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NATURAL RESOURCE DAMAGE ASSESSMENT
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Impact of Oil Spill on Juvenile Pink and Chum Salmon and their Prey in Critical Nearshore Habitats

Fisheries Study Number 4
NMFS Component

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PROJECT 4. NMFS COMPONENT: IMPACT OF OIL SPILL ON JUVENILE PINK AND CHUM SALMON AND THEIR PREY IN CRITICAL NEARSHORE HABITATS

Executive Summary

The objectives of this component of Study F-4 were to compare the hydrocarbon contamination and exposure, abundance, size, nominal growth rates, and diet of juvenile salmon, and the relative abundance of their prey, in nearshore habitats in oiled and non-oiled areas of western Prince William Sound.

Juvenile pink salmon were contaminated by hydrocarbons in oiled areas of Prince William Sound. Although sample processing is incomplete for both 1989 and 1990, juvenile pink salmon collected in oiled areas in 1989 were carrying detectable levels of hydrocarbons in their tissues. In order to test that hydrocarbons detected in samples were not due to external contamination, flesh samples and viscera were processed separately from some samples of fish from oiled locations; both types of tissues were contaminated by hydrocarbons, with higher levels in the viscera. The composition of the hydrocarbon in the tissues indicated that ingestion, either of whole oil or oil-contaminated prey, was the likely route of contamination. Contamination of both juvenile pink and chum salmon by oil was also shown by MFO induction in 1989 samples from oiled locations.

Samples of juvenile pink salmon from 1990 processed to date show no hydrocarbon tissue burden, indicating a marked decline in the level of exposure of juvenile pink salmon from oil year 1 to year 2. Preliminary results for 1990 samples analyzed for MFO induction indicate no or very low continued contamination in 1990. Sediment and mussel samples from 1990 show continued pollution by hydrocarbons in some oiled locations, indicating some degree of risk of exposure to juvenile salmon.

Juvenile pink and chum salmon were more abundant in the non-oiled area in both 1989 and 1990. Because the pattern of abundance did not change as exposure levels diminished, we conclude that the differences observed in abundance were more likely due to geographic differences or distribution of spawning populations rather than to exposure to oil.

Juvenile pink salmon moved rapidly from sheltered bays to more exposed, steep shorelines in migration corridors, where they fed predominately on zooplankton. This rapid movement is considered to be an adaptive feeding strategy in response to the distribution of zooplankton in nearshore habitats in Prince William Sound. The observation of this behavior over a wide geographic range reinforces the conclusion drawn in the UAF component of F/S-4, that the presence of oil-deflection boom in Port San Juan in 1989

disrupted the normal migration behavior of fish released from AFK hatchery.

Juvenile chum salmon in oiled areas are more susceptible to hydrocarbon exposure than pink salmon because of their distribution in nearshore habitats. Juvenile chum salmon utilized bays and low gradient shorelines to a greater extent, and thus are more likely to forage in contaminated habitats.

Although there were some indications in this component of F/S-4 of smaller size and reduced growth of juvenile pink salmon in oiled locations in 1989, the results were ambiguous and not conclusive. Size-specific movement of juvenile salmon makes detection of differences between groups of unmarked fish difficult. Better resolution has been provided by the analysis of tagged pink salmon in the ADFG component of F/S-4. Otolith increment analysis of pink salmon sampled in oiled and non-oiled areas in 1989 and 1990, and size and growth analysis for unmarked fish in 1990 are not yet complete. These analyses may provide additional association of the metabolic load of hydrocarbon contamination with reduced growth in 1989.

No detrimental effects of oil were detected in the biomass of pelagic zooplankton or epibenthic prey between oiled and non-oiled areas in 1989. Zooplankton biomass was significantly higher in corridors than bays in 1989; 1990 samples are processed but not yet analyzed. Epibenthic prey biomass, including harpacticoid copepods, tended to be higher in oiled locations than in non-oiled locations sampled in 1989. This trend could be due to geographic variability, reduced cropping associated with lower abundance of juvenile pink salmon, or direct enhancement by oil contamination. The latter explanation is supported by preliminary results of colonization of azoic, contaminated sediments imported to Prince William Sound. There was an increase in abundance of harpacticoid copepods and other meiofauna in these sediments with increasing hydrocarbon contamination. More information on the impact of oil on harpacticoid copepod prey suites will be provided by analysis of samples collected on lightly- and heavily-contaminated beaches in 1990; these samples are not yet processed.

Feeding habits and amount of prey consumed by juvenile pink salmon in 1989 was generally similar between oiled and non-oiled areas. An exception was a significantly greater utilization of zooplankton by juvenile pink salmon in oiled bays relative to non-oiled bays, even though epibenthic prey abundance tended to be greater in oiled bays. The higher utilization of zooplankton in the oiled bays may reflect a shift from contaminated prey. Comparisons with 1990 stomach sample data, now being processed, will show whether this difference was reversed as the degree of hydrocarbon contamination in the environment declined.

Introduction

The salmon harvest is the most valuable commercial fishery in Prince William Sound; in 1988, salmon had an ex-vessel value of $76 million dollars, over 80% of the total for all fisheries (Anon. 1989). Salmon also represent the largest harvested biomass of the fisheries resources in the Sound. Most of the salmon landed are pink salmon, with chum salmon the second most abundant species. The importance of the salmon resource is reflected in the money and effort the NRDA process has allocated towards studying the effects of the oil spill on these fish.

Early marine residency is a critical phase in the life history of salmon and significantly affects year-class strength (Parker 1968; Walters et al. 1978; Bax 1983; Nichelson 1986). Growth during the early marine phase of pink salmon and chum salmon is extremely rapid (LeBrasseur and Parker 1964; Healey 1980), and is important to escape such mortality mechanisms as size-selective predation (Parker 1971; Hargreaves and LeBrasseur 1985). To attain rapid growth, food resources must be abundant; standing crops of food organisms must be high (Bailey et al. 1975) or delivered to rearing areas at a high rate by currents (Cooney et al. 1978). Epibenthic prey such as harpacticoid copepods are the main food items in some study areas (Kaczynski et al. 1973; Landingham 1982; Volk et al. 1984), whereas zooplankton such as calanoid copepods and euphasiid eggs and larvae are the predominant prey in others (Bailey et al. 1975; Healey 1980; Cooney et al. 1981). The subarctic marine ecosystem has a highly seasonal production cycle, characterized by high levels of primary and secondary production in the spring (Goering et al. 1973; Lawrence 1977; Smetacek et al. 1984). The timing of pink and chum salmon emigration to seawater has presumably evolved to exploit this period of high productivity (Murphy et al. 1988; Holtby et al. 1989). Growth and mortality of juvenile fish may be coupled with the magnitude or timing of spring primary and secondary production (Cushing 1975; D'Amours 1987).

Oil in the marine environment can affect juvenile salmon in a variety of ways. Oil can be directly toxic to salmon; juvenile salmon are especially susceptible when first in seawater (Rice et al. 1975; Rice et al. 1984). Sublethal levels of hydrocarbons can affect metabolism and reduce growth of juvenile salmon (Rice et al. 1975). Sublethal levels of water-soluble hydrocarbons can also damage olfactory lamellar surfaces, conceivably impacting migratory behavior and feeding patterns (Babcock 1985). Oil can also be toxic to meiofauna and zooplankton (Caldwell et al. 1977; Bonsdorff 1981; Gundlach et al. 1983). Mortality, reduction of reproductive potential, or growth inhibition of prey populations could result in reduced growth of juvenile salmon, and thus increase their exposure to predation. Contamination of prey with hydrocarbons has also been shown to reduce feeding behavior and growth of juvenile salmon (Schwartz 1985).

To determine the impact of the oil spill on juvenile salmon, the NMFS component of F-4 compared juvenile salmon distribution, abundance, size and nominal growth rates, feeding habits, contamination by hydrocarbons, and prey abundance between pairs of oiled and non-oiled locations in Western Prince William Sound. The effects of oiled sediments on the littoral prey resources of juvenile salmon were also examined. The emphasis was on juvenile pink salmon, both because of their economic value and because of their numerical abundance relative to other salmon species. Some information was also collected for juvenile chum salmon.

Objectives

To test the hypothesis that the abundance of juvenile pink and chum salmon does not differ between oiled and non-oiled areas.

To compare distribution and habitat utilization by juvenile salmon between 1989 and 1990.

To test the hypothesis that the size and growth of juvenile salmon do not differ between oiled and non- oiled areas.

To test the hypothesis that the prey available to juvenile pink and chum salmon in littoral areas and the pelagic water column does not differ between oiled and non-oiled areas.

To compare the feeding habits of juvenile pink and chum salmon captured in oiled and non-oiled areas.

To test the hypothesis that the abundance of epibenthic prey species of juvenile salmon does not differ between heavily contaminated and lightly contaminated beaches within the same geographic area.

To test the hypothesis that the utilization of sediments by epibenthic prey species of juvenile salmon is not affected by the presence of oil in the sediments.

To determine migratory behavior and specific growth rates of hatchery juvenile salmon based on coded-wire tag recoveries; tag recoveries were incorporated in the cooperative data base managed by ADFG.

To test if hydrocarbon levels in juvenile pink salmon and multi-function oxidase (MFO) induction in juvenile pink and chum salmon differs between oiled and non-oiled areas.

Methods

A brief overview of design and sampling methodology are given here. For more detailed information and maps of sampling sites, see the detailed study plans for this project.

Fish sampling

The general sampling design incorporated 8 locations: 4 oiled and 4 non-oiled (Figure 1). For both the oiled and non-oiled locations, two sites each were selected in embayments and migration corridors. The study locations were paired a priori for pairwise comparisons between oiled and non-oiled locations. These pairings were (non-oiled first): McClure Bay-Herring Bay; Long Bay-Snug Harbor; Culross Passage-Prince of Wales Passage; Wells Passage-Knight Island Passage. Three habitat types (low, medium, and steep gradient beaches) were sampled at each location. In 1989, one beach of each habitat type was sampled at each location, for a total of 24 systematically sampled sites. In 1990, two beaches of each habitat type were sampled at each location, for a total of 48 systematically sampled sites. Particular sample sites within paired oiled and non-oiled locations were selected for similarity in such characteristics as wave exposure, macrophyte coverage, and substrate. There were five sampling trips over the time period April 10 - June 26, 1989, and four sampling trips over the period April 16 - June 14, 1990. Temperature and salinity data at 1-m and 4-m depths were collected at each location using a conductivity-temperature meter.

In addition to the systematic sampling of these sites, 2-3 miles of shoreline adjacent to the sites at each location were sampled to locate congregations of juvenile salmon, using both "blind" sets (no fish observed) and "directed" sets (fish observed). Effort was higher in the oiled area because of the emphasis on recovering juvenile pink salmon for hydrocarbon analysis.

Catches were sorted by species and enumerated; all salmon were checked for the presence of coded-wire tags. Samples of juvenile pink and chum salmon were preserved in 10% buffered formalin for later length and weight, diet, and mixed-function oxidase (MFO) analyses. Samples of juvenile pink salmon were frozen for hydrocarbon analysis; 50 juvenile pink salmon from each embayment site were also frozen for analysis of otolith growth patterns.

Fish collected for size and stomach analysis were retained in formalin for at least 45 d to assure uniform shrinkage. When fish from each site were weighed and measured, ten individuals were randomly subsampled for analysis of stomach content. Total wet weight of stomach contents were determined for fish selected for stomach analysis, and index values for stomach fullness and digestion state of contents were assigned. The contents were then identified and counted by taxon, generally to the order level.

Calanoid copepods were also classified as to larger or smaller than 2.5 mm total length, and in a subsample of stomachs harpacticoid copepods were identified to genus or family level.

Prey sampling

Triplicate samples of pelagic zooplankton were taken with a 20-m vertical haul of a 0.5 m diameter 243 micron net in both 1989 and 1990. Epibenthic crustaceans were sampled in 1989 using a 10-m horizontal haul of an epibenthic sled with attached 0.3 m diameter 243 micron net. Epibenthic sled samples were taken at the 0.5 m water depth at each habitat site sampled systematically for fish. These samples are referred to as the "systematic epibenthic sled samples". A series of epibenthic sled samples were also taken in 1989 at 2 ft tide intervals at tide heights of from the -1 to +9 ft tide levels (actual water depths sampled were 0.5 m deeper than the nominal tide levels). These samples are referred to as the "tidal transect epibenthic sled samples". Tidal transects were sampled at each embayment on each sampling trip in 1989, except Trip 1, when tidal transects were sampled only at McClure Bay and Herring Bay.

In 1990, epibenthic prey species were sampled at lightly oiled and heavily oiled beaches within the same embayment, in order to minimize the noise caused by geographic variation in the prey populations. The embayments sampled were Herring Bay in April and June, and Bay of Isles in May. Four 40 m transects were sampled at the 0 tide level for each of the contamination categories at each embayment. The beaches sampled in Herring Bay in April were resampled in June.

In order to examine the effects of oil contamination on the colonization of sediments by epibenthic crustaceans and other meiofauna, sediments were collected in Auke Bay, Alaska, and made azoic by subjecting them to three freeze-thaw cycles over a 1 month period. The sediment was divided into three equal groups: control, light-oil, and heavy-oil. The oiled treatments were mixed with Prudhoe Bay crude oil recovered from the Exxon Valdez to concentrations of 0.5% and 1.7% for light- and heavy-oil, respectively. Three pans (13 x 28 x 33 cm) of each treatment group were buried at each of two sites in Herring Bay. Core samples were taken from each pan and from the natural sediments around the pans at 0,1,2,30, and 90 d.

Hydrocarbon samples

Juvenile pink salmon, mussels, and surface sediments (top 2 cm) were sampled for hydrocarbon analysis at each of the sampling locations in 1989 and 1990 throughout the extent of the sampling period. Sampling procedures followed those developed by the Hydrocarbon Technical Committee. Water samples were taken at each

location in 1989 only. Sediments were also sampled in association with the tidal epibenthic prey transects in 1989, the epibenthic prey transects at light- and heavy-oiled beaches in 1990, and the azoic sediment pans in 1990. Tissue and sediment samples taken for direct evaluation of hydrocarbon content were frozen immediately after collection. Water samples were immediately processed with dichloromethane to extract hydrocarbons; the extracts were then frozen. An exception to the immediate freezing of samples was in April, 1989, when freezing capability was not available on the chartered fishing vessel used to support the first sampling trip. Hydrocarbon samples on this trip were packed in ice in an insulated box until they could be frozen. Field blanks were included with hydrocarbon samples for quality control on collection vials, storage, and processing.

Juvenile pink and chum salmon were also preserved in 10% buffered formalin in both 1989 and 1990 for analysis of induction of MFO's as an indicator of exposure to hydrocarbons. The 1990 samples were transferred to 40% isopropanol after 6-8 wk in formalin. MFO samples were processed by Applied Marine Sciences. Approximately 6 fish per sample group were examined by histological sectioning and immunochemical staining for P450E content. Slides were stained in duplicate for both specific antibody and control antibody. Prevalence and intensity of staining were ranked by the contractor.

Statistical analysis

Analysis of hydrocarbon samples to date is incomplete and patchy. Electronic copies of sample hydrocarbon breakdowns are not yet available. For these reasons, analysis of hydrocarbon data is limited to reporting the YES/NO assessment provided with the sample data by NRDA Technical Services 1.

The univariate approach to analysis of variance (ANOVA) of a repeated measures design (Frane 1980) was used to analyze temperature, salinity, systematic catch data, pelagic zooplankton, and epibenthic sled collections. The factors in the environmental data ANOVA were time, oil, bay/corridor, and location, with location nested in oil and bay/corridor. Three replicate observations of temperature and salinity were taken for each cell. In the systematic catch data, the factors considered were time, oil, bay/corridor, location, and habitat, with location nested in oil and bay/corridor. There was only one observation per cell in 1989, and two observations per cell in 1990. In 1989, no systematic sets were made at the steep gradient beaches on the first sampling trip, because of sampling gear availability; therefore only Trips 2-5 were included in the ANOVA for catch in 1989. Because of the high number of zero catches in the fish catch data, the data were highly skewed. Transformation was not effective in reducing the skew, so analysis was performed on the

untransformed data with the understanding that the distribution of the data was non-normal.

A second analytical approach to test the hypothesis of no difference in abundance of juvenile pink and chum salmon between oiled and non-oiled locations was to use the nonparametric Wilcoxon paired-ranks test. Differences in abundance between matched cells of the a priori pairs of oiled and non-oiled locations were compared; 56 such comparisons were possible for each species. For pink salmon, differences in abundance were also tested separately in bays and corridors.

Based on Box-Cox diagnostic plots (Dixon et al. 1988), the biomass of zooplankton and epibenthos were transformed prior to the ANOVA procedure by natural logarithms (ln) in order to normalize distribution and maximize variance homogeneity. For pelagic zooplankton, the factors considered in the ANOVA were time, oil, bay/corridor, and location, with location nested in oil and bay/corridor. There were three observations per cell, except in one case where a replicate sample was lost due to improper preservation. For the systematic epibenthic samples, the factors considered were time, oil, bay/corridor, location, and habitat, with location nested in oil and bay corridor. There was only one observation per cell, and 6 empty cells due to samples destroyed in shipping. For the tidal transect epibenthic sampling, the factors were time, oil, location, habitat, and tide level, with location nested in oil. Trip 1 was excluded from the ANOVA because all embayments were not sampled on the first sampling trip. The number of species or species groups of zooplankton and epibenthic crustaceans was used as a simple measure of diversity (Pielou 1975), and was also compared using ANOVA. Preliminary analysis of meiofauna core samples was one-way ANOVA at one site at 29 d after sediment transplant.

Size and growth of juvenile salmon were examined by comparing mean sizes, apparent growth rates, and the weight/length relationship between oiled and non-oiled areas. Mean sizes of pink salmon were analyzed using the two statistical approaches: ANOVA and the nonparametric Wilcoxon paired-ranks test. Because of the large number of empty cells due to zero catches, habitats and sites were pooled so that the ANOVA tested a 3-factor (time, oil, bay/corridor) completely crossed model. The nonparametric approach tested only the null hypothesis that there was no difference between fish size in oiled and non-oiled locations. It preserved possible location and habitat differences by comparing samples from the same time period and habitat type for the a priori pairs of oiled and non-oiled locations. Only samples with at least 5 observations were used for these comparisons. Of the 56 comparisons possible for each species if all cells had been filled, 22 comparisons for pink salmon and 7 for chum salmon could actually be made from the data. Only the nonparametric approach was used

for chum salmon because of the preponderance of empty cells for this species in oiled locations.

Apparent growth rates (change in size over time) were calculated for each habitat type within a location using the regression of natural logarithm weight over time. Analysis of covariance was used to determine if fish could be pooled over habitats within a sampling locations. Pooling was rejected. Growth rates for fish captured in corridors were compared using ANOVA with the factors oil, location nested in oil, and habitat. Data were too sparse to include bays.

The weight/length relationship was used to compare the condition of juvenile pink and chum salmon between oiled and non-oiled areas, as recommended by Cone (1989). The exponential rate of increase of weight with length was determined by the slope of the regression of the natural logarithm (ln) weight on ln length. For each species, fish sizes were partitioned as to bay/corridor and oil. Analysis of covariance was used to test for homogeneity of slopes and equality of adjusted means between bays and corridors within each oiled area. If the slopes and adjusted means were not significantly ($P > 0.1$) different, the sizes were pooled as to bay/corridor and tested between oiled and non-oiled areas. If slopes or adjusted means were significantly different between bays and corridors, tests between oiled and non-oiled areas were made separately for bays and corridors.

Stomach contents were categorized as to production system: epibenthos, pelagic zooplankton, and drift insects. Epibenthos was further divided into harpacticoid copepods and other epibenthos. Pelagic zooplankton were further divided into large and small calanoids and other zooplankton. For these prey categories, dry weight, dry weight as a percent of total prey weight in a stomach, standardized dry weight (dry weight as a percentage of fish dry weight), numbers, and numbers as a percent of total numbers in a stomach were calculated for each fish. Weight of stomach contents was also calculated as a percent of total fish weight for each fish. Index of relative importance (IRI, where IRI = % frequency of occurrence x (%number + %weight)) was calculated for each habitat type by oil and bay/corridor. Minimum variance clustering of standardized dry weights was used to identify associations among habitats, bays and corridors, and oiled and non-oiled areas. Wilcoxin signed-rank test was used to compare diet parameters between paired sets in oiled and non-oiled areas.

Results

Temperature and salinity

There were no significant differences observed in temperature between oiled and non-oiled sampling locations (Table 1). Temperature generally increased at all locations over the duration of the study at both 1-M and 4-M sampling depths (Fig.2). Differences in temperature between sampling periods were statistically significant (Table 1). These differences in response over time were more pronounced at the 1-M sampling depth, which was characterized by occasional temperature spikes (Fig. 2). At both the 1-M and 4-M depths, there were no significant differences between bay and corridor sampling locations (Tables 1). However, there were significant time*bay/corridor and time*oil*bay/corridor interactions at the 4-M depth, due to different patterns in the change in temperature over time between bays and corridors. In the corridors, temperature increased steadily with time while in the bays, temperature changes were more variable, with oiled bays actually showing a temperature decline between the April and early May sampling periods (Fig. 2).

Salinities were consistently higher at both sampling depths at the oiled locations (Fig. 3). Salinities averaged 23.0 and 28.6 at 1-M, and 29.7 ppt and 27.9 ppt at 4-M for oiled and non-oiled locations, respectively. The differences between the oiled and non-oiled areas were significant (Table 2). Salinities also varied significantly between sampling times, and tended to decrease over the sampling period. At the 4-M depth, salinities declined to a greater extent over time in the non-oiled locations (Fig. 3), resulting in a significant time*oil interaction (Table 2). At the 1-M depth, there was significant interaction between bay/corridor and oil, due to extreme low salinities observed in the non-oiled bays (Fig. 3). These interactions reflect differences in the degree to which oiled and non-oiled locations differed, but do not contradict the conclusion that salinities were higher overall in the oiled sampling locations.

The variability over time was again most pronounced at the 1-M depth, especially in the non-oiled bays (Fig. 3). The low salinities observed in June in the non-oiled bays at the 1-M depth drove the overall mean salinity in bays considerably lower than in corridors at 1-M 23.0 and 28.6 ppt, respectively. Lower salinities between bays and corridors at 1-M was characteristic only of the non-oiled area; there was a significant oil*bay/corridor interaction. In contrast, overall mean salinity in bays at 4-M was significantly higher than in corridors (29.1 vs. 28.4 ppt, respectively). This bay/corridor difference was confounded by a significant interaction with time; there was no consistent pattern of higher salinity in bays over the five sampling periods.

Environmental hydrocarbons

Of 11 field blanks analyzed to date, 10 were negative for hydrocarbons, and 1 (#116310) may have had trace amounts of hydrocarbons (Table 3). The amounts of hydrocarbon in this sample were so low as to be at detection limits; the sample was not a definitive positive.

Mussel tissues collected in oiled locations during 1989 (April 29 - August 5) contained hydrocarbons; with one exception, mussel tissues from control locations were uncontaminated during 1989 (Table 4). The exception was at Culross Passage on May 4 (sample id# 3063). We observed small amounts of mousse on beaches in the vicinity of the collection site on this date, and thus attribute the contamination to the Valdez spill. Level of contamination in this sample was low, and did not persist; samples collected from the same location on May 20, June 23, and July 31, 1989 were negative for hydrocarbons (id# 3288, 4790, 6226; Table 4). Based on the one sample has been analyzed to date from 1990 collections, mussel tissue contamination in oiled locations persisted into 1990 (Table 4).

Sediments in oiled areas were contaminated by hydrocarbons: no 1989 analyses have been returned, but 1990 analyses indicate that oiled embayments remained contaminated (Table 5). Hydrocarbons have not been detected in the sediments analyzed to date from oiled corridors in 1990; the one 1990 mussel sample from 1990 analyzed, however, does indicate contamination in the corridor sites persisted in 1990. Sediment contamination was patchy in oiled bays (Table 5); more samples most be processed and analysis must be extended to quantification of amount of hydrocarbons present to adequately define the pattern of contamination persisting in 1990, as well as the degree of contamination occurring in 1989.

Sediments from non-oiled locations processed to date showed no definite contamination. Samples from Wells Passage may have been slightly contaminated in 1990; triplicate samples from two beaches sampled in April, 1990, were rated NO?, YES, NO (id# 116148-116150), and YES, NO?, NO? (id# 116202,116205,116206; Table 5). Contamination at this location, if present, was near detection limits.

All sediments from the meiofauna colonization experiment, including controls prior to deployment in the experimental pans, artificially oiled sediments, and naturally occurring sediments collected at the pan site, show some degree of hydrocarbon contamination (Table 6). Sediments collected in Auke Bay were apparently contaminated to some degree by recreational and commercial boating activity in the area. Quantitative analysis of the degree of contamination is needed; qualitative inspection of the samples processed to date show the control sediments had low hydrocarbon levels, at least an order of magnitude lower than those in the treated sediments.

Exposure to hydrocarbons: fish tissues

The tissues of pink salmon fry collected in 1989 (April 15 - May 13) from areas contaminated by the Exxon Valdez oil spill contained detectable quantities of petroleum hydrocarbons. Hydrocarbons were not detected in the tissues of fry collected from control areas. By 1990 hydrocarbons were not detectable in fry collected from oiled areas, and tissues from fry in control areas remained uncontaminated (Table 7).

To ensure that hydrocarbons detected in pink salmon tissues were not due to external contamination, we dissected fry and analyzed the carcasses (integument and muscle) and viscera separately. If contamination were an external artifact of sampling in polluted water where sheen and mousse were often present, we reasoned that the viscera should show no or little hydrocarbon contamination relative to the carcass. In 4 samples from oiled areas, both carcasses and viscera showed hydrocarbon contamination, and viscera concentrations were significantly ($P < 0.05$) higher (Figure 4). The mean ratio of total aromatics to total hydrocarbons for these samples was 0.02, indicating that exposure to whole oil, either through direct ingestion or feeding on contaminated prey, was the source of contamination.

MFO analysis of 8 samples of juvenile pink salmon captured in 1989 showed "very mild" induction of P-450 at non-oiled locations and ranged from "mild" to "strong" at oiled locations (Table 8). The levels observed from the 2 non-oiled samples are typical of "relatively pristine" areas, while the samples from the oiled areas were "significantly above normal" (personal communication, R. Smolowitz, Woods Hole Oceanographic Institution). Two chum samples from 1989 have also been processed. One from a control location was negative for MFO induction, whereas one from Herring Bay showed "strong" induction (Table 8).

A total of 5 samples have been processed from 1990. The samples had been transferred to isopropanol following fixation in formalin. Test of fish from Snug Harbor in 1989 (sample #32104) indicated a decrease in staining intensity from "moderate/mild' to "mild" following transfer to isopropanol, indicating a reduction in test sensitivity with this fixative. The three pink salmon samples from 1990 analyzed to date were rated "very mild" from two oiled locations, and negative from a control location. Because of the complicating effect of the isopropanol, the "very mild" staining may be indicative of low level exposure. However, chum salmon from both a control and an oiled location stained "very mild" (Table 8). Additional 1990 samples from both control and oiled locations must be processed to determine if there is a consistent pattern for higher, albeit threshold, levels of staining in pink salmon sampled in oiled locations.

Abundance of juvenile pink salmon

Systematic catch. In the systematic sampling in both 1989 and 1990, considerably more pink salmon were captured in the non-oiled locations. In 1989, a total of 33,290 pink salmon were captured in 120 systematic sets, with 43% zero catches and a high catch of over 8000. More than 4 times as many pink salmon were captured in the non-oiled area, 27,200 fish compared to 6090 fish in the oiled area. In 1990, a total of 81,869 pink salmon were captured in 191 sets, with 28% zero catches and a high catch of 22,977. More than 6 times as many pink salmon juveniles were captured in the non-oiled area in 1989, 70,496 fish compared to 11,373 fish in the oiled area.

In 1989, the ANOVA of the systematic catch data showed that the large differences in mean catch between oiled and non-oiled areas were statistically significant ($P = 0.038$, Table 9). However, in 1990, the ANOVA did not indicate that the mean catch was significantly greater in the non-oiled area, in spite of the fact that the difference in catch was actually greater in 1990. In 1990, more sets were made within the individual sampling location, which increased the variability allocated to the sampling locations (l(ob), Table 9). Because sampling location and interactions with sampling locations are the measures of variation used as the denominator in the F-tests, increases in this error term reduce the F-values. In both years, the Wilcoxin rank test for matched pairs of sets indicated higher abundance in the non-oiled rather than the oiled areas ($P = 0.086$, 0.092 in 1989 and 1990, respectively; Table 10).

The ANOVA of the 1989 catch data also indicated that habitat and bay/corridor affected the catch ($P < 0.001$ and $P = 0.011$, respectively). Fish were much more abundant in the corridors than in bays (Figure 5); only 2.3% of the catch occurred in bays. The main factor effects identified must be considered in the context of the significant interactions: oil*bay/corridor, oil*habitat, bay/corridor*habitat, oil*bay/corridor*habitat (Table 9). These interactions are indicative of very different catch patterns between bays and corridors (Figure 5). Because of these differences, separate ANOVAs were run for bays and corridors in 1989.

Although 3 times as many pink salmon were captured in non-oiled bays compared to oiled bays in 1989, none of the factors was significant in explaining the variations in pink salmon abundance (Table 11). The Wilcoxon signed-rank test for matched pairs also did not indicate a significant difference in catch between oiled and non-oiled bays ($P = 0.737$); the median difference was 0.0 (Table 10).

In corridors, however, oil was marginally significant ($P = 0.096$), and habitat and the oil*habitat interaction were highly

significant in explaining pink salmon abundance (Table 10). The oil*habitat interaction was due to differences between the oiled and non-oiled areas in the observed abundance at low and medium gradient habitats; in the oiled area, more fish were caught in medium gradient sites than in low gradient sites, whereas the reverse was true for the non-oiled area (Figure 5). For all habitat types, however, the catch was greater in the non-oiled area, and for both areas, the catch was much greater in the steep gradient sample sites (Figure 5). The Wilcoxon signed rank test also indicated that pink salmon were significantly more abundant in non-oiled corridors than in oiled corridors ($P = 0.030$); median difference was 120 fish (Table 10).

For the 1990 catches, there was no significant difference in abundance associated with any factor in the ANOVA. The pattern of the catches was similar to 1989, however (Figure 5). As noted above, the catch in the non-oiled area was six-fold greater than in the oiled locations. The difference between oiled and non-oiled areas was again greater for the corridor locations; the median difference in catches between oiled and non-oiled pairs was 4 fish in the bays and 52.5 fish in the corridors (Table 10). Most of the pink salmon (94%) were again caught in the corridors. There was no consistent trend in habitat utilization in the bays, while in the corridors, catches were greatest in the steep gradient habitat in both the oiled and non-oiled areas (Figure 5).

Total Catch. In 1989, a total of 232,126 pink salmon were captured in all seine sets, of which 136,496 (59%) were in the non-oiled area and 95,630 (41%) were in the oiled area. In 1990, a total of 202,793 pink salmon were captured, of which 80,750 (40%) were in the non-oiled area and 122,043 (60%) were in the oiled area. At first glance, these numbers seem contradictory to the systematic catch data. However, effort outside the systematic sampling was not uniform, and usually was inversely related to the catch during systematic sampling: given a limited amount of time at each site, the amount of effort that could be directed at searching for aggregations of fish was greater if catches in the systematic sites were low. The total catch numbers are of value in assessing where and when aggregations of fish were encountered, but not for direct comparisons of abundance.

In both years, most of the juvenile pink salmon were caught in the corridor sites in both oiled and non-oiled areas; few juvenile pink salmon were captured in bays (Figure 6). An exception to this result was the outer bay of Snug Harbor, where large numbers of pink salmon were captured (Figure 6). This portion of Snug Harbor was outside the area of systematic sampling in this embayment; within the inner bay, both systematic and nonsystematic sets caught few fish. Catches were uniformly low in both oiled and non-oiled bays (excluding outer Snug Harbor) during both systematic and non-systematic sampling. The physical characteristics of the outer bay

of Snug Harbor, in terms of exposure to the open Sound and continuity with the eastern Knight Island shoreline, were more similar to the other corridor locations than the embayments. For these reasons, and because the outer bay was not systematically sampled, we excluded these catches from the bay/corridor comparisons.

There were no consistent differences in the frequencies of large aggregations (catches of > 100 pink salmon) between oiled and non-oiled locations (Figure 7). Large catches of juvenile pink salmon were more common in the corridor locations in both 1989 and 1990; frequencies of catches > 100 pink salmon per set exceeded 26% in all cases for corridors and was less than 12% in all cases for bays (Figure 7).

The pattern of abundance of juvenile pink salmon over time differed markedly between bays and corridors in both 1989 and 1990 (Figure 8); oiled and non-oiled areas also differed to some degree. Catches in bays were generally lower than those in corridors, except for the early (April) sampling period. Catches in bays were small and relatively stable in April and May, although in 1990 there was a pronounced increase in catch in May (Figure 8). In both 1989 and 1990, catches increased rapidly to a peak in May. Catches then declined in early June. In 1989, when sampling extended to late June, catches continued to decline in the non-oiled corridors, but increased in the oiled corridors.

Coded-wire tag recoveries. A principal objective of the non-systematic sampling was to capture coded-wire tagged juvenile pink salmon for growth and migration behavior analysis. Of the 143 coded-wire tagged pink salmon recovered in 1989, 131 (92%) were in the non-systematic sampling. In 1990, 139 (52%) of the 266 tagged pink salmon were in the non-systematic sampling. These tag recoveries are included in the tag data-base analyzed in the ADFG component of this report. In 1989, 110 of the tagged pink salmon were captured at the Wells Passage location (Table 12), which was on the north end of Culross Island across Wells Passage from the large hatchery on Ester Island. Tag recoveries in other corridor sites ranged from 4-13. Tag recoveries were rare in bays in 1989; no tagged pink salmon were recovered in the non-oiled bays, one was captured in Herring Bay, none was recovered in the inner bay of Snug Harbor, and five in the outer bay of Snug Harbor. In 1990, 111 tagged pink salmon were recovered in Herring Bay (Table 12), due to the wild-stock tagging operation at Herring Creek in Herring Bay (no wild-stock tagging occurred in 1990). No other tags were recovered in bays in 1990. Tagged pink salmon were also recovered at all corridor locations in 1990, with Wells Passage again having the largest number of recoveries (103).

The percentage of hatchery fish in the catch was estimated from the number of fish represented by each tag recovery (based on the tag/untagged release ratio). In 1989, hatchery fish composed 66%

of the pink salmon captured at Wells Passage overall, and 92% in early May (Table 12). Hatchery fish made up 44% of the small Herring Bay catch. A substantial number of hatchery pink salmon were also captured in Prince of Wales and Knight Island Passages (14-16%, respectively). In all other locations, including outer Snug Harbor, hatchery fish made up 4% or less of the catch (Table 12). Final release data is not yet available for 1990 recoveries.

Abundance of juvenile chum salmon

Systematic catch. A total of 7,532 and 12,857 chum salmon were captured in the systematic sampling in 1989 and 1990, respectively. There were 47% zero catches in 1989 and 50% in 1990. Few chum salmon were captured in the oiled area (Figure 4): 179 (2.4%) in 1989, 48 (0.4%) in 1990. Unlike pink salmon, juvenile chum salmon did not show a preference for steep gradient habitats; CPUE of chum salmon were highest at medium gradient beaches in bays, and low gradient beaches in corridors. Oil was the only significant factor in the ANOVA of the catch data ($P = 0.013$, 0.069 in 1989,1990; Table 13). The matched-pairs rank test also indicated a highly significant ($P < 0.001$) difference in catches between oiled and non-oiled areas in both 1989 and 1990, with a median difference in catch of 64.8 and 53.0 fish per set, respectively (Table 10).

Total catch. A total of 30,195 and 32,737 juvenile chum salmon were captured in all seine sets in 1989 and 1990. Juvenile chum salmon had a similar catch pattern for both the systematic and non-systematic sets: relatively large numbers recovered in the non-oiled area in both bays and corridors, and very few fish in the oiled area (Figure 6). This pattern was also seen in the frequency of large catches (Figure 7). Only in one set were more than 100 chum salmon captured in the oiled area, while in the non-oiled areas frequency of catches >100 fish ranged from 11-66% in bays and 12-49% in corridors over both years (Figure 7).

The difference between oiled and non-oiled areas was also apparent in the pattern of catches of chum salmon over time (Figure 8). The timing of the catches of juvenile chum salmon was similar in oiled bays and corridors, with peak catches occurring in late May. Catches in non-oiled bays and corridors were consistently at least an order of magnitude greater than catches in non-oiled. The catches in non-oiled corridors peaked in early May, while those in non-oiled bays peaked in late May.

Size and growth

Pink salmon. Analysis on fish size is complete for the 1989 data. The 1990 samples have been processed, but the data have not yet been analyzed.

Because a simultaneous analysis of size in 1989 in relation to all factors (time, oil, bay/corridor, habitat) was not possible due to the large number of empty cells associated with zero catches, the data were first evaluated by pooling over sampling location and habitat, and testing time, oil, and bay/corridor as a fully-crossed design. When considered in this manner, pink salmon were significantly larger in the non-oiled area ($P = 0.011$), in the corridor locations ($P < 0.001$), and over time ($P < 0.001$). There were significant interactions with time*bay/corridor ($P < .001$) and time*oil ($P = .025$). These interactions were caused by similar sizes between oiled and non-oiled locations and between bays and corridors in April and early May; in later sampling periods mean sizes diverged between oiled and non-oiled locations and between bays and corridors (Figure 9).

The preceding analysis was considered only a preliminary indicator of size differences, as it did not account for effects of specific locations or habitats. These factors were considered in the analysis of a subset (corridors, trips 3-5) of the data where sufficient information was available to use the repeated measures approach. In this analysis, there was no significant difference between oiled and non-oiled corridors. Habitat had a significant effect on size ($P = 0.001$, Table 14); fish were consistently larger at the steep gradient habitat over time (Figure 10A) and in the oiled and non-oiled locations (Figure 10B). Size also changed significantly with time ($P = 0.048$), generally increasing with time.

In the non-parametric paired difference test, median size for all possible pairs was slightly (0.5 mm) greater for non-oiled locations, but the difference was not significant ($P = 0.32$, Table 15). When bays and corridors were considered separately, median differences were greater for oiled locations in bays, and for non-oiled locations in corridors (Table 15); these median differences were not significantly different from zero in either case.

Histograms of pink salmon sizes by time period showed very different size distributions in bays and corridors (Figure 11). In bays, fish sizes in bays had a mode of 32 mm during April and May, indicating the fish were predominately recent migrants from freshwater. There was no distinct peak to the size distributions of the few fish captured in the nearshore habitats of bays in June. In the corridors, the mode of the size distribution shifted from 31-32 mm in April to 40 mm by late May and 45 mm by late June (Figure 11). The distribution of sizes generally shifted towards larger sizes and widened until late June, when the tails of the distribution began to truncate.

Apparent growth rates and their standard deviations, calculated by regressing the natural log of weight over time, are shown for each sampling location by habitat in Table 16. Tests for homogeneity of slopes for habitats within each sampling location indicated that

apparent growth rates varied between habitats, so that pooling across habitats was not appropriate. There were sufficient observations to estimate apparent growth at each habitat in the corridor locations. Growth rates in corridors were then compared using ANOVA. Apparent growth rates were significantly higher (P = 0.016) in the non-oiled corridors. This difference was consistent across habitats (see means for habitats, Table 16); there was no significant habitat*oil interaction or habitat effect on apparent growth identified in the ANOVA. There were not sufficient data to compare apparent growth in bays using ANOVA. However, some very different trends were observed in bays: apparent growth rates were uniformly higher across habitats in oiled bays, and was substantially higher in the steep gradient habitat for both non-oiled and oiled bays (Table 16).

Juvenile pink salmon were collected in May in 1989 and 1990 from the oiled and non-oiled embayments for otolith increment analysis. These samples are now being processed by the Washington Department of Fisheries Otolith Laboratory; data should be available in February 1991. If otolith increments are assumed to be a measure of time since emigration, increment analysis provides a much more refined measure of growth than the change in mean size of fish captured over time.

Analysis of covariance showed no significant difference ($P > 0.1$) in the logarithmic weight/length relationship between bays and corridors within oiled and non-oiled areas(Table 17); therefore the condition relationship was compared between oiled and non-oiled areas for pink salmon pooled from bays and corridors. Although the resulting regression equations did not differ significantly in slope; the adjusted means were significantly different (P = 0.000; Table 16), however. Adjusted mean weights were 0.439 g and 0.431 g for the oiled and non-oiled areas, respectively, indicating pink salmon juveniles tended to be more robust in the oiled area.

Chum salmon. Based on the nonparametric matched-pairs comparison, chum salmon were significantly larger (P= 0.052) in the oiled area, with a median difference of 7.5 mm (Table 14). Mean size of chum salmon, pooled over sampling period, location, and habitat, was greater in oiled bays than non-oiled bays, while the reverse was the case in corridors (Table 18). Because few chum salmon were caught in oiled sampling locations in 1989, there were too many empty cells to use ANOVA to test for effects between oiled and non-oiled areas.

There were differences in the condition regressions for juvenile chum salmon between bays and corridors in both oiled and non-oiled areas (Table 17); therefore, comparisons between oiled and non-oiled areas were considered separately for bays and corridors. There were no significant differences in slopes or adjusted means for chum salmon between oiled and non-oiled corridors; however, the

condition regression was significantly different between oiled and non-oiled bays (Table 17). The intersection of the regression lines for chums in oiled and non-oiled bays is 48.8 mm. Below this intersection point, chum salmon in oiled bays were more robust (heavier at a given length); above this point, the reverse was true, and chum salmon in non-oiled bays were more robust. Of the chum salmon caught in oiled bays, 49% were less than the intersection point, and 51% were below it.

Feeding Habits

A total of 608 pink salmon stomachs and 493 chum salmon stomachs have been processed from the 1989 sample collections. Overall description of diet was based on this complete sample set. Pair-wise comparisons between oiled and non-oiled areas were limited to a sub-set of these data: 196 pink salmon and 58 chum salmon from oiled locations, and 201 pink salmon and 54 chum salmon from non-oiled locations. Processing of 1990 stomach samples are scheduled for completion by February, 1991.

Pelagic zooplankton formed the largest proportion of the dietary biomass of pink salmon juveniles over the spring of 1989 (Figure 12). In bays, the diets were dominated by pelagic zooplankton at all habitats. In corridor locations, zooplankton dominated the pink salmon diets at the steep and medium gradient habitats. Epibenthos was a more important component of the diet at the low gradient habitats; this trend was more pronounced in non-oiled than in oiled corridors (Figure 12). Calanoid copepods were the most important zooplankton prey in all locations; harpacticoid copepods were the most important epibenthic prey in most locations (Table 19). Large calanoids made up the majority of the calanoid biomass consumed in most habitats. IRI percentages generally followed the results of the percent dry weight.

In the cluster analysis of the weight-standardized dietary data, no oiled vs. non-oiled clustering pattern emerged for the twelve habitat-bay/corridor-oil combinations (Figure 13). Indeed, initial clustering of any two habitats involved an oiled site combining with a non-oiled site. The trend at initial clustering was for grouping of bays and corridors.

None of the Wilcoxon tests between paired oiled and non-oiled sets were significant for total prey, stomach fullness, or fish size (Table 20). Because sizes of pink salmon in these subsamples were similar, size effects on diet should not be skewing the tests. In comparisons of other pink salmon dietary attributes, zooplankton percent number, dry weight and percent dry weight were significantly ($P < 0.053$) higher in oiled samples (Table 21). The differences in zooplankton in the diet were due to greater utilization of large calanoids in oiled locations (Table 21). Although not significant, all epibenthic and harpacticoid

parameters had correspondingly negative medians, suggesting that the presence of oil may have decreased the utilization of epibenthos in the diets. A comparison between paired sets from oiled and non-oiled locations of the frequency of occurrence of given prey categories also indicated a difference for epibenthic prey: total epibenthos and harpacticoids occurred more frequently in fish from non-oiled locations (Table 22).

The overall diet composition of juvenile chum salmon varied between areas and habitats (Figure 14). Drift insects were utilized to a greater extent in the non-oiled locations. In non-oiled bays, drift insects made up the highest proportion of the prey items by weight in all three habitats. In non-oiled corridors, drift insects were the most utilized prey category in medium gradient habitats; zooplankton prey items were highest in low and steep gradient habitats. Insects were never the dominant prey category in oiled habitats. Zooplankton was the dominant prey category in the low and medium habitats in corridors and the low gradient habitat in oiled bays; epibenthos was highest in the medium gradient habitat in oiled bays. Zooplankton was also the highest prey category in the one chum salmon processed for stomach contents from steep gradient habitats in the oiled area.

Calanoid copepods were the most important component of pelagic zooplankton prey items in the chum salmon (Table 23). Of the calanoids eaten, large calanoids made up the greatest proportion by weight in all cases except non-oiled bays. Harpacticoid copepods did not generally dominate the composition of epibenthos prey; where epibenthos exceeded 1% of the total prey by weight, harpacticoids contributed more than 50% by weight in only two of nine cases (Table 23).

Comparisons of juvenile chum salmon diets from paired non-oiled and oiled areas were limited to only six pairs of sets from low gradient bays and corridors and medium gradient bays. There were no differences in measures of fullness and total prey between oiled and non-oiled locations (Table 24). Sizes of chum salmon sampled for stomachs from the oiled locations were significantly larger than those from the non-oiled sample, reflective of the larger size of juvenile chum salmon in oiled bays. There were no significant differences in the pair-wise comparisons of prey categories, except for a marginally significant ($P = 0.093$) difference in the number of small calanoids eaten (Table 25).

The composition of the harpacticoid copepod component of the diet was examined in greater detail in a subsample of 61 pink salmon and 109 chum salmon juveniles. The fish consumed only epibenthic harpacticoid representatives, either phytal or sediment-oriented; interstitial forms were not eaten. For both pink and chum salmon, the most important harpacticoid prey groups were Harpacticus, Tisbe, and Dactylopodia (Figure 15). These genera composed 48%, 22%, and 14%, respectively, of the total biomass of harpacticoids

consumed by juvenile pink salmon. For chum salmon juveniles, Tisbe was the largest proportion of the harpacticoid component with 47%, followed by Harpacticus and Dactylopodia at 27% and 11%, respectively. Pink salmon consumed Harpacticus and Tisbe in close approximation to their occurrence in the environment, based on their representation in epibenthic sled samples from the same locations (Figure 15). Chum salmon, however, selected a greater biomass of Tisbe and less Harpacticus relative to their occurrence in the sled tows. Both species consumed Dactylopodia at a much higher proportion than its abundance in the sled samples (Figure 15).

Approximately 20% of the harpacticoids captured in the sled samples were characterized as 'other' in Figure 15. This category consists of 29 different taxa (family or genus level) of epibenthic harpacticoids, both phytal and sediment-oriented, that did not occur in the diets of the juvenile salmon. The high utilization of particular harpacticoids and apparent avoidance of others indicate that species composition of the epibenthic harpacticoid community is important to the feeding of juvenile salmon.

Prey abundance

Pelagic zooplankton. Sample processing and data analysis are complete for the 1989 collections. Processing of the 1990 samples is scheduled to be completed by November, 1990.

Numbers and biomass of pelagic zooplankton in 1989 fluctuated widely between time periods and locations, and even between replicates at the same time and location (Tables 26 and 27). Some 52 taxa of pelagic zooplankton were identified in the samples (Table 28). In terms of overall biomass, the dominant organisms in both bays and corridors were Calanus sp. and Pseudocalanus sp. (Table 28). Pseudocalanus sp. was the most numerous organism overall in both bays and corridors, followed by Calanus sp. in corridors and Ectoprocta (Cyphonautes) in bays (Table 28). At each location calanoid copepods comprised over half of the abundance (Figure 16) and biomass (Figure 17) of pelagic zooplankton. Small calanoids were more abundant than large calanoids at each of the 8 sampling locations (Figure 16), although large calanoids had higher relative biomass at all 4 corridor locations and 2 of the bays (Figure 17).

There were no detectable differences in zooplankton biomass between oiled and non-oiled areas (Table 29). Time ($P < 0.001$) was significant in explaining the variation in total biomass of pelagic zooplankton (Table 29). The biomass of pelagic zooplankton peaked at different times in the different locations (Table 27). Biomass fluctuated up to 200-fold between different time periods at the same location, and peak biomass varied 10-fold between locations.

Bay/corridor (P = 0.042) was also significant in explaining the variation in total biomass of pelagic zooplankton (Table 29). Mean biomass was 3.4 times higher overall in corridors than in bays. When examined over time (Figure 18A), the biggest differences in biomass of pelagic zooplankton between bays and corridors occurred in April and May. Overall, pelagic zooplankton peaked in early May in both bays and corridors. By June the biomass of pelagic zooplankton had declined sharply in both bays and corridors.

The biomass of calanoid copepods followed a pattern similar to that of the biomass of pelagic zooplankton in general. There were no detectable differences between oiled and non-oiled areas (Table 29). Time (P < 0.001) was again significant in explaining the variation of calanoid copepods, reflective of the seasonality of abundance of calanoid copepods (Table 29). Bay/corridor was marginally significant (P = 0.062) in explaining the variation in biomass of calanoid copepods (Table 29). The mean biomass of calanoid copepods was 3.7 times higher in corridors than bays. When examined over time (Figure 18B), the biggest differences in biomass of calanoid copepods between bays and corridors occurred in April and May. Overall, calanoid copepods peaked in early May in both bays and corridors. By June the biomass of calanoid copepods declined sharply in both bays and corridors.

Calanoid copepods were further split into large and small size categories. These size categories were chosen to parallel the analysis of juvenile salmon diets. Again, there were no detectable differences between oiled and non-oiled areas (Table 30). Time (P < 0.001) was once again significant in explaining variations in mean biomass of both small and large calanoid copepods (Table 30). Bay/corridor (P = 0.053) was marginally significant in explaining the variation of small calanoid copepods (Table 28). The mean biomass of small calanoids was 3 times higher in corridors than in bays. Although the biomass of large calanoid copepods was 4 times higher in corridors than in bays, the factor bay/corridor was not significant (P = 0.129) in explaining this variation (Table 30). When examined over time (Figure 19), the biggest differences in biomass of both small and large calanoids between bays and corridors occurred in April and May. In the corridors the biomass of both small and large calanoids peaked in early May. In the bays the biomass of large calanoids also peaked in early May; in contrast, the biomass of small calanoids peaked in late April (Figure 19). By June the biomass of both small and large calanoid copepods had declined to near zero.

There were no detectable differences in diversity of pelagic zooplankton between oiled and non-oiled areas. The number of identified taxa captured in the tows varied over 2-fold between locations during the same time period. The number of taxa peaked at different times at different locations (Table 31). There was a marginally significant difference (P = 0.082) between bays and corridors; the mean number of taxa were 15.9 and 14.3 in bays and

corridors, respectively. The interaction time*oil*bay/corridor was also marginally significant (P = 0.085), but there were no consistent and easily understandable trends in interpreting the significance of this interaction.

Epibenthic crustaceans. Processing for the epibenthic sled samples taken in 1989 has been completed. Preliminary data analyses, to the level of harpacticoid biomass, have been completed for the systematic sled samples and the -1 to +3 tide levels of the tidal transect samples. Data from the +5 to +9 tide levels still need to be incorporated into the analysis, and the analyses need to be extended to examine the abundance of particular genera identified as important in the diet of juvenile salmon.

Abundance and biomass of organisms in the systematic epibenthic sled samples fluctuated widely between time periods, habitats, and locations (Tables 32 and 33). Species composition of organisms of both epibenthic and pelagic origin captured over the course of the season is shown (Table 34). Epibenthic organisms comprised less than half of the total abundance and biomass of organisms sampled by the sled; pelagic zooplankton in the water column were also sampled by the sled (Table 34). Harpacticoid copepods comprised 87% of the biomass of epibenthos important in the diets of juvenile pink salmon. In terms of both abundance and biomass, harpacticoid copepods were the dominant epibenthic organism at each location (Figures 20 and 21).

In the systematic sled samples, oil (P = 0.025) and habitat (P = 0.025) were each significant in explaining the variation in biomass of harpacticoid copepods (Table 35). The mean biomass of harpacticoids was 2.5 times higher overall in oiled than non-oiled areas. Biomass was much lower in the steep gradient than in either the low or medium habitats (Figure 22A). At each habitat type biomass was greater in oiled rather than non-oiled areas (Figure 22A).

Time (P = 0.066) and bay/corridor (P = 0.057) were marginally significant in explaining the variation in biomass of harpacticoid copepods in the systematic sled samples (Table 35). Biomass was 3 times higher overall in corridors than bays, mainly because of the large peak in biomass during time period 3 in late May (Figure 22B). By June the biomass of harpacticoids was uniformly low in both bays and corridors (Figure 22B).

In the tidal transect sled samples, time (P = 0.068) and habitat (P = 0.068) were marginally significant in explaining the variation in the biomass of harpacticoid copepods in the bays sampled (Table 35). Once again the biomass of harpacticoids was lowest in the steep gradient habitat compared to the low and medium gradient habitats (Figure 23). Although the biomass of harpacticoids was 7 times higher overall in oiled rather than non-oiled areas, this

difference was not significant (Table 35). In all habitats biomass was higher in oiled rather than non-oiled areas (Figure 23). Tide level (over the -1 to +3 range analyzed to date) was not significant in explaining variation in harpacticoid biomass, although biomass was generally higher at the lower tide levels (Table 35).

There were no detectable differences in species diversity (as measured by the number of species) of epibenthic organisms between oiled and non-oiled areas in the systematic sled samples (Table 36). Time ($P < 0.001$), habitat ($P = 0.015$), and the interaction of time and oil ($P = 0.047$) were significant in explaining the variation in number of species sampled. The number of species increased over time in both oiled and non-oiled areas, and the number of species was generally greater in the oiled areas (Figure 24A). The number of species was highest in the low gradient and lowest in the steep gradient habitat (Figure 24B).

Epibenthos were also sampled in contaminated embayments in 1990 along transects at the 0 tide level on beaches classified as to the degree of oiling. Results are not yet available from this experiment. Processing for one series of transects from Bay of Isles is due for completion in December 1990. Data from this series will be analyzed as soon as available to make a preliminary assessment of perturbation to the harpacticoid copepod species, in order to determine if sampling should continue in 1991.

Processing of the core samples from the 1990 sediment colonization experiment has been completed. Preliminary data analysis comparing control, natural, and heavy-oiled sediments at the lightly oiled site showed no significant difference in mean numbers of harpacticoid copepods, nematodes, or total meiofauna 29 d after sediment transplant. The trend was for higher densities of organisms in the heavy-oiled sediments relative to the control; greater numbers of copepods, nematodes, and total meiofauna were observed in the oiled sediments at Day 29, and oiled sediments had a higher density of copepods than did the adjacent natural sediments (Figure 25).

Status of injury assessment

The main criterion in selecting for sampling locations in this study was the categorization as to "oiled" and "non-oiled". Because of the distribution of the spill, non-oiled study locations were clustered in the northwest region of Prince William Sound, on or close to the mainland, while oiled locations were generally more southerly and on islands (Figure 1). These geographic differences were reflected in differences in the physical environment at the locations; salinities in the non-oiled area were lower, especially at the surface.

Analysis of samples of environmental contamination at the various study sites are still incomplete, with patchy amounts of data from both 1989 and 1990. Mussel samples processed from 1989 did, in general, support the dichotomous separation of the control and treatment locations. Mussels from oiled sites were contaminated, and those from non-oiled sites were not, with one exception. The exception, May 4, 1989 at Culross Passage, had much lower levels of contamination than the "oiled" locations, but contamination by the oil spill at this location is considered a valid observation. Small globs of mousse were observed in this vicinity on May 4; Rounds and Short (1990) have shown contamination of caged mussels throughout much of Prince William Sound. Based on these results, we recognize that comparisons between oiled and non-oiled areas in Prince William Sound in the spill year may be a comparison between degree of oiling, rather than between a polluted and a pristine environment.

Sediment samples from 1990 showed continued contamination of the beaches in the oiled bays sampled. The few sediment samples processed to date from oiled corridors were not contaminated, but the one mussel sample analyzed to date from 1990, oiled corridor, was contaminated. These data indicate that beach contamination in 1990 in the oiled area was patchy; data from more of the outstanding samples are needed to define the contamination pattern. The preliminary data do show that oiled locations were contaminated in 1990, indicating some degree of exposure for juvenile salmon.

Based on the few samples analyzed to date from 1989, juvenile pink salmon were contaminated by hydrocarbons in oiled areas of Prince William Sound. Juvenile pink salmon collected in oiled areas in 1989 were carrying detectable levels of hydrocarbons in their tissues. In order to test that hydrocarbons detected in samples were not due to external contamination, flesh samples and viscera were processed separately from some samples of fish from oiled locations; both types of tissues were contaminated by hydrocarbons, with higher levels in the viscera. The composition of the hydrocarbon in the tissues indicated that ingestion, either of whole oil or oil-contaminated prey, was the likely route of contamination. Contamination of juvenile pink salmon by oil in

1989 was also corroborated by higher levels of MFO induction in samples from oiled locations. Samples from 1990 processed to date show no hydrocarbon tissue burden, indicating a marked decline in the level of exposure of juvenile pink salmon from oil year 1 to year 2. Little or no induction of MFO's was observed in samples of pink salmon from 1990 processed to date, also indicating that exposure was reduced in 1990 in response to the reduced levels of contamination in the environment. It should be noted, however, that the sensitivity of the MFO analysis was affected by the fixative used in the 1990 samples.

Based on MFO analysis, juvenile chum salmon were also contaminated by hydrocarbons in 1989. Again, no continued induction of MFO's was observed in the few 1990 samples of juvenile chum salmon processed to date.

Juvenile pink and chum salmon were more abundant in the non-oiled area in both 1989 and 1990. Avoidance of oiled habitats or direct mortality are possible explanations of the differences in abundance. There was, however, no evidence of direct mortality in oiled areas. In both years, large schools of juvenile pink salmon were observed and sampled in both oiled and non-oiled locations. Pink salmon fry did not appear to avoid oil; schools of pink salmon were observed under large expanses of mousse accumulated along booms in outer Snug Harbor in 1989; the fish were apparently using the mousse for cover. Because the pattern of abundance did not change as exposure levels diminished, we conclude that the differences observed in abundance were more likely due to geographic differences or distribution of spawning populations and their migration pathways to the Gulf of Alaska, rather than to exposure to oil.

Juvenile pink salmon moved rapidly from sheltered bays to more exposed, steep shorelines in migration corridors, where they fed predominately on zooplankton. This rapid movement is considered to be an adaptive feeding strategy in response to the distribution of zooplankton in nearshore habitats in Prince William Sound; similar movement to zooplankton-rich foraging areas has been described in the Port San Juan area by Cooney et al. (1981). The observation of this behavior over a wide geographic range reinforces the conclusion drawn by the UAF component of F/S-4 (Cooney 1990), that the presence of oil-deflection boom in Port San Juan in 1989 disrupted the normal migration behavior of fish released from AFK hatchery.

Juvenile chum salmon in oiled areas may be more susceptible to hydrocarbon exposure than pink salmon because of their distribution in nearshore habitats. Juvenile chum salmon utilized bays and low gradient shorelines to a greater extent than did pink salmon, and thus are more likely to forage in contaminated habitats.

Although there were some indications in this component of F/S-4 of smaller size and reduced growth of juvenile pink salmon in oiled locations in 1989, the results were ambiguous and not conclusive. Recruitment of newly-emerged pink salmon fry to the marine environment, and size-specific movement from nearshore to offshore (LeBrasseur and Parker 1964; Healey 1980) and between near-shore habitats (Celewycz 1990) makes detection of differences between groups of unmarked fish difficult. Better resolution has been provided by the analysis of tagged pink salmon in the ADFG component of F/S-4 (Raymond 1990). Otolith increment analysis of pink salmon sampled in oiled and non-oiled areas in 1989 and 1990, and size and growth analysis for unmarked fish in 1990 are not yet complete. These analyses may provide additional association of the metabolic load of hydrocarbon contamination with reduced growth in 1989.

There was no evidence that the condition of juvenile pink salmon in oiled areas was reduced; pink salmon in oiled areas actually had a higher adjusted mean weight. Chum salmon captured in corridors also showed no difference in condition between oiled and non-oiled areas. Chum salmon juveniles captured in oiled bays had a very different length-weight relationship than the other groups considered, with a much lower exponential rate of increase (Table 17). This anomalous relationship could be interpreted that chum salmon in contaminated bays were not growing as robustly. However, this interpretation is confounded by the substantially larger size of the chum salmon captured in oil bays, and by the observation that the length-weight relationship intersects with the non-oiled chums at approximately the mid-point of the length-frequency distribution for the chums from the oiled bays, that is, half of these fish were heavier than fish of similar length from non-oiled locations, and half were not.

No detrimental effects of oil were detected in the biomass of pelagic zooplankton or epibenthic prey between oiled and non-oiled areas in 1989. Zooplankton biomass was significantly higher in corridors than bays in 1989; 1990 samples have been processed but not yet analyzed. Epibenthic prey biomass, including harpacticoid copepods, tended to be higher in oiled areas sampled in 1989. This trend could be due to geographic variability, reduced cropping associated with lower abundance of juvenile pink salmon, or direct enhancement by oil contamination. The latter explanation is supported by preliminary results of colonization of azoic, contaminated sediments imported to Prince William Sound. There was an increase in abundance of harpacticoid copepods and other meiofauna in these sediments with increasing hydrocarbon contamination. Feder et al. (1990) also found increases in certain harpacticoid copepods, including the important salmon prey species Harpacticus uniremis, in experimentally oiled plots near Port Valdez. More information on the impact of oil on harpacticoid copepod prey suites will be provided by analysis of samples

collected on lightly- and heavily-contaminated beaches in 1990; these samples are not yet processed.

Feeding habits and amount of prey consumed by juvenile pink salmon in 1989 were generally similar between oiled and non-oiled areas. An exception was a significantly greater utilization of zooplankton by juvenile pink salmon in oiled bays relative to non-oiled bays, even though epibenthic prey abundance tended to be greater in oiled bays. The higher utilization of zooplankton in the oiled bays may reflect a shift from contaminated prey. Comparisons with 1990 stomach sample data, now being processed, will show whether this difference was reversed as the degree of hydrocarbon contamination in the environment declined.

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Table 1. ANOVA table, 1-M and 4-M temperatures in Prince William Sound, 1989; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
1-M Depth						
o	l(ob)	1	1.67	1.67	0.71	0.446
b	l(ob)	1	9.78	9.78	4.17	0.111
ob	l(ob)	1	0.56	0.56	0.24	0.651
l(ob)		4	9.38	2.35		
t	tl(ob)	4	252.79	63.20	18.42	0.000
to	tl(ob)	4	8.24	2.06	0.60	0.668
tb	tl(ob)	4	9.53	2.38	0.69	0.607
tob	tl(ob)	4	3.52	0.88	0.26	0.901
tl(ob)		16	54.90	3.43		
Error		72	3.41	0.05		
Total		111	353.78			
4-M Depth						
o	l(ob)	1	6.24	6.24	3.72	0.126
b	l(ob)	1	3.98	3.98	2.10	0.221
ob	l(ob)	1	0.20	0.20	0.01	0.923
l(ob)		4	7.57	1.89		
t	tl(ob)	4	290.82	72.70	438.12	0.000
to	tl(ob)	4	0.69	0.17	1.05	0.415
tb	tl(ob)	4	5.04	1.26	7.60	0.001
tob	tl(ob)	4	1.92	0.48	2.90	0.056
tl(ob)		16	2.66	0.17		
Error		72	1.90	0.03		
Total		111	321.65			

Table 2. ANOVA table, 1-M and 4-M salinities in Prince William Sound, 1989; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
1-M Depth						
o	l(ob)	1	880.30	880.30	53.51	0.002
b	l(ob)	1	95.83	95.83	5.82	0.073
ob	l(ob)	1	157.90	157.90	9.60	0.036
l(ob)		4	65.81	16.45		
t	tl(ob)	4	801.83	200.46	3.47	0.032
to	tl(ob)	4	346.52	86.63	1.50	0.249
tb	tl(ob)	4	91.51	22.88	0.40	0.809
tob	tl(ob)	4	93.16	23.29	0.40	0.804
tl(ob)		16	924.85	57.80		
Error		72	55.41	0.77		
Total		111	3513.17			
4-M Depth						
o	l(ob)	1	97.13	97.13	144.14	0.000
b	l(ob)	1	15.68	15.68	23.26	0.009
ob	l(ob)	1	0.02	0.02	0.03	0.871
l(ob)		4	2.70	0.67		
t	tl(ob)	4	192.99	48.25	49.13	0.000
to	tl(ob)	4	27.91	6.98	7.11	0.002
tb	tl(ob)	4	17.64	4.41	4.49	0.013
tob	tl(ob)	4	1.22	0.31	0.31	0.866
tl(ob)		16	15.71	0.98		
Error		72	7.70	0.10		
Total		111	378.07			

Table 3. Field sample blanks taken in association with hydrocarbon tissue and sediment samples in F/S-4. CULRP = Culross Passage; WELLP = Wells Passage; HERRB = Herring Bay; KNIGHI = Knight Island Passage; PWALE = Prince of Wales Passage; SNUGH = Snug Harbor.

id	invest#	oil?	matrix	spp	date	location	lab	s	folder,page
116114	23201	NO	BLANK	-0-	04/18/90	CULRP	TAMU	C	2.2 4
116123	-0-	NO	BLANK	-0-	04/18/90	CULRP	TAMU	C	2.2 5
116201	24201	NO	BLANK	-0-	04/21/90	WELLP	TAMU	C	2.5 3
116207	24101	NO	BLANK	-0-	04/21/90	WELLP	TAMU	C	2.2 7
116233	HB-1	NO	BLANK	-0-	04/24/90	HERRB	TAMU	C	2.4 1
116238	HB-2	NO	BLANK	-0-	04/24/90	HERRB	TAMU	C	2.4 1
116310	HBL	Y?	BLANK	-0-	04/24/90	HERRB	TAMU	C	2.5 3
116430	HBH N	NO	BLANK	-0-	04/27/90	HERRB	TAMU	C	2.4 9
116223	33201	NO	BLANK	-0-	04/23/90	KNIGI	TAMU	C	2.2 9
116139	34101	NO	BLANK	-0-	04/20/90	PWALE	TAMU	C	4. -0-
116127	32201	NO	BLANK	-0-	04/19/90	SNUGH	TAMU	C	2.2 5
116131	32101	NO	BLANK	-0-	04/19/90	SNUGH	TAMU	C	2.2 6

Table 4. Presence or absence of hydrocarbons in tissues of mussels (*Mytilus trossulus*) collected in oiled and non-oiled locations of Prince William Sound in 1989 and 1990. CULRP = Culross Passage; LONGB = Long Bay; MCCLB = McClure Bay; WELLP = Wells Passage; HERRB = Herring Bay; KNIGHI = Knight Island Passage; PWALE = Prince of Wales Passage; SNUGH = Snug Harbor.

id	invest#	oil?	matrix	spp	date	location	lab	s	folder,page	
1475	22101	NO	TISSUE	MUSS	04/16/89	CULRP	TAMU	C	2.1	1
3063	23102	YES	TISSUE	MUSS	05/04/89	CULRP	TAMU	C	2.1	2
3288	23203	NO	TISSUE	MUSS	05/20/89	CULRP	TAMU	C	2.1	4
4790	23205-M	NO	TISSUE	MUSS	06/23/89	CULRP	TAMU	C	2.1	6
6226	-0-	NO	TISSUE	MUSS	07/31/89	CULRP	TAMU	C	2.1	6
3020	22102	NO	TISSUE	MUSS	05/01/89	LONGB	TAMU	C	2.1	2
3236	22203(M)	NO	TISSUE	MUSS	05/16/89	LONGB	TAMU	C	2.1	4
4712	22205-M	NO	TISSUE	MUSS	06/17/89	LONGB	TAMU	C	2.1	5
6217	-0-	NO	TISSUE	MUSS	07/30/89	LONGB	TAMU	C	2.1	6
1451	21301	NO	TISSUE	MUSS	04/13/89	MCCLB	TAMU	C	2.1	1
3013	21102	NO	TISSUE	MUSS	04/30/89	MCCLB	TAMU	C	2.1	1
3226	21003(M)	NO	TISSUE	MUSS	05/15/89	MCCLB	TAMU	C	2.1	3
4704	21005-M	NO	TISSUE	MUSS	06/16/89	MCCLB	TAMU	C	2.1	5
6216	-0-	NO	TISSUE	MUSS	07/29/89	MCCLB	TAMU	C	2.1	6
1501	NR 24301	NO	TISSUE	MUSS	04/19/89	WELLP	TAMU	C	2.1	1
3065	24102	NO	TISSUE	MUSS	05/05/89	WELLP	TAMU	C	2.1	2
4741	24205-M	NO	TISSUE	MUSS	06/20/89	WELLP	TAMU	C	2.1	5
6235	-0-	NO	TISSUE	MUSS	08/01/89	WELLP	TAMU	C	2.1	7
3006	31202	YES	TISSUE	MUSS	04/29/89	HERRB	TAMU	C	1.	9
3219	31103(M)	YES	TISSUE	MUSS	05/14/89	HERRB	TAMU	C	2.1	3
4696	31005	YES	TISSUE	MUSS	06/15/89	HERRB	TAMU	C	2.1	4
6253	-0-	YES	TISSUE	MUSS	08/03/89	HERRB	TAMU	C	2.1	7
1494	33201	YES	TISSUE	MUSS	04/18/89	KNIGI	TAMU	C	2.1	1
3051	33202	YES	TISSUE	MUSS	05/03/89	KNIGI	TAMU	C	2.1	2
3272	33103	YES	TISSUE	MUSS	05/19/89	KNIGI	TAMU	C	2.1	4
4734	33105-M	YES	TISSUE	MUSS	06/19/89	KNIGI	TAMU	C	2.1	5
6244	-0-	YES	TISSUE	MUSS	08/02/89	KNIGI	TAMU	C	2.1	7
3035	34202	YES	TISSUE	MUSS	05/02/89	PWALE	TAMU	C	2.1	2
3216	34103	YES	TISSUE	MUSS	05/18/89	PWALE	TAMU	C	2.1	3
4832	34105-M	YES	TISSUE	MUSS	06/25/89	PWALE	TAMU	C	2.1	6
6262	-0-	YES	TISSUE	MUSS	08/04/89	PWALE	TAMU	C	2.1	7
1466	32000	YES	TISSUE	MUSS	04/15/89	SNUGH	TAMU	C	1.	9
3026	32000	YES	TISSUE	MUSS	05/02/89	SNUGH	TAMU	C	1.	9
3247	32003(M)	YES	TISSUE	MUSS	05/17/89	SNUGH	TAMU	C	2.1	4
4722	32005-M	YES	TISSUE	MUSS	06/18/89	SNUGH	TAMU	C	2.1	5
6271	-0-	YES	TISSUE	MUSS	08/05/89	SNUGH	TAMU	C	2.1	7
116140	34201	YES	TISSUE	MUSS	04/20/90	PWALE	TAMU	C	4.	-0-

Table 5. Presence or absence of hydrocarbons in sediments collected at oiled and non-oiled locations of Prince William Sound in 1990 (no 1989 sample analyses available to date). CULRP = Culross Passage; LONGB = Long Bay; WELLP = Wells Passage; HERRB = Herring Bay; KNIGHI = Knight Island Passage; PWALE = Prince of Wales Passage; SNUGH = Snug Harbor.

id	invest#	oil?	matrix	spp	date	location	lab	s	folder,page
116111	23201	NO	SEDIMENT	-0-	04/18/90	CULRP	TAMU	C	2.2 3
116112	23201	NO	SEDIMENT	-0-	04/18/90	CULRP	TAMU	C	2.2 3
116113	23201	NO	SEDIMENT	-0-	04/18/90	CULRP	TAMU	C	2.2 4
116115	23101	NO	SEDIMENT	-0-	04/18/90	CULRP	TAMU	C	2.2 4
116116	23101	NO	SEDIMENT	-0-	04/18/90	CULRP	TAMU	C	2.2 4
116117	23101	NO	SEDIMENT	-0-	04/18/90	CULRP	TAMU	C	2.2 4
116215	22201	NO?	SEDIMENT	-0-	04/22/90	LONGB	TAMU	C	2.2 8
116216	22201	NO?	SEDIMENT	-0-	04/22/90	LONGB	TAMU	C	2.2 8
116217	22201	NO?	SEDIMENT	-0-	04/22/90	LONGB	TAMU	C	2.2 8
116148	24201	NO?	SEDIMENT	-0-	04/21/90	WELLP	TAMU	C	4. -0-
116149	24201	YES	SEDIMENT	-0-	04/21/90	WELLP	TAMU	C	4. -0-
116150	24201	NO	SEDIMENT	-0-	04/21/90	WELLP	TAMU	C	4. -0-
116202	24101	YES	SEDIMENT	-0-	04/21/90	WELLP	TAMU	C	2.5 3
116205	24101	NO?	SEDIMENT	-0-	04/21/90	WELLP	TAMU	C	2.2 7
116206	24101	NO?	SEDIMENT	-0-	04/21/90	WELLP	TAMU	C	2.2 7
116229	HB-1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.2 9
116231	HB-1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.2 10
116232	HB-1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.2 10
116234	HB-2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4 1
116236	HB-2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4 1
116237	HB-2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4 1
116239	HB-3	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.4 2
116240	HB-3	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.4 2
116241	HB-3	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.4 2
116432	HB-7	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 9
116433	HB-7	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 9
116434	HB-7	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 9
116423	HBL N	NO	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 7
116424	HBL N	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 8
116425	HBL N	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 8
116427	HBH N	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 8
116428	HBH N	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 8
116429	HBH N	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4 9
116220	33201	NO?	SEDIMENT	-0-	04/23/90	KNIGI	TAMU	C	2.2 9
116221	33201	NO	SEDIMENT	-0-	04/23/90	KNIGI	TAMU	C	2.2 9
116222	33201	NO?	SEDIMENT	-0-	04/23/90	KNIGI	TAMU	C	2.2 9
116136	34101	NO?	SEDIMENT	-0-	04/20/90	PWALE	TAMU	C	2.2 6
116137	34101	NO?	SEDIMENT	-0-	04/20/90	PWALE	TAMU	C	2.2 6
116138	34101	NO?	SEDIMENT	-0-	04/20/90	PWALE	TAMU	C	2.2 7
116141	34201	NO	SEDIMENT	-0-	04/20/90	PWALE	TAMU	C	4. -0-
116142	34201	NO	SEDIMENT	-0-	04/20/90	PWALE	TAMU	C	4. -0-
116124	32201	YES	SEDIMENT	-0-	04/19/90	SNUGH	TAMU	C	2.2 5
116125	32201	YES	SEDIMENT	-0-	04/19/90	SNUGH	TAMU	C	2.2 5
116126	32201	YES	SEDIMENT	-0-	04/19/90	SNUGH	TAMU	C	2.2 5
116128	32101	YES	SEDIMENT	-0-	04/19/90	SNUGH	TAMU	C	2.2 6
116129	32101	YES	SEDIMENT	-0-	04/19/90	SNUGH	TAMU	C	2.2 6

Table 6. Presence or absence of hydrocarbons in sediment samples from meiofauna colonization experiment. C = control, L = low oil contamination, and H = high oil contamination. Corresponding indigenous sediments are contained in table 5, listed as HBL Nn or HBH Nn.

id	invest#	oil?	matrix	spp	date	location	lab	s	folder,page	
116248	HBL C1.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	3
116249	HBL C1.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116246	HBL C2.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	3
116247	HBL C2.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	3
116304	HBL C3.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116305	HBL C3.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116301	HBL H1.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116250	HBL H1.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116309	HBL H2.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.5	3
116308	HBL H2.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.5	3
116245	HBL H3.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	3
116244	HBL H3.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	3
116242	HBL L1.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	2
116243	HBL L1.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	2
116306	HBL L2.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116307	HBL L2.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116303	HBL L3.1	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116302	HBL L3.2	YES	SEDIMENT	-0-	04/24/90	HERRB	TAMU	C	2.4	4
116412	HBL H3	YES	SEDIMENT	-0-	04/26/90	HERRB	TAMU	C	2.4	5
116312	HBH C1.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	3
116313	HBH C1.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	3
116314	HBH C2.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	3
116315	HBH C2.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	3
116316	HBH C3.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	4
116317	HBH C3.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	4
116324	HBH H1.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	5
116325	HBH H1.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	5
116318	HBH L1.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	4
116319	HBH L1.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	4
116320	HBH L2.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	4
116321	HBH L2.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	5
116322	HBH L3.1	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	5
116323	HBH L3.2	YES	SEDIMENT	-0-	04/25/90	HERRB	TAMU	C	2.5	5
116413	HBH C1	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	6
116414	HBH C2	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	6
116415	HBH C3	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	6
116419	HBH H1	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	7
116420	HBH H2	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	7
116421	HBH H3	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	7
116416	HBH L1	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	6
116417	HBH L2	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	6
116418	HBH L3	YES	SEDIMENT	-0-	04/27/90	HERRB	TAMU	C	2.4	7

Table 7. Presence or absence of hydrocarbons in tissues of juvenile pink salmon sampled at oiled and non-oiled locations in Prince William Sound in 1989 and 1990. CULRP = Culross Passage; LONGB = Long Bay; MCCLB = McClure Bay; WELLP = Wells Passage; HERRB = Herring Bay; KNIGHI = Knight Island Passage; PWALE = Prince of Wales Passage; SNUGH = Snug Harbor.

id	invest#	oil?	matrix	spp	date	location	lab	s	folder,page
3023	22202-A	NO	TISSUE	PINK	05/01/89	LONGB	ABL	C	3. -0-
1453	21101	NO	TISSUE	PINK	04/13/89	MCCLB	TAMU	C	1. 9
1456	21201	NO	TISSUE	PINK	04/13/89	MCCLB	TAMU	C	1. 9
3228	21303-A	NO	TISSUE	PINK	05/15/89	MCCLB	ABL	C	3. -0-
3132	31202	YES	TISSUE	PINK	05/07/89	HERRB	TAMU	C	1. 22
3133	31202	YES	TISSUE	PINK	05/07/89	HERRB	TAMU	C	1. 22
3134	31202	YES	TISSUE	PINK	05/07/89	HERRB	ABL	C	3. -0-
3210	31003-A	YES	TISSUE	PINK	05/13/89	HERRB	ABL	C	3. -0-
1470	32201 A	YES	TISSUE	PINK	04/15/89	SNUGH	TAMU	C	1. 9
1801	32201 B	YES	TISSUE	PINK	04/15/89	SNUGH	TAMU	C	1. 9
1802	32201 C	YES	TISSUE	PINK	04/15/89	SNUGH	ABL	C	3. -0-
3031	32000-A	YES	TISSUE	PINK	05/02/89	SNUGH	TAMU	C	1. 10
3032	32000-B	YES	TISSUE	PINK	05/02/89	SNUGH	TAMU	C	1. 22
3033	32000-C	Y/N	TISSUE	PINK	05/02/89	SNUGH	ABL	C	3. -0-
116120	23211	NO	TISSUE	PINK	04/18/90	CULRP	TAMU	C	2.3 2
116121	23211	NO	TISSUE	PINK	04/18/90	CULRP	TAMU	C	2.3 2
116122	23211	NO	TISSUE	PINK	04/18/90	CULRP	TAMU	C	2.3 2
116601	123222	NO	tissue	pink	05/07/90	CULRP	TAMU	C	2.3 8
116602	123212	NO	tissue	pink	05/07/90	CULRP	TAMU	C	2.3 8
116603	123212	NO	tissue	pink	05/07/90	CULRP	TAMU	C	2.3 8
116537	22202	NO	tissue	pink	05/05/90	longb	TAMU	C	2.3 6
116538	22202	NO	tissue	pink	05/05/90	longb	TAMU	C	2.3 6
116539	22202	NO	tissue	pink	05/05/90	longb	TAMU	C	2.3 6
116528	21212	NO?	tissue	pink	05/04/90	mcclb	TAMU	C	2.3 6
116208	24211	NO	TISSUE	PINK	04/21/90	WELLP	TAMU	C	2.3 4
116209	24211	NO	TISSUE	PINK	04/21/90	WELLP	TAMU	C	2.3 4
116210	24211	NO	TISSUE	PINK	04/21/90	WELLP	TAMU	C	2.3 4
116605	124212	NO	tissue	pink	05/08/90	wellp	TAMU	C	2.3 8
116606	124212	NO	tissue	pink	05/08/90	wellp	TAMU	C	2.3 9
116607	124212	NO	tissue	pink	05/08/90	wellp	TAMU	C	2.3 9
116228	131311	NO	TISSUE	PINK	04/23/90	HERRB	TAMU	C	2.3 4
116342	131321	NO	TISSUE	PINK	04/24/90	HERRB	TAMU	C	2.3 4
116431	31000	NO	TISSUE	PINK	04/26/90	HERRB	TAMU	C	2.5 5
116501	131312	NO	tissue	pink	05/03/90	herrb	TAMU	C	2.3 5
116502	131312	NO?	tissue	pink	05/03/90	herrb	TAMU	C	2.3 5
116503	131312	NO?	tissue	pink	05/03/90	herrb	TAMU	C	2.3 6
116547	133322	NO	tissue	pink	05/06/90	KNIGI	TAMU	C	2.3 7
116548	133322	NO	tissue	pink	05/06/90	KNIGI	TAMU	C	2.3 7
116549	133322	NO	tissue	pink	05/06/90	KNIGI	TAMU	C	2.3 8
116145	34211	NO	TISSUE	PINK	04/20/90	PWALE	TAMU	C	2.3 3
116146	34211	NO	TISSUE	PINK	04/20/90	PWALE	TAMU	C	2.3 3
116147	34211	NO	TISSUE	PINK	04/20/90	PWALE	TAMU	C	2.3 3
116730	34312	NO	tissue	pink	05/10/90	pwale	TAMU	C	2.3 9
116731	34312	NO	tissue	pink	05/10/90	pwale	TAMU	C	2.3 9
116732	34312	NO	tissue	pink	05/10/90	pwale	TAMU	C	2.3 9
116133	32111	NO	TISSUE	PINK	04/19/90	SNUGH	TAMU	C	2.3 2
116134	32111	NO	TISSUE	PINK	04/19/90	SNUGH	TAMU	C	2.3 3
116135	32111	NO	TISSUE	PINK	04/19/90	SNUGH	TAMU	C	2.3 3
116544	132322	NO	tissue	pink	05/05/90	snugh	TAMU	C	2.3 7
116545	132322	NO	tissue	pink	05/05/90	snugh	TAMU	C	2.3 7
116546	132322	NO	tissue	pink	05/05/90	snugh	TAMU	C	2.3 7

Table 8. Ranking of overall prevalence and intensity of staining for mixed function oxidase activity in juvenile pink salmon sampled in oiled and non-oiled locations in Prince William Sound in 1989 and 1990. Sample rankings were based on histological sectioning and immunochemical staining for P450E content.

Sampling Location	Sample #	MFO Activity Ranking	Evidence of hydrocarbon Induction
	Pink Salmon		
1989: Non-oiled			
McClure Bay	21303	very mild	no
Wells Passage	24103	very mild	no
1989: Oiled			
Herring Bay	131223	mild	yes
Herring Bay	31304	strong	yes
Snug Harbor-Inner Bay	32203	mild/moderate	yes
Snug Harbor-Outer Bay (Oiled Bay)	132313	moderate	yes
Snug Harbor-Inner Bay	32104	moderate	yes
Knight Island Passage	133313	moderate	yes
1990: Non-oiled			
McClure Bay	21331	negative	no
1990: Oiled			
Herring Bay	31202	very mild	no?
Snug Harbor-Inner Bay	32111	very mild	no?
	Chum Salmon		
1989: Non-oiled			
McClure Bay	21103	negative	no
1989: Oiled			
Herring Bay	31103	strong	yes
1990: Oiled			
Mc Clure Bay	21113	very mild	no
1990: Non-oiled	31113	very mild	no

Table 9. ANOVA table, systematic catches of juvenile pink salmon in Prince William Sound, 1989 and 1990; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
1989						
o	l(ob)	1	4308266	4308266	9.28	0.038
b	l(ob)	1	9374375	9374375	20.20	0.010
ob	l(ob)	1	4006160	4006160	8.63	0.042
l(ob)		4	1856676	464169		
t	tl(ob)	3	4417494	1472498	0.81	0.513
to	tl(ob)	3	6139720	2043240	1.12	0.379
tb	tl(ob)	3	4602357	1534119	0.84	0.496
tob	tl(ob)	3	6462021	2154007	1.18	0.357
tl(ob)		12	21864828	1822069		
h	hl(ob)	2	9301412	4650706	117.0	0.000
oh	hl(ob)	2	3387454	1693727	42.61	0.000
bh	hl(ob)	2	9553178	4776589	120.2	0.000
obh	hl(ob)	2	3594754	1797377	45.22	0.000
hl(ob)		8	318000	39750		
th	thl(ob)	6	7963638	1327273	0.69	0.656
toh	thl(ob)	6	9686112	1614352	0.84	0.548
tbh	thl(ob)	6	7122378	1187063	0.62	0.712
tobh	thl(ob)	6	9176238	1529373	0.80	0.579
thl(ob)		24	45916032	1913168		
1990						
o	l(ob)	1	18874446	18874446	1.62	0.273
b	l(ob)	1	28011202	28011202	2.40	0.196
ob	l(ob)	1	19424680	19424680	1.66	0.267
l(ob)		4	46745556	11686389		
t	tl(ob)	3	22409028	7469676	1.71	0.219
to	tl(ob)	3	31557118	10519039	2.40	0.118
tb	tl(ob)	3	20349340	6783114	1.55	0.253
tob	tl(ob)	3	28577966	9525989	2.18	0.144
tl(ob)		12	52514976	4376248		
h	hl(ob)	2	22477742	11238871	0.75	0.501
oh	hl(ob)	2	14438157	7219079	0.48	0.633
bh	hl(ob)	2	22092888	11046444	0.74	0.506
obh	hl(ob)	2	16147706	8073853	0.54	0.602
hl(ob)		8	119174656	14896832		
th	thl(ob)	6	14202273	2367045	0.45	0.840
toh	thl(ob)	6	19563422	3260570	0.62	0.715
tbh	thl(ob)	6	14460311	2410052	0.46	0.834
tobh	thl(ob)	6	23108968	3851494	0.73	0.632
tlh(ob)		24	127051120	5293796		

Table 10. Summary table of Wilcoxon paired-rank tests for abundance of juvenile pink and chum salmon in Prince William Sound in 1989 and 1990. A negative value for the median indicates non-oiled > oiled; median values are in number of fish per set.

Species/year	Pairs	Wilcoxin Statistic	P-Value	Estimated Median	95% C.I. of Median
Pink Salmon/1989					
All	56	313.5	0.086	-5.0	111.0,1.0
Bays	28	75.0	0.737	0.0	-2.0,8.0
Corridors	28	89.5	0.030	-119.8	-706.0,-1.0
Pink Salmon/1990					
All	95	925.0	0.092	-4.0	-31.5,-0.5
Bays	48	328.0	0.273	-2.0	-14.0,1.0
Corridors	47	260.5	0.112	-52.5	-290.0,3.0
Chum Salmon/1989	56	27.0	0.000	-64.8	-130,-41.5
Chum Salmon/1990	95	55.5	0.000	-53.0	-92.0,-35.5

Table 11. ANOVA table, systematic catches of juvenile pink salmon in Prince William Sound in 1989 considered separately for bays and corridors. t = time, o = oil, h = habitat, l = location, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
BAYS						
o	l(o)	1	2745	2745	1.03	0.417
l(o)		2	5343	2672		
t	tl(o)	3	9159	3053	0.63	0.623
to	tl(o)	3	14628	4876	1.00	0.453
tl(o)		6	29176	4863		
h	hl(o)	2	6767	3383	0.62	0.584
oh	hl(o)	2	7608	3803	0.69	0.552
hl(o)		4	21990	5498		
th	thl(o)	6	28796	4799	1.14	0.398
toh	thl(o)	6	26095	4349	1.03	0.451
thl(o)		12	50656	4221		
CORRIDORS						
o	l(o)	1	8311681	8311681	8.98	0.095
l(o)		2	1851334	925667		
t	tl(o)	3	9010695	3003564	0.83	0.526
to	tl(o)	3	12577138	4192371	1.15	0.402
tl(o)		6	21835644	3639274	0.93	0.505
h	hl(o)	2	18847824	9423912	127.4	0.000
oh	hl(o)	2	6974600	3487300	47.12	0.001
hl(o)		4	296008	74002		
th	thl(o)	6	15057222	2509537	0.66	0.685
toh	thl(o)	6	18776256	3139376	0.82	0.574
thl(o)		12	45865392	3822116		

Table 12. Number of observed coded-wire tags, the expanded number of hatchery fish, and the percent hatchery composition in the catch of juvenile pink salmon for non-oiled and oiled locations sampled in Prince William Sound in 1989 and 1990.

Location	Total Catch	Observed Tags	Total Hatchery Catch	Percent Hatchery Fish
	1989			
Oiled Bays				
Herring Bay	1108	1	484	44
Snug Harbor (Inside)	949	0	0	0
Snug Harbor (Outside)	48026	5	1445	3
Non-oiled Bays				
McClure Bay	1010	0	0	0
Long Bay	611	0	0	0
Oiled Corridors				
Knight Island Psg.	15909	8	2497	16
Prince of Wales Psg.	29638	13	4259	14
Non-oiled Corridors				
Culross Psg.	45899	4	1936	4
Wells Psg.	88976	110	58906	66
	1990			
Oiled Bays				
Herring Bay	5061	111		
Snug Harbor (Inside)	3514	0		
Snug Harbor (Outside)	37255	0		
Non-oiled Bays				
McClure Bay	1722	0		
Long Bay	2640	0		
Oiled Corridors				
Knight Island Psg.	8072	10		
Prince of Wales Psg.	68436	40		
Non-oiled Corridors				
Culross Psg.	16745	2		
Wells Psg.	59643	103		

Table 13. ANOVA table, systematic catches of juvenile chum salmon in Prince William Sound, 1989 and 1990; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
1989						
o	l(ob)	1	501271	501271	17.88	0.013
b	l(ob)	1	49914	49914	1.78	0.253
ob	l(ob)	1	63294	63294	2.26	0.207
l(ob)		4	112142	28036		
t	tl(ob)	3	110491	36830	1.88	0.186
to	tl(ob)	3	97079	32360	1.65	0.229
tb	tl(ob)	3	38619	12873	0.66	0.593
tob	tl(ob)	3	50469	16823	0.86	0.488
tl(ob)		12	234717	19560		
h	hl(ob)	2	19546	9773	0.28	0.762
oh	hl(ob)	2	12751	6375	0.18	0.836
bh	hl(ob)	2	52880	26440	0.76	0.498
obh	hl(ob)	2	66088	33044	0.95	0.426
hl(ob)		8	277728	34716		
th	thl(ob)	6	87428	14571	0.53	0.779
toh	thl(ob)	6	84739	14123	0.52	0.791
tbh	thl(ob)	6	65718	10953	0.40	0.872
tobh	thl(ob)	6	74903	12484	0.46	0.834
thl(ob)		24	657996	27416		
1990						
o	l(ob)	1	2027943	2027943	6.11	0.069
b	l(ob)	1	34990	34990	0.11	0.762
ob	l(ob)	1	43330	43330	0.13	0.762
l(ob)		4	1326944	331736		
t	tl(ob)	3	1037646	345882	2.20	0.141
to	tl(ob)	3	1045038	348346	2.21	0.139
tb	tl(ob)	3	97719	32573	0.21	0.890
tob	tl(ob)	3	91329	30443	0.19	0.899
tl(ob)		12	1890168	157514		
h	hl(ob)	2	635378	317689	1.55	0.269
oh	hl(ob)	2	595628	297814	1.46	0.289
bh	hl(ob)	2	413132	206566	1.01	0.406
obh	hl(ob)	2	375266	187633	0.92	0.438
hl(ob)		8	1636632	204579		
th	thl(ob)	6	1000212	166702	1.22	0.329
toh	thl(ob)	6	1001964	166994	1.23	0.328
tbh	thl(ob)	6	1485744	247624	1.82	0.138
tobh	thl(ob)	6	1498098	249683	1.83	0.135
tlh(ob)		24	3270888	136287		

Table 14. Summary table of Wilcoxon paired-rank tests for size of juvenile pink and chum salmon in Prince William Sound in 1989. A negative value for the median indicates non-oiled > oiled; median values are in mm fork length.

Species/year	Pairs	Wilcoxin Statistic	P-Value	Estimated Median	95% C.I. of Median
Pink Salmon					
All	23	70.0	0.324	-0.5	-2.5,1.0
Trips 3-5	18	32.0	0.209	-1.0	-3.5,1.0
Bays	8	12.0	0.281	1.0	-1.0,3.0
Corridors	15	27.0	0.117	-2.0	-4.5,0.5
Chum Salmon	7	26.0	0.052	7.5	0.5,14.5

Table 15. ANOVA table, size of juvenile pink salmon in Prince William Sound in 1989 captured in corridors during sampling trips 3-5. t = time, o = oil, h = habitat, l = location, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of squares	Mean Square	F	Prob.
o	l(o)	1	925.5	925.5	1.89	0.303
l(o)		2	978.9	489.4		
t	tl(o)	2	6921.1	3460.5	7.13	0.048
to	tl(o)	2	162.2	81.1	0.17	0.852
tl(o)		4	1942.5	485.6		
h	hl(o)	2	10092.4	5046.2	61.67	0.001
oh	hl(o)	2	1554.6	777.3	9.50	0.030
hl(o)		4	327.3	81.8		
toh		4	1418.4			
error		1496	64200.6			
total		1523	90212.5			

Table 16. Apparent daily growth rate and associated standard deviation of juvenile pink salmon at oiled and non-oiled sampling locations in Prince William Sound in 1989, by habitat type. Growth was assumed to be exponential over time, and was determined as the slope of the regression of the natural logarithm of weight over time in days. Numbers shown in table are expressed as % increase in body weight per day, with standard deviation in parens. LG = low gradient; MG = medium gradient; SG = steep gradient.

Sampling Location	Habitat		
	LG	MG	SG
Oiled Bays			
Snug Harbor	2.16(0.53)	1.04(0.10)	3.97(0.52)
Herring Bay	--	1.68(0.44)	4.92(0.42)
Mean	2.16	1.36	4.45
Non-oiled Bays			
Long Bay	--	-	--
		0.51(0.29)	
McClure Bay	0.11(0.11)		4.15(0.65)
		0.55(0.15)	
Mean	0.11	0.02	4.15
Oiled Corridors			
Knight Island Passage	0.94(0.17)	2.61(0.17)	2.08(0.34)
Prince of Wales Passage	2.18(0.20)	0.68(0.39)	0.45(0.42)
Mean	1.56	1.64	1.27
Non-oiled Corridors			
Wells Passage	2.46(0.26)	3.86(0.35)	1.81(0.40)
Culross Passage	2.05(0.18)	2.61(0.15)	4.53(0.30)
Mean	2.25	3.23	3.17

Table 17. Comparison of weight/length relationship of juvenile pink and chum salmon between oiled and non-oiled areas of western Prince William Sound sampled in 1989. The natural logarithm of weight was regressed on the natural logarithm of length. The slope of the resulting equation is the exponential rate of increase of weight with length, x, in the equation

$$w = a(l^x),$$

where w = weight, a is a constant described by the intercept of the regression, and l is the length. P,x is the probability value for the tests of homogeneity of slopes for the pairs of regression lines shown. P,w is the probability value for differences in weighted means, given if slopes are equal.

Species/area	N	a	x	R^2	P,x	P,w
Pink Salmon						
Non-oiled bays	235	-13.2	3.32	85.8	0.129	0.425
Non-oiled corridors	898	-13.6	3.44	97.8		
Oiled bays	244	-13.8	3.50	93.1	0.276	0.239
Oiled corridors	849	-13.5	3.44	97.1		
Non-oiled pooled	1135	-13.6	3.44	97.7	0.343	0.000
Oiled pooled	1095	-13.6	3.46	97.1		
Chum Salmon						
Non-oiled bays	831	-13.3	3.39	91.2	0.000	
Oiled bays	91	-11.4	2.92	93.2		
Non-oiled corridors	956	-13.7	3.52	96.7	0.257	0.132
Oiled corridors	44	-14.1	3.63	98.6		

Table 18. Mean fork-length and standard error of mean of juvenile chum salmon captured in oiled and non-oiled bays and corridors in Prince William Sound in 1989. Sample numbers are pooled over all sampling periods, habitats, and sampling locations within bays and corridors.

Area	Bay/Corridor	N	Mean(mm)	SE
Oil	Bay	92	50.1	0.67
	Corridor	45	43.0	1.25
No-oil	Bay	832	38.9	0.17
	Corridor	957	45.8	0.25

Table 19. Percent dry weight of prey categories in the diet of 608 pink salmon fry collected in Prince William Sound, Alaska, April-June 1989, in oiled and non-oiled areas, by low, medium, and steep gradient habitats in bays and corridors. Samples are pooled by time (trip number) and fry size. Large Calanoids ≥ 2.5 mm, Small Calanoids < 2.5 mm. (Epi. = Epibenthic Zooplankton, Pelagic = Pelagic Zooplankton).

Species Category	Bays			Corridors		
	Low	Medium	Steep	Low	Medium	Steep
NON-OILED						
Large Calanoids	44.46	39.95	44.09	20.51	39.24	29.91
Small Calanoids	42.98	41.36	13.79	14.90	15.18	25.89
Other Pelagic	3.49	3.67	6.60	3.61	5.78	9.47
Harpacticoids	6.02	9.98	0.29	31.49	29.28	5.82
Other Epi.	1.63	1.60	1.28	24.90	7.86	23.52
Drift Insects	1.29	3.37	33.87	4.54	2.43	4.63
OILED						
Large Calanoids	81.36	21.47	24.13	25.41	24.75	38.66
Small Calanoids	5.15	6.49	34.51	11.41	42.56	18.27
Other Pelagic	2.23	33.60	2.38	10.09	12.20	7.78
Harpacticoids	4.00	4.84	1.01	32.59	15.34	5.64
Other Epi.	5.12	16.68	18.99	13.22	3.73	22.10
Drift Insects	2.05	16.86	18.96	7.22	1.40	7.51

Table 20. Summary table of Wilcoxon paired-signed rank tests for average diet and size parameters of juvenile pink salmon in Prince William Sound, 1989. Comparisons are based on 17 pairs in all cases. An * indicates a P-value < 0.1. A negative value for the median indicates non-oiled > oiled. t = number of ties deleted from comparison. W.W. = wet weight, D.W. = dry weight, B.W. = body weight, Full = stomach fullness index, Digest = state of digestion index, % Empty = stomachs without food, No. Categ. = number of prey categories, FL = mm Fork Length, Weight = g wet weight.

Parameter	t	Wilcoxon Stat.	P-Value	Est. Median	95% C.I. of Median
Fullness					
Gut W.W.	0	97.0	0.344	0.0022	-0.0014, 0.0062
W.W. % B.W.	0	101.0	0.256	0.0054	-0.0046, 0.0147
D.W. % B.W.	0	105.0	0.185	0.0173	0.0073, 0.0409
Full	2	78.0	0.320	0.4000	-0.55, 1.05
Digest	0	25.5	0.017*	-0.2583	-0.439, -0.059
% Empty	7	30.5	0.799	0.0000	-0.052, 0.069
Total Prey					
No. Categ.	0	44.0	0.130	-1.600	-4.47, 0.54
Number	0	83.0	0.776	17.05	-56, 104
D.W.	0	110.0	0.118	1.127	-0.202, 0.542
Size					
FL	0	68.0	0.705	-0.2931	-2.52, 1.55
Weight	0	71.0	0.813	-0.0081	-0.123, 0.079

Table 21. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey categories consumed by juvenile pink salmon in paired sets from oiled (n = 196) vs. non-oiled (n = 201) areas of Prince William Sound, 1989. An * indicates a P-value < 0.1. A negative value for the median indicates non-oiled > oiled. t = number of ties deleted from comparison, Dry wt. = mg dry weight, Cal. = Calanoids.

Prey Category	t	Wilcoxon Stat.	P-Value	Estimated Median	95% C.I. of Median
Zooplankton					
Number	0	107.0	0.156	38.50	-12, 92
% Number	0	119.0	0.047*	0.1799	0.029, 0.346
Dry Wt.	0	134.0	0.007*	38.50	0.5, 92.0
% Dry Wt.	0	118.0	0.052*	0.1706	0.021, 0.322
Epibenthos					
Number	0	52.0	0.256	-17.00	-57.0, 27.5
% Number	0	48.0	0.185	-0.1275	-0.313, 0.052
Dry Wt.	0	61.0	0.478	-0.2016	-0.59, 0.46
% Dry Wt.	0	53.0	0.276	-0.1024	-0.267, 0.080
Drift Insects					
Number	15	0.0	0.371	0.0000	0.000, 0.000
% Number	3	28.0	0.132	-0.0072	-0.029, 0.001
Dry Wt.	3	54.0	0.950	0.0000	-0.060, 0.083
% Dry Wt.	3	30.0	0.167	-0.0362	-0.109, 0.009
Harpacticoids					
Number	0	49.0	0.201	-12.00	-37.0, 31.0
% Number	0	50.0	0.218	-0.0423	-0.236, 0.059
Dry Wt.	0	50.0	0.218	-0.1320	-0.424, 0.351
% Dry Wt.	0	61.0	0.478	-0.0340	-0.146, 0.093
Tot. Cal.					
Number	2	70.0	0.589	5.500	-15.5, 40.0
% Number	0	110.0	0.118	0.1656	-0.052, 0.322
Dry Wt.	0	124.0	0.026*	0.9841	0.12, 1.96
% Dry Wt.	0	105.0	0.185	0.1543	-0.080, 0.312
Small Cal.					
Number	0	93.0	0.449	119.5	-126, 2.85
% Number	0	104.0	0.201	0.8531	-0.67, 2.85
Dry Wt.	0	93.0	0.449	3.286	-3, 414
% Dry Wt.	0	85.0	0.705	0.2617	-1.39, 2.19
Large Cal.					
Number	3	92.0	0.014*	9.000	1.5, 25.0
% Number	2	98.0	0.033*	0.5156	0.01, 1.26
Dry Wt.	3	92.0	0.014*	4.419	0.7, 12.3
% Dry Wt.	2	85.0	0.164	0.5877	-0.20, 1.86

Table 22. Frequency of occurrence (F.O.) of prey categories in juvenile pink salmon fry stomachs from the paired sets, Prince William Sound, 1989. F.O. is derived from the occurrence of prey in the stomachs of fish containing food. Of 196 and 201 fry from paired sets in oiled and non-oiled areas, respectively, 169 fry from each area had food organisms in their stomachs. Epi. = Epibenthos, Zoop. = Pelagic Zooplankton, Cal. = Calanoids, Harp. = Harpacticoids.

Area	Total Epi.	Total Zoop.	Total Cal.	Small Cal.	Lg. Cal.	Harp.	Drift Insects
Nonoiled							
Number	146	150	113	98	62	132	31
Percent	86.4	88.8	66.9	58.0	36.7	78.1	18.3
Oiled							
Number	127	161	133	123	80	119	25
Percent	75.2	95.3	78.7	72.8	47.3	70.4	14.8
Total							
Number	273	311	246	221	142	251	56
Percent	80.8	92.0	72.8	65.4	42.0	74.3	16.6

Table 23. Percent dry weight of prey categories in the diet of 493 chum salmon fry diets from fish collected in Prince William Sound, Alaska, April-June 1989, in oiled and non-oiled areas, listed by low, medium, and steep gradient habitats in bays and corridors. Samples are pooled by time (trip number) and fry size. Large Calanoids ≥ 2.5 mm, Small Calanoids < 2.5 mm. (Epi. = Epibenthic Zooplankton, Pelagic = Pelagic Zooplankton, N/A = Insufficient Data).

Species Category	Bays			Corridors		
	Low	Medium	Steep	Low	Medium	Steep
NON-OILED						
Large Calanoids	7.55	10.91	10.96	32.03	24.27	37.20
Small Calanoids	19.91	14.99	19.07	3.52	0.68	0.84
Other Pelagic	1.80	1.53	12.07	8.70	10.30	27.80
Harpacticoids	6.76	11.48	0.21	7.95	2.33	4.06
Other Epi.	6.75	7.54	2.29	30.98	23.49	9.53
Drift Insects	57.18	53.48	55.26	16.80	38.84	20.52
OILED						
Large Calanoids	74.30	37.01	53.79	63.99	93.56	N/A
Small Calanoids	0.00	0.81	3.01	0.29	0.10	N/A
Other Pelagic	1.62	6.58	0.77	1.42	5.46	N/A
Harpacticoids	0.69	6.00	1.11	0.54	0.84	N/A
Other Epi.	6.46	46.92	1.77	0.05	0.02	N/A
Drift Insects	16.92	2.66	39.40	33.69	0.00	N/A

Table 24. Summary table of Wilcoxon paired-signed rank tests for average diet and size parameters of juvenile chum salmon in Prince William Sound, 1989. Comparisons are based on 6 pairs in all cases. t = number of ties deleted from comparison. A negative value for the median indicates non-oiled > oiled. W.W. = wet weight, D.W. = dry weight, B.W. = body weight, Full = stomach fullness index, Digest = state of digestion Index, No. Categ. = number of prey categories, FL = mm Fork Length, Weight = g wet weight.

Parameter	t	Wilcoxon Stat.	P-Value	Estimated Median	95% C.I. of Median
Fullness					
Gut W.W.	0	18.0	0.142	0.00570	-0.0008, 0.0193
W.W. % B.W.	0	11.0	1.000	0.00049	-0.0132, 0.0193
D.W. % B.W.	0	10.0	1.000	-0.00690	-0.0132, 0.0298
Full	1	5.0	0.590	-0.5000	-1.00, 2.00
Digest	4	1.5	1.000	0.0000	-0.50, 0.50
Total Prey					
No. Categ.	2	5.0	1.000	0.0000	-4.50, 2.50
Number	0	7.0	0.529	-46.50	-139, 22
D.W.	0	14.0	0.529	1.261	-4.5, 6.6
Size					
FL	0	21.0	0.036*	7.054	2.0, 16.3
Weight	0	21.0	0.036*	0.3702	0.1, 16.3

Table 25. Summary table of Wilcoxon paired-signed rank tests for comparing average values for prey categories consumed by juvenile chum salmon in paired sets from oiled (n = 58) vs. non-oiled (n = 54) areas of Prince William Sound, 1989. Comparisons are based on six pairs in all cases. An * indicates a P-value < 0.1. A negative value for the median indicates non-oiled > oiled. t = number of ties deleted from comparison, Dry wt. = mg dry weight, Cal. = Calanoids.

Prey Category	t	Wilcoxon Stat.	P-Value	Estimated Median	95% C.I. of Median
Zooplankton					
Number	0	9.0	0.834	-2.000	-83.0, 14.5
% Number	0	9.0	0.834	-0.09133	0.000, 0.000
Dry Wt.	0	11.0	1.000	0.07645	-2.41, 5.36
% Dry Wt.	0	9.0	0.834	-0.06632	-0.334, 0.409
Epibenthos					
Number	0	9.0	0.834	-4.500	-67.0, 22.5
% Number	0	10.0	1.000	-0.02127	-0.342, 0.443
Dry Wt.	0	9.0	0.834	-0.06182	-1.31, 0.44
% Dry Wt.	0	10.0	1.000	-0.02620	-0.276, 0.338
Drift Insects					
Number	3	5.0	0.423	0.5000	-0.50, 3.00
% Number	1	10.0	0.590	0.02966	-0.054, -.131
Dry Wt.	1	12.0	0.281	0.3051	-0.242, 0.131
% Dry Wt.	1	9.0	0.787	0.04758	-0.188, 0.352
Harpacticoids					
Number	0	8.0	0.675	-2.500	-69.5, 8.0
% Number	0	9.0	0.834	-0.05672	-0.276, 0.243
Dry Wt.	0	8.0	0.675	-0.03051	-0.698, 0.102
% Dry Wt.	0	5.0	0.295	-0.04616	-0.183, 0.071
Tot. Cal.					
Number	1	5.0	0.590	-2.500	-79.0, 8.5
% Number	0	7.0	0.529	-0.05243	-0.42, 8.50
Dry Wt.	0	11.0	1.000	0.04803	-0.42, 5.27
% Dry Wt.	0	9.0	0.834	-0.1276	-0.449, 0.403
Small Cal.					
Number	0	2.0	0.093*	-6.500	-79.0, 0.0
% Number	0	4.0	0.208	-6.500	-0.423, 0.042
Dry Wt.	0	3.0	0.142	-0.1753	-2.17, 0.00
% Dry Wt.	0	4.0	0.208	-0.1204	-0.449, 0.109
Large Cal.					
Number	3	5.0	0.423	3.500	-1.0, 11.0
% Number	2	7.0	0.584	0.03995	-0.196, 0.417
Dry Wt.	2	7.0	0.584	1.596	-0.63, 5.30
% Dry Wt.	2	5.0	1.000	0.000	-0.236, 0.465

Table 26.--Mean abundance (organisms/m^3) and standard deviation (SD) of pelagic zooplankton collected from four pairs of non-oiled and oiled locations in Prince William Sound, April-June 1989.

	Non-oiled locations		Oiled locations	
Time period	$\bar{x}$	(SD)	$\bar{x}$	(SD)
		Bays		
	McClure Bay		Herring Bay	
Late April	2866	(203.4)	5342	(956.6)
Early May	4674	(2086.7)	1580	(125.3)
Late May	1008	(159.5)	2423	(165.6)
Early June	240	(44.7)	1017	(260.6)
Late June	1170	(403.9)	1193	(101.0)
April-June	1992		2311	
	Long Bay		Snug Harbor	
Late April	5975	(2542.3)	2493	(1189.9)
Early May	337	(65.2)	1332	(308.3)
Late May	1081	(349.9)	1303	(388.0)
Early June	565	(237.3)	318	(83.6)
Late June	1732	(480.9)	716	(359.2)
April-June	1938		1232	
		Corridors		
	Culross Passage		Prince of Wales Passage	
Late April	10,036	(1127.2)	4021	(818.4)
Early May	3657	(694.1)	4902	(1715.2)
Late May	2098	(459.9)	1745	(442.4)
Early June	1536	(206.0)	914	(231.7)
Late June	3100	(586.4)	1523	(259.6)
April-June	4085		2621	
	Wells Passage		Knight Island Passage	
Late April	6830	(1255.4)	2364	(585.1)
Early May	3812	(469.1)	13,313	(1438.1)
Late May	2796	(858.7)	3974	(198.9)
Early June	959	(198.7)	756	(292.7)
Late June	1428	(178.3)	1156	(106.4)
April-June	3165		4313	

Table 27--Mean biomass (g/m^3) and standard deviation (SD) of pelagic zooplankton collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1989.

Time period	Unoiled sites		Oiled sites	
	$\bar{x}$	(SD)	$\bar{x}$	(SD)
	Bays			
	McClure Bay		Herring Bay	
Late April	0.2315	(0.0615)	0.5127	(0.1118)
Early May	1.4426	(0.9533)	0.5615	(0.0964)
Late May	0.1395	(0.0415)	0.7463	(0.0803)
Early June	0.0074	(0.0025)	0.1322	(0.0262)
Late June	0.0393	(0.0163)	0.0184	(0.0025)
April-June	0.3720		0.3942	
	Long Bay		Snug Harbor	
Late April	0.4054	(0.2960)	0.2669	(0.1534)
Early May	0.0080	(0.0014)	0.1046	(0.0544)
Late May	0.0192	(0.0064)	0.1183	(0.0544)
Early June	0.0156	(0.0081)	0.0048	(0.0013)
Late June	0.0339	(0.0094)	0.0085	(0.0037)
April-June	0.0964		0.1003	
	Corridors			
	Culross Passage		Prince of Wales Passage	
Late April	1.3188	(0.2832)	1.5952	(0.8344)
Early May	1.0819	(0.4486)	1.2065	(0.3507)
Late May	0.4850	(0.0492)	0.7147	(0.3524)
Early June	0.1046	(0.0211)	0.0452	(0.0223)
Late June	0.1091	(0.0235)	0.0468	(0.0098)
April-June	0.6199		0.7699	
	Wells Passage		Knight Island Passage	
Late April	1.0491	(0.5192)	0.9543	(0.4006)
Early May	1.6763	(0.6447)	2.5263	(0.4503)
Late May	0.5795	(0.2642)	2.1638	(0.7042)
Early June	0.1587	(0.0396)	0.0625	(0.0384)
Late June	0.0249	(0.0017)	0.0416	(0.0064)
April-June	0.6977		1.1497	

Table 28. Percent abundance and biomass of identified taxa of pelagic zooplankton in bays and corridors of Prince William Sound from April to June, 1989.

Organism	Percent Abundance		Percent Biomass	
	Bay	Corridor	Bay	Corridor
Protozoa				
Radiolaria	0.0000	0.0018	0.0000	0.0001
Cnidaria				
Hydrozoa	2.8930	0.2939	0.3869	0.0130
Annelida				
Polychaeta	2.6407	0.0976	1.7318	0.0463
Mollusca				
Bivalvia	0.4761	0.9839	0.0368	0.0435
Gastropoda	2.1383	0.4585	0.2476	0.0342
Littorina sp.	0.0352	0.0000	0.0027	0.0000
Thecosomata	0.9735	2.8729	0.0837	1.0535
Egg case	0.0012	0.0000	0.0001	0.0000
Arthropoda				
Cladocera				
Evadne sp.	0.3197	0.1469	0.0387	0.0094
Podon sp.	0.5827	0.0356	0.1202	0.0016
Copepoda				
Copepod general	4.3770	1.4661	0.9399	0.2283
Calanoida				
Acartia clausi	0.0000	0.0060	0.0000	0.0027
Acartia longiremis	7.9265	5.3165	2.5340	1.1766
Acartia tumida	1.6612	0.0735	4.6416	0.0766
Calanus marshallae	0.0170	0.1067	0.2714	0.9212
Calanus sp.	7.9421	12.4219	49.2626	58.5162
Centropages abdominalis	0.8256	0.2166	0.5963	0.0839
Epilabidocera longipedata	0.0012	0.0018	0.0007	0.0044
Epilabidocera sp.	0.0000	0.0006	0.0000	0.0012
Eucalanus bungii	0.1081	0.0623	0.2234	0.1267
Eurytemora sp.	0.0061	0.0000	0.0041	0.0000
Heterorhabdus sp.	0.0000	0.0012	0.0000	0.0005
Metridia okhotensis	0.0000	0.0030	0.0000	0.0273
Metridia pacifica	0.2052	0.9238	0.3699	0.8990
Metridia sp.	0.0000	0.0012	0.0000	0.0014
Microcalanus sp.	0.0023	0.0000	0.0009	0.0000
Neocalanus cristatus	0.0000	0.0436	0.0000	2.0015
Pseudocalanus sp.	32.9174	63.3863	24.7522	28.0898
Tortanus discaudatus	0.0012	0.0000	0.0008	0.0000
Harpacticoida				
Harpacticoid general	0.0668	0.1058	0.0166	0.0379
Tisbe sp.	0.0113	0.0000	0.0088	0.0000
Zaus sp.	0.0622	0.0000	0.0176	0.0000
Cyclopoida				
Oithona similis	2.6132	1.2994	0.2281	0.0582
Oithona spinirostris	0.2272	0.0205	0.0227	0.0010
Oithona sp.	0.0523	0.0000	0.0041	0.0000
Poecilostomatoida				
Oncaea sp.	0.0012	0.0000	0.0001	0.0000
Monstrilloida				
Monstrilla sp.	0.0012	0.0000	0.0009	0.0000
Cirripedia				
Cirriped general	4.8731	0.6206	1.7404	0.0823

Table 28. (Continued)

Organism	Percent Abundance		Percent Biomass	
	Bay	Corridor	Bay	Corridor
Malacostraca				
Isopoda				
Cryptoniscidae	0.0037	0.0000	0.0029	0.0000
Amphipoda				
Parathemisto sp.	0.0049	0.0205	0.0060	0.0095
Hyperiidea	0.0227	0.0277	0.0335	0.0127
Euphausiacea				
Euphausid general	2.8139	0.3162	1.2829	0.3297
Decapoda				
Anomura	0.0285	0.0202	0.0470	0.0460
Brachyura	0.0450	0.0264	0.1103	0.0507
Phoronida				
Phoronid general	0.0355	0.0030	0.0099	0.0001
Bryozoa				
Cyphonautes	13.4078	4.9832	1.1472	0.2203
Echinodermata				
Bipinnaria	0.0034	0.0571	0.0003	0.0025
Pluteus	0.2508	0.0000	0.0371	0.0000
Urochordata				
Fritillaria sp.	6.0048	0.6696	0.7365	0.0296
Oikopleura sp.	3.2702	2.7490	8.1121	5.4744
Chaetognatha				
Sagitta sp.	0.1391	0.1289	0.0974	0.2259
Chordata				
Teleostei	0.0090	0.0296	0.0912	0.0601
Unknown	0.0012	0.0000	0.0001	0.0000
Total	100.0000	100.0000	100.0000	100.0000

Table 29. ANOVA table, ln biomass of pelagic zooplankton and calanoid copepods in Prince William Sound, April-June, 1989; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Total Zooplankton						
o	l(ob)	1	1.96	1.96	0.23	0.657
b	l(ob)	1	74.96	74.96	8.76	0.042
ob	l(ob)	1	2.16	2.16	0.25	0.642
l(ob)		4	34.24	8.56		
t	tl(ob)	4	197.34	49.34	16.84	0.000
to	tl(ob)	4	12.02	3.00	1.03	0.424
tb	tl(ob)	4	7.35	1.84	0.63	0.649
tob	tl(ob)	4	6.08	1.52	0.52	0.723
tl(ob)		16	46.86	2.92		
Error		79	12.72	0.16		
Total		118	395.74			
Total Calanoid Copepods						
o	l(ob)	1	1.00	1.00	0.07	0.807
b	l(ob)	1	97.38	97.38	6.58	0.062
ob	l(ob)	1	0.39	0.39	0.03	0.878
l(ob)		4	59.17	14.79		
t	tl(ob)	4	295.16	73.79	19.06	0.000
to	tl(ob)	4	25.71	6.42	1.66	0.208
tb	tl(ob)	4	9.79	2.44	0.63	0.647
tob	tl(ob)	4	3.57	0.89	0.23	0.917
tl(ob)		16	61.93	3.87		
Error		79	17.05	0.21		
Total		118	571.19			

Table 30. ANOVA table, ln biomass of small (<2.6 mm total length), and large (>2.5 mm total length) calanoid copepods in Prince William Sound, April-June, 1989. Species classified as large were Calanus marshallae; Calanus sp.; Eucalanus bungii; Heterorhabdus sp.; Neocalanus cristatus; Metridia okhotensis; and adult female Metridia pacifica. All other calanoids identified in the samples were classified as small; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Small Calanoid Copepods						
o	l(ob)	1	0.05	0.05	0.01	0.938
b	l(ob)	1	59.13	59.13	7.45	0.053
ob	l(ob)	1	3.17	3.17	0.40	0.562
l(ob)		4	31.76	7.94		
t	tl(ob)	4	175.96	43.99	16.80	0.000
to	tl(ob)	4	23.55	5.88	2.25	0.109
tb	tl(ob)	4	9.75	2.43	0.93	0.471
tob	tl(ob)	4	7.99	2.00	0.76	0.564
tl(ob)		16	41.90	2.61		
Error		79	14.36	0.18		
Total		118	367.67			
Large Calanoid Copepods						
o	l(ob)	1	35.69	35.69	0.54	0.504
b	l(ob)	1	240.69	240.69	3.63	0.129
ob	l(ob)	1	1.48	1.48	0.02	0.888
l(ob)		4	265.22	66.30		
t	tl(ob)	4	1138.78	295.95	22.86	0.000
to	tl(ob)	4	47.16	11.79	0.91	0.481
tb	tl(ob)	4	39.20	9.80	0.76	0.568
tob	tl(ob)	4	24.89	6.22	0.48	0.750
tl(ob)		16	207.10	12.94		
Error		79	156.54	1.98		
Total		118	2201.79			

Table 31. Number of species (No.) and standard deviation (sd) of pelagic zooplankton by time period, oil, bay/corridor in Prince William Sound, 1989.

	Bay		Corridor	
	Non-oiled	Oiled	Non-oiled	Oiled
Time period	No. (sd)	No. (sd)	No. (sd)	No. (sd)
Late April	16.7 (1.8)	15.5 (2.5)	13.0 (3.1)	16.3 (2.7)
Early May	12.8 (3.3)	17.7 (3.0)	13.7 (2.0)	9.8 (0.7)
Late May	16.7 (2.1)	16.3 (2.0)	14.7 (2.0)	12.2 (1.3)
Early June	13.8 (2.6)	15.8 (2.3)	14.0 (2.0)	16.7 (3.7)
Late June	17.7 (2.2)	16.0 (1.9)	16.5 (2.7)	17.0 (2.0)

Table 32. Abundance (organisms/m^3) of epibenthos by habitat collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1989, in the systematic epigenthic sled samples. Habitat designations are LG (low gradient), MG (medium gradient) and SG (steep gradient).

Time Period	Non-oiled locations			Oiled locations		
	LG	MG	SG	LG	MG	SG
	McClure Bay			Herring Bay		
Late April	21	3613	127	1657	167	415
Early May	75	217	85	378	301	831
Late May	26	51	--	250	73	1093
Early June	42	18	11	725	2390	1071
Late June	613	997	9	1882	--	414
April-June	155	979	58	978	733	765
	Long Bay			Snug Harbor		
Late April	1122	1333	169	361	197	663
Early May	169	1637	22	11027	815	106
Late May	311	55	6	229	237	63
Early June	4421	2999	242	1349	1162	150
Late June	713	125	146	1290	--	66
April-June	1347	1230	117	2851	603	210
	Culross Passage			Prince of Wales Passage		
Late April	66	666	171	1173	5573	165
Early May	278	1746	114	1642	527	119
Late May	710	6367	262	6861	4066	319
Early June	35	--	454	1397	211	54
Late June	55	--	311	2439	578	31
April-June	229	2926	262	2702	2191	138
	Wells Passage			Knight Island Passage		
Late April	3066	207	253	205	725	290
Early May	853	613	170	1759	1986	95
Late May	1621	2490	71	7621	4967	1419
Early June	327	746	3	--	4816	709
Late June	1882	171	49	197	--	389
April-June	1550	845	109	2446	3124	580

Table 33. Biomass (organisms/m^3) of epibenthos by habitat collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1989, in the systematic epigenthic sled samples. Habitat designations are LG (low gradient), MG (medium gradient) and SG (steep gradient).

Time Period	Non-oiled locations			Oiled locations		
	LG	MG	SG	LG	MG	SG
	McClure Bay			Herring Bay		
Late April	0	140	12	168	6	58
Early May	2	5	10	15	113	34
Late May	1	1	--	9	740	4957
Early June	1	1	1	237	684	253
Late June	5	21	0	842	--	83
April-June	2	33	4	254	386	1077
	Long Bay			Snug Harbor		
Late April	32	43	4	74	28	115
Early May	9	37	4	422	40	38
Late May	15	1	0	214	12	4
Early June	84	55	4	43	55	4
Late June	12	1	2	39	--	16
April-June	30	27	3	158	34	35
	Culross Passage			Prince of Wales Passage		
Late April	1	16	4	29	344	14
Early May	17	144	7	115	32	8
Late May	31	465	23	552	541	43
Early June	1	--	8	50	7	6
Late June	1	--	4	201	28	1
April-June	10	208	9	189	190	14
	Wells Passage			Knight Island Passage		
Late April	259	6	33	33	50	46
Early May	77	57	11	107	151	14
Late May	58	94	4	1120	395	142
Early June	8	22	0	--	132	40
Late June	70	7	3	6	--	31
April-June	94	37	10	317	182	55

Table 34. Percent abundance and biomass of organisms of epibenthic and pelagic origin captured by the epibenthic sled in Prince William Sound from April to June, 1989. Whether the organism is a potential prey item of juvenile salmon is also indicated.

Organism	Percent Abundance	Percent Biomass	Prey Item
EPIBENTHIC ORIGIN			
Cnidaria			
Hydroida	0.4424	0.3036	no
Platyhelminthes			
Turbellaria	0.1093	0.0131	no
Nematoda			
Nematode general	2.3984	0.0961	no
Annelida			
Oligochaeta	0.0254	0.0081	no
Mollusca			
Mollusk general	0.0163	0.0519	no
Mytilus sp.	0.0280	0.0444	no
Arthropoda			
Halacaridae	0.6315	0.0432	yes
Nematocera	0.0036	0.0063	yes
Chironomidae	0.3488	0.2387	yes
Collembola	0.0066	0.0004	yes
Copepoda			
Halicyclops sp.	0.0005	0.0000	no
Harpacticoida			
Harpacticoid general	0.4149	0.0081	yes
Alteutha sp.	0.0084	0.0000	no
Amonardia sp.	0.1354	0.0224	yes
Amphiascoides sp.	0.0168	0.0000	yes
Amphiascopsis sp.	0.3020	0.0709	no
Amphiascus sp.	0.2863	0.0061	no
Danielssenia sp.	0.0076	0.0000	yes
Diosaccus sp.	5.8165	1.2962	yes
Harpacticus sp.	13.9517	4.0891	yes
Mesochra sp.	0.0331	0.0000	yes
Microarthridion sp.	0.0010	0.0000	yes
Paralteutha sp.	0.0056	0.0046	no
Paramphiascella sp.	0.1083	0.0327	no
Parastenhelia sp.	0.1088	0.0000	yes
Porcellidium sp.	0.0041	0.0000	no
Pseudonychocamptus sp.	0.0158	0.0004	no
Robertsonia sp.	0.0341	0.0010	yes
Scutellidium sp.	0.6739	0.0796	yes
Stenhelia sp.	0.0036	0.0000	yes
Tisbe sp.	11.7791	1.7109	yes
Zaus sp.	0.5030	0.0316	yes

Table 34. (Continued)

Organism	Percent Abundance	Percent Biomass	Prey Item
Ameiridae	0.0557	0.0000	yes
Ameira sp.	0.0203	0.0000	no
Cletodidae	0.0005	0.0000	yes
Huntemannia sp.	0.0051	0.0000	yes
Ectinosomatidae	0.1807	0.0017	yes
Microsetella sp.	0.0010	0.0000	no
Laophontidae	0.7639	0.0183	yes
Echinolaophonte sp.	0.2464	0.0190	yes
Heterolaophonte sp.	2.6611	0.2087	yes
Laophonte sp.	0.0076	0.0006	yes
Laophontodes sp.	0.0158	0.0000	no
Paralaophonte	1.3371	0.0694	yes
Tegastidae	0.0086	0.0000	no
Tegastes sp.	0.0015	0.0000	no
Thalestridae	0.0061	0.0008	yes
Dactylopodia sp.	0.8264	0.0648	yes
Diarthrodes sp.	0.0102	0.0000	yes
Idomene sp.	0.0107	0.0000	no
Paradactylopodia sp.	0.0633	0.0002	yes
Parathalestris sp.	0.1481	0.0607	yes
Rhyncothalestris sp.	0.0010	0.0000	no
Thalestris sp.	0.0025	0.0002	no
Ostracoda			
Podocopa	1.1925	0.1581	yes
Malacostraca			
Cumella sp.	0.2609	0.1737	yes
Mysidacea	0.0020	0.0008	yes
Euphausiacea	0.1142	0.0088	yes
Isopoda			
Epicaridea	0.0168	0.0006	no
Gnorimosphaeroma sp.	0.0005	0.0006	no
Ianiropsis sp.	0.0041	0.0000	no
Munna sp.	0.0005	0.0002	no
Amphipoda			
Gammaridea			
Gammarid general	0.1141	0.0265	yes
Allorchestes sp.	0.0290	0.1113	yes
Ischyrocerus sp.	0.0651	0.0156	yes
Megamphopus sp.	0.0112	0.0029	yes
Paramoera sp.	0.0824	0.2414	yes
Pleustes sp.	0.0005	0.0021	yes
Pontogeneia sp.	0.0168	0.0605	yes
Synchelidium sp.	0.0102	0.0000	yes
Ampithoidae	0.0071	0.0158	yes
Ampithoe sp.	0.0092	0.0869	yes

Table 34. (Continued)

Organism	Percent Abundance	Percent Biomass	Prey Item
Calliopiidae	0.0224	0.0129	yes
Calliopius sp.	0.0165	0.0710	yes
Paracalliopiella sp.	0.2809	0.3907	yes
Gammaridae	0.0163	0.0077	yes
Stenothoidae	0.0005	0.0000	yes
Decapoda			
Brachyura	0.0005	0.0065	yes
Cancer sp.	0.0010	0.0171	yes
Pleocyemata-Caridea	0.0112	0.0208	no
Heptacarpus sp.	0.0961	13.5913	no
Pandalus sp.	0.0005	0.7248	no
Paguridae	0.0005	0.0033	no
Echinodermata	0.0081	0.0000	no
Epibenthic subtotal	46.9859	24.3557	
PELAGIC ORIGIN			
Cnidaria			
Scyphozoa	0.0025	0.0025	no
Rotifera	0.0813	0.0000	no
Annelida			
Polychaeta	0.5598	0.3075	yes
Polynoidae	0.0439	0.0127	yes
Mollusca			
Bivalvia	0.8665	0.4829	yes
Gastropoda	0.3758	0.0934	yes
Archaeogastropoda	0.0910	0.3824	yes
Mesogastropoda	0.7292	1.1876	yes
Lacuna sp.	0.0066	0.2585	yes
Littorina sp.	4.6362	0.5765	yes
Opisthobranchia	0.0051	0.0042	yes
Gymnosomata	0.0219	0.1165	no
Thecosomata	0.1074	0.0769	yes
Limacina sp.	0.1135	1.7372	yes
Arthropoda			
Cladocera			
Evadne sp.	0.1213	0.0052	yes
Podon sp.	0.0712	0.0019	yes
Copepoda			
Calanoida			
Calanoid general	2.1776	0.2326	yes
Acartia sp.	0.8958	0.1444	yes
Centropages sp.	0.2036	0.0434	yes
Epilabidocera sp.	0.0020	0.0004	yes
Eucalanus sp.	0.0071	0.0071	yes

Table 34. (Continued)

Organism	Percent Abundance	Percent Biomass	Prey Item
Eurytemora sp.	7.5643	0.7931	yes
Metridia sp.	0.1256	0.0813	yes
Neocalanus sp.	8.3888	53.3785	yes
Paracalanus sp.	0.0073	0.0000	yes
Pseudocalanus sp.	15.1919	5.1085	yes
Calanidae	0.9774	0.3524	yes
Calanus sp.	2.9014	8.2628	yes
Stephidae	0.0005	0.0000	yes
Cyclopoida			
Oithona sp.	1.4568	0.0388	no
Poecilostomatoida	0.4321	0.0207	no
Oncaea sp.	0.0005	0.0000	no
Monstrilloida	0.1541	0.0125	yes
Cirripedia			
Balanomorpha	2.5929	1.2285	yes
Malacostraca			
Amphipoda			
Caprellidea	0.0254	0.0088	yes
Decapoda			
Brachyura	0.0056	0.0044	yes
Bryozoa			
Gymnolaemata	1.5659	0.0423	yes
Urochordata			
Larvacea	0.0041	0.0000	yes
Fritillaria sp.	0.1246	0.0025	yes
Oikopleura sp.	0.3244	0.3522	yes
Chaetognatha			
Chaetognath general	0.0320	0.0113	yes
Chordata			
Teleostei	0.0193	0.2719	yes
Pelagic subtotal	53.0141	75.6443	
Total	100.0000	100.0000	

Table 35. ANOVA table, ln biomass of epibenthic harpacticoid copepods captured in the systematic epibenthic sled samples in Prince William Sound, 1989; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(ob)	1	125.169	125.17	12.25	0.025
b	l(ob)	1	71.689	71.69	7.02	0.057
ob	l(ob)	1	12.824	12.82	1.25	0.325
l(ob)		4	40.877	10.22		
t	tl(ob)	4	35.770	8.94	2.74	0.066
to	tl(ob)	4	19.303	4.83	1.48	0.256
tb	tl(ob)	4	86.248	21.56	6.60	0.002
tob	tl(ob)	4	5.569	1.39	0.43	0.788
tl(ob)		16	52.296	3.27		
h	hl(ob)	2	93.146	46.57	6.01	0.025
oh	hl(ob)	2	19.355	9.68	1.25	0.337
bh	hl(ob)	2	0.137	0.07	0.01	0.991
obh	hl(ob)	2	8.586	4.29	0.55	0.595
hl(ob)		8	61.993	7.75		

Table 36. ANOVA table, ln biomass of epibenthic harpacticoid copepods captured in the tidal transect epibenthic sled samples in Prince William Sound, April-June, 1989; t = time, o = oil, h = habitat, l = location, r = tide level, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(o)	1	377.8	377.8	3.29	0.211
l(o)		2	229.4	114.7		
t	tl(o)	3	55.2	18.4	4.07	0.068
to	tl(o)	3	7.8	2.6	0.57	0.652
tl(o)		6	27.1	4.5		
h	hl(o)	2	46.1	23.0	5.67	0.068
oh	hl(o)	2	4.1	2.0	0.50	0.640
hl(o)		4	16.2	4.1		
th	thl(o)	6	70.9	11.8	1.78	0.187
toh	thl(o)	6	22.6	3.8	0.56	0.751
thl(o)		12	79.9	6.7		
r	rl(o)	2	63.5	31.7	3.84	0.117
or	rl(o)	2	20.0	10.0	1.21	0.387
rl(o)		4	33.0	8.3		
tr	trl(o)	6	14.4	2.4	0.64	0.699
tor	trl(o)	6	8.1	1.3	0.36	0.891
trl(o)		12	45.3	3.8		
hr	rhl(o)	4	37.5	9.4	2.49	0.126
ohr	rhl(o)	4	28.5	7.1	1.90	0.205
rhl(o)		8	30.1	3.7		
thr	thrl(o)	12	26.5	2.2	0.65	0.777
tohr	thrl(o)	12	22.2	1.8	0.54	0.863
thrl(o)		24	81.4	3.4		

Table 37. ANOVA table, number of epibenthic taxa captured in the systematic epibenthic sled samples in Prince William Sound, June-April, 1989; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(ob)	1	197.72	197.7	1.34	0.312
b	l(ob)	1	8.35	8.347	0.06	0.824
ob	l(ob)	1	181.47	181.5	1.23	0.330
l(ob)		4	591.85	148.0		
t	tl(ob)	4	575.12	143.8	9.71	0.000
to	tl(ob)	4	182.07	45.52	3.08	0.047
tb	tl(ob)	4	99.39	24.85	1.68	0.204
tob	tl(ob)	4	127.15	31.79	2.15	0.122
tl(ob)		16	236.82	14.80		
h	hl(ob)	2	478.21	239.1	7.37	0.015
oh	hl(ob)	2	7.96	3.982	0.12	0.886
bh	hl(ob)	2	27.83	13.92	0.43	0.665
obh	hl(ob)	2	48.71	24.36	0.75	0.503
hl(ob)		8	259.71	32.46		

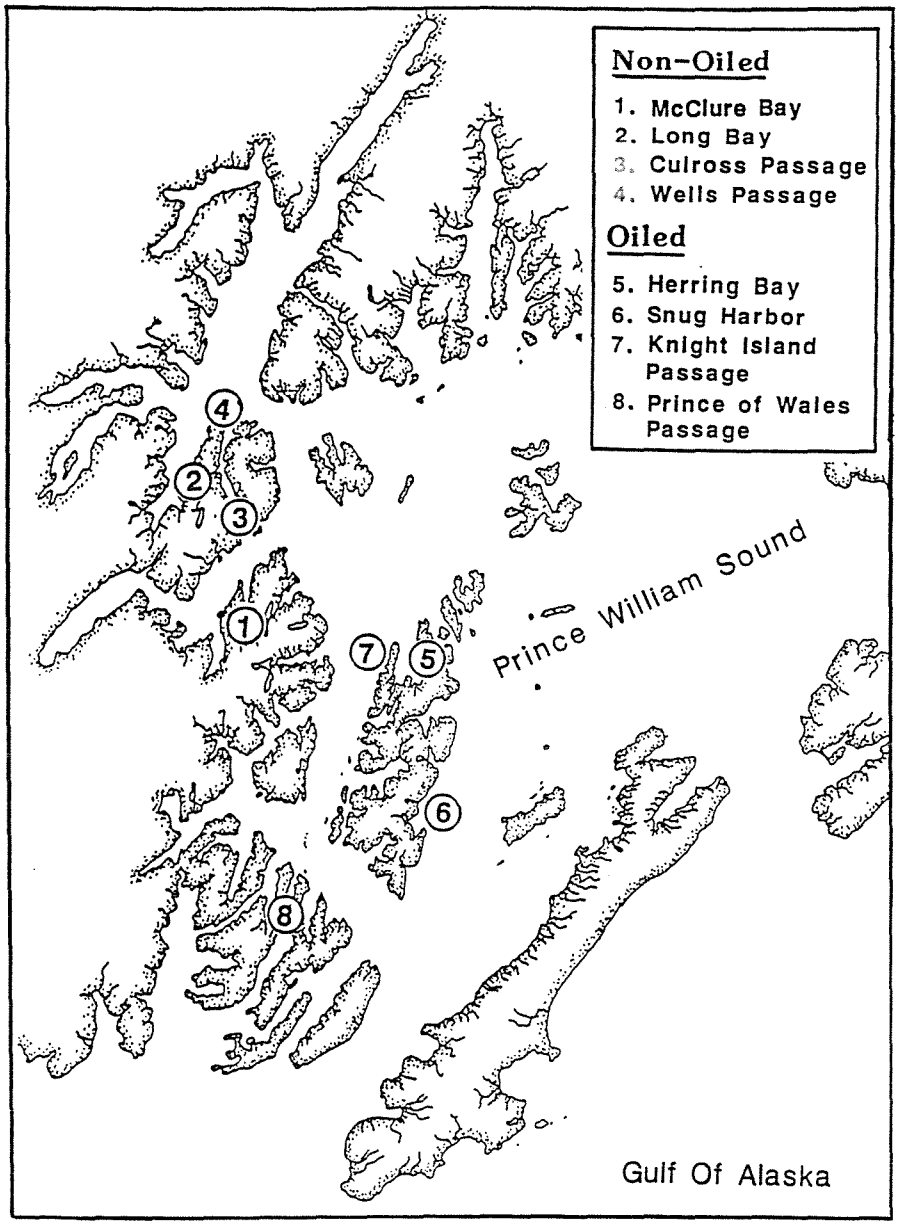

Fig. 1.--Locations of oiled and non-oiled sampling locations for NMFS component of NRDA study F/S-4. Locations 1, 2, 5 and 6 were classified as embayments; locations 3, 4, 7 and 8 were classified as corridors.

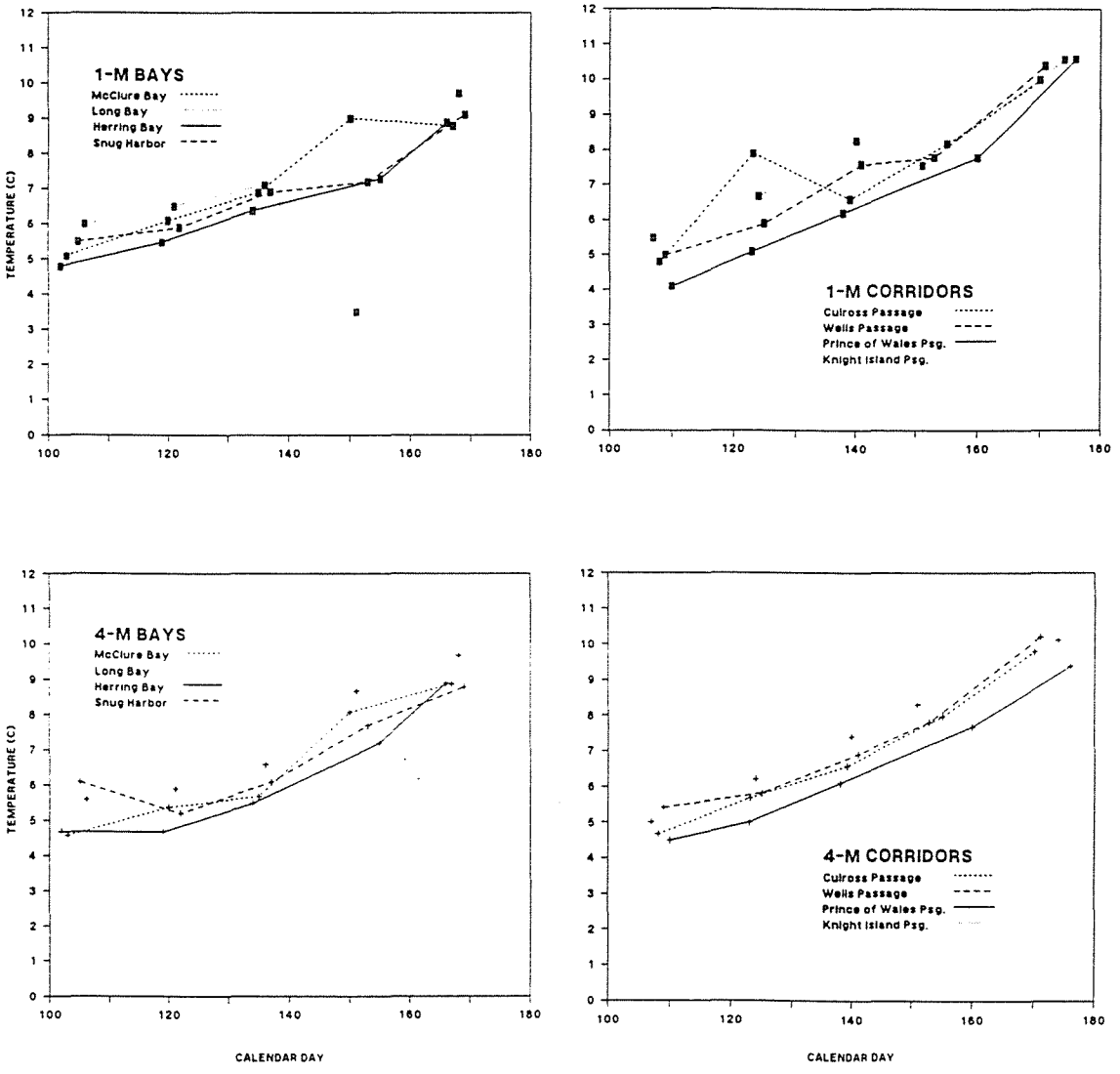

Figure 2. Temperatures at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1989. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

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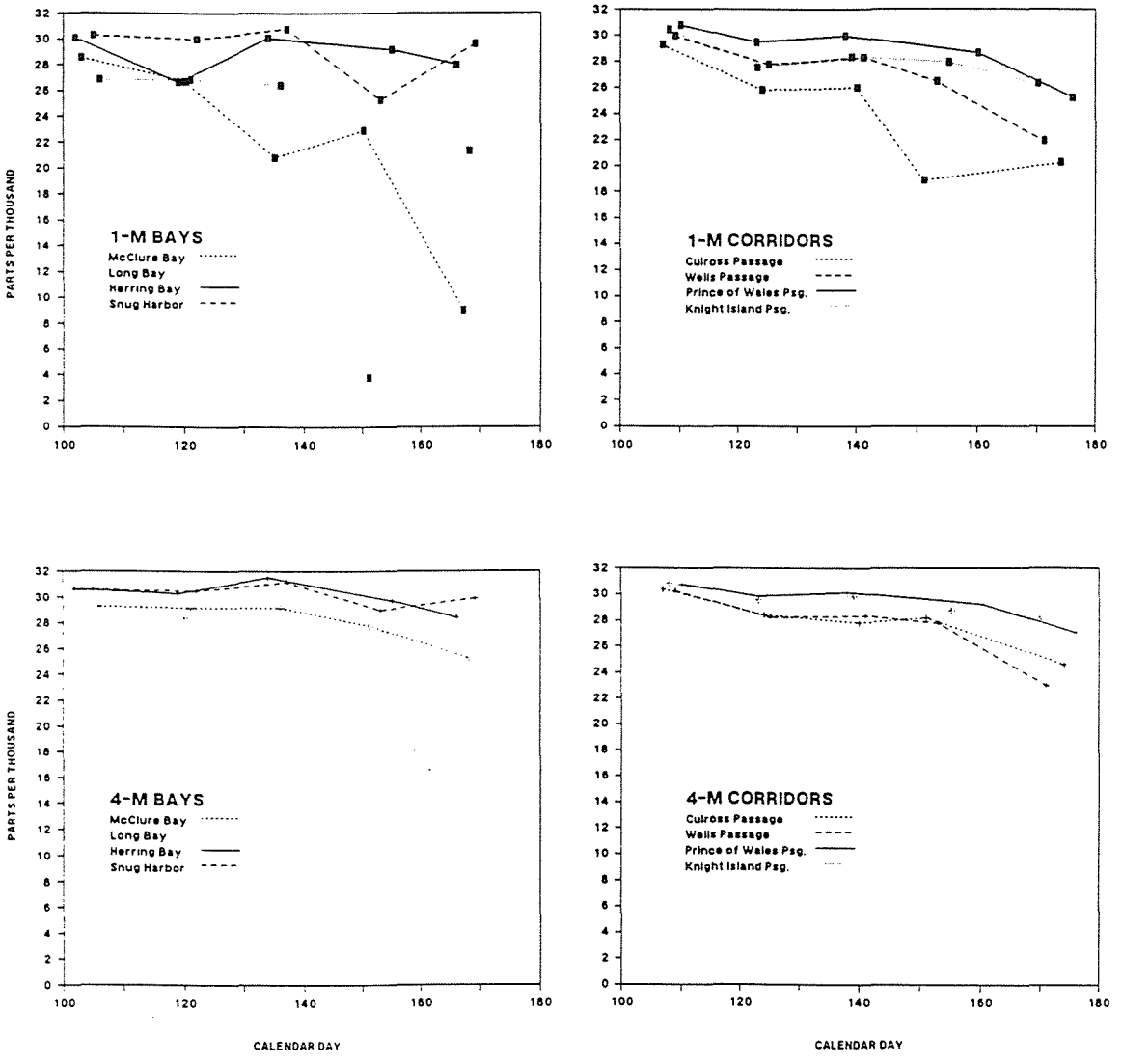

Figure 3. Salinities at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1989. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

File: SALINALL.DRW

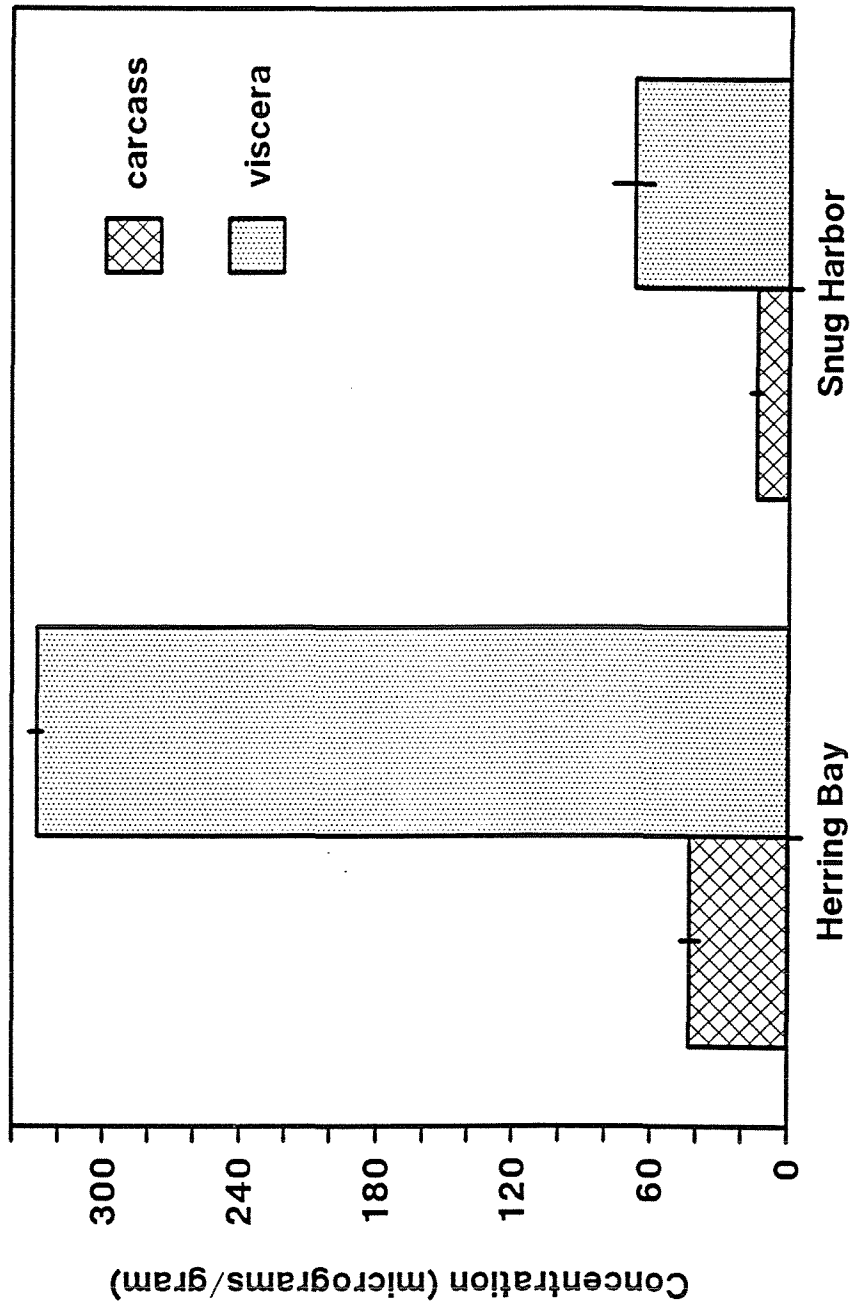

Figure 4. Concentrations of hydrocarbons in pink salmon fry carcasses compared to concentrations in viscera. Error bars are ±1 standard error.

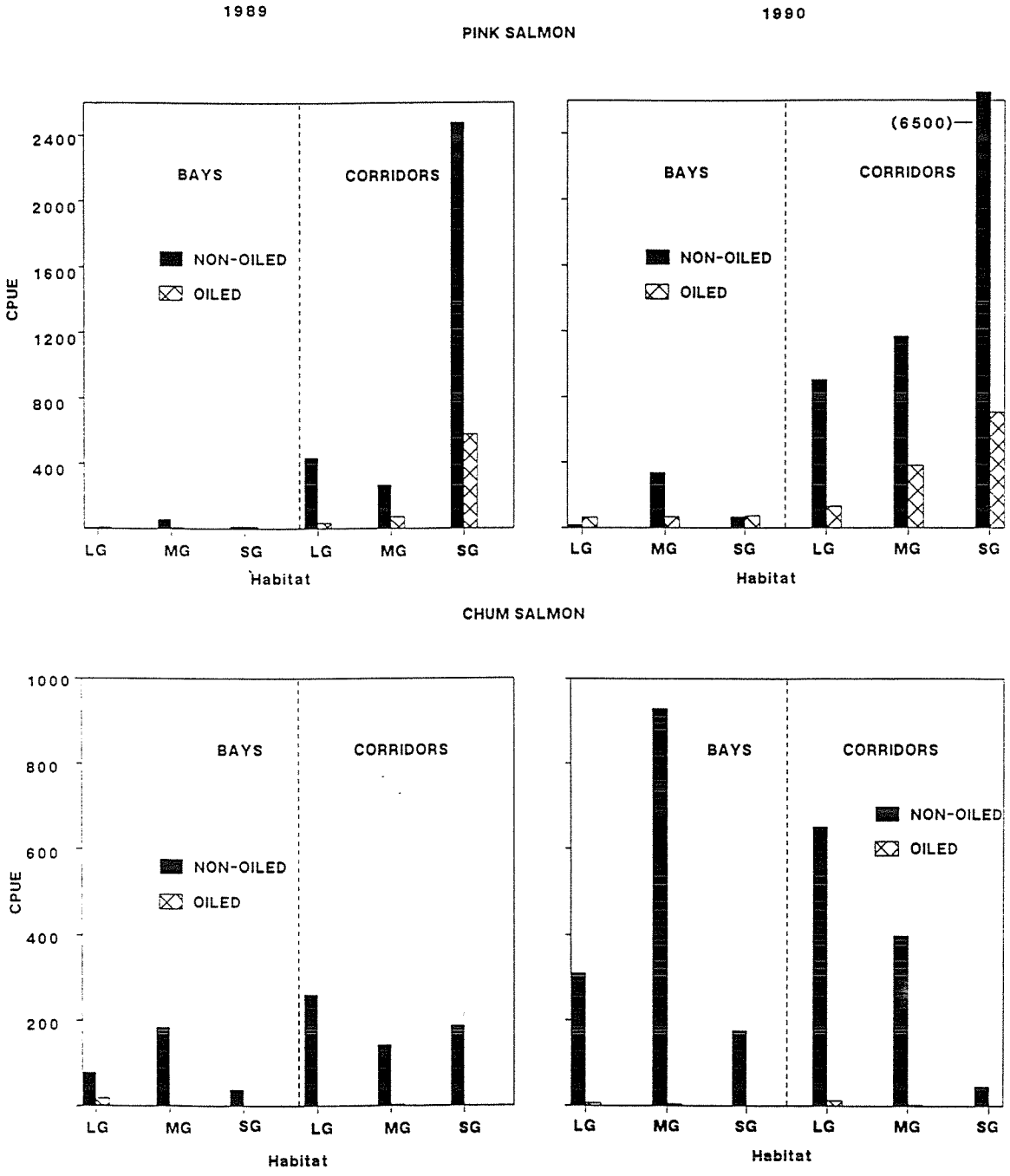

Figure 5. Systematic catch of juvenile pink and chum salmon by habitat type for oiled and non-oiled bays and corridors in Prince William Sound in 1989 and 1990. LG = low gradient; MG = medium gradient; SG = steep gradient.

REPORT90/ABNDALL

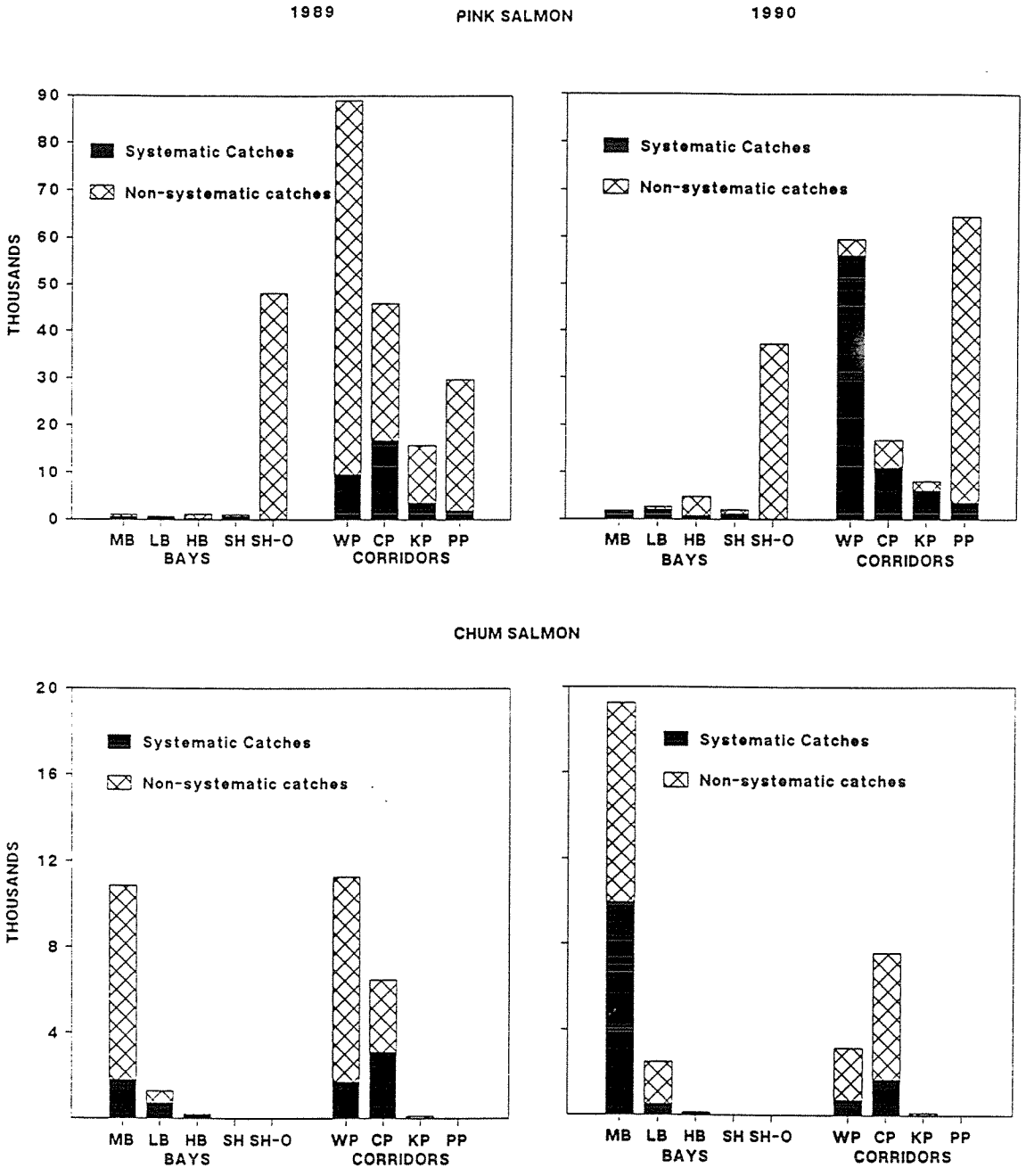

Figure 6. Total catch of juvenile pink and chum salmon at bay and corridor sampling locations in Prince William Sound in 1989 and 1990. MB = McClure Bay; LB = Long Bay; HB = Herring Bay; SH = Snug Harbor; SH-O = Snug Harbor, outer bay; WP = Wells Passage; CP = Culross Passage; KP = Knight Island Passage; PP = Prince of Wales Passage.

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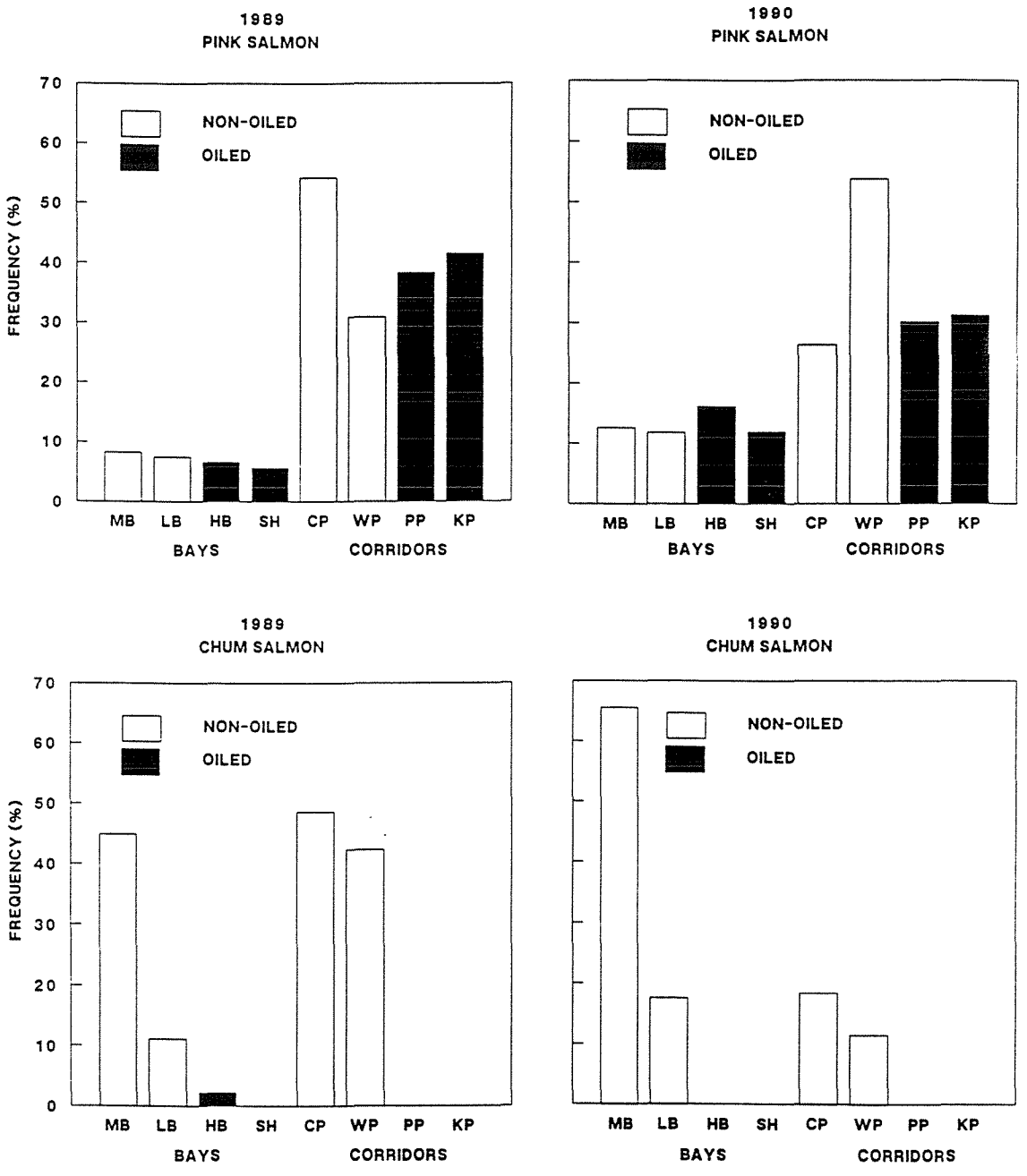

Figure 7. Frequency of large (> 100) catches of juvenile pink and chum salmon in oiled and non-oiled sampling locations in Prince William Sound in 1989 and 1990. MB = McClure Bay; LB = Long Bay; HB = Herring Bay; SH = Snug Harbor (inner bay); CP = Culross Passage; WP = Wells Passage; PP = Prince of Wales Passage; KP = Knight Island Passage.

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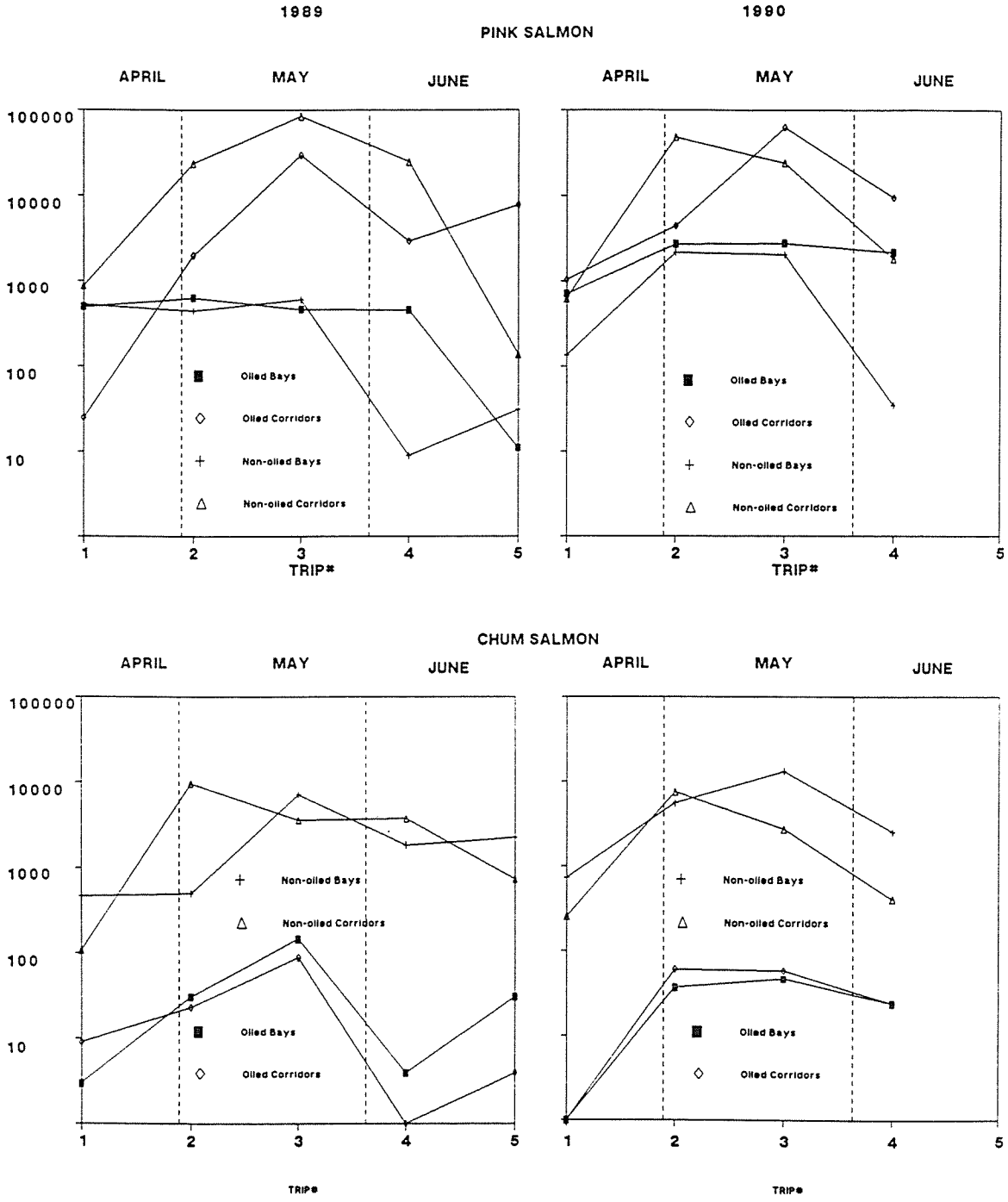

Figure 8. Numbers (in logarithmic scale) of juvenile pink and chum salmon captured by sampling period in Prince William Sound in April-June, 1989 and 1990. Fish captured in outer Snug Harbor are not included in the figure.

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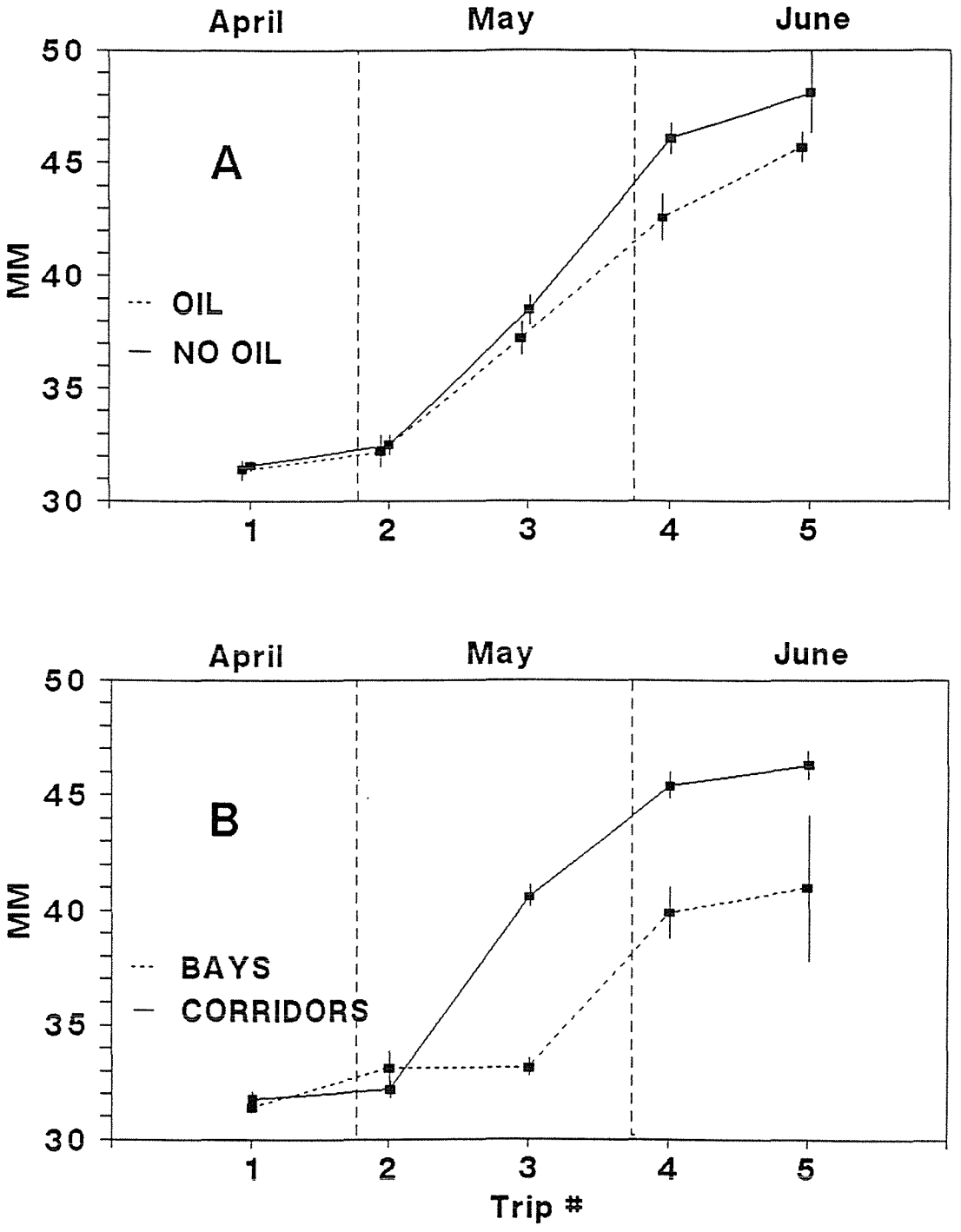

Figure 9. Mean fork length of juvenile pink salmon captured in Prince William Sound in 1989, pooled by oiled and non-oiled areas (A) and by bays and corridors (B). Vertical bars are 95% confidence intervals of the means. REPORT90/LPL89.DRW

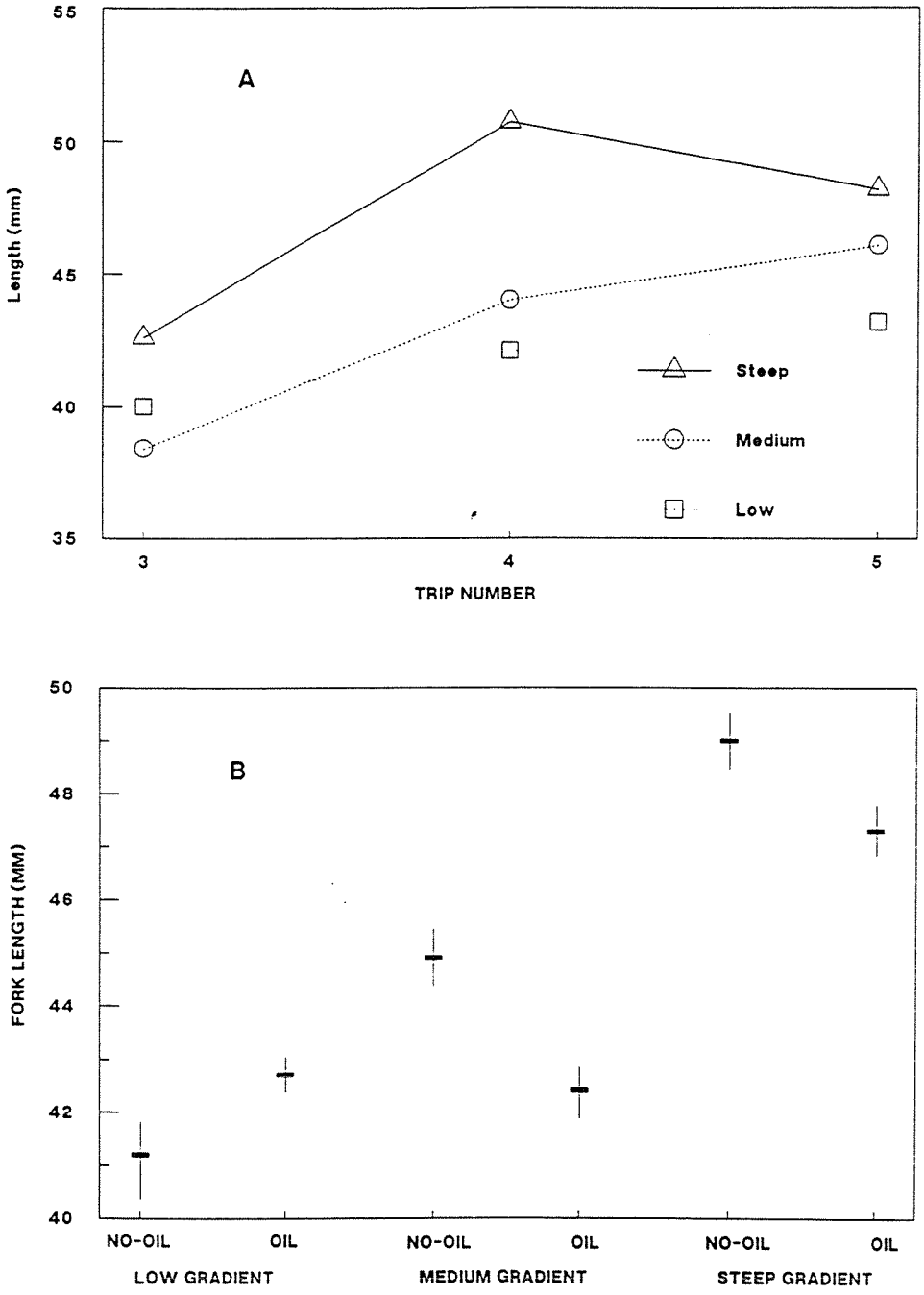

Figure 10. Size of juvenile pink salmon captured at corridor locations in Prince William Sound during sampling trips 3-5, 1989. The upper graph (A) (A) shows the change in mean fork length over time for three different near-shore habitats. The lower figure (B) shows the mean fork length (horizontal lines) and 95 % CI (vertical lines) for the three habitat types in oiled and non-oiled areas.

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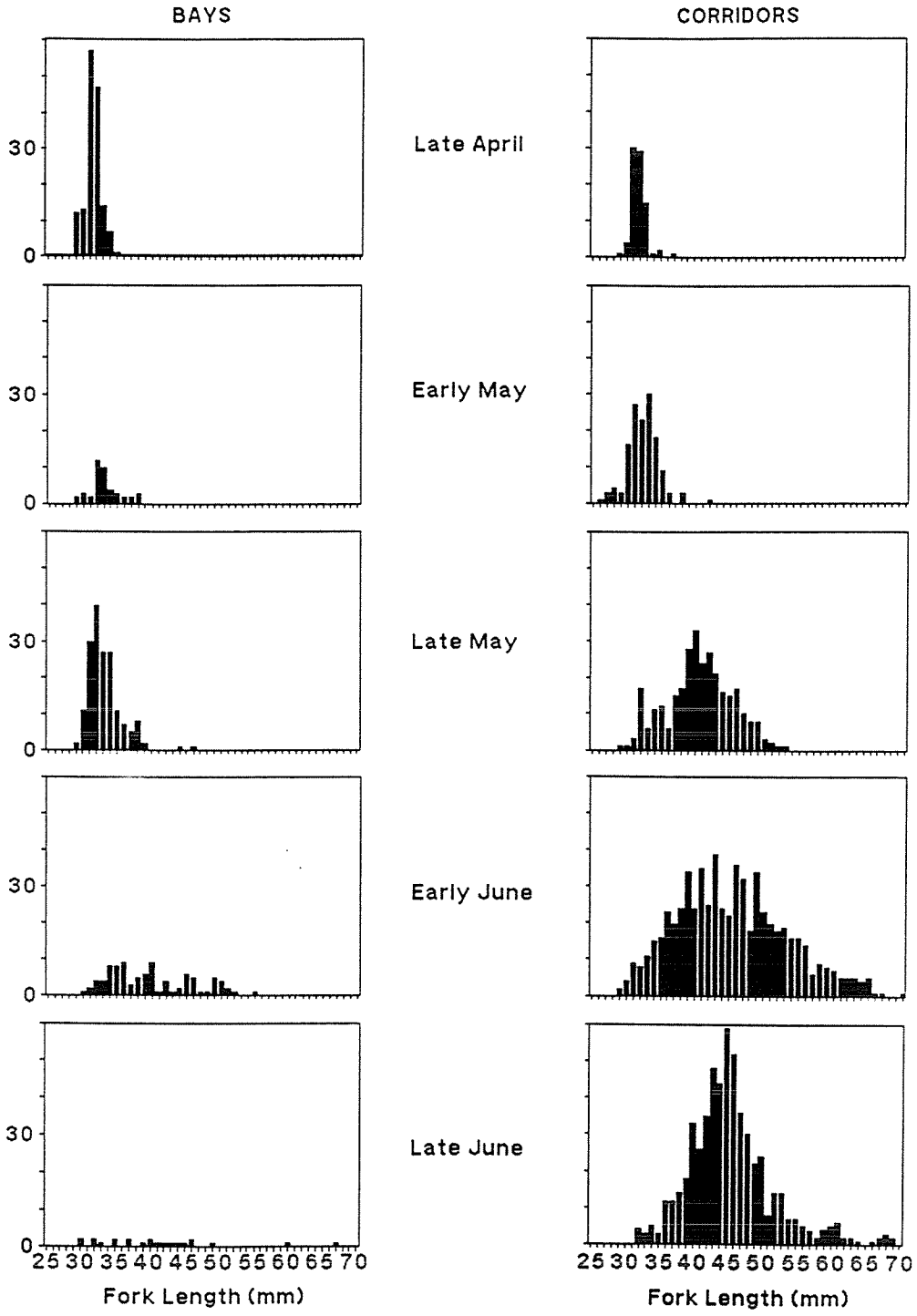

Figure 11. Histograms of fork lengths of juvenile pink salmon captured in Prince William Sound in 1989.

SUMTABLE\HISALLP1,P2

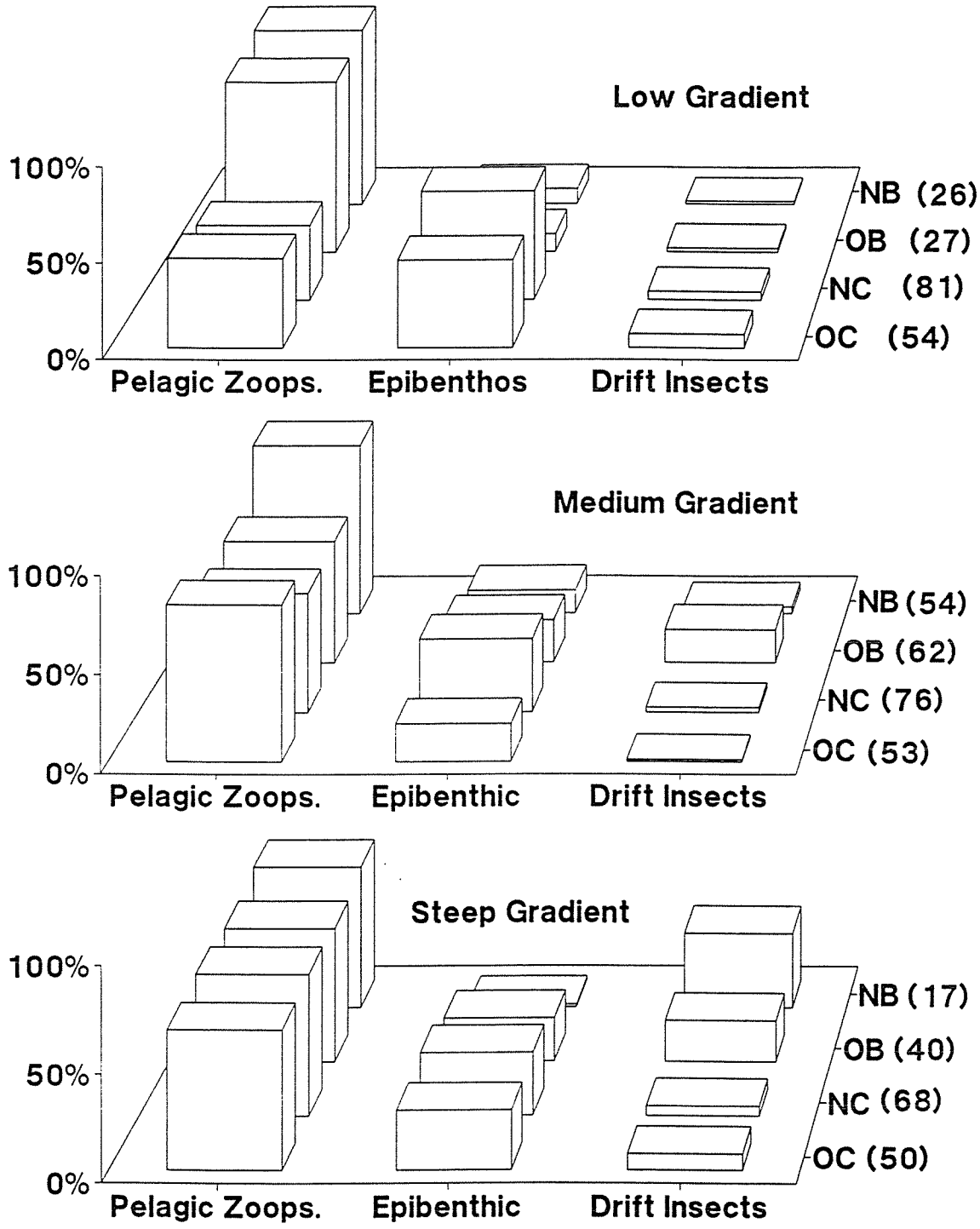

Figure 12. Prey percent dry weight from 608 pink salmon fry stomachs collected in Prince William Sound, Alaska 1989. NB = Non-oiled Bays, OB = Oiled Bays, NC = Non-oiled Corridors, OC = Oiled Corridors. Sample sizes are indicated in parentheses.

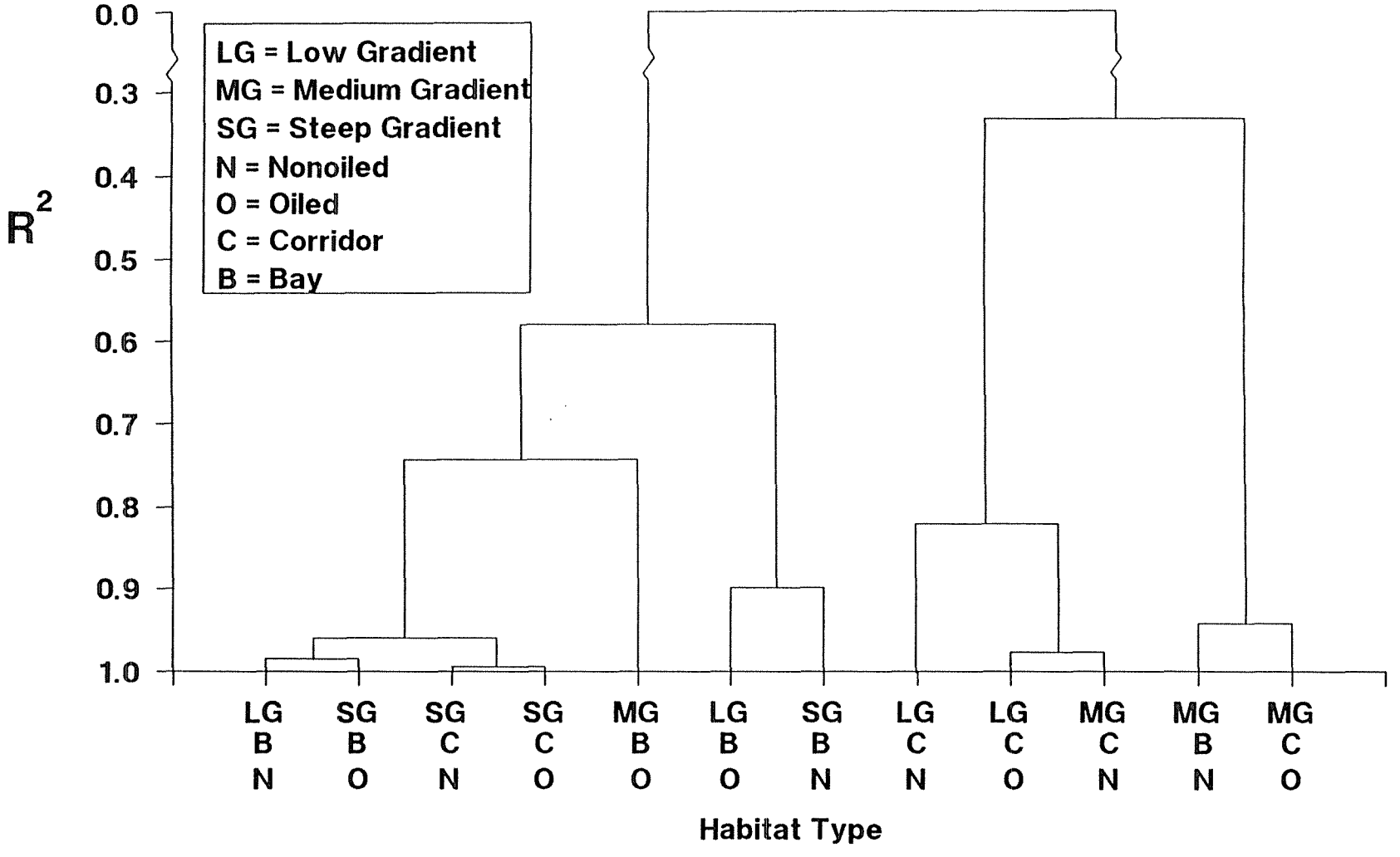

Figure 13. Cluster analysis of pink salmon fry diets standardized by fish weight at twelve habitat types in Prince William Sound, Alaska, 1989.

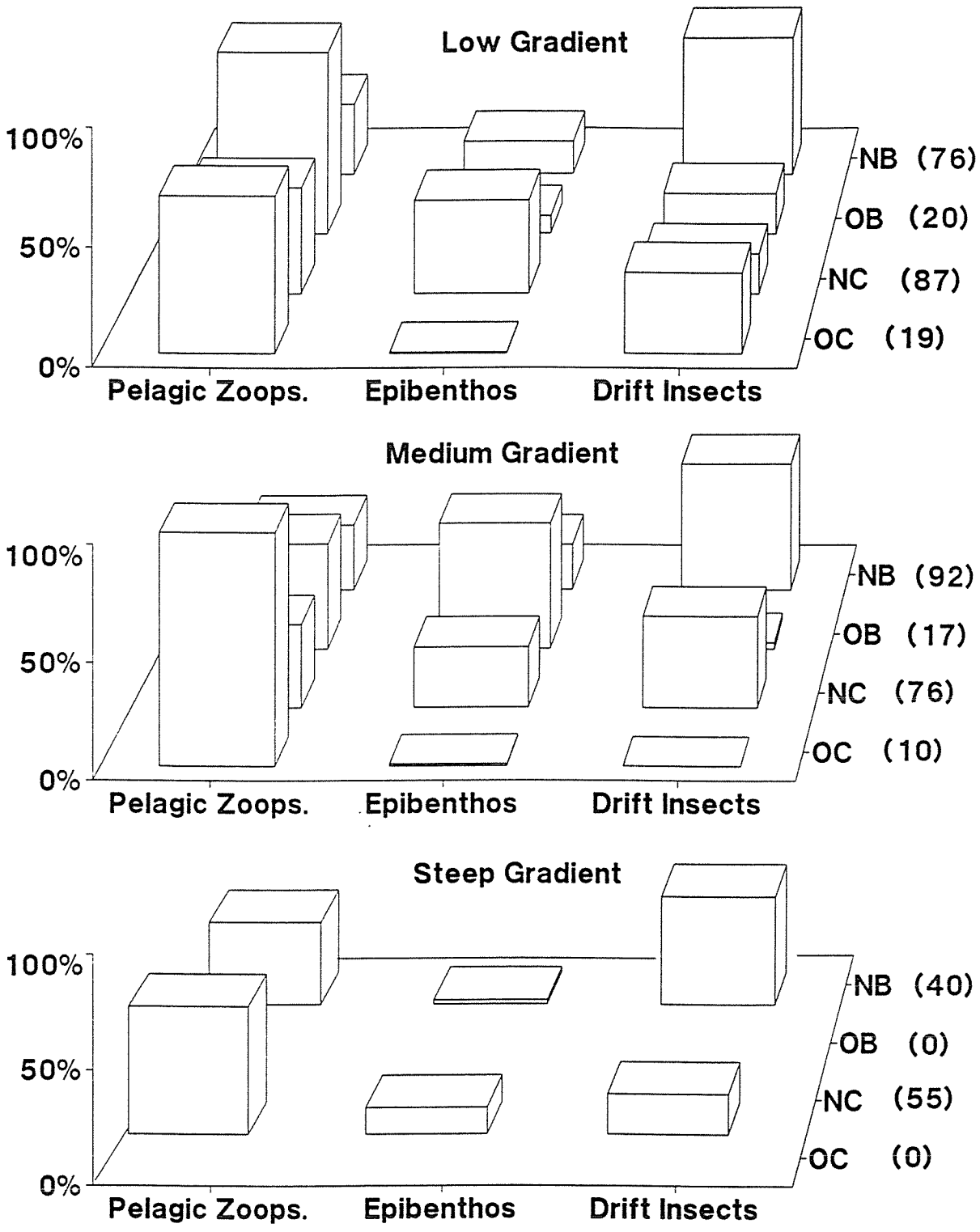

Figure 14. Prey percent dry weight from 493 chum salmon fry stomachs collected in Prince William Sound, Alaska 1989. NB = Non-oiled Bays, OB = Oiled Bays, NC = Non-oiled Corridors, OC = Oiled Corridors. Sample size is indicated in parentheses.

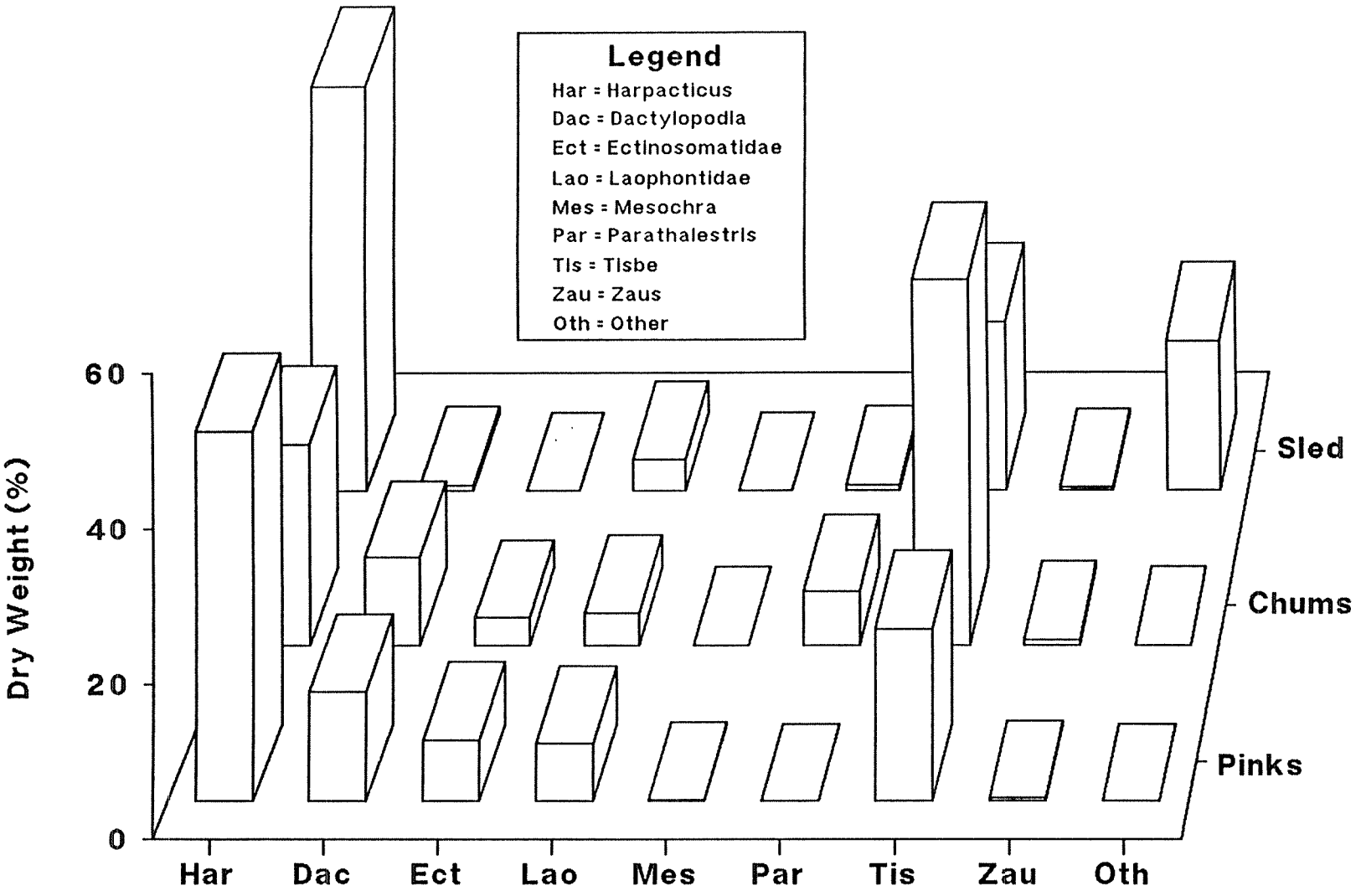

Figure 15. Harpacticoid composition of juvenile salmon diets and epibenthic environment in all locations of Prince William Sound, 1989.

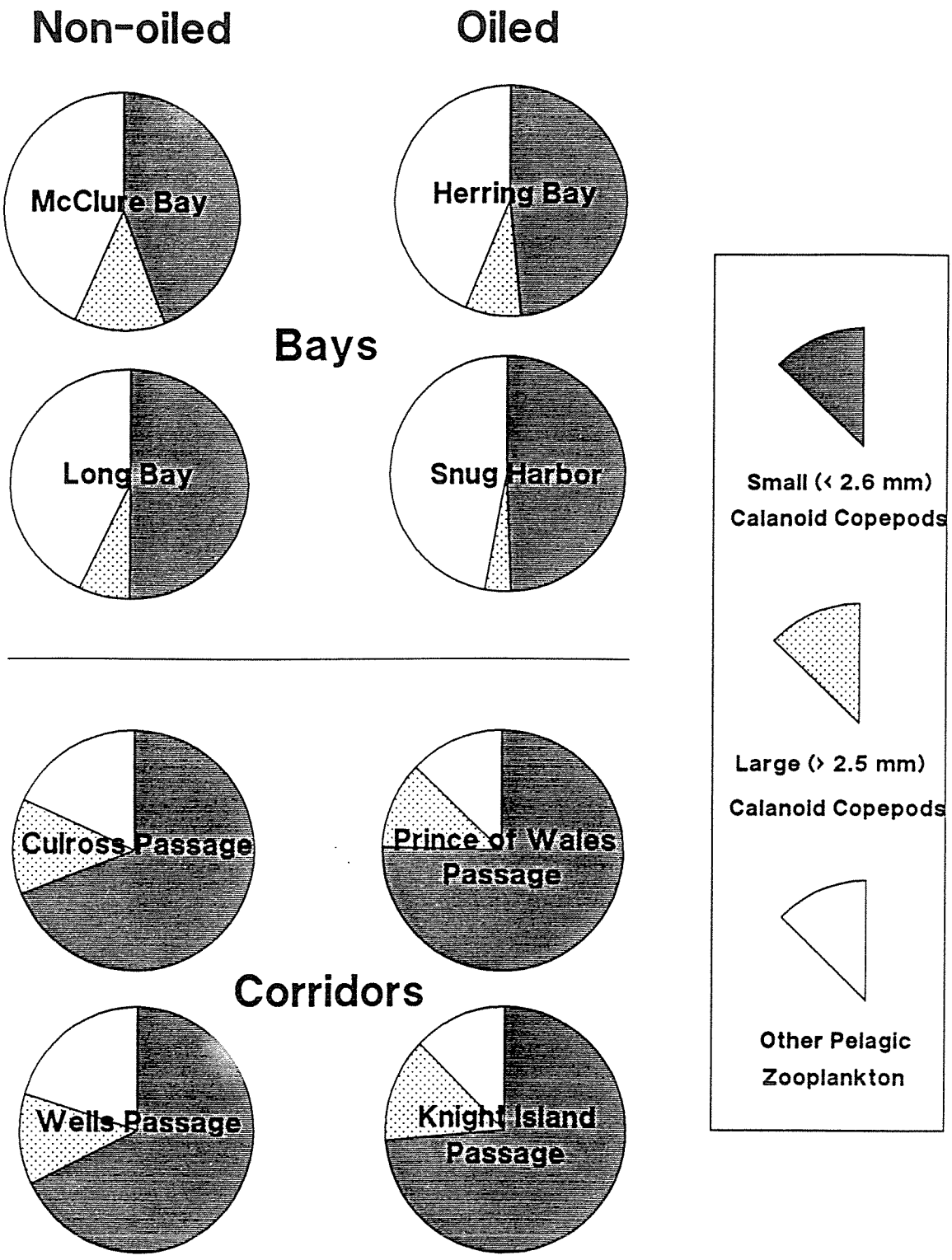

Figure 16. Relative abundance of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

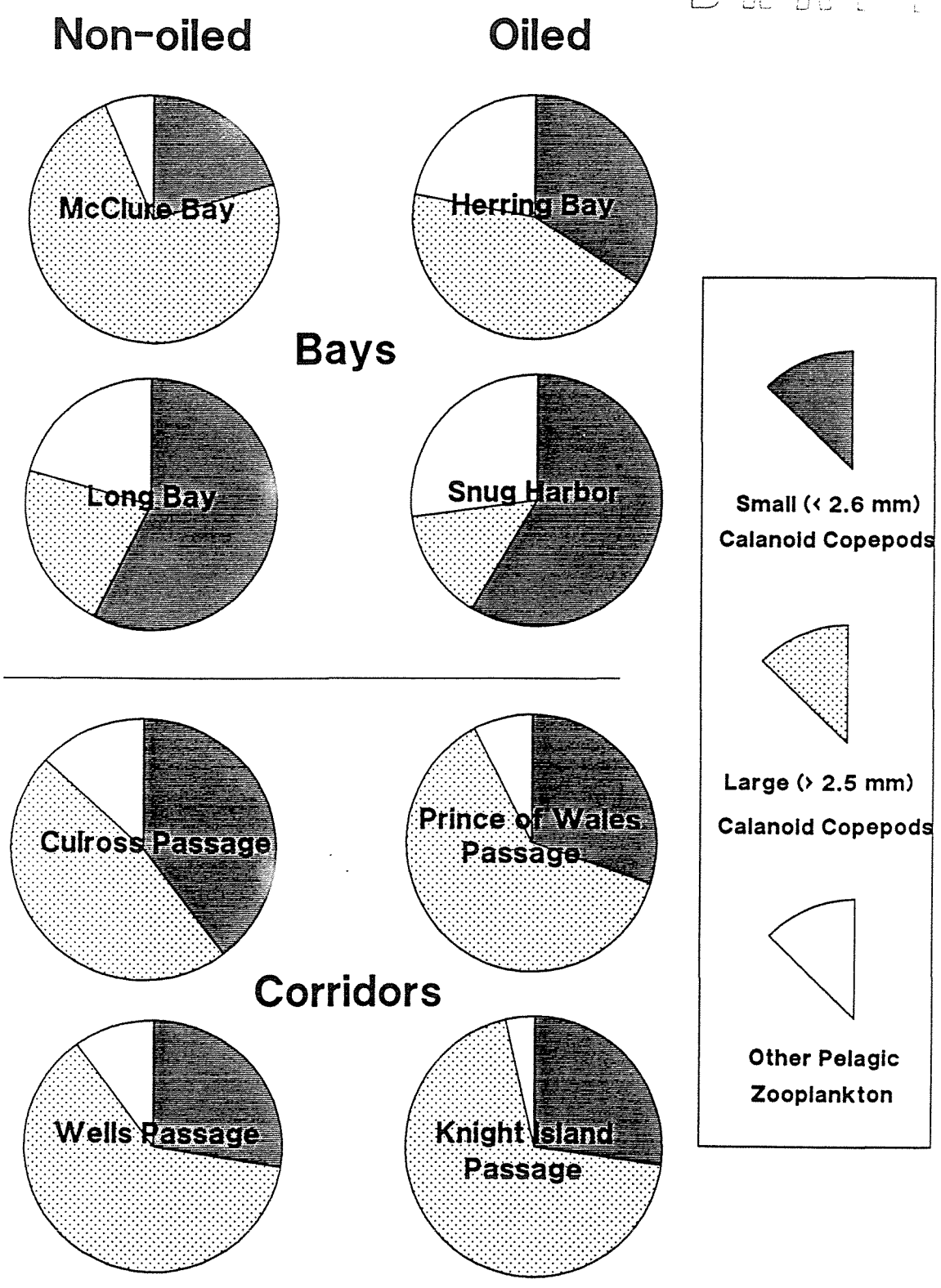

Figure 17. Relative biomass of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

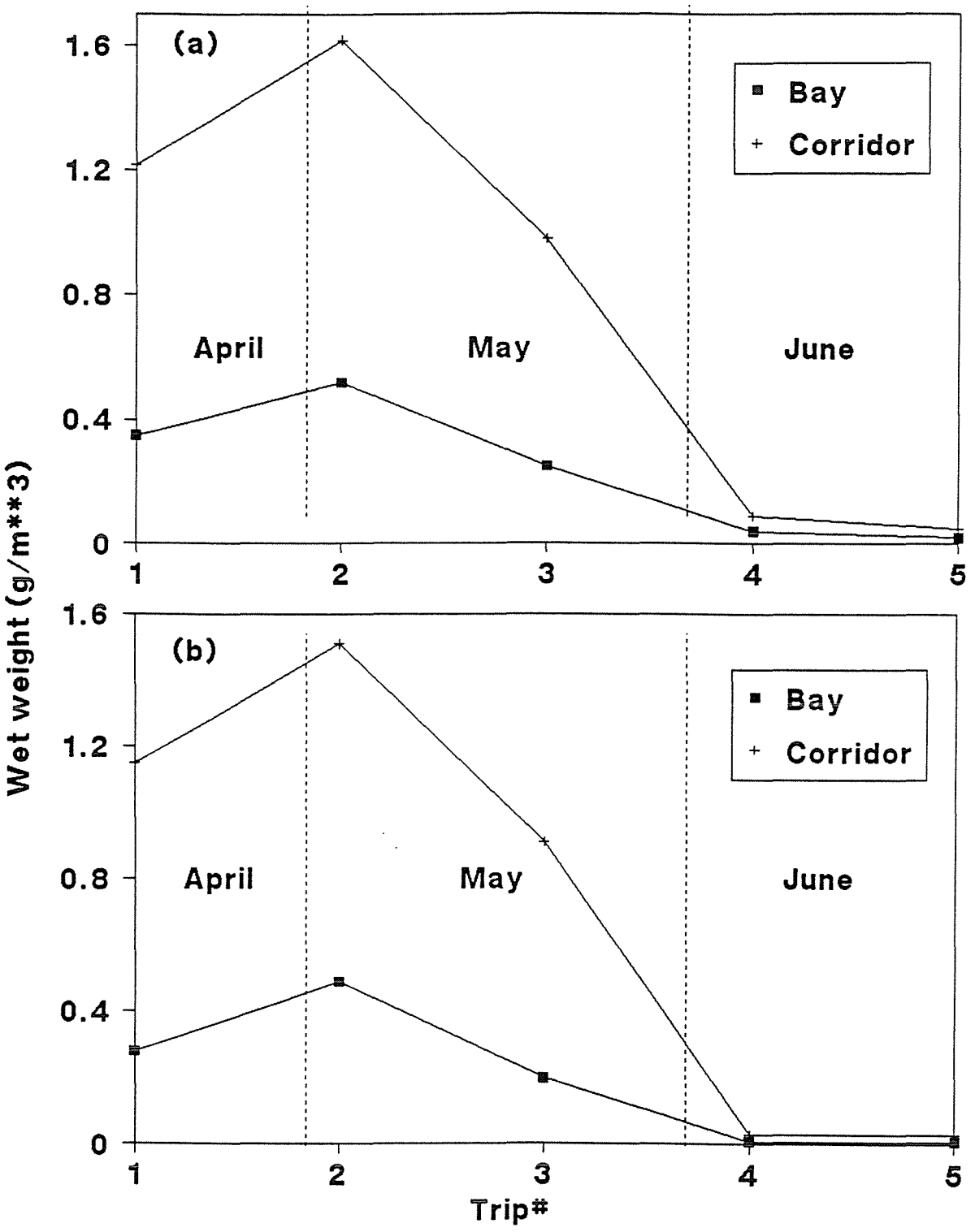

Figure 18. Biomass of (a) Pelagic zooplankton and (b) Calanoid copepods in Prince William Sound from April-June, 1989.

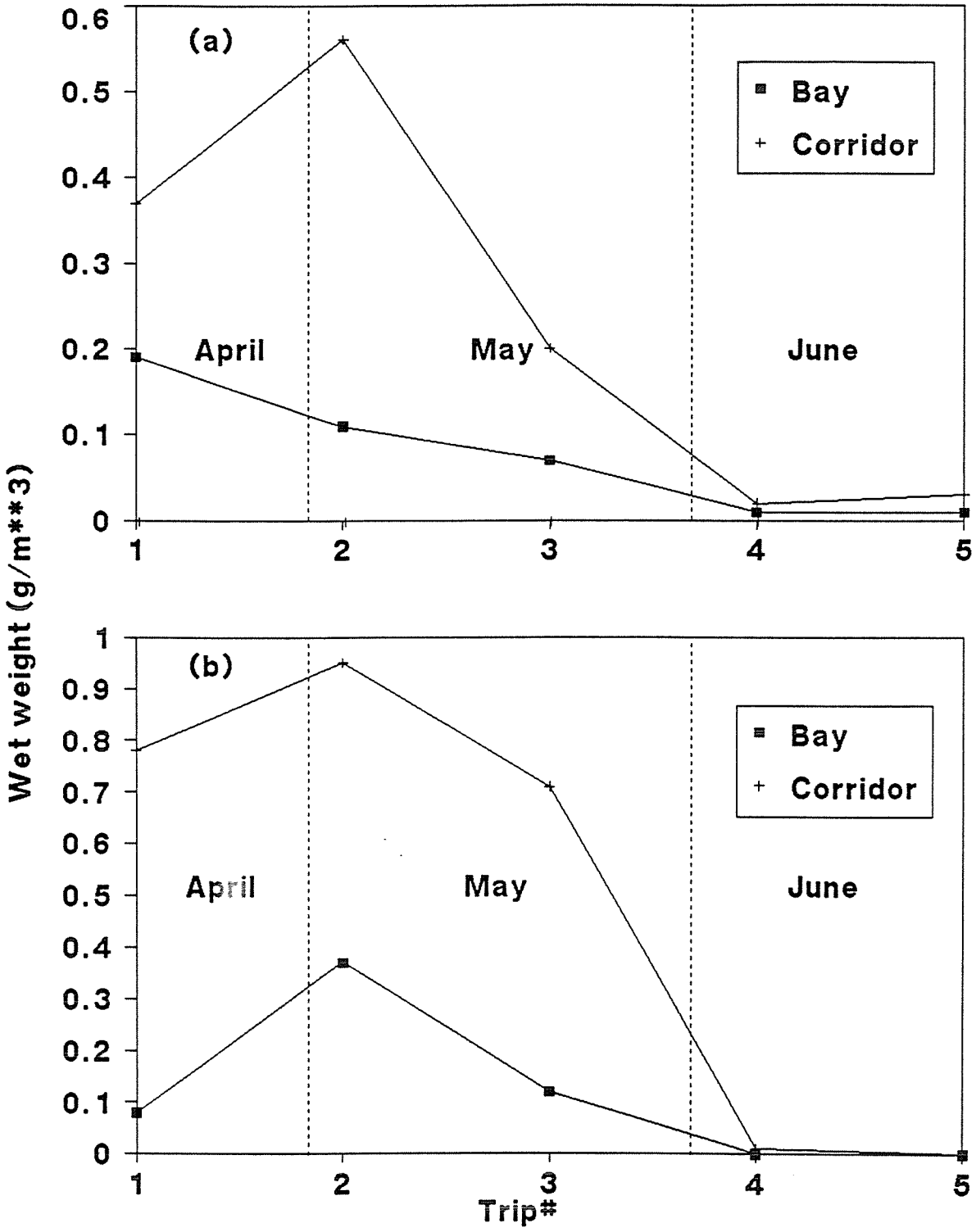

Figure 19. Biomass of (a) Small (< 2.6 mm total length) and (b) Large (> 2.5 mm total length) calanoid copepods in Prince William Sound from April-June, 1989.

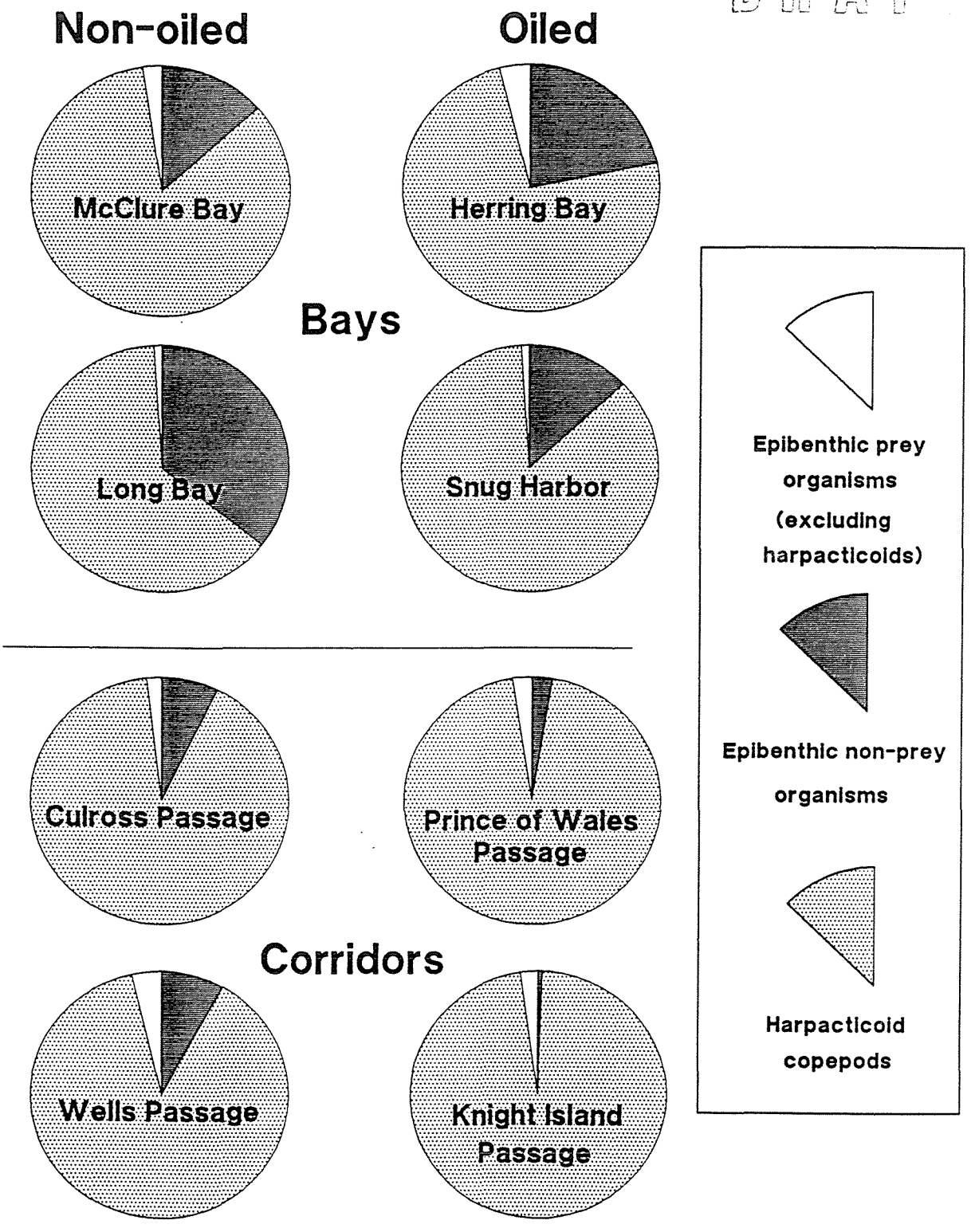

Figure 20. Relative abundance of epibenthos collected in the epibenthic sled systematic samples from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

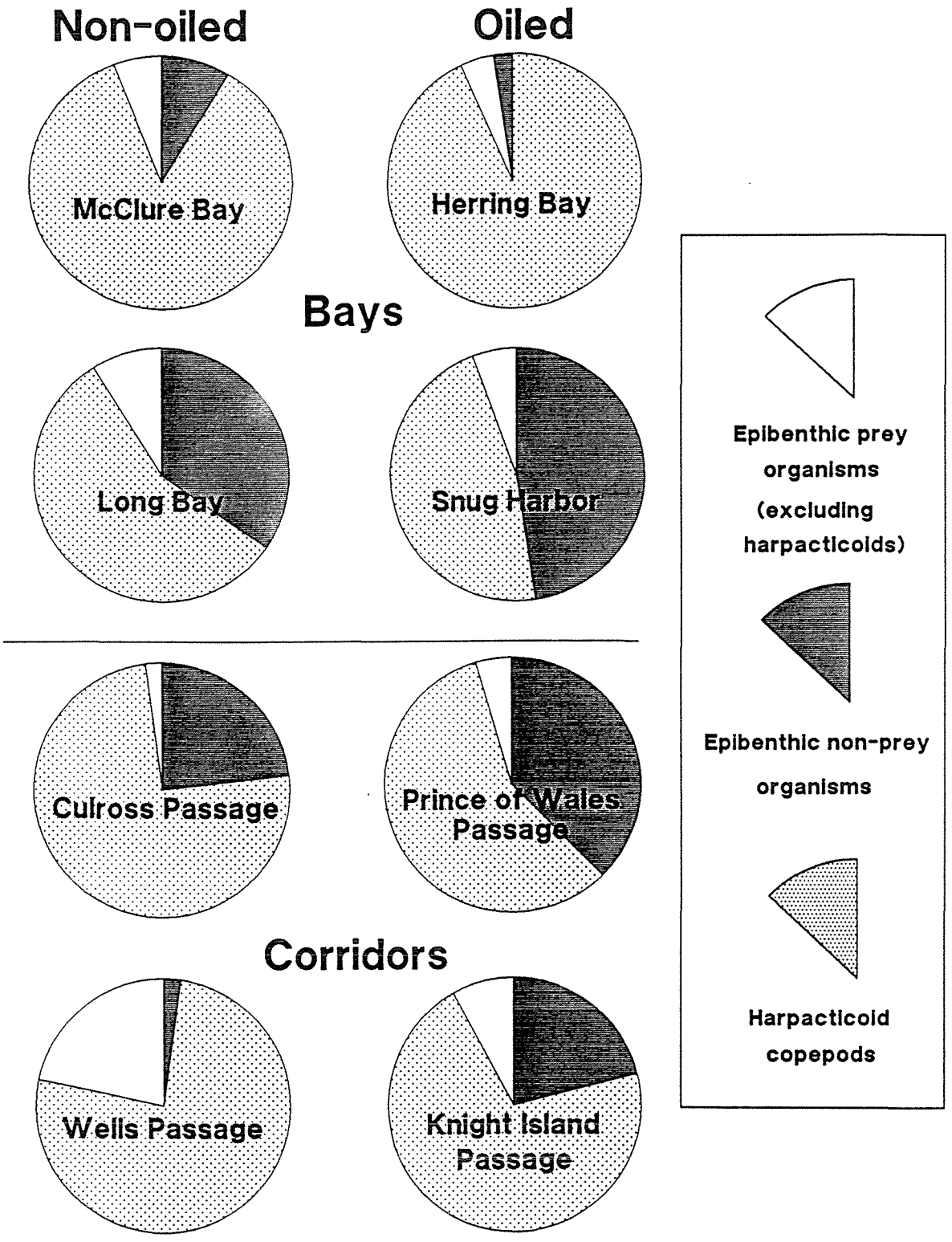

Figure 21. Relative biomass of epibenthos collected in the epibenthic sled systematic samples from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

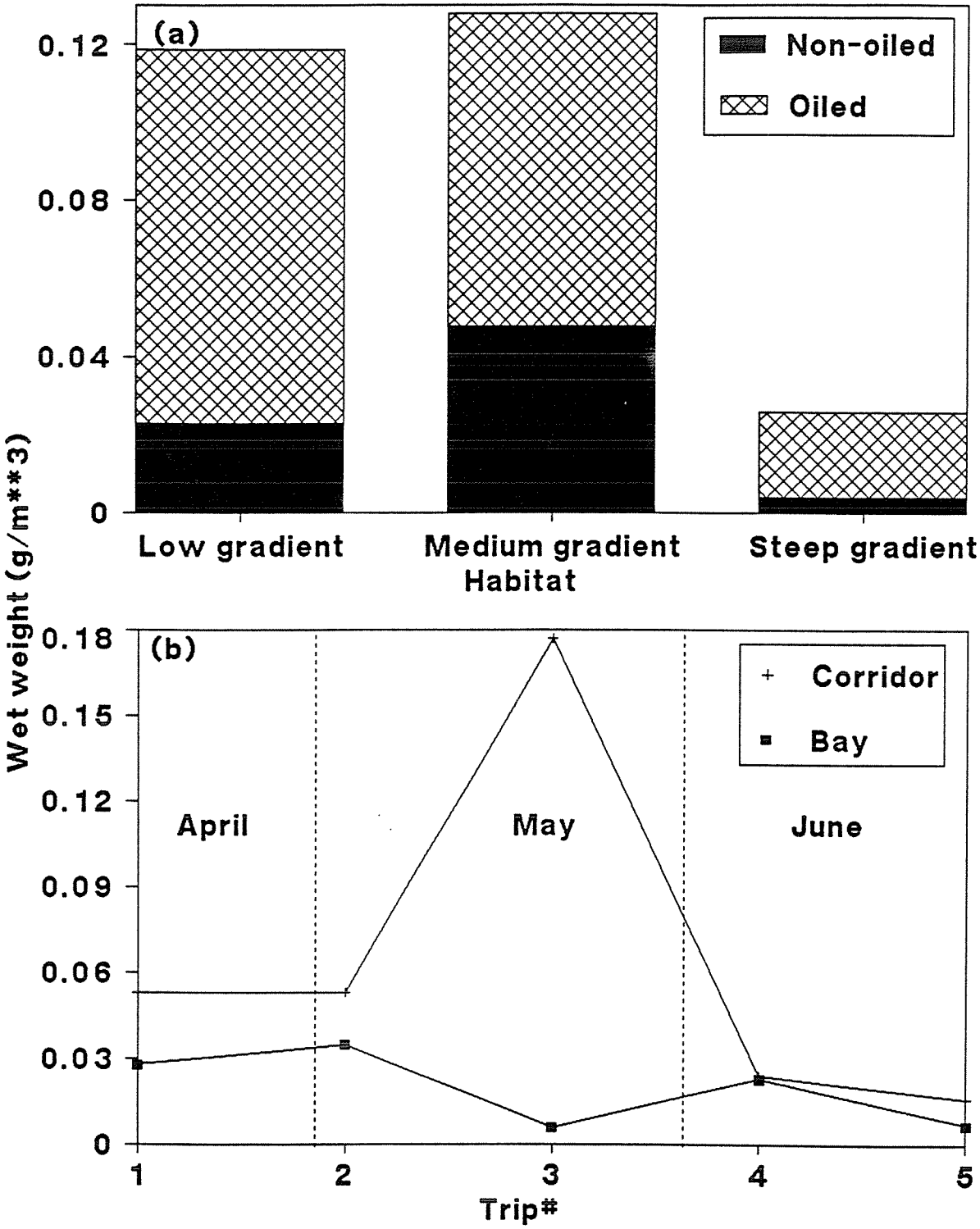

Figure 22. Harpacticoid copepod biomass in the systematic epibenthic sled samples in (a) oiled and non-oiled habitats, and (b) bays and corridors over time in Prince William Sound, April-June, 1989.

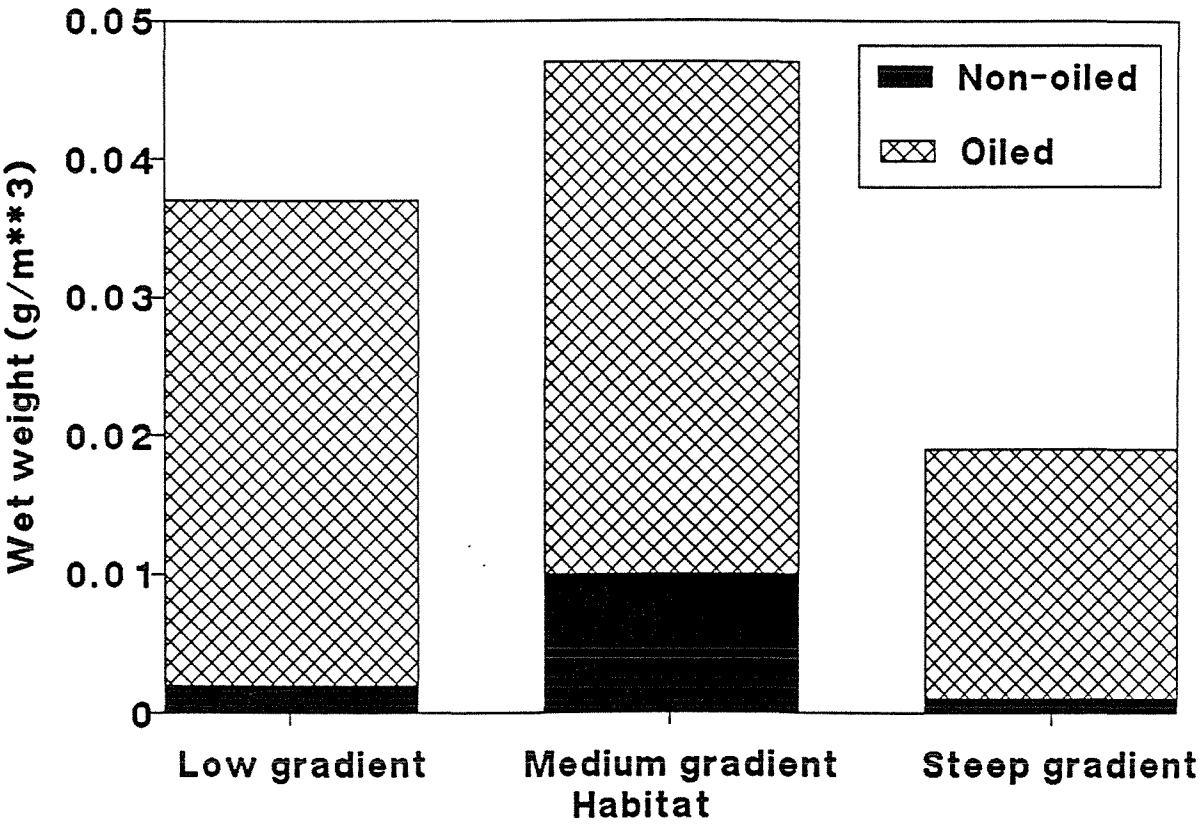

Figure 23. Harpacticoid copepod biomass in the tidal transect epibenthic sled samples from oiled and non-oiled habitats in bays of Prince William Sound, April-June, 1989.

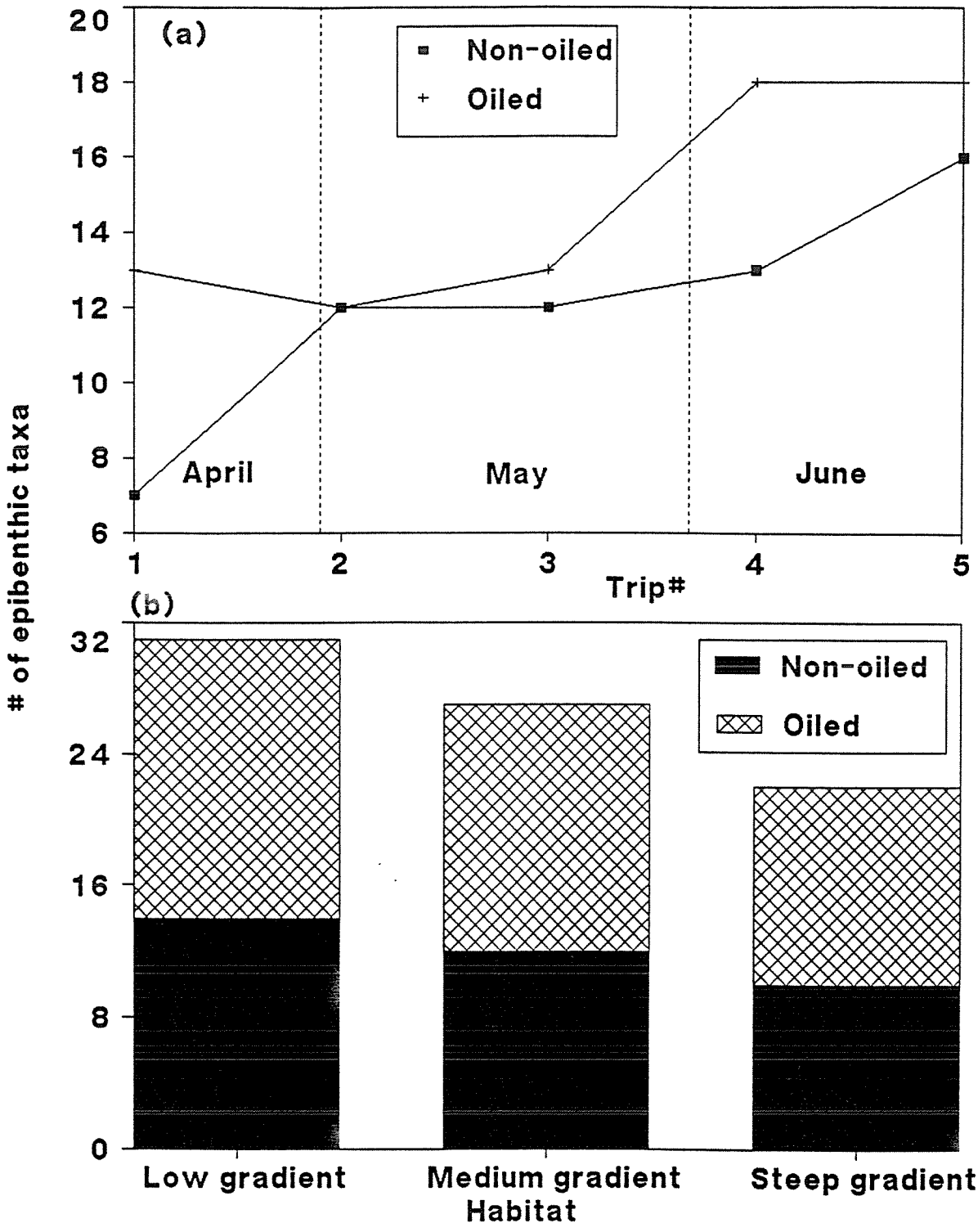

Figure 24. Number of epibenthic taxa captured in the systematic epibenthic sled samples in (a) oiled and non-oiled areas over time, and (b) oiled and non-oiled habitats in Prince William Sound, April-June, 1989.

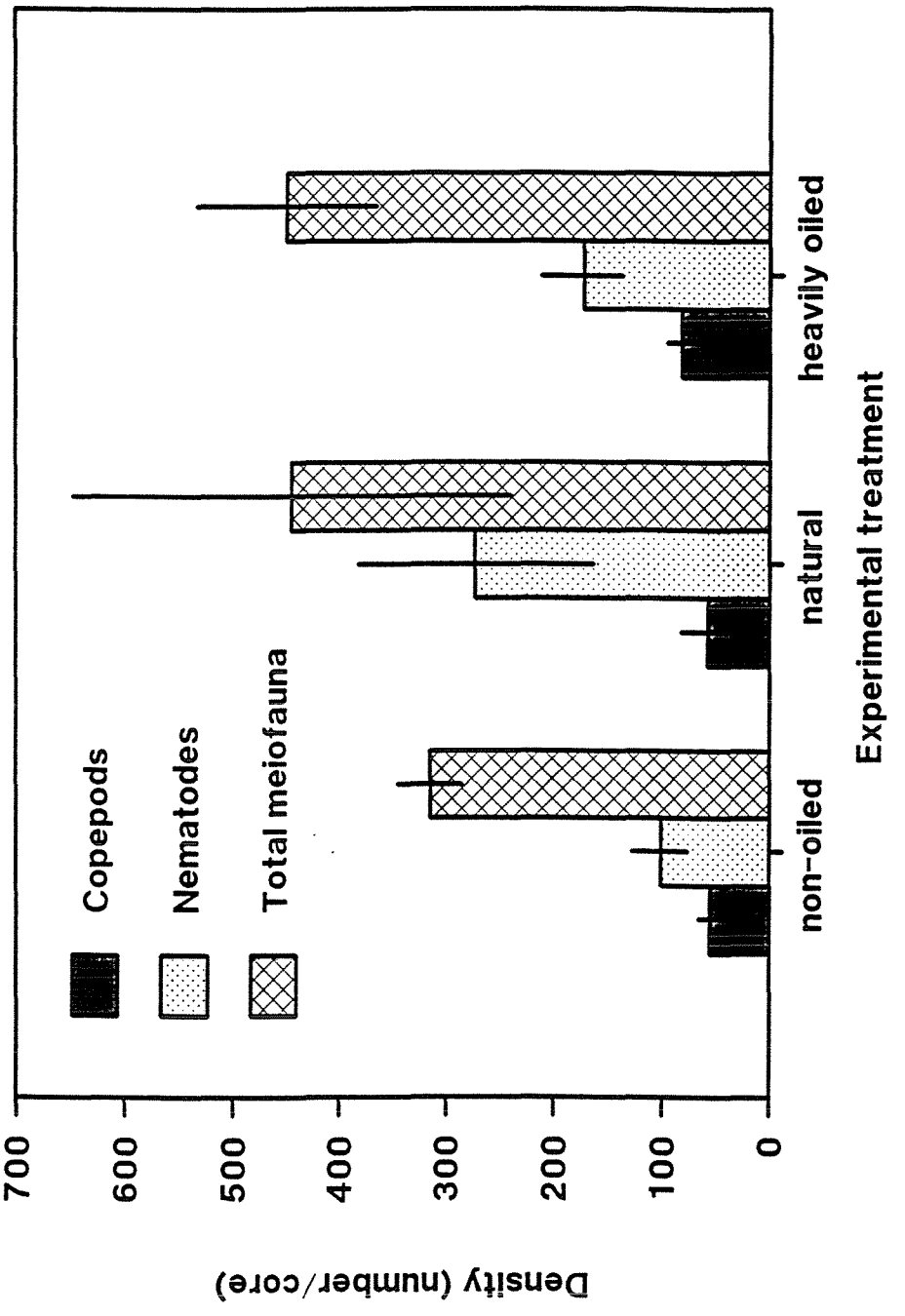

Figure 25. Preliminary densities of meiofauna in experimental treatments and natural sediments in a heavily oiled cove 29 d after the experiment began. Error bars are ±1 standard error.

Confidential Attorney/Client Work Product

STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT

DRAFT STATUS REPORT

Project Title:	Early marine salmon injury assessment in Prince William Sound
Study I D Number:	Fish/Shellfish Study No. 4
Lead Agencies:	State of Alaska, ADF&G, FRED Division Federal, NMFS, Auke Bay Lab
Principal Investigators:	Mark Willette, Fishery Biologist, ADF&G Alex Wertheimer, Fishery Biologist, NMFS
Date submitted:	20 November 1991

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OVERVIEW SUMMARY

The NRDA **Fish**/Shellfish Study No. 4 contains three components:

I. Impacts of oil spill on migratory behavior, growth and mortality (ADF&G),
II. Impact of oil spill on juvenile pink and chum salmon and their prey in critical nearshore habitats (NMFS), and
III. Prey fields and the feeding behavior and growth of pink salmon fry released from the Armin F. Koernig Hatchery at Sawmill Bay, Evans Island, Alaska: May and June, 1989 (UAF-IMS)

Excerpts from the executive summaries of each component study are presented in this Overview Summary. Complete executive summaries are included with each component section. Component III was discontinued after 1989. No additional data analyses have been completed for component III, and no report is included here.

Component I.

The objectives of the ADF&G component of F/S-4 were to determine the impacts of the oil spill on juvenile pink salmon during the first two months of their marine residency in Prince William Sound and to estimate the effect of these impacts on subsequent survival to the adult stage. This study has focused on the growth, migration, and fry-to-adult survival of coded-wire tagged pink salmon released from four hatcheries and six streams in Prince William Sound (PWS). Samples of coded-wire tagged juvenile pink salmon were collected in the same four geographic areas in 1989, 1990, and 1991. The fry-to-adult survival of fish in tag lots studied in F/S-4 were estimated from recoveries of coded-wire tagged adults in F/S-3.

Growth rates of early-fed fry released from the Armin F. Koernig (AFK) Hatchery in 1989 were significantly lower ($P<0.003$) in the heavily oiled area near the hatchery than along the lightly oiled southern coast of Knight Island. Growth rates of AFK Hatchery fry were not significantly different ($P=0.39$) in these two areas in 1990. In 1991, growth rates of AFK Hatchery fry were again significantly lower ($P<0.001$) in the previously oiled area, but the magnitude of the difference was nearly half that observed in 1989. Growth rates of early-fed fry released from the Wally H. Noerenberg (WHN) Hatchery were lower in oiled than in non-oiled areas in 1989, but the difference was marginally significant ($P=0.12$). Growth rates of fry released from the WHN Hatchery were not significantly different between oiled and non-oiled areas in 1990 ($P=0.30$) and 1991 ($P=0.44$). Analyses of length:weight regression slopes as a measure of condition were inconclusive.

Otoliths were used to back calculate the size-at-age and weekly growth rates of coded-wire tagged pink salmon fry recovered in oiled and non-oiled areas. Otolith data from the early-fed group released from the AFK Hatchery in 1989 has been analyzed. Weekly otolith growth estimates showed a significant (P=0.05) time-by-area interaction. Growth rates of fish remaining in the heavily oiled area near AFK Hatchery declined over time while the growth of fry that migrated to the relatively lightly oiled southern coast of Knight Island did not decline. Growth rates of fry in the heavily oiled area were significantly lower (P=0.003) than those in the lightly oiled area by the third week after release. Growth rates of fish recovered in the heavily oiled area were significantly lower (P=0.04) in the third week than in the first week after release.

A bioenergetic model was used to examine whether fry growth in 1989 was affected by small-scale differences in zooplankton biomass between oiled and non-oiled areas of PWS. Feeding rates were estimated for the ranges of water temperature and zooplankton biomass measured in PWS in 1989. Results indicated that fry growth was not food limited at the levels of zooplankton biomass measured in oiled and non-oiled areas of PWS during May 1989. However, zooplankton biomass during June was low and fry growth may have been affected by small-scale differences in food abundance between oiled and non-oiled areas.

The migration of coded-wire tagged fish from AFK Hatchery appeared to be affected by heavy oil contamination near the hatchery in 1989. One hundred and thirteen coded-wire tagged fish from AFK hatchery were recovered along the southern coast of Knight Island in 1989. Only 14 and 43 AFK Hatchery fry were recovered in this area in 1990 and 1991, respectively. Visual observations of juvenile salmon abundance also indicated that much higher numbers of fish were present along the southern coast of Knight Island in 1989 than in 1990 and 1991.

Pink salmon fry growth in 1989 was significantly related (P=0.009) to fry-to-adult survival. A reduction of fry growth of 1% body weight per day resulted in a 2.5% reduction in survival to the adult stage. Fry growth in 1990 was not significantly related (P=0.49) to fry-to-adult survival.

The level of mixed-function oxidase (MFO) activity in pink salmon fry generally coincided with the degree of oil contamination observed in the sampling area. Fish captured in a non-oiled area exhibited very mild or negative MFO activity. Fish captured in the heavily oiled area near the AFK Hatchery exhibited strong to moderate MFO activity. Fish captured along the southern coast of Knight Island exhibited declining MFO activity over time, coincident with an apparent decline in oil contamination in the area. The distribution of stained monoclonal antibodies indicated that hydrocarbons were taken up primarily through the gills and

secondarily through the gastrointestinal tract. Of the 104 fish exhibiting some level of MFO activity, 51% and 19% exhibited staining in the gills and gastrointestinal tract, respectively.

Component II.

The objectives of the NMFS component of F/S-4 were to determine the impact of the oil spill on juvenile pink and chum salmon during their initial period of marine residency in nearshore habitats. Field studies in 1989 and 1990 compared (1) distribution, abundance, size and nominal growth rates; (2) exposure to and contamination by hydrocarbons; (3) feeding habits; and (4) prey abundance for these fish between pairs of oiled and non-oiled locations in Western Prince William Sound. The effects of oiled sediments on the littoral prey resources of juvenile salmon were also examined. In 1991, field work was discontinued, and a laboratory study was initiated examining the effects of ingestion of food contaminated with whole oil. The emphasis was on juvenile pink salmon, both because of their economic value and because of their numerical abundance relative to other salmon species.

Based on the analyses to date of field and laboratory samples, we have reached a series of preliminary conclusions regarding the impacts of oil in the nearshore marine environment. Juvenile pink and chum salmon were contaminated by oil in 1989; the probable route of contamination was through ingestion of whole oil, either directly or by feeding on contaminated prey. Growth was reduced in pink salmon in oiled areas in 1989 as a physiological consequence of this contamination. Laboratory studies in 1991 demonstrated that ingestion of whole oil can reduce the growth of juvenile pink salmon at sub-lethal dosages.

There were detectable levels of hydrocarbons in tissues of juvenile pink salmon collected in the nearshore environment of oiled areas of Prince William Sound in 1989 processed to date. In order to test that hydrocarbons detected in samples were not due to external contamination, flesh samples and viscera were processed separately from some samples of fish from oiled locations; both types of tissues were contaminated by hydrocarbons, with higher levels in the viscera. The composition of the hydrocarbon in the tissues indicated that ingestion, either of whole oil or oil-contaminated prey, was the likely route of contamination. Sample processing is still incomplete; additional samples need to be analyzed to finalize these preliminary findings. However, evidence of oil was also observed in the stomachs of a small percentage of pink and chum salmon collected at oiled sites.

Exposure of both pink and chum salmon fry to physiologically significant levels of oil in 1989 was also indicated by levels of mixed-function oxidase (MFO) activity in fry from oiled areas.

MFO activity levels in pink salmon declined by late June 1989, suggesting that the degree of exposure of pink salmon in the nearshore marine environment decreased in late spring, 1989.

Samples of juvenile pink salmon from 1990 processed to date show no evidence of hydrocarbon contamination, indicating a marked decline in the level of exposure of juvenile pink salmon from oil year 1 to year 2. Results for 1990 samples analyzed for MFO also show no evidence of induced activity in 1990.

Juvenile pink and chum salmon were more abundance in the non-oiled area in both 1989 and 1990. Because the pattern of abundance did not change as exposure levels diminished, we concluded that the differences observed in abundance were more likely due to geographic differences or distribution of spawning populations rather than to exposure to oil.

Juvenile pink salmon moved rapidly from sheltered bays to more exposed, steep shorelines in migration corridors, where they fed predominately on zooplankton. This rapid movement is considered to be an adaptive feeding strategy in response to the distribution of zooplankton in nearshore habitats in Prince William Sound. The observation of this behavior over a wide geographic range reinforces the conclusion drawn in the UAF-IMS component of F/S-4, that the presence of oil-deflection boom in Port San Juan in 1989 disrupted the normal migration behavior of fish released from the Armin F. Koernig Hatchery.

Juvenile chum salmon in oiled areas may be more susceptible to hydrocarbon exposure than pink salmon because of their distribution in nearshore habitats. Juvenile chum salmon utilized bays and low gradient shorelines to a grater extent and thus were more likely to forage over contaminated sediments. Juvenile chum salmon were generally rare in the oiled locations sampled, however.

There were no significant differences observed in the size of juvenile pink salmon between the oiled and non-oiled locations sampled. Pink salmon tended to be larger in the non-oiled area in both 1989 and 1990. There was no evidence of a reduction in condition of juvenile pink salmon in oiled areas: in both 1989 and 1990, pink salmon tended to have a greater weight at a given length in the oiled locations.

There was a significant reduction in the apparent growth rate of juvenile pink salmon in oiled corridors relative to oiled bays in 1989. This reduction was not observed in 1990. This analysis of unmarked fish corroborates the significant reduction in growth of tagged pink salmon in oiled areas reported to the ADF&G component of F/S-4. We attribute this reduction in growth to a physiological effect of the observed oil contamination. The laboratory studies in 1991 showed food contaminated by Prudhoe

Bay Crude Oil reduced survival and growth of juvenile pink salmon growth. Temperature, prey availability, and feeding efficiency were as high or higher in oiled locations in 1989, and therefore do not explain the observed reduction in growth.

Juvenile chum salmon were significantly larger in the oiled locations in both 1989 and 1990. As with pink salmon, there was no evidence of a reduction in condition factor in the oiled area. Chum salmon were rarely captured in oiled habitats; there was insufficient data to compare apparent growth rates for this species.

Pelagic zooplankton dominated the diet of juvenile pink and chum salmon in both 1989 and 1990. Calanoid copepods were the primary prey group of zooplankton. There was no indication of reduced feeding of pink or chum salmon in the oiled areas in 1989, based on measures of stomach fullness and numbers and biomass of prey consumed. There was a significant switch in the diet composition of juvenile pink salmon between the oiled and non-oiled areas. In 1989, epibenthic prey was utilized to a greater extent in the non-oiled area than the oiled area, and zooplankton prey was used to a greater extent in the oiled area than in non-oiled area. The reverse pattern was observed in 1990. This switch in diet composition is attributed to differences in the timing and abundance of the spring zooplankton bloom.

We found no evidence of a reduction in available prey organisms of juvenile salmon due to oil contamination. No significant differences were detected in the biomass of pelagic zooplankton between oiled and non-oiled areas in either 1989 or 1990. However, the trend in 1989 was for higher zooplankton biomass in the oiled area; zooplankton biomass declined more rapidly from seasonal peaks in the non-oiled area than in the oiled area. The reverse was true in 1990. Zooplankton biomass was greater in corridors than bays in 1989 and 1990. Epibenthic prey biomass, including harpacticoid copepods, was higher in oiled locations than in non-oiled locations in 1989. This trend could have been due to geographic variability, reduced cropping associated with lower abundance of juvenile pink salmon, or direct enhancement by oil contamination. Preliminary analyses of results from 1990 field studies on epibenthic prey support the latter explanation. Harpacticoid copepods were more abundant in 1990 on heavily oiled beaches than lightly oiled beaches within the same embayment. Although the differences were not significant in the preliminary analysis, harpacticoid copepods and meiofauna also tended to be higher in the oiled sediments in the field experiment examining the colonization of azoic sediments.

INTRODUCTION

Recruitment to adult salmon populations appears to be strongly affected by mortality during the early marine period, because mortality at this time is typically very high (Parker 1968, Ricker 1976, Hartt 1980, Bax 1983). During this period, slow-growing individuals sustain higher mortality because they are vulnerable to predators for a longer time than fast-growing individuals (Parker 1971, Healey 1982, West and Larkin 1987). In the laboratory, sublethal hydrocarbon exposure caused reduced growth of juvenile salmon (Rice et al. 1975, Schwartz 1985). Thus, in the wild, sublethal hydrocarbon exposure is expected to cause reduced growth resulting in increased size-selective predation.

Oil contamination may also reduce survival by decreasing salmon prey populations or disrupting migration patterns. Oil can be toxic to littoral and pelagic macroinvertebrates (Caldwell et al. 1977, Gundlach et al. 1983). Hydrocarbon exposure can damage olfactory lamellar surfaces (Babcock 1985) and cause an avoidance reaction (Rice 1973).

During the past decade, five salmon hatcheries have been established within Prince William Sound (PWS). These facilities, operated by private non-profit corporations, produced approximately 535 million juvenile salmon in 1989. Approximately one million of these fish were marked with a coded-wire tag (CWT). Recoveries of these marked fish in PWS has played a major role in our assessment of the impact of the oil spill.

In 1991, the impact assessment was conducted by the Fisheries Rehabilitation, Enhancement, and Development (FRED) Division of the Alaska Department of Fish and Game (ADF&G), and by the National Marine Fisheries Service (NMFS). The ADF&G component studied the impact of oil on fry growth, migratory behavior, and fry-to-adult survival. Studies conducted by NMFS focused on fry abundance, growth, and behavior, and oil contamination of the fish and their prey. An experiment was also conducted to determine the effect of ingestion of whole oil on the survival and growth of pink salmon fry.

GENERAL OBJECTIVES

A. Determine the effects of oil contamination on abundance, distribution, growth, feeding habits, and behavior of pink salmon fry during their early marine residency.

B. Describe the apparent effect of oil contamination on the migration patterns of pink salmon fry in western PWS.

C. Quantify hydrocarbon contamination in tissues of juvenile salmon collected in oiled and non-oiled areas.

D. Determine the relationship between pink salmon fry growth and fry-to-adult survival.

E. Determine if hydrocarbon contamination affected the abundance of primary prey species of pink salmon fry.

F. Determine the effects of ingestion of whole oil on survival and growth of pink salmon fry.

COMPONENT STUDIES

I. Impacts of oil spill on migratory behavior, growth and mortality (ADF&G)

Project Leader: Mark Willette
Biometrician: James J. Hasbrouck

Executive Summary

The objectives of the ADF&G component were to determine the impacts of the oil spill on juvenile pink salmon during the first two months of their marine residency in Prince William Sound and to estimate the effect of these impacts on subsequent survival to the adult stage. This study has focused on the growth, migration, and fry-to-adult survival of coded-wire tagged pink salmon released from four hatcheries and six streams in Prince William Sound (PWS). Samples of coded-wire tagged juvenile pink salmon were collected in the same four geographic areas in 1989, 1990, and 1991. The fry-to-adult survival of fish in tag lots studied in F/S-4 were estimated from recoveries of coded-wire tagged adults in F/S-3.

Growth rates of early-fed fry released from the Armin F. Koernig (AFK) Hatchery in 1989 were significantly lower ($P<0.003$) in the heavily oiled area near the hatchery than along the lightly oiled southern coast of Knight Island. Growth rates of AFK Hatchery fry were not significantly different ($P=0.39$) in these two areas in 1990. In 1991, growth rates of AFK Hatchery fry were again significantly lower ($P<0.001$) in the previously oiled area, but the magnitude of the difference was nearly half that observed in 1989. Growth rates of early-fed fry released from the Wally H. Noerenberg (WHN) Hatchery were lower in oiled than in non-oiled areas in 1989, but the difference was marginally significant ($P=0.12$). Growth rates of fry released from the WHN Hatchery were not significantly different between oiled and non-oiled areas in 1990 ($P=0.30$) and 1991 ($P=0.44$). Analyses of length:weight regression slopes as a measure of condition were inconclusive.

Otoliths were used to back calculate the size-at-age and weekly growth rates of coded-wire tagged pink salmon fry recovered in oiled and non-oiled areas. Otolith data from the early-fed group released from the AFK Hatchery in 1989 has been analyzed. Weekly otolith growth estimates showed a significant ($P=0.05$) time-by-area interaction. Growth rates of fish remaining in the heavily oiled area near AFK Hatchery declined over time while the growth of fry that migrated to the relatively lightly oiled southern coast of Knight Island did not decline. Growth rates of fry in the heavily oiled area were significantly lower ($P=0.003$) than those in the lightly oiled area by the third week after release.

Growth rates of fish recovered in the heavily oiled area were significantly lower (P=0.04) in the third week than in the first week after release.

A bioenergetic model was used to examine whether fry growth in 1989 was affected by small-scale differences in zooplankton biomass between oiled and non-oiled areas of PWS. Feeding rates were estimated for the ranges of water temperature and zooplankton biomass measured in PWS in 1989. Results indicated that fry growth was not food limited at the levels of zooplankton biomass measured in oiled and non-oiled areas of PWS during May 1989. However, zooplankton biomass during June was low and fry growth may have been affected by small-scale differences in food abundance between oiled and non-oiled areas.

The migration of coded-wire tagged fish from AFK Hatchery appeared to be affected by heavy oil contamination near the hatchery in 1989. One hundred and thirteen coded-wire tagged fish from AFK hatchery were recovered along the southern coast of Knight Island in 1989. Only 14 and 43 AFK Hatchery fry were recovered in this area in 1990 and 1991, respectively. Visual observations of juvenile salmon abundance also indicated that much higher numbers of fish were present along the southern coast of Knight Island in 1989 than in 1990 and 1991.

Pink salmon fry growth in 1989 was significantly related (P=0.009) to fry-to-adult survival. A reduction of fry growth of 1% body weight per day resulted in a 2.5% reduction in survival to the adult stage. Fry growth in 1990 was not significantly related (P=0.49) to fry-to-adult survival.

The level of mixed-function oxidase (MFO) activity in pink salmon fry generally coincided with the degree of oil contamination observed in the sampling area. Fish captured in a non-oiled area exhibited very mild or negative MFO activity. Fish captured in the heavily oiled area near the AFK Hatchery exhibited strong to moderate MFO activity. Fish captured along the southern coast of Knight Island exhibited declining MFO activity over time, coincident with an apparent decline in oil contamination in the area. The distribution of stained monoclonal antibodies indicated that hydrocarbons were taken up primarily through the gills and secondarily through the gastrointestinal tract. Of the 104 fish exhibiting some level of MFO activity, 51% and 19% exhibited staining in the gills and gastrointestinal tract, respectively.

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Figure 5. Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1990: (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.

Figure 6. Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1991. (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.

Figure 7. Relationship between fry-to-adult survival and mean growth rate by coded-wire tag code for pink salmon fry released into Prince William Sound in 1989 and 1990.

Objectives

(Letters refer to goals described above)

A-1. Estimate pink salmon fry growth in oiled and non-oiled areas of western PWS in 1991.

A-2. Complete an otolith microstructure analysis on all CWT fry collected in 1989, 1990, and 1991. Use the analysis to estimate fry growth during the two week time periods immediately after the fish were released and immediately prior to recapture. Estimate the 95% confidence intervals on all growth estimates.

A-3. Determine the amount of mixed-function oxidase (MFO) activity in selected samples of fry collected in 1989, 1990, and 1991. Use the results from this analysis in conjunction with data on beach oil contamination to group samples in an analysis of variance.

A-4. Conduct an analysis of variance on fry growth during the two week time period immediately after release using otolith growth estimates from fry collected in 1989, 1990, and 1991. If significant differences (P=0.05) in fry growth are found among tag lots or years, a multiple comparison of means test will be performed.

A-5. Conduct a repeated measures analysis of variance on fry growth during the two week time period immediately prior to recapture using otolith growth estimates from fry collected in 1989, 1990, and 1991. If significant differences (P=0.05) in fry growth are found among areas or years, a multiple comparison of means test will be performed.

A-6. Conduct a multiple regression analysis to estimate the effects of oil exposure and environmental conditions on fry growth during the two week time period immediately after release. Conduct residuals analysis and other diagnostic tests to determine whether the growth of fry in oiled areas was significantly different (P=0.05) from the expected value given the environmental conditions in 1989.

A-7. Conduct a multiple regression analysis to estimate the effects of oil exposure and environmental conditions on fry growth during the two week time period immediately prior to recapture. Conduct residuals analysis and other diagnostic tests to determine whether the growth of fry in oiled areas was significantly different (P=0.05) from the expected value given the environmental conditions in 1989.

A-8. Test for differences (P=0.05) in prey composition between oiled and non-oiled areas using chi-square analysis.

A-9. Test for differences (P=0.05) in stomach contents weight between oiled and non-oiled areas using repeated measures analysis of variance.

A-10. Use a bioenergetics model to estimate the relative effects of water temperature, prey density, and prey composition on fry growth in 1989.

B-1. Describe CWT fry migration patterns in western PWS in 1991.

B-2. Qualitatively compare CWT fry migration patterns in 1989, 1990, and 1991.

D-1. Conduct a linear regression analysis to estimate (P=0.05) the relationship between mean fry growth and the fry-to-adult survival of pink salmon from specific tag lots released in 1989 and 1990.

Methods

Objective A-1:

In 1991, pink salmon fry sampling was restricted to areas 1, 2, 4, and 5 (Figure 1). Six areas were originally sampled in 1989 but recoveries of CWT fish were very low in areas 3 and 6. Fry were captured using beach and purse seines deployed from a 6 m long aluminum skiff. Sampling began on May 25 and extended to June 27. A 40 m long beach seine and 70 m long purse seine were used to capture the fish. Methods used to isolate, handle, and preserve CWT fry in 1991 were similar to those in previous years (Raymond 1990). Samples of untagged fry were collected and preserved in 70% ethanol at sites where CWT fry were recovered.

Coded-wire tags were extracted and interrogated in the field using methods developed by the FRED Division Tag Laboratory. The remains of the head and the body were placed in a pre-weighed vial and frozen. Damage to the head was kept to a minimum. The vials were weighed later on shore when accuracies of 0.01 g could be obtained.

The following criteria (listed in order of priority) were employed in making sampling decisions in the field:

1) Recover a minimum of 30 tagged fish from each tag lot.
2) Recover fish from each tag lot in at least three different areas during a single time period. Sampling sites where fry were collected in 1989 received priority (Raymond 1990).
3) Recover fish from each tag lot during at least three different time periods.

Because nearly 60 tag codes were used in 1991, it was not possible to meet each of the sampling objectives for each tag code lot. To circumvent this problem, tag codes from the same hatchery with similar mean weight and time of release were treated as a group. Sampling criteria were initially applied to these groups, then to individual lots if time permitted. Tag lots or groups having characteristics similar to important tag lots in the 1989 database received priority (Raymond 1990). Water temperature at 1 m depth was measured at all sample sites using a hand held thermometer.

Fry (n=60) were collected from each tag code lot at the Wally H. Noerenberg (WHN) and Armin F. Koernig (AFK) Hatcheries in 1991 immediately before the fry were released. These samples were placed in 10% formalin and later weighed to an accuracy of 0.01 g in the laboratory. In addition, CWT (n=30) and untagged fry (n=30) were taken at both hatcheries from each of two net pens. These samples will be used to determine if fry body weight was different between CWT and untagged fry in the same net pen. Each sample from the net pens was composed of at least three subsamples taken at various places in the pen.

Recoveries of CWT pink salmon fry occurred at the same areas during different time periods each year. Thus, repeated measures analysis of variance was used to examine effects of tag code groups, oiled/non-oil recovery area, and time for each year (Neter et al. 1990). Areas 1, 5, and 6 were classified as having no or light amounts of oil in 1989 and areas 2, 3, and 4 were heavily oiled. A length:weight relationship of tagged pink salmon fry was estimated by regressing natural log of body weight on natural log of fork length (Cone 1989). An analysis of covariance for each year examined differences in the slope parameter of recoveries between oiled/non-oiled areas.

Objective A-2:

Otolith microstructure analysis was used to estimate fry growth during weekly time periods immediately after fry were released from hatcheries. Thin sections of the otoliths were prepared using methods developed by Volk et. al. (1984). A computer image analysis system was used to collect data from the otoliths. A reference line was drawn on left sagittal otoliths from the rostrum through the center of the primordial mass. Right sagittal otoliths were used if the left otolith was in poor condition. On left and right sagittal otoliths, primary radius lines were drawn from the center of the primordial mass to the outer edge at 30° and 330° to the reference line, respectively. Distances to the marine check and outer edge were measured along the primary radius line. The marine check was visually identified as a dark band. Increments laid down before the marine check were typically much less distinct than those laid down after the fish were released.

Five shorter radius lines were drawn across the marine zone near the primary radius line to obtain detailed pixel luminance series. The luminance series from the first line was cross correlated with the luminance series from the other four lines. The maximum lag correlation was then used to align the five luminance series. A principal components analysis was performed on the five aligned luminance series. The amplitude time series from the first principal component was used in subsequent analyses.

To verify that otolith measurements were related to fry growth, otolith radius length (um) and increment count were regressed against fry body weight (g) and age (number of days after release), respectively. Otolith increments were counted from the marine check to the outer edge. Increments were identified in the amplitude time series as a minimum amplitude within any five consecutive data points. To date only early-fed fry released from AFK Hatchery in 1989 have been analyzed. The precise age of individual fry from this group was not known because the fry were released over a period of six days. The mean time-of-release for the group was used to estimate age from time-of-release.

A modified Fraser-Lee procedure was used to back calculate fish body weight at age (Campana 1990). The relationship between fry weight and otolith size may vary systematically with somatic growth rate, resulting in relatively large otoliths in slow growing fish. The modified Fraser-Lee method accurately estimates fish weight at age in the presence of a growth effect. The equation to back calculate fry weight is

$$W_a = W_c + (O_a - O_c)(W_c - W_o)(O_c - O_o)^{-1} \qquad (1)$$

where W_a = ln(body weight) at age, O_a = otolith radius at age, W_c = ln(body weight) at capture, O_c = otolith radius at capture, W_o = ln(body weight) at the beginning of the experiment, and O_o = otolith radius at the beginning of the experiment (Campana 1990). This method assumes that fry weight and otolith size are the same among all individuals at the beginning of the experiment. In the present study, the beginning of the experiment was egg hatch. Fry weight and otolith radius length at hatch were estimated to be 100 mg and 136.2 um, respectively, for all individuals. These estimates were based on measurements along the primary radius line to the hatch check. An exponential model was used to estimate weekly growth rates (G) in percent body weight per day as

$$G = 100[(\ln(W_2) - \ln(W_1))/(t_2 - t_1)] \qquad (2)$$

where W_1 = body weight at time t_1, and W_2 = body weight at time t_2. Otolith increments were assumed to be formed daily.

Objective A-3:

Untagged pink salmon fry were collected for MFO analysis at a number of sites where CWT fry were also recovered. Untagged fry (n=8) similar in length to fry from the dominant tag code lot in the catch were preserved in a 10% formaldehyde solution for MFO analysis. The samples were embedded in paraffin and thin sectioned (J. Stegeman, Woods Hole Oceanographic Institute, pers. commun.). A monoclonal antibody that binds to P450-dependent monooxygenases was applied to each sample and later detected by staining. Degree of MFO induction involved a subjective visual assessment of stain distribution and intensity in various tissues.

A second set of samples was analyzed at Woods Hole to evaluate changes in P450 enzyme activity over time. A comparison of AFK Hatchery releases in 1989 may indicate fry captured in heavily oiled areas near the hatchery continued to have high MFO levels while those recovered from lightly oiled areas near Knight Island show a decline in MFO activity over time. In the marine teleost, Fundulus heteroclitus, an increase in P450E protein and enzyme activity occurs 31 hours after chemical exposure. P450E activity remains elevated for 13 days after chemical exposure (Kloepper-Sams and Stegeman 1989). Some samples from the second set were blind replicates of sites analyzed in the first set. Untagged fry in the replicate samples were similar in length to those in the first set.

Objective A-4 & A-5:

Repeated measures analysis of covariance was used to examine differences in weekly growth rates obtained from otoliths. Only early-fed fry released from the AFK Hatchery in 1989 (tag code 301) and recovered in area 4 (oiled) and 5 (lightly oiled) were included in the analysis. Weekly growth rates during the first three weeks after release were the dependent variables. Oil/non-oil recovery area was the independent variable with body weight at release used as a covariate. A simple two-factor analysis of variance was performed to test for differences in weekly growth rate between fish recovered in the two areas. Univariate and multivariate procedures were used to test for between subject, within subject, and within-subject-by-between-subject interactions (Winer 1971, Cole and Grizzle 1966).

Objective A-6 & A-7:

A multiple regression analysis will be performed to determine effects of oil exposure and release conditions on growth estimates obtained from otoliths during the two week time period immediately after release. Data from tag lots released in 1989,

1990, and 1991 will be used in the analysis. The effects of the number of fry released, mean fry weight at release, timing of release, zooplankton abundance, water temperature, and oil exposure on fry growth will be examined. Examination of residuals and other diagnostic tests will assess adequacy of the fit of the model and any violation of assumptions. Fry from AFK Hatchery in 1989 were released into oiled areas while all other fry were released into non-oiled areas. Influence of data from AFK Hatchery in 1989 on regression parameter estimates will also be investigated using dummy variables (Draper and Smith 1981).

Objectives A-8 & A-9:

Measurements of prey composition and stomach contents weight will be taken from 480 untagged fry collected at various oiled and non-oiled sites where important CWT fry samples were obtained in 1989. Prey items in the following categories will be enumerated: large calanoid copepods (>2.5 mm), small calanoid copepods (<2.5 mm), harpacticoid copepods, and other. The prey biomass in each category will be estimated by multiplying the number of individuals in each category by the mean dry weight of the individuals in that category. Fry will be weighed to an accuracy of 0.01 g before dissection.

Prey composition of the diet in 1989 will be examined using separate chi-squared tests on the proportion of stomach contents weight in each of four prey categories. The analysis will test for differences (P=0.05) in the proportion of stomach contents weight among prey categories between oiled and non-oiled areas. Analysis of covariance will be used to test for differences (P=0.05) in stomach contents weight between oiled and non-oiled areas. Variables in the analysis will include oil/non-oil area and time-of-day, with fish weight as a covariate. Stomach weight will be examined to determine if a transformation of the data is needed.

Objective A-10:

A bioenergetic model was used to examine whether differences in zooplankton biomass may have caused differences in fry growth between oiled and non-oiled areas of PWS in 1989. The model estimated the feeding rates of juvenile pink salmon at maximum ration between 4 and 14 °C. This is the approximate range of temperatures observed during May and June in PWS in 1989. Feeding rates at specific prey densities were estimated to evaluate whether fry could obtain maximum daily ration.

Kepshire (1976) estimated the growth rates of pink salmon (2.0 - 9.0 g) fed an excess ration at 12.8, 15.5, and 18.3 °C. Kepshire's data was used to relate growth and temperature by

$$G = 0.2141(T) + 1.2813 \quad (3)$$

where G = growth rate (% body weight/day), and T = water temperature (°C). Kepshire (1976) also estimated food consumption for the same experimental group. Gross conversion efficiency may be different for fish in this experiment compared with fish in the wild; therefore, food consumption at maximum ration was estimated by a simple mass balance equation:

$$I_m = \frac{G - R}{A} \quad (4)$$

where I_m = food consumption (cal/day), R = total metabolism (cal/day), and A = assimilation coefficient. An assimilation coefficient of 0.85 was used (Ware 1975). Energy content was assumed to be 5400 cal/g dry weight (Griffiths and Dillinger 1991). In the present study, total metabolism was assumed to be equal to active and feeding metabolism. Total metabolism is composed of energy expenditures for maintenance, activity, feeding, and migration (Brett and Groves 1979).

Brett and Glass (1973) estimated the active metabolism (including maintenance metabolism) of sockeye salmon at the critical swimming speed. The critical swimming speed is the maximum speed that can be sustained without incurring an oxygen debt. The critical swimming speed is typically 2.5 to 3.0 body lengths per second. Juvenile pink salmon appear to swim at this speed while feeding along steep rocky shorelines (Bailey et al. 1975). Brett and Glass (1973) provided parameter estimates for power functions relating active metabolism to body weight at three temperatures. This data was used to estimate the active metabolism of a 1 g pink salmon at 5.3 and 15.0 °C. Metabolic rates at other temperatures were estimated assuming a linear relationship between temperature and metabolic rate. An oxycalorific equivalent of 3.25 cal/mg O^2 was used to convert oxygen consumption to calories (Brett and Groves 1979).

Feeding metabolism is a function of food consumption, i.e. $R_f = sI$, where s is the weighted mean of the specific dynamic action factors associated with protein, lipid, and carbohydrate catabolism (~0.16, Ware 1975). Feeding metabolism was added to active metabolism after an initial estimate of food consumption. Food consumption including feeding metabolism was then estimated again using equation 4.

The time required for a 1 g pink salmon to obtain maximum daily ration at specific prey densities was estimated to evaluate whether prey density limited fry growth in 1989. The range of prey densities used in this analysis included the lowest density measured in PWS in 1989 (Wertheimer 1990). Holling (1966)

estimated the feeding rate of invertebrates in relation to prey density by

$$I_f = \frac{\gamma p U}{1 + \gamma p U h} \qquad (5)$$

where I_f = the feeding rate ($g\ sec^{-1}$), γ = the cross-sectional area of the reactive field (cm^2), p = the prey density ($g\ cm^{-3}$), U = the swimming speed (cm/sec), and h = the prey handling time (sec/g). Ware (1975, 1978) used this equation to estimate the feeding rate of fish. To account for prey that are attacked but not captured, equation (5) was multiplied by the prey capture success rate. A prey capture success rate of 85% is typical for juvenile fishes (Ware 1972).

The cross-sectional area of the reactive field (γ) is estimated by $\gamma = \pi(d_r)^2$, where d_r = the reactive distance. The reactive distance, the distance at which a fish will approach prey, is a function of fish size (Ware 1978) and prey size (Ware 1972). Reactive distance (d_r) increases more rapidly than fish length (L_f), i.e. $d_r \propto L_f^{1.1}$ (Ware 1978). Data from Ware (1972) were used to relate reactive distance to fish length and prey length by

$$d_r = 0.29\ L_f^{1.1} + 3.3\ L_p \qquad (6)$$

(R^2=0.96, P<0.005), where d_r = the reactive distance (cm), L_f = total fish length (cm), and L_p = prey length (mm). Pink salmon swim at 11 to 20 cm/sec when feeding in currents (Bailey et al. 1979). In the present study, an average swimming speed of 15 cm/sec was used. For a 1 g pink salmon (L_f = 5.0 cm), this is approximately the critical swimming speed. Parsons and LeBrasseur (1973) estimated the feeding rates of juvenile pink salmon in tanks at different prey densities. Their data could not be used to estimate feeding rates because the prey densities in their experiment were an order of magnitude greater than those measured in PWS. Their data were used to estimate handling times for fish feeding on Pseudocalanus spp. and Neocalanus plumchrus assuming an experimental duration of two hours. The ratio I_m/I_f was used to estimate the amount of time (hours) required for a fish to obtain maximum daily ration.

Objective B-1 & B-2:

The total number of CWT fish recovered at different sites was mapped for each hatchery in each year. A qualitative comparison of migration patterns was made by simple visual evaluation of the maps from 1989, 1990 and 1991.

Objective D-1:

A linear regression analysis (Draper and Smith 1981) was conducted to determine the relationship between fry-to-adult survival estimated in NRDA Fish/Shellfish Study No. 3 and mean fry growth of CWT fish. Data from tag code lots released in 1989 and 1990 with a sufficient number ($n \geq 15$) of CWT fry recoveries was used in the analysis. The regression equation was used to examine possible differences between estimated and predicted survival of fry in oiled and non-oiled areas in 1989.

Preliminary Study Results

Objective A-1:

There was a significant difference in growth rate among tag code lots released from WHN Hatchery in 1989 ($P<0.001$); from WHN ($P<0.001$), AFK ($P=0.03$), and Cannery Creek ($P<0.001$) Hatcheries in 1990; and a marginal difference ($P=0.07$) among tag lots released from WHN Hatchery in 1991. Multiple comparison tests indicated that, in general, tag codes could be combined by release groups employed at the hatcheries. Release groups, based on zooplankton abundance and feeding regime at the hatchery, include early-fed (fry fed 1-2 weeks and released at high zooplankton abundance), direct release or unfed (fry fed 2-5 days and released at high zooplankton abundance), and late-fed (fry fed 1-2 weeks and released as zooplankton abundance declines). Such groupings also allowed better comparison of results in 1990 and 1991 to those in 1989 when only 1 tag code was used for a release group at each hatchery. This approach also provided an objective way of combining the large number of tag codes released by the Prince William Sound Aquaculture Corporation (PWSAC) in 1990 and 1991.

Differences in growth existed in 1989 ($P=0.006$) and 1991 ($P<0.001$) among the release groups (Table 1). Multiple comparisons showed no consistent groupings across years. This result is not surprising because differences in environmental and rearing conditions at time-of-release would make growth among the release groups quite variable. Because tag codes could not be combined further, we examined the number of tag recoveries within each release group to determine which groups had enough recoveries to test effects of oil/non-oil recovery area and time on growth. Of all tag recoveries during the 3 years, 82% were from PWSAC hatcheries. The early-fed release groups from AFK and WHN Hatcheries consistently comprised the largest proportion of recoveries from PWSAC facilities (39% and 24% in 1989, 35% and 17% in 1990, and 42% and 32% in 1991, respectively). In 1989 and 1990 at least 47% of tag recoveries of early-fed fry occurred within 30 days after release. As the field season progressed

beyond 30 days after release, few tags were recovered in both oiled and non-oiled areas. In 1991, a smaller proportion of fry were recovered within 30 days after release because the field crew began sampling later than in the previous 2 years. To allow consistent comparison among all 3 years, the analyses of effects of oil/non-oil recovery area on growth were restricted to early-fed releases from AFK and WHN Hatcheries recovered within 30 days after release.

In 1989, growth rates of AFK Hatchery fry were significantly lower ($P<0.003$) in the heavily oiled area near the hatchery than along the lightly oiled southern coast of Knight Island. Growth rates of AFK Hatchery fry recovered during the third recovery time period were not significantly different ($P=0.39$) in these areas in 1990. This was the only time period in which early-fed AFK Hatchery pink salmon fry were recovered in both oiled and non-oiled areas. In 1991, growth rates of AFK Hatchery fry were again significantly lower ($P<0.001$) in the previously oiled area, but the magnitude of the difference was nearly half that observed in 1989. Growth rates of fry released from the WHN Hatchery were lower in oiled than in non-oiled areas in 1989, but the difference was marginally significant ($P=0.12$). Growth rates of WHN Hatchery fry were not significantly different between oiled and non-oiled areas in 1990 ($P=0.30$) and 1991 ($P=0.44$).

The ln(length):ln(weight) slope estimates were not significantly different ($P>0.15$) between oiled and non-oiled areas for AFK and WHN Hatcheries in 1989 and 1990 (Table 2). In 1991, the slope estimate was significantly greater for AFK Hatchery fry ($P<0.001$) recovered in oiled areas but was greater for WHN Hatchery fry ($P=0.03$) recovered in non-oiled areas.

Objective A-2:

Analyses of early-fed fry released from AFK Hatchery in 1989 indicated that otolith measurements can be used to back calculate fish body weight at age. Otolith radius length was proportional to fish body weight (Figure 2a). Regression of fish age on otolith increment count resulted in a slope nearly equal to one, indicating that increments were generally formed each day (Figure 2b).

Objective A-3:

Results from MFO analyses generally coincided with the degree of oil contamination observed in the sampling area. Fish captured in the moderately to heavily oiled area near the AFK Hatchery (area 4) exhibited strong to moderate MFO activity (Table 3). Fish captured in the non-oiled area near Cannery Creek Hatchery (area 1) exhibited very mild or negative MFO activity. Fish captured

along the southern coast of Knight Island (area 5) exhibited declining MFO activity over time, coincident with an apparent decline in oil contamination in the area. Small wild stock fry captured in area 5 exhibited a slightly lower MFO activity than larger fish that likely originated from the AFK Hatchery. These differences may not be significant, however, because MFO activity in blind replicate samples also differed slightly.

The distribution of stained monoclonal antibodies indicated that hydrocarbons were taken up primarily through the gills and secondarily through the gastrointestinal tract. Of the 104 fish exhibiting some level of MFO activity, 51% and 19% exhibited staining in the gills and gastrointestinal tract, respectively.

Objectives A-4 & A-5:

Otolith data from 73 early-fed fry released from the AFK Hatchery in 1989 has been analyzed at this time. Repeated measures analysis of covariance of weekly growth estimates obtained from otoliths indicated a significant (P=0.05) time-by-area interaction (Table 4). Growth rates of fish remaining in the heavily oiled area near AFK Hatchery (area 4) declined over time while the growth of fry that migrated to the relatively lightly oiled southern coast of Knight Island (area 5) showed no decline (Figure 3). Growth rates of fry recovered from these two areas were not significantly different from each other until the third week (P=0.003) after release (Table 5). Growth rates of fish during the third week after release were significantly different (P=0.04) from the first week in area 4 (Table 6).

Objectives A-6 & A-7:

Regression of environmental variables against weekly growth rate estimates obtained from otoliths cannot be completed until all otoliths are processed.

Objectives A-8 & A-9:

Laboratory analyses of stomach contents are not yet completed.

Objective A-10:

The estimated temperature-specific growth rates at maximum ration were within the range of growth rates measured for pink salmon fry in PWS (Table 7). Gross growth conversion efficiencies were within the normal range for juvenile fish (Brett and Groves 1979).

Estimated times required to obtain maximum daily ration indicated that growth of pink salmon fry likely was not affected by small-scale differences in zooplankton biomass between oiled and non-oiled areas during May 1989. This conclusion is based on the assumption that fry feed continuously during daylight (20 hours per day) if necessary to obtain maximum daily ration. Field observations indicate that pink salmon fry feed continuously throughout the day (Parker and Vanstone 1966). Within the range of zooplankton biomass observed during May, fry growth is not food limited if large copepods (Neocalanus plumchrus) are consumed or water temperatures are below 8° C (Table 8). In May 1989, the biomass of large copepods ranged from 0.10 to 1.20 g/m^3, and water temperatures were generally less than 10° C. Diets of pink salmon fry (April-June 1989) were composed of large copepods (20-81%), small copepods (5-43%), and various other species (Wertheimer 1990). Under these conditions, pink salmon fry will likely obtain maximum daily ration.

Fry growth may have been affected by small-scale differences in zooplankton biomass between oiled and non-oiled areas in June 1989. At that time, zooplankton biomass decreased to less than 0.10 g/m^3 and temperatures exceeded 10° C. Under these conditions, fry may not obtain maximum daily ration if feeding exclusively on small copepods (Pseudocalanus spp.) (Table 8).

Objectives B-1 and B-2:

The migration of CWT fish from AFK Hatchery in 1989 appeared to be affected by heavy oil contamination near the hatchery. A total of 113 CWT fish from AFK Hatchery were recovered along the southern coast of Knight Island (area 5) in 1989 (Figure 4). In 1990 and 1991, only 14 and 43 CWT fish from AFK Hatchery were recovered in area 5, respectively (Figures 5 and 6). Visual observations also indicated that much higher numbers of salmon fry were present in area 5 in 1989 than in 1990 and 1991. The relatively high catch of CWT fish in this area in 1991 resulted from a large amount of effort on relatively few fish to obtain enough CWT fry for comparison of growth rates between years.

Objective D-1:

There was a significant (P=0.009) linear relationship between fry-to-adult survival and mean growth rate for tag codes released in 1989 (Figure 7). Fry released in 1990 and recovered as adults in 1991 showed no significant (P=0.49) linear relationship. Mean fry-to-adult survival of a number of tag codes released in 1990 was 4.4% (Figure 7).

Status of Injury Assessment

Objective A-1:

In 1989, growth rates of early-fed AFK Hatchery fry were significantly lower ($P<0.003$) in the heavily oiled area near the hatchery than along the lightly oiled southern coast of Knight Island. Growth rates of AFK Hatchery fry were not significantly different ($P=0.39$) in these two areas in 1990. In 1991, growth rates of AFK Hatchery fry were again significantly lower ($P<0.001$) in the previously oiled area, but the magnitude of the difference was nearly half that observed in 1989. Growth rates of fry released from the WHN Hatchery were lower in oiled than in non-oiled areas in 1989, but the difference was marginally significant ($P=0.12$). Growth rates of WHN Hatchery fry were not significantly different between oiled and non-oiled areas in 1990 ($P=0.30$) and 1991 ($P=0.44$). Analyses of length:weight regression slopes as a measure of condition were inconclusive.

Objective A-2:

Otolith samples from the early-fed group released from the AFK Hatchery in 1989 have been analyzed. Otolith radius length and increment count were significantly related ($P<0.001$) to fish body weight and age. Otolith increments were generally formed each day.

Objective A-3:

Results from MFO analyses generally coincided with the degree of oil contamination observed in the sampling area. Fish captured in the moderately to heavily oiled area near the AFK Hatchery exhibited strong to moderate MFO activity. Fish captured in the non-oiled area near Cannery Creek Hatchery exhibited very mild or negative MFO activity. Fish captured along the southern coast of Knight Island exhibited declining MFO activity over time, coincident with an apparent decline in oil contamination in the area. The distribution of stained monoclonal antibodies indicated that hydrocarbons were taken up primarily through the gills and secondarily through the gastrointestinal tract. Of the 104 fish exhibiting some level of MFO activity, 51% and 19% exhibited staining in the gills and gastrointestinal tract, respectively.

Objectives A-4 & A-5:

Otolith data from 73 early-fed fry released from the AFK Hatchery in 1989 has been analyzed. Weekly otolith growth estimates showed a significant ($P=0.05$) time-by-area interaction. Growth rates of

fish remaining in the heavily oiled area near AFK Hatchery (area 4) declined over time while the growth of fry that migrated to the relatively lightly oiled southern coast of Knight Island (area 5) did not decline. Growth rates of fry recovered from these two areas were not significantly different from each other until the third week (P=0.003) after release. Growth rates of fish during the third week after release were significantly different (P=0.04) from the first week in area 4.

Objectives A-6 & A-7:

Regression of environmental variables against weekly growth estimates obtained from otoliths cannot be completed until all otoliths are processed.

Objectives A-8 & A-9:

Laboratory analyses of stomach contents are not yet completed.

Objective A-10:

Results from a bioenergetic model indicated that fry growth likely was not affected by small-scale differences in zooplankton biomass between oiled and non-oiled areas of PWS during May 1989. Within the range of zooplankton biomass observed during May, fry growth is not food limited if large copepods (Neocalanus plumchrus) are consumed or water temperatures are below 8° C. In May 1989, the biomass of large copepods ranged from 0.10 to 1.20 g/m^3, and water temperatures were generally less than 10° C. Diets of pink salmon fry (April-June 1989) were composed of large copepods (20-81%), small copepods (5-43%), and various other species (Wertheimer 1990). Model output indicated that pink salmon fry will likely obtain maximum daily ration under these conditions.

Fry growth may have been affected by small-scale differences in zooplankton biomass between oiled and non-oiled areas in June 1989. At that time, zooplankton biomass was less than 0.10 g/m^3 and temperatures exceeded 10° C. Under these conditions, fry may not obtain maximum daily ration if feeding exclusively on small copepods (Pseudocalanus spp.).

Objectives B-1 & B2:

The migration of CWT fish from AFK Hatchery appeared to be affected by heavy oil contamination near the hatchery in 1989. A total of 113 CWT fish from AFK Hatchery were recovered along the southern coast of Knight Island in 1989. In 1990 and 1991, only

14 and 43 coded-wire tagged fish from AFK Hatchery were recovered in this area, respectively. Visual observations also indicated that juvenile salmon were more abundant along the southern coast of Knight Island in 1989 than in 1990 and 1991.

Objective D-1:

Pink salmon fry growth in 1989 was significantly related (P=0.009) to fry-to-adult survival. A reduction of fry growth of 1% body weight per day resulted in a 2.5% reduction in survival to the adult stage. Fry growth in 1990 was not significantly related (P=0.49) to fry-to-adult survival.

Future Research Needs

Completion of additional analyses will strengthen the evidence of the impacts of oil on the growth and survival of juvenile pink salmon. Analyses of otoliths from untagged fry will provide additional fry growth estimates for areas and times when few CWT fry were recovered. Analyses of stomach contents and zooplankton samples will improve our knowledge of how environmental conditions may have affected fry growth in oiled and non-oiled areas. Studies examining the effects of temperature on growth are needed to eliminate temperature differences as a possible cause of observed growth differences between oiled and non-oiled areas. MFO analyses of untagged fry will provide evidence of the degree of oil contamination of fry in oiled and non-oiled areas.

Objectives (to be completed in oil year 4):

1. Complete microstructural analyses of otoliths from CWT and selected untagged fry collected in 1989, 1990, and 1991. Use repeated measures analysis of variance to test for differences (P=0.05) in weekly growth rate estimates obtained from otoliths between oiled and non-oiled areas.

2. Complete additional analyses of stomach contents of fry collected in 1990 and 1991. Use chi-square tests and analysis of covariance to test for differences (P=0.05) in prey composition and stomach contents weight, respectively, between oiled and non-oiled areas.

3. Complete analyses of zooplankton samples collected in 1991. Use chi-square analysis and analysis of variance to test for differences (P=0.05) in species composition and biomass, respectively, between oiled and non-oiled areas.

4. Conduct a laboratory experiment to determine the effect of temperature (4 - 14° C) on the growth of pink salmon fry

(0.2 - 2.0 g) fed an excess ration.

5. Complete MFO analyses of samples of untagged fry collected at different times in oiled and non-oiled areas in 1989 and 1990.

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Table 1. Mean growth rate of coded-wire tagged pink salmon fry from different hatcheries and release groups recovered in Prince William Sound in 1989-1991.

Hatchery	Release[a] Group	1989			1990			1991		
		n	$\bar{x}$	SE	n	$\bar{x}$	SE	n	$\bar{x}$	SE
AFK	EF	248	4.07	0.09	272	4.37	0.04	315	3.06	0.04
	UF	51	2.71	0.18	97	3.81	0.05	53	3.00	0.09
	LF	24	3.92	0.30	63[b]	5.22	0.16	92	5.58	0.23
	OT	80	3.04	0.24						
	Total	403	3.69	0.08	432	4.36	0.04	460	3.56	0.07
WHN	EF	150	4.70	0.16	126	3.18	0.25	236	3.43	0.04
	UF	21	4.06	0.51	25	2.94	0.38	24	2.84	0.16
	LF	7	9.92	1.67	12	6.98	1.69			
	OT				43	2.45	0.36			
	Total	178	4.83	0.18	206	3.22	0.21	260	3.38	0.04
Cannery Creek	EF	18	5.42	0.26	21	4.74	0.13	24	3.14	0.12
	UF	15	4.19	0.16	8	4.61	0.30			
	LF	24	3.99	0.28	84	5.14	0.21	4	2.80	0.11
	Total	57	4.49	0.17	113	5.03	0.16	28	3.09	0.11

[a] EF = early-fed (fed 1-2 weeks and released at high zooplankton abundance), UF = unfed (fed 2-5 days and released at high zooplankton abundance), LF = late-fed (fed 1-2 weeks and released during declining zooplankton abundance), and OT = other release groups.

[b] Excludes 8 fry.

Table 2. Mean growth rate of coded-wire tagged pink salmon fry recovered within 30 days after release and length-weight parameter estimate of all fry recovered from early-fed release groups from Armin F. Koernig (AFK) and Wally H. Noerenberg (WHN) Hatcheries in Prince William Sound from 1989-1991.

Year	Hatchery	Recovery Area	Growth			Condition		
			n	$\bar{x}$	SE	n	Slope[a]	SE
1989	AFK	Non-oil	95	4.78	0.11	119	3.27	0.06
		Oil	64	3.16	0.17	129	3.30	0.08
	WHN	Non-oil	101	4.89	0.21	119	2.90	0.08
		Oil	23	3.72	0.40	31	3.15	0.13
1990	AFK[b]	Non-oil	13	5.17	0.23	14	3.14	0.49
		Oil	114	4.55	0.07	258	2.79	0.04
	WHN	Non-oil	73	2.67	0.40	95	3.28	0.11
		Oil	8	1.49	0.51	31	3.13	0.08
1991	AFK	Non-oil	39	3.42	0.08	43	1.70	0.21
		Oil	59	2.51	0.08	272	2.66	0.04
	WHN	Non-oil	29	3.39	0.17	116	3.05	0.08
		Oil	15	3.65	0.27	120	2.81	0.07

[a] Slope parameter estimate of linear regression of ln(weight) on ln(length).

[b] Analysis only for recovery time period 3.

Table 3. Summary of results from MFO analyses of untagged pink salmon fry captured in oiled and non-oiled areas in 1989.

Set Number	Capture Date	Capture Area	No. CWT[a]	Mean Length[b]	Origin[c]	Oil[d]	MFO Activity
BS104	6/08	1	16	50	CC	none	very mild
BS141	6/24	1	3	60	CC	none	negative
BS164	7/01	1	4	52	CC	none	negative
BS166	7/01	1	4	50	CC	none	negative
BS068	5/21	4	6	40	AFK	moderate	moderate
BS092	6/02	4	6	40	AFK	moderate	moderate
BS095	6/05	4	27	50	AFK	moderate	moderate
BS095	6/05	4	27	44	AFK	moderate	strong
BS072	5/22	5	34	45	AFK	light	strong
BSO72	5/22	5	34	49	AFK	light	moderate
BS097	6/06	5	15	62	AFK	light	moderate
BS097	6/06	5	15	48	Wild	light	mild
BS101	6/06	5	5	66	AFK	none	mild
BS101	6/06	5	5	38	Wild	none	very mild
BS135	6/22	5	3	55	Wild	none	very mild
PS004	6/22	5	4	66	AFK	none	negative

[a] Number of coded-wire tagged fish captured in the set.
[b] Average length of fish selected for MFO analysis.
[c] Probable origin of fish selected for MFO analysis.
[d] Degree of oil contamination in the sampling area.

Table 4. Repeated measures analysis of covariance of back-calculated weekly growth rates obtained from otoliths examining between subject and within subject effects.

Source	DF	Type III SS	Mean Square	F	Prob>F
Between Subject Effects					
BW0[a]	1	0.1941	0.1941	0.10	0.75
Area	1	7.7055	7.7055	4.07	0.05
Error	70	132.6826	1.8954		
Within Subject Effects					
Time	2	0.2809	0.1404	0.61	0.55
Time*BW0	2	0.0768	0.0384	0.17	0.85
Time*Area	2	1.4036	0.7018	3.03	0.05
Error	140	32.4015	0.2314		

[a] BW0 = body weight at release, Area = oiled or lightly oiled recovery area.

Table 5. Analysis of covariance by week of back-calculated weekly growth rates obtained from otoliths.

Source	DF	Type I SS	Mean Square	F Value	Prob>F
First Week					
BW0[a]	1	0.0252	0.0252	0.03	0.87
Area	1	1.0301	1.0301	1.06	0.31
Error	70	67.7295	0.9675		
Second Week					
BW0	1	0.0001	0.0001	0.00	0.99
Area	1	1.5156	1.5156	2.22	0.14
Error	70	47.7130	0.6816		
Third Week					
BW0	1	0.1016	0.1016	0.14	0.71
Area	1	6.5634	6.5634	9.26	0.003
Error	70	49.6415	0.7091		

[a] BW0 = body weight at release, Area = oiled or lightly oiled recovery area.

Table 6. Repeated measures analysis of covariance of back-calculated weekly growth rates obtained from otoliths examining differences in growth between the first and second weeks, and between the first and third weeks.

Source	DF	Type III SS	Mean Square	F Value	Prob>F
First and second weeks					
BW0[a]	1	0.0189	0.0189	0.04	0.85
Area	1	0.0467	0.0467	0.10	0.76
Error	70	34.4175	0.4916		
First and third weeks					
BW0	1	0.0620	0.0620	0.11	0.74
Area	1	2.3931	2.3931	4.40	0.04
Error	70	38.0347	0.5433		

[a] BW0 = body weight at release, Area = oiled or lightly oiled recovery area.

Table 7. Estimated growth rate (%BW/day), feeding rate (%BW/day), and gross conversion efficiency (%) at different temperatures (°C) for a 1.0 g pink salmon provided an excess ration.

Temperature	Growth	Feeding Rate	Conversion Efficiency
4	2.1	8.3	25
6	2.6	10.2	25
8	3.0	12.1	25
10	3.4	14.0	24
12	3.9	15.9	24
14	4.3	17.9	24

Table 8. Estimated time (hours) for a 1.0 g pink salmon to obtain maximum ration at different temperatures (°C) when feeding on Pseudocalanus spp. and Neocalanus plumchrus.

	Prey Biomass (g wet wt/ m^3)					
Temperature	0.001	0.010	0.100	1.000	1.500	2.000
Pseudocalanus spp.						
4	27.5	15.2	14.0	13.9	13.9	13.9
6	33.9	18.8	17.2	17.1	17.1	17.1
8	40.3	22.3	20.5	20.3	20.3	20.3
10	46.7	25.8	23.7	23.5	23.5	23.5
12	53.0	29.4	27.0	26.8	26.7	26.7
14	59.4	32.9	30.2	30.0	30.0	30.0
Neocalanus plumchrus						
4	5.1	3.4	3.2	3.2	3.2	3.2
6	6.3	4.2	4.0	4.0	4.0	4.0
8	7.5	5.0	4.7	4.7	4.7	4.7
10	8.7	5.8	5.5	5.5	5.5	5.5
12	9.8	6.6	6.2	6.2	6.2	6.2
14	11.0	7.4	7.0	7.0	7.0	7.0

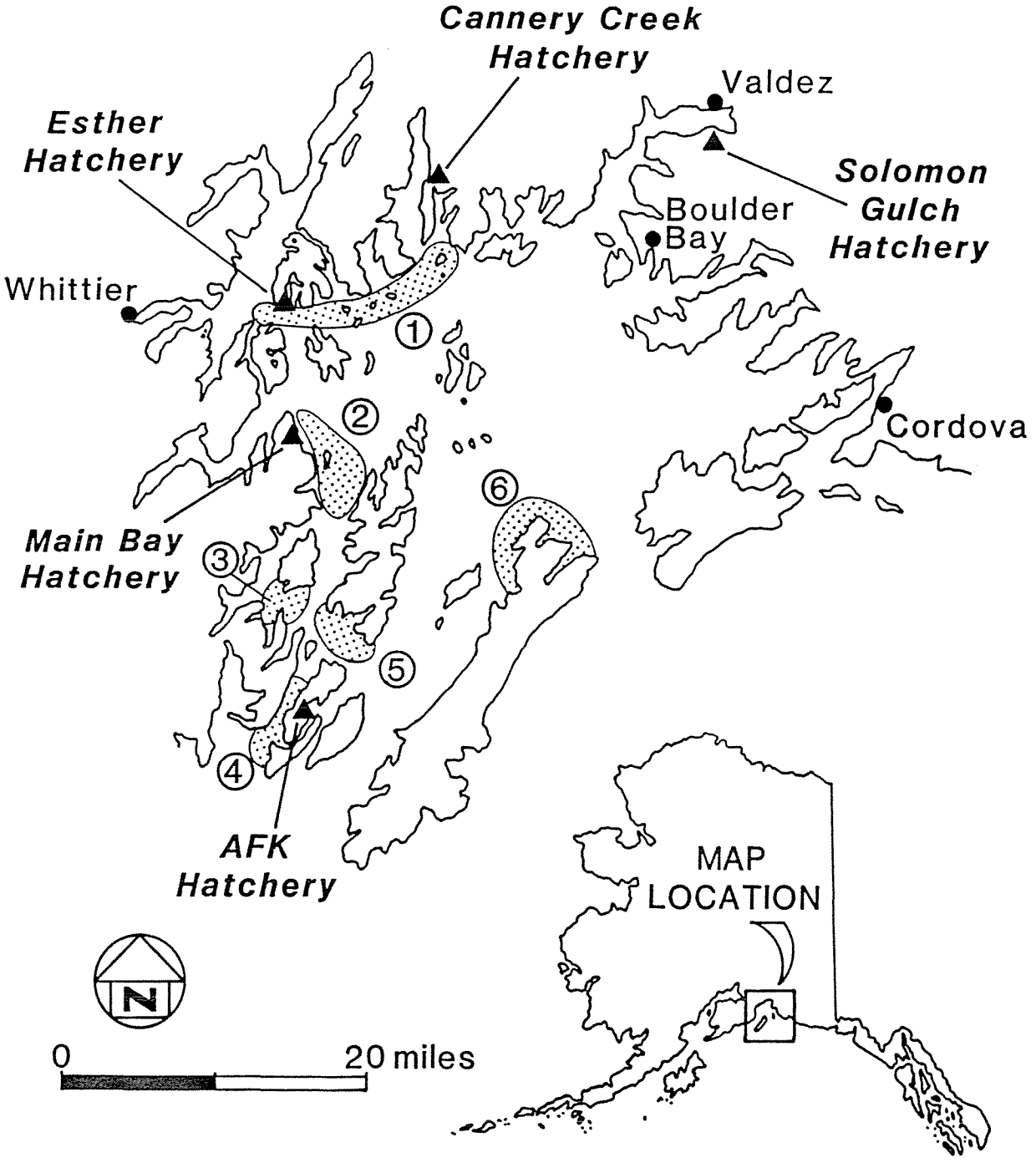

Figure 1: Six areas sampled for juvenile salmon in Prince William Sound in 1989, 1990, and 1991.

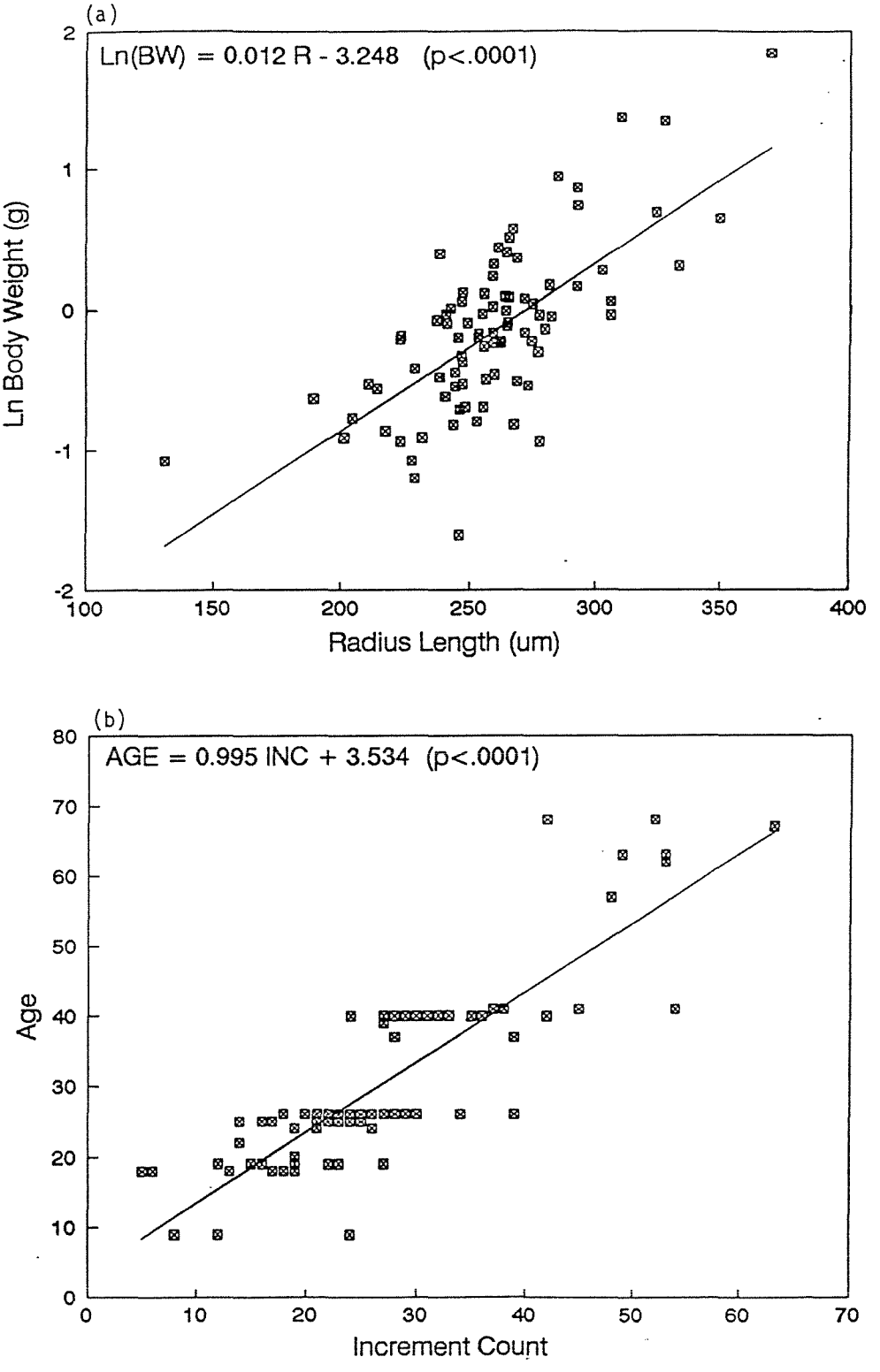

Figure 2: Regression of (a) ln(body weight) on otolith radius length and (b) fish age on otolith increment count. Data from the early-fed treatment group released from the Armin F. Koernig Hatchery in 1989.

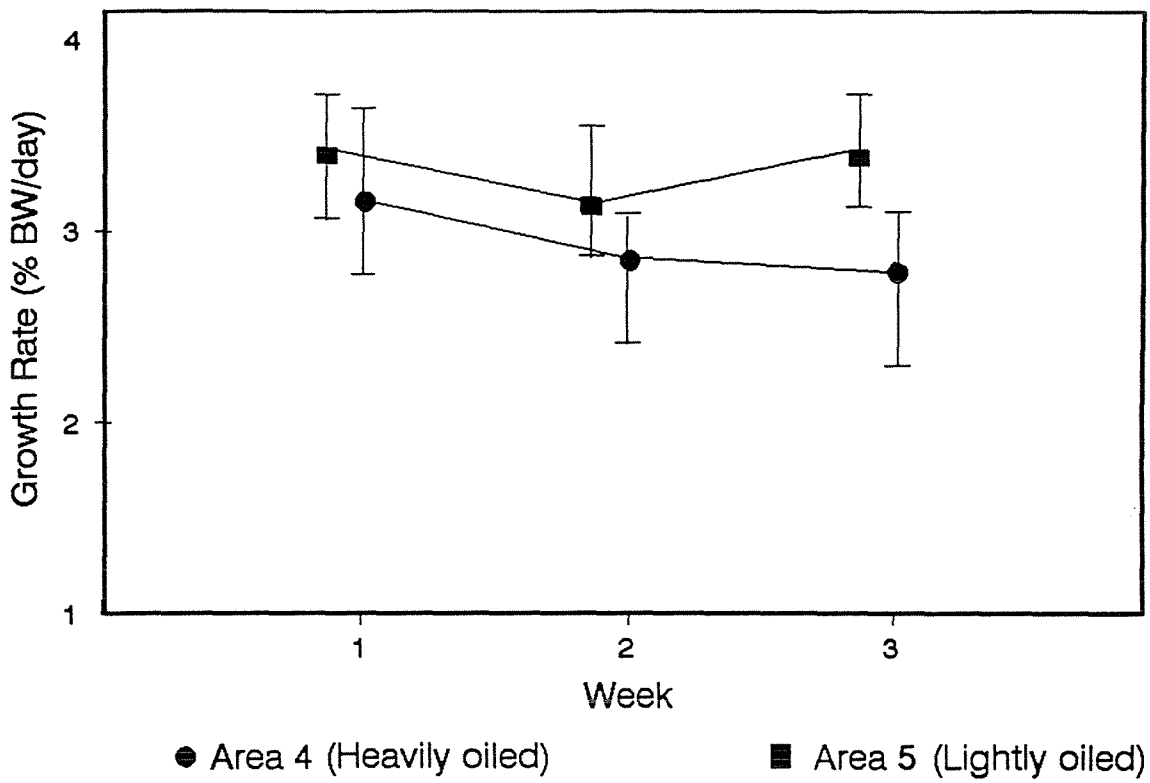

Figure 3: Back-calculated weekly mean growth rates obtained from otoliths with 95% confidence intervals. Data from the early-fed treatment group released from the Armin F. Koernig Hatchery in 1989.

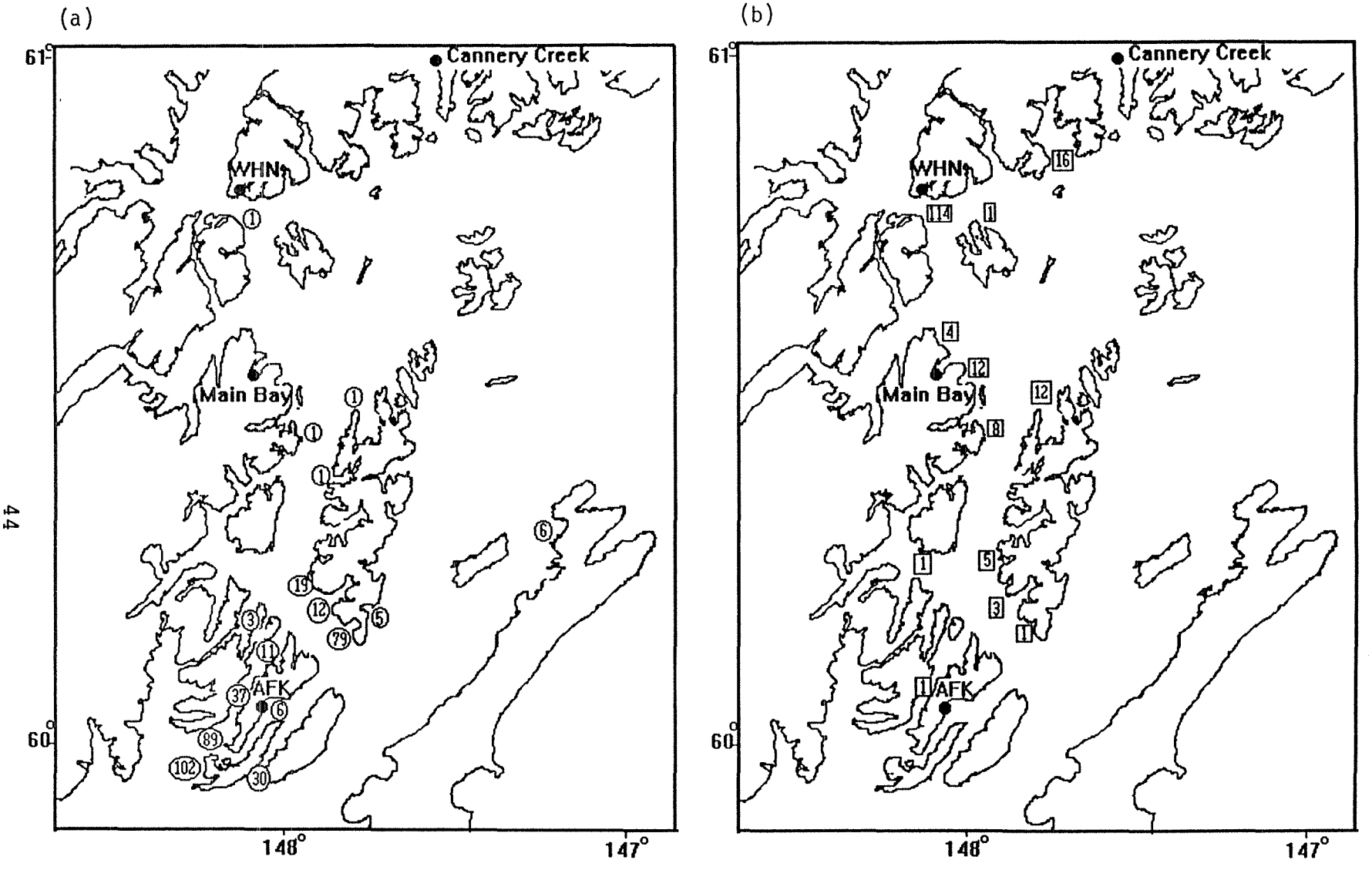

Figure 4: Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1989: (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.

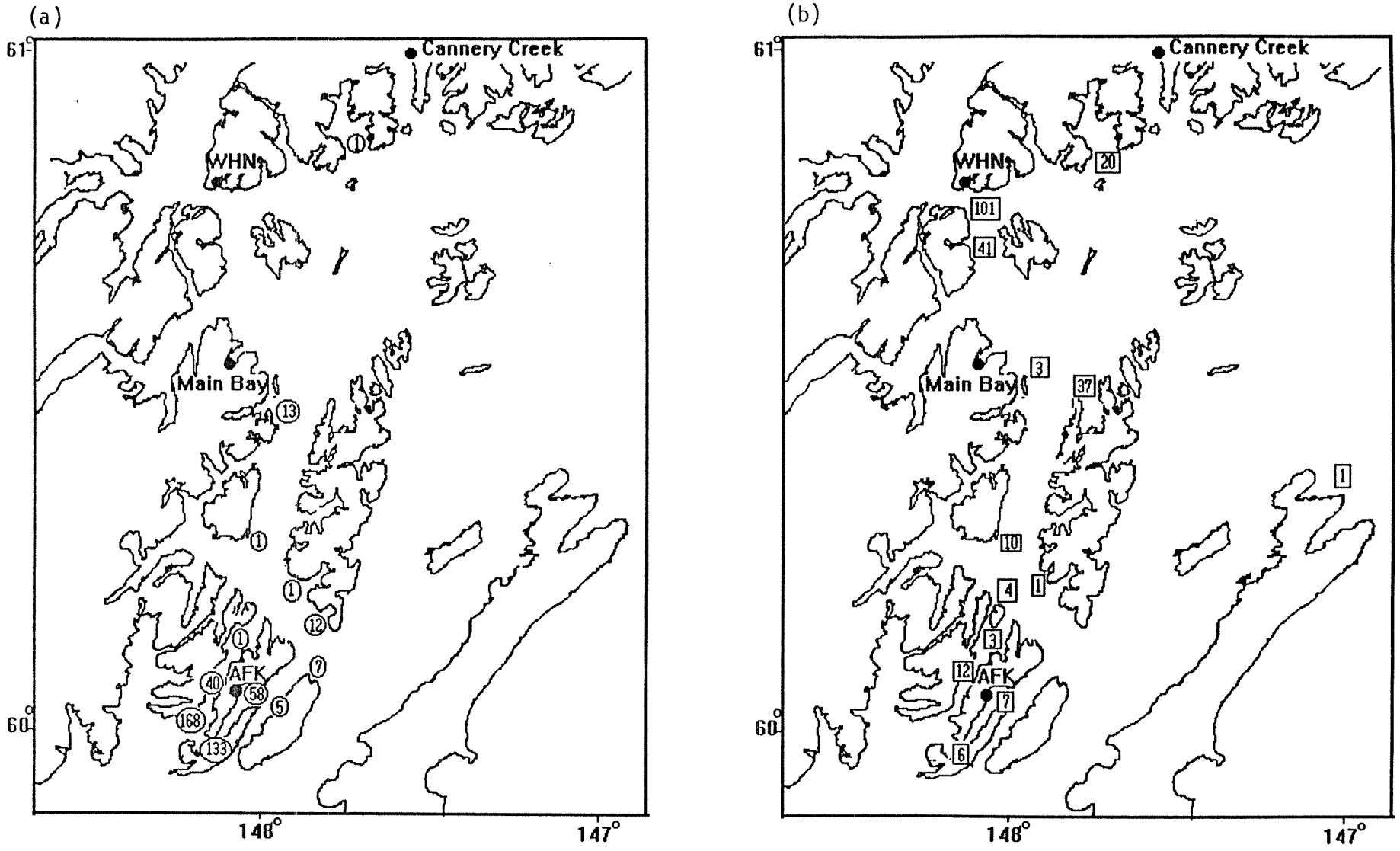

Figure 5: Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1990: (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.

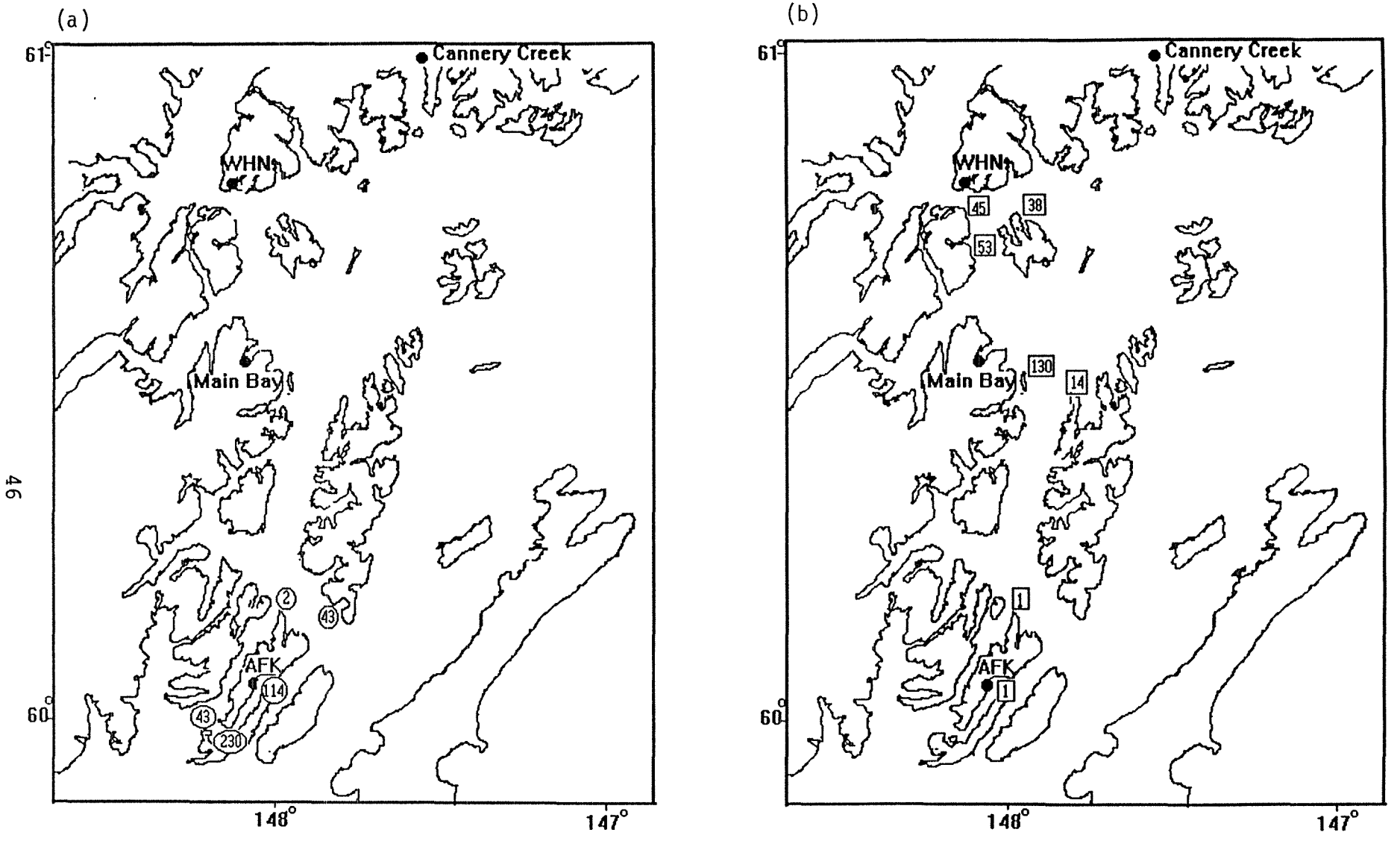

Figure 6: Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1991. (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.

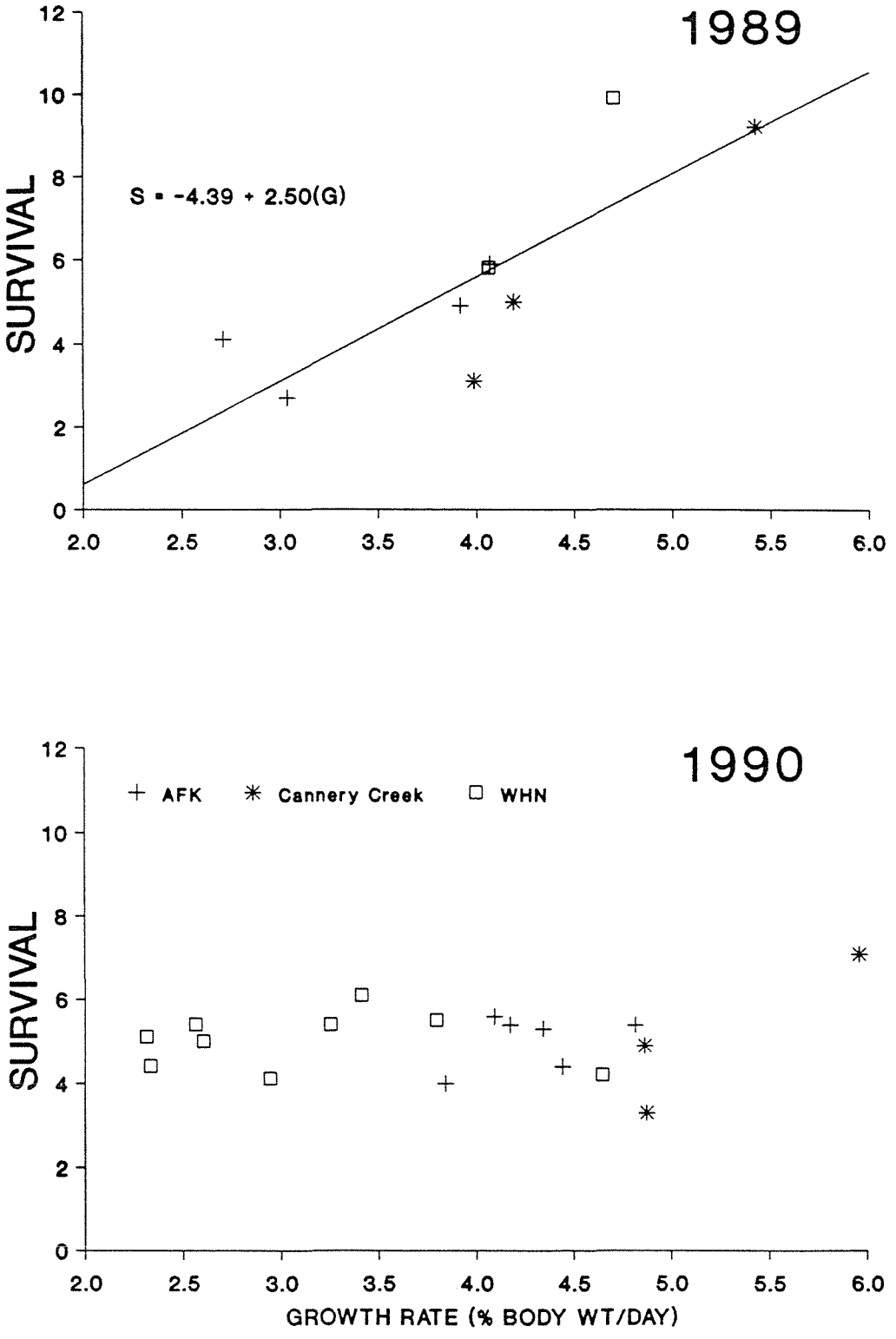

Figure 7. Relationship between fry-to-adult survival and mean growth rate by coded-wire tag code for pink salmon fry released into Prince William Sound in 1989 and 1990.

NATURAL RESOURCE DAMAGE ASSESSMENT
DRAFT STATUS REPORT 1991

Impact of Oil Spill on Juvenile Pink and Chum Salmon and their Prey in Critical Nearshore Habitats

Fisheries Study Number 4
NMFS Component

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PROJECT 4. NMFS COMPONENT: IMPACT OF OIL SPILL ON JUVENILE PINK AND CHUM SALMON AND THEIR PREY IN CRITICAL NEARSHORE HABITATS

Executive Summary

The objectives of the NMFS component of F/S-4 were to determine the impact of the oil spill on juvenile pink and chum salmon during their initial period of marine residency in nearshore habitats. Field studies in 1989 and 1990 compared (1) distribution, abundance, size and nominal growth rates; (2) exposure to and contamination by hydrocarbons; (3) feeding habits; and (4) prey abundance for these fish between pairs of oiled and non-oiled locations in Western Prince William Sound. The effects of oiled sediments on the littoral prey resources of juvenile salmon were also examined. In 1991, field work was discontinued, and a laboratory study was initiated examining the effects of ingestion of food contaminated with whole oil. The emphasis was on juvenile pink salmon, both because of their economic value and because of their numerical abundance relative to other salmon species.

Based on the analyses to date of field and laboratory samples, we have reached a series of preliminary conclusions regarding the impacts of oil in the nearshore marine environment. Juvenile pink and chum salmon were contaminated by oil in 1989; the probable route of contamination was through ingestion of whole oil, either directly or by feeding on contaminated prey. Growth was reduced in pink salmon in oiled areas in 1989 as a physiological consequence of this contamination. Laboratory studies in 1991 demonstrated that ingestion of whole oil can reduce the growth of juvenile pink salmon at sub-lethal dosages.

There were detectable levels of hydrocarbons in tissues of juvenile pink salmon collected in the nearshore environment of oiled areas of Prince William Sound in 1989 processed to date. In order to test that hydrocarbons detected in samples were not due to external contamination, flesh samples and viscera were processed separately from some samples of fish from oiled locations; both types of tissues were contaminated by hydrocarbons, with higher levels in the viscera. The composition of the hydrocarbon in the tissues indicated that ingestion, either of whole oil or oil-contaminated prey, was the likely route of contamination. Sample processing is still incomplete; additional samples need to be analyzed to finalize these preliminary findings. However, evidence of oil was also observed in the stomachs of a small percentage of pink and chum salmon collected at oiled sites.

Exposure of both pink and chum salmon fry to physiologically significant levels of oil in 1989 was also indicated by levels of mixed-function oxidase (MFO) activity in fry from oiled areas.

MFO activity levels in pink salmon declined by late June 1989, suggesting that the degree of exposure of pink salmon in the nearshore marine environment decreased in late spring, 1989.

Samples of juvenile pink salmon from 1990 processed to date show no evidence of hydrocarbon contamination, indicating a marked decline in the level of exposure of juvenile pink salmon from oil year 1 to year 2. Results for 1990 samples analyzed for MFOs also show no evidence of induced activity in 1990.

Juvenile pink and chum salmon were more abundant in the non-oiled area in both 1989 and 1990. Because the pattern of abundance did not change as exposure levels diminished, we concluded that the differences observed in abundance were more likely due to geographic differences or distribution of spawning populations rather than to exposure to oil.

Juvenile pink salmon moved rapidly from sheltered bays to more exposed, steep shorelines in migration corridors, where they fed predominately on zooplankton. This rapid movement is considered to be an adaptive feeding strategy in response to the distribution of zooplankton in nearshore habitats in Prince William Sound. The observation of this behavior over a wide geographic range reinforces the conclusion drawn in the UAF component of F/S-4, that the presence of oil-deflection boom in Port San Juan in 1989 disrupted the normal migration behavior of fish released from the Armin F. Koerning Hatchery.

Juvenile chum salmon in oiled areas may be more susceptible to hydrocarbon exposure than pink salmon because of their distribution in nearshore habitats. Juvenile chum salmon utilized bays and low gradient shorelines to a greater extent, and thus were more likely to forage over contaminated sediments. Juvenile chum salmon were generally rare in the oiled locations sampled, however.

There were no significant differences observed in the size of juvenile pink salmon between the oiled and non-oiled locations sampled. Pink salmon tended to be larger in the non-oiled area in both 1989 and 1990. There was no evidence of a reduction in condition of juvenile pink salmon in oiled areas: in both 1989 and 1990, pink salmon tended to have a greater weight at a given length in the oiled locations.

There was a significant reduction in the apparent growth rate of juvenile pink salmon in oiled corridors relative to oiled bays in 1989. This reduction was not observed in 1990. This analysis of unmarked fish corroborates the significant reduction in growth of tagged pink salmon in oiled areas reported in the ADFG component of F/S-4. We attribute this reduction in growth to a physiological effect of the observed oil contamination. The laboratory studies in 1991 showed food contaminated by Prudhoe

Bay Crude Oil reduced survival and growth of juvenile pink salmon growth. Temperature, prey availability, and feeding efficiency were as high or higher in oiled locations in 1989, and therefore do not explain the observed reduction in growth.

Juvenile chum salmon were significantly larger in the oiled locations in both 1989 and 1990. As with pink salmon, there was no evidence of a reduction in condition factor in the oiled area. Chum salmon were rarely captured in oiled habitats; there was insufficient data to compare apparent growth rates for this species.

Pelagic zooplankton dominated the diet of juvenile pink and chum salmon in both 1989 and 1990. Calanoid copepods were the primary prey group of zooplankton. There was no indication of reduced feeding of pink or chum salmon in the oiled areas in 1989, based on measures of stomach fullness and numbers and biomass of prey consumed. There was a significant switch in the diet composition of juvenile pink salmon between the oiled and non-oiled areas. In 1989, epibenthic prey was utilized to a greater extent in the non-oiled area than the oiled area, and zooplankton prey was used to a greater extent in the oiled area than in non-oiled area. The reverse pattern was observed in 1990. This switch in diet composition is attributed to differences in the timing and abundance of the spring zooplankton bloom.

We found no evidence of a reduction in available prey organisms of juvenile salmon due to oil contamination. No significant differences were detected in the biomass of pelagic zooplankton between oiled and non-oiled areas in either 1989 or 1990. However, the trend in 1989 was for higher zooplankton biomass in the oiled area; zooplankton biomass declined more rapidly from seasonal peaks in the non-oiled area than in the oiled area. The reverse was true in 1990. Zooplankton biomass was greater in corridors than bays in 1989 and 1990. Epibenthic prey biomass, including harpacticoid copepods, was higher in oiled locations than in non-oiled locations in 1989. This trend could have been due to geographic variability, reduced cropping associated with lower abundance of juvenile pink salmon, or direct enhancement by oil contamination. Preliminary analyses of results from 1990 field studies on epibenthic prey support the latter explanation. Harpacticoid copepods were more abundant in 1990 on heavily oiled beaches than lightly oiled beaches within the same embayment. Although the differences were not significant in the preliminary analysis, harpacticoid copepods and meiofauna also tended to be higher in the oiled sediments in the field experiment examining the colonization of azoic sediments.

CHAPTER 1. INTRODUCTION AND OBJECTIVES

The salmon harvest is the most valuable commercial fishery in Prince William Sound; in 1988, salmon had an ex-vessel value of $76 million dollars, over 80% of the total for all fisheries in the Sound (Anon. 1989). Salmon also represent the largest harvested biomass of the fisheries resources in the Sound. Most of the salmon landed are pink salmon, with chum salmon the second most abundant species. The importance of the salmon resource is reflected in the money and effort the NRDA process has allocated towards studying the effects of the oil spill on these fish.

Early marine residency is a critical phase in the life history of salmon and significantly affects year-class strength (Parker 1968; Walters et al. 1978; Bax 1983; Nichelson 1986. Growth during the early marine phase of pink salmon and chum salmon is extremely rapid (LeBrasseur and Parker 1964; Healey 1980), and is important to escape such mortality mechanisms as size-selective predation (Parker 1971; Hargreaves and LeBrasseur 1985; Mortensen et al. 1991). Food resources must be abundant to sustain high growth rates; standing crops of food organisms must be high (Bailey et al. 1975) or delivered to rearing areas at a high rate by currents (Cooney et al. 1978). Epibenthic prey such as harpacticoid copepods are the main food items in some study areas (Kaczynski et al. 1973; Landingham 1982; Volk et al. 1984), whereas zooplankton such as calanoid copepods and euphasiid eggs and larvae are the predominant prey in others (Bailey et al. 1975; Healey 1980; Cooney et al. 1981). The subarctic marine ecosystem has a highly seasonal production cycle, characterized by high levels of primary and secondary production in the spring (Goering et al. 1973; Larrance 1977; Smetacek et al. 1984). The timing of pink and chum salmon emigration to seawater has presumably evolved to exploit this period of high productivity (Murphy et al. 1988; Holtby et al. 1989). Growth and mortality of juvenile fish may be coupled with the magnitude or timing of spring primary and secondary production (Cushing 1975; D'Amours 1987).

Oil in the marine environment can affect juvenile salmon in a variety of ways. Oil can be directly toxic to salmon; juvenile salmon are especially susceptible when first in seawater (Rice et al. 1975; Rice et al. 1984). Sublethal levels of hydrocarbons can affect metabolism and reduce growth of juvenile salmon (Rice et al. 1975). Sublethal levels of water-soluble hydrocarbons can also damage olfactory lamellar surfaces, conceivably impacting migratory behavior and feeding patterns (Babcock 1985). Oil can also be toxic to meiofauna and zooplankton (Caldwell et al. 1977; Bonsdorff 1981; Gundlach et al. 1983). Mortality, reduction of

reproductive potential, or growth inhibition of prey populations could result in reduced growth of juvenile salmon, and thus increase their exposure to predation. Contamination of prey with water-soluble fraction of crude oil has also been shown to reduce feeding behavior and growth of juvenile salmon (Schwartz 1985).

To determine the impact of the oil spill on juvenile salmon, the NMFS component of FS-4 compared juvenile salmon distribution, abundance, size and nominal growth rates, feeding habits, contamination by hydrocarbons, and prey abundance between pairs of oiled and non-oiled locations in Western Prince William Sound in 1989 and 1990. The effects of oiled sediments on the littoral prey resources of juvenile salmon were also examined. The emphasis was on juvenile pink salmon, both because of their economic value and because of their numerical abundance relative to other salmon species. Some information was also collected for juvenile chum salmon. This status report will expand on the preliminary analysis of the 1989 and 1990 field collections given previously (Wertheimer et al. 1990).

We also summarize preliminary results and the status of analysis of an experiment initiated in 1991 to examine the effects of ingestion of oil-contaminated food on the survival and growth of juvenile pink salmon. One of our preliminary conclusions in the 1990 Status Report was that juvenile pink and chum salmon had been contaminated by oil in the nearshore marine environment, that whole oil and not water-soluble fraction was the probable source of contamination, and that ingestion was the hypothesized route of contamination, either directly or through feeding on contaminated prey. Most research on the effects on hydrocarbon exposure to juvenile salmon has focused on exposure to water-soluble fraction (Rice et al. 1975; Rice et al. 1984) or prey contaminated with water-soluble fraction (Schwartz 1985). There is virtually no information on the effects of whole oil exposure to pink and chum salmon. Such laboratory data is needed to link evidence of ingestion with observed or speculative effects in pink salmon.

Specific objectives for this research are listed below. Because of the diversity and scope of the objectives, we have divided the report into separate chapters. The Introduction and listing of objectives is Chapter 1. Subsequent Chapters will summarize the methods and results for one or more of the objectives. We will then conclude with a section summarizing our preliminary conclusions and the status of injury assessment. The number preceding the objectives listed below indicates the particular Chapter in which the objective is covered.

Objectives

2.A To test the hypothesis that the abundance of juvenile pink

and chum salmon does not differ between oiled and non-oiled areas.

2.B To compare distribution and habitat utilization by juvenile salmon between 1989 and 1990.

2.C To test the hypothesis that the size and growth of juvenile salmon do not differ between oiled and non-oiled areas.

2.D To recover coded-wire tag pink salmon for inclusion in the tag-recovery data base used to determine migratory behavior and specific growth rates of hatchery juvenile salmon (analyzed by ADFG component of F/S-4).

3. To test if hydrocarbon levels in juvenile pink salmon and multi-function oxidase (MFO) induction in juvenile pink and chum salmon differ between oiled and non-oiled areas.

4. To compare the feeding habits of juvenile pink and chum salmon between oiled and non-oiled areas.

5.A To test the hypothesis that the abundance of prey available to juvenile pink and chum salmon in littoral areas and the pelagic water column does not differ between oiled and non-oiled areas.

5.B To test the hypothesis that the abundance of epibenthic prey species of juvenile salmon does not differ between heavily contaminated and lightly contaminated beaches within the same geographic area.

5.C To test the hypothesis that the utilization of sediments by epibenthic prey species of juvenile salmon is not affected by the presence of oil in the sediments.

6. Determine the effects of oil ingestion on juvenile pink salmon in terms of degree of contamination (hydrocarbon tissue burden and MFO induction), survival, and growth (measured by lengths, weight gain, otolith increment, and RNA/DNA ratio).

CHAPTER 2: ABUNDANCE, DISTRIBUTION, SIZE, AND GROWTH OF JUVENILE SALMON

Objectives

2.A To test the hypothesis that the abundance of juvenile pink and chum salmon does not differ between oiled and non-oiled areas.

2.B To compare distribution and habitat utilization by juvenile salmon between 1989 and 1990.

2.C To test the hypothesis that the size and growth of juvenile salmon do not differ between oiled and non-oiled areas.

2.D To recover coded-wire tag pink salmon for inclusion in the tag-recovery data base used to determine migratory behavior and specific growth rates of hatchery juvenile salmon (analyzed by ADFG component of F/S-4).

Methods

Sample collection and processing

The general sampling design incorporated 8 locations: 4 oiled and 4 non-oiled (Figure 2.1). For both the oiled and non-oiled locations, two sites each were selected in embayments and migration corridors. The study locations were paired *a priori* for pairwise comparisons between oiled and non-oiled locations. These pairings were (non-oiled first): McClure Bay-Herring Bay; Long Bay-Snug Harbor; Culross Passage-Prince of Wales Passage; Wells Passage-Knight Island Passage.

Three habitat types (low, medium, and steep gradient beaches) were sampled at each location. Low gradient beaches were <10% grade, with granule-pebble substrate; medium gradient beaches were 12-25% grade, with pebble-cobble substrate; and steep gradient beach were >50% grade, with bedrock or large boulder substrate. Particular sample sites within paired oiled and non-oiled locations were selected for similarity in such characteristics as wave exposure, macrophyte coverage, and substrate.

In 1989, one beach of each habitat type was sampled at each location, for a total of 24 systematically sampled sites. In 1990, two beaches of each habitat type were sampled at each location, for a total of 48 systematically sampled sites. The locations of each systematic sample site are shown on Maps A-F, Appendix 2.1. There were five sampling trips over the time period April 10 - June 26, 1989, and four sampling trips over the

period April 16 - June 14, 1990. Triplicate measures of temperature and salinity data at 1-m and 4-m depths were collected at each location for each sampling period using a conductivity-temperature meter.

In addition to the systematic sampling of these sites, 2-3 miles of shoreline adjacent to the sites at each location were sampled to locate congregations of juvenile salmon, using both "blind" sets (no fish observed) and "directed" sets (fish observed). This sampling effort was intended to provide additional coded-wire tag collections, as well as to supplement samples for hydrocarbon and otolith analyses when insufficient numbers were collected at the systematically sampled beaches. Effort was higher in the oiled area because of the emphasis on recovering juvenile pink salmon for hydrocarbon analysis.

Sampling at the systematic study sites was restricted to the -1 to +3 tide levels to minimize tidal effects between sites. Fish were captured using 37 m beach seines (outer wings, 10 m long, 32 mm "scare" mesh, dyed green, tapering from 1 to 3 m deep; inner wings, 4 m long 13 mm mesh dyed green, tapering from 3 to 4 m deep; bunt, 8 m long, 6 mm mesh dyed green, tapering from 4 to 5 m deep) and a 37 m seine modified to sample the steep gradient sites (3 m deep; wings 10 m long with 32 mm "scare" mesh dyed white; bunt 17 m long with 6 mm mesh dyed green and a floor of 6 mm green mesh formed by a 9 m lead line connecting the bottom intersections of the wings with the bunt). Dip nets were also used to collect fish during the non-systematic sampling.

Catches were sorted by species and enumerated; all salmon were checked for the presence of coded-wire tags. Samples of juvenile pink and chum salmon were preserved in 10% buffered formalin for later length and weight, diet, and mixed-function oxidase (MFO) analyses. Samples of juvenile pink salmon were frozen for hydrocarbon analysis; 50 juvenile pink salmon from each embayment site were also preserved for analysis of otolith growth patterns. Fish collected for size and stomach analysis were retained in formalin for at least 45 d to assure uniform shrinkage. Coded-wire tagged fish were stored frozen until processed for tags by the ADFG Tag Processing Laboratory in Juneau.

Otolith samples in 1989 were taken from frozen fish processed for hydrocarbons. The heads were removed from the fish and placed in 100% ethanol when the samples were prepped for the hydrocarbon processing. In 1990, fish were subsampled in the field specifically for otolith samples; the fish were measured, and the heads removed immediately and placed into 100% ethanol. Samples were processed from fish captured in the first half of May. The heads were sent to the Washington Department of Fisheries (WDF) Calcified Tissues Laboratory, where the sagittal otoliths were removed, mounted in epoxy resin, ground, and examined to determine the number of increments subsequent to the hatching and

saltwater entry check; width of these increments along a standard axis in the posterodorsal quadrat of the otolith; and the mean increment width and associated error term for each group.

Statistical analysis

The univariate approach to analysis of variance (ANOVA) of a repeated measures design (Frane 1980) was used to analyze temperature and salinity data. The factors in the environmental data ANOVA were time, oil, bay/corridor, and location, with location nested in oil and bay/corridor. Three replicate observations of temperature and salinity were taken for each cell.

Repeated measures ANOVA was also applied to the systematic catch data for pink salmon and chum salmon separately. First, in each overall analysis for 1989 and 1990 combined, the factors considered were year, time period, oil bay/corridor, location, and habitat, with location nested within oil and bay/corridor. This analysis included only the same time periods and sites that were sampled in both years.

There were two major differences for the systematic catch data between years. First, there were only three time periods with complete systematic catch data between years (Trips 2-4). In 1989, the net for sampling steep gradient beaches was unavailable for Trip 1, and there was no Trip 5 (late June) sampling in 1990. Second, there was only one beach seining site at each habitat at each location in 1989; in 1990 systematic sampling effort was doubled, and there were two systematic beach seining sites at each habitat at each location.

Because the data for each overall ANOVA for each species were comprised of only a subset of all the systematic seine sets from each year, separate ANOVA's were also run on the complete data sets of systematic catches from each year separately. For chum salmon the factors for each of the separate ANOVA's for 1989 and 1990 were time period, oil, bay/corridor, location, and habitat, with location nested within oil and bay/corridor. For pink salmon, because of the results of the overall ANOVA, the data were subdivided on level further, and separate analyses were conducted on: (1) bays in 1989, (2) corridors in 1989, (3) bays in 1990, and (4) corridors in 1990. For each of the 1989 analyses the factors were time period, oil, location, and habitat, with location nested within oil. For the 1990 analyses another factor, replicate, was added to account for the doubling of the number of sampling sites at each habitat at each location.

Because of the high number of zero catches in the fish abundance data, the statistical distributions were highly skewed. Transformations were not effective at eliminating this skewness. Thus, in each of the analyses mentioned above, 3 different data

sets were analyzed: the raw catches, the natural logarithm (Ln) transformation of catches, and a rank transformation of the catches. An ANOVA on ranks is conditionally distribution free, usually has good efficiency, and the true level of significance is usually fairly close to the approximate level of significance used in the test, no matter what the underlying population distribution may be (Conover 1980). The recommended procedure is to run the ANOVA on both the data and the ranks; if the two procedures five nearly identical results the parametric analysis is probably valid, but if the 2 procedures give substantially different results, the analysis on ranks is probably more accurate (Conover 1980). We feel that in certain instances presenting results from an analysis of ranks only could possibly mask important information on the abundance of large schools of juvenile salmon; thus we generally present results from each of these 3 analyses (raw catch, Ln catch, and ranks). In addition, frequency of occurrence was also examined in terms of: (1) catch > 0 fish, (2) catch > 100 fish, and (3) catch > 1000 fish. Frequency of occurrence data were analyzed with a chi-square test.

Another analytical approach to test the hypothesis of no difference in abundance of juvenile pink and chum salmon between oiled and non-oiled locations was to use the nonparametric Wilcoxon paired-ranks test. Differences in abundance between matched cells of the a priori pairs of oiled and non-oiled locations were compared. For each species 56 such comparisons were possible in 1989, and 95 were possible in 1990. For pink salmon, differences in abundance were also tested separately in bays and corridors.

Size and growth of juvenile salmon were examined by comparing mean sizes, apparent growth rates, and the weight/length relationship between oiled and non-oiled areas. Mean sizes of pink salmon were analyzed using the two statistical approaches: ANOVA and the nonparametric Wilcoxon paired-ranks test. Because of the large number of empty cells in 1989 due to zero catches, habitats and sites were pooled so that the ANOVA tested a 3-factor (time, oil, bay/corridor) fully crossed model (Wertheimer et al. 1990). Two ANOVA analyses were run on the 1990 data. In 1990 two analyses were conducted. The first analysis tested the reduced model described above. The second analysis tested the full model with the factors time period, oil, bay/corridor, location, and habitat, with location nested within oil and bay/corridor. Testing the full model was possible in 1990 because of the much smaller number of empty cells in 1990 compared to 1989. Both models were tested in 1990 in order to compare the results of each and determine whether pooling over location and habitat biased the results, which would invalidate the conclusions of the 1989 size analysis.

The nonparametric approach tested only the null hypothesis that

there was no difference between fish size in oiled and non-oiled locations. It preserved possible location and habitat differences by comparing samples from the same time period and habitat type for the a priori pairs of oiled and non-oiled locations. Only cells with at least 5 observations were used for these comparisons.

For chum salmon a parametric approach to the analysis of fork lengths was not possible because of the large number of empty cells, especially from oiled sites. Only the nonparametric Wilcoxon paired-ranks test was used to compare sizes of chum salmon between oiled and non-oiled locations.

Apparent growth rates (change in size over time) were calculated for pink salmon for each habitat type within a location using the regression of natural logarithm of weight over time. Analysis of covariance was used to determine if fish could be pooled over habitats within a sampling location. Pooling was rejected. Apparent growth rates were derived by regressing the natural logarithm (Ln) of weight over time. ANOVA was used to compare the apparent growth rates of pink salmon in corridors; the factors considered were year, oil, location, and habitat, with location nested within oil. Bays were not considered in the ANOVA because there were too many empty cells to calculate valid growth rates in bays in 1989.

The weight/length relationship was used to compare the condition of juvenile pink and chum salmon between oiled and non-oiled areas, as recommended by Cone (1989). The exponential rate of increase of weight with length was determined by the slope of the regression of the natural logarithm (ln) weight on ln length. For each species, fish sizes were partitioned as to bay/corridor and oil. Analysis of covariance was used to test for homogeneity of slopes and equality of adjusted means between bays and corridors within each oiled area. If the slopes and adjusted means were not significantly ($P > 0.1$) different, the sizes were pooled as to bay/corridor and tested between oiled and non-oiled areas. If slopes or adjusted means were significantly different between bays and corridors, tests between oiled and non-oiled areas were made separately for bays and corridors.

Results

Temperature and salinity

There were no significant differences observed in temperature between oiled and non-oiled sampling locations in 1989 or 1990 (Table 2.1). Temperature generally increased at all locations over the duration of the study at both 1-M and 4-M sampling depths (Fig.2.2, 2.3). Differences in temperature between sampling periods were statistically significant (Table 2.1).

These differences in response over time were more pronounced at the 1-M sampling depth, which was characterized by occasional temperature spikes (Fig. 2.2). At both the 1-M and 4-M depths, there were no significant differences between bay and corridor sampling locations (Table 2.1). However, there were significant time*bay/corridor and time*oil*bay/corridor interactions at the 4-M depth in 1989, due to different patterns in the change in temperature over time in the bays in 1989. Temperature generally increased steadily with time except in the bays in 1989, where temperature changes were more variable (Fig. 2.2).

Salinities were consistently higher at both sampling depths at the oiled locations (Fig. 2.4, 2.5). In oiled locations, salinities averaged 28.6 and 29.9 ppt at 1-M in 1989 and 1990, respectively, and 29.7 and 30.8 at 4-M. In the non-oiled locations, salinities averaged 23.0 and 25.1 ppt in 1989 and 1990, respectively, and 27.9 and 30.2 ppt at 4-M. The differences between the oiled and non-oiled areas were significant at 1-M in both 1989 and 1990, and at 4-M in 1989 (Table 2.2). Salinities also varied significantly between sampling times, and tended to decrease over the sampling period. In 1989, salinities at 4-M declined to a greater extent over time in the non-oiled locations (Fig. 2.4), resulting in a significant time*oil interaction (Table 2.2). Also in 1989, there was significant interaction between bay/corridor and oil at the 1-M depth, due to extreme low salinities observed in the non-oiled bays (Fig. 2.4). These interactions reflect differences in the degree to which oiled and non-oiled locations differed, but do not contradict the conclusion that salinities were higher overall in the oiled sampling locations. No significant interactions were seen in the salinity comparisons in 1990 (Table 2.2).

Abundance of juvenile pink salmon

Systematic catch. In the systematic sampling in both 1989 and 1990, considerably more pink salmon were captured in non-oiled than oiled locations. In 1989 a total of 33,290 pink salmon were captured in 120 systematic sets, with 43% zero catches and a high catch of over 8000. More than 4 times as many pink salmon were captured in the non-oiled area, 27,200 fish compared to 6090 fish in the oiled area. In 1990 a total of 81,869 pink salmon were captured in 191 sets, with 28% zero catches and a high catch of 22,977. More than 6 times as many pink salmon juveniles were captured in the non-oiled area in 1990, 70,496 fish compared to 11,373 fish in the oiled area.

The ANOVA's of the systematic catch data for 1989 and 1990 combined indicated that pink salmon were significantly more abundant in the non-oiled area than the oiled area in terms of both Ln catch ($P = 0.03$) and ranks ($P = 0.03$, Table 2.3). This trend was consistent in both years; in neither analysis was the

year * oil interaction significant ($\underline{P} > 0.100$). Over both years there were over 5 times more pink salmon captured in the non-oiled rather than the oiled area (Figure 2.6). Additionally, in each year, the Wilcoxon rank test for matched pairs of sets indicated higher abundance in the non-oiled than the oiled area ($\underline{P} = 0.086$, 0.092 in 1989 and 1990, respectively, Table 2.4).

The overall ANOVA also indicated a significant difference between bays and corridors in terms of both Ln catch ($\underline{P} = 0.003$) and ranks ($\underline{P} = 0.004$, Table 2.3). Over both years, 94% of the pink salmon were captured in corridors and only 6% were captured in bays (Figure 2.6). Because of the dramatic difference in catch patterns between bays and corridors, separate analyses were run on bays and corridors for each year, and any further interpretation of significance for other factors will be discussed separately for bays and corridors.

For each year there were several consistent patterns in the catch trends of pink salmon in bays. First, there was no difference ($\underline{P} > 0.100$) in the abundance of pink salmon between oiled and non-oiled bays either of the ANOVA's (Tables 2.5, 2.6), in the nonparametric Wilcoxon test (Table 2.4), or in frequency of occurrence (Table 2.7). Second, none of the factors were significant in explaining differences in the raw catch of pink salmon in bays in either 1989 or 1990 (Tables 2.5, 2.6). However, in 1989, time ($\underline{P} = 0.023$) and time * habitat ($\underline{P} = 0.055$) were significant in explaining variations in pink salmon ranks in bays (Table 2.2); mean ranks peaked in early May at the medium gradient habitat, late May in the low gradient habitat, and early June in the steep gradient habitat.

Medium gradient was the most important habitat overall for pink salmon in bays. In 1990 medium gradient was the preferred habitat type in the analyses of Ln catch ($\underline{P} = 0.076$) and ranks ($\underline{P} = 0.042$, Table 2.6). Although habitat was not significant ($\underline{P} > 0.100$) in the 1989 analyses (Table 2.5), pink salmon in bays exhibited the same pattern of abundance in 1989 as in 1990: in both years pink salmon were most abundant in the medium gradient habitat in terms of each of our measures of abundance: raw catch (Figure 2.6), Ln catch, ranks, and frequency of occurrence (Table 2.8). There were no significant differences in the abundance of pink salmon in bays between replicates of the same habitat type in 1990 except a fourth-order interaction which is difficult to interpret (Table 2.6).

When pink salmon abundance indices in corridors were examined separately by year, different factors were significant in explaining variations each year. In 1989 pink salmon abundance was higher in non-oiled rather than oiled corridors in terms of raw catch ($\underline{P} = 0.096$), Ln catch ($\underline{P} = 0.078$), ranks ($\underline{P} = 0.035$, Table 2.5), frequency of occurrence (Table 2.7), and the non-parametric Wilcoxon test ($\underline{P} = 0.030$, Table 2.4). In 1990 there

were no significant differences in pink salmon abundance between oiled and non-oiled corridors ($\underline{P} > 0.100$, Tables 2.4, 2.6, 2.7) although abundance as measured by raw catch, Ln catch, ranks, and frequency of occurrence was always higher in non- oiled compared to oiled areas (Table 2.7). More than 6 times as many pink salmon juveniles were captured in the non-oiled than the oiled area in 1990 (Figure 2.6). In 1990 oil was significant only in the context of the time * oil interaction in the analysis of Ln catch ($\underline{P} = 0.014$) and ranks ($\underline{P} = 0.027$, Table 2.6). Whereas pink salmon abundance peaked in early May in non-oiled corridors and declined sharply afterwards, in oiled corridors pink salmon abundance was still high when sampling was terminated in mid-June (Figure 2.7).

Similar to bays, there were no significant differences ($\underline{P} > 0.100$) between replicates of the same habitat type in 1990. In 1989, oil * habitat ($\underline{P} = 0.022$) was also significant in explaining variations in the raw catch of pink salmon (Table 2.5), due to differences between the oiled and non-oiled areas in the observed abundance at low and medium gradient habitats. In the oiled area more fish were captured at medium gradient sites than at low gradient sites, whereas the reverse was true for the non-oiled area (Figure 2.6).

Larger numbers of pink salmon were captured in the steep gradient habitat in both 1989 and 1990 (Figure 2.6). These differences in raw catch were significant ($\underline{P} < 0.001$) in 1989, but not in 1990. This is an example where raw numbers present only part of the picture. There were no significant differences in either year, and no trend for greater abundance in the steep gradient habitat in terms of Ln catch and ranks (Table 2.8). Pink salmon were captured more frequently in the medium gradient habitat in both years although this trend was only significant in 1990 ($\underline{P} < 0.050$, Table 2.7). The largest catches and greatest variability in catch of pink salmon occurred in the steep gradient habitat; over both years 25% of the seine sets at steep gradient sites in corridors captured more than 1000 pink salmon, and 40% captured no pink salmon (Table 2.7). It is these very large catches that drive the raw abundance graph (Figure 2.6). These analytical results are consistent with our observations during non-systematic sampling. We observed juvenile pink salmon aggregated in large numbers in patchy schools along rocky shorelines. In contrast, we observed pink salmon more frequently but in smaller numbers along lower gradient beaches.

Total Catch. In 1989, a total of 232,126 pink salmon were captured in all seine sets, of which 136,496 (59%) were in the non-oiled area and 95,630 (41%) were in the oiled area. In 1990, a total of 202,793 pink salmon were captured, of which 80,750 (40%) were in the non-oiled area and 122,043 (60%) were in the oiled area. At first glance, these numbers seem contradictory to the systematic catch data. However, effort outside the

systematic sampling was not uniform, and usually was inversely related to the catch during systematic sampling: given a limited amount of time at each site, the amount of effort that could be directed at searching for aggregations of fish was greater if catches in the systematic sites were low. The total catch numbers are of value in assessing where and when aggregations of fish were encountered, but not for direct comparisons of abundance.

In both years, most of the juvenile pink salmon were caught in the corridor sites in both oiled and non-oiled areas; few juvenile pink salmon were captured in bays (Figure 2.8). An exception to this result was the outer bay of Snug Harbor, where large numbers of pink salmon were captured. This portion of Snug Harbor was outside the area of systematic sampling in this embayment; within the inner bay, both systematic and nonsystematic sets caught few fish (Figure 2.8).

The pattern of abundance of juvenile pink salmon over time differed markedly between bays and corridors in both 1989 and 1990 (Figure 2.7); oiled and non-oiled areas also differed to some degree. Catches in bays were generally lower than those in corridors, except for the early (April) sampling period. Catches in bays were small and relatively stable in April and May, although in 1990 there was a pronounced increase in catch in May (Figure 2.7). In both 1989 and 1990, catches increased rapidly to a peak in May. Catches then declined in early June. In 1989, when sampling extended to late June, catches continued to decline in the non-oiled corridors, but increased in the oiled corridors.

Coded-wire tag recoveries. An objective of the non-systematic sampling was to capture coded-wire tagged juvenile pink salmon for growth and migration behavior analysis. Of the 143 coded-wire tagged pink salmon recovered in 1989, 131 (92%) were in the non-systematic sampling. In 1990, (49%) of the 281 tagged pink salmon were in the non-systematic sampling. These tag recoveries are included in the tag data-base analyzed in the ADFG component of F/S-4. A very cursory description of the tag recovery patterns from the NMFS component is given below.

In 1989, 110 of the tagged pink salmon were captured at Wells Passage (Table 2.9) on the north end of Culross Island across Wells Passage from the large hatchery on Ester Island. Tag recoveries in other corridor sites ranged from 4-13. Tag recoveries were rare in bays in 1989; no tagged pink salmon were recovered in the non-oiled bays, one was captured in Herring Bay, none was recovered in the inner bay of Snug Harbor, and five in the outer bay of Snug Harbor.

In 1990, 111 tagged pink salmon were recovered in Herring Bay (Table 2.9). Of these, 106 tags were from wild-stock tagging

operations at Herring Creek in Herring Bay (102 tags), Loomis Creek (3 tags), and Totemoff Creek (1 tag). No other tags were recovered in bays in 1990. Tagged pink salmon were also recovered at all corridor locations in 1990, with Wells Passage again having the largest number of recoveries (118).

The percentage of hatchery fish in the catch was estimated from the number of fish represented by each tag recovery (based on the tag/untagged release ratio). Hatchery fish comprised 66% and 100% of the catch in Wells Passage in 1989 and 1990, respectively (Table 2.9). Hatchery fish also made up 44% of the Herring Bay catch in 1989, and 58% in 1990. An additional 1% of the catch at Herring Bay in 1990 can be attributed wild stocks originating outside of Herring Bay itself. The proportion of hatchery fish at the Knight Island Passage location increased from 16% in 1989, to 43% in 1990. The proportion captured at Prince of Wales declined from 14% to 3%. In all other locations, including outer Snug Harbor, hatchery fish made up 7% or less of the catch; no hatchery fish were recovered in Long Bay, McClure Bay, or Inside Snug Harbor (Table 2.9).

Abundance of juvenile chum salmon

Systematic catch. A total of 7532 and 12,857 chum salmon were captured in the systematic sampling in 1989 and 1990, respectively. There were 47% zero catches in 1989 and 50% in 1990.

In the overall ANOVA for 1989 and 1990 combined there were significant differences between the oiled and non-oiled areas in terms of Ln catch ($P = 0.005$) and ranks ($P = 0.004$, Table 2.10). Few chum salmon were captured in the oiled area in either year (Figure 2.6): 179 (2.4%) in 1989 and 48 (0.4%) in 1990. In neither analysis was the year * oil interaction significant ($P > 0.100$) which indicates similar abundance patterns for chum salmon in oiled compared to non-oiled areas in both years.

When each year was analyzed separately, chum salmon were again much more abundant in the non-oiled rather than the oiled area (Figure 2.6). As shown in Table 2.11, chum salmon were significantly more abundant in non-oiled than oiled areas in terms of raw catch ($P = 0.013$, 0.074 in 1989 and 1990, respectively), Ln catch ($P = 0.002$, 0.008 in 1989 and 1990, respectively), and ranks in 1989 ($P = 0.002$). The matched-pairs rank test also indicated a highly significant ($P < 0.001$) difference in catches between oiled and non-oiled areas in both 1989 and 1990, with a median difference in catch of 64.8 and 53.0 fish per set, respectively (Table 2.5).

In 1990, habitat was also significant in explaining differences

in Ln catch ($\underline{P}$ = 0.017) and ranks ($\underline{P}$ = 0.026) of chum salmon (Table 2.11). Juvenile chum salmon were almost equally distributed in low gradient and medium gradient habitats, but at a much higher level of abundance than in steep gradient habitats (Figure 2.6). The oil * habitat interaction was also significant ($\underline{P}$ = 0.054) in the 1990 analysis of Ln catch because the Ln catch of chum salmon in non-oiled areas was highest in the medium gradient habitat, whereas in oiled areas the Ln catch was highest in the low gradient habitat (Figure 2.6). In both cases, Ln catch was much lower at the steep gradient habitat (Figure 2.6). Time period was also significant ($\underline{P}$ = 0.032) in the analysis of Ln catch; the Ln catch of chum salmon peaked in late May in 1990. As with pink salmon, there were no significant differences in the abundance of chum salmon between replicates of the same habitat in 1990 except in the context of 3rd and 4th order interactions which are difficult to interpret (Table 2.11).

Size and growth of juvenile pink salmon

Mean sizes of fish in oiled and non-oiled areas in 1989 and 1990 were similar in early spring, then diverged in May, with higher mean sizes observed for fish from the non-oiled area (Figure 2.9A, 2.10A). The same temporal pattern of divergence was apparent for fish from bays and corridors, with fish from corridors having higher mean values after early May (Figure 2.9B, 2.10B).

In our previous Status Report (Wertheimer et al. 1990), we assigned statistical significance to the data shown in Figure 2.9 by pooling size observations across locations and habitats, and using a three-factor, fully-crossed ANOVA. We used this approach because there were too many empty cells to run the five-factor nested ANOVA. In 1990, additional sampling effort provided sufficient data to utilize the appropriate nested design. We compared the results of statistical tests on the 1990 data from the nested design (Table 2.12) with tests on the 1990 data using the pooled design (Table 2.13). The results differed drastically. Thus the reduced model ANOVA conducted in 1989 was inappropriate; it was not valid to pool size observations over locations and habitats. Therefore we use only the Wilcoxon non-parametric to compare size statistically between oiled and non-oiled locations in 1989.

Based on the matched pair comparisons, there were no significant differences in sizes of juvenile pink salmon between oiled and non-oiled locations in either 1989 or 1990 (Table 2.14). There were 23 and 32 possible comparisons overall between oiled and non-oiled pairs in 1989 and 1990 respectively. There was no significant difference between oiled and non-oiled if the data were considered separately for bays and corridors (Table 2.14).

There was also no significant difference between oiled and non-oiled areas in 1990 when sizes were compared using the full model ANOVA (Table 2.12). Size did increase significantly with time ($P < 0.001$). Time * bay/corridor ($P = 0.047$) was also significant in explaining variations in fork lengths of pink salmon (Table 2.12), indicating that the size divergence observed between bays and corridors in May was significant.

Histograms of pink salmon sizes by time period showed very different size distributions in bays and corridors in both years (Figures 2.11, 2.12). In bays, fish sizes had a mode of 32-33 mm during April and May, indicating that the fish were predominantly recent migrants from freshwater. There was no distinct peak to the size distributions of the few fish captured in the nearshore habitats of bays in June. In corridors the mode of the size distribution shifted from 31-32 mm in April to 40 mm by late May and 45 mm by June. The distribution in corridors generally shifted towards larger sizes and widened until June when the tails of the distribution began to truncate.

Otoliths from juvenile pink salmon captured in May in oiled and non-oiled bays in 1990 also indicated that most of the fish were recent emigrants from freshwater. The percentage of fish with discernable early marine growth increments on the otoliths was 17% and 27% in Long Bay and McClure Bay, respectively, and 23% in Herring Bay (Table 2.15). In Snug Harbor, however, a majority of the fish (64%) did have discernable early marine growth increments. One-way ANOVA did not indicate a significant ($P > .1$) difference in mean increment widths among bays of fish with measurable marine zones. Mean increment widths tended to be larger in the oiled bays, especially Snug Harbor (Table 2.15).

Otoliths from the 1989 collections were not usable for increment analysis. The edges of the otoliths were eroded to the extent that the early marine zone could not be discriminated. This erosion of the otoliths was probably due to extensive frozen storage prior to preservation in ethanol.

Apparent growth rates were calculated for each habitat type in the corridor locations (Table 2.16). There was a significant year * oil ($P = 0.054$, Table 2.17) interaction. This effect was due to lower apparent growth rates in oiled corridors in 1989, and similar rates between oiled and non-oiled areas in 1990 (Figure 2.13). At each habitat apparent growth rates of pink salmon in 1989 were lower in oiled than non-oiled corridors. This pattern did not persist in 1990; apparent growth rates were then higher in low and medium gradient habitats in oiled corridors (Table 2.16). Growth rates were significantly ($P = 0.035$) higher in general in 1990 than 1989. There was also a

significant year * habitat effect (P = 0.008; Table 2.17); growth rates were substantially higher in steep gradient habitats in 1990 (Table 2.17).

There was no significant difference (P > 0.1) in the logarithmic weight/length relationship between bays and corridors within either oiled and non-oiled areas in 1989 (Table 2.18). Because of this result, the condition relationship was compared between oiled and non-oiled areas for pink salmon pooled from bays and corridors. The resulting regression equations did not differ significantly in slope; the adjusted means were significantly different (P = 0.000; Table 2.18), however. Pink salmon juveniles had higher condition factor (i. e., were heavier at a given length) in the oiled area: adjusted mean weights were 0.439 g and 0.431 g for the oiled and non-oiled areas, respectively.

In 1990, there again was no significant difference (P > 0.1) in the condition regressions between bays and corridors in the oiled area. There was a significant difference (P < 0.001) in the slopes of the regressions between bays and corridors in the non-oiled area in 1990. Because of this, the comparisons between oiled and non-oiled areas were considered separately in 1990.

There were significant differences in the regression slopes between oiled and non-oiled areas in 1990 for both bays and corridors (Table 2.18). In both cases, the slope is steeper for pink salmon in the non-oiled area, and the intercept of the regression line is greater in the oiled area. The oiled and non-oiled regression lines intersect at 40 mm in bays and 65 mm in corridors (Table 2.18). Below this intersection point, pink salmon in oiled bays had a higher condition factor. Above the intersection point, pink salmon in non-oiled bays were heavier at a given length. Because the intersection points occur at sizes at which most fish have left the near-shore environments in bays and corridors (Figures 2.11, 2.12), the interpretation of the condition relationship is the same in 1990 as in 1989: over the range of sizes occurring in the habitats sampled, juvenile pink salmon were heavier at a given length in the oiled area.

Size and growth of juvenile chum salmon

Because few chum salmon were caught in oiled sampling locations in 1989 or 1990, there were too many empty cells to use ANOVA to test for effects between oiled and non-oiled areas in either year. Based on the nonparametric matched-pairs comparison, chum salmon were significantly larger in oiled compared to non-oiled areas in both 1989 (P = 0.052) and 1990 (P = 0.047, Table 2.14). The median difference between sizes in the oiled and non-oiled areas was 7.5 mm in 1989 and 5.0 mm in 1990 (Table 2.14). In each year the mean size of chum salmon pooled over time period, location, and habitat was greater in oiled bays than non-oiled

bays (Table 2.19). In 1989 chum salmon were larger in non-oiled corridors than oiled corridors, whereas the reverse was true in 1990.

There were differences in the condition regressions for juvenile chum salmon between bays and corridors in oiled and non-oiled areas in both 1989 and 1990 (Table 2.18); therefore, comparisons between oiled and non-oiled areas were considered separately for bays and corridors. There were no significant differences in slopes or adjusted means for chum salmon between oiled and non-oiled corridors in 1989 or 1990.

The condition regressions were significantly different between oiled and non-oiled bays in both years (Table 2.18). The intersection of the regression lines for chums in oiled and non-oiled bays is 57 mm in 1989, and 44 mm in 1990. Below the intersection point within a particular year, chum salmon in oiled bays were heavier at a given length; above the intersection point, chum salmon in non-oiled bays were heavier at a given length. Chum salmon had distinctly different size distributions in oiled versus non-oiled bays; they were generally much larger in the oiled bays (Table 2.19). Of the chum salmon caught in bays in 1989, 85% and 99% of the fish were below 57 mm in oiled and non-oiled bays, respectively. In general, therefore, chum salmon juveniles had a higher condition factor in oiled bays in 1989.

In 1990, there was not a consistent difference over the size range sampled in the bays. Most (94%) of the chum salmon in non-oiled bays were below the intersection point, the size range where condition given by the non-oiled regression is lower relative to fish in the oiled area of similar length. However, most (82%) of the chum salmon in oiled bays were larger than 44 mm, the size range where condition given by the oiled regression relationship is lower relative to fish in the non-oiled area of similar length.

Discussion

Juvenile pink and chum salmon were more abundant in the non-oiled area in both 1989 and 1990. Avoidance of oiled habitats or direct mortality are possible explanations of the differences in abundance. There was, however, no evidence of direct mortality in oiled areas. In both years, large schools of juvenile pink salmon were observed and sampled in both oiled and non-oiled locations. Pink salmon fry did not appear to avoid oil; schools of pink salmon were observed under large expanses of mousse accumulated along booms in outer Snug Harbor in 1989; the fish may actually have been using the mousse for cover.

Because the pattern of abundance did not change between years as exposure levels diminished, we conclude that the differences observed in abundance were more likely due to geographic differences in the distribution of spawning populations and their migration pathways to the Gulf of Alaska, rather than to exposure to oil. The main criterion in selecting for sampling locations in this study was the categorization as to "oiled" and "non-oiled". Because of the distribution of the spill, non-oiled study locations were clustered in the northwest region of Prince William Sound, on or close to the mainland, while oiled locations were generally more southerly and on islands (Figure 2.1). These geographic differences were reflected in differences in the physical environment at the locations; salinities in the non-oiled area were lower, especially at the surface. There are substantially more and larger spawning populations of pink and chum salmon located in the non-oiled portion of western Prince William Sound than in the oiled section (Pirtle 1977). More of the hatchery production for these species is also located out of the spill area (Anon. 1983).

Juvenile pink salmon moved rapidly from sheltered bays to more exposed, steep shorelines in migration corridors. There were exceptions to this generalization, such as the aggregations of fish observed in outer Snug Harbor, and the recovery of tags from hatchery and non-local wild-stocks inside Herring Bay. But the abundance, timing, size distribution, and otolith data indicate that most of the juvenile fish leave the bays rapidly, and aggregate in large schools in steep gradient habitats in the corridors. Previous work in Sawmill Bay in the southwestern Sound also showed that juvenile pink salmon moved rapidly from the bay to adjacent migration corridors (Cooney et al. 1981). Our observations of this behavior over a wider geographic range reinforces the conclusion drawn in the UAF component of F/S-4 (Cooney 1990), that the presence of oil-deflection boom in Port San Juan in 1989 disrupted the normal migration behavior of fish released from the Armin F. Koerning Hatchery into Sawmill Bay.

Juvenile chum salmon showed a different pattern of habitat utilization. There was no difference in abundance between bays and corridors, and chum salmon preferred the low and medium gradient beaches. The tendency of chum salmon to utilize bays and low gradient beaches, where hydrocarbon contamination was most acute, may have resulted in greater exposure of chum salmon utilizing oiled areas relative to pink salmon juveniles in the same area.

There was not a significant difference in size of juvenile pink salmon between oiled and non-oiled areas. In both 1989 and 1990, the size of pink salmon diverged, with fish in the non-oiled area larger after mid-May. In our previous status report (Wertheimer et al. 1990), we assigned statistical significance to this pattern for the 1989 data. However, analysis of the 1990 data

showed that the pooling required for the parametric statistical analysis in 1990 was inappropriate. Non-parametric analysis of matched pairs of 1989 data did not show a significant difference in size of pink salmon between oiled and non-oiled areas in either year.

In both 1989 and 1990, chum salmon juveniles were significantly larger in the oiled area than the non-oiled area. Chum salmon were rare in the catches in oiled areas, and when captured, actually averaged larger in the one bay in which they were sampled (Herring Bay) than in the corridors. The rare occurrence and large size of chum salmon juveniles in Herring Bay suggest that these fish had migrated into Herring Bay from other locations.

There was also no indication that exposure to oil was affecting the relative condition of the fish. Both pink and chum salmon juveniles tended to be heavier at a given length in the oiled sites in both 1989 and 1990.

While no negative effect in the size or condition of juvenile pink salmon could be attributed to the presence of oil, there was a significant differences in the apparent growth rate of juvenile pink salmon in oiled and non-oiled corridors. Apparent growth rates of fish in oiled locations were lower in 1989, and similar between the two areas in 1990. Apparent growth of juvenile salmon based on changes over time of unmarked fish is complicated by recruitment of newly-emerged pink salmon fry to the marine environment, and size-specific movement from nearshore to offshore (LeBrasseur and Parker 1964; Healey 1980) and between near-shore habitats (Celewycz 1990). We did account for habitat differences in comparing apparent growth rates. More importantly, our analysis of apparent growth rates of unmarked pink salmon is consistent with the results of the analysis of tagged pink salmon in the ADFG component of F/S-4 (Raymond 1990): pink salmon from the same tag groups were significantly smaller when recovered in oiled areas in 1989, but not in 1990.

It was not feasible to examine apparent growth rates for juvenile pink salmon in bays for two reasons. First, there were insufficient data because of the low catches in bays to compare growth rates across habitat types. Second, the distribution, size, and otolith data indicated short residence times and thus little growth in bays. The limited amount of data available from otoliths of fish captured in bays in 1990 was consistent with the apparent growth data from corridors in 1990: growth was not reduced in oiled bays the year following the spill. Unfortunately, we could not recover this information from samples collected in bays the year of the spill.

Table 2.1. Summary of ANOVA of 1-M and 4-M temperatures in Prince William Sound, 1989 and 1990; DF = degrees of freedom, t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	1989 DF	1989 F	1989 Prob.	1990 DF	1990 F	1990 Prob.
1-M Depth							
o	l(ob)	1	0.71	0.446	1	0.01	0.911
b	l(ob)	1	4.17	0.111	1	0.15	0.718
ob	l(ob)	1	0.24	0.651	1	0.03	0.863
l(ob)		4			4		
t	tl(ob)	4	18.42	0.000	3	69.49	0.000
to	tl(ob)	4	0.60	0.668	3	0.46	0.713
tb	tl(ob)	4	0.69	0.607	3	0.20	0.896
tob	tl(ob)	4	0.26	0.901	3	0.87	0.483
tl(ob)		16			12		
Error		72			63		
Total		111			94		
4-M Depth							
o	l(ob)	1	3.72	0.126	1	0.30	0.615
b	l(ob)	1	2.10	0.221	1	0.01	0.944
ob	l(ob)	1	0.01	0.923	1	0.00	0.964
l(ob)		4			4		
t	tl(ob)	4	438.12	0.000	3	189.80	0.000
to	tl(ob)	4	1.05	0.415	3	2.38	0.121
tb	tl(ob)	4	7.60	0.001	3	0.30	0.825
tob	tl(ob)	4	2.90	0.056	3	0.32	0.812
tl(ob)		16			12		
Error		72			63		
Total		111			94		

Table 2.2. Summary of ANOVAs of 1-M and 4-M salinities in Prince William Sound, 1989 and 1990; DF = degrees of freedom, t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	1989 DF	1989 F	1989 Prob.	1990 DF	1990 F	1990 Prob.
1-M Depth							
o	l(ob)	1	53.51	0.002	1	100.45	0.022
b	l(ob)	1	5.82	0.073	1	2.60	0.182
ob	l(ob)	1	9.60	0.036	1	1.26	0.325
l(ob)		4			4		
t	tl(ob)	4	3.47	0.032	3	4.64	0.022
to	tl(ob)	4	1.50	0.249	3	0.29	0.829
tb	tl(ob)	4	0.40	0.804	3	0.29	0.896
tob	tl(ob)	4	0.40	0.809	3	0.29	0.832
tl(ob)		16			12		
Error		72			63		
Total		111			94		
4-M Depth							
o	l(ob)	1	144.14	0.000	1	1.60	0.274
b	l(ob)	1	23.26	0.009	1	2.00	0.230
ob	l(ob)	1	0.03	0.871	1	0.64	0.467
l(ob)		4			4		
t	tl(ob)	4	49.13	0.000	3	6.80	0.006
to	tl(ob)	4	7.11	0.002	3	0.46	0.713
tb	tl(ob)	4	4.49	0.013	3	0.25	0.857
tob	tl(ob)	4	0.31	0.866	3	0.91	0.463
tl(ob)		16			12		
Error		72			63		
Total		111			94		

Table 2.3. ANOVA table, systematic catches (transformed by ranks and natural logarithms) of juvenile pink salmon in Prince William Sound, 1989 and 1990. Each factor without an associated probability is used as the error term in the significance test for the factors listed above it; t = time, o = oil, b = bay/corridor, l = location, h = habitat, y = year and (ob) indicates nesting within oil and bay/corridor.

		Rank transformation			Natural Log transformation		
Source	df	MS	F	P	MS	F	P
o	1	9312.25	10.54	0.03**	40.49	11.09	0.03**
b	1	29440.84	33.33	0.004***	161.31	44.19	0.003***
ob	1	10626.17	12.03	0.03**	45.25	12.40	0.02**
l(ob)	4	883.44			3.65		
y	1	1863.36	0.76	>0.40	3.58	0.31	>0.45
yo	1	2162.25	0.89	0.40	8.05	0.70	0.45
yb	1	480.34	0.20	0.68	0.99	0.09	0.78
yob	1	3979.51	1.63	0.27	14.36	1.24	0.33
yl(ob)	4	2442.82			11.58		
t	2	1549.01	0.97	0.42	5.04	0.58	>0.37
to	2	6616.26	4.12	0.06*	28.05	3.24	0.09*
tb	2	3353.51	2.09	0.19	9.79	1.13	0.37
tob	2	329.74	0.21	0.82	2.31	0.27	0.77
tl(ob)	8	1605.10			8.66		
yt	2	2951.41	2.28	>0.27	10.04	3.01	>0.10
yto	2	2228.38	1.72	0.24	11.97	3.58	0.08*
ytb	2	1235.18	0.96	0.42	4.71	1.41	0.30
ytob	2	549.95	0.43	0.67	9.59	2.87	0.11
ytl(ob)	8	1293.34			3.34		
h	2	7496.48	4.20	0.06*	12.91	1.45	0.29
ho	2	396.20	0.22	0.81	1.87	0.21	0.81
hb	2	488.77	0.27	0.77	2.20	0.25	0.79
hob	2	367.37	0.21	0.82	1.82	0.20	0.82
hl(ob)	8	1784.38			8.92		
yh	2	598.91	0.30	0.75	2.20	0.26	0.78
yho	2	378.39	0.19	0.83	0.50	0.06	0.94
yhb	2	154.51	0.08	0.93	0.42	0.05	0.95
yhob	2	44.86	0.02	0.98	0.78	0.09	0.91
yhl(ob)	8	1977.43			8.35		

Table 2.3. (Continued)

		Rank transformation			Natural Log transformation		
Source	df	MS	F	P	MS	F	P
th	4	3971.29	7.58	0.001***	12.94	9.24	0.005***
tho	4	96.69	0.18	0.94	1.61	1.15	0.37
thb	4	509.88	0.97	0.45	1.50	1.07	0.40
thob	4	622.21	1.19	0.35	2.31	1.65	0.21
thl(ob)	16	524.07			1.40		
yth	4	772.71	0.96	0.46	2.36	0.43	0.78
ytho	4	156.97	0.20	0.94	1.03	0.19	0.94
ythb	4	370.58	0.46	0.76	1.75	0.32	0.86
ythob	4	1768.25	2.20	0.12	7.93	1.46	0.26
ythl(ob)	16	804.35			5.45		

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 2.4. Summary table of Wilcoxon paired-rank tests for abundance of juvenile pink and chum salmon in Prince William Sound in 1989 and 1990. A negative value for the median indicates non-oiled > oiled; median values are in number of fish per set.

Species/year	Pairs	Wilcoxon Statistic	P-Value	Estimated Median	95% C.I. of Median
Pink Salmon/1989					
All	56	313.5	0.086*	-5.0	111.0,1.0
Bays	28	75.0	0.737	0.0	-2.0,8.0
Corridors	28	89.5	0.030**	-119.8	-706.0,-1.0
Pink Salmon/1990					
All	95	925.0	0.092*	-4.0	-31.5,-0.5
Bays	48	328.0	0.273	-2.0	-14.0,1.0
Corridors	47	260.5	0.112	-52.5	-290.0,3.0
Chum Salmon/1989	56	27.0	0.000***	-64.8	-130,-41.5
Chum Salmon/1990	95	55.5	0.000***	-53.0	-92.0,-35.5

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 2.5. Probabilities associated with six ANOVA's conducted on systematic catches of juvenile pink salmon in Prince William Sound in 1989. Abundance was analyzed separately in bays and corridors and the dependent variable catch was analyzed untransformed (raw), transformed by natural logarithms (Ln) and transformed by ranks. Each factor without an associated probability is used as the error term in the significance test for the factors listed above it; t = time, o = oil, h = habitat, l = location and (o) indicates nesting within oil.

	Probability					
	Bays			Corridors		
Source	Raw	Ln	Ranks	Raw	Ln	Ranks
o	0.417	0.637	0.698	0.096*	0.078*	0.035**
l (o)						
t	0.623	0.104	0.023**	0.526	0.309	0.245
to	0.454	0.293	0.329	0.402	0.172	0.117
tl (o)						
h	0.585	0.617	0.416	0.001***	0.729	0.943
oh	0.552	0.789	0.715	0.002***	0.814	0.951
hl (o)						
th	0.398	0.359	0.055*	0.686	0.249	0.202
toh	0.452	0.854	0.815	0.574	0.803	0.838
thl (o)						

* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$

Table 2.6. Probabilities associated with six ANOVA's conducted on systematic catches of juvenile pink salmon in Prince William Sound in 1990. Abundance was analyzed separately in bays and corridors and the dependent variable catch was analyzed untransformed (raw), transformed by natural logarithms (Ln) and transformed by ranks. Each factor without an associated probability is used as the error term in the significance test for the factors listed above it; t = time, o = oil, h = habitat, r = replicate, l = location and (o) indicates nesting within oil.

Probability

	Bays			Corridors		
Source	Raw	Ln	Ranks	Raw	Ln	Ranks
o	0.165	0.155	0.180	0.338	0.208	0.184
l (o)						
t	0.469	0.710	0.764	0.242	0.039**	0.031**
to	0.584	0.633	0.789	0.166	0.014**	0.027**
tl (o)						
h	0.170	0.076*	0.042**	0.534	0.656	0.347
oh	0.167	0.778	0.989	0.631	0.969	0.977
hl (o)						
th	0.423	0.219	0.209	0.823	0.364	0.178
toh	0.376	0.702	0.926	0.669	0.704	0.436
thl (o)						
r	0.156	0.327	0.282	0.830	0.991	0.880
or	0.368	0.768	0.747	0.338	0.476	0.924
rl (o)						
tr	0.463	0.415	0.515	0.856	0.958	0.991
tor	0.481	0.244	0.283	0.768	0.414	0.285
trl (o)						
hr	0.240	0.245	0.452	0.534	0.271	0.212
ohr	0.015	0.429	0.797	0.576	0.581	0.586
hrl (o)						
thr	0.492	0.353	0.450	0.180	0.528	0.702
tohr	0.256	0.077*	0.138	0.189	0.371	0.729
thrl (o)						

* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$

Table 2.7. Abundance of pink salmon captured in systematic seine sets in Prince William Sound in 1989 and 1990 as measured by six different parameters broken down into oiled and non-oiled areas separately in bays and corridors.

	1989					
	Bays (n=48)			Corridors (n=48)		
	Non-Oiled	Oiled	Significance	Non-Oiled	Oiled	Significance
CPUE	23	8	n.s.	1,057	225	*
Ln	0.8	1.0	n.s.	3.90	2.0	*
Mean ranks	23.6	25.4	n.s.	29.00	20.0	**
Frequency of occurrence	37%	42%	n.s.	83%	54%	**
Frequency of >100 fish	1%	0%	----	37%	21%	n.s.
Frequency of >1000 fish	0%	0%	----	25%	8%	----

	1990					
	Bays (n=96)			Corridors (n=95)		
	Non-Oiled	Oiled	Significance	Non-Oiled	Oiled	Significance
CPUE	70	34	n.s.	1,429	203	n.s.
Ln	2.1	1.5	n.s.	3.70	2.3	n.s.
Mean ranks	53.2	43.8	n.s.	54.70	41.4	n.s.
Frequency of occurrence	75%	62%	n.s.	83%	69%	n.s.
Frequency of >100 fish	10%	8%	----	43%	25%	*
Frequency of >1000 fish	2%	0%	----	17%	6%	n.s.

n.s. = not significant
* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$
---- = not enough samples to conduct valid test

Table 2.8. Abundance of pink salmon captured in systematic seine sets in Prince William Sound in 1989 and 1990 as measured by six different parameters broken down by habitats separately in bays and corridors; LG = low gradient habitat, MG = medium gradient habitat and SG = steep gradient habitat.

	1989 Abundance							
	Bays (n = 48)				Corridors (n = 48)			
	LG	MG	SG	Significance	LG	MG	SG	Significance
CPUE	5	32	11	n.s.	230	166	1526	***
Ln Catch	0.74	1.35	0.71	n.s.	2.75	2.88	3.33	n.s.
Mean ranks	23	28	22	n.s.	24	25	25	n.s.
Frequency of occurrence	31%	56%	31%	n.s.	69%	75%	62%	n.s.
Frequency of catches >100 fish	0%	6%	0%	----	31%	31%	31%	n.s.
Frequency of catches >1000 fish	0%	0%	0%	----	12%	6%	31%	----

	1990 Abundance							
	Bays (n = 96)				Corridors (n = 95)			
	LG	MG	SG	Significance	LG	MG	SG	Significance
CPUE	20	100	35	n.s.	259	449	1793	n.s.
Ln Catch	1.43	2.43	1.52	*	2.59	3.70	2.91	n.s.
Mean ranks	80	104	75	**	102	125	93	n.s.
Frequency of occurrence	69%	87%	50%	***	81%	87%	59%	**
Frequency of catches >100 fish	3%	19%	6%	----	28%	45%	28%	n.s.
Frequency of catches >1000 fish	0%	3%	0%	----	3%	9%	22%	----

n.s. = not significant
* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010
---- = not enough samples to conduct valid test

Table 2.9. Number of observed coded-wire tags, the expanded number of hatchery fish, and the percent hatchery composition in the catch of juvenile pink salmon for non-oiled and oiled locations sampled in Prince William Sound in 1989 and 1990.

Location	Total Catch	Observed Tags	Total Hatchery Catch	Percent Hatchery Fish
1989				
Oiled Bays				
Herring Bay	1108	1	484	44
Snug Harbor (Inside)	949	0	0	0
Snug Harbor (Outside)	48026	5	1445	3
Non-oiled Bays				
McClure Bay	1010	0	0	0
Long Bay	611	0	0	0
Oiled Corridors				
Knight Island Psg.	15909	8	2497	16
Prince of Wales Psg.	29638	13	4259	14
Non-oiled Corridors				
Culross Psg.	45899	4	1936	4
Wells Psg.	88976	110	58906	66
1990				
Oiled Bays				
Herring Bay	5061	111[1]	2959	58
Snug Harbor (Inside)	3514	0	0	0
Snug Harbor (Outside)	37255	0	0	0
Non-oiled Bays				
McClure Bay	1722	0	0	0
Long Bay	2640	0	0	0
Oiled Corridors				
Knight Island Psg.	8072	10[2]	3495	43
Prince of Wales Psg.	68436	40[3]	1179	3
Non-oiled Corridors				
Culross Psg.	16745	2	1182	7
Wells Psg.	59643	118	68616	100

[1]Includes 106 tags from wild stocks.
[2]Includes 4 tags from wild stocks.
[3]Includes 37 tags from wild stocks.

Table 2.10. ANOVA table, systematic catches (transformed by ranks and natural logarithms) of juvenile chum salmon captured in Prince William Sound, 1989 and 1990. Each factor without an associated probability is used as the error term in the significance test for the factors listed above it; t = time, o = oil, b = bay/corridor, l = location, h = habitat, y = year and (ob) indicates nesting within oil and bay/corridor.

		Rank transformation			Natural Log transformation		
Source	df	MS	F	P	MS	F	P
o	1	104922	33.56	0.004***	328.10	32.52	0.005***
b	1	210.25	0.07	0.81	0.25	0.02	0.88
ob	1	12.84	0	0.95	0.08	0.01	0.94
l(ob)	4	3126.82			10.09		
y	1	1.78	0	0.95	0.16	0.06	>0.78
yo	1	2508.34	1.53	0.28	6.27	2.48	0.19
yb	1	266.78	0.16	0.71	0.31	0.12	0.75
yob	1	2201.17	1.34	0.31	7.72	3.05	0.16
yl(ob)	4	1644.39			2.53		
t	2	317.79	0.40	>0.63	0.72	0.17	>0.81
to	2	1038.10	1.32	0.32	2.73	0.64	0.55
tb	2	155.48	0.20	0.82	0.72	0.17	0.85
tob	2	56.28	0.07	0.93	0.61	0.14	0.87
tl(ob)	8	788.19			4.29		
yt	2	728.09	1.08	>0.37	3.94	1.98	>0.19
yto	2	495.17	0.73	0.73	3.46	1.74	0.24
ytb	2	104.54	0.15	0.86	0.45	0.23	0.80
ytob	2	331.26	0.49	0.63	0.92	0.46	0.65
ytl(ob)	8	675.52			1.99		
h	2	7352.21	8.18	0.01**	23.64	6.09	0.02**
ho	2	2020.73	2.25	0.17	7.96	2.05	0.19
hb	2	1004.83	1.12	0.37	5.41	1.39	0.30
hob	2	924.19	1.03	0.40	4.76	1.23	0.34
hl(ob)	8	898.37			3.88		
yh	2	1209.13	1.14	0.37	3.28	0.86	0.46
yho	2	391.53	0.37	0.70	1.36	0.36	0.71
yhb	2	0.38	0	1.00	0.03	0.01	0.99
yhob	2	129.48	0.12	0.89	1.68	0.44	0.66
yhl(ob)	8	1059.45			3.81		

Table 2.10. (Continued)

		Rank transformation			Natural Log transformation		
Source	df	MS	F	P	MS	F	P
th	4	1504.99	2.55	0.08*	5.00	1.85	0.17
tho	4	477.66	0.81	0.54	2.60	0.96	0.45
thb	4	250.00	0.42	0.79	0.60	0.22	0.92
thob	4	161.71	0.27	0.89	0.49	0.18	0.94
thl(ob)	16	589.10			2.70		
yth	4	494.08	0.75	0.58	1.47	0.79	0.55
ytho	4	145.36	0.22	0.92	0.18	0.10	0.98
ythb	4	529.78	0.80	0.54	1.85	0.99	0.43
ythb	4	364.20	0.55	0.70	1.23	0.66	0.63
ythl(ob)	16	662.65			1.86		

* = 0.050 < $\underline{P}$ < 0.100
** = 0.010 < $\underline{P}$ < 0.050
*** = $\underline{P}$ < 0.010

Table 2.11. Probabilities associated with six ANOVA's conducted on systematic catches of juvenile chum salmon in Prince William Sound in 1989 and 1990. For each year, the dependent variable catch was analyzed untransformed (raw), transformed by natural logarithms (Ln) and transformed by ranks. Each factor without an associated probability is used as the error term in the significance test for the factors listed above it; t = time, o = oil, b = bay/corridor, h = habitat, r = replicate (1990 only), l = location and (ob) indicates nesting within oil and bay/corridor.

	1989			1990		
Source	Raw	Ln	Ranks	Raw	Ln	Ranks
o	0.013**	0.002***	0.002***	0.074*	0.008***	0.759
b	0.253	0.606	0.818	0.739	0.637	0.697
ob	0.207	0.371	0.530	0.730	0.432	0.741
l (ob)						
t	0.186	0.192	0.282	0.179	0.032**	0.364
to	0.229	0.187	0.216	0.189	0.238	0.594
tb	0.593	0.915	0.628	0.936	0.934	0.716
tob	0.488	0.845	0.681	0.936	0.918	0.637
tl (ob)						
h	0.762	0.436	0.322	0.277	0.017**	0.026**
oh	0.836	0.830	0.877	0.286	0.054*	0.568
bh	0.498	0.262	0.374	0.381	0.758	0.427
obh	0.426	0.192	0.382	0.391	0.762	0.627
hl (ob)						
th	0.779	0.538	0.249	0.333	0.223	0.496
toh	0.791	0.905	0.883	0.327	0.467	0.322
tbh	0.872	0.946	0.832	0.107	0.399	0.769
tobh	0.834	0.838	0.648	0.112	0.554	0.855
thl (ob)						
r				0.147	0.698	0.800
or				0.139	0.188	0.674
br				0.672	0.497	0.825
obr				0.659	0.740	0.725
rl (ob)						
tr				0.507	0.466	0.617
tor				0.498	0.631	0.431
tbr				0.945	0.872	0.090*
tobr				0.947	0.665	0.130
trl (ob)						
hr				0.798	0.185	0.292
ohr				0.781	0.630	0.550
bhr				0.702	0.397	0.975
obhr				0.679	0.818	0.182
hrl (ob)						
thr				0.754	0.941	0.357
tohr				0.753	0.970	0.043**
tbhr				0.378	0.299	0.749
tobhr				0.368	0.120	0.609
thrl (ob)						

* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$

Table 2.12. ANOVA table, size analysis of juvenile pink salmon in Prince William Sound in 1990; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor. Each factor without an associated probability is used as the error term in the significance test for the factors listed above it.

Source	D.F.	Sum of Squares	Mean Square	F	Prob.
o	1	0.6	0.6	0.00	0.967
b	1	745.0	745.0	2.31	0.203
ob	1	123.2	123.2	0.38	0.570
l(ob)	4	1292.5	323.1		
t	3	7230.9	2410.3	16.76	0.001***
to	3	520.0	173.3	1.21	0.350
tb	3	1544.5	514.8	3.58	0.047**
tob	3	5.7	1.9	0.01	0.998
tl(ob)	12	1725.5	143.8		
h	2	162.5	81.2	0.16	0.851
oh	2	259.9	130.0	0.26	0.775
bh	2	203.3	101.7	0.21	0.818
obh	2	9.3	4.6	0.01	0.991
hl(ob)	8	3945.1	493.1		
th	6	1314.8	219.1	0.50	0.795
toh	6	706.8	117.8	0.27	0.941
tbh	6	252.4	42.1	0.10	0.995
thl(ob)	13	5662.7	435.6		

* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$

Table 2.13. ANOVA table, size analysis of juvenile pink salmon in Prince William Sound in 1990; t = time, o = oil, b = bay/corridor.

Source	D.F.	Sum of Squares	Mean Square	F	Prob.
t	3	45134	15045	440.5	0.000***
o	1	442	442	12.9	0.000***
b	1	7812	7812	228.7	0.000***
to	3	493	164	4.8	0.002***
tb	3	7043	2348	68.7	0.000***
ob	1	225	225	6.6	0.010**
tob	3	520	173	5.1	0.002***
error	3921	133925	34		
total	3936	273297			

* = 0.050 < $\underline{P}$ < 0.100
** = 0.010 < $\underline{P}$ < 0.050
*** = $\underline{P}$ < 0.010

Table 2.14. Summary table of Wilcoxon paired-rank tests for size of juvenile pink and chum salmon in Prince William Sound in 1989 and 1990. A negative value for the median indicates non-oiled > oiled; median values are in mm fork length.

Species/year	Pairs	Wilcoxon Statistic	P-Value	Estimated Median	95% C.I. of Median
1989					
Pink salmon					
All	23	70.0	0.324	-0.5	-2.5, 1.0
Bays	8	12.0	0.281	1.0	-1.0, 3.0
Corridors	15	27.0	0.117	-2.0	-4.5, 0.5
Chum Salmon (all)	7	26.0	0.052*	7.5	0.5, 14.5
1990					
Pink salmon					
All	32	252.5	0.837	0.0	-1.5, 1.5
Bays	15	78.5	0.307	1.0	-1.0, 3.0
Corridors	17	51.5	0.246	-1.5	-4.0, 1.0
Chum Salmon (all)	10	47.5	0.047**	5.0	0.5,10.0

* = $0.050 < P < 0.100$
** = $0.010 < P < 0.050$
*** = $P < 0.010$

Table 2.15. Numbers of fish processed for otolith increments, numbers of otolith samples with discernable marine zone (DMZ), percent of samples processed with DMZ, mean and SE of number of otolith increments in DMZ, mean, SE, and 95% confidence intervals (CI) of otolith increment widths in DMZ for juvenile pink salmon sampled in four bays in Prince William Sound, May, 1990.

	Non-oiled		Oiled	
	McClure Bay	Long Bay	Herring Bay	Snug Harbor
Sample Date	5/04/90	5/05/90	5/03/90	5/05/90
Number Processed	44	46	35	44
Number w/ DMZ	12	8	8	28
Percent w/ DMZ	27%	17%	23%	64%
Mean No. Increments	11.4	9.8	11.0	14.1
SE, Mean No. Increments	0.80	1.96	1.44	1.08
Mean Increment Widths	1.0340	1.0720	1.2778	1.1042
SE, Mean Increment widths	0.0455	0.1107	0.0888	0.0381
95% CI, Mean Increment Widths	.914-1.154	.925-1.219	1.130-1.425	1.051-1.168

Table 2.16. Apparent daily growth rate and associated standard deviation of juvenile pink salmon at oiled and non-oiled corridors in Prince William Sound in 1989 and 1990, by habitat type. Growth was assumed to be exponential over time, and was determined as the slope of the regression of the natural logarithm of weight over time in days. Numbers shown in table are expressed as % increase in body weight per day, with standard deviation in parentheses; LG = low gradient; MG = medium gradient; SG = steep gradient.

Sampling Location	Habitat		
	LG	MG	SG
1989 Oiled Corridors			
Knight Island Passage	0.94(0.17)	2.61(0.17)	2.08(0.34)
Prince of Wales Passage	2.18(0.20)	0.68(0.39)	0.45(0.42)
Mean	1.56	1.64	1.26
1989 Non-oiled Corridors			
Wells Passage	2.46(0.26)	3.86(0.35)	1.81(0.40)
Culross Passage	2.05(0.18)	2.61(0.15)	4.53(0.30)
Mean	2.25	3.23	3.17
1990 Oiled Corridors			
Knight Island Passage	2.37(0.20)	4.14(0.32)	5.03(0.24)
Prince of Wales Passage	2.36(0.16)	2.87(0.18)	3.86(0.29)
Mean	2.36	3.50	4.44
1990 Non-oiled Corridors			
Wells Passage	2.09(0.11)	1.99(0.11)	3.48(0.17)
Culross Passage	1.68(0.31)	1.74(0.18)	7.69(0.44)
Mean	1.88	1.86	5.58

Table 2.17. ANOVA table, apparent daily growth of juvenile pink salmon in oiled and non-oiled corridors in Prince William Sound in 1989 and 1990; y = year, o = oil, h = habitat, l = location, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(o)	1	0.00017	0.00017	0.94	0.435
l(o)		2	0.00037	0.00018		
y	yl(o)	1	0.00071	0.00071	27.35	0.035**
yo	yl(o)	1	0.00044	0.00044	17.14	0.054*
yl(o)		2	0.00005	0.00002		
h	hl(o)	2	0.00106	0.00053	1.51	0.324
oh	hl(o)	2	0.00029	0.00015	0.42	0.681
hl(o)		4	0.00140	0.00035		
yh	yhl(o)	2	0.00088	0.00044	21.00	0.008***
yoh	yhl(o)	2	0.00017	0.00009	4.19	0.104
yhl(o)		4	0.00008	0.00002		

* = 0.050 < p < 0.100
** = 0.010 < p < 0.050
*** = p < 0.010

Table 2.18. Comparison of weight/length relationship of juvenile pink and chum salmon between oiled and non-oiled areas of western Prince William Sound sampled in 1989 AND 1990. The natural logarithm of weight was regressed on the natural logarithm of length. The slope of the resulting equation is the exponential rate of increase of weight with length, x, in the equation

$$w = a(l^x),$$

where w = weight, a is a constant described by the intercept of the regression, and l is the length. P,x is the probability value for the tests of homogeneity of slopes for the pairs of regression lines shown. P,w is the probability value for differences in weighted means, shown in parens if slopes are equal. Intersect is the length at which non-parallel regression lines intersect; NA indicated regression slopes were parallel. NON = non-oiled, OIL = oiled.

Area	N	a	x	R^2	P,x (P,w)	Intersect (mm)
		PINK SALMON:1989				
NO, Bays	236	-13.2	3.32	85.8	0.129	NA
NO, Corridors	899	-13.6	3.44	97.8	(0.425)	
OIL, Bays	245	-13.8	3.50	93.1	0.276	NA
OIL, Corridors	850	-13.5	3.44	97.1	(0.239)	
NO, Pooled	1136	-13.6	3.44	97.7	0.343	NA
OIL, Pooled	1096	-13.6	3.46	97.1	(0.000)	
		PINK SALMON:1990				
NO, Bays	791	-14.3	3.63	92.7	0.000	40
OIL, Bays	796	-13.5	3.42	95.3		
NO, Corridors	1464	-13.6	3.45	97.2	0.000	65
OIL, Corridors	1067	-13.4	3.38	97.6		
		CHUM SALMON:1989				
NO, Bays	832	-13.3	3.39	91.2	0.000	57
OIL, Bays	92	-11.4	2.92	93.2		
NO, Corridors	957	-13.7	3.52	96.7	0.257	NA
OIL, Corridors	45	-14.1	3.63	98.6	(0.132)	
		CHUMS:1990				
NO, Bays	1476	-14.9	3.83	90.5	0.000	44
OIL, Bays	83	-13.2	3.37	97.9		
NO, Corridors	1122	-13.8	3.52	96.1	0.423	NA
OIL, Corridors	129	-13.9	3.56	97.5	(0.426)	

Table 2.19. Mean fork-length (SE in parantheses) in mm of juvenile chum salmon captured in oiled and non-oiled bays and corridors in Prince William Sound in 1989 and 1990. Sample numbers are pooled over all sampling periods, habitats, and sampling locations within bays and corridors.

	1989		1990	
Area	N	Mean(SE)	N	Mean(SE)
Oil/Bay	92	50.1 (0.67)	83	54.5 (1.27)
Oil/Corridor	45	43.0 (1.25)	129	48.3 (0.78)
No Oil/Bay	832	38.9 (0.17)	1476	39.9 (0.10)
No Oil/Corridor	957	45.8 (0.25)	1122	43.8 (0.21)

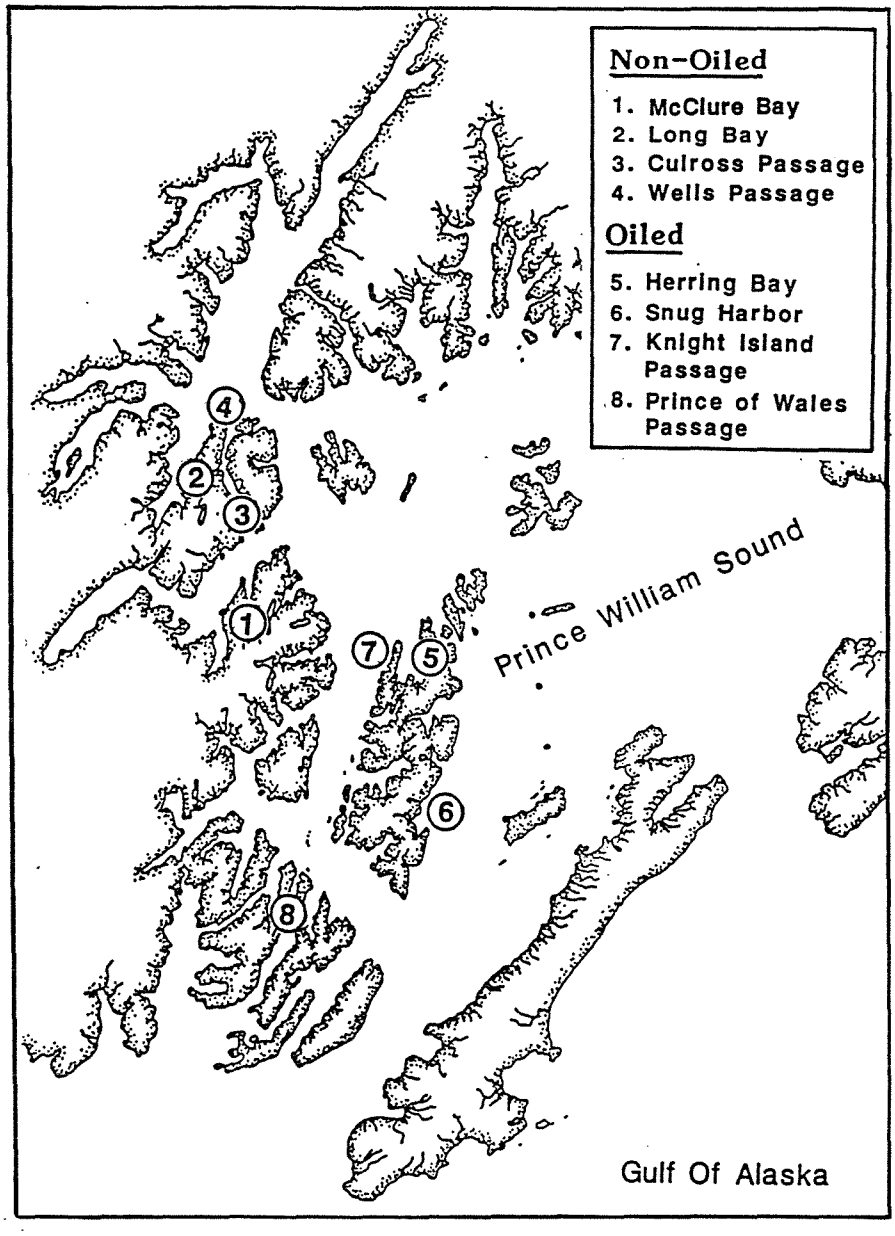

Fig. 2.1--Locations of oiled and non-oiled sampling locations for NMFS component of NRDA study F/S-4. Locations 1, 2, 5 and 6 were classified as embayments; locations 3, 4, 7 and 8 were classified as corridors.

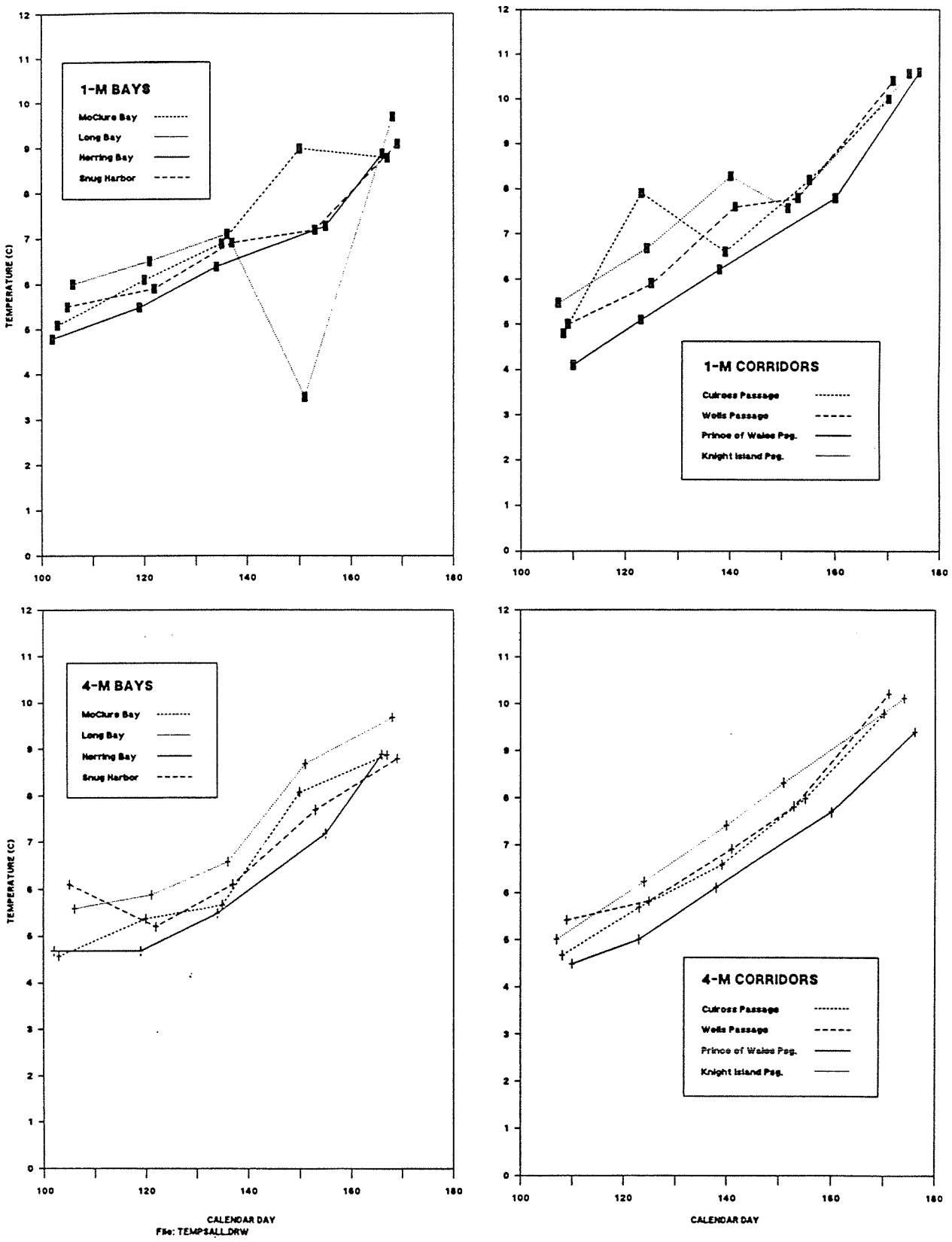

Figure 2.2. Temperatures at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1989. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

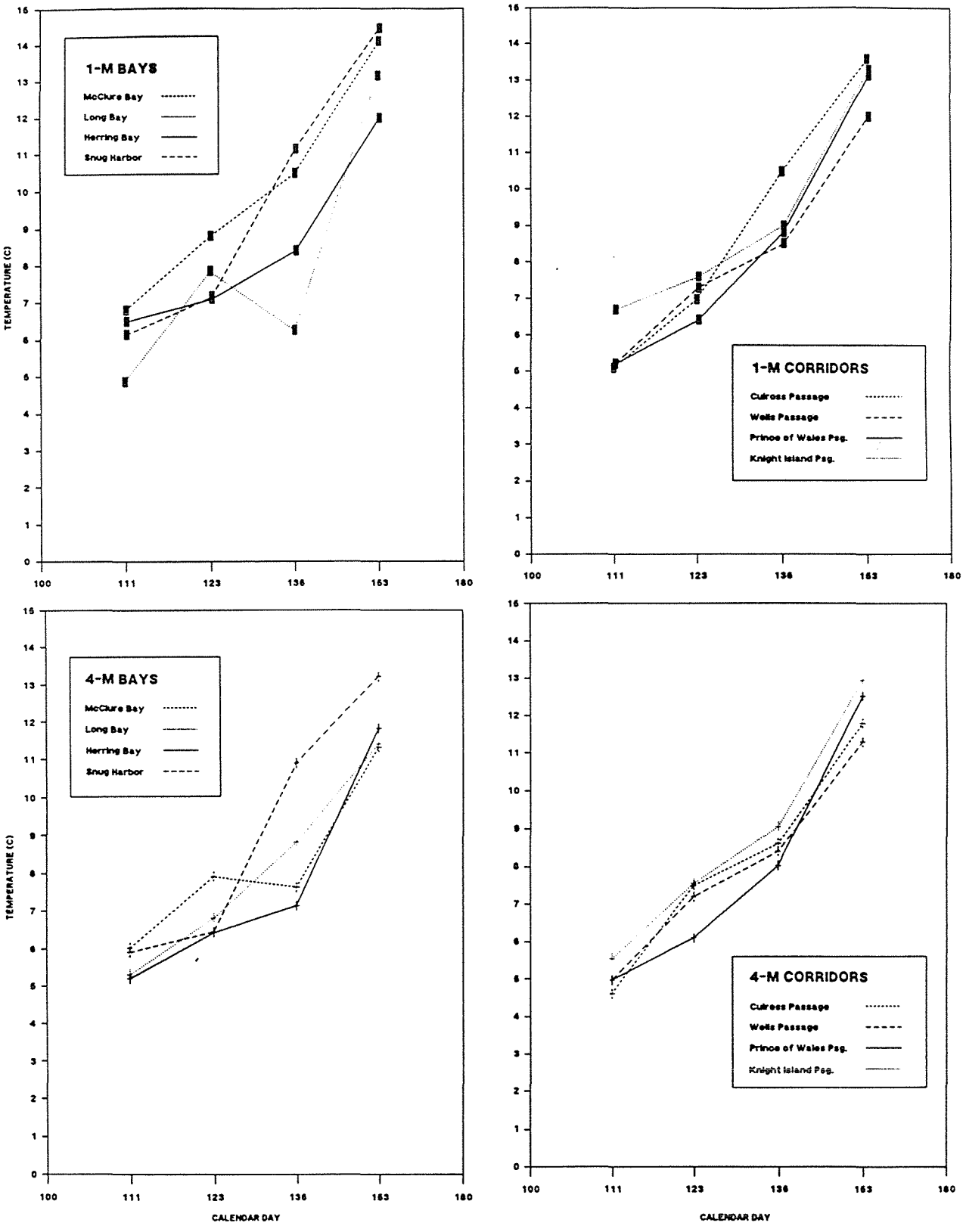

Figure 2.3. Temperatures at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1990. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

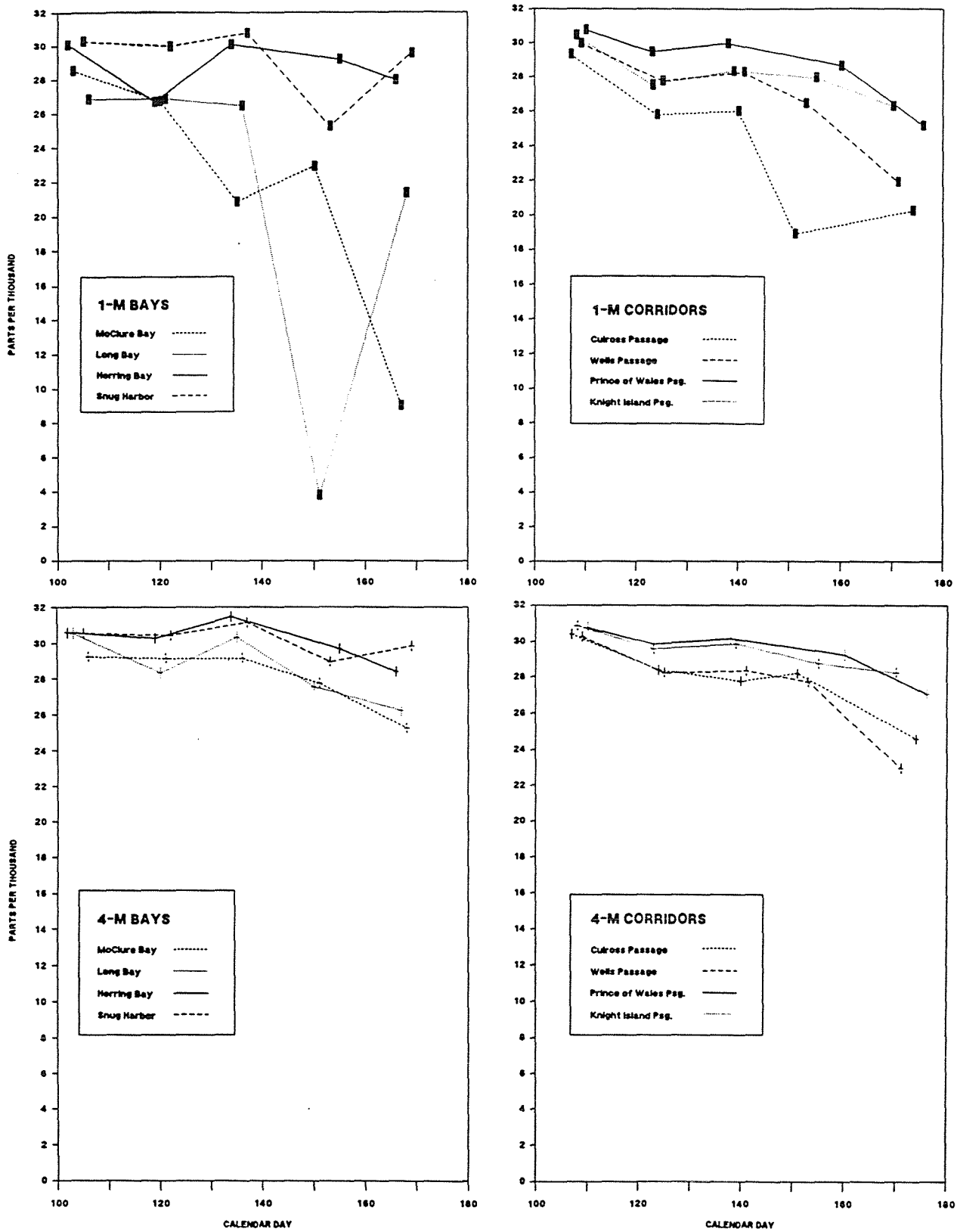

Figure 2.4. Salinities at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1989. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

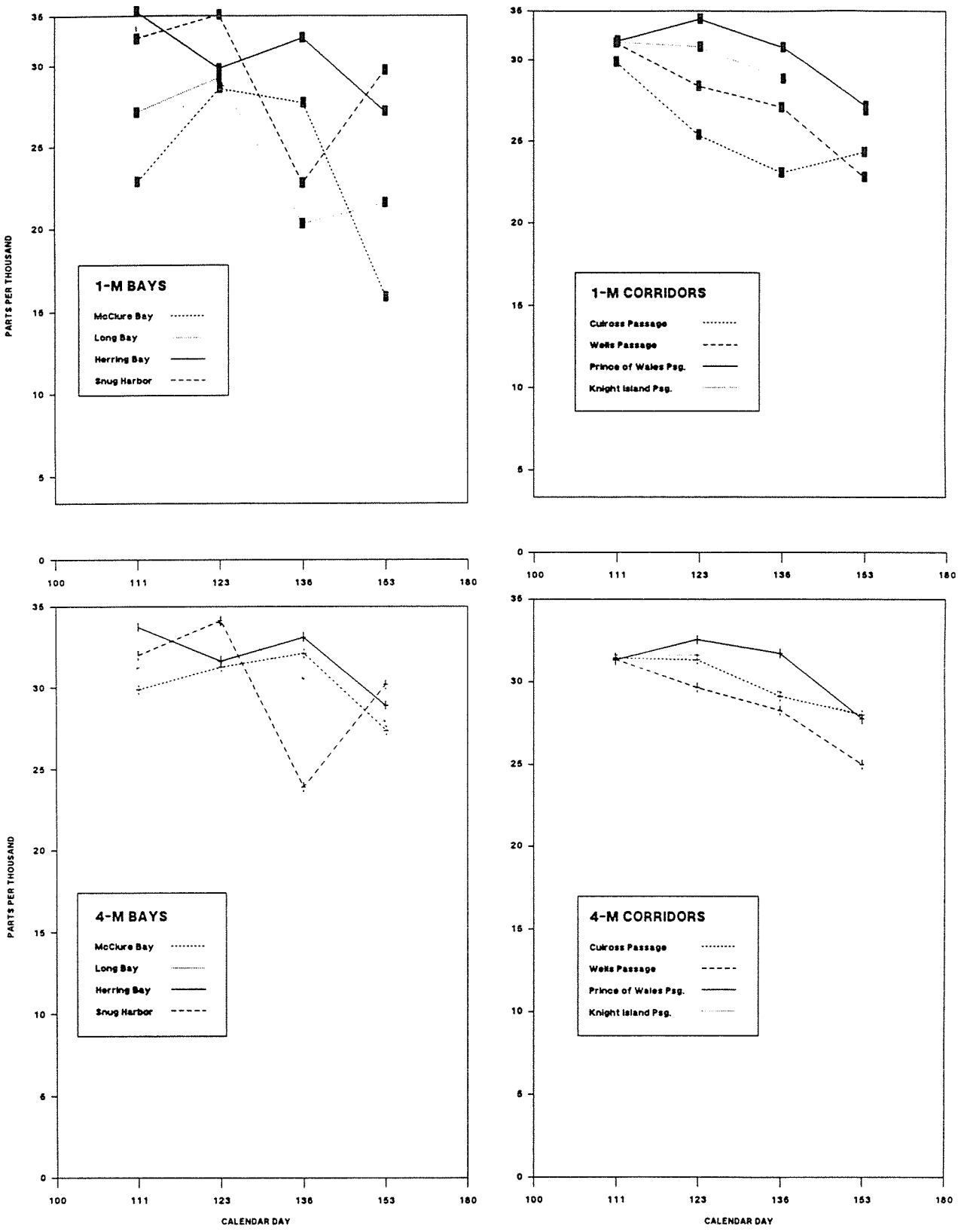

Figure 2.5. Salinities at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1990. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

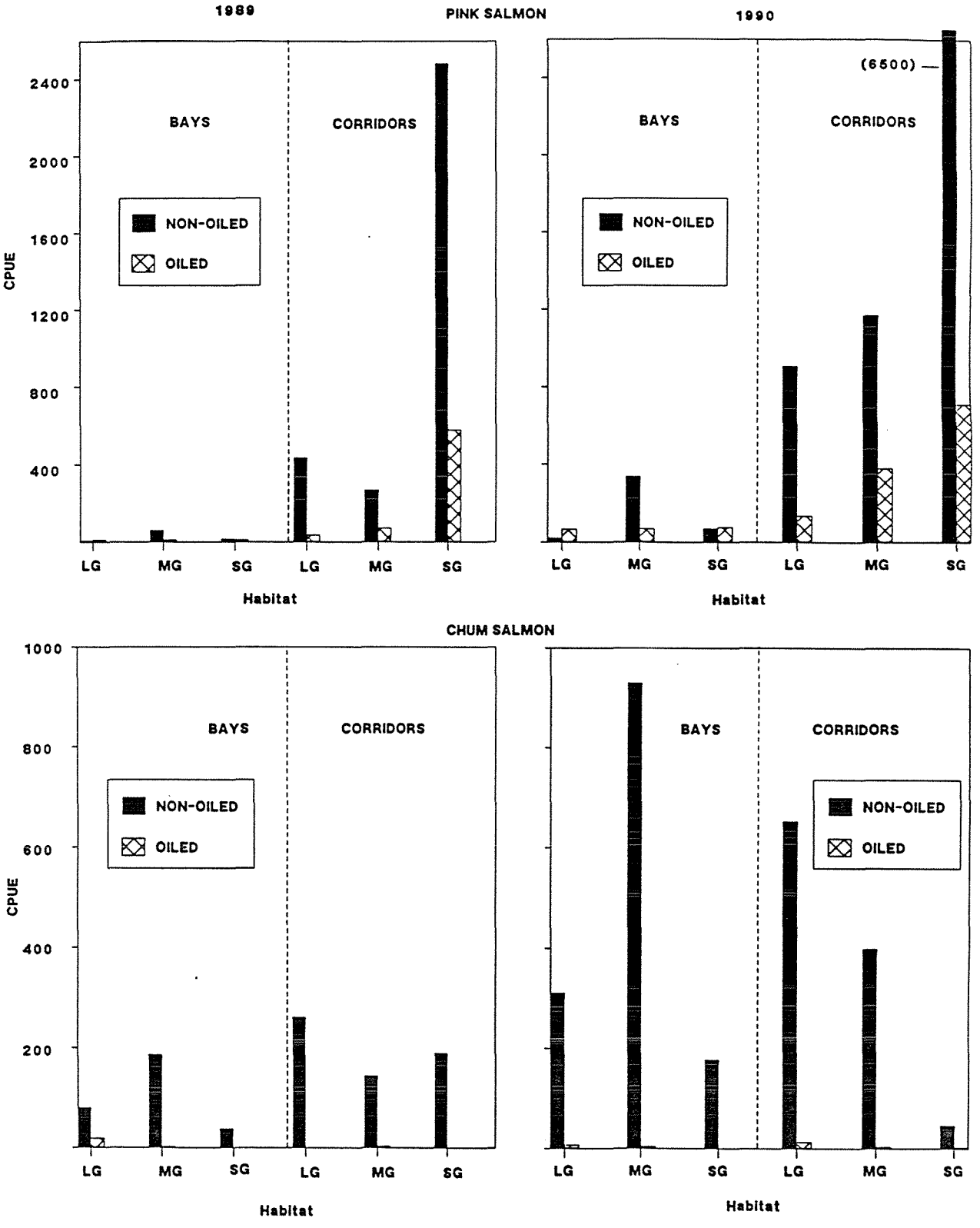

Figure 2.6. Systematic catch of juvenile pink and chum salmon by habitat type for oiled and non-oiled bays and corridors in Prince William Sound in 1989 and 1990. LG = low gradient; MG = medium gradient; SG = steep gradient.

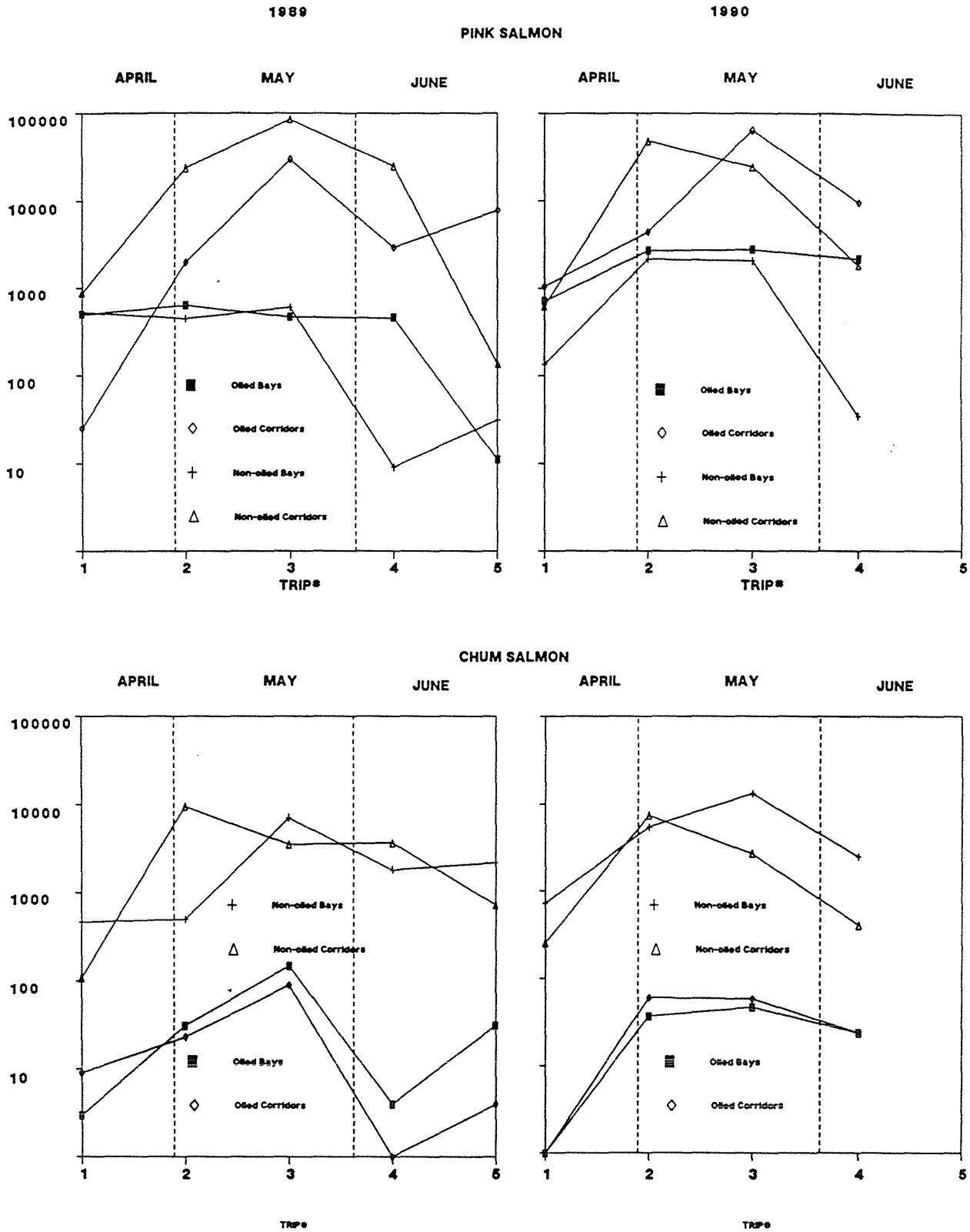

Figure 2.7. Numbers (in logarithmic scale) of juvenile pink and chum salmon captured by sampling period in Prince William Sound in April-June, 1989 and 1990. Fish captured in outer Snug Harbor are not included in the figure.

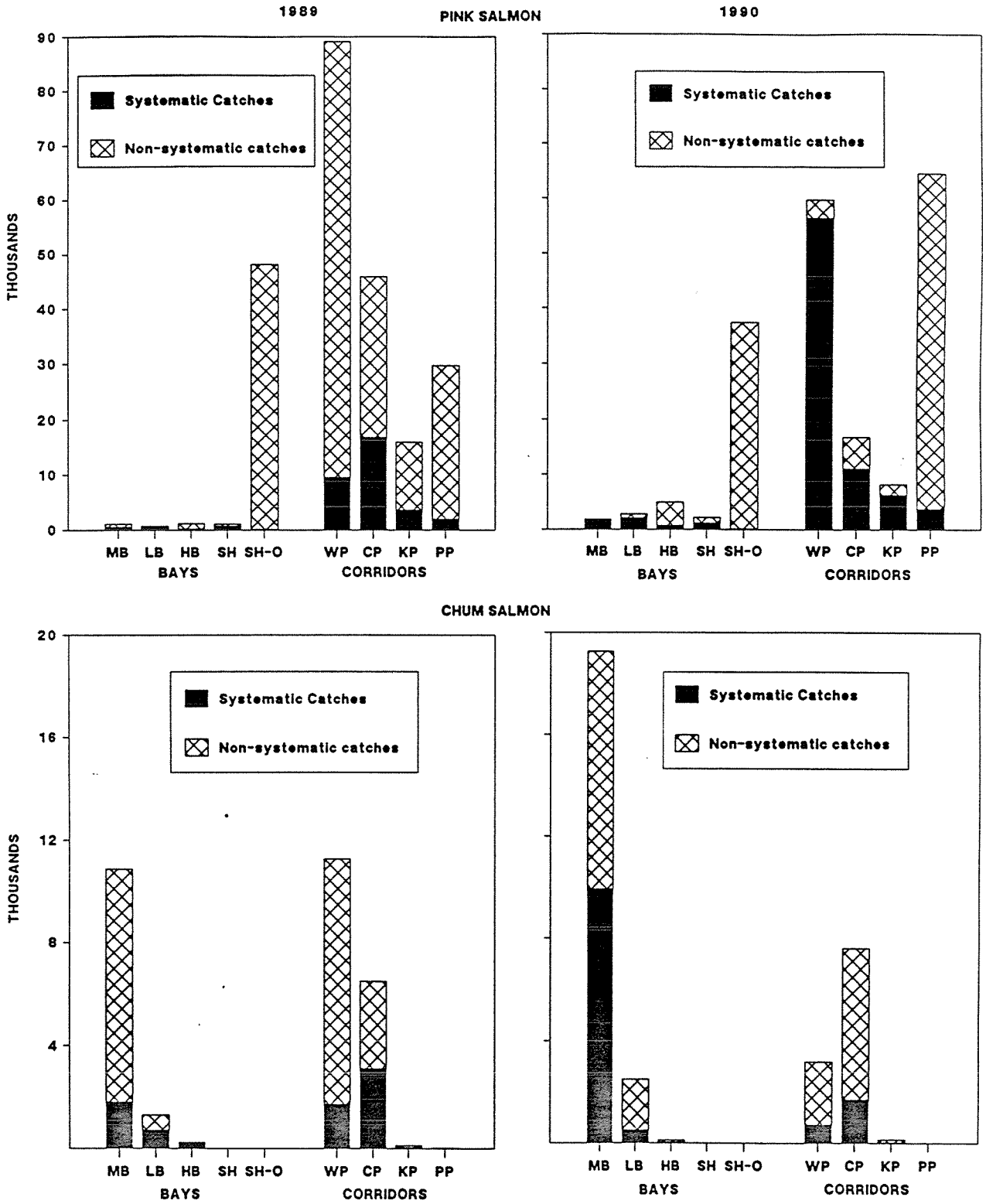

Figure 2.8. Total catch of juvenile pink and chum salmon at bay and corridor sampling locations in Prince William Sound in 1989 and 1990. MB = McClure Bay; LB = Long Bay; HB = Herring Bay; SH = Snug Harbor; SH-O = Snug Harbor, outer bay; WP = Wells Passage; CP = Culross Passage; KP = Knight Island Passage; PP = Prince of Wales Passage.

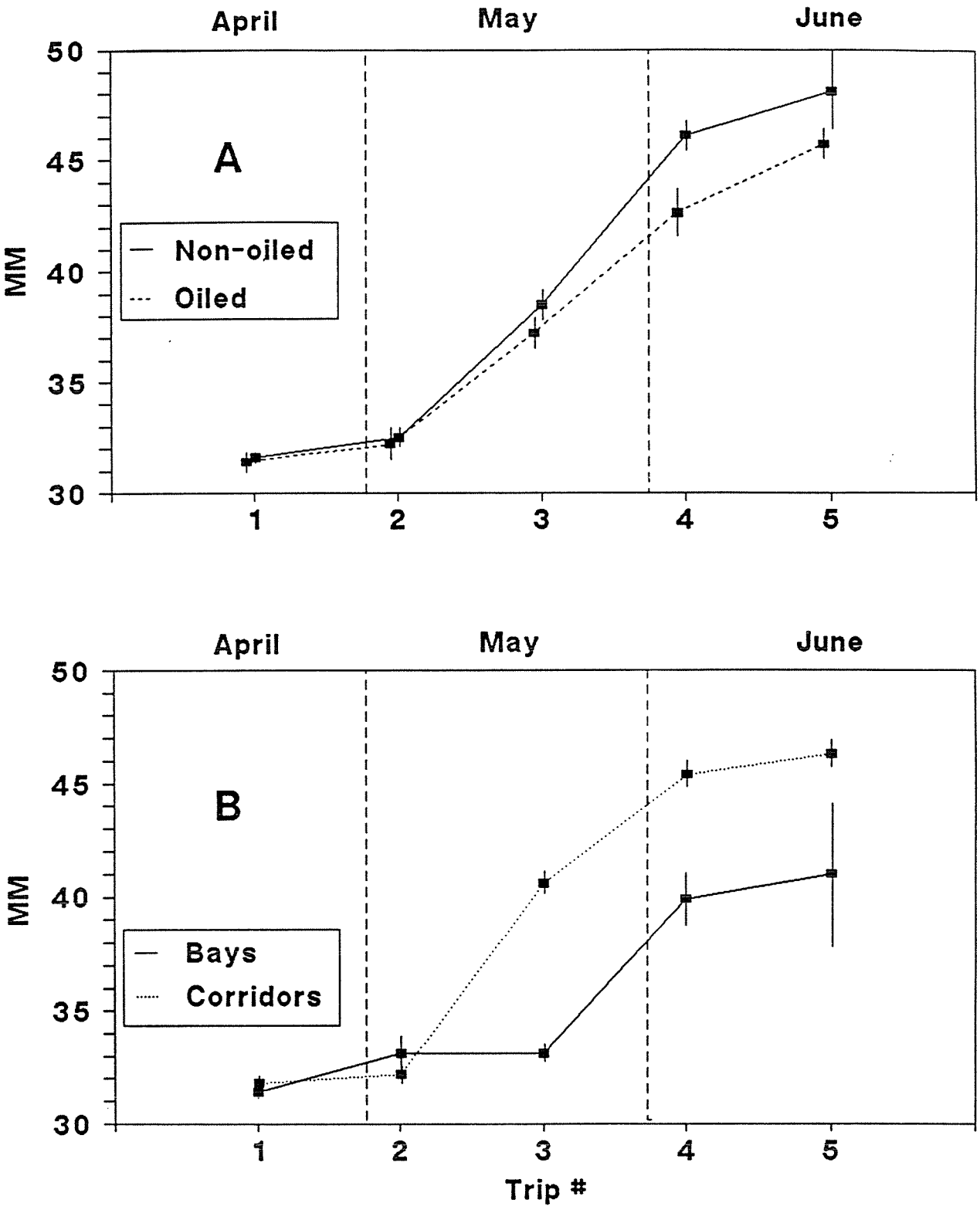

Figure 2.9. Mean fork length of juvenile pink salmon captured in Prince William Sound in 1989, pooled by oiled and non-oiled areas (A) and by bays and corridors (B). Vertical bars are 95% confidence intervals of the means.

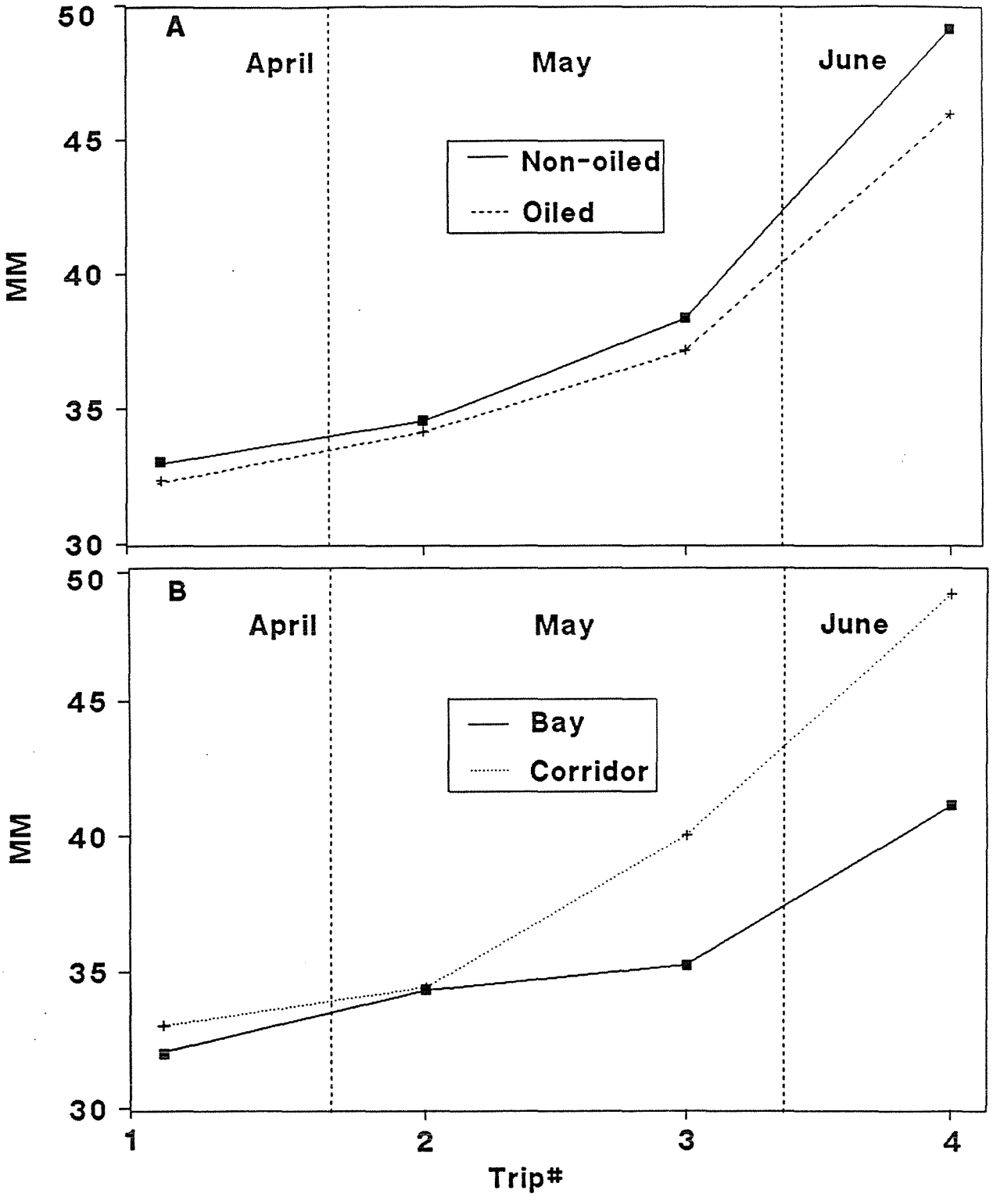

Figure 2.10. Mean fork lengths of pink salmon captured in Prince William Sound in 1990 in (A) oiled vs. non-oiled areas and (B) bays vs. corridors; 95% confidence intervals were all within 0.5 mm of the indicated means.

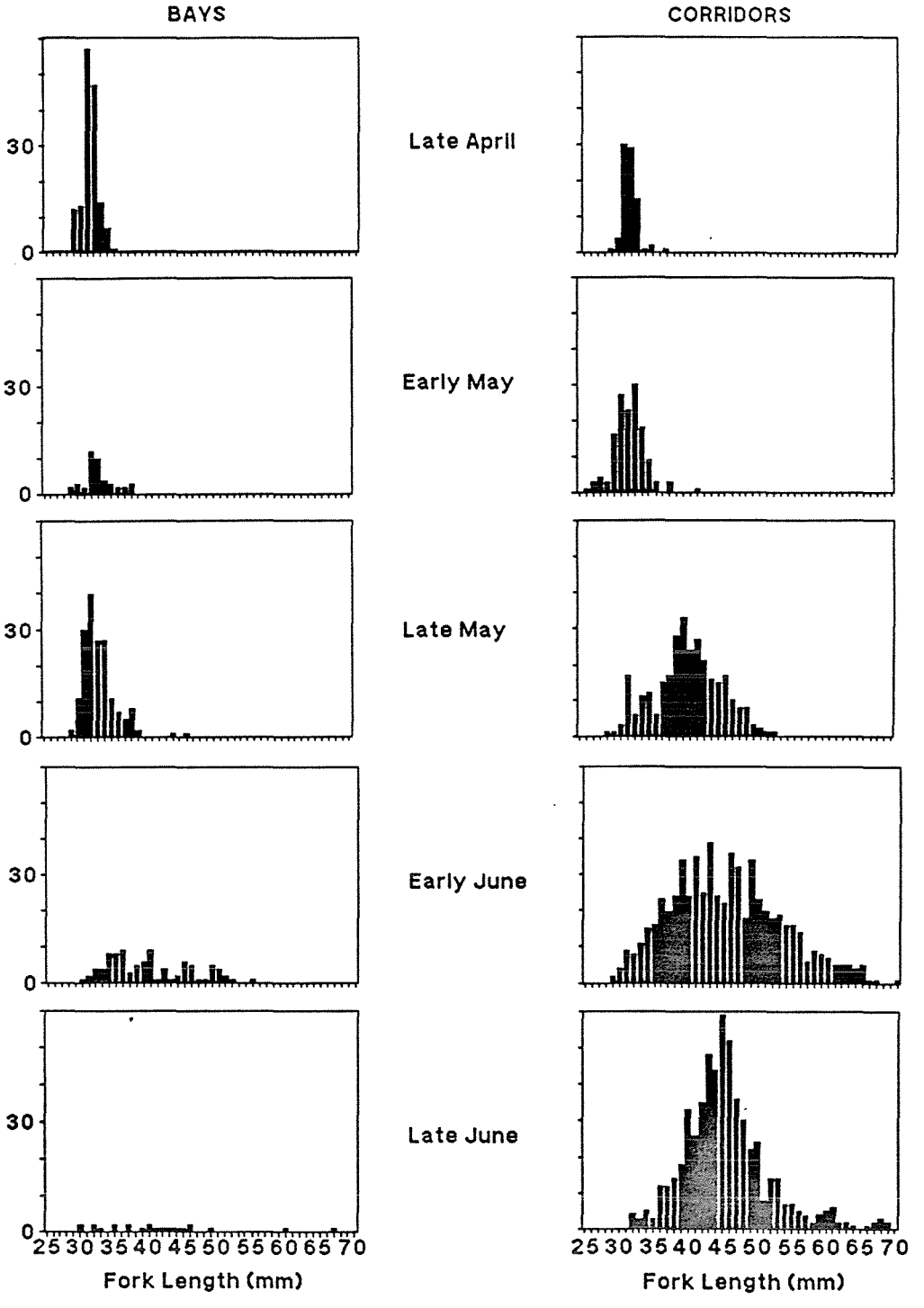

Figure 2.11. Histograms of fork lengths of juvenile pink salmon captured in Prince William Sound in 1989.

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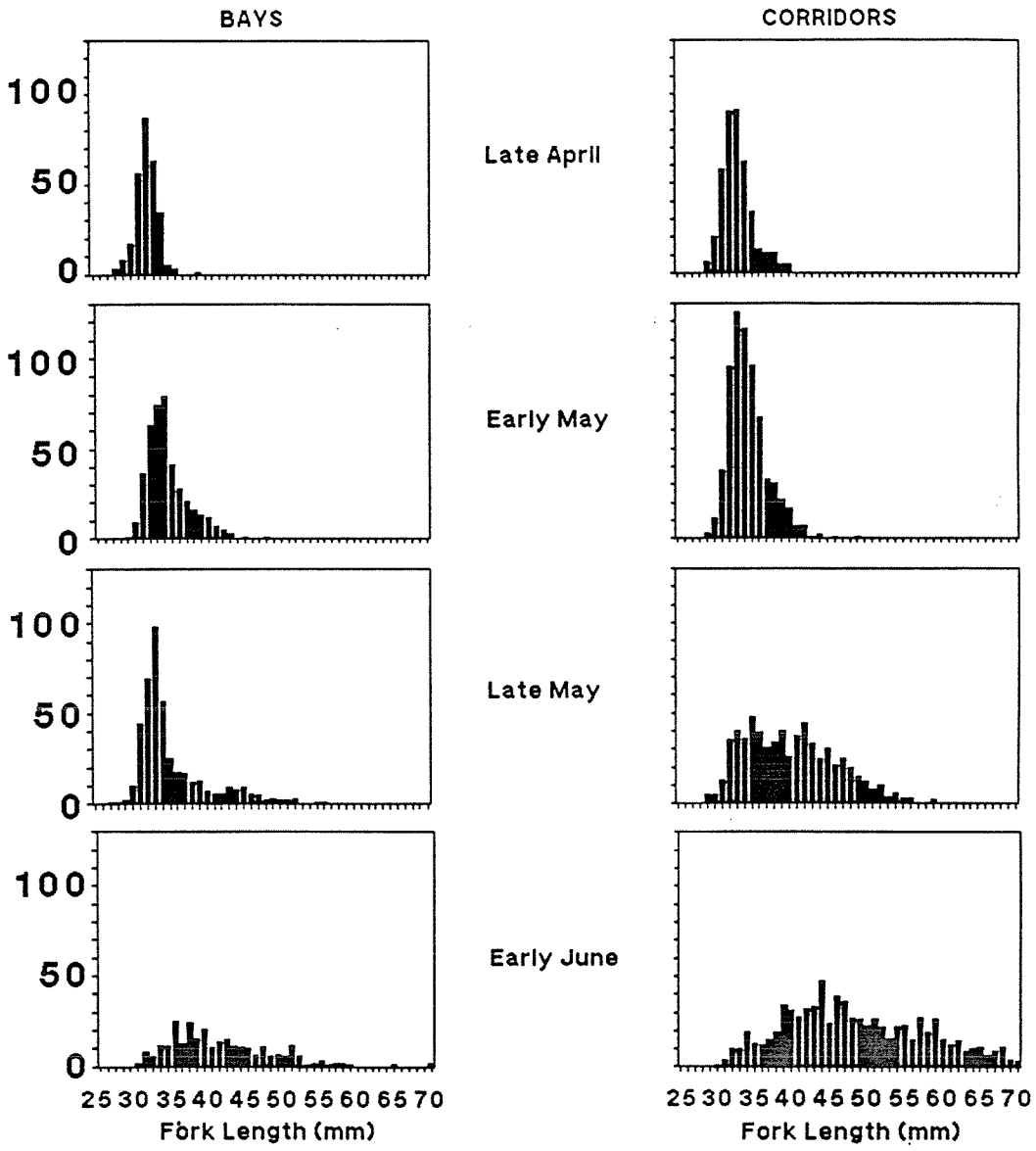


Figure 2.12. Histograms of fork lengths of juvenile pink salmon captured in Prince William Sound in 1990.

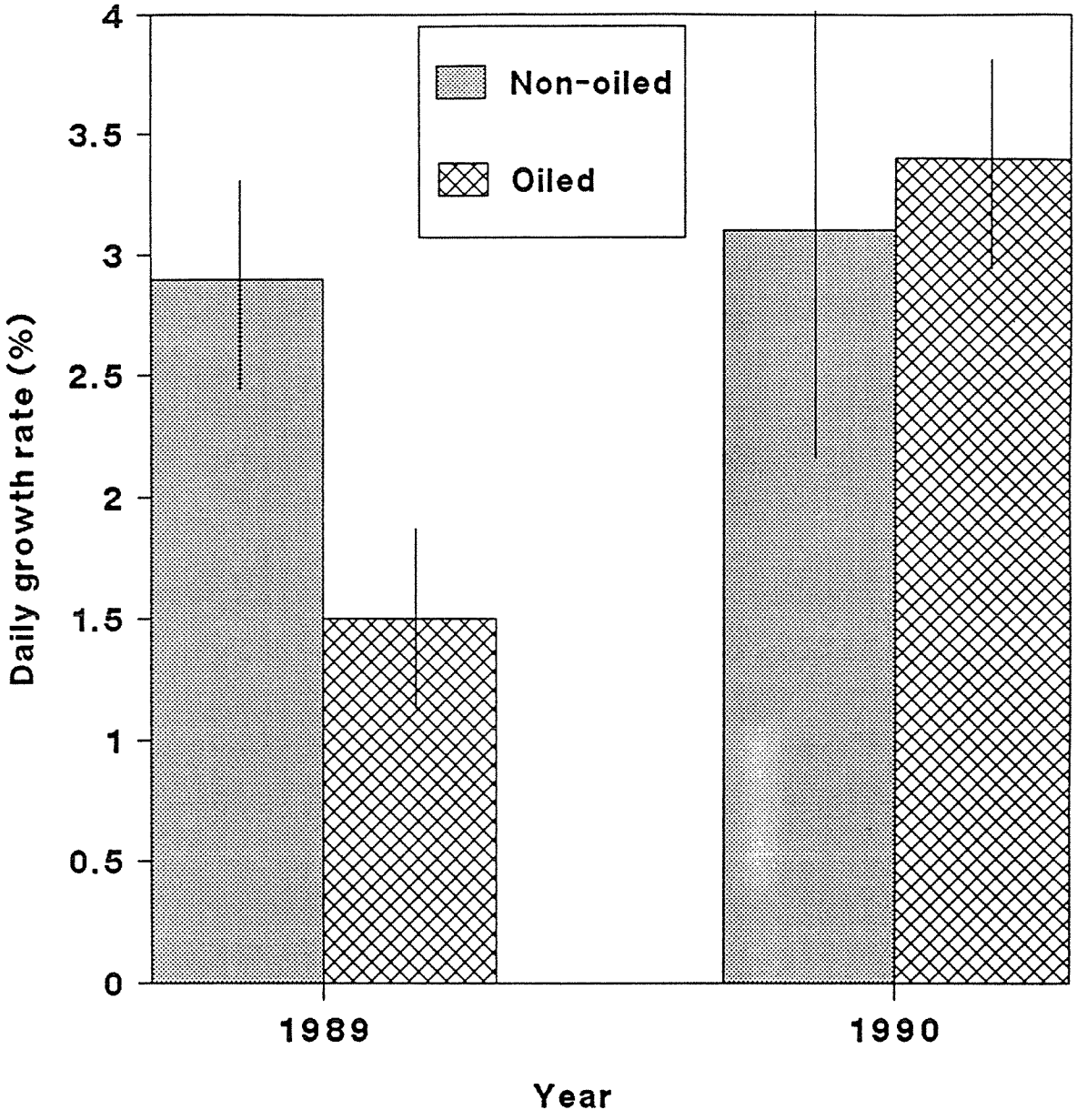
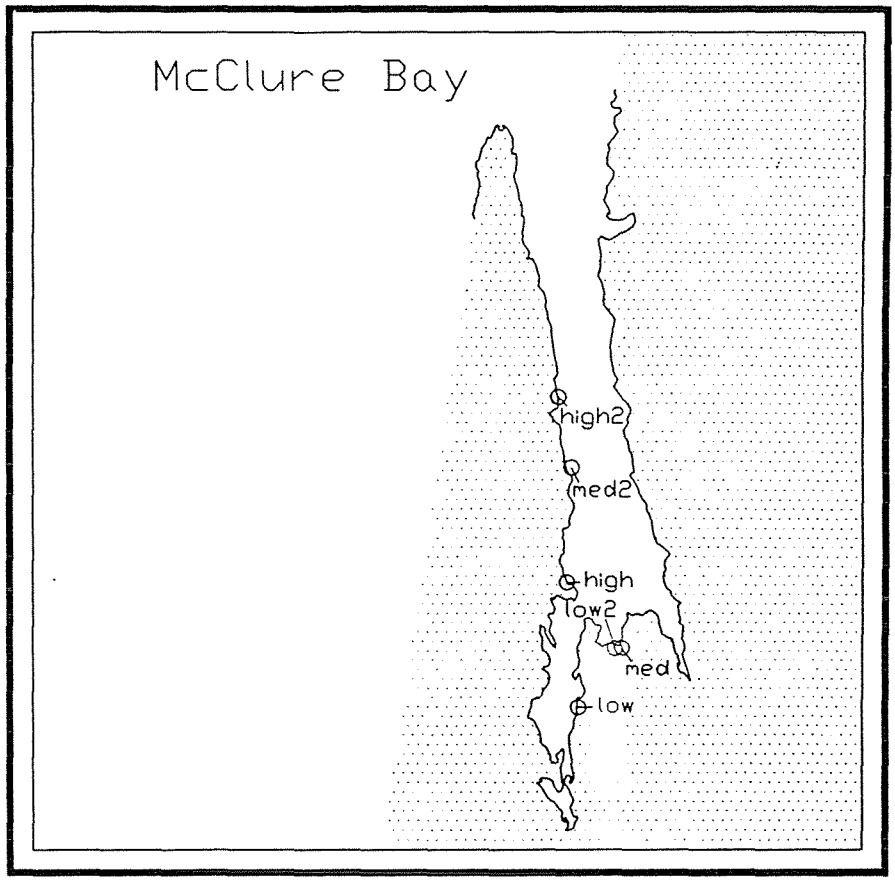
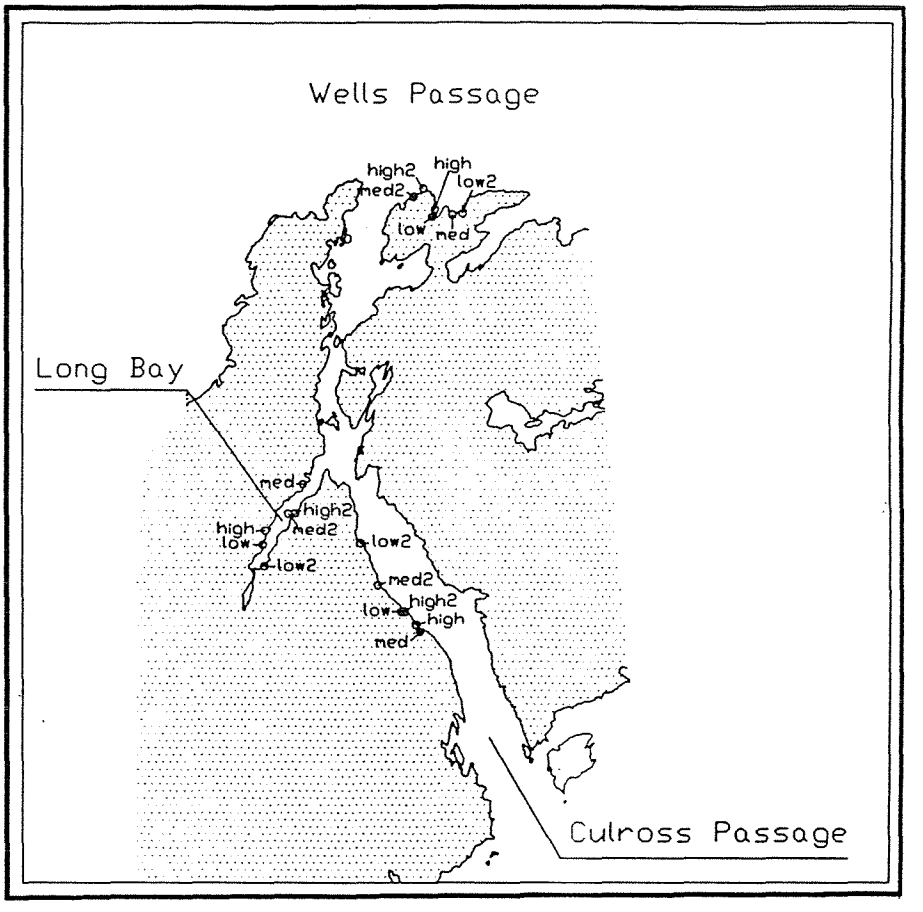


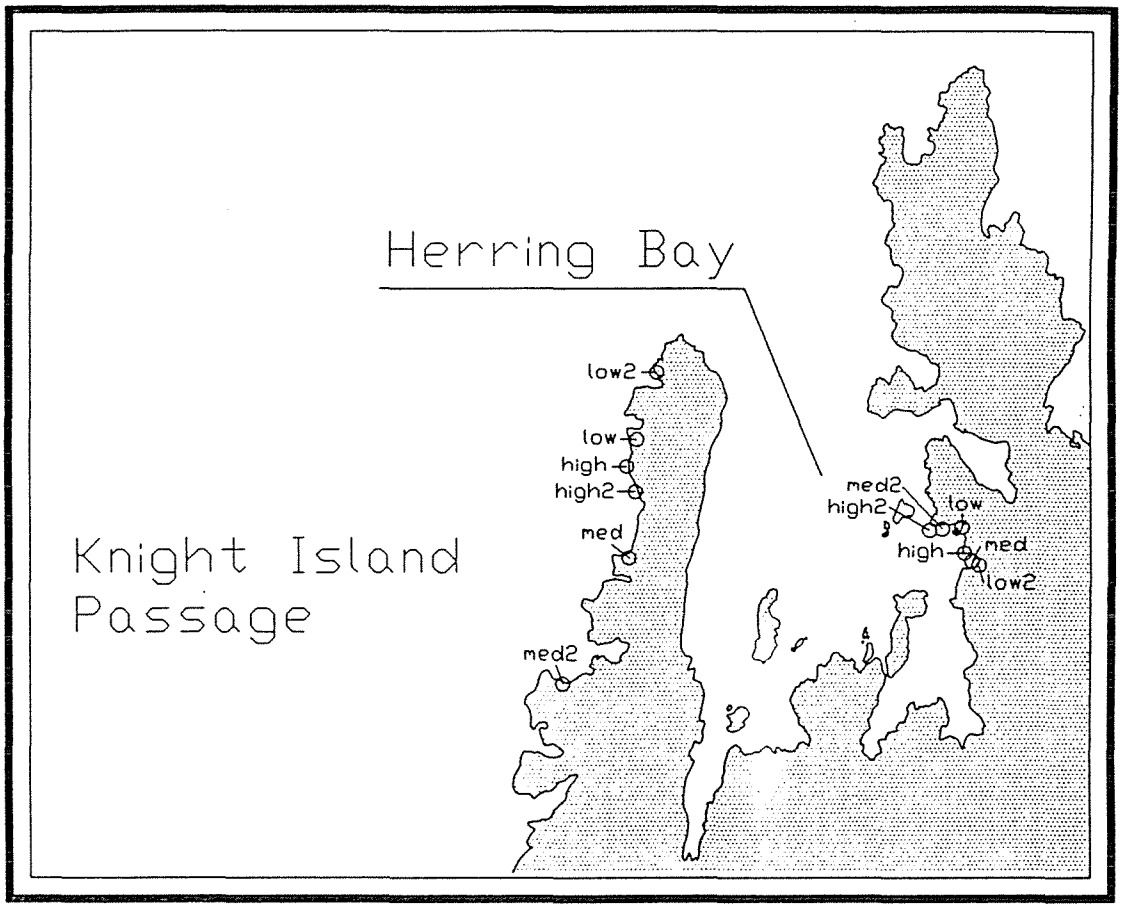
Figure 2.13. Apparent daily growth rate (%) and associated standard errors of juvenile pink salmon in corridor locations in Prince William Sound in 1989 and 1990.



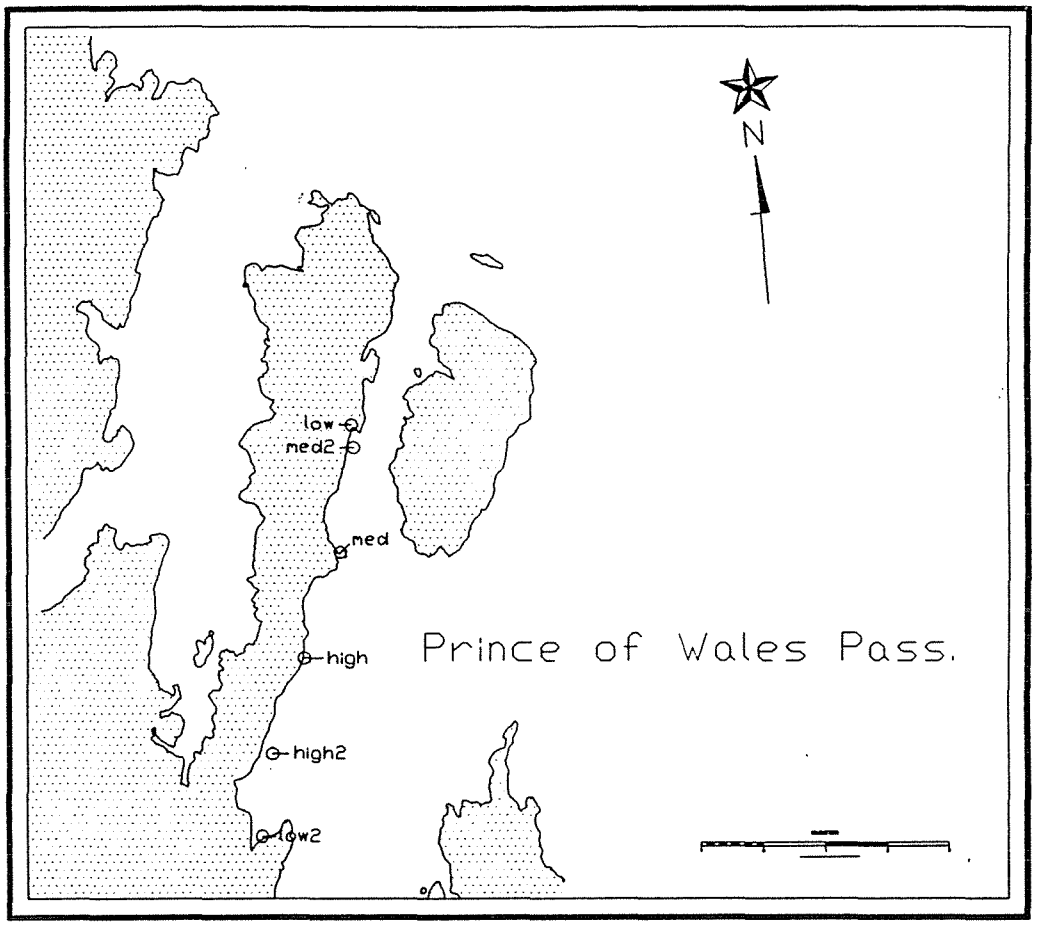
Appendix 2.1A. Systematic sampling sites at McClure Bay; low = low gradient, med = medium gradient, and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.



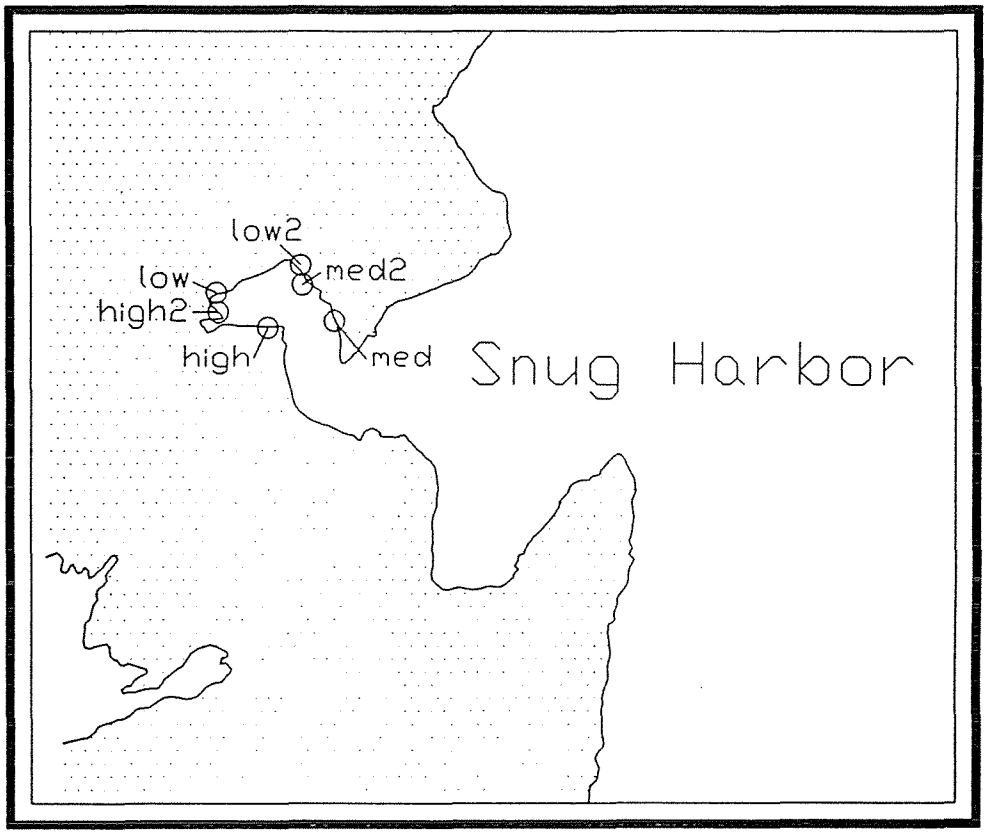
Appendix 2.1B. Systematic sampling sites at Long Bay, Wells Passage and Culross Passage; low = low gradient, med = medium gradient and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.



Appendix 2.1C. Systematic sampling sites in Herring Bay and Knight Island Passage; low = low gradient, med = medium gradient and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.



Appendix 2.1E. Systematic sampling sites in Prince of Wales Passage; low = low gradient, med = medium gradient, and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.



Appendix 2.1D. Systematic sampling sites in Snug Harbor; low = low gradient, med = medium gradient and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.

CHAPTER 3. EXPOSURE AND CONTAMINATION OF JUVENILE SALMON TO HYDROCARBONS

Objectives

3. To test if hydrocarbon levels in juvenile pink salmon and multi-function oxidase (MFO) induction in juvenile pink and chum salmon differed between oiled and non-oiled areas.

Methods

Juvenile pink salmon, mussels, and surface sediments (top 2 cm) were sampled for hydrocarbon analysis at each of the sampling locations in 1989 and 1990 throughout the extent of the sampling period. Sampling procedures followed those developed by the Hydrocarbon Technical Committee. Water samples were taken at each location in 1989 only. Sediments were also sampled in association with the tidal epibenthic prey transects in 1989, the epibenthic prey transects at light- and heavy-oiled beaches in 1990, and the azoic sediment pans in 1990. Tissue and sediment samples taken for direct evaluation of hydrocarbon content were frozen immediately after collection. Water samples were immediately processed with dichloromethane to extract hydrocarbons; the extracts were then frozen. An exception to the immediate freezing of samples was in April, 1989, when freezing capability was not available on the chartered fishing vessel used to support the first sampling trip. Hydrocarbon samples on this trip were packed in ice in an insulated box until they could be frozen. Field blanks were included with hydrocarbon samples for quality control on collection vials, storage, and processing.

Salmon tissues were analyzed for aliphatic hydrocarbons using gas chromatography with a flame ionization detector (GCFID) and aromatic hydrocarbons using high pressure liquid chromatography (HPLC) techniques followed by gas chromatography with a mass spectometer (GCMS) at two independent laboratories: Geochemical and Environmental Research Group (GERG) at Texas A&M University, and by the Auke Bay Laboratory (ABL). The majority of our samples were analyzed by GERG.

Samples of juvenile pink and chum salmon were also preserved in 10% buffered formalin in both 1989 and 1990 for analysis of induction of MFO's as an indicator of exposure to hydrocarbons. MFO samples were processed at Woods Hole Oceanographic Institute. Approximately 6 fish per sample group were examined by histological sectioning and immunochemical staining for P450E content. Slides were stained in duplicate for both specific antibody and control antibody. Prevalence and intensity of staining were qualitatively ranked on a scale of 0 = negative; 1

= very mild; 2 = mild; 3 = mild/moderate; 4 = moderate; 5 = moderate/strong; and 6 = strong. Ratings of 0-1 reflect normal, background staining; 2 is a borderline level that may indicate induction from anthropogenic pollutants or may be high natural background; and 3-6 indicate definite induction (personal communication, Roxanna Smolowitz, Woods Hole Oceanic Institute).

In 1989, groups of formalin-preserved fish were weighed and measured, subsamples were selected for stomach analysis and transferred to 40% isopropanol, and the remaining fish returned to formalin. The same procedure was to be followed in 1990; however, all fish were incorrectly transferred to isopropanol following size measurements instead of only the subsamples for diet analysis. As a result, it was necessary to test the effect of transfer of samples to isopropanol after 6-8 wk in formalin. Four paired samples of 1989 fish from oiled locations were processed for MFO activity, where subsamples of fish from the same set had been transferred to isopropanol and retained in formalin.

Results

Sediment contamination

In general most sediments collected at oiled sites during 1989 were contaminated ('yes' score, Table 3.1) and sediments at control sites were not contaminated by oil ('no' score, Table 3.1). The 'yes' score observed in Culross Passage is unexplained because of its late collection date (June 23, 1989) and may in error.

Not included in the 'yes/no' sediment data analysis (Table 3.1) are some returns that appear highly suspicious. Having been previously alerted to likely errors in the GERG sediment data returns, we find the following observations unlikely: 5 'yes' + 1 'yes?' from Long Bay collected June 23, 1989 and 4 'yes' + 1 'yes?' from McClure Bay, June 22, 1989. Catalog numbers are 6546 and 6550.

Of the many compounds available from analysis, only a few were used during sediment analysis: sum hydrocarbons, sum alkanes, sum aromatics, unresolved complex mixture (UCM), pristane, phytane, sum naphthalenes, sum fluorenes, sum phenanthrenes, sum dibenzothiophenes, and sum chrysenes. Certain index values were also considered during analysis: pristane/phytane ratio, n-C18/phytane ratio, saturated hydrocarbon weathering index (SHWR), carbon preference index (CPI), and high/low aromatic ratio. Future analysis will likely include all individual analytes, possibly using principal component analysis.

Differences in hydrocarbon concentrations among sediments

collected during 1989 from control and oiled sites are clearly evident graphically (Figure 3.1). Control sites were significantly different from oiled sites on the basis of pristane/phytane ratios, n-C18/phytane ratio, SHWR, and CPI (α = 0.05: Scheffe' a posteriori multiple comparison test). Several other analytes showed similar patterns (phytane, sum phenanthrenes, sum naphthalenes, sum fluorenes, sum dibenzothiophenes, and sum chrysenes), but did not yield statistically significant separation (Figure 3.1). This single factor analysis of variance includes all available data and does not separate multiple replicates collected on a specific date (eg tidal transect collections) from those collected at other times. This analysis will be refined at a later date.

Oddly, hydrocarbon concentrations in sediments collected from Prince of Wales Passage in 1989 appear more like control concentrations than oiled site concentrations. These beaches were heavily coated by oil (visual observation), but the oiled zone formed a distinct band. Collections of sediments at the time of fry sampling (from -1 to +3 feet relative to mean low water) were below this heavily oiled band. We have a small amount of vertical profile data; some has been analyzed and supports the idea of substantial differences in hydrocarbon concentrations as a function of elevation. Mussel tissues collected from Prince of Wales Passage showed high concentrations of hydrocarbons characteristic of oiled sites (Figure 3.3); mussel beds were within the heavily oiled band.

The amount of surface sediment contamination decreased from 1989 to 1990. Contamination was observed at 31% of the oiled sites ('yes' score, Table 3.2); control sites remained generally uncontaminated ('no' score, Table 3.2) (Figure 3.2).

The positive sediment contamination results from sediments collected in Wells Passage during 1990 seem odd because 1 replicate out of 3 at the low and medium gradient sites indicated hydrocarbon contamination on April 21. It is likely these results are erroneous. Contamination at this location, if present, was near detection limits.

Not included in the 'yes/no' sediment data analysis (Table 3.2) are some returns that appear highly suspicious. Having been previously alerted to likely errors in the GERG sediment data returns, we find the following observations unlikely: 2 'yes' from McClure Bay collected May 17, 1990. Catalog number is 6550.

Mussels (*Mytilus trossulus*)

Based on the samples analyzed to date from 1989 (April 13 - August 5), 100% of the mussels sampled in oiled areas of Prince

William Sound were contaminated by hydrocarbons ('yes' score, Table 3.3). Mussel tissues collected from control areas generally did not contain hydrocarbons (91%, 'no' score, Table 3.3). The hydrocarbons observed in control areas were collected from Culross Passage on April 17 and on May 4. We observed small amounts of mousse on beaches in the vicinity of the collection site on May 4, and thus attribute the contamination to the Valdez spill. Hydrocarbon contamination of mussel tissues in Culross Passage did not persist; samples collected from the same location on May 20 and later did not contain hydrocarbons.

The presence of hydrocarbons in mussel tissues was clearly evident in some hydrocarbon analytes or groups of analytes. Phytane, sum phenanthrenes, sum fluorenes, sum dibenzothiophenes, and sum chrysenes concentrations were significantly greater at oiled sites than at control sites ($\alpha = 0.05$: Scheffe' a posterior multiple comparison test) (Figure 3.3). Pristane, sum hydrocarbons, sum aromatics, and the unresolved complex mixture (UCM) also were significantly greater at oiled sites. Results of analysis were basically the same whether the two contaminated Culross Passage samples were included or excluded; levels of contamination in these samples was low, and did not persist over time.

Based on the one sample has been analyzed to date from 1990 collections, mussel tissue contamination in oiled locations persisted into 1990 (Table 3.4).

Juvenile pink salmon

Based on the samples analyzed to date from 1989 (April 15 -June 25), 43% of the juvenile pink salmon tissues sampled in oiled areas of Prince William Sound were contaminated by hydrocarbons ('yes' score, Table 3.5). None of the juvenile pink salmon tissues collected in control areas contained hydrocarbons ('yes' score, Table 3.5). Data were analyzed without considering time as a factor.

Relatively few juvenile pink salmon tissues collected in 1989 have been analyzed to date, or are available for analysis (Table 3.5). (Data are considered available for analysis when they are contained in the electronic database). For this reason results are preliminary, and will benefit from continued analysis.

Salmon tissues were analyzed for hydrocarbons by GERG and by ABL. It is possible that analyses from these two independent sources increases systematic error, but insufficient quantities have been analyzed to compare the results statistically between laboratories. Nonetheless, inspection of the data suggests that analyte concentrations may vary between laboratories. Until

recently, method blank corrections for individual analytes from the two labs differed; changes will be made to the ABL data set soon.

Of the many compounds available from analysis, only a few were used during the succeeding analysis: sum hydrocarbons, sum alkanes, sum aromatics, unresolved complex mixture (UCM), pristane, phytane, sum naphthalenes, sum fluorenes, sum phenanthrenes, sum dibenzothiophenes, and sum chrysenes.

The presence of hydrocarbons in juvenile pink salmon tissues during 1989 was clearly evident for some hydrocarbon analytes or groups of analytes. Phytane concentrations were significantly greater at oiled sites than at control ($\alpha = 0.05$: Scheffe' a posteriori multiple comparison test) (Figure 3.4). Several other analytes showed similar patterns (sum phenanthrenes, sum naphthalenes, sum fluorenes, sum dibenzothiophenes, and sum chrysenes), but did not yield statistically significant separation (Figure 3.4). This single factor analysis of variance includes all available data and does not separate multiple replicates collected on a specific date from those collected at other times. This analysis will be improved as more data become available.

Not all juvenile pink salmon collected at contaminated sites had hydrocarbons in their tissues. Because they are highly mobile pelagic fish, this is not surprising; uncontaminated samples may indicate the salmon had not been in the oiled area long enough to become contaminated. In one instance tissues from a control site (Wells Passage, May 5, 1989) showed possible contamination. The migratory nature of the pink salmon may also explain this discrepancy. Alternatively, the Wells Passage sites may have been exposed to a small amount of oil for a short period of time; we observed small amounts of oil nearby (Culross Passage on May 4).

For these reasons, and because of certain irregularities between ABL and GERG data, the data were reanalyzed without including crossover observations (hydrocarbons in control areas and no hydrocarbons in oiled areas), and the analysis was limited to the GERG data. Results of this analysis were similar to the initial analysis: only phytane showed statistically significant differences between control and oiled sites. Analyte concentrations were again generally lower in control areas than in oiled areas.

By 1990 hydrocarbons were not detectable in juvenile pink salmon collected from oiled areas, and tissues from fry in control areas remained uncontaminated ('yes' score, Table 3.6; Figure 3.5).

To ensure that hydrocarbons detected in pink salmon tissues were not due to external contamination, we dissected fry collected in

oiled areas during 1989 and analyzed the carcasses (integument and muscle) and viscera separately. If contamination were an external artifact of sampling in polluted water where sheen and mousse were often present, we reasoned that the viscera should show no or little hydrocarbon contamination relative to the carcass. In 4 samples from oiled areas, both carcasses and viscera showed hydrocarbon contamination (Figure 3.6), and viscera concentrations were significantly ($\underline{P} < 0.05$) higher.

Although more carcass:viscera tissue analyses (12 samples) are pending, no additional data were available since the 1990 report. Because the original data set left some questions, analysis will benefit from increased sample size.

MFO analysis also indicated that juvenile pink salmon were exposed to physiologically significant levels of hydrocarbons in the nearshore marine environment in 1989. None of the four samples from non-oiled locations had MFO activity levels above 2, the level characteristic of high natural or low contaminant induction, while all of the 13 samples of pink salmon from oiled locations were at level 2 or above (Figure 3.7a). Nine of the samples from oiled areas had MFO activity rankings of 3 or greater, indicative of definite induction (Table 3.7).

High MFO activity was also observed in juvenile chum salmon sampled in oiled areas in 1989, indicating that this species was also exposed to physiologically significant levels of hydrocarbon contaminants. No MFO activity above Level 1 (very mild) was observed in samples of chums from non-oiled sites in 1989, while the three samples of chums collected from Herring Bay had strong or very strong induction of MFO's (Figure 3.7b).

There was a temporal aspect to the MFO induction in juvenile pink salmon in 1989. Nine of 10 samples of pink salmon taken from oiled areas before June 8 showed definite induction (activity levels of 3 or greater; Table 3.7). Samples with strong (5-6 rank) induction were observed in all four oiled locations in mid-May to early June (Figure 3.8). MFO activity declined to marginal induction levels, however, in all three locations where samples of juvenile pink salmon were collected in the latter half of June. This decline was not observed in chum salmon samples from Herring Bay; MFO activity was still strong in these fish in late June (Figure 3.8).

The transfer of 1990 samples from formalin to isopropanol reduced the sensitivity of the immunohistochemical assay on average by one level of detectable activity. Four comparisons were possible where subsamples of pink salmon from the same seine set in 1989 had been preserved in both formalin and isopropanol. In one case the samples were rated the same; in two cases the activity in the fish preserved in isopropanol was rated one level lower than the corresponding fish preserved in formalin; and in one case the

activity in the fish preserved in isopropanol was two levels lower (Figure 3.9).

There was no indication that MFO induction occurred in pink and chum salmon juveniles in nearshore habitats in 1990. All of the samples in 1990 from both oiled and non-oiled locations were rated either 1 or 0. If we assume that isopropanol reduced staining by a level of activity, and increase the activity level by 1, there is still no sample that would be increased to the "definite induction" range (3-6). A higher percentage of samples of pink salmon from oiled locations showed some degree of staining: four of seven were rated 1 compared to one of four from non-oiled locations (Table 3.7). However, the opposite trend was observed for chum salmon, where one of three samples in non-oiled locations had some degree of staining and all three samples from the oiled locations were negative (Table 3.8).

Discussion

Contamination of sediments and mussel tissues have established that petroleum hydrocarbon contamination was present in oiled areas but not in control areas with a few possible low level exceptions. Contrasts between oiled and non-oiled sites should therefore provide a valid measure of oil impact.

Sediment hydrocarbon concentrations in oiled areas are highly variable. We expect that refinements in the analysis, such as accounting for sample elevations and time, will probably decrease this variability. Variability will tend to remain high, however, because oil distributions were patchy; in particular oiled sediments frequently occurred as oiled bands at various elevations. Analysis of the detailed tide transect sediment data should more clearly define these distributions in Herring Bay and Snug Harbor. There is also a limited amount of data available from other oiled sites that can be used to examine the relationship of sediment contamination to elevation at our sample sites. Completion of the analysis of sediment contamination will also require processing a few additional frozen samples to fill in identified gaps in the data set.

Mussel tissues are an excellent measure of the biological availability of petroleum hydrocarbons at specific locations because they are sessile and because they accumulate hydrocarbons in their tissues without appreciable depuration. Despite the extremely low concentrations of hydrocarbons in the water column in the spill area (Short 1990; Maki 1991; our water samples have not yet been analyzed), mussels showed a dramatic separation between control and oiled sites. Concentrations of hydrocarbons in mussel tissues will be tested over time as more data become available.

Analysis of pink salmon tissue samples is complete for 1990; there are still 42 samples collected in 1989 that need to be analyzed. However, there is sufficient information from the 1989 samples to reach some preliminary conclusions.

Juvenile pink salmon tissues were contaminated by petroleum hydrocarbons in oiled areas. Hydrocarbon contamination patterns observed in juvenile salmon tissues were similar to the more clearly defined patterns observed in mussel tissues collected at the same sites. Because mussels are sessile and depurate hydrocarbons relatively slowly, while pink salmon fry are pelagic and depurate hydrocarbons more rapidly, we believe the results compare favorably.

Although hydrocarbons in CWT fry tissues did not differ significantly between oiled and non-oiled areas (Knight Island Passage versus Wells Passage), observed concentrations were always higher in tissues collected from the oiled site; the single exception was the phytane observation (Figure 3.10). Although not statisticly significant, this trend suggests that tagged fry, released from known locations, did accumulate hydrocarbons.

Not all juvenile pink salmon collected at contaminated sites had hydrocarbons in their tissues. Because they are highly mobile pelagic fish, this is not surprising; uncontaminated samples may indicate the salmon had not been in the oiled area long enough to become contaminated.

Because juvenile pink salmon viscera contained significantly higher hydrocarbon concentrations that carcasses, we rule out the possibility that observed contamination was caused by superficial contamination by collection techniques. Contaminated visceral tissues may also support the uptake by ingestion mechanism. The MFO induction in oiled areas also corroborates direct hydrocarbon measurements; juvenile pink salmon accumulated biologically significant quantities of petroleum hydrocarbons and expended energy to depurate it.

Induction of MFO's in juvenile pink salmon decreased over time in 1989, suggesting that hydrocarbon concentrations began to decline. We will be looking more closely at the mussel, sediment and pink salmon tissue data as it becomes available for similar trends. By 1990, hydrocarbon concentrations in pink salmon tissues and surface sediments had clearly declined. Insufficient data are available for mussels in 1990 to determine trends, but it is likely they will be similar.

The mean ratio of total aromatics to total hydrocarbons observed in juvenile pink salmon tissues was 0.02, indicating that exposure to whole oil was the source of contamination. At the time of these observations, concentrations of hydrocarbons

dissolved in the water column were near or below detection limits (Short 1991; Maki 1991), excluding water soluble fractions (WSF) as the probable route of contamination.

Direct ingestion could have been the route of contamination of juvenile salmon. We have evidence of oil ingestion by juvenile pink and chum salmon. During analysis of stomach contents, oil sheen or droplets were observed from several fish collected in oiled areas; no similar occurrences were noted from fish collected in control areas (Chapter 4). Oil particles that are the same size prey could be mistaken as prey and ingested directly. Oil particles ranging from 0.01 - 1.0 mm diameter were observed as deep as 80 m in Chedabucto Bay following the wreck of the tanker *Arrow* (Forrester, 1971).

Contaminated prey could also have been a route of contamination. Particulate crude oil may be ingested directly by zooplankton (Conover 1971). Various studies have also shown hydrocarbon uptake from the WSF of oil by crustaceans (e.g. Macek et al 1977, Schwartz 1985, Carls 1987). Epibenthic microcrustaceans, such as harpacticoid copepods may bioaccumulate oil from sediments, and therefore pass hydrocarbons up the food chain. Uptake of hydrocarbons by benthic organisms may be via interstitial water and is therefore kinetically controlled by desorption from sediment particles and organic matter (Landrum, 1989). Hydrocarbons, particularly the more strongly sorbed compounds, may also be assimilated via ingestion (Landrum, 1989).

Table 3.1. Analysis of hydrocarbons in sediments collected at standard beach sites during 1989. CP ≡ Culross Passage, LB ≡ Long Bay, MB ≡ McClure Bay, and WP ≡ Wells Passage, HB ≡ Herring Bay, KP ≡ Knight Island Passage, PP ≡ Prince of Wales Passage, and SH ≡ Snug Harbor.

Control sites

Local	sampled	requested	analyzed	available	no	maybe	yes
CP	16	11	10	8	9	0	1
LB	63	26	19	15	18	1	0
MB	77	28	18	18	16	1	0
WP	16	12	11	9	7	4	0
sum	172	77	63	50	50	6	1
percent					88%	11%	2%

Oiled sites

Local	sampled	requested	analyzed	available	no	maybe	yes
HB	79	44	33	15	6	5	22
KP	19	12	11	10	2	1	8
PP	21	14	12	11	4	1	7
SH	64	54	50	37	2	5	43
sum	183	124	106	73	14	12	80
percent					13%	11%	75%

Table 3.2. Analysis of hydrocarbons in sediments collected at standard beach sites during 1990. CP ≡ Culross Passage, LB ≡ Long Bay, MB ≡ McClure Bay, and WP ≡ Wells Passage, HB ≡ Herring Bay, KP ≡ Knight Island Passage, PP ≡ Prince of Wales Passage, and SH ≡ Snug Harbor.

Control sites

Local	sampled	requested	analyzed	available	no	maybe	yes
CP	18	10	10	10	10	0	0
LB	18	7	7	7	2	5	0
MB	18	5	4	4	2	0	0
WP	18	10	10	10	4	4	2
sum	72	32	31	31	18	9	2
percent					62%	31%	7%

Oiled sites

Local	sampled	requested	analyzed	available	no	maybe	yes
HB	18	10	10	10	2	1	1
KP	15	7	7	7	3	4	0
PP	18	9	9	9	5	3	1
SH	18	9	9	9	1	1	7
sum	69	35	35	35	11	9	9
percent					38%	31%	31%

Table 3.3. Analysis of hydrocarbons contained in mussel (*Mytilus trossulus*) tissues collected in 1989. CP ≡ Culross Passage, LB ≡ Long Bay, MB ≡ McClure Bay, and WP ≡ Wells Passage, HB ≡ Herring Bay, KP ≡ Knight Island Passage, PP ≡ Prince of Wales Passage, and SH ≡ Snug Harbor.

Control sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
CP	6	6	6	6	4	1	1*
LB	6	6	6	6	6	0	0
MB	6	6	6	6	6	0	0
WP	6	6	5	5	5	0	0
sum	24	24	23	23	21	1	1
percent					91%	4%	4%

Oiled sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
HB	6	6	5	5	0	0	5
KP	6	6	6	6	0	0	6
PP	7	7	6	6	0	0	6
SH	6	6	6	6	0	0	6
sum	25	25	23	23	0	0	23
percent					0%	0%	100%

Table 3.4. Analysis of hydrocarbons contained in mussel (*Mytilus trossulus*) tissues collected in 1990. CP ≡ Culross Passage, LB ≡ Long Bay, MB ≡ McClure Bay, and WP ≡ Wells Passage, HB ≡ Herring Bay, KP ≡ Knight Island Passage, PP ≡ Prince of Wales Passage, and SH ≡ Snug Harbor.

Control sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
CP	3	3	0	0	-	-	-
LB	3	3	0	0	-	-	-
MB	3	3	0	0	-	-	-
WP	3	3	0	0	-	-	-
sum	12	12	0	0	-	-	-
percent					-	-	-

Oiled sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
HB	3	3	0	0	-	-	-
KP	3	3	0	3	-	-	-
PP	4	4	1	1	0	0	1
SH	3	3	0	0	-	-	-
sum	45	45	21	21	0	0	1
percent					0%	0%	100%

Table 3.5. Analysis of hydrocarbons contained in juvenile pink salmon tissues collected during 1989. CP ≡ Culross Passage, LB ≡ Long Bay, MB ≡ McClure Bay, and WP ≡ Wells Passage, HB ≡ Herring Bay, KP ≡ Knight Island Passage, PP ≡ Prince of Wales Passage, and SH ≡ Snug Harbor.

Control sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
CP	17	8	6	3	5	1	0
LB	7	4	1	1	1	0	0
MB	11	7	5	3	4	1	0
WP	11	7	7	4	4	2	0
sum	46	26	19	11	14	4	0
percent					78%	22%	0%

Oiled sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
HB	10	9	6	4	0	2	4
KP	12	8	5	3	2	2	1
PP	13	10	5	5	3	0	2
SH	32	21	12	8	3	4	5
sum	67	48	28	20	8	8	12
percent					29%	29%	43%

Table 3.6. Analysis of hydrocarbons contained in juvenile pink salmon tissues collected during 1990. CP ≡ Culross Passage, LB ≡ Long Bay, MB ≡ McClure Bay, and WP ≡ Wells Passage, HB ≡ Herring Bay, KP ≡ Knight Island Passage, PP ≡ Prince of Wales Passage, and SH ≡ Snug Harbor.

Control sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
CP	9	9	6	6	6	0	0
LB	6	6	3	3	3	0	0
MB	4	4	1	1	0	1	0
WP	12	12	6	6	6	0	0
sum	31	31	16	16	15	1	0
percent					94%	6%	0%

Oiled sites:

Local	sampled	requested	analyzed	available	no	maybe	yes
HB	12	12	6	6	4	2	0
KP	9	9	3	3	3	0	0
PP	12	12	6	6	6	0	0
SH	12	12	6	6	6	0	0
sum	45	45	21	21	19	2	0
percent					90%	10%	0

Table 3.7. Ranking of overall prevalence and intensity of staining for mixed function oxidase activity in juvenile pink salmon sampled in oiled and non-oiled locations in Prince William Sound in 1989 and 1990. Sample rankings were based on histological sectioning and immunochemical staining for P450E content. Ranks below 2 are characteristic of natural background levels in unpolluted habitats; ranks above 2 are indicative of xenobiotic induction. A rank of 2 is inconclusive.

Sampling Location	Sample #	Date	MFO Activity Ranking	Evidence of hydrocarbon Induction
		1989		
Non-oiled				
McClure Bay	21303	May 15	1	no
Wells Passage	24103	May 21	1	no
Culross Passage	23103	May 20	2	yes?
Culross Passage	23104	May 31	1	no
Oiled				
Herring Bay	131223	May 14	2	yes?
Herring Bay	31304	May 30	6	yes
Snug Harbor-Inner Bay	32203	May 17	3	yes
Snug Harbor-Inner Bay	32104	June 2	4	yes
Snug Harbor-Outer Bay	132313	May 16	4	yes
Snug Harbor-Outer Bay	132294	June 8	5	yes
Snug Harbor-Outer Bay	132215	June 18	2	yes?
Knight Island Psg	133313	May 19	4	yes
Knight Island Psg	133123	May 19	5	yes
Knight Island Psg	133315	June 18	2	yes?
Prince of Wales Psg	134233	May 17	6	yes
Prince of Wales Psg	34104	June 9	4	yes
Prince of Wales	34105	June 25	2	yes?
		1990		
Non-oiled				
McClure Bay	21331	Apr 22	0	no
Long Bay	22202	May 5	0	no
Wells Passage	24101	Apr 21	0	no
Culross Passage	23102	May 8	1	no
Oiled				
Herring Bay	31202	May 3	1	no
Herring Bay	31214	June 2	0	no
Herring Bay	31215	June 11	0	no
Snug Harbor-Inner Bay	32111	Apr 19	1	no
Snug Harbor-Inner Bay	32213	May 19	0	no
Knight Island Psg	33102	May 7	1	no
Prince of Wales Psg	34211	Apr 20	1	no

Table 3.8. Ranking of overall prevalence and intensity of staining for mixed function oxidase activity in juvenile chum salmon sampled in oiled and non-oiled locations in Prince William Sound in 1989 and 1990. Sample rankings were based on histological sectioning and immunochemical staining for P450E content. Ranks below 2 are characteristic of natural background levels in unpolluted habitats; ranks above 2 are indicative of xenobiotic induction. A rank of 2 is inconclusive.

Sampling Location	Sample #	Date	MFO Activity Ranking	Evidence of hydrocarbon Induction
	1989			
Non-oiled				
McClure Bay	21103	May 15	0	no
Long Bay	22203	May 16	1	no
Culross Passage	23103	May 20	1	no
Wells Passage	24103	May 21	1	no
Culross Passage	123215	June 23	1	no
Oiled				
Herring Bay	31103	May 14	6	yes
Herring Bay	31104	May 30	6	yes
Herring Bay	131215	June 15	5	yes
	1990			
Non-oiled				
McClure Bay	21102	May 9	0	no
McClure Bay	21113	May 17	1	no
Long Bay	22102	May 5	0	no
Oiled				
Herring Bay	31202	May 3	0	no
Herring Bay	31113	May 16	0	no
Herring Bay	31104	June 2	0	no

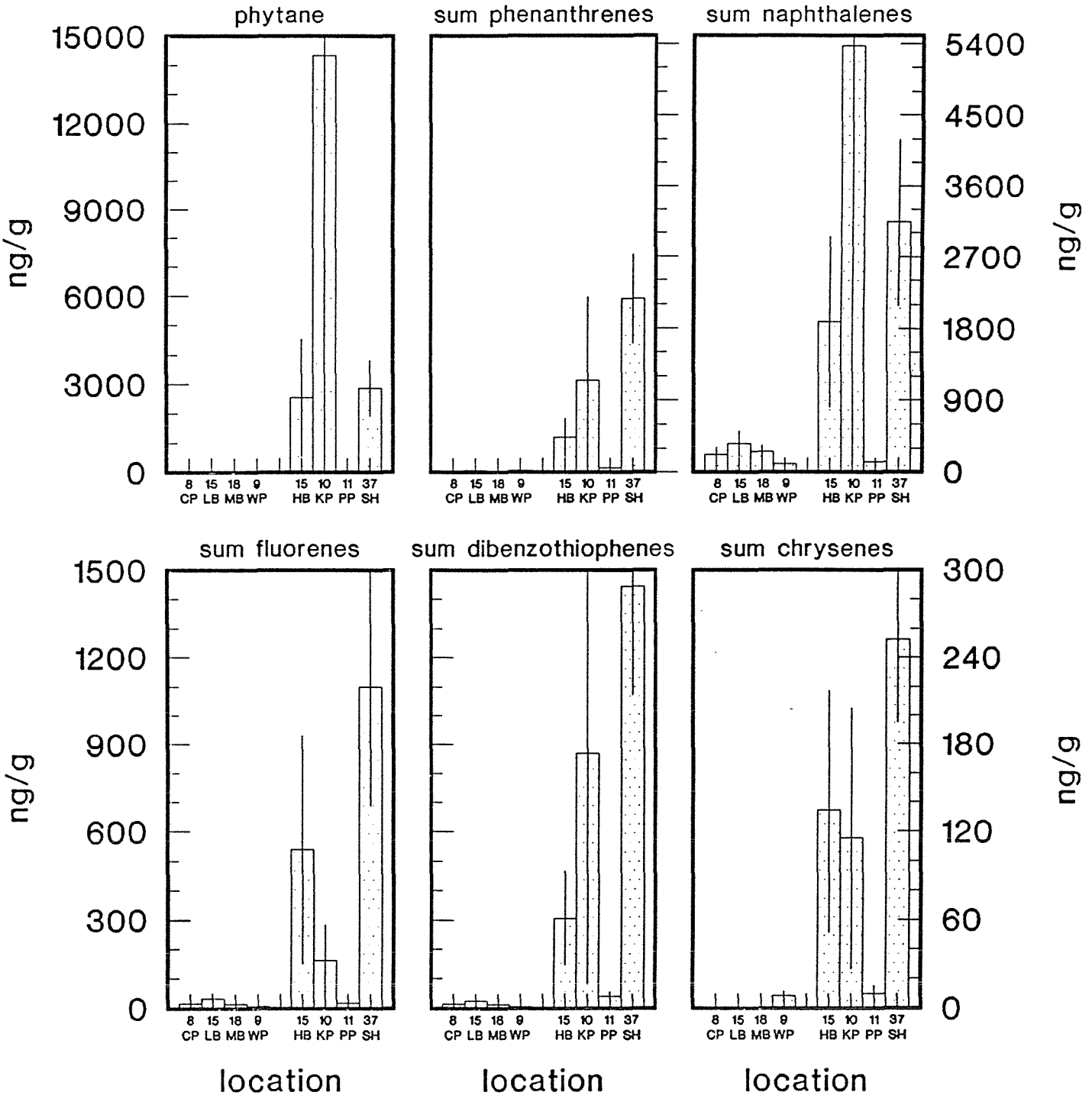


Figure 3.1--Concentrations of selected hydrocarbon analytes observed in sediments collected during 1989. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Hering Bay, KP = Knight Island Passage, PP = Prince of Wales Passage and SH = Snug Harbor.

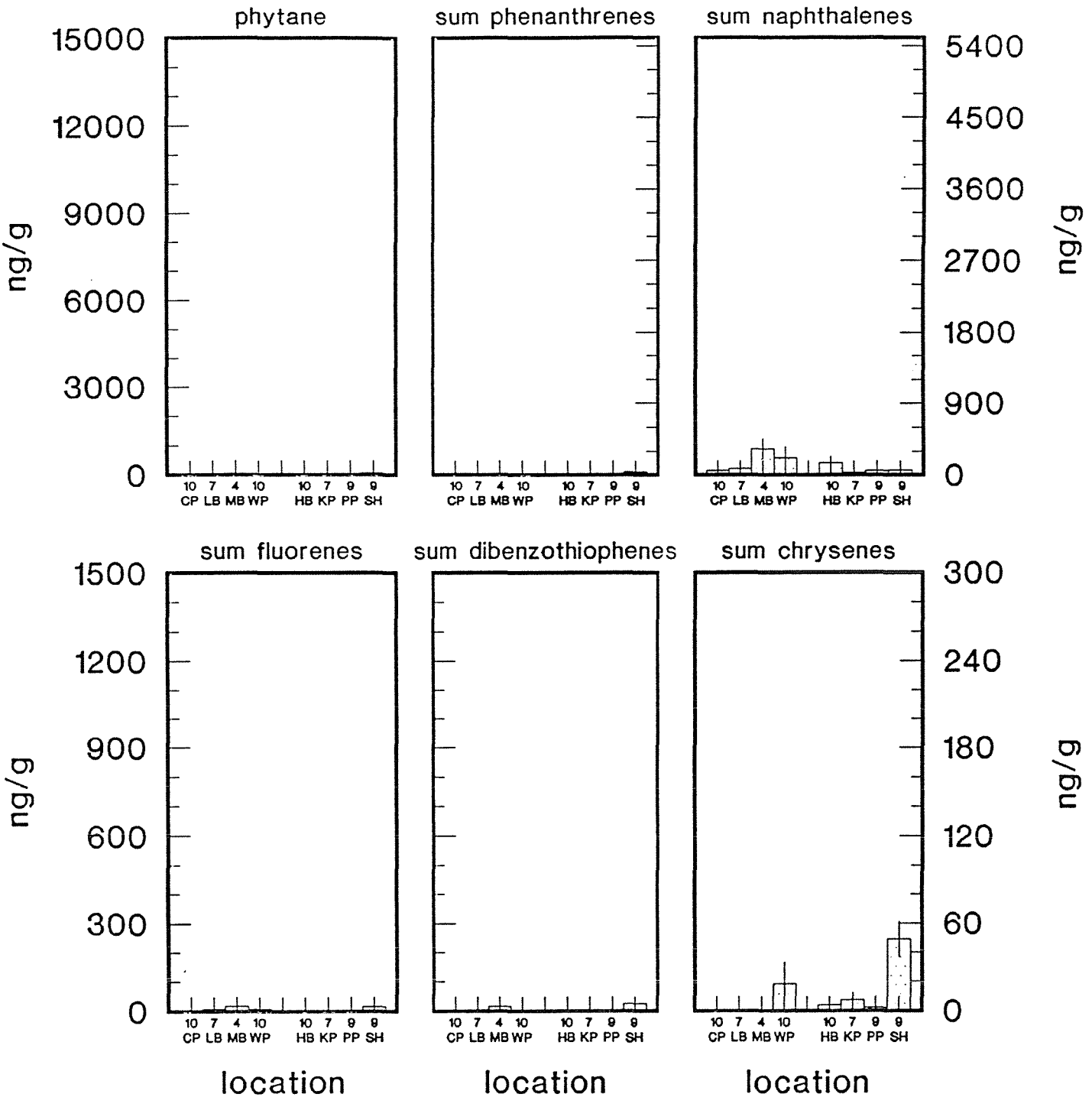


Figure 3.2--Concentrations of selected hydrocarbon analytes observed in sediments collected during 1990. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP = Prince of Wales Passage and SH = Snug Harbor.

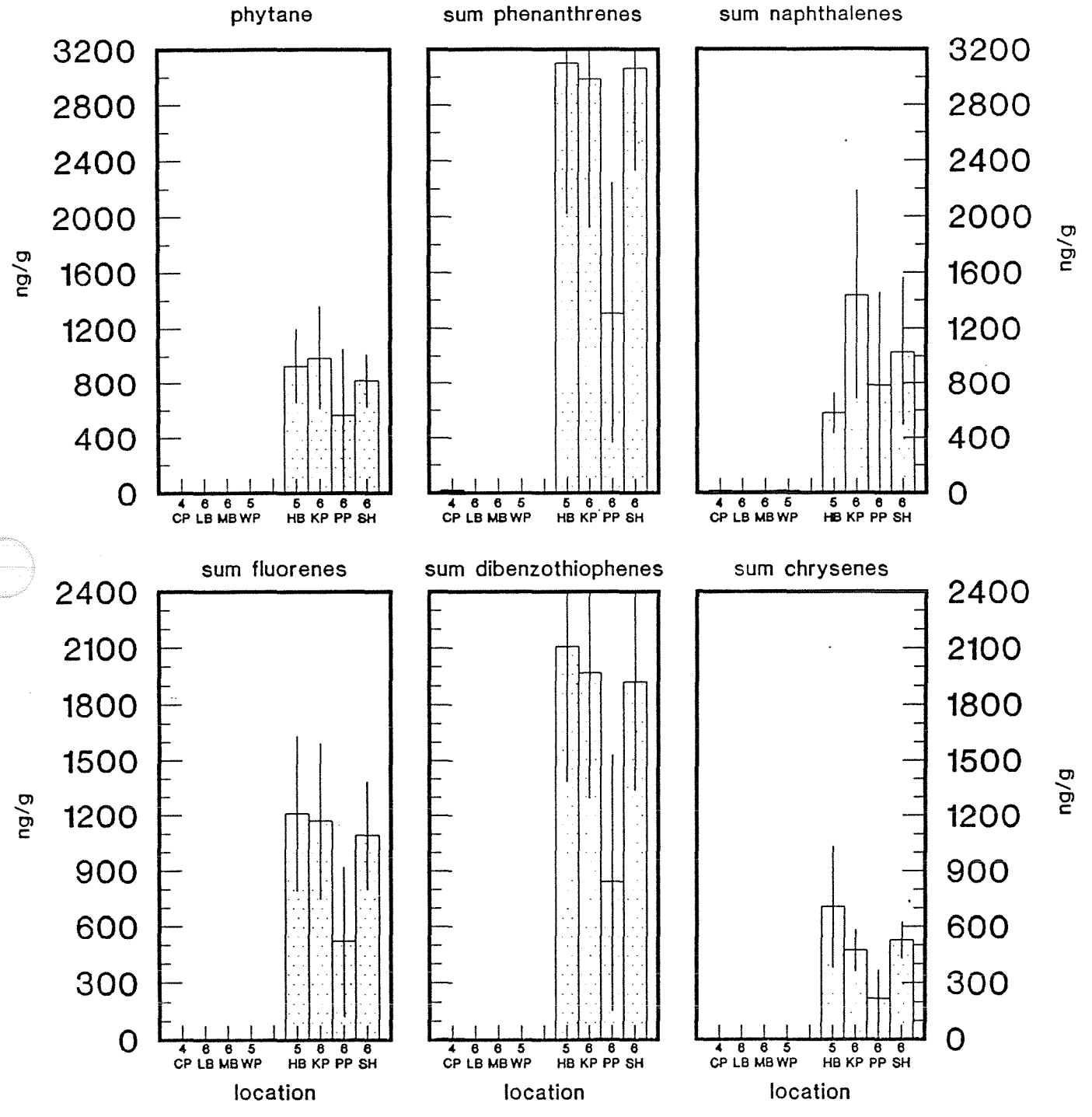


Figure 3.3--Concentrations of selected hydrocarbon analytes observed in mussel tissues collected during 1989. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP = Prince of Wales Passage and SH = Snug Harbor.

Includes both positive Culross Passage observations

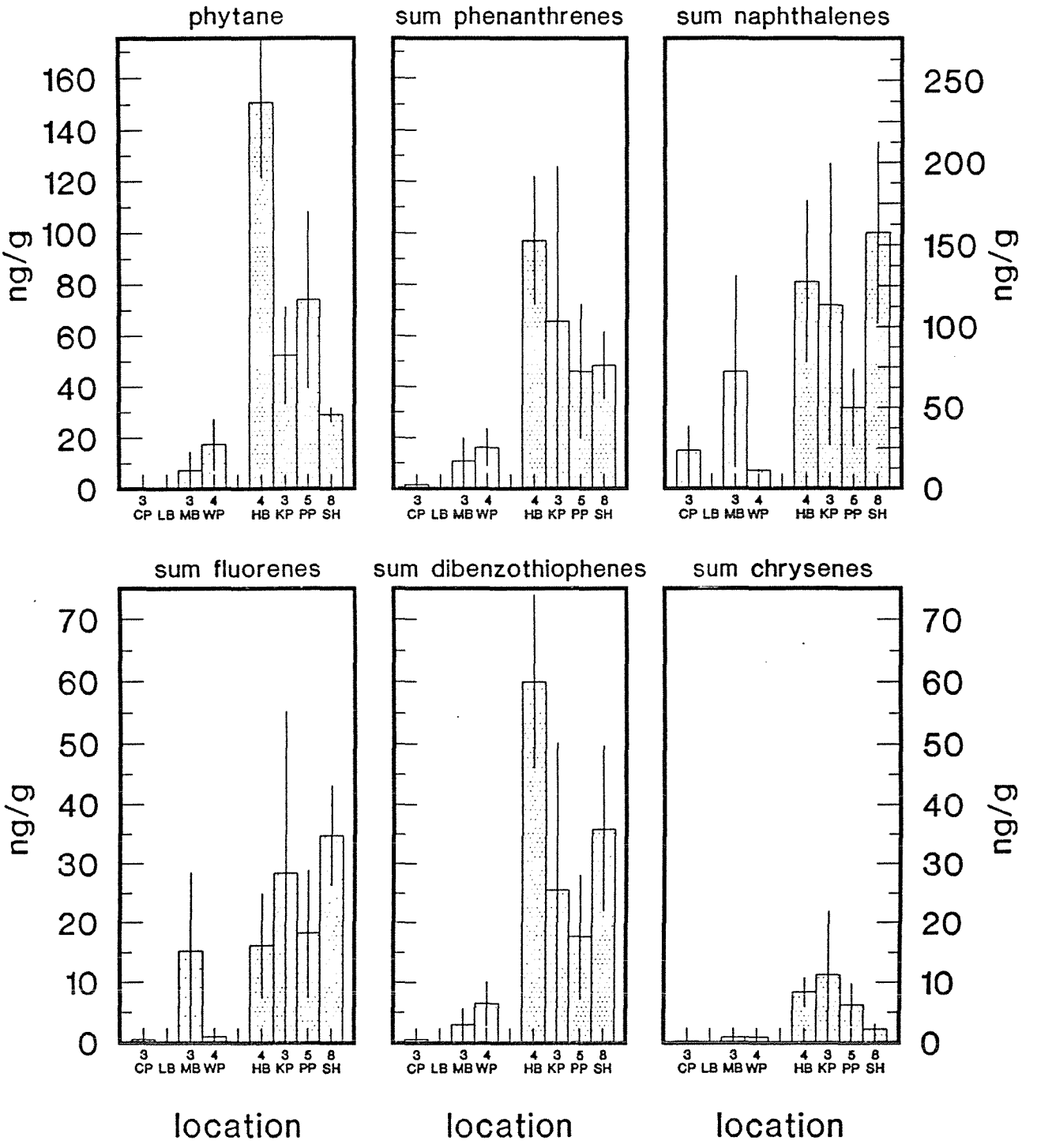


Figure 3.4--Concentrations of selected hydrocarbon analytes observed in juvenile pink salmon tissues collected during 1989. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP = Prince of Wales Passage and SH = Snug Harbor.

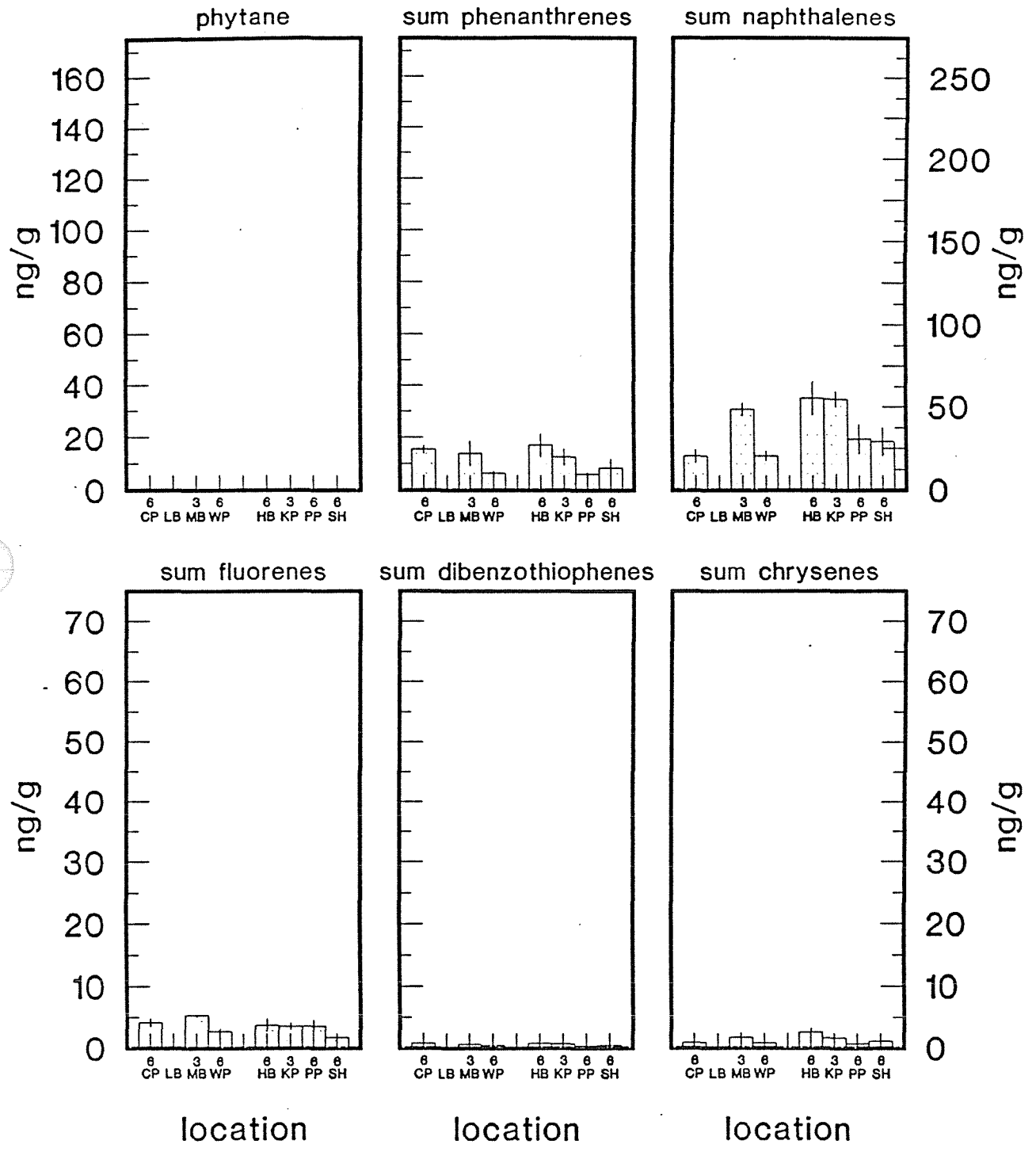


Figure 3.5--Concentrations of selected hydrocarbon analytes observed in juvenile pink salmon tissues collected during 1990. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP = Prince of Wales Passage and SH = Snug Harbor.

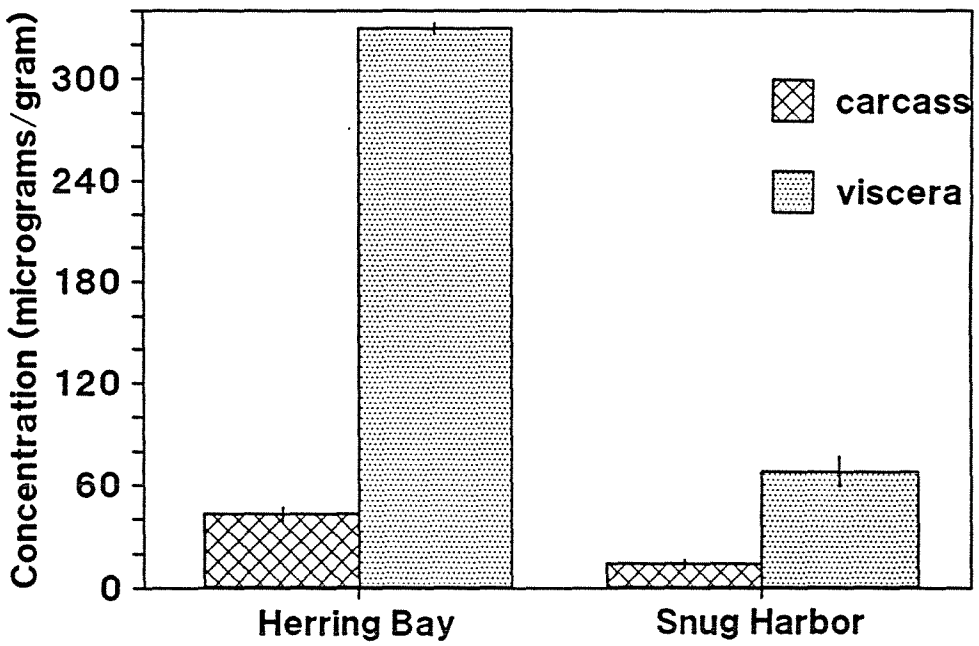


Figure 3.6--Concentrations of hydrocarbons in pink salmon fry carcasses compared to concentrations in viscera. Error bars are ±1 standard error.

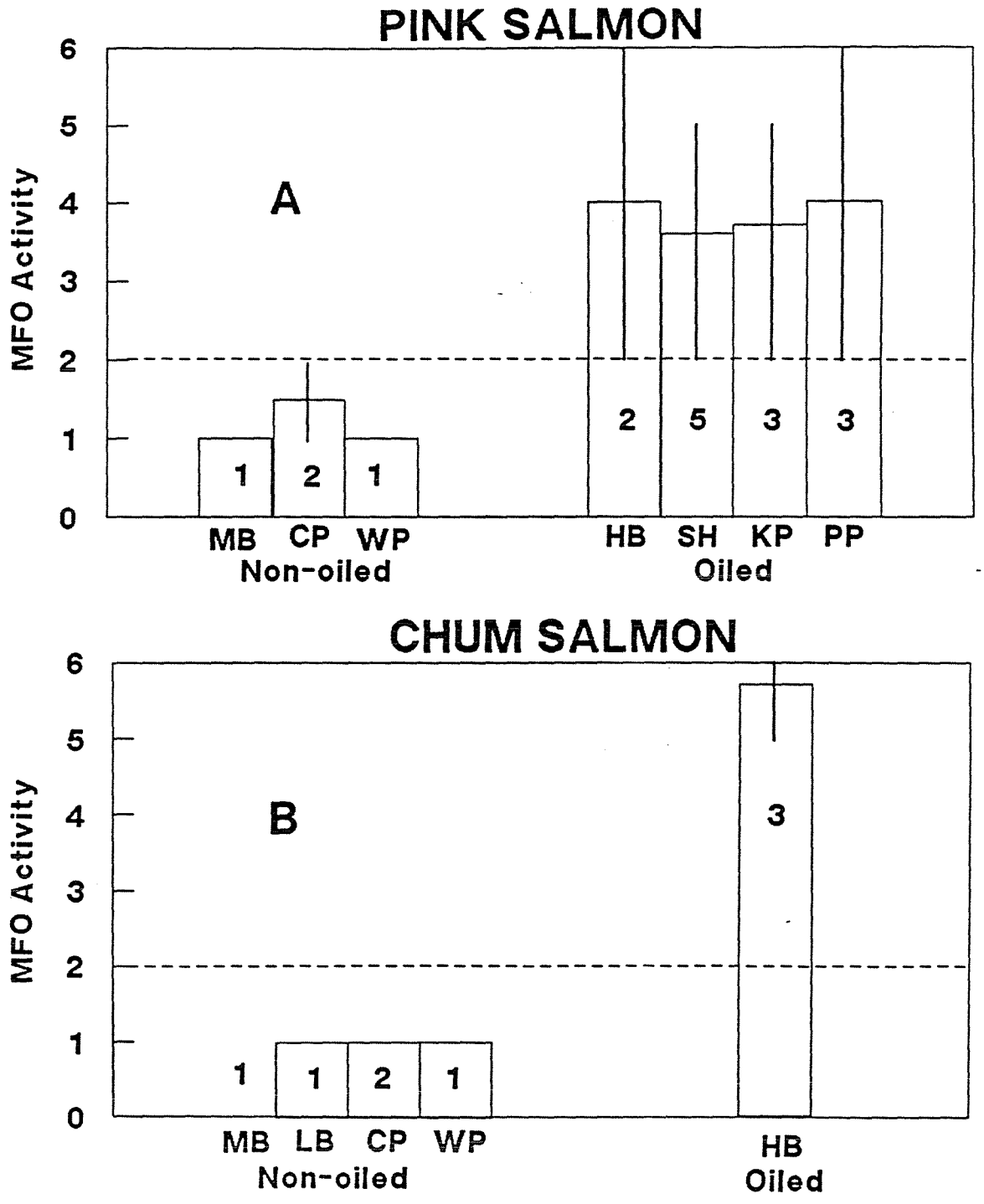


Figure 3.7. Mixed-function oxidase (MFO) levels observed in juvenile pink and chum salmon captured in nearshore marine waters of western Prince William Sound in 1989. Vertical bars show the range of MFO activity levels observed. The number shown with each bar is the number of samples analyzed for that location. MB = McClure Bay; LB = Long Bay; CP = Culross Passage; WP = Wells Passage; HB = Herring Bay; SH = Snug Harbor; KP = Knight Island Passage; PP = Prince of Wales Passage.

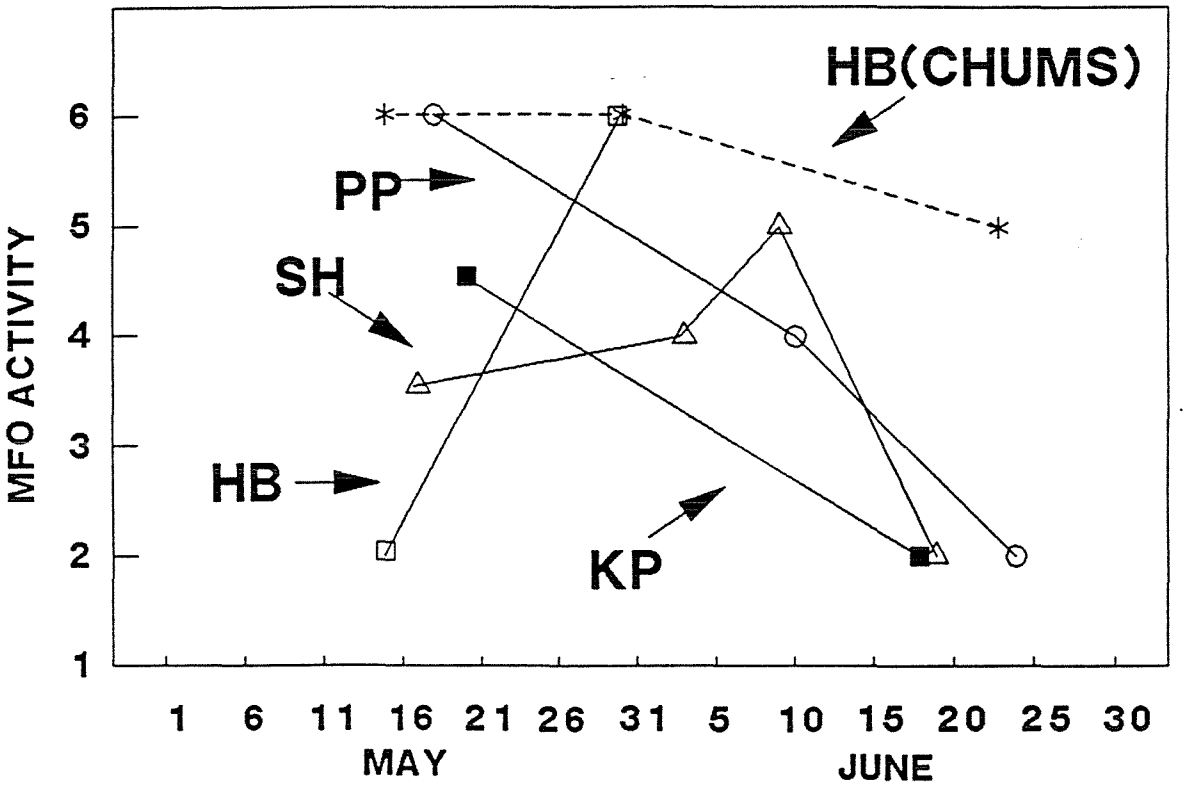


Figure 3.8. Mixed-function oxidase (MFO) activity in juvenile salmon sampled in nearshore marine waters in oiled areas of Prince William Sound in 1989. Solid lines are pink salmon; dashed line is chum salmon. HB = Herring Bay; SH = Snug Harbor; PP = Prince of Wales Passage; KP = Knight Island Passage.

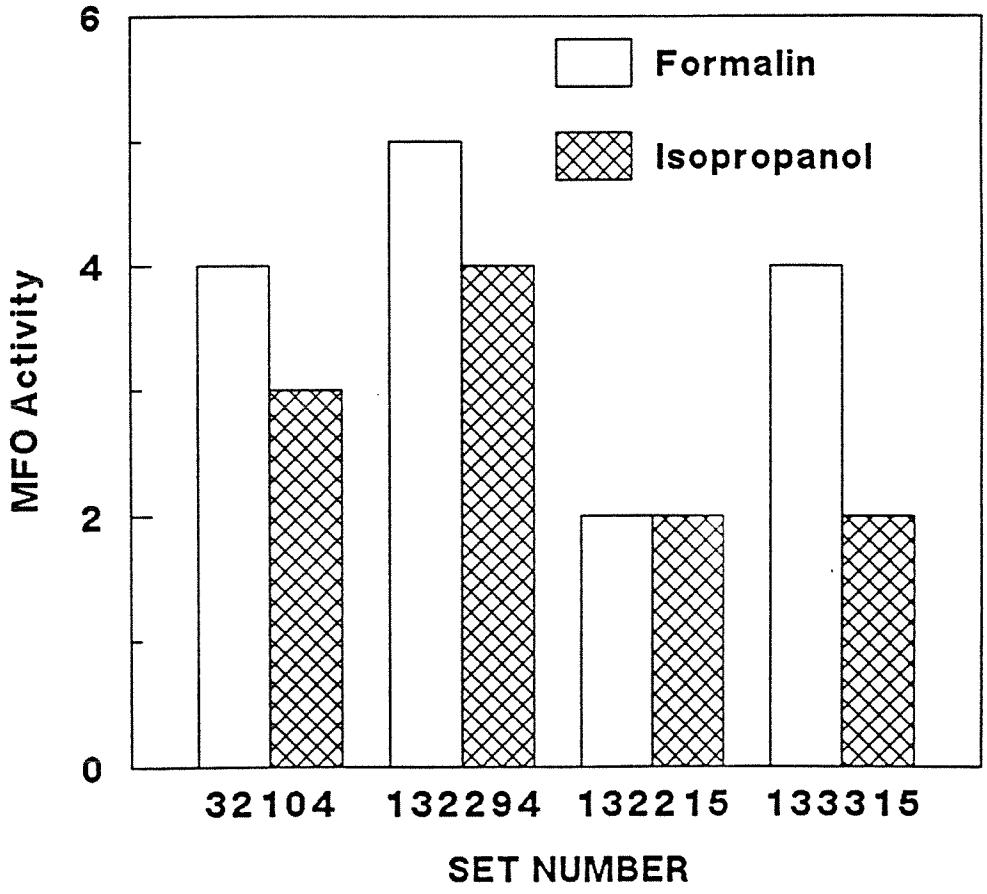


Figure 3.9. Comparison of MFO activity between subsamples of pink salmon juveniles collected in oiled areas of Prince William Sound in 1989. Comparisons are between subsamples of fish from the same set preserved in formalin or isopropanol.

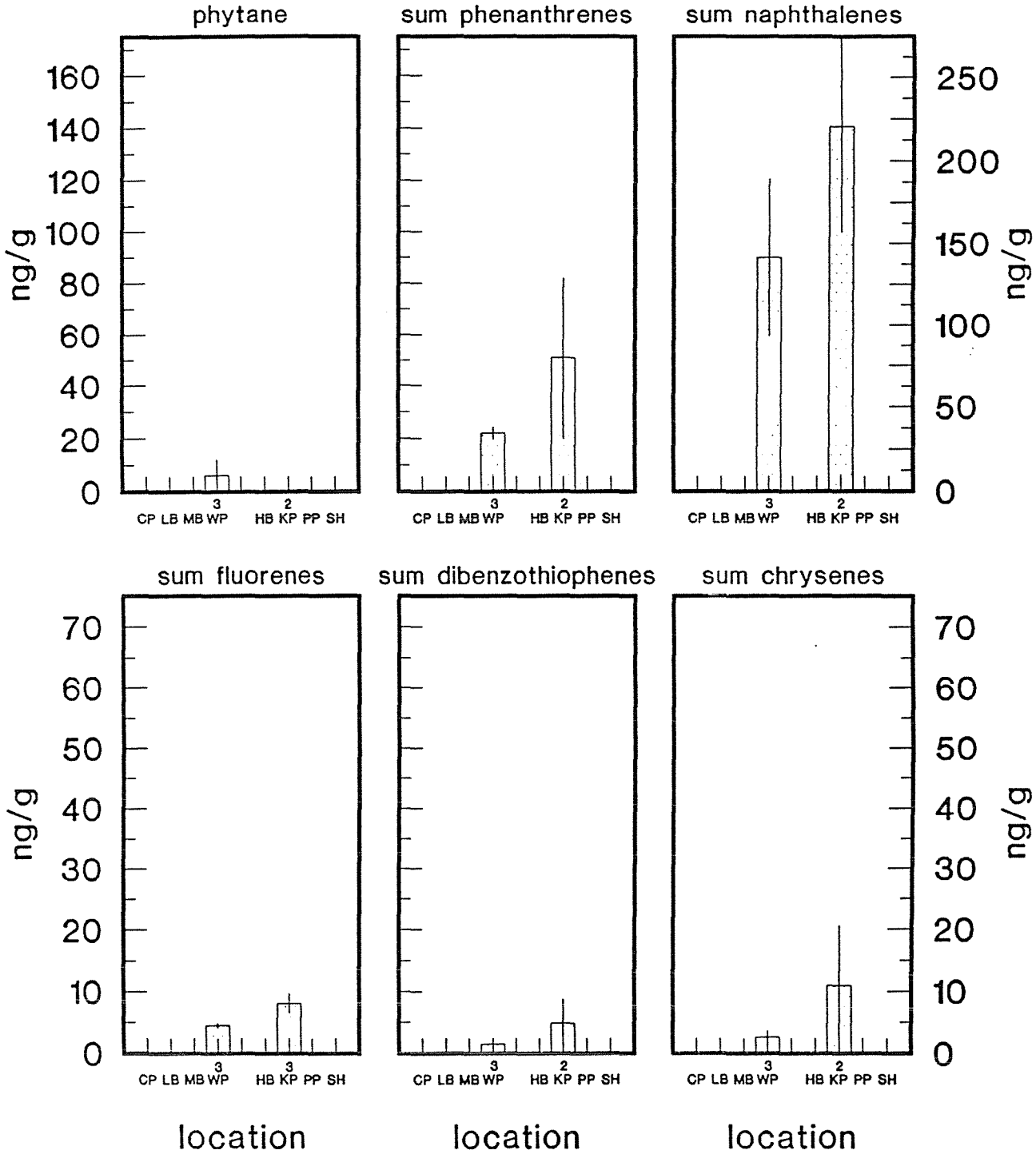


Figure 3.10--Concentrations of selected hydrocarbon analytes observed in CWT juvenile pink salmon tissues collected during 1989. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP = Prince of Wales Passage and SH = Snug Harbor.

CHAPTER 4: FEEDING HABITS

Objective 4. To compare the feeding habits of juvenile pink and chum salmon between oiled and non-oiled areas.

Methods

When fish from each site were weighed and measured (Chapter 2), individuals were randomly subsampled for analysis of stomach content. In 1989, 10 each pinks and chums (depending on availability) were subsampled from each site. In 1990, the 10 fish were randomly selected from the pooled hauls from replicate sites for each habitat type. Each fish retained for stomach analysis was put into 40% isopropyl alcohol. When the fish was processed, the foregut was excised and weighed, stomach fullness was estimated, and the contents removed. The empty foregut was then weighed to get a measure of total content wet weight.

The stomach contents were identified and counted by taxa, generally to the order level. In 1989, harpacticoid copepods were identified to genus or family level in a subsample of stomachs. Calanoid copepods were also classified by total length as large ($\geq$ 2.5 mm) or small (< 2.5 mm). Biomass of prey taxa were estimated from dry weights computed for the same or similar taxa in other feeding habits research (Landingham 1982; Cooney et al. 1981; Landingham and Mothershead 1988). If adequate literature values were not available, dry weights were computed by weighing a sample of up to 100 intact representatives of a taxon dried in a constant- temperature oven at 60°C for 24 hr.

Stomach contents were categorized as to production system: epibenthos, pelagic zooplankton, and drift insects. Epibenthos was further divided into harpacticoid copepods and other epibenthos. Pelagic zooplankton was further divided into large and small calanoids and other zooplankton. For these prey categories, dry weight, dry weight as a percent of total prey weight in a stomach, numbers, and numbers as a percent of total numbers in a stomach were calculated for each fish. Stomach content weights were also calculated as a percent of fish weight for each fish. Frequencies of occurrence for the prey categories were calculated as a percentage of the occurrence in the stomachs processed from a particular set.

The general overview of juvenile pink and chum salmon feeding habits is presented in terms of the biomass of the prey consumed. This single parameter best represents the importance of prey items from the energetics perspective of the predator (Bowen 1983). Wilcoxon signed-rank tests were used to compare the broad

spectrum of diet parameters identified above between paired sets in oiled and non-oiled areas. These comparisons were between the a priori pairs of locations identified in Chapter 2, matched as to time period and habitat. This test determines if the estimated median difference of the pairs is significantly different from zero. Tables of the Wilcoxon tests include mean values for the parameters tested. Because the oiled and non-oiled means are generated by pooling over all comparison values, differences between means are not necessarily the same magnitude or even direction as the median difference between pairs.

Results

Observations of oil ingestion

During processing of samples from 1989 collections, oil sheen and globules of a tarry material were observed on occasion from the stomachs of juvenile pink and chum salmon. Out of a total of 286 stomachs from pink salmon from oiled sites in 1989, one was observed with sheen and one with tar globules. No sheen or tar globules were observed from stomachs of pink salmon collected from non-oiled sites. Sheen was also noted from two of 67 chum salmon stomachs from oiled sites in 1989. Again, no sheen or tar globules were observed from the 426 stomachs from chum salmon captured at non-oiled sites. There was no observation of sheen or globules from any of the 595 pink salmon stomachs or 136 chum salmon stomachs processed from 1990 collections.

Pink salmon feeding habits

Processing of pink salmon stomach samples is complete. A total of 608 pink salmon stomachs were analyzed from the 1989 fish collection. The general description of the diet and the statistical comparisons between oiled and non-oiled areas were based on a subset of these data that could be used for a priori paired comparisons: 397 pink salmon, 196 (68 from bays, 128 from corridors) from non-oiled sites and 201 (71 from bays, 130 from corridors) from oiled sites. A total of 595 pink salmon stomachs were analyzed from the 1990 collection: 296 (141 from bays, 155 from corridors) from non-oiled areas and 299 (139 from bays and 160 from corridors) from oiled areas. All of the 1990 data could be used for the direct pairwise comparisons between oiled and non-oiled sites.

Pelagic zooplankton formed the largest proportion of the dietary biomass of pink salmon juveniles in bays over the spring in both 1989 and 1990. In 1989, pelagic zooplankton comprised 84% and 83% of the diet in oiled and non-oiled bays, respectively (Figure 4.1). In 1990, zooplankton again made up the bulk of the diet in bays (Figure 4.2). The proportion of zooplankton decreased to

66% in 1990 in oiled bays, while it increased to 91% in 1990 in non-oiled bays. The utilization of harpacticoid copepods and insects increased commensurately in oiled bays in 1990 (Figure 4.2).

Pelagic zooplankton also dominated the diets of pink salmon in the corridor locations in both years, although a higher proportion of the diet was composed of epibenthos in these sites. In 1989, pelagic zooplankton comprised 73% and 53% of the diet in oiled and non-oiled corridors, respectively (Figure 4.1). In 1990, the proportion of pelagic zooplankton decreased slightly to 70% of the diet in oiled corridors, and increased to 68% in non-oiled corridors (Figure 4.2).

Most of the pelagic zooplankton consumed consisted of calanoid copepods. Both large and small calanoids were eaten extensively, with no clear pattern of specificity for either size class of copepods. Other pelagic zooplankton made up large components of the diet in non-oiled corridors and oiled bays in 1990 (Figure 4.2). Cladocerans were particularly important in the non-oiled corridors in 1990, and polychaete larvae and adults and fish larvae in the oiled bays in 1990.

Harpacticoid copepods were the single most important epibenthic prey order, often composing the majority of total epibenthic prey consumed (Figures 4.1, 4.2). Other important epibenthic prey included bivalve juveniles, gammarid amphipods, and cumaceans. Drift insects (primarily of adult dipterans) were generally a low percentage of the prey, except in oiled bays in 1990, where they comprised 20% of the diet by weight (Figure 4.2).

The composition of the harpacticoid copepod component of the diet was examined in greater detail in a subsample of 61 pink salmon stomachs. The fish consumed only epibenthic harpacticoid representatives, either phytal or sediment-oriented; interstitial forms were not eaten. The most important harpacticoid prey groups were Harpacticus, Tisbe, and Dactylopodia (Figure 4.3 = OLD 15). These genera composed 48%, 22%, and 14%, respectively, of the total biomass of harpacticoids consumed by juvenile pink salmon. Pink salmon consumed Harpacticus and Tisbe in close approximation to their occurrence in the environment, based on their representation in epibenthic sled samples from the same locations (Figure 4.3).

There was a weak but consistent trend for the proportion of zooplankton in the diet to decrease with pink salmon size, and a commensurate increase in the proportion of epibenthic prey with fish size. The index of association (r) between the proportion of epibenthic prey and pink salmon size were positive and significantly ($P < 0.05$) different from 0 in both 1989 (Figure 4.4) and 1990 (Figure 4.5). The r values were negative for zooplankton in 1989 (Figure 4.6) and 1990 (Figure 4.7), although

only the 1990 r value differed significantly from 0. Consistent with this trend was a decline in the proportion of zooplankton in the diet over time in both 1989 and 1990 (Figure 4.8). Pink salmon juveniles were feeding almost exclusively on zooplankton early in the spring.

The diet of juvenile pink salmon was also examined at particular habitats. Zooplankton was always the dominant prey category consumed by pink salmon in steep gradient habitats in both 1989 (Table 4.1) and 1990 (Table 4.2). Zooplankton also generally comprised the majority of the prey biomass consumed in low and medium gradient habitats, but there were exceptions in these habitat types. In 1989, epibenthic prey composed a higher proportion of the diet in low and medium gradient habitats in non-oiled corridors (Table 4.1). In 1990, epibenthic prey composed an essentially equivalent proportion of the diet as pelagic zooplankton in low gradient habitats in non-oiled corridors and drift insects composed an equivalent proportion of the diet as pelagic zooplankton in medium gradient, oiled bays (Table 4.2).

The sizes of the fish used in the Wilcoxon paired-signed rank tests to compare diets in oiled and non-oiled areas were not significantly different in FL or weight in either 1989 or 1990 (Tables 4.3, 4.4). Size effects on diet should not, therefore, be skewing the results of the Wilcoxon tests.

Several measures of stomach fullness were compared between samples from oiled and non-oiled areas, including wet weight of stomach contents, wet weight of stomach contents as a percent of body weight, dry weight of stomach contents as a percent of dry body weight, the percent of empty stomachs, and a qualitative ranking of fullness given by processors during dissection. All measures of fullness were higher for fish from the oiled sites in 1989; only one of these measures, however, was even marginally significant: dry weight as a percent of body weight ($\underline{P} = 0.065$, Table 4.3). In 1990, measures of fullness were again higher for fish from oiled sites, but none of the comparisons was significantly different (Table 4.4).

The total number and dry weight of prey were also compared between fish from oiled and non-oiled sites. In 1989, the total number and dry weight of prey were greater at oiled sites; the difference for dry weight of prey was significant ($\underline{P} = 0.048$, Table 4.3). In 1990, both the total number of prey and the total dry weight were greater for fish from non-oiled sites; the difference in dry weight was not significant, while the difference in numbers was marginally significant ($\underline{P} = 0.073$, Table 4.4).

The major prey categories (zooplankton, epibenthos, and drift insects) were compared between fish from oiled and non-oiled

sites for five diet categories: percent frequency of occurrence in a sample, number, percent number of total number, dry weight, and percent dry weight of total prey dry weight. The patterns of these comparisons changed dramatically between 1989 and 1990. In 1989, all five diet parameters were higher in the fish from oiled areas for zooplankton, and higher in the fish from non-oiled areas for epibenthos (Table 4.5). Statistically significant differences were indicated for % number zooplankton ($\underline{P}$ = 0.020); dry weight of zooplankton ($\underline{P}$ = 0.003); % dry weight zooplankton ($\underline{P}$ = 0.016); and % number epibenthos ($\underline{P}$ = 0.083). There was no trend or significant differences in the comparisons for drift insects in the diet in 1989 (Table 4.5).

In 1990, the trends observed in the 1989 comparisons were reversed. Diet parameters were higher for pelagic zooplankton consumed by fish from non-oiled sites,with one exception: % frequency of occurrence was identical between oiled and non-oiled sites (Table 4.6). Statistically significant differences were indicated for % number zooplankton ($\underline{P}$ = 0.004), dry weight zooplankton ($\underline{P}$ = 0.086), and percent dry weight zooplankton ($\underline{P}$ = 0.003). Diet parameters were higher for epibenthos consumed by fish from oiled sites in 1990 (Table 4.6). Statistically significant differences were indicated for % number epibenthos ($\underline{P}$ = 0.003) and % dry weight epibenthos ($\underline{P}$ = 0.008). Diet parameters for drift insects were also higher for fish from oiled sites in 1990 (Table 4.6). Statistically significant differences in the comparisons of drift insects were indicated for number ($\underline{P}$ = 0.006), % number ($\underline{P}$ = 0.069), dry weight ($\underline{P}$ = 0.007), and %dry weight ($\underline{P}$ = 0.015).

The interannual shift in the diets of pink salmon from oiled and non-oiled areas was also evident when the major prey categories were split into sub-categories. In 1989, all the diet parameters were higher for harpacticoid copepods consumed by fish from non-oiled sites, although none of the comparisons was statistically significant (Table 4.7). In contrast, diet parameters were higher for calanoid copepods eaten by fish from oiled sites (Table 4.7). Statistically significant differences in total calanoids were indicated for % number ($\underline{P}$ = 0.065), dry weight ($\underline{P}$ = 0.016), and % dry weight ($\underline{P}$ = 0.076). In 1990, the pattern was reversed. All the diet parameters were greater for harpacticoid copepods consumed by fish from oiled sites in 1990 (Table 4.8); all were at least marginally statistically significant ($\underline{P}$ <.1). Diet parameters for total calanoids were higher for fish from the non-oiled sites; all were statistically significant except for total number (Table 4.8).

The pattern is the same for large and small calanoids as for total calanoids: all diet parameters are higher for fish from oiled sites in 1989 (Table 4.7), and from non-oiled sites in 1990 (Table 4.8). Statistical significance for the paired comparisons in 1989 was indicated only for large calanoids, for the same diet

parameters as total calanoids: number, % number, and dry weight (Table 4.7). In 1990, statistical significance was indicated for the differences in small calanoids for % frequency of occurrence, % number, dry weight, and % dry weight, and for large calanoids for % frequency of occurrence (Table 4.8).

Chum salmon

Processing of chum salmon stomach samples is complete. A total of 493 chum salmon stomachs were analyzed from the 1989 fish collection. The general description of the diet and the statistical comparisons between oiled and non-oiled areas were based on a subset of these data that could be used for a priori paired comparisons: 112 chum salmon, 54 from oiled sites and 58 from non-oiled sites. A total of 136 chum salmon stomachs were analyzed from the 1990 collection, 66 from oiled areas and 70 from non-oiled areas. All of these data could be used for the direct pairwise comparisons between oiled and non-oiled sites. Comparisons of juvenile chum salmon diets from oiled and non-oiled areas were limited to only six pairs of sets in 1989 and seven pairs in 1990, representing low gradient corridors and low and medium gradient bays.

Because of the paucity of chum salmon samples from paired sets, the overview of diet composition between oiled and non-oiled areas was based on data pooled from bays and corridors. Zooplankton composed the bulk of the diet in both oiled and non-oiled areas in 1989 (Figure 4.9). In 1990, zooplankton again dominated the diet in non-oiled sites, but epibenthic prey made up the bulk of the diet in samples from the oiled area (Figure 4.9).

Most of the zooplankton eaten consisted of calanoid copepods. Chum salmon juveniles were more selective for large calanoids than were pink salmon; large calanoids consistently made up the majority of the calanoid biomass consumed (Figure 4.9). In the oiled area in 1990, pelagic polychaetes (Family Syllidae) were the dominant zooplankton prey consumed.

Harpacticoid copepods did not make up as high a proportion of the epibenthic prey consumed by chum salmon as they did for pink salmon. Other, larger, epibenthic prey, especially gammarid amphipods and intertidal chironomids, made up the majority of the epibenthos consumed by juvenile chum salmon. In the oiled area in 1990, epibenthic prey dominated the chum salmon diet (Figure 4.9). Intertidal chironomids comprised the largest proportion of the epibenthic biomass consumed in this stratum.

Because of the limited number of samples, diet composition of chum salmon at the habitats sampled was only examined for low and medium gradient sites in bays and low gradient sites in

corridors. Zooplankton generally dominated the diet at these habitats in five of six cases in 1989 (Table 4.9). The exception was the medium gradient habitat in oiled bays, where epibenthic prey made up the greatest proportion of prey biomass consumed. In 1990, zooplankton comprised the majority of the prey consumed in five of six cases; epibenthos dominated in low gradient habitats in non-oiled corridors (Table 4.10).

The composition of the harpacticoid copepod component of the diet was examined in greater detail in a subsample of 109 chum salmon juveniles. The fish consumed only epibenthic harpacticoid representatives, either phytal or sediment-oriented; interstitial forms were not eaten. Tisbe comprised the largest proportion of the harpacticoid component with 47%, followed by Harpacticus and Dactylopodia at 27% and 11%, respectively. Chum salmon selected a greater biomass of Tisbe and less Harpacticus relative to their occurrence in the sled tows. Chum salmon also consumed Dactylopodia at a much higher proportion than its abundance in the sled samples (Figure 4.3).

The same weak but consistent trend in the change in diet composition and fish size observed for pink salmon also occurred for chum salmon. The proportion of zooplankton in the diet tended to decrease with chum salmon size, and the proportion of epibenthic prey tended to increase with fish size. The correlation coefficients (r) between epibenthic prey and pink salmon size were positive in both 1989 and 1990 (Figure 4.10); the r values were not significantly different from 0, however ($P > 0.1$). The correlation coefficients between zooplankton consumed and fish size were negative in both 1989 and 1990 (Figure 4.11); the r value was significantly ($P < 0.05$) different from 0 in 1989 but not in 1990.

There were differences between years and areas in the proportion of zooplankton in the diet of chum salmon over time. In 1989, chum salmon were eating almost exclusively zooplankton in both oiled and non-oiled areas in early spring. The proportion of zooplankton in the diet in 1989 then declined in both areas, with greater variability in the oiled area (Figure 4.12). In 1990, chum salmon in the non-oiled areas were again feeding predominately on zooplankton in May, declining rapidly in June (Figure 4.12). In the oiled area, zooplankton was a relatively low proportion of the diet in early May, dominated the diet in late May, then decreased in June (Figure 4.12).

The sizes of the fish used in the Wilcoxon paired rank tests to compare diets in oiled and non-oiled areas were significantly different in FL and weight in both 1989 and 1990 (Tables 4.11, 4.12), mirroring the size differences identified in Chapter 2. Therefore, we cannot rule out the possibility that differential size of fish could be affecting the results of the Wilcoxon tests of the diet parameters.

There were no consistent differences in fullness and total prey between oiled and non-oiled locations. In 1989, there were no significant differences in these parameters (Table 4.11). Of the seven measures of fullness or total prey listed in Table 4.11, the estimated median difference was greater for oiled in three cases, greater for non-oiled in three cases, and zero in one case. In 1990, there was significantly higher dry weight of prey as a percent of total body weight for non-oiled samples (Table 4.12). No other parameters were significantly different, and there was no consistent trend for lower values of fullness or total prey consumed for oiled samples: oiled was higher in four cases, non-oiled in two cases, and the estimated median difference was zero in one case.

There were no significant differences in 1989 in the utilization of the major prey categories between chum salmon from oiled and non-oiled areas (Table 4.13). In 1990, there was significantly ($\underline{P}$ = 0.052) higher proportion of zooplankton consumed by chum salmon in the non-oiled area, in terms of both number and weight (Table 4.14). Frequency of occurrence and total prey dry weight of zooplankton were also higher for non-oiled samples, although they were not significantly different. Number of zooplankton consumed, however, tended to be higher in the oiled samples. This may be an instance of size differences skewing the comparisons; larger fish may be consuming absolutely larger numbers, but proportionately less of the prey category.

When the major prey categories are subdivided into harpacticoid and calanoid copepods, there are again no significant differences between oiled and non-oiled samples in 1989 (Table 4.15). In 1990, the consumption of calanoids was significantly greater in the non-oiled sites (Table 4.16). Total calanoids were higher for non-oiled samples for all five diet parameters, and significantly greater for all except total number. Large calanoids were significantly greater for non-oiled in all the diet parameters tested. These differences are reflective of the relatively low utilization of calanoids by chum salmon in the oiled sites in 1990 (Figure 4.9). There was also a consistent trend of greater harpacticoid copepod consumption in oiled sites in 1990; total biomass of harpacticoids consumed was significantly ($\underline{P}$ = 0.076) higher in the chum salmon from the oiled area (Table 4.16). This is another case where large size of fish in oiled sites could be affecting the significance of the test, since larger fish would be expected to consume a higher biomass of prey.

Discussion

There was evidence that oil was being ingested by juvenile salmon in 1989; sheen or tar globules were observed from 0.7% of the

pink salmon and 3.0% of the chum salmon stomachs examined from fish collected at oiled sites. The sheen could have been residue from either direct ingestion of oil or from oiled prey. The size of a tar globule was similar to a large prey item, indicating that it would have been directly ingested. There were no such observations from fish from non-oiled sites in 1989, or from fish from either oiled or non-oiled areas in 1990.

There was no indication that feeding effectiveness, as measured by stomach fullness, was reduced in the oiled area compared to the non-oiled area for either pink or chum salmon. There was a significant shift in the dietary habits of pink salmon from 1989 and 1990 between oiled and non-oiled areas. Juvenile pink salmon ate less epibenthic prey in the oiled area relative to the non-oiled area in 1989, in spite of the fact that epibenthic prey were more abundant at the oiled sites sampled (see Chapter 5). In 1990, juvenile pink salmon ate more epibenthos and less zooplankton in the oiled area than in the non-oiled area. Juvenile chum salmon also ate significantly less zooplankton in oiled sites in 1990. These shifts in diet composition are best explained by the pattern of abundance of the primary food resource, pelagic zooplankton. In 1989, biomass of zooplankton tended to be higher in the oiled locations than in the non-oiled locations; the reverse was true in 1990 (see Chapter 5).

We found pelagic zooplankton to be the dominant component of juvenile pink salmon and chum salmon diets of fish in Prince William Sound. Early in their marine residency, the fish were feeding almost exclusively on pelagic zooplankton, especially calanoid copepods. Epibenthic prey became increasing important over time, coincidental with increasing size of the fish. This pattern is the reverse of what has been reported from other regions. Epibenthic prey, especially harpacticoid copepods, have been reported to be the main initial prey source of these fish in estuaries and nearshore marine habitats (Kacynski et al. 1973; Healey 1979, 1980; Godin 1981; Landingham 1982; Volk et al. 1984). Kacynski et al. (1973) speculated that dependence on littoral epibenthos represented a distinct ecological stage in the life history of these fish. Cooney et al. (1981) also reported high utilization of zooplankton in Prince William Sound, although they did find juvenile pink salmon feeding largely on harpacticoids during their short period of initial residency in Sawmill Bay. In our study, zooplankton dominated the diet of pink salmon in bays as well as in migration corridors.

There was some degree of habitat specificity in the diet of juvenile pink salmon. The fish utilized epibenthos and insects to a greater degree at low and medium gradient beaches, especially in migration corridors. In other studies of nearshore diets of pink salmon, the fish were often sampled exclusively at pebble-cobble beaches, e.g. Kacynzski et al (1973), Godin (1981). In Prince William Sound, juvenile pink salmon were most abundant

in the spring along steep, rocky shorelines; in these habitats, zooplankton always dominated the diet of the fish.

The rapid movement of juvenile of pink salmon from more protected bays to migration corridors (Chapter 2) may be an adaptive feeding strategy to take advantage of the higher zooplankton biomass in corridors in early spring (Chapter 5). The increase in epibenthic prey with time coincides with the decline of the spring zooplankton bloom (see Chapter 5). This shift in feeding habits, in conjunction with the collapse of the spring calanoid populations in Prince William Sound has been identified previously by Cooney et al. (1981). As calanoid copepods become less abundant, the juvenile salmon in the nearshore utilize alternative prey resources to a greater degree. This change in availability of prey over time probably explains the weak relationship between fish size and prey categories. At the same time, juvenile pink salmon are also dispersing from the nearshore environment to more off-shore waters, where they are obligate feeders on pelagic food webs. Further analysis is needed to determine the relative effects of prey availability and size of fish on the feeding habits of the salmon.

Although pelagic zooplankton composed the majority of the diet of both pink and chum salmon juveniles, chum salmon did tend to eat a higher proportion of epibenthic prey. The higher proportion of epibenthos may reflect the affinity of chum salmon for lower gradient habitats during their nearshore phase (Chapter 2). Epibenthic prey were more abundant in the lower gradient habitats than in the steep habitats (Chapter 5). Barnard (1979) also found a higher proportion of harpacticoid copepods and other epibenthic organisms in the diet of chum salmon than in the diet of pink salmon in Prince William Sound. Because of their distribution in nearshore habitats and their propensity to forage to a greater extent on epibenthos, juvenile chum salmon may have been more susceptible than juvenile pink salmon to hydrocarbon exposure in the oiled area.

Table 4.1. Percent dry weight of prey categories in the diet of 397 pink salmon fry collected in Prince William Sound, Alaska, April-June 1989, in oiled and non-oiled area by habitat in bays and corridors. Samples are pooled over time (trip number) and fry size. Cal. = Calanoids, Zoop. = Pelagic Zooplankton, Epi. = Epibenthos.

Species Category	Bays			Corridors		
	Low	Medium	Steep	Low	Medium	Steep
NON-OILED						
Large Cal.	41.03	8.70	69.31	22.43	28.02	41.72
Small Cal.	46.53	62.13	10.48	13.54	3.54	30.16
Other Zoop.	0.23	7.21	4.48	4.14	8.22	6.74
(Total Zoop.)	(87.79)	(78.04)	(84.27)	(40.11)	(39.78)	(78.62)
Harpacticoids	4.71	17.38	0.18	26.52	44.24	6.13
Other Epi.	1.44	2.24	1.48	31.67	11.79	10.59
(Total Epi.)	(6.15)	(19.62)	(1.66)	(58.19)	(56.03)	(16.72)
Drift Insects	5.95	2.30	13.96	1.60	4.14	4.63
OILED						
Large Cal.	91.62	26.60	51.35	31.64	24.52	50.94
Small Cal.	5.80	8.74	36.98	13.83	43.75	23.26
Other Zoop.	1.62	28.84	0.00	7.90	12.09	10.50
(Total Zoop.)	(99.04)	(64.18)	(88.33)	(53.37)	(80.36)	(84.70)
Harpacticoids	0.90	1.82	0.77	35.40	14.28	6.63
Other Epi.	0.01	19.63	1.04	10.03	3.87	7.12
(Total Epi.)	(0.91)	(21.45)	(1.81)	(45.43)	(18.15)	(13.75)
Drift Insects	0.00	14.33	9.85	1.13	1.47	1.53

Table 4.2. Percent dry weight of prey categories in the diet of 595 pink salmon fry collected in Prince William Sound, Alaska, April-June 1990, in oiled and non-oiled areas, by low, medium, and steep gradient habitats in bays and corridors. Samples are pooled by time (trip number) and fry size. Cal. = Calanoids, Zoop. = Pelagic Zooplankton, Epi. = Epibenthos.

Species Category	Bays			Corridors		
	Low	Medium	Steep	Low	Medium	Steep
NON-OILED						
Large Cal.	57.58	70.21	21.50	7.80	27.88	12.58
Small Cal.	30.20	20.87	39.54	24.76	37.46	11.92
Other Zoop.	6.49	3.75	21.79	17.13	17.17	51.86
(Total Zoop.)	(94.27)	(94.83)	(82.83)	(49.69)	(82.50)	(76.36)
Harpacticoids	4.48	0.89	1.54	27.31	6.55	1.03
Other Epi.	1.00	0.94	5.91	21.49	10.10	21.81
(Total Epi.)	(5.48)	(1.83)	(7.45)	(48.81)	(16.65)	(22.84)
Drift Insects	0.00	3.26	9.30	1.29	0.74	0.60
OILED						
Large Cal.	0.00	18.08	17.81	49.76	57.78	45.81
Small Cal.	18.02	11.35	65.12	4.41	11.56	7.48
Other Zoop.	44.62	13.46	9.05	5.55	9.21	12.72
(Total Zoop.)	(62.64)	(42.89)	(91.99)	(59.71)	(78.54)	(66.01)
Harpacticoids	13.97	10.54	5.48	19.19	13.92	5.29
Other Epi.	4.40	5.00	1.60	18.54	2.30	23.58
(Total Epi.)	(18.37)	(15.54)	(7.08)	(37.73)	(16.23)	(28.86)
Drift Insects	18.50	41.48	0.80	2.31	5.06	4.46

Table 4.3. Summary table of Wilcoxon paired-signed rank tests for average diet and size parameters of juvenile pink salmon in 21 paired sets from oiled vs. non-oiled areas in Prince William Sound, 1989. Wilc. Stat. = Wilcoxon statistic. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from the comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. W.W. = wet weight, D.W. = dry weight, B.W. = body weight, Full = stomach fullness index, % Empty = stomachs without food, FL = mm Fork Length, Weight = g wet weight.

Parameter	t	Wilc. Stat.	P-Value	Est. Median	N-O Mean	Oiled Mean
Fullness						
Gut W.W.	1	141.0	0.185	0.002	0.0061	0.0085
W.W. % B.W.	1	147.0	0.121	0.006	0.015	0.020
D.W. % B.W.	0	169.0	0.065*	0.019	0.033	0.045
Full	3	116.5	0.184	0.450	2.3	2.6
% Empty	9	39.5	1.000	0.000	0.162	0.163
Total Prey						
Number	0	119.0	0.917	11.15	91.3	119.5
D.W.	0	173.0	0.048**	1.107	2.10	3.14
Size						
FL	0	97.0	0.532	- 0.500	387	378
Weight	0	103.0	0.677	- 0.013	442	411

*indicates a P-value < 0.10
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.4. Summary table of Wilcoxon paired-signed rank tests for average diet and size parameters of juvenile pink salmon in 31 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1990. Wilc. Stat. = Wilcoxon statistic. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. W.W. = mg wet weight, D.W. = mg dry weight, B.W. = body weight, Full = stomach fullness index, % Empty = percent of stomachs without food, FL = mm Fork Length, Weight = g wet weight.

Parameter	t	Wilc. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Fullness						
Gut W.W.	0	261.0	0.806	0.207	5.80	5.63
W.W. % B.W.	0	274.0	0.617	0.001	0.014	0.014
D.W. % B.W.	0	216.0	0.537	0.003	0.033	0.031
Full	1	266.5	0.491	0.200	2.8	2.9
% Empty	17	39.0	0.414	0.000	10.4	8.7
Total Prey						
Number	0	156.0	0.073*	-38.97	141.1	73.5
D.W.	0	205.0	0.405	- 0.183	2.482	2.035
Size						
FL	0	261.0	0.806	0.161	368	373
Weight	0	291.0	0.405	23.2	363	411

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.5. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey categories consumed by juvenile pink salmon in 20 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1989. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. Zoop. = Zooplankton, %F.O. = Percent Frequency of Occurrence, Dry wt. = mg dry weight.

Prey Category	t	Wilcox. Stat.	P-value	Est. Median	N-O Mean	Oiled Mean
Pelagic Zoop.						
%F.O.	7	61.0	0.295	0.050	0.769	0.829
Number	0	142.5	0.167	34.25	38.1	72.8
% Number	0	168.0	0.020**	0.191	0.440	0.637
Dry Wt.	0	184.0	0.003***	1.218	1.273	2.518
% Dry Wt.	0	170.0	0.016**	0.202	0.508	0.695
Epibenthos						
%F.O.	2	55.5	0.199	- 0.100	0.755	0.662
Number	0	73.0	0.240	-19.75	60.9	54.7
% Number	0	58.0	0.083*	- 0.138	0.481	0.318
Dry Wt.	0	85.0	0.467	- 0.176	0.950	0.838
% Dry Wt.	0	61.0	0.104	- 0.135	0.384	0.255
Drift Insects						
%F.O.	7	25.0	0.162	- 0.033	0.183	0.132
Number	17	2.0	0.789	0.000	0.2	0.15
% Number	4	36.0	0.103	- 0.007	0.020	0.015
Dry Wt.	4	68.5	1.000	0.000	0.086	0.106
% Dry Wt.	4	40.0	0.155	- 0.025	0.081	0.048

*indicates P-value < 0.1
**indicates P-value < 0.05
***indicates P-value < 0.01

Table 4.6. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey categories consumed by juvenile pink salmon in 31 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1990. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg. dry weight, Cal. = Calanoids, Zoop. = Zooplankton.

Prey Category	t	Wilcox. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Pelagic Zoop.						
%F.O.	10	116.5	0.986	0.000	0.829	0.828
Number	0	185.0	0.221	-11.61	85.7	31.7
% Number	0	101.0	0.004***	- 0.193	0.664	0.476
Dry Wt.	0	160.0	0.086*	- 0.361	1.916	1.385
% Dry Wt.	0	95.0	0.003***	- 0.223	0.768	0.559
Epibenthos						
%F.O.	4	247.0	0.167	0.125	0.431	0.421
Number	0	255.5	0.891	0.475	55.7	39.30
% Number	0	399.0	0.003***	0.188	0.251	0.442
Dry Wt.	0	283.0	0.499	0.040	0.611	0.527
% Dry Wt.	0	383.0	0.008***	0.160	0.205	0.359
Drift Insects						
%F.O.	9	159.0	0.299	0.030	0.099	0.139
Number	10	194.5	0.006***	0.125	0.084	0.312
% Number	9	183.0	0.069*	0.004	0.006	0.023
Dry Wt.	9	209.5	0.007***	0.057	0.034	0.198
% Dry Wt.	9	202.0	0.015**	0.035	0.022	0.074

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.7. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey sub-categories consumed by juvenile pink salmon in 20 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1989. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg dry weight, Cal. = Calanoids.

Prey Category	t	Wilcox. Stat.	P-Value	Est. Median	N-O Mean	Oiled Mean
Harpacticoids						
%F.O.	2	64.0	0.360	- 0.058	0.686	0.619
Number	0	77.0	0.305	-16.50	46.8	48.0
% Number	0	76.0	0.287	- 0.085	0.346	0.262
Dry Wt.	0	80.0	0.360	- 0.184	0.555	0.576
% Dry Wt.	0	84.0	0.444	- 0.054	0.234	0.192
Tot. Cal.						
%F.O.	4	86.0	0.366	0.109	0.588	0.681
Number	2	103.0	0.459	3.500	26.1	34.7
% Number	0	155.0	0.065*	0.168	0.278	0.428
Dry Wt.	0	170.0	0.016**	0.989	1.134	2.15
% Dry Wt.	0	153.0	0.076*	0.169	0.384	0.522
Small Cal.						
%F.O.	2	109.5	0.306	0.175	0.511	0.627
Number	1	116.0	0.409	5.000	19.2	30.6
% Number	0	141.0	0.185	0.085	0.213	0.288
Dry Wt.	0	125.0	0.467	0.137	0.524	0.838
% Dry Wt.	0	114.0	0.751	0.030	0.207	0.231
Large Cal.						
%F.O.	5	85.5	0.156	0.069	0.314	0.413
Number	7	83.0	0.010**	1.000	1.3	2.7
% Number	3	117.0	0.058*	0.032	0.031	0.132
Dry Wt.	4	120.0	0.008**	0.529	0.609	1.314
% Dry Wt.	3	105.0	0.185	0.051	0.176	0.290

*indicates P-value < 0.1
**indicates P-value < 0.05
***indicates P-value < 0.01

Table 4.8. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey sub-categories consumed by juvenile pink salmon in 31 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1990. A negative value for the estimated median difference indicates non-oiled > oiled. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. t = number of ties deleted from comparison. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg. dry weight, Cal. = Calanoids.

Prey Category	t	Wilcox. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Harpacticoids						
%F.O.	1	317.5	0.082*	0.170	0.518	0.679
Number	0	339.0	0.076*	7.725	28.9	28.6
% Number	0	376.0	0.012**	0.172	0.172	0.339
Dry Wt.	0	344.0	0.061*	0.080	0.241	0.287
% Dry Wt.	0	365.0	0.022*	0.120	0.111	0.225
Total Cal.						
%F.O.	4	80.0	0.009***	-0.194	0.776	0.569
Number	0	193.0	0.286	-5.278	33.0	20.8
% Number	0	122.0	0.014**	-0.152	0.459	0.293
Dry Wt.	0	156.0	0.073*	-0.310	1.305	1.143
% Dry Wt.	0	82.0	0.001***	-0.229	0.570	0.361
Small Cal.						
%F.O.	2	105.0	0.015**	-0.227	0.766	0.539
Number	0	186.0	0.228	-6.273	31.7	19.0
% Number	0	132.0	0.024**	-0.127	0.403	0.257
Dry Wt.	0	134.0	0.026**	-0.209	0.669	0.257
% Dry Wt.	0	97.0	0.003***	-0.182	0.364	0.118
Large Cal.						
%F.O.	3	89.0	0.010*	-0.245	0.766	0.528
Number	1	91.0	0.614	-0.072	1.29	1.804
% Number	1	81.0	0.380	-0.004	0.056	0.036
Dry Wt.	1	91.0	0.614	-0.035	0.635	0.886
% Dry Wt.	1	89.0	0.563	-0.020	0.206	0.183

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.9. Percent dry weight of prey categories in the diet of 112 chum salmon fry diets from fish collected in Prince William Sound, Alaska, April-June 1989, in oiled and non-oiled areas by habitat in bays and corridors. Samples are pooled over time (trip number) and fry size. Cal. = Calanoids, Zoop. = Pelagic Zooplankton, Epi. = Epibenthos, N/A = Insufficient Data).

Species Category	Bays			Corridors		
	Low	Medium	Steep	Low	Medium	Steep
NON-OILED						
Large Cal.	0.00	64.72	N/A	65.02	N/A	N/A
Small Cal.	78.10	13.38	N/A	0.49	N/A	N/A
Other Zoop.	0.00	2.79	N/A	1.86	N/A	N/A
(Total Zoop.)	(78.10)	(80.89)	N/A	(67.37)	N/A	N/A
Harpacticoids	3.26	1.72	N/A	16.86	N/A	N/A
Other Epi.	13.60	1.39	N/A	14.08	N/A	N/A
Total Epi.	(16.86)	(3.11)	N/A	(30.94)	N/A	N/A
Drift Insects	5.00	15.99	N/A	1.68	N/A	N/A
OILED						
Large Cal.	74.30	36.37	N/A	63.60	N/A	N/A
Small Cal.	0.00	0.83	N/A	0.29	N/A	N/A
Other Zoop.	1.62	6.16	N/A	1.43	N/A	N/A
Total Zoop.	(75.92)	(43.36)	N/A	(65.32)	N/A	N/A
Harpacticoids	0.69	6.11	N/A	0.55	N/A	N/A
Other Epi.	6.46	47.81	N/A	0.05	N/A	N/A
Total Epi.	(7.15)	(53.92)	N/A	(0.60)	N/A	N/A
Drift Insects	16.92	2.71	N/A	34.06	N/A	N/A

Table 4.10. Percent dry weight of prey categories in the diet of 136 chum salmon fry collected in Prince William Sound, Alaska, April-June 1990, in oiled and non-oiled areas, by habitat in bays and corridors. Samples are pooled over time and fry size. Cal. = Calanoids, Zoop. = Pelagic Zooplankton, Epi. = Epibenthos, N/A = insufficient data available.

Species Category	Bays			Corridors		
	Low	Medium	Steep	Low	Medium	Steep
NON-OILED						
Large Cal.	69.43	92.82	N/A	19.28	N/A	N/A
Small Cal.	4.91	4.50	N/A	0.50	N/A	N/A
Other Zoop.	12.25	0.03	N/A	3.11	N/A	N/A
(Total Zoop.)	(86.58)	(97.36)	N/A	(22.89)	N/A	N/A
Harpacticoids	1.57	0.22	N/A	1.97	N/A	N/A
Other Epi.	9.76	0.25	N/A	74.24	N/A	N/A
(Total Epi.)	(11.33)	(0.47)	N/A	(76.22)	N/A	N/A
Drift Insects	1.92	2.16	N/A	0.85	N/A	N/A
OILED						
Large Cal.	2.99	0.00	N/A	36.89	N/A	N/A
Small Cal.	0.60	0.00	N/A	5.40	N/A	N/A
Other Zoop.	48.37	0.01	N/A	24.78	N/A	N/A
(Total Zoop.)	(51.96)	(0.01)	N/A	(67.07)	N/A	N/A
Harpacticoids	1.17	1.08	N/A	19.09	N/A	N/A
Other Epi.	46.02	98.80	N/A	10.18	N/A	N/A
(Total Epi.)	(47.20)	(99.89)	N/A	(29.27)	N/A	N/A
Drift Insects	0.35	0.00	N/A	3.36	N/A	N/A

Table 4.11. Summary table of Wilcoxon paired-signed rank tests for average diet and size parameters of juvenile chum salmon in six paired sets from oiled vs. non-oiled areas of Prince William Sound, 1989. t = number of ties deleted from comparison. Wilc. Stat. = Wilcoxon Statistic. A negative value for the estimated median difference indicates non-oiled > oiled. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. W.W. = wet weight, D.W. = dry weight, B.W. = body weight, Full = stomach fullness index, % Empty = percentage of empty stomachs, FL = mm Fork Length, Weight = g wet weight.

Parameter	t	Wilc. Stat.	P-Value	Estimated Median	N-O Mean	Oiled Mean
Fullness						
Gut W.W.	0	18.0	0.142	0.0057	0.009	0.016
W.W. % B.W.	0	11.0	1.000	0.0005	0.017	0.020
D.W. % B.W.	0	10.0	1.000	- 0.0069	0.033	0.027
Full	0	7.0	0.529	- 0.4833	2.7	2.8
% Empty	3	3.0	1.000	0.0000	0.083	0.033
Total Prey						
Number	0	7.0	0.529	-46.28	66.4	25.9
D.W.	0	14.0	0.529	1.261	2.90	4.60
Size						
FL	0	21.0	0.036*	7.054	386	470
Weight	0	21.0	0.036*	0.3702	442	885

Table 4.12. Summary table of Wilcoxon paired-signed rank tests for average diet and size parameters of juvenile chum salmon in 7 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1990. Wilc. Stat. = Wilcoxon statistic. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. W.W. = mg wet weight, D.W. = mg dry weight, B.W. = body weight, Full = stomach fullness index, % Empty = percent of stomachs without food, FL = mm Fork Length, Weight = g wet weight.

Parameter	t	Wilc. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Fullness						
Gut W.W.	0	23.0	0.151	8.875	0.013	0.022
W.W. % B.W.	0	15.0	0.933	0.0002	0.023	0.022
D.W. % B.W.	0	0.0	0.022*	-0.0232	0.063	0.015
Full	0	18.0	0.554	0.5021	3.6	4.0
% Empty	5	1.5	1.000	0.0000	0.017	0.017
Total Prey						
Number	0	21.0	0.272	33.40	45.9	84.4
D.W.	0	7.0	0.272	-0.9878	5.93	2.66
Size						
FL	0	26.0	0.052*	6.950	418	511
Weight	0	26.0	0.052*	429.3	583	1291

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.13. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey categories consumed by juvenile chum salmon in 6 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1989. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O and Oiled Mean are means of non-oiled and oiled comparison values, respectively. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg. dry weight, Cal. = Calanoids, Zoop. = Zooplankton.

Prey Category	t	Wilc. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Pelagic Zoop.						
%F.O.	3	3.0	1.000	0.0000	0.900	0.907
Number	0	9.0	0.834	-3.761	35.7	12.3
% Number	0	10.0	1.000	-0.0820	0.544	0.474
Dry Wt.	0	11.0	1.000	0.0771	2.145	3.025
% Dry Wt.	0	9.0	0.834	-0.0463	0.594	0.583
Epibenthos						
%F.O.	0	7.0	0.529	-0.2220	0.825	0.674
Number	0	9.0	0.834	-5.714	29.4	12.1
% Number	0	10.0	1.000	-0.0213	0.381	0.374
Dry Wt.	0	9.0	0.834	-0.0560	0.611	0.581
% Dry Wt.	0	8.0	0.675	-0.0262	0.263	0.229
Drift Insects						
%F.O.	1	9.0	0.787	0.0060	0.313	0.296
Number	1	9.0	0.787	0.5944	0.5	1.2
% Number	1	9.0	0.787	0.0303	0.044	0.067
Dry Wt.	1	12.0	0.281	0.2922	0.192	1.037
% Dry Wt.	1	9.0	0.787	0.0392	0.142	0.168

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.14. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey categories consumed by juvenile chum salmon in 7 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1990. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. Wilc. Stat. = Wilcoxon Statistic. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg. dry weight, Cal. = Calanoids, Zoop. = Zooplankton.

Prey Category	t	Wilc. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Pelagic Zoop.						
%F.O.	1	2.5	0.116	-0.1854	0.907	0.681
Number	0	16.0	0.800	3.200	17.6	30.4
% Number	0	2.0	0.052*	-0.2767	0.581	0.2865
Dry Wt.	0	5.0	0.151	-0.9985	2.354	1.309
% Dry Wt.	0	2.0	0.052*	-0.2598	0.692	0.388
Epibenthos						
%F.O.	1	18.0	0.142	0.2000	0.730	0.948
Number	0	19.0	0.447	23.67	25.0	44.6
% Number	0	22.0	0.205	11.82	0.296	0.553
Dry Wt.	0	20.0	0.353	0.8637	3.539	1.313
% Dry Wt.	0	23.0	0.151	0.2891	0.270	0.570
Drift Insects						
%F.O.	2	2.0	0.178	0.2917	0.214	0.097
Number	3	1.0	0.201	-0.1500	0.286	0.100
% Number	1	8.0	0.675	-0.0009	0.016	0.010
Dry Wt.	3	2.0	0.361	-0.0198	0.067	0.039
% Dry Wt.	1	10.0	1.000	-0.0010	0.022	0.034

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.15. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey sub-categories consumed by juvenile chum salmon in 6 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1989. A negative value for the estimated median difference indicates non-oiled > oiled. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg. dry weight, Cal. = Calanoids, Zoop. = Zooplankton.

Prey Category	t	Wilc. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Harpacticoids						
%F.O.	1	4.0	0.418	-0.125	0.638	0.537
Number	0	8.0	0.675	-2.133	27.9	6.2
% Number	0	9.0	0.834	-0.061	0.273	0.224
Dry Wt.	0	8.0	0.675	-0.033	0.288	0.072
% Dry Wt.	0	5.0	0.295	-0.069	0.136	0.061
Total Cal.						
%F.O.	2	3.0	0.584	-0.238	0.846	0.669
Number	0	8.0	0.675	-2.989	30.9	6.6
% Number	0	6.0	0.402	-0.081	0.394	0.286
Dry Wt.	0	11.0	1.000	0.048	2.101	2.919
% Dry Wt.	0	9.0	0.834	-0.128	0.574	0.496
Small Cal.						
%F.O.	3	4.0	0.789	0.000	0.567	0.085
Number	0	3.0	0.142	-6.314	27.1	0.5
% Number	0	3.0	0.142	-0.174	0.370	0.042
Dry Wt.	0	3.0	0.142	-0.174	0.754	0.014
% Dry Wt.	0	3.0	0.142	-0.123	0.195	0.040
Large Cal.						
%F.O.	0	0.0	0.036**	-0.494	0.479	0.608
Number	2	7.0	0.584	3.250	2.7	5.9
% Number	2	7.0	0.584	0.040	0.105	0.185
Dry Wt.	2	7.0	0.584	1.596	1.346	2.905
% Dry Wt.	2	5.0	1.000	0.000	0.379	0.455

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

Table 4.16. Summary table of Wilcoxon paired-signed rank tests comparing average values for prey sub-categories consumed by juvenile chum salmon in 7 paired sets from oiled vs. non-oiled areas of Prince William Sound, 1990. A negative value for the estimated median difference indicates non-oiled > oiled. Wilc. Stat. = Wilcoxon Statistic. t = number of ties deleted from comparison. N-O Mean and Oiled Mean are means of non-oiled and oiled values used in the comparisons, respectively. %F.O. = Percent Frequency of Occurrence, Dry wt. = mg. dry weight, Cal. = Calanoids, Zoop. = Zooplankton.

Prey Category	t	Wilc. Stat.	P - Value	Est. Median	N-O Mean	Oiled Mean
Harpacticoids						
%F.O.	0	21.0	0.272	0.2917	0.479	0.685
Number	0	20.0	0.353	2.908	10.4	18.7
% Number	0	16.0	0.800	0.0337	0.124	0.195
Dry Wt.	0	25.0	0.076*	0.0955	0.104	0.216
% Dry Wt.	0	20.0	0.353	0.0417	0.049	0.115
Total Cal.						
%F.O.	0	3.0	0.076*	-0.503	0.736	0.422
Number	0	6.0	0.205	-4.333	7.5	3.2
% Number	0	0.0	0.022**	-0.304	0.369	0.053
Dry Wt.	0	2.0	0.052*	-1.715	2.109	0.484
% Dry Wt.	0	2.0	0.052*	-0.417	0.572	0.163
Small Cal.						
%F.O.	2	4.0	0.418	-0.0473	0.409	0.269
Number	1	6.0	0.402	-2.514	3.4	2.3
% Number	1	4.0	0.208	-2.514	0.112	0.022
Dry Wt.	1	6.0	0.402	-0.0691	0.094	0.063
% Dry Wt.	1	6.0	0.402	-0.0310	0.053	0.024
Large Cal.						
%F.O.	0	1.0	0.035**	-0.3237	0.651	0.210
Number	0	2.0	0.052*	-2.182	4.1	0.9
% Number	0	3.0	0.076*	-1.884	0.257	0.030
Dry Wt.	0	2.0	0.052*	-1.727	2.015	0.422
% Dry Wt.	0	3.0	0.076*	-0.3861	0.520	0.139

*indicates a P-value < 0.1
**indicates a P-value < 0.05
***indicates a P-value < 0.01

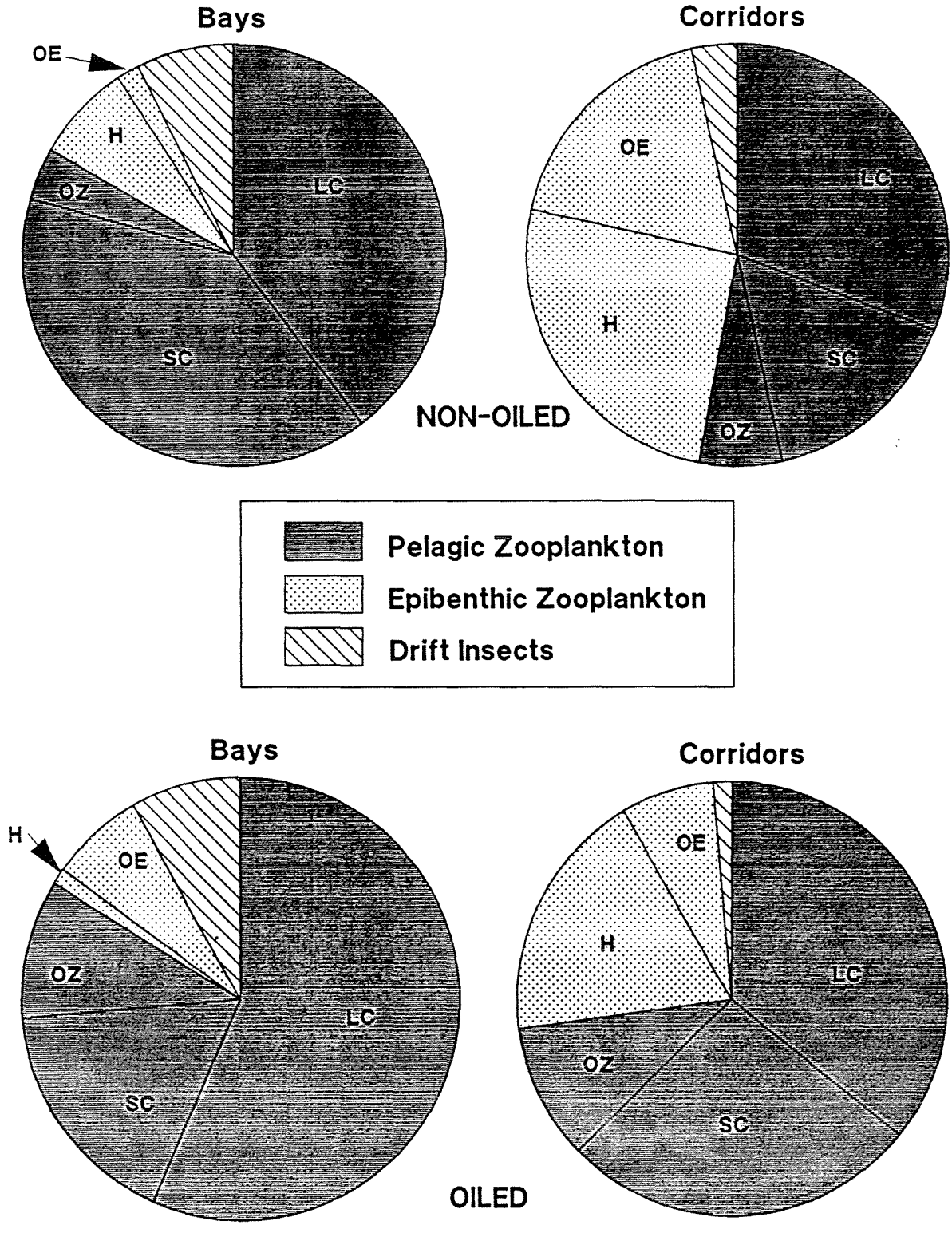


Figure 4.1. Prey percent dry weight from 397 pink salmon fry stomachs collected in Prince William Sound, Alaska, 1989. LC = Large Calanoids, SC = Small Calanoids, OZ = Other Zooplankton, H = Harpacticoids, OE = Other Epibenthic.

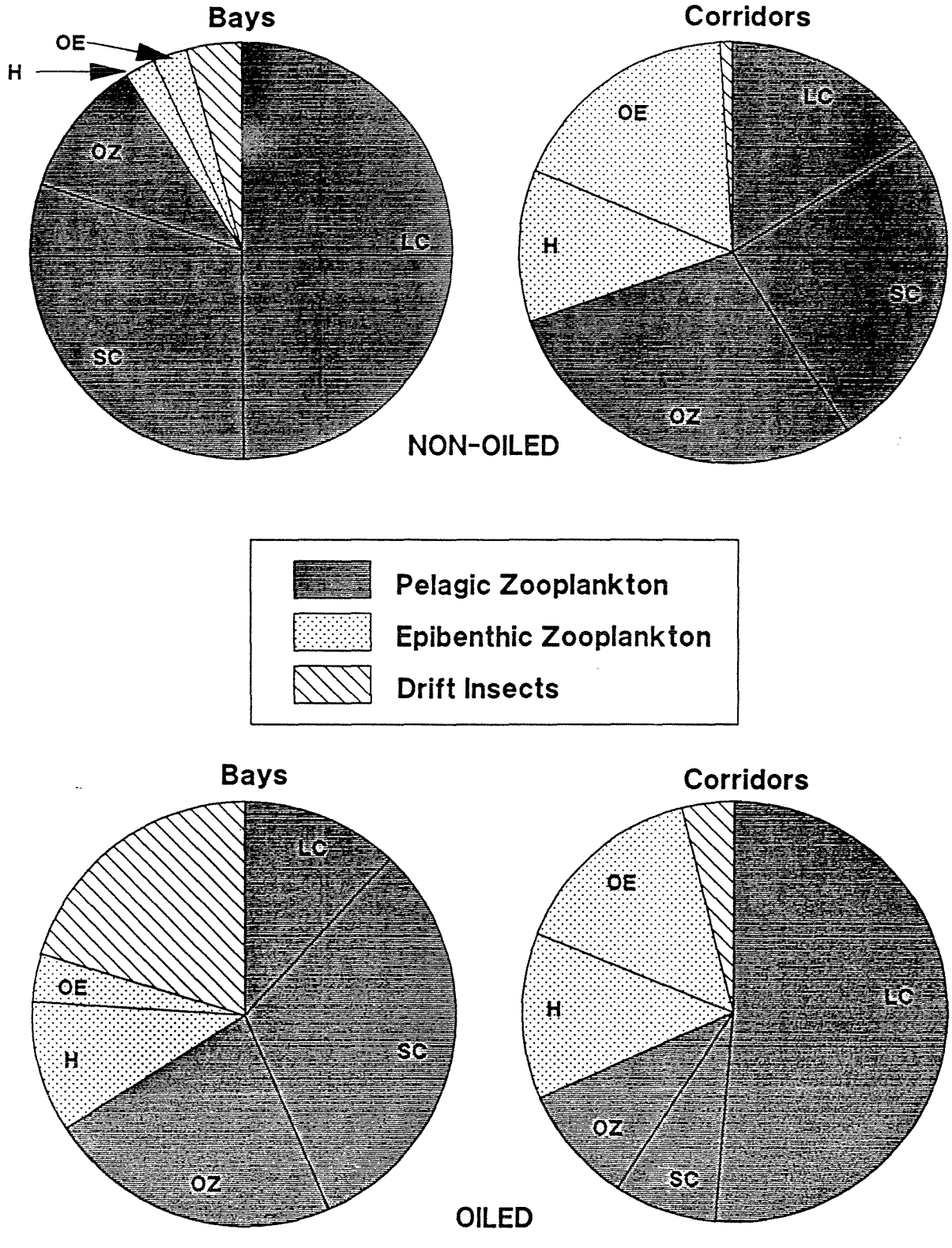


Figure 4.2. Prey percent dry weight from 595 pink salmon fry stomachs collected in Prince William Sound, Alaska, 1990. LC = Large Calanoids, SC = Small Calanoids, OZ = Other Zooplankton, H = Harpacticoids, OE = Other Epibenthic.

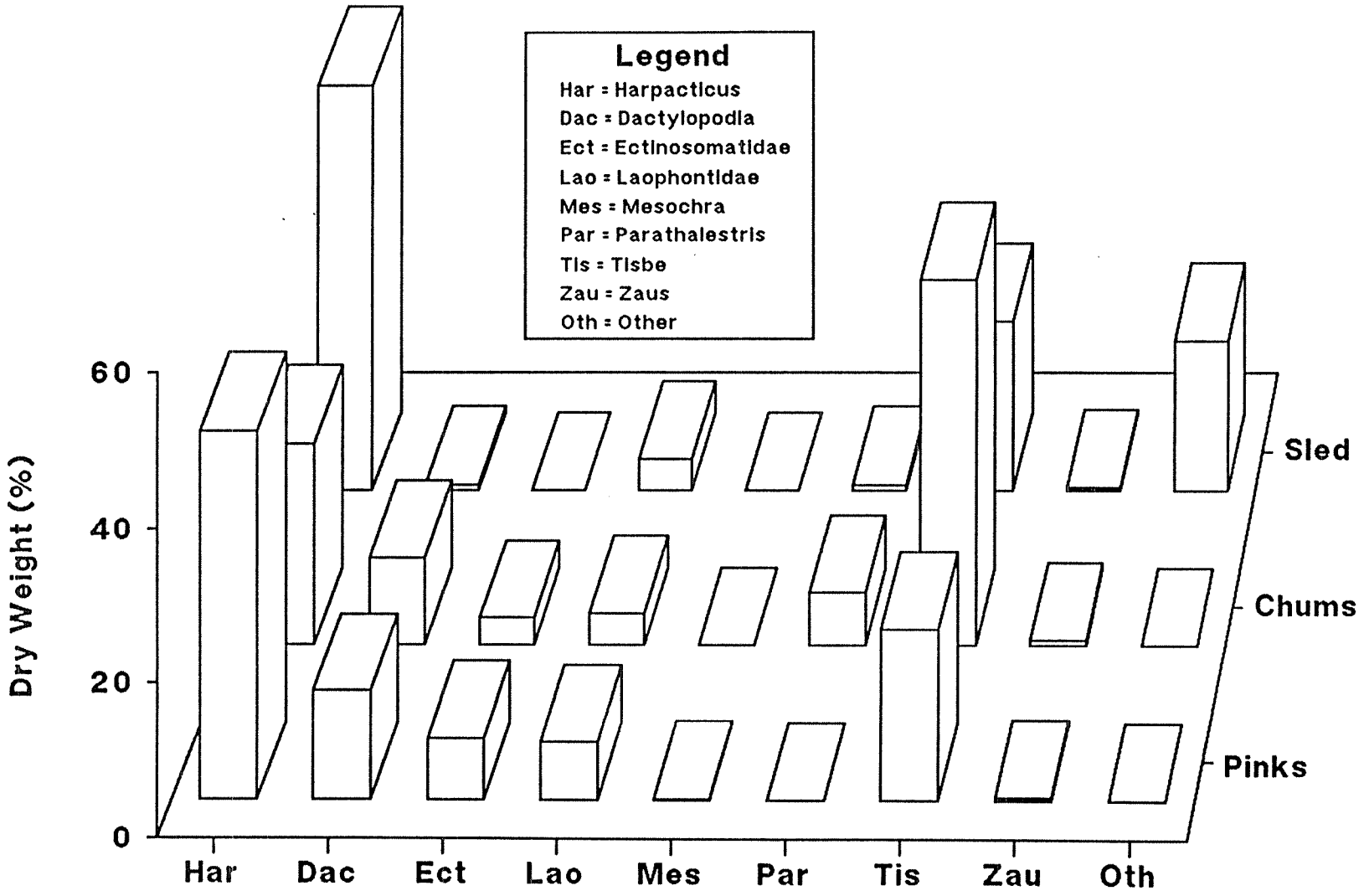


Figure 4.3. Harpacticoid composition of juvenile salmon diets and epibenthic environment in all locations of Prince William Sound, 1989.

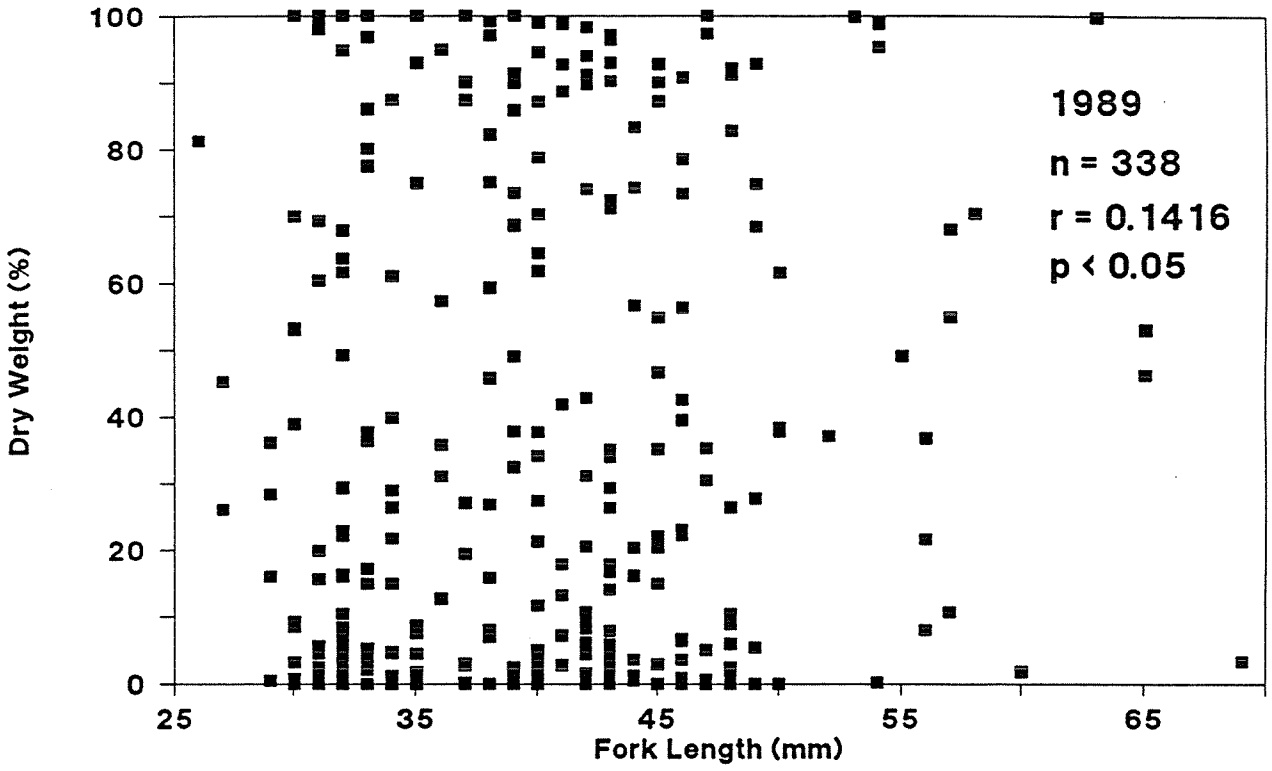


Figure 4.4. Relationship of biomass of epibenthic prey consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1989. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.

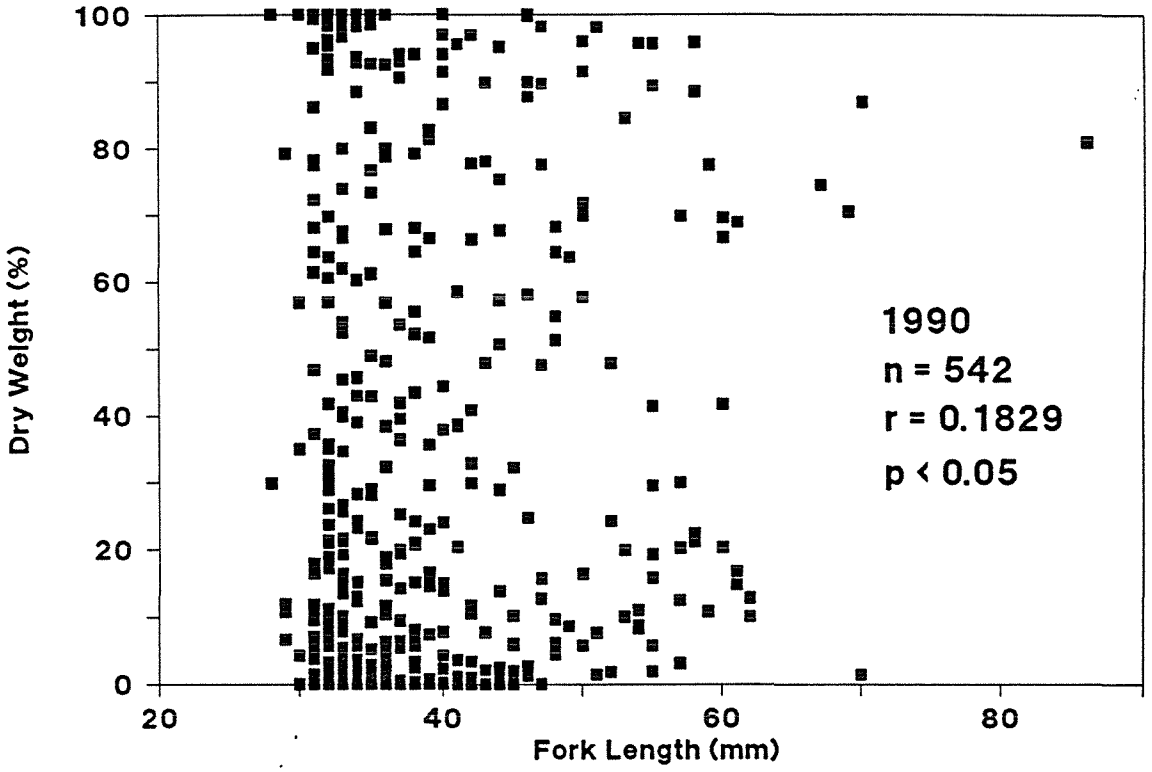


Figure 4.5. Relationship of biomass of epibenthic prey consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1990. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.

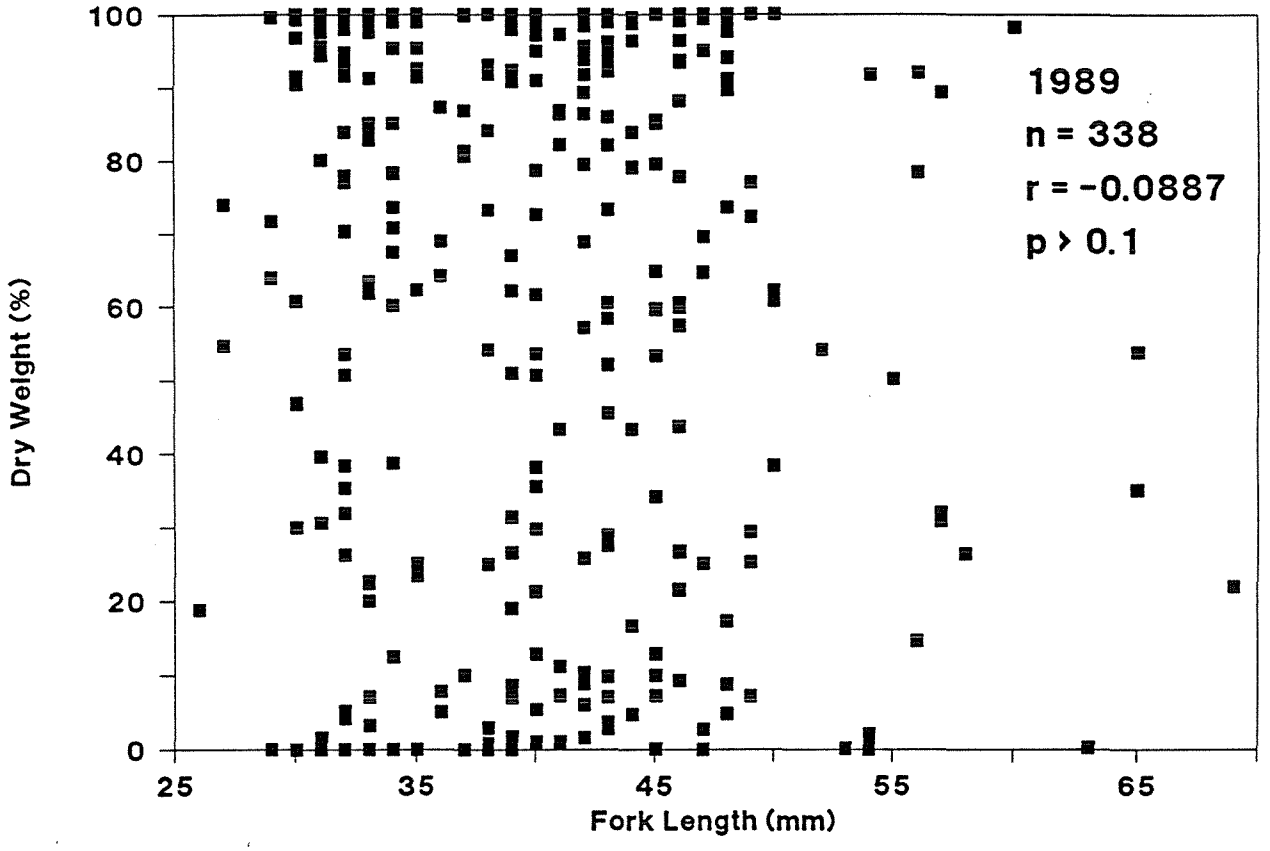


Figure 4.6. Relationship of biomass of pelagic zooplankton consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1989. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.

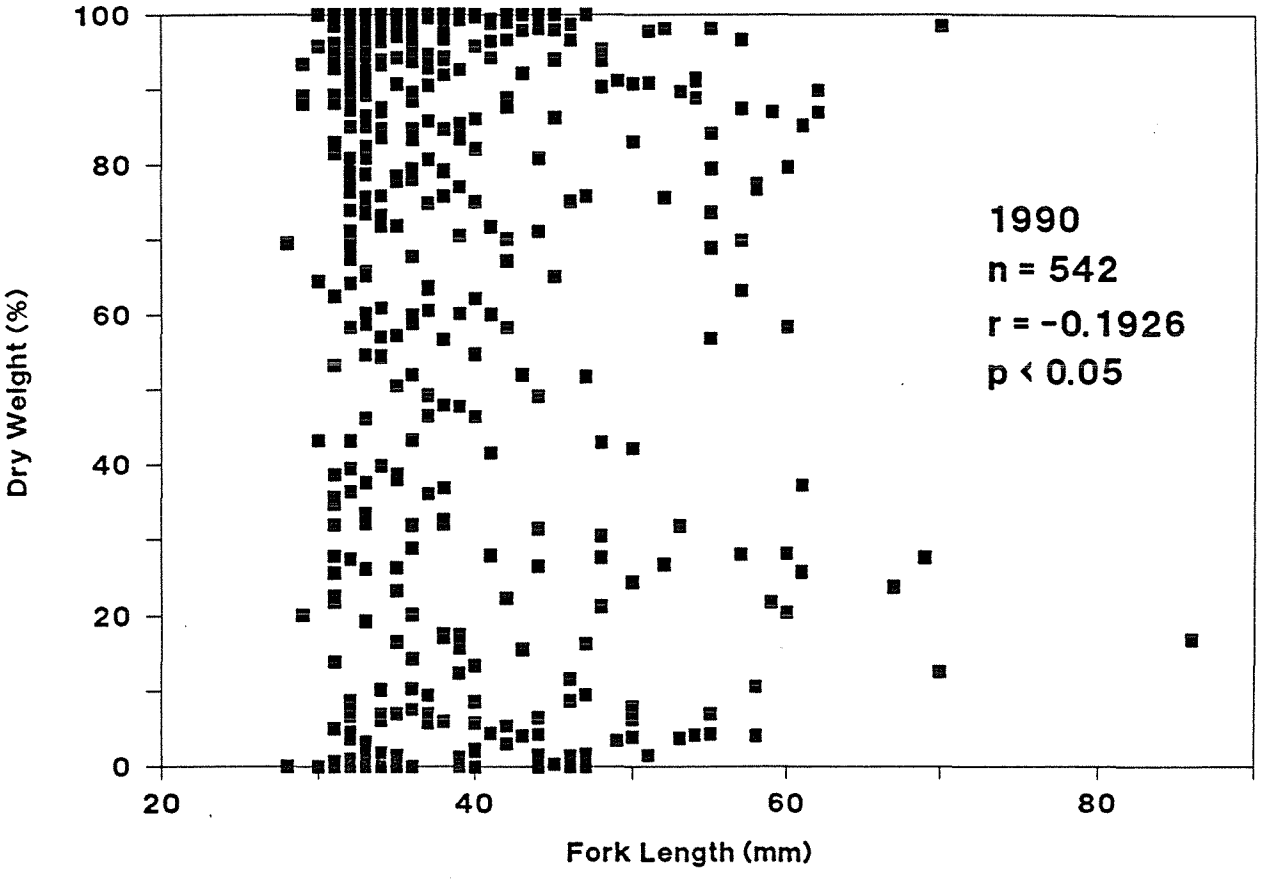


Figure 4.7. Relationship of biomass of pelagic zooplankton consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1990. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.

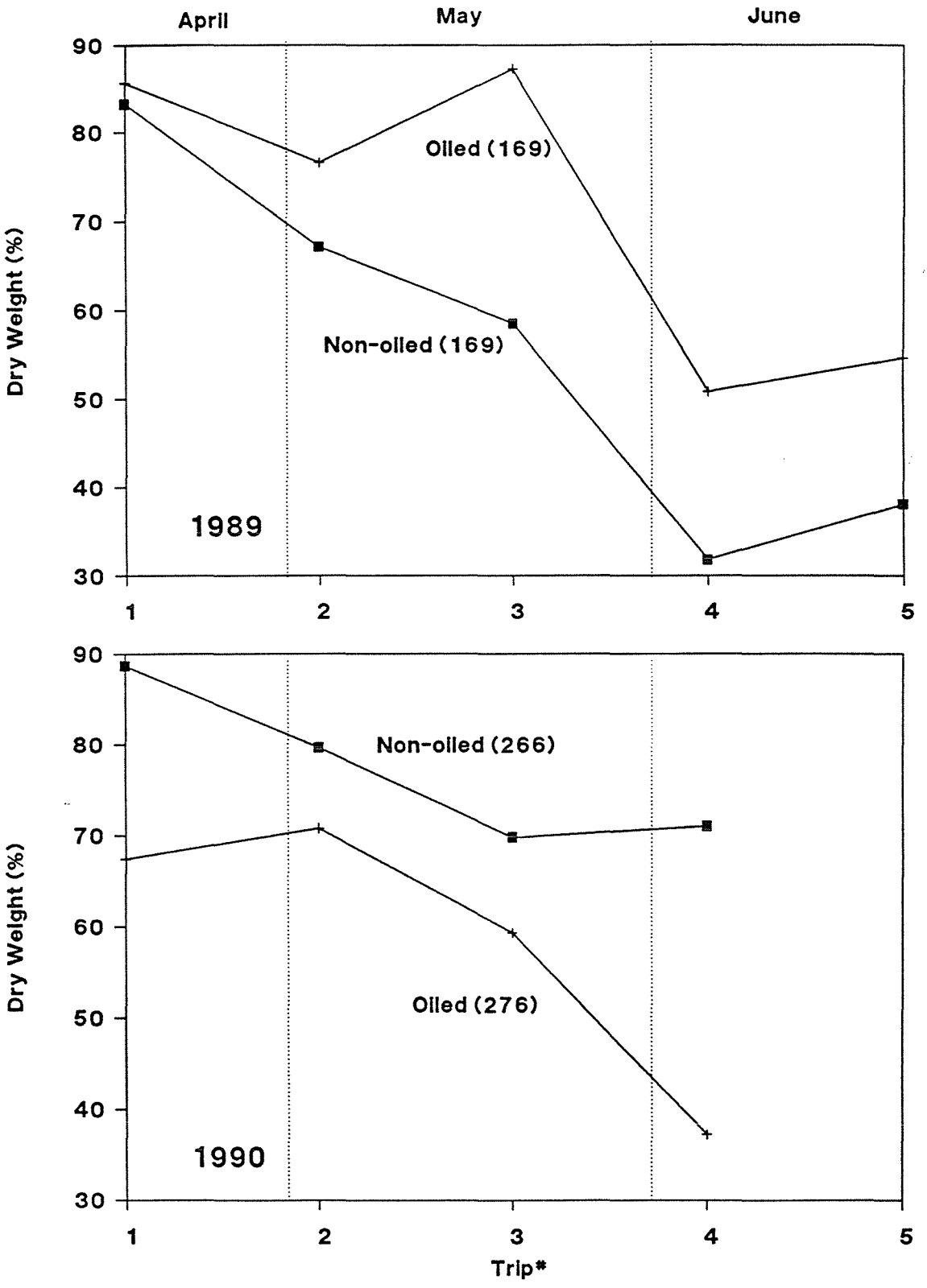


Figure 4.8. Average percent zooplankton consumed over time by pink salmon juveniles in oiled and non-oiled areas of Prince William Sound, 1989 and 1990. Numbers of fish in parentheses exclude those with empty stomachs.

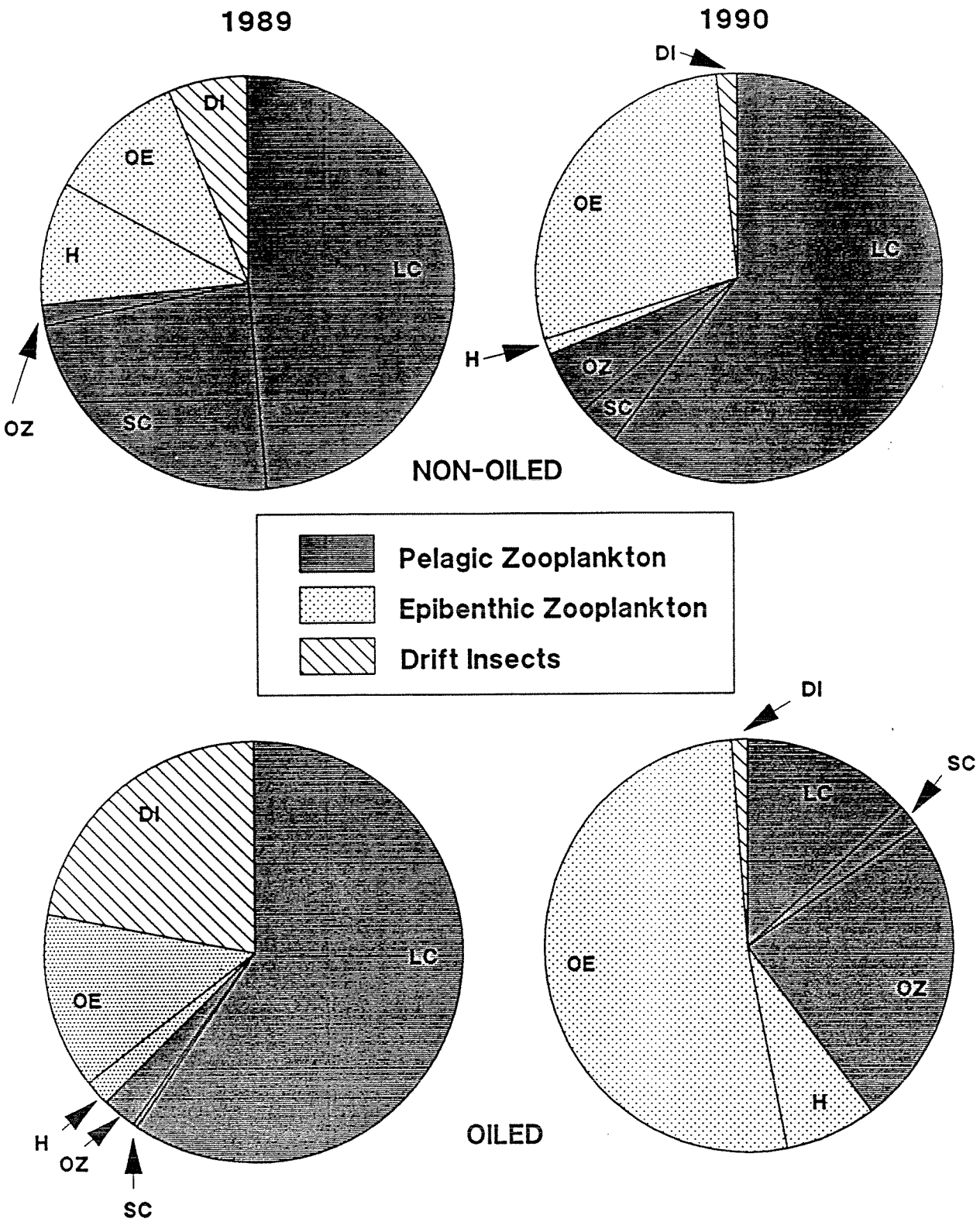


Figure 4.9. Prey percent dry weight from chum salmon fry stomachs collected in Prince William Sound, Alaska, in 1989 (n = 112) and 1990 (n = 136). LC = Large Calanoids, SC = Small Calanoids, OZ = Other Zooplankton, H = Harpacticoids, OE = Other Epibenthic, DI = Drift Insects.

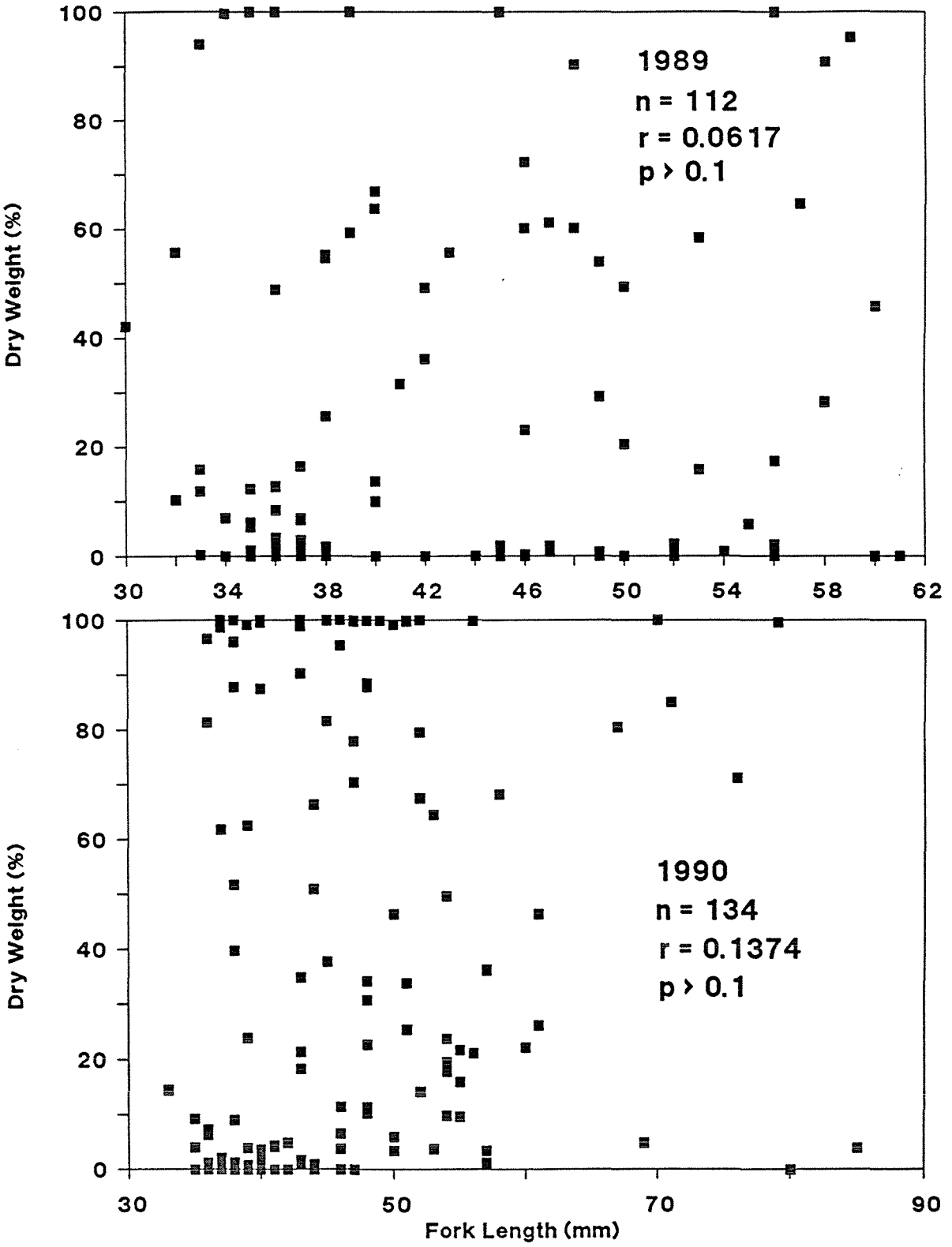


Figure 4.10. Relationship of biomass of epibenthos consumed to size of juvenile chum salmon in all areas of Prince William Sound, 1989 and 1990. Numbers of fish (n) exclude those with empty stomachs. r = index of association, p = probability of r being different from zero.

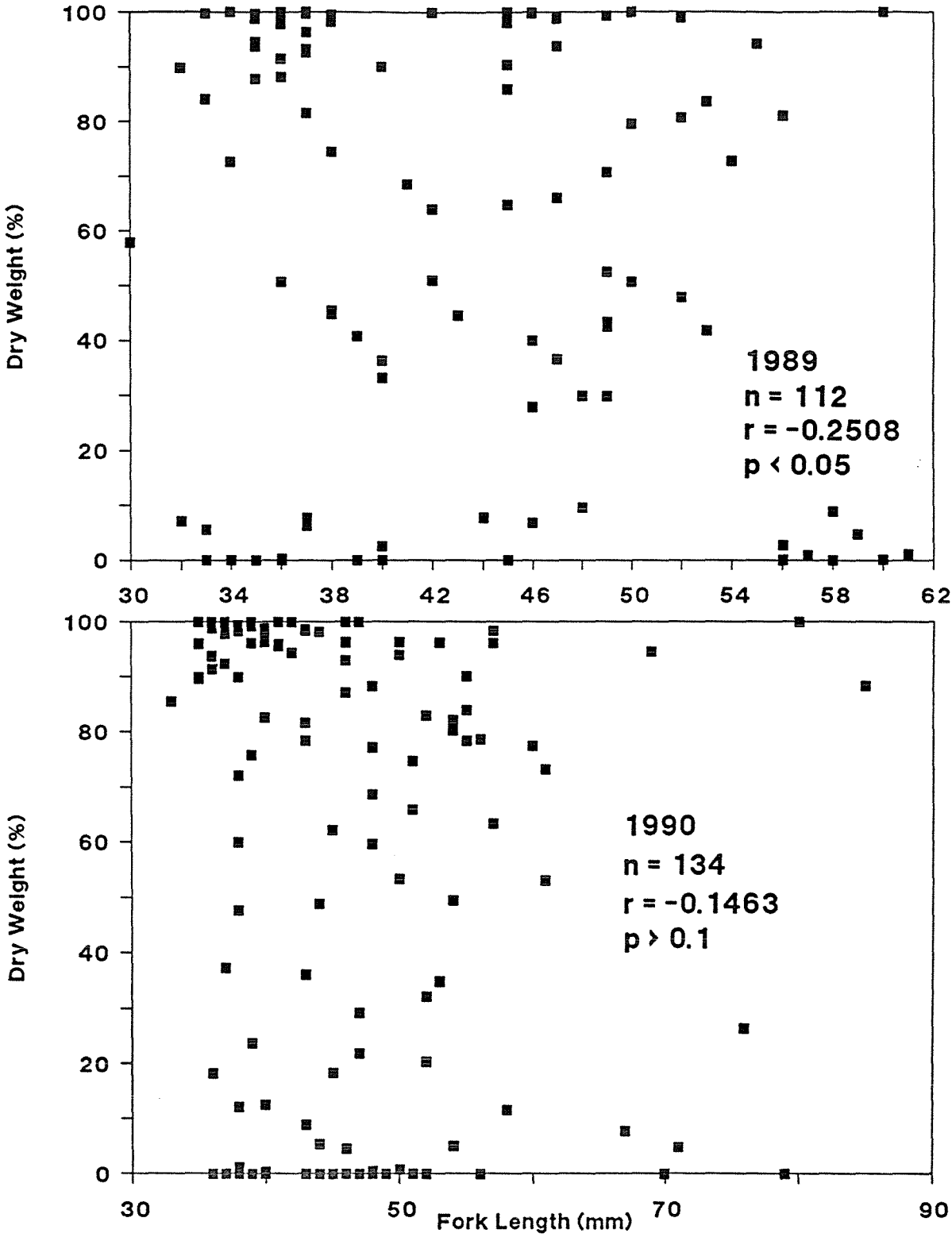


Figure 4.11. Relationship of biomass of zooplankton consumed to size of juvenile chum salmon in all areas of Prince William Sound, 1989 and 1990. Numbers of fish (n) exclude those with empty stomachs. r = index of association, p = probability of r being different from zero.

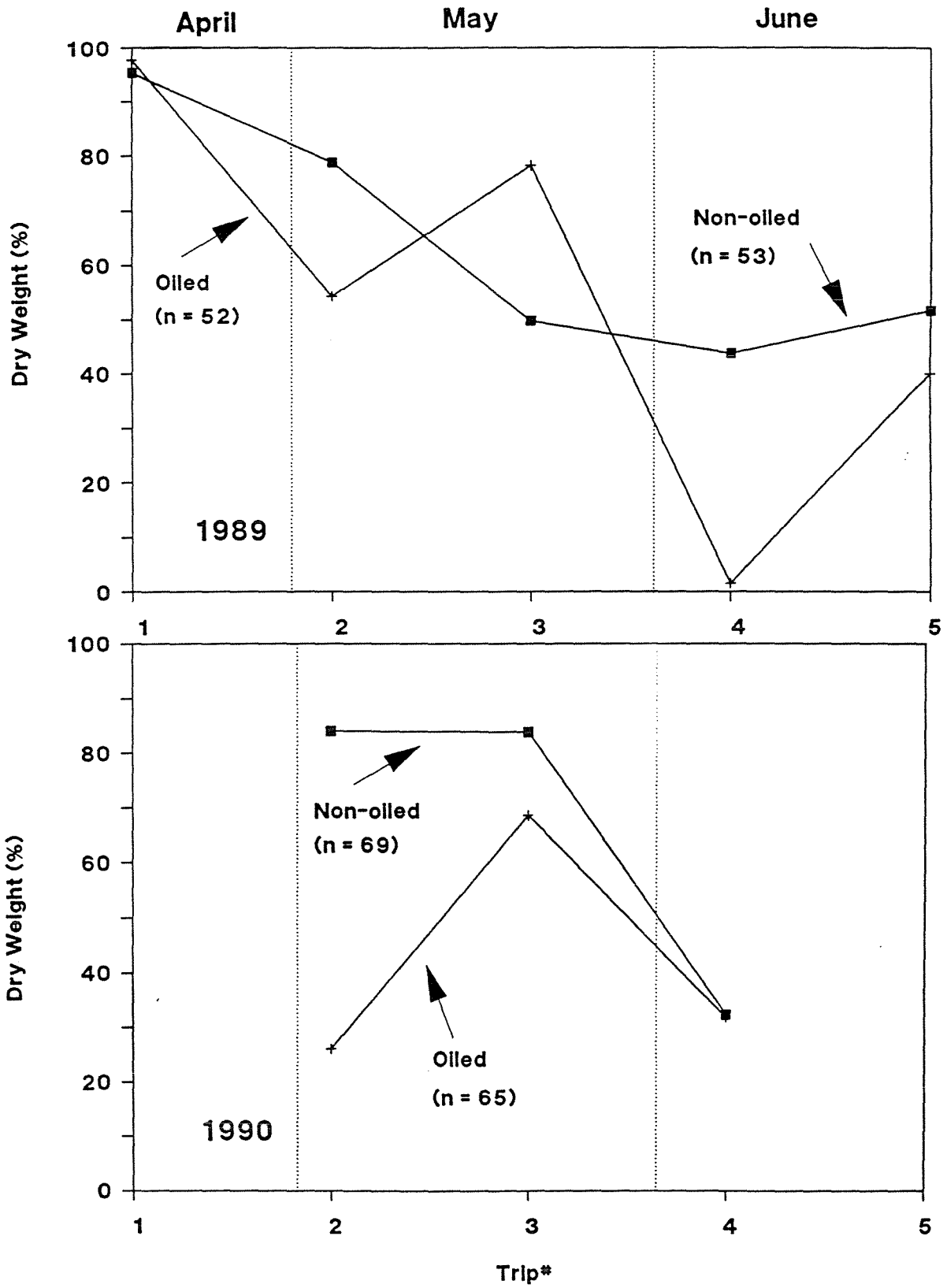


Figure 4.12. Average percent zooplankton consumed over time by chum salmon juveniles in oiled and non-oiled areas of Prince William Sound, 1989 and 1990. Numbers of fish (n) exclude those with empty stomachs.

CHAPTER 5: PREY ABUNDANCE

Objectives

5.A To test the hypothesis that the abundance of prey available to juvenile pink and chum salmon in littoral areas and the pelagic water column does not differ between oiled and non-oiled areas.

5.B To test the hypothesis that the abundance of epibenthic prey species of juvenile salmon does not differ between heavily contaminated and lightly contaminated beaches within the same geographic area.

5.C To test the hypothesis that the utilization of sediments by epibenthic prey species of juvenile salmon is not affected by the presence of oil in the sediments.

Methods

Pelagic Zooplankton

Triplicate samples of pelagic zooplankton were taken at each location sampled for fish (Figure 2.1) on each sampling trip with a 20-m vertical haul of a 0.5 m diameter 243 micron net. Water of sufficient depth for the haul was located using a depth-sounder or a sounding line. A battery-powered seawater pump was used to wash down the outside of the sampling nets. The contents of the cup were then rinsed with filtered seawater, and preserved in a 5% formalin solution.

Zooplankton samples were analyzed by the ADFG Limnology Laboratory. The number of organisms in each sample were identified as to taxa and life history stage, and counted. Identification was generally taken to the order level, except for calanoid and harpacticoid copepods, which were identified to genus or species level. In 1989, wet weights of organisms were calculated for each sample by weighing up to 100 individuals from each taxa within a particular sample. Biomass of an organism within a sample was then computed by multiplying the mean weight by the number in the sample. In 1990, only counts were made. Mean weights of the taxa across all samples processed in 1989 were used to estimate biomass of taxa in 1990.

Zooplankton data were analyzed using the repeated measures ANOVA. Measures of abundance analyzed with ANOVA were total zooplankton, all calanoid copepods, and calanoids by two size categories, chosen to parallel the size categories identified in the feeding habits (Chapter 4). For pelagic zooplankton, the factors considered in the ANOVA were time, oil, bay/corridor, and location, with location nested in oil and bay/corridor. There

were three observations per cell, except in one case where a replicate sample was lost due to improper preservation. Based on Box-Cox diagnostic plots (Dixon et al. 1988), the biomass and numbers of zooplankton were transformed prior to the ANOVA procedure by natural logarithms (ln) in order to normalize distribution and maximize variance homogeneity. The number of species or species groups of zooplankton and epibenthic crustaceans was used as a simple measure of diversity (Pielou 1975), and was also compared using ANOVA.

Epibenthic Prey

Epibenthic prey in 1989. Epibenthic crustaceans were sampled in 1989 using a 10-m horizontal haul of an epibenthic sled with attached 0.3 m diameter 243 micron net. Epibenthic sled samples were taken at the 0.5 m water depth at each habitat site sampled systematically for fish (Appendix 2.1), on adjacent shoreline to that actually seined. The sled tow was made immediately after the seine set. These samples are referred to as the "systematic epibenthic sled samples". A series of epibenthic sled samples were also taken in 1989 at 2 ft tide intervals at tide heights of from the -1 to +9 ft tide levels (actual water depths sampled were 0.5 m deeper than the nominal tide levels). These samples are referred to as the "tidal transect epibenthic sled samples". Tidal transects were sampled at each embayment on each sampling trip in 1989, except Trip 1, when tidal transects were sampled only at McClure Bay and Herring Bay.

A battery-powered seawater pump was used to wash down the outside of the sampling nets. The contents of the cup were then rinsed with filtered seawater, and preserved in a 5% formalin solution.

Epibenthic tow samples were analyzed by the Jeff Cordell of the Fisheries Research Institute, University of Washington. The number of organisms in each sample were identified as to taxa and life history stage, and counted. Identification was generally taken to the order level, except for calanoid and harpacticoid copepods, which were identified to genus or species level. Wet weights of organisms were calculated for each sample by weighing up to 100 individuals from each taxa within a particular sample. Biomass of an organism within a sample was then computed by multiplying the mean weight by the number in the sample.

Data analysis of the organisms in the epibenthic sled samples was limited to those epibenthic organisms that occur as prey of juvenile salmon. Data were analyzed using the repeated measures ANOVA. Measures of abundance analyzed with ANOVA were total epibenthos and total harpacticoid copepods. For the systematic epibenthic samples, the factors considered were time, oil, bay/corridor, location, and habitat, with location nested in oil and bay corridor. There was only one observation per cell, and 6

empty cells due to samples destroyed in shipping. For the tidal transect epibenthic sampling, the factors were time, oil, location, habitat, and tide level, with location nested in oil. Trip 1 was excluded from the ANOVA because all embayments were not sampled on the first sampling trip. The number of species or species groups epibenthic crustaceans was again used as a simple measure of diversity, and compared using ANOVA.

Effects of degree of oiling on harpacticoid copepods. To examine whether the degree of oiling within a local area affected the abundance of important prey taxa of harpacticoid copepods, beaches in Bay of Isles and Herring Bay were sampled for harpacticoids in the spring of 1990. In each bay, eight beaches were selected for sampling. Four transects were located on heavily oiled beaches, and four on lightly oiled beaches, as categorized by ADEC beach survey maps (Table 5.1). Locations of transects are shown on maps in Appendix 5.1, Maps A and B. Other factors considered in choosing beaches for sampling were similarities in grade, substrate, exposure, and macrophyte coverage.

A 40-m transect tape was placed at the mean low tide contour. The 40 m was divided into six sections, and four or five pump sampling sites and one hydrocarbon sampling site were placed at 1-M intervals using random numbers within each section. Harpacticoid samples were taken using a 12-volt submersible pump enclosed in a housing of 15 cm diameter with 0.0177 m^3 volume. Ports in the housing were covered with 0.123 mm mesh. The housing was set on the substrate and water was pumped for 30 sec into a 0.123 mm collecting net. Samples were then rinsed into a 500-ml bottle and preserved in a 5% buffered formalin solution. A total of 25 pump samples were taken per transect, except at one Bay of Isles site, where 24 pump samples were taken.

A 0.25 m^2 area was defined at each hydrocarbon sampling site within a transect. Surface substrate composition was visually classified into four categories following the Wentworth scale (Holme and McIntyre 1984). The categories were boulder (>256 mm); cobble (64-256 mm); pebble (4-64 mm); and granule or finer (< 4 mm). Percent macrophyte coverage was also estimated at each site. The site was then photographed, and fine sediments from the upper 2 cm of the substrate collected into 4 hydrocarbon-free glass jars. Sediments were aggregated from each of the six hydrocarbon sampling sites along the transects. Three of the sediment samples collected from each transects were submitted for hydrocarbon analysis; the other sediment sample was used for total organic carbon analysis.

Harpacticoid copepod samples were processed by contractors chosen by competitive bid among qualified proposers. Pentec Environmental processed the 199 pump samples taken May 24-27 in

Bay of Isles. Kinnetic Laboratories processed pump samples taken in Herring Bay April 24-27. Because of the processing cost per sample greatly exceeded budgeted estimates, only 120 of the 200 samples taken in Herring Bay in April could be processed. Therefore 15 samples were randomly chosen from the 25 taken from each transect. The contractors were responsible for sorting, counting, and identifying taxa of harpacticoid copepods that are important dietary components of juvenile salmon.

Sediment samples were submitted to the NRDA process for hydrocarbon analysis. Total organic carbon (TOC) of sediments sampled for this parameter were determined by ignition by HUB Testing Laboratories.

At each location the univariate approach to analysis of variance (ANOVA) was used to analyze: (1) Abundance of all harpacticoid copepods; (2) Abundance of Harpacticus genera only; Abundance of Tisbe genera only; Proportion of egg carrying female Harpacticus to all female adult Harpacticus; (5) Proportion of egg carrying female Tisbe to all female adult Tisbe; (6) Proportion of transect covered by small (< 64mm) substrate; (7) Proportion of transect covered by macrophytes; (8) TOC. In each analysis of harpacticoid copepod abundance, the dependent variable was transformed by natural logs (ln). In the analyses using proportional data, the dependent variable was transformed by the arcsine transformation. The factors in each ANOVA were oil and transect nested within the factor oil. The factor oil had 2 levels, lightly oiled and heavily oiled; and the factor transect had 4 levels. In each case the F value of interest was derived by dividing the mean square of oil by the mean square of transect (nested within oil). Because there was only one observation per transect for TOC, the ANOVA model for this parameter collapsed to a one-way test between levels of oiling.

If differences in total harpacticoids or specific taxa were identified using analysis of variance, these parameters were then examined with multiple linear regression to determine what degree of the variability between transects was explained by the degree of oiling relative to other parameters measured. In each regression, the mean of the ln transformed harpacticoid count by transect was the dependent variable, and the independent variables were the arcsine transformed mean proportion of substrate that was pebble or smaller, the arcsine transformed mean proportion of macrophyte coverage, the TOC, and the categorical designation of heavy or light oiling. The partial F test for each variable had to be significant at $P < 0.1$ for the variable to remain in the regression model. It is our intent to ultimately use the actual measures of hydrocarbons in the sediments rather than the dichotomous categorization of oiling, but we do not have final figures for those measures at this time.

Meiofauna in experimentally contaminated sediments.

In order to examine the effects of oil contamination on the colonization of sediments by epibenthic crustaceans and other meiofauna, sediments were collected in Auke Bay, Alaska, and made azoic by subjecting them to three freeze-thaw cycles over a 1 month period. The sediment was divided into three equal groups: control, light-oil, and heavy-oil. The oiled treatments were mixed with
Prudhoe Bay crude oil recovered from the Exxon Valdez to concentrations of 0.5% and 1.6% for light- and heavy-oil, respectively. Three pans from each treatment group were buried at each of two sites in Herring Bay (Appendix 5.1C). The pans were placed parallel to the water line, 1.5 m apart, at the -2.0 (-0.6 m) tide level at the upper edge of an eel grass bed. Treatment positions were random within 3 consecutive 4 m blocks. Pans were buried flush with the natural substrate; excess mud was disposed well away shore from the transects. Treatment pans (13 x 28 x 33 cm) were plastic with bottoms and sides perforated with 3 mm holes spaced at approximately 6 mm intervals. Trowels used to move mud during installation were cleaned with acetone and dichloromethane and were kept separate by treatment to prevent cross-contamination. Triplicate core samples plus two hydrocarbon samples were collected as each pan was filled.

Sediment from each pan was subsampled for meiofauna with 60 ml plastic syringes (2.6 cm dia. x 4 cm) modified for coring. Hydro-carbon samples were collected with a 3.0 cm dia. chrome plated brass tube; a spoon was slipped down beside the corer to cap it off at 4 cm. All equipment used for hydrocarbon sampling was prewashed with soap and hot water, rinsed, dried, rinsed with acetone and then dichloromethane. Corers were separated by treatment to avoid cross-contamination. Selection of core positions was random without replacement over the first 2 d period so that no area was resampled, and completely random thereafter. Core placement was at least 2 cm from the margin of the pans to avoid possible edge effects. Triplicate core samples plus one hydrocarbon sample were collected from each treatment pan on days 1, 2, 29, and 89. Additionally, eight natural meiofauna and three hydrocarbon cores were collected from randomly selected spots between the pans at each sample time. Meiofauna samples were preserved with 10% formalin. Hydrocarbon samples were placed directly into hydrocarbon free glass jars with teflon lids and frozen.

In the laboratory, samples were sieved through 500 and 63 μm filters to separate macrofauna and collect meiofauna, then centrifuged at 350 rpm. Supernatant was decanted through 63 μm sieve and material remaining on the filter was collected. The pellet was re-centrifuged at least two times in sucrose syrup (700 g sugar in 500 ml water), decanted and collected as before. Centrifugation continued until at least 95% of the meiofauna was

removed from the pellet. Samples were then stained with Rose Bengal in 5% buffered formalin. Meiofauna were then sorted by major taxa and counted. Harpacticoid copepods were identified to species, and were examined to determine condition (live or dead) at time of preservation.

Meiofauna samples were processed at the University of Alaska Meiofauna Laboratory at the Juneau Center for Fisheries Science. Organisms were identified generally to order, except harpacticoid copepods, which were identified to species. Preliminary analysis of meiofauna core samples was a one-way ANOVA at one site at 29 d after sediment transplant.

Results

Pelagic Zooplankton

Numbers and biomass of pelagic zooplankton fluctuated widely between time periods and locations in both 1989 (Tables 5.2, 5.3) and 1990 (Tables 5.4, 5.5). Variation between replicates at the same time and location was also often large, as reflected in the high standard deviations associated with the means (Tables 5.2, 5.3).

In 1989, 52 taxa of pelagic zooplankton were identified in the samples (Table 5.6). The dominant organisms in both bays and corridors in terms of biomass were Calanus sp. and Pseudocalanus sp. (Table 5.6). Pseudocalanus sp. was the most numerous organism overall in both bays and corridors, followed by Calanus sp. in corridors and Ectoprocta (Cyphonautes) in bays. At each location calanoid copepods comprised over half of the abundance (Figure 5.1) and biomass (Figure 5.2) of pelagic zooplankton. Small calanoids were more abundant than large calanoids at each of the 8 sampling locations (Figure 5.1), although large calanoids had higher relative biomass at all 4 corridor locations and 2 of the bays (Figure 5.2).

In 1990, 43 taxa of pelagic zooplankton were identified (Table 5.7). In terms of overall biomass, in corridors the dominant organisms were Neocalanus plumchrus and Calanus sp., whereas in bays the dominant organisms were Calanus sp. and Calanus marshallae (Table 5.7). Pseudocalanus sp. was the most numerous organism in both bays and corridors, followed by Acartia longiremis in bays and Calanus sp. in corridors. Calanoid copepods comprised over 75% of the number of pelagic zooplankton at all locations except the 2 oiled bays, Herring Bay and Snug Harbor (Figure 5.3). At these sites the most numerous organisms excluding calanoid copepods were euphausids and Fritillaria sp., respectively in Herring Bay, and Podon sp. and euphausids, respectively in Snug Harbor. Calanoid copepods comprised over

85% of the biomass of pelagic zooplankton at each site (Figure 5.4). At each of the 8 sampling locations small calanoids were more abundant than large calanoids (Figure 5.3), although large calanoids comprised a much higher proportion of the total biomass than small calanoids (Figure 5.4).

There were no significant differences in zooplankton biomass between oiled and non-oiled areas in either 1989 or 1990 (Tables 5.8,5.9). In 1989, mean zooplankton biomass was virtually identical in non-oiled and oiled areas in early spring, peaking in early May, and then declined more rapidly in the latter part of May in the non-oiled area (Figure 5.5). In June, mean biomass was again virtually identical in the oiled and non-oiled areas.

Mean biomass was also similar between oiled and non-oiled areas in early spring in 1990, again peaking in both areas in early May (Figure 5.5). Peak total biomass was around two times higher in 1990. In contrast to 1989, the mean biomass in the oiled area declined more rapidly in May following the seasonal peak (Figure 5.5). Biomass in the oiled area continued to decline to seasonal lows in 1990, while in the non-oiled area mean biomass actually increased in June. This increase was due to the unusually high abundance of zooplankton in Long Bay in June, 1990; abundance at all other non-oiled locations actually decreased from May to June (Table 5.5).

Biomass of pelagic zooplankton did vary significantly ($\underline{P} < 0.001$) with time in both years (Tables 5.8,5.9). The biomass peaked at different times in the different locations (Tables 5.3, 5.5). Biomass fluctuated up to 200-fold between different time periods at the same location, and peak biomass varied 10-fold between locations.

Bay/corridor was significant ($\underline{P} = 0.042$) in explaining the variation in total biomass of pelagic zooplankton in 1989 (Table 5.8). Mean biomass was 3.4 times higher overall in corridors than in bays in 1989. When examined over time (Figure 5.6A), the biggest differences in biomass of pelagic zooplankton between bays and corridors occurred in April and May. Overall, pelagic zooplankton peaked in early May in both bays and corridors in 1989. By June 1989 the biomass of pelagic zooplankton had declined sharply in both bays and corridors.

In 1990, total biomass of pelagic zooplankton was not statistically significant overall between bays and corridors (Table 5.9), although mean biomass was 2.5 times higher in the corridors. Biomass was higher in corridors during April and May sampling periods; however, in early June, while biomass declined sharply in corridors, it increased to the highest level observed in bays in 1990 (Figure 5.7A).

In general, the biomass of calanoid copepods followed a pattern

similar to that of the biomass of pelagic zooplankton (Figure 5.6B, 5.7B). This result is not unexpected considering calanoid copepods composed most of the biomass of the zooplankton sampled (Tables 5.6, 5.7). Copepod biomass declined rapidly to seasonal lows in June in 1989 in both bays and corridors. However, in 1990, while the pattern held for corridors, total calanoid biomass increased to a seasonal high in bays in 1990 (Figure 5.7).

Calanoid copepods were further split into large and small size categories. These size categories were chosen to parallel the analysis of juvenile salmon diets. Again, there were no significant differences between oiled and non-oiled areas in either year (Tables 5.10, 5.11). There were some seasonal differences in the biomass of small and large calanoid copepods. Large copepods generally tracked very closely the pattern of total zooplankton biomass in both years (Figure 5.8A, 5.9A). Small zooplankton biomass declined to low levels in early June in 1989, but showed a dramatic increase in early June 1990 in both bays and corridors (Figure 5.8B, 5.9B).

There was no significant difference in diversity of pelagic zooplankton between oiled and non-oiled areas in 1989 or 1990, as measured by the number of identified taxa (Table 5.12). The number of taxa peaked at different times at different locations, but generally increased over time (Table 5.13). Although more taxa were identified in all sets in 1989 than in 1990, the mean number of taxa per set was higher in 1990 (17.4) than in 1989 (15.1) There was a marginally significant difference ($\underline{P} = 0.082$) between bays and corridors in 1989 (Table 5.13); the mean number of taxa were 15.9 and 14.3 in bays and corridors in 1989, respectively. However, the numbers of taxa observed in bays and corridors were not significantly different in 1990 (Table 5.13); the mean number per set was actually higher in bays (17.7) than in corridors (17.2) in 1990.

Epibenthic crustaceans

1989 sled samples. Species composition of organisms of both epibenthic and pelagic origin captured in 1989 is shown in Table 5.13; organisms considered prey of juvenile salmon are indicated in the table. Abundance and biomass of organisms in the systematic epibenthic sled samples fluctuated widely between time periods, habitats, and locations (Tables 5.15, 5.16). Epibenthic organisms comprised less than half of the total abundance and biomass of organisms sampled by the sled; pelagic zooplankton in the water column were also sampled by the sled (Table 5.14). Harpacticoid copepods comprised 87% of the biomass of epibenthos important in the diets of juvenile pink salmon. In terms of both abundance and biomass, harpacticoid copepods were the dominant epibenthic organism at each location (Figures 5.10, 5.11). Because of their dominance in both the epibenthic samples and in

the epibenthos utilized by the juvenile salmon as prey (see Chapter 4), further analysis of the epibenthic prey abundance focused on the harpacticoid copepod component.

In the systematic sled samples, oil ($P = 0.025$) and habitat ($P = 0.025$) were each significant in explaining the variation in biomass of harpacticoid copepods (Table 5.17). The mean biomass of harpacticoids was 2.5 times higher overall in oiled than non-oiled areas. Biomass was much lower in the steep gradient than in either the low or medium habitats (Figure 5.12A). At each habitat type biomass was greater in oiled rather than non-oiled areas (Figure 5.12A).

Time ($P = 0.066$) and bay/corridor ($P = 0.057$) were marginally significant in explaining the variation in biomass of harpacticoid copepods in the systematic sled samples (Table 5.17). Biomass was 3 times higher overall in corridors than bays, mainly because of the large peak in biomass during time period 3 in late May (Figure 5.12B). By June the biomass of harpacticoids was uniformly low in both bays and corridors.

For the tidal transect sled samples, only tows from the -1 to +3 tide levels have been included in the analysis to date. As in the systematic sled samples, the biomass of harpacticoid copepods was higher overall in oiled rather than non-oiled areas, and higher in oiled areas in all habitats (Figure 5.13). However, although the overall biomass was 7-fold greater in the oiled area, this difference was not significant (Table 5.18) because of the high variability associated with the samples. Time ($P = 0.068$) and habitat ($P = 0.068$) were marginally significant in explaining the variation in the biomass of harpacticoid copepods in the bays sampled (Table 5.18). As in the systematic sled samples, the biomass of harpacticoids was lowest in the steep gradient habitat compared to the low and medium gradient habitats (Figure 5.13). Tide level (over the -1 to +3 range analyzed to date) was not significant in explaining variation in harpacticoid biomass, although biomass was generally higher at the lower tide levels.

There was no significant difference in the number of taxa of epibenthic organisms between oiled and non-oiled areas in the systematic sled samples (Table 5.19). Time ($P < 0.001$), habitat ($P = 0.015$), and the interaction of time and oil ($P = 0.047$) were significant in explaining the variation in number of taxa sampled. The number of taxa increased over time in both oiled and non-oiled areas, and was generally greater in the oiled areas (Figure 5.14A). The number of taxa was highest in the low gradient and lowest in the steep gradient habitat (Figure 5.14B).

Effects of degree of oiling on harpacticoid copepods. Analysis of pump samples for identification and enumeration of

harpacticoid copepods was completed in 1991. Sediment samples have been analyzed for TOC; we have not received complete data on sediment samples submitted for hydrocarbon analysis. The data returned to date on presence of oil indicates some degree of hydrocarbon contamination at all except one transects scored (Table 5.20). The exception is BI-2, a "lightly-oiled" transect in Bay of Isles. We require complete and quantified measures of degree of oiling to finalize the regression analysis examining what factors cause the observed variability in harpacticoid abundances between heavily and lightly oiled beaches. We have also contracted Pentec Environmental to review the statistical analysis and interpret the results in the context of literature information on the effects of oil on epibenthic harpacticoid copepods.

In general, the beaches sampled for harpacticoid copepod abundances did not vary significantly between oiling categories for the other physical and biological parameters measured. There were no significant differences between the degree of oiling for substrate composition, macrophyte coverage, or TOC in the fine sediments (Table 5.21). The overall mean values for oiled and non-oiled transects were similar for macrophyte coverage and TOC at both Herring Bay and Bay of Isles (Table 5.22). There was considerable variability in the values observed for individual transects for TOC at both locations, and for macrophyte coverage at Herring Bay. Substrate composition was also similar between the oiling categories in Bay of Isles; substrate that was < 65 mm (pebble or smaller) composed 69% (range 50-80%) of the heavily oiled transects, compared to 64% (range 52-82%) of the lightly oiled transects (Table 5.23). In Herring Bay, the lightly oiled transects tended to have a coarser substrate composition. Heavily oiled transects had an overall mean of 66% (range 63-90%) substrate < 65 mm, compared to 55% (range 27-70%) for lightly oiled transects (Table 5.22). The P-value in the ANOVA for this comparison was 0.106 (Table 5.21).

At Herring Bay the degree of oiling had a significant effect on the abundance of all harpacticoid copepods combined ($P = 0.039$) and *Harpacticus uniremis* alone ($P = 0.046$, Table 5.24). There were more harpacticoid copepods in general and *Harpacticus uniremis* in particular in heavily oiled relative to lightly oiled areas (Figures 5.15A, 5.16). There was no difference in the abundance of *Tisbe sp.* between heavily oiled and lightly oiled areas ($P = 0.278$, Table 5.24). There was also no difference in the proportion of egg carrying females to all adult females for either *Harpacticus uniremis* ($P = 0.205$) or *Tisbe sp.* ($P = 0.621$, Table 5.24).

At Bay of Isles oil had a marginally significant effect on the abundance of harpacticoid copepods ($P = 0.082$, Table 5.25). As in Herring Bay, there were more harpacticoid copepods in the heavily oiled transects (Figure 5.15). There was no significant

difference in the abundance of Harpacticus sp. ($P = 0.217$) or Tisbe sp. ($P = 0.919$) between heavily oiled and lightly oiled areas (Table 5.25). There was also no significant difference in the proportion of egg carrying females to total adult females for either Harpacticus sp. ($P = 0.234$) or Tisbe sp. ($P = 0.797$).

Differences in abundance of harpacticoid copepods were more highly correlated with degree of oiling than with the other physical and biotic parameters measured. The r values for the associations between the harpacticoid abundance indices examined and the degree of oiling were significant, not surprising given that these measures had already been identified as significantly different between degree of oiling in the ANOVA; however, none of the r values for the other beach characteristics were significantly different from 0 at $P < 0.1$ (Table 5.26). In all cases, the next highest r after degree of oiling was for the association of harpacticoid abundance with macrophyte coverage. When the beach characteristics were used as independent predictors of harpacticoid abundance in a stepwise multiple regression, degree of oiling was the most significant predictor variable in all three cases. Only in the case of total harpacticoid abundance in Herring Bay did another predictor variable, macrophyte coverage, remain in the multiple regression model, increasing the R^2 from 53.5% to 75.3%.

Meiofauna in oiled sediments

Processing of the core samples from the 1990 sediment colonization experiment has been completed. The majority (90%) of the hydrocarbon cores collected from the meiofauna experiment during 1990 have been analyzed (Table 5.27).

Because these sediments were artificially oiled, and because the sediment used at the two meiofauna transect sites was randomly distributed between sites, we expected that the characteristics of the oil and its concentrations would match between sites. This assumption appears to be valid (Figure 5.17); error bars closely overlap. Sediments in the meiofauna experiment were also contaminated in the expected pattern (control < low oil < high oil). The control baseline, however, was higher than expected; presence of hydrocarbons was observed in all control sediments (Table 5.27), including those sampled at time 0. We hypothesize that sediments collected from Auke Bay for this experiment were mildly contaminated by recreational and commercial boating activity in the area.

Oil was lost rapidly from the sediments after burial in the two transects (Figure 5.18). The loss pattern appears to conform to characteristic loss patterns for petroleum hydrocarbons. Data are not available on day 28 for the high oil transect, so the

curve shapes appear to be different between the two sites. It is likely that oil loss for the high oil transect actually follows the same pattern determined for the low oil transect. Burial of experimental sediments by indigenous sediments and detritus may also have influenced the observed concentration patterns.

In spite of the oil loss, control concentrations remained lower that low oil concentrations, which in turn were lower than high oil concentrations. For the analytes, sum of analytes, and hydrocarbon indices considered, concentrations in oiled sediments were frequently significantly greater than concentrations in control sediments (Table 5.28).

Preliminary data analysis comparing control, natural, and heavy-oiled sediments at the lightly oiled site showed no significant difference in mean numbers of harpacticoid copepods, nematodes, or total meiofauna 29 d after sediment transplant. The trend was for higher densities of organisms in the heavy-oiled sediments relative to the control; greater numbers of copepods, nematodes, and total meiofauna were observed in the oiled sediments at Day 29, and oiled sediments had a higher density of copepods than did the adjacent natural sediments (Figure 5.19). We have contracted the University of Alaska for completion of analysis and reporting of the meiofauna study.

Discussion

No significant differences in the biomass of pelagic zooplankton were observed between oiled and non-oiled areas sampled in either 1989 or 1990. Much of the zooplankton in the nearshore area in Prince William Sound during the spring period consisted of calanoid copepods. The abundance of these organisms in nearshore regions is strongly influenced by the circulation processes within Prince William Sound and from the Gulf of Alaska. The copepodid stages of large, oceanic calanoid species which overwinter and reproduce at depth (e.g., Neocalanus plumchrus, Neocalanus cristatus) migrate to the surface and are advected into shallow waters, with peak abundances occurring in late spring (Cooney 1986; Cooney and Willette 1991). Here they mix with neritic, smaller calanoid forms whose numbers increase with the spring phytoplankton bloom. A seasonal succession of smaller forms (e. g., Metridia spp., and Pseudocalanus spp.) follow the decline of the large species (Cooney 1986). Lee and Nicol (1977) found that oceanic zooplankton are more susceptible to water-soluble fraction of fuel oil than are neretic forms. Samain et al. (1980) concluded that there were short-term detrimental effects on zooplankton following the Amoco Cadiz spill off Brittany. In Prince William Sound, the constant advection of zooplankton from deeper waters of the Sound and the Gulf of Alaska could easily obscure any detrimental effects that might

have occurred on zooplankton in the upper water column. Conover (1971), however, saw no apparent effect of bunker C oil on zooplanktors in Chedabucto Bay, even though the zooplanktors were consuming large amounts of oil. Whether there was no direct effect or the effect was obscured by large-scale oceanographic processes, the result was no detectable difference in available zooplankton prey between the oiled and non-oiled locations compared.

The presence of petroleum hydrocarbons in intertidal areas has been shown to affect the growth, reproduction, and survival of meiofaunal populations. The changes caused by oil are not always predictable: some researchers have observed declines in harpacticoid copepod populations as a result of oil (Wormald 1976; Bonsdorf 1981; Bodin 1988), but others have observed increases in harpacticoid copepods and other meiofauna in association with oil contamination (Fleeger and Chandler 1983; Stacey and Marcotte 1987; Feder et al 1990). Species richness and diversity may decrease after an oil spill, and the index of dominance may increase, but the community structure may not change significantly (Bonsdorff 1981).

Several different approaches were used to examine the effect of oil on epibenthic prey of juvenile salmon in Prince William Sound as part of this component of F/S-4. The analyses of these studies is still incomplete, as noted in the Results. However, there is a clear pattern of increased abundance of epibenthic prey in oiled habitats in both 1989 and 1990.

In 1989, biomass of total prey epibenthos and total harpacticoids were compared between oiled and non-oiled sites. Oiled sites consistently had higher biomass of these prey assemblages. These differences could be a result of geographic variability, and not a direct enhancement of these organisms by oil. There was some indication that biomass of epibenthic prey assemblages increased with decreasing depth (tide level). Salinities also varied significantly between oiled and non-oiled locations, which could have affected the relative abundance or depth distribution of the epibenthic prey between oiled and non-oiled sites. Abundance of predator populations was also lower in the oiled areas (Chapter 2); reduced cropping of epibenthos by juvenile salmon could have affected the abundances of these organisms. However, even when juvenile salmon are utilizing epibenthic crustaceans as their primary prey, they do not appear to affect the population densities of the prey populations to a significant degree (Webb 1991). While such factors may contribute to the observed differences, they do not obviate the conclusion that there was not a catastrophic reduction in the abundance of epibenthic prey available to juvenile salmon in oiled areas in 1989.

Analysis of the 1990 samples support the explanation that oil did indeed enhance the abundance of the epibenthic prey populations

of interest. When harpacticoid copepod abundances were compared between heavily-oiled and lightly-oiled beaches within the same embayment, higher abundances were associated with the heavily-oiled beaches. Factors other than oil did not explain the differences observed. Beaches with high oil deposition may be detrital "sinks"; current patterns responsible for depositing oil may also deposit large amounts of organic detritus on such beaches. Organic detritus is an important base for epibenthic crustacean production (Sibert et al 1977; Sibert 1979). TOC was measured as an index for such detrital input; no significant difference was observed between the oiling categories compared.

Table 5.1. Alaska Department of Environmental Conservation (ADEC) beach segment identification and degree of oiling associated with transects sampled for harpacticoid copepods in the spring of 1992. Degree of oiling shown was that assigned in the ADEC surveys in the fall of 1991.

Location	Transect	ADEC Segment	Degree of Oiling
Herring	HB-1	KN118	High
Bay	HB-2	KN5001	None
	HB-3	KN119	High
	HB-4	KN120	Very low
	HB-5	KN126	High
	HB-6	KN5006	None
	HB-7	KN115	High
	HB-8	KN5004	None
Bay of	BI-1	KN005	High
Isles	BI-2	KN006	Very low
	BI-3	KN024	High
	BI-4	KN206	Very low
	BI-5	KN135	High
	BI-6	KN006	Very low
	BI-7	KN136	High
	BI-8	KN205	None

Table 5.2.--Mean abundance (organisms/m^3) and standard deviation (SD) of pelagic zooplankton collected from four pairs of non-oiled and oiled locations in Prince William Sound, April-June 1989.

	Non-oiled locations		Oiled locations	
Time	$\bar{x}$	(SD)	$\bar{x}$	(SD)
		Bays		
	McClure Bay		Herring Bay	
Late April	2866	(203.4)	5342	(956.6)
Early May	4674	(2086.7)	1580	(125.3)
Late May	1008	(159.5)	2423	(165.6)
Early June	240	(44.7)	1017	(260.6)
Late June	1170	(403.9)	1193	(101.0)
April-June	1992		2311	
	Long Bay		Snug Harbor	
Late April	5975	(2542.3)	2493	(1189.9)
Early May	337	(65.2)	1332	(308.3)
Late May	1081	(349.9)	1303	(388.0)
Early June	565	(237.3)	318	(83.6)
Late June	1732	(480.9)	716	(359.2)
April-June	1938		1232	
		Corridors		
	Culross Passage		Prince of Wales Passage	
Late April	10,036	(1127.2)	4021	(818.4)
Early May	3657	(694.1)	4902	(1715.2)
Late May	2098	(459.9)	1745	(442.4)
Early June	1536	(206.0)	914	(231.7)
Late June	3100	(586.4)	1523	(259.6)
April-June	4085		2621	
	Wells Passage		Knight Island Passage	
Late April	6830	(1255.4)	2364	(585.1)
Early May	3812	(469.1)	13,313	(1438.1)
Late May	2796	(858.7)	3974	(198.9)
Early June	959	(198.7)	756	(292.7)
Late June	1428	(178.3)	1156	(106.4)
April-June	3165		4313	

Table 5.3.--Mean biomass (g/m^3) and standard deviation (SD) of pelagic zooplankton collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1989.

Time period	Unoiled sites $\bar{x}$	(SD)	Oiled sites $\bar{x}$	(SD)
		Bays		
	McClure Bay		Herring Bay	
Late April	0.2315	(0.0615)	0.5127	(0.1118)
Early May	1.4426	(0.9533)	0.5615	(0.0964)
Late May	0.1395	(0.0415)	0.7463	(0.0803)
Early June	0.0074	(0.0025)	0.1322	(0.0262)
Late June	0.0393	(0.0163)	0.0184	(0.0025)
April-June	0.3720		0.3942	
	Long Bay		Snug Harbor	
Late April	0.4054	(0.2960)	0.2669	(0.1534)
Early May	0.0080	(0.0014)	0.1046	(0.0544)
Late May	0.0192	(0.0064)	0.1183	(0.0544)
Early June	0.0156	(0.0081)	0.0048	(0.0013)
Late June	0.0339	(0.0094)	0.0085	(0.0037)
April-June	0.0964		0.1003	
		Corridors		
	Culross Passage		Prince of Wales Passage	
Late April	1.3188	(0.2832)	1.5952	(0.8344)
Early May	1.0819	(0.4486)	1.2065	(0.3507)
Late May	0.4850	(0.0492)	0.7147	(0.3524)
Early June	0.1046	(0.0211)	0.0452	(0.0223)
Late June	0.1091	(0.0235)	0.0468	(0.0098)
April-June	0.6199		0.7699	
	Wells Passage		Knight Island Passage	
Late April	1.0491	(0.5192)	0.9543	(0.4006)
Early May	1.6763	(0.6447)	2.5263	(0.4503)
Late May	0.5795	(0.2642)	2.1638	(0.7042)
Early June	0.1587	(0.0396)	0.0625	(0.0384)
Late June	0.0249	(0.0017)	0.0416	(0.0064)
April-June	0.6977		1.1497	

Table 5.4.--Mean abundance (organisms/m^3) and standard deviation (SD) of pelagic zooplankton collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1990.

Time period	Non-oiled locations $\bar{x}$	(SD)	Oiled locations $\bar{x}$	(SD)
		Bays		
	McClure Bay		Herring Bay	
Late April	363	(34.3)	2312	(433.3)
Early May	180	(109.8)	1838	(605.5)
Late May	978	(354.9)	1175	(149.6)
Early June	541	(202.4)	931	(275.6)
April-June	515		1564	
	Long Bay		Snug Harbor	
Late April	3057	(70.2)	1243	(310.0)
Early May	7095	(967.3)	2583	(487.0)
Late May	2330	(1373.4)	1630	(330.8)
Early June	14254	(2071.2)	3750	(1012.9)
April-June	6684		2302	
		Corridors		
	Culross Passage		Prince of Wales Passage	
Late April	4630	(593.0)	1163	(438.1)
Early May	14407	(7111.7)	2071	(56.2)
Late May	3986	(896.4)	1782	(313.7)
Early June	12416	(4878.6)	1668	(179.3)
April-June	8860		1671	
	Wells Passage		Knight Island Passage	
Late April	2105	(404.2)	1582	(134.9)
Early May	2932	(601.8)	5212	(160.4)
Late May	2638	(1315.7)	612	(33.6)
Early June	2474	(509.0)	2623	(636.8)
April-June	2537		2507	

Table 5.5.--Mean biomass (g/m^3) and standard deviation (SD) of pelagic zooplankton collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1990.

Time period	Unoiled sites $\bar{x}$	(SD)	Oiled sites $\bar{x}$	(SD)
		Bays		
	McClure Bay		Herring Bay	
Late April	0.1913	(0.0376)	0.1734	(0.0168)
Early May	0.2449	(0.0508)	0.3294	(0.1303)
Late May	0.6099	(0.2200)	0.2624	(0.1279)
Early June	0.0859	(0.0437)	0.0532	(0.0130)
April-June	0.2830		0.2046	
	Long Bay		Snug Harbor	
Late April	0.5382	(0.0531)	0.0660	(0.0129)
Early May	2.3013	(0.3341)	0.3108	(0.1033)
Late May	0.2345	(0.1837)	0.1962	(0.0399)
Early June	4.1551	(5.3142)	0.1579	(0.0484)
April-June	1.8073		0.1827	
		Corridors		
	Culross Passage		Prince of Wales Passage	
Late April	0.7314	(0.0469)	0.1729	(0.0313)
Early May	5.6138	(2.7484)	0.7149	(0.1362)
Late May	1.4010	(0.6287)	0.3794	(0.1039)
Early June	1.3293	(0.4338)	0.1006	(0.0234)
April-June	2.2689		0.3419	
	Wells Passage		Knight Island Passage	
Late April	0.5276	(0.1469)	1.6192	(0.3876)
Early May	1.6533	(0.1115)	6.4063	(0.6112)
Late May	3.0914	(1.8533)	0.4928	(0.1833)
Early June	0.2222	(0.0694)	0.1423	(0.0069)
April-June	1.3736		2.1651	

Table 5.6. Percent abundance and biomass of identified taxa of pelagic zooplankton in bays and corridors of Prince William Sound from April to June, 1989.

Organism	Percent Abundance		Percent Biomass	
	Bay	Corridor	Bay	Corridor
Protozoa				
Radiolaria	0.0000	0.0018	0.0000	0.0001
Cnidaria				
Hydrozoa	2.8930	0.2939	0.3869	0.0130
Annelida				
Polychaeta	2.6407	0.0976	1.7318	0.0463
Mollusca				
Bivalvia	0.4761	0.9839	0.0368	0.0435
Gastropoda	2.1383	0.4585	0.2476	0.0342
Littorina sp.	0.0352	0.0000	0.0027	0.0000
Thecosomata	0.9735	2.8729	0.0837	1.0535
Egg case	0.0012	0.0000	0.0001	0.0000
Arthropoda				
Cladocera				
Evadne sp.	0.3197	0.1469	0.0387	0.0094
Podon sp.	0.5827	0.0356	0.1202	0.0016
Copepoda				
Copepod general	4.3770	1.4661	0.9399	0.2283
Calanoida				
Acartia clausi	0.0000	0.0060	0.0000	0.0027
Acartia longiremis	7.9265	5.3165	2.5340	1.1766
Acartia tumida	1.6612	0.0735	4.6416	0.0766
Calanus marshallae	0.0170	0.1067	0.2714	0.9212
Calanus sp.	7.9421	12.4219	49.2626	58.5162
Centropages abdominalis	0.8256	0.2166	0.5963	0.0839
Epilabidocera longipedata	0.0012	0.0018	0.0007	0.0044
Epilabidocera sp.	0.0000	0.0006	0.0000	0.0012
Eucalanus bungii	0.1081	0.0623	0.2234	0.1267
Eurytemora sp.	0.0061	0.0000	0.0041	0.0000
Heterorhabdus sp.	0.0000	0.0012	0.0000	0.0005
Metridia okhotensis	0.0000	0.0030	0.0000	0.0273
Metridia pacifica	0.2052	0.9238	0.3699	0.8990
Metridia sp.	0.0000	0.0012	0.0000	0.0014
Microcalanus sp.	0.0023	0.0000	0.0009	0.0000
Neocalanus cristatus	0.0000	0.0436	0.0000	2.0015
Pseudocalanus sp.	32.9174	63.3863	24.7522	28.0898
Tortanus discaudatus	0.0012	0.0000	0.0008	0.0000
Harpacticoida				
Harpacticoid general	0.0668	0.1058	0.0166	0.0379
Tisbe sp.	0.0113	0.0000	0.0088	0.0000
Zaus sp.	0.0622	0.0000	0.0176	0.0000
Cyclopoida				
Oithona similis	2.6132	1.2994	0.2281	0.0582
Oithona spinirostris	0.2272	0.0205	0.0227	0.0010
Oithona sp.	0.0523	0.0000	0.0041	0.0000
Poecilostomatoida				
Oncaea sp.	0.0012	0.0000	0.0001	0.0000
Monstrilloida				
Monstrilla sp.	0.0012	0.0000	0.0009	0.0000
Cirripedia				
Cirriped general	4.8731	0.6206	1.7404	0.0823

Table 5.6. (Continued)

Organism	Percent Abundance		Percent Biomass	
	Bay	Corridor	Bay	Corridor
Malacostraca				
Isopoda				
Cryptoniscidae	0.0037	0.0000	0.0029	0.0000
Amphipoda				
Parathemisto sp.	0.0049	0.0205	0.0060	0.0095
Hyperiidea	0.0227	0.0277	0.0335	0.0127
Euphausiacea				
Euphausid general	2.8139	0.3162	1.2829	0.3297
Decapoda				
Anomura	0.0285	0.0202	0.0470	0.0460
Brachyura	0.0450	0.0264	0.1103	0.0507
Phoronida				
Phoronid general	0.0355	0.0030	0.0099	0.0001
Bryozoa				
Cyphonautes	13.4078	4.9832	1.1472	0.2203
Echinodermata				
Bipinnaria	0.0034	0.0571	0.0003	0.0025
Pluteus	0.2508	0.0000	0.0371	0.0000
Urochordata				
Fritillaria sp.	6.0048	0.6696	0.7365	0.0296
Oikopleura sp.	3.2702	2.7490	8.1121	5.4744
Chaetognatha				
Sagitta sp.	0.1391	0.1289	0.0974	0.2259
Chordata				
Teleostei	0.0090	0.0296	0.0912	0.0601
Unknown	0.0012	0.0000	0.0001	0.0000
Total	100.0000	100.0000	100.0000	100.0000

Table 5.7. Percent abundance and biomass of identified taxa of pelagic zooplankton in bays and corridors of Prince William Sound from April to June, 1990.

Organism	Percent Abundance		Percent Biomass	
	Bay	Corridor	Bay	Corridor
Cnidaria				
Hydrozoa	1.5605	0.3672	0.1112	0.0146
Annelida				
Polychaeta	1.0340	0.2090	0.3942	0.0446
Mollusca				
Bivalvia	1.8911	2.8758	0.0838	0.0712
Gastropoda	0.0301	0.0136	0.0021	0.0005
Thecosomata	6.1296	1.9181	1.9557	0.3423
Arthropoda				
Cladocera				
Evadne sp.	0.6793	1.8515	0.0454	0.0692
Podon sp.	5.9617	0.7034	0.6572	0.0435
Copepoda				
Copepod general	3.8989	3.6812	0.5298	0.2772
Calanoida				
Acartia clausi	0.3216	0.0000	0.1393	0.0000
Acartia longiremis	13.3836	5.4525	2.7438	0.6137
Acartia tumida	0.1762	0.0240	0.2535	0.0239
Acartia sp.	0.8917	0.0000	0.3754	0.0000
Calanus marshallae	3.1631	1.2725	26.7848	3.7953
Calanus sp.	7.2932	12.8575	32.2616	31.8116
Centropages abdominalis	2.7225	0.9571	1.0663	0.2533
Epilabidocera sp.	0.0023	0.0033	0.0043	0.0008
Eucalanus bungii	0.1115	0.0759	0.1813	0.0690
Eurytemora sp.	0.2252	0.0016	0.0896	0.0003
Heterorhabdus sp.	0.0045	0.0000	0.0020	0.0000
Metridia pacifica	0.2839	1.7375	0.2933	0.8418
Neocalanus cristatus	0.0000	0.0016	0.0000	0.0422
Neocalanus plumchrus	0.8216	4.5194	15.1279	46.5408
Pseudocalanus sp.	28.4173	51.0185	12.7534	12.9000
Tortanus discaudatus	0.0023	0.0000	0.0204	0.0000
Harpacticoida				
Harpacticoid general	0.1092	0.0398	0.0411	0.0084
Tisbe sp.	0.0859	0.0289	0.0380	0.0072
Zaus sp.	0.0083	0.0000	0.0013	0.0000
Cyclopoida				
Oithona similis	2.2390	2.0714	0.1065	0.0552
Oithona spinirostris	0.0580	0.0726	0.0029	0.0021
Poecilostomatoida				
Oncaea sp.	0.1408	0.0704	0.0098	0.0028
Monstrilloida				
Monstrilla sp.	0.0008	0.0000	0.0003	0.0000
Cirripedia				
Cirriped general	6.4610	1.0237	1.1231	0.1054
Malacostraca				
Amphipoda				
Parathemisto sp.	0.0000	0.0628	0.0000	0.0162
Euphausiacea				
Euphausid general	6.9799	1.7331	1.0485	0.1715
Decapoda				
Anomura	0.0241	0.0120	0.0412	0.0115
Brachyura	0.0324	0.0426	0.0543	0.0399

Table 5.7. (Continued)

Organism	Percent Abundance		Percent Biomass	
	Bay	Corridor	Bay	Corridor
Bryozoa				
Cyphonautes	1.2479	1.5372	0.0586	0.0404
Echinodermata				
Bipinnaria	0.1167	0.0791	0.0052	0.0020
Pluteus	0.0030	0.0000	0.0003	0.0000
Urochordata				
Fritillaria sp.	2.6359	1.8488	0.1708	0.0670
Oikopleura sp.	0.6740	1.4526	1.1957	1.4412
Chaetognatha				
Sagitta sp.	0.1755	0.3803	0.2216	0.2687
Chordata				
Teleostei	0.0023	0.0033	0.0058	0.0047
Total	100.0000	100.0000	100.0000	100.0000

Table 5.8. ANOVA table, ln biomass of pelagic zooplankton and calanoid copepods in Prince William Sound, April-June, 1989; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Total Zooplankton						
o	l(ob)	1	1.96	1.96	0.23	0.657
b	l(ob)	1	74.96	74.96	8.76	0.042**
ob	l(ob)	1	2.16	2.16	0.25	0.642
l(ob)		4	34.24	8.56		
t	tl(ob)	4	197.34	49.34	16.84	0.000***
to	tl(ob)	4	12.02	3.00	1.03	0.424
tb	tl(ob)	4	7.35	1.84	0.63	0.649
tob	tl(ob)	4	6.08	1.52	0.52	0.723
tl(ob)		16	46.86	2.92		
Error		79	12.72	0.16		
Total		118	395.74			
Total Calanoid Copepods						
o	l(ob)	1	1.00	1.00	0.07	0.807
b	l(ob)	1	97.38	97.38	6.58	0.062
ob	l(ob)	1	0.39	0.39	0.03	0.878
l(ob)		4	59.17	14.79		
t	tl(ob)	4	295.16	73.79	19.06	0.000***
to	tl(ob)	4	25.71	6.42	1.66	0.208
tb	tl(ob)	4	9.79	2.44	0.63	0.647
tob	tl(ob)	4	3.57	0.89	0.23	0.917
tl(ob)		16	61.93	3.87		
Error		79	17.05	0.21		
Total		118	571.19			

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 5.9. ANOVA table, ln biomass of pelagic zooplankton and calanoid copepods in Prince William Sound, April-June, 1990; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Total Zooplankton						
o	l(ob)	1	2.41	2.41	2.20	0.212
b	l(ob)	1	3.52	3.52	3.21	0.147
ob	l(ob)	1	0.01	0.01	0.02	0.897
l(ob)		4	4.39	1.10		
t	tl(ob)	3	4.95	1.65	3.46	0.051*
to	tl(ob)	3	0.67	0.23	0.47	0.706
tb	tl(ob)	3	2.63	0.88	1.84	0.194
tob	tl(ob)	3	0.80	0.27	0.57	0.648
tl(ob)		12	5.72	0.48		
Error		64	3.34	0.05		
Total		95	28.47			
Total Calanoid Copepods						
o	l(ob)	1	2.46	2.46	2.41	0.195
b	l(ob)	1	3.71	3.71	3.63	0.129
ob	l(ob)	1	0.03	0.03	0.06	0.815
l(ob)		4	4.08	1.02		
t	tl(ob)	3	5.14	1.71	3.54	0.048**
to	tl(ob)	3	0.69	0.23	0.48	0.701
tb	tl(ob)	3	2.63	0.88	1.81	0.198
tob	tl(ob)	3	0.85	0.28	0.58	0.637
tl(ob)		12	5.81	0.48		
Error		64	3.47	0.05		
Total		95	28.88			

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 5.10. ANOVA table, ln biomass of small (<2.6 mm total length), and large (>2.5 mm total length) calanoid copepods in Prince William Sound, April-June, 1989. Species classified as large were Calanus marshallae; Calanus sp.; Eucalanus bungii; Heterorhabdus sp.; Neocalanus cristatus; Metridia okhotensis; and adult female Metridia pacifica. All other calanoids identified in the samples were classified as small; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Small Calanoid Copepods						
o	l(ob)	1	0.05	0.05	0.01	0.938
b	l(ob)	1	59.13	59.13	7.45	0.053*
ob	l(ob)	1	3.17	3.17	0.40	0.562
l(ob)		4	31.76	7.94		
t	tl(ob)	4	175.96	43.99	16.80	0.000***
o	tl(ob)	4	23.55	5.88	2.25	0.109
tb	tl(ob)	4	9.75	2.43	0.93	0.471
tob	tl(ob)	4	7.99	2.00	0.76	0.564
tl(ob)		16	41.90	2.61		
Error		79	14.36	0.18		
Total		118	367.67			
Large Calanoid Copepods						
o	l(ob)	1	35.69	35.69	0.54	0.504
b	l(ob)	1	240.69	240.69	3.63	0.129
ob	l(ob)	1	1.48	1.48	0.02	0.888
l(ob)		4	265.22	66.30		
t	tl(ob)	4	1138.78	295.95	22.86	0.000***
to	tl(ob)	4	47.16	11.79	0.91	0.481
tb	tl(ob)	4	39.20	9.80	0.76	0.568
tob	tl(ob)	4	24.89	6.22	0.48	0.750
tl(ob)		16	207.10	12.94		
Error		79	156.54	1.98		
Total		118	2201.79			

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 5.11. ANOVA table, ln biomass of small (<2.6 mm total length), and large (>2.5 mm total length) calanoid copepods in Prince William Sound, April-June, 1990. Species classified as large were Calanus marshallae; Calanus sp.; Eucalanus bungii; Heterorhabdus sp.; Neocalanus cristatus; Neocalanus plumchrus; and adult female Metridia pacifica. All other calanoids identified in the samples were classified as small; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Small Calanoid Copepods						
o	l(ob)	1	0.48	0.48	1.77	0.254
b	l(ob)	1	0.17	0.17	0.61	0.478
ob	l(ob)	1	0.02	0.02	0.62	0.445
l(ob)		4	1.09	0.27		
t	tl(ob)	3	0.32	0.11	2.780	0.087*
to	tl(ob)	3	0.23	0.08	2.02	0.165
tb	tl(ob)	3	0.06	0.02	0.49	0.697
tob	tl(ob)	3	0.02	0.01	0.16	0.924
tl(ob)		12	0.46	0.04		
Error		64	0.26	0.01		
Total		95	3.11			
Large Calanoid Copepods						
o	l(ob)	1	1.39	1.39	1.81	0.249
b	l(ob)	1	3.04	3.04	3.95	0.118
ob	l(ob)	1	0.07	0.07	0.16	0.695
l(ob)		4	3.07	0.77		
t	tl(ob)	3	5.96	1.99	4.62	0.023**
to	tl(ob)	3	0.38	0.13	0.29	0.830
tb	tl(ob)	3	3.17	1.06	2.45	0.113
tob	tl(ob)	3	0.89	0.30	0.69	0.575
tl(ob)		12	5.16	0.43		
Error		64	4.67	0.07		
Total		95	27.82			

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 5.12. ANOVA table, number of taxa of pelagic zooplankton in Prince William Sound, April-June, 1990; t = time, o = oil, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
1989						
o	l(ob)	1	4.4	4.4	0.34	0.593
b	l(ob)	1	69.6	69.6	5.36	0.082*
ob	l(ob)	1	4.5	4.5	0.35	0.587
l(ob)		4	52.0	13.0		
t	tl(ob)	4	128.8	32.2	2.11	0.127
to	tl(ob)	4	53.5	13.4	0.88	0.499
tb	tl(ob)	4	71.8	17.9	1.18	0.358
tob	tl(ob)	4	151.4	37.8	2.48	0.085*
tl(ob)		16	244.0	15.3		
Error		79	273.2	3.5		
Total		118	1053.1			

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
1990						
o	l(ob)	1	96.0	96.0	1.31	0.317
b	l(ob)	1	6.0	6.0	0.08	0.789
ob	l(ob)	1	84.4	84.4	3.17	0.100
l(ob)		4	294.2	73.6		
t	tl(ob)	3	296.9	99.0	3.72	0.042**
to	tl(ob)	3	52.5	17.5	0.66	0.593
tb	tl(ob)	3	6.9	2.3	0.09	0.966
tob	tl(ob)	3	10.2	3.4	0.13	0.942
tl(ob)		12	319.1	26.6		
Error		64	243.3	3.8		
Total		95	1409.6			

* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$

Table 5.13. Number of species (No.) and standard deviation (sd) of pelagic zooplankton by time period, oil, bay/corridor in Prince William Sound in 1989 and 1990.

	Bay				Corridor			
Time Period	Non-oiled No.	(sd)	Oiled No.	(sd)	Non-oiled No.	(sd)	Oiled No.	(sd)
1989								
Late April	16.7	(1.8)	15.5	(2.5)	13.0	(3.1)	16.3	(2.7)
Early May	12.8	(3.3)	17.7	(3.0)	13.7	(2.0)	9.8	(0.7)
Late May	16.7	(2.1)	16.3	(2.0)	14.7	(2.0)	12.2	(1.3)
Early June	13.8	(2.6)	15.8	(2.3)	14.0	(2.0)	16.7	(3.7)
Late June	17.7	(2.2)	16.0	(1.9)	16.5	(2.7)	7.0	(2.0)
1990								
Late April	13.3	(4.1)	17.3	(2.2)	14.8	(4.0)	14.2	(1.2)
Early May	13.7	(6.8)	20.3	(2.4)	15.2	(1.5)	17.5	(2.5)
Late May	17.8	(5.0)	21.2	(3.1)	19.2	(1.2)	18.0	(2.4)
Early June	18.2	(2.4)	19.7	(2.7)	19.3	(3.5)	19.3	(2.3)

Table 5.14. Percent abundance and biomass of organisms of epibenthic and pelagic origin captured by the epibenthic sled in Prince William Sound from April to June, 1989. Whether the organism is a potential prey item of juvenile salmon is also indicated.

Organism	Percent Abundance	Percent Biomass	Prey Item
EPIBENTHIC ORIGIN			
Cnidaria			
Hydroida	0.4424	0.3036	no
Platyhelminthes			
Turbellaria	0.1093	0.0131	no
Nematoda			
Nematode general	2.3984	0.0961	no
Annelida			
Oligochaeta	0.0254	0.0081	no
Mollusca			
Mollusk general	0.0163	0.0519	no
Mytilus sp.	0.0280	0.0444	no
Arthropoda			
Halacaridae	0.6315	0.0432	yes
Nematocera	0.0036	0.0063	yes
Chironomidae	0.3488	0.2387	yes
Collembola	0.0066	0.0004	yes
Copepoda			
Halicyclops sp.	0.0005	0.0000	no
Harpacticoida			
Harpacticoid general	0.4149	0.0081	yes
Alteutha sp.	0.0084	0.0000	no
Amonardia sp.	0.1354	0.0224	yes
Amphiascoides sp.	0.0168	0.0000	yes
Amphiascopsis sp.	0.3020	0.0709	no
Amphiascus sp.	0.2863	0.0061	no
Danielssenia sp.	0.0076	0.0000	yes
Diosaccus sp.	5.8165	1.2962	yes
Harpacticus sp.	13.9517	4.0891	yes
Mesochra sp.	0.0331	0.0000	yes
Microarthridion sp.	0.0010	0.0000	yes
Paralteutha sp.	0.0056	0.0046	no
Paramphiascella sp.	0.1083	0.0327	no
Parastenhelia sp.	0.1088	0.0000	yes
Porcellidium sp.	0.0041	0.0000	no
Pseudonychocamptus sp.	0.0158	0.0004	no
Robertsonia sp.	0.0341	0.0010	yes
Scutellidium sp.	0.6739	0.0796	yes
Stenhelia sp.	0.0036	0.0000	yes
Tisbe sp.	11.7791	1.7109	yes
Zaus sp.	0.5030	0.0316	yes

Table 5.14. (Continued)

Organism	Percent Abundance	Percent Biomass	Prey Item
Ameiridae	0.0557	0.0000	yes
Ameira sp.	0.0203	0.0000	no
Cletodidae	0.0005	0.0000	yes
Huntemannia sp.	0.0051	0.0000	yes
Ectinosomatidae	0.1807	0.0017	yes
Microsetella sp.	0.0010	0.0000	no
Laophontidae	0.7639	0.0183	yes
Echinolaophonte sp.	0.2464	0.0190	yes
Heterolaophonte sp.	2.6611	0.2087	yes
Laophonte sp.	0.0076	0.0006	yes
Laophontodes sp.	0.0158	0.0000	no
Paralaophonte	1.3371	0.0694	yes
Tegastidae	0.0086	0.0000	no
Tegastes sp.	0.0015	0.0000	no
Thalestridae	0.0061	0.0008	yes
Dactylopodia sp.	0.8264	0.0648	yes
Diarthrodes sp.	0.0102	0.0000	yes
Idomene sp.	0.0107	0.0000	no
Paradactylopodia sp.	0.0633	0.0002	yes
Parathalestris sp.	0.1481	0.0607	yes
Rhyncothalestris sp.	0.0010	0.0000	no
Thalestris sp.	0.0025	0.0002	no
Ostracoda			
Podocopa	1.1925	0.1581	yes
Malacostraca			
Cumella sp.	0.2609	0.1737	yes
Mysidacea	0.0020	0.0008	yes
Euphausiacea	0.1142	0.0088	yes
Isopoda			
Epicaridea	0.0168	0.0006	no
Gnorimosphaeroma sp.	0.0005	0.0006	no
Ianiropsis sp.	0.0041	0.0000	no
Munna sp.	0.0005	0.0002	no
Amphipoda			
Gammaridea			
Gammarid general	0.1141	0.0265	yes
Allorchestes sp.	0.0290	0.1113	yes
Ischyrocerus sp.	0.0651	0.0156	yes
Megamphopus sp.	0.0112	0.0029	yes
Paramoera sp.	0.0824	0.2414	yes
Pleustes sp.	0.0005	0.0021	yes
Pontogeneia sp.	0.0168	0.0605	yes
Synchelidium sp.	0.0102	0.0000	yes
Ampithoidae	0.0071	0.0158	yes
Ampithoe sp.	0.0092	0.0869	yes

Table 5.14. (Continued)

Organism	Percent Abundance	Percent Biomass	Prey Item
Calliopiidae	0.0224	0.0129	yes
Calliopius sp.	0.0165	0.0710	yes
Paracalliopiella sp.	0.2809	0.3907	yes
Gammaridae	0.0163	0.0077	yes
Stenothoidae	0.0005	0.0000	yes
Decapoda			
Brachyura	0.0005	0.0065	yes
Cancer sp.	0.0010	0.0171	yes
Pleocyemata-Caridea	0.0112	0.0208	no
Heptacarpus sp.	0.0961	13.5913	no
Pandalus sp.	0.0005	0.7248	no
Paguridae	0.0005	0.0033	no
Echinodermata	0.0081	0.0000	no
Epibenthic subtotal	46.9859	24.3557	
PELAGIC ORIGIN			
Cnidaria			
Scyphozoa	0.0025	0.0025	no
Rotifera	0.0813	0.0000	no
Annelida			
Polychaeta	0.5598	0.3075	yes
Polynoidae	0.0439	0.0127	yes
Mollusca			
Bivalvia	0.8665	0.4829	yes
Gastropoda	0.3758	0.0934	yes
Archaeogastropoda	0.0910	0.3824	yes
Mesogastropoda	0.7292	1.1876	yes
Lacuna sp.	0.0066	0.2585	yes
Littorina sp.	4.6362	0.5765	yes
Opisthobranchia	0.0051	0.0042	yes
Gymnosomata	0.0219	0.1165	no
Thecosomata	0.1074	0.0769	yes
Limacina sp.	0.1135	1.7372	yes
Arthropoda			
Cladocera			
Evadne sp.	0.1213	0.0052	yes
Podon sp.	0.0712	0.0019	yes
Copepoda			
Calanoida			
Calanoid general	2.1776	0.2326	yes
Acartia sp.	0.8958	0.1444	yes
Centropages sp.	0.2036	0.0434	yes
Epilabidocera sp.	0.0020	0.0004	yes
Eucalanus sp.	0.0071	0.0071	yes

Table 5.14. (Continued)

Organism	Percent Abundance	Percent Biomass	Prey Item
Eurytemora sp.	7.5643	0.7931	yes
Metridia sp.	0.1256	0.0813	yes
Neocalanus sp.	8.3888	53.3785	yes
Paracalanus sp.	0.0073	0.0000	yes
Pseudocalanus sp.	15.1919	5.1085	yes
Calanidae	0.9774	0.3524	yes
Calanus sp.	2.9014	8.2628	yes
Stephidae	0.0005	0.0000	yes
Cyclopoida			
Oithona sp.	1.4568	0.0388	no
Poecilostomatoida	0.4321	0.0207	no
Oncaea sp.	0.0005	0.0000	no
Monstrilloida	0.1541	0.0125	yes
Cirripedia			
Balanomorpha	2.5929	1.2285	yes
Malacostraca			
Amphipoda			
Caprellidea	0.0254	0.0088	yes
Decapoda			
Brachyura	0.0056	0.0044	yes
Bryozoa			
Gymnolaemata	1.5659	0.0423	yes
Urochordata			
Larvacea	0.0041	0.0000	yes
Fritillaria sp.	0.1246	0.0025	yes
Oikopleura sp.	0.3244	0.3522	yes
Chaetognatha			
Chaetognath general	0.0320	0.0113	yes
Chordata			
Teleostei	0.0193	0.2719	yes
Pelagic subtotal	53.0141	75.6443	
Total	100.0000	100.0000	

Table 5.15. Abundance (organisms/m^3) of epibenthos by habitat collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1989, in the systematic epigenthic sled samples. Habitat designations are LG (low gradient), MG (medium gradient) and SG (steep gradient).

Time Period	Non-oiled locations			Oiled locations		
	LG	MG	SG	LG	MG	SG
	McClure Bay			Herring Bay		
Late April	21	3613	127	1657	167	415
Early May	75	217	85	378	301	831
Late May	26	51	--	250	73	1093
Early June	42	18	11	725	2390	1071
Late June	613	997	9	1882	--	414
April-June	155	979	58	978	733	765
	Long Bay			Snug Harbor		
Late April	1122	1333	169	361	197	663
Early May	169	1637	22	11027	815	106
Late May	311	55	6	229	237	63
Early June	4421	2999	242	1349	1162	150
Late June	713	125	146	1290	--	66
April-June	1347	1230	117	2851	603	210
	Culross Passage			Prince of Wales Passage		
Late April	66	666	171	1173	5573	165
Early May	278	1746	114	1642	527	119
Late May	710	6367	262	6861	4066	319
Early June	35	--	454	1397	211	54
Late June	55	--	311	2439	578	31
April-June	229	2926	262	2702	2191	138
	Wells Passage			Knight Island Passage		
Late April	3066	207	253	205	725	290
Early May	853	613	170	1759	1986	95
Late May	1621	2490	71	7621	4967	1419
Early June	327	746	3	--	4816	709
Late June	1882	171	49	197	--	389
April-June	1550	845	109	2446	3124	580

Table 5.16. Biomass (g/m^3) of epibenthos by habitat collected from four pairs of non-oiled and oiled locations in Prince William Sound, Alaska, April-June 1989, in the systematic epigenthic sled samples. Habitat designations are LG (low gradient), MG (medium gradient) and SG (steep gradient).

Time Period	Non-oiled locations LG	MG	SG	Oiled locations LG	MG	SG
	McClure Bay			Herring Bay		
Late April	0	140	12	168	6	58
Early May	2	5	10	15	113	34
Late May	1	1	--	9	740	4957
Early June	1	1	1	237	684	253
Late June	5	21	0	842	--	83
April-June	2	33	4	254	386	1077
	Long Bay			Snug Harbor		
Late April	32	43	4	74	28	115
Early May	9	37	4	422	40	38
Late May	15	1	0	214	12	4
Early June	84	55	4	43	55	4
Late June	12	1	2	39	--	16
April-June	30	27	3	158	34	35
	Culross Passage			Prince of Wales Passage		
Late April	1	16	4	29	344	14
Early May	17	144	7	115	32	8
Late May	31	465	23	552	541	43
Early June	1	--	8	50	7	6
Late June	1	--	4	201	28	1
April-June	10	208	9	189	190	14
	Wells Passage			Knight Island Passage		
Late April	259	6	33	33	50	46
Early May	77	57	11	107	151	14
Late May	58	94	4	1120	395	142
Early June	8	22	0	--	132	40
Late June	70	7	3	6	--	31
April-June	94	37	10	317	182	55

Table 5.17. ANOVA table, ln biomass of epibenthic harpacticoid copepods captured in the systematic epibenthic sled samples in Prince William Sound, 1989; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(ob)	1	125.169	125.17	12.25	0.025**
b	l(ob)	1	71.689	71.69	7.02	0.057*
ob	l(ob)	1	12.824	12.82	1.25	0.325
l(ob)		4	40.877	10.22		
t	tl(ob)	4	35.770	8.94	2.74	0.066*
to	tl(ob)	4	19.303	4.83	1.48	0.256
tb	tl(ob)	4	86.248	21.56	6.60	0.002***
tob	tl(ob)	4	5.569	1.39	0.43	0.788
tl(ob)		16	52.296	3.27		
h	hl(ob)	2	93.146	46.57	6.01	0.025**
oh	hl(ob)	2	19.355	9.68	1.25	0.337
bh	hl(ob)	2	0.137	0.07	0.01	0.991
obh	hl(ob)	2	8.586	4.29	0.55	0.595
hl(ob)		8	61.993	7.75		

* = $0.050 < \underline{P} < 0.100$
** = $0.010 < \underline{P} < 0.050$
*** = $\underline{P} < 0.010$

Table 5.18. ANOVA table, ln biomass of epibenthic harpacticoid copepods captured in the tidal transect epibenthic sled samples in Prince William Sound, April-June, 1989; t = time, o = oil, h = habitat, l = location, r = tide level, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(o)	1	377.8	377.8	3.29	0.211
l(o)		2	229.4	114.7		
t	tl(o)	3	55.2	18.4	4.07	0.068*
to	tl(o)	3	7.8	2.6	0.57	0.652
tl(o)		6	27.1	4.5		
h	hl(o)	2	46.1	23.0	5.67	0.068*
oh	hl(o)	2	4.1	2.0	0.50	0.640
hl(o)		4	16.2	4.1		
th	thl(o)	6	70.9	11.8	1.78	0.187
toh	thl(o)	6	22.6	3.8	0.56	0.751
thl(o)		12	79.9	6.7		
r	rl(o)	2	63.5	31.7	3.84	0.117
or	rl(o)	2	20.0	10.0	1.21	0.387
rl(o)		4	33.0	8.3		
tr	trl(o)	6	14.4	2.4	0.64	0.699
tor	trl(o)	6	8.1	1.3	0.36	0.891
trl(o)		12	45.3	3.8		
hr	rhl(o)	4	37.5	9.4	2.49	0.126
ohr	rhl(o)	4	28.5	7.1	1.90	0.205
rhl(o)		8	30.1	3.7		
thr	thrl(o)	12	26.5	2.2	0.65	0.777
tohr	thrl(o)	12	22.2	1.8	0.54	0.863
thrl(o)		24	81.4	3.4		

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 5.19. ANOVA table, number of epibenthic taxa captured in the systematic epibenthic sled samples in Prince William Sound, June-April, 1989; t = time, o = oil, h = habitat, b = bay/corridor, l = location, and (ob) indicates nesting within oil and bay/corridor.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
o	l(ob)	1	197.72	197.7	1.34	0.312
b	l(ob)	1	8.35	8.347	0.06	0.824
ob	l(ob)	1	181.47	181.5	1.23	0.330
l(ob)		4	591.85	148.0		
t	tl(ob)	4	575.12	143.8	9.71	0.000***
to	tl(ob)	4	182.07	45.52	3.08	0.047*
tb	tl(ob)	4	99.39	24.85	1.68	0.204
tob	tl(ob)	4	127.15	31.79	2.15	0.122
tl(ob)		16	236.82	14.80		
h	hl(ob)	2	478.21	239.1	7.37	0.015**
oh	hl(ob)	2	7.96	3.982	0.12	0.886
bh	hl(ob)	2	27.83	13.92	0.43	0.665
obh	hl(ob)	2	48.71	24.36	0.75	0.503
hl(ob)		8	259.71	32.46		

* = 0.050 < $\underline{P}$ < 0.100
** = 0.010 < $\underline{P}$ < 0.050
*** = $\underline{P}$ < 0.010

Table 5.20. Numbers of samples analyzed and ratings for presence of oil in sediments from transects sampled for epibenthic harpacticoid copepods in Bay of Isles (BI) and Herring Bay (HB).

transect	sampled	requested	analyzed	available	no	maybe	yes
BI-1	4	3	1	1	-	-	1
BI-2	4	3	1	1	1	-	-
BI-3	4	4	2	2	-	-	2
BI-4	4	3	1	1	-	-	1
BI-5	4	3	1	1	-	-	1
BI-6	4	3	1	1	-	-	1
BI-7	4	3	1	1	-	-	1
BI-8	4	3	1	1	-	-	1
Sum	32	25	9	9	1	0	8
HB-1	4	4	4	4	1	0	3
HB-2	4	4	4	4	1	0	3
HB-3	4	4	4	4	0	1	3
HB-4	4	3	4	4	-	-	-
HB-5	4	3	3	3	-	-	-
HB-6	4	3	3	3	-	-	-
HB-7	4	4	3	3	-	-	3
HB-8	4	3	3	3	-	-	-
Sum	32	28	28	28	2	1	12

Table 5.21. ANOVA tables for proportion substrate composition pebble or smaller (< 65 mm), proportion macrophyte coverage, and total organic carbon (TOC), between lightly-oiled and heavily-oiled transects in two embayments in Prince William Sound. o = oil level, r = transect, and (o) indicates nesting within oil. Proportions were arcsine transformed prior to the statistical test.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Herring Bay substrate						
o	r(o)	1	1.06	1.06	3.61	0.106
r(o)		6	1.77	0.29		
Error		40	3.46	0.09		
Total		47	6.29			
Herring Bay macrophyte						
o	r(o)	1	0.21	0.21	0.28	0.613
r(o)		6	4.53	0.75		
Error		40	6.41	0.16		
Total		47	11.15			
Herring Bay total organic carbon						
o	Error	1	3	3	0.00	0.995
Error		6	513096	85516		
Total		7	513099			
Bay of Isles substrate						
o	r(o)	1	0.11	0.11	0.46	0.522
r(o)		6	1.41	0.24		
Error		40	3.63	0.09		
Total		47	5.15			
Bay of Isles macrophyte						
o	r(o)	1	0.12	0.12	0.67	0.417
r(o)		6	1.40	0.23		
Error		40	7.26	0.18		
Total		47	8.78			
Bay of Isles total organic carbon						
o	Error	1	98	98	0.00	0.967
Error		6	319160	53193		
Total		7	319258			

Table 5.22. Macrophyte coverage and total organic carbon composition of sediments from transects sampled for harpacticoid copepod abundance in Prince William Sound in 1990. Macrophyte proportions shown are means, with standard errors in parentheses, of values from six 0.25 m^2 quadrats placed along each transect line. TOC was measured from a single sample of fine sediments from each transect.

Transect Number	TOC (mg/kg)	Macrophyte Coverage
Herring Bay: Heavily Oiled		
HB-1	494	1.00(0.0)
HB-3	328	0.48(.07)
HB-5	1009	0.85(.10)
HB-7	223	0.58(.18)
Mean	514(174)	0.73(.10)
Herring Bay: Lightly Oiled		
HB-2	793	0.80(.06)
HB-4	255	0.60(.08)
HB-6	461	0.60(.10)
HB-8	540	0.82(.13)
Mean	512(111)	0.70(.06)
Bay of Isles: Heavily Oiled		
BI-1	110	0.83(.10)
BI-3	148	0.88(.08)
BI-5	560	0.82(.15)
BI-7	596	0.87(.07)
Mean	354(130)	0.85(.01)
Bay of Isles: Lightly Oiled		
BI-2	74	1.00(0.0)
BI-4	501	0.73(.11)
BI-6	331	0.98(.02)
BI-8	480	0.87(.08)
Mean	330(114)	0.90(.06)

Table 5.23. Surface substrate composition of transects sampled for harpacticoid copepod abundance in Prince William Sound in 1990. Proportions shown are means, with SE in parentheses, of values from six 0.25 m^2 quadrats randomly placed within each of six equidistant sections of the transect line. Substrate composition was estimated using the Wentworth scale: Boulder > 256 mm; Cobble = 64-256 mm; Pebble = 4-64 m; and Granule or smaller < 4 mm.

Transect Number	Surface Substrate			
	Boulder	Cobble	Pebble	Granule
Herring Bay: Heavily Oiled				
HB-1	0(0)	.10(.04)	.55(.08)	.35(.08)
HB-3	0(0)	.18(.03)	.47(.04)	.35(.04)
HB-5	0(0)	.37(.06)	.50(.04)	.13(.03)
HB-7	0(0)	.30(.08)	.45(.10)	.25(.13)
Mean	0(0)	.24(.06)	.49(.02)	.27(.05)
Herring Bay: Lightly Oiled				
HB-2	0(0)	.73(.13)	.15(.06)	.12(.07)
HB-4	0(0)	.38(.09)	.28(.05)	.33(.08)
HB-6	0(0)	.30(.12)	.42(.09)	.28(.10)
HB-8	0(0)	.38(.12)	.52(.09)	.10(.07)
Mean	0(0)	.45(.10)	.34(.08)	.21(.06)
Bay of Isles: Heavily Oiled				
BI-1	0(0)	.23(.10)	.42(.08)	.35(.10)
BI-3	.02(.02)	.18(.04)	.63(.03)	.17(.05)
BI-5	0(0)	.30(.06)	.52(.10)	.18(.06)
BI-7	.02(.02)	.48(.06)	.47(.06)	.03(.02)
Mean	.01(.01)	.30(.07)	.51(.04)	.18(.07)
Bay of Isles: Lightly Oiled				
BI-2	.02(.02)	.47(.09)	.52(.09)	0(0)
BI-4	0(0)	.43(.14)	.47(.12)	.10(.15)
BI-6	0(0)	.37(.07)	.52(.10)	.12(.07)
BI-8	0(0)	.19(.05)	.77(.07)	.05(.02)
Mean	0(.005)	.36(.06)	.57(.07)	.07(.03)

Table 5.24. ANOVA table, ln abundance of harpacticoid copepods, Harpacticus uniremis, Tisbe sp., and arcsine proportion of egg carrying females to total adult females of Harpacticus uniremis and Tisbe sp. sampled with epibenthic pump in Herring Bay, Prince William Sound, April 24-27, 1990; o = oil, r = transect, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Total Harpacticoid copepods						
o	r(o)	1	44.66	44.66	6.89	0.039**
r(o)		6	38.89	6.48		
Error		112	48.98	0.44		
Total		119	132.53			
Harpacticus uniremis						
o	r(o)	1	103.04	103.04	6.33	0.046**
r(o)		6	97.68	16.28		
Error		112	65.30	0.58		
Total		119	266.03			
Tisbe sp.						
o	r(o)	1	15.00	15.00	1.42	0.278
r(o)		6	63.14	10.52		
Error		112	66.91	0.60		
Total		119	145.05			
Harpacticus uniremis, proportion egg carrying females to all adult females						
o	r(o)	1	0.55	0.55	2.02	0.205
r(o)		6	1.65	0.27		
Error		112	6.49	0.06		
Total		119	8.70			
Tisbe sp., proportion egg carrying females to all adult females						
o	r(o)	1	0.04	0.04	0.27	0.621
r(o)		6	0.97	0.16		
Error		112	3.16	0.03		
Total		119	4.18			

* = $0.050 < P < 0.100$
** = $0.010 < P < 0.050$
*** = $P < 0.010$

Table 5.25. ANOVA table, ln abundance of harpacticoid copepods, Harpacticus uniremis, Tisbe sp., and arcsine proportion of egg carrying females to total adult females of Harpacticus uniremis and Tisbe sp. sampled with epibenthic pump in Bay of Isles, Prince William Sound, May 24-27, 1990; o = oil, r = transect, and (o) indicates nesting within oil.

Source	Error Term	D.F.	Sum of Squares	Mean Square	F	Prob.
Total Harpacticoid copepods						
o	r(o)	1	11.13	11.13	4.36	0.082*
r(o)		6	15.30	2.55		
Error		191	218.86	1.15		
Total		198	245.30			
Harpacticus sp.						
o	r(o)	1	19.76	19.76	1.90	0.217
r(o)		6	62.29	10.38		
Error		191	209.06	1.09		
Total		198	291.12			
Tisbe sp.						
o	r(o)	1	0.19	0.19	0.01	0.919
r(o)		6	100.39	16.73		
Error		191	267.98	1.40		
Total		198	368.55			
Harpacticus sp., proportion egg carrying females to all adult females						
o	r(o)	1	0.0035	0.0035	1.75	0.234
r(o)		6	0.0120	0.0020		
Error		188	0.1704	0.0009		
Total		195	0.1859			
Tisbe sp., proportion egg carrying females to all adult females						
o	r(o)	1	0.0094	0.0094	0.07	0.797
r(o)		6	0.7789	0.1298		
Error		187	6.2835	0.0336		
Total		194	7.0718			

* = 0.050 < P < 0.100
** = 0.010 < P < 0.050
*** = P < 0.010

Table 5.26. Correlation coefficients (r) of measures of harpacticoid copepod abundance (transformed by natural logs) with beach characteristics in two embayments in Prince William Sound in 1990. The measures of abundance were those indicated by ANOVA to be different ($P < 0.1$) between heavily-oiled and lightly-oiled transects.

Harpacticoid Abundance	Level of Oiling	Macrophyte Coverage	Substrate < 65 mm	Total Organic Carbon
Herring Bay Total	.713[1]	.608	.560	.154
Herring Bay *H. uniremis*	.717[1]	.284	.205	.226
Bay of Isles Total	.651[2]	.160	.122	.101

[1] Significantly different from zero at $P < .05$

[2] Significantly different from zero at $P < .10$

Table 5.27. Numbers of samples analyzed and ratings for presence of oil in sediments from the meiofauna colonization experiment.

Low oil site (HBL):

Treatment	sampled	requested	analyzed	available	no	maybe	yes
Control	15	15	15	15	0	0	12
Low oil	15	15	15	15	0	0	12
High oil	15	15	15	15	0	0	13
Indigenous	10	4	4	4	1	0	3
sum	55	49	49	49	1	0	40

High oil site (HBH):

Treatment	sampled	requested	analyzed	available	no	maybe	yes
Control	15	15	13	13	0	0	13
Low oil	15	15	13	13	0	0	13
High oil	15	15	13	13	0	0	9
Indigenous	9	6	5	5	0	0	5
sum	25	25	23	23	0	0	23

Table 5.28. Groups oiled sediments which were significantly different (P = 0.05) from the control sediments in the meiofauna colonization experiment. Multiple comparisons between controls and treatments were made using the Dunnett *a posteriori* test. L ≡ low oil treatment, H ≡ high oil treatment.

Analyte	day: 0	2	29	89
Low oil site (HBL)				
sum hydrocarbons	H	-	-	H
sum alkanes	H	-	-	H
sum aromatics	-	H	-	L,H
alkanes	H	-	-	H
unresolved complex mixture	H	-	L,H	H
pristane	H	-	-	L,H
phytane	H	-	-	H
pristane/phytane ratio	L,H	L,H	L	H
C18/phytane ratio	L,H	L,H	L,H	-
Saturated hydrocarbon weathering ratio	H	L,H	L,H	H
carbon preference index	H	L,H	L,H	-
sum naphthalenes	H	H	-	L,H
sum fluorenes	-	H	-	H
sum phenanthrenes	H	H	-	H
sum dibenzothiophenes	H	H	-	H
sum chrysenes	H	H	-	H
high/low aromatic ratio	L,H	-	L,H	L,H
High oil site (HBH)				
sum hydrocarbons	L,H		H	H
sum alkanes	L,H		H	H
sum aromatics	L,H		H	L,H
alkanes	L,H		H	H
unresolved complex mixture	L,H		H	-
pristane	L,H		H	H
phytane	L,H	-	H	H
pristane/phytane ratio	L,H		L,H	L,H
n-C18/phytane ratio	L,H		L,H	H
Saturated hydrocarbon weathering ratio	-		L,H	L,H
carbon preference index	L,H		L,H	L,H
sum naphthalenes	L,H		L,H	L,H
sum fluorenes	H		-	L,H
sum phenanthrenes	H		L,H	H
sum dibenzothiophenes	H		H	H
sum chrysenes	L,H		H	L,H
high/low aromatic ratio	L,H	-	L,H	H

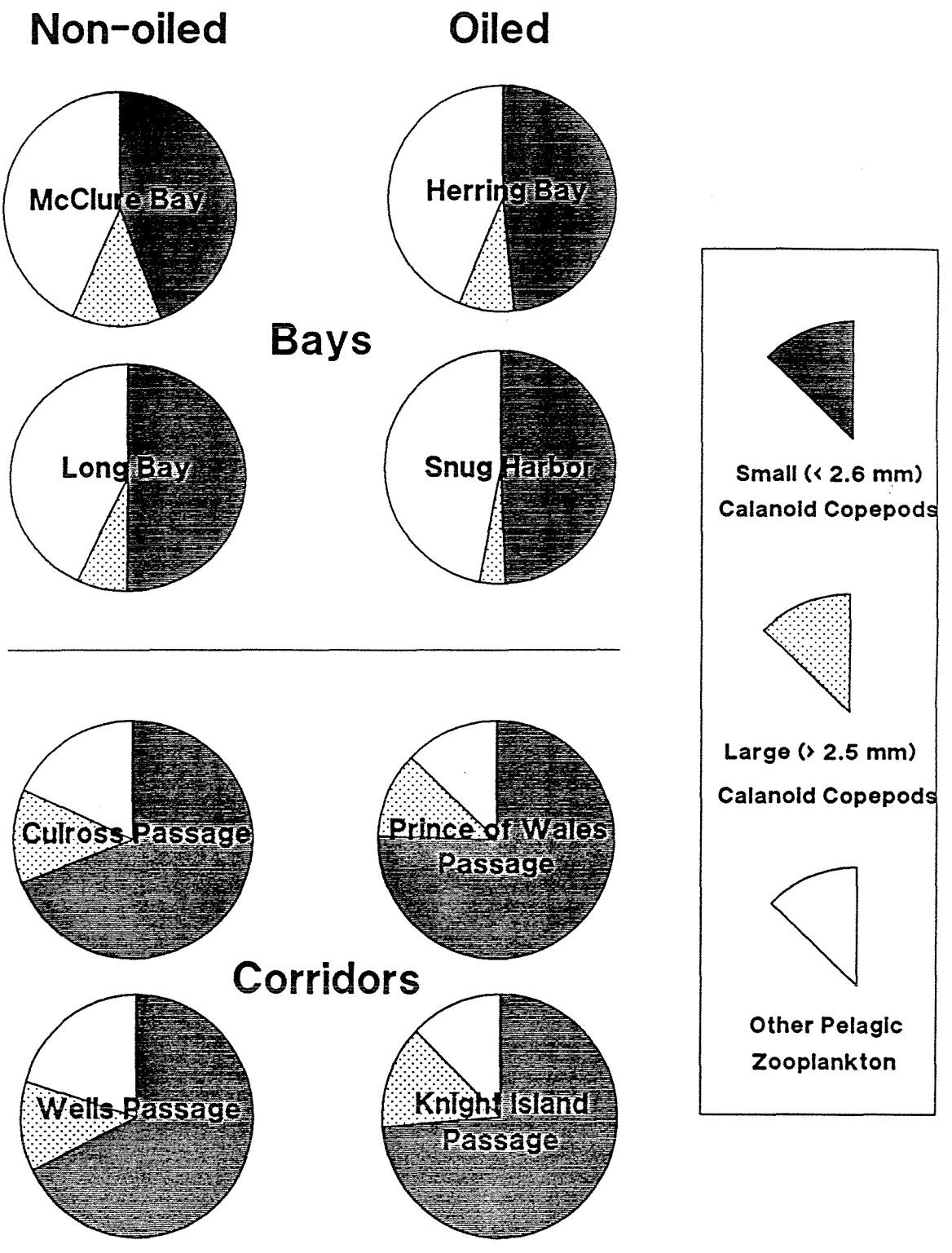


Figure 5.1. Relative abundance of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

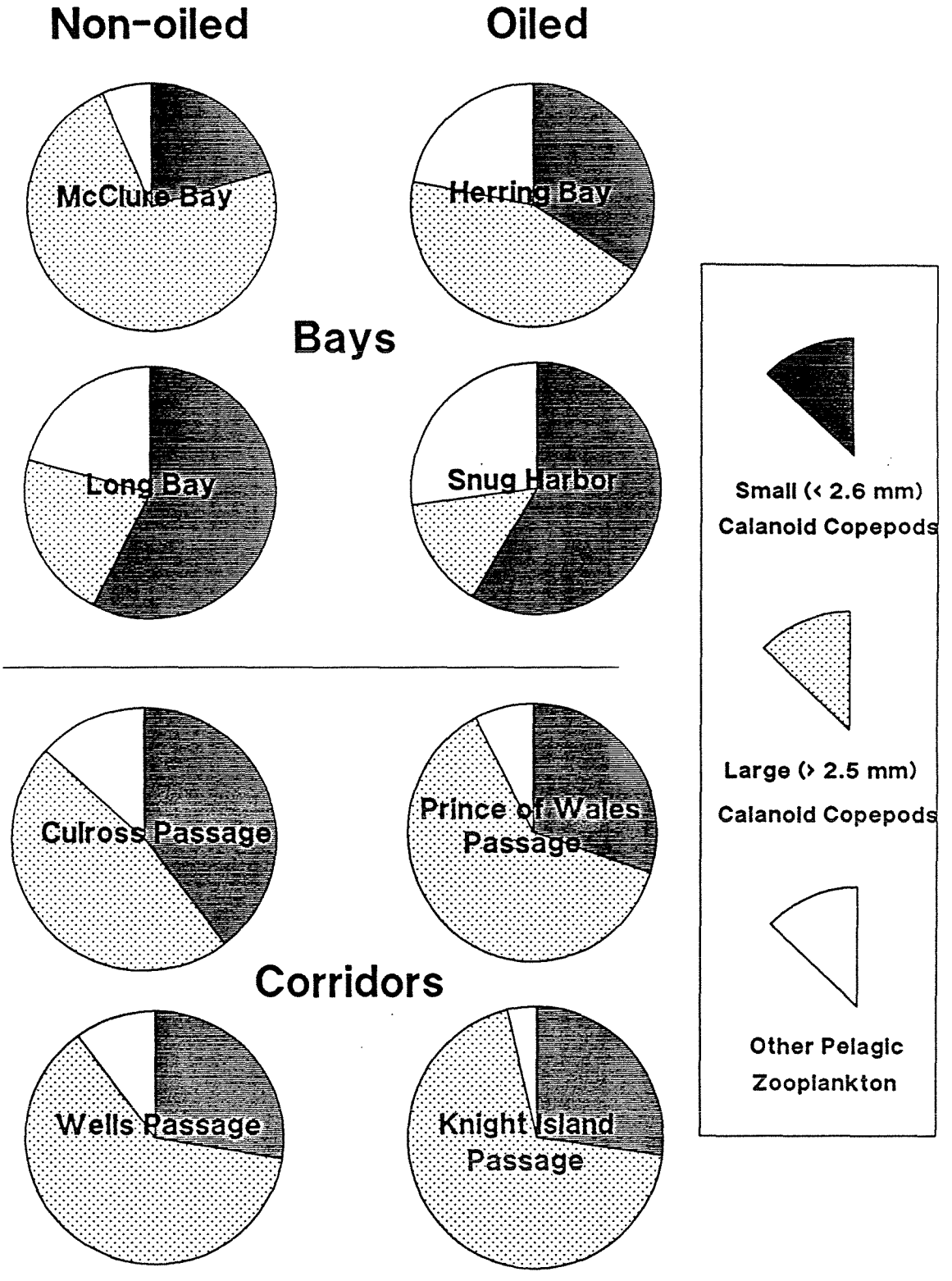


Figure 5.2. Relative biomass of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

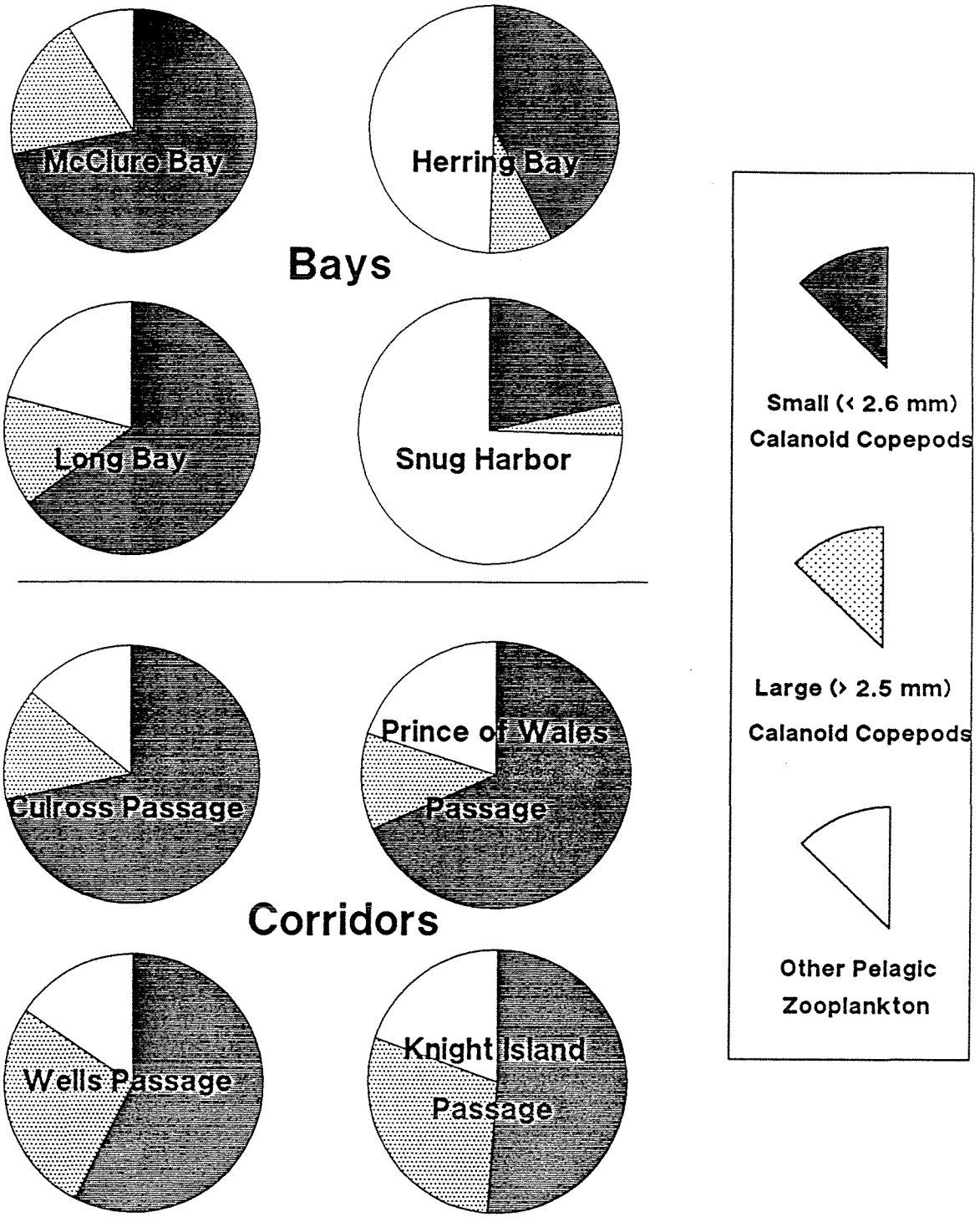


Figure 5.3. Relative abundance of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1990.

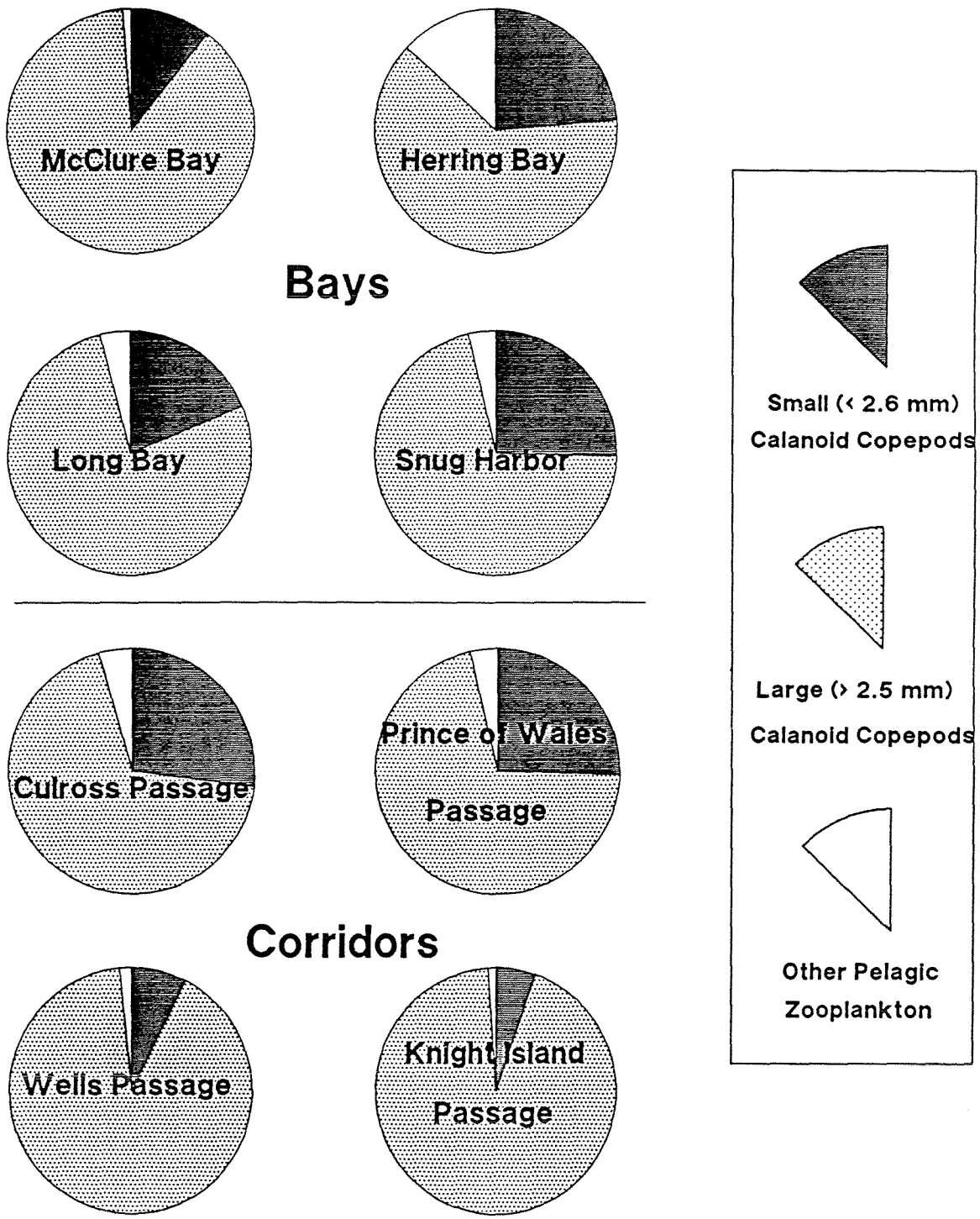


Figure 5.4. Relative biomass of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1990.

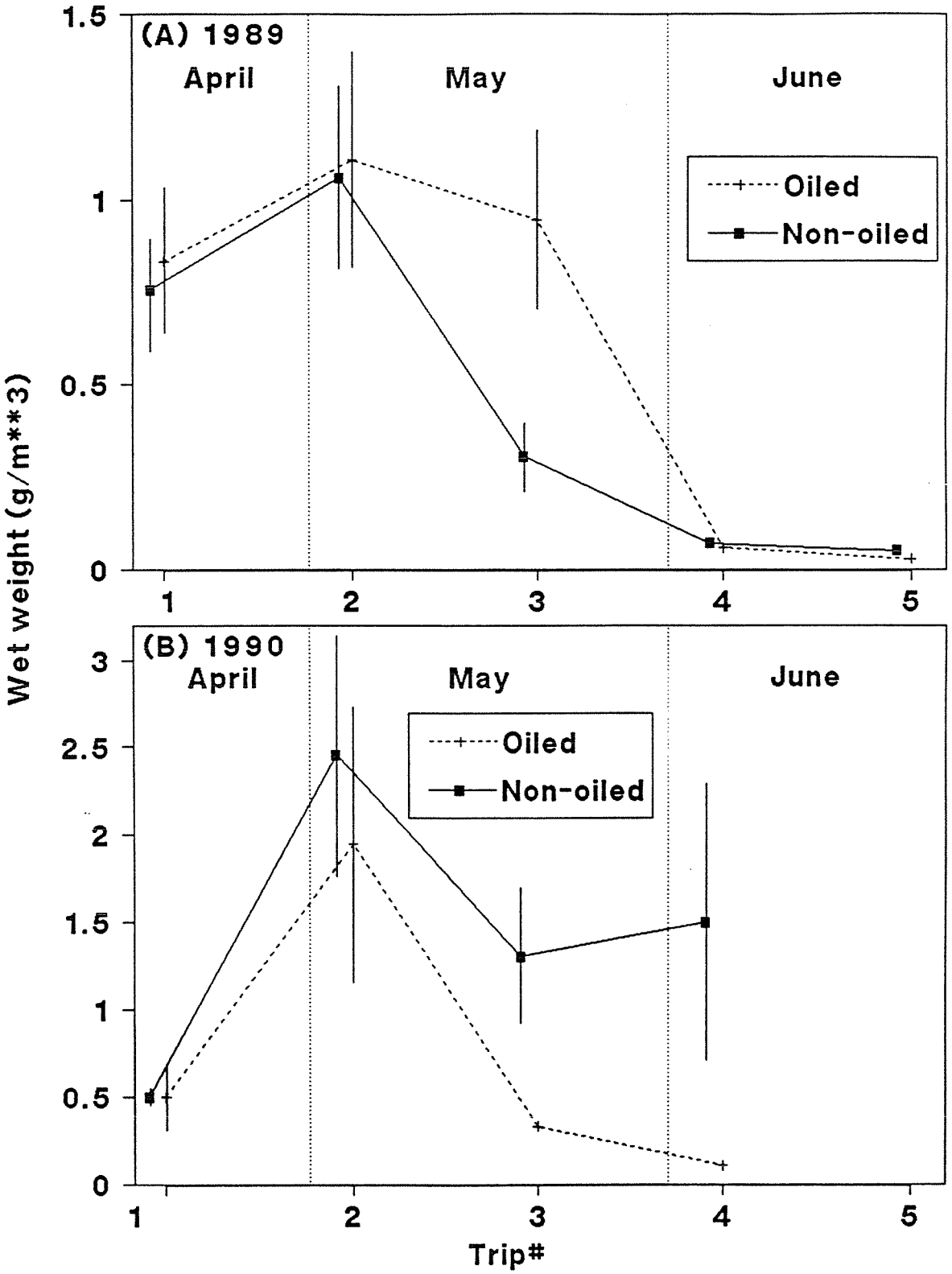


Figure 5.5. Biomass and standard errors of pelagic zooplankton in oiled and non-oiled areas of Prince William Sound in (A) 1989 and (B) 1990.

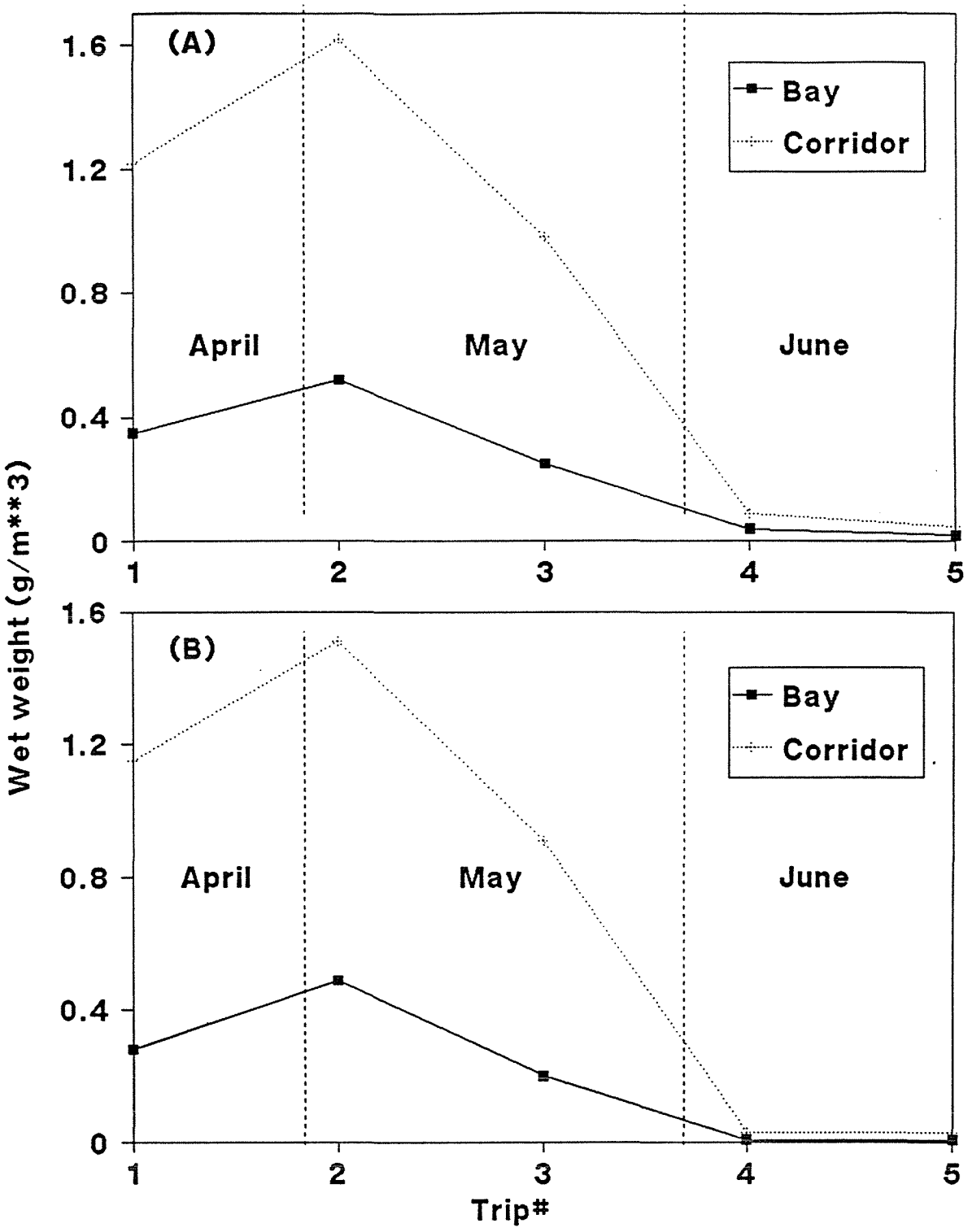


Figure 5.6. Biomass of (A) Pelagic zooplankton and (B) Calanoid copepods in Prince William Sound from April-June, 1989.

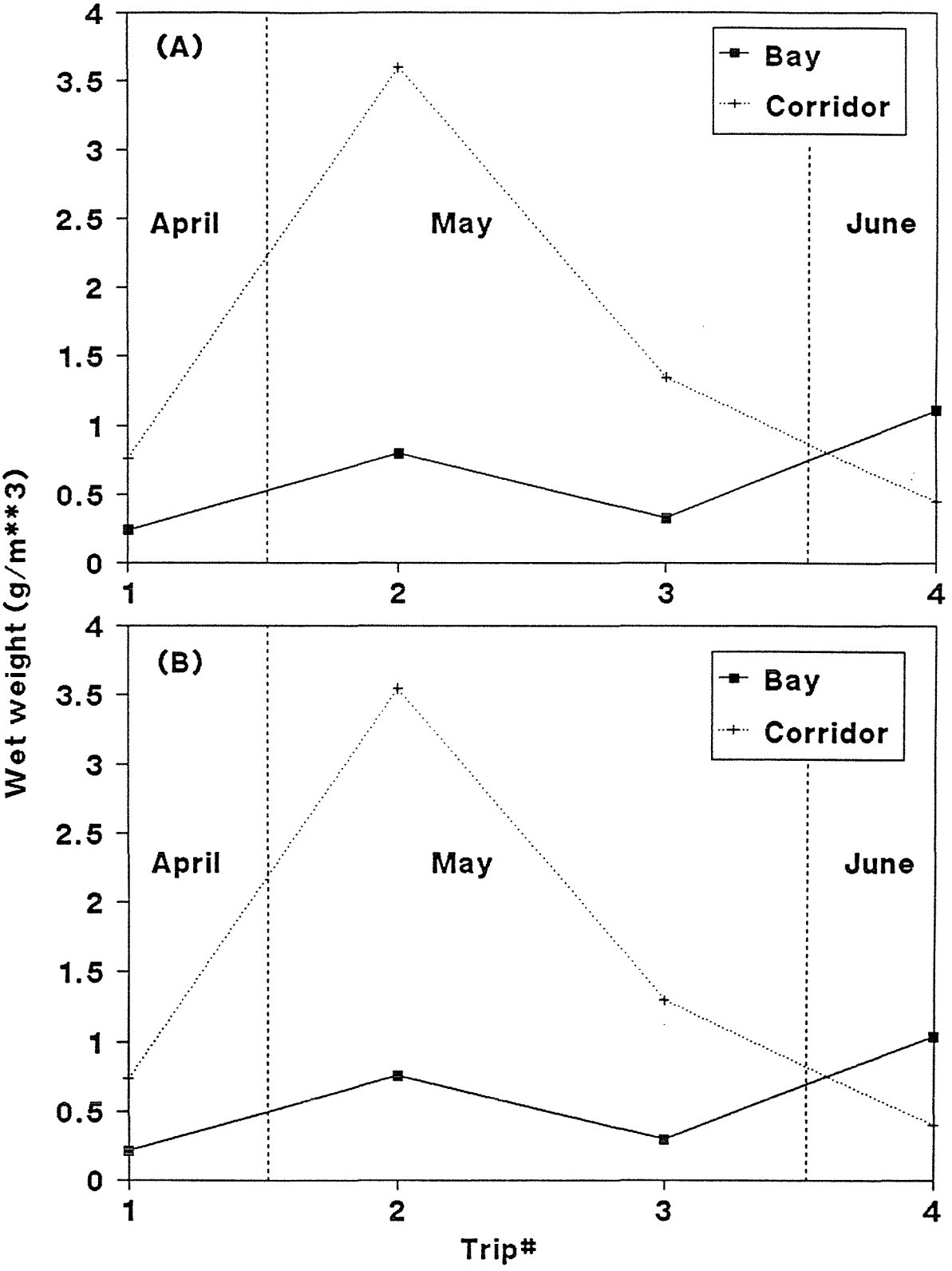


Figure 5.7. Biomass of (A) Pelagic zooplankton and (B) Calanoid copepods in Prince William Sound from April-June, 1990.

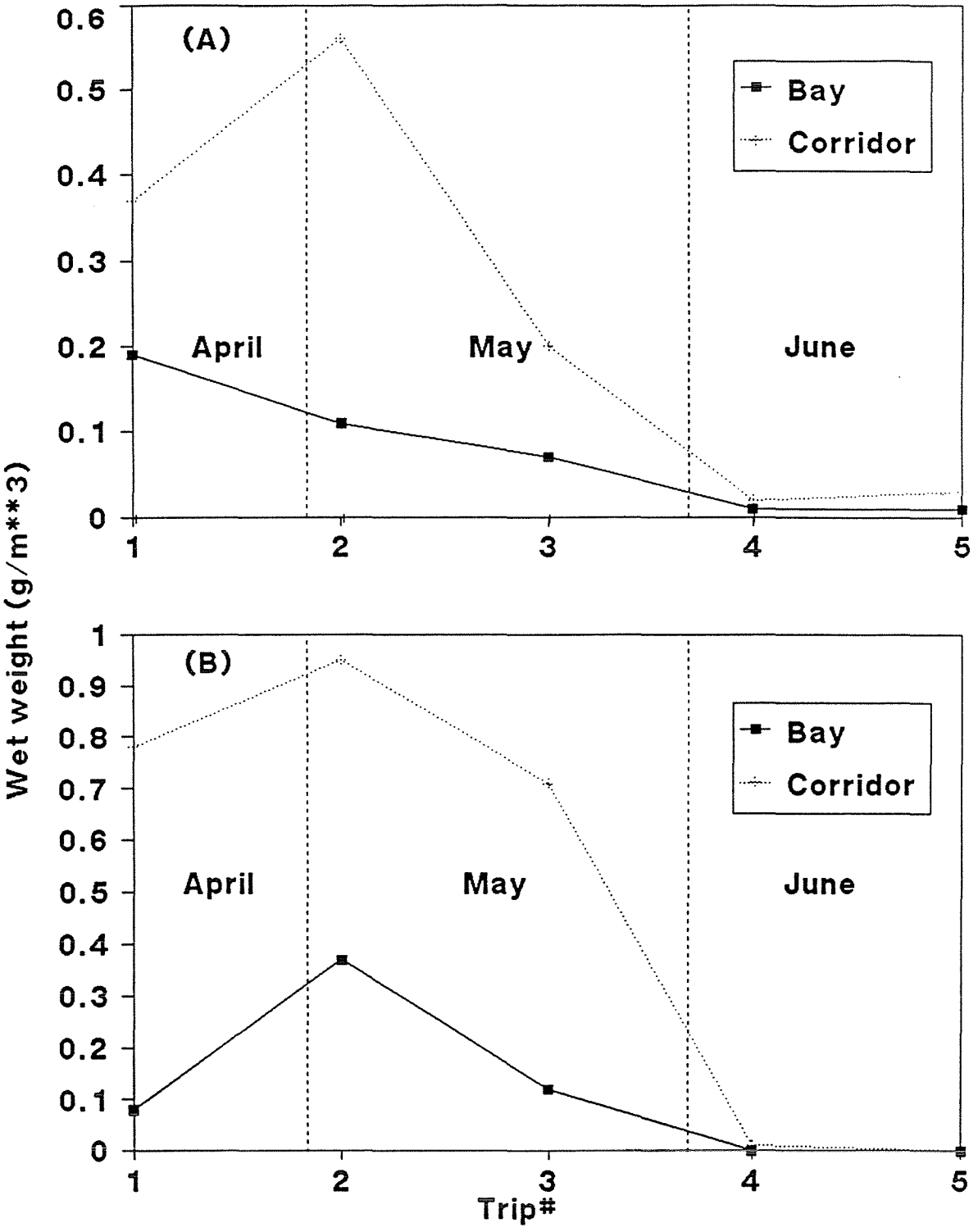


Figure 5.8. Biomass of (A) small (< 2.6 mm total length) and (B) Large (> 2.5 mm total length) calanoid copepods in Prince William Sound from April-June, 1989.

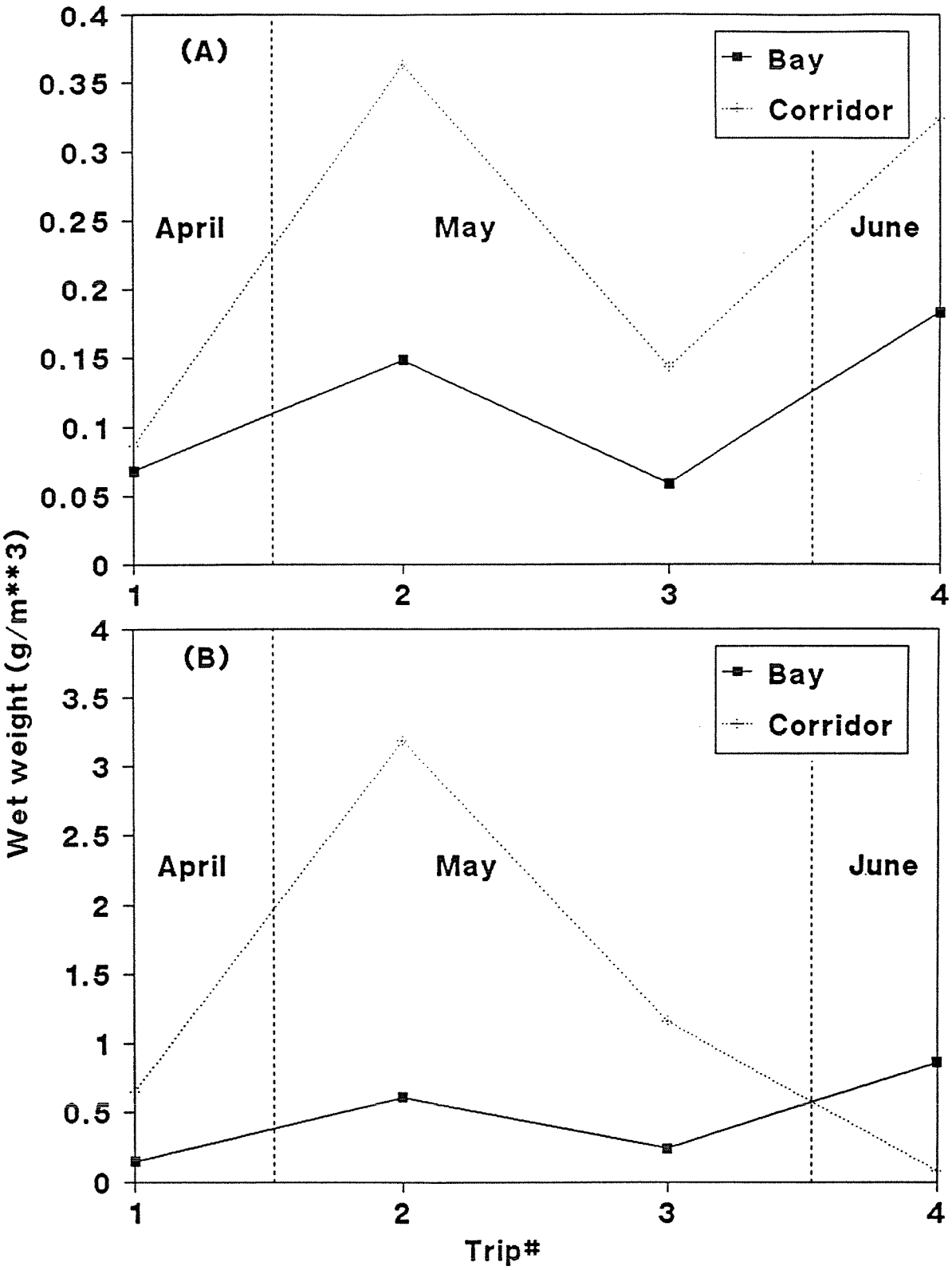


Figure 5.9. Biomass of (A) small (< 2.6 mm total length) and (B) Large (> 2.5 mm total length) calanoid copepods in Prince William Sound from April-June, 1990.

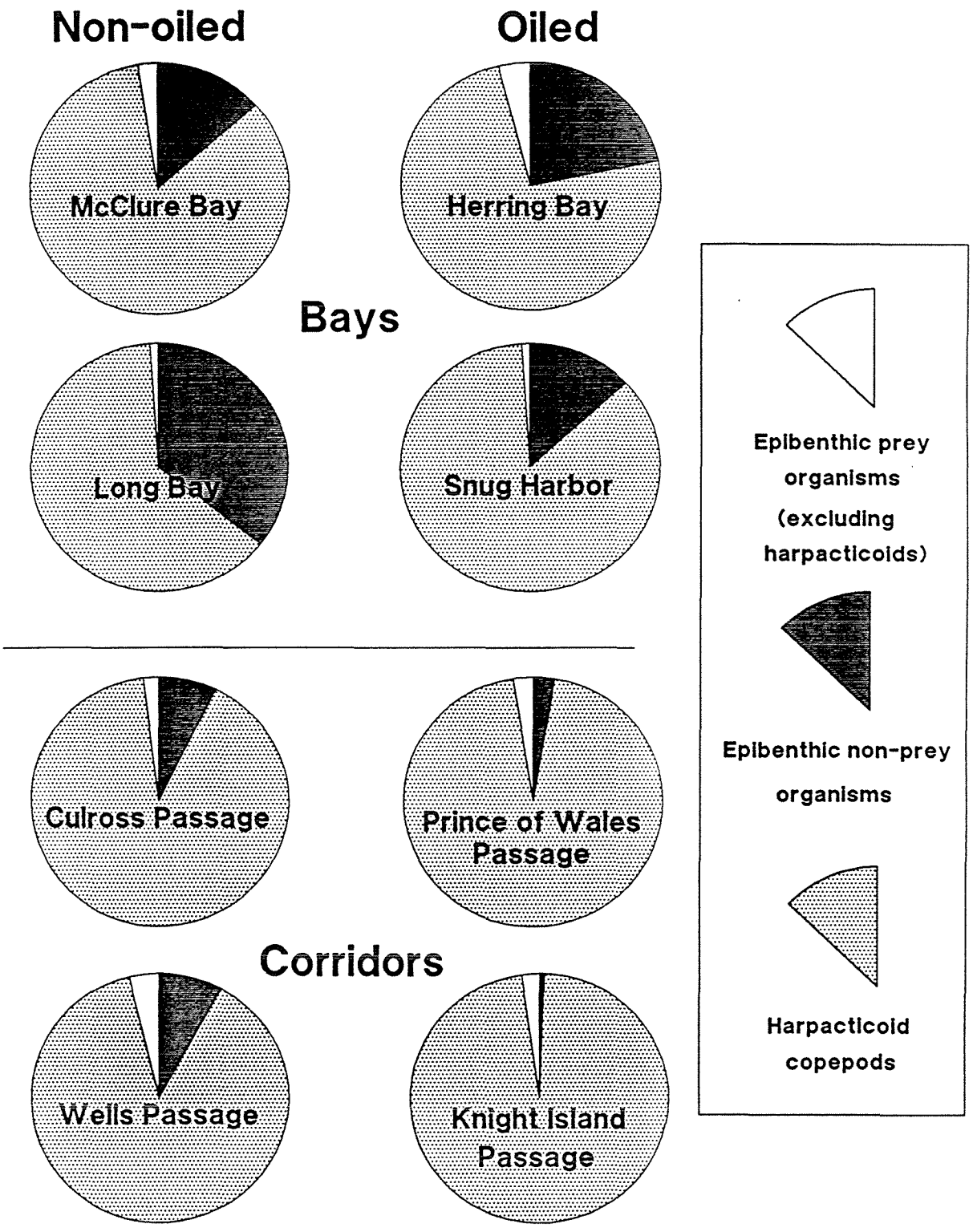


Figure 5.10. Relative abundance of epibenthos collected in the epibenthic sled systematic samples from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

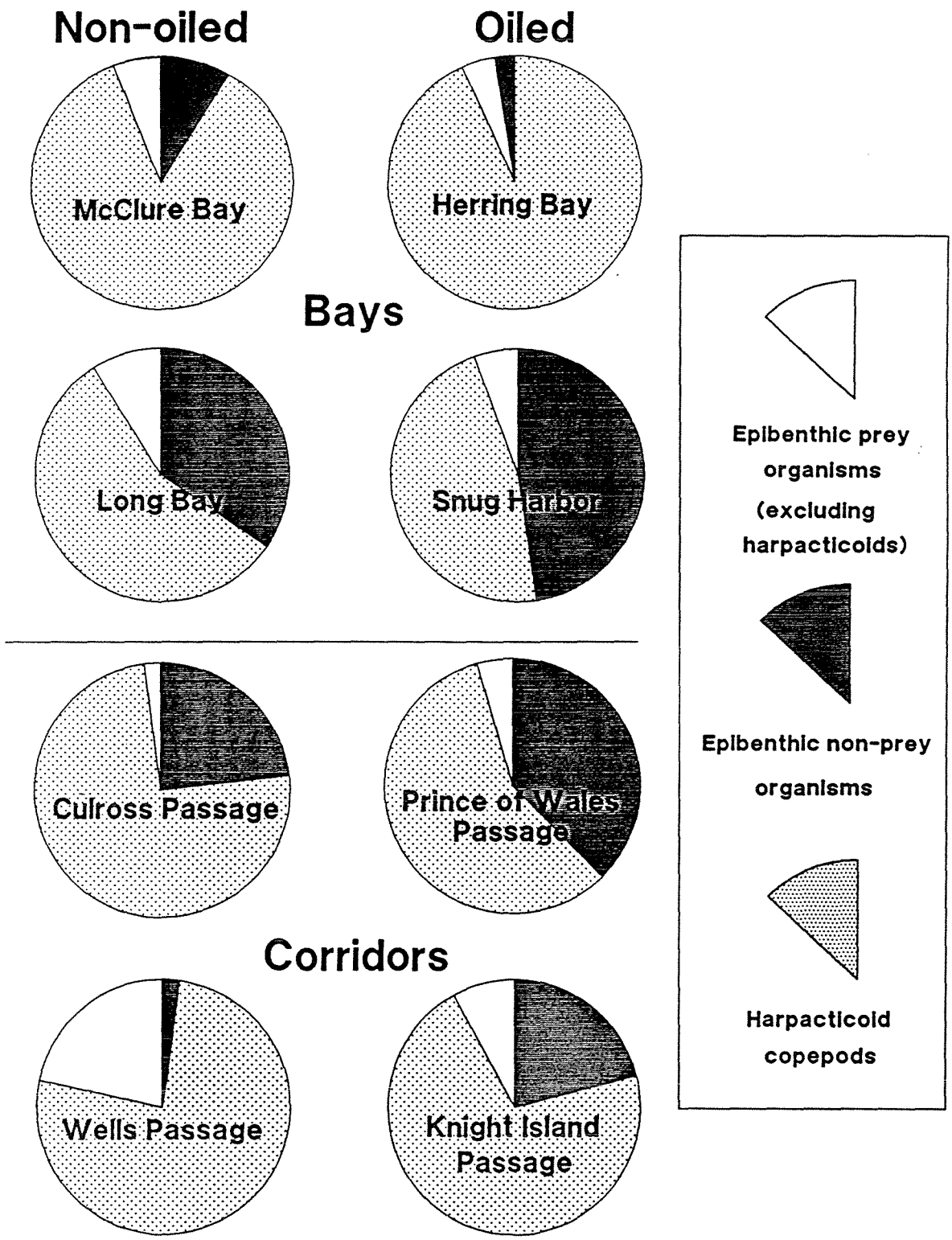


Figure 5.11. Relative biomass of epibenthos collected in the epibenthic sled systematic samples from four pairs of oiled and non-oiled locations in Prince William Sound, April-June, 1989.

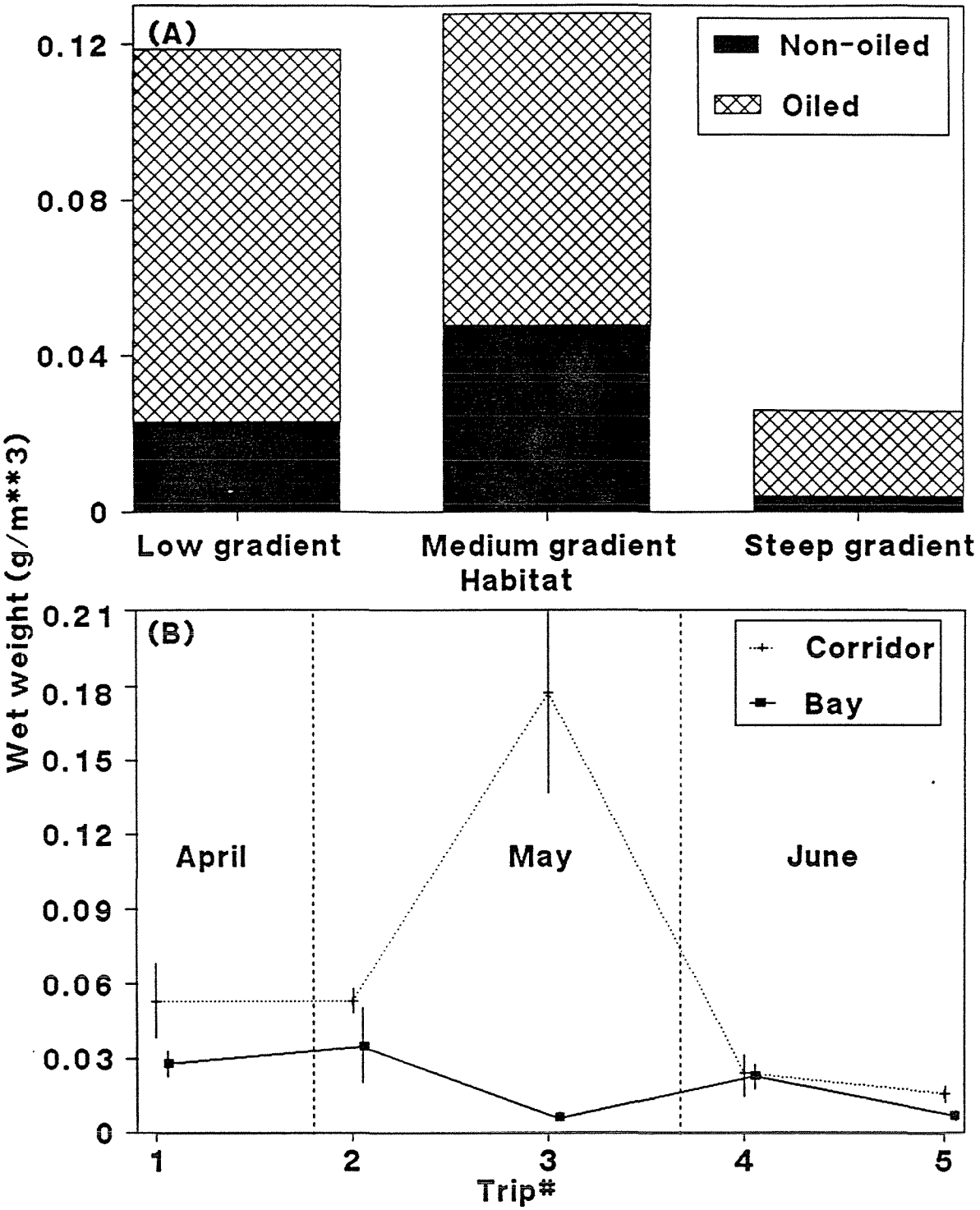


Figure 5.12. Harpacticoid copepod biomass in the systematic epibenthic sled samples in (A) oiled and non-oiled habitats, and (B) bays and corridors over time in Prince William Sound, April-June, 1989. Means in (b) are shown ± 1 standard error.

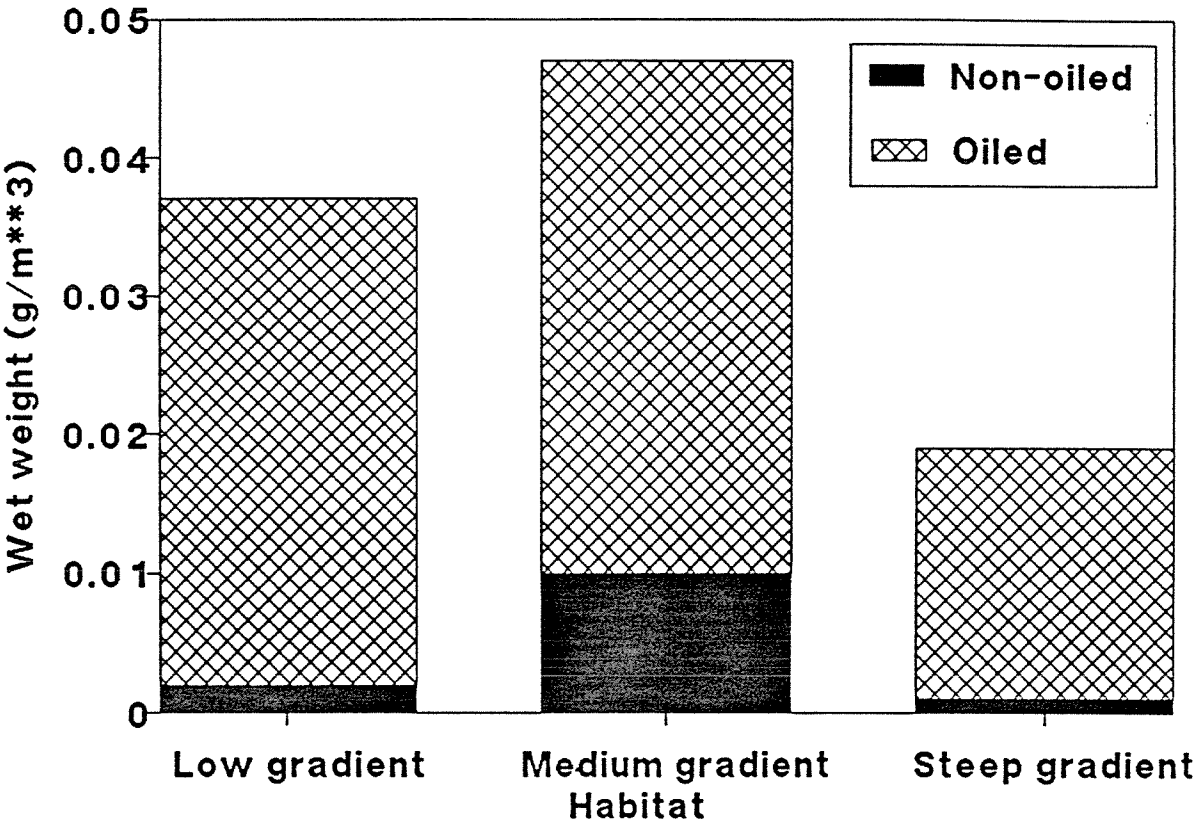


Figure 5.13. Harpacticoid copepod biomass in the tidal transect epibenthic sled samples from oiled and non-oiled habitats in bays of Prince William Sound, April-June, 1989.

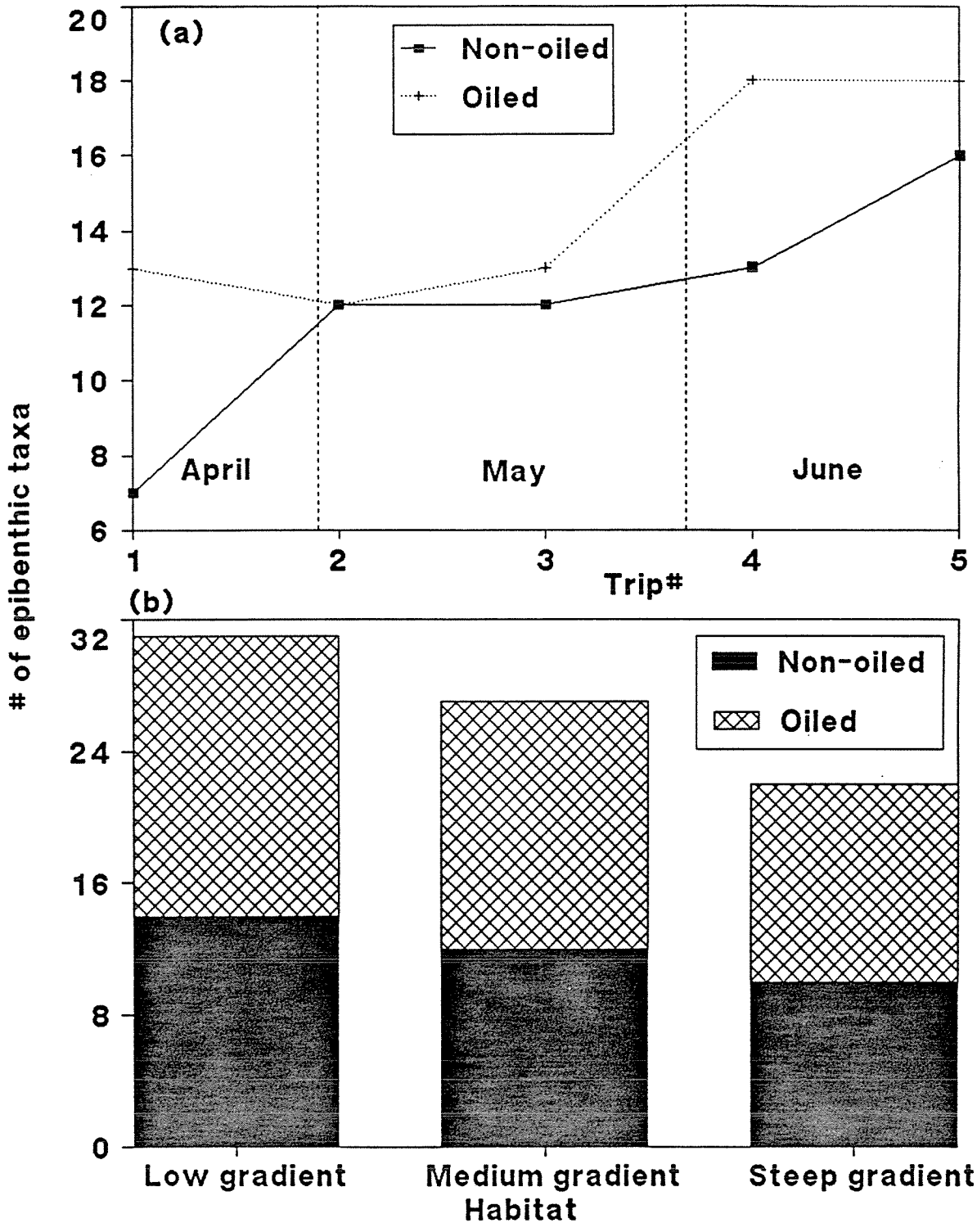


Figure 5.14. Number of epibenthic taxa captured in the systematic epibenthic sled samples in (a) oiled and non-oiled areas over time, and (b) oiled and non-oiled habitats in Prince William Sound, April-June, 1989.

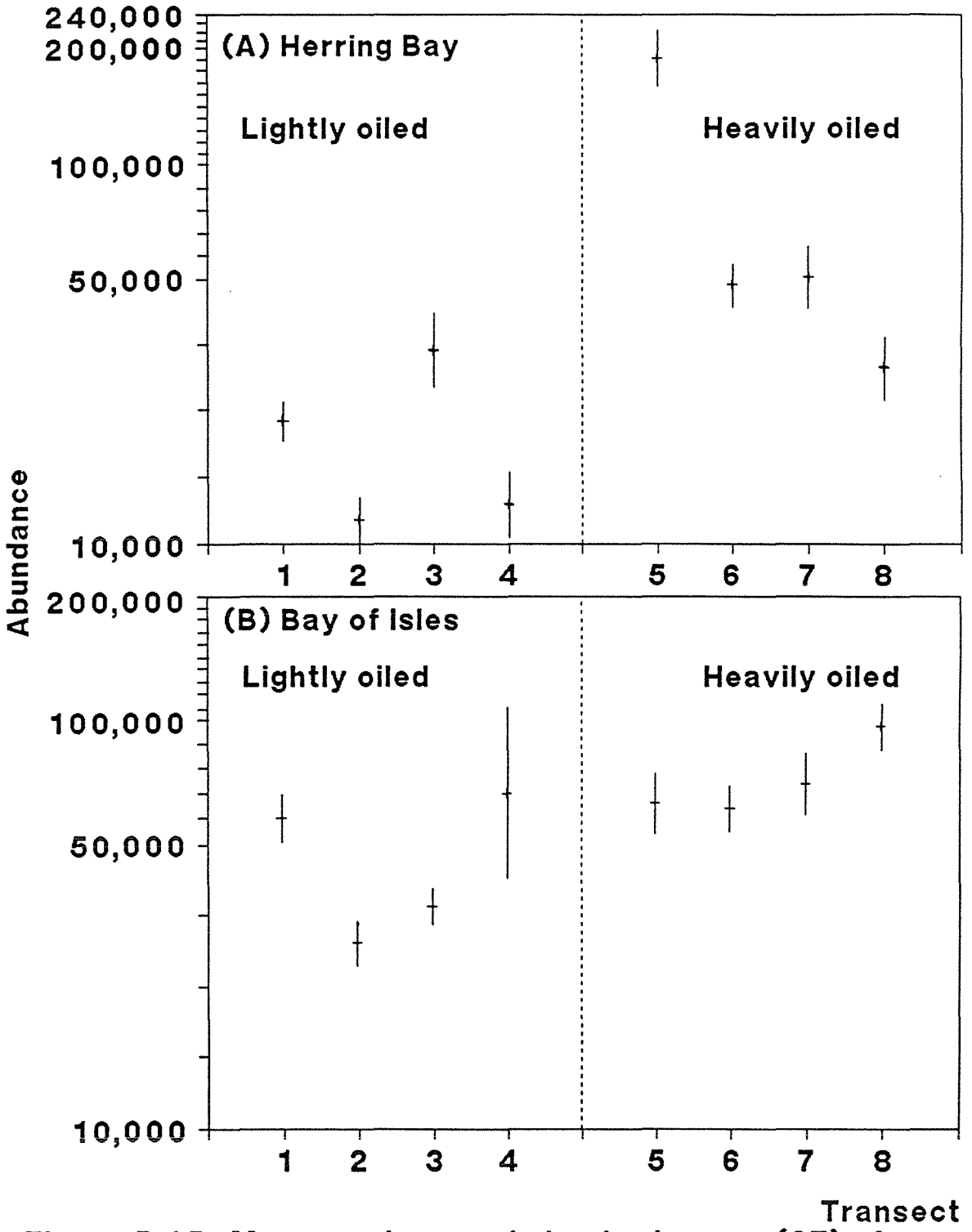


Figure 5.15. Mean numbers and standard errors (SE) of harpacticoid copepods sampled with the epibenthic pump along 4 lightly oiled and 4 heavily oiled transects in (A) Herring Bay in April, 1990, and (B) Bay of Isles in May, 1990, Prince William Sound.

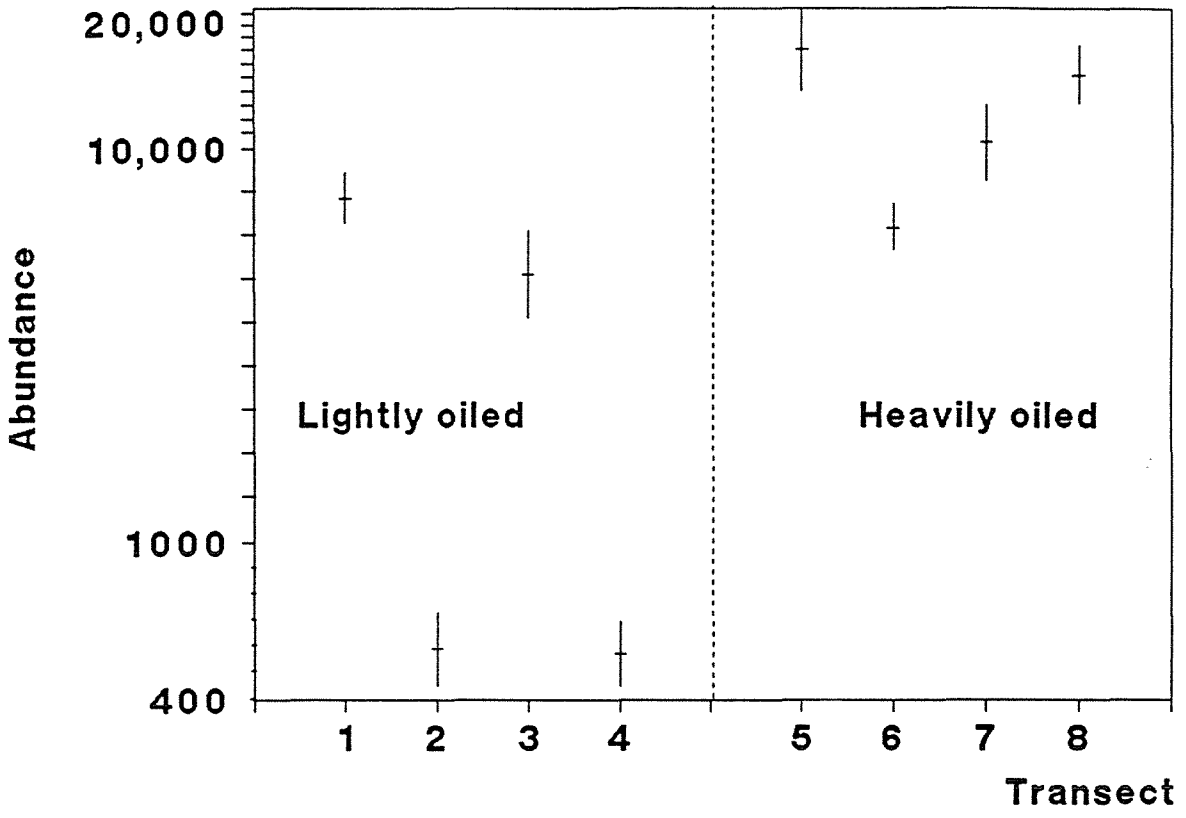


Figure 5.16. Mean numbers and standard errors (SE) of Harpacticus uniremis sampled with the epibenthic pump along 4 lightly oiled and 4 heavily oiled transects in Herring Bay, Prince William Sound in April, 1990.

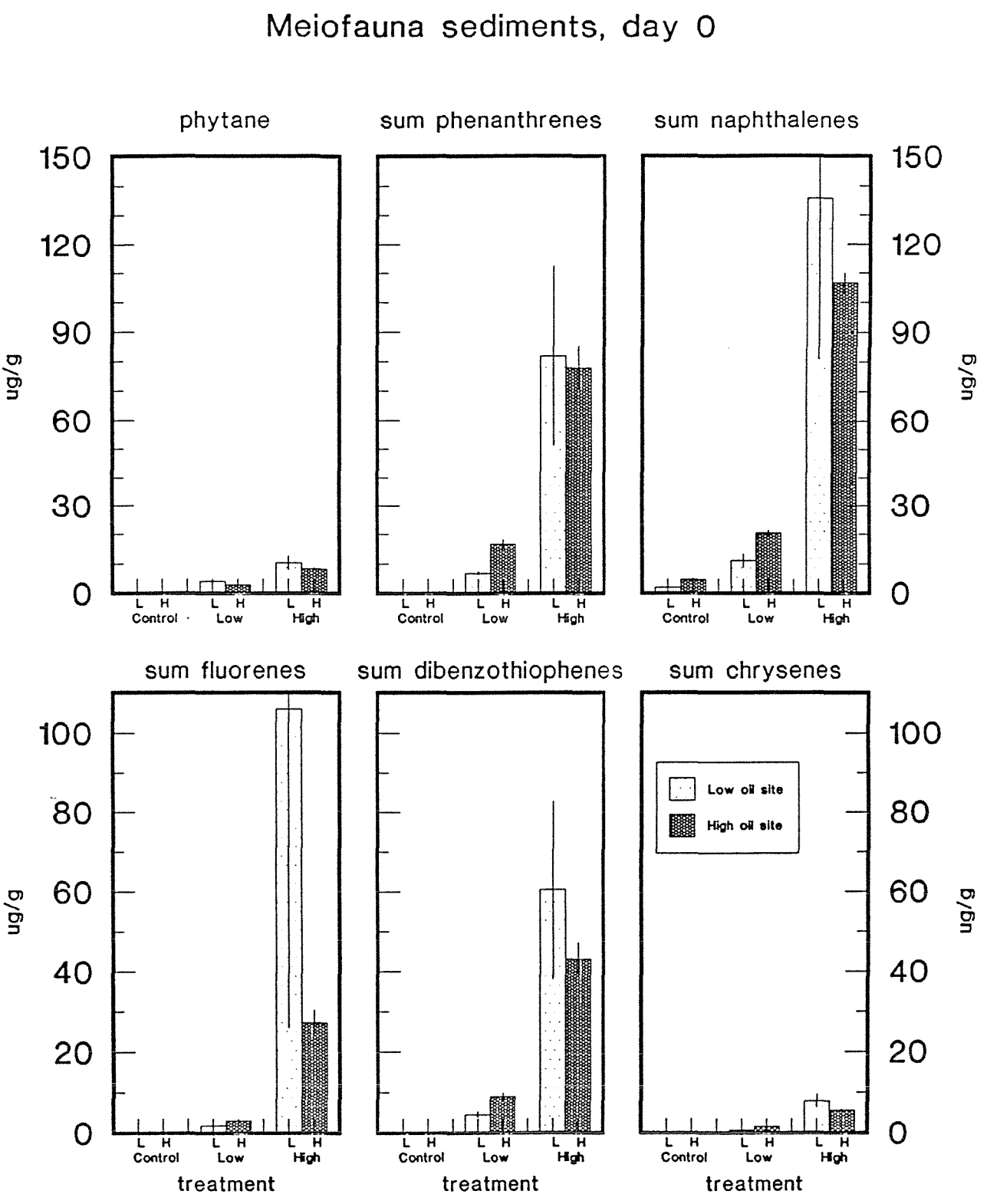


Figure 5.17. Summary characteristics of oil compounds contained in the sediments used in the meiofauna experiment. Control, low and high refer to sediment treatments buried at two discrete sites.

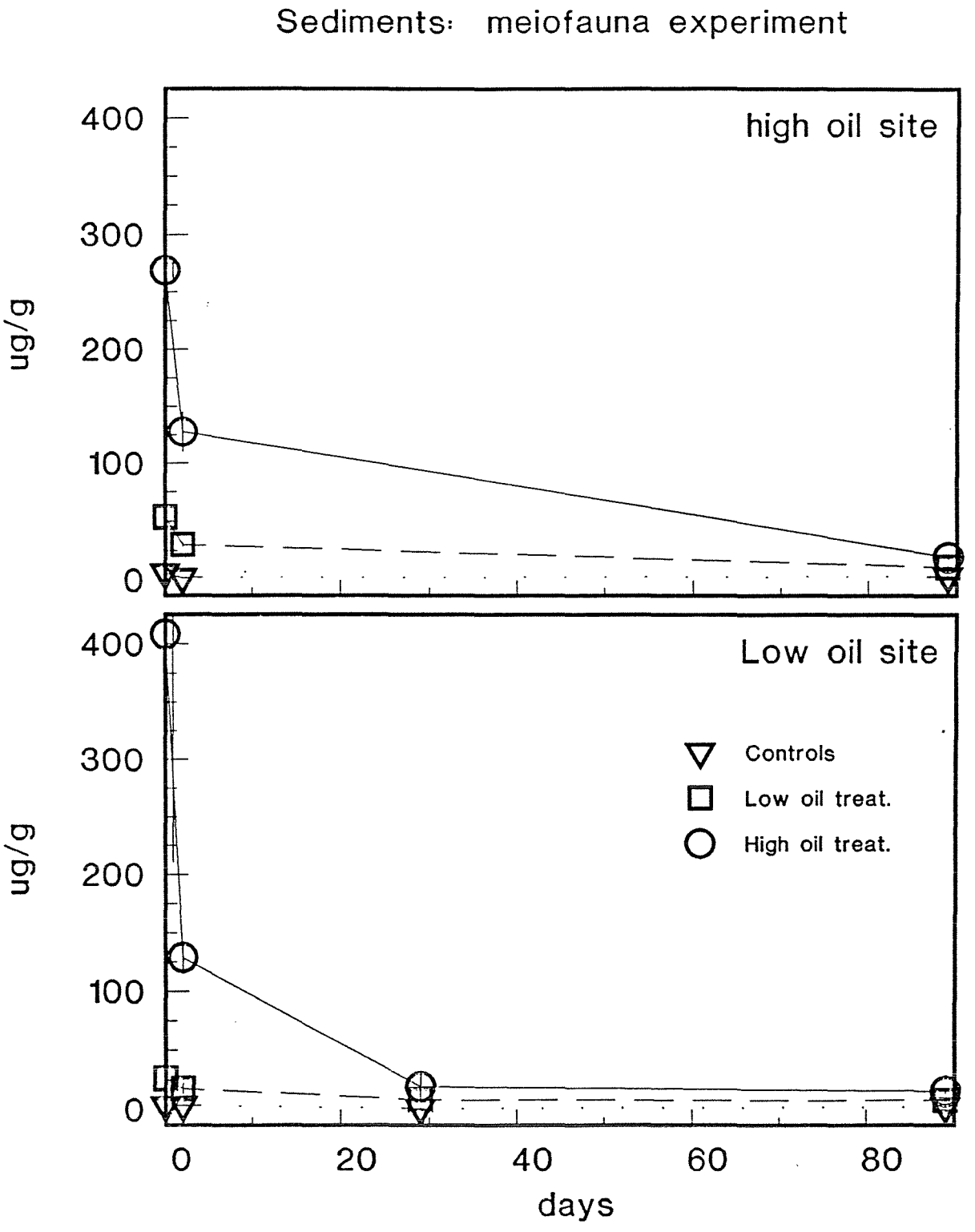


Figure 5.18. Aromatic hydrocarbon concentration (micrograms/gram) in treated meiofauna sediments over time.

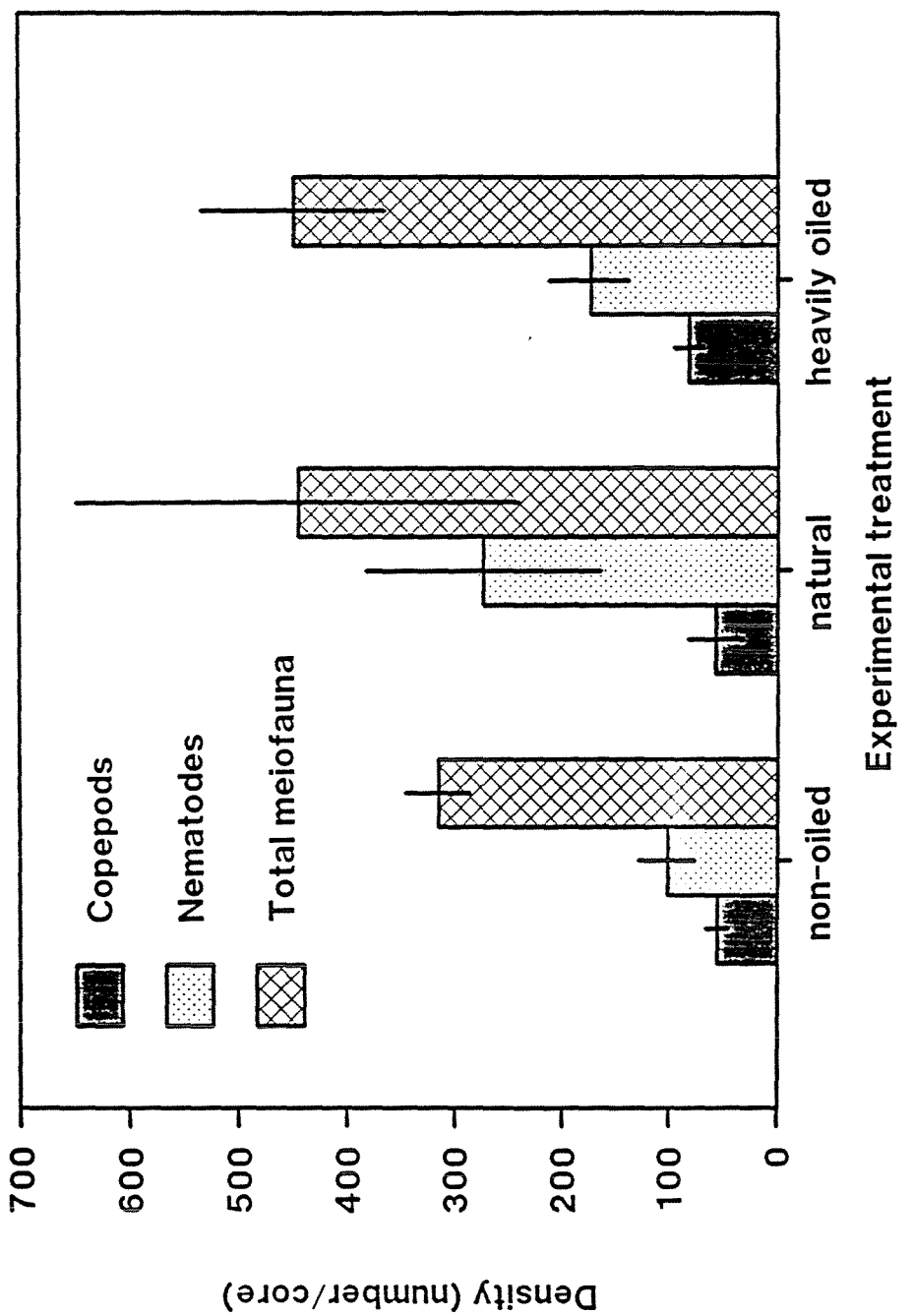
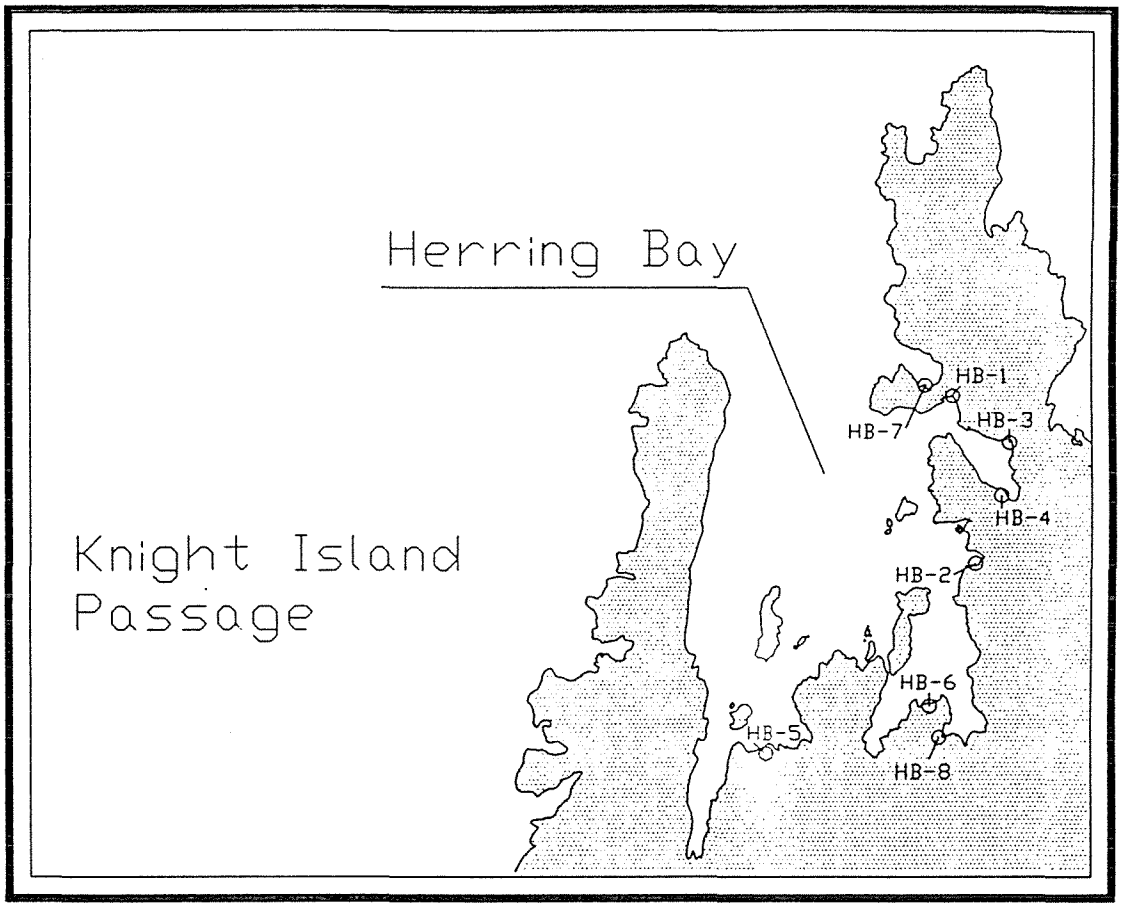
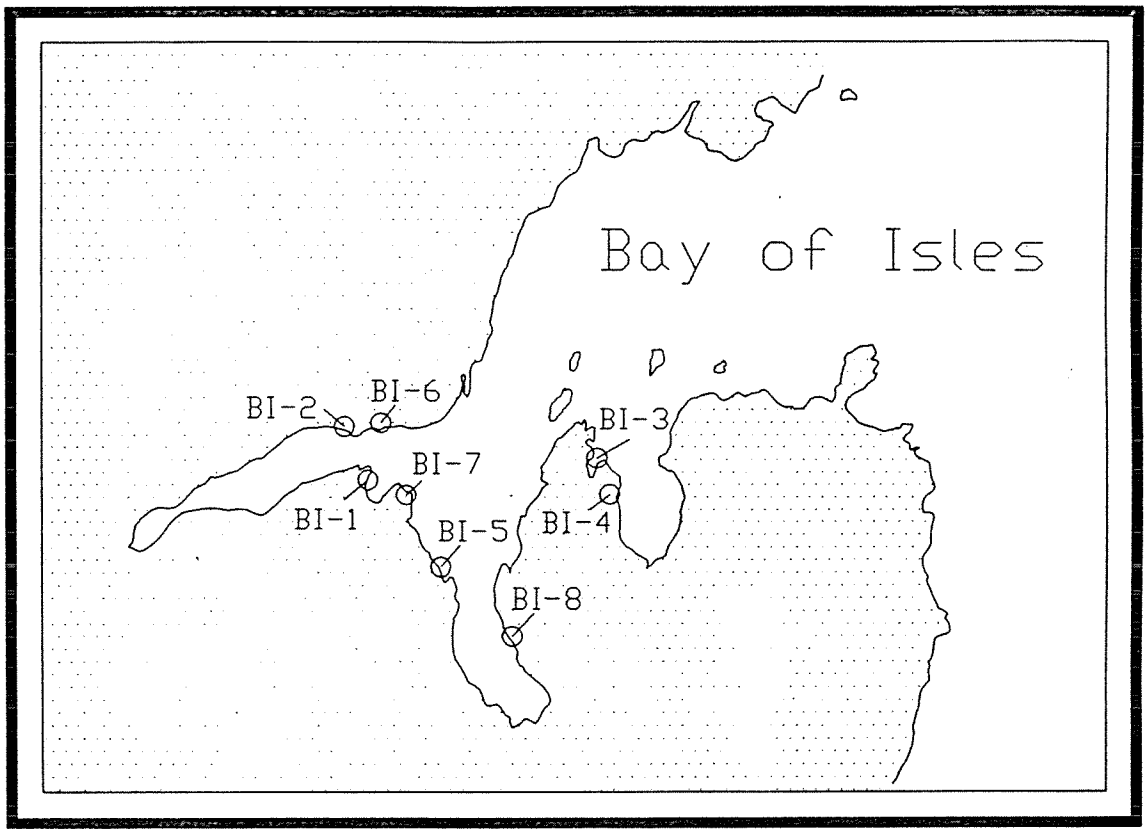


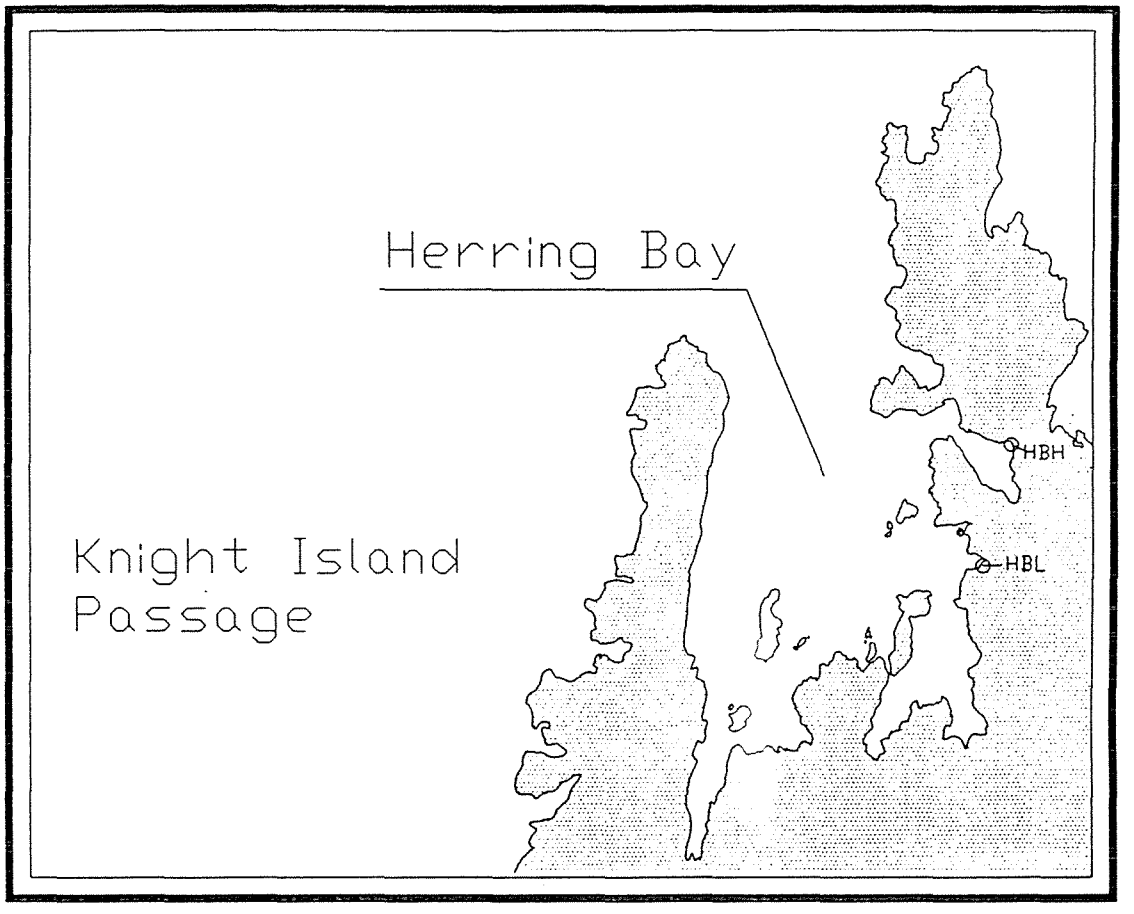
Figure 5.19. Preliminary densities of meiofauna in experimental treatments and natural sediments in a heavily oiled cove 29 d after the experiment began. Error bars are ±1 standard error.



Appendix 5.1A. Locations of epibenthic pump transects in Herring Bay in 1990.



Appendix 5.1B. Location of epibenthic pump transects in Bay of Isles in 1990.



Appendix 5.1C. Sites where azoic sediments were buried to examine meiofauna colonization. HBL = Lightly-oiled site; HBH = heavily-oiled site.

CHAPTER 6: EFFECTS OF OIL INGESTION

Objective

6. Determine the effects of oil ingestion on juvenile pink salmon in terms of degree of contamination (hydrocarbon tissue burden and MFO induction), survival, and growth (measured by lengths, weight gain, otolith increment, and RNA/DNA ratio).

Methods

Juvenile pink salmon (*Oncorhynchus gorbuscha*), hereafter referred to as fry, were obtained from the Auke Creek Hatchery after emergence April 16, 1991. Fry were reared in 800 l cylindrical tanks receiving approximately 20 lm^{-1} single-pass filtered seawater. Fry were fed #2 BioDiet starter feed (0.6 - 0.8 mm dia).

Fry were randomly allocated into five treatment groups (3 oiled, 1 dichloromethane control, and 1 untreated control) and placed in rectangular (30 x 41 x 53 cm) tanks receiving 1.4 lm^{-1} seawater. There were 3 replicate tanks per treatment, for a total of 15 tanks. The initial number of fry per tank averaged 1076. Before distribution to the experimental tanks, 100 fry were subsampled randomly to establish baseline characteristics at the beginning of the experiment.

Experimental tanks were located under translucent panels outdoors; lighting was natural. Seawater temperatures were elevated to approximately 8°C and controlled by resistive heaters, mercury switches, and associated relays. Tanks were grouped in two parallel systems with 8 tanks per group. Analysis of temperature data has not been completed.

Fry in appropriate treatment groups received oiled food for 6 weeks (May 13 - June 26). We continued observations for another 4 weeks after discontinuing oiled food to observe possible recovery. Food size was increased to 1 mm pellets on July 10.

Disease (external myxobacterial infections) became a problem just after the recovery phase of the experiment began. We controlled disease with Diquat treatments and by adding tetracycline to the food (beginning July 10). We also began removing and destroying obviously diseased fry twice daily. Nets and siphon gear were routinely soaked in Wescadine solutions. Disease data have not yet been analyzed.

Food pellets for the oiled treatment groups were contaminated with Prudhoe Bay crude oil. Pellets (200 g per sub-batch) were weighed to the nearest milligram and placed in 1 l glass, pear-shaped flasks and approximately 400 ml of dichloromethane were added.

Appropriate quantities of oil were weighed into a 10 ml beaker to yield 0.80, 7.94, and 74.1 mg/g of oil by weight, then rinsed into the flask. Samples were briefly swirled, then rotovaped to to dryness (120 minutes). Rotovaps were stopped briefly after approximately 60 - 90 minutes; flasks were shaken vigorously to break pellets, then evaporation continued. After removal from the rotovap, pellets were placed in shallow 23 x 33 cm glass pans; lumps were crushed, and sub-batches were allowed further evaporation for 1 hour at room temperature. Preliminary observations indicated additional dichloromethane would evaporate for approximately 30 - 40 minutes. Multiple sub-batch preparations were produced on a weekly basis to yield a one week supply of food. These sub-batches were mixed together and stored frozen in 32 oz glass jars with Teflon lids. Food for the dichloromethane controls was similarly treated, except no oil was added: control food was not treated. All food was stored frozen to minimize hydrocarbon loss and maintain freshness. Contaminated food samples were collected from each batch for hydrocarbon analysis. All glassware and equipment used during these procedures were initially hydrocarbon free.

Feeding rates were 10% total biomass d^{-1}. The quantity of food offered was updated weekly, based on the estimated fry biomass in each tank; the minimum quantity was 10 g d^{-1}. Food was delivered by 12 hour, automatic belt feeders. Feeding began at approximately 08:00 each day; belts were reset during the day, and food was redistributed to extend the daily feeding period to approximately 16 h. Analysis of actual feeding rates has not been completed.

Lethal and sublethal effects of contamination were evaluated. Mortality was routinely monitored; dead fish were removed twice daily. Sublethal growth measurements included lengths to the nearest millimeter, wet weights to milligrams, otolith growth, and the ratio of ribonucleic acid (RNA) to deoxyribonucleic acid (DNA). Otolith increment widths and RNA/DNA ratios are growth processes that may be more sensitive over short time spans than total somatic growth (Volk et al. 1984; Barron and Adelman 1984). Formalin preserved fry tissues were examined histologically for mixed function oxidase (MFO) induction. Tissues examined included gills, anterior intestine/cecal epithelium, kidney, liver, heart, vertebral cord, and skeletal muscle. Condition factor will be calculated.

Fry were randomly subsampled weekly from each replicate. Because of the time involved in processing, fry were sampled Mondays for hydrocarbons; all other types of samples were collected Tuesdays and Wednesdays. Cytology samples for analysis of DNA lesions were collected at the experiment endpoint.

Fry sampled for hydrocarbon analysis were isolated without food in 4 l beakers provided with airstones for approximately 40 h to avoid

the presence of oiled food in gastrointestinal tract; 50 fry replicate^{-1} week^{-1} were narcotized with MS-222, measured, blotted dry, and weighed. Tissues were then separated into carcass and viscera; pooled tissues from each replicate tank were frozen for analysis. Carcasses did not include the head, and usually contained at least some kidney. Viscera excluded the gills; sections of the gastrointestinal tract containing food were also excluded. Samples were weighed then frozen in hydrocarbon free jars with Teflon lids for analysis of hydrocarbons. Tissues were maintained in aluminum pans on crushed ice during dissection procedures. All dissection equipment, dishes, and aluminum pans were washed with soap and water, dried, and rinsed with dichloromethane to remove any hydrocarbon residues. Samples from week 0, 1, 3, 6 will be processed for hydrocarbons. Concentrations of hydrocarbons in viscera and carcasses will be analyzed by GCMS and GCFID using standard protocols established by NRDA Technical Services #1.

Fry sampled for growth analysis were randomly netted from experimental tanks immediately before processing began and narcotized with MS-222, measured, blotted dry, and weighed. Fry were randomly subdivided into histological and MFO, stomach, and hydrocarbon groups. We slit the bellies of 20 fry for histological and MFO analyses and preserved them in 10% buffered formaldehyde. Histological and MFO samples will be processed by contract with Woodshole Oceanographic Institute. Stomachs were excised from 15 fry and weighed to determine fullness as a percentage of body weight. The carcasses of these fry were frozen individually for RNA/DNA analysis, and the heads were removed and stored in 95% reagent-grade ethanol for otolith analysis. Each fry was uniquely identified. Additional hydrocarbon samples, generally carcasses only, were collected to allow collection without depuration time. As procedures evolved we also collected viscera, but avoided any food. Samples collected during weeks 0, 1, 3, 6, 7, and 10 will be processed for histology, MFO, and hydrocarbons; samples collected during weeks 2, 4, 5, and 8 will be held in reserve. Otolith increments, and RNA/DNA samples were initially processed for weeks 1 and 6.

Using the method described by Winter (1985), the sagittal otoliths were removed from each of the preserved pink salmon heads for analysis of size and increments by removing the lower jaw and gill rakers and extracting the sagittal otoliths (visible through the clear wall of the neurocranium) with number 5 fine-tipped forceps. The medial side of the right otolith from each of the fish was attached to an acetate sheet and imbedded in casting resin (Schultz and Taylor 1987). The otolith within the resin pellet was thin-sectioned with a diamond cut-off saw to expose the plane containing the focus. The thin section of the otolith was then lapped and polished to remove excess resin and extraneous scratches and cutting marks (Neilson and Geen 1981; Schultz and Taylor 1987).

The section of otolith will be viewed directly under a transmitted-light compound microscope or the image from the microscope will be transferred to an image enhancement and analysis system for viewing and analysis. A standard axis between the saltwater transition check and the edge of the otolith will be measured in the posterodorsal quadrant and the number of rings bisected by this axis counted (Wilson and Larkin 1982; Volk et al. 1984; Deegan and Thompson 1987). Incremental increase in the size of the otolith along the standard axis, the number of increments and their respective widths will be used as parameters to test for treatment effects.

The protocol fro the measurement of nucleic acids was developed using guidelines provided by Munro and Fleek (1966). Rna content was measured by a modified Schmidt and Thannhauser (1945) procedure in which ultraviolet absorption is measured instead of phosphorous. DNA content was measured by the diphenylamine procedure described by Burton (1956). White muscle was homogenized in 10 volumes of ice-cold water. A 1 ml subsample was dried at 80°C for at least 8 h to determine the dry weight of each sample. Homogenate subsamples were mixed with perchloric acid (100 μl 0.6N $HClO_4$ + 200 μl homogenate + 500 μl 0.2N $HClO_4$), incubated on ice for 10 minutes, then spun 10 min at 10^4 x g at 4°C. Supernatant was discarded and pellet washed with 0.75 ml 0.2N $HClO_4$, and spun at 10^4 x g for 5 min for a total of 2 washes. Perchloric acid (0.5 ml 0.5N) and 1 ml diphenylamine reagent (1.5 g diphenylamine dissolved in 100 ml glacial acetic acid + 1.5 ml concentrated H_2SO_4) was added to each of 2 replicate DNA subsamples, covered, and incubated 20 h at 25 - 30°C.

DNA subsamples were then spun 3 min at 10^4 x g to remove pellet and debris, and the optical density (OD) was measured at 600 nm; blank density was determined using a similarly incubated blank sans fish sample. DNA concentrations were determined from a standard curve generated using purified DNA.

RNA subsamples were incubated at 37°C for 1 h after addition of 1 ml 0.3N KOH; subsamples were inverted a few times about half way through incubation to ensure thorough mixing. Next 0.5 ml 1.5N $HClO_4$ was added, and allowed to remain on ice for 10 min. Subsamples were spun 10 min at 10^4 x g; supernatant was saved. Pellets were washed with 1 ml 0.2N $HClO_4$ and spun 3 min at 10^4 x g for two washings; supernatants were pooled and saved. The OD_{260} of the supernatant was measured; concentrations were determined from a standard curve generated using purified RNA.

Because fry were regularly removed for analysis, cummulative mortality (Σp) was calculated as follows: $\Sigma p = (m_i/(n_0 - \Sigma s_i - \Sigma d_i))*100 + p_{i-1}$, where m_i = number of dead fry observed daily, n_0 = initial number of fry, Σs_i = cummulative number sampled for experimentation up to the time of observation, and Σd_i =

cummulative number of fry removed for disease control up to the time of observation.

Data were analyzed with nested ANOVA techniques. Replicate tanks were nested in treatment. If a significant difference among means was detected, the Dunnett a posteriori multiple comparison test was used to compare treatments to the control mean.

Results

Concentrations used for the analysis are target concentrations; actual oil concentrations in the food preparations will be determined from GC analysis as data become available. Nominal concentrations for control, treated control, low oil, mid oil, and high oil were 0, 0, 0.80, 7.94, and 74.1 mg/g, respectively.

Except for the high oil treatment, mortality remained low in all treatments and controls (Figure 6.1). Mortality in the high oil group separated significantly from controls after two weeks (α = 0.05) and increased rapidly until fry began feeding on clean food (day 45) (Figure 6.1). Mortality did not change much after the oiled food was discontinued (day 44) until the end of the experiment (day 72) (Figure 6.2). The estimated median lethal response at the end of the experiment was 48 ± 1.8 mg/g.

Fry growth was inhibited by oiled food (Figure 6.3). Data have been analyzed statistically through week 7. Fry in the medium and high treatments were significantly shorter and weighed less than controls after 1 week exposure. In the low treatment group fry tested significantly shorter than controls on four separate occasions, and lighter twice.

Feeding rates were also affected by oiled food. Percent stomach weights declined immediately in the high oil treatment group and remained depressed until clean food was available (Figure 6.3). No other groups separated from the controls. We also observed declines in feeding rates for high treatment fry, based on observation of fry striking food, and based on accumulation of uneaten food at the tank bottoms. Fecal output has not yet been analyzed.

Oiled food caused RNA/DNA ratios to decline (Figure 6.4). Partial data processing and analysis has been completed for weeks 1 and 6. The RNA/DNA ratio for the high oil treatment group was significantly smaller than controls (and treated controls), measured after 6 weeks with 110 samples analyzed. Declines in RNA/DNA ratios were observed after 1 week and were marginally significant (P = 0.056) with 95 samples analyzed.

Otoliths have been extracted and mounted. Thin-section preparation is proceeding; no data are available for analysis at this time.

Analysis of histological and MFO data has not been completed. However, we have preliminary data for the low treatment after 8 d exposure (personal communication, John Stegeman, Woods Hole Oceanographic Institute). Strong MFO induction was observed in the gut, and mild induction was observed in the heart and liver. Gut tissues showed signs of necrosis.

Discussion

This experiment has shown that at sufficiently high dosages, food contaminated with Prudhoe Bay crude oil can cause mortality of pink salmon fry. Although we did not design the experiment as a bioassay, we were able to roughly estimate the median lethal response (62 mg/g).

This experiment has also shown that food contaminated by Prudhoe Bay Crude oil definitely reduces fry growth and feeding. We believe the outcome of this experiment compares favorably with a similar experiment involving food contaminated with the water soluble fraction of crude oil (Schwartz, 1985). In that experiment, prey contaminated with WSF of hydrocarbons affected juvenile salmon in a variety of ways. Feeding and growth rates of pink salmon fry fed oil contaminated *Aretemia* nauplii declined with increasing oil concentrations. Bicyclic hydrocarbon concentrations in fry tissue peaked in 3 h, but concentrations declined by more than 50% after 12 h. Hydrocarbons were detectable in fry tissue after 10 d, but not after 23 d even though fry continued to consume OCP (Schwartz, 1985). A more thorough discussion of these two experiments will be completed at a later date.

Despite the fact that feeding rates did not decline in the low and mid oil treatment groups, significant depression in lengths and weights were observed in these groups. This suggests that changes in growth were not simply due to starvation, but rather were due to metabolic demand or oil-induced necrosis.

The very limited amount of histological and MFO analysis available indicates that the fry were suffering from the effects of oiled food in the low oil treatment. Because the hydrocarbons were passing directly through the gut with the food, it is not surprising that induction was strongest in the gut. Necrosis of the gut may explain drops in feeding rates (observed in the high treatment). Although MFO induction was generally stronger and more uniform throughout the tissues of fry collected from Prince William Sound (1989-1990), gut necrosis was not observed; it is possible that these fry did not encounter food as contaminated as that presented in the laboratory. Alternatively, if fry from Prince William Sound were ingesting oiled food, the oil was not fresh but weathered. Because weathering tends to remove the more acutely toxic, low molecular weight aromatic hydrocarbons histological responses may be different.

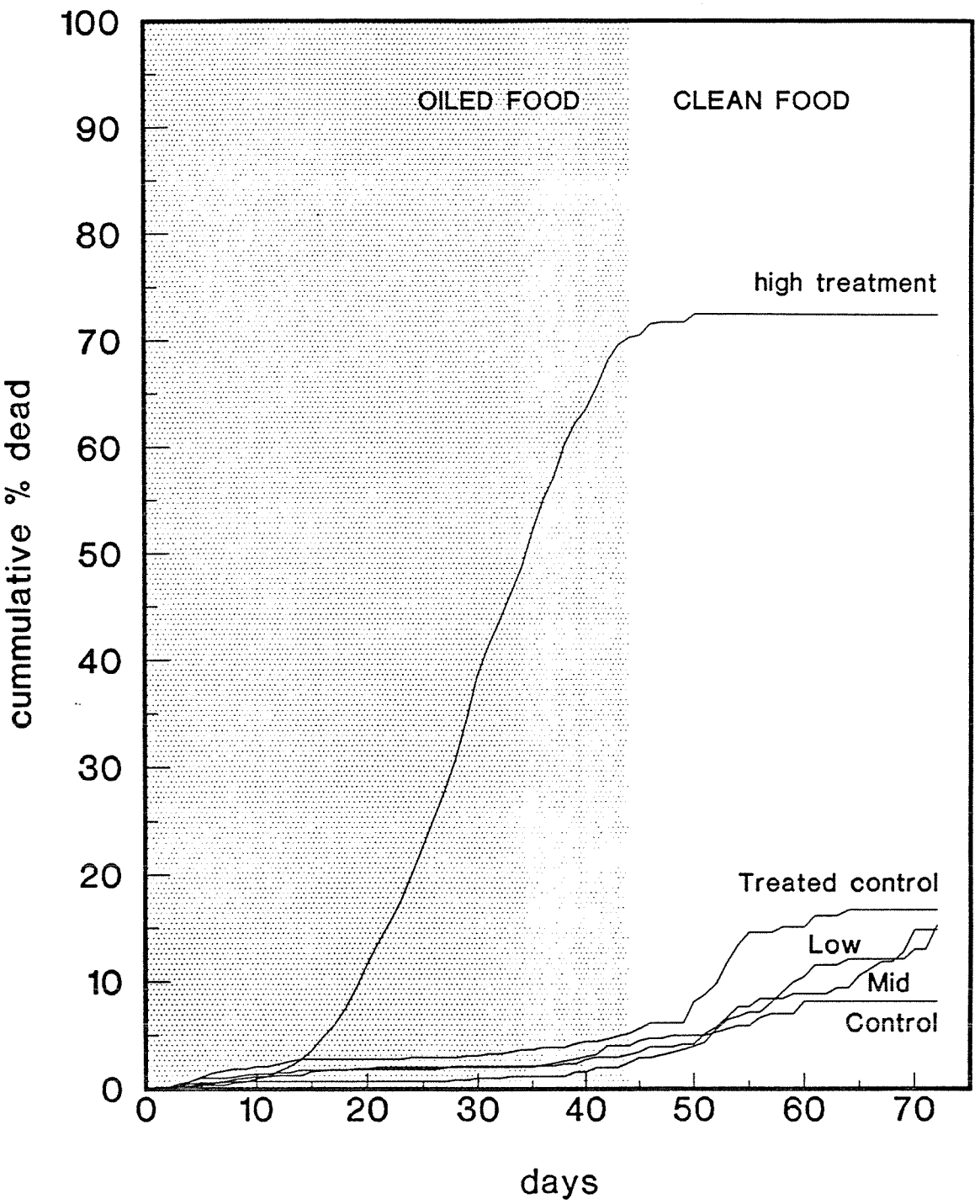


Figure 6.1--Cumulative fry mortality over time. Shaded region indicates period where fry received oiled food. For clarity, data from only 1 of 3 replicates is presented (replicate 3).

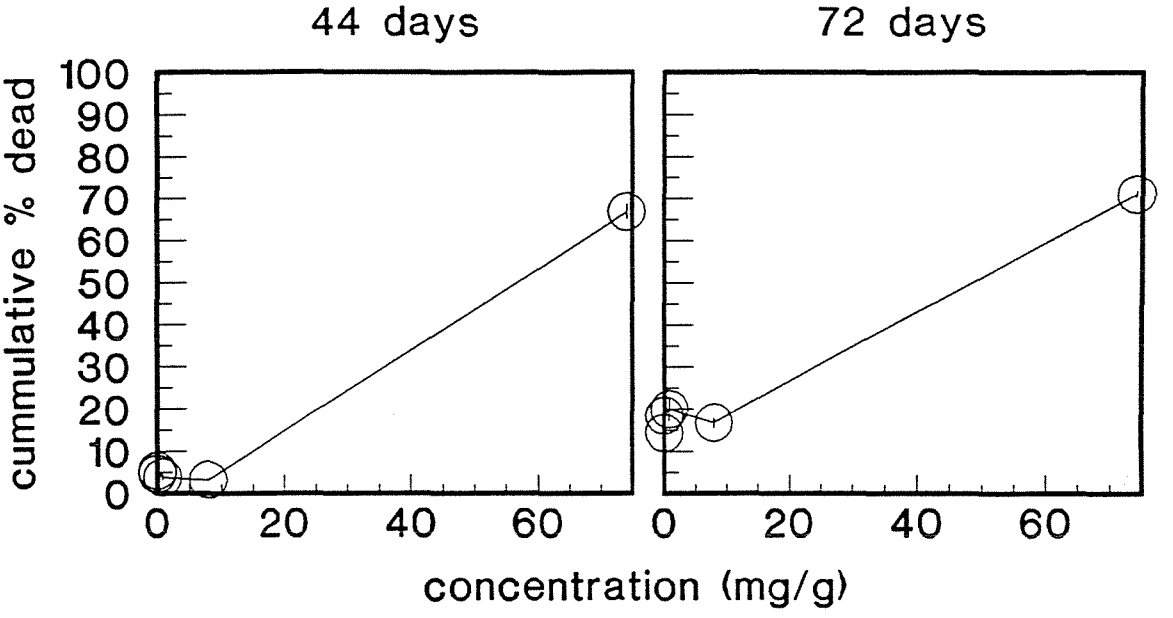


Figure 6.2--Cumulative fry mortality as a function of concentration, measured at the end of the uptake period (44 d) and at the end of the experiment (72 d). Error bars are ± 1 standard error.

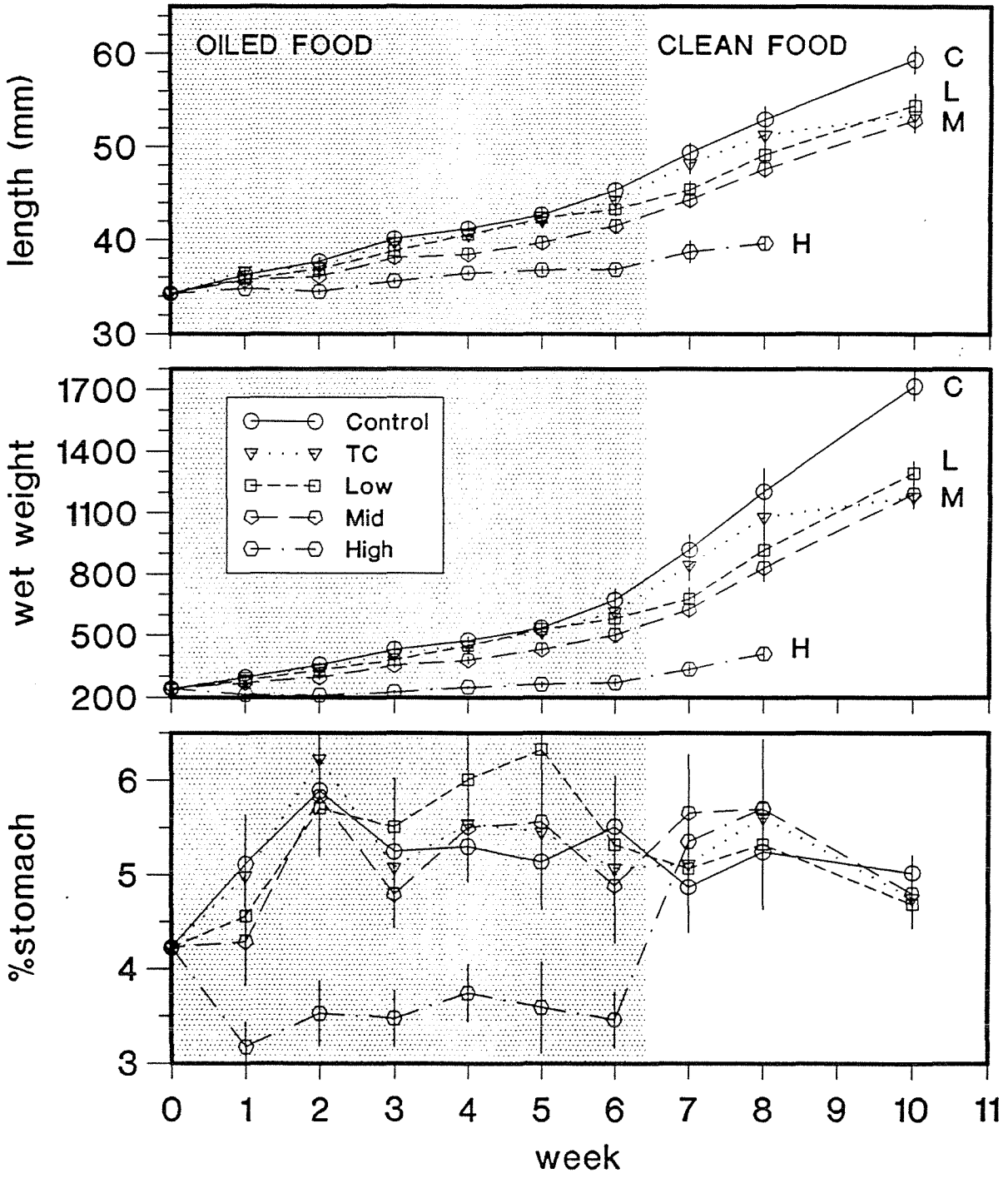


Figure 6.3--Time series showing changes in length, wet weight and % stomach weight. Error bars define the 95% confidence interval.

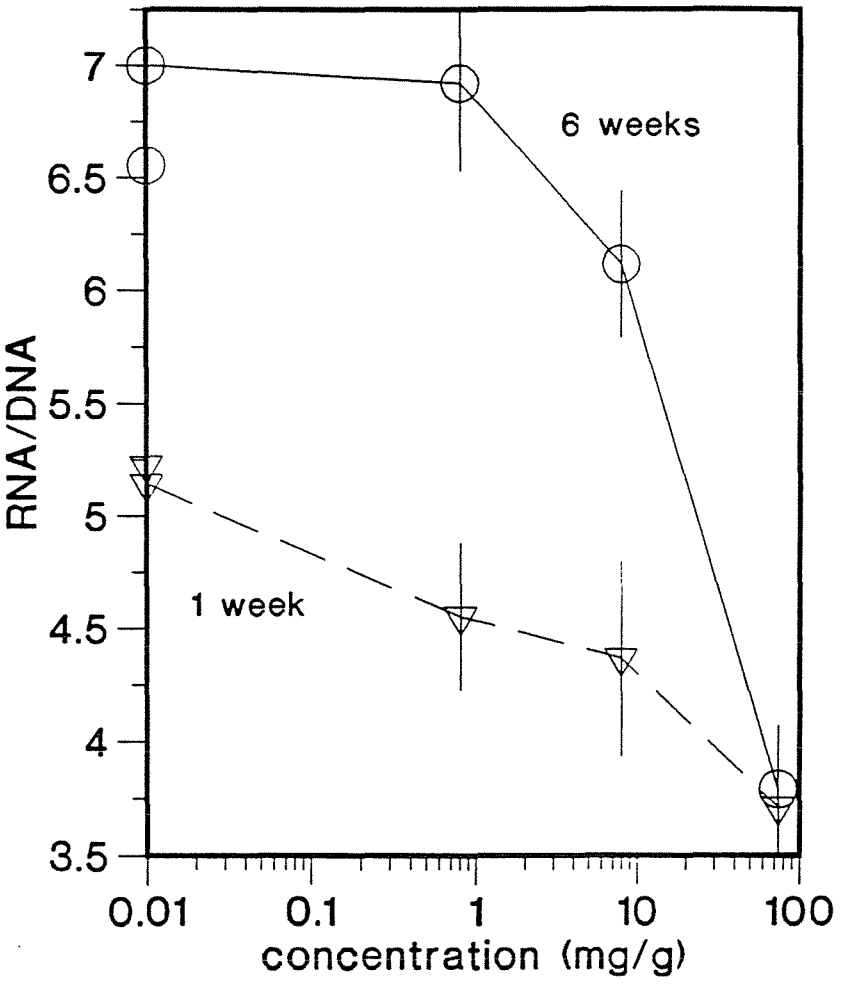


Figure 6.4--RNA/DNA ratios, measured 1 and 6 weeks after exposure, as a function of concentration. Error bars are ± 1 standard error.

CHAPTER 7. STATUS REPORT

Discussion

The objectives of the NMFS component of F/S-4 were to determine the impact of the oil spill on juvenile pink and chum salmon during their initial period of marine residency in nearshore habitats. Field studies in 1989 and 1990 compared (1) distribution, abundance, size and apparent growth rates; (2) exposure to and contamination by hydrocarbons; (3) feeding habits; and (4) prey abundance for these fish between pairs of oiled and non-oiled locations in western Prince William Sound. The effects of oiled sediments on the littoral prey resources of juvenile salmon were also examined. The emphasis of this research was juvenile pink salmon, both because of their economic value and because of their numerical abundance relative to other salmon species. In 1991, field work was discontinued, and a laboratory study was initiated examining the effects of ingestion by juvenile pink salmon of food contaminated with whole oil.

Substantial progress has been made in finalizing data sets and analyses; however, some gaps remain from both the 1989/1990 field studies and the 1991 laboratory research. We have completed the analysis of distribution, abundance, size, and growth (Chapter 2). We consider conclusions regarding exposure and contamination of juvenile pink and chum salmon preliminary (Chapter 3); we require additional sample and data analyses to finalize this section. We have completed processing and analysis of stomach samples (Chapter 4). Sample processing from prey collections is also complete; analyses of these data sets range from final on zooplankton to preliminary on meiofauna colonization (Chapter 5).

Results from the laboratory research on the effects of ingestion of oil-contaminated food are preliminary (Chapter 6). Collection of growth data is complete and has been partially analyzed. Samples for RNA/DNA and otolith increment analyses are now being processed, and samples for hydrocarbon, MFO, and histological evaluation are in the appropriate processing queue.

We have reviewed in detail the mosaic of complete and preliminary analyses in the proceeding chapters; in this Chapter we summarize the overall results, give our preliminary conclusions, and discuss their implications.

We have substantiated our dichotomous classification of our general sampling areas as "oiled" and "non-oiled", based on measurements of hydrocarbons in both mussel tissues and surface sediments collected in 1989. Based on surface sediment collections, the degree of contamination in the oiled sites we sampled had greatly diminished in 1990. The mussel tissue analysis for 1990 collections is not yet available.

There were detectable levels of hydrocarbons in tissues of juvenile pink salmon collected in the nearshore environment of oiled areas of Prince William Sound in 1989. In order to test that hydrocarbons detected in samples were not due to external contamination, flesh samples and viscera were processed separately from some samples of fish from oiled locations; both types of tissues were contaminated by hydrocarbons, with higher levels in the viscera.

The composition of the hydrocarbon in the tissues indicated that ingestion, either of whole oil or oil-contaminated prey, was the likely route of contamination. Evidence of oil was also observed in the stomachs of a small percentage of pink and chum salmon collected at oiled sites in 1989.

Exposure of both pink and chum salmon fry to physiologically significant levels of oil in 1989 was also indicated by levels of mixed-function oxidase (MFO) activity in fry from oiled areas. MFO activity levels in pink salmon declined by late June 1989, suggesting that the degree of exposure of pink salmon in the nearshore marine environment decreased in late spring, 1989.

Samples of juvenile pink salmon from 1990 processed to date show no evidence of hydrocarbon contamination, indicating a marked decline in the level of exposure of juvenile pink salmon from oil year 1 to year 2. Results for 1990 samples analyzed for MFOs also show no evidence of induced activity in 1990.

Juvenile pink and chum salmon were more abundant in the non-oiled area in both 1989 and 1990. Because the pattern of abundance did not change as exposure levels diminished, we conclude that the differences observed in abundance were more likely due to geographic differences or distribution of spawning populations rather than a response to exposure to oil.

Juvenile pink salmon moved rapidly from sheltered bays to more exposed, steep gradient beaches in migration corridors, where they fed predominately on zooplankton. This rapid movement is considered to be an adaptive feeding strategy in response to the distribution of zooplankton in nearshore habitats in Prince William Sound. The observation of this behavior over a wide geographic range reinforces the conclusion drawn in the UAF component of F/S-4, that the presence of oil-deflection boom in Port San Juan in 1989 disrupted the normal migration behavior of fish released from the Armin F. Koerning Hatchery (Cooney 1990).

There was no indication of reduced feeding by pink and chum salmon juveniles in oiled areas in 1989, based on measures of stomach fullness and numbers and biomass of prey consumed. There was a significant switch in the diet composition of juvenile pink salmon between the oiled and non-oiled areas. In 1989, epibenthic prey was utilized to a greater extent in non-oiled areas than in

oiled areas, and zooplankton prey was utilized to a greater extent in oiled areas and non-oiled areas. The reverse pattern was observed in 1990. We attribute this switch in diet composition to differences in the timing and abundance of the spring zooplankton bloom.

Juvenile chum salmon in oiled areas may be more susceptible to hydrocarbon exposure than pink salmon because of their distribution in nearshore habitats. Juvenile chum salmon utilized low gradient shorelines to a greater extent, and thus were more likely to forage over contaminated sediments. This habitat preference is also reflected in the higher utilization of epibenthic prey by chum salmon relative to pink salmon. The MFO induction observed for chum salmon in 1989 was consistently strong, and tended to persist longer than in pink salmon. However, juvenile chum salmon were generally rare in the oiled locations sampled.

There were no significant differences observed in the size of juvenile pink salmon between the oiled and non-oiled locations sampled. Pink salmon tended to be larger in the non-oiled area in both 1989 and 1990. There was no evidence of a reduction in condition of juvenile pink salmon in oiled areas: in both 1989 and 1990, pink salmon tended to have a greater weight at a given length in the oiled locations.

There was a significant reduction in the apparent growth rate of juvenile pink salmon in oiled corridors relative to non-oiled corridors in 1989. This reduction was not observed in 1990. This analysis of unmarked fish corroborates the significant reduction in growth of tagged pink salmon in oiled areas reported in the ADFG component of F/S-4. We attribute this reduction in growth to a physiological response to oil contamination. In the laboratory experiment, ingestion of oil-contaminated food reduced the growth of juvenile pink salmon, and at high doses also reduced their survival. Temperature, prey availability, and feeding efficiency were as high or higher in oiled locations as in non-oiled locations in 1989, and therefore do not explain the observed reduction in growth.

Juvenile chum salmon were significantly larger in the oiled locations in both 1989 and 1990. As with pink salmon, there was no evidence of a reduction in condition factor in the oiled area. Chum salmon were rarely captured in oiled habitats; there was insufficient data to compare apparent growth rates for this species between oiled and non-oiled areas.

We found no evidence of a reduction in available prey organisms of juvenile salmon due to oil contamination. No significant differences were detected in the biomass of pelagic zooplankton between oiled and non-oiled areas in either 1989 or 1990. However, the trend in 1989 was for higher zooplankton biomass in

the oiled area; zooplankton biomass declined more rapidly from seasonal peaks in the non-oiled area than in the oiled area. The reverse was true in 1990. Zooplankton biomass was greater in corridors than bays in 1989 and 1990. Epibenthic prey biomass, including harpacticoid copepods, was higher in oiled locations than in non-oiled locations in 1989. This trend could have been due to geographic variability, reduced cropping associated with lower abundance of juvenile pink salmon, or direct enhancement by oil contamination. Preliminary analyses of results from 1990 field studies on epibenthic prey support the latter explanation. Harpacticoid copepods were more abundant in 1990 on heavily oiled beaches than lightly oiled beaches within the same embayment. Harpacticoid copepods and meiofauna also tended to be higher in the oiled sediments in the field experiment examining the colonization of azoic sediments; however, the differences were not significant in the preliminary analysis of these data.

Conclusions

Based on these results, we have reached a series of preliminary conclusions regarding the impacts of oil in the nearshore marine environment. Juvenile pink and chum salmon were contaminated by oil in 1989; the probable route of contamination was through ingestion of whole oil, either directly or by feeding on contaminated prey. Growth was reduced in pink salmon in oiled areas in 1989 as a physiological consequence of this contamination. Laboratory studies in 1991 demonstrated that ingestion of whole oil can reduce the growth of juvenile pink salmon at sub-lethal dosages.

It is likely that there was some incremental reduction in the potential survival of pink salmon juveniles contaminated by oil in 1989. Growth during this period is important to escape such mortality mechanisms as size-selective predation (Parker 1971; Hargreaves and LeBrasseur 1985). Within a year-class, slower-growing groups of pink salmon fry have lower marine survival than their faster-growing cohorts (Mortensen et al. 1991).

The predominate migration route of juvenile salmon from Prince William Sound to the Gulf of Alaska is thought to be through the southwest passages (Raymond 1989,1990). This migration route coincides with the general movement of Exxon Valdez oil from Prince William Sound (ADFG 1989). Thus large numbers of juvenile salmon, including populations originating from outside the actual spill area, were exposed to hydrocarbon contamination in the marine environment. The ADFG results indicated that fish originating from outside the spill area itself did indeed have reduced growth when recaptured in oiled sites (Raymond 1989, 1990). Such large scale exposures, linked with growth reductions, may have caused an incremental reduction in the survival and overall recruitment of pink salmon to Prince William

Sound in 1990.

In fact, the return of pink salmon to Prince William Sound in 1990 was the highest on record (Royce et al. 1991; Eggers et al. 1991). The magnitude of the return has been used to argue that the pink salmon fishery was not harmed by the spill, and that other salmon fisheries were "likewise unharmed" (Royce et al. 1991). While the record return to the Sound clearly shows that there was not a catastrophic loss of the marine ecosystems capacity to sustain high productivity of pink salmon, it does not preclude the possibility of damage to the resource. Conditions in the Sound in the spring of 1989 were appropriate for a record return. There were near-record releases of pink salmon fry from hatcheries (Eggers et al. 1991); spring zooplankton abundances were high in 1989, providing an excellent forage base for juvenile salmon (Cooney and Willette 1991). However, the record return was not a function of record marine survivals. Survival rates of hatchery pink salmon returning in 1990 were well within the documented range for pink salmon in Prince William Sound (Eggers et al. 1991). Higher overall marine survivals and even more fish may have returned in 1990 if there had not been exposure to oil of a component of the total pink salmon population.

From our results, we also conclude that any reduction in growth and subsequent survival of juvenile pink salmon to exposure to hydrocarbons in the marine environment was limited to the first year of the spill. We found no evidence of measurable contamination or physiological effects (apparent growth, MFO induction) in 1990.

The effects observed for pink salmon could have also occurred in other species. Chum salmon juveniles captured along oiled beaches showed definite MFO induction. A wide variety of other fishes utilize the nearshore environment of Prince William Sound and the adjacent Gulf of Alaska (Rogers et al. 1986). Many pelagic schooling fishes and larval fishes utilize zooplankton as their principal prey (Rogers et al. 1986). If ingestion of either whole oil or contaminated prey were the route of exposure for juvenile pink salmon, then a large number of other fishes with similar feeding habits may also have been contaminated.

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