60	
		2	1	gs72	0.00	90.89	1.98	7.13	9.11	2.77	2.29	4.89	0.70	7.00	-22.40
		3	1	gs74	0.00	84.45	7.33	8.22	15.55	3.32	1.90	6.52	0.82	8.00	
				Mean	0.00	84.17	7.89	7.94	15.83	3.22	2.13	6.43	0.78	8.20	
		1	2	gs71	0.00	93.27	2.39	4.34	6.73	2.60	0.98	3.89	0.68	5.70	
		2	2	gs73	0.00	98.53	1.42	0.00	1.42	2.40	0.62	4.52	0.77	5.90	
		3	2	gs75	0.00	99.83	0.17	0.00	0.17	2.07	0.93	4.16	0.62	6.70	
				Mean	0.00	97.21	1.33	1.45	2.77	2.36	0.84	4.19	0.69	6.10	
		1	3	gs76	0.00	96.66	3.34	0.00	3.34	2.58	0.55	4.75	0.72	6.60	-22.40
		2	3	gs77	0.00	98.63	1.37	0.00	1.37	2.28	0.69	4.69	0.65	7.20	-21.90
		3	3	gs78	0.00	90.51	4.33	5.16	9.49	2.30	1.60	6.16	0.81	7.60	-21.60
				Mean	0.00	95.27	3.01	1.72	4.73	2.39	0.95	5.20	0.73	7.13	-21.97
Puffin Bay Site (26)	Control	1	1	gs79	0.00	31.73	40.87	27.39	68.27	6.33	3.57	15.51	2.27	6.80	
		2	1	gs81	21.43	66.95	5.00	6.62	11.62	1.13	4.73	6.38	0.95	6.70	-22.30
		3	1	gs83	0.00	84.54	7.37	8.09	15.46	3.20	1.69	5.95	0.80	7.40	
				Mean	7.14	61.07	17.75	14.03	31.78	3.55	3.33	9.28	1.34	6.97	
		1	2	gs80	0.00	89.27	6.75	3.98	10.73	1.63	2.43	4.01	0.68	5.90	
		2	2	gs82	73.45	17.32	2.91	6.33	9.23	-1.95	3.06	6.91	0.84	8.20	
		3	2	gs84	1.33	95.90	2.77	0.00	2.77	2.02	0.97	4.20	0.68	6.20	
				Mean	24.93	67.50	4.14	3.44	7.58	0.57	2.15	5.04	0.73	6.77	
		1	3	gs85	0.24	80.41	19.35	0.00	19.35	2.43	1.30	4.11	0.65	6.30	-22.70
		2	3	gs86	0.00	96.22	3.78	0.00	3.78	2.63	0.60	4.80	0.76	6.30	-22.30
		3	3	gs87	0.00	98.59	1.40	0.00	1.40	2.18	0.65	3.96	0.64	6.20	-22.70
				Mean	0.08	91.74	8.18	0.00	8.18	2.41	0.85	4.29	0.68	6.27	-22.57

[1]Depth Transects 1 = 6-20 m, 2 = 3-6 m, 3 = < 3 m [2]Silt and clay

Appendix I-2. Granulometric composition, organic carbon (OC), nitrogen (N), OC/N ratios and stable carbon isotope ratios ($\delta^{13}C$) of surficial sediments from *Zostera* (eelgrass) habitats in western Prince William Sound, Alaska, Summer 1991.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz[3] Mean	δ[3] Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Bay of	Oiled	1	1	25	0.00	30.98	45.09	23.94	69.03	6.39	3.09	112.40	11.40	9.90	
Isles		2	1	26	0.10	7.04	86.16	6.97	93.13	4.33	1.44	110.70	11.20	9.90	-21.10
Site (13)		3	1	27	0.00	18.79	45.63	35.58	81.21	10.00	5.20	111.00	10.90	10.20	
				Mean	0.03	18.94	58.96	22.16	81.12	6.91	3.24	111.37	11.17	10.00	
		1	3	28	0.00	33.82	34.78	31.40	66.18	9.03	7.22	144.40	11.60	12.40	
		2	3	29	0.00	30.69	40.46	28.84	69.31	6.80	3.46	63.40	4.00	15.90	-24.10
		3	3	30	0.00	29.32	60.41	10.27	70.68	3.98	1.58	155.20	12.90	12.00	
				Mean	0.00	31.28	45.22	23.50	68.72	6.60	4.09	121.00	9.50	13.43	
Drier Bay	Control	1	1	13	1.45	61.54	30.73	6.28	37.01	3.62	1.52	46.10	3.50	13.20	
Site (14)		2	1	14	1.00	61.80	18.06	19.14	37.20	3.50	1.57	42.30	2.90	14.60	-22.60
		3	1	15	44.83	36.07	9.28	9.82	19.10	0.54	3.28	28.00	2.90	9.60	
				Mean	15.76	53.14	19.36	11.75	31.10	2.55	2.12	38.80	3.10	12.47	
		1	3	16	4.25	49.72	30.98	15.05	46.03	3.90	1.45	62.90	6.10	10.30	
		2	3	17	0.69	75.95	18.35	5.01	23.36	2.09	1.32	60.60	4.70	12.90	-21.50
		3	3	18	0.22	43.16	31.34	25.28	56.62	3.95	1.81	69.20	6.90	10.00	
				Mean	1.72	56.28	26.89	15.11	42.00	3.31	1.53	64.23	5.90	11.07	

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m

[2]Silt and clay.

[3]Some mean and sorting values were not calculated because all relevant percentiles could not be obtained from the cumulative curve.

Appendix I-2. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz[3] Mean	δ[3] Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Herring Bay	Oiled	1	1	34	37.08	46.77	12.93	3.22	16.15	12.47	4.30	17.50	1.50	11.70	
Site (16)		2	1	35	27.54	61.38	8.29	2.79	11.07	0.59	3.29	3.80	0.50	7.60	-22.10
		3	1	36	48.65	42.90	7.57	0.88	8.44	-1.65	4.08	9.50	0.90	10.50	
				Mean	37.76	50.35	9.60	2.30	11.89	3.80	3.89	10.27	0.97	9.93	
		1	3	37	12.24	68.73	14.21	4.83	19.03	1.42	2.84	15.20	1.30	11.70	
		2	3	38	64.54	30.82	3.45	1.20	4.64	-1.25	1.90	3.10	0.30	10.30	-21.60
		3	3	39	13.11	73.78	5.76	7.36	13.12	1.92	3.16	24.10	1.50	16.10	
				Mean	29.96	57.78	7.81	4.46	12.26	0.70	2.63	14.13	1.03	12.70	
Lower	Control	1	1	40	90.89	7.25	1.86	1.00	1.87	-3.18	1.32	25.10	2.70	9.30	
Herring Bay		2	1	41	91.19	2.23	3.81	2.76	6.58	-4.07	2.16	50.10	5.50	9.10	-21.70
Site (15)		3	1	42	15.51	47.85	24.73	11.90	36.64	3.12	5.05	84.50	4.60	18.40	
				Mean	65.86	19.11	10.13	5.22	15.03	-1.38	2.84	53.23	4.27	12.27	
		1	3	43	0.00	25.93	18.87	55.21	74.08	6.57	3.82	66.60	4.30	15.50	
		2	3	44	20.49	45.57	11.13	22.81	33.94	3.80	6.54	40.00	3.80	10.50	-15.50
		3	3	45	73.32	21.59	2.38	2.71	5.09	-2.20	2.85	7.10	0.60	11.80	
				Mean	31.27	31.03	10.79	26.91	37.70	2.72	4.40	37.90	2.90	12.60	

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m

[2]Silt and clay.

[3]Some mean and sorting values were not calculated because all relevant percentiles could not be obtained from the cumulative curve.

Appendix I-2. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz[3] Mean	δ[3] Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Sleepy Bay Site (17)	Oiled	1	1	46	1.12	91.41	3.74	3.74	7.47	3.17	1.00	10.00	0.90	11.10	
		2	1	47	0.21	95.18	4.62	0.00	4.62	1.72	1.28	6.80	0.70	9.70	-22.90
		3	1	48	0.34	91.82	4.75	3.08	7.83	3.12	0.80	5.10	0.50	10.20	
				Mean	0.56	92.80	4.37	2.27	6.64	2.67	1.03	7.30	0.70	10.33	
		1	3	49	0.58	88.52	9.15	1.00	10.15	2.95	0.74	8.20	0.80	10.30	
		2	3	50	0.00	97.09	2.91	0.00	2.91	2.36	0.58	5.20	0.50	10.40	-22.50
		3	3	51	0.00	96.51	3.49	0.00	3.47	1.35	0.78	6.30	0.60	10.50	
				Mean	0.19	94.04	5.18	0.33	5.51	2.22	0.70	6.57	0.63	10.40	
Moose Lips Bay Site (18)	Control	1	1	52	84.77	15.24	0.00	0.00	0.00	-5.18	3.27	3.60	0.60	6.00	
		2	1	53	0.00	67.66	32.34	0.00	32.34	3.68	0.49	24.40	2.00	12.20	-22.10
		3	1	54	0.00	72.18	27.82	0.00	27.82	3.63	0.57	5.20	0.60	8.70	
				Mean	28.26	51.69	20.05	0.00	20.05	0.71	1.44	11.07	1.07	8.97	
		1	3	55	0.00	92.84	7.16	0.00	7.16	3.43	0.43	3.40	0.40	8.50	
		2	3	56[4]								4.90	0.70	7.00	-19.70
		3	3	57[4]								4.40	0.60	7.30	
				Mean	0.00	92.84	7.16	0.00	7.16	3.43	0.43	4.23	0.57	7.60	

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m
[2]Silt and clay.
[3]Some mean and sorting values were not calculated because all relevant percentiles could not be obtained from the cumulative curve.
[4]Insufficient quantity for complete analysis.

Appendix I-2. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz[3] Mean	δ[3] Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Clammy Bay Site (25)	Oiled	1	1	7	0.24	77.97	11.24	10.55	21.79	3.44	1.78	8.80	1.10	8.00	
		2	1	8	0.38	92.83	4.80	1.99	6.79	3.12	0.52	7.50	1.00	7.50	-22.70
		3	1	9	0.12	92.77	2.12	4.99	7.11	2.29	1.36	6.20	0.90	6.90	
				Mean	0.25	87.86	6.05	5.84	11.90	2.95	1.22	7.50	1.00	7.47	
		1	3	10	0.07	92.04	6.05	1.84	7.89	2.36	0.86	6.20	0.70	8.90	
		2	3	11	0.11	96.49	2.04	1.29	3.33	1.90	0.63	6.90	0.80	8.60	-22.10
		3	3	12	0.10	95.95	2.29	1.75	4.04	2.29	0.74	5.30	0.70	7.50	
				Mean	0.09	94.83	3.46	1.63	5.09	2.18	0.74	6.13	0.73	8.33	
Puffin Bay Site (26)	Control	1	1	1	1.68	73.82	20.26	4.24	24.50	2.11	1.82	14.10	1.40	10.10	
		2	1	3	42.32	52.88	3.66	1.14	4.80	0.02	3.13	5.20	0.80	6.50	-20.00
		3	1	5	0.15	94.94	3.11	2.00	5.11	2.19	0.97	5.80	0.90	6.40	
				Mean	14.72	73.88	9.01	2.46	11.47	1.44	1.97	8.37	1.03	7.67	
		1	3	2	0.45	87.24	0.60	11.71	12.31	2.52	1.76	5.40	0.90	6.00	
		2	3	4	0.47	92.71	4.37	0.85	5.22	2.77	0.59	7.10	1.00	7.10	-22.10
		3	3	6	0.07	87.69	2.55	8.29	10.84	2.57	1.95	8.30	1.00	8.30	
				Mean	0.33	89.21	2.51	6.95	9.46	2.62	1.43	6.93	0.97	7.13	

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m
[2]Silt and clay.
[3]Some mean and sorting values were not calculated because all relevant percentiles could not be obtained from the cumulative curve.

Appendix I-2. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[2] %	Mz[3] Mean	δ[3] Sort	O C mg/g	N mg/g	OC/N	$\delta^{13}C$
Short Arm	Oiled	1	3	31	0.00	2.49	22.85	74.66	97.51	12.47	5.52	44.80	5.20	8.60	
(Bay of		2	3	32	0.00	26.55	34.13	39.31	73.44			80.30	5.60	14.30	-20.30
Isles)		3	3	33	0.00	21.77	20.60	57.63	78.23			132.10	10.90	12.10	
Site(35)				**Mean**	0.00	16.94	25.86	57.20	83.06	12.47	5.52	85.73	7.23	11.67	
Mallard Bay	Control	1	1	19	0.00	82.30	11.36	6.34	17.70	4.09	1.26	85.50	9.20	9.30	
Site (34)		2	1	20	51.98	26.44	14.55	7.03	21.58	-1.46	5.57	43.80	5.30	8.30	-19.80
		3	1	21	0.00	45.64	35.29	19.07	56.36	4.26	1.29	53.70	6.20	8.70	
				Mean	17.33	51.46	20.40	10.81	31.88	2.30	2.71	61.00	6.90	8.77	
		1	3	22	0.00	62.40	20.25	17.35	37.60	6.54	1.43	102.00	10.60	9.60	
		2	3	23	0.00	57.94	24.38	17.68	42.06	3.64	1.52	68.40	6.60	10.30	-18.70
		3	3	24	4.34	43.73	30.81	21.12	51.93	3.93	1.88	68.40	6.60	10.40	
				Mean	1.45	54.69	25.15	18.72	43.86	4.70	1.61	79.60	7.93	10.10	

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m
[2]Silt and clay.
[3]Some mean and sorting values were not calculated because all relevant percentiles could not be obtained from the cumulative curve.

Appendix I-3. Granulometric composition of surficial sediments from *Zostera* (eelgrass) habitats in western Prince William Sound, Alaska, Summer 1993.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Mud %
Bay of Isles Site (13)	Oiled	1	1	S19	9.91	32.69	57.40
		2	1	S20	0.55	43.34	56.11
		3	1	S21	0.26	45.76	53.98
				Mean	3.57	40.60	55.83
		1	3	S22	1.56	46.28	52.16
		2	3	S23	0.55	52.32	47.13
		3	3	S24	1.11	35.97	62.92
				Mean	1.07	44.86	54.07
Drier Bay Site (14)	Control	1	1	S25	0.36	75.40	24.24
		2	1	S26	0.09	59.65	40.26
		3	1	S27	18.62	45.06	36.32
				Mean	6.36	60.04	33.61
		1	3	S28	0.59	54.89	44.52
		2	3	S29	0.00	45.28	54.72
		3	3	S30	0.00	8.38	91.62
				Mean	0.20	36.18	63.62

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m

Appendix I-3. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Mud %
Herring Bay Site (16)	Oiled	1	1	S13	29.50	60.97	9.53
		2	1	S14	12.02	64.78	23.20
		3	1	S15	2.34	94.35	3.31
				Mean	14.62	73.37	12.01
		1	3	S16	18.91	74.78	6.31
		2	3	S17	99.23	0.16	0.61
		3	3	S18	60.60	37.57	1.83
				Mean	59.58	37.50	2.92
Lower Herring Bay Site (15)	Control	1	1	S31	74.85	11.03	14.12
		2	1	S32	92.95	1.25	5.80
		3	1	S33	82.41	10.61	6.98
				Mean	83.40	7.63	8.97
		1	3	S34	2.79	10.27	86.94
		2	3	S35	2.21	34.67	63.12
		3	3	S36	1.39	17.22	81.39
				Mean	2.13	20.22	77.15

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m

Appendix I-3. Continued.

Site (#)	Site Oiling Status	Sta.	Depth[1] Trans.	Sample #	Gravel %	Sand %	Mud %
Sleepy Bay Site (17)	Oiled	1	1	S1	0.19	86.01	13.80
		2	1	S2	0.54	84.28	15.18
		3	1	S3	1.35	88.38	10.27
				Mean	0.69	86.22	13.08
		1	3	S4	0.40	94.39	5.21
		2	3	S5	0.17	98.35	1.48
		3	3	S6	1.65	96.42	1.93
				Mean	0.74	96.39	2.87
Moose Lips Bay Site (18)	Control	1	1	S7	0.43	65.38	34.19
		2	1	S8	0.04	65.80	34.16
		3	1	S9	0.15	64.94	34.91
				Mean	0.21	65.37	34.91
		1	3	S10	0.00	96.71	3.29
		2	3	S11	0.00	94.66	5.34
		3	3	S12	0.13	96.45	3.42
				Mean	0.04	95.94	4.12

[1]Depth Transects 1 = 6-20 m, 3 = < 3 m

Appendix I-4. Granulometric composition, organic carbon (OC), nitrogen (N), OC/N ratios and stable carbon isotope ratios ($\delta^{13}C$) of surficial sediments from silled fjord habitats in western Prince William Sound, Alaska, Summer 1990, 1991, and 1993.

1990

Site (#)	Site Oiling Status	Sta.	Depth Trans.	Sample #	Gravel		Sand	Silt	Clay	Mud[1]	Mz	δ	OC	N	
					%	%	%	%	%	Mean	Sort	mg/g	mg/g	OC/N	$\delta^{13}C$
Herring Bay Site (28-601)	Oiled	1	1	gs1	0.00	1.75	48.22	50.03	98.25	7.60	2.57	41.96	7.97	5.30	-21.00
		2	1	gs2	0.00	0.69	36.11	63.20	99.31	8.80	2.16	48.48	7.67	6.30	
		3	1	gs3	0.00	1.00	67.13	31.91	99.04	6.93	2.56	64.40	10.50	6.10	-21.10
				Mean	0.00	1.15	50.49	48.38	98.87	7.78	2.43	51.61	8.71	5.90	-21.05
Inner Lucky Bay Site (29)	Control	5	1	gs8	0.00	6.80	44.12	49.03	93.15	8.07	2.70	34.29	6.14	5.60	-20.70
Inner Bay of Isles Site (30)	Oiled	5	1	gs13	92.71	2.20	1.59	3.50	5.09	-1.92	1.34	42.01	5.32	7.90	
		6	1	gs14	42.73	24.60	8.82	23.85	32.67	2.97	5.06	31.98	5.53	5.80	
				Mean	67.72	13.40	5.21	13.68	18.88	0.53	3.20	37.00	5.43	6.85	

[1]Silt and clay. Sta.=Station; Depth Transect = 20 m

Appendix I-4. Continued.

1991

Site (#)	Site Oiling Status	Sta.	Depth Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[1] %	Mz Mean	δ Sort	OC mg/g	N mg/g	OC/N	$\delta^{13}C$
Inner Lucky Bay Site (29)	Control	5	1	98	26.67	48.68	14.58	10.07	24.65	3.02	2.83	87.20	8.80	9.90	-20.50
Herring Bay	Oiled	1	1	100	32.12	57.54	8.36	1.98	10.34	3.12	1.75	99.90	10.50	9.50	-20.40
Site		2	1	101	0.00	34.95	51.20	13.85	65.05	4.61	1.50	41.40	4.90	8.50	-20.40
(28-601)		3	1	102	0.00	47.62	38.76	13.62	52.38	4.22	1.60	62.80	7.80	8.10	-20.30
				Mean	10.71	46.70	32.77	9.82	42.59	3.98	1.62	68.03	7.73	8.70	-20.37

1993

Site (#)	Site Oiling Status	Sta.	Depth Trans.	Sample #	Gravel %	Sand %	Silt %	Clay %	Mud[1] %
Herring Bay	Oiled	1	1	37	1.51	51.41	-	-	47.08
Site		3	1	39	0.00	49.54	-	-	50.46
(28-601)									
				Mean	0.76	50.48	-	-	48.77

[1]Silt and clay. Sta.=Station; Depth Transect = 20 m

APPENDIX J.

Benthic invertebrates from shallow subtidal habitats in Prince William Sound, 1989, 1990, 1991, and 1993. All habitats were sampled by suction dredge, except *Zostera* DN, which was sampled by dropnet.

Appendix J. Benthic invertebrates from shallow subtidal habitats in western Prince William Sound, 1989, 1990, 1991, and 1993. All habitats were sampled by suction dredge, except *Zostera* DN, which was sampled by dropnet.

					HABITAT						
TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	*ZOSTERA*[3] T1	*ZOSTERA*[3] T2[6]	*ZOSTERA*[3] T3	*ZOSTERA*[3] DN[7]	*LAMINARIA*[4] T1	*LAMINARIA*[4] T2	SILLED[5] FJORD
37	Cnidaria		E/I	SF,P	X		X			X	X
3701	Hydrozoa		E	SF,P	X	X	X	X	X	X	X
373101	Eleutherocarpidae		E	P			X	X			
3740	Anthozoa		E/I	SF,P	X	X	X			X	
3743	Ceriantharia	Tube Anemones	I	P		X			X		X
3758	Actiniaria	Sea Anemones	E/I	P		X					
43	Rhynchocoela	Ribbon Worms	I	P	X	X	X	X	X	X	X
430302	Lineidae	Ribbon Worms	I	P	X	X	X				
50	Annelida		E/I								
5001	Polychaeta	Polychaetes	E/I	SDF,SF,P,O	X	X	X	X	X	X	X
500101	Aphroditidae	"	E/I	P					X		
500102	Polynoidae	"	E/I	P,O	X	X	X	X	X	X	X
500104	Polyodontidae	"	E/I	SDF,SSDF,P,O	X	X			X	X	X
500106	Sigalionidae	"	I	P,O	X	X	X		X	X	X
500108	Chrysopetalidae	"	E/I	P		X	X		X	X	
500111	Euphrosinidae	"	E/I	P						X	
500113	Phyllodocidae	"	E/I	P,O	X	X	X	X	X	X	X
500121	Hesionidae	"	E/I	P	X	X	X	X	X	X	X
500123	Syllidae	"	I	SDF,P,O	X	X	X	X	X	X	X
500124	Nereidae	"	I	SDF,SF,P	X	X	X	X	X	X	X
500125	Nephtyidae	"	I	SSDF,P	X	X	X		X	X	X
500126	Sphaerodoridae	"	E/I	SDF	X		X		X	X	X
500127	Glyceridae	"	I	P	X	X	X		X	X	X
500128	Goniadidae	"	I	P,O	X	X	X		X	X	X
500129	Onuphidae	"	I	SDF,P,O	X		X		X		X
500131	Lumbrineridae	"	I	SDF,SSDF,P,O	X	X	X		X	X	X
500136	Dorvilleidae	"	E/I	P,O	X	X	X	X	X	X	X

Appendix J. continued

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT *ZOSTERA*[3] T1	T2[6]	T3	DN[7]	*LAMINARIA*[4] T1	T2	SILLED[5] FJORD
500140	Orbiniidae	Polychaetes	I	SSDF	X	X	X		X	X	X
500141	Paraonidae	"	I	SSDF,SDF	X	X	X		X	X	X
500142	Apistobranchidae	"	I	SDF	X						
500143	Spionidae	"	I	SDF,SF	X	X	X	X	X	X	X
500144	Magelonidae	"	I	SDF	X	X	X		X	X	
500149	Chaetopteridae	"	I	SF	X	X	X		X		X
500150	Cirratulidae	"	I	SDF	X	X	X		X	X	X
500151	Acrocirridae	"	I	SDF	X				X	X	X
500154	Flabelligeridae	"	I	SDF	X	X			X	X	X
500157	Scalibregmidae	"	I	SDF,SSDF	X		X		X	X	X
500158	Opheliidae	"	I	SSDF	X	X	X	X	X	X	X
500160	Capitellidae	"	I	SSDF	X	X	X	X	X	X	X
500162	Arenicolidae	"	I	SDF			X				
500163	Maldanidae	"	I	SSDF	X	X	X		X	X	X
500164	Oweniidae	"	I	SDF,SSDF,SF	X	X	X		X	X	X
500165	Sabellariidae	"	I	SF	X				X		
500166	Amphictenidae	"	I	SSDF	X	X	X	X	X	X	X
500167	Ampharetidae	"	I	SDF	X	X	X	X	X	X	X
500168	Terebellidae	"	I	SDF	X	X	X		X	X	X
500169	Trichobranchidae	"	I	SDF	X				X	X	X
500170	Sabellidae	"	I	SF	X	X	X		X	X	X
500173	Serpulidae	"	E	SF	X	X	X		X	X	
500178	Spirorbidae	"	E	SDF,SSDF,SF,P,O	X	X	X	X	X	X	X
500205	Polygordiidae	"	E/I	SDF	X	X			X	X	
5012	Hirudinea	Leeches	E/I	P,O	X						
	Mollusca		E/I						X		
51	Gastropoda		E/I	SDF,SF,P,O	X	X	X	X	X	X	X
5102	Archaeogastropoda	Limpets	E	O	X	X	X		X	X	X

Appendix J. continued

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT						
					ZOSTERA[3]				*LAMINARIA*[4]		SILLED[5]
					T1	T2[6]	T3	DN[7]	T1	T2	FJORD
510204	Fissurellidae	Snails	E	O	X				X	X	
510205	Lottidae (Acmaeidae)	"	E	O	X	X	X		X	X	
510207	Lepetidae	"	E	O	X	X	X		X	X	X
510210	Trochidae	"	I	O	X	X	X	X	X	X	X
510309	Lacunidae	"	I	O	X	X	X	X	X	X	
510310	Littorinidae	Periwinkle	E	O	X						
510320	Rissoidae	Snails	I	O	X	X	X	X	X	X	X
510324	Skeneopsidae	"	E	O		X					
510333	Turritellidae	"	E/I	SDF						X	
510336	Caecidae	Caecum	I	O	X	X	X		X	X	X
510346	Cerithiidae	Snails	E/I	O		X			X	X	
510353	Eulimidae	"	?	Ectoparasites	X						
510362	Trichotropidae	"	E/I	SF	X				X	X	
510364	Calyptraeidae	"	E	SF	X	X	X		X	X	X
510376	Naticidae	"	E/I	P	X	X	X			X	
510386	Barleeiidae	"	I	O						X	
510501	Muricidae	"	E/I	P	X	X			X	X	
510503	Pyrenidae	"	E/I	P	X	X				X	X
510508	Nassariidae	"	E/I	P,O	X	X	X		X	X	X
510510	Olividae	"	E/I	P,O	X	X	X	X	X	X	
510515	Marginellidae	"	E/I	O	X					X	
510602	Turridae	"	E/I	P	X	X	X		X	X	X
510801	Pyramidellidae	"	?	Ectoparasites	X	X	X		X	X	X
5110	Cephalaspidea	Bubble Shells	E/I	P,O	X	X	X		X	X	X
511004	Cylichnidae	"	E/I	P,O	X	X	X		X	X	X
511005	Philinidae	Paperbubble	E/I	P	X	X					X
511007	Gastropteridae	Batwing Seaslug	E/I	P,O	X	X	X	X	X	X	X
511009	Diaphanidae	Paperbubble	E/I	P,O	X		X		X	X	

Appendix J. continued

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT: *ZOSTERA*[3] T1	*ZOSTERA*[3] T2[6]	*ZOSTERA*[3] T3	*ZOSTERA*[3] DN[7]	*LAMINARIA*[4] T1	*LAMINARIA*[4] T2	SILLED[5] FJORD
511012	Haminoidae	Glassy-bubble	E/I	P,O	X			X			X
5123	Sacoglossa	Nudibranchia	E	O	X	X	X		X	X	X
512306	Stiligeridae	"	E	O		X	X		X		
5127	Nudibranchia	"	E	P,O	X	X	X	X	X	X	X
5128	Doridacea	"	E	P	X	X	X	X		X	
513003	Dorididae	"	E	P			X				
513105	Onchidorididae	"	E	P	X	X	X	X	X	X	X
513107	Corambidae	"	E	P		X	X	X			X
513406	Dendronotidae	"	E	P		X				X	
513408	Tethydidae	"	E	P				X		X	
5181	Opisthobranchia	"	E/I	P,O			X				
53	Polyplacophora	Chitons	E	O	X	X	X		X	X	X
530201	Lepidopleuridae	"	E	O	X	X			X	X	X
530302	Ischnochitonidae	"	E	O	X	X	X		X	X	
530307	Mopaliidae	"	E	P,O	X	X	X		X	X	
55	Bivalvia	Bivalves	E/I	SDF,SSDF,SF	X	X	X	X	X	X	X
550202	Nuculidae	Nutclam	I	SSDF	X	X			X		X
550204	Nuculanidae	"	I	SSDF	X	X	X		X		X
550606	Glycymeridae	Clams	E/I	SF	X	X					
550701	Mytilidae	Mussels	E	SF	X	X	X	X	X	X	X
550905	Pectinidae	Scallops	E	SF	X				X	X	X
550909	Anomiidae	Jingles	E	SF	X	X	X		X	X	X
551501	Lucinidae	Clams	I	SDF,SF	X	X	X	X	X	X	X
551502	Thyasiridae	"	I	SDF,SF	X	X	X		X	X	X
551505	Ungulinidae	"	I	SF	X	X	X		X	X	
551508	Kelliidae	"	E/I	SF,SDF		X					
551510	Montacutidae	"	I	SF,SDF	X	X	X	X	X	X	X
551514	Turtoniidae	"	E/I	SF	X		X	X	X	X	

Appendix J. continued

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT *ZOSTERA*[3] T1	T2[6]	T3	DN[7]	*LAMINARIA*[4] T1	T2	SILLED[5] FJORD
551517	Carditidae	Clams	E/I	SF	X				X	X	X
551519	Astartidae	"	E/I	SF	X	X			X		X
551522	Cardiidae	Cockles	E/I	SDF,SF	X	X	X		X	X	X
551525	Mactridae	Clams	I	SF	X						
551531	Tellinidae	"	I	SDF,SF,SSDF	X	X	X		X	X	X
551547	Veneridae	"	I	SF	X	X	X		X	X	X
551701	Myidae	"	I	SDF	X	X	X		X	X	X
551706	Hiatellidae	"	E/I	SF	X	X	X	X	X	X	X
552002	Pandoridae	"	E/I	SF	X						
552005	Lyonsiidae	"	E/I	SF	X	X	X		X	X	X
552008	Thraciidae	"	I	SF	X				X		
552010	Cuspidariidae	"	I	P	X				X		
56	Scaphapoda	Tuskshells	I	SSDF,P					X		
560001	Dentaliidae	Tuskshells	I	SSDF,P	X						
61	Arthropoda	Crustaceans	E/I		X	X	X	X	X	X	X
6134	Balanomorpha	Barnacles	E	SF	X	X	X	X	X	X	X
613401	Chthamalidae	"	E	SF	X						
613402	Balanidae	"	E	SF	X	X	X		X	X	X
6154	Cumacea	Cumaceans	I	SDF,P	X	X	X		X	X	X
615401	Lampropidae	"	I	SDF	X	X	X		X	X	X
615404	Leuconidae	"	I	SDF	X	X	X		X	X	X
615405	Diastylidae	"	I	SDF	X	X	X		X	X	X
615407	Campylaspidae	"	I	SDF,P	X						
615408	Nannastacidae	"	I	SDF	X	X	X		X	X	X
615409	Bodotriidae	"	I	SDF	X				X	X	X
6155	Tanaidacea	Tanaids	E/I	SF,P			X			X	
615701	Tanaidae	"	E/I	U			X				
615702	Paratanaidae	"	E/I	U	X	X	X	X	X	X	

Appendix J. continued

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT: *ZOSTERA*[3] T1	*ZOSTERA*[3] T2[6]	*ZOSTERA*[3] T3	*ZOSTERA*[3] DN[7]	*LAMINARIA*[4] T1	*LAMINARIA*[4] T2	SILLED[5] FJORD
6158	Isopoda	Isopods	E/I	SDF							X
615901	Gnathiidae	"	E/I	SDF	X				X	X	
616105	Limnoridae	"	WB	O	X	X	X			X	
616202	Idoteidae	"	E	O		X		X			
6163	Asellota	"	E/I	SDF						X	
616306	Janiridae	Isopods	E/I	U					X		
616311	Jaeropsidae	"	U	U	X						
616312	Munnidae	"	E/I	U	X	X	X	X	X	X	X
6169	Amphipoda	Amphipods	E/I		X	X	X	X	X	X	X
616901	Acanthonotozomatidae	"	E/I	U	X						
616902	Ampeliscidae	"	I	SDF,SF	X	X	X		X	X	
616904	Ampithoidae	"	E/I	U	X	X	X	X	X	X	X
616906	Aoridae	"	E/I	U	X	X	X	X	X	X	
616912	Calliopiidae	"	E/I	O	X			X	X	X	
616915	Corphiidae	"	I	SDF,SF	X	X	X	X	X	X	X
616917	Dexaminidae	"	E/I	SF	X	X	X		X	X	X
616920	Eusiridae	"	E/I	P	X	X	X	X	X	X	
616921	Gammaridae	"	E/I	SDF,SF	X	X	X		X	X	X
616923	Hyalellidae	"	U	U					X	X	
616926	Isaeidae	"	I	SDF	X	X	X	X	X	X	X
616927	Ischyroceridae	"	I	SDF,O	X	X	X	X	X	X	X
616934	Lysianassidae	"	I	O	X	X	X		X	X	X
616937	Oedicerotidae	"	I	SDF,O	X	X	X		X	X	X
616942	Phoxocephalidae	"	I	SDF,P,O	X	X	X		X	X	X
616943	Pleustidae	"	I	SDF,O	X	X	X	X	X	X	X
616944	Podoceridae	"	E	U	X				X	X	
616948	Stenothoidae	"	E	P	X	X	X	X	X	X	
616950	Synopiidae	"	E	SF	X				X	X	X

Appendix J. continued

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT: *ZOSTERA*[3] T1	*ZOSTERA*[3] T2[6]	*ZOSTERA*[3] T3	*ZOSTERA*[3] DN[7]	*LAMINARIA*[4] T1	*LAMINARIA*[4] T2	SILLED[5] FJORD
6171	Caprellidea	Caprellids	E/I	SDF,P,O	X	X	X	X	X	X	X
6175	Decapoda		E	P,O	X	X	X	X	X	X	X
6178	Pleocyemata	Shrimps	E	P,O	X		X	X	X	X	
617916	Hippolytidae	"	E	P,O	X	X	X	X	X	X	X
617918	Pandalidae	"	E	P,O	X		X	X		X	X
617922	Crangonidae	"	E	P,O	X		X	X	X	X	X
618306	Paguridae	Hermit Crabs	E	P,O	X		X	X	X	X	X
618308	Lithodidae	Crabs	E	P,O						X	
6184	Brachyura	"	E	P,O						X	
618701	Majidae	"	E	P,O	X		X			X	
618802	Atelecyclidae	"	E	P,O	X	X	X	X	X	X	
618803	Cancridae	"	E	O	X					X	
6189	Brachyrhyncha	"	E	O						X	
72	Sipuncula	Peanut Worms	I	SDF,SF	X		X		X	X	
720002	Golfingiidae	"	I	SDF	X	X			X	X	X
73	Echiura	Spoon Worms	I	SDF,SF			X				
74	Priapulida		I	SSDF,P						X	
740001	Priapulidae		I	P		X					
77	Phoronida		E/I	SF	X	X	X		X	X	
78	Bryozoa		E	SF,P	X	X	X	X	X	X	X
80	Brachiopoda	Lamp Shells	E	SF					X		
800507	Cancellothyridae	"	E	SF	X						
800511	Dallinidae	"	E	SF					X		
81	Echinodermata		E/I						X	X	
8104	Asteroidea	Sea Stars	E	P,O	X	X	X	X	X	X	
811703	Asteriidae	"	E	P,O	X		X	X			
8120	Ophiuroidea	Brittle Stars	E	SDF,SF,P,O	X	X	X	X	X	X	X
812902	Ophiactidae	"	E	SDF,SF						X	

Appendix J. continued.

TAXON CODE	TAXON	COMMON NAME	EPIFAUNA/ INFAUNA[1]	FEEDING TYPE[2]	HABITAT *ZOSTERA*[3] T1	T2[6]	T3	DN[7]	*LAMINARIA*[4] T1	T2	SILLED[5] FJORD
812903	Amphiuridae	Brittle Stars	E/I	SDF,SF	X	X	X		X	X	
8136	Echinoidea		E		X		X	X	X	X	
8149	Echinoida	Sea Urchins	E								
814903	Strongylocentrotida	"	E	O	X	X	X	X	X	X	
815502	Echinarachniidae	Sand Dollars	I	SDF,SF	X	X	X				
8172	Holothuroidea	Sea Cucumbers	E/I	SDF,SSDF,SF							
817206	Cucumariidae	"	E	SF,P	X	X			X		
817801	Synaptidae	"	I	SSDF	X		X		X	X	
84	Urochordata	Tunicates	E		X	X	X		X	X	
8401	Ascidiacea	"	E	SF	X	X	X		X	X	X
840601	Styelidae	"	E	SF		X					
840602	Pyuridae	"	E	SF					X		

Notes:

[1]E = Epifauna; I = Infauna; E/I = Both Epifaunal and Infaunal members.

[2]Feeding Type: SDF=surface deposit feeder; SSDF=subsurface deposit feeder; SF=suspension feeder; P=predator (carnivore); O=Other (scavenger, herbivore); WB=woodborer; U=unknown.

[3]This habitat was sampled in 1990-91, & 1993;
Zostera T1=Transect 1 (6-20m),
Zostera T2=Transect 2 (3-6m),
Zostera T3=Transect 3 (Eelgrass Bed).

[4]This habitat was sampled in 1990-91;
Laminaria T1=Transect 1 (11-20m),
Laminaria T2=Transect 2 (2-11m).

[5]This habitat was sampled in 1989-91 & 1993.

[6]*Zostera* T2 was only sampled in 1990.

[7]Dropnet samples were only collected in 1990.

APPENDIX K.

Mean values for community parameters of infaunal and small infaunal invertebrates that were sampled by suction dredge at oiled and control sites in the eelgrass habitat in 1990, 1991, and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix K. Mean values for community parameters of infaunal and small infaunal invertebrates that were sampled by suction dredge at oiled and control sites in the eelgrass habitat in 1990, 1991, and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

1990 Infauna Diversity Indices for Alaskan Eelgrass Habitats
All Families & Higher

Transect = Deep

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	0.92	0.61	12	244	1.054	2.082
Drier Bay	14 (C)	2.23	0.17	27	592	6.836	4.123
Herring Bay	16 (O)	3.13	0.09	54	696	8.475	8.203
Lower H. Bay	15 (C)	2.96	0.08	52	482	3.265	8.384
Sleepy Bay	17 (O)	2.70	0.13	57	768	11.307	8.417
Moose Lips	18 (C)	2.29	0.16	29	1007	10.089	4.096
Clammy Bay	25 (O)	2.58	0.14	38	661	7.089	5.716
Puffin Bay	26 (C)	3.35	0.06	62	1165	19.388	8.683
	Mean (O)	2.33	0.24	40	592	6.981	6.105
	Mean (C)	2.71	0.12	43	812	9.894	6.321
	P-value	0.13	0.045	0.70	0.07	0.35	0.83

Transect = Shallow

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	2.04	0.22	22	309	1.792	3.659
Drier Bay	14 (C)	2.86	0.09	43	428	2.892	7.137
Herring Bay	16 (O)	2.82	0.09	44	1205	6.183	6.224
Lower H. Bay	15 (C)	2.64	0.10	42	569	4.628	6.432
Sleepy Bay	17 (O)	2.22	0.18	41	2361	18.388	5.196
Moose Lips	18 (C)	2.50	0.13	37	769	7.913	5.438
Clammy Bay	25 (O)	2.67	0.11	34	573	8.891	5.247
Puffin Bay	26 (C)	2.68	0.14	54	1532	9.120	7.227
	Mean (O)	2.44	0.15	35	1112	8.813	5.082
	Mean (C)	2.67	0.12	44	824	6.138	6.558
	P-value	0.16	0.26	0.14	0.56	0.13	0.07

Transect = Bed

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	1.64	0.28	20	708	0.553	3.014
Drier Bay	14 (C)	2.29	0.14	20	200	0.905	3.645
Herring Bay	16 (O)	2.27	0.17	38	1611	5.968	4.969
Lower H. Bay	15 (C)	1.70	0.26	18	436	1.141	2.792
Sleepy Bay	17 (O)	2.43	0.14	45	2577	19.334	5.619
Moose Lips	18 (C)	2.50	0.13	38	1428	7.971	5.130
Clammy Bay	25 (O)	2.45	0.15	44	2640	39.325	5.506
Puffin Bay	26 (C)	2.67	0.13	45	1834	15.220	5.861
	Mean (O)	2.20	0.18	37	1884	16.295	4.777
	Mean (C)	2.29	0.17	30	975	6.309	4.357
	P-value	0.58	0.48	0.12	<0.01	<0.01	0.39

1991 Infauna Diversity Indices for Alaskan Eelgrass Habitats
All Families & Higher

Transect = Deep

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	1.30	0.50	17	367	2.498	2.721
Drier Bay	14 (C)	2.22	0.20	39	1213	21.800	5.311
Herring Bay	16 (O)	3.49	0.05	67	1257	8.474	9.262
Lower H. Bay	15 (C)	2.86	0.14	56	1011	3.726	8.072
Sleepy Bay	17 (O)	2.71	0.14	53	1620	12.041	7.214
Moose Lips	18 (C)	2.57	0.19	54	1713	24.346	7.137
Clammy Bay	25 (O)	2.66	0.15	43	1057	9.782	6.176
Puffin Bay	26 (C)	3.31	0.07	71	1251	8.028	9.886
	Mean (O)	2.54	0.21	45	1075	8.199	6.343
	Mean (C)	2.74	0.15	55	1297	14.475	7.602
	P-value	0.46	0.44	0.11	0.26	0.46	0.15

Transect = Bed

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	2.14	0.16	26	2030	2.024	3.352
Drier Bay	14 (C)	2.44	0.14	33	1115	5.313	4.512
Herring Bay	16 (O)	2.41	0.16	47	2613	8.023	5.878
Lower H. Bay	15 (C)	2.37	0.14	30	1496	2.277	3.916
Sleepy Bay	17 (O)	2.28	0.17	47	3207	12.794	5.791
Moose Lips	18 (C)	2.47	0.14	52	4072	18.910	6.175
Clammy Bay	25 (O)	2.42	0.16	50	3427	34.933	6.024
Puffin Bay	26 (C)	1.95	0.34	64	7997	36.333	7.127
Short Arm Bay	35 (O)	2.36	0.16	35	1752	3.538	4.512
Mallard Bay	34 (C)	2.39	0.14	33	1933	4.081	4.292
	Mean (O)	2.32	0.16	41	2606	12.262	5.111
	Mean (C)	2.32	0.18	42	3322	13.383	5.205
	P-value	0.97	0.53	0.73	0.32	0.66	0.83

1993 Infauna Diversity Indices for Alaskan Eelgrass Habitats
All Families & Higher

Transect = Deep

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	2.35	0.15	29	461	2.067	4.627
Drier Bay	14 (C)	2.19	0.19	39	2515	18.762	4.982
Herring Bay	16 (O)	3.02	0.10	61	1575	14.357	8.336
Lower H. Bay	15 (C)	2.99	0.09	70	1141	11.435	9.759
Sleepy Bay	17 (O)	2.55	0.16	53	1737	12.816	7.038
Moose Lips	18 (C)	2.43	0.17	51	1224	14.138	7.040
	Mean (O)	2.64	0.14	48	1258	9.747	6.667
	Mean (C)	2.54	0.15	53	1627	14.778	7.260
	P-value	0.42	0.48	0.24	0.52	0.24	0.36

Transect = Bed

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Bay of Isles	13 (O)	2.52	0.13	39	1278	2.938	5.449
Drier Bay	14 (C)	2.35	0.15	34	1444	2.649	4.517
Herring Bay	16 (O)	2.23	0.17	44	6177	20.123	4.978
Lower H. Bay	15 (C)	2.58	0.11	32	792	1.616	4.617
Sleepy Bay	17 (O)	2.13	0.21	48	4065	32.190	5.679
Moose Lips	18 (C)	2.12	0.22	33	1034	15.443	4.657
	Mean (O)	2.29	0.17	44	3840	18.417	5.368
	Mean (C)	2.35	0.16	33	1090	6.570	4.597
	P-value	0.61	0.55	0.02	0.01	0.098	0.055

APPENDIX L.

Mean values for abundance and biomass of dominant invertebrate families that were sampled by suction dredge at oiled and control sites in the eelgrass habitat in 1990, 1991, and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix L. Mean values for abundance and biomass of dominant invertebrate families that were sampled by suction dredge at oiled and control sites in the eelgrass habitat in 1990, 1991 and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests. Densities are #/0.1m^2 and biomass units are grams/0.1m^2. Analyses using percent mud as a covariate are identified with an 'm' next to the P-value. Names of some dominant taxa are abbreviated. See Appendix J for the complete spellings.

Abundance - 1990

Deep

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	BIVALVIA	CAECIDAE	CAPITELL	LUCINIDA	MALDANID	MYTILIDA	NEPHTYID
1	13	O	0.00	0.00	0.17	7.00	0.00	0.00	0.00	0.00	0.00	188.00
1	14	C	6.67	14.00	4.00	78.00	0.00	17.33	58.67	17.25	1.83	0.00
2	16	O	3.56	8.89	31.11	4.45	35.11	12.45	132.44	7.11	12.89	0.00
2	15	C	10.00	6.33	63.83	54.67	0.33	8.00	7.50	0.00	2.00	2.83
3	17	O	1.67	17.91	32.05	9.33	0.00	7.05	10.71	10.19	133.74	2.00
3	18	C	0.00	18.04	90.75	5.42	0.00	5.95	88.80	0.00	4.09	2.67
4	25	O	12.67	48.00	12.67	1.33	0.00	8.67	175.33	40.39	2.67	4.33
4	26	C	22.22	43.56	28.45	10.22	70.22	92.00	35.11	30.67	21.94	10.22
	mean	O	4.47	18.70	19.00	5.53	8.78	7.04	79.62	14.42	37.32	48.58
	mean	C	9.72	20.48	46.76	37.08	17.64	30.82	47.52	11.98	7.47	3.93
	P		0.70m	0.76m	<0.01	0.14	0.02m	0.20m	0.59m	0.03m	0.23	0.18m

Deep (continued)

Pair	Site#	Oilcode	OPHELIID	OPHIUROI	RISSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	THYASIRI
1	13	O	4.00	0.00	2.17	0.00	0.00	0.67	0.00	0.00	4.33
1	14	C	68.17	0.17	0.00	4.67	77.17	11.17	8.67	4.83	84.00
2	16	O	36.00	13.33	22.22	6.67	62.84	70.67	8.45	0.00	0.89
2	15	C	36.67	6.17	11.50	21.67	36.83	41.67	4.67	0.00	6.50
3	17	O	32.05	0.00	0.00	0.33	177.48	4.17	66.83	17.64	6.17
3	18	C	116.89	3.11	0.89	0.00	144.36	9.33	1.33	238.67	102.93
4	25	O	11.11	12.00	0.00	2.67	94.44	0.00	9.33	50.39	46.89
4	26	C	5.33	67.11	1.33	40.00	140.44	40.89	69.33	4.00	0.89
	mean	O	20.79	6.33	6.10	2.42	83.69	18.88	21.15	17.01	14.57
	mean	C	56.76	19.14	3.43	16.58	99.70	25.76	21.00	61.88	48.58
	P		0.75m	0.49	0.72m	0.08m	0.95m	0.66	0.31m	0.80m	0.98m

Shallow

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CAPRELLI	GASTROPO	LACUNIDA	LUCINIDA	MONTACUT	MYTILIDA
1	13	O	6.27	1.67	26.70	0.00	10.45	0.00	10.22	62.93	4.67
1	14	C	23.78	31.61	42.94	2.06	31.78	2.89	15.22	6.89	1.05
2	16	O	40.89	40.66	53.11	45.78	203.33	35.11	35.78	15.78	194.67
2	15	C	13.67	8.33	18.67	0.83	40.67	9.17	92.00	41.17	1.50
3	17	O	28.00	14.67	10.83	5.33	50.83	166.67	89.33	178.67	152.33
3	18	C	9.11	116.45	55.11	101.78	16.67	74.55	4.67	20.33	40.45
4	25	O	19.33	20.00	5.33	4.00	4.67	1.33	6.67	33.33	0.67
4	26	C	43.11	44.89	11.56	10.22	33.33	24.44	15.56	62.22	4.00
	mean	O	23.62	19.25	23.99	13.78	67.32	50.78	35.50	72.68	88.08
	mean	C	22.42	50.32	32.07	28.72	30.61	27.76	31.86	32.65	11.75
	P		0.28m	0.07	0.80	0.82m	0.34	0.75m	0.94m	0.48m	0.21

Shallow (continued)

Pair	Site#	Oilcode	OPHELIID	PHOXOCEP	RISSOIDA	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID
1	13	O	6.45	0.00	2.67	4.53	9.60	0.53	0.00
1	14	C	72.11	0.00	16.55	48.33	9.17	9.33	2.50
2	16	O	54.44	0.67	26.67	59.33	173.56	35.78	1.55
2	15	C	29.00	0.33	73.83	98.33	2.00	12.50	0.67
3	17	O	401.33	6.67	6.67	582.17	354.67	18.67	36.00
3	18	C	53.00	67.00	1.33	68.45	0.33	0.00	88.33
4	25	O	48.67	12.67	0.00	116.00	2.00	8.67	109.33
4	26	C	122.67	24.45	26.67	364.44	229.33	39.11	28.89
	mean	O	127.72	5.00	9.00	190.51	134.96	15.91	36.72
	mean	C	69.19	22.94	29.60	144.89	60.21	15.24	30.10
	P		0.14m	0.06m	0.06m	0.74m	0.58	0.54m	0.56m

Eelgrass Bed

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CAPITELL	CAPRELLI	GASTROPO	LACUNIDA	MONTACUT	MYTILIDA	OPHELIID
1	13	O	5.05	11.79	48.87	2.93	0.38	121.58	0.00	170.86	1.14	13.58
1	14	C	1.90	9.69	7.34	2.87	26.99	20.44	0.00	21.26	0.17	21.05
2	16	O	31.33	32.83	118.67	49.83	152.00	253.33	5.50	13.17	178.17	102.00
2	15	C	0.00	2.67	11.33	32.00	9.33	96.45	0.00	13.33	0.67	2.22
3	17	O	83.33	30.45	17.11	45.56	4.45	146.22	344.22	26.67	309.28	194.22
3	18	C	40.67	232.00	92.00	24.00	246.67	58.00	130.00	22.67	38.00	112.00
4	25	O	86.67	34.00	6.67	54.00	231.33	86.67	111.33	78.00	654.67	108.00
4	26	C	78.67	54.67	13.33	36.00	89.33	9.33	97.33	96.00	149.33	177.33
	mean	O	51.60	27.27	47.83	38.08	97.04	151.95	115.26	72.17	285.81	104.45
	mean	C	30.31	74.76	31.00	23.72	93.08	46.06	56.83	38.32	47.04	78.15
	P		0.34m	0.17	0.08	0.24m	0.66m	0.40	0.25m	0.52m	0.00	0.85m

Eelgrass Bed (continued)

Pair	Site#	Oilcode	PHOXOCEP	POLYNOID	RISSOIDA	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	TROCHIDA
1	13	O	0.00	25.81	0.00	0.38	284.62	0.53	0.00	0.00
1	14	C	0.00	14.45	2.39	2.16	49.79	2.83	0.00	4.50
2	16	O	0.00	37.83	3.17	13.33	396.00	125.83	4.33	0.00
2	15	C	0.00	37.11	0.00	0.89	188.22	15.33	0.00	0.00
3	17	O	0.67	11.56	29.56	554.00	430.67	6.00	44.00	0.00
3	18	C	112.67	3.33	4.00	190.67	2.67	10.67	108.00	0.00
4	25	O	2.67	6.67	26.00	634.67	50.67	48.00	180.83	0.00
4	26	C	26.67	2.67	16.00	525.67	92.00	9.33	113.33	26.67
	mean	O	0.83	20.47	14.68	300.60	290.49	45.09	57.29	0.00
	mean	C	34.83	14.39	5.60	179.84	83.17	9.54	55.33	7.79
	P		<0.01m	0.22m	0.15m	0.06m	0.02	0.73m	0.93m	<0.01m

Biomass - 1990

Deep

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CARDIIDA	CHAETOPT	CRYPTOBR	DIPLODON	GLYCERID	GLYCYMER	GONIADID	LUCINID
1	13	O	0.000	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.013	0.000
1	14	C	0.002	0.002	0.794	0.825	0.000	0.000	0.000	1.200	0.000	0.209	0.628
2	16	O	0.042	0.084	0.003	0.000	0.000	0.000	0.000	0.003	0.000	0.004	2.369
2	15	C	0.003	0.093	0.131	0.001	0.000	0.085	0.000	0.000	0.000	0.018	0.277
3	17	O	0.159	0.096	0.321	0.000	0.292	0.000	0.399	0.026	0.003	0.022	0.028
3	18	C	0.088	0.115	0.012	0.001	0.000	0.000	0.000	0.000	0.000	0.250	5.238
4	25	O	0.111	0.022	0.008	0.000	0.001	0.000	0.174	0.001	0.000	0.031	1.830
4	26	C	0.045	0.114	4.823	1.197	0.001	0.007	0.000	0.065	0.000	0.022	0.525
	mean	O	0.078	0.051	0.087	0.000	0.073	0.000	0.143	0.007	0.001	0.018	1.057
	mean	C	0.034	0.081	1.440	0.506	0.000	0.023	0.000	0.316	0.000	0.125	1.667
	P		0.40 m	0.23	0.05	0.12 m	0.53 m	<0.01	0.49	0.84 m	0.77 m	0.34 m	0.37 m

Deep (continued)

Pair	Site#	Oilcode	LUMBRINE	MYTILIDA	NEPHTYID	OLIVIDAE	ORBINIID	RHYNCHOC	SPIONIDA	TELLINID	THYASIRI	VENERIDA
1	13	O	0.135	0.000	0.299	0.000	0.000	0.000	0.000	0.000	0.004	0.000
1	14	C	0.489	0.001	0.003	0.000	0.104	0.268	0.042	0.657	0.404	0.000
2	16	O	0.409	0.145	0.000	0.000	0.137	1.108	0.071	0.000	0.000	1.897
2	15	C	0.348	0.005	0.006	0.000	0.001	0.013	0.051	0.000	0.089	1.338
3	17	O	0.000	1.096	0.069	5.737	0.007	0.723	0.044	0.262	0.015	0.001
3	18	C	0.248	0.012	0.003	0.011	0.379	0.063	0.108	1.906	0.572	0.172
4	25	O	0.186	0.004	0.132	0.471	0.016	0.075	0.159	0.720	0.258	0.452
4	26	C	0.257	0.236	0.054	0.593	0.020	0.401	0.103	0.015	0.018	4.380
	mean	O	0.182	0.311	0.125	1.552	0.040	0.477	0.069	0.246	0.069	0.587
	mean	C	0.336	0.064	0.016	0.151	0.126	0.186	0.076	0.645	0.271	1.472
	P		0.27 m	0.49	0.97 m	0.95 m	0.48 m	0.40 m	0.72 m	0.98 m	0.74 m	0.02 m

Depth = Shallow

Pair	Site#	Oilcode	AMPHIPOD	CHAETOPT	LUCINIDA	LYONSIID	MYTILIDA	NEPHTYID	OLIVIDAE	OPHELIID
1	13	O	0.003	0.000	0.608	0.000	0.011	0.112	0.000	0.005
1	14	C	0.032	0.003	0.514	0.001	0.001	0.107	0.000	0.017
2	16	O	0.117	0.000	0.962	0.000	1.799	0.000	0.000	0.037
2	15	C	0.015	0.000	1.997	0.000	0.001	0.000	0.000	0.022
3	17	O	0.038	3.677	2.112	0.015	0.861	0.896	0.531	0.772
3	18	C	0.185	0.348	0.088	0.000	0.004	0.021	0.267	0.054
4	25	O	0.089	0.707	0.021	0.693	0.001	0.000	0.639	0.609
4	26	C	0.084	0.737	0.213	0.387	0.067	0.007	1.044	0.256
	mean	O	0.062	1.096	0.926	0.177	0.668	0.252	0.292	0.356
	mean	C	0.079	0.272	0.703	0.097	0.018	0.034	0.328	0.087
	P		0.56	0.34 m	0.86 m	0.80	0.16	0.15 m	0.93 m	0.05 m

Shallow (continued)

Pair	Site#	Oilcode	OPHIUROI	ORBINIID	RHYNCHOC	SPIONIDA	TELLINID	VENERIDA
1	13	O	0.019	0.000	0.371	0.002	0.000	0.000
1	14	C	0.172	0.024	0.002	0.035	0.974	0.173
2	16	O	0.043	0.403	0.332	0.129	0.070	0.079
2	15	C	0.847	0.248	0.045	0.155	0.094	0.000
3	17	O	0.051	0.067	1.987	0.288	0.559	0.000
3	18	C	0.039	0.452	0.014	0.095	0.591	2.340
4	25	O	0.292	0.258	0.043	0.109	0.894	0.000
4	26	C	0.058	0.022	0.354	0.200	0.123	0.000
	mean	O	0.101	0.182	0.683	0.132	0.381	0.020
	mean	C	0.279	0.187	0.104	0.121	0.445	0.628
	P		0.54	0.95 m	0.44 m	0.92 m	0.01 m	0.10 m

Eelgrass Bed

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	ATELECYC	BIVALVIA	GLYCERID	GONIADID	LACUNIDA	LUCINIDA	LUMBRINE	MONTACUT	MYIDAE
1	13	O	0.004	0.021	0.000	0.009	0.000	0.000	0.000	0.000	0.000	0.204	0.000
1	14	C	0.001	0.008	0.010	0.014	0.000	0.000	0.000	0.005	0.000	0.017	0.000
2	16	O	0.039	0.129	0.753	0.224	0.007	0.219	0.002	0.000	0.001	0.027	0.000
2	15	C	0.000	0.004	0.259	0.003	0.000	0.000	0.000	0.000	0.000	0.008	0.000
3	17	O	0.226	0.090	0.119	0.016	0.245	0.191	0.504	1.268	0.222	0.051	0.000
3	18	C	0.424	0.276	0.044	0.034	0.003	0.143	0.137	0.000	0.714	0.031	0.002
4	25	O	0.229	0.032	0.000	0.011	0.247	0.336	0.322	1.288	0.000	0.110	4.060
4	26	C	0.099	0.080	0.363	0.013	0.924	0.269	0.140	0.260	0.128	0.137	0.077
	mean	O	0.124	0.068	0.218	0.065	0.125	0.187	0.207	0.639	0.056	0.098	1.015
	mean	C	0.131	0.092	0.169	0.016	0.232	0.103	0.069	0.066	0.211	0.048	0.020
	P		0.79 m	0.58	0.76	0.77	0.41 m	0.70 m	0.05 m	0.20 m	0.43 m	0.63 m	0.40 m

Eelgrass Bed (continued)

Pair	Site#	Oilcode	MYTILIDA	NEREIDAE	OPHELIID	ORBINIID	PHYLLODO	POLYNOID	RHYNCHOC	SPIONIDA	TELLINID	VENERIDA
1	13	O	0.002	0.000	0.006	0.000	0.005	0.068	0.005	0.002	0.000	0.000
1	14	C	0.000	0.003	0.007	0.000	0.000	0.035	0.155	0.001	0.000	0.000
2	16	O	1.080	0.203	0.044	0.003	0.150	0.101	0.042	0.012	2.014	0.040
2	15	C	0.001	0.076	0.001	0.000	0.097	0.088	0.003	0.001	0.000	0.000
3	17	O	1.882	1.039	0.272	0.000	1.077	0.065	0.154	0.453	0.229	5.155
3	18	C	0.022	0.343	0.083	0.238	0.000	0.009	0.082	0.075	0.171	3.943
4	25	O	11.082	0.448	0.144	0.312	0.001	0.015	0.095	0.686	1.057	16.811
4	26	C	3.710	0.447	0.601	0.221	0.421	0.043	0.191	0.413	1.805	1.253
	mean	O	3.511	0.423	0.117	0.079	0.308	0.062	0.074	0.288	0.825	5.502
	mean	C	0.933	0.217	0.173	0.115	0.130	0.044	0.108	0.123	0.494	1.299
	P		<0.01	0.27 m	0.64 m	0.67 m	0.68 m	0.66 m	0.72 m	<0.01 m	0.67 m	0.07 m

Abundance - 1991

Deep

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	BIVALVIA	CAECIDAE	CAPITELL	LUCINIDA	MALDANID	MYTILIDA	NEPHTYID
1	13	O	10.16	6.22	1.65	10.76	0.00	5.16	5.71	0.00	1.33	168.29
1	14	C	40.61	21.55	10.00	49.56	0.00	6.89	407.56	3.33	0.00	2.67
2	16	O	11.33	6.00	57.33	4.67	149.33	54.67	33.33	13.33	7.33	0.00
2	15	C	86.23	7.71	36.83	62.99	1.14	6.89	12.19	11.17	0.00	2.60
3	17	O	0.89	81.33	109.77	11.56	0.00	13.33	14.22	35.78	101.28	0.83
3	18	C	9.33	32.00	114.67	10.83	0.00	96.83	90.00	4.00	0.67	4.83
4	25	O	19.73	12.53	44.80	18.67	0.00	12.27	116.00	57.07	11.20	3.00
4	26	C	12.13	41.27	43.24	8.19	51.37	49.43	61.30	35.43	33.27	0.89
	mean	O	10.53	26.52	53.39	11.41	37.33	21.36	42.32	26.54	30.29	43.03
	mean	C	37.08	25.63	51.18	32.89	13.13	40.01	142.76	13.48	8.48	2.75
	P		0.58m	0.95m	0.87	0.24	0.25m	0.18m	0.75m	0.06m	0.17	0.55m

Deep (continued)

Pair	Site#	Oilcode	OPHELIID	OPHIUROI	RISSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	THYASIRI
1	13	O	47.14	0.00	4.89	0.00	2.16	0.00	0.89	1.52	12.19
1	14	C	8.89	4.00	31.33	0.89	247.94	1.67	4.00	122.39	65.78
2	16	O	8.00	30.67	97.33	56.67	78.00	72.67	30.67	5.33	0.00
2	15	C	18.35	22.86	51.94	121.38	37.73	192.75	13.65	0.00	0.89
3	17	O	84.44	7.11	0.00	1.33	542.22	5.33	206.89	8.45	1.33
3	18	C	505.50	8.67	19.33	12.67	81.17	25.00	19.17	91.33	206.67
4	25	O	69.07	2.40	0.00	1.33	341.33	0.00	49.07	44.80	29.33
4	26	C	101.81	27.30	1.27	12.57	145.75	27.55	142.13	23.59	1.78
	mean	O	52.16	10.04	25.56	14.83	240.93	19.50	71.88	15.03	10.71
	mean	C	158.64	15.71	25.97	36.88	128.15	61.74	44.74	59.33	68.78
	P		0.17m	0.31	0.68m	0.76m	0.08m	0.34	0.56m	0.85m	0.79m

Eelgrass Bed

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CAPITELL	CAPRELLI	GASTROPO	LACUNIDA	MONTACUT	MYTILIDA	OPHELIID
1	13	O	18.22	6.67	275.11	7.33	0.00	369.11	0.00	287.33	37.56	145.33
1	14	C	18.67	6.40	26.67	200.70	47.47	95.20	0.00	53.07	5.87	24.00
2	16	O	22.89	65.33	135.11	29.33	257.33	273.56	36.00	142.00	514.45	413.72
2	15	C	2.67	67.11	28.89	5.33	93.33	148.89	1.33	61.78	5.78	172.45
3	17	O	52.30	72.71	11.11	26.02	65.09	91.35	228.05	35.73	789.32	616.12
3	18	C	78.28	606.00	56.64	34.70	557.65	189.81	253.87	38.00	189.59	1159.21
4	25	O	23.55	101.33	33.33	160.89	904.00	23.55	55.56	132.89	700.00	276.44
4	26	C	57.33	89.77	134.67	131.56	557.33	109.78	242.67	82.67	4656.44	391.72
5	35	O	6.67	162.67	22.67	6.67	116.00	61.33	0.00	538.67	24.00	144.00
5	34	C	4.55	39.55	7.78	80.56	215.33	151.67	14.67	49.22	10.33	86.22
	mean	O	24.73	81.74	95.47	46.05	268.48	163.78	63.92	227.32	413.06	319.12
	mean	C	32.30	161.77	50.93	90.57	294.22	139.07	102.51	56.95	973.60	366.72
	P		0.92m	0.23	0.71	0.87m	0.78m	0.98	0.19m	0.61m	0.39	0.96m

Eelgrass Bed (continued)

Pair	Site#	Oilcode	PHOXOCEP	POLYNOID	RISSOIDA	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	TROCHIDA
1	13	O	0.00	17.78	233.33	6.22	196.89	2.22	8.89	20.00
1	14	C	0.00	227.20	24.80	27.20	95.73	56.80	5.50	100.53
2	16	O	0.00	31.33	59.33	31.55	291.78	57.56	7.55	34.67
2	15	C	0.00	93.78	5.33	20.00	376.44	237.78	0.00	13.78
3	17	O	7.43	1.38	2.00	426.40	382.38	4.05	50.79	2.38
3	18	C	129.78	17.43	180.45	217.97	0.00	19.36	123.81	0.00
4	25	O	13.33	8.00	1.33	429.11	42.67	49.78	163.11	0.00
4	26	C	4.45	9.33	118.22	432.44	272.89	42.22	143.11	91.11
5	35	O	0.00	41.33	4.00	8.00	178.67	36.00	0.00	38.67
5	34	C	0.00	128.22	36.28	29.22	385.17	411.33	0.89	98.00
	mean	O	4.15	19.96	60.00	180.26	218.48	29.92	46.07	19.14
	mean	C	26.84	95.19	73.02	145.37	226.05	153.50	54.66	60.68
	P		0.16m	0.85m	0.47m	0.47m	0.92	0.57m	0.79m	<0.01m

Biomass - 1991

Deep

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CARDIIDA	CHAETOPT	LEPETIDA	DIPLODON	GLYCERID	GLYCYMER	GONIADID	LUCINID
1	13	O	0.196	0.001	0.076	0.001	0.000	0.000	0.000	0.000	0.000	0.066	0.170
1	14	C	0.034	0.006	0.231	0.009	0.007	0.000	0.000	0.000	0.000	0.063	9.966
2	16	O	0.019	0.214	0.007	1.116	0.000	0.032	0.000	0.239	0.000	0.024	0.573
2	15	C	0.093	0.040	0.302	0.000	0.000	0.003	0.000	0.003	0.000	0.001	0.521
3	17	O	0.177	0.204	2.890	0.000	0.684	0.000	0.057	0.043	0.189	0.029	0.099
3	18	C	0.529	0.176	0.010	0.604	0.000	1.135	0.000	0.000	0.000	0.209	2.303
4	25	O	0.406	0.110	0.009	0.000	0.483	0.000	0.565	0.061	1.018	0.036	1.358
4	26	C	0.062	0.054	0.031	0.000	0.205	0.085	1.001	0.070	0.029	0.081	0.482
	mean	O	0.200	0.132	0.746	0.279	0.292	0.008	0.155	0.086	0.302	0.039	0.550
	mean	C	0.179	0.069	0.143	0.153	0.053	0.306	0.250	0.018	0.007	0.088	3.318
	P		0.56 m	0.13	0.80	0.98 m	0.41 m	0.33	0.46	0.57 m	0.30 m	0.39 m	0.76 m

Deep (continued)

Pair	Site#	Oilcode	LUMBRINE	MYTILIDA	NEPHTYID	OLIVIDAE	ORBINIID	RHYNCHOC	SPIONIDA	TELLINID	THYASIRI	VENERIDA
1	13	O	0.000	0.001	0.429	0.000	0.000	0.187	0.011	0.387	0.098	0.000
1	14	C	0.029	0.000	0.385	0.000	0.004	0.093	0.233	8.739	0.392	0.040
2	16	O	0.419	0.051	0.000	0.000	0.062	0.961	0.120	0.009	0.000	0.019
2	15	C	0.132	0.000	0.004	0.000	0.049	0.087	0.042	0.000	0.012	0.000
3	17	O	0.000	2.667	0.718	1.492	0.004	0.289	0.285	0.132	0.017	0.005
3	18	C	0.063	0.001	1.545	0.284	0.584	0.062	0.062	5.756	0.967	0.204
4	25	O	0.196	0.017	0.444	1.021	0.006	0.168	0.186	0.657	0.195	0.079
4	26	C	0.095	0.184	0.008	0.823	0.064	0.085	0.078	0.768	0.021	0.004
	mean	O	0.154	0.684	0.398	0.628	0.018	0.401	0.151	0.296	0.077	0.026
	mean	C	0.080	0.046	0.486	0.277	0.175	0.082	0.104	3.816	0.348	0.062
	P		0.55 m	0.18	0.47 m	0.47 m	0.09 m	0.19 m	0.08 m	0.77 m	0.80 m	0.46 m

Eelgrass Bed

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	ATELECYC	BIVALVIA	GLYCERID	GONIADID	LACUNIDA	LUCINIDA	LUMBRINE	MONTACUT	MYIDAE
1	13	O	0.021	0.003	0.000	0.125	0.000	0.011	0.000	0.000	0.000	0.284	0.000
1	14	C	0.153	0.008	0.000	0.300	0.000	0.119	0.000	0.143	0.000	0.066	0.000
2	16	O	0.061	0.063	1.083	0.101	0.330	0.060	0.025	0.000	0.000	0.108	0.000
2	15	C	0.001	0.053	0.000	0.008	0.000	0.136	0.001	0.000	0.000	0.028	0.000
3	17	O	0.378	0.150	0.000	0.003	0.139	0.123	0.194	0.874	0.107	0.047	0.000
3	18	C	0.439	0.516	0.000	0.035	0.000	0.266	0.275	0.000	1.163	0.019	0.053
4	25	O	0.077	0.060	0.209	0.055	0.080	0.285	0.016	1.160	0.000	0.138	2.844
4	26	C	0.024	0.061	1.560	1.078	0.064	0.057	0.202	0.598	0.582	0.037	0.860
5	35	O	0.001	0.105	0.000	0.036	0.000	0.005	0.000	0.103	0.001	0.739	0.000
5	34	C	0.001	0.080	1.644	0.029	0.000	0.034	0.008	0.000	0.000	0.058	0.000
	mean	O	0.108	0.076	0.258	0.064	0.110	0.097	0.047	0.427	0.022	0.263	0.569
	mean	C	0.124	0.143	0.641	0.290	0.013	0.122	0.097	0.148	0.349	0.042	0.183
	P		0.44 m	0.18	0.79	0.60	0.52 m	0.83 m	0.03 m	0.51 m	0.01 m	0.65 m	0.78 m

Eelgrass Bed (continued)

Pair	Site#	Oilcode	MYTILIDA	NEREIDAE	OPHELIID	ORBINIID	PHYLLODO	POLYNOID	RHYNCHOC	SPIONIDA	TELLINID	VENERIDA
1	13	O	0.049	0.032	0.055	0.000	0.024	0.101	0.012	0.006	0.346	0.000
1	14	C	0.010	0.072	0.013	0.000	0.001	0.490	0.380	0.025	1.183	0.000
2	16	O	1.920	0.397	0.409	0.381	0.020	0.318	0.050	0.042	0.542	0.011
2	15	C	0.001	0.055	0.030	0.000	0.159	0.342	0.376	0.025	0.000	0.000
3	17	O	4.668	0.123	0.567	0.114	0.029	0.026	0.037	1.311	0.188	0.195
3	18	C	0.132	0.324	0.612	0.402	0.006	0.136	0.760	0.443	0.288	8.137
4	25	O	5.675	0.516	0.828	0.587	0.046	0.075	0.029	0.673	0.823	17.119
4	26	C	19.069	0.078	0.202	0.910	0.118	0.069	0.655	0.266	1.900	5.765
5	35	O	0.160	0.127	0.050	0.049	0.001	0.229	0.693	0.009	0.000	0.000
5	34	C	0.019	0.352	0.058	0.000	0.000	0.581	0.002	0.025	0.050	0.000
	mean	O	2.495	0.239	0.382	0.226	0.024	0.150	0.165	0.408	0.380	3.465
	mean	C	3.846	0.176	0.183	0.262	0.057	0.324	0.435	0.157	0.684	2.780
	P		0.47	0.03 m	0.24 m	0.92 m	0.10 m	0.85 m	0.045m	0.16 m	0.22 m	0.03 m

Abundance - 1993

Deep

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	BIVALVIA	CAECIDAE	CAPITELL	LUCINIDA	MALDANID	MYTILIDA	NEPHTYID
1	13	O	22.39	18.17	3.72	116.06	0.00	0.00	15.56	0.00	5.05	139.83
1	14	C	5.33	15.78	2.00	815.78	0.00	84.67	429.11	41.11	1.33	0.67
2	16	O	18.22	32.89	72.89	202.22	46.67	62.67	126.67	6.22	2.22	0.00
2	15	C	48.98	13.71	14.43	231.71	10.88	35.27	162.46	9.50	0.00	0.00
3	17	O	53.33	34.67	120.00	582.67	1.33	63.33	29.33	17.33	505.33	4.67
3	18	C	12.00	37.83	66.50	578.67	0.00	13.50	108.17	1.83	1.33	6.67
	mean	O	31.31	28.57	65.54	300.32	16.00	42.00	57.19	7.85	170.87	48.17
	mean	C	22.10	22.44	27.64	542.05	3.63	44.48	233.25	17.48	0.89	2.44
	P		0.130m	0.309m	0.001	0.122	0.058m	0.069m	0.700m	0.952m	0.007	0.319m

Deep (continued)

Pair	Site#	Oilcode	OPHELIID	OPHIUROI	RISSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	THYASIRI	TOTAL
1	13	O	49.11	0.50	19.00	0.00	11.78	0.00	0.00	9.11	0.89	461.27
1	14	C	997.11	12.00	2.00	13.56	272.67	3.11	86.89	47.78	120.00	2515.33
2	16	O	153.33	33.33	12.89	84.00	312.44	80.00	79.11	2.67	1.78	1574.68
2	15	C	233.75	29.98	1.60	78.19	123.50	49.61	13.86	0.70	26.30	1140.78
3	17	O	64.00	4.00	0.00	0.00	423.33	7.33	125.33	4.00	8.00	1736.67
3	18	C	114.83	4.67	0.00	6.00	202.33	11.00	4.00	43.50	384.67	1223.83
	mean	O	88.82	12.61	10.63	28.00	249.18	29.11	68.15	5.26	3.56	1257.54
	mean	C	448.57	15.55	1.20	32.58	199.50	21.24	34.92	30.66	176.99	1626.65
	P		0.693m	0.615	0.414m	1.000m	0.174m	0.707	0.051m	0.643m	0.514m	0.542

Depth = Deep (continued)

Pair	Site#	Oilcode	MONTACUT	OEDICERO
1	13	O	2.61	0.00
1	14	C	178.45	0.00
2	16	O	32.00	25.78
2	15	C	10.63	0.89
3	17	O	12.67	55.33
3	18	C	8.00	0.33
	mean	O	15.76	27.04
	mean	C	65.69	0.41
	P		0.227m	0.223m

Eelgrass Bed

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CAPITELL	CAPRELLI	GASTROPO	LACUNIDA	MONTACUT	MYTILIDA	OPHELIID
1	13	O	14.12	36.30	290.12	15.58	35.82	272.00	1.33	114.61	82.48	69.09
1	14	C	8.45	37.33	64.00	57.11	83.78	130.00	0.00	35.33	5.33	246.67
2	16	O	16.00	85.33	3041.33	36.00	574.67	418.67	25.33	618.67	1968.00	501.33
2	15	C	20.27	56.53	122.85	11.02	64.27	161.24	0.00	94.75	4.45	44.89
3	17	O	38.44	233.11	200.22	32.22	1316.67	139.78	41.33	14.00	136.67	576.89
3	18	C	1.60	200.08	220.03	3.73	362.64	53.25	24.07	0.00	39.31	102.81
	mean	O	22.85	118.25	1177.23	27.93	642.38	276.81	22.67	249.09	729.05	382.44
	mean	C	10.10	97.98	135.63	23.96	170.23	114.83	8.02	43.36	16.36	131.46
	P		0.132m	0.631	0.042	0.110m	0.037m	0.021	0.353m	0.586m	<0.001	0.009m

Eelgrass Bed (continued)

Pair	Site#	Oilcode	PHOXOCEP	POLYNOID	RISSOIDA	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	TROCHIDA	TOTAL
1	13	O	0.00	22.55	38.67	8.00	256.06	5.15	0.24	22.55	1278.36
1	14	C	0.00	103.56	0.00	20.44	161.33	130.67	0.00	2.67	1444.44
2	16	O	0.00	58.67	0.00	20.00	981.33	121.33	5.33	28.00	6177.33
2	15	C	0.00	68.09	0.00	7.20	49.16	101.87	0.98	1.07	792.44
3	17	O	20.67	4.67	0.00	149.78	948.45	2.67	28.89	2.67	4064.89
3	18	C	98.20	0.00	0.00	12.25	0.53	0.00	179.67	0.00	1034.08
	mean	O	6.89	28.63	12.89	59.26	728.61	43.05	11.49	17.74	3840.19
	mean	C	32.73	57.21	0.00	13.30	70.34	77.51	60.21	1.24	1090.32
	P		0.037m	0.056m	0.906m	0.006m	0.006	0.111m	0.054m	0.606m	0.022

Eelgrass Bed (continued)

Pair	Site#	Oilcode	ISCHYROC	NEREIDAE	SIGALION
1	13	O	0.00	0.67	88.67
1	14	C	2.22	3.11	16.00
2	16	O	18.67	73.33	98.67
2	15	C	0.53	6.40	26.40
3	17	O	117.55	48.00	0.00
3	18	C	26.11	10.08	0.00
	mean	O	45.41	40.67	62.44
	mean	C	9.62	6.53	14.13
	P		0.126m	0.023m	0.434m

Biomass - 1993

Deep

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CARDIIDA	CHAETOPT	CRYPTOBR	DIPLODON	GLYCERID	GLYCYMER	GONIADID	LUCINID
1	13	O	0.004	0.007	0.592	0.046	0.000	0.000	0.000	0.000	0.000	0.000	0.375
1	14	C	0.293	0.004	14.736	0.002	0.083	0.000	0.000	0.000	0.000	0.008	9.679
2	16	O	0.040	0.165	8.894	4.455	0.000	0.126	0.000	0.035	0.000	0.008	1.987
2	15	C	0.040	0.024	6.106	0.518	0.000	0.898	0.000	0.001	0.000	0.001	4.919
3	17	O	0.425	0.162	6.668	0.000	0.804	0.000	0.000	0.081	0.655	0.117	0.316
3	18	C	0.349	0.104	10.321	0.000	0.000	0.000	0.000	0.000	0.000	0.291	4.487
	mean	O	0.157	0.111	5.384	1.500	0.268	0.042	0.000	0.039	0.218	0.042	0.893
	mean	C	0.227	0.044	10.388	0.173	0.028	0.299	0.000	0.000	0.000	0.100	6.362
	P		0.082m	0.053	0.183	0.393m	0.976m	0.142	.	0.192m	0.941m	0.915m	0.988m

Deep (continued)

Pair	Site#	Oilcode	LUMBRINE	MYTILIDA	NEPHTYID	OLIVIDAE	ORBINIID	RHYNCHOC	SPIONIDA	TELLINID	THYASIRI	VENERIDA	TOTAL
1	13	O	0.000	0.002	0.553	0.000	0.000	0.000	0.003	0.112	0.000	0.000	2.067
1	14	C	0.071	0.003	0.086	0.072	0.039	0.029	0.328	3.601	0.981	0.000	18.762
2	16	O	0.138	0.013	0.000	0.009	0.141	0.188	0.150	0.003	0.022	0.012	14.357
2	15	C	0.050	0.000	0.000	0.000	0.103	0.175	0.116	0.121	0.261	0.031	11.435
3	17	O	0.203	4.878	0.004	1.767	0.010	0.075	0.275	0.369	0.095	0.061	12.816
3	18	C	0.218	0.012	0.043	0.664	0.303	0.042	0.118	0.926	2.472	0.178	14.138
	mean	O	0.114	1.631	0.186	0.592	0.050	0.088	0.143	0.161	0.039	0.024	9.747
	mean	C	0.113	0.005	0.043	0.245	0.149	0.082	0.188	1.549	1.238	0.070	14.778
	P		0.385m	0.032	0.142m	0.901m	0.754m	0.986m	0.225m	0.774m	0.592m	0.696m	0.219

Deep (continued)

Pair	Site#	Oilcode	AMPHARET	BRYOZOA	ISCHNOCH	NASSARII	OPHIUROI
1	13	O	0.597	0.006	0.000	0.000	0.001
1	14	C	0.016	0.004	0.000	0.087	0.698
2	16	O	0.016	0.410	0.104	0.152	0.349
2	15	C	0.013	0.500	1.190	0.013	0.283
3	17	O	0.075	0.031	0.000	0.553	0.060
3	18	C	0.029	0.066	0.000	0.008	0.094
	mean	O	0.229	0.149	0.035	0.235	0.136
	mean	C	0.019	0.190	0.397	0.036	0.358
	P		0.699m	0.823	0.162	0.718m	0.198m

Eelgrass Bed

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	ATELECYC	BIVALVIA	GLYCERID	GONIADID	LACUNIDA	LUCINIDA	LUMBRINE	MONTACUT	MYIDAE
1	13	O	0.014	0.021	0.000	0.797	0.000	0.142	0.000	0.034	0.000	0.141	0.000
1	14	C	0.043	0.037	0.119	0.429	0.000	0.000	0.000	0.348	0.000	0.020	0.000
2	16	O	0.042	0.081	0.497	15.585	0.352	0.000	0.040	0.015	0.013	0.625	0.000
2	15	C	0.021	0.064	0.000	0.347	0.000	0.007	0.000	0.000	0.000	0.053	0.000
3	17	O	0.184	0.280	0.024	24.528	0.054	0.132	0.079	0.000	0.000	0.019	1.551
3	18	C	0.000	0.304	0.237	1.975	0.000	0.209	0.066	0.000	1.327	0.000	0.000
	mean	O	0.080	0.127	0.174	13.637	0.135	0.091	0.040	0.016	0.004	0.262	0.517
	mean	C	0.022	0.135	0.119	0.917	0.000	0.072	0.022	0.116	0.442	0.024	0.000
	P		0.014m	0.882	0.841	0.061	0.518m	0.295m	0.637m	0.054m	0.080m	0.676m	0.235m

Eelgrass Bed (continued)

Pair	Site#	Oilcode	MYTILIDA	NEREIDAE	OPHELIID	ORBINIID	PHYLLODO	POLYNOID	RHYNCHOC	SPIONIDA	TELLINID	VENERIDA	TOTAL
1	13	O	0.425	0.002	0.029	0.000	0.004	0.113	0.250	0.009	0.000	0.000	2.938
1	14	C	0.005	0.094	0.063	0.000	0.004	0.319	0.446	0.024	0.000	0.000	2.649
2	16	O	10.836	0.597	0.243	0.017	0.008	0.131	0.244	0.006	3.623	0.000	20.123
2	15	C	0.002	0.173	0.014	0.000	0.000	0.226	0.071	0.013	0.204	0.000	1.616
3	17	O	1.323	0.186	0.307	0.307	0.004	0.080	0.079	0.380	0.290	21.304	32.190
3	18	C	0.040	0.280	0.091	0.239	0.005	0.000	0.069	0.055	1.934	0.001	15.443
	mean	O	4.195	0.262	0.193	0.108	0.005	0.108	0.191	0.132	1.304	7.101	18.417
	mean	C	0.015	0.182	0.056	0.080	0.003	0.182	0.195	0.031	0.713	0.000	6.570
	P		0.002	0.824m	0.099m	0.789m	0.786m	0.040m	0.361m	0.055m	0.751m	0.205m	0.088

Eelgrass Bed (continued)

Pair	Site#	Oilcode	BRYOZOA	CAPRELLI	MONTACUT
1	13	O	0.001	0.006	0.141
1	14	C	0.223	0.013	0.020
2	16	O	0.994	0.063	0.625
2	15	C	0.063	0.012	0.053
3	17	O	0.043	0.434	0.019
3	18	C	7.968	0.259	0.000
	mean	O	0.346	0.167	0.262
	mean	C	2.752	0.095	0.024
	P		0.173	0.295m	0.655m

APPENDIX M.

Mean values for community parameters of epifaunal invertebrate that were sampled by dropnet at oiled and control sites in the eelgrass habitat in 1990. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix M. Mean values for community parameters of epifaunal invertebrate that were sampled by dropnet at oiled and control sites in the eelgrass habitat in 1990. Also given are probabilities that the means from the oiled anc control sites were similar as determined by randomization tests.

Abundance (#/m^2)

Pair	Site#	Oilcode	AMPHIPOD	BIVALVIA	CAPRELLI	COROPHII	GASTROPO	HIPPOLYT	ISCHYROC	LACUNIDA	MONTACUT
1	13	O	0.52	146.76	1.32	5.68	34.35	0.00	0.52	24.98	160.00
1	14	C	8.33	15.61	65.31	0.00	0.00	2.08	2.08	4.16	5.20
2	16	O	0.00	0.00	111.89	2.60	2.60	11.97	8.33	355.97	0.00
2	15	C	0.00	6.25	12.49	14.05	69.32	1.41	3.12	197.66	9.37
3	17	O	0.00	0.00	0.00	0.00	12.49	0.00	0.00	1192.82	3.12
3	18	C	0.00	1.04	77.57	3.12	9.63	6.32	87.07	516.45	0.00
4	25	O	0.00	0.00	48.71	0.00	4.16	21.86	17.90	183.40	0.00
4	26	C	0.00	3.12	63.49	0.00	0.00	10.41	11.45	562.06	0.00
	mean	O	0.13	36.69	40.48	2.07	13.40	8.46	6.69	439.29	40.78
	mean	C	2.08	6.51	54.72	4.29	19.74	5.05	25.93	320.08	3.64
	P										

Abundance (continued)

Pair	Site#	Oilcode	MYTILIDA	NEREIDAE	ONCHIDOR	POLYNOID	RISSOIDA	SPIRORBI	SYLLIDAE	TROCHIDA	TOTAL
1	13	O	54.15	1.85	0.00	82.92	37.44	169.23	0.00	70.29	1299.48
1	14	C	9.37	18.74	0.00	33.31	3.12	258.13	5.20	189.44	662.89
2	16	O	623.99	2.08	22.38	5.72	0.00	466.30	0.00	98.88	1743.95
2	15	C	6.87	3.12	2.50	57.46	7.18	768.15	16.86	121.47	1435.75
3	17	O	145.10	0.00	32.47	0.00	5.62	274.16	0.00	0.00	1684.73
3	18	C	43.46	0.00	7.83	0.00	4.68	0.00	0.00	0.00	804.74
4	25	O	1169.29	1.25	5.20	0.00	1.25	345.36	0.00	3.12	1813.58
4	26	C	1057.51	3.12	0.00	0.00	0.00	256.05	6.25	70.78	2082.88
	mean	O	498.13	1.30	15.01	22.16	11.08	313.76	0.00	43.07	1635.43
	mean	C	279.30	6.25	2.58	22.69	3.75	320.58	7.08	95.42	1246.56
	P										

Biomass (gm/1m^2)

Pair	Site#	Oilcode	AMPHIPOD	CAPRELLI	COROPHII	GASTROPO	HIPPOLYT	ISCHYROC	LACUNIDA	MONTACUT	MYTILIDA
1	13	O	0.001	0.001	0.008	0.010	0.000	0.001	0.112	0.589	0.204
1	14	C	0.006	0.020	0.000	0.009	0.241	0.001	0.007	0.008	0.020
2	16	O	0.002	0.028	0.003	0.004	0.450	0.004	0.384	0.000	5.251
2	15	C	0.000	0.006	0.009	0.041	0.399	0.003	0.480	0.025	0.014
3	17	O	0.000	0.000	0.000	0.009	0.000	0.000	2.318	0.002	1.065
3	18	C	0.000	0.048	0.006	0.017	0.112	0.064	0.868	0.000	0.271
4	25	O	0.002	0.025	0.000	0.002	0.323	0.006	0.704	0.000	24.124
4	26	C	0.002	0.036	0.000	0.005	0.582	0.005	1.258	0.000	27.380
	mean	O	0.001	0.013	0.003	0.006	0.193	0.003	0.879	0.148	7.661
	mean	C	0.002	0.027	0.004	0.018	0.333	0.018	0.653	0.008	6.921
	P										

Biomass (continued)

Pair	Site#	Oilcode	NEREIDAE	ONCHIDOR	PLEUSTID	POLYNOID	RISSOIDA	SPIRORBI	TROCHIDA	TOTAL
1	13	O	0.017	0.000	0.002	0.183	0.072	0.017	0.186	3.493
1	14	C	0.180	0.000	1.194	0.044	0.005	0.023	0.465	2.352
2	16	O	0.002	0.049	0.000	0.006	0.000	0.026	0.097	7.709
2	15	C	0.002	0.012	0.000	0.174	0.011	0.042	0.382	4.269
3	17	O	0.000	0.057	0.041	0.000	0.010	0.038	0.000	4.148
3	18	C	0.000	0.009	0.023	0.000	0.005	0.000	0.000	2.263
4	25	O	0.003	0.005	0.000	0.000	0.003	0.006	0.184	25.437
4	26	C	0.021	0.000	0.018	0.000	0.000	0.009	0.187	30.781
	mean	O	0.005	0.028	0.011	0.047	0.021	0.022	0.117	10.197
	mean	C	0.051	0.005	0.309	0.054	0.005	0.019	0.259	9.916
	P									

APPENDIX N.

Mean values for abundance and biomass of dominant epifaunal invertebrate families that were sampled by dropnet at oiled and control sites in the eelgrass habitat in 1990. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix N. Mean values for abundance and biomass of dominant epifaunal invertebrate families that were sampled by dropnet at oiled and control sites in the eelgrass habitat in 1990. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests. Names of some dominant taxa are abbreviated. See Appendix J for the complete spellings.

Abundance (#/m^2) - 1990

Pair	Site#	Oilcode	AMPHIPOD	BIVALVIA	CAPRELLI	COROPHII	GASTROPO	HIPPOLYT	ISCHYROC	LACUNIDA	MONTACUT
1	13	O	0.52	146.76	1.32	5.68	34.35	0.00	0.52	24.98	160.00
1	14	C	8.33	15.61	65.31	0.00	0.00	2.08	2.08	4.16	5.20
2	16	O	0.00	0.00	111.89	2.60	2.60	11.97	8.33	355.97	0.00
2	15	C	0.00	6.25	12.49	14.05	69.32	1.41	3.12	197.66	9.37
3	17	O	0.00	0.00	0.00	0.00	12.49	0.00	0.00	1192.82	3.12
3	18	C	0.00	1.04	77.57	3.12	9.63	6.32	87.07	516.45	0.00
4	25	O	0.00	0.00	48.71	0.00	4.16	21.86	17.90	183.40	0.00
4	26	C	0.00	3.12	63.49	0.00	0.00	10.41	11.45	562.06	0.00
	mean	O	0.13	36.69	40.48	2.07	13.40	8.46	6.69	439.29	40.78
	mean	C	2.08	6.51	54.72	4.29	19.74	5.05	25.93	320.08	3.64
	P		0.12	0.97	0.55	0.46	0.93	0.39	0.19	0.46	0.30

Abundance (#/m^2) - 1990 (continued)

Pair	Site#	Oilcode	MYTILIDA	NEREIDAE	ONCHIDOR	POLYNOID	RISSOIDA	SPIRORBI	SYLLIDAE	TROCHIDA	TOTAL
1	13	O	54.15	1.85	0.00	82.92	37.44	169.23	0.00	70.29	1299.48
1	14	C	9.37	18.74	0.00	33.31	3.12	258.13	5.20	189.44	662.89
2	16	O	623.99	2.08	22.38	5.72	0.00	466.30	0.00	98.88	1743.95
2	15	C	6.87	3.12	2.50	57.46	7.18	768.15	16.86	121.47	1435.75
3	17	O	145.10	0.00	32.47	0.00	5.62	274.16	0.00	0.00	1684.73
3	18	C	43.46	0.00	7.83	0.00	4.68	0.00	0.00	0.00	804.74
4	25	O	1169.29	1.25	5.20	0.00	1.25	345.36	0.00	3.12	1813.58
4	26	C	1057.51	3.12	0.00	0.00	0.00	256.05	6.25	70.78	2082.88
	mean	O	498.13	1.30	15.01	22.16	11.08	313.76	0.00	43.07	1635.43
	mean	C	279.30	6.25	2.58	22.69	3.75	320.58	7.08	95.42	1246.56
	P		0.34	0.08	<0.01	0.88	0.37	0.97	<0.01	0.15	0.33

Biomass (gm/m^2) - 1990

Pair	Site#	Oilcode	AMPHIPOD	CAPRELLI	COROPHII	GASTROPO	HIPPOLYT	ISCHYROC	LACUNIDA	MONTACUT	MYTILIDA
1	13	O	0.001	0.001	0.008	0.010	0.000	0.001	0.112	0.589	0.204
1	14	C	0.006	0.020	0.000	0.009	0.241	0.001	0.007	0.008	0.020
2	16	O	0.002	0.028	0.003	0.004	0.450	0.004	0.384	0.000	5.251
2	15	C	0.000	0.006	0.009	0.041	0.399	0.003	0.480	0.025	0.014
3	17	O	0.000	0.000	0.000	0.009	0.000	0.000	2.318	0.002	1.065
3	18	C	0.000	0.048	0.006	0.017	0.112	0.064	0.868	0.000	0.271
4	25	O	0.002	0.025	0.000	0.002	0.323	0.006	0.704	0.000	24.124
4	26	C	0.002	0.036	0.000	0.005	0.582	0.005	1.258	0.000	27.380
	mean	O	0.001	0.013	0.003	0.006	0.193	0.003	0.879	0.148	7.661
	mean	C	0.002	0.027	0.004	0.018	0.333	0.018	0.653	0.008	6.921
	P		0.03	0.19	0.75	0.30	0.42	0.17	0.44	0.18	0.89

Biomass (gm/m^2) - 1990 (continued)

Pair	Site#	Oilcode	NEREIDAE	ONCHIDOR	PLEUSTID	POLYNOID	RISSOIDA	SPIRORBI	TROCHIDA	TOTAL
1	13	O	0.017	0.000	0.002	0.183	0.072	0.017	0.186	3.493
1	14	C	0.180	0.000	1.194	0.044	0.005	0.023	0.465	2.352
2	16	O	0.002	0.049	0.000	0.006	0.000	0.026	0.097	7.709
2	15	C	0.002	0.012	0.000	0.174	0.011	0.042	0.382	4.269
3	17	O	0.000	0.057	0.041	0.000	0.010	0.038	0.000	4.148
3	18	C	0.000	0.009	0.023	0.000	0.005	0.000	0.000	2.263
4	25	O	0.003	0.005	0.000	0.000	0.003	0.006	0.184	25.437
4	26	C	0.021	0.000	0.018	0.000	0.000	0.009	0.187	30.781
	mean	O	0.005	0.028	0.011	0.047	0.021	0.022	0.117	10.197
	mean	C	0.051	0.005	0.309	0.054	0.005	0.019	0.259	9.916
	P		0.04	0.05	0.47	0.72	0.39	0.74	0.11	0.97

APPENDIX O.

Mean values and results of 2-way randomization ANOVAs comparing community parameters for invertebrates that were sampled by suction dredge at oiled and control sites in the eelgrass habitat in 1990, 1991, and 1993.

Appendix O. Mean values and results of 2-way randomization ANOVAs comparing community parameters for invertebrates that were sampled by suction dredge at oiled and control sites in the eelgrass habitat in 1990, 1991, and 1993. All taxa were used at the family level or higher. Only sites sampled all three years were used for analyses. * = <0.1 ** = <0.05 *** = <0.01.

Transect = Deep (1)

Year	Oilcode	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
1990	(O)	2.25	0.28	41	569	6.945	6.234
1990	(C)	2.49	0.14	36	694	6.730	5.534
1991	(O)	2.50	0.23	46	1081	7.671	6.399
1991	(C)	2.55	0.18	50	1312	16.624	6.840
1993	(O)	2.64	0.14	48	1258	9.747	6.667
1993	(C)	2.54	0.15	53	1627	14.778	7.260
Mean	(O)	2.46	0.21	45	969	8.121	6.433
Mean	(C)	2.53	0.16	46	1211	12.711	6.545
P-Oilcode:		0.641	0.132	0.646	0.279	0.037**	0.801
P-Year:		0.453	0.420	0.010***	0.001***	0.070*	0.134
P-Interaction:		0.608	0.326	0.437	0.897	0.236	0.440

Transect = Bed (3)

Year	Oilcode	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
1990	(O)	2.11	0.20	34	1632	8.618	4.534
1990	(C)	2.16	0.18	26	688	3.339	3.856
1991	(O)	2.28	0.16	40	2616	7.613	5.007
1991	(C)	2.43	0.14	38	2228	8.833	4.868
1993	(O)	2.29	0.17	44	3840	18.417	5.368
1993	(C)	2.35	0.16	33	1090	6.570	4.597
Mean	(O)	2.23	0.18	39	2696	11.549	4.970
Mean	(C)	2.31	0.16	32	1335	6.247	4.440
P-Oilcode:		0.360	0.318	0.011**	<0.001***	0.035**	0.109
P-Year:		0.107	0.195	0.013**	0.025**	0.122	0.082*
P-Interaction:		0.880	0.976	0.479	0.079*	0.142	0.729

APPENDIX P.

Mean values and results of 2-way randomized ANOVAs comparing abundance and biomass of dominant invertebrates sampled by suction dredge at oiled and control sites in the eelgrass habitat during 1990, 1991, and 1993 subtidal surveys in Prince William Sound. Only sites common to all survey years were used in the analyses.

Appendix P. Mean values and results of 2-way randomized ANOVAs comparing abundance and biomass of dominant invertebrates sampled by suction dredge at oiled and control sites in the eelgrass habitat during 1990, 1991, and 1993 subtidal surveys in Prince William Sound. Only sites common to all survey years were used in the analyses. Densities are #/0.1m2 and biomass units are grams/0.1m2. Taxa analyzed using percent mud as a covariate are identified with an 'm' next to the interaction value. Names of some dominant taxa are abbreviated. See Appendix J for the complete spellings.

Abundance Depth = Deep

Year		Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	BIVALVIA	CAECIDAE	CAPITELL	LUCINIDA	MALDANID	MYTILIDA	NEPHTYID
1990	mean	O	1.74	8.93	21.11	137.14	11.70	6.50	47.72	5.77	48.88	63.33
1990	mean	C	5.56	12.79	52.86	262.92	0.11	10.43	51.66	3.83	2.64	1.83
1991	mean	O	7.46	31.18	56.25	112.34	49.78	24.39	17.76	16.37	36.65	56.38
1991	mean	C	45.39	20.42	53.83	415.51	0.38	36.87	169.92	6.17	0.22	3.37
1993	mean	O	31.31	28.57	65.54	300.32	16.00	42.00	57.19	7.85	170.87	48.17
1993	mean	C	22.10	22.44	27.64	542.05	3.63	44.48	233.25	17.48	0.89	2.44
Oilcode		P	0.742	0.380	0.761	0.003	0.012	0.931	0.551	0.062	<0.001	0.098
Year		P	0.040	0.626	0.260	0.046	0.362	0.216	0.031	0.060	0.138	0.964
Interaction		P	0.804m	0.920m	0.003	0.640	0.711m	0.173	0.256m	0.336m	0.171	0.953m

Abundance Depth = Deep (Continued)

Year		Oilcode	OPHELIID	OPHIUROI	RISSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	THYASIRI	TOTAL
1990	mean	O	24.02	4.44	8.13	2.33	80.10	25.17	25.09	5.88	3.80	569.37
1990	mean	C	73.91	2.54	4.13	8.78	86.12	20.72	4.89	81.17	64.48	693.84
1991	mean	O	46.53	18.22	34.07	19.33	207.46	26.00	79.48	5.10	4.51	1081.24
1991	mean	C	177.58	10.51	34.20	44.98	122.28	73.14	12.27	71.24	91.11	1312.24
1993	mean	O	88.82	12.61	10.63	28.00	249.18	29.11	68.15	5.26	3.56	1257.54
1993	mean	C	448.57	15.55	1.20	32.58	199.50	21.24	34.92	30.66	176.99	1626.65
Oilcode		P	0.899	0.594	0.737	0.888	0.040	0.770	0.003	0.968	0.100	0.268
Year		P	0.222	0.013	0.002	0.161	0.129	0.609	0.407	0.154	0.921	<0.001
Interaction		P	0.730m	0.539	0.641m	0.721m	0.693m	0.561	0.717m	0.175m	0.811m	0.912

Abundance Depth = Deep (Continued)

Year		Oilcode	MONTACUT	OEDICERO
1990	mean	O	13.76	6.60
1990	mean	C	7.26	2.44
1991	mean	O	14.78	10.52
1991	mean	C	21.70	2.91
1993	mean	O	15.76	27.04
1993	mean	C	65.69	0.41
Oilcode		P	0.005	0.044
Year		P	0.209	0.275
Interaction		P	0.234m	0.170m

Abundance Depth = Bed

Year		Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CAPITELL	CAPRELLI	GASTROPO	LACUNIDA	MONTACUT	MYTILIDA	OPHELIID
1990	mean	O	39.91	25.02	336.55	32.77	52.28	312.44	116.57	70.23	162.86	103.27
1990	mean	C	14.19	81.45	115.55	19.62	94.33	107.90	43.33	19.09	12.94	45.09
1991	mean	O	31.14	48.24	896.88	20.89	107.47	470.64	88.02	155.02	447.11	391.72
1991	mean	C	33.20	226.50	229.93	80.24	232.82	345.65	85.07	50.95	67.08	451.88
1993	mean	O	22.85	118.25	1177.23	27.93	642.38	276.81	22.67	249.09	729.05	382.44
1993	mean	C	10.10	97.98	135.63	23.96	170.23	114.83	8.02	43.36	16.36	131.46
Oilcode		P	0.049	0.030	0.001	0.903	0.558	0.010	0.242	0.508	<0.001	0.028
Year		P	0.123	0.130	0.223	0.309	0.095	0.009	0.111	0.216	0.257	0.141
Interaction		P	0.942m	0.034	0.309	0.354m	0.231m	0.905	0.735m	0.158m	0.292	0.416m

Abundance Depth = Bed (Continued)

Year		Oilcode	PHOXOCEP	POLYNOID	RISSOIDA	SPIONIDA	SPIRORBI	SYLLIDAE	TELLINID	TROCHIDA	TOTAL
1990	mean	O	0.22	25.07	10.91	189.24	370.43	44.12	16.11	0.00	1631.99
1990	mean	C	37.56	18.30	2.13	64.57	80.22	9.61	36.00	1.50	688.17
1991	mean	O	2.48	16.83	98.22	154.72	290.35	21.28	22.41	19.02	2616.47
1991	mean	C	43.26	112.80	70.19	88.39	157.39	104.65	43.10	38.10	2227.57
1993	mean	O	6.89	28.63	12.89	59.26	728.61	43.05	11.49	17.74	3840.19
1993	mean	C	32.73	57.21	0.00	13.30	70.34	77.51	60.21	1.24	1090.32
Oilcode		P	<0.001	0.690	0.837	0.036	<0.001	0.635	0.006	0.202	0.001
Year		P	0.822	0.567	0.834	0.234	0.204	0.583	0.299	0.972	0.025
Interaction		P	0.665m	0.274m	0.971m	0.958m	0.052	0.787m	0.191m	0.277m	0.070

Abundance Depth = Bed (Continued)

Year		Oilcode	ISCHYROC	NEREIDAE	SIGALION
1990	mean	O	7.61	17.99	7.96
1990	mean	C	9.09	1.98	1.68
1991	mean	O	9.35	19.57	21.52
1991	mean	C	73.38	7.38	8.74
1993	mean	O	45.41	40.67	62.44
1993	mean	C	9.62	6.53	14.13
Oilcode		P	0.812	<0.001	0.262
Year		P	0.185	0.373	0.677
Interaction		P	0.010m	0.494m	0.195m

Biomass Depth = Deep

Year		Oilcode	AMPHICTE	AMPHIPOD	BIVALVIA	CARDIIDA	CHAETOPT	CRYPTOBR	DIPLODON	GLYCERID	GLYCYMER	GONIADID	LUCINIDA
1990	mean	O	0.067	0.060	2.556	0.000	0.097	0.000	0.133	0.010	0.001	0.013	0.799
1990	mean	C	0.031	0.070	4.409	0.276	0.000	0.028	0.000	0.400	0.000	0.159	2.048
1991	mean	O	0.131	0.140	3.011	0.372	0.228	0.011	0.019	0.094	0.063	0.040	0.281
1991	mean	C	0.218	0.074	11.002	0.204	0.002	0.379	0.000	0.001	0.000	0.091	4.264
1993	mean	O	0.157	0.111	5.384	1.500	0.268	0.042	0.000	0.039	0.218	0.042	0.893
1993	mean	C	0.227	0.044	10.388	0.173	0.028	0.299	0.000	0.000	0.000	0.100	6.362
Oilcode		P	0.599	0.081	0.006	0.596	0.416	0.159	0.719	0.533	0.673	0.040	0.945
Year		P	0.777	0.328	0.126	0.868	0.855	0.677	0.809	0.839	0.337	0.301	0.201
Interaction		P	0.310m	0.294	0.452	0.789m	0.858m	0.757	0.707m	0.852m	0.668m	0.050m	0.477m

Biomass Depth = Deep (Continued)

Year		Oilcode	LUMBRINE	MYTILIDA	NEPHTYID	OLIVIDAE	ORBINIID	RHYNCHOC	SPIONIDA	TELLINID	THYASIRI	VENERIDA	TOTAL
1990	mean	O	0.181	0.414	0.123	1.912	0.048	0.610	0.038	0.087	0.006	0.633	6.945
1990	mean	C	0.362	0.006	0.004	0.004	0.162	0.115	0.067	0.854	0.355	0.503	6.730
1991	mean	O	0.140	0.906	0.383	0.497	0.022	0.479	0.139	0.176	0.038	0.008	7.671
1991	mean	C	0.074	0.000	0.645	0.095	0.212	0.080	0.113	4.832	0.457	0.081	16.624
1993	mean	O	0.114	1.631	0.186	0.592	0.050	0.088	0.143	0.161	0.039	0.024	9.747
1993	mean	C	0.113	0.005	0.043	0.245	0.149	0.082	0.188	1.549	1.238	0.070	14.778
Oilcode		P	0.653	<0.001	0.506	0.427	0.045	0.046	0.078	0.753	0.112	0.026	0.044
Year		P	0.009	0.763	0.935	0.782	0.836	0.603	0.137	0.754	0.914	0.043	0.072
Interaction		P	0.072m	0.753	0.343m	0.707m	0.689m	0.487m	0.805m	0.915m	0.809m	0.034m	0.233

Biomass Depth = Deep (Continued)

Year		Oilcode	AMPHARET	BRYOZOA	ISCHNOCH	NASSARII	OPHIUROI
1990	mean	O	0.003	0.031	0.028	0.032	0.020
1990	mean	C	0.004	0.008	0.041	0.022	0.023
1991	mean	O	0.014	0.121	0.244	0.030	0.260
1991	mean	C	0.083	0.055	0.019	0.022	0.056
1993	mean	O	0.229	0.149	0.035	0.235	0.136
1993	mean	C	0.019	0.190	0.397	0.036	0.358
Oilcode		P	0.963	0.871	0.744	0.429	0.924
Year		P	0.972	0.119	0.409	0.070	0.018
Interaction		P	0.598m	0.868	0.016	0.545m	0.032

Biomass Depth = Bed

Year		Oilcode	AMPHICTE	AMPHIPOD	ATELECYC	BIVALVIA	GLYCERID	GONIADID	LACUNIDA	LUCINIDA	LUMBRINE	MONTACUT	MYIDAE
1990	mean	O	0.089	0.080	0.291	4.083	0.084	0.137	0.169	0.423	0.074	0.094	0.000
1990	mean	C	0.141	0.096	0.104	1.418	0.001	0.048	0.046	0.002	0.238	0.019	0.001
1991	mean	O	0.153	0.072	0.361	3.314	0.156	0.065	0.073	0.291	0.036	0.147	0.000
1991	mean	C	0.198	0.192	0.000	3.529	0.000	0.174	0.092	0.048	0.388	0.038	0.018
1993	mean	O	0.080	0.127	0.174	13.637	0.135	0.091	0.040	0.016	0.004	0.262	0.517
1993	mean	C	0.022	0.135	0.119	0.917	0.000	0.072	0.022	0.116	0.442	0.024	0.000
Oilcode		P	0.723	0.150	0.131	0.014	0.116	0.241	0.270	0.140	0.022	0.490	0.745
Year		P	0.139	0.500	0.965	0.385	0.993	0.593	0.314	0.724	0.903	0.294	0.981
Interaction		P	0.202m	0.341	0.677	0.055	0.911m	0.221m	0.396m	0.760m	0.794m	0.220m	0.936m

Biomass Depth = Bed (Continued)

Year		Oilcode	MYTILIDA	NEREIDAE	OPHELIID	ORBINIID	PHYLLODO	POLYNOID	RHYNCHOC	SPIONIDA	TELLINID	VENERIDA	TOTAL
1990	mean	O	0.988	0.414	0.107	0.001	0.411	0.078	0.067	0.156	0.748	1.732	8.618
1990	mean	C	0.008	0.140	0.030	0.079	0.032	0.044	0.080	0.026	0.057	1.314	3.339
1991	mean	O	2.213	0.184	0.344	0.165	0.024	0.148	0.033	0.453	0.359	0.069	7.613
1991	mean	C	0.048	0.150	0.218	0.134	0.055	0.323	0.505	0.164	0.490	2.712	8.833
1993	mean	O	4.195	0.262	0.193	0.108	0.005	0.108	0.191	0.132	1.304	7.101	18.417
1993	mean	C	0.015	0.182	0.056	0.080	0.003	0.182	0.195	0.031	0.713	0.000	6.570
Oilcode		P	<0.001	0.172	0.039	0.692	0.480	0.736	0.884	0.002	0.872	0.657	0.036
Year		P	0.237	0.318	0.038	0.861	0.713	0.188	0.922	0.246	0.377	1.000	0.141
Interaction		P	0.251	0.902m	0.959m	0.177m	0.186m	0.629m	0.507m	0.979m	0.993m	0.751	0.148

Biomass Depth = Bed (Continued)

Year		Oilcode	BRYOZOA	CAPRELLI	MONTACUT
1990	mean	O	0.313	0.011	0.094
1990	mean	C	0.149	0.031	0.019
1991	mean	O	0.013	0.023	0.147
1991	mean	C	0.539	0.131	0.038
1993	mean	O	0.346	0.167	0.262
1993	mean	C	2.752	0.095	0.024
Oilcode		P	0.092	0.681	0.526
Year		P	0.098	0.062	0.276
Interaction		P	0.206	0.449m	0.216m

APPENDIX Q.

Mean values for community parameters of infaunal and small epifaunal invertebrates that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* bay habitat in 1990 and 1991. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix Q. Mean values for community parameters of infaunal and epifaunal invertebrates that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* bay habitat in 1990 and 1991. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests. All infauna taxa were used at the family level and higher.

Deep - 1990

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Northwest Bay	2 (O)	3.23	0.06	50	450	6.421	8.213
Cabin Bay	1 (C)	2.29	0.18	26	210	2.479	4.708
Herring Bay	3 (O)	3.40	0.05	51	815	4.149	7.558
L. Herring Bay	4 (C)	2.97	0.10	59	933	7.697	8.505
Bay of Isles	6 (O)	2.93	0.08	48	773	7.338	7.119
Mummy Bay	5 (C)	2.91	0.10	56	1111	6.884	7.832
Mean	(O)	3.19	0.06	50	679	5.969	7.630
Mean	(C)	2.72	0.13	47	752	5.687	7.015
	P	0.02	<0.01	0.66	0.61	0.85	0.58

Shallow - 1990

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Northwest Bay	2 (O)	2.57	0.18	49	801	5.620	7.238
Cabin Bay	1 (C)	2.59	0.12	32	741	2.304	4.744
Herring Bay	3 (O)	2.45	0.18	43	1361	6.392	5.940
L. Herring Bay	4 (C)	2.65	0.12	37	626	3.671	5.649
Bay of Isles	6 (O)	2.85	0.11	50	1003	13.325	7.172
Mummy Bay	5 (C)	2.51	0.16	42	849	4.481	6.038
Mean	(O)	2.62	0.16	47	1055	8.446	6.783
Mean	(C)	2.59	0.13	37	739	3.485	5.477
	P	0.80	0.44	0.01	0.12	0.03	0.02

Deep - 1991

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Northwest Bay	2 (O)	3.17	0.07	53	723	11.387	7.978
Cabin Bay	1 (C)	2.99	0.07	42	657	5.608	6.290
Herring Bay	3 (O)	3.40	0.05	62	1288	6.244	8.577
L. Herring Bay	4 (C)	3.07	0.07	46	757	11.088	6.921
Bay of Isles	6 (O)	3.10	0.08	62	1441	8.151	8.341
Mummy Bay	5 (C)	2.90	0.10	67	2124	9.013	8.611
Mean	(O)	3.22	0.07	59	1151	8.594	8.299
Mean	(C)	2.98	0.08	51	1179	8.569	7.274
	P	0.06	0.07	0.26	0.91	0.99	0.20

Shallow - 1991

Site	Site Code	Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
Northwest Bay	2 (O)	2.77	0.12	54	1595	3.793	7.234
Cabin Bay	1 (C)	3.02	0.10	63	2063	16.210	8.095
Herring Bay	3 (O)	3.03	0.08	63	1912	7.205	8.171
L. Herring Bay	4 (C)	2.79	0.15	57	1427	7.190	7.701
Bay of Isles	6 (O)	2.96	0.10	75	3912	25.156	8.965
Mummy Bay	5 (C)	2.67	0.15	68	2903	14.639	8.391
Mean	(O)	2.92	0.10	64	2473	12.052	8.124
Mean	(C)	2.83	0.13	62	2131	12.680	8.062
	P	0.46	0.15	0.74	0.37	0.90	0.92

APPENDIX R.

Mean values for abundance and biomass of dominant invertebrate families that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* bay habitat in 1990 and 1991. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix R. Mean values for abundance and biomass of dominant invertebrate families that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* bay habitat in 1990 and 1991. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests. Names of some dominant taxa are abbreviated. See Appendix J for the complete spellings.

Abundance (#/0.1m^2) - 1990

Deep

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	CAECIDAE	CAPITELL	CIRRATUL	DORVILLE	LEPIDOPL	LUCINIDA	LUMBRINE
1	2	O	9.47	1.33	17.44	28.00	13.06	53.98	11.81	22.12	1.87	20.42
1	1	C	0.17	1.50	1.78	2.00	15.56	4.45	2.17	2.67	51.94	8.11
2	3	O	4.00	0.00	166.67	84.00	21.33	13.33	33.33	30.67	18.67	8.00
2	4	C	0.53	1.63	61.16	135.65	19.26	3.56	30.87	15.08	79.23	10.52
3	6	O	1.33	2.67	23.33	98.00	11.11	1.78	37.56	29.33	92.22	13.06
3	5	C	6.84	2.53	39.86	273.65	10.89	11.11	56.69	63.73	66.49	18.92
	mean	O	4.93	1.33	69.15	70.00	15.17	23.03	27.57	27.37	37.59	13.83
	mean	C	2.52	1.89	34.27	137.10	15.23	6.37	29.91	27.16	65.89	12.52
	P		0.42	0.39	0.45	0.09	0.99	0.08	0.82	0.98	0.19	0.80

Deep (continued)

Pair	Site#	Oilcode	OPHELIID	OPHIUROI	PEISIDIC	PROTOMED	SERPULID	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE
1	2	O	0.00	10.53	38.87	1.33	6.11	12.72	23.48	2.33	10.33
1	1	C	0.00	0.00	9.50	0.00	5.50	0.00	5.56	16.28	1.33
2	3	O	0.00	33.33	16.00	78.67	0.00	49.33	33.33	2.67	24.00
2	4	C	0.00	93.81	13.96	15.62	30.70	42.40	160.03	35.38	4.45
3	6	O	20.67	60.00	29.50	2.67	3.22	62.00	25.78	42.39	5.89
3	5	C	0.00	97.98	53.45	2.67	39.30	49.19	81.01	10.40	52.61
	mean	O	6.89	34.62	28.12	27.56	3.11	41.35	27.53	15.80	13.41
	mean	C	0.00	63.93	25.63	6.09	25.17	30.53	82.20	20.69	19.46
	P		0.11	0.21	0.83	0.12	0.02	0.37	0.09	0.72	0.62

Shallow

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	AORIDAE_	BIVALVIA	CAECIDAE	CAPITELL	DORVILLE	GASTROPO	HIATELLI	LUCINID
1	2	O	2.31	7.07	6.93	0.00	6.45	8.62	34.57	6.09	34.80	5.50	14.92
1	1	C	1.33	4.00	45.67	4.00	42.67	0.00	35.17	10.67	56.00	0.00	4.00
2	3	O	0.00	12.89	57.78	0.00	28.00	28.89	95.11	33.78	21.78	0.45	278.67
2	4	C	0.00	3.55	55.11	13.33	6.67	5.78	32.00	5.33	5.33	0.89	36.89
3	6	O	0.00	31.20	36.53	4.27	5.87	21.33	40.53	25.60	28.53	0.53	61.07
3	5	C	1.87	8.53	22.93	0.00	4.53	135.20	54.13	16.00	8.27	0.00	74.40
	mean	O	0.77	17.05	33.75	1.42	13.44	19.61	56.74	21.82	28.37	2.16	118.22
	mean	C	1.07	5.36	41.24	5.78	17.96	46.99	40.43	10.67	23.20	0.30	38.43
	P		0.57	0.09	0.62	0.41	0.79	0.32	0.40	0.25	0.39	0.19	0.24

Shallow (continued)

Pair	Site#	Oilcode	MONTACUT	OPHELIID	OPHIUROI	POLYNOID	ROSSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE
1	2	O	11.56	3.91	9.96	1.78	30.35	19.11	345.68	47.04	13.89
1	1	C	70.67	56.00	16.00	0.00	40.00	12.00	165.50	47.17	17.50
2	3	O	48.89	7.55	21.78	31.55	24.00	14.67	442.22	71.56	17.33
2	4	C	26.67	11.56	35.11	21.78	76.89	33.33	143.56	37.72	11.56
3	6	O	9.87	27.47	15.60	54.93	27.20	79.47	125.60	190.97	1.87
3	5	C	5.07	5.60	24.00	6.93	14.67	9.60	290.40	46.93	6.40
	mean	O	23.44	12.98	15.78	29.42	27.19	37.75	304.50	103.19	11.03
	mean	C	34.13	24.39	25.04	9.57	43.85	18.31	199.82	43.94	11.82
	P		0.56	0.58	0.53	0.05	0.58	0.24	0.34	0.13	0.85

Biomass (gm/0.1m^2) - 1990

Deep

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	CAECIDAE	CARDIIDA	CYLICHNI	HIATELLI	ISCHNOCH	LEPIDOPL	LUCINIDA	LUMBRINE	MYIDAE
1	2	O	0.001	0.044	0.215	0.000	0.001	0.001	0.250	0.032	0.001	0.495	0.014
1	1	C	0.048	0.002	0.017	0.001	0.000	0.000	0.000	0.011	1.438	0.080	0.000
2	3	O	0.000	0.279	0.751	0.041	0.087	0.000	0.333	0.063	0.030	0.036	0.025
2	4	C	0.247	0.046	0.987	0.668	0.032	0.000	0.447	0.082	1.842	0.291	0.029
3	6	O	0.030	0.033	0.705	0.042	0.098	0.000	0.154	0.158	1.627	0.157	0.000
3	5	C	0.012	0.072	1.672	0.000	0.034	0.001	0.058	0.131	0.978	0.107	0.001
	mean	O	0.010	0.119	0.557	0.028	0.062	0.000	0.246	0.084	0.553	0.229	0.013
	mean	C	0.102	0.040	0.892	0.223	0.022	0.000	0.168	0.074	1.419	0.159	0.010
	P		0.16	0.17	0.15	0.75	0.12	0.53	0.50	0.69	0.12	0.64	0.80

Deep (continued)

Pair	Site#	Oilcode	MYTILIDA	NUCULANI	ONUPHIDA	OPHIUROI	PEISIDIC	RHYNCHOC	SERPULID	SPIONIDA	TELLINID
1	2	O	0.099	0.000	0.013	0.022	0.122	0.002	0.417	0.038	0.000
1	1	C	0.053	0.000	0.000	0.000	0.038	0.014	0.185	0.003	0.000
2	3	O	0.042	0.069	0.232	0.116	0.039	0.328	0.000	0.043	0.000
2	4	C	0.000	0.050	0.008	0.216	0.023	0.051	0.114	0.114	0.012
3	6	O	0.627	0.000	0.011	0.365	0.048	0.175	0.007	0.012	0.000
3	5	C	0.003	0.049	0.244	0.161	0.074	0.135	0.140	0.071	0.008
	mean	O	0.256	0.023	0.085	0.168	0.069	0.168	0.141	0.031	0.000
	mean	C	0.018	0.033	0.084	0.126	0.045	0.067	0.146	0.062	0.007
	P		0.10	0.63	0.95	0.90	0.43	0.19	0.95	0.21	.

Shallow

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	ANOMIIDA	CAECIDAE	CANCRIDA	CAPITELL	CARDIIDA	CYLICHNI	GLYCERID	ISCHNOCH
1	2	O	0.002	0.006	0.003	0.070	1.658	0.024	0.000	0.011	0.346	0.077
1	1	C	0.003	0.084	0.000	0.000	0.000	0.008	0.000	0.015	0.131	0.000
2	3	O	0.104	0.084	0.000	0.249	0.000	0.040	0.000	0.096	0.384	0.013
2	4	C	0.005	0.112	0.000	0.040	0.171	0.013	0.000	0.011	0.436	0.000
3	6	O	0.036	0.062	0.000	0.161	0.485	0.006	0.091	0.069	0.000	0.018
3	5	C	0.058	0.017	0.007	0.886	0.000	0.006	0.000	0.015	0.155	0.292
	mean	O	0.047	0.051	0.001	0.160	0.714	0.023	0.030	0.059	0.243	0.036
	mean	C	0.022	0.071	0.002	0.308	0.057	0.009	0.000	0.013	0.241	0.097
	P		0.56	0.48	0.80	0.45	0.22	0.04	0.51	0.05	0.91	0.99

Shallow (continued)

Pair	Site#	Oilcode	LUCINIDA	LUMBRINE	LYONSIID	MONTACUT	NASSARII	NEREIDAE	OPHELIID	OPHIUROI	ORBINIID	RHYNCHOC
1	2	O	0.891	0.240	0.001	0.020	0.000	0.078	0.011	0.015	0.093	0.043
1	1	C	0.029	0.000	0.000	0.119	0.000	0.000	0.221	0.037	0.199	0.208
2	3	O	3.176	0.158	0.000	0.056	0.000	0.002	0.071	0.098	0.149	0.028
2	4	C	0.947	0.000	0.000	0.038	0.000	0.066	0.040	0.102	0.187	0.331
3	6	O	2.313	0.287	0.036	0.013	0.002	0.328	0.069	0.073	0.251	0.168
3	5	C	1.290	0.137	0.000	0.002	0.000	0.000	0.016	0.017	0.033	0.322
	mean	O	2.127	0.228	0.012	0.030	0.001	0.136	0.050	0.062	0.164	0.080
	mean	C	0.755	0.046	0.000	0.053	0.000	0.022	0.092	0.052	0.139	0.287
	P		0.04	0.10	0.13	0.45	.	0.04	0.59	0.73	0.79	0.20

Shallow (continued)

Pair	Site#	Oilcode	ROSSOIDA	SERPULID	SPIONIDA	VENERIDA
1	2	O	0.027	0.003	0.338	0.362
1	1	C	0.047	0.001	0.487	0.124
2	3	O	0.033	0.006	0.535	0.024
2	4	C	0.078	0.000	0.136	0.000
3	6	O	0.012	0.247	0.154	6.473
3	5	C	0.012	0.001	0.213	0.000
	mean	O	0.024	0.085	0.342	2.286
	mean	C	0.046	0.001	0.279	0.041
	P		0.35	0.02	0.63	0.15

Abundance (#/0.1m^2) - 1991

Deep

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	CAECIDAE	CAPITELL	CIRRATUL	DORVILLE	LEPIDOPL	LUCINIDA	LUMBRINE
1	2	O	9.33	5.20	55.47	19.33	7.33	13.33	16.00	20.00	17.33	8.13
1	1	C	33.56	57.11	47.78	3.11	15.33	7.78	0.00	0.67	13.78	3.33
2	3	O	30.67	26.22	103.56	140.45	36.89	33.78	42.22	50.67	46.22	28.89
2	4	C	12.89	6.67	112.78	37.78	8.89	8.00	46.67	5.78	34.11	4.00
3	6	O	126.66	17.16	28.89	105.33	19.47	13.69	42.22	41.33	80.35	15.29
3	5	C	64.00	41.33	55.11	357.56	26.44	15.11	76.67	107.11	81.33	10.44
	mean	O	55.55	16.19	62.64	88.37	21.23	20.27	33.48	37.33	47.97	17.44
	mean	C	36.81	35.04	71.89	132.81	16.89	10.30	41.11	37.85	43.07	5.93
	P		0.56	0.38	0.75	0.64	0.67	0.19	0.65	0.98	0.71	0.09

Deep (continued)

Pair	Site#	Oilcode	OPHELIID	OPHIUROI	PEISIDIC	PROTOMED	SERPULID	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE
1	2	O	88.27	24.00	12.53	0.67	1.33	38.27	76.80	2.67	48.40
1	1	C	29.78	1.78	0.00	4.00	2.67	2.22	91.78	5.78	4.44
2	3	O	18.22	56.45	22.67	18.67	1.33	120.45	150.67	21.33	37.33
2	4	C	14.67	24.00	26.67	66.67	10.72	89.11	20.00	38.78	24.89
3	6	O	80.71	91.72	40.45	1.87	7.29	80.35	197.23	122.20	16.94
3	5	C	7.05	116.45	34.00	5.11	44.00	202.45	404.67	26.00	90.67
	mean	O	62.40	57.39	25.22	7.07	3.32	79.69	141.57	48.73	34.23
	mean	C	17.17	47.41	20.22	25.26	19.13	97.93	172.15	23.52	40.00
	P		0.03	0.88	0.68	0.60	0.06	0.79	0.62	0.43	0.79

Shallow

Pair	Site#	Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	AORIDAE_	BIVALVIA	CAECIDAE	CAPITELL	DORVILLE	GASTROPO	HIATELLI	LUCINID
1	2	O	47.33	35.33	38.00	0.67	37.33	6.67	29.33	6.67	44.67	90.00	10.67
1	1	C	114.67	98.67	56.00	5.33	5.33	61.33	72.00	17.33	6.67	20.00	94.67
2	3	O	52.00	104.76	95.72	25.33	3.43	89.81	83.71	64.19	33.24	15.81	88.09
2	4	C	19.55	96.00	61.33	1.33	9.33	69.78	21.78	7.55	49.33	16.00	40.00
3	6	O	104.89	122.22	125.56	48.67	22.67	6.00	13.28	16.44	112.89	90.89	81.55
3	5	C	28.53	66.04	162.04	80.27	21.69	24.00	59.56	1.78	30.13	54.31	32.00
	mean	O	68.07	87.44	86.42	24.89	21.14	34.16	42.11	29.10	63.60	65.57	60.11
	mean	C	54.25	86.90	93.12	28.98	12.12	51.70	51.11	8.89	28.71	30.10	55.56
	P		0.63	0.98	0.78	0.77	0.48	0.50	0.63	0.08	0.07	0.20	0.86

Shallow (continued)

Pair	Site#	Oilcode	MONTACUT	OPHELIID	OPHIUROI	POLYNOID	ROSSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE
1	2	O	16.67	379.33	14.00	12.00	242.67	18.67	219.33	66.67	14.67
1	1	C	17.33	135.17	25.33	4.00	254.67	58.67	430.67	52.17	40.00
2	3	O	31.62	283.33	43.81	8.86	88.10	26.00	295.14	228.67	23.81
2	4	C	6.67	315.56	29.33	32.45	70.22	34.22	138.22	170.22	16.89
3	6	O	80.00	486.22	38.22	44.00	953.11	155.78	113.11	407.78	93.56
3	5	C	52.45	277.15	38.67	21.23	173.69	31.20	908.00	469.69	36.71
	mean	O	42.76	382.96	32.01	21.62	427.96	66.81	209.20	234.37	44.01
	mean	C	25.48	242.63	31.11	19.23	166.19	41.36	492.30	230.69	31.20
	P		0.23	0.16	0.68	0.79	0.15	0.45	0.10	0.95	0.86

Biomass ($gm/0.1m^2$) - 1991

Deep

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	CAECIDAE	CARDIIDA	CYLICHNI	HIATELLI	ISCHNOCH	LEPIDOPL	LUCINIDA	LUMBRINE	MYIDAE
1	2	O	0.003	0.111	0.155	0.592	0.073	0.015	0.204	0.045	0.055	0.040	0.017
1	1	C	0.175	0.153	0.026	0.416	0.023	1.534	0.000	0.003	0.111	0.013	0.366
2	3	O	0.060	0.137	1.180	0.000	0.057	0.065	0.277	0.098	0.524	0.830	1.211
2	4	C	0.001	0.053	0.351	0.000	0.107	0.000	0.124	0.034	0.811	0.035	0.259
3	6	O	0.022	0.115	0.780	0.006	0.042	0.005	0.166	0.156	0.884	0.237	0.100
3	5	C	0.051	0.126	2.418	0.003	0.105	0.000	0.279	0.278	1.227	0.331	0.041
	mean	O	0.028	0.121	0.705	0.199	0.057	0.028	0.216	0.100	0.488	0.369	0.443
	mean	C	0.076	0.111	0.932	0.139	0.078	0.511	0.134	0.105	0.716	0.126	0.222
	P		0.69	0.81	0.74	0.38	0.56	0.97	0.39	0.99	0.31	0.35	0.82

Deep (continued)

Pair	Site#	Oilcode	MYTILIDA	NUCULANI	ONUPHIDA	OPHIUROI	PEISIDIC	RHYNCHOC	SERPULID	SPIONIDA	TELLINID
1	2	O	0.004	0.085	0.019	0.166	0.017	0.005	0.001	0.099	0.000
1	1	C	0.088	0.001	0.000	0.001	0.000	0.139	0.002	0.142	0.150
2	3	O	0.003	0.196	0.026	0.143	0.023	0.082	0.001	0.080	0.007
2	4	C	0.041	0.053	0.040	0.147	0.048	0.137	0.054	0.023	0.003
3	6	O	0.058	0.000	0.000	0.529	0.086	0.169	0.003	0.240	0.022
3	5	C	0.707	0.001	0.153	0.216	0.112	0.204	0.018	0.350	0.175
	mean	O	0.022	0.094	0.015	0.279	0.042	0.085	0.002	0.140	0.010
	mean	C	0.279	0.018	0.064	0.121	0.053	0.160	0.025	0.171	0.109
	P		0.27	0.32	0.35	0.13	0.66	0.37	0.07	0.56	0.13

Shallow

Pair	Site#	Oilcode	AMPHICTE	AMPHIPOD	ANOMIIDA	CAECIDAE	CANCRIDA	CAPITELL	CARDIIDA	CYLICHNI	GLYCERID
1	2	O	0.024	0.074	0.019	0.037	0.006	0.022	0.001	0.093	0.134
1	1	C	0.639	0.071	1.561	0.369	0.189	0.027	0.803	0.152	0.147
2	3	O	0.056	0.135	0.000	0.797	1.691	0.052	0.000	0.057	0.012
2	4	C	0.004	0.097	0.000	0.624	0.000	0.007	0.000	0.048	0.008
3	6	O	0.157	0.113	0.003	0.049	0.312	1.813	0.025	0.130	0.315
3	5	C	0.015	0.165	0.012	0.180	0.280	0.029	0.009	0.053	0.000
	mean	O	0.079	0.107	0.007	0.294	0.670	0.629	0.009	0.094	0.154
	mean	C	0.220	0.111	0.524	0.391	0.156	0.021	0.271	0.084	0.051
	P		0.40	0.90	0.41	0.62	0.49	0.33	0.54	0.84	0.59

Shallow (continued)

Pair	Site#	Oilcode	ISCHNOCH	LUCINIDA	LUMBRINE	LYONSIID	MONTACUT	NASSARII	NEREIDAE	OPHELIID	OPHIUROI
1	2	O	0.001	0.574	0.164	0.035	0.064	0.191	0.000	0.294	0.019
1	1	C	0.859	1.729	0.100	0.887	0.025	0.000	0.000	0.394	0.125
2	3	O	0.076	1.069	0.008	0.041	0.046	0.017	0.000	0.479	0.235
2	4	C	0.013	1.741	0.100	0.002	0.005	0.269	0.007	0.126	0.150
3	6	O	0.082	2.306	0.048	0.015	0.108	0.355	0.095	0.423	0.217
3	5	C	0.000	0.369	0.000	0.000	0.060	0.304	0.001	0.084	0.122
	mean	O	0.053	1.316	0.073	0.030	0.073	0.188	0.032	0.399	0.157
	mean	C	0.291	1.280	0.067	0.296	0.030	0.191	0.003	0.202	0.133
	P		0.44	0.96	0.91	0.40	0.13	0.98	0.38	0.19	0.77

Shallow (continued)

Pair	Site#	Oilcode	ORBINIID	RHYNCHOC	ROSSOIDA	SERPULID	SPIONIDA	VENERIDA
1	2	O	0.001	0.013	0.285	0.003	0.205	0.003
1	1	C	0.005	0.577	0.404	0.042	0.685	0.156
2	3	O	0.000	0.058	0.111	0.001	0.349	0.449
2	4	C	0.199	0.142	0.076	0.005	0.119	0.000
3	6	O	0.019	1.830	0.826	0.012	0.084	0.190
3	5	C	0.197	0.027	0.214	0.009	0.846	0.010
	mean	O	0.007	0.634	0.407	0.005	0.212	0.214
	mean	C	0.134	0.249	0.231	0.019	0.550	0.055
	P		0.29	0.40	0.30	0.22	0.08	0.38

APPENDIX S.

Mean values and results of 2-way randomization ANOVAs comparing community parameters for invertebrates that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* habitat in 1990 and 1991.

Appendix S. Mean values and results of 2-way randomization ANOVAs comparing community parameters for invertebrates that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* habitat in 1990 and 1991. All taxa were used at the family level and higher.

Deep

Year	Site Code		Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
1990	Mean	(O)	3.19	0.06	50	679	5.969	7.630
1990	Mean	(C)	2.72	0.13	47	752	5.687	7.015
1991	Mean	(O)	3.22	0.07	59	1151	8.594	8.299
1991	Mean	(C)	2.98	0.08	51	1179	8.569	7.274
Oilcode		P	<0.01	<0.01	0.20	0.78	0.91	0.10
Year		P	0.20	0.20	0.12	<0.01	0.11	0.36
Interaction		P	0.34	0.07	0.60	0.91	0.95	0.68

Shallow

Year	Site Code		Shannon-Weiner	Simpson	Families	Total Individuals	Total Biomass	Species Richness
1990	Mean	(O)	2.62	0.16	47	1055	8.446	6.783
1990	Mean	(C)	2.59	0.13	37	739	3.485	5.477
1991	Mean	(O)	2.92	0.10	64	2473	12.052	8.124
1991	Mean	(C)	2.83	0.13	62	2131	12.680	8.062
Oilcode		P	0.55	0.81	0.25	0.38	0.46	0.18
Year		P	<0.01	0.13	<0.01	<0.01	0.01	<0.01
Interaction		P	0.78	0.09	0.41	0.97	0.34	0.27

APPENDIX T.

Mean values and results of 2 way randomization ANOVAs comparing abundance and biomass of dominant invertebrates that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* habitat in 1990 and 1991.

Appendix T. Mean values and results of 2-way randomization ANOVAs comparing abundance and biomass of dominant invertebrates that were sampled by suction dredge at oiled and control sites in the *Laminaria/Agarum* habitat in 1990 and 1991. Abundance units are #/0.1m^2 and Biomass units are gm/0.1m^2. Names of some dominant taxa are abbreviated. See Appendix J for the complete spellings.

Abundance - Deep

Year		Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	CAECIDAE	CAPITELL	CIRRATUL	DORVILLE	LEPIDOPL	LUCINIDA	LUMBRINE
1990	mean	O	4.93	1.33	69.15	70.00	15.17	23.03	27.57	27.37	37.59	13.83
1990	mean	C	2.52	1.89	34.27	137.10	15.23	6.37	29.91	27.16	65.89	12.52
1991	mean	O	55.55	16.19	62.64	88.37	21.23	20.27	33.48	37.33	47.97	17.44
1991	mean	C	36.81	35.04	71.89	132.81	16.89	10.30	41.11	37.85	43.07	5.93
Oilcode		P	0.59	0.40	0.55	0.10	0.67	0.03	0.61	1.00	0.37	0.11
Year		P	<0.01	<0.01	0.46	0.87	0.44	0.93	0.38	0.56	0.62	0.72
Interaction		P	0.65	0.41	0.32	0.80	0.68	0.60	0.82	0.98	0.21	0.21

Abundance - Deep (continued)

Year		Oilcode	OPHELIID	OPHIUROI	PEISIDIC	PROTOMED	SERPULID	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE
1990	mean	O	6.89	34.62	28.12	27.56	3.11	41.35	27.53	15.80	13.41
1990	mean	C	0.00	63.93	25.63	6.09	25.17	30.53	82.20	20.69	19.46
1991	mean	O	62.40	57.39	25.22	7.07	3.32	79.69	141.57	48.73	34.23
1991	mean	C	17.17	47.41	20.22	25.26	19.13	97.93	172.15	23.52	40.00
Oilcode		P	0.06	0.46	0.66	0.72	<0.01	0.91	0.36	0.55	0.68
Year		P	<0.01	0.95	0.59	0.87	0.67	0.01	0.01	0.21	0.11
Interaction		P	0.18	0.27	0.87	0.22	0.65	0.70	0.81	0.34	0.99

Abundance - Shallow

Year		Oilcode	AMPHARET	AMPHICTE	AMPHIPOD	AORIDAE_	BIVALVIA	CAECIDAE	CAPITELL	DORVILLE	GASTROPO	HIATELLI
1990	mean	O	0.77	17.05	33.75	1.42	13.44	19.61	56.74	21.82	28.37	2.16
1990	mean	C	1.07	5.36	41.24	5.78	17.96	46.99	40.43	10.67	23.20	0.30
1991	mean	O	68.07	87.44	86.42	24.89	21.14	34.16	42.11	29.10	63.60	65.57
1991	mean	C	54.25	86.90	93.12	28.98	12.12	51.70	51.11	8.89	28.71	30.10
Oilcode		P	0.74	0.77	0.74	0.66	0.74	0.26	0.73	0.02	0.08	0.24
Year		P	<0.01	<0.01	<0.01	0.01	0.89	0.61	0.84	0.70	0.07	<0.01
Interaction		P	0.76	0.80	0.99	1.00	0.42	0.79	0.26	0.52	0.34	0.31

Abundance - Shallow (continued)

Year		Oilcode	LUCINID	MONTACUT	OPHELIID	OPHIUROI	POLYNOID	ROSSOIDA	SIGALION	SPIONIDA	SPIRORBI	SYLLIDAE
1990	mean	O	118.22	23.44	12.98	15.78	29.42	27.19	37.75	304.50	103.19	11.03
1990	mean	C	38.43	34.13	24.39	25.04	9.57	43.85	18.31	199.82	43.94	11.82
1991	mean	O	60.11	42.76	382.96	32.01	21.62	427.96	66.81	209.20	234.37	44.01
1991	mean	C	55.56	25.48	242.63	31.11	19.23	166.19	41.36	492.30	230.69	31.20
Oilcode		P	0.28	0.83	0.41	0.89	0.08	0.21	0.12	0.36	0.63	0.86
Year		P	0.81	0.71	<0.01	0.21	0.89	<0.01	0.07	0.32	<0.01	0.01
Interaction		P	0.39	0.33	0.33	0.46	0.14	0.17	0.85	0.04	0.61	0.80

Biomass - Deep

Year		Oilcode	AMPHICTE	AMPHIPOD	CAECIDAE	CARDIIDA	CYLICHNI	HIATELLI	ISCHNOCH	LEPIDOPL	LUCINIDA	LUMBRINE	MYIDAE
1990	mean	O	0.010	0.119	0.557	0.028	0.062	0.000	0.246	0.084	0.553	0.229	0.013
1990	mean	C	0.102	0.040	0.892	0.223	0.022	0.000	0.168	0.074	1.419	0.159	0.010
1991	mean	O	0.028	0.121	0.705	0.199	0.057	0.028	0.216	0.100	0.488	0.369	0.443
1991	mean	C	0.076	0.111	0.932	0.139	0.078	0.511	0.134	0.105	0.716	0.126	0.222
Oilcode		P	0.19	0.22	0.29	0.81	0.62	0.10	0.27	0.97	0.04	0.30	0.82
Year		P	0.92	0.31	0.75	0.86	0.21	0.03	0.65	0.63	0.17	0.71	<0.01
Interaction		P	0.59	0.39	0.86	0.44	0.15	0.98	0.98	0.91	0.25	0.59	0.82

Biomass - Deep (continued)

Year		Oilcode	MYTILIDA	NUCULANI	ONUPHIDA	OPHIUROI	PEISIDIC	RHYNCHOC	SERPULID	SPIONIDA	TELLINID
1990	mean	O	0.256	0.023	0.085	0.168	0.069	0.168	0.141	0.031	0.000
1990	mean	C	0.018	0.033	0.084	0.126	0.045	0.067	0.146	0.062	0.007
1991	mean	O	0.022	0.094	0.015	0.279	0.042	0.085	0.002	0.140	0.010
1991	mean	C	0.279	0.018	0.064	0.121	0.053	0.160	0.025	0.171	0.109
Oilcode		P	0.88	0.41	0.49	0.18	0.78	0.81	0.83	0.50	0.09
Year		P	0.86	0.55	0.22	0.47	0.63	0.92	0.05	<0.01	0.03
Interaction		P	0.01	0.27	0.50	0.41	0.40	0.07	0.91	1.00	0.25

Biomass - Shallow

Year		Oilcode	AMPHICTE	AMPHIPOD	ANOMIIDA	CAECIDAE	CANCRIDA	CAPITELL	CARDIIDA	CYLICHNI	GLYCERID
1990	mean	O	0.047	0.051	0.001	0.160	0.714	0.023	0.030	0.059	0.243
1990	mean	C	0.022	0.071	0.002	0.308	0.057	0.009	0.000	0.013	0.241
1991	mean	O	0.079	0.107	0.007	0.294	0.670	0.629	0.009	0.094	0.154
1991	mean	C	0.220	0.111	0.524	0.391	0.156	0.021	0.271	0.084	0.051
Oilcode		P	0.56	0.58	0.43	0.35	0.18	0.08	0.56	0.29	0.70
Year		P	0.12	0.02	0.04	0.44	0.86	0.14	0.32	0.03	0.27
Interaction		P	0.38	0.72	0.65	0.84	0.73	0.71	0.25	0.49	0.67

Biomass - Shallow (continued)

Year		Oilcode	ISCHNOCH	LUCINIDA	LUMBRINE	LYONSIID	MONTACUT	NASSARII	NEREIDAE	OPHELIID	OPHIUROI
1990	mean	O	0.036	2.127	0.228	0.012	0.030	0.001	0.136	0.050	0.062
1990	mean	C	0.097	0.755	0.046	0.000	0.053	0.000	0.022	0.092	0.052
1991	mean	O	0.053	1.316	0.073	0.030	0.073	0.188	0.032	0.399	0.157
1991	mean	C	0.291	1.280	0.067	0.296	0.030	0.191	0.003	0.202	0.133
Oilcode		P	0.27	0.12	0.12	0.50	0.64	0.99	0.14	0.36	0.74
Year		P	0.31	0.75	0.31	0.07	0.61	<0.01	0.34	<0.01	0.02
Interaction		P	0.44	0.13	0.16	0.38	0.11	0.98	0.66	0.13	0.89

Biomass - Shallow (continued)

Year		Oilcode	ORBINIID	RHYNCHOC	ROSSOIDA	SERPULID	SPIONIDA	VENERIDA
1990	mean	O	0.164	0.080	0.024	0.085	0.342	2.286
1990	mean	C	0.139	0.287	0.046	0.001	0.279	0.041
1991	mean	O	0.007	0.634	0.407	0.005	0.212	0.214
1991	mean	C	0.134	0.249	0.231	0.019	0.550	0.055
Oilcode		P	0.51	0.63	0.49	0.64	0.21	0.11
Year		P	0.27	0.18	<0.01	0.99	0.53	0.68
Interaction		P	0.27	0.13	0.35	0.04	0.05	0.64

APPENDIX U.

List of large (>10 cm) epifaunal invertebrates enumerated from shallow subtidal habitats in Prince William Sound, 1990-91.

Appendix U. List of large (>10 cm) epifaunal invertebrates enumerated from shallow subtidal habitats in Prince William Sound, 1990-1991.

Taxonomic Name	Common Name
Metridium senile	White-plumed anemone
Tealia crassicornis	Red & green anemone
Cnidaria	Orange anemone
Cryptochiton stelleri	Gum boot chiton
Isochnochiton sp.	Chiton
Ceratostoma sp.	Whelk
Fusitriton oregonensis	Oregon hairy triton
Triopha sp.	Nudibranch
Anisodoris sp.	Nudibranch
Cadlina luteomarginata	Nudibranch
Hermissenda crassicornis	Horned nudibranch
Doridae	Nudibranch
Nudibranch	Nudibranch
Hyas lyratus	Lyre crab
Octopus sp.	Octopus
Sclerocrangon boreas	Tank shrimp
Hippolytidae	Hippolytid shrimp
Pugettia sp.	Kelp crab
Telmessus cheiragonus	Helmet crab
Majidae	Spider crab
Oregonia gracilis	Decorator crab
Cancer sp.	Cancer crab
Cancer magister	Cancer crab
Cancer oregonensis	Cancer crab
Placetron wossnessenskii	Scaled crab
Rhinolithodes wossnessenskii	Rhinocerous crab
Phyllolithodes papillosus	Flat-spined triangle crab
Parastichopus californicus	California sea cucumber
Strongylocentrotus droebachiensis	Green sea urchin
Strongylocentrotus franciscanus	Red sea urchin
Asteroidea	Orange star
Leptasterias hexactus	Six-rayed sea star
Orthasterias koehleri	Rainbow sea star
Pisaster brevispinus	Short-spined sea star
Pycnopodia helianthoides	Sunflower sea star
Dermasterias imbricata	Leather star
Evasterias troschelli	False Ochre sea star
Mediaster aequalis	Vermillion sea star
Solaster sp.	Sun star
Stylasterias forreri	Sea star
Henricia leviuscula	Blood star
Pteraster tessalatus	Cushion sea star
Tunicata	Orange colonial tunicate
Tunicata	Orange solitary tunicate

APPENDIX V.

Mean values for the abundance (#/100m^2) of large (>10 cm) epibenthic invertebrates at oiled and control sites in eelgrass, *Laminaria/Agarum* bay, *Laminaria/Agarum* point, and *Nereocystis* habitats in 1990, 1991, and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix V. Mean values for the abundance (#/100m^2) of large (>10 cm) epibenthic invertebrates at oiled and control sites in eelgrass, *Laminaria/Agarum* bay, *Laminaria/Agarum* point, and *Nereocystis* habitats in 1990, 1991 and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Eelgrass Bed - 1990 Depth = Bed

Pair	Site#	Oilcode	CRABS	Dermas-terias	Evas-terias	Orthas-terias	Tel-messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	13	O	0.00	0.56	0.00	0.00	0.00	4.44	1.67	2.78
1	14	C	0.56	1.11	0.00	0.00	0.56	10.00	4.44	5.56
2	16	O	1.11	0.56	0.56	1.11	1.11	3.33	1.67	1.67
2	15	C	6.11	5.56	1.67	0.00	5.00	1.67	1.67	0.00
3	17	O	0.56	1.67	0.00	0.00	0.56	5.00	2.78	2.22
3	18	C	4.44	0.56	0.00	0.00	3.89	6.67	6.67	0.00
4	25	O	0.00	0.00	0.00	0.00	0.00	13.57	10.32	3.25
4	26	C	3.89	0.00	0.00	0.00	3.33	12.22	9.44	2.78
	mean	O	0.42	0.69	0.14	0.28	0.42	6.59	4.11	2.48
	mean	C	3.75	1.81	0.42	0.00	3.19	7.64	5.56	2.08
	P		<0.01	0.15	.	.	<0.01	0.63	0.38	0.79

Island Bay - 1990 Depth = Deep

Pair	Site#	Oilcode	CRABS	Dermas-terias	Evas-terias	Hen-ricia	Orthas-terias	Tel-messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	2	O	0.00	0.00	1.11	0.00	0.00	0.00	2.78	2.78	0.00
1	1	C	0.00	0.00	0.00	0.00	0.56	0.00	3.33	3.33	0.00
2	3	O	1.11	1.11	1.11	0.00	2.22	0.56	5.56	5.00	0.56
2	4	C	3.89	1.11	2.22	0.00	1.67	2.22	1.11	0.56	0.56
3	6	O	0.00	0.56	0.00	0.00	3.33	0.00	16.11	15.56	0.56
3	5	C	3.33	2.22	2.22	1.67	8.33	1.11	9.44	9.44	0.00
	mean	O	0.37	0.56	0.74	0.00	1.85	0.19	8.15	7.78	0.37
	mean	C	2.41	1.11	1.48	0.56	3.52	1.11	4.63	4.44	0.19
	P		<0.01	0.18	0.20	.	0.18	<0.01	0.22	0.19	0.19

Island Bay - 1990 Depth = Shallow

Pair	Site#	Oilcode	CRABS	Dermas-terias	Evas-terias	Hen-ricia	Orthas-terias	Tel-messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	2	O	4.44	1.11	5.00	0.56	1.67	3.89	26.11	23.33	2.78
1	1	C	6.11	3.33	1.67	3.33	1.67	6.11	20.56	20.56	0.00
2	3	O	3.33	3.89	6.11	0.00	10.00	3.33	24.44	23.89	0.56
2	4	C	7.22	3.89	3.89	0.00	1.11	2.78	10.00	10.00	0.00
3	6	O	2.22	0.00	3.33	1.67	1.11	1.67	35.56	35.56	0.00
3	5	C	8.33	16.67	4.44	0.00	7.78	7.78	17.22	16.67	0.56
	mean	O	3.33	1.67	4.81	0.74	4.26	2.96	28.70	27.59	1.11
	mean	C	7.22	7.96	3.33	1.11	3.52	5.56	15.93	15.74	0.19
	P		0.07	0.046	0.36	0.43	0.81	0.29	0.03	0.05	0.26

Island Point - 1990 Depth = Deep

Pair	Site#	Oilcode	CRABS	Dermas- terias	Evas- terias	Hen- ricia	Orthas- terias	Tel- messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	19	O	0.56	1.67	0.56	6.11	10.00	0.00	18.89	16.11	2.78
1	20	C	3.33	1.67	2.22	0.56	12.22	1.67	35.56	28.33	7.22
2	22	O	0.56	3.33	1.67	3.33	11.67	0.00	30.00	24.44	5.56
2	21	C	1.67	8.33	7.78	4.44	18.33	0.00	13.33	10.56	2.78
3	23	O	1.11	0.56	3.89	5.00	15.56	0.00	14.44	14.44	0.00
3	24	C	1.11	0.00	0.00	13.89	9.44	0.00	8.89	6.11	2.78
	mean	O	0.74	1.85	2.04	4.81	12.41	0.00	21.11	18.33	2.78
	mean	C	2.04	3.33	3.33	6.30	13.33	0.56	19.26	15.00	4.26
	P		0.07	0.36	0.37	0.57	0.75	<0.01	0.83	0.61	0.60

Island Point - 1990 Depth = Shallow

Pair	Site#	Oilcode	CRABS	Dermas- terias	Evas- terias	Hen- ricia	Orthas- terias	Tel- messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	19	O	0.00	3.33	1.11	8.89	19.44	0.00	42.78	26.67	16.11
1	20	C	7.78	8.89	10.00	3.33	10.56	6.11	21.11	16.11	5.00
2	22	O	6.11	3.89	5.00	1.67	6.11	2.78	38.89	30.56	8.33
2	21	C	10.56	28.33	16.11	2.22	14.44	8.33	14.44	10.56	3.89
3	23	O	1.11	6.67	3.33	10.00	15.56	0.00	38.33	36.11	2.22
3	24	C	0.56	8.89	0.56	16.11	30.56	0.00	43.33	35.00	8.33
	mean	O	2.41	4.63	3.15	6.85	13.70	0.93	40.00	31.11	8.89
	mean	C	6.30	15.37	8.89	7.22	18.52	4.81	26.30	20.56	5.74
	P		0.09	0.05	0.05	0.77	0.38	0.03	0.10	0.09	0.41

Nereocystis Bed - 1990 Depth = Shallow

Pair	Site#	Oilcode	CRABS	Dermas- terias	Evas- terias	Hen- ricia	Orthas- terias	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	7	O	0.00	10.00	0.00	13.89	1.67	50.00	50.00	0.00
1	8	C	0.00	34.44	3.33	21.11	13.33	125.00	122.78	2.22
2	12	O	0.00	18.67	0.67	6.67	14.33	96.00	81.67	14.33
2	11	C	0.28	8.89	1.39	8.61	19.17	39.44	31.39	8.06
	mean	O	0.00	14.33	0.33	10.28	8.00	73.00	65.83	7.17
	mean	C	0.14	21.67	2.36	14.86	16.25	82.22	77.08	5.14
	P		0.39	0.79	0.05	0.13	0.20	0.68	0.79	0.35

Island Bay - 1991   Depth = Shallow

Pair	Site#	Oilcode	Dermas- terias	Evas- terias	Orthas- terias	Tel- messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	2	O	0.56	0.00	0.00	0.56	8.89	6.11	2.78
1	1	C	0.00	0.00	0.56	0.00	8.33	7.78	0.56
2	3	O	4.44	4.44	4.44	1.67	12.22	7.78	4.44
2	4	C	0.56	2.22	0.56	0.56	1.11	1.11	0.00
3	6	O	3.89	3.89	6.67	0.00	37.78	11.67	26.11
3	5	C	22.22	6.11	3.89	6.11	23.89	9.44	14.44
	mean	O	2.96	2.78	3.70	0.74	19.63	8.52	11.11
	mean	C	7.59	2.78	1.67	2.22	11.11	6.11	5.00
	P		0.36	0.92	0.22	0.27	0.08	0.38	<0.01

Eelgrass Bed - 1991   Depth = Bed

Pair	Site#	Oilcode	Dermas- terias	Evas- terias	Orthas- terias	Tel- messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	13	O	2.78	0.00	0.00	2.78	30.00	3.33	26.67
1	14	C	8.33	0.00	0.00	2.78	44.44	8.33	36.11
2	16	O	1.11	1.11	0.00	1.11	36.67	4.44	32.22
2	15	C	10.00	0.00	0.00	3.89	29.44	3.89	25.56
3	17	O	1.67	0.00	0.00	0.56	21.67	2.22	19.44
3	18	C	0.00	0.00	0.00	0.56	58.33	6.11	52.22
4	25	O	0.00	0.00	0.00	0.00	216.11	1.67	214.44
4	26	C	0.56	0.00	0.00	0.00	10.56	3.33	7.22
5	35	O	0.00	0.00	0.00	0.56	42.22	2.22	40.00
5	34	C	3.89	0.00	0.00	0.56	6.67	3.89	2.78
	mean	O	1.11	0.22	0.00	1.00	69.33	2.78	66.56
	mean	C	4.56	0.00	0.00	1.56	29.89	5.11	24.78
	P		0.02	0.23	.	0.23	0.18	0.03	0.12

Island Bay - 1993 Depth = Shallow

Pair	Site#	Oilcode	DERM	EVA	ORTH	TELM	HEN	CROSS	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	3	O	21.67	6.11	8.33	2.78	0.00	0.56	94.44	16.67	77.78
1	4	C	1.11	0.56	1.11	1.11	0.56	0.00	106.11	12.78	93.33
2	6	O	2.22	1.11	3.33	0.00	0.00	1.11	76.67	21.11	55.56
2	5	C	14.44	6.67	5.00	0.00	0.00	0.00	67.78	10.00	57.78
	mean	O	11.94	3.61	5.83	1.39	0.00	0.83	85.56	18.89	66.67
	mean	C	7.78	3.61	3.06	0.56	0.28	0.00	86.94	11.39	75.56
	P		0.68	0.95	0.41	0.35	.	<0.01	0.88	0.18	0.63

Eelgrass Bed - 1993 Depth = Bed

Pair	Site#	Oilcode	DERM	EVA	ORTH	TELM	HEN	CROSS	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1	13	O	2.78	0.00	0.00	0.00	0.00	0.00	440.56	17.22	423.33
1	14	C	7.78	0.00	0.00	0.00	0.00	0.00	132.78	2.78	130.00
2	16	O	0.00	0.00	0.00	0.56	0.00	0.00	0.56	0.56	0.00
2	15	C	6.67	0.00	0.00	1.67	0.00	0.00	137.78	2.22	135.56
3	17	O	2.22	0.00	0.00	0.00	0.00	0.00	8.89	3.33	5.56
3	18	C	0.00	0.00	0.00	0.00	0.00	0.00	12.22	2.22	10.00
	mean	O	1.67	0.00	0.00	0.19	0.00	0.00	150.00	7.04	142.96
	mean	C	4.81	0.00	0.00	0.56	0.00	0.00	94.26	2.41	91.85
	P		0.20	.	.	.	.	.	0.97	0.13	0.99

APPENDIX W.

Mean values and results of 2-way randomization ANOVAs comparing abundance (#/100m2) of large (>10 cm) epibenthic invertebrates at oiled and control sites in the eelgrass and *Laminaria/Agarum* bay habitats in 1990, 1991, and 1993. Only sites sampled all years were used for analyses.

Appendix W. Mean values and results of 2-way randomization ANOVAs comparing abundance (#/100m2) of large (>10 cm) epibenthic invertebrates at oiled and control sites in the eelgrass and *Laminaria/Agarum* bay habitats in 1990, 1991 and 1993. Only sites sampled all years were used for analyses.

Eelgrass Bed - Bed

Year	Oilcode	Dermas-terias	Evas-terias	Orthas-terias	Tel-messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1990 mean	O	0.93	0.19	0.37	0.56	4.26	2.04	2.22
1990 mean	C	2.41	0.56	0.00	3.15	6.11	4.26	1.85
1991 mean	O	1.85	0.37	0.00	1.48	29.44	3.33	26.11
1991 mean	C	6.11	0.00	0.00	2.41	44.07	6.11	37.96
1993 mean	O	1.67	0.00	0.00	0.19	150.00	7.04	142.96
1993 mean	C	4.81	0.00	0.00	0.56	94.26	2.41	91.85
Oilcode:	P	<0.01	0.81	0.84	0.02	0.98	0.96	0.98
Year:	P	0.23	0.14	0.69	0.03	0.01	0.47	0.01
Interaction:	P	0.60	0.22	0.35	0.26	0.99	<0.01	0.99

Island Bay - Shallow

Year	Oilcode	Dermas-terias	Evas-terias	Orthas-terias	Tel-messus	Pycnopodia ALL	Pycnopodia ADULT	Pycnopodia JUV.
1990 mean	O	1.94	4.72	5.56	2.50	30.00	29.72	0.28
1990 mean	C	10.28	4.17	4.44	5.28	13.61	13.33	0.28
1991 mean	O	4.17	4.17	5.56	0.83	25.00	9.72	15.28
1991 mean	C	11.39	4.17	2.22	3.33	12.50	5.28	7.22
1993 mean	O	11.94	3.61	5.83	1.39	85.56	18.89	66.67
1993 mean	C	7.78	3.61	3.06	0.56	86.94	11.39	75.56
Oilcode:	P	0.29	0.90	0.14	0.18	0.59	0.03	0.99
Year:	P	0.73	0.87	0.88	0.12	<0.01	<0.01	<0.01
Interaction:	P	0.26	0.97	0.86	0.39	0.91	0.39	0.91

APPENDIX X.

Fishes sampled during 1990 and 1991 shallow subtidal surveys in Prince William Sound.

Appendix X. Fishes sampled during 1990 and 1991 shallow subtidal surveys in Prince William Sound.

1990

family	common name	species	spcode	group
Gadidae	Pacific Cod	*Gadus macrocephalus*	pac cod	Gadidae without Pollock
Gadidae	Pacific Tom Cod	Microgadus proximus	tom cod	Gadidae without Pollock
Gadidae	Walleye Pollock	Theragra chlacogramma	poll	Other
Gadidae	Unidentified cod	Gadus sp.	cod	Gadidae without Pollock
Hexagrammidae	Kelp Greenling	Hexagrammos decagrammus	kelp grn	Hexagrammos spp.
Hexagrammidae	Masked Greenling	Hexagrammos octogrammus	mask grn	Hexagrammos spp.
Hexagrammidae	Rock Geenling	Hexagrammos lagocephalus	rock grn	Hexagrammos spp.
Hexagrammidae	White Spotted Greenling	Hexagrammos stellari	white grn	Hexagrammos spp.
Hexagrammidae	Lingcod	Ophiodon elongatus	ling	Other
Cottidae	Brown Irish Lord	Hemilepidotus spinosus	brown lord	Large Cottidae
Cottidae	Red Irish Lord	Hemilepidotus hemilepidotus	red lord	Large Cottidae
Cottidae	Yellow Irish Lord	Hemilepidotus jordani	yell lord	Large Cottidae
Cottidae	Unidentified Irish lord	Hemilepidotus sp.	lord	Large Cottidae
Cottidae	Great Sculpin	Myoxocephalus polyacanthoclus	grt sculp	Large Cottidae
Cottidae	Buffalo Sculpin	*Enophrys bison*	buf sculp	Large Cottidae
Cottidae	Unidentified large sculpins	--	lg sculp	Large Cottidae
Cottidae	Crested Sculpin	Blepsias bilobus	crest sculp	Small Cottidae
Cottidae	Silverspotted sculpin	Blepsias cirrhosus	silver scul	Small Cottidae
Cottidae	Unidentified Blepsias	Blepsias sp.	blepsias	Small Cottidae
Cottidae	Antlered Sculpin	Enophrys diceraus	ant sculp	Small Cottidae
Cottidae	Pit-head Sculpin	Icelinus cavifrons	ice	Small Cottidae
Cottidae	Mosshead sculpin	Clinocottus globiceps	mosshead	Small Cottidae
Cottidae	Grunt Sculpin	Rhamphocottus richardsonii	rhampho	Small Cottidae
Cottidae	Sailfin Sculpin	Nautichthys oculofasciatus	sail sculp	Small Cottidae
Cottidae	Sand Sculpin	--	sand cot	Small Cottidae
Cottidae	Atredius sculpins	*Artedius sp.*	art	Small Cottidae
Cottidae	Unidentified small sculpins	--	cot	Small Cottidae
Pholidae	Crescent Gunnel	Pholis laeta	cres gun	Pholidae
Pholidae	Penpoint Gunnel	Apodichthys flavidus	pen gun	Pholidae
Pholidae	Saddleback Gunnel	Pholis ornata	sad gun	Pholidae
Pholidae	Unidentified gunnels	--	gun	Pholidae

Stachaeidae	Arctic Shanny	Stichaeus punctatus	arc shan	Stichaeus punctatus
Stachaeidae	Mosshead Warbonnet	Chirolophis nugator	warbon	Other
Stachaeidae	Slender Eelblenny	Lumpenus fabricii	slen eel	Other
Stachaeidae	Black prickleback	Xiphister atropurpureus	xiphis	Other
Stachaeidae	Unidentified eelblenny	--	eelblen	Other
Stachaeidae	Unidentified prickleback	--	stich	Other
Scorpaenidae	China Rockfish	Sebastes nebulosus	china	Scorpienidae
Scorpaenidae	Dusky Rockfish	Sebastes ciliatus	dusky	Scorpienidae
Scorpaenidae	Quillback Rockfish	Sebastes maliger	quill	Scorpienidae
Scorpaenidae	Copper Rockfish	Sebastes caurinus	s caurinus	Scorpienidae
Scorpaenidae	Dusky Rockfish	Sebastes ciliatus	s ciliatus	Scorpienidae
Scorpaenidae	Yelloweye Rochfish	Sebastes ruberrimus	yell eye	Scorpienidae
Scorpaenidae	Black rockfish	Sebastes melanops	blk rock	Scorpienidae
Scorpaenidae	Unidentified rockfish	Sebastes sp.	rockfish	Scorpienidae
Bathymasteridae	Alaskan Ronquil	Bathymaster caeruleofasciatus	ak ronquil	Bathymasteridae
Bathymasteridae	Creme Ronquil	Bathymaster sp.	creme ronq	Bathymasteridae
Bathymasteridae	Searcher	Bathymaster signatus	search	Bathymasteridae
Bathymasteridae	Unidentified ronquil	Bathymaster sp.	bathy	Bathymasteridae
Bathymasteridae	Northern Ronquil	Ronquilis jordani	no. ronq	Bathymasteridae
Agonidae	Smooth Alligatorfish	Anoplagonus inermis	alligator	Other
Agonidae	Unidentified poacher	--	poach	Other
Pleuronectidae	Rock sole	Lepidopsetta bilineata	rock sole	Other
Pleuronectidae	Unidentified right-eyed flounder	--	pleuron	Other
Pleuronectidae	Unidentified flatfish/flounder	--	flatfish	Other
Salmonidae	Pink Salmon	Oncorhynchus gorbuscha	pink sal	Other
Ammodytidae	Pacific Sand Lance	Ammodytes hexapterus	san lan	Other
Aulorhynchidae	Tubesnout	Aulorhynchus flavidus	tubesnout	Other
Anarachthyidae	Wolf-eel	Anarrhidchthys ocellatus	wolf-eel	Other
Clupeidae	Pacific Herring	Clupea harengus	clupeiformes	Other
Zoarcidae	Wattled Eelpout	Lycodes palearis	lycodes pal.	Other
Other	fish	--	fish	Other
Other	larval fish	--	ich larv	Other
Other	oar-like pectorals fish	--	oar-pects fish	Other
Other	snake	--	snake	Other

1991

family	common name	species	spcode	group
Stachaeidae	Arctic Shanny	Stichaeus punctatus	yarc harc & aarc	Stichaeus punctatus
Gadidae	Pacific Cod	Gadus macrocephalus	ypcod hpcod & apcod	*Gadidae* without Pollock
Gadidae	*Pacific Tom Cod*	Microgadus proximus	ytcod htcod & atcod	Gadidae without Pollock
Cottidae	Unidentified small sculpins	--	cotd	Small Cottidae
Scorpaenidae	Copper Rockfish	Sebastes *caurinus*	curf	Scorpienidae

APPENDIX Y.

Mean values for the abundance (#/100m^2) of dominant fishes at oiled and control sites in eelgrass, *Laminaria/Agarum* bay, *Laminaria/Agarum* point, and *Nereocystis* habitats in 1990, 1991, and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Appendix Y. Mean values for the abundance (#/100m^2) of dominant fishes at oiled and control sites in eelgrass, *Laminaria/Agarum* bay, *Laminaria/Agarum* point, and *Nereocystis* habitats in 1990, 1991 and 1993. Also given are probabilities that the means from the oiled and control sites were similar as determined by randomization tests.

Eelgrass Bed - 1990 Depth = Bed

Pair	Site#	Oilcode	All GADIDAE	All HEXAGRAM	All PHOLIDAE	Adult GADIDAE	Juvenile GADIDAE
1	13	O	14.44	1.11	0.56	9.44	5.00
1	14	C	5.56	0.56	0.56	2.78	2.78
2	16	O	140.56	8.89	12.78	2.78	137.78
2	15	C	12.78	7.22	5.56	1.11	11.67
3	17	O	169.44	3.33	0.00	8.33	161.11
3	18	C	13.33	5.56	5.56	0.00	13.33
4	25	O	62.78	6.51	3.81	0.00	62.78
4	26	C	30.00	5.56	2.78	0.00	30.00
	mean	O	96.81	4.96	4.29	5.14	91.67
	mean	C	15.42	4.72	3.61	0.97	14.44
	P		<0.01	0.90	0.76	<0.01	<0.01

Eelgrass Bed - 1991 Depth = Bed

Pair	Site#	Oilcode	Adult GADIDAE	Juvenile GADIDAE
1	13	O	9.44	4.44
1	14	C	10.00	6.67
2	16	O	15.56	108.89
2	15	C	0.00	1.11
3	17	O	0.00	775.56
3	18	C	29.44	0.00
4	25	O	21.67	95.00
4	26	C	1.11	262.78
5	35	O	1.67	0.00
5	34	C	2.22	0.56
	mean	O	9.67	196.78
	mean	C	8.56	54.22
	P		0.88	0.19

Eelgrass Bed - 1993 Depth = Bed

Pair	Site#	Oilcode	Adult GADIDAE	Juvenile GADIDAE
1	13	O	0.74	7.41
1	14	C	0.37	3.33
2	16	O	0.74	30.37
2	15	C	0.74	2.22
3	17	O	0.00	30.74
3	18	C	0.00	2.59
	mean	O	0.49	22.84
	mean	C	0.37	2.72
	P		0.	

Island Bay - 1990 Depth = Deep

Pair	Site#	Oilcode	All HEXAGRAM	All LARGECOT	All SMALLCOT	All PHOLIDAE	Adult STICHAEU	Juvenile STICHAEU
1	2	O	0.00	1.11	3.89	0.00	1.11	0.00
1	1	C	0.00	0.00	2.22	0.56	2.22	0.00
2	3	O	0.56	0.56	30.00	2.78	7.22	0.00
2	4	C	0.00	0.56	6.11	2.22	8.89	0.00
3	6	O	0.00	0.56	4.44	0.00	16.11	1.11
3	5	C	0.56	1.11	25.00	3.33	18.89	0.00
	mean	O	0.19	0.74	12.78	0.93	8.15	0.37
	mean	C	0.19	0.56	11.11	2.04	10.00	0.00
	P		0.47	0.69	0.85	0.17	0.22	0.23

Island Bay - 1990 Depth = Shallow

Pair	Site#	Oilcode	All HEXAGRAM	All LARGECOT	All SMALLCOT	All PHOLIDAE	Adult STICHAEU	Juvenile STICHAEU
1	2	O	1.67	0.00	1.67	0.56	11.11	0.00
1	1	C	0.00	0.56	5.56	22.22	5.56	27.78
2	3	O	1.67	1.67	12.78	3.89	28.89	0.00
2	4	C	0.00	0.00	6.11	0.56	4.44	0.00
3	6	O	1.67	0.56	1.11	5.00	28.89	11.11
3	5	C	0.00	3.33	17.78	2.78	63.33	1.11
	mean	O	1.67	0.74	5.19	3.15	22.96	3.70
	mean	C	0.00	1.30	9.81	8.52	24.44	9.63
	P		0.07	0.43	0.32	0.39	0.84	0.85

Island Bay - 1991 Depth = Shallow

Pair	Site#	Oilcode	Adult GADIDAE	Juvenile GADIDAE	Adult SMALLCOT	Adult STICHAEU	Juvenile STICHAEU
1	2	O	6.67	0.00	0.00	5.56	2.78
1	1	C	16.67	0.00	3.33	30.56	3.33
2	3	O	2.78	0.00	0.56	15.56	0.56
2	4	C	1.11	25.00	1.67	12.22	1.11
3	6	O	8.33	16.67	1.11	0.00	11.67
3	5	C	0.00	0.56	1.11	10.56	0.56
	mean	O	5.93	5.56	0.56	7.04	5.00
	mean	C	5.93	8.52	2.04	17.78	1.67
	P		0.98	0.80	0.02	0.06	0.25

Island Bay - 1993 Depth = Shallow

Pair	Site#	Oilcode	Adult GADIDAE	Juvenile GADIDAE	Adult STICHAEU	Juvenile STICHAEU	Adult Copper Rockfish
1	3	O	2.96	192.22	2.22	0.74	0.37
1	4	C	0.74	15.19	0.00	0.00	0.00
2	6	O	0.37	1.11	0.00	0.00	0.37
2	5	C	0.00	555.56	0.00	0.00	0.37
	mean	O	1.67	96.67	1.11	0.37	0.37
	mean	C	0.37	285.37	0.00	0.00	0.19
	P		0.17	0.86	.	.	0.16

Island Point - 1990 Depth = Deep

Pair	Site#	Oilcode	All BATHYMAS	All HEXAGRAM	All LARGECOT	All PHOLIDAE	All SCORPIEN	All SMALLCOT	Adult STICHAEU	Juvenile STICHAEU	Juvenile GADIDAE
1	19	O	25.00	4.44	1.11	0.00	33.33	24.44	2.78	13.33	0.00
1	20	C	8.89	1.11	3.33	1.67	2.22	31.11	52.78	8.89	11183.33
2	22	O	2.22	2.22	1.11	1.11	1.11	43.89	48.89	34.44	21.67
2	21	C	7.22	0.56	0.00	3.33	4.44	36.67	27.22	21.11	51.11
3	23	O	10.00	2.22	1.11	0.00	1.67	30.56	0.00	18.89	0.00
3	24	C	1.67	1.67	1.11	1.11	0.00	15.56	1.67	2.22	9.44
	mean	O	12.41	2.96	1.11	0.37	12.04	32.96	17.22	22.22	7.22
	mean	C	5.93	1.11	1.48	2.04	2.22	27.78	27.22	10.74	3747.96
	P		0.48	0.10	0.67	0.08	0.70	0.39	0.57	0.07	0.02

Island Point - 1990 Depth = Shallow

Pair	Site#	Oilcode	All BATHYMAS	All HEXAGRAM	All LARGECOT	All PHOLIDAE	All SCORPIEN	All SMALLCOT	Adult SCORPIEN	Adult STICHAEU	Juvenile STICHAEU	Juvenile GADIDAE
1	19	O	17.22	9.44	3.33	1.67	12.78	17.22	4.44	4.44	24.44	0.00
1	20	C	6.11	5.56	2.22	1.11	1.11	8.89	0.56	56.11	52.78	5630.00
2	22	O	7.22	8.89	0.56	6.11	0.00	40.00	0.00	55.00	54.44	6.11
2	21	C	1.11	7.78	2.78	12.78	0.56	5.00	0.00	74.44	26.11	75.00
3	23	O	2.78	2.22	1.67	3.33	1.11	62.78	0.00	5.00	38.33	0.00
3	24	C	2.78	7.22	2.22	0.00	36.67	18.89	7.78	0.00	2.22	0.00
	mean	O	9.07	6.85	1.85	3.70	4.63	40.00	1.48	21.48	39.07	2.04
	mean	C	3.33	6.85	2.41	4.63	12.78	10.93	2.78	43.52	27.04	1901.67
	P		0.05	0.95	0.52	0.81	0.90	<0.01	0.81	0.12	0.34	0.02

Nereocystis Bed - 1990 Depth = Shallow

Pair	Site#	Oilcode	All HEXAGRAM	All LARGECOT	All SMALLCOT	Juvenile GADIDAE
1	7	O	0.00	0.00	0.00	0.00
1	8	C	4.44	1.67	1.67	0.00
2	12	O	24.00	3.33	1.33	333.33
2	11	C	7.22	1.67	0.56	69.44
	mean	O	12.00	1.67	0.67	166.67
	mean	C	5.83	1.67	1.11	34.72
	P		0.08	0.53	0.79	0.57

APPENDIX Z.

Mean values and results of 2-way randomization ANOVAs comparing abundance and biomass of dominant families of fish at oiled and control sites in the eelgrass and *Laminaria/Agarum* bay habitats in 1990 and 1991.

Appendix Z. Mean values and results of 2-way randomization ANOVAs comparing abundance (#/100m^2) of dominant families of fish at oiled and control sites in the eelgrass and *Laminaria/Agarum* bay habitats in 1990 and 1991. Only sites sampled during both years were used for analyses.

Island Bays - Shallow

YEAR	GROUP	STAGE	OILCODE	DENSITY	SE	N
1990	Stichaeus punctatus	A	O	22.96	5.93	3
1990	Stichaeus punctatus	A	C	24.44	19.45	3
1991	Stichaeus punctatus	A	O	7.04	4.55	3
1991	Stichaeus punctatus	A	C	17.78	6.41	3

Oilcode P 0.36
Year P 0.08
Interaction P 0.47

Island Bays - Shallow

YEAR	GROUP	STAGE	OILCODE	DENSITY	SE	N
1990	Stichaeus punctatus	J	O	3.70	3.70	3
1990	Stichaeus punctatus	J	C	9.63	9.08	3
1991	Stichaeus punctatus	J	O	5.00	3.39	3
1991	Stichaeus punctatus	J	C	1.67	0.85	3

Oilcode P 0.99
Year P 0.78
Interaction P 0.42

Eelgrass - Bed

YEAR	GROUP	STAGE	OILCODE	DENSITY	SE	N
1990	Gadidae without Pollock	A	O	5.14	2.25	4
1990	Gadidae without Pollock	A	C	0.97	0.66	4
1991	Gadidae without Pollock	A	O	11.67	4.62	4
1991	Gadidae without Pollock	A	C	10.14	6.81	4

Oilcode	P	0.47
Year	P	0.015
Interaction	P	0.74

Eelgrass - Bed

YEAR	GROUP	STAGE	OILCODE	DENSITY	SE	N
1990	Gadidae without Pollock	J	O	91.67	35.70	4
1990	Gadidae without Pollock	J	C	14.44	5.68	4
1991	Gadidae without Pollock	J	O	245.97	178.04	4
1991	Gadidae without Pollock	J	C	67.64	65.06	4

Oilcode	P	0.015
Year	P	0.08
Interaction	P	0.45

APPENDIX AA.

Concentrations of PAHs (ng/g^{-1}) in shallow subtidal surficial sediments in Prince William Sound, 1990, 1991, and 1993. (Data provided by the Technical Service Task Force: Analytical Chemistry Group).

Appendix AA. Estimated concentrations of PAHs (ng/g^{-1}) in shallow subtidal surficial sediments in Prince William Sound during 1990, 1991, and 1993. Estimates were made by summing values for all analytes. Analytes are presented in Appendix E.

Eelgrass Beds - Deep

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	13	Bay of Isles	1663.88	725.755	2	61.685	1026.37
1990	1	C	14	Drier Bay	715.21	341.455	2	67.518	482.89
1990	2	O	16	Herring Bay	46.19	15.297	3	57.362	26.50
1990	2	C	15	L. Herring Bay	686.49	111.995	2	23.071	158.38
1990	3	O	17	Sleepy Bay	428.03	239.785	2	79.226	339.11
1990	3	C	18	Moose Lips Bay	80.75	3.115	2	5.455	4.41
1990	4	O	25	Clammy Bay	62.81	18.097	3	49.902	31.35
1990	4	C	26	Puffin Bay	70.53	12.983	3	31.882	22.49
1990		O Mean			550.228	381.531	4	138.681	763.062
1990		C Mean			388.247	180.589	4	93.028	361.177
		P-value for Oilcode = 0.709							

Eelgrass Beds - Shallow

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	13	Bay of Isles	1349.86	532.202	3	68.288	921.800
1990	1	C	14	Drier Bay	364.18	192.799	3	91.696	333.938
1990	2	O	16	Herring Bay	49.11	18.388	3	64.852	31.849
1990	2	C	15	L. Herring Bay	116.31	58.495	3	87.110	101.317
1990	3	O	17	Sleepy Bay	146.67	38.012	3	44.890	65.838
1990	3	C	18	Moose Lips Bay	84.41	18.528	3	38.017	32.092
1990	4	O	25	Clammy Bay	311.53	108.858	3	60.524	188.547
1990	4	C	26	Puffin Bay	588.93	277.553	3	81.629	480.736
1990		O Mean			464.292	300.116	4	129.279	600.232
1990		C Mean			288.458	118.070	4	81.863	236.140
		P-value for Oilcode = 0.503							

Eelgrass Beds - Bed

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	13	Bay of Isles	1213.13	545.724	3	77.916	945.222
1990	1	C	14	Drier Bay	333.67	139.512	3	72.419	241.641
1990	2	O	16	Herring Bay	151.84	55.708	3	63.545	96.489
1990	2	C	15	L. Herring Bay	69.37	11.108	3	27.737	19.240
1990	3	O	17	Sleepy Bay	188.29	109.857	3	101.054	190.277
1990	3	C	18	Moose Lips Bay	97.45	22.205	3	39.465	38.460
1990	4	O	25	Clammy Bay	598.59	199.943	3	57.855	346.312
1990	4	C	26	Puffin Bay	443.06	164.669	3	64.374	285.216
1990		O Mean			537.963	246.793	4	91.751	493.585
1990		C Mean			235.888	91.001	4	77.157	182.003
		P-value for Oilcode = 0.035							

Eelgrass Beds - Deep

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1991	1	O	13	Bay of Isles	220.217	68.4864	3	53.8660	118.622
1991	1	C	14	Drier Bay	62.473	10.7355	3	29.7637	18.594
1991	2	O	16	Herring Bay	89.590	36.9234	3	71.3843	63.953
1991	2	C	15	L. Herring Bay	55.620	2.7400	2	6.9668	3.875
1991	3	O	17	Sleepy Bay	186.247	32.2127	3	29.9570	55.794
1991	3	C	18	Moose Lips Bay	97.947	6.8280	3	12.0743	11.826
1991	4	O	25	Clammy Bay	140.400	15.9161	3	19.6350	27.568
1991	4	C	26	Puffin Bay	133.943	32.7433	3	42.3411	56.713
1991		O Mean			159.113	28.3630	4	35.6513	56.726
1991		C Mean			87.496	18.0480	4	41.2546	36.096

P-value for Oilcode = 0.019

Eelgrass Beds - Bed

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1991	1	O	13	Bay of Isles	155.493	46.6642	3	51.9796	80.825
1991	1	C	14	Drier Bay	115.133	23.2539	3	34.9828	40.277
1991	2	O	16	Herring Bay	92.050	14.3514	3	27.0043	24.857
1991	2	C	15	L. Herring Bay	16.060	2.0573	3	22.1881	3.563
1991	3	O	17	Sleepy Bay	129.903	60.4542	3	80.6059	104.710
1991	3	C	18	Moose Lips Bay	55.290	4.3844	3	13.7348	7.594
1991	4	O	25	Clammy Bay	127.260	14.9968	3	20.4111	25.975
1991	4	C	26	Puffin Bay	125.903	30.8268	3	42.4084	53.394
1991	5	O	35	Short Arm Bay	163.433	21.6038	3	22.8955	37.419
1991	5	C	34	Mallard Bay	158.390	59.8224	3	65.4179	103.615
1991		O Mean			133.628	12.5491	5	20.9991	28.061
1991		C Mean			94.155	25.6744	5	60.9734	57.410

P-value for Oilcode = 0.084

Eelgrass Beds - Deep

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1993	1	O	13	BAY OF ISLES	100.707	50.7981	3	87.3674	87.9848
1993	1	C	14	DRIER BAY	39.410	13.0471	3	57.3413	22.5982
1993	2	O	16	HERRING BAY	48.107	12.3285	3	44.3881	21.3536
1993	2	C	15	L. HERRING BAY	2.723	1.3684	3	87.0314	2.3702
1993	3	O	17	SLEEPY BAY	66.247	12.6892	3	33.1766	21.9784
1993	3	C	18	MOOSE LIPS BAY	45.167	9.7646	3	37.4454	16.9128
1993		O Mean			71.687	15.4260	3	37.2714	26.7186
1993		C Mean			29.100	13.2926	3	79.1185	23.0235

P-value for Oilcode = 0.013

Eelgrass Beds - Bed

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1993	1	O	13	BAY OF ISLES	53.9767	14.3126	3	45.9276	24.7902
1993	1	C	14	DRIER BAY	13.9333	5.3958	3	67.0745	9.3457
1993	2	O	16	HERRING BAY	20.6500	10.2777	3	86.2060	17.8015
1993	2	C	15	L. HERRING BAY	3.6333	1.0156	3	48.4125	1.7590
1993	3	O	17	SLEEPY BAY	6.8900	2.7176	3	68.3160	4.7070
1993	3	C	18	MOOSE LIPS BAY	30.1367	5.5947	3	32.1544	9.6903
1993		O Mean			27.1722	13.9785	3	89.1036	24.2114
1993		C Mean			15.9011	7.7139	3	84.0243	13.3608

P-value for Oilcode = 0.304

Island Bays - Deep

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	2	Northwest Bay	301.833	167.301	3	96.0045	289.773
1990	1	C	1	Cabin Bay	71.337	13.322	3	32.3458	23.074
1990	2	O	3	Herring Bay	84.807	7.609	3	15.5412	13.180
1990	2	C	4	L. Herring Bay	38.900	17.408	3	77.5092	30.151
1990	3	O	6	Bay of Isles	281.043	30.231	3	18.6310	52.361
1990	3	C	5	Mummy Bay	60.237	30.543	3	87.8230	52.902
1990		O Mean			222.561	69.138	3	53.8058	119.751
1990		C Mean			56.824	9.518	3	29.0110	16.485

P-value for Oilcode = 0.018

Island Bays - Shallow

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	2	Northwest Bay	376.880	101.475	3	46.636	175.760
1990	1	C	1	Cabin Bay	148.117	17.121	3	20.021	29.654
1990	2	O	3	Herring Bay	922.437	347.285	3	65.209	601.516
1990	2	C	4	L. Herring Bay	299.760	64.960	2	30.647	91.867
1990	3	O	6	Bay of Isles	504.827	431.020	3	147.882	746.549
1990	3	C	5	Mummy Bay	198.993	42.653	3	37.125	73.876
1990		O Mean			601.381	164.722	3	47.442	285.307
1990		C Mean			215.623	44.558	3	35.793	77.177

P-value for Oilcode = 0.070

Island Points - Deep

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	19	Discovery Pt.	35.4167	13.4638	3	65.845	23.320
1990	2	C	21	O.L. Herring B	79.8400	26.0811	3	56.580	45.174
1990	3	O	23	Ingot Point	81.6333	60.8769	3	129.165	105.442
1990	3	C	24	Peak Point	61.0367	7.8495	3	22.275	13.596
1990		O Mean			58.5250	23.1083	2	55.840	32.680
1990		C Mean			70.4383	9.4017	2	18.876	13.296

P-value for Oilcode = 0.759

Island Points - Shallow

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	C	20	Lucky Point	15.8833	5.20697	3	56.7812	9.01874
1990		C Mean			15.8833	.	1	.	.

Insufficient data for analysis

Nereocystis Beds - Deep

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	7	Latouche Pt.	48.7350	39.9150	2	115.827	56.4483
1990	1	C	8	Procession Rks	45.7433	4.5405	3	17.193	7.8644
1990	2	O	12	Little Smith	22.8067	2.6971	3	20.483	4.6715
1990	2	C	11	Naked Island	30.7100	6.6841	3	37.699	11.5773
1990		O Mean			35.7708	12.9642	2	51.254	18.3341
1990		C Mean			38.2267	7.5167	2	27.808	10.6302

P-value for Oilcode = 0.802

Nereocystis Beds - Shallow

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	7	Latouche Pt.	45.1200	.	1	.	.
1990		O Mean			45.1200	.	1	.	.

Insufficient data for analysis

Silled Fjords

YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1990	1	O	30	I. Bay of Isle	317.325	185.395	2	82.625	262.188
1990	1	O	31	O. Bay of Isle	304.732	79.839	4	52.399	159.678
1990	1	C	27	O. Lucky Bay	80.260	28.610	2	50.412	40.461
1990	1	C	29	I. Lucky Bay	601.610	67.650	2	15.903	95.672
1990		O Mean			311.029	6.296	2	2.863	8.904
1990		C Mean			340.935	260.675	2	108.129	368.650

P-value for Oilcode = 0.879

Means of Herring Bay Silled Fjord Summed Analytes for 1989 - 1993.

YEAR	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1989	28	Herring Bay SF	1213.77	137.560	2	16.0277	194.539
1990	28	Herring Bay SF	336.19	83.485	2	35.1182	118.066
1991	28	Herring Bay SF	65.17	25.207	3	66.9924	43.659
1993	28	Herring Bay SF	55.72	5.926	3	18.4211	10.264

P-value for Year = 0.005 (1-way comparing year within site)

APPENDIX BB.

Estimated concentrations of PAHs (ng/g) in shallow subtidal surficial sediments in the eelgrass habitat of Prince William Sound during 1990, 1991, 1993 and the results of 2-way ANOVA randomization tests for sites sampled in all three years. (Data provided by the Technical Service Task Force: Analytical Chemistry Group).

Appendix BB. Estimated concentrations of PAHs (ng/g) in shallow subtidal surficial sediments in the eelgrass habitat of Prince William Sound during 1990, 1991, 1993 and all three years. Estimates were made by summing values for all analytes. Analytes are presented in Appendix E.

Eelgrass Beds - Deep Transects

TRANSECT	YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
1	1990	1	O	13	Bay of Isles	1663.88	725.755	2	61.6853	1026.37
1	1990	1	C	14	Drier Bay	715.21	341.455	2	67.5177	482.89
1	1990	2	O	16	Herring Bay	46.19	15.297	3	57.3621	26.50
1	1990	2	C	15	L. Herring Bay	686.49	111.995	2	23.0715	158.38
1	1990	3	O	17	Sleepy Bay	428.03	239.785	2	79.2260	339.11
1	1990	3	C	18	Moose Lips Bay	80.75	3.115	2	5.4551	4.41
1	1991	1	O	13	Bay of Isles	220.22	68.486	3	53.8660	118.62
1	1991	1	C	14	Drier Bay	62.47	10.735	3	29.7637	18.59
1	1991	2	O	16	Herring Bay	89.59	36.923	3	71.3843	63.95
1	1991	2	C	15	L. Herring Bay	55.62	2.740	2	6.9668	3.87
1	1991	3	O	17	Sleepy Bay	186.25	32.213	3	29.9570	55.79
1	1991	3	C	18	Moose Lips Bay	97.95	6.828	3	12.0743	11.83
1	1993	1	O	13	Bay of Isles	100.71	50.798	3	87.3674	87.98
1	1993	1	C	14	Drier Bay	39.41	13.047	3	57.3413	22.60
1	1993	2	O	16	Herring Bay	48.11	12.329	3	44.3881	21.35
1	1993	2	C	15	L. Herring Bay	2.72	1.368	3	87.0314	2.37
1	1993	3	O	17	Sleepy Bay	66.25	12.689	3	33.1766	21.98
1	1993	3	C	18	Moose Lips Bay	45.17	9.765	3	37.4454	16.91

Oilcode Means Across Sites

TRANSECT	YEAR	OILCODE	SUMPAH	SE	N	CV	STD
1	1990	O	712.700	488.199	3	118.645	845.585
1	1990	C	494.152	206.864	3	72.508	358.300
1	1991	O	165.351	39.129	3	40.988	67.774
1	1991	C	72.013	13.117	3	31.548	22.719
1	1993	O	71.687	15.426	3	37.271	26.719
1	1993	C	29.100	13.293	3	79.119	23.023

Oilcode Means Across Years

TRANSECT	OILCODE	SUMPAH	SE	N	CV	STD
1	O	316.579	199.897	3	109.367	346.233
1	C	198.422	148.383	3	129.526	257.007

P-value: Interaction = 0.975
P-value: Oilcode = 0.517
P-value: Year < 0.001

Eelgrass Beds - Bed Transects

TRANSECT	YEAR	PAIR	OILCODE	SITNUM	SITNAME	SUMPAH	SE	N	CV	STD
3	1990	1	O	13	Bay of Isles	1213.13	545.724	3	77.916	945.222
3	1990	1	C	14	Drier Bay	333.67	139.512	3	72.419	241.641
3	1990	2	O	16	Herring Bay	151.84	55.708	3	63.545	96.489
3	1990	2	C	15	L. Herring Bay	69.37	11.108	3	27.737	19.240
3	1990	3	O	17	Sleepy Bay	188.29	109.857	3	101.054	190.277
3	1990	3	C	18	Moose Lips Bay	97.45	22.205	3	39.465	38.460
3	1991	1	O	13	Bay of Isles	155.49	46.664	3	51.980	80.825
3	1991	1	C	14	Drier Bay	115.13	23.254	3	34.983	40.277
3	1991	2	O	16	Herring Bay	92.05	14.351	3	27.004	24.857
3	1991	2	C	15	L. Herring Bay	16.06	2.057	3	22.188	3.563
3	1991	3	O	17	Sleepy Bay	129.90	60.454	3	80.606	104.710
3	1991	3	C	18	Moose Lips Bay	55.29	4.384	3	13.735	7.594
3	1993	1	O	13	Bay of Isles	53.98	14.313	3	45.928	24.790
3	1993	1	C	14	Drier Bay	13.93	5.396	3	67.075	9.346
3	1993	2	O	16	Herring Bay	20.65	10.278	3	86.206	17.802
3	1993	2	C	15	L. Herring Bay	3.63	1.016	3	48.412	1.759
3	1993	3	O	17	Sleepy Bay	6.89	2.718	3	68.316	4.707
3	1993	3	C	18	Moose Lips Bay	30.14	5.595	3	32.154	9.690

Oilcode Means Across Sites

TRANSECT	YEAR	OILCODE	SUMPAH	SE	N	CV	STD
3	1990	O	517.754	347.845	3	116.365	602.486
3	1990	C	166.830	83.813	3	87.016	145.169
3	1991	O	125.816	18.428	3	25.369	31.919
3	1991	C	62.161	28.806	3	80.264	49.893
3	1993	O	27.172	13.978	3	89.104	24.211
3	1993	C	15.901	7.714	3	84.024	13.361

Oilcode Means Across Years

TRANSECT	OILCODE	SUMPAH	SE	N	CV	STD
3	O	223.581	149.818	3	116.062	259.492
3	C	81.631	44.644	3	94.726	77.325

P-value: Interaction = 0.355
P-value: Oilcode = 0.101
P-value: Year < 0.001

Exxon Valdez Oil Spill
Restoration Project Final Report

Recovery of Sediments in the Lower Intertidal and Subtidal Environment

Restoration Project 93047-1
Final Report

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May 1996

Recovery of Sediments in the Lower Intertidal and Subtidal Environment

Restoration Project 93047-1
Final Report

Study History: This study began as NRDA Air/Water Study Number 2 "Petroleum Hydrocarbon-Induced Injury to Subtidal Marine Sediment Resources" in 1989. Status reports under this study number were submitted in 1989 and 1990. In 1991, the number of the study was changed to Subtidal Study Number 1. The title remained the same. A status report under the new number was submitted in November 1991. The final report for Subtidal Study Number 1 was submitted in September 1994. No field work was performed in 1992. In 1993, Restoration Study Number 93047 "*Exxon Valdez* Restoration Project: Subtidal Monitoring" was initiated. The final report for Restoration Study Number 93047 was submitted in July 1995. Peer review comments were received on 25 October 1995. A paper titled "Contamination of Subtidal Sediments by Oil from the *Exxon Valdez* in Prince William Sound, Alaska" will appear in The *Exxon Valdez* Oil Spill Symposium Proceedings.

Abstract: Sediments were collected at ten locations in Prince William Sound in July 1993 to determine the geographical and bathymetric distribution of oil from the *Exxon Valdez* oil spill in the low intertidal zone and subtidal region. We sampled sediments at mean lower low water (0 m) and at five subtidal depths from 3 to 100 m. No *Exxon Valdez* oil was found in sediments at 0 m where the greatest mean intertidal concentration of total polynuclear aromatic hydrocarbons excluding perylene (54 ng/g) was observed at Moose Lips Bay. Subtidal sediments showed polynuclear aromatic hydrocarbon composition patterns similar to *Exxon Valdez* oil at three sites, Herring Bay, Northwest Bay and Sleepy Bay. Contamination of sediments by *Exxon Valdez* oil reached a depth of 20 m at Northwest Bay and Sleepy Bay. The greatest mean concentration of total polynuclear aromatic hydrocarbons excluding perylene in benthic sediments (1,231 ng/g) occurred at 20 m at Northwest Bay. In deep sediments (≥40 m) we found no evidence of weathered *Exxon Valdez* oil. The hydrocarbon concentrations in sediments at these depths were similar at reference and assessment locations. Petroleum hydrocarbons at the 100 m depth were chiefly from the Katalla source.

Key Words: *Exxon Valdez*, hydrocarbon concentrations, Prince William Sound, recovery, subtidal sediments

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EXECUTIVE SUMMARY

In 1993, four years after the *Exxon Valdez* oil spill, we sampled subtidal sediments at ten locations in Prince William Sound to determine the geographical and bathymetric distribution of oil from the Spill in the sediments. We sampled sediments in July near mean lower low water and at five subtidal depths in the 3-100 m range.

Sediments at mean lower low water (0 m) at both assessment and reference sites showed no evidence of *Exxon Valdez* oil. The greatest mean concentration of total polynuclear aromatic hydrocarbons found in intertidal sediments in 1993 was at Moose Lips Bay (54 ng/g).

Subtidal sediments showed polynuclear aromatic hydrocarbon composition patterns similar to *Exxon Valdez* oil at three sites where oil had come ashore in 1989: Herring Bay, Northwest Bay and Sleepy Bay. Contamination of subtidal sediments by *Exxon Valdez* oil at oiled locations reached a depth of 20 m only at Northwest Bay and Sleepy Bay. In subtidal sediments the greatest concentration of *Exxon Valdez* oil was at the 20 m depth. The highest mean total polynuclear aromatic hydrocarbon concentration, where the *Exxon Valdez* oil-polynuclear aromatic hydrocarbon composition pattern was evident, was 1,231 ng/g in sediment collected at 20 m at Northwest Bay.

In deep sediments (≥40 m) we found little evidence of *Exxon Valdez* oil. The total polynuclear aromatic hydrocarbon concentrations in sediments at these depths were similar at oiled and reference locations. The polynuclear aromatic hydrocarbon composition pattern characteristic of weathered *Exxon Valdez* oil was absent at these depths. The total polynuclear aromatic hydrocarbon concentration in the deepest sediments (≥100 m) usually exceeded that at 40 m. Petroleum hydrocarbons at the 100 m depth were chiefly from the Katalla source.

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INTRODUCTION

In the months following the *Exxon Valdez* oil spill (EVOS) petroleum hydrocarbons attributable to *Exxon Valdez* oil (EVO) were observed in subtidal sediments in a number of locations over a broad geographical range in Prince William Sound (PWS). Patterns in the distribution of the concentration of individual polynuclear aromatic hydrocarbon (PAH) analytes in subtidal sediments were similar to the PAH composition pattern found in EVO (EVO-PAH) at 80% of the locations where oil had come ashore in 1989 (O'Clair et al., 1996). This result indicated that detectable quantities of EVO were transported to the subtidal region at a large proportion of those locations where oil had become stranded on shore after the Spill. It is possible that oil was transported to the subtidal region at the remaining 20% of the locations where oil had come ashore in 1989, but that the oil was either not present subtidally in detectable quantities or was missed by our sampling methodology. The greatest concentration of total polynuclear aromatic hydrocarbons (TPAH, excluding perylene) in subtidal sediments exhibiting the EVO-PAH composition pattern averaged 1,486 ng/g in sediments collected at the 3-m depth at Northwest Bay in July 1989. Subtidal EVO contamination was largely confined to shallow depths (3-20 m) adjacent to shorelines where moderate to heavy oiling occurred. Between 1989 and 1991, concentrations of petroleum hydrocarbons derived from EVO decreased and became more patchily distributed in subtidal sediments, and sediment hydrocarbons became more difficult to match with EVO. By 1991, the EVO-PAH pattern was consistently present in subtidal sediments only at Northwest Bay; although, the EVO-PAH pattern occurred sporadically in the subtidal sediments of three other moderately to heavily oiled locations. Wolfe et al. (1994) estimated that about 13% of the spilled oil was transported to the subtidal region and remained there as of October 1992. Although most of the oil transported subtidally is thought to occur in the Gulf of Alaska (Wolfe et al. 1994), a substantial amount may have remained in the subtidal sediments of PWS in 1993.

The purpose of this report is to describe the geographical and bathymetric distribution of petroleum hydrocarbons from the EVOS in subtidal sediments in PWS four years after the Spill. Measurements of the chemical composition of the hydrocarbons were used to distinguish EVO from other sources of petroleum hydrocarbons. We report here the extent to which EVO has persisted in low intertidal and subtidal sediments between 1989 and 1993; thereby, providing information on the natural recovery of the subtidal sediments from EVO contamination. Because Karinen et al. (1993) measured background petroleum hydrocarbon concentrations in intertidal sediments before the EVOS, we can report the degree of recovery of low intertidal sediments to prespill concentrations.

OBJECTIVES

A. Determine the composition and concentration of petroleum hydrocarbons from the EVOS in intertidal and subtidal sediments (0-100 m) in PWS by gas chromatography/mass spectrometry.

1. Determine the concentrations of TPAHs and *n*-alkanes in subtidal sediments and compare with concentrations in intertidal sediments and in subtidal sediments in previous years after the EVOS.

B. Determine the distribution of EVO with bathymetric depth and compare with bathymetric distribution of EVO in previous years.

C. Determine persistence of EVO in subtidal sediments over time.

D. Compare the distribution of EVO in subtidal sediments with those of hydrocarbons from other sources.

METHODS

Study Sites

The geographical nomenclature in this report follows O'Clair et al. (1996). Geographical position is described by three terms: location, site, and station. Location refers to a general area where one or more sampling sites were established (e.g., Northwest Bay). Site refers to a relatively small geographical area containing the bathymetric transect used to sample various bottom depths for sediments. Only one site was sampled at each location in 1993. The origin of the bathymetric transect (where it intersected the shore) is shown as the geographical position of each site in Table 1 and Figure 1. Station refers a specific spot along a bathymetric transect where sediment samples were collected (e.g., the 20 m depth station). Assessment locations are those where EVO was reported to have come ashore. Reference locations are those where no oil came ashore. Sediments were sampled at ten sites (five reference sites and five assessment sites; Table 1, Fig. 1) in PWS in 1993. Dates of sampling in 1993 were 8-16 July (Table 1).

Sediment Collection

Standard operating procedures were adopted for the collection of all sediments (Appendix I). Intertidal collections were made at about mean lower low water (MLLW, 0 m); actual sampling elevation was within the range of +0.5 to -1 m depending on the distribution of fine sediments. Depending on the tide stage, intertidal sediments were collected by beach teams or by divers. Subtidal sediment sample collections were made at depths of 3, 6, 20, 40, and 100 m below MLLW. Collections at 3, 6, and 20 m were made by divers on transects laid along the appropriate isobath. Three samples, each a composite of eight subsamples collected randomly along a 30 m transect laid along the appropriate isobath, were taken at each of the shallow stations (0-20 m).

Table 1.--Location of sites and date stations were sampled at each site where intertidal and subtidal sediments were collected in 1993 in PWS. Six stations were sampled at each site. Depths sampled were 0, 3, 6, 20, 40, and 100 m.

Site		North Latitude	West Longitude	
No.[1]	Name	o ' "	o ' "	Date
Reference Sites				
10	Drier Bay	60 19 12	147 44 00	11 July
26	Lower Herring Bay	60 24 12	147 47 48	10 July
28	Moose Lips Bay	60 12 30	147 18 06	13 July
32	Olsen Bay	60 45 05	146 11 13	16 July
45	Zaikof Bay	60 16 53	147 02 19	13 July
Assessment Sites				
5	Bay of Isles	60 23 00	147 44 54	15 July
20	Herring Bay	60 25 51	147 47 06	9 July
31	Northwest Bay	60 33 07	147 34 36	8 July
38	Sleepy Bay	60 04 01	147 50 11	12 July
40	Snug Harbor 25	60 14 13	147 43 58	14 July

[1]Site numbers follow O'Clair et al. (1996).

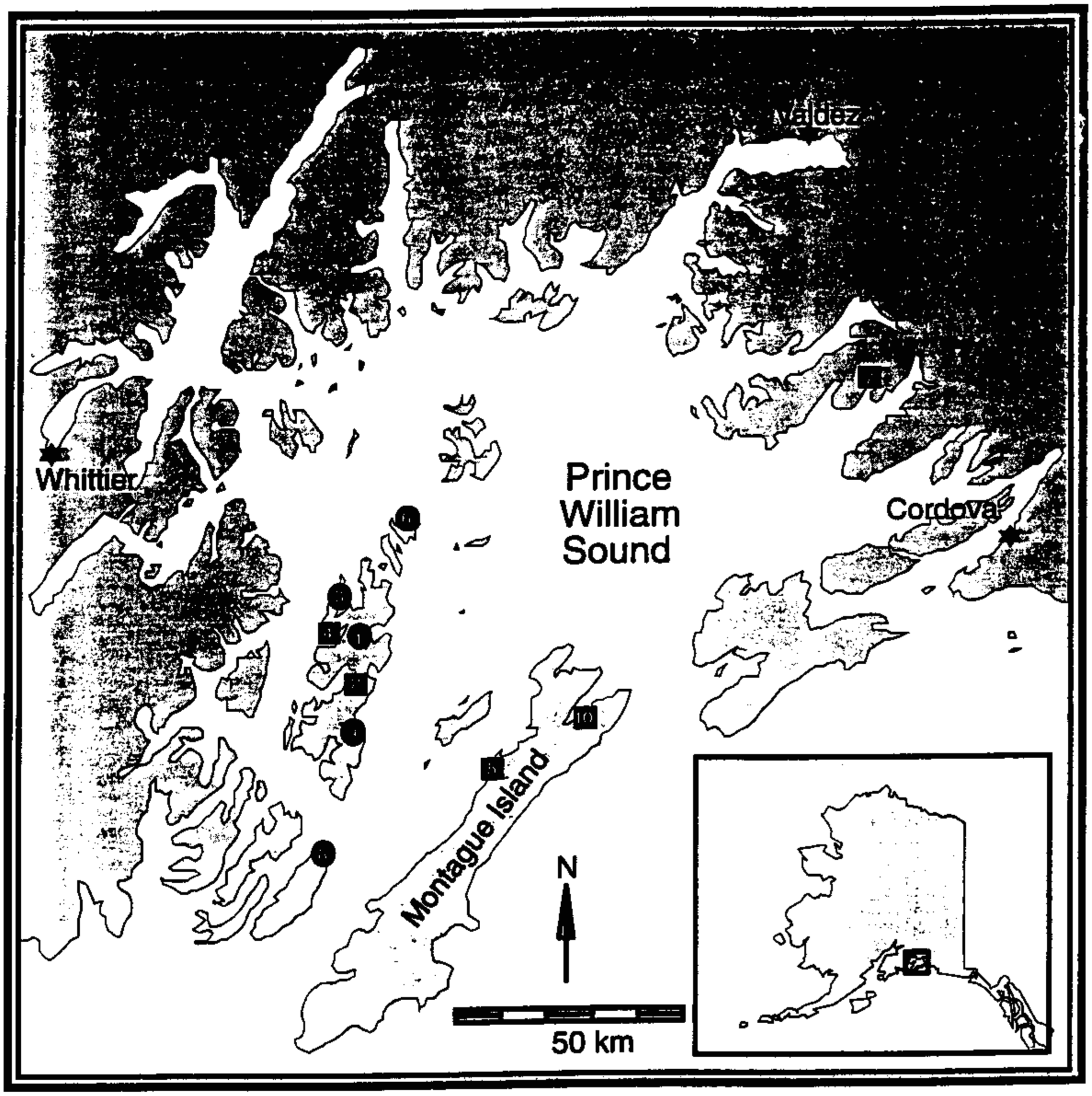

Figure 1.--Distribution of assessment (circles) and reference (squares) sites sampled in 1993 in PWS. See Table 1 for the geographical coordinates of each site. Numbered sites are: 1) Bay of Isles; 2) Drier Bay; 3) Herring Bay; 4) Lower Herring Bay; 5) Moose Lips Bay; 6) Northwest Bay; 7) Olsen Bay; 8) Sleepy Bay; 9) Snug Harbor 25; 10) Zaikof Bay.

A stainless-steel Smith-McIntyre grab was used to collect sediments at 40 and 100 m depths. Remote sampling with a grab included three grabs taken at each station. Four cores were removed from randomly selected points on the surface of the sediment contained in each grab. The subsamples were combined to form one sample per grab.

All samples collected by hand (including those removed by hand from the grab) were taken from the surface (top 0-2 cm) of the sediment column. Samples taken by hand in the intertidal region or by divers were collected with a stainless-steel core tube or spoon. Each subsample was transferred to a sample jar by a spatula. The core tube and the spatula were washed, dried, and rinsed with methylene chloride between sampling periods. Sample jars certified hydrocarbon-clean according to Environmental Protection Agency standards were used to store sediments. Samples were kept cool after collection and frozen within a few hours. Appropriate blanks were collected at each site.

Chain-of-custody procedures were followed after sample collection. The samples were packed in boxes which were sealed with custody tape. Boxes of samples were placed in coolers with enough blue ice to keep the samples frozen while in transit from the field to the Laboratory. All samples were accompanied by chain-of-custody forms from the field to the Auke Bay Laboratory for temporary storage in a locked freezer before shipment to the analytical facility. At least one field worker traveled with the samples from the field to the Laboratory. At the Auke Bay Laboratory, custody of the samples was signed over to a representative of Technical Services Study Number 1, Hydrocarbon Analytical Support Services and Analysis of Distribution and Weathering of Spilled Oil.

Hydrocarbon and Data Analysis

Sediment samples were analyzed for petroleum hydrocarbons by means of gas chromatography/mass spectrometry at the Auke Bay Laboratory. Short et al. (In press (a)) summarize the analytes, methods, detection limits, and the accuracy and precision of the methods used in the chemical analysis. For a detailed description of the analytical methods used in this study see Short et al. (In press(a)) and the references therein.

Results of the chemical analysis were screened on the basis of surrogate recoveries and minimum detection limits (MDLs). Individual analytes and the summary statistics affected by them [e.g., total polynuclear aromatic hydrocarbons including perylene ($\sum$PAH), TPAH, total normal alkanes (TNA, i.e the sum of the normal alkanes), and total hydrocarbons] were excluded from the analysis if the recoveries of corresponding analyte surrogates fell outside the range 30-150%. Concentrations of individual analytes reported below MDLs were replaced by "0's" for our analyses. The MDL for aromatic hydrocarbons was 1 ng/g, and for aliphatic hydrocarbons was 10 ng/g. These are conservative MDL concentrations. All concentrations above the MDLs were considered to have the same accuracy and precision. Hydrocarbon concentrations are reported on a dry weight basis to three significant figures when concentrations exceeded 10 ng/g, and to two significant figures for lower concentrations. A total of 180 sediment samples was analyzed for hydrocarbons from the ten sites sampled.

The high sulfur content of EVO helped to distinguish it from other PAH sources. In particular, concentrations of alkyl-dibenzothiophenes that reach at least 20% of the concentrations of alkyl-phenanthrenes are characteristic of higher-sulfur oils such as EVO, and the presence of alkyl-chrysenes (at concentrations 3% or more of those of alkyl-phenanthrenes) distinguishes EVO from products refined from it (Short et al., In press (b)). Accordingly, we used the following criteria to compare hydrocarbon concentrations in sediments in individual composite samples with those in EVO. The pattern of PAH concentrations in the sediment samples was judged similar to EVO if it consistently met each of three criteria in all replicated samples: (1) the ratio of alkyl dibenzothiophenes (summed) to alkyl phenanthrenes (summed) exceeded 0.20; (2) the ratio of alkyl chrysenes (summed) to alkyl phenanthrenes (summed) exceeded 0.03; and (3) the concentration of alkyl phenanthrenes (summed) exceeded 20 ng/g. This latter criterion was necessary to insure that chrysenes would be detected if present. Although these criteria for distinguishing the EVO source are not unique to this paper (e.g. see O'Clair et al., 1996; and Babcock and Short, 1996) they have not been used widely and should be considered *ad hoc*.

The carbon preference index (CPI; Farrington and Tripp 1977) was used to distinguished oiled from non-oiled sediments. The index has the form:

$$CPI=\frac{2(n\text{-}C_{27}+n\text{-}C_{29})}{n\text{-}C_{26}+2n\text{-}C_{28}+n\text{-}C_{30}}$$

where n-C_i is the concentration (ng/g) of the *n*-alkane of carbon number I. The CPI is near 1 for oiled sediments. Values from 5 to 7 indicate unoiled sediment.

Concentrations shown in the text are given as mean concentration ● the standard error of the mean. Unless otherwise noted means are the average of three replicates. Coefficients of variation shown in Tables 2 and 3 are corrected for bias (Sokal and Rohlf 1981). The unbiased estimator is:

$$V*=(1+\tfrac{1}{4n})V$$

Table 2.--Concentration (ng/g) of TPAH in sediments from all stations in PWS, Alaska sampled in 1993. Numbers in the body of the table are mean TPAH and coefficient of variation (in parentheses). Numbers are preceded by an asterisk where the PAH composition pattern matched weathered EVO in at least one replicate. Unless otherwise noted the number of replicates is three. ND indicates that all TPAH analytes were below detection limits.

Site			Depth					
No.	Name	Date	0 m	3 m	6 m	20 m	40 m	100 m
Reference Sites								
10	Drier Bay	11 Jul	0.36 (93.9)	2.67(103.7)	38.8 (44.0)	138 (41.2)	214 (93.8)	931 (9.3)
26	Lower Herring Bay	10 Jul	2.13 (74.4)	1.80 (34.6)	0.84 (118.0)	9.82 (62.2)	50.1 (55.2)	520 (16.0)
28	Moose Lips Bay	13 Jul[a]	54.0 (59.7)	106 (36.0)	108 (26.4)	155 (67.0)	280 (13.2)	449 (45.7)
32	Olsen Bay	16 Jul[b]	7.72 (50.5)	25.0 (16.7)	97.7 (34.3)	167 (41.4)	172 (54.2)	469 (12.0)
44	Zaikof Bay	13 Jul	8.28 (14.2)	88.4 (3.7)	121 (27.3)	178 (11.9)[c]	290 (19.5)	377 (48.2)
Assessment Sites								
5	Bay of Isles	15 Jul	ND	1.06 (15.0)	74.3 (143.8)	393 (34.0)	181 (41.8)	686 (20.3)
20	Herring Bay	9 Jul	18.2 (97.1)	* 320 (59.0)	* 58.2 (55.5)	97.5 (85.6)	64.0 (70.2)	351 (54.5)
31	Northwest Bay	8 Jul	24.5 (47.6)	* 140 (105.9)	* 524 (68.1)	* 1231 (53.8)	151 (8.6)	687 (6.0)
38	Sleepy Bay	12 Jul[d]	9.98 (35.4)	13.5 (71.4)	8.14 (65.4)	* 963 (44)[c]	134 (39.4)	550 (13.8)
40	Snug Harbor 25	14 Jul	10.0 (26.2)	5.06 (63.2)	27.0 (168.4)	35.1 (13.3)	184 (28.2)	724 (3.0)

a. Stations at 40 and 100 m at Moose Lips Bay sampled on 12 July.
b. Stations at 40 and 100 m at Olsen Bay sampled on 15 July.
c. $n = 2$
d. Stations at 40 and 100 m at Sleepy Bay sampled on 11 July.

Table 3.--Concentration of TNA in sediments from all stations in PWS, Alaska sampled in 1993. Numbers in the body of the table are mean TNA (ng/g) and coefficient of variation (in parentheses). Unless otherwise noted the number of replicates is three.

Site			Depth					
No.	Name	Date	0 m	3 m	6 m	20 m	40 m	100 m
Reference Sites								
10	Drier Bay	11 Jul	30.9 (110)	79.8(62.4)	732 (42.8)	1042 (24.3)	597 (83.3)	1708 (15)
26	Lower Herring Bay	10 Jul	40.3 (42.7)	15.4 (126.2)	5.32 (187.6)	62.6 (47.9)	204 (40.1)	1271 (9.1)
28	Moose Lips Bay	13 Jul[a]	76.4 (88.4)	116 (34.9)	167 (30.6)	106 (29.5)	321 (25.3)	535 (44.4)
32	Olsen Bay	16 Jul[b]	413 (47.5)	912 (42.2)	1462 (64.1)	1136 (20)	394 (53.4)	823 (2.9)
44	Zaikof Bay	13 Jul	27.1 (68.3)	198 (33.6)	254 (30.3)	242 (46.8)[c]	427 (32.2)	865 (106.7)
Assessment Sites								
5	Bay of Isles	15 Jul	11.1(98.7)	45.4 (24.6)	1392 (123)	2806 (26.5)	734 (46.8)	1211 (14.2)
20	Herring Bay	9 Jul	184 (36.6)	1089 (33)	453 (31.6)	285 (39)[c]	162 (90)	701 (65)
31	Northwest Bay	8 Jul	981 (80.4)	357 (51.9)	762 (13.3)	3288 (55.2)	379 (6.8)	1171 (19.4)
38	Sleepy Bay	12 Jul[d]	53.4 (34.7)	39 (14.2)	73.6 (67)	837 (81.7)[c]	108 (59.7)	633 (3.4)
40	Snug Harbor 25	14 Jul	7.6 (187.6)	15.4 (63.1)	289 (180)	94.4 (22)	684 (19)	1176 (9.3)

a. Stations at 40 and 100 m at Moose Lips Bay sampled on 12 July.

b. Stations at 40 and 100 m at Olsen Bay sampled on 15 July.

c. $n = 2$

d. Stations at 40 and 100 m at Sleepy Bay sampled on 11 July.

RESULTS

Assessment Sites

Five assessment locations were sampled in 1993; four (Herring Bay, Northwest Bay, Sleepy Bay, and Snug Harbor) were heavily oiled in the upper intertidal zone during the EVOS. The fifth, Bay of Isles, is a protected bay on the eastern side of Knight Island that was sporadically oiled during the Spill.

Intertidal Stations

We found relatively low aromatic hydrocarbon concentrations in intertidal sediments (0 m station) at the five assessment sites sampled in 1993 (Table 2). This station was located at a tidal height of about MLLW. Most of the EVO was stranded at higher elevations on the shore (about mean high water). The highest mean TPAH concentration found at the 0 m station of assessment locations sampled in 1993 was 24.5 ± 6.2 ng TPAH/g dry sediment weight. This concentration was found at Northwest Bay, and it was markedly less than that found in intertidal sediments at Northwest Bay in July 1989 (Table 2, Fig. 2). At three of the other assessment sites sampled in July 1993, the mean TPAH concentrations were 18.2 ± 9.4, 10 ± 1.9, and 10 ± 1.4 ng TPAH/g sediment in 0 m sediments from Herring Bay, Sleepy Bay and Snug Harbor 25, respectively. All PAH analytes in intertidal sediments collected at Bay of Isles were below detection limits (Table 2). The TPAH concentration never exceeded 36 ng TPAH/g sediment in 0 m sediment samples from assessment locations in 1993. The PAH concentrations in sediments at intertidal stations at the five assessment locations were too low to permit the discrimination of a PAH composition pattern consistent with weathered EVO.

The TNA concentration in intertidal sediments at those assessment sites sampled in 1993 was relatively low. We found the highest mean TNA concentration (981 ± 420 ng/g) at Northwest Bay where the highest assessment site TPAH was found (Tables 2 and 3). This mean TNA concentration was more than twice as high as the highest mean TNA concentration at any reference station. The ratio of mean TNA to mean TPAH at assessment sites ranged greatly from 0.76 (Snug Harbor) to 40 (Northwest Bay).

The CPI values for intertidal sediments generally could not be calculated because the concentrations of alkanes C_{26}, C_{28} and/or C_{30} were below detection limits. Only those from Northwest Bay could be calculated. There, a mean CPI of 1.1 indicated the presence of oil. However, the PAH concentrations in the Northwest Bay sediments were too low to permit us to conclude that the oil was weathered EVO.

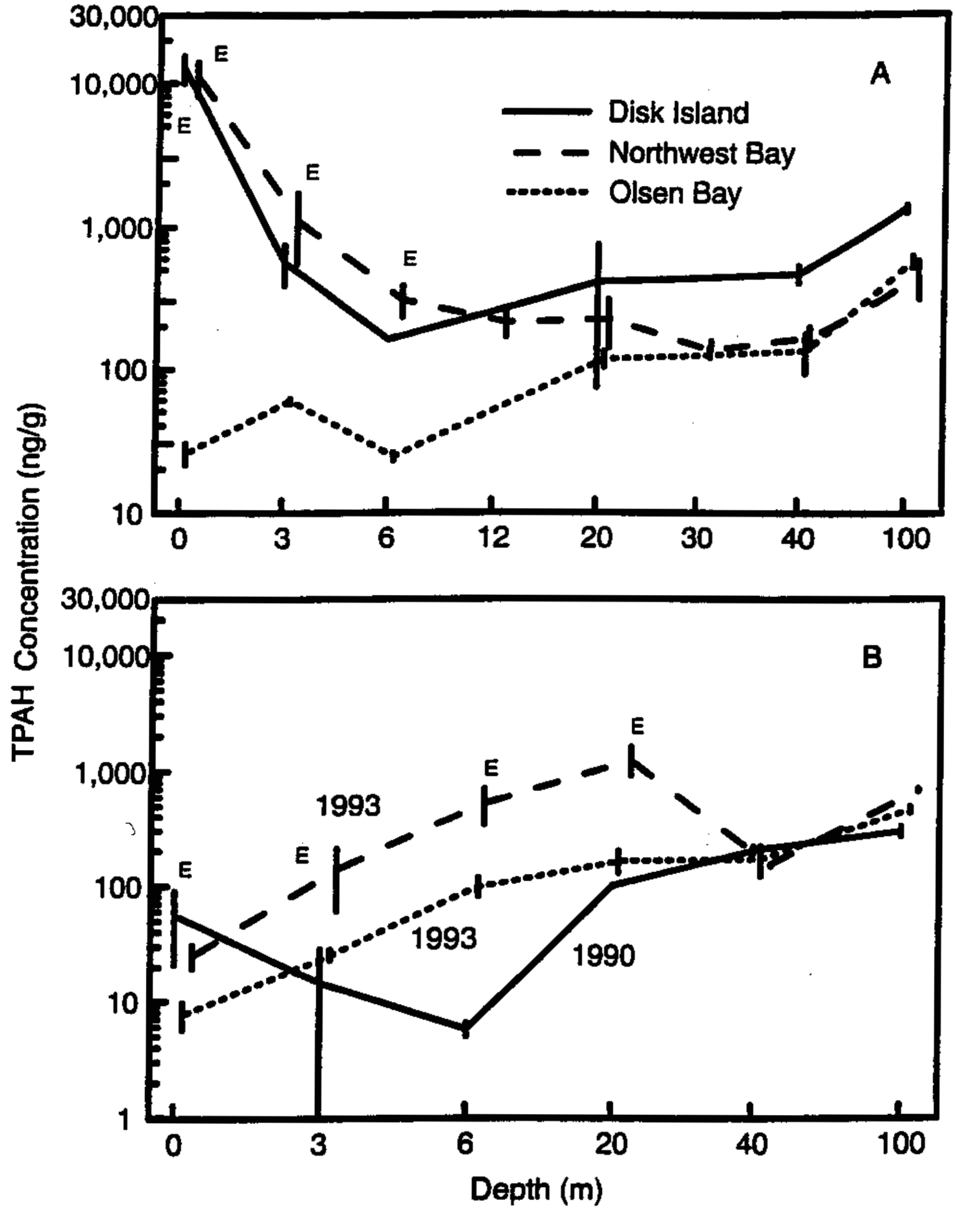

Figure 2.--Depth distribution of mean concentrations of TPAHs at Disk Island, Northwest Bay and Olsen Bay in July 1989 (A) and from 1 to 4 years later (B). Disk Island was not sampled after 1990 because of low hydrocarbon concentrations in intertidal and shallow subtidal sediments there in July 1990. Error bars are ± one standard error of the mean. An "E" identifies those sediments that exhibited a PAH analyte pattern characteristic of EVO.

Shallow Subtidal Stations

Concentrations of EVO hydrocarbons in shallow subtidal sediments (3-20 m) at assessment sites were usually greater than those in intertidal sediments at those sites. Shallow subtidal sediment samples were collected at all locations where intertidal samples had been collected. At the two locations (Northwest Bay and Herring Bay) where we found the highest mean TPAH concentrations in intertidal sediments; we found substantially higher mean TPAH concentrations in shallow subtidal sediments. This increase was more pronounced at Northwest Bay than at Herring Bay (Table 2). At the three other assessment sites TPAH concentrations in shallow subtidal sediments were generally about the same as or greater than TPAH concentrations in intertidal sediments.

We found a PAH composition pattern consistent with weathered EVO in subtidal sediments in three (Northwest Bay, Herring Bay and Sleepy Bay) of the five assessment sites sampled in 1993. At Northwest Bay, the EVO-PAH pattern was consistently present in subtidal sediments from 3 m to 20 m (Fig. 2). The mean TPAH concentration in these sediments ranged from 140 ± 79.1 ng/g at the 3 m depth to 1231 ± 353 ng/g at the 20 m depth (Table 2).

At Herring Bay, the EVO-PAH pattern was found in all three samples collected at the 3 m depth. The mean TPAH concentration in these samples was 320 ± 100 ng/g (Table 2). One of three samples collected at the 6 m depth at Herring Bay showed the EVO-PAH pattern. The TPAH concentration in that sample was 87.1 ng/g. The second of the three samples from 6 m exhibited a PAH pattern indicating contamination by diesel oil because: (1) alkyl chrysenes were absent [Reference to a PAH in the plural (e.g. chrysenes) denotes the unsubstituted PAH together with the alkyl-substituted homologues collectively as a group]; (2) alkyl phenanthrenes (summed) exceeded 20 ng/g; and (3) the ratio of alkyl dibenzothiophenes (summed) to alkyl phenanthrenes (summed) exceeded 0.20. The concentrations of PAH analytes (especially alkyl phenanthrenes which were present in the aggregate at a concentration below 20 ng/g) in the third sample from 6 m at Herring Bay were too low to discern a petroleum hydrocarbon pattern. Mean TPAH concentrations were less than 320 ng/g in shallow subtidal sediments from depths greater than 3 m at Herring Bay (Table 2).

The EVO-PAH pattern was found in one sample from Sleepy Bay. The sample was collected at the 20 m depth, and it contained a TPAH concentration of 697 ng/g. The other two samples from the 20 m depth exhibited a PAH pattern characterized by: (1) a ratio of alkyl dibenzothiophenes to alkyl phenanthrenes less than 0.20; (2) a ratio of alkyl chrysenes to alkyl phenanthrenes that exceeded 0.03; and (3) a concentration of alkyl phenanthrenes that exceeded 20 ng/g. This pattern is indicative of petroleum hydrocarbons from the Katalla oil seep identified by Page et al. (1994); although, another possible source for the Katalla hydrocarbons may be coal (O'Clair et al., 1996 and Short et al., In press(a)).

As with TPAH, the TNA concentration in shallow subtidal sediments at assessment sites tended to exceed the intertidal TNA concentration. A notable exception was Northwest Bay where the intertidal TNA concentration exceeded that at the 3 and 6 m depths (Table 3). The greatest mean TNA concentration (3288 ± 968 ng/g) found in subtidal sediments in 1993 occurred in sediments exhibiting the EVO-PAH pattern from the 20 m depth at Northwest Bay. Sediments from this station also exhibited the greatest mean TPAH concentration observed in 1993 (Table 2). The mean TNA concentration at other stations where sediments showed the EVO-PAH pattern ranged from 357 ± 98.7 ng/g (Northwest Bay, 3 m station) to 1089 ± 192 ng/g (Herring Bay, 3 m station) (Table 3).

The ratio of mean TNA to mean TPAH in the shallow subtidal region at assessment sites ranged from 0.9 (Sleepy Bay, 20 m station) to 43 (Bay of Isles, 3 m station). The range in this ratio was comparable to that observed in intertidal sediments at assessment sites. The range was markedly narrower (0.9 to 7.8) for sediments from shallow subtidal stations where the EVO-PAH pattern was observed.

The CPI values could be calculated for two-thirds of the shallow subtidal stations at assessment sites. Values for the remainder of the stations could not be calculated because the concentrations of alkanes C_{26}, C_{28} and/or C_{30} were below detection limits. The CPI values for these stations reflected alkane distributions that were not strongly indicative of oiled sediments. The lowest mean CPI values were observed at the 6 m (CPI = 4.6) and 20 m (CPI = 3.4) stations at Northwest Bay. The PAH concentrations at these stations showed the EVO-PAH pattern. Mean CPI values for other shallow subtidal assessment stations where the EVO-PAH pattern was found ranged from 8.8 to 16.8. (At the 6 m depth at Herring Bay the one replicate for which a CPI could be calculated had a value of 21.)

Deep Subtidal Stations

The TPAH concentration and the PAH composition pattern in sediments at depths ≥40 m at assessment sites were similar to those at reference sites (Fig. 2, see below). The EVO-PAH pattern was absent from all sediment samples collected at deep subtidal stations (Table 2). When the concentration of PAH analytes was great enough to discern a hydrocarbon source, the PAH composition pattern differed from that of weathered EVO such that the concentrations of dibenzothiophenes were relatively low. The ratio of alkyl dibenzothiophenes to alkyl phenanthrenes was less than 0.20 in those deep subtidal samples. The TPAH concentration in sediments at depths of 40 m and 100 m was often higher than in sediments in the 3 m to 20 m depth range.

At the 40 m depth, the concentration of PAH analytes was too low to distinguish a hydrocarbon source in a third of the replicates from assessment locations. In 47% of the replicates from assessment locations, the PAH composition pattern showed a ratio of alkyl dibenzothiophenes to alkyl phenanthrenes less than 0.20, an absence of alkyl chrysenes, and a concentration of alkyl phenanthrenes that exceeded 20 ng/g. This pattern was characteristic of an unknown hydrocarbon source, possibly diesel oil. The remaining replicates (20%) showed a PAH composition pattern indicative of the Katalla source. The median TPAH concentration in replicates from 40 m at assessment sites was 146 ng/g (range, 26-238 ng/g; Fig. 3).

At the 100 m depth at assessment sites, all of the replicates showed a PAH composition pattern indicative of the Katalla source. The median concentration was 643 ng/g (range, 204-763 ng/g; Fig. 3).

The TNA concentration in deep subtidal sediments at assessment sites tended to vary from station to station and showed no consistent pattern of change relative to shallower sediments, although values usually exceeded intertidal TNA concentrations. The only exception was Northwest Bay where the intertidal TNA concentration exceeded that at the 40 m depth (Table 3). The greatest mean TNA concentration (1211 ± 91 ng/g) found in deep subtidal sediments at assessment sites in 1993 occurred in sediments from the 100 m depth at Bay of Isles. Sediments from this station also exhibited a mean TPAH concentration among the highest observed in deep sediments in 1993 (Table 2).

The ratio of mean TNA to mean TPAH in the deep subtidal region at assessment sites ranged from 0.8 (Sleepy Bay, 40 m station) to 4 (Bay of Isles, 40 m station). The range in this ratio was much narrower than that observed in intertidal and shallow subtidal sediments at assessment sites. The range at 100 m (1.2 to 2) was narrower than that for sediments from 40 m.

The CPI values could be calculated for all but one (Sleepy Bay, 40 m station) of the deep subtidal stations at assessment sites. The CPI values for the 40 m stations reflected alkane distributions that were not strongly indicative of oiled sediments. The lowest mean CPI value (4.2) at this depth at assessment stations was observed at Northwest Bay. The mean CPI values for the 100 m depth were lower than those for the 40 m depth at all assessment sites. The lowest values (2.4-2.6) for sediments at 100 m were found at Northwest Bay, Sleepy Bay and Snug Harbor 25. These values approached that (CPI ≈ 1) considered to be indicative of oiled sediments (Table 4).

Reference Sites

Intertidal Stations

The EVO-PAH pattern was not found at intertidal stations at the five reference sites sampled in 1993. All replicate sediment samples contained concentrations of PAH analytes too low to distinguish a hydrocarbon source. The highest mean TPAH concentration found, at the 0 m station of the reference sites sampled in 1993, was 54 ± 17.2 ng TPAH/g dry sediment weight. This concentration was found at Moose Lips Bay (Table 2). At the other four reference sites sampled in July 1993, the mean TPAH concentrations were 0.36 ± 0.18, 2.1 ± 0.84, 7.7 ± 2.1, and 8.3 ± 0.63 ng TPAH/g sediment in 0 m sediments from Drier Bay, Lower Herring Bay, Olsen Bay and Zaikof Bay, respectively. The mean TPAH concentration at these stations was generally

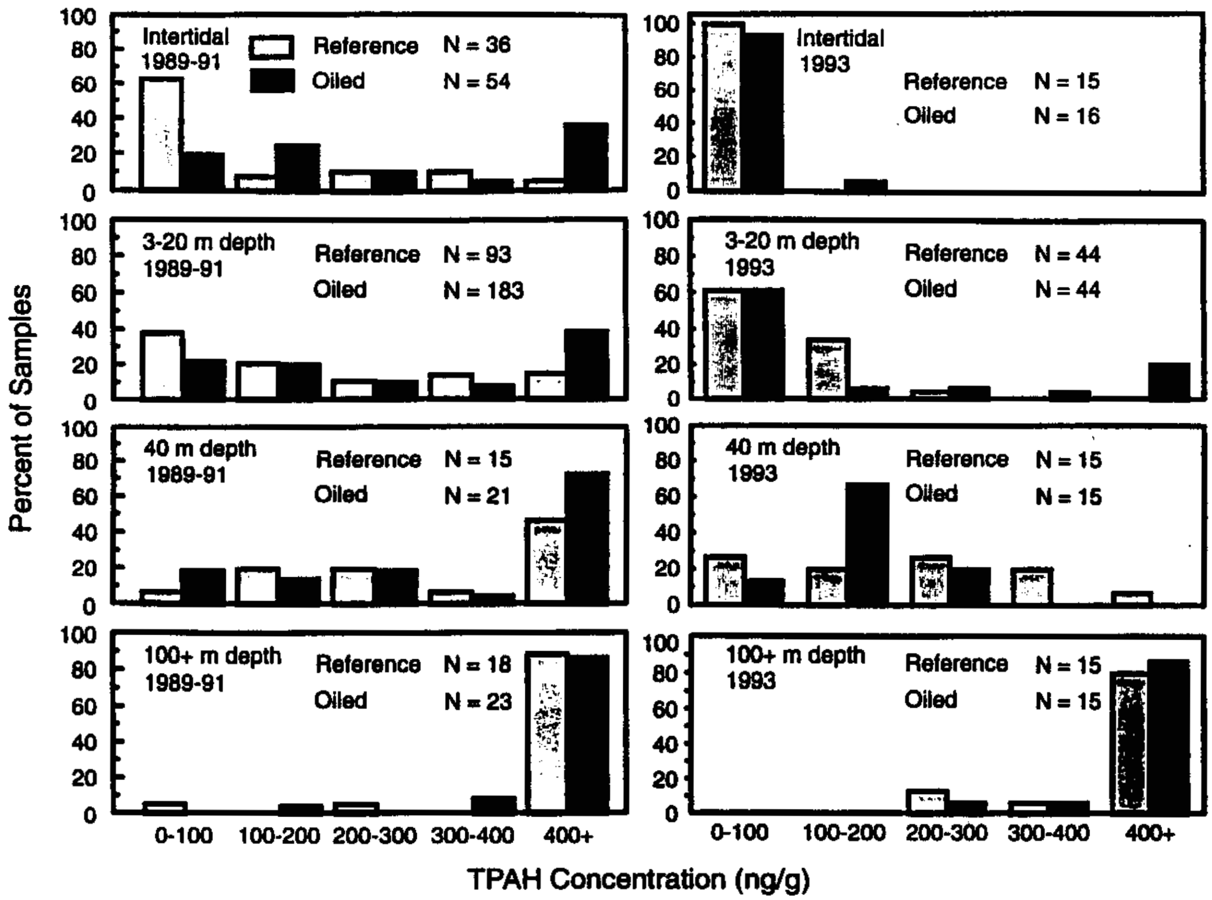

Figure 3.--Percentage of sediment samples in five concentration ranges of TPAH in sediments from the intertidal region (0 m) and the subtidal region at bathymetric depths of 3 m to 20 m, 40 m and 100 m at reference stations and heavily oiled stations from 1989 to 1991 and 1993.

Table 4.--Mean CPI for sediments from all stations in PWS, Alaska sampled in 1993. Superscripts indicate sample size where *n* is not equal to three. NA indicates that CPI could not be calculated.

Site			Depth					
No.	Name	Date	0 m	3 m	6 m	20 m	40 m	100 m
Reference Sites								
10	Drier Bay	11 Jul	NA	NA	19.3[2]	22.1	13.3	5.72
26	Lower Herring Bay	10 Jul	NA	NA	NA	NA	11.1[1]	10.3
28	Moose Lips Bay	13 Jul[a]	NA	NA	NA	NA	9.0[1]	2.9[2]
32	Olsen Bay	16 Jul[b]	NA	15.4	19.2	22.4[2]	14.0[1]	6.0[2]
44	Zaikof Bay	13 Jul	NA	7.6[1]	5.1[1]	NA	7.1[2]	5.8
Assessment Sites								
5	Bay of Isles	15 Jul	NA	NA	64.7[1]	10.7[2]	8.0	5.3
20	Herring Bay	9 Jul	NA	16.8	21[1]	21.1[1]	7.0[1]	3.6
31	Northwest Bay	8 Jul	1.1	8.8	4.6	3.4	4.2	2.4
38	Sleepy Bay	12 Jul[c]	NA	NA	NA	9.3	NA	2.6
40	Snug Harbor 25	14 Jul	NA	NA	0	NA	12.9	2.6

a. Stations at 40 and 100 m at Moose Lips Bay sampled on 12 July.
b. Stations at 40 and 100 m at Olsen Bay sampled on 15 July.
c. Stations at 40 and 100 m at Sleepy Bay sampled on 11 July.

similar in magnitude to that found at assessment sites (Fig. 2). The median TPAH concentration at reference intertidal stations was 7 ng/g (range, 0-87.5; Fig. 3). The TPAH concentration was consistently below the median in intertidal sediments from Lower Herring Bay and Drier Bay.

The TNA concentration in intertidal sediments at reference sites was relatively low, averaging somewhat lower than that in intertidal sediments from assessment sites. The highest mean TNA concentration (413 ± 104 ng/g) at reference sites occurred at Olsen Bay (Table 3). This mean TNA concentration was more than five times higher than the highest mean TNA concentration at any of the other reference stations. The ratio of mean TNA to mean TPAH at intertidal reference stations showed a greater range (1.4 to 86) than at assessment sites (0.76 to 40). No CPI values could be calculated for the intertidal sediments collected at reference sites because the concentrations of alkanes C_{26}, C_{28} and/or C_{30} were below detection limits.

Shallow Subtidal Stations

As at assessment sites the concentration of TPAH in shallow subtidal sediments (3-20 m) at reference sites was usually markedly greater than those in intertidal sediments at those sites (Table 2). The TPAH concentrations tended to increase with increasing depth in the shallow subtidal zone at reference sites. The exception to this trend occurred at Lower Herring Bay where the mean TPAH concentration at the intertidal station exceeded that at the 3 and 6 m stations.

No evidence of the EVO-PAH pattern was found in shallow subtidal sediments at the reference sites sampled in 1993. Most of the sediment samples from shallow subtidal stations at reference sites contained concentrations of PAH analytes too low to distinguish a hydrocarbon source. However, in one replicate sediment sample each at the 20 m station at Olsen Bay, Moose Lips Bay and Zaikof Bay, and at the 6 m station at Zaikof Bay, the PAH composition pattern was characteristic of an unknown hydrocarbon source, possibly diesel oil. The remaining replicate from the 20 m station at Zaikof Bay (just two replicates were analyzed from the 20 m station at Zaikof Bay) had a PAH composition pattern consistent with the Katalla source.

The highest mean TPAH concentration found at shallow subtidal stations at the reference sites was 178 ± 13.3 ng TPAH/g dry sediment weight at 20 m at Zaikof Bay (Table 2). The TPAH concentration in sediments that showed a PAH composition pattern indicative of the unknown hydrocarbon source ranged from 156 ng/g (Zaikof Bay, 6 m) to 265 ng/g (Moose Lips Bay, 20 m). The TPAH concentration in the replicate from the 20 m station at Zaikof Bay that showed the Katalla pattern was 192 ng/g. At those shallow subtidal reference stations where no replicate samples were found, that exhibited one of these two PAH patterns, the mean TPAH concentration never exceeded 138 ng/g. The mean TPAH concentration varied greatly between sites within both the group of reference sites and the group of assessment sites such that only at 20 m did the TPAH concentration tend to differ between groups. At 20 m, the TPAH concentration at assessment sites tended to exceed that at reference sites.

As with TPAH, the TNA concentration in shallow subtidal sediments at reference sites tended to exceed the intertidal TNA concentration. The sole exception to this trend was Lower Herring Bay where the mean intertidal TNA concentration exceeded that at the 3 and 6 m depths (Table 3). The greatest mean TNA concentration (1462 ± 499 ng/g) found in subtidal sediments at reference sites occurred in sediments from the 6 m depth at Olsen Bay. By contrast, the mean TPAH concentration at the 6 m depth at Olsen Bay was substantially lower than the greatest mean TPAH concentration found in the shallow subtidal zone at reference sites. The mean TPAH concentration at the 6 m depth at Olsen Bay (98 ± 17.9 ng/g) was the median of the mean TPAH concentrations at the reference sites. The opposite relationship held for the station showing the greatest mean TPAH concentration in shallow subtidal reference sediments (Zaikof Bay, 20 m). The mean TNA concentration at the 20 m station at Zaikof Bay (242 ± 71 ng/g) was slightly above the median of the mean TNA concentrations at the reference sites.

The ratio of mean TNA to mean TPAH in the shallow subtidal region at reference sites ranged from 0.7 (Moose Lips Bay, 20 m station) to 36.4 (Olsen Bay, 3 m station). The range in this ratio was comparable to that observed in shallow subtidal sediments at assessment sites.

The CPI values could be calculated for less than half (47%) of the shallow subtidal stations at reference sites. Values for the remainder of the stations could not be calculated because the concentrations of alkanes C_{26}, C_{28} and/or C_{30} were below detection limits. The CPI values for these stations reflected alkane distributions indicative of unoiled sediments. The lowest CPI value recorded for shallow subtidal sediments at reference sites was 5.1 in one replicate from the 6 m depth at Zaikof Bay (Table 4).

Deep Subtidal Stations

As stated above, the TPAH concentration and the PAH composition pattern in sediments at depths ≥40 m at reference sites were similar to those at assessment sites. The EVO-PAH pattern was absent from all sediment samples collected at deep subtidal stations (Table 2). When the concentration of PAH analytes was great enough to discern a hydrocarbon source, the PAH composition pattern differed from that of weathered EVO such that the concentrations of dibenzothiophenes were relatively low. The ratio of alkyl dibenzothiophenes to alkyl phenanthrenes was less than 0.20 in those deep subtidal samples. The mean TPAH concentration in sediments at depths of 40 m and 100 m at reference sites was often higher than in sediments at shallower reference depths (Fig. 2), and on average somewhat higher at 40 m but not 100 m than the mean TPAH concentration at these depths at assessment sites.

At the 40 m depth, the concentration of PAH analytes was too low to distinguish a hydrocarbon source in a third of the replicates from reference sites. In 40% of the replicates from reference sites the PAH composition pattern was characteristic of the unknown (possibly diesel oil) hydrocarbon source. The remaining replicates (27%) showed a PAH composition pattern indicative of the Katalla source. The highest mean TPAH concentration found at the 40 m depth at the reference sites was 290 ± 30 ng TPAH/g dry sediment weight at Zaikof Bay (Table 2).

Two replicates from the 40 m depth at Zaikof Bay exhibited the PAH composition pattern characteristic of the unknown hydrocarbon source, and the third replicate showed the Katalla pattern. The mean TPAH concentration in those replicates for which a hydrocarbon source could not be distinguished was 73 ± 16 ng/g. The mean TPAH concentration in those replicates with the PAH composition pattern characteristic of the unknown hydrocarbon source was 248 ± 48 ng/g. Finally, the mean TPAH concentration in those replicates showing the Katalla pattern was 292 ± 18 ng/g.

At the 100 m depth at reference sites all but one of the replicates showed a PAH composition pattern indicative of the Katalla source. The one replicate that did not show the Katalla pattern was collected at Olsen Bay. The PAH composition pattern of that replicate was characteristic of the unknown (possibly diesel oil) hydrocarbon source. The TPAH concentration in that replicate was 444 ng/g. The mean TPAH concentration in the rest of the replicates was 557 ± 63 ng/g. The greatest mean TPAH concentration found at the 100 m depth at the reference sites was 931 ± 46 ng/g at Drier Bay (Table 2)

The TNA concentration in deep subtidal sediments at reference sites tended to vary from station to station, and although values did not show a consistent pattern of change relative to shallower sediments, they often exceeded intertidal and shallow subtidal TNA concentrations. The greatest mean TNA concentration (1708 ± 136 ng/g) found in deep subtidal sediments at reference sites occurred at the 100 m depth at Drier Bay, the same station that showed the greatest mean TPAH (Tables 2 and 3).

The ratio of mean TNA to mean TPAH in the deep subtidal region at reference sites ranged from 1.1 (Moose Lips Bay, 40 m station) to 4.1 (Lower Herring Bay, 40 m station). The range in this ratio was much narrower than that observed in intertidal and shallow subtidal sediments at reference sites, and about the same as that observed in the deep subtidal region at assessment sites. As at assessment sites, the range of the ratio of mean TNA to mean TPAH at the 100 m depth (1.2 to 2.4) at the reference sites was narrower than that for reference sediments from the 40 m depth (1.1 to 4.1).

The CPI values could be calculated for all deep subtidal stations at reference sites. The mean CPI values for both the 40 m stations and the 100 m stations reflected alkane distributions that were indicative of unoiled sediments (Table 4). The only exception may have been the 100 m station at Moose Lips Bay where the mean CPI value (2.9) approached that expected to indicate oiled sediment. As at the assessment sites, the mean CPI values for the 100 m depth were lower than those for the 40 m depth at all reference sites.

DISCUSSION

Assessment Sites

Intertidal sediments

The EVOS clearly contaminated lower intertidal sediments (near MLLW) at some locations with crude oil (O'Clair et al., 1996). The highest mean concentration of TPAH observed in the lower intertidal zone was 12,729 ng/g at Disk Island in July 1989. Very high concentrations of TPAH were also found at Northwest Bay (mean TPAH, 11,686 ng/g) and Herring Bay (mean TPAH, 1,837) in July 1989. By July 1991 the mean concentration of TPAH in sediments from the 0 m station at Northwest Bay had dropped to 584 ng/g. However, at the 0 m station at Herring Bay in June 1991 the concentration of TPAH remained high (mean TPAH, 2,346 ng/g); although the distribution of PAHs did not indicate EVO as the source (O'Clair et al., 1996). The present study found further reductions in the concentration of TPAH at the 0 m station at Northwest Bay (mean TPAH, 24 ng/g) and Herring Bay (mean TPAH, 18 ng/g) by July 1993.

Lower-intertidal sediments were also contaminated by EVO in 1989 at other locations such as Bay of Isles (mean TPAH, 243 ng/g, September 1989) and Sleepy Bay (mean TPAH, 335 ng/g, September 1989). [The 0 m station at Snug Harbor 25 was not sampled until June 1990. EVO contamination appeared in sediments from that station in July 1990 (mean TPAH, 2,551 ng/g).] The EVO in lower-intertidal sediments at these sites was present at a lower TPAH concentration than initially found at Disk Island or Northwest Bay. The PAHs in the intertidal sediments at these sites were qualitatively similar to PAHs at Disk Island and at Northwest Bay in 1989. Moderate to heavy oiling was observed in the upper intertidal zone at all of the locations (O'Clair et al., 1996). By July 1993 the mean TPAH in lower-intertidal sediments had decreased to 10 ng/g or less at Bay of Isles, Sleepy Bay and Snug Harbor.

EVO was indicated as the source of the PAHs in lower-intertidal sediments at Disk Island, Northwest Bay, Herring Bay and other heavily oiled locations in 1989-91 by: (1) the close similarity between relative PAH abundances in the intertidal sediments and those in floating mousse collected 11 days after the Spill; (2) high concentration of *n*-alkanes and CPI near 1 indicating a petrogenic source of the alkanes; and (3) the proximity of the intertidal station to the heavily-oiled upper intertidal shoreline where oil was visually apparent in spring 1989 (indicating oil concentrations near percent levels; O'Clair et al., 1996). Characteristics of the hydrocarbons in sediments that indicated weathered EVO in 1993 were: (1) a the ratio of alkyl dibenzothiophenes to alkyl phenanthrenes that exceeded 0.20; (2) a ratio of alkyl chrysenes to alkyl phenanthrenes that exceeded 0.03; and (3) a concentration of alkyl phenanthrenes that exceeded 20 ng/g. In 1989 Bay of Isles, Block Island, Foxfarm, Herring Bay, Northwest Bay, Sleepy Bay and Snug Harbor showed PAH distributions indicative of EVO contamination in sediments from the 0 m station. By 1991, EVO was indicated in lower-intertidal sediments at Herring Bay (April), Northwest Bay (June), Sleepy Bay (June) and Snug Harbor 25 (June;

O'Clair et al., 1996). In 1993, PAH concentrations in lower-intertidal sediments were too low to discriminate among the known possible sources of petroleum hydrocarbons in PWS.

Prior to the EVOS Karinen et al. (1993) monitored a suite of PAHs in intertidal sediments in eastern PWS near the oil tanker route in case of an oil spill. Their study began in 1977 (when the Trans Alaska Pipeline Terminal at Valdez began operations) and continued until 1980. The analytical methods used in their study were the same as those used in the present study. After the EVOS, the concentrations of individual aromatic analytes in sediment samples collected in 1989 from the 0 m station at such heavily-oiled sites as Disk Island usually averaged one to three orders of magnitude greater than the baseline concentrations of those same analytes reported by Karinen et al. (1993). Individual aromatic analytes in sediment samples from the 0 m station at Northwest Bay and Herring Bay in 1989 averaged up to two orders of magnitude greater than the concentrations of individual aromatic analytes reported by Karinen et al. (1993) depending on the analyte (O'Clair et al., 1996). Concentrations of individual aromatic analytes in intertidal sediments at Northwest Bay and Herring Bay in 1993 decreased to levels well within the range of those reported by Karinen et al. (1993), never exceeding 4 ng/g.

In 1989, EVO contamination of many of the intertidal sediments at heavily-oiled sites was supported by an associated high *n*-alkane concentration and a low CPI at stations where the TPAH concentration was also high. At stations where the TPAH concentration was lower, the magnitude and distribution of *n*-alkane concentrations were often confounded by alkanes from terrigenous sources indicated by higher CPI values. TNA concentrations ranging to over 1,000 ng/g derived, in large part, from terrestrial plant waxes (Kolattukudy 1976; Eglinton and Hamilton 1967; Eglinton et al. 1962) and from marine bacteria (Oro et al. 1967), blue-green algae (Winters et al. 1969), and planktonic and macrophytic algae (Clark and Blumer 1967; Blumer 1971) were widespread in intertidal sediments at reference stations and at assessment stations where oiling in the upper intertidal zone was low or absent (O'Clair et al., 1996). The concentrations of *n*-alkanes in lower-intertidal sediments at most sites in 1989 and at those sites studied in 1993 were similar to *n*-alkane concentrations in pre-EVOS intertidal sediments in PWS (Karinen et al. 1993). The greatest mean TNA found in lower-intertidal sediments in 1993 was 981 ng/g at Northwest Bay. The CPI of those sediments (1.1) indicated a petroleum source. A CPI could not be calculated for the 0 m station at other assessment sites in 1993 because the concentrations of alkanes C_{26}, C_{28} and/or C_{30} were below detection limits.

Subtidal Sediments

O'Clair et al. (1996) concluded that detectable contamination of subtidal sediments by EVO in 1989 was "not widespread throughout the Spill path, but rather was restricted to those relatively few locations where conditions favored subtidal accumulation". Those conditions included shorelines that were: (1) heavily oiled; (2) exposed to wave action or cleaned; and (3) were adjacent to shallow-subtidal sediment deposits on low-gradient slopes. Those conditions prevailed at Herring Bay and Northwest Bay where good evidence of EVO contamination in shallow subtidal sediments in 1989 was consistently found. The mean TPAH concentration in shallow subtidal sediments that exhibited the EVO-PAH pattern at Herring Bay and Northwest Bay in 1989 ranged from 239 to 921 ng/g and from 517 to 1,486 ng/g, respectively (O'Clair et al., 1996). Contamination by EVO of shallow subtidal sediments at Herring Bay and Northwest Bay persisted to July 1993. At these two sites in July 1993, the PAH composition pattern indicative of weathered EVO was found at 3 m and 6 m depths at Herring Bay and at 3-20 m depths at Northwest Bay. The mean TPAH concentration in shallow subtidal sediments showing the EVO-PAH composition pattern at Herring Bay and Northwest Bay in 1993 ranged from 58 to 320 ng/g and from 140 to 1,231 ng/g, respectively.

The EVO-PAH pattern was frequently found at depths to 20 m but rarely deeper in 1989, presumably because there was adequate energy available from waves or currents to transport contaminated sediments to the 20 m depth, but not to depths as great as 40 m or 100 m and/or the quantity of contaminated sediments transported to greater depths was not great enough to permit the detection of EVO-PAHs above the hydrocarbon background (O'Clair et al., 1996). By 1993 the EVO-PAH pattern was found in sediments at the 20 m depth only at Northwest Bay and Sleepy Bay (see below).

At some moderately to heavily oiled sites environmental conditions were less favorable for transport of EVO-contaminated intertidal sediments to subtidal depths. These sites included Bay of Isles and Snug Harbor 25 which were more sheltered from wave action than Herring Bay and Northwest Bay or had shorelines that were less heavily oiled initially than those of Herring Bay and Northwest Bay. Conversely, at sites such as Sleepy Bay, shorelines were heavily oiled, but intertidal and shallow subtidal sediments were probably exposed to wave action that was heavier than that experienced by intertidal and shallow subtidal sediments at Herring Bay and Northwest Bay. These conditions may have precluded long sediment residence times in shallow subtidal sediments at least as deep as 6 m. Evidence for EVO contamination of subtidal sediments at these sites was less consistent, and the TPAH concentration was generally lower than at Herring Bay and Northwest Bay (O'Clair et al., 1996). In July 1993 we found no evidence for EVO contamination of shallow subtidal sediments at these sites except at Sleepy Bay where the EVO-PAH composition pattern was found in sediments from the 20 m depth. The mean TPAH concentration in these sediments was 963 ng/g.

In the first three years following the EVOS, the EVO-PAH composition pattern was rarely found at assessment sites in sediments from subtidal depths below the 20 m depth. The EVO-PAH pattern was found in sediments below the 20 m depth on two occasions only during the time period 1989-91— at the 40 m depth at Bay of Isles and Northwest Bay in June 1991 (O'Clair et al., 1996). In 1993, the EVO-PAH pattern was never observed below the 20 m depth at assessment sites.

Reference Sites

Intertidal sediments

Lower-intertidal sediments at reference sites were clearly not contaminated by EVO in 1989. The TPAH concentration at these sites was usually less than 100 ng/g, and where comparable, selected PAH concentrations were similar to those in intertidal sediments sampled by Karinen et al. (1993) during the period 1977 to 1980 in eastern PWS (O'Clair et al., 1996). We found no evidence of EVO contamination of lower-intertidal sediments at reference sites in 1993. The TPAH concentration of lower-intertidal sediments at all reference sites in 1993 was less than 55 ng/g. Individual PAH concentrations in these sediments were similar to those reported by Karinen et al. (1993), where comparable.

Subtidal Sediments

The PAH composition pattern resembled that of weathered EVO in shallow subtidal sediments at reference sites on only a few occasions during the first years following the EVOS (1989-91). Where the EVO-PAH pattern was observed at these sites it was present in one replicate only, and probably reflected a mixture of PAHs from other sources. The TPAH concentration at those shallow subtidal reference stations, where the EVO-PAH pattern was found, ranged from 303 to 800 ng/g (O'Clair et al., 1996). In 1993, no evidence of the EVO-PAH composition pattern was found in shallow subtidal reference sediments. The mean TPAH concentration in these sediments ranged from 0.84 to 178 ng/g.

As at assessment sites, the EVO-PAH composition pattern was rarely found in deep subtidal sediments in the first three years after the EVOS. The EVO-PAH pattern was found in sediments at the 100 m depth at Olsen Bay in July 1989 and at the 100 m depth at Lower Herring Bay in July 1990. As with those instances when the EVO-PAH composition pattern was found in shallow subtidal sediments at reference sites, these observations indicating the presence of EVO in deep subtidal reference sediments were probably spurious, reflecting a mixture of PAHs from other sources. The mean TPAH concentration at those deep subtidal reference stations where the EVO-PAH pattern was found ranged from 574 to 1,702 ng/g (O'Clair et al., 1996). In 1993, the EVO-PAH pattern was never observed in deep subtidal sediments at reference sites. The mean TPAH concentration in these sediments ranged from 50 to 931 ng/g.

Geographic distribution of EVO

O'Clair et al. (1996) found EVO in lower intertidal and subtidal sediments over a broad geographic range in PWS in 1989. The area over which EVO contamination of these sediments was found ranged from Northwest Bay at the north end of Eleanor Island to Foxfarm (intertidal sediments only) at the southern end of Elrington Island; although, EVO contamination was geographically patchy depending on where large quantities of oil came ashore. Subtidal sediments contained EVO at eight locations where oil had come ashore (oiled locations) in 1989.

Contamination of subtidal sediments by EVO at oiled locations reached a depth of at least 20 m at five locations in 1989. By 1991, the distribution of EVO contaminated subtidal sediments was restricted to four locations on Eleanor Island (Northwest Bay) and Knight Island (Bay of Isles, Herring Bay and Snug Harbor). EVO contamination was also found in intertidal but not subtidal sediments at Sleepy Bay on Latouche Island. By 1991, contamination of subtidal sediments by EVO at oiled locations was found to reach a depth of 20 m at only two sites, Northwest Bay and Snug Harbor 25 (O'Clair et al., 1996).

By 1993, EVO contaminated subtidal sediments were further restricted in geographical distribution. The EVO-PAH composition pattern was found in shallow subtidal sediments at only three locations: Herring Bay, Northwest Bay and Sleepy Bay. EVO contamination in 1993 reached a depth of 20 m at just two sites, Northwest Bay and Sleepy Bay.

Other sources of hydrocarbon contamination

O'Clair et al. (1996) reported that the TPAH concentration of sources of petroleum hydrocarbons other than EVO in lower- intertidal sediments was usually below 30 ng/g and rarely exceeded 200 ng/g in the first three years after the EVOS. They concluded that intertidal sediments in PWS not affected by the EVOS remained substantially free of petrogenic hydrocarbons for the most part. They found mainly three patterns of PAH composition in intertidal samples: (1) predominantly 2-ring PAHs of unknown source found most frequently in intertidal sediments collected in 1989; (2) a pattern consistent with diesel oil derived from North Slope crude oil in which the PAH composition pattern was nearly identical to that of EVO except for the general absence of chrysenes (Page et al. 1994); and (3) a pattern characteristic of a pyrolytic source composed predominantly of unsubstituted PAHs, sometimes found in conjunction with concentrations of alkyl-substituted PAHs that decreased with the degree of alkyl substitution. O'Clair et al. (1996) suggested that the probable sources of PAHs in intertidal sediments where EVO was absent included diesel oil and products of pyrolysis associated with small (and often temporary) human settlements, and forest fires. Residues of asphalt spilled from storage tanks at Valdez during the Great Alaska Earthquake of 1964 were found by Kvenvolden et al. (1993a and 1993b) in intertidal sediments PWS. Although they do not indicate at which tidal level their samples were taken, Kvenvolden et al. (1993a and 1993b) residues probably came from upper tidal levels; our sediments were collected at MLLW. We did not analyze our sediments using Kvenvolden et al. (1993a and 1993b) methods for these California asphalt residues (O'Clair et al. 1996). In 1993, no evidence of hydrocarbons from any petrogenic source was found in sediments from the lower intertidal zone. The concentration of PAHs in intertidal sediments was too low to discriminate a petrogenic source.

As with intertidal sediments, O'Clair et al. (1996) occasionally found a mean TPAH concentration greater than 100 ng/g in shallow subtidal sediments where EVO was not indicated. The probable sources of these PAHs were the same as for PAHs in intertidal sediments. In 1993, we found three patterns of PAH composition in subtidal sediments indicative of hydrocarbon sources other than EVO. The first pattern indicated diesel oil and was characterized by: (1) alkyl chrysenes absent, (2) a concentration of alkyl phenanthrenes (summed) that exceeded 20 ng/g; and (3) a ratio of alkyl dibenzothiophenes (summed) to alkyl phenanthrenes (summed) that exceeded 0.20. The second pattern indicated oil (or coal?) from the Katalla source that was characterized by: (1) a ratio of alkyl chrysenes to alkyl phenanthrenes that exceeded 0.03; (2) a concentration of alkyl phenanthrenes that exceeded 20 ng/g; and (3) a ratio of alkyl dibenzothiophenes to alkyl phenanthrenes less than 0.20. The final pattern indicated an unknown petrogenic source, perhaps diesel that was characterized by: (1) alkyl chrysenes absent; (2) a concentration of alkyl phenanthrenes that exceeded 20 ng/g; and (3) a ratio of alkyl dibenzothiophenes to alkyl phenanthrenes less than 0.20.

The majority of sediment samples collected in the shallow subtidal region at reference sites and assessment sites in 1993, not exhibiting the EVO-PAH composition pattern, contained PAH concentrations too low to distinguish a petrogenic source from them. The percentage of samples not exhibiting the EVO-PAH pattern that contained these low PAH concentrations ranged from 55% (20 m depth) to 100% (3 m depth) at assessment sites and from 71% (20 m depth) to 100% (3 m depth) at reference sites.

Only one sample collected at 6 m at Herring Bay showed a PAH pattern indicative of diesel oil. Two samples (20 m depth, Sleepy Bay) exhibited the Katalla pattern at assessment sites, and one sample (20 m depth, Zaikof Bay) showed the Katalla pattern at reference sites. The number of samples exhibiting the unknown (possibly diesel) PAH pattern ranged from one (6 m depth) to three (20 m depth) at both the assessment and the reference sites.

O'Clair et al. (1996) found that deep subtidal sediments were uniformly contaminated by PAHs derived from marine oil seeps or some other natural source of PAHs. The PAH composition pattern characteristic of this source was similar to that of weathered EVO, except for substantially lower relative abundances of dibenzothiophenes. Page et al. (1994) attributed this PAH composition pattern to marine oil seeps near Katalla Island. The present study also found the Katalla PAH pattern to be common in deep subtidal sediments, especially at 100 m. At the 40 m depth, the Katalla pattern was observed in 20% of the sediment samples from the assessment sites and 27% of the samples from the reference sites. At the 100 m depth, the Katalla pattern was observed in 100% of the sediment samples from the assessment sites and 93% of the samples from the reference sites.

CONCLUSIONS

Although oil from the EVOS contaminated shores over a broad geographic range in PWS in 1989, by 1993 the distribution of EVO in shallow subtidal sediments was much more restricted and no low intertidal sediments were found to be contaminated. Contamination of subtidal sediments was restricted to three sites within the trajectory of the oil spill: Herring Bay, Northwest Bay and Sleepy Bay. The bathymetric distribution of oil at contaminated sites in 1993 showed the greatest concentration of petroleum hydrocarbons at the 20 m depth. In the subtidal region, petroleum hydrocarbons exhibiting a concentration pattern consistent with EVO were restricted to shallow depths (3-20 m). Petroleum hydrocarbons at depths ≥40 m were found to be from sources other than EVO. At the 100 m depth petroleum hydrocarbons were chiefly from the Katalla source.

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APPENDIX I

Standard operating procedures for sampling benthic sediments.

INTERTIDAL SEDIMENTS

1. Choose an area of intertidal beach having a substrate as homogeneous as possible with particle sizes of 2 mm or less. The area must be large enough to accommodate a 30 m transect. Lay the transect parallel to the water's edge within the designated area.

2. Choose eight random distances along the transect from a random number table or pocket calculator.

3. Three samples of substrate will be collected at each station (= transect). Each sample will represent a composite of eight subsamples, each subsample having been taken at one of the eight randomly selected points. Using a metal core tube and spatula or metal scoop, remove approximately 10 g of sediment from the upper 2 cm of substrate at one of the eight randomly selected points on the transect and place in a properly cleaned 4 oz jar. Repeat the procedure for two more jars, collecting 10 g of sediment from adjacent patches of substrate and placing it in each of the two additional jars.

4. Repeat the procedure described in 3 for the seven remaining points on the transect.

5. At one station per site, a sample blank (handled in the same way as the sediment samples except without receiving any sediment) will be taken.

6. Label, seal (with custody control seal), and freeze sediment samples and blank as soon as possible after collection.

7. Proper cleaning procedure for sampling implements and jars.

Sampling implements - All sampling implements will be washed with soap and water, rinsed, dried, rinsed with methylene chloride, and if not used immediately, wrapped in clean aluminum foil that has been rinsed with methylene chloride. The cleaning procedure will be performed before each transect is sampled.

Jars - If sample jars have not come from the supplier cleaned to Environmental Protection Agency specifications, they will be baked for 4 hours at 440°C or rinsed with methylene chloride. Sample jars will have teflon-lined lids rinsed with methylene chloride or will be capped with aluminum foil rinsed with methylene chloride before the lid is replaced after sample collection.

SUBTIDAL SEDIMENTS

Diver collected

Sampling will be conducted as described above for intertidal sediments, with the following modifications.

1. Lids will be closed on sample jars on the surface before divers descend to the bottom to prevent contamination by petroleum hydrocarbons floating on the surface of the water.

2. Care must be taken to avoid contamination of dive mitts/gloves with petroleum hydrocarbons.

Remote sampling by van Veen grab or Smith-McIntyre grab.

1. The interior surfaces of the grab must be clean prior to deployment. The grab will be lowered to the bottom and activated to enclose a sample of substrate and then retrieved. The surface of the water will be checked visually for sign of contamination by petroleum hydrocarbons (such as an oil sheen) before the grab is lowered or retrieved through it. If any indication of oil is observed, the vessel will be moved to a visually clean area.

2. When the grab is brought to the surface and placed on deck, care must be taken to avoid contamination of the surface of the grab sample with lubricants from the grab sampling equipment and vessel exhaust. The grab sample will be subsampled with a stainless-steel core tube and spatula. The location of the subsamples will be determined randomly. Four subsamples will be taken from each sample and placed in a properly cleaned 4 oz jar. Three samples will be taken at each station. Subsamples of different grabs will be placed in separate jars. Samples will be labeled, sealed, and frozen as soon as possible after being collected.

3. Sampling implements and jars will be cleaned as described in the section on intertidal sediments above.

Exxon Valdez Oil Spill
Restoration Project Final Report

Microbiology of Subtidal Sediments: Monitoring Microbial Populations

Restoration Project 93047-2
Final Report

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Microbiology of Subtidal Sediments: Monitoring Microbial Populations

Restoration Project 93047-2
Final Report

Study History: This study began as a part of NRDA Air/Water Study Number 2 Petroleum Hydrocarbon-Induced Injury to Subtidal Marine Sediment Resources in 1989. Status reports under this study number were submitted in 1989 and 1990. In 1991 the number of the study was changed to Subtidal Study Number 1. The title remains the same. A status report under the new title was submitted in 1991. The final report for Subtidal Study Number 1 (microbiology) was submitted in June 1992, reviewed, then revised in April 1993. No field work was performed in 1992. In 1993 Restoration Study Number 93047 *Exxon Valdez* Restoration Project: Subtidal Monitoring was initialed. Our project, Microbiology of Subtidal Sediments: Monitoring Microbial Populations, is part of Restoration Project 93047, Subtidal Monitoring: Recovery of Sediments, and Hydrocarbon-Degrading Microorganisms in the Subtidal Environment. The Restoration project was led by the National Oceanic and Atmospheric Agency with cooperation from the Alaska Department of Environmental Conservation and the University of Alaska Fairbanks. The University of Alaska Fairbanks was responsible for the microbiological portion of the study. Previous findings on microbial numbers and activity in subtidal sediments can be found in two summary reports from Natural Resource Damage Assessment projects: (1) Braddock, J.F., M.R. Brockman, J.E. Lindstrom and E.J. Brown, 1990, Microbial hydrocarbon degradation in sediments impacted by the *Exxon Valdez* Oil Spill, NOAA Report for contract no. 50-DSNC-8-00141, Washington, DC and (2) Braddock, J.F., B.T. Rasley, T.R. Yeager, J.E. Lindstrom and E.J. Brown, 1993, Hydrocarbon mineralization potentials and microbial populations in marine sediments following the *Exxon Valdez* oil spill, *Exxon Valdez* Oil Spill Project Final Report, University of Alaska, Fairbanks, AK. Some of the results from these studies have been published: (1) Brown, E.J. and J.F. Braddock. 1990. Sheen Screen: a miniaturized most probable number technique for oil-degrading microorganisms. *Appl. Environ. Microbiol.* 56:3895-3896 and (2) Braddock , J.F., J.E. Lindstrom and E.J. Brown. 1995. Distribution of hydrocarbon-degrading microorganisms in sediments from Prince William Sound, Alaska following the *Exxon Valdez* oil spill, *Mar. Pollut. Bull.* 30:125-132. A second manuscript (Braddock, J.F., J.E. Lindstrom, T.R. Yeager, B.T. Rasley and E.J. Brown, Patterns of microbial activity in oiled and unoiled sediments in Prince William Sound) has been accepted for publication in the *Exxon Valdez* Oil Spill Symposium Proceedings.

Abstract: An increase in the biodegradation activity of naturally occurring populations of microorganisms can lead to substantial removal of petroleum from the environment. Therefore, measurements of microbial populations are an important component of contaminated site assessment studies. Following the *Exxon Valdez* oil spill in 1989, we measured numbers of hydrocarbon-degrading microorganisms and hydrocarbon mineralization potentials of microorganisms in oiled and unoiled surface sediments from the shore through 100 m depth offshore. We found both temporal and spatial variations in numbers and activity of hydrocarbon-degrading microorganisms with statistically significant higher values at the oiled sites than at reference sites. In the summer of 1993 we returned to ten study sites within Prince William Sound to monitor the changes in the numbers and activities of hydrocarbon-degrading microorganisms at these sites with time. In 1993 the numbers and activities of hydrocarbon-degrading microorganisms were generally very low at all sites although elevated populations and activities were measured in intertidal sub-surface samples at several sites (Northwest Bay, Herring Bay and Sleepy Bay) with observable sub-surface oiling.

Key Words: Biodegradation, *Exxon Valdez,* microbiology, Prince William Sound, subtidal sediments.

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Executive Summary

Assessment of microbial populations is an essential component of oil spill monitoring since a major fate of spilled petroleum depends on the ability of microorganisms to use hydrocarbons as a source of carbon and energy (Leahy and Colwell, 1990). Microbial measurements also can be used to provide evidence for the presence of in situ biodegradation (Madsen et al. 1991). In addition, monitoring microbial populations is a tool for assessing the extent and persistence of oil contamination following a spill.

We have monitored the total numbers and activity of hydrocarbon-degrading microorganisms since 1989 in sediments (intertidal and subtidal) impacted by the *Exxon Valdez* oil spill. We sampled both oiled and unoiled sites in Prince William Sound on six separate cruises spanning 1989-1991. Surface sediment samples were collected from the shoreline (intertidal) through 100 m depth offshore. Both the numbers and activity of microbial populations were assayed in these samples. We used most probable number techniques to estimate the numbers of oil-degrading microorganisms and radiorespirometry to measure the mineralization potentials of the microbial community for various hydrocarbons including benzene, hexadecane, phenanthrene and naphthalene.

We found that the numbers and activity of hydrocarbon-degrading microorganisms are indicators of the presence of hydrocarbons in sediments from Prince William Sound. We found statistically significant differences in the populations of hydrocarbon degraders in shoreline sediments collected from bays within the path of the oil slick relative to populations at reference sites which were not oiled during the *Exxon Valdez* spill. We also saw differences in populations of hydrocarbon degraders with time following the spill. Populations of hydrocarbon-degrading microorganisms dropped substantially in most surficial intertidal sediments from 1989 to 1991 indicating a reduction in readily biodegradable fractions with time. However, high numbers still existed on several shorelines in 1991 particularly in buried sediments. In these sediments hydrocarbon degrader population numbers and activities were as great as seen in early summer 1989.

We returned to Prince William Sound in the summer of 1993 to ten sites previously sampled for microbial populations and activities. Our objective in this study was to continue to monitor the numbers of hydrocarbon-degrading microorganisms to determine if active populations remained at heavily contaminated sites within Prince William Sound and to validate microbial techniques as relatively cheap and quick assays for monitoring the extent and persistence of hydrocarbon contaminants following an oil spill. In 1993 the numbers and activities of hydrocarbon-degrading microorganisms were generally very low at all sites although elevated populations and activities were measured in intertidal sub-surface samples at several sites (Northwest Bay, Herring Bay and Sleepy Bay) with observable sub-surface oiling. We found that microbial population estimates were good indicators of exposure of sediments in Prince William Sound to oil after the spill.

Introduction

The grounding of the tanker vessel *Exxon Valdez* on Bligh Reef on 24 March 1989 released about 35,500 metric tons of crude oil into the waters of Prince William Sound (PWS). The oil spread southwest by coastal circulation and winds to the shorelines of many islands within PWS and eventually into the Gulf of Alaska (Royer et al., 1990). Shortly after the grounding, the National Oceanic and Atmospheric Administration (NOAA) organized a multi-investigator survey cruise to document the extent of oil contamination of coastal habitats in Alaska. This first survey cruise was followed by five seasonal cruises over the next two years organized as a joint effort of NOAA and the Alaska Department of Environmental Conservation (ADEC). The purpose of these cruises was to document oil concentration distributions and assess the relative effects of the spill on various communities in intertidal and subtidal areas. Assessment of microbial populations was an important component of the surveys since a major fate of petroleum contaminants in marine environments depends on the ability of microorganisms to use hydrocarbons as a source of carbon and energy (Leahy and Colwell, 1990). The results of the first six cruises (1989-1991) have been previously reported (Braddock et al., 1993; Braddock et al., in press).

In the study spanning 1989-1991 we measured numbers of hydrocarbon-degrading microorganisms in shoreline sediments and in subtidal surface sediments offshore at depths to 100 m. We found statistically significant differences in the populations of hydrocarbon degraders in shoreline sediments collected from bays within the path of the oil slick relative to populations at reference sites which were not oiled during the *Exxon Valdez* spill. We also saw differences in populations of hydrocarbon degraders with time following the spill. These differences were observed despite mounting evidence that substantial quantities of older weathered oil may exist in PWS from other sources such as natural seeps (Page et al., 1993) or from spills (Kvenvolden et al., 1993) likely related to the 1964 earthquake (Kvenvolden as cited in the New York Times, p. C1, Dec. 1,1993). Measurements of numbers of hydrocarbon-degrading microorganisms provide evidence of the presence of less weathered oil that can be readily used by microorganisms and, therefore, may be useful in determining the extent, movement and persistence of labile hydrocarbon contamination following an oil spill.

We returned to PWS in the summer of 1993 to ten sites previously sampled for microbial populations and activities. We report here the results of the 1993 monitoring cruise and compare the microbial numbers and activities measured in 1993 in intertidal and subtidal surface sediments to those previously measured at these same sites from 1989 to 1991. We believe the microbial monitoring following the *Exxon Valdez* spill is unique by virtue of the extensive data set that has been generated from frequent sampling at a large number of sites after a major spill. Such data provide insights into the extent of both temporal and spatial microbial responses to an environmental perturbation.

Objective

To monitor numbers of hydrocarbon-degrading microorganisms and the continuing potential for biodegradation of selected hydrocarbon substrates in intertidal and subtidal sediments from oiled and unoiled sites.

Methods

Sampling: Surface sediment (top 0 - 3 cm) samples were previously collected and analyzed for microbial populations and activities on six cruises: R/V Fairweather (Summer 1989), M/V Nautilus (Winter 1989), R/V Cobb (Spring 1990), R/V Davidson (Summer 1990), R/V Cobb (Fall 1990) and F/V Big Valley (Summer 1991)(see Braddock et al., 1993). In 1993 ten sites in PWS were visited from 8 to 16 July on the F/V Scorpius (Summer 1993; Table 1 and Fig. 1). The season designators for the cruises used here are meant to reflect the weather in PWS during the time of the cruise even though the dates of the cruise do not strictly follow traditional season definitions. During the three summer cruises surface sediments were collected in the intertidal zone (referred to as shoreline or 0 m) and at 3, 6, 20, 40 and 100 m depths offshore at mean low tide. On the other cruises surface sediment samples were collected only in the intertidal zone and at the shallower water depths offshore (Winter 1989, 0 and 3 m; Spring 1990 and Fall 1990, 0, 3, 6 and 20 m), due either to the restricted capabilities of the support vessel or abbreviated cruise schedules for those sampling trips. Surface sediments at the 40 or 100 m depths were collected using either a Van Veen grab or a Smith-McIntyre grab. Composite samples at each depth from three grabs were obtained by subsampling surface sediment (top 0-3 cm) into sterile bags. Samples at the 3, 6 and 20 m depths were collected by SCUBA divers while shoreline samples were collected by either SCUBA divers or a shore party in the low intertidal zone as close to low tide as was feasible. The intertidal (shoreline), 3, 6 and 20 m samples were composites of eight subsamples collected at random intervals along a 30 m transect parallel to the shoreline. Only one bag of sediment was collected for each site at each depth on the Summer 1989 cruise while three replicate bags were collected at each depth for all subsequent cruises so that statistical procedures could be used to compare the study sites to reference sites. All sediment and water samples were placed in coolers at the time of collection for transport to the support vessel. Processing for microbiological analyses was performed within three hours of collection. We assayed samples from which all rocks greater than 1 cm in diameter were removed due to the prevalence of rocks and coarse-grained sediments at several locations and depths in PWS.

Microbial Population Estimates: Heterotrophic and hydrocarbon-degrading microbial populations were estimated using most probable number (MPN) techniques. While no technique to enumerate specific metabolic types of microorganisms in marine systems is absolute, the MPN technique can give consistent results that are appropriate for relative comparisons among stations and depths. The number of hydrocarbon-degrading microorganisms in each sediment sample was estimated using the Sheen Screen MPN (Brown and Braddock, 1990). Hydrocarbon degrading microorganisms were defined as those microbes capable of dispersing a sterile Prudhoe Bay oil sheen layered on Bushnell-Haas marine mineral salts (Difco Laboratories, Detroit, MI) broth. On the Summer 1989 cruise, duplicate sets of cell well plates were prepared for each subtidal depth at each site. For all other cruises one set of cell well plates was prepared from each replicate sediment sample at a given site and depth to yield triplicate values. The Sheen Screen plates were incubated at approximately 15 °C for three weeks before being scored for disruption of the oil sheen. Marine heterotrophs were enumerated in a similar manner, except that the growth medium was marine broth (Difco Laboratories, Detroit, MI) and growth was indicated by turbidity (Lindstrom et al., 1991). The heterotrophs plates were incubated for 1 week after inoculation before being scored for turbidity.

Table 1. Site names and locations for the F/V Scorpius cruise (8- 16 July 1993).

Site	Latitude	Longitude	Date Sampled
North West Bay	60°33.3'N	147°34.6'W	7-8-93
Herring Bay	60°26.5'N	147°47.1'W	7-9-93
Lower Herring Bay	60°24.4'N	147°47.8'W	7-10-93
Drier Bay	60°19.4'N	147°45.3'W	7-11-93
Sleepy Bay	60°04.0'N	147°50.1'W	7-11 to 7-12-93
Mooselips Bay	60°12.5'N	147°18.0'W	7-12 to 7-13-93
Zaikof Bay	60°16.1'N	147°05.5'W	7-13-93
Snug Harbor	60°14.4'N	147°43.1'W	7-14-93
Bay of Isles	60°22.9'N	147°42.8'W	7-15-93
Olsen Bay	60°45.1'N	146°11.5'W	7-15 to 7-16-93

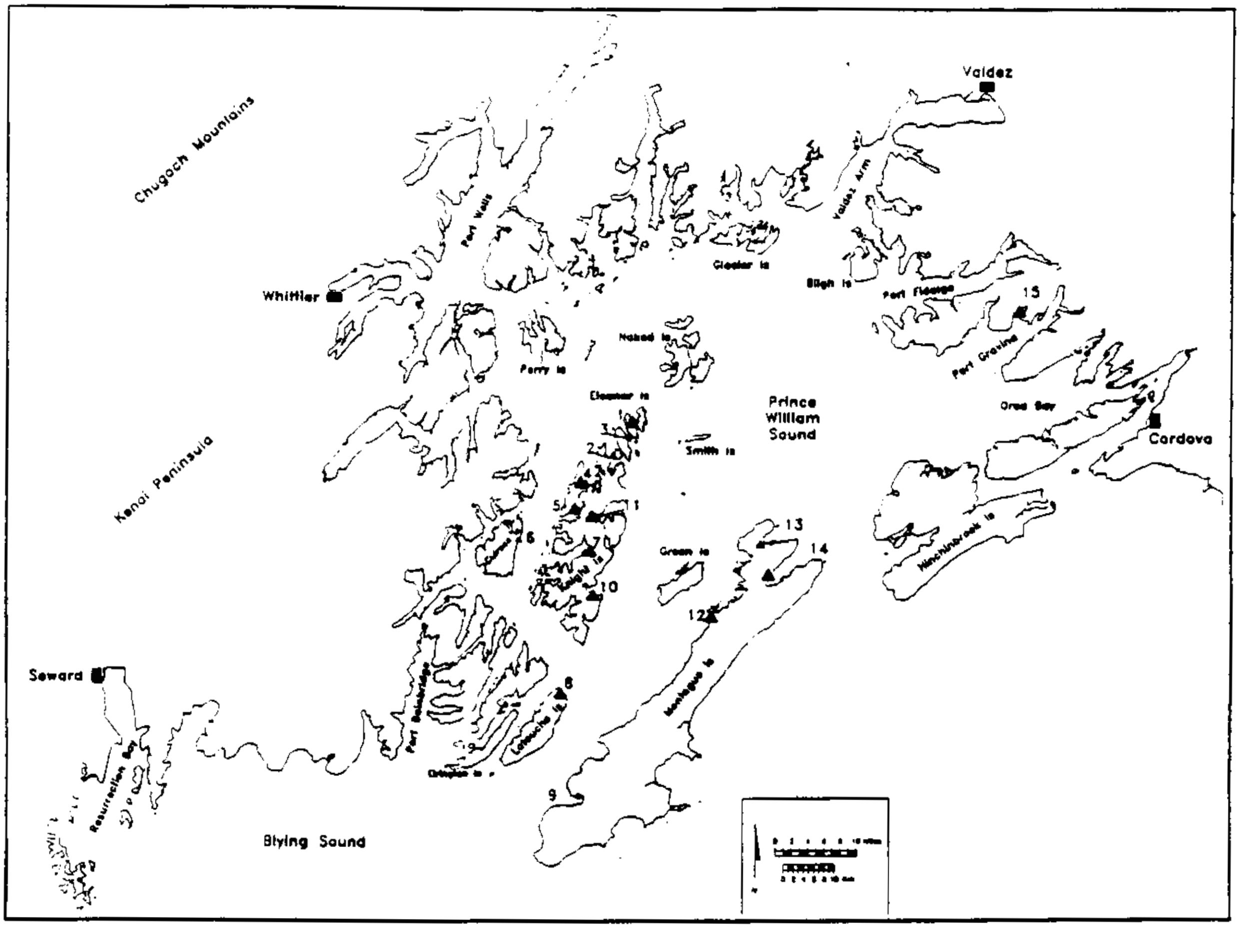


Figure 1. Locations of study sites sampled in 1993 (indicated by bold triangle). Site numbers correspond to sites as follows: 1. Northwest Bay; 4. Herring Bay; 5. Lower Herring Bay; 7. Drier Bay; 8. Sleepy Bay; 10. Snug Harbor; 11. Bay of Isles; 12. Mooselips Bay; 14. Zaikof Bay and; 15. Olsen Bay.

Hydrocarbon Mineralization Potential: Radiorespirometry was used to assay the hydrocarbon-mineralization potentials of microorganisms in sediment slurries (Brown et al. 1991). The radiolabeled hydrocarbons, [1-^{14}C]-hexadecane and [1,(4,5,8)-^{14}C]-naphthalene or [9-^{14}C]-phenanthrene were used as representatives of aliphatic and polycyclic aromatic hydrocarbons. The assay was designed to be independent of most of the complex factors regulating microbial hydrocarbon metabolism (including hydrocarbon availability) except microbial biomass and its potential to degrade hydrocarbons in each sample. Sediment was diluted (1:10) in sterile mineral salts medium (Bushnell-Haas Medium; Difco, Detroit, MI) amended with 2.5% NaCl. After shaking vigorously by hand for one minute, the samples (10 ml) were pipetted into 40-ml pre-cleaned and sterilized glass incubation vials fitted with Teflon-lined septa (I-Chem Research, Hayward, CA).

Replicate vials of the 10-ml slurries from each of the sediments samples were injected with 50 µl of a 2-g/l solution (in acetone) of radiolabelled hydrocarbon. The resulting initial concentration of added hydrocarbon was then 100 µg per vial (100 µg/g wet weight sediment; 10 µg/ml slurry; approximately 50,000 dpm/vial). By adding 100 µg of hydrocarbon substrate to each vial, the hydrocarbon mineralization potential was independent of the degree of oil contamination of the sediment tested (see Brown et al. 1991).

For the Fairweather cruise, duplicate vials were prepared from each sediment (one bag per depth per site) for three incubation times and two radiolabelled hydrocarbon substrates. In addition, "time zero" killed controls were prepared at each site for each isotope. For all other cruises, three bags of sediment were collected for each depth at each site. From each bag, seven replicate vials of each concentration of each substrate were prepared: one "time zero" killed control, and three vials each at two incubation times. All vials were placed on a rotary shaker for the first 24 hours and then stored off the shaker at approximately 15 °C for the duration of the incubation period. At the end of the designated incubation period, samples were "killed" and the CO_2 fixed by adding 1 ml 10 N NaOH per vial. At the end of each cruise the vials were returned to the lab where they were acidified and the radiolabelled CO_2 stripped and counted on a model LSC 1800 liquid scintillation counter (Beckman Instruments, Irvine, CA) by the procedure described in Brown et al. (1991).

The "zero time" values for each isotope for each cruise served as negative controls and were averaged and subtracted from each mineralization potential sample to yield a corrected dpm value. In addition to the NaOH "killed zero time" controls, a series of sediment samples were inoculated, spiked with radioisotopes and killed (autoclaved) at the beginning of Fairweather cruise. These samples were run approximately four months later to check for abiotic evolution of CO_2. The values from all these samples fell within the range for a scintillation cocktail blank. Positive controls showed that the purging system could recover greater than 99% of radiolabelled CO_2 from radiolabelled bicarbonate processed as if it were a sediment sample. The potential for carryover between samples was monitored by running blank controls through the purging line periodically. Blank controls run in this manner always fell within the range for "time-zero" control samples. All reported values have been corrected to dry weight sediment.

Results

The distribution of the surface slick of oil after the grounding on Bligh Reef was dependent on winds and currents and generally resulted in a spread of the oil to the southwest (Royer et al., 1990; Galt et al., 1991). By about six days after the spill the surface slick had heavily coated many shorelines around Knight Island and other smaller islands in that area (Fig. 2). The study sites sampled followed, in general, the path of the oil slick (see Fig. 1).

Microbial populations (heterotrophs and hydrocarbon degraders) were estimated at each site in 1993 (Table 2, Appendix A). The numbers of hydrocarbon-degrading microorganisms were generally low at all sites visited in 1993 relative to populations measured at many of these sites in 1989 or 1990 (Fig. 3a-e). In 1993 the only samples which contained high populations of hydrocarbon-degrading microorganisms were collected from sub-surface samples collected by digging shallow pits (approximately 20 cm deep). Northwest Bay, Herring Bay and Sleepy Bay all had visible sub-surface oiling in 1993 and all of these same sites had populations of hydrocarbon degraders greater than 10^4/g sediment. No other sediment samples collected in 1993 were recorded as containing visible oil and the populations of hydrocarbon degraders were 10^3/g sediment or less.

The activity potentials for the hydrocarbon degrader populations were measured by assaying the mineralization of radiolabelled hydrocarbon fractions in laboratory incubations. Hexadecane and phenanthrene were used as representatives of a linear alkane and a polycyclic aromatic hydrocarbon, respectively. Mineralization potentials for hexadecane were low (less than 10% mineralized after a two day incubation; Table 3) except in two sub-surface samples collected at Northwest Bay and Sleepy Bay. Temporal decreases were detected in the mineralization potentials for hexadecane at all sites and depths since 1989 (Fig. 4a-e).

In a similar manner, mineralization potentials for phenanthrene were measured in 1993 sediment slurries after two-day and four-day incubations (Tables 4 and 5, respectively). Phenanthrene mineralized was less than three percent after a two day incubation for all depths and sites except one anomalous value of 7.9% at Drier Bay at 100 m (Table 4). The variability in replicates measured at this site was also high (see Appendix A) and the same trend was not reflected in the hydrocarbon degrader populations measured or the hexadecane or four day phenanthrene mineralization potentials measured. The mineralization potentials measured after four day incubations were less than four percent except in two subsurface samples collected at Northwest and Sleepy Bays. The two day phenanthrene data from 1993 were compared to values measured in samples collected in 1989-1991 (Fig. 5a-e). As with the hexadecane mineralization potential data (Fig. 4a-e) the phenanthrene potentials generally have declined since 1989.

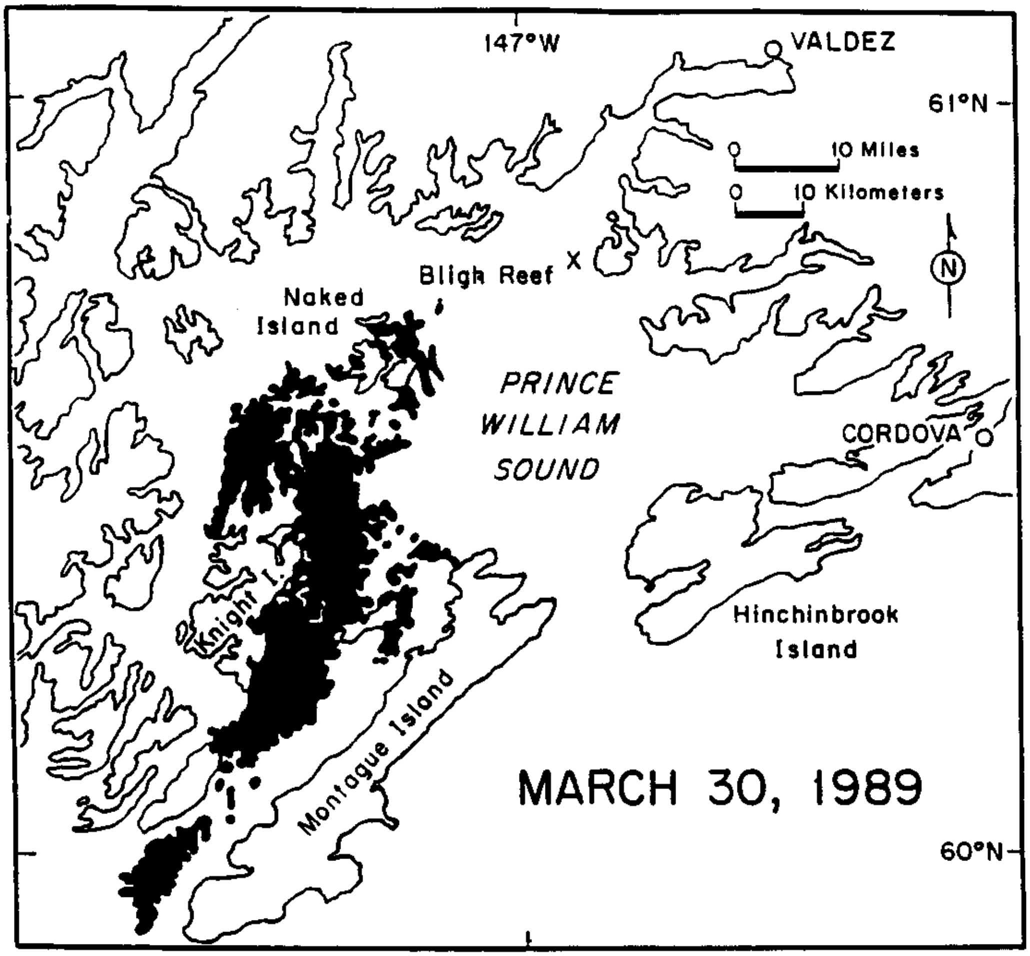


Figure 2. Distribution of *Exxon Valdez* oil in Prince William Sound approximately six days after the spill which began when the tanker ran aground on Bligh Reef at midnight March 24, 1989. The figure is redrawn from output from the National Oceanic and Atmospheric Administration On-Scene Spill Model described in Galt et al. (1991).

Table 2. Summary of microbial population data (heterotrophs and hydrocarbon degraders) from intertidal and subtidal sediments collected in July 1993 (Scorpius cruise).

		Heterotrophs (cells/g dry sed.)			Hydrocarbon Degraders (cells/g dry sed.)		
	Depth (m)	Mean	Std. Dev.	Log Mean	Mean	Std. Dev.	Log Mean
Northwest Bay	Beach	9.0E+05	9.1E+05	6.0	2.1E+02	3.3E+01	2.3
7/8/93	Sub-Surf	8.6E+05	8.8E+05	5.9	1.3E+05	2.0E+05	5.1
Site #1	3	3.0E+05	1.7E+05	5.5	2.5E+02	7.2E+01	2.4
	6	7.7E+04	3.4E+04	4.9	9.7E+00	1.7E+01	1.0
	20	3.1E+05	3.4E+05	5.5	1.6E+03	1.8E+03	3.2
	40	4.7E+04	2.3E+04	4.7	0.0E+00	0.0E+00	
	100	3.3E+04	1.5E+04	4.5	0.0E+00	0.0E+00	
Herring Bay	Beach	7.4E+05	3.9E+05	5.9	4.9E+01	8.1E+01	1.7
7/9/93	Sub-Surf	4.0E+04	3.1E+04	4.6	3.2E+04	5.6E+04	4.5
Site #2	3	1.1E+05	1.3E+05	5.0	5.7E+02	5.7E+02	2.8
	6	6.1E+04	3.2E+04	4.8	0.0E+00	0.0E+00	
	20	3.2E+04	1.4E+04	4.5	3.6E+01	6.2E+01	1.6
	40	2.3E+04	2.8E+04	4.4	3.0E+01	2.6E+01	1.5
	100	7.1E+03	7.1E+03	3.9	0.0E+00	0.0E+00	
Lower Herring Bay	Beach	3.5E+05	4.1E+05	5.5	0.0E+00	0.0E+00	
7/10/93	Sub-Surf	1.2E+04	1.3E+04	4.1	0.0E+00	0.0E+00	
Site #3	3	6.5E+05	9.5E+05	5.8	0.0E+00	0.0E+00	
	6	2.6E+05	2.5E+05	5.4	0.0E+00	0.0E+00	
	20	1.9E+04	1.0E+04	4.3	3.3E+00	5.7E+00	0.5
	40	9.2E+03	4.7E+03	4.0	0.0E+00	0.0E+00	
	100	2.5E+04	2.0E+04	4.4	0.0E+00	0.0E+00	
Drier Bay	Beach	1.9E+05	1.3E+05	5.3	1.3E+02	8.9E+01	2.1
7/11/93	Sub-Surf	2.4E+04	1.9E+04	4.4	0.0E+00	0.0E+00	
Site #4	3	8.5E+04	3.4E+04	4.9	0.0E+00	0.0E+00	
	6	1.8E+06	2.1E+06	6.2	0.0E+00	0.0E+00	
	20	1.1E+05	2.3E+04	5.0	0.0E+00	0.0E+00	
	40	7.2E+04	8.8E+04	4.9	0.0E+00	0.0E+00	
	100	3.4E+04	3.7E+04	4.5	0.0E+00	0.0E+00	
Sleepy Bay	Beach	1.2E+05	8.1E+04	5.1	0.0E+00	0.0E+00	
7/11 to 7/12/93	Sub-Surf	3.6E+08	6.2E+08	8.6	1.2E+05	2.1E+05	5.1
Site #5	3	4.7E+05	2.5E+05	5.7	2.0E+02	1.2E+02	2.3
	6	3.1E+05	1.3E+05	5.5	1.9E+02	1.4E+02	2.3
	20	7.5E+04	4.4E+04	4.9	2.0E+02	2.4E+02	2.3
	40	9.6E+03	5.0E+03	4.0	0.0E+00	0.0E+00	
	100	1.5E+04	9.8E+03	4.2	0.0E+00	0.0E+00	

Table 2 cont. Summary of microbial population data (heterotrophs and hydrocarbon degraders) from intertidal and subtidal sediments collected in July 1993 (Scorpius cruise).

		Heterotrophs (cells/g dry sed.)			Hydrocarbon Degraders (cells/g dry sed.)		
	Depth (m)	Mean	Std. Dev.	Log Mean	Mean	Std. Dev.	Log Mean
Mooselips Bay	Beach	5.6E+05	4.5E+05	5.8	0.0E+00	0.0E+00	
7/12 to 7/13/93	Sub-Surf	2.5E+05	6.3E+04	5.4	0.0E+00	0.0E+00	
Site #6	3	3.1E+05	1.7E+05	5.5	0.0E+00	0.0E+00	
	6	8.0E+05	6.7E+05	5.9	0.0E+00	0.0E+00	
	20	9.4E+04	2.2E+04	5.0	0.0E+00	0.0E+00	
	40	9.8E+04	9.1E+04	5.0	0.0E+00	0.0E+00	
	100	9.4E+04	1.4E+05	5.0	0.0E+00	0.0E+00	
Zaikof Bay	Beach	1.0E+05	3.9E+04	5.0	0.0E+00	0.0E+00	
7/13/93	Sub-Surf	2.7E+06	9.6E+05	6.4	3.4E+01	4.1E+01	1.5
Site #7	3	3.2E+05	1.5E+05	5.5	0.0E+00	0.0E+00	
	6	2.6E+05	2.7E+05	5.4	0.0E+00	0.0E+00	
	20	8.9E+04	7.5E+04	4.9	0.0E+00	0.0E+00	
	40	2.2E+04	2.0E+04	4.3	0.0E+00	0.0E+00	
	100	5.8E+04	4.3E+04	4.8	0.0E+00	0.0E+00	
Snug Harbor	Beach	2.1E+05	2.3E+05	5.3	0.0E+00	0.0E+00	
7/14/93	Sub-Surf	3.4E+05	1.9E+05	5.5	7.6E+00	1.3E+01	0.9
Site #8	3	1.4E+05		5.2	0.0E+00	0.0E+00	
	6	1.3E+05		5.1	0.0E+00	0.0E+00	
	20	1.4E+05	4.4E+04	5.2	2.5E+01	4.2E+01	1.4
	40	3.4E+05	4.6E+05	5.5	2.9E+01	5.1E+01	1.5
	100	1.5E+06	9.4E+05	6.2	0.0E+00	0.0E+00	
Bay of Isles	Beach	7.6E+04	4.8E+04	4.9	0.0E+00	0.0E+00	
7/15/93	Sub-Surf	1.1E+06	2.1E+05	6.0	0.0E+00	0.0E+00	
Site #9	3	1.6E+07	2.4E+07	7.2	0.0E+00	0.0E+00	
	6	5.6E+07	6.6E+07	7.7	1.2E+01	2.1E+01	1.1
	20	4.8E+05	4.9E+05	5.7	0.0E+00	0.0E+00	
	40	3.5E+06	1.9E+06	6.5	0.0E+00	0.0E+00	
	100	1.2E+06	1.4E+06	6.1	0.0E+00	0.0E+00	
Olsen Bay	Beach	1.8E+05	5.4E+04	5.3	0.0E+00	0.0E+00	
7-15 to 7-16-93	Sub-Surf	1.0E+05	1.7E+04	5.0	0.0E+00	0.0E+00	
Site #10	3	7.3E+05	5.2E+05	5.9	0.0E+00	0.0E+00	
	6	3.9E+05		5.6	0.0E+00	0.0E+00	
	20	3.0E+05	1.4E+05	5.5	0.0E+00	0.0E+00	
	40	2.2E+07	3.8E+07	7.3	0.0E+00	0.0E+00	
	100	2.9E+04	1.1E+04	4.5	0.0E+00	0.0E+00	

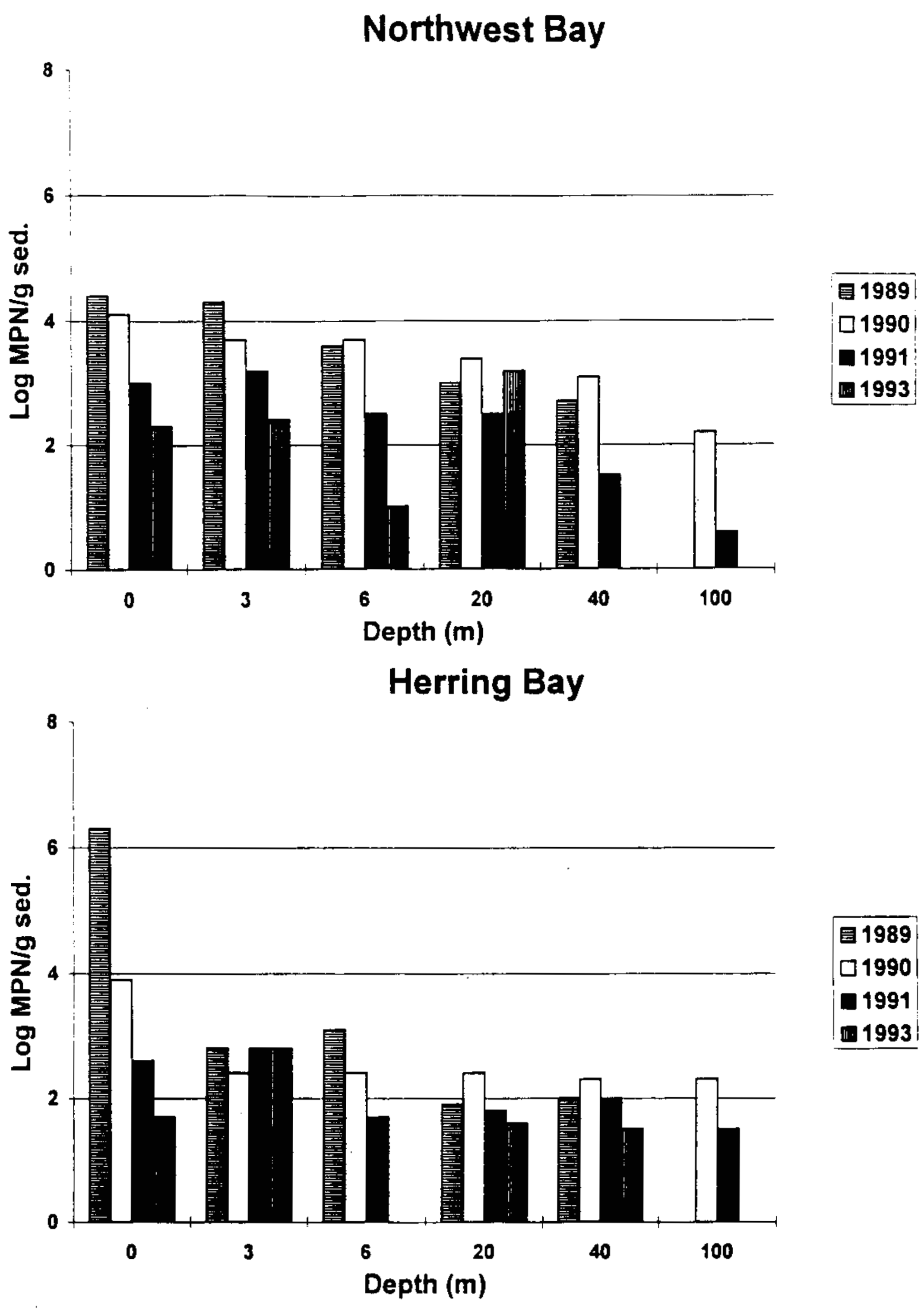
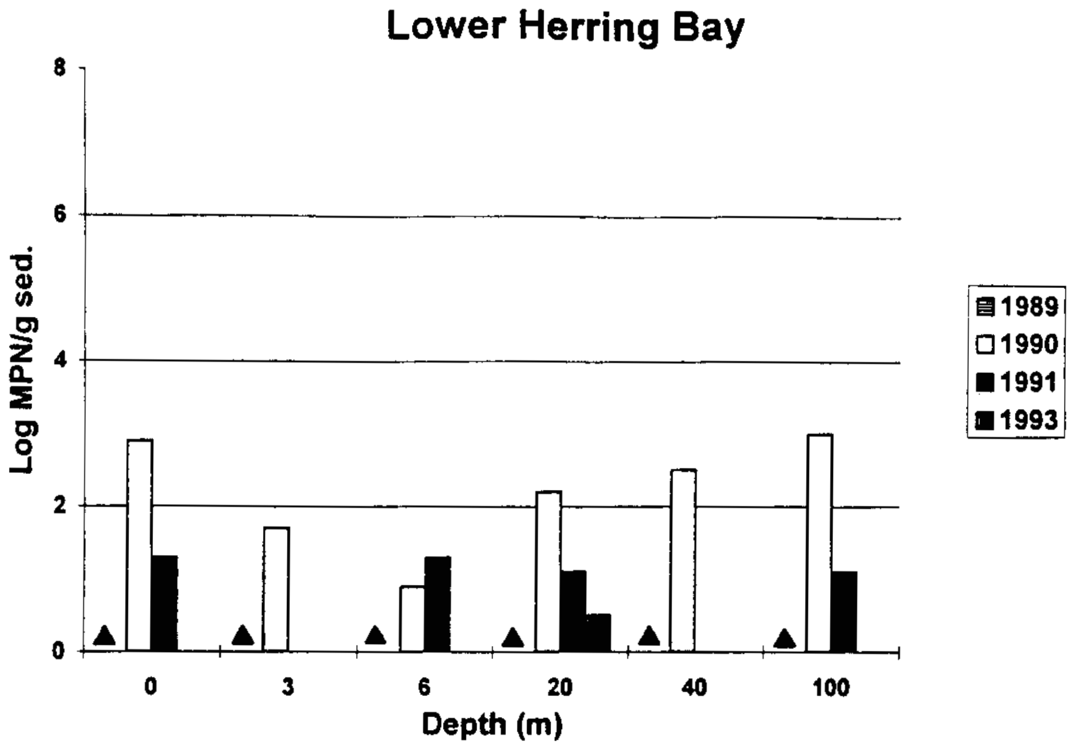


Figure 3a. Log Most Probable Number of hydrocarbon-degrading microorganisms in surface sediments from the shoreline to 100 m depth offshore collected from Northwest Bay and Herring Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar for a date or depth indicates that the measured value was < 1.3 which reflects the lower sensitivity of the MPN technique used.



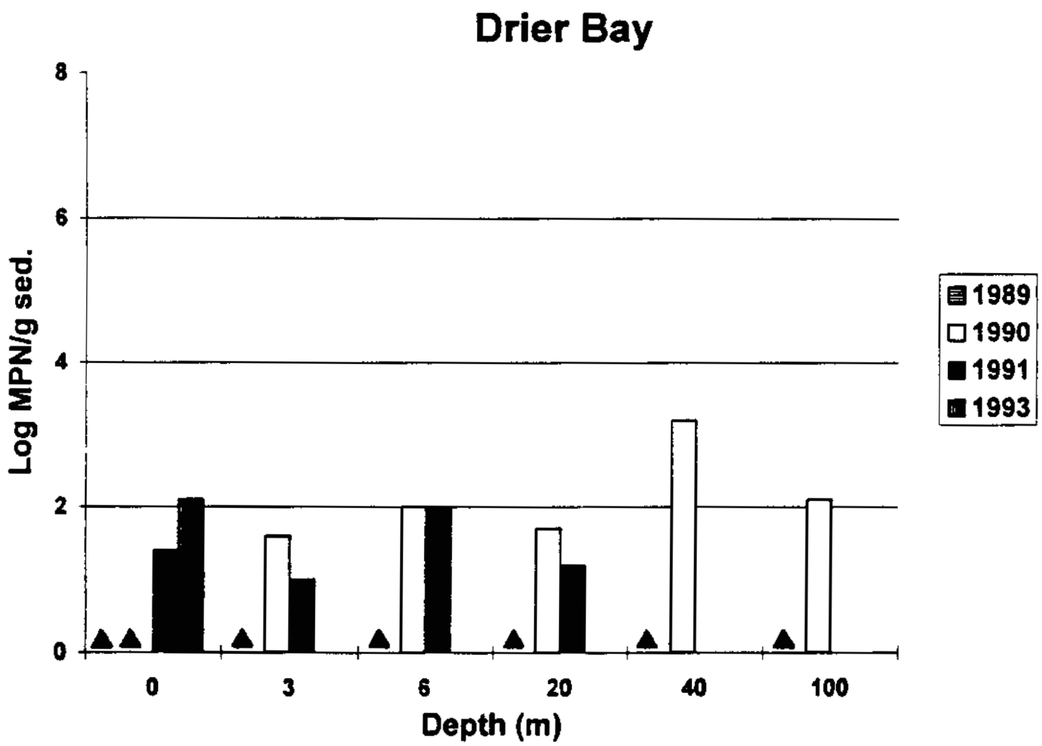
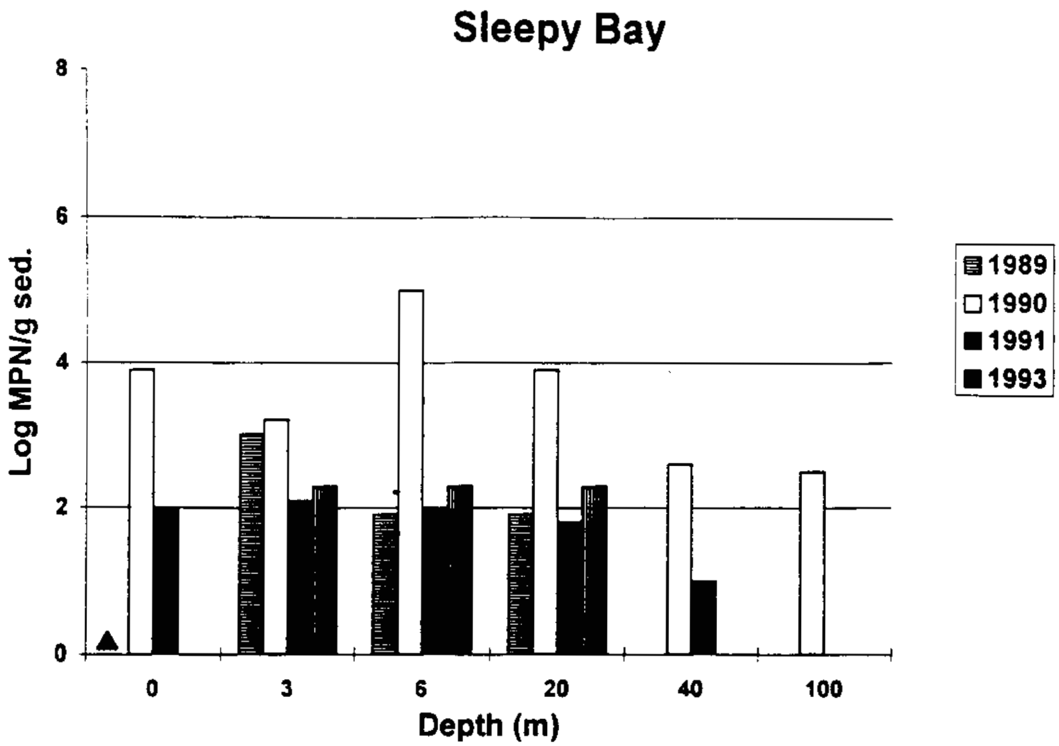


Figure 3b. Log Most Probable Number of hydrocarbon-degrading microorganisms in surface sediments from the shoreline to 100 m depth offshore collected from Lower Herring Bay and Drier Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar for a date or depth indicates that the measured value was < 1.3 which reflects the lower sensitivity of the MPN technique used.



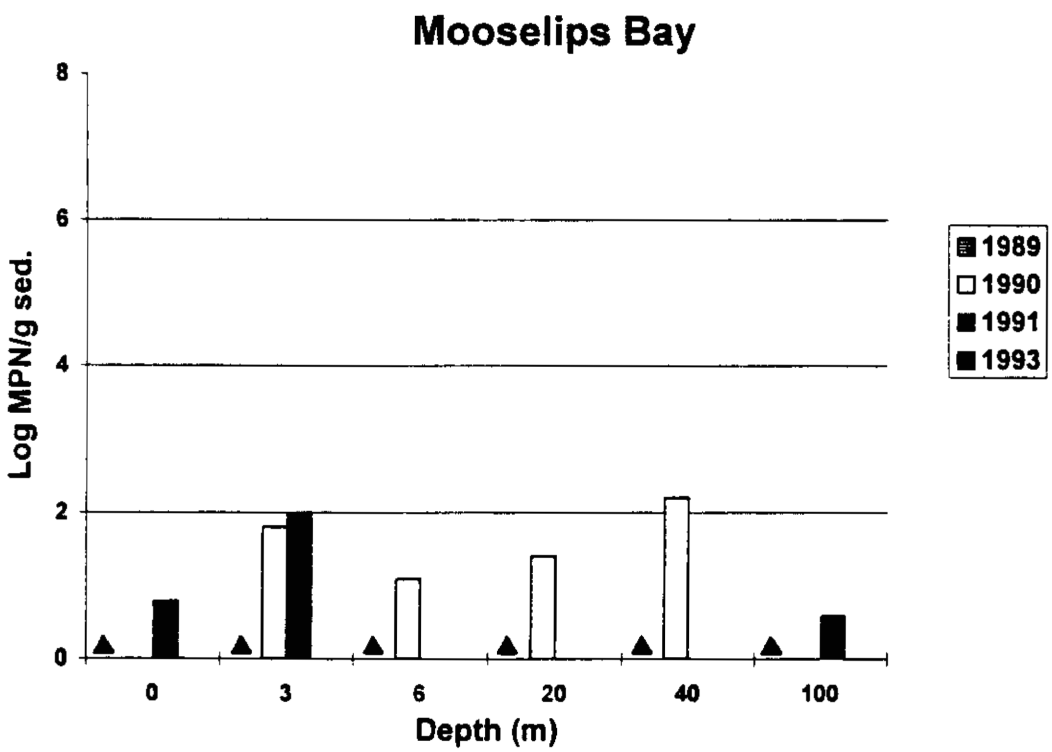
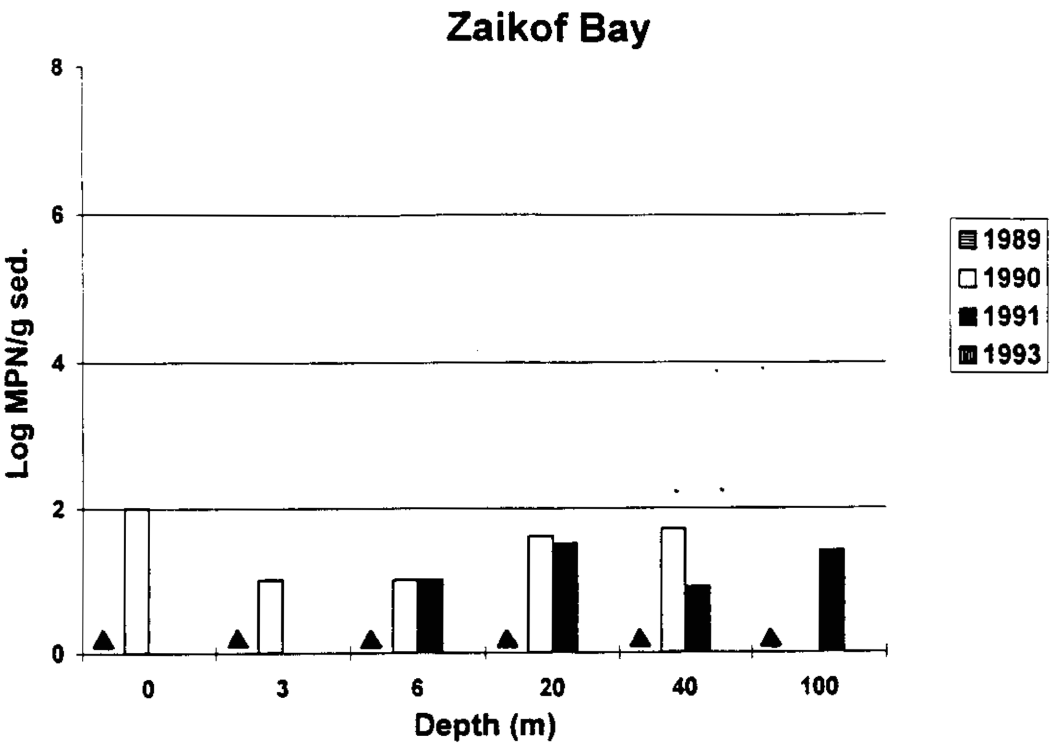


Figure 3c. Log Most Probable Number of hydrocarbon-degrading microorganisms in surface sediments from the shoreline to 100 m depth offshore collected from Sleepy Bay and Mooselips Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar for a date or depth indicates that the measured value was < 1.3 which reflects the lower sensitivity of the MPN technique used.



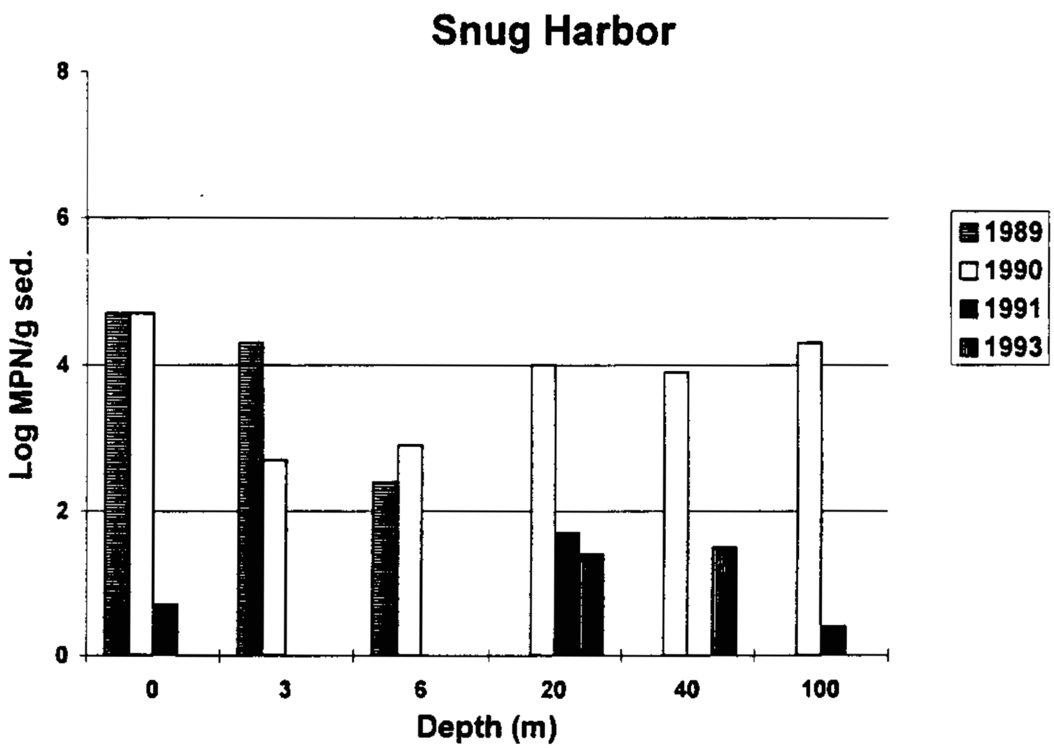
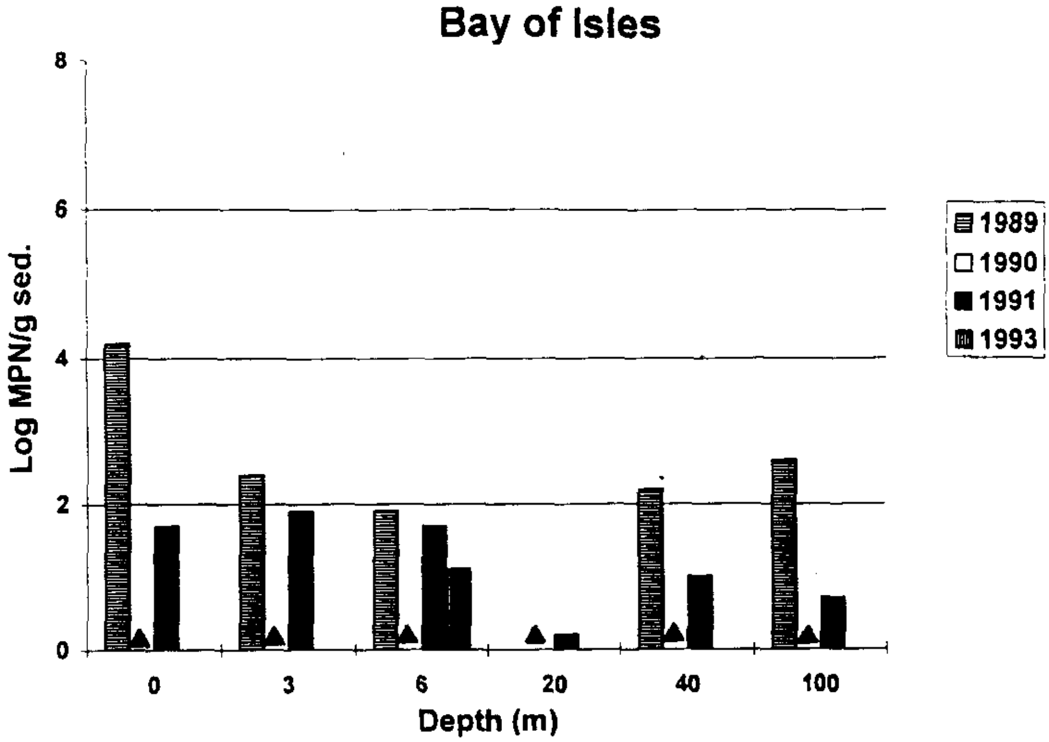


Figure 3d. Log Most Probable Number of hydrocarbon-degrading microorganisms in surface sediments from the shoreline to 100 m depth offshore collected from Zaikof Bay and Snug Harbor in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar for a date or depth indicates that the measured value was < 1.3 which reflects the lower sensitivity of the MPN technique used.



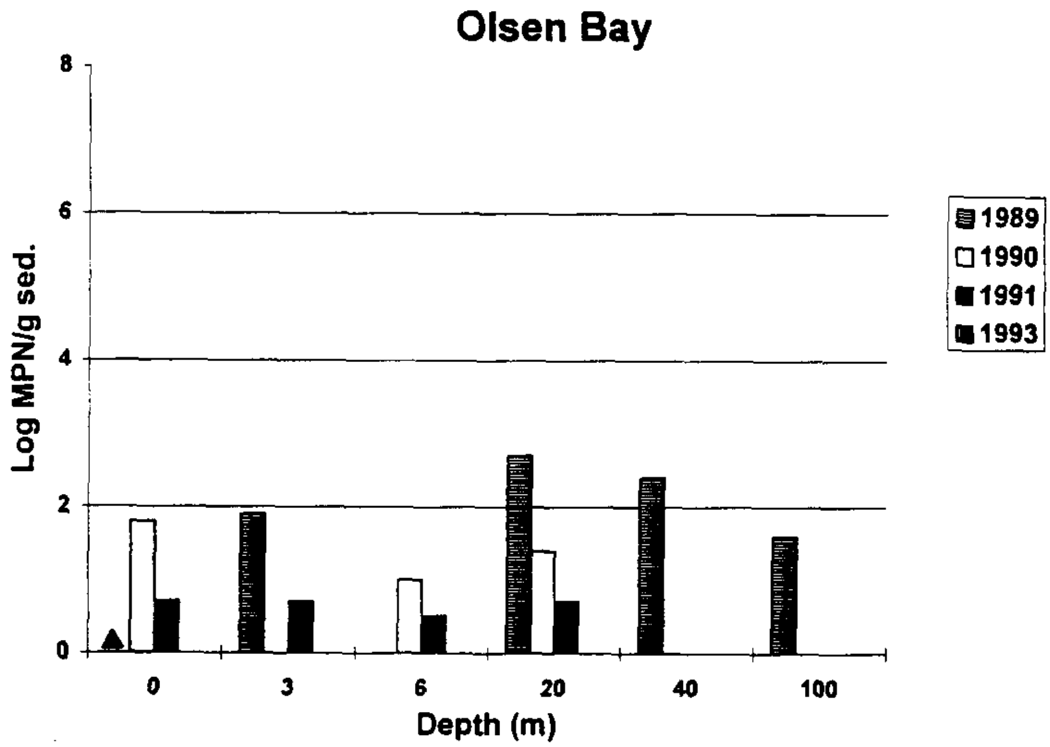


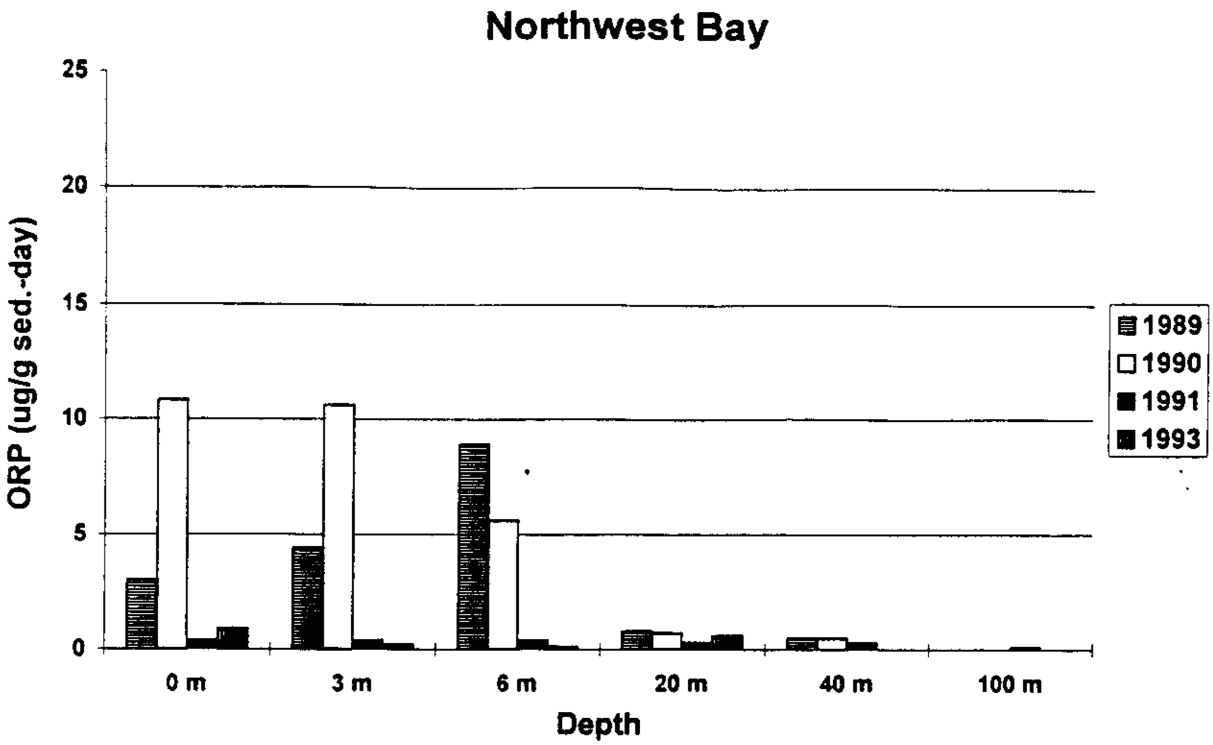
Figure 3e. Log Most Probable Number of hydrocarbon-degrading microorganisms in surface sediments from the shoreline to 100 m depth offshore collected from Bay of Isles and Olsen Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar for a date or depth indicates that the measured value was < 1.3 which reflects the lower sensitivity of the MPN technique used.

Table 3. Summary of hexadecane oxidation rate potentials (average rate for two day incubation) for sediment slurries from samples collected in July 1993 (Scorpius cruise).

	Depth (m)	% Dry Weight	% Mineralized	ORP µg/(g dry wt.-day) (@95% Confid. Level)		
Northwest Bay	Beach	0.88	1.7	0.9	±	0.9
7/8/93	Sub-Surf	0.92	12.2	6.1	±	1.4
Site #1	3	0.80	0.4	0.2	±	0.1
	6	0.69	0.2	0.1	±	0.1
	20	0.47	1.2	0.6	±	0.2
	40	0.70	0.0	0.0	±	0.1
	100	0.46	0.1	0.0	±	0.1
Herring Bay	Beach	0.77	10.9	5.5	±	1.6
7/9/93	Sub-Surf	0.72	5.7	2.8	±	2.1
Site #2	3	0.66	1.3	0.7	±	0.3
	6	0.75	2.1	1.1	±	1.1
	20	0.74	0.3	0.1	±	0.1
	40	0.89	0.1	0.0	±	0.0
	100	0.72	0.1	0.0	±	0.1
Lower Herring Bay	Beach	0.85	0.5	0.3	±	0.1
7/10/93	Sub-Surf	0.82	0.0	0.0	±	0.0
Site #3	3	0.97	3.1	1.5	±	0.7
	6	0.91	3.2	1.6	±	1.3
	20	0.81	0.5	0.2	±	0.1
	40	0.75	0.1	0.1	±	0.1
	100	0.37	0.1	0.1	±	0.1
Drier Bay	Beach	0.97	3.1	1.6	±	0.5
7/11/93	Sub-Surf	0.81	1.5	0.7	±	0.6
Site #4	3	0.90	0.5	0.3	±	0.1
	6	0.51	1.3	0.7	±	0.2
	20	0.52	1.8	0.9	±	0.4
	40	0.63	0.2	0.1	±	0.1
	100	0.37	0.0	0.0	±	0.0
Sleepy Bay	Beach	0.76	1.2	0.6	±	0.2
7/11 to 7/12/93	Sub-Surf	0.85	16.5	8.3	±	5.3
Site #5	3	0.75	1.6	0.8	±	0.3
	6	0.75	1.0	0.5	±	0.1
	20	0.70	1.0	0.5	±	0.1
	40	0.77	0.4	0.2	±	0.1
	100	0.66	0.3	0.1	±	0.1

Table 3 cont. Summary of hexadecane oxidation rate potentials (average rate for two day incubation) for sediment slurries from samples collected in July 1993 (Scorpius cruise).

	Depth (m)	% Dry Weight	% Mineralized	ORP µg/(g dry wt.-day) (@95% Confid. Level)		
Mooselips Bay 7/12 to 7/13/93 Site #6	Beach	0.75	8.8	4.4	±	1.3
	Sub-Surf	0.88	0.4	0.2	±	0.1
	3	0.71	1.6	0.8	±	0.2
	6	0.70	1.0	0.5	±	0.1
	20	0.70	1.2	0.6	±	0.2
	40	0.66	0.7	0.3	±	0.1
	100	0.71	0.4	0.2	±	0.1
Zaikof Bay 7/13/93 Site #7	Beach	0.81	1.2	0.6	±	0.1
	Sub-Surf	0.87	0.7	0.3	±	0.1
	3	0.72	1.5	0.7	±	0.1
	6	0.61	1.4	0.7	±	0.1
	20	0.65	4.4	2.2	±	1.3
	40	0.63	0.6	0.3	±	0.1
	100	0.74	0.5	0.2	±	0.1
Snug Harbor 7/14/93 Site #8	Beach	0.75	1.2	0.6	±	0.1
	Sub-Surf	0.88	5.3	2.7	±	0.3
	3	0.76	2.6	1.3	±	1.1
	6	0.73	0.4	0.2	±	0.1
	20	0.68	0.3	0.2	±	0.1
	40	0.57	0.3	0.2	±	0.1
	100	0.43	0.2	0.1	±	0.1
Bay of Isles 7/15/93 Site #9	Beach	0.84	7.2	3.6	±	2.3
	Sub-Surf	0.85	4.0	2.0	±	0.5
	3	0.81	0.6	0.3	±	0.1
	6	0.54	1.8	0.9	±	0.2
	20	0.23	1.0	0.5	±	0.2
	40	0.62	0.7	0.3	±	0.1
	100	0.38	0.6	0.3	±	0.1
Olsen Bay 7/15 to 7/16/93 Site #10	Beach	0.71	0.4	0.2	±	0.1
	Sub-Surf	0.90	0.1	0.1	±	0.1
	3	0.54	0.8	0.4	±	0.1
	6	0.53	1.1	0.5	±	0.1
	20	0.34	1.2	0.6	±	0.1
	40	0.70	0.3	0.2	±	0.1
	100	0.44	0.3	0.1	±	0.1



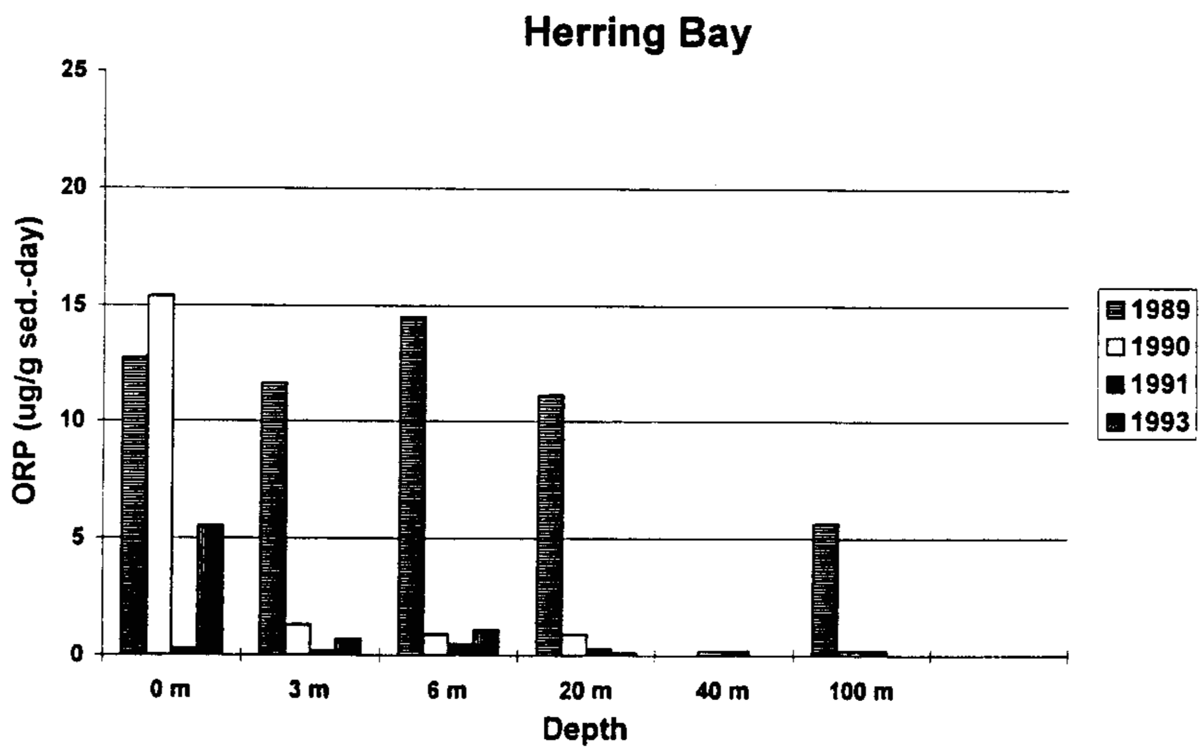
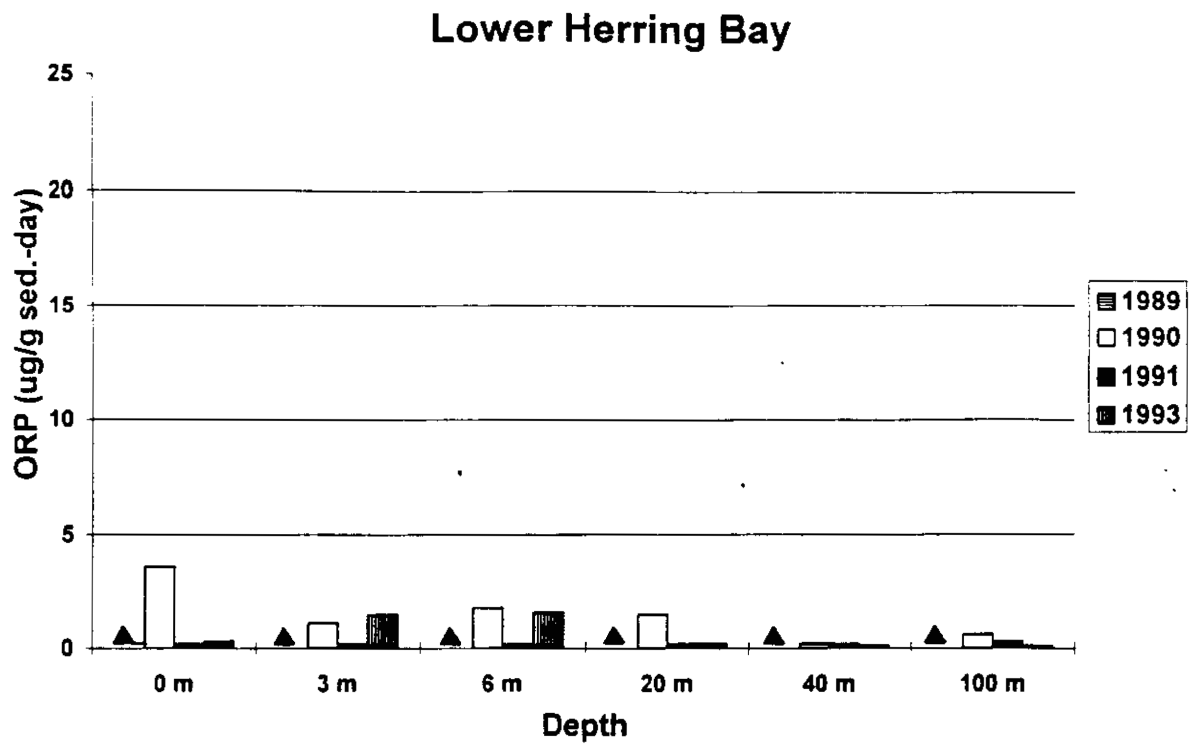


Figure 4a. Oxidation rate potentials for hexadecane (average for a two day incubation) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Northwest Bay and Herring Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.



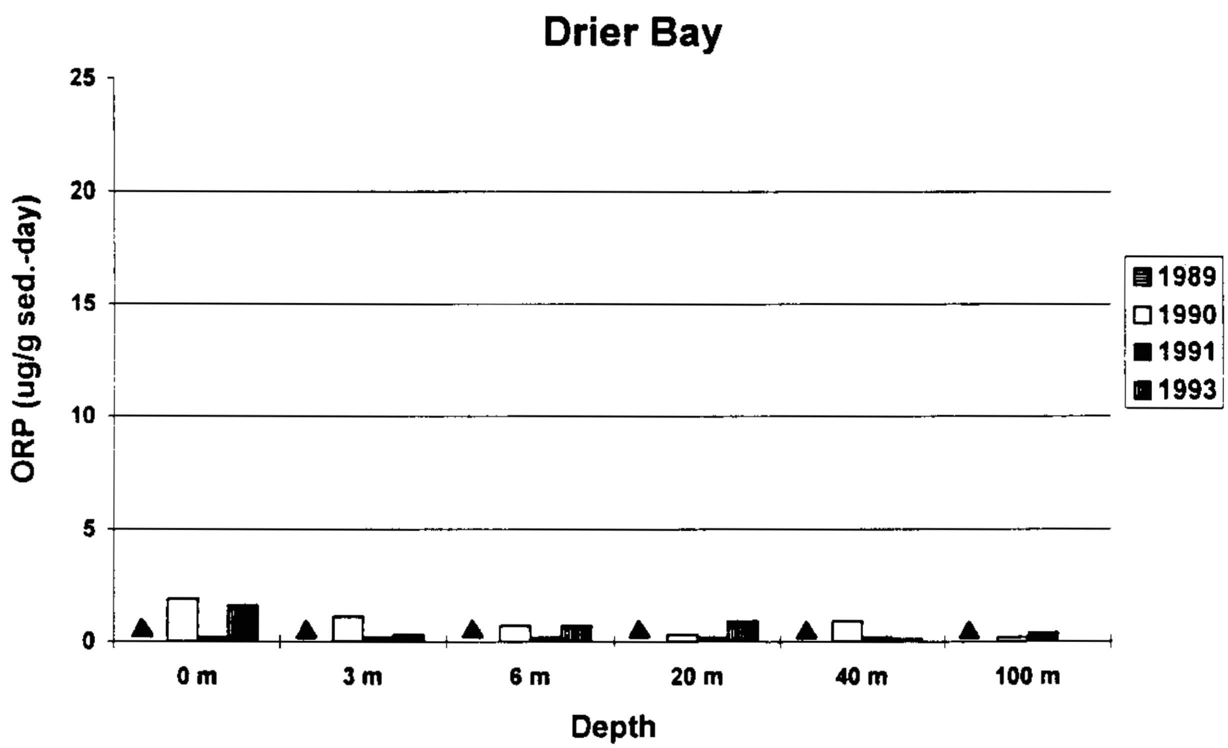


Figure 4b. Oxidation rate potentials for hexadecane (average for a two day incubation) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Lower Herring Bay and Drier Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.

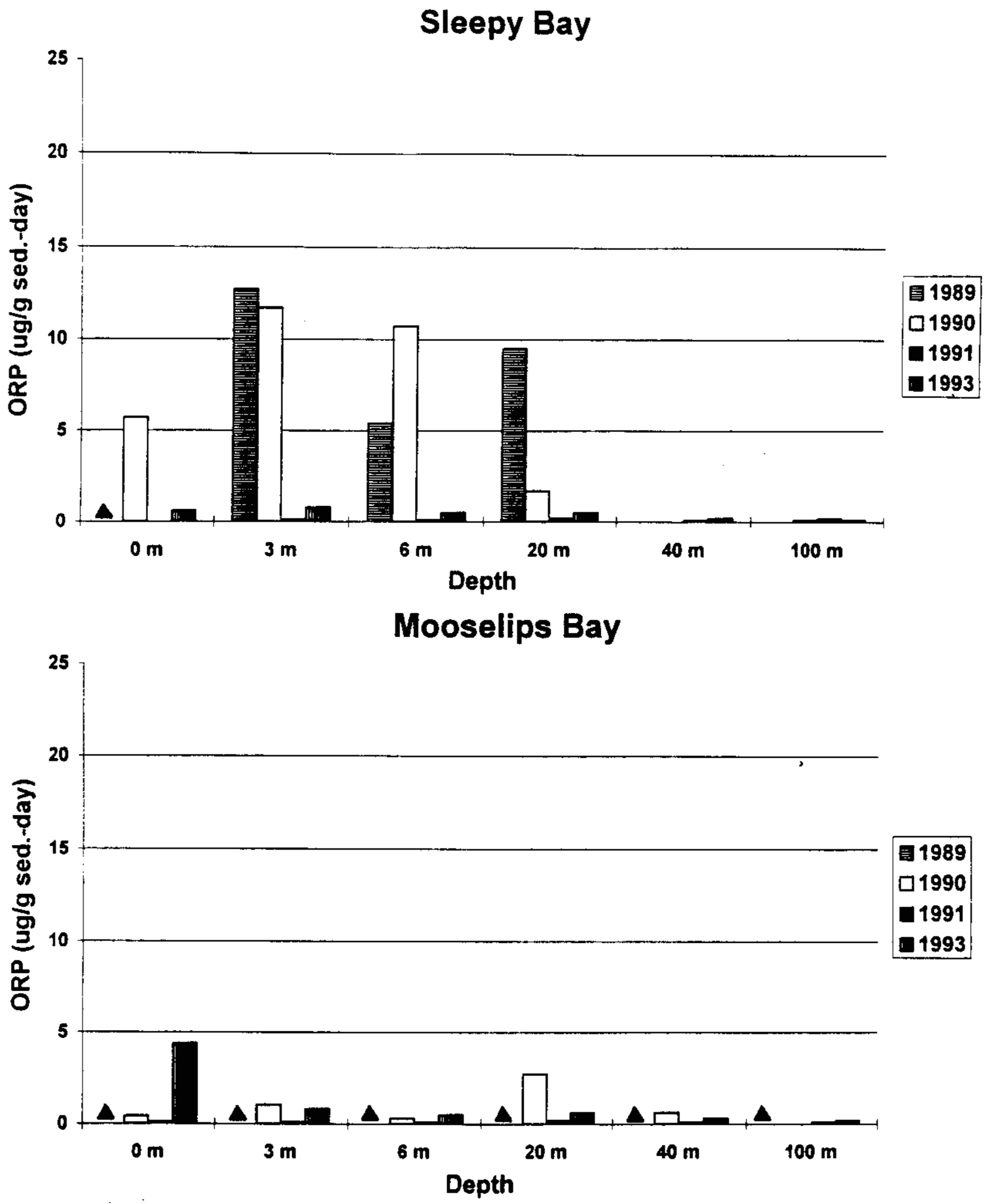


Figure 4c. Oxidation rate potentials for hexadecane (average for a two day incubation) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Sleepy Bay and Mooselips Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.

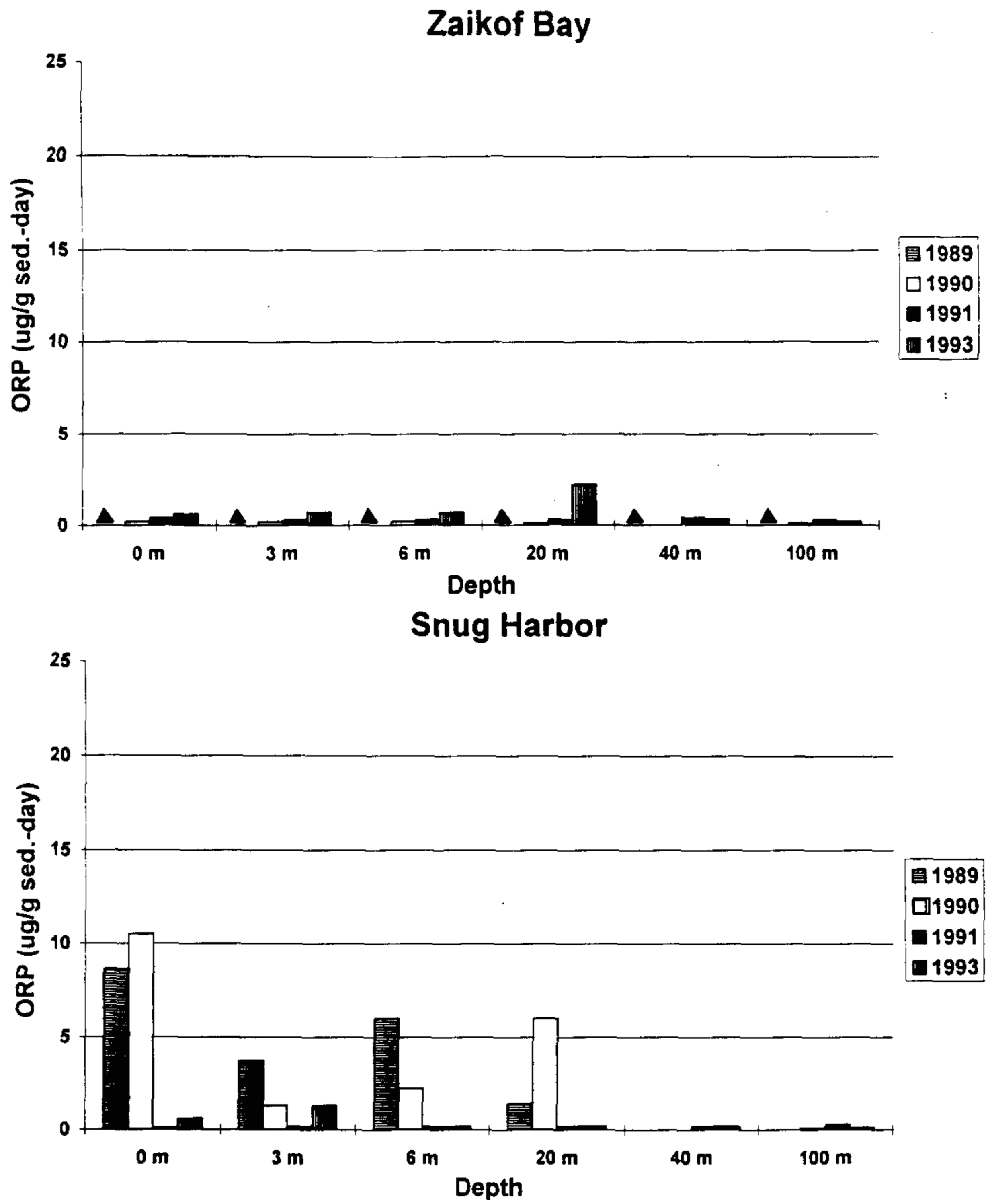


Figure 4d. Oxidation rate potentials for hexadecane (average for a two day incubation) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Zaikof Bay and Snug Harbor in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.

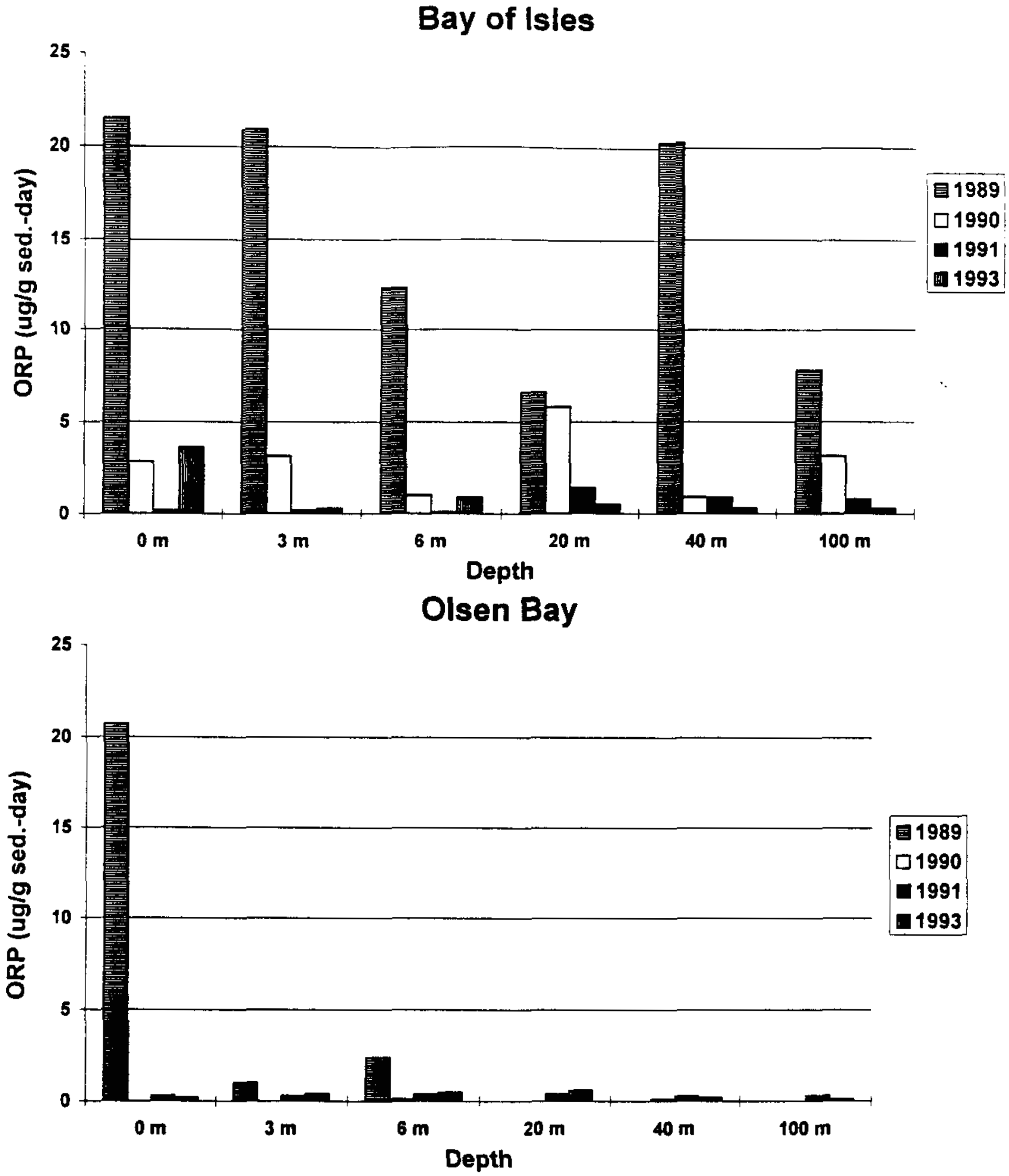


Figure 4e. Oxidation rate potentials for hexadecane (average for a two day incubation) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Bay of Isles and Olsen Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.

Table 4. Summary of phenanthrene oxidation rate potentials (average rate for two day incubation) for sediment slurries from samples collected in July 1993 (Scorpius cruise).

	Depth (m)	%Dry Weight	% Mineralized	ORP µg/g dry wt.-day (@95% confid. level)		
	Beach	0.88	0.0	0.0	±	0.0
Northwest Bay	Sub-Surf	0.92	0.6	0.3	±	0.1
7/8/93	3	0.80	0.0	0.0	±	0.0
Site #1	6	0.69	0.0	0.0	±	0.0
	20	0.47	0.0	0.0	±	0.1
	40	0.70	0.0	0.0	±	0.0
	100	0.46	0.0	0.0	±	0.0
Herring Bay	Beach	0.77	0.0	0.0	±	0.0
7/9/93	Sub-Surf	0.72	0.2	0.1	±	0.1
Site #2	3	0.66	0.0	0.0	±	0.0
	6	0.75	0.0	0.0	±	0.0
	20	0.74	0.0	0.0	±	0.0
	40	0.89	0.0	0.0	±	0.0
	100	0.72	0.0	0.0	±	0.0
Lower Herring Bay	Beach	0.85	0.0	0.0	±	0.0
7/10/93	Sub-Surf	0.82	0.0	0.0	±	0.0
Site #3	3	0.97	0.0	0.0	±	0.0
	6	0.91	0.0	0.0	±	0.0
	20	0.81	0.0	0.0	±	0.0
	40	0.75	0.0	0.0	±	0.0
	100	0.37	0.0	0.0	±	0.1
Drier Bay	Beach	0.97	0.8	0.4	±	0.3
7/11/93	Sub-Surf	0.81	0.4	0.2	±	0.2
Site #4	3	0.90	2.3	1.1	±	0.9
	6	0.51	0.5	0.2	±	0.2
	20	0.52	0.3	0.1	±	0.1
	40	0.63	0.4	0.2	±	0.1
	100	0.37	7.9	4.0	±	2.5
Sleepy Bay	Beach	0.76	0.3	0.1	±	0.1
7/11 to 7/12/93	Sub-Surf	0.85	1.5	0.8	±	0.3
Site #5	3	0.75	0.3	0.1	±	0.1
	6	0.75	0.2	0.1	±	0.0
	20	0.70	0.2	0.1	±	0.1
	40	0.77	0.2	0.1	±	0.0
	100	0.66	2.7	1.4	±	0.7

Table 4 cont. Summary of phenanthrene oxidation rate potentials (average rate for two day incubation) for sediment slurries from samples collected in July 1993 (Scorpius cruise).

	Depth (m)	%Dry Weight	% Mineralized	ORP µg/g dry wt.-day (@95% confid. level)		
Mooselips Bay	Beach	0.75	0.6	0.3	±	0.1
7/12 to 7/13/93	Sub-Surf	0.88	0.4	0.2	±	0.0
Site #6	3	0.71	0.1	0.0	±	0.0
	6	0.70	0.3	0.1	±	0.1
	20	0.70	0.6	0.3	±	0.1
	40	0.66	0.3	0.1	±	0.1
	100	0.71	0.2	0.1	±	0.0
Zaikof Bay	Beach	0.81	0.2	0.1	±	0.0
7/13/93	Sub-Surf	0.87	0.1	0.1	±	0.0
Site #7	3	0.72	0.2	0.1	±	0.0
	6	0.61	0.2	0.1	±	0.0
	20	0.65	0.2	0.1	±	0.0
	40	0.63	0.1	0.1	±	0.0
	100	0.74	0.3	0.1	±	0.1
Snug Harbor	Beach	0.75	0.1	0.0	±	0.1
7/14/93	Sub-Surf	0.88	0.3	0.1	±	0.1
Site #8	3	0.76	0.0	0.0	±	0.0
	6	0.73	0.0	0.0	±	0.0
	20	0.68	0.0	0.0	±	0.0
	40	0.57	0.0	0.0	±	0.0
	100	0.43	0.1	0.0	±	0.1
Bay of Isles	Beach	0.84	0.0	0.0	±	0.0
7/15/93	Sub-Surf	0.85	0.1	0.1	±	0.0
Site #9	3	0.81	0.0	0.0	±	0.0
	6	0.54	0.1	0.0	±	0.1
	20	0.23	0.5	0.3	±	0.2
	40	0.62	0.5	0.2	±	0.1
	100	0.38	0.3	0.1	±	0.1
Olsen Bay	Beach	0.71	0.0	0.0	±	0.0
7/15 to 7/16/93	Sub-Surf	0.90	0.0	0.0	±	0.0
Site #10	3	0.54	0.2	0.1	±	0.1
	6	0.53	0.0	0.0	±	0.0
	20	0.34	0.0	0.0	±	0.1
	40	0.70	0.0	0.0	±	0.0
	100	0.44	0.0	0.0	±	0.0

Table 5. Summary of phenanthrene oxidation rate potentials (average rate for four day incubation) for sediment slurries from samples collected in July 1993 (Scorpius cruise).

	Depth (m)	% Dry Weight	% Mineralized	ORP µg/g dry wt.-day (@95% confid. level)		
Northwest Bay	Beach	0.88	0.0	0.0	±	0.0
7/8/93	Sub-Surf	0.92	10.1	2.5	±	0.9
Site #1	3	0.80	0.0	0.0	±	0.0
	6	0.69	0.0	0.0	±	0.0
	20	0.47	0.0	0.0	±	0.1
	40	0.70	0.0	0.0	±	0.0
	100	0.46	0.0	0.0	±	0.0
Herring Bay	Beach	0.77	0.0	0.0	±	0.0
7/9/93	Sub-Surf	0.72	0.6	0.2	±	0.2
Site #2	3	0.66	0.0	0.0	±	0.0
	6	0.75	0.0	0.0	±	0.0
	20	0.74	0.0	0.0	±	0.0
	40	0.89	0.0	0.0	±	0.0
	100	0.72	0.0	0.0	±	0.0
Lower Herring Bay	Beach	0.85	0.0	0.0	±	0.0
7/10/93	Sub-Surf	0.82	0.0	0.0	±	0.0
Site #3	3	0.97	0.0	0.0	±	0.0
	6	0.91	0.0	0.0	±	0.0
	20	0.81	0.0	0.0	±	0.0
	40	0.75	0.0	0.0	±	0.0
	100	0.37	0.1	0.0	±	0.1
Drier Bay	Beach	0.97	0.2	0.0	±	0.0
7/11/93	Sub-Surf	0.81	0.1	0.0	±	0.0
Site #4	3	0.90	0.5	0.1	±	0.1
	6	0.51	0.7	0.2	±	0.2
	20	0.52	0.4	0.1	±	0.2
	40	0.63	3.9	1.0	±	0.9
	100	0.37	0.7	0.2	±	0.1
Sleepy Bay	Beach	0.76	0.1	0.0	±	0.0
7/11 to 7/12/93	Sub-Surf	0.85	4.4	1.1	±	1.0
Site #5	3	0.75	0.2	0.1	±	0.0
	6	0.75	0.2	0.0	±	0.0
	20	0.70	0.3	0.1	±	0.0
	40	0.77	0.2	0.0	±	0.0
	100	0.66	1.5	0.4	±	0.3

Table 5 cont. Summary of phenanthrene oxidation rate potentials (average rate for four day incubation) for sediment slurries from samples collected in July 1993 (Scorpius cruise).

	Depth (m)	% Dry Weight	% Mineralized	ORP μg/g dry wt.-day (@95% confid. level)		
Mooselips Bay 7/12 to 7/13/93 Site #6	Beach	0.75	0.7	0.2	±	0.2
	Sub-Surf	0.88	0.3	0.1	±	0.1
	3	0.71	0.3	0.1	±	0.1
	6	0.70	1.5	0.4	±	0.2
	20	0.70	0.2	0.1	±	0.1
	40	0.66	0.5	0.1	±	0.1
	100	0.71	0.2	0.0	±	0.0
Zaikof Bay 7/13/93 Site #7	Beach	0.81	0.2	0.1	±	0.0
	Sub-Surf	0.87	0.2	0.1	±	0.0
	3	0.72	0.2	0.1	±	0.0
	6	0.61	0.2	0.1	±	0.0
	20	0.65	0.2	0.0	±	0.0
	40	0.63	0.1	0.0	±	0.0
	100	0.74	0.2	0.1	±	0.0
Snug Harbor 7/14/93 Site #8	Beach	0.75	0.0	0.0	±	0.0
	Sub-Surf	0.88	0.1	0.0	±	0.0
	3	0.76	0.0	0.0	±	0.0
	6	0.73	0.0	0.0	±	0.0
	20	0.68	0.0	0.0	±	0.0
	40	0.57	0.0	0.0	±	0.0
	100	0.43	0.1	0.0	±	0.1
Bay of Isles 7/15/93 Site #9	Beach	0.84	0.0	0.0	±	0.0
	Sub-Surf	0.85	0.1	0.0	±	0.0
	3	0.81	0.0	0.0	±	0.0
	6	0.54	0.3	0.1	±	0.1
	20	0.23	0.6	0.1	±	0.1
	40	0.62	0.5	0.1	±	0.0
	100	0.38	0.5	0.1	±	0.1
Olsen Bay 7/15 to 7/16/93 Site #10	Beach	0.71	0.0	0.0	±	0.0
	Sub-Surf	0.90	0.0	0.0	±	0.0
	3	0.54	0.0	0.0	±	0.0
	6	0.53	0.0	0.0	±	0.0
	20	0.34	0.0	0.0	±	0.1
	40	0.70	0.0	0.0	±	0.0
	100	0.44	0.0	0.0	±	0.0

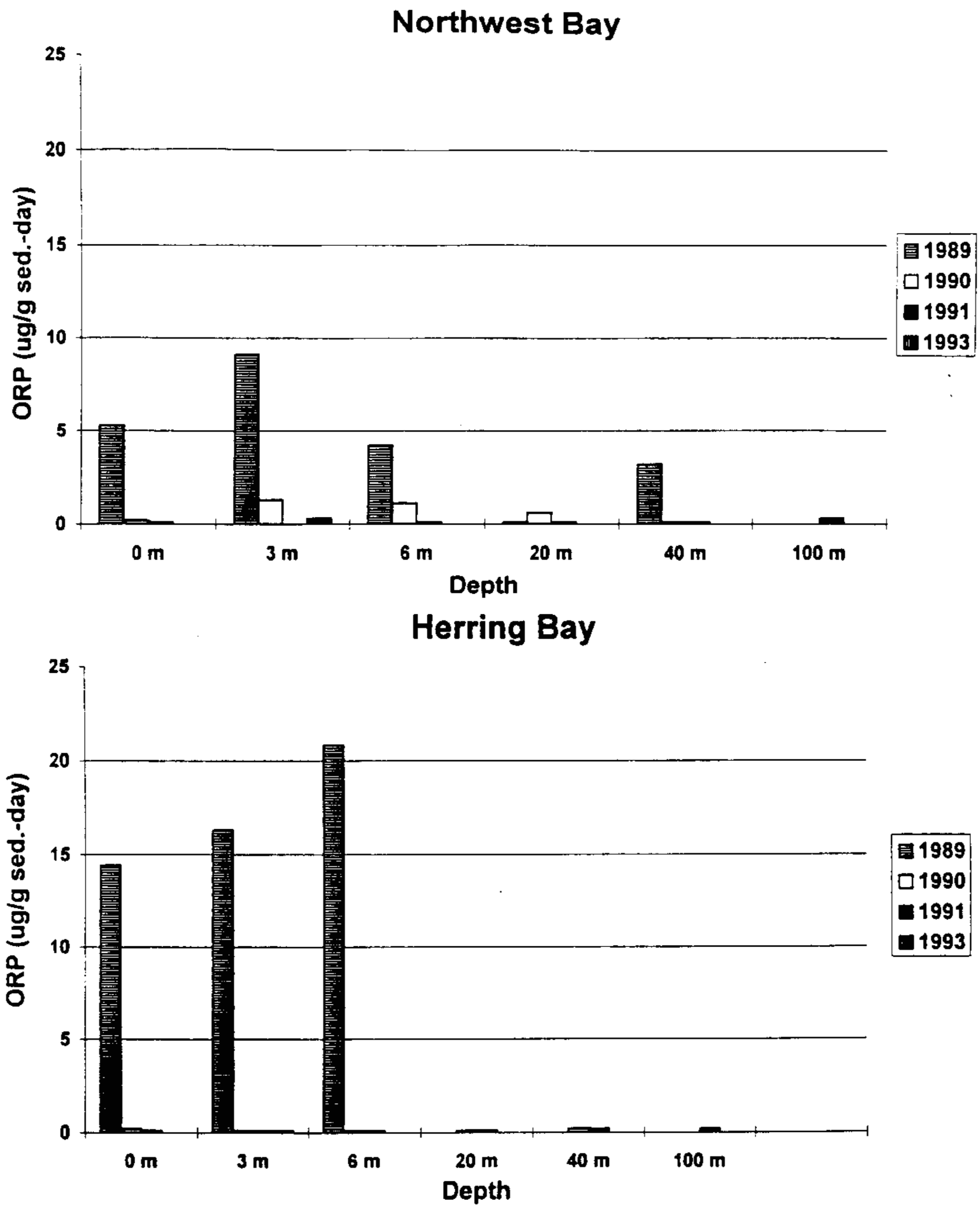


Figure 5a. Oxidation rate potentials (average for a two day incubation) for naphthalene (1989) and phenanthrene (1990,1991 and 1993) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Northwest Bay and Herring Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.

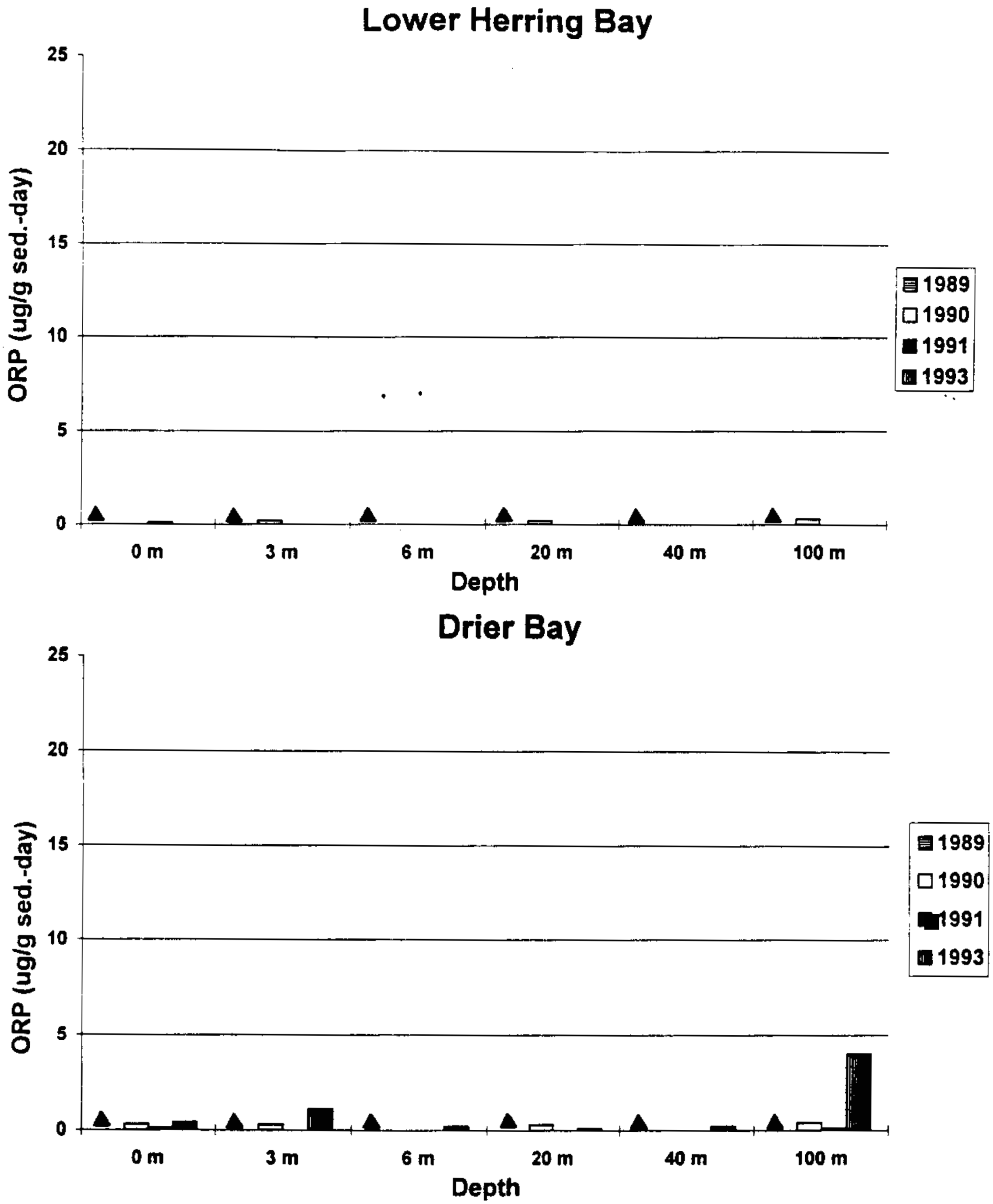
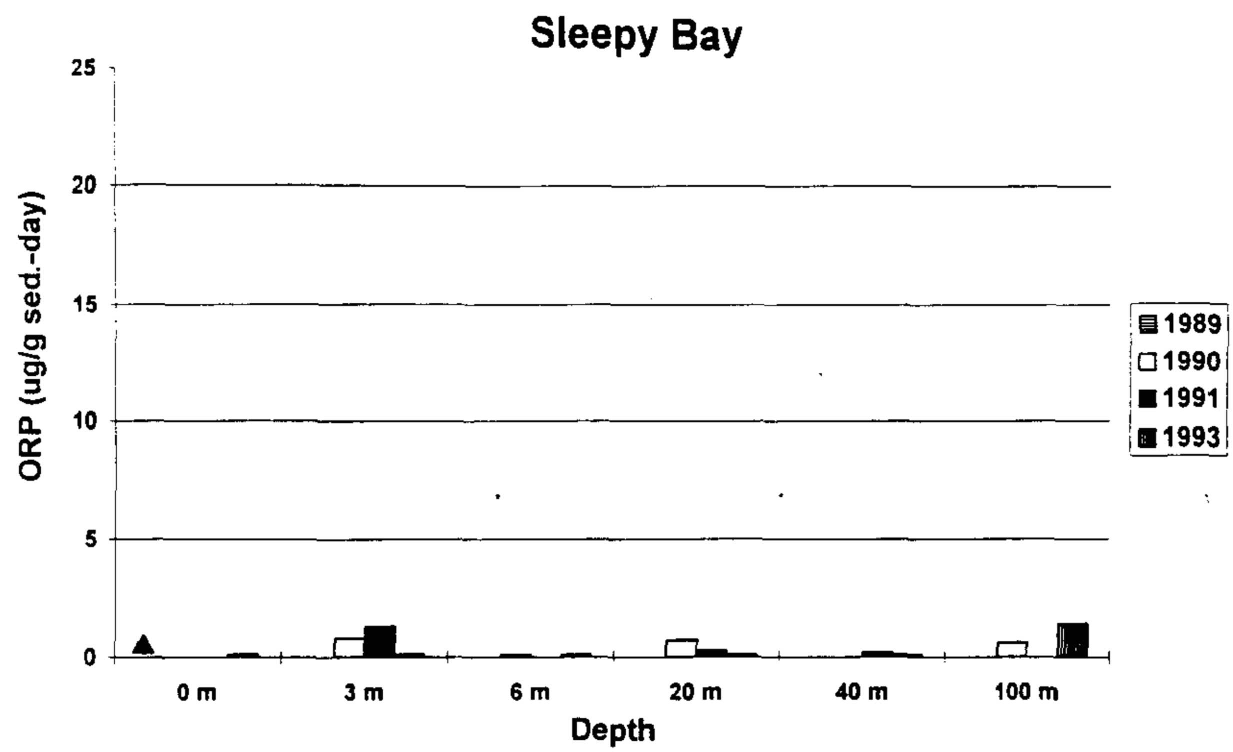


Figure 5b. Oxidation rate potentials (average for a two day incubation) for naphthalene (1989) and phenanthrene (1990,1991 and 1993) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Lower Herring Bay and Drier Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.



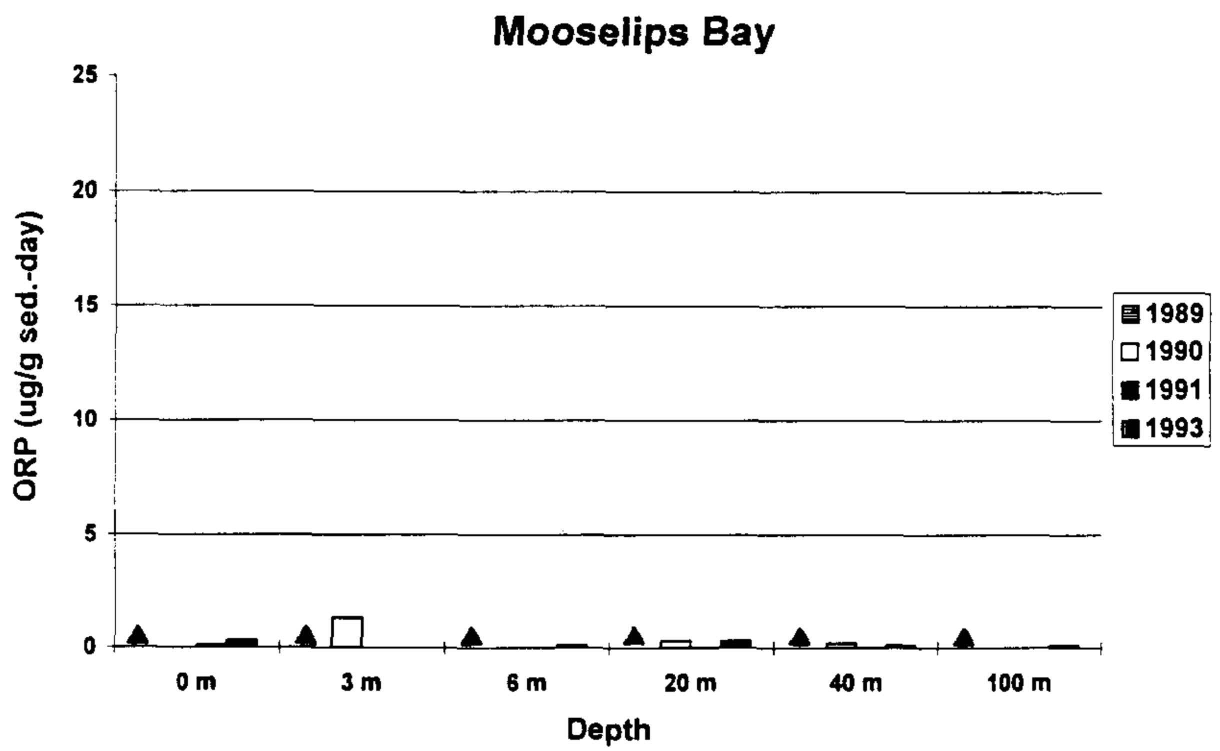
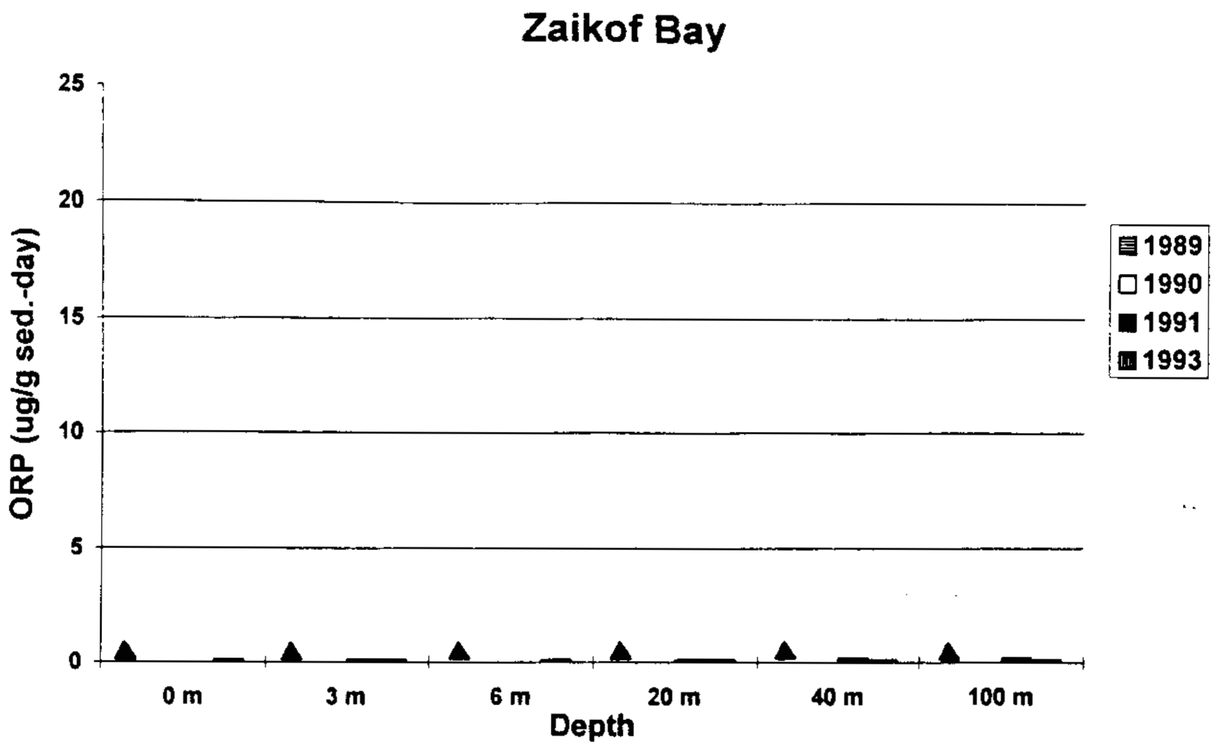


Figure 5c. Oxidation rate potentials (average for a two day incubation) for naphthalene (1989) and phenanthrene (1990, 1991 and 1993) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Sleepy Bay and Mooselips Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.



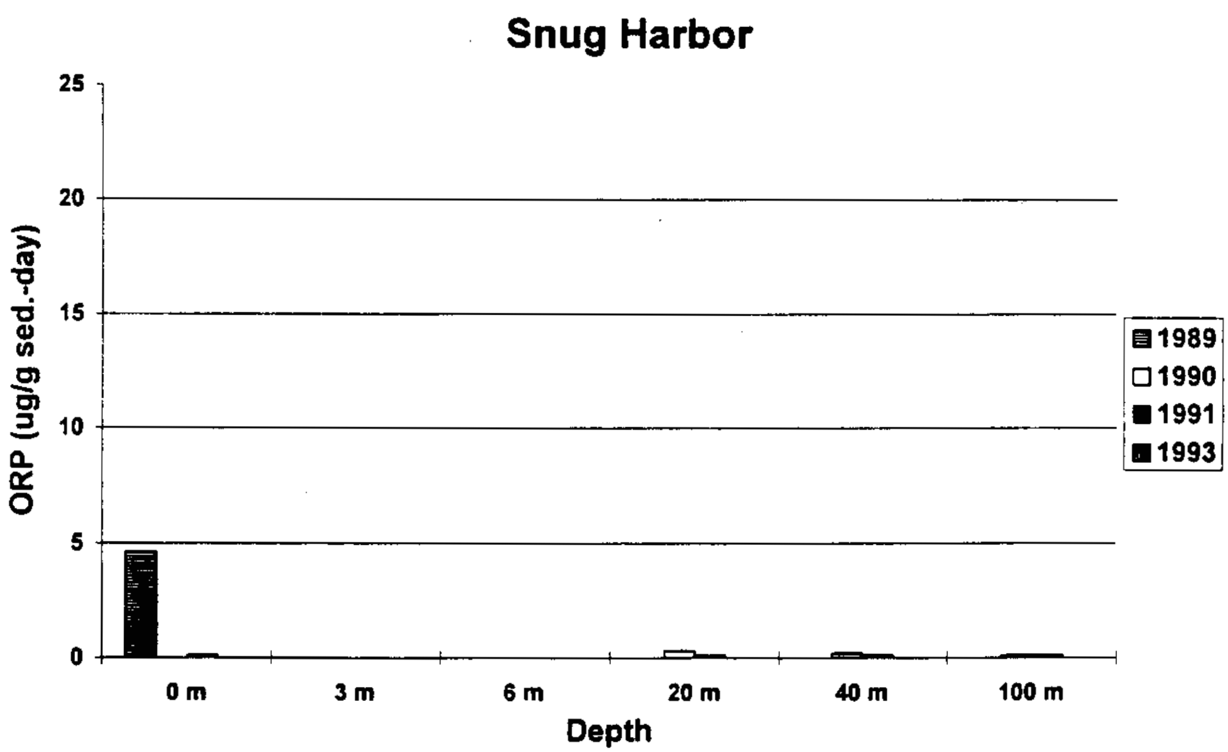
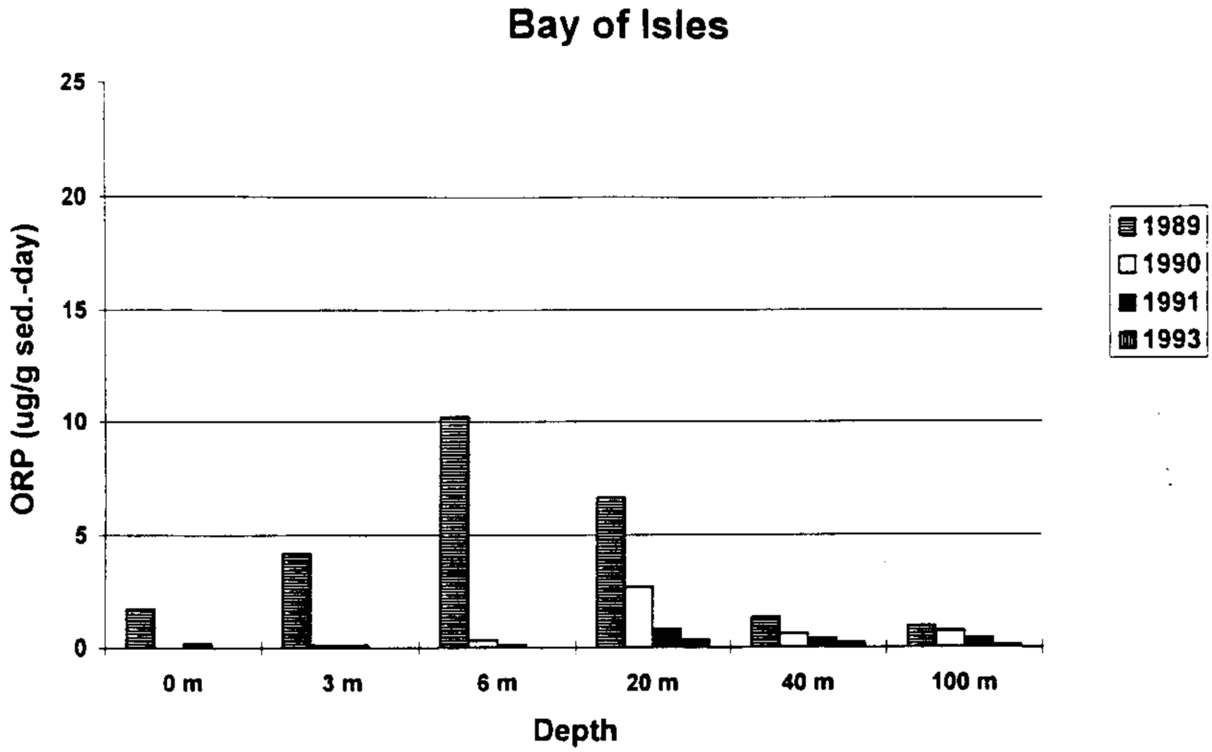


Figure 5d. Oxidation rate potentials (average for a two day incubation) for naphthalene (1989) and phenanthrene (1990,1991 and 1993) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Zaikof Bay and Snug Harbor in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.



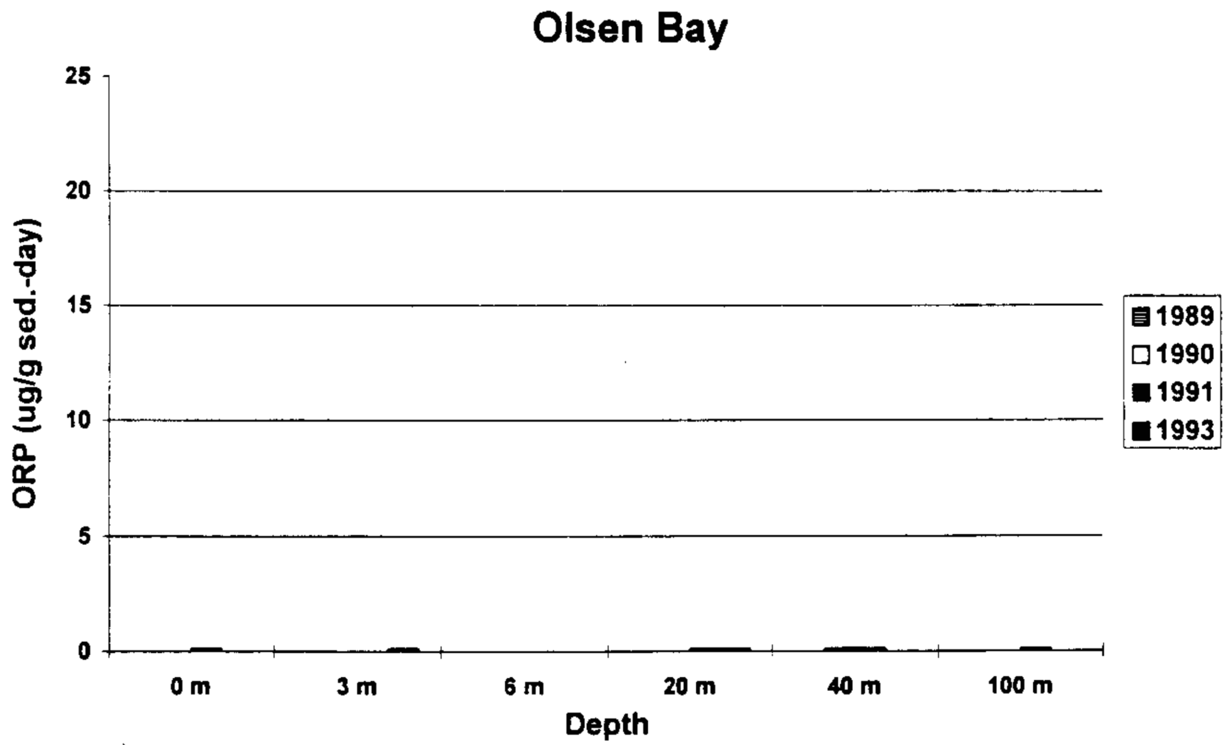


Figure 5e. Oxidation rate potentials (average for a two day incubation) for naphthalene (1989) and phenanthrene (1990,1991 and 1993) in surface sediment slurries from the shoreline to 100 m depth offshore collected from Bay of Isles and Olsen Bay in the summers of 1989, 1990, 1991 and 1993 (see also Braddock et al., 1993). A bold triangle indicates that data were unavailable for that date or depth. The absence of a bar or triangle indicates a measured value of zero.

Discussion

Microorganisms capable of degrading a variety of petroleum hydrocarbons are widespread in marine environments (Atlas et al., 1981; Leahy and Colwell, 1990). Our results show that the numbers of hydrocarbon-degrading microorganisms vary by several orders of magnitude among sites sampled after the *Exxon Valdez* oil spill (Braddock et al., 1993; Braddock et al., in press) and with time since the spill (this report). A number of studies have shown a positive correlation between the numbers of hydrocarbon-degrading microorganisms and oiling patterns in marine systems polluted by hydrocarbons (Colwell et al., 1978; Roubal and Atlas, 1978; Ward et al., 1980; Lizarraga-Partida et al., 1991).

Enrichment of hydrocarbon degraders was apparent after the *Amoco Cadiz* oil spill. Ward et al. (1980) found that, of a total of 10^7-10^8 bacteria per gram of sediment, there were 10^4-10^7 hydrocarbon-degrading bacteria per gram of sediment in oiled areas versus less than 5×10^2 cells/g of sediment in unoiled areas. Similar numbers were found for the relative proportion of hydrocarbon degraders to total numbers of microorganisms in shoreline sediments in 1989 in PWS (Braddock et al., 1993). Total bacterial populations in shoreline sediments during the Fairweather cruise were approximately 10^7-10^8 cells/g sediment while numbers of hydrocarbon-degrading bacteria ranged from 10^4-10^5 cells/g in oiled sediments and less than 3×10^2 at the reference sites. We have had the opportunity to follow these microbial populations with time since the *Exxon Valdez* spill. While overall numbers of hydrocarbon degraders have generally decreased since the spill (Fig. 3a-e), the numbers increased offshore at the 40 and 100 m depths with time reaching a peak in 1990, indicating that there may have been movement of oil to offshore sediments with time. By 1993 the numbers were generally low at all sites and depths (Table 2 and Fig. 3a-e) except a few intertidal samples collected from shallow pits (Table 2).

The only baseline data available for a geographical area near that affected by the *Exxon Valdez* are from studies performed more than ten years ago. Roubal and Atlas (1978) studied natural populations of hydrocarbon-degrading microorganisms in sediments along the coast of south-central Alaska and reported finding only 0.6-12 colony-forming units per gram of sediment. Cook Inlet populations were two or three orders of magnitude higher. The highest mean numbers of hydrocarbon degraders measured were 8.4×10^3 CFU/g sediment at a site in upper Cook Inlet near several oil wells (Roubal and Atlas, 1978). These authors hypothesized that sediments containing 10^3 to 10^4 oil degraders/g probably had a previous history of oil exposure from either biogenic or polluting sources. At the time of this 1978 study there were already several oil platforms producing oil in upper Cook Inlet where the high numbers of hydrocarbon oxidizers were found. In 1993 PWS samples analyzed in our study, only three sites had populations of hydrocarbon degraders greater than 10^4/g sediment. All three of these samples were collected from pits on shorelines heavily oiled during the *Exxon Valdez* oil spill (Northwest, Herring and Sleepy Bays).

It has been recently proposed that substantial quantities of hydrocarbons are naturally found in PWS derived from seeps in the eastern Gulf of Alaska (Page et al., 1993) and from refined products originating in California (Kvenvolden et al., 1993). This oil can be distinguished from

Exxon Valdez oil by very expensive and time-consuming advanced chemical hydrocarbon fingerprinting techniques. These additional sources of oil in PWS confound the use of standard chemical analyses alone in the collection of data for damage assessment purposes. If this older weathered oil is present (in surface sediments) at our study sites then our data indicate that the older oil has not led to increased populations of hydrocarbon degraders. The response of microbial populations may then be a useful complement to hydrocarbon chemistry data in defining the extent of recent pollution occurring from the spill.

There was no statistically significant correlation between the total numbers of hydrocarbon-degrading bacteria and mineralization potentials for hexadecane. However, when high hexadecane mineralization potentials were measured the numbers of hydrocarbon oxidizers were generally also high. Increased populations of Sheen Screen positive organisms represent an increased potential for biodegradation of hydrocarbons in oil (Bartha and Atlas, 1987). But other factors such as salinity, temperature, mineral nutrient availability, oxygen availability, hydrocarbon concentration, and acclimation of the microbial population to a particular hydrocarbon component of the oil can affect the mineralization potential as well (Bartha and Atlas, 1987; Leahy and Colwell, 1990). Experiments in this study were designed to minimize as many of these factors as possible (including hydrocarbon availability) except the in situ microbial biomass and its potential to degrade the hydrocarbons added experimentally (see Brown et al., 1991). Using this "optimal" procedure, rates of hexadecane, naphthalene and phenanthrene mineralization among sites and sampling stations could be compared. For example, mineralization potential samples were run in a mineral salts medium with nutrients such as nitrogen and phosphorus, were well oxygenated and were incubated at a constant temperature (15 °C). In addition, a relatively large amount of hydrocarbon substrate was added to each sample to be assayed so that the final rate was dependent on added substrate rather than the hydrocarbon substrate in the original sample. The concentrations of the specific hydrocarbon we added greatly exceeded ambient levels in heavily oiled samples collected in 1989 (see Brown et al., 1991). The reported potentials thus reflect the potential of the in situ microbial populations (Bartha and Atlas, 1987; Aelion and Bradley, 1991) to transform hydrocarbons when incubated in conditions that are standardized and essentially optimal.

Bartha and Atlas (1987) summarized the results of a number of published studies on biodegradation rates (potentials) of samples from marine systems. They found a range of 5-2,500 µg/g-day for seawater communities under partially optimized conditions. These rates for nutrient enriched samples were found to be as much as 300-fold higher than for non-nutrient enriched samples. Values from our study range from 0 to approximately 40 µg/g sed-day. Therefore, our values fall at the low end of those reported by Bartha and Atlas for samples incubated under partially optimized conditions. A more recent study (Karl, 1992) conducted about six weeks after the grounding of the *Bahia Paraiso* in Antarctica in 1989 found extremely low rates for hexadecane mineralization potential (0.13-1.21 pmol/g sed-day) in samples run without nutrient amendments and incubated at 1 °C (sub-optimal conditions).

We found apparent differences in microbial preference for hexadecane, naphthalene or phenanthrene in Prince William Sound sediments temporally and with depth. Hexadecane potentials nearly always exceeded those for PAH except for sediments collected in the spring of

1990 where potentials for both hydrocarbon fractions were high in sediments from the shoreline through the 20 m depth. However, there did not appear to be a significant preference for naphthalene over phenanthrene when potentials were measured for both isotopes in samples collected at the same time (see Braddock et al., 1993). Both phenanthrene and naphthalene mineralization potentials were measured in shoreline and 3 m sediments in the fall of 1989. In these sediments the median degradation potentials for phenanthrene were approximately the same as those measured for naphthalene. Hydrocarbon polluted surficial sediments in Boston Harbor showed a similar relationship between phenanthrene and naphthalene utilization where turnover times measured for these hydrocarbons were similar at all sites (Shiaris, 1989).

When incubated under optimal conditions, hexadecane and naphthalene and/or phenanthrene degradation potentials are useful indicators of previous exposure to hydrocarbons but are not good indicators of in situ mineralization rates. In concert with hydrocarbon concentration data they can be used to estimate maximum biodegradation rates in situ. Similar data were used to estimate a biodegradation rate of 0.5 μg/g sed-day for sediments polluted by the *Amoco Cadiz* oil spill (Ward et al., 1980). Mineralization potential data using this method with non-nutrient amended samples (not optimal) were obtained in a bioremediation monitoring study in Prince William Sound. These data, along with hydrocarbon chemistry data were used to estimate differences in in situ biodegradation rates for fertilized and unfertilized shoreline sediments. These rates were estimated to range from 1.9-10 μg/g sed-day on unfertilized beaches and up to several fold higher on fertilized beaches (Prince et al., 1990, 1994).

For almost every sediment sample collected for microbial analyses from 1989 to 1993 a sample was almost always collected at the same time for chemical analysis by either ADEC or NOAA personnel. By combining the microbial data with the complementary chemistry data it should be possible to estimate upper and lower limits for persistence of various hydrocarbon fractions in sediments in PWS. It may also allow validation of the use of microbial analyses for screening contaminated samples for monitoring movement and persistence of contaminants in other oil spills. A synthesis of the chemistry data with the microbiology data was one of the major recommendations of the Council-appointed peer reviewer of our previous final report (Braddock et al., 1993). We wholeheartedly agree with this reviewer and recommend this as an area for future work.

The objective of this study was to document the effect of the *Exxon Valdez* oil spill on hydrocarbon-degrading microorganism populations and activities in PWS sediments. We found elevated numbers of hydrocarbon degraders in sediments collected in the path of the *Exxon Valdez* spill. In general, the populations and activities were greatest in surface sediments collected from shoreline and nearshore shallow subtidal sites in 1989. In surface sediments collected at greater depths further offshore, maximum numbers were observed about one year after the spill (in 1990). As has been observed in other spills, the increase in numbers of hydrocarbon degraders compared to likely pre-spill values also provides evidence of rapid acclimation of naturally occurring microbial populations to biodegradation of these compounds in most sediments. The numbers and activity of these microorganisms are good indicators of exposure of PWS sediments to labile hydrocarbons and may be useful indicators of the mobilization of hydrocarbons with time. Microbial population and activity patterns and hydrocarbon levels should be measured periodically for several years following other major oil spill events to monitor transport of petroleum compounds in the environment.

Conclusions

1. Populations of hydrocarbon-degrading microorganisms were good indicators of the distribution of *Exxon Valdez* oil following the spill.

2. Populations of hydrocarbon-degrading microorganism generally declined with time at most sites probably as a result of a decline in readily biodegradable hydrocarbon fractions. By 1993 few oiled sites sampled had populations of hydrocarbon degraders that were significantly higher than those measured at reference sites. High populations were only measured in samples collected from the intertidal 10-20 cm below the surface.

3. The numbers of hydrocarbon degraders were highest in sediments offshore heavily oiled beaches in summer 1990. These populations declined to levels observed at reference sites by 1991 and continued to be low in 1993.

4. Mineralization potentials for hexadecane and for phenanthrene were not statistically correlated to the populations of hydrocarbon-degrading microorganisms measured in sediment samples. Hexadecane potentials were generally higher than those for phenanthrene (or naphthalene).

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APPENDIX A

Raw data and calculations for microbial populations and activities in sediments collected in 1993, F/V Scorpius cruise.

	Depth (m)	% Dry Weight	HETEROTROPHS (cells/g sed.) Sediment A	Sediment B	Sediment C	Mean (corr. for dry wt. sed)	Std. Dev.	Log Mean	SHEEN SCREENS (cells/g sed) Sediment A	Sediment B	Sediment C	Mean (corr. for dry wt. sed.)	Std. Dev.	Log Mean
Northwest Bay	Beach	0.88	4.6E+05	2.1E+05	1.7E+06	9.0E+05	9.1E+05	6.0	2.2E+02	1.7E+02	1.7E+02	2.1E+02	3.3E+01	2.3
7/8/93	Sub-Surf	0.92	1.7E+06	4.9E+05	1.7E+05	8.6E+05	8.8E+05	5.9	3.3E+04	3.1E+03	3.3E+05	1.3E+05	2.0E+05	5.1
Site #1	3	0.80	9.4E+04	2.8E+05	3.5E+05	3.0E+05	1.7E+05	5.5	2.3E+02	2.3E+02	1.3E+02	2.5E+02	7.2E+01	2.4
	6	0.69	7.9E+04	4.6E+04	3.4E+04	7.7E+04	3.4E+04	4.9	2.0E+01	0.0E+00	0.0E+00	9.7E+00	1.7E+01	1.0
	20	0.47	4.9E+04	3.3E+05	6.0E+04	3.1E+05	3.4E+05	5.5	1.7E+03	4.9E+02	5.0E+01	1.6E+03	1.8E+03	3.2
	40	0.70	4.9E+04	1.7E+04	3.3E+04	4.7E+04	2.3E+04	4.7	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.46	1.1E+04	2.3E+04	1.1E+04	3.3E+04	1.5E+04	4.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Herring Bay	Beach	0.77	7.9E+05	2.3E+05	7.0E+05	7.4E+05	3.9E+05	5.9	4.0E+00	1.1E+02	0.0E+00	4.9E+01	8.1E+01	1.7
7/9/93	Sub-Surf	0.72	4.9E+03	3.3E+04	4.9E+04	4.0E+04	3.1E+04	4.6	6.0E+00	1.1E+02	7.0E+04	3.2E+04	5.6E+04	4.5
Site #2	3	0.66	1.7E+05	2.2E+04	2.3E+04	1.1E+05	1.3E+05	5.0	2.6E+02	7.0E+01	7.9E+02	5.7E+02	5.7E+02	2.8
	6	0.75	4.6E+04	2.2E+04	7.0E+04	6.1E+04	3.2E+04	4.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.74	2.6E+04	1.3E+04	3.3E+04	3.2E+04	1.4E+04	4.5	0.0E+00	0.0E+00	8.0E+01	3.6E+01	6.2E+01	1.6
	40	0.89	7.9E+03	4.9E+03	4.9E+04	2.3E+04	2.8E+04	4.4	0.0E+00	4.0E+01	4.0E+01	3.0E+01	2.6E+01	1.5
	100	0.72	1.1E+04	2.1E+03	2.3E+03	7.1E+03	7.1E+03	3.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Lower Herring Bay	Beach	0.85	7.0E+04	7.0E+05	1.3E+05	3.5E+05	4.1E+05	5.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7/10/93	Sub-Surf	0.82	2.2E+04	3.3E+03	3.3E+03	1.2E+04	1.3E+04	4.1	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Site #3	3	0.97	1.7E+06	1.1E+05	9.0E+04	6.5E+05	9.5E+05	5.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.91	1.7E+05	4.9E+04	4.9E+05	2.6E+05	2.5E+05	5.4	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.81	2.3E+04	7.0E+03	1.7E+04	1.9E+04	1.0E+04	4.3	0.0E+00	8.0E+00	0.0E+00	3.3E+00	5.7E+00	0.5
	40	0.75	1.1E+04	4.9E+03	4.9E+03	9.2E+03	4.7E+03	4.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.37	1.8E+04	4.9E+03	4.9E+03	2.5E+04	2.0E+04	4.4	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Drier Bay	Beach	0.97	4.6E+04	2.2E+05	2.8E+05	1.9E+05	1.3E+05	5.3	8.0E+01	8.0E+01	2.3E+02	1.3E+02	8.9E+01	2.1
7/11/93	Sub-Surf	0.81	3.3E+04	2.3E+04	3.3E+03	2.4E+04	1.9E+04	4.4	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Site #4	3	0.90	4.9E+04	1.1E+05	7.0E+04	8.5E+04	3.4E+04	4.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.51	4.9E+05	1.3E+05	2.1E+06	1.8E+06	2.1E+06	6.2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.52	7.0E+04	4.9E+04	4.9E+04	1.1E+05	2.3E+04	5.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	40	0.63	1.1E+05	1.4E+04	1.3E+04	7.2E+04	8.8E+04	4.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.37	4.6E+03	4.6E+03	2.8E+04	3.4E+04	3.7E+04	4.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Sleepy Bay	Beach	0.76	2.3E+04	1.3E+05	1.3E+05	1.2E+05	8.1E+04	5.1	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7/11 to 7/12/93	Sub-Surf	0.85	9.2E+08	4.9E+04	1.7E+05	3.6E+08	6.2E+08	8.6	3.1E+05	1.4E+02	2.8E+03	1.2E+05	2.1E+05	5.1
Site #5	3	0.75	1.7E+05	3.5E+05	5.4E+05	4.7E+05	2.5E+05	5.7	2.3E+02	5.0E+01	1.7E+02	2.0E+02	1.2E+02	2.3
	6	0.75	3.3E+05	1.4E+05	2.3E+05	3.1E+05	1.3E+05	5.5	1.7E+02	2.3E+02	2.0E+01	1.9E+02	1.4E+02	2.3
	20	0.70	7.0E+04	7.0E+04	1.7E+04	7.5E+04	4.4E+04	4.9	3.3E+02	7.0E+01	2.0E+01	2.0E+02	2.4E+02	2.3
	40	0.77	3.3E+03	7.9E+03	1.1E+04	9.6E+03	5.0E+03	4.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.66	1.7E+04	7.0E+03	4.9E+03	1.5E+04	9.8E+03	4.2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	

	Depth (m)	% Dry Weight	HETEROTROPHS (cells/g sed.) Sediment A	Sediment B	Sediment C	Mean (corr. for dry wt. sed)	Std. Dev.	Log Mean	SHEEN SCREENS (cells/g sed) Sediment A	Sediment B	Sediment C	Mean (corr. for dry wt. sed.)	Std. Dev.	Log Mean
Mooselips Bay	Beach	0.75	1.3E+05	3.5E+05	7.9E+05	5.6E+05	4.5E+05	5.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7/12 to 7/13/93	Sub-Surf	0.88	1.7E+05	2.2E+05	2.8E+05	2.5E+05	6.3E+04	5.4	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Site #6	3	0.71	2.1E+05	3.5E+05	1.1E+05	3.1E+05	1.7E+05	5.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.70	2.4E+05	3.5E+05	1.1E+06	8.0E+05	6.7E+05	5.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.70	7.9E+04	7.0E+04	4.9E+04	9.4E+04	2.2E+04	5.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	40	0.66	5.4E+04	1.1E+04	1.3E+05	9.8E+04	9.1E+04	5.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.71	1.8E+05	1.3E+04	7.0E+03	9.4E+04	1.4E+05	5.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Zaikof Bay	Beach	0.81	4.9E+04	9.4E+04	1.1E+05	1.0E+05	3.9E+04	5.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7/13/93	Sub-Surf	0.87	2.1E+06	1.7E+06	3.3E+06	2.7E+06	9.6E+05	6.4	0.0E+00	7.0E+01	2.0E+01	3.4E+01	4.1E+01	1.5
Site #7	3	0.72	2.2E+05	1.3E+05	3.5E+05	3.2E+05	1.5E+05	5.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.61	3.5E+05	4.9E+04	7.9E+04	2.6E+05	2.7E+05	5.4	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.65	1.4E+04	4.9E+04	1.1E+05	8.9E+04	7.5E+04	4.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	40	0.63	4.9E+03	7.9E+03	2.8E+04	2.2E+04	2.0E+04	4.3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.74	1.7E+04	7.9E+04	3.3E+04	5.8E+04	4.3E+04	4.8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Snug Harbor	Beach	0.75	2.3E+04	1.1E+05	3.5E+05	2.1E+05	2.3E+05	5.3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7/14/93	Sub-Surf	0.88	4.9E+05	2.4E+05	1.7E+05	3.4E+05	1.9E+05	5.5	0.0E+00	0.0E+00	2.0E+01	7.6E+00	1.3E+01	0.9
Site #8	3	0.76	1.1E+05			1.4E+05		5.2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.73	1.7E+04	1.7E+05		1.3E+05		5.1	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.68	1.3E+05	7.0E+04	9.4E+04	1.4E+05	4.4E+04	5.2	0.0E+00	5.0E+01	0.0E+00	2.5E+01	4.2E+01	1.4
	40	0.57	7.0E+04	2.2E+04	4.9E+05	3.4E+05	4.5E+05	5.5	0.0E+00	5.0E+01	0.0E+00	2.9E+01	5.1E+01	1.5
	100	0.43	4.9E+05	1.1E+06	3.3E+05	1.5E+06	9.4E+05	6.2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Bay of Isles	Beach	0.84	3.5E+04	4.6E+04	1.1E+05	7.6E+04	4.8E+04	4.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7/15/93	Sub-Surf	0.85	1.1E+06	7.9E+05	7.9E+05	1.1E+06	2.1E+05	6.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Site #9	3	0.81	3.5E+07	7.9E+05	2.4E+06	1.6E+07	2.4E+07	7.2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.54	2.4E+06	1.8E+07	7.0E+07	5.6E+07	6.6E+07	7.7	2.0E+01	0.0E+00	0.0E+00	1.2E+01	2.1E+01	1.1
	20	0.23	2.4E+04	2.4E+05	7.0E+04	4.8E+05	4.9E+05	5.7	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	40	0.62	3.5E+06	1.3E+06	1.7E+06	3.5E+06	1.9E+06	6.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.38	1.1E+06	7.9E+04	2.4E+05	1.2E+06	1.4E+06	6.1	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Olsen Bay	Beach	0.71	1.7E+05	9.4E+04	1.3E+05	1.8E+05	5.4E+04	5.3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
7-15 to 7-16-93	Sub-Surf	0.90	9.4E+04	7.9E+04	1.1E+05	1.0E+05	1.7E+04	5.0	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
Site #10	3	0.54	1.4E+05	7.0E+05	3.5E+05	7.3E+05	5.2E+05	5.9	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	6	0.53	1.7E+05		2.4E+05	3.9E+05		5.6	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	20	0.34	1.3E+05	4.9E+04	1.3E+05	3.0E+05	1.4E+05	5.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	40	0.70	1.1E+05	4.6E+07	1.7E+05	2.2E+07	3.8E+07	7.3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	
	100	0.44	1.7E+04	7.9E+03	1.4E+04	2.9E+04	1.1E+04	4.5	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	

HEXADECANE 2 Day Incubations

	Depth (m)	% Dry Weight	Day 0 (DPM)	Sediment A (DPM) rep 1	Sediment A (DPM) rep 2	Sediment B (DPM) rep 1	Sediment B (DPM) rep 2	Sediment C (DPM) rep 1	Sediment C (DPM) rep 2	mean dpm	std. dev.	corr mean dpm	% Mineral.	ORP µg/(g dry wt.-day) (@95% Confid. Level)		
Northwest Bay	Beach	0.88	39	135	3661	157		44	190	698	1579	583	1.7	0.9	±	0.9
7/8/93	Sub-Surf	0.92	65	6250	7056	1666	2085	4614	4867	4423	2171	4308	12.2	6.1	±	1.4
Site #1	3	0.80	52	258	239	202	262	250	238	242	22	127	0.4	0.2	±	0.1
	6	0.69	49	179	184	177	149	177	190	176	14	61	0.2	0.1	±	0.1
	20	0.47	47	266	271	315	547	305	283	331	107	216	1.2	0.6	±	0.2
	40	0.70	51	130	141	131	115	109	114	123	12	8	0.0	0.0	±	0.1
	100	0.46	54	139	144	112	122	126	122	128	12	13	0.1	0.0	±	0.1
Herring Bay	Beach	0.77	74	5763	211	3611	1671	4398	4400	3342	2038	3227	10.9	5.5	±	1.6
7/9/93	Sub-Surf	0.72		119	127	188	174	6187	3339	1689	2546	1574	5.7	2.8	±	2.1
Site #2	3	0.66	57	1106	425	439	200	395	158	454	341	339	1.3	0.7	±	0.3
	6	0.75	55	259	3615	208	153	156	101	732	1364	617	2.1	1.1	±	1.1
	20	0.74	49	200	173	208	223	165	207	196	22	81	0.3	0.1	±	0.1
	40	0.89	55	150	165	124	147	146	121	142	17	27	0.1	0.0	±	0.0
	100	0.72	44	141	141	119	134	120	118	129	11	14	0.1	0.0		0.1
Lower Herring Bay	Beach	0.85	55	277	247	307	331	261	295	286	31	171	0.5	0.3	±	0.1
7/10/93	Sub-Surf	0.82	49	129	114	113	119	121	135	122	9	7	0.0	0.0	±	0.0
Site #3	3	0.97	146	3553	1241	381	569	609	1242	1266	1177	1151	3.1	1.5	±	0.7
	6	0.91	88	5439	485	394	327	374	400	1237	2059	1122	3.2	1.6	±	1.3
	20	0.81	50	243	301	247	256	279	252	263	22	148	0.5	0.2	±	0.1
	40	0.75	47	140	157	144	148	179	158	154	14	39	0.1	0.1	±	0.1
	100	0.37	47	136	124	147	123	143	114	131	13	16	0.1	0.1	±	0.1
Drier Bay	Beach	0.97	54	2354	2268	509	347	1277	970	1288	859	1173	3.1	1.6	±	0.5
7/11/93	Sub-Surf	0.81	864	137	278	174	203	317	2349	576	871	461	1.5	0.7	±	0.6
Site #4	3	0.90	44	276	276	371	297	347	257	304	45	189	0.5	0.3	±	0.1
	6	0.51	64	362	287	277	262	625	445	376	140	261	1.3	0.7	±	0.2
	20	0.52	50	634	1097	302	164	328	319	474	342	359	1.8	0.9	±	0.4
	40	0.63	74	196	202	262	240	53	58	169	91	54	0.2	0.1	±	0.1
	100	0.37	188	76	81	48	104	126	126	94	31	0	0.0	0.0	±	0.0
Sleepy Bay	Beach	0.76	156	329	406	382	231	935	534	470	249	355	1.2	0.6	±	0.2
7/11 to 7/12/93	Sub-Surf	0.85	612	16336	14662	312	550	600	622	5514	7753	5399	16.5	8.3	±	5.3
Site #5	3	0.75	153	1288	608	317	592	375	334	586	367	471	1.6	0.8	±	0.3
	6	0.75	272	303	526	362	548	322	273	389	118	274	1.0	0.5	±	0.1
	20	0.70	83	339	322	432	327	399	430	375	51	260	1.0	0.5	±	0.1
	40	0.77	151	237	240	259	272	194	182	231	36	116	0.4	0.2	±	0.1
	100	0.66	135	233	335	123	98	151	153	182	88	67	0.3	0.1	±	0.1

Mean killed control = 115 dpm

HEXADECANE - 2 Day Incubations

	Depth (m)	% Dry Weight	Day 0 (DPM)	Sediment A (DPM) rep 1	Sediment A (DPM) rep 2	Sediment B (DPM) rep 1	Sediment B (DPM) rep 2	Sediment C (DPM) rep 1	Sediment C (DPM) rep 2	mean dpm	std. dev.	corr mean dpm	% Mineral.	ORP µg/(g dry wt.-day) (@95% Confid. Level)		
Mooselips Bay	Beach	0.75	121	290	815	3032	3347	4474	4006	2661	1717	2546	8.8	4.4	±	1.3
7/12 to 7/13/93	Sub-Surf	0.88	363	123	141	403	454	134	179	239	149	124	0.4	0.2	±	0.1
Site #6	3	0.71	161	736	428	564	922	355	341	558	232	443	1.6	0.8	±	0.2
	6	0.70	70	472	466	371	309	312	344	379	73	264	1.0	0.5	±	0.1
	20	0.70	120	294	313	785	609	246	313	427	218	312	1.2	0.6	±	0.2
	40	0.66	112	229	305	231	374	303	300	290	54	175	0.7	0.3	±	0.1
	100	0.71	57	240	307	151	171	268	210	225	59	110	0.4	0.2	±	0.1
Zaikof Bay	Beach	0.81	258	578	499	463	536	450	458	497	51	382	1.2	0.6	±	0.1
7/13/93	Sub-Surf	0.87	146	340	335	278	275	385	410	337	55	222	0.7	0.3	±	0.1
Site #7	3	0.72	223	475	287	607	621	719	466	529	152	414	1.5	0.7	±	0.1
	6	0.61	98	531	529	434	419	393	348	442	74	327	1.4	0.7	±	0.1
	20	0.65	112	250	269	259	262	2942	3256	1206	1469	1091	4.4	2.2	±	1.3
	40	0.63	120	274	264	293	281	247	251	268	18	153	0.6	0.3	±	0.1
	100	0.74	132	242	264	242	233	268	258	251	14	136	0.5	0.2	±	0.1
Snug Harbor	Beach	0.75	65	550	343	434	522	616	356	470	110	355	1.2	0.6	±	0.1
7/14/93	Sub-Surf	0.88	50	2522	1710	1264	1516	2206	2287	1918	493	1803	5.3	2.7	±	0.3
Site #8	3	0.76	160	346	306	233	360	230	3704	863	1393	748	2.6	1.3	±	1.1
	6	0.73	46	290	167	149	344	295	139	231	89	116	0.4	0.2	±	0.1
	20	0.68	45	194	191	229	196	232	128	195	38	80	0.3	0.2	±	0.1
	40	0.57	50	174	168	208	216	181	183	188	19	73	0.3	0.2	±	0.1
	100	0.43	53	184	190	151	111	126	122	147	33	32	0.2	0.1	±	0.1
Bay of Isles	Beach	0.84	197	2079	717	685	350	1852	8874	2426	3234	2311	7.2	3.6	±	2.3
7/15/93	Sub-Surf	0.85	113	964	1590	2073	481	1219	2208	1423	664	1308	4.0	2.0	±	0.5
Site #9	3	0.81	104	293	298	407	305	294	255	309	51	194	0.6	0.3	±	0.1
	6	0.54	147	505	765	385	484	371	390	483	149	368	1.8	0.9	±	0.2
	20	0.23	139	191	216	176	197	212	209	200	15	85	1.0	0.5	±	0.2
	40	0.62	147	232	292	319	274	236	301	276	35	161	0.7	0.3	±	0.1
	100	0.38	137	212	233	188	155	236	209	206	30	91	0.6	0.3	±	0.1
Olsen Bay	Beach	0.71	46	248	212	236	242	236	218	232	14	117	0.4	0.2	±	0.1
7/15 to 7/16/93	Sub-Surf	0.90	48	177	206	187	188	64	154	163	51	48	0.1	0.1	±	0.1
Site #10	3	0.54	39	277	267	298	286	294	226	275	26	160	0.8	0.4	±	0.1
	6	0.53	51	346	330	348	291	328	341	331	21	216	1.1	0.5	±	0.1
	20	0.34	41	271	241	319	260	282	270	274	26	159	1.2	0.6	±	0.1
	40	0.70	47	235	192	213	175	209	213	206	21	91	0.3	0.2	±	0.1
	100	0.44	47	156	176	158	177	155	155	163	11	48	0.3	0.1	±	0.1

Mean killed control = 115 dpm

PHENANTHRENE-- 2 Day Incubations

Site	Depth (m)	%Dry Weight	Day 0 (DPM)	Sediment A (DPM) rep 1	Sediment A (DPM) rep 2	Sediment B (DPM) rep 1	Sediment B (DPM) rep 2	Sediment C (DPM) rep 1	Sediment C (DPM) rep 2	Mean DPM	Std. Dev.	Corr. Mean DPM	% Mineral.	ORP µg/g dry wt.-day (@95% confid. level)		
	Beach	0.88	50	108	109	92	103	93	100	101	7	0	0.0	0.0	±	0.0
Northwest Bay	Sub-Surf	0.92	75	655	598	267	251	428	403	434	166	314	0.6	0.3	±	0.1
7/8/93	3	0.80	53	103	108	78	79	99	92	93	13	0	0.0	0.0	±	0.0
Site #1	6	0.69	57	108	112	115	98	104	93	105	8	0	0.0	0.0	±	0.0
	20	0.47	56	108	113	130	120	139	134	124	12	4	0.0	0.0	±	0.1
	40	0.70	53	113	108	107	100	112	104	107	5	0	0.0	0.0	±	0.0
	100	0.46	57	117	112	112	109	111	110	112	3	0	0.0	0.0	±	0.0
Herring Bay	Beach	0.77	52	121	109	95	96	100	106	105	10	0	0.0	0.0	±	0.0
7/9/93	Sub-Surf	0.72		69	70	106	94	357	687	231	249	111	0.2	0.1	±	0.1
Site #2	3	0.66	59	80	101	92	101	89	85	91	9	0	0.0	0.0	±	0.0
	6	0.75	131	102	77	85	105	87	99	93	11	0	0.0	0.0	±	0.0
	20	0.74	86	96	138	111	109	97	105	109	15	0	0.0	0.0	±	0.0
	40	0.89	61	91	113	99	107	113	84	101	12	0	0.0	0.0	±	0.0
	100	0.72	59	114	104	113	94	100	117	107	9	0	0.0	0.0	±	0.0
Lower Herring Bay	Beach	0.85	68	120	87	138	179	122	116	127	30	7	0.0	0.0	±	0.0
7/10/93	Sub-Surf	0.82	44	94	89	117	106	83	93	97	12	0	0.0	0.0	±	0.0
Site #3	3	0.97	67	109	95	92	118	120	119	109	13	0	0.0	0.0	±	0.0
	6	0.91	60	125	121	122	107	120	109	117	7	0	0.0	0.0	±	0.0
	20	0.81	71	122	125	116	115	108	107	116	7	0	0.0	0.0	±	0.0
	40	0.75	65	110	107	105	102	117	107	108	5	0	0.0	0.0	±	0.0
	100	0.37	63	129	111	113	122	128	118	120	8	0	0.0	0.0	±	0.1
Drier Bay	Beach	0.97	63	193	193	246	2428	220	231	585	903	465	0.8	0.4	±	0.3
7/11/93	Sub-Surf	0.81	63	135	140	129	151	171	1154	313	412	193	0.4	0.2	±	0.2
Site #4	3	0.90	55	182	197	280	1772	163	5743	1391	2222	1271	2.3	1.1	±	0.9
	6	0.51	61	110	109	119	815	190	318	277	276	157	0.5	0.2	±	0.2
	20	0.52	112	146	182	325		199	179	206	69	86	0.3	0.1	±	0.1
	40	0.63	178	170	167	200	713	209	176	273	216	153	0.4	0.2	±	0.1
	100	0.37	191	303	3840	193	757	6219	319	1939	2517	1619	7.9	4.0	±	2.5
Sleepy Bay	Beach	0.76	227	147	159	248	665	133	144	249	208	129	0.3	0.1	±	0.1
7/11 to 7/12/93	Sub-Surf	0.85	450	1635	1430	672	233	1274	336	930	595	810	1.5	0.8	±	0.3
Site #5	3	0.75	113	187	164	156	570	166	176	237	164	117	0.3	0.1	±	0.1
	6	0.75	339	184	192	185	277	169	137	191	47	71	0.2	0.1	±	0.0
	20	0.70	86	175	174	162	341	175	186	202	68	82	0.2	0.1	±	0.1
	40	0.77	156	178	171	180	303	162	166	193	54	73	0.2	0.1	±	0.0
	100	0.66	228	359	1852	1304	3260	286	317	1230	1183	1110	2.7	1.4	±	0.7

Mean killed control = 120 dpm

PHENANTHRENE-- 2 Day Incubations

	Depth (m)	%Dry Weight	Day 0 (DPM)	Sediment A (DPM) rep 1	Sediment A (DPM) rep 2	Sediment B (DPM) rep 1	Sediment B (DPM) rep 2	Sediment C (DPM) rep 1	Sediment C (DPM) rep 2	Mean DPM	Std. Dev.	Corr. Mean DPM	% Mineral.	ORP µg/g dry wt.-day (@95% confid. level)		
Mooselips Bay	Beach	0.75	226	444	440		510	248	259	380	119	260	0.6	0.3	±	0.1
7/12 to 7/13/93	Sub-Surf	0.88	322	338	287	360	315	320	378	333	33	213	0.4	0.2	±	0.0
Site #6	3	0.71	116	161	96	189	225	111	121	151	50	31	0.1	0.0	±	0.0
	6	0.70	173	257	247	178	102	211	378	229	92	109	0.3	0.1	±	0.1
	20	0.70	111	184	170	506	773	349	424	401	225	281	0.6	0.3	±	0.1
	40	0.66	204	118	112	356	501	167	162	236	158	116	0.3	0.1	±	0.1
	100	0.71	143	205	186	171	268	150	148	188	45	68	0.2	0.1	±	0.0
Zaikof Bay	Beach	0.81	234	180	202	182	281	173	189	201	40	81	0.2	0.1	±	0.0
7/13/93	Sub-Surf	0.87	122	174	196	183	183	176	276	198	39	78	0.1	0.1	±	0.0
Site #7	3	0.72	204	183	197	202	257	155	183	196	34	76	0.2	0.1	±	0.0
	6	0.61	171	185	191	178	218	158	184	186	20	66	0.2	0.1	±	0.0
	20	0.65	138	126	189	161	220	206	194	183	34	63	0.2	0.1	±	0.0
	40	0.63	118	170	107	185	205	176	111	159	41	39	0.1	0.1	±	0.0
	100	0.74	168	206	212	268	134	342	375	256	91	136	0.3	0.1	±	0.1
Snug Harbor	Beach	0.75	189	72	118	187	453	79	80	165	148	45	0.1	0.0	±	0.1
7/14/93	Sub-Surf	0.88	234	128	436	166	254	287	360	272	116	152	0.3	0.1	±	0.1
Site #8	3	0.76	49	84	192	119	88	82	90	109	43	0	0.0	0.0	±	0.0
	6	0.73	67	81	90	156	103	85	69	97	31	0	0.0	0.0	±	0.0
	20	0.68	62	100	109	103	91	92	98	99	7	0	0.0	0.0	±	0.0
	40	0.57	62	102	100	128	120	116	118	114	11	0	0.0	0.0	±	0.0
	100	0.43	62	127	138	159	140	121	122	135	14	15	0.1	0.0	±	0.1
Bay of Isles	Beach	0.84	126	125	54	121	115	106	108	105	26	0	0.0	0.0	±	0.0
7/15/93	Sub-Surf	0.85	121	200	212	170	169	236	165	192	29	72	0.1	0.1	±	0.0
Site #9	3	0.81	139	152	122	117	122	97	106	119	19	0	0.0	0.0	±	0.0
	6	0.54	149	128	135	202	111	190	121	148	38	28	0.1	0.0	±	0.1
	20	0.23	120	117	95	213	307	250	172	192	81	72	0.5	0.3	±	0.2
	40	0.62	179	402	338	523	255	140	138	299	152	179	0.5	0.2	±	0.1
	100	0.38	129	285	286	140	120	135	122	181	81	61	0.3	0.1	±	0.1
Olsen Bay	Beach	0.71	57	127	141	101	128	132	113	124	14	4	0.0	0.0	±	0.0
7/15 to 7/16/93	Sub-Surf	0.90	56	103	108	109	97	168	105	115	26	0	0.0	0.0	±	0.0
Site #10	3	0.54	53	145	500	137	122	109	133	191	152	71	0.2	0.1	±	0.1
	6	0.53	62	101	124	127	167	115	139	129	23	9	0.0	0.0	±	0.0
	20	0.34	80	147	137	120	109	99	125	123	18	3	0.0	0.0	±	0.1
	40	0.70	54	129	112	96	75	112	100	104	18	0	0.0	0.0	±	0.0
	100	0.44	58	109	113	119	82	109	119	109	14	0	0.0	0.0	±	0.0

Mean killed control = 120 dpm

PHENANTHRENE-- 4 Day Incubations

	Depth (m)	% Dry Weight	Sediment A (DPM) rep 1	Sediment A (DPM) rep 2	Sediment B (DPM) rep 1	Sediment B (DPM) rep 2	Sediment C (DPM) rep 1	Sediment C (DPM) rep 2	Mean DPM	Std. Dev.	Corr. Mean DPM	% Mineral.	ORP µg/g dry wt.-day (@95% confid. level)		
Northwest Bay	Beach	0.88	106	100	98	114	98	110	104	7	0	0.0	0.0	±	0.0
7/8/93	Sub-Surf	0.92	7792	8059	3247	2875	7001	6163	5856	2267	5736	10.1	2.5	±	0.9
Site #1	3	0.80	112	96	92	108	89	90	98	10	0	0.0	0.0	±	0.0
	6	0.69	110	116	104	91	109	97	105	9	0	0.0	0.0	±	0.0
	20	0.47	119	126	119	108	131	127	122	8	2	0.0	0.0	±	0.1
	40	0.70	118	100	111	109	108	112	110	6	0	0.0	0.0	±	0.0
	100	0.46	107	116	103	97	105	116	107	8	0	0.0	0.0	±	0.0
Herring Bay	Beach	0.77	113	123	104	118	122	105	114	8	0	0.0	0.0	±	0.0
7/9/93	Sub-Surf	0.72	80	82	110	112	1095	897	396	469	276	0.6	0.2	±	0.2
Site #2	3	0.66	114	118	120	116	115	113	116	3	0	0.0	0.0	±	0.0
	6	0.75	108	135	128	219	120	113	137	41	17	0.0	0.0	±	0.0
	20	0.74	105	109	98	115	114	112	109	7	0	0.0	0.0	±	0.0
	40	0.89	114	114	114	121	105	70	106	19	0	0.0	0.0	±	0.0
	100	0.72	124	105	122	106	113	133	117	11	0	0.0	0.0	±	0.0
Lower Herring Bay	Beach	0.85	128	92	48	121	86	135	102	33	0	0.0	0.0	±	0.0
7/10/93	Sub-Surf	0.82		119	113	124	145	101	120	16	0	0.0	0.0	±	0.0
Site #3	3	0.97	123	194	117	135	137	125	139	28	19	0.0	0.0	±	0.0
	6	0.91	137	135	115	123	124	116	125	9	5	0.0	0.0	±	0.0
	20	0.81	125	134	123	155	124	117	130	14	10	0.0	0.0	±	0.0
	40	0.75	119	124	113	108	125	132	120	9	0	0.0	0.0	±	0.0
	100	0.37	143	140	112	125	129	146	133	13	13	0.1	0.0	±	0.1
Drier Bay	Beach	0.97	204	312	214	213	221		233	45	113	0.2	0.0	±	0.0
7/11/93	Sub-Surf	0.81	167	144	167	157	185	328	191	68	71	0.1	0.0	±	0.0
Site #4	3	0.90	166	537	202	266	121	957	375	321	255	0.5	0.1	±	0.1
	6	0.51	364	154	152	282	197	838	331	261	211	0.7	0.2	±	0.2
	20	0.52	195	151	223	138	159	679	258	209	138	0.4	0.1	±	0.2
	40	0.63	3582	1824	230	170	3364	719	1648	1535	1528	3.9	1.0	±	0.9
	100	0.37	544	231	219	170	263		285	148	165	0.7	0.2	±	0.1
Sleepy Bay	Beach	0.76	184	98	162	190	183	316	189	71	69	0.1	0.0	±	0.0
7/11 to 7/12/93	Sub-Surf	0.85	4047	4075	151	388	5479	449	2432	2362	2312	4.4	1.1	±	1.0
Site #5	3	0.75	243	210	183	145	189	317	215	60	95	0.2	0.1	±	0.0
	6	0.75	200	201	184	192	197	172	191	11	71	0.2	0.0	±	0.0
	20	0.70	205	222	211	219	235	377	245	66	125	0.3	0.1	±	0.0
	40	0.77	204	197	188	166	192	330	213	59	93	0.2	0.0	±	0.0
	100	0.66	962	1647	238	412	443	612	719	516	599	1.5	0.4	±	0.3

Mean killed control = 120 dpm

PHENANTHRENE-- 4 Day Incubations

	Depth (m)	% Dry Weight	Sediment A (DPM) rep 1	rep 2	Sediment B (DPM) rep 1	rep 2	Sediment C (DPM) rep 1	rep 2	Mean DPM	Std. Dev.	Corr. Mean DPM	% Mineral.	ORP µg/g dry wt.-day (@95% confid. level)		
Mouselips Bay	Beach	0.75	1311	395	249	255	193	282	448	428	328	0.7	0.2	±	0.2
7/12 to 7/13/93	Sub-Surf	0.88	366	391	336	303	106	163	278	116	158	0.3	0.1	±	0.1
Site #6	3	0.71	143	140	248	144	335	406	236	114	116	0.3	0.1	±	0.1
	6	0.70	959	1108	381	366	1157	687	776	352	656	1.5	0.4	±	0.2
	20	0.70	124	135	290	323	164	227	211	83	91	0.2	0.1	±	0.1
	40	0.66	323	426	370	344	176	231	312	92	192	0.5	0.1	±	0.1
	100	0.71	188	204	209	182	177	233	199	21	79	0.2	0.0	±	0.0
Zaikof Bay	Beach	0.81	206	220	175	194	209	330	222	55	102	0.2	0.1	±	0.0
7/13/93	Sub-Surf	0.87	227	197	206	226	215	298	228	36	108	0.2	0.1	±	0.0
Site #7	3	0.72	213	205	203	222	174	264	214	30	94	0.2	0.1	±	0.0
	6	0.61	204	176	200	189	202	268	207	32	87	0.2	0.1	±	0.0
	20	0.65	177	176	196	198	206	218	195	16	75	0.2	0.0	±	0.0
	40	0.63	134	185	130	185	155	254	174	46	54	0.1	0.0	±	0.0
	100	0.74	188	223	130	339	210	184	212	70	92	0.2	0.1	±	0.0
Snug Harbor	Beach	0.75	98	121	91	101	101	102	102	10	0	0.0	0.0	±	0.0
7/14/93	Sub-Surf	0.88	97	217	112	190	180	212	168	51	48	0.1	0.0	±	0.0
Site #8	3	0.76	95	106	90	113	125	108	106	13	0	0.0	0.0	±	0.0
	6	0.73	89	101	91	93	161	89	104	28	0	0.0	0.0	±	0.0
	20	0.68	105	102	104	101	101	111	104	4	0	0.0	0.0	±	0.0
	40	0.57	130	122	107	140	146	133	130	14	10	0.0	0.0	±	0.0
	100	0.43	121	135	112	126	154	153	134	17	14	0.1	0.0	±	0.1
Bay of Isles	Beach	0.84	127	136	86	200	158	123	138	38	18	0.0	0.0	±	0.0
7/15/93	Sub-Surf	0.85	200	219	177	181	193	153	187	22	67	0.1	0.0	±	0.0
Site #9	3	0.81	122	129	128	121	132	128	127	4	7	0.0	0.0	±	0.0
	6	0.54	46	296	126	118	283	353	204	123	84	0.3	0.1	±	0.1
	20	0.23	166	166	179	222	282	188	201	45	81	0.6	0.1	±	0.1
	40	0.62	353	231	302	322	291	296	299	40	179	0.5	0.1	±	0.0
	100	0.36	252	264	321	96	218	222	229	75	109	0.5	0.1	±	0.1
Olsen Bay	Beach	0.71	124	133	137	132	115	108	125	11	5	0.0	0.0	±	0.0
7/15 to 7/16/93	Sub-Surf	0.90	135	108	114	119	78	115	112	19	0	0.0	0.0	±	0.0
Site #10	3	0.54	130	127	119	128	123	133	127	5	7	0.0	0.0	±	0.0
	6	0.53	152	162	111	141	124	120	135	20	15	0.0	0.0	±	0.0
	20	0.34	142	150	149	142	95	86	127	29	7	0.0	0.0	±	0.1
	40	0.70	133	116	84	80	111	90	102	21	0	0.0	0.0	±	0.0
	100	0.44	112	120	128	125	125	86	116	16	0	0.0	0.0	±	0.0

Mean killed control = 120 dpm