Exxon Valdez Oil Spill
State/Federal Natural Resource Damage Assessment
Final Report

COMPREHENSIVE ASSESSMENT OF COASTAL HABITAT

COASTAL HABITAT STUDY NUMBER 1A
FINAL REPORT

VOLUME I

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Comprehensive Assessment of Coastal Habitat

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Study History: Comprehensive assessment of coastal habitat was initiated as Coastal Habitat Study No. 1 in 1989. Phase 1 was conducted in summer 1989/spring 1990 and involved site selection/ground truthing. Phase II involved an intensive evaluation of study sites to determine extent of injury to natural resources in supratidal, intertidal and subtidal areas. Phase II commenced in the fall of 1989 and continued through the summer of 1991. The supratidal component was completed in 1991 and a final report was submitted separately. The subtidal portion was integrated into a suite of other subtidal studies and findings were also reported separately. Draft preliminary status reports were issued for the intertidal component in 1990, 1991, 1992 and 1993 by Highsmith *et al.* as Coastal Habitat Study No. 1: Phase II in 1990 and 1991 and No. 1A in 1992 and 1993.

Abstract: The Coastal Habitat Injury Assessment Study was initiated to assess injury to intertidal habitats impacted by the *Exxon Valdez* oil spill. The study, conducted from 1989-1991, encompassed three major geographic areas impacted by the spill: Prince William Sound, Cook Inlet-Kenai Peninsula and Kodiak-Alaska Peninsula. Oiled sites were selected randomly and matched with non-oiled sites and classified into sheltered rocky, exposed rocky, coarse textured or estuarine habitat. Statistically significant differences between oiled and non-oiled sites were interpreted as impact due to the spill and/or clean-up activities. Most observed differences varied across regions, habitats and tidal heights. Algae, especially the perennial *Fucus*, was generally negatively impacted on oiled sites. Conversely, an increase in annual and ephemeral species in the lower intertidal occurred. Limpets, mussels, littorines, and the high cockscomb prickleback were injured by the spill, while oligochaetes and a single barnacle species were enhanced at most tidal heights following the spill. Although intertidal communities showed widespread impact from oiling/clean-up activities for algal, invertebrate and fish components, data revealed that most habitats were recovering but had not fully recovered by 1991.

Key Words: algae, barnacles, *Exxon Valdez*, *Fucus*, intertidal, invertebrates, limpets, littorines, mussels, oil spill, oligochaetes, Prince William Sound, recolonization, succession.

Project Data: Data collected through the Coastal Habitat Injury Assessment Study is contained in volumes II-VII of this report. These volumes are housed at the Alaska Resources Library and Information Services (ARLIS), 3150 C Street, Anchorage, Alaska 99503; telephone 907-272-7547; fax 907-271-4742.

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VOLUME 1

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EXECUTIVE SUMMARY

The Coastal Habitat Injury Assessment Study was initiated to assess and quantify injury to biological resources in shallow subtidal, intertidal and supratidal habitats impacted by the *Exxon Valdez* oil spill. Intertidal communities were subjected to the most severe impacts of the spill and subsequent clean-up operations. The intertidal zone is not only a very productive and diverse ecosystem, but it serves as an interface between marine and terrestrial organisms. Algae form the structure of the ecosystem, providing protective habitat and forage for a number of species of fish (e.g., herring) and invertebrates. In turn, birds and otters prey on these fish and invertebrates. The intertidal is also utilized by bears, deer and other land mammals. An understanding of the effects of the spill on the intertidal is critical in determining the extent of injury and the rate of recovery of the affected areas.

The study encompassed the three major geographic areas impacted by the spill: Prince William Sound (PWS), Cook Inlet-Kenai Peninsula (CIK) and Kodiak-Alaska Peninsula (KAP). Oiled sites were selected randomly and matched with non-oiled, control sites. All sites were classified into sheltered rocky, exposed rocky, coarse textured or estuarine habitat. Sampling was conducted via randomly placed quadrats in the upper three meters of the intertidal zone. This report documents the impacts of the spill on the intertidal community through studies on algae, invertebrates and fish.

Intertidal marine algae are a major component of nearshore marine ecosystems. An environmental disturbance, such as the *Exxon Valdez* oil spill, can have a significant impact on intertidal algae, altering the population structure and the function of the algal community. The algal component of the Coastal Habitat Injury Assessment study (CHIA) investigated the effects of the spill at three ecological levels: individuals of the predominant alga species *Fucus gardneri*, population structure of the algal taxa, and algal community function. Within each of these levels injury is assessed for each area, habitat, and tidal elevation (meter vertical drop, MVD). Injury to either the structure or function of the algal community by the spill can have further impacts on the nearshore marine ecosystem.

Results of intensive sampling and research during three summers (1989-1991) and limited percent cover sampling during the summers of 1992, 1993 and 1994 show that the oil spill had serious and long lasting effects on intertidal algae. Analyses of algal percent cover and biomass data from three study areas: Prince William Sound (PWS), Cook Inlet/Kenai (CIK), and Kodiak/Alaska Peninsula (KAP), showed that generally there were lower abundances and biomass of marine algae, especially the perennial *Fucus*, on oiled sites compared to unoiled, control sites. There was a corresponding increase of bare rock at the oiled sites, plus an increase in annual and ephemeral species in the lower intertidal. The affected species included a variety of red, green, and brown algae. There were, however, different patterns for each area, habitat, and tidal elevation.

Effects of the oil spill and cleanup activities caused significant declines in *Fucus* biomass and percent cover on oiled sites at eight out of nine habitats sampled. These values were greater,

however, at oiled sites in CIK sheltered rocky and estuarine sites at MVD 3 and at coarse textured sites also in CIK. *Fucus* plants at oiled sites were not as reproductive as those at control sites. In the upper intertidal at oiled sites *Fucus* plants had fewer receptacles, fewer receptacles per mature plant, and a lower reproductive index. Also, more adult *Fucus* plants had attached epiphytes at oiled sites and these plants had a greater percentage of their surface covered with epiphytes.

Effects of the spill and cleanup on the algal population structure showed that several taxa other than *Fucus* were also injured. Bladed greens (Chlorophyta) were less abundant at oiled sites in estuarine habitats and *Acrosiphonia* had lower coverage at CIK sheltered rocky oiled sites. The brown alga *Myelophycus/Scytosiphon* (Phaeophyta) had lower coverage on PWS sheltered rocky oiled sites. The high intertidal fucoid, *Fucus cottoni*, disappeared from oiled sites in PWS and CIK. The low intertidal kelp *Alaria* had lower biomass and coverage at oiled CIK sheltered rocky sites. The percent cover of filamentous browns on coarse textured beaches in PWS and CIK was lower at MVD 3 on oiled sites. Red algal species (Rhodophyta) that had lower values at oiled sites were *Halosaccion*, *Endocladia*, *Odonthalia*, *Palmaria*, *Polysiphonia/Pterosiphonia* at sheltered rocky sites in CIK, *Gloiopeltis* in sheltered rocky sites in PWS, and *Neorhodomela/Rhodomela* at both exposed rocky sites in PWS and sheltered rocky sites in PWS and CIK. *Porphyra* species were injured at CIK sheltered rocky and estuarine sites.

There were many algal taxa that were enhanced after the spill, showing higher values at oiled sites. *Fucus gardneri* was enhanced at MVD 3 at all habitats in CIK. Biomass of fine filamentous brown algae was greater at oiled sites in sheltered rocky habitat in PWS and coarse textured habitat in CIK, due mainly to *Pilayella*. *Myelophycus/Scytosiphon* was enhanced at the exposed rocky sites. Several red algae were enhanced, mainly at KAP sheltered rocky sites. These species included *Cryptosiphonia*, members of the Gigartinaceae, *Gloiopeltis*, *Halosaccion*, *Odonthalia*, *Palmaria*, and *Porphyra*. These enhancements are an indication of disturbance and some can be considered a "greening" effect, although most of the enhanced species were red algae at the lower MVDs. There were also enhancements of perennials that are not usually considered part of the "greening" response.

The number of significant differences found between oiled and control site algal data increased over time, from about 3% to over 12% by 1991. The relative number of differences was about the same at each tide height, but more taxa at MVD 3 showed some level of enhancement at oiled sites. Taxa in CIK showed more significant differences, both decreases and enhancements, than PWS and KAP. KAP algal taxa showed primarily injury at oiled sites. Estuarine and coarse textured habitats also had more significant differences with values lower at oiled sites. Estuarine habitats had the highest relative number of significant differences overall.

Invertebrate community attributes of species diversity, richness and dominance were determined for oiled and control shorelines in all habitats. Comparisons showed similar community parameters by 1991 for sheltered and exposed rocky habitat. For a majority of the cases in which significant differences were observed, diversity and/or richness were actually higher on oiled sites. Results for coarse textured and estuarine habitats were reversed, with lowered diversity and richness and higher dominance on oiled sites for most cases of significance, representing an incomplete recovery of these habitats as of 1991.

Abundance-biomass comparison (ABC or k-dominance) curves for several oiled sites were non-standard (indicative of disturbance) and in many cases represented the same oiled sites for which significantly different (in comparison with control sites) diversity indices were identified. Of the 20 instances in which ABC curves were non-standard, 13 represented oiled sites.

A few taxa were primarily responsible for the changes in community composition reflected in species diversity indices and ABC-curve comparisons. Analyses of intertidal invertebrate abundance and biomass revealed differences between oiled and control sites for the limpet *Tectura persona*, the barnacles *Chthamalus dalli*, *Balanus glandula* and *Semibalanus balanoides*, the mussel *Mytilus edulis*, two species of periwinkle, *Littorina sitkana* and *L. scutulata*, and oligochaetes. Differences varied between regions and habitat types. In addition, the degree of oiling, duration of exposure and cleaning methods used may have affected the extent of impacts at a site.

The limpet *Tectura persona*, primarily an upper intertidal inhabitant, displayed most significant differences between oiled and control populations in MVD 1. In PWS and CIK sheltered rocky, KAP coarse textured and PWS exposed rocky habitats, abundances and biomass were generally higher on control sites at MVD 1. By 1991, significant differences were no longer detected in coarse textured and exposed rocky habitats. In lower beach elevations of PWS and CIK coarse textured habitat, abundances and biomass were higher for oiled sites in most cases. No consistent pattern was observed for *T. persona* from estuarine habitat.

Three barnacle species were examined in detail for abundance/biomass differences, with only *Chthamalus dalli* showing consistent results. Abundances and biomass of *C. dalli* were higher for oiled sites in all cases but one in which significant differences were detected. The trend was consistent throughout sheltered rocky habitat in all regions as well as exposed rocky habitat in PWS and persisted through the last sampling period of 1991. *C. dalli* were not found in great numbers on coarse textured sites and significant differences were not observed. In CIK estuaries, *C. dalli* abundances and biomass remained higher on oiled sites, although the trend was weaker than that observed for sheltered or exposed rocky habitats. Abundance and biomass values for *Balanus glandula* in CIK estuaries, however, were consistently higher on oiled sites through time and the trend was still evident as of the last sampling in 1991. Significant differences were not revealed for *C. dalli* in PWS estuaries, where *B. glandula* and *Semibalanus balanoides* were the dominant barnacle taxa, with higher abundance and biomass values on control sites in most cases of significance.

Mussels exhibited similar trends in each region and habitat with the exception of coarse textured sites in CIK. For all other cases in which significant differences were demonstrated, mussel abundances and biomass were higher on control sites. The impact was less apparent in KAP than PWS or CIK for sheltered rocky habitat and was weaker in general for estuary and exposed rocky habitats.

Differences between littorine populations from oiled and control sites were found for most habitat types. In sheltered rocky habitat, abundance and biomass values were higher for *Littorina sitkana* on control sites. The trend weakened over time, with distance from spill source and in lower MVDs. *L. scutulata*, in contrast, had higher values on oiled sites in all regions. The trend persisted through time and was still apparent as of the last sampling in 1991. Contrasting responses of the two species in sheltered rocky habitat are most likely due to their differing reproductive modes. *L. sitkana* are direct developers with crawl-away young and *L. scutulata* broadcast planktonic larvae.

Exposed rocky habitat revealed an inconsistent pattern for the two species. Abundance and biomass values were higher on control sites at all MVDs for *L. sitkana* and at MVD 2 and 3 for *L. scutulata*. For MVD 1, abundance and biomass values for *L. scutulata* were higher on oiled sites. The trend was no longer apparent in 1991. The two littorine species responded similarly in coarse textured habitat, although the response varied with region. In PWS and KAP, higher abundances and biomass were detected for littorines from control sites. Populations in CIK showed an opposite effect with higher values on oiled sites. The above patterns were observed for all sampling periods and were more pronounced in PWS and KAP than in CIK. Strong patterns were not observed for littorine populations from estuarine habitat in CIK. In PWS estuaries, however, littorines had a tendency toward higher abundances and biomass on control sites. This was observed in both species and was still apparent in most cases as of the last sampling in 1991.

Oligochaetes had higher abundances and biomass on oiled sites in most habitats and regions, particularly for coarse textured habitat in CIK, where >90% of the total invertebrate community was comprised of oligochaetes.

An attempt was made to analyze intertidal fish community structure through species diversity and richness. Abundance and biomass of all fish as a group and specifically the high cockscomb prickleback (*Anoplarchus purpurescens*) were examined between oiled and control sites for different habitat types, time periods, and MVDs (meter of vertical drop). The age structure of the high cockscomb was also examined.

Fish were sampled in a quasi-experimental matched-pairs (oiled and control sites) design stratified on three habitat types with random selection of oiled sites. Matched pairs were sampled twice each in 1990 and 1991. Of the 20 species caught, consisting of six families, five species made up 98% and one species (high cockscomb) 74% of total abundance.

No significant differences between control and oiled sites in species diversity were detected. Abundance for fish as a group was significantly greater at control sites in 1990; no significant differences were observed in 1991. Within-habitats abundance was significantly greater at control sites for coarse textured and sheltered rocky habitats. Biomass for all species was 1.6 times greater at control sites during both visits in 1990 but these were not statistically different. Biomass within habitat types was not significantly different during 1990, however in

1991 there were significant differences. In forward multiple-linear stepwise-regression models, oil was a negative predictor of abundance at MVDs 2 and 3 in 1990 but not in 1991. In logistic regression analyses, oil was a negative predictor of fish presence in MVDs 2 and 3 in 1991. We concluded that oil had a significant negative impact on intertidal fishes in 1990; however, populations were in the process of recovery by 1991.

The most abundant species, the high cockscomb, in general, had a higher average abundance at control sites as a whole, and within different habitat types. This trend was more evident in 1990, however, few of these differences were significant. Within each MVD, average abundance and biomass tended to be greater at control sites; again there were few significant differences. High cockscomb occurred more frequently in MVDs 2 and 3 during all time periods. Differences in MVD 4 for all visits were not consistent. The stepwise logistic regression analysis and bootstrap procedures indicated that presence of oil and a number of habitat variables significantly influenced the probability of finding high cockscomb in 1990 but were not important in 1991. Multiple regression analysis showed oil as a significant negative predictor during 1990 for MVDs 3 and 4.

The ages of 53 high cockscomb pricklebacks were estimated by two readers from hypural bones of the caudal complex, quadrates (a bone in the suspensorium of the skull), otoliths (surface-viewed and broken-and-burned), opercules, and vertebrae. Fleiss' index of interrater agreement indicated excellent agreement between surface-viewed otoliths, and hypurals and quadrates; however, ages from otoliths had consistently lower estimates. Comparison of age estimates between hypurals and quadrates produced a 91% complete agreement for reader 1 and 96% for reader 2. The overall index of agreement between both of these structures was the highest (0.97 $\pm$ 0.138) of all comparisons for both readers. A comparison of ages obtained by both readers from 52 hypurals resulted in 77% complete agreement and 94% within one year, and an index of 0.97 ($\pm$ 0.138). An additional 329 hypural bone complexes were evaluated for interreader agreement, the results of which suggests there is some difficulty in determining the characteristics of annuli in fish aged older than three years. A preliminary assessment of the use of hypurals for aging *Phytichthys chirus* (ribbon prickleback) and *Xiphister atropurpureus* (black prickleback) was also conducted and appeared applicable for the former but not the latter. Although the hypurals were not appropriate for this population of ribbon prickleback, we concluded that hypurals were the most appropriate structures for aging fishes in this family.

Intertidal fish were collected from oiled and control sites in Prince William Sound in 1990 for gill histopathologic examination. Two species, the high cockscomb, *Anoplarchus purpurescens* and the tidepool sculpin, *Oligocottus maculosus* were examined. Parasites observed on the gills (*Trichodina* sp.) were counted. In a separate laboratory study, *A. purpurescens* were captured at an oiled site, transported to the laboratory, and held in a "recovery" tank with unoiled rocks. Additional *A. purpurescens* were captured at an unoiled site and kept in an "oil exposure" tank with oiled rocks gathered in Prince William Sound, or in a control tank with unoiled rocks. Gill histology, gill parasite loads, liver histology, liver protein induction and oxygen consumption were studied in fish sampled from the tanks at increasing intervals over a four-month period. In the field study, gill abnormalities were present to varying degrees in individuals in each sample, but no significant differences were found between paired samples from oiled and unoiled sites. No consistent differences were found between parasite loads in fish from paired oiled and control sites, in the field study. In the laboratory study, individuals in each group also displayed gill abnormalities to varying degrees, with no significant differences among the treatment groups. *Trichodina* infestation was initially highest in fish captured at the oiled site, and decreased with time. No significant differences in relative concentrations of liver proteins were seen among treatment groups. Oxygen consumption was significantly higher in fish from oiled beaches, and in fish exposed to oiled rocks in the laboratory than in the control group.

The time required for intertidal communities to return to pre-spill conditions will vary with the type of oil spilled, the intensity of the cleanup, and the sensitivity of the plants at a particular habitat. Although the intertidal communities that we studied showed widespread impact from oiling/clean-up activities for algal, invertebrate and fish components, all observed some degree of recovery. For this study, recovery was defined as no significant differences with convergence of the oiled values to those of the controls. Full recovery of the intertidal is anticipated, especially since the impacted environment (boreo-arctic) is one in which the life-history strategy of a number of opportunistic organisms is r-selected. Larger, less abundant K-strategists may require more time for recovery. Our intensive collection of abundance and biomass data, ending in the summer of 1991, showed that most habitats were recovering but had not yet fully recovered, although taxa differences were increasing over time up through 1991. The algal percent cover data collected during 1992 through 1994 showed that many habitats appeared to meet our criteria of recovery by the summer of 1992. A few regions had not completely recovered by the summer of 1994, such as the upper MVDs in sheltered rocky habitats and MVD 3 at PWS coarse textured sites. Therefore, we cannot estimate a time to full recovery for those beaches impacted by the *Exxon Valdez* oil spill.

CHAPTER 1

OVERALL INTRODUCTION AND OBJECTIVES

The Coastal Habitat Injury Assessment (CHIA) study was designed to document and quantify injuries to biological resources found in the intertidal zone throughout the regions affected by the *Exxon Valdez* oil spill. The study encompassed all three major coastal regions impacted by the spill, Prince William Sound (PWS), Cook Inlet-Kenai Peninsula (CIK) and Kodiak-Alaska Peninsula (KAP). In addition to the broad examination of intertidal habitats impacted by the oil spill, a field station was established in Herring Bay on Knight Island in PWS. The Herring Bay study was established as a result of a Natural Resource Damage Assessment (NRDA) Management Team recommendation, to provide a research platform for intertidal damage and recovery assessment through field experimentation (see separate report).

The intertidal zone is a unique area of high productivity supporting a diverse array of organisms including many commercially and ecologically important species. This zone is particularly vulnerable to oil spills due to the grounding of oil, its persistence in the intertidal and subtidal sediments, and the effects of associated cleanup activities. Oil may affect intertidal organisms directly by coating or ingestion, with toxic effects leading to death or reproductive failures (Shaw *et al.* 1986, Paine *et al.* 1988, Jackson *et al.* 1989, Garrity and Levings 1990, and Pople *et al.* 1990). Oil contamination may also affect commercially important fishes using intertidal habitats as breeding or nursery areas (Brule 1984, Moles *et al.* 1987, and Paine *et al.* 1988). Indirectly, oiling may cause decreased productivity of food organisms, accumulation of toxins through the food chain, and loss of microhabitat such as algal beds. Dispersants and emulsifiers can be highly toxic (Southward and Southward 1978 and Farke *et al.* 1985) and hot water washing may be harmful or fatal to many organisms (Ganning *et al.* 1983). The above effects can lead to long term modifications of intertidal populations and communities (Southward and Southward 1978 and Dauvin and Gentil 1989). Assessment of injuries to coastal habitat resources and determination of rates of recovery requires consideration of the various coastal geomorphologic types, the degree of oiling, the affected biota, and trophic interactions.

The Coastal Habitat project was designed to determine the effects of oil and subsequent cleanup activities on intertidal invertebrates, algae, and fishes in regions impacted by the oil. This was accomplished by matching oiled sites to control, or non-oiled sites. In 1989, the selection of basic experimental units (study sites) for the Coastal Habitat project was accomplished using a stratified random sample with probability proportional to size. Following ground truthing surveys, a set of oiled and non-oiled (control) sites was selected for study. The sites represented five coastal habitat categories distributed among three geographical regions (PWS, CIK, KAP). In 1991, the total number of sites was reduced as recommended by the Management Team, Legal Team, P.I.s and Peer Reviewers. The resultant set of paired oiled and control sites included sheltered rocky and coarse textured beaches from PWS, CIK, and KAP; sheltered estuarine beaches from PWS and CIK; and exposed rocky beaches from PWS.

The overall objective of this study was to estimate the effects of oiling and cleanup activities on the quantity (abundance and biomass), quality (reproductive condition and growth rate), and composition (diversity, richness and dominance) of key species in the various trophic levels of intertidal communities. The data included in this report will provide estimates of injury to the overall health and productivity of these important coastal habitats, and provide information relevant to the more species specific studies on the effects of the oil spill on birds, mammals and fish that use these habitats. Specifically, the objectives were:

A. Estimate the quantity (abundance and biomass), quality (reproductive condition and size), and composition (diversity, richness and dominance) of various trophic levels (and subsequent impact on trophic interactions) in moderately and heavily oiled sites relative to lightly oiled or non-oiled sites.

B. Estimate hydrocarbon concentrations in sediments and biological samples.

C. Establish the response of these parameters to varying degrees of oiling and subsequent cleanup activities.

D. Extrapolate impact results to the entire oil affected region.

E. Estimate the rate of recovery of the habitats studied and their potential for restoration.

F. Provide linkages to other studies by demonstrating the relationships between oil, trophic level impacts, and higher organisms.

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CHAPTER 2

OVERALL METHODS

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CHAPTER 2

OVERALL METHODS

Methods common to all components of the study are included in this chapter. Procedures specific to a particular component of the study are described in the chapter for that component.

Site Selection Methods - 1989 and 1990.

The Coastal Habitat Study consisted of Phase I and Phase II. Selection of study sites was conducted under Phase I with the methods outlined in Sundberg (1989). Basic details of site selection are repeated here in the interest of completeness. Due to the great extent of the oil spill, three study regions were identified: Prince William Sound (PWS), Cook Inlet-Kenai Peninsula (CIK), and Kodiak-Alaska Peninsula (KAP). A Geographic Information System (GIS) was used to combine oiling and habitat data to select an array of study sites representative of the shoreline habitat available and potentially impacted by the spill. The GIS database for Phase I was developed by combining data from three sources. GIS data layers used for site selection included: the mean high water shoreline digitized from U.S. Geological Survey 1:63,360 quadrangles in the spill area, Environmental Sensitivity Index maps that classified the shoreline into nineteen geomorphologic types, and Oil Spill Impact maps that classified the shoreline by degrees of oiling. The three degrees of oiling originally used for site selection were moderately to heavily oiled, lightly to moderately oiled, and non-oiled. The various geomorphologic types were combined into five habitat types: exposed rocky, fine textured, coarse textured, sheltered rocky and estuarine. Fine textured habitats were dropped after 1989.

The shoreline was classified into fifteen strata (three oiling levels by five habitat types) based on data available in June-July, 1989. The GIS was programmed to divide the shoreline in each stratum into segments (arcs) ranging in length from 100 to 600 meters. Arcs less than 100 meters were not used because they were judged to be too small to capture the natural variance of species composition, distribution, and abundance within a stratum. Further, the sites would be too small to allow for the required number of quadrats for three years of data collection. Arc lengths were limited to 600 meters to ensure that the study site could be subsampled efficiently during a low tide event. Each arc was then given a unique identification number (site number) in the GIS.

Potential study sites (arcs) were randomly selected using commercial software for the GIS. The probability that a particular arc would be selected was proportional to the ratio of its length to the total shoreline. Sites were then visited during a reconnaissance survey to determine accessibility for the Phase II quantitative sampling, to describe and verify habitat and oiling classifications, to collect oil and sediment samples, and to permanently mark sites to aid in Phase II sampling.

After visiting and sampling study sites in 1989 we found that there was large variation in the habitat within the strata. With the original study design it would not be possible to detect statistically significant differences between biological variables measured on sites in oiled and non-oiled (control) strata. Control strata had unacceptable variation when sites on the PWS mainland were combined with control sites on the islands and subsequently compared to oiled sites due to numerous fresh water sources on the mainland. Most oiled sites were on the islands of the central and western PWS where salinity was much higher. Extreme variation in habitat was noted within all 15 strata. Many sites were miss-classified in the original GIS stratification.

The survey design was modified during the winter of 1989-1990 to an "after control-impact pair" design (Dean et al. 1993) to reduce habitat variation and miss-classifications. Each of the accessible, moderate-heavily oiled sites selected for the original stratified random sample was post-classified into the correct habitat stratum and deductively matched with a control site based on physical characteristics of the unique oiled site. Post-classification of oiled sites resulted in sites being pooled into "new strata" with unequal probabilities of inclusion.

Physical characteristics considered for selection of matching control sites included substrate composition, wave exposure, slope, proximity of freshwater, and nearshore bathymetry (Sundberg *et al.* 1990). The first sites considered for potential matched controls were those island sites selected and sampled in 1989. The second group considered were sites surveyed and marked in Phase I, but not sampled. If suitable controls were not found in these groups, five potential controls selected from the GIS were considered in order of proximity to the oiled site. The final set of sites selected for inclusion in Phase II are listed in Tables 2.1 and 2.2 and represented in Figures 2.1-2.4.

A Monte Carlo study mimicking the procedures and protocols used in the site selection process was conducted to estimate the probability that a given site pair was chosen for study (Erickson and McDonald 1992). Inclusion probabilities and weights (importance values) of each site pair within each region and habitat are given in Appendix A. Some additional oiled sites were subjectively selected for habitat strata that did not meet the minimum objectives for sample sizes. These sites have a probability of inclusion P_i equal to 100% in the resulting statistical analyses.

Initial Site Layout

During the first visit to the site the length was marked and measured along the mean high water (MHW) line. Then the length of the sampleable (slope less than 35 degrees) beach within the primary habitat was determined. A black lichen, *Verrucaria*, occurs on rocks just above MHW throughout the spill region. The lowest edge of the *Verrucaria* zone (>20% cover), at the interface between the *Verrucaria* and barnacle zones, was used to locate the MHW line. In 1989, three invertebrate/alga transects perpendicular to the MHW line were placed equal distances apart within the primary habitat type using a random starting point. It was later decided that three transects were insufficient replications. Therefore during the first visit of 1990, three additional transects (ghost transects) were created at equal distances from the original 1989 transects. This procedure resulted in a baseline set of six transects. Additionally, during this and each successive visit for 1990 and 1991, new transects were established three meters from the left of the most recently established set of transects. For sites that were first established in 1990, the procedures used to set up sites in 1989 were used, except that six transects were established at the onset. General sampling periods for each visit are listed in Table 2.3. The sampling dates for each individual site are listed in Appendix Tables B.1-29.

During the initial visit to each site in PWS, survey transects for sampling fish were established three meters to the right of the baseline invertebrate/algae transects. During each subsequent visit, new transects for sampling fish were established three meters to the right of the most recent fish transect.

For all transects used in the intertidal study, permanent quadrats were randomly established within each of the first three meters of vertical drop (MVD) from the head of the transect (MHW). For the remainder of the report, the quadrats within each meter of vertical drop (Figure 2.5) will be called: first meter of vertical drop = MVD 1, second meter of vertical drop = MVD 2, and third meter of vertical drop = MVD 3.

Algae/Invertebrate Quadrat Sampling

Permanent quadrats were randomly established along a transect at each MVD (Figure 2.6) The quadrat was centered on the transect line. In 1989 the quadrat was 50 cm long by 40 cm wide. The quadrat was divided lengthwise into an undisturbed control quadrat (50 cm x 20 cm) on the right and collection quadrat (50 cm x 20 cm) on the left where samples were taken. In 1990 the size of the quadrat was enlarged to 50 cm long by 80 cm wide. This quadrat was also divided lengthwise into a control quadrat on the right and a collection quadrat on the left. From the 50 cm x 40 cm undisturbed control quadrat, photographs and algal percent cover were taken. The left side was a 50cm x 40cm collection quadrat. Photographs and algal percent cover were taken before any samples were removed. Then the collection quadrat was divided lengthwise into two equal halves. From the right side of the collection quadrat, all visible algae and invertebrates were collected for identification and enumeration in the laboratory. On nonbedrock substrates the first 10cm of substrate was collected for separation of infauna in the laboratory. Samples collected from the quadrat were preserved in formlin. The quadrat that was cleared in 1990 through 1991 was the same size as the 1989 quadrat. These quadrats were subsequently monitored using percent cover to assess the ability of the algae to recolonize cleared areas. From the left side of the collection quadrat all overstory algae were removed and discarded. These quadrats (overstory removed) were also monitored for agal colonization ability. It was necessary to move to a new sampling location during each visit so that collections would not be made from an area previously cleared. A one meter radius semicircle centered at the midpoint of the left side of the sample quadrat was used to collect limpets and fertile *Fucus*. Hydrocarbon samples were collected to the left of this semicircle.

Figure 2.6 illustrates the sizes of the 1989 and 1990/1991 quadrats. Figure 2.7 is a schematic of a theoretical site showing the relative locations of transects for each visit and the placement of quadrats along the individual invertebrate/algae transects.

Site Characterization

Water temperature and salinity were recorded during each visit. These measurements were made to verify that the physical characteristics of the seawater were similar for paired sites and to aid in the interpretation of data between regions. Temperature and salinity profiles were measured at the 15 meter isobath at the center of the site. Measurements were taken at the surface and at every meter of depth down to ten meters using a YSI SCT Meter.

Slopes of each MVD on a site were calculated by averaging the slopes of the six transects. A horizontal distance was measured for each MVD by stretching the tape tight from the top of the MVD to the top of a meter stick placed at the lower end of the MVD. Geological characterizations, sketches and photos of sites were made during the first site visits (Sundberg 1989, 1990). Additionally, during the first sampling of each site in 1990, photos were taken along each transect and of the entire site. Appendix Tables B-1 through B-29 contain site characterization information, latitude, longitude, and the dates each site was visited. Exposure was estimated by 1) looking at aspect relative to the fetch and prevailing winds, 2) location relative to any lees from storm waves, 3) photographs and personal observations on rock/cobble/boulder angularity, and 4) the presence or absence of storm berms and drift lines.

Sediment and mussel tissue samples were collected for hydrocarbon analyses during each site visit from two randomly selected transects. Sediment immediately to the left of the sampling semicircles was collected. Mussel samples were collected from within an 80-cm swath centered along the transect line. No samples were collected from sites with an inadequate supply of sediment and/or mussels. After the 1990 field season, all sediment or tissue collected from different transects on a given site and visit were combined during field collections. Many samples not combined during field collections in 1990 were combined during laboratory analysis.

Hydrocarbons in sediment and/or mussel tissue samples were initially analyzed with gas chromatography (GC) coupled with flame ionization detection (FID) or mass spectrometry (MS). These techniques were too expensive and time consuming to continue, so a new "screening" method was employed. This method involved high performance liquid chromatography (HPLC) coupled with ultraviolet fluorescence (UVF) (Krahn *et al.* 1988 and 1991), and replaced the GC/MS analyses in 1990. The UVF/HPLC method does not give any information on concentrations of individual components, and is best used for ranking relative amounts of hydrocarbon contamination (Krahn *et al.* 1991). Samples analyzed by UVF/HPLC cannot be directly compared with those analyzed by GC/MS. This led to complications when the samples from either site of a matched pair were analyzed by different methods. Tables 2.4-2.7 list the number of mussel and sediment samples that were collected during each visit. In addition, the number of those samples that were ultimately analyzed by either GC/MS or UVF/HPLC methods are shown. Appendix Tables B-30 through B-34 contain the hydrocarbon results. The low number of samples make interpretation of these results difficult.

Statistical Methods

There are two levels of statistical inference presented in the analysis. The first, known commonly as "fixed effects analysis" uses standard statistical procedures for making inferences to the unique set of oiled and control pairs in the study (and the protocols for selection of matching control sites and subsampling of sites). For these fixed effects tests, no statistical inferences are drawn beyond the specific set of sites in the study. In the second level, meta-analysis procedures (Folks 1984) are used to provide inferences to the universe of oiled sites (and the protocols for selection of matching control sites and subsampling of sites).

In fixed effects analysis, the null hypothesis of no significant difference between a specific oiled and matched control site was tested. For the analysis of variables measured on invertebrate and on most algal taxa, Levene's test (Milliken and Johnson 1984) was used to test for homogeneity of variances. If variances were not significantly different at the $P = 0.01$ level, then ordinary one-way-analysis of variance was conducted to obtain the pooled estimate of variance. Pairs of oiled and control sites were then compared by a two-tailed t-test (Milliken and Johnson 1984). If variances were significantly different, data were transformed to logarithms and the above tests were repeated. If Levene's test remained significant on the transformed values, then regular two-sample t-tests were conducted to compare matched pairs with Satterthwaite's correction on the degrees of freedom for unequal variances.

For the analysis of variables measured on *Fucus* attributes expressed as ratios, two-sample randomization tests were conducted to compare pairs of oiled and control sites. Proportional data (e.g. percent cover of algae) were transformed using the arcsine square root transformation (Steel and Torrie 1980) before comparisons were made between matched pairs of sites.

The jackknife procedure (Manly 1991) was used to analyze data for invertebrate diversity and richness indices. Indices between sites were considered significantly different if the confidence intervals on the indices did not overlap.

Fisher's procedure for combining results of independent tests (Sokal and Rohlf 1981) was used with equal weights (importance values) on each oiled-control site pair to synthesize the results of the fixed effects analyses. Inferences are to the specific set of site pairs in the study following the logic that each site pair is a separate experiment with equal weight.

For inferences beyond the specific set of study sites, Stouffer's meta-analysis procedure (Folks 1984) was used to combine P-values of independent analyses on matched pairs. Stouffer's method uses the unequal inclusion probabilities inherent for each site pair in the original site selection process. Inferences are to the universe of oiled-control site pairs that could have been obtained by the sampling and site selection protocol. The statistical inferences are then based on the logic that if the whole process had been replicated using sites selected by the same protocols, then similar results would be obtained.

Significance levels (P-values) below 0.01 are judged to indicate strong sources of corroborating evidence for the effect of oil/clean up. Values in the range $0.01 < P < 0.05$

indicate moderate corroborating evidence of oil effects. Values in the range $0.05 < P < 0.10$ are weak indications of corroborating evidence of effects. P-values above 0.10 may still serve as corroborating evidence but will not be viewed as important standalone sources of evidence unless they fit into a pattern that is consistent across more than one site and period.

If both Fisher and Stouffer's methods showed significant results, then we judged that an overall oil effect existed for the organism in the given region, habitat type, MVD, and in the time. If Fisher's test is significant and Stouffer's is not, then inferences are limited to the specific study sites. Stouffer's method weights the data according to the probabilities of site selection. Occasionally, the Stouffer's test may indicate that significant results exist while the Fisher's test does not.

If significant differences were detected in 1990, but not in 1991, and convergence of values occurred or power was high, we judged that recovery was proceeding. Evidence that the control sites were properly matched to the oiled sites is also gained when an initial effect is detected, but recovery has taken place (Skalski and Robson 1992).

In large experiments of this type with no prior conjectures on the possible effect of oil on many of the organisms, there will be a certain unknown rate of "false positives." That is, some differences may be erroneously tagged with a small P-value due to random change, high variance, and the large number of comparisons being made. These false positives should not exhibit meaningful patterns or yield corroborating information. Conclusions and discussions must be based on overall weight of corroborating evidence on all sites, periods, and regions using statistical results from both the Fisher and Stouffer's tests.

Statistical Power

Power is the probability of obtaining a significant result when the null hypothesis being tested is not true (Manly 1991). Appendix Table B.35 contains approximate power values, calculated for a two-sample t-test assuming a sample size of six quadrats per site and $\alpha=0.05$. Approximate power values are calculated under assumed variability (coefficient of variation) and a magnitude of an effect due to oil/cleanup defined as the oiled mean expressed as a percentage of the control. For example, with coefficients of variation around 50%, a 50% reduction (B=0.50) in the mean of a measured variable on an oiled site relative to the matched control would have a 48.7% chance of being detected. This table can be used to get an approximation of the power that exists in detecting certain effects for those comparisons between matched pairs of sites that did not reject the hypothesis of equal means.

The power values of Fisher and Stouffer's tests were approximated for every overall test conducted. Closed form formulas for calculating power exist for only a few parametric statistical tests (e.g. t-tests, ANOVA) and do not exist for Fisher and Stouffer's tests. Monte Carlo methods (Manly 1991) were used to generate power for overall tests. In this process, each iteration consists of 1) generating data from empirical distributions based on parameter estimates and sample sizes in the sample data, 2) conducting t-tests between matched oiled and control sites, and 3) conducting Fisher and Stouffer's tests using the p-values from the t-tests. Each iteration was repeated 5000 times, where data were regenerated from the empirical distributions. The power was approximated by the proportion of overall tests that were significant at the $\alpha=0.05$ level.

The data for each site were generated from a mixture of distributions. The proportion of quadrats with a value of zero (i.e., empty) for the given taxonomic group was used as the probability of obtaining an empty quadrat from a binomial distribution. The nonzero quadrat data was simulated from a normal distribution with the mean and variance from the log transformed nonzero data. Power values calculated from the observed data must be interpreted by looking at the estimated effects seen in the data, since the means generated in the simulation are based on the actual sample means.

Monte Carlo methods were also employed to approximate the power under the assumption that the effect of the oil spill was to decrease the value of the parameter on the oiled sites by 50% relative to the control sites. The data for each control site were generated from the same mixture of distributions described above. To simulate a 50% effect on the oiled sites, data were generated by increasing the probability of obtaining a zero quadrat by 50%, and by decreasing the mean of the nonzero data by 50%, both relative to the control site values. If the proportion of zero quadrats for the control site was greater than 0.67, an increase by 50% would generate a probability of greater than 100%. In these cases, a probability of obtaining a zero quadrat for the oiled site was fixed at 95%. For each iteration, t-tests were conducted between matched oiled and control sites, and Fisher and Stouffer's tests were conducted using the p-values from the t-tests. Each iteration was repeated 1000 times, where data were regenerated from the empirical distributions. The power was approximated by the proportion of overall tests that were significant at the $\alpha=0.05$ level.

Statistical power calculations for Fisher and Stouffer's tests were used to interpret recovery of injured algal and invertebrate taxa when significant differences were initially detected for both Fisher and Stouffer's tests, but not later. When either Fisher's or Stouffer's tests showed $p \geq 0.10$ and the power calculated for the observed data or for a 50% decrease showed results greater than 50% for both Fisher and Stouffer's tests, then the injured resource was defined as recovered. When statistical power was low, the injured resource is not listed as recovered even if no statistically significant differences were detected for Fisher and Stouffer's tests. Because we were employing power values from two separate statistical tests, we elected to use 50% power as the benchmark rather than the more traditional 80%. Using this 50% value may slightly underestimate the time when recovery has occurred. The actual power values for a given test are presented in the narrative tables and appendices.

Multi-dimensional Scaling

Multi-dimensional scaling (MDS) was used to ordinate the proximity or distance between sites spatially in a map using the mean biomass values for the alga and invertebrate taxa across all three meters of vertical drop. Several studies on environmental impacts of pollution on soft sediment subtidal habitats have used the exploratory MDS data analysis technique to show the differences in the community structure between the polluted and nonpolluted sites (Gray *et al.* 1988, Warwick 1988, Agard *et al.* 1993, and Warwick 1993). Means were calculated at the family level. See the algae and invertebrate methods sections

(Chapters 3 and 4, respectively) for specifics on how the data were prepared for MDS analysis. The Bray-Curtis dissimilarity measure (Bray and Curtis 1957, Field *et al.* 1982) was used to calculate distances between sites. The index, δ_{jk}, is calculated from the following equation:

$$\delta_{jk}=\frac{\sum_{i=1}^{s}|Y_{ij}-Y_{ik}|}{\sum_{i=1}^{s}(Y_{ij}+Y_{ik})}$$

where Y_{ij}= mean biomass for the *i*-th species at the *j*-th site; Y_{ik}= mean biomass for the *i*th species at the *k*-th site; δ_{jk}= dissimilarity between the *j*-th and *k*-th samples summed for all s species, δ_{jk} ranges from O (identical means for all species), to 1 (no species in common).

The procedure "MDS" in the statistical computer package SYSTAT (1990) was used for these analyses. The following steps were used in the MDS procedure: A starting map of the n sites was constructed, and the interpoint distances $\{d_{jk} : k>j; j=1,....n\}$ of this configuration are then regressed on the corresponding dissimilarities using general monotonic regression. Note that the ranks of the distances were being regressed. Stress was used as the measure of goodness of fit. The formula for stress is:

$$stress=\frac{\sum_{j}^{n}\sum_{k>j}^{n}(d_{jk}-\hat{d}_{jk})^2}{\sum_{j}^{n}\sum_{j>k}^{n}d_{ij}^2}$$

where d_{jk}= distance estimated from the regression, corresponding to dissimilarity, δ_{jk}.

Results are reported only for the two-dimensional solution because of the large number of MDS runs that were conducted and because solutions greater than two dimensional are difficult to display and interpret. Environmental data were overlaid upon the MDS configurations to relate patterns in the ordination back to environmental factors.

The following questions were developed to be answered from the MDS analyses: 1) Do the three regions (PWS, KAP, CIK) tend to ordinate separately within each habitat type? 2) Do the habitat types tend to ordinate separately within each region? 3) What environmental factors (e.g., exposure, oiling, aspect, salinity) tend to explain the patterns in the ordinations of the sites?

Environmental data that were collected from each site include salinity, water temperature, site exposure, and average site slope. Additionally, initial MDS analyses included oil cover, penetration, and thickness obtained from Alaska Department of Environmental Conservation (ADEC) Coastal Habitat Injury Assessment Shoreline Surveys (1991). Initial runs of the MDS program included many missing data points on sites for hydrocarbon sediment and mussel samples, and for the ADEC oil data. Thus, these environmental variables were not included in further analyses. In addition, the salinity and temperature data showed no trends any time and therefore the results are not presented.

Quality Assurance/Quality Control

All samples collected in the field were tracked by chain of custody procedures. Sample tags were used for noting date, site, transect, quadrat, type of sample, and name of collector. Each sample tag was assigned a unique number. As each sample was collected, a sample tag was filled out and stored in the same container as the sample (except hydrocarbon samples that had labels on the outside). Field data sheets were also prepared for each transect to record information such as site, habitat, locations, and sample tag numbers for each quadrat along the transect. Each sample could then be identified in two ways to avoid error, with the field data sheets and/or the sample tag. After returning to the vessel, all samples for a given site were recorded on a chain of custody form that remained with the collection. This form was signed by any individual relinquishing samples to another individual for shipping and/or storage.

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Table 2.1. Site locations in the Prince William Sound region. "Segment" corresponds to the DEC segment number located in the GIS data base. Oil codes are: 9 = no oil, 2 = light to no oil, 1 = moderate to heavy oil. Habitat codes are: 5 = sheltered estuarine, 4 = sheltered rocky, 3 = coarse textured, 1 = exposed rocky.

Segment	Site Number	Location	Latitude/ Longitude	Oil Code	Oiled/ Control	Habitat Code
Prince William Sound						
Sheltered Rocky						
KN0578	4825C	Deer Cove	60° 14.60'N/147° 53.50'W	9	Control	4
EL054	1424	Northwest Bay	60° 33.30'N/147° 36.60'W	1	Oiled	4
IN023	453C	Ingot Island	60° 32.10'N/147° 37.70'W	2	Control	4
DI059	453	Disk Island	60° 30.30'N/147° 39.20'W	1	Oiled	4
KN0551	601C	Lower H. Bay	60° 23.35'N/147° 49.55'W	9	Control	4
KN0118	601	Herring Bay	60° 28.10'N/147° 42.20'W	1	Oiled	4
KN0552	598C	Lower H. Bay	60° 22.58'N/147° 49.21'W	2	Control	4
KN0118	598	Herring Bay	60° 28.20'N/147° 42.40'W	1	Oiled	4
KN5011	1522C	Herring Bay	60° 26.55'N/147° 44.55'W	2	Control	4
KN0121	1522	Herring Bay	60° 27.60'N/147° 42.90'W	1	Oiled	4
Coarse Textured						
SQ002	506C	Squire Island	60° 15.85'N/147° 55.60'W	2	Control	3
CR001	506	Crafton Island	60° 30.60'N/147° 56.50'W	1	Oiled	3
KN0205	1598C	Bay of Isles	60° 22.05'N/147° 41.67'W	2	Control	3
KN0204	1598	Bay of Isles	60° 21.80'N/147° 42.00'W	1	Oiled	3
WH504	846C	Whale Bay	60° 12.60'N/147° 17.90'W	2	Control	3
KN0205	846	Bay of Isles	60° 21.80'N/147° 41.90'W	1	Oiled	3
KN0608	1650C	Little Bay	60° 10.50'N/147° 47.80'W	2	Control	3
KN0403	1650	Snug Harbor	60° 15.30'N/147° 45.30'W	1	Oiled	3
Sheltered Estuarine						
NONE	15.1C	Stockdale Hbr.	60° 17.20'N/147° 12.30'W	9	Control	5
KN0136	15.1	Bay of Isles	60° 23.00'N/147° 42.60'W	1	Oiled	5
BS505	2397C	Puffin Cove	60° 10.80'N/148° 19.50'W	9	Control	5
AE006	208/09	Applegate Is.	60° 37.70'N/148° 08.35'W	1	Oiled	5
Exposed Rocky						
PK001	19C	Peak Island	60° 42.50'N/147° 24.70'W	9	Control	1
NA021	19	Naked Island	60° 42.00'N/147° 26.90'W	1	Oiled	1
CH016	1642C	Chenega Island	60° 16.70'N/148°04.00'W	2	Control	1
KN0212	833	E. Knight Is.	60° 22.15'N/147° 37.18'W	1	Oiled	1
GR301	4537C	Green Island	60° 13.60'N/147° 29.20'W	2	Control	1
GR001A	979	Green Island	60° 15.90'N/147° 29.00'W	1	Oiled	1

Table 2.2. Site locations in the Cook Inlet – Kenai Peninsula and Kodiak Island – Alaska Peninsula region. "Segment" corresponds to the DEC segment number located in the GIS data base. Oil codes are: 9 = no oil, 2 = light to no oil, 1 = moderate to heavy oil. Habitat codes are: 5 = sheltered estuarine, 4 = sheltered rocky, 3 = coarse textured, 1 = exposed rocky.

Segment	Site Number	Location	Latitude/ Longitude	Oil Code	Oiled/ Control	Habitat Code
Cook Inlet/Kenai Peninsula						
Sheltered Rocky						
NC001	14.1C	Nuka Bay	59° 28.45'N/150° 21.65'W	2	Control	4
MR001	14.1	McArthur Pass	59° 27.70'N/150° 22.60'W	1	Oiled	4
BM001	14.2C	Chance Cove	59° 29.09'N/150° 18.21'W	2	Control	4
PY008	14.2	Morning Cove	59° 26.95'N/150° 19.70'W	1	Oiled	4
YB005	62762C	Yalik Bay	59° 27.30'N/150° 36.60'W	9	Control	4
TB002	50983	Tonsina Bay	59° 18.50'N/150° 55.40'W	1	Oiled	4
Coarse Textured						
PD010	50389C	S.E. Pt. Dick	59° 15.45'N/151° 07.18'W	9	Control	3
NONE	50389	One Haul Bay	59° 13.10'N/151° 13.60'W	1	Oiled	3
CS001	51091C	Chrome Bay	59° 12.60'N/151° 49.35'W	9	Control	3
CB003	51091	Chugach Bay	59° 11.30'N/151° 37.90'W	1	Oiled	3
NONE	62802C	Sadie Cove	59° 27.90'N/151° 20.30'W	9	Control	3
PD002	50226	W. Arm Pt. Dick	59° 18.70'N/151° 17.70'W	1	Oiled	3
Sheltered Estuarine						
PD011	15.1C	Taylor Bay	59° 18.72'N/151° 01.31'W	9	Control	5
NK001	15.1	N.E. Nuka Is.	59° 23.50'N/150° 37.45'W	1	Oiled	5
TB003	50221	Tonsina Bay	59° 18.60'N/150° 57.20'W	1	Oiled	5
NK004	50981C	Berger Bay	58° 20.05'N/150° 44.00'W	9	Control	5
TB003	50981	Tonsina Bay	59° 18.50'N/150° 56.70'W	1	Oiled	5
Kodiak/Alaska Peninsula						
Sheltered Rocky						
PI001	30196C	E. Perevalnie Is.	58° 38.10'N/152° 20.51'W	9	Control	4
SI003	30196	Perevalnie Psg.	58° 37.90'N/152° 22.00'W	1	Oiled	4
FB007	31252	Foul Bay	58° 21.60'N/152° 45.90'W	1	Oiled	4
FB005	31252C	Foul Bay	58° 20.52'N/152° 45.70'W	9	Control	4
XX500	31248	Foul Bay	58° 21.70'N/152° 46.10'W	1	Oiled	4
XX509	99826C	Takli Island	58° 04.20'N/154° 29.50'W	9	Control	4
XX501	33141	Chief Cove	57° 42.50'N/153° 54.00'W	1	Oiled	4
Coarse Textured						
SP901	94935C	Uganik Psg.	57° 49.60'N/153° 11.20'W	9	Control	3
FB007	31288	Foul Bay	58° 21.00'N/152° 45.20'W	1	Oiled	3
XX500	13.1C	Dakavak Bay	58° 02.85'N/154° 38.85'W	9	Control	3
KA002	13.1	Kashvik Bay	57° 53.20'N/155° 05.50'W	1	Oiled	3

Table 2.3 Sampling Periods for individual site visits to each region and habitat combination.

Region	Visit	Sheltered Rocky	Coarse Textured	Sheltered Estuary	Exposed Rocky
PWS	1989	August	September	September	September
	1990 Visit 1	May	June	June	June
	1990 Visit 2	July	July	August	August
	1991	May	May	June	June
CIK	1989	September	September	September	--
	1990 Visit 1	June	July	June	--
	1990 Visit 2	August	August	July	--
	1991	May	May	May	--
KAP	1989	September	September	--	--
	1990 Visit 1	June	July	--	--
	1990 Visit 2	August	September	--	--
	1991	May	May	--	--

Table 2.4. Summary of Hydrocarbon samples collected and analyzed from Prince William Sound during the 1989, 1990, and 1991 visits to CHIA sites. GCMS = Gas Chromatography/Mass Spectrometry; UVF = Ultraviolet Fluorescence/High Performance Liquid Chromatography; "#" = sediment samples composited across a site; "*" = sample analysis was corrupt, sample listed in NOAA ; 'Bad Catalog'.

				Mussels			Sediment			Blanks		
Year	Habitat	Visit	Site	Collected	Analyzed	Method	Collected	Analyzed	Method	Collected	Analyzed	Method
1989	Coarse Textured	1	506	2	2	GCMS	0	0	---	1	1	GCMS
1989	Exposed Rocky	1	833	2	0	---	0	0	---	1	0	---
		2	833	2	2	GCMS	0	0	---	1	1	GCMS
		1	979	2	0	---	0	0	---	1	0	---
		2	979	2	2	GCMS	0	0	---	0	0	---
1990	Sheltered Rocky	2	4825C	0	0	---	1	0	---	1	0	---
		2	601C	1	1	GCMS	1	1	GCMS	2	0	---
		2	601	2	2	GCMS	4	4	GCMS	2	1	GCMS
		2	598C	2	2	GCMS	2	2	GCMS	2	0	---
		2	598	1	1	GCMS	3	3	GCMS	2	1	GCMS
		2	1522C	1	1	GCMS	0	0	---	1	0	---
		1	1522	2	1	GCMS	0	0	---	1	0	---
		2	1522	1	1	GCMS	0	0	---	1	0	---
1990	Coarse Textured	1	506C	2	2	GCMS	3	2 #	*GCMS/UVF	2	0	---
		2	506C	2	0	---	6	0	---	2	0	---
		1	506	2	2	GCMS	4	2 #	*GCMS/UVF	2	1	GCMS
		2	506	2	0	---	3	0	---	2	0	---
		2	1598C	1	0	---	4	1 #	UVF	2	0	---
		1	1598	2	2	GCMS	1	1	*GCMS	2	1	GCMS
		2	1598	2	0	---	7	0	---	2	0	---
		1	846C	2	2	GCMS	6	2 #	*GCMS/UVF	2	1	UVF
		2	846C	2	0	---	6	0	---	2	0	---
		1	846	2	2	GCMS	4	1 #	UVF	2	1	GCMS
		2	846	2	0	---	8	0	---	2	0	---
		2	1650C	0	0	---	8	1 #	UVF	1	0	---
		2	1650	0	0	---	7	1 #	UVF	1	0	---
1990	Estuary	1	15.1C	0	0	---	3	2 #	*GCMS/UVF	1	0	---
		2	15.1C	0	0	---	2	0	---	1	0	---
		1	15.1	4	1	GCMS	4	1 #	UVF	2	0	---
		1	2397C	2	2	GCMS	6	2 #	*GCMS/UVF	2	1	GCMS
		2	2397C	2	0	---	8	0	---	2	0	---
		1	208/09	2	1	GCMS	5	2 #	*GCMS/UVF	2	0	---
		2	208/09	2	0	---	6	0	---	2	0	---

Table 2.4. Continued.

Year	Habitat	Visit	Site	Mussels			Sediment			Blanks		
				Collected	Analyzed	Method	Collected	Analyzed	Method	Collected	Analyzed	Method
1990	Exposed Rocky	1	19	2	1	GCMS	0	0	---	1	0	---
		1	1642C	2	1	GCMS	0	0	---	1	0	---
		1	833	3	1	GCMS	0	0	---	1	0	---
		2	833	1	0	---	0	0	---	1	0	---
		1	4537C	2	1	GCMS	0	0	---	1	0	---
		2	979	2	0	---	0	0	---	1	0	---
1991	Sheltered Rocky	1	4825C	1	1	GCMS	0	0	---	1	0	---
		1	453	1	0	---	0	0	---	1	0	---
		1	601C	1	0	---	0	0	---	1	0	---
		1	601	1	0	---	0	0	---	1	0	---
		1	598C	1	0	---	0	0	---	1	0	---
		1	598	0	0	---	1	1	UVF	1	0	---
		1	1522C	1	0	---	0	0	---	1	0	---
		1	1522	1	0	---	0	0	---	1	0	---
1991	Coarse Textured	1	506C	1	1	GCMS	0	0	---	2	0	---
		1	506	1	1	GCMS	0	0	---	1	0	---
		1	1598C	1	1	GCMS	0	0	---	1	0	---
		1	1598	1	1	GCMS	0	0	---	1	0	---
		1	846C	1	1	GCMS	0	0	---	1	0	---
		1	846	1	1	GCMS	0	0	---	1	0	---
		1	1650C	1	1	GCMS	0	0	---	1	0	---
1991	Estuary	1	15.1C	0	0	---	1	1	UVF	1	0	---
		1	15.1	1	0	---	0	0	---	1	0	---
		1	2397C	1	1	GCMS	0	0	---	1	0	---
		1	208/09	1	1	GCMS	0	0	---	1	0	---
1991	Exposed Rocky	1	19C	1	1	GCMS	0	0	---	1	0	---
		1	1642C	1	1	GCMS	0	0	---	1	0	---
		1	833	1	1	GCMS	0	0	---	1	0	---
		1	4537C	1	1	GCMS	0	0	---	1	0	---
		1	979	1	1	GCMS	0	0	---	1	0	---

Table 2.5. Summary of Hydrocarbon samples collected and analyzed from Cook Inlet-Kenai Peninsula during the 1989, 1990, and 1991 visits to CHIA sites. GCMS = Gas Chromatography/Mass Spectrometry; UVF = Ultraviolet Fluorescence/High Performance Liquid Chromatography; "#" = sediment samples composited across a site.

				Mussels			Sediment			Blanks		
Year	Habitat	Visit	Site	Collected	Analyzed	Method	Collected	Analyzed	Method	Collected	Analyzed	Method
1989	Sheltered Rocky	1	50983	1	1	GCMS	3	3	GCMS	2	2	GCMS
1989	Coarse Textured	1	51091	0	0	---	3	0	---	1	0	---
		1	50226	0	0	---	3	0	---	1	0	---
1990	Sheltered Rocky	2	14.2	2	2	GCMS	0	0	---	1	0	---
		1	50983	2	2	GCMS	0	0	---	1	1	GCMS
		2	. 50983	0	0	---	3	3	GCMS	1	0	---
		1	62762C	2	1	GCMS	0	0	---	1	0	---
1990	Coarse Textured	1	50389C	1	0	---	7	1 #	UVF	2	1	UVF
		2	50389C	1	1	GCMS	6	0	---	3	0	---
		1	50389	1	1	GCMS	4	1 #	UVF	2	0	---
		2	50389	2	2	GCMS	0	0	---	0	0	---
		1	51091C	0	0	---	6	1 #	UVF	1	1	UVF
		2	51091C	0	0	---	8	0	---	1	0	---
		1	51091	0	0	---	4	1 #	UVF	2	0	---
		2	51091	0	0	---	4	0	---	1	0	---
		1	62802C	0	0	---	7	1 #	UVF	1	0	---
		2	62802C	0	0	---	8	0	---	1	0	---
		1	50226	2	2	GCMS	5	1 #	UVF	2	0	---
		2	50226	0	0	---	2	0	---	1	0	---
1990	Estuary	1	15.1C	2	2	GCMS	0	0	---	1	0	---
		2	15.1C	0	0	---	6	1 #	UVF	1	0	---
		1	15.1	2	2	GCMS	0	0	---	1	1	GCMS
		2	15.1	2	0	---	7	1 #	UVF	2	0	---
		1	50981C	2	0	---	0	0	---	1	0	---
		2	50981C	0	0	---	6	1 #	UVF	1	0	---
		1	50981	0	0	---	2	1 #	UVF	1	0	---
		2	50981	2	2	GCMS	6	0	---	2	0	---
		1	50221	1	1	GCMS	3	1 #	UVF	2	0	---
		2	50221	1	0	---	3	0	---	2	0	---

Table 2.5. Continued.

Year	Habitat	Visit	Site	Mussels Collected	Mussels Analyzed	Mussels Method	Sediment Collected	Sediment Analyzed	Sediment Method	Blanks Collected	Blanks Analyzed	Blanks Method
1991	Sheltered Rocky	1	62762C	2	2	GCMS	0	0	---	1	0	---
		1	50983	2	2	GCMS	0	0	---	1	0	---
1991	Coarse Textured	1	50389C	0	0	---	1	1	UVF	1	0	---
		1	51091C	0	0	---	1	1	UVF	1	0	---
		1	51091	0	0	---	1	0	---	1	0	---
		1	62802C	2	2	GCMS	1	0	---	2	0	---
		1	50226	2	2	GCMS	1	0	---	2	0	---
1991	Estuary	1	15.1C	1	1	GCMS	1	1	UVF	2	0	---
		1	15.1	2	2	GCMS	1	1	UVF	2	0	---
		1	50981C	1	1	GCMS	1	1	UVF	2	0	---
		1	50981	1	1	GCMS	1	1	UVF	2	0	---
		1	50221	1	1	GCMS	1	1	UVF	2	0	---

Table 2.6. Summary of Hydrocarbon samples collected and analyzed from Kodiak-Alaska Peninsula during the 1989, 1990, and 1991 visits to CHIA sites. GCMS = Gas Chromatography/Mass Spectrometry; UVF = Ultraviolet Fluorescence/High Performance Liquid Chromatography; "#" = sediment samples composited across a site.

				Mussels			Sediment			Blanks		
Year	Habitat	Visit	Site	Collected	Analyzed	Method	Collected	Analyzed	Method	Collected	Analyzed	Method
1989	Sheltered Rocky	1	30196	0	0	---	3	3	GCMS	1	1	GCMS
		1	99826C	1	1	GCMS	0	0	---	1	1	GCMS
		1	33141	2	2	GCMS	6	6	GCMS	2	2	GCMS
1990	Sheltered Rocky	2	30196C	2	0	---	0	0	---	1	0	---
		2	30196	2	0	---	0	0	---	1	0	---
		2	31252C	2	1	GCMS	0	0	---	1	0	---
		2	31252	2	2	GCMS	0	0	---	1	0	---
		2	31248	2	2	GCMS	0	0	---	1	0	---
		1	99826C	2	2	GCMS	2	2	GCMS	2	1	GCMS
		2	99826C	2	2	GCMS	0	0	---	1	0	---
		1	33141	2	0	---	4	0	---	2	0	---
		2	33141	2	0	---	7	0	---	2	0	---
1990	Coarse Textured	1	94935C	1	1	GCMS	5	1 #	UVF	2	1	UVF
		2	94935C	2	0	---	8	0	---	2	0	---
		1	31288	2	2	GCMS	8	1 #	UVF	2	0	---
		2	31288	0	0	---	7	0	---	1	0	---
		1	13.1C	0	0	---	8	1 #	UVF	1	0	---
		2	13.1C	2	0	---	8	0	---	2	0	---
		1	13.1	2	2	GCMS	8	1 #	UVF	2	2	GCMS/UVF
1991	Sheltered Rocky	1	30196	1	1	GCMS	0	0	---	1	0	---
		1	31252	1	1	GCMS	0	0	---	1	0	---
		1	99826C	1	1	GCMS	1	1	UVF	1	0	---
		1	33141	1	1	GCMS	1	1	UVF	1	0	---
1991	Coarse Textured	1	94935C	1	1	GCMS	1	1	UVF	1	0	---
		1	31288	1	1	GCMS	1	1	UVF	1	0	---
		1	13.1C	1	1	GCMS	1	1	UVF	1	0	---
		1	13.1	1	1	GCMS	1	1	UVF	1	0	---

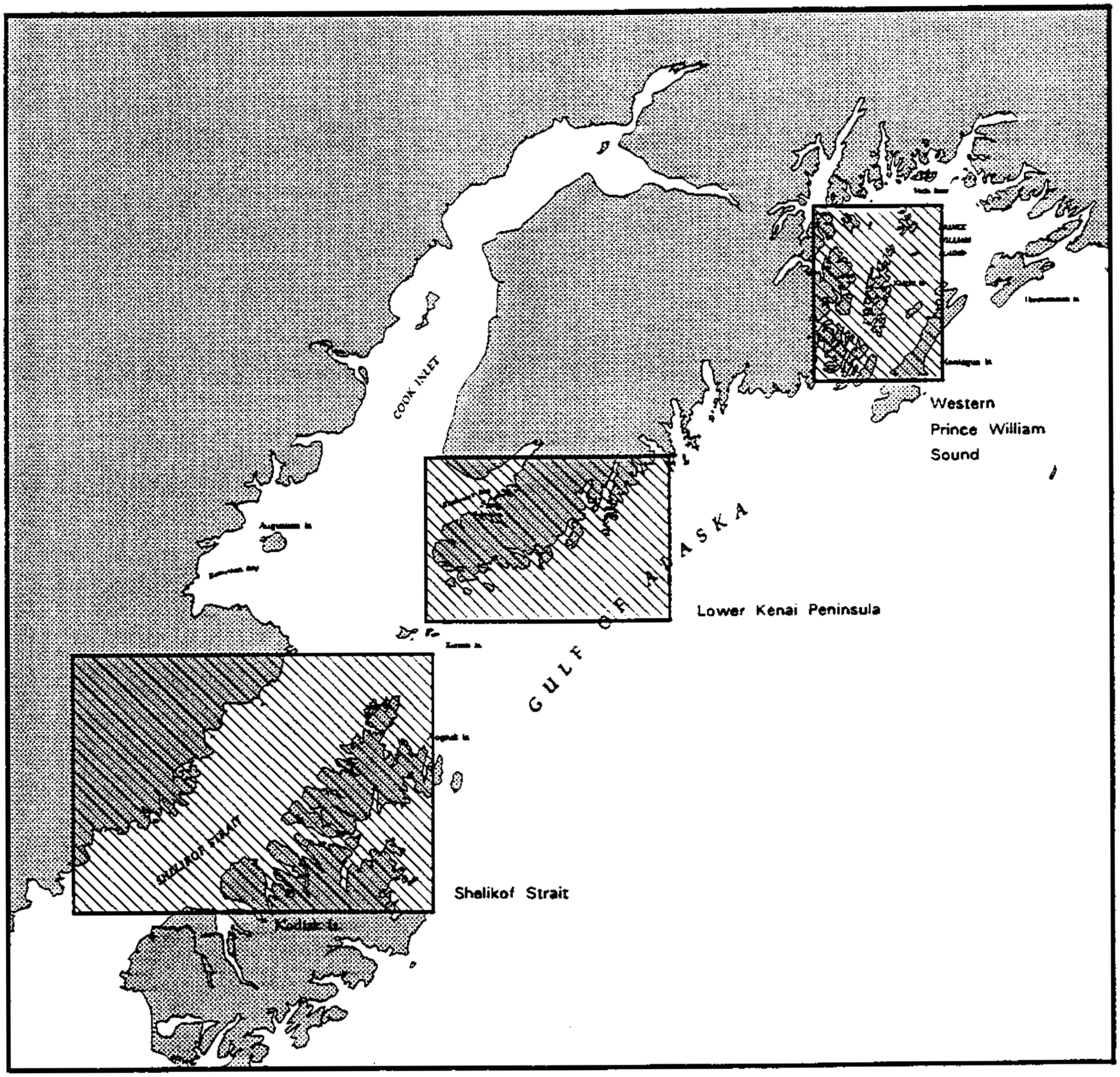

Figure 2.1. Map showing the locations of the three regions sampled during this study. The upper right shaded region represents the Prince William Sound (PWS) region, the middle shaded region represents the Cook Inlet-Kenai Peninsula (CIK) region, and the lower left shaded region represents the Kodiak Island-Alaska Peninsula (KAP) region. Map produced by ADNR, Land Records Information Section, Technical Services 3.

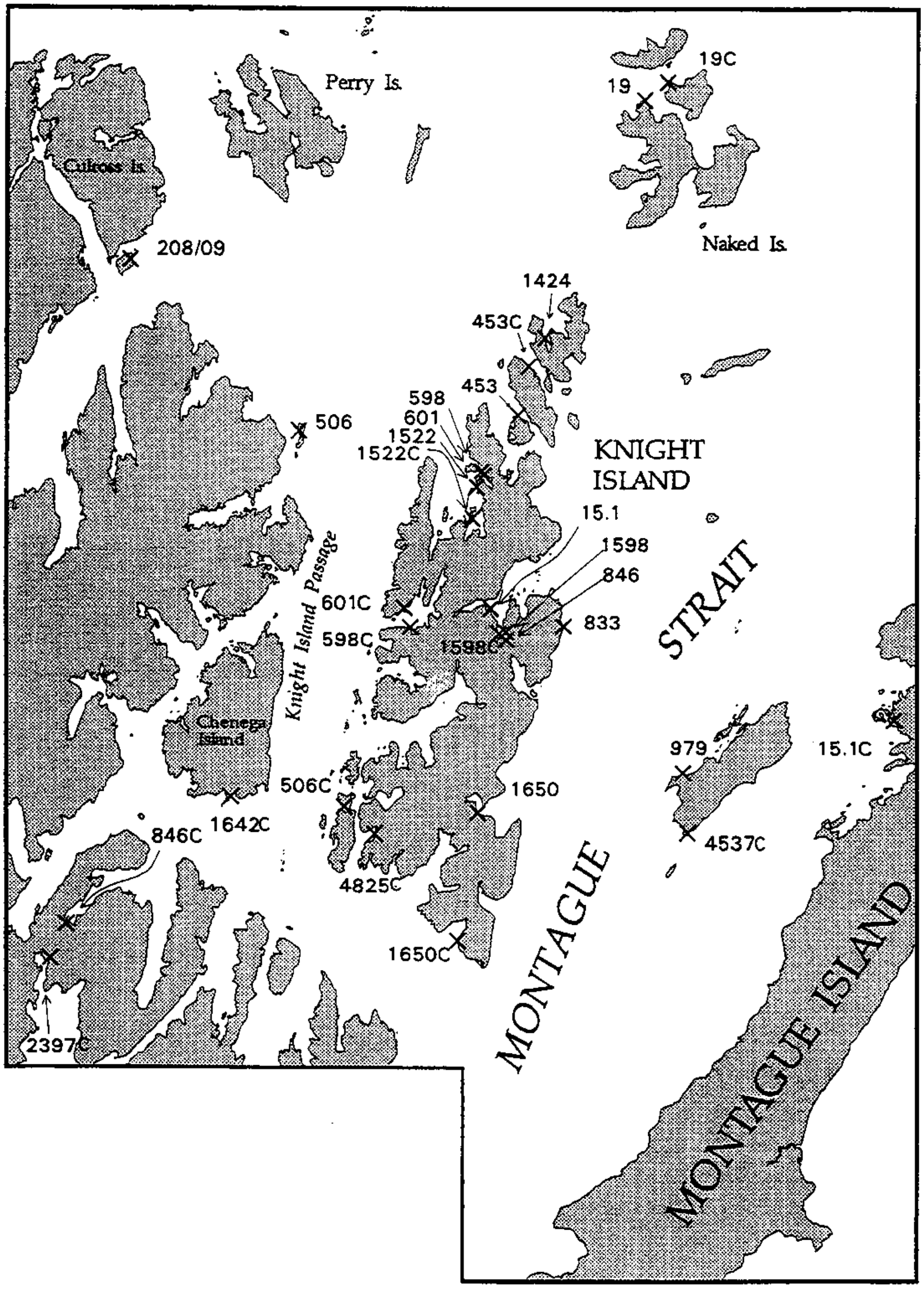

Figure 2.2. Prince William Sound (PWS) study area showing site locations. Sites with a "C" after the number are control sites. All other sites are oiled sites. Map produced by ADNR, Land Records Information Section, Technical Services 3.

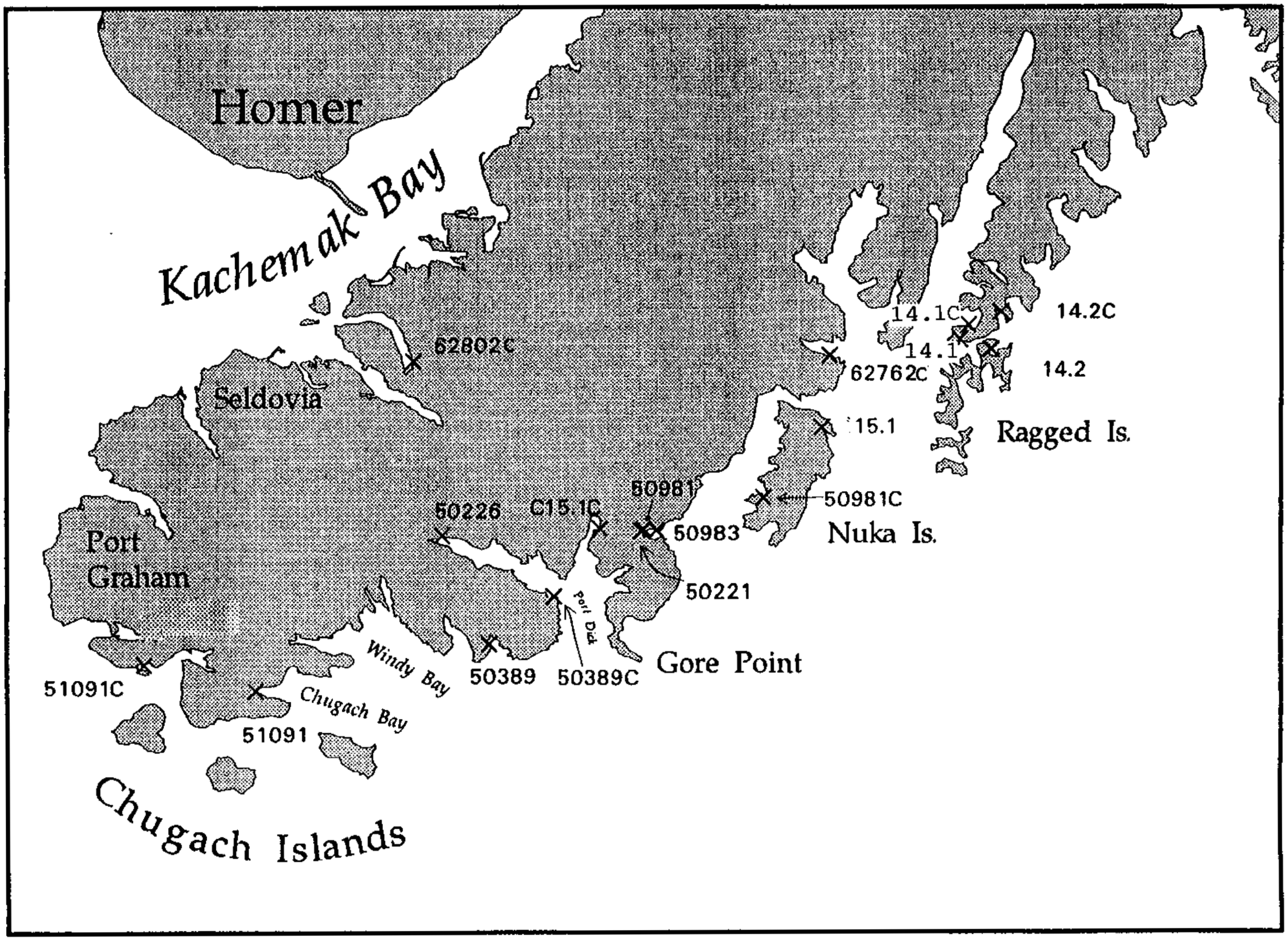

Figure 2.3. Cook Inlet-Kenai Peninsula (CIK) study area showing site locations. Sites with a "C" after the number are control sites. All other sites are oiled sites. Map produced by ADNR, Land Records Information Section, Technical Services 3.

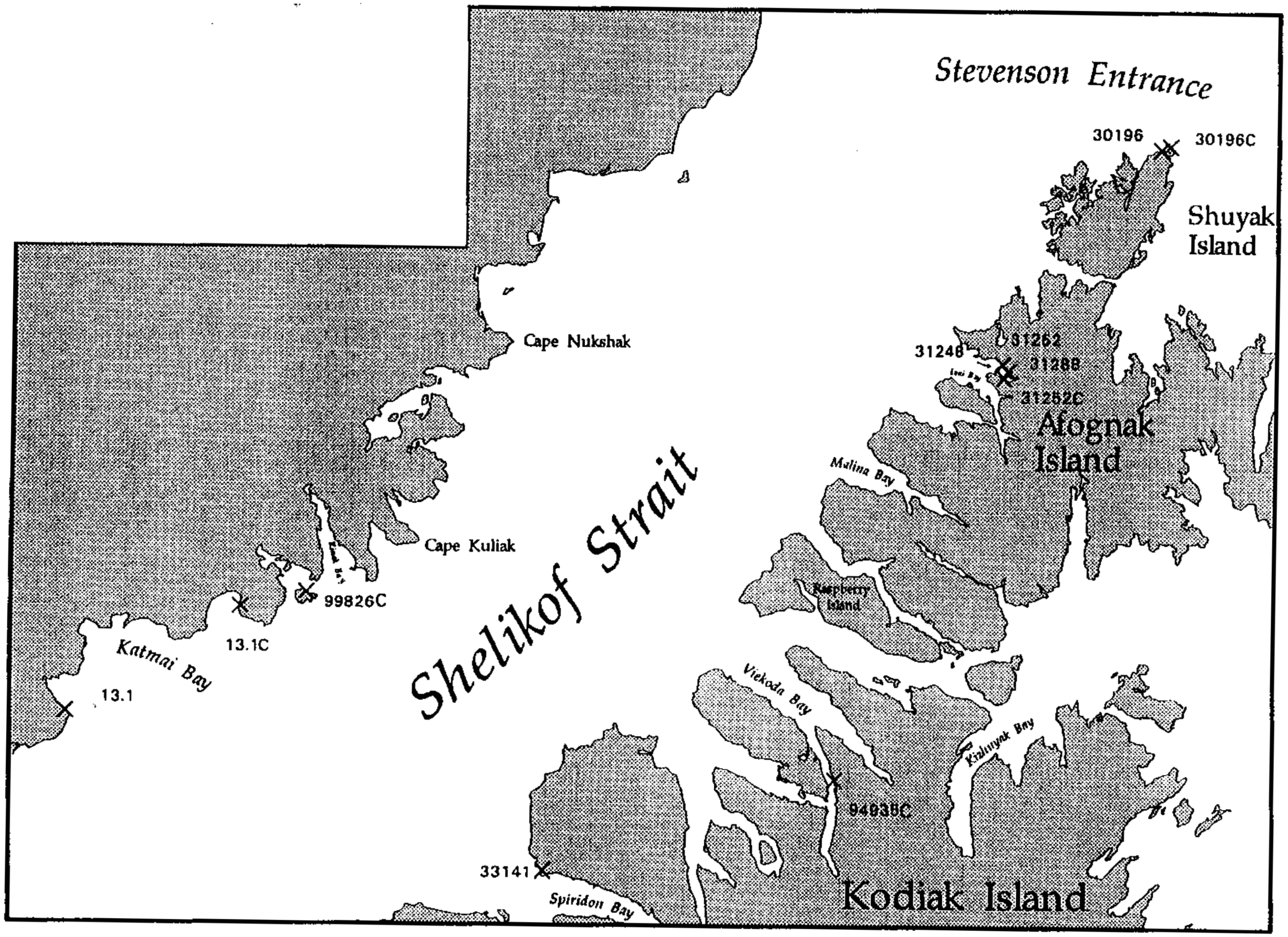

Figure 2.4. Kodiak Island-Alaska Peninsula (KAP) study area showing site locations. Sites with a "C" after the number are control sites. All other sites are oiled sites. Map produced by ADNR, Land Records Information Section, Technical Services 3.

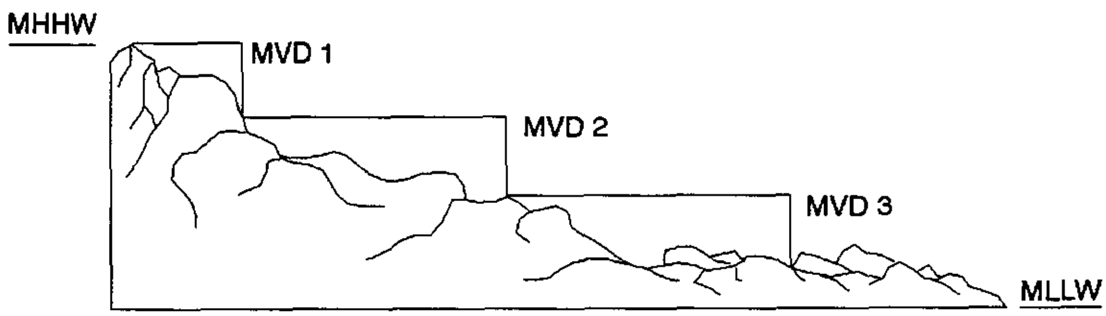

Figure 2.5. Schematic cross-section of a site, showing the possible locations of Meter Vertical Drops (MVDs) along a transect in relation to MHHW. Each MVD represents one vertical meter as determined with a surveyor's sight level.

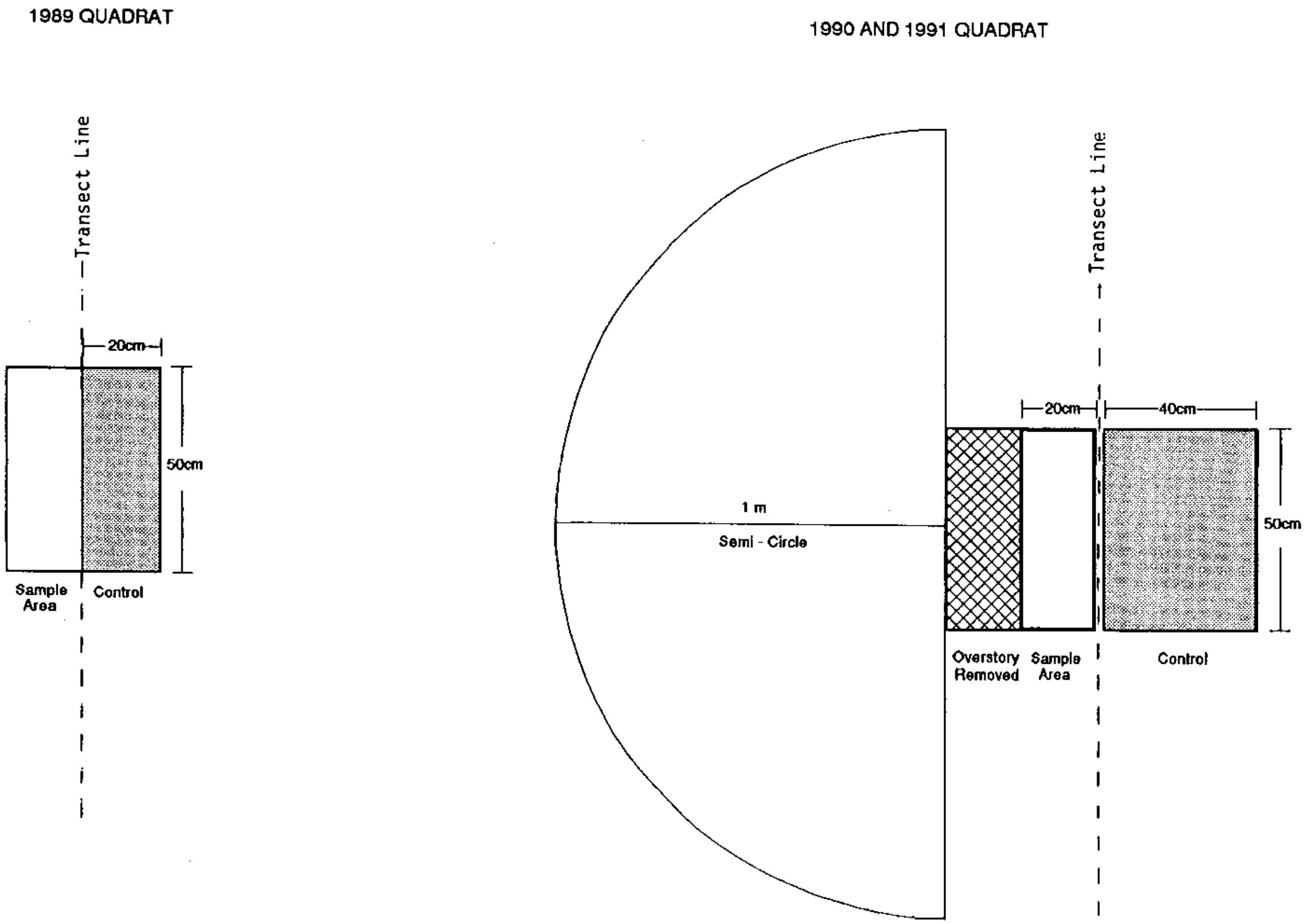

Figure 2.6. Schematic of quadrats showing sizes and locations of sampling areas relative to the control area. The initial quadrat frame used in 1989 had a smaller control area and no "overstory removed" sampling area. The sampling area used for percent cover and for invertebrate sampling remained the same.

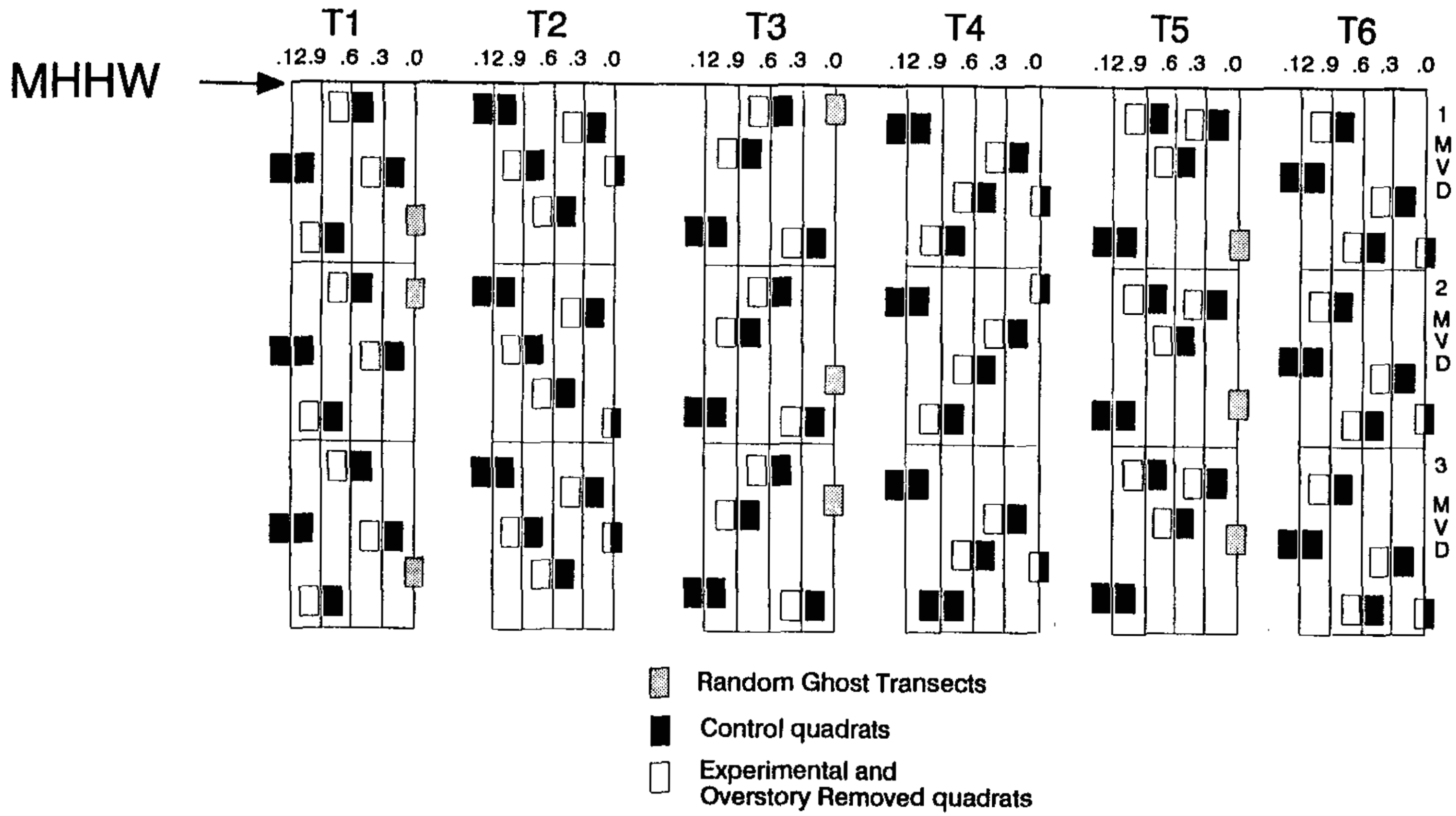

Figure 2.7. Schematic of transect and quadrat positions on an example site if sampled from 1989 through the second visit in 1991. "T" stands for transect and labels transects one through six near the mean high high water line MHHW line. The numbers .0, .3, .6, .9, and .12 represent the location of transects that are placed 3, 6, 9, and 12 meters to the left of the original 1989 transects, respectively. Only three transects were sampled in 1989, thus "Ghost Transects" are shown where transects would have been located if six transects had been sampled, as in 1990 and 1991. During the second visit in 1991, on the T*.12 transects, no quadrat samples were collected, only percent cover data and semi-circle data were recorded. Thus, there is no experimental or overstory removed sampling area. Depending on changes in the slope of the beach at different transects, the location of the bottom of each Meter Vertical Drop (MVD) may be at different horizontal distances from the Mean High High Water (MHHW) line. For simplicity, fish transects were not shown, but would be measured toward the right from the 1989 transects and would be moved 3 meters over during each new visit. Note that the distance along the MHHW line is condensed.