FISH / SHELLFISH

Project Title: INJURY TO SALMON SPAWNING AREAS IN
                                     PRINCE WILLIAM SOUND (NRDA)
                                             and
                                  ADULT ESCAPEMENT ENUMERATION
                                        (RESTORATION)

Study ID Number: Fish/Shellfish Study Number 1
                                             and
                                  Restoration Study Number 9

Lead Agency: State of Alaska, ADF&G;
                                  Commercial Fisheries Division

Cooperating Agency(ies):   Federal: NPS, USFS, USFWS
                                  State: DNR

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EXECUTIVE SUMMARY

Wild returns of pink (*Oncorhynchus gorbuscha*) and chum salmon (O. keta) to Prince William Sound (PWS) have averaged approximately 8.1 million and 870 thousand fish since 1961. Both species were susceptible to the detrimental effects of the *TV Exxon Valdez* oil spill (EVOS) because much of their spawning occurs in the intertidal zone. To demonstrate injury to pink and chum salmon stocks from oil exposure, intertidal contamination must be documented, reduced survival for some life history stage associated with the oil must be demonstrated, or adult returns in oiled areas must be depressed. Natural Resources Damage Assessment Fish/Shellfish Study 2 (NRDA F/S) has demonstrated significant reductions in pink salmon egg survival in streams contaminated by oil. To determine how adult returns were affected, accurate appraisals of catch and spawning escapement are needed. The NRDA project described in this report is designed to document oil contamination of intertidal spawning habitat and provide accurate estimates of wild stock escapements.

Aerial survey estimates of fish in streams were compared with data from weirs on 10 pink salmon streams. The correlation between weir data and concurrent aerial surveys was poor (R^2 = 0.495). The correlation of weir and ground survey data was good (R^2 = 0.949) but both methods displayed negative bias (slope = 2.98 and 1.88). Differences between aerial survey counts and weir estimates became greater as numbers of salmon increased, were greater on long streams with significant upstream spawning, and were greater in 1991 than in 1990.

Average stream residence time (stream life) for pink salmon estimated in 21 streams in the ground survey and weir program in 1990, was 15.1 days. The average stream life for pink salmon returning to weired systems ranged from 9.8 to 11 days for the three most reliable estimation procedures used in 1991. Previous escapement estimates based on a 17.5 day stream life may, therefore, be too low, particularly in the western half of PWS. Comparison of escapement estimates using either aerial or ground counts to known escapements through four weirs indicated both aerial and ground estimates tended to be low. The 1990 pink salmon escapement to 209 streams included in the historic pink salmon escapement index program was 1.3 million fish based on a traditional analysis of aerial survey data. An analysis of the same data which incorporated new estimates of stream life and a correction factor for bias in the aerial method yielded an escapement estimate of 2.3 million fish.

Tissues were removed from adult pink salmon collected from 22 western PWS spawning streams in 1990 and 1991 to test for cellular abnormalities and the presence of mixed-function oxidases (MFO's), enzymes known to be induced by exposure to oil,

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Stocks which sustained damage must be restored. The commercial fishery in PWS is a significant source of mortality for adult salmon. Fishery exploitation rates appropriate for healthy salmon stocks may be too high for stocks damaged by the EVOS. Restoration through altered harvest management is predicated on the ability to accurately enumerate the escapement to damaged stocks and alter fishing effort in response to escapement trends. Restoration Study 9 expands NRDA F/S Study 1 to include more streams and places greater emphasis on timely inseason analysis of escapement trends. Data from weirs and foot surveys were used inseason in 1991 to help justify restriction of fishing time and area in southwestern PWS near oil damaged streams where poor escapement trends were being observed. These time and area closures reduced fishing effort on damaged stocks and resulted in above average numbers of spawning adults in oil damaged streams despite intense pressure to fish heavily on the abundant hatchery returns in this mixed stock area.

OBJECTIVES

Although the emphasis is slightly different, Restoration Study 9
differs very little from NRDA F/S Study 1. Objectives 4 through 10
for NRDA F/S Study 1 are identical to those described for the three
weirs and 12 survey streams in the Restoration Study 9.

OBJECTIVES

1.   Determine the presence or absence of oil on intertidal
        habitat used by spawning salmon through visual
        observation, aerial photography, and hydrocarbon analysis
        of tissue samples from intertidal mussels at stream
        mouth.

2.   Document the physical extent of oil distribution on
        intertidal spawning areas.

3.   Document the presence or absence of hydrocarbons from the
        EVOS in the tissues of adult salmon originating from the
        fry outmigrations in 1989 and subsequent years in oiled
        and unoiled areas.

4.   Estimate the number of spawning salmon, by species,
        within standardized intertidal and upstream zones for 27
        streams in PWS.

5.   Enumerate the total intertidal and upstream escapement of
        pink and chum salmon through weirs installed on seven
        streams which are representative of streams in the aerial
        and ground escapement survey programs.

6.   Estimate the accuracy of aerial counts for the 218 aerial
        index streams by comparison of paired ground and aerial
        counts from the same streams on the same or adjacent
        survey dates and by comparison of aerial, ground, and
        weir counts on seven streams.

7.   Estimate average stream life of pink and chum salmon in
        at least 27 streams in PWS using a variety of techniques.

8.   Estimate 1961 through 1988 pink and chum salmon
        escapements to the 218 aerial index streams using the
        average observed error in the aerial survey method and
        stream life data from 1989, 1990 and, 1991.

9.   Produce a catalog of aerial photographs and detailed maps
        of spawner distribution for the more important pink and
        chum salmon streams of Prince William Sound for use in

designing sampling transects in the egg deposition and pre-emergent fry studies.

10. Enumerating adult returns in streams where coded wire tags were applied to wild pink salmon stocks and assist in the spawning ground sampling for tag recovery.

INTRODUCTION

This project is an integral component of the impact study of the *Exxon Valdez* oil spill (EVOS) on Pacific salmon populations in *Prince William Sound* (PWS). Wild salmon play a major role in the PWS ecosystem. Salmon not only provide a significant source of food for many fish, bird, and mammal species but also convey needed nutrients from the marine system to the estuary, freshwater, and terrestrial environments. Although NRDA F/S Study 1 and Restoration Study 9 differ slightly, the principal objectives are very similar and the two studies will be treated as one escapement enumeration study in this report. Both are integral to the investigation and of impacts of the EVOS on Pacific salmon populations in PWS and to the restoration of those populations.

Additional NRDA and Restoration studies in PWS rely on information obtained in this study. Escapement enumeration of coded-wire tagged wild stocks and coded-wire tag recoveries in wilds stock streams are critical to the wild stock total return and survival estimates made by NRDA F/S Study 3 and Restoration Study 8. NRDA F/S Study 3 provides estimates of wild stock contributions to the catch but results of NRDA F/S Studies 1 and 3 must be combined to estimate total wild stock returns. NRDA F/S Study 28 will reconstruct stock specific returns in prior years so that historic and current returns can be compared, and stock specific damages determined. Stream life and aerial survey efficiency gained from the present study will be used in the complex reconstruction model. NRDA F/S Study #2 (injury to salmon eggs and pre-emergent fry studies) relies on spawner density and distribution information from this study .

Streams examined by this project are also a subset of the anadromous salmon streams monitored by the ongoing ADF&G aerial survey program. The results of this study will provide; 1) a total count of salmon escapement past weirs on twelve streams; 2) an adjustment factor for pink salmon escapement estimates from ground and aerial survey data based on comparisons with known escapements through 10 of the weirs; 3) adjusted current year and historic escapement estimates based on ground and aerial data for 353 streams; 4) estimates of post oil-spill spawning distribution within stream zones and among streams; 5) estimates of average stream life for pink salmon in PWS; 6) collections of

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histopathology samples and baseline genetic data on hatchery stocks and a cross section of wild stocks; 7) and an atlas of aerial photographs and detailed maps of important spawning sites.

STUDY METHODOLOGY

Study Design

Streams examined by this project are a subset of the anadromous salmon streams monitored by the ongoing ADF&G aerial survey program (Figure 1).

Total Enumeration Studies

A weir acts as a fence which channels the upstream migration of salmon through a small opening where they are counted visually. Total escapement was enumerated through intertidal weirs installed on two moderately large pink salmon streams in eastern PWS, eight small to medium sized pink salmon streams in western PWS, and two important sockeye salmon streams in western PWS (Figure 2). Weired pink salmon streams were selected from the list of streams included in the aerial and ground survey programs. Weirs were similar to standard picket weirs which have been employed successfully by ADF&G. Each weir was installed at the six foot tide level or as close to the downstream limit of intertidal spawning as possible. Counts were made periodically during the day in response to tides and fish movement. Weir crews conducted stream life studies at their weired stream and other assigned streams in the same geographic area.

Ground Surveys of Escapements

Field crews at eleven remote field camps in Prince William Sound plus crews stationed in Cordova and Valdez performed daily foot surveys of intertidal and upstream portions of the 10 pink salmon streams which were weired and at 47 additional pink and chum salmon spawning streams (Figure 2). As time and conditions allowed, weekly, semi-weekly and random surveys were performed on an additional 28 streams during the spawning season. Streams to be surveyed daily were selected on the following criteria:

1. The stream was included in the ADF&G aerial survey program for pink and chum salmon escapements;
2. The stream was included in the pink and chum salmon egg deposition and pre-emergent fry project (NRDA Study 2);
3. The stream was included in prior spawning ground foot survey programs;

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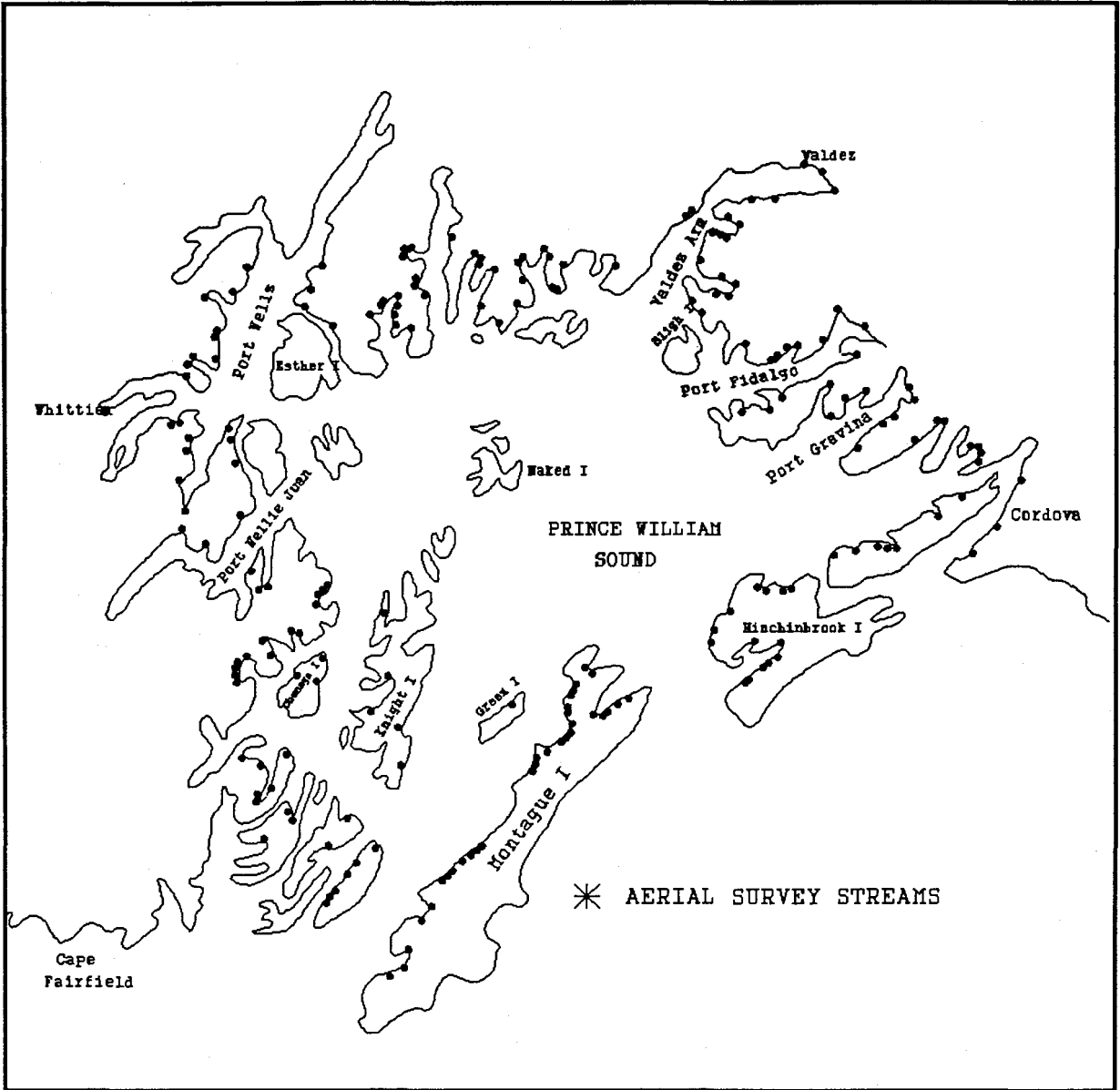
Figure 1. Map showing the locations of streams included in the traditional aerial and ground survey programs for pink and chum salmon escapements in Prince William Sound, 1960-1991.
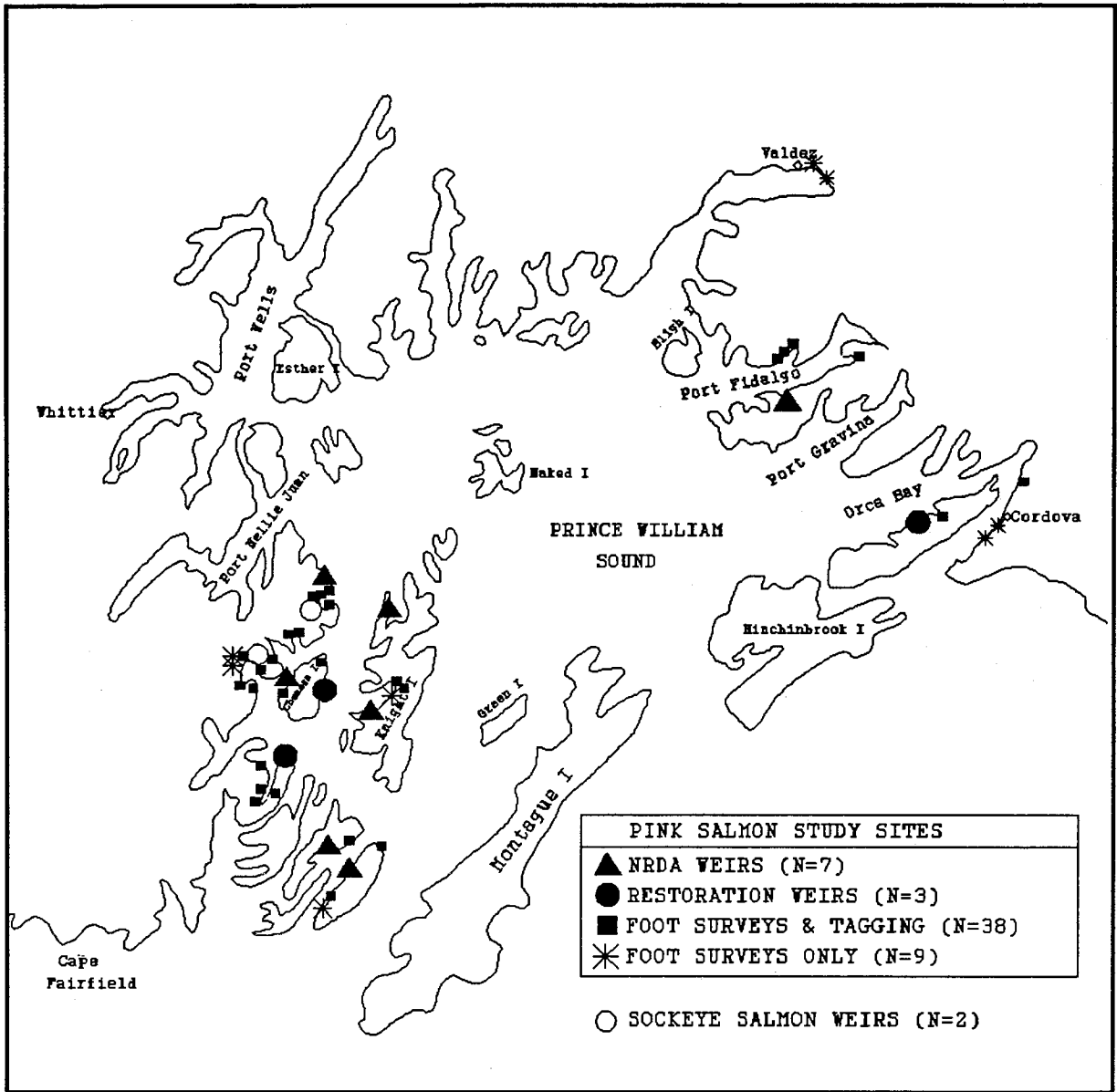
Figure 2. Map showing the locations of streams weired to enumerate salmon escapements and additional streams streams where grounds surveys and tagging studies were conducted on pink salmon in Prince William Sound, 1991.

4. The streams were representative of the early, middle, and late run pink and chum salmon stocks in PWS;
5. The streams were representative of the spatial distribution of pink and chum salmon stocks in PWS and included streams from oiled and unoiled areas.

Surveys to mark tide zones were conducted in June, prior to the return of pink and chum salmon. The locations of tide levels 1.8, 2.4, 3.0, and 3.7 m above mean low water were measured from sea level using a surveyors's level and stadia rod. Sea level at each site was referenced to mean low water with site specific, computer generated tide tables which predict tides at five minute intervals. Tide zone boundaries were delineated with color coded steel stakes.

During the escapement enumeration portion of the project, streams were surveyed visually from the ground in a systematic order. Each field crew used a skiff to travel between their respective base camps and survey streams. During each stream survey the following data were recorded for each stream on printed data forms:

1. Anadromous stream number and name (if available);
2. Date and time (24 hour military time);
3. Tide stage;
4. Observer names;
5. Counts of live and dead salmon by species for five zones; four intertidal zones between elevations of 0.0-1.8 m, 1.8-2.4 m, 2.4-3.0 m, and 3.0-3.7 m above mean low water; and one upstream zone encompassing the entire stream above 3.7 m (mean high water);
6. A record of stream life tag observations detailing tagged fish location, tag color, and individual tag number;   ·
7. A record of adipose fin clipped carcasses recovered by time and stream location;
8. A survey condition factor in each zone based on weather, water clarity, glare, and other survey conditions. Conditions were standardized and assigned a number from 1 (excellent) to 5 (very poor).
9. A survey rating factor for each zone ranging from 1 (excellent) to 3 (poor) based on the surveyors subjective assessment. Ratings were indicative of problems associated with the conditions but also quantified other unrelated problems such lapses of concentration or difficulties associated with counting huge, mobile schools.
10. A code indicating which sections were counted together by both observers and which were counted by only one observer.

Survey patterns were adjusted using computer generated tide tables. If tide height at the beginning of the survey was at or below 1.8 m the crew started the survey at the stream mouth (ie. the point where a clearly recognizable stream channel disappeared or

was submerged by salt water). Pink or chum salmon seen below the stream mouth were recorded separately as a comment on the data form. If the intertidal portion of the stream above the 1.8 m level was submerged, the crew started the survey at the upstream limit of spawning as determined by the presence of natural barriers to salmon (ie. waterfalls), the end of the stream, or the upstream limit of observed spawning.

Counts of live and dead pink and chum salmon were made by a two person crew. For streams of moderate size and having a single channel the crew members walked together but independently recorded their counts of live fish in each stream zone. To isolate and quantify observer bias, crew members were not permitted to compare or discuss counts at any time. The count for each zone was replicated a maximum of three times at the request of either observer. Upstream counts in a single channel were similarly enumerated. Long upstream zones were frequently subdivided into subsections at convenient stopping points (ie. log jams or other clear counting delineators). On large braided or branched streams, duplicate counting was not possible and each crew member counted separate channels or upstream forks. To avoid confusion with counts of live fish, counts of dead fish and tagged fish were recorded on the return leg of the stream walk or by an independent third observer. When possible, camp personnel rotated creek surveying assignments each day to avoid counting biases.

All counts were recorded on mechanical hand tallies for each stream section. At the end of each section or tide zone, counts were recorded together with other survey data on pre-printed data sheets. Data were all stored electronically on microcomputers in a relational data base (RBASE). Records in the data base were stratified by stream number, survey date, tide zone, zonal section, replicate counts, and species. Strata which were replicated by more than one observer were coded for later categorical analysis of differences between observers.

Maps of all streams to be surveyed daily in 1991 were originally prepared in 1989 from aerial photographs and improved during the course of the 1989 and 1990 field seasons. Maps were again modified and updated at the beginning of the 1991 stream surveys to include information from initial surveys regarding the location of stakes and key landmarks which identified tide zones, spawner distribution within each zone and the upstream limit of spawning. Spawner density and distribution observations were used for the 46 streams to be sampled as part of NRDA Study 2.

Aerial Surveys

Aerial survey estimates of pink and chum salmon within 209 index streams have been made since 1961 by ADF&G's commercial fisheries management biologists based in Cordova. Surveys have been flown

weekly from mid-June to mid-September each year (Figure 1). Counts of salmon by species have been recorded for the bay at the terminus of each stream, the mouth of each stream, and within the stream. Prior to 1991, aerial survey counts within the stream were not stratified by tide height as they have been in the ground survey program. This year, results of aerial surveys on creeks with weirs, and on creeks that were surveyed on foot each day, were broken down into above and below the weir counts, and intertidal and upstream counts, respectively. The division between intertidal and upstream sections of surveyed streams was marked by a large orange buoy anchored at the 3.7 m tide level and visible from the air. Aerial survey methods used in PWS have been described in more detail by Pirtle (1977). In 1989, eight streams in the oiled portions of PWS were added to the survey roster. In 1990 and 1991 funds from the fishing industry and local aquaculture associations were use to approximately double the frequency of survey flights. For most weeks there were at least two observations per stream. In 1991, an additional 144 streams were added to the 209 streams examined by aerial surveyors. Added streams were selected from among all streams listed in the ADF&G Habitat Division catalogue of anadromous salmon streams (Anonymous 1990). The list of anadromous streams was stratified by area and streams were randomly selected for inclusion in the aerial survey program. The number selected from each area stratum was proportional to the total number of streams in the area.

Stream Life Studies

Stream life estimates based on tagging studies were similar to those described by McCurdy (1984), Helle et al (1964), and Sharr et al (1990). Once a week, fish from each of 38 streams (Figure 2) were captured with beach seines at the stream mouths and Peterson disk tags were applied. At larger streams, 200 tags were applied each week. At smaller streams 120 tags were applied weekly. If fewer than the desired number of fish were available, all fish captured were tagged. Tags were uniquely colored to represent day of capture, uniquely lettered to identify the stream where tags were applied, and uniquely numbered for identification of individual fish. All streams in the tagging study were included among those in the daily ground survey program. Tagged live and dead fish were tallied by color within each tide zone, and where possible individual numeric codes were recorded for live fish. Tallies of dead fish included only fish that had died since the last survey. The tail and tags, when present, were removed from all dead fish to identify carcasses which had been counted.

Independent estimates of stream life were made using two other methods which did not rely on tags. These methods incorporated daily counts of live and dead fish from the foot survey program and weir counts where available.

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Documentation of Oil Contamination

In 1989 a 2-person crew conducted aerial and foot surveys to document the presence of oil in the intertidal spawning and rearing habitat of all known anadromous salmon spawning streams in western and central Prince William Sound. Most important salmon streams in the northern and eastern portions of PWS which were part of the ground escapement enumeration portion of this project and included in NRDA Study 2 were also surveyed (Sharr et al, 1990).

Hydrocarbon Sampling

In 1989 and 1990 composite samples of mussels (*Mytilus sp.*) were collected at the mouth of 135 streams for hydrocarbon analysis (Sharr 1990). Results of this analysis will be used to corroborate visual evidence of oil contamination and will be indicative of the availability of hydrocarbons to other organisms such as pink and chum salmon eggs and fry which share the same intertidal habitat for long periods of time.

Histopathology, Cytogenetic, and Electrophoretic Sampling

Histopathology. Tissue samples were removed from adult salmon for histopathological, MFO, and cytogenetic analyses. Salmon were selected for sampling according to the following criteria:

1. Equal numbers of stocks were chosen from streams in oiled and unoiled areas. Stocks in the "oiled" category represented a continuum of contamination ranging from returns to streams where large amounts of oil was visible to those where the presence of oil was only suspected;
2. Wild salmon stocks from oiled and unoiled areas were chosen from those studied in NRDA F/S Study 2 (Injury to Salmon Eggs and Fry) and NRDA F/S Study 3 (Coded-Wire Tagging Studies);
3. Stocks were selected from areas suspected of having been oiled but with mussel samples which gave ambiguous results.

Twenty two stocks were sampled in 1990 and again in 1991. Twelve stocks were from streams suspected of having oil contamination, and 10 were from unoiled sites in close geographic proximity (Figure 3). Fish were sampled immediately after entering the stream and before undergoing gross morphological changes and tissue deterioration associated with spawning. Twenty fish of each sex were sampled from each stock. Fish sampled for histopathological analyses were captured with beach seines, stored immediately on ice, and were typically sampled in the laboratory in Cordova within six hours of the time of capture. Samples of liver, spleen, posterior kidney, and olfactory tissue were remove from each animal. Liver, spleen, and kidney tissues were thin sectioned. One entire nare was removed to represent olfactory tissue. All tissues
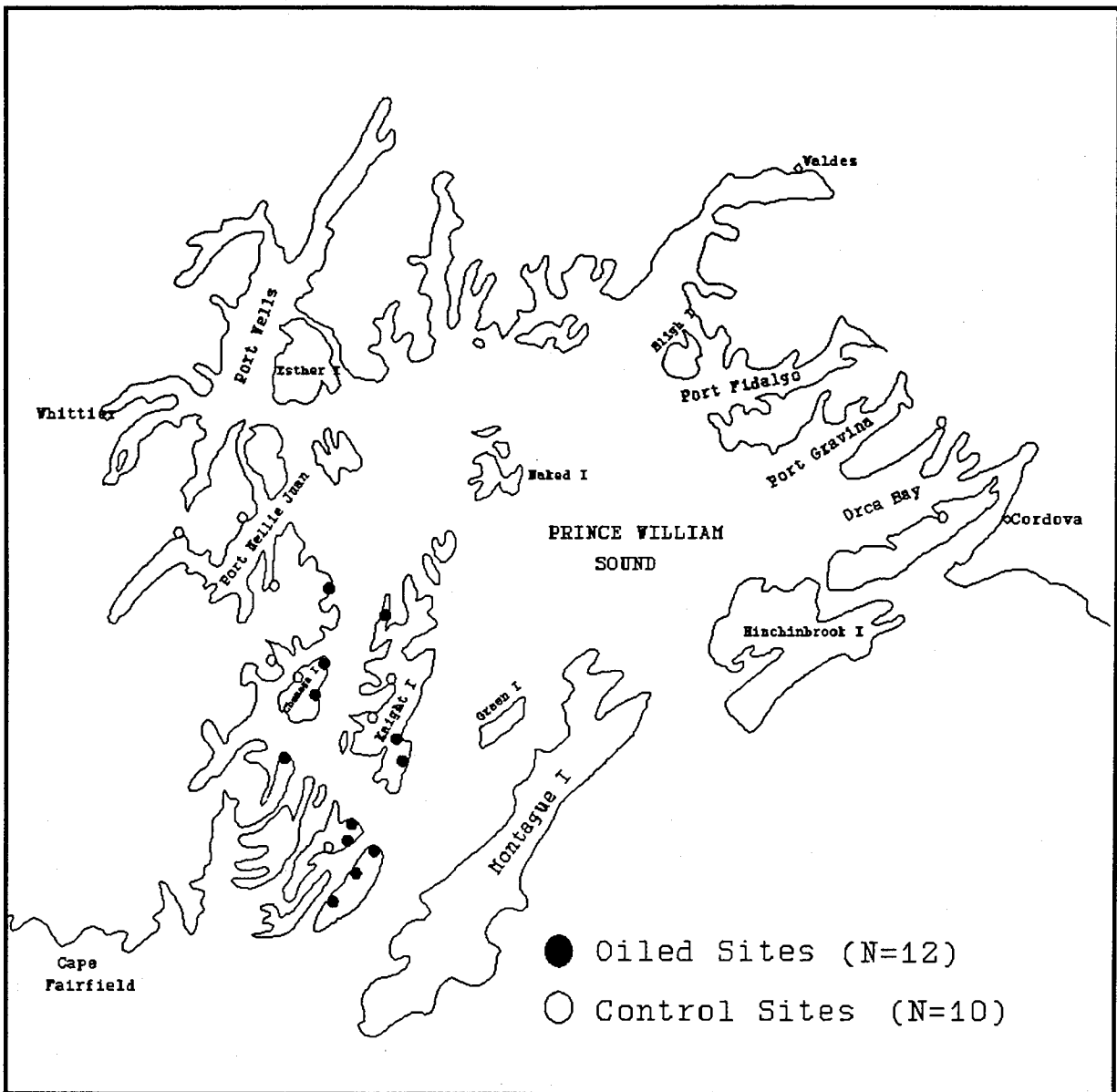
Figure 3. Map showing the locations of streams where tissue samples were taken from adult pink salmon for histopathological and cytogenetic examination and MFO analyses.

from one animal were stored in a single jar filled with 10% phosphate buffered formalin. Each sample jar was labeled inside and out with printed labels indicating species, sex, ADF&G anadromous stream number, stream name, geographic location, latitude, and longitude of the stream mouth, date, time, tissue type, preservative, and sampler(s). Corresponding information was entered on chain of custody forms. The samples were sealed with evidence tape and stored in a secure office. A subset of samples from five streams, two oiled, two control and, one suspect have been remitted to the custody of Dr. David Hinton for analysis.

Cytogenetic. Sperm samples for cytogenetic analysis were taken from all males captured at 20 of the 22 streams sampled for histopathology analyses. Males were removed live from the beach seine at each capture site and milked for sperm into cryogenic vials which were pre-labeled according to the same protocol described for histopathology samples. To avoid sample contamination by debris or other tissue types, the vent area of each fish was wiped dry prior to milking, vials used to store sperm from each male were not brought in contact with the fish, and any sample containing blood was discarded and replaced by a clean sample from another fish. Samples were transported on ice to Cordova, diluted with of phosphate buffer, frozen in liquid nitrogen, and shipped on dry ice to the Anchorage ADF&G genetics laboratory for processing.

Electrophoresis. To begin characterizing genetic stock composition of PWS pink and sockeye salmon populations, returns to thirteen pink salmon streams, three pink salmon hatcheries, two sockeye salmon streams, and one sockeye salmon hatchery were sampled for electrophoretic analysis (Figure 4). One hundred fish from each stock were sampled for tissues from the muscle, liver, heart tissue and ocular fluid. Fish were captured with beach seines at wild stock systems or removed from brood stock raceways at hatcheries, placed on ice and transported to Cordova for immediate dissection. During dissection, tissues were carefully isolated to avoid inter-fish and inter-tissue contamination. Samples were placed in pre-labeled cryogenic vials and stored, frozen in liquid nitrogen, and shipped to the ADF&G genetics lab in Anchorage.

Data Analysis

The collective data base from the ground survey program, weir projects, and stream life studies is huge and data entry alone has been a formidable task. Data editing and analyses are incomplete at this time. Many of the methods described here are proposed, are not completed, and are subject to change as analysis proceeds in the coming months.
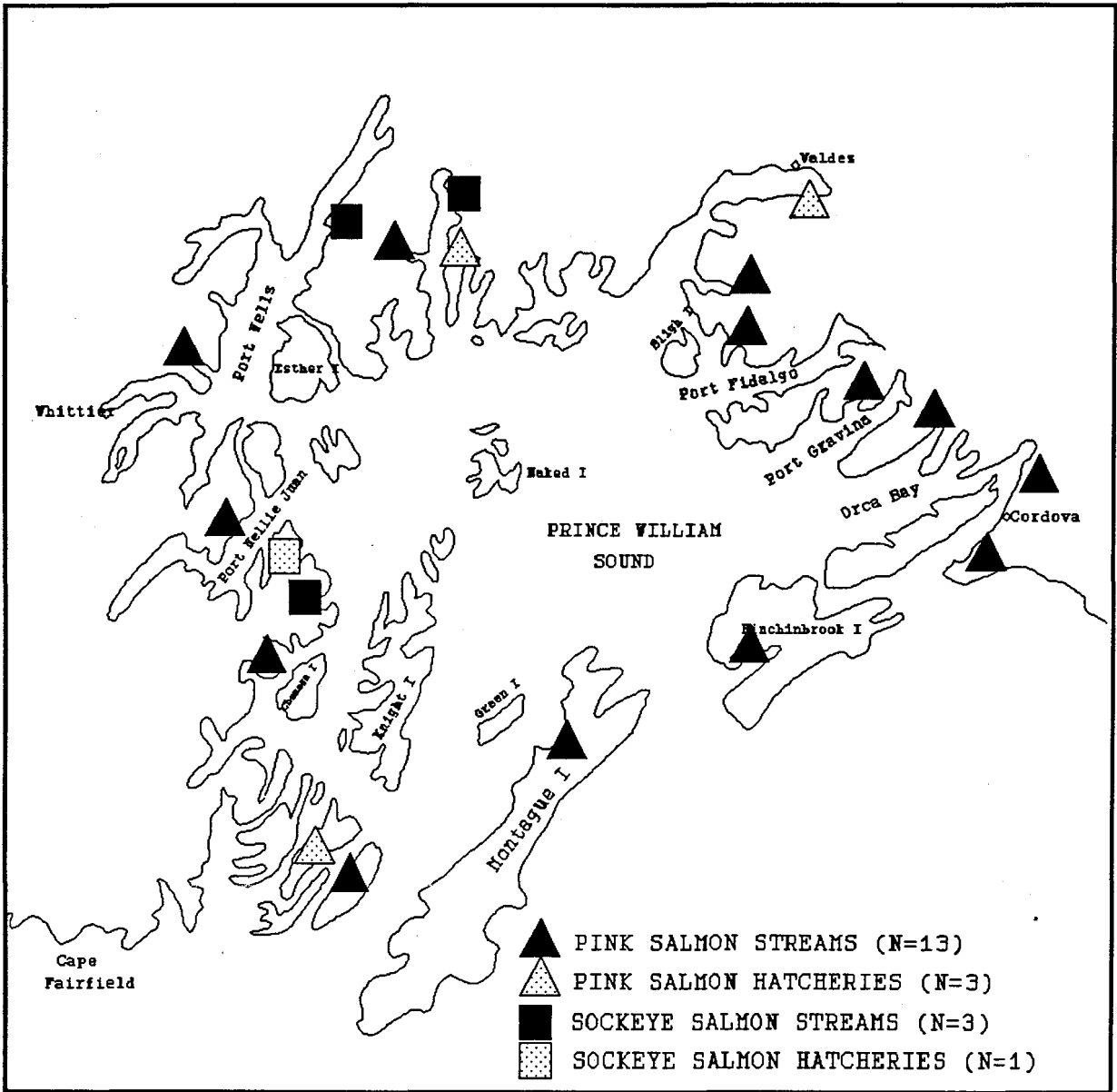
Figure 4. Map showing sites where tissue samples were taken from pink salmon and sockeye salmon for electrophoretic analyses, 1991.

Total Escapement Enumeration Data

Total escapement for streams with weirs is the summation of daily counts of fish through the weir. Very infrequently pickets at a few of the weirs had to be pulled during flooding to prevent the weir from being washed away. These periods when a weir was no longer fish tight typically lasted less than 24 hours and in most instances less than 12 hours. When they occurred, missing counts were inferred from ground counts of live and dead fish from the day preceding and the day follow the event as follows:

$$W_{(i-n)} = \Sigma ((L_i - L_{(i-n)}) + D_i) \tag{1}$$

where i =   survey number,
        n =   days elapsed since last survey,
        L_i =   number of live fish tagged,
        D_i =   number of tagged dead fish recovered on survey i,

Adjustment of Aerial and Ground Counts

Streams with weirs were used as standards to define stream categories based on stream size, extent of upstream and intertidal spawning, and other characteristics such as water clarity and extent of forest canopy. Other streams in the aerial and ground survey programs were categorized according to these same criteria. A bias adjustment function for a weired stream was applied to aerial and ground counts from unweired streams in the same category.

Daily aerial and ground counts at weired streams were adjusted for bias using the regression of survey counts to live fish in the stream by date (L_{ij}) estimated as:

$$L_{ij} = \Sigma W_{ij} - \Sigma D_{ij}, \tag{2}$$

where i =   serial day of weir operation,
        j =   stream category,
        W_{ij} =   live fish passed through the weir j on day i,
        D_{ij} =   count of dead fish in the stream j on day i.

Stream Life Data

Streams in the stream life study were used as standards to define stream categories based on stream size, gradient, and extent of

upstream and intertidal spawning, and run timing. Other streams in the aerial and ground survey programs were categorized according to these same criteria. The stream life for a stream in the stream life study was applied to aerial and ground counts from streams in the same category which were not studied. Stream life was estimated using four methods.

Estimates From Tagging. Tagging data were used to calculate stream life values for individual fish as:

$$S = J_r - J_t \qquad\qquad (3)$$

where J_t = julian date when tags were applied at the mouth of the stream.

J_r = julian date of tag recovery from the dead fish.

The stream life estimates for each stream and weekly strata were the average for individual fish in the strata. The season-average stream life estimate was the average of strata estimates. During tagging studies in 1990 (Sharr et al 1990) tagged fish were observed milling at the stream mouth. Stream life estimates calculated using the date of tag application may not accurately represent in stream residence time and may be too large. To reduce bias associated with milling time at the mouth weekly stream life estimates were adjusted as follows:

$$S = \frac{\Sigma (R_i J_i)}{\Sigma R_i} - \frac{\Sigma [((T_i - T_{(i-1)}) + R_i) J_i]}{\Sigma [(T_i - T_{(i-1)}) + R_i]} \qquad\qquad (4)$$

where i = survey number,

T = number of live fish tagged,

J_t = Julian date of tagging

R_i = number of tagged dead fish recovered on survey i,

J_i = Julian date of survey i.

Estimates Using Fish Days and Total Escapement. For streams with weirs, an estimate of mean stream life based on daily counts of live fish through the weir and daily dead counts in the stream will be as follows:

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$$S = \frac{\Sigma \left[(J_i - J_{(i-1)}) \Sigma (W_i - D_i) \right]}{\Sigma W_i},$$ (5)

Where   i   =   serial day of weir operation,
         J_i =   Julian date,
         W_i =   live fish passed through the weir on day i,
         D_i =   count of dead fish in the stream on day i,
         S   =   stream life (in days).

Where observations for day i were missing, total live fish in the creek on day i ($\Sigma(W_i - D_i)$) was linearly interpolated. A similar, though less reliable estimate can be made using live and dead counts from ground surveys as follows:

$$S = \frac{\Sigma \left[(J_i - J_{(i-1)}) \Sigma L_i \right]}{\Sigma D_i},$$ (6)

Where   i   =   serial day of weir operation,
         J_i =   Julian date,
         L_i =   count of live fish in the stream on day i,
         D_i =   count of dead fish in the stream on day i,
         S   =   stream life (in days).

This method assumes that counts of dead fish in the stream are a reliable estimate of the total escapement. Where observations for day i were missing, total live fish in the creek on day i (L_i) was linearly interpolated.

Estimates From Run Timing. Another mean stream life estimate was calculated as the difference between the mean date of abundance of new arrivals in the stream and the mean date of abundance of daily dead counts as follows:

$$S = \frac{\Sigma D_i J_i}{\Sigma D_i} - \frac{\Sigma \left[((L_i - L_{(i-1)}) + D_i) J_i \right]}{\Sigma \left[(L_i - L_{(i-1)}) + D_i \right]}$$ (7)

where
i	=	survey number,
L_i	=	number of live fish observed on survey i,
D_i	=	number of dead fish observed on survey i,
J_i	=	Julian date of survey i.

For weired systems a similar estimate was calculated using the mean date of daily weir counts as follows:

$$S = \frac{\Sigma D_i J_i}{\Sigma D_i} - \frac{\Sigma W_i J_i}{\Sigma W_i} \qquad (8)$$

Escapement Estimates Based on Aerial Survey Data

Annual spawning escapement estimates (E) for pink salmon within each surveyed stream were made using a geometric approach similar to that described by Johnson and Barrett (1986):

$$E = \frac{\sum \left[(J_i - J_{(i-1)}) L_i - \frac{(J_i - J_{(i-1)})(L_i - L_{(i-1)})}{2} \right]}{S} \qquad (9)$$

Where
i	=	survey number,
j	=	stream category,
J_i	=	julian date,
L_{ji}	=	survey estimate of live fish in the stream adjusted for stream category j survey bias on survey i,
S	=	stream life (in days).

If the maximum daily survey of live fish in the stream exceeded the total escapement estimate based on the geometric method, the maximum daily survey count was treated as the total escapement.

Escapement Estimates Based on Ground Survey Data

Ground survey counts were summarized by species, stream, survey date, the four intertidal zones and upstream zone, and by observer for all 51 streams in the study. Spawning escapement to streams surveyed from the ground was estimated using the geometric method described for aerial survey data. Frequently survey counts (L_i) were replicated as paired observations from two observers walking in tandem. The estimated number of fish in a section walked in tandem was the mean of the observations. In instances where the maximum daily sum of live and dead fish in a stream exceeds the

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total escapement estimate for the stream based on the geometric method, the maximum daily sum of live and dead will be the total escapement estimate.

Hydrocarbon and Histopathology Sampling

Samples of mussels for hydrocarbon analysis and tissue samples from adult salmon for MFO analysis and histopathological examination are processed by contractual agreement with Dr. David Hinton at the University of California, Davis, California. Samples for cytogenetic analysis are being processed by contractual agreement with Dr. Stan Alan at Rutgers University. Electrophoretic analyses of pink and sockeye salmon tissues will be are archived at the ADF&G Genetics laboratory in Anchorage and will be processed by that facility.

RESULTS

Oil Survey

The presence of oil on the intertidal substrate was documented at the mouths of 43 of the 411 streams surveyed in 1989 and the results were summarized by Sharr et al. (1990). The oil survey included 183 of the 211 streams enumerated by the ADF&G pink and chum salmon escapement aerial survey program, 130 of the 140 streams studied in this project, and 57 of the 58 streams sampled in NRDA Study 2. All photographs, maps and data sheets are archived in the Cordova area ADF&G office. A complete catalogue of photos, maps, and data from data sheets has been stored in both LOTUS and RBASE format on an IBM compatible microcomputer.

Total Escapement Enumeration Through Weirs

Pink Salmon

Total escapement results from weirs operated on 10 pink salmon streams in 1991 are summarized in Table 1 and Appendix A. Weirs were also operated at four of these streams in 1990 (Sharr et al 1990). Escapements in 1991 were significantly greater at three and slightly greater at the fourth. The 1991 escapement to Irish Creek was more than double that of 1990 (95,627 versus 43,564), the escapement to Totemoff Creek was more than triple that of 1990 (37,633 versus 11,454), and the escapement to Herring Creek was more than four times that of 1990 (16,723 versus 4,966) (Table 2). Only Cathead Creek had similar escapements in 1991 and 1990 (9,655

Table 1. Weir counts, carcass counts, and stream life estimates for ten Prince William Sound pink salmon streams, 1991. Stream life estimates are based on tagging (equation 3), fish days at total escapement (equations 4 and 5), and run timing (equations 6 and 7).

| Stream | Cumulative Counts | | Stream Life Estimates by Method | | | | |
| | | | | | Run Timing | | Tagging |
	Live	Dead	Weir	Surveys	Weir	Surveys	
Irish Creek	95,627	94,487	16.13	9.06	15.93	9.03	13.87
Loomis Creek	17,694	18,889	5.97	5.42	6.87	5.38	6.75
Totemoff Creek	27,350	37,633	3.43	9.09	10.99	9.07	10.96
Chenega Creek	48,745	51,790	9.42	7.06	10.47	6.85	8.91
Countess Creek	15,028	14,172	9.47	6.94	8.98	6.66	8.56
O'Brien Creek	27,174	33,133	7.82	5.42	10.43	5.41	8.19
Hayden Creek	18,372	16,403	11.69	6.47	9.40	6.46	9.63
Herring Creek	16,723	13,691	13.09	10.86	10.06	10.82	9.96
Cathead Creek	9,765	8,724	11.88	8.97	10.44	8.92	10.48
Hawkins Creek	48,825	42,357	16.56	10.78	16.39	10.77	10.57
Totals	325,303	331,279					
Averages			10.55	8.01	11.00	7.94	9.79

Table 2. Comparisons of 1990 and 1991 aerial escapement estimates to results from weirs and comparisons of traditional aerial estimation procedures used in Prince William Sound versus procedures incorporating correction factors for bias in the aerial method and using revised streamlife values.

Stream Name	Stream Life	Aerial Correction Factor	Total Escapement	Aerial Escapement Estimates			
				Adjusted		Traditional	
				Numbers	% Error	Numbers	% Error
1990							
Irish Creek	18.3	1.11	43,564	29,352	-32.6%	27,607	-36.6%
Totemoff Creek	7.2	0.62	16,128	13,503	-16.3%	8,961	-44.4%
Herring Creek	11.2	0.94	4,966	3,187	-35.8%	2,700	-45.6%
Cathead Creek	8.5	0.87	7,586	6,112	-19.4%	3,534	-53.4%
Totals			72,244	52,154	-27.8%	42,802	-40.8%
1991							
Irish Creek	16.13	3.51	95,627	86,376	-9.7%	22,682	-76.3%
Totemoff Creek	9.10	1.98	37,633	24,088	-36.0%	9,500	-74.8%
Herring Creek	13.90	1.87	16,723	14,382	-14.0%	5,967	-64.3%
Cathead Creek	11.88	3.85	9,765	7,583	-22.3%	1,500	-84.6%
Subtotal Totals			159,748	132,429	-17.1%	39,649	-75.2%
Loomis Creek	5.97	1.83	17,694	18,276	3.3%	3,407	-80.7%
Chenega Creek	9.42	3.01	48,745	43,421	-10.9%	7,765	-84.1%
Countess creek	9.47	1.11	15,028	6,923	-53.9%	5,400	-64.1%
O'Brien Creek	8.19	2.47	27,174	39,646	45.9%	7,512	-72.4%
Hayden Creek	11.69	1.31	18,372	7,744	-57.8%	5,000	-72.8%
Hawkins Creek	16.56	2.47	48,825	35,154	-28.0%	13,468	-72.4%
Totals			335,586	283,593	-15.5%	82,201	-75.5%

versus 7,586). The mean date of fish passage through the weirs was later in 1991 than in 1990. The largest difference (17 days) was at Cathead Creek and the smallest was at Herring Creek (2 days).

At Totemoff Creek, cumulative carcass counts from daily surveys significantly exceeded live counts through the weir (Table 1). A similar phenomenon occurred at this site in 1990 (Sharr et al. 1990). At that time it was assumed that when carcasses accumulated too rapidly on the weir, counting crews inadvertently overlooked tail clips and double counted some. It now appears more likely that the water volume, steep gradient, and loose gravel substrate in this creek resulted in frequent gaps at the bottom of weir pickets which may allow live fish to pass uncounted. In any event, estimates of live fish in the stream based on weir counts are suspect.

Sockeye Salmon

The sockeye salmon escapement through the Eshamy River weir was 46,226 fish. This was the fourth largest escapement to that system in the last 25 years and only the fifth time that the 40,000 fish escapement goal was met. The escapement of sockeye salmon to Jackpot lake was 5,495 fish.

Adjustment of Aerial and Ground Counts

Results of the regression analyses of ground and aerial counts of live fish in streams compared to estimates calculated from weir data (Equation 2) are summarized for all streams combined (Figure 5) and for individual streams (Figures 5 through 15). For all streams combined, both ground and aerial surveys were negatively biased estimators of escapement. Ground surveys were more accurate than aerial surveys at predicting fish in the stream (slope = 1.89 versus 2.98) and the fit of the regression estimates was better (R^2 =0.949 versus 0.495). This differs from 1990 results in which aerial surveys were unbiased with respect to ground surveys and is consistent with a higher proportion of spawning above the intertidal zone in the odd year cycle. Fish in upstream areas are more difficult to see from the air due to canopy and stream configuration. The fit of the regression line for ground surveys was unchanged when data points were removed for days when aerial surveys were not flown.

The results of regression analyses for individual streams are highly variable but the bias trends are the same as for all streams combined. Excluding suspect results from Totemoff Creek, the correction factor from regressions (slopes) range from 1.1 to 3.8 for aerial estimates and from 1.0 to 1.6 for the ground estimates.
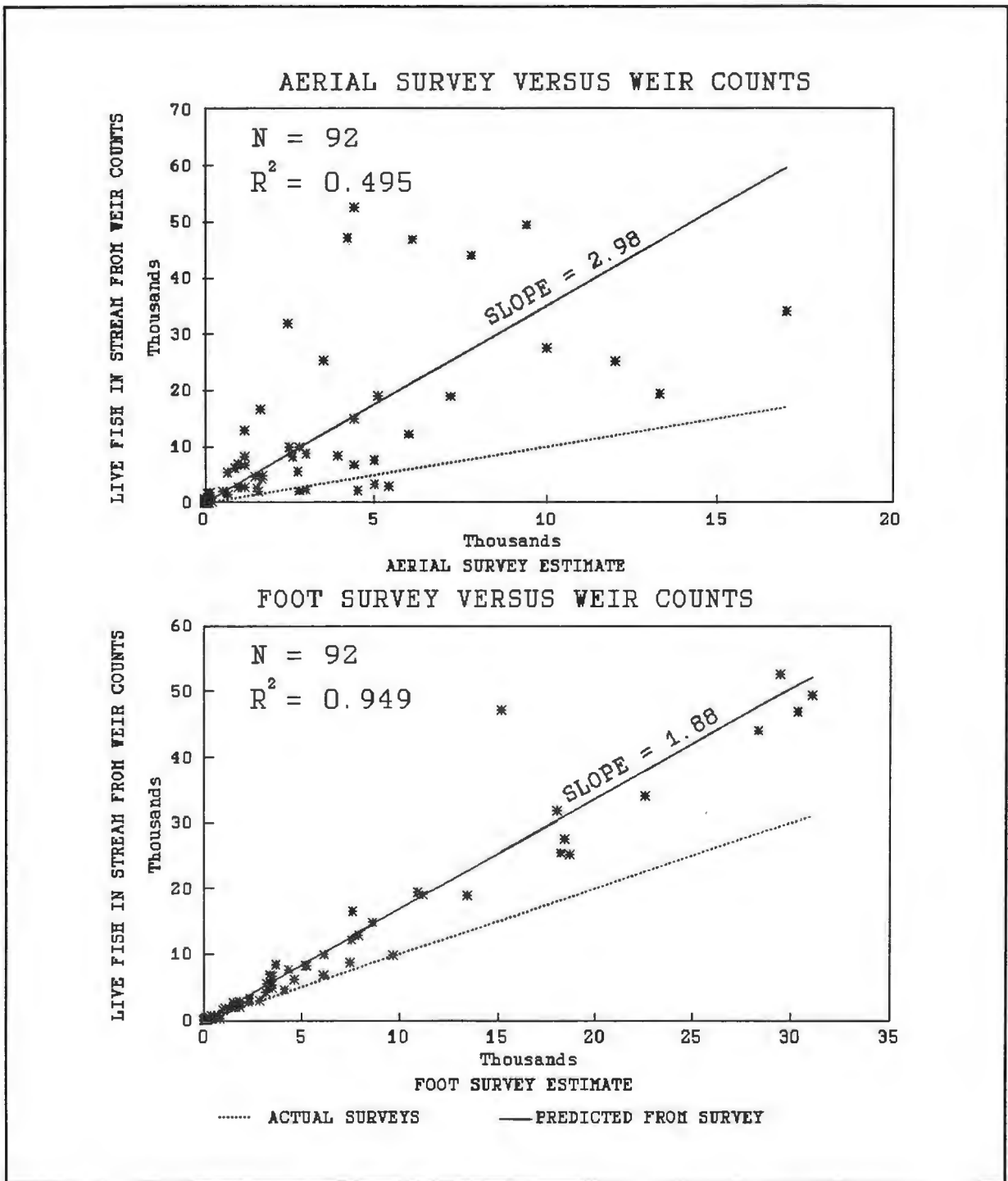
Figure 5. Regression of 1991 aerial counts and ground counts of pink salmon against concurrent weir and carcass counts.

Figure 6. Daily numbers of fish in Irish Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.
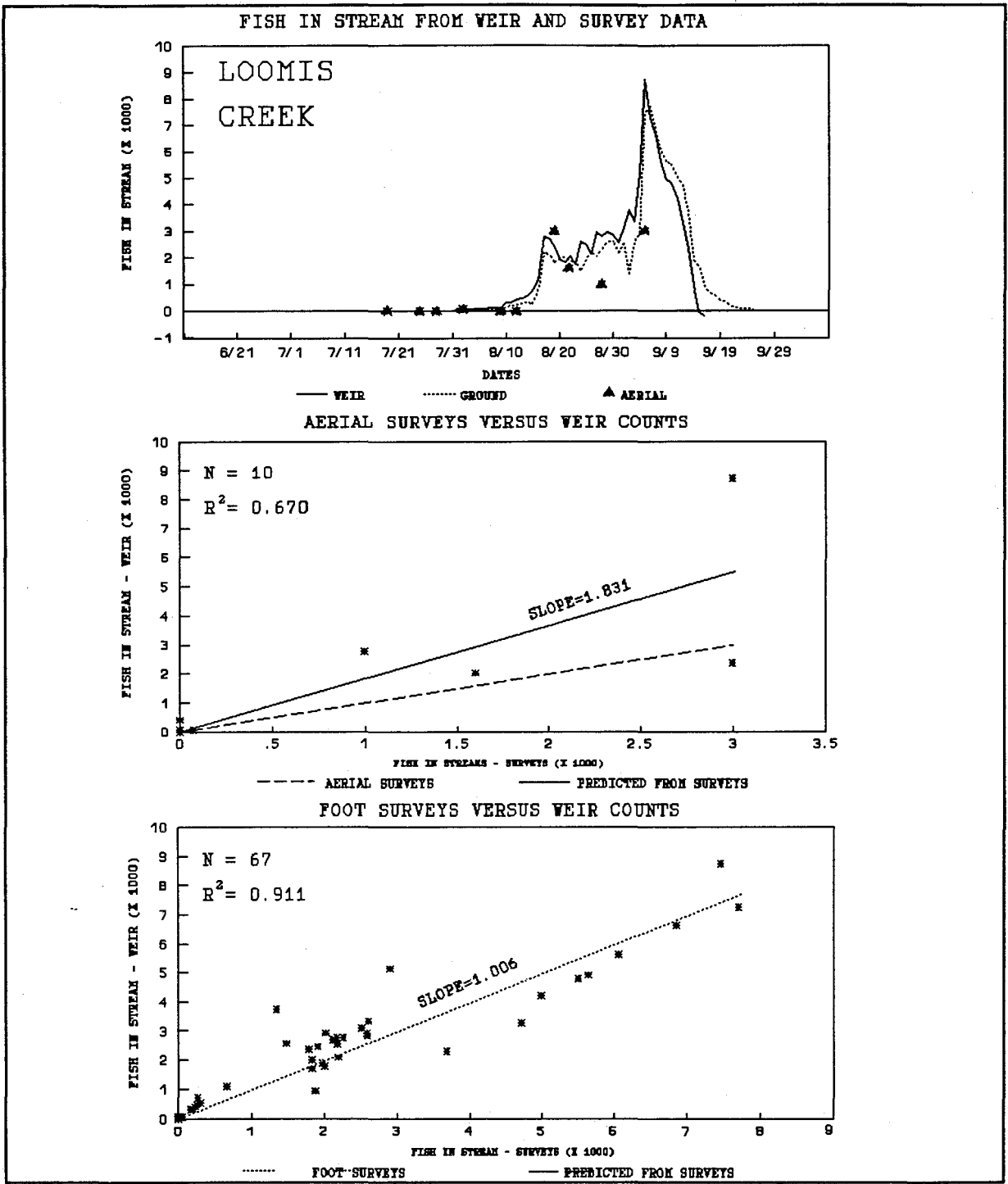
Figure 7. Daily numbers of fish in Loomis Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

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FISH IN STREAM FROM WEIR AND SURVEY DATA

TOTEMOFF CREEK

AERIAL SURVEYS VERSUS WEIR COUNTS

FOOT SURVEYS VERSUS WEIR COUNTS
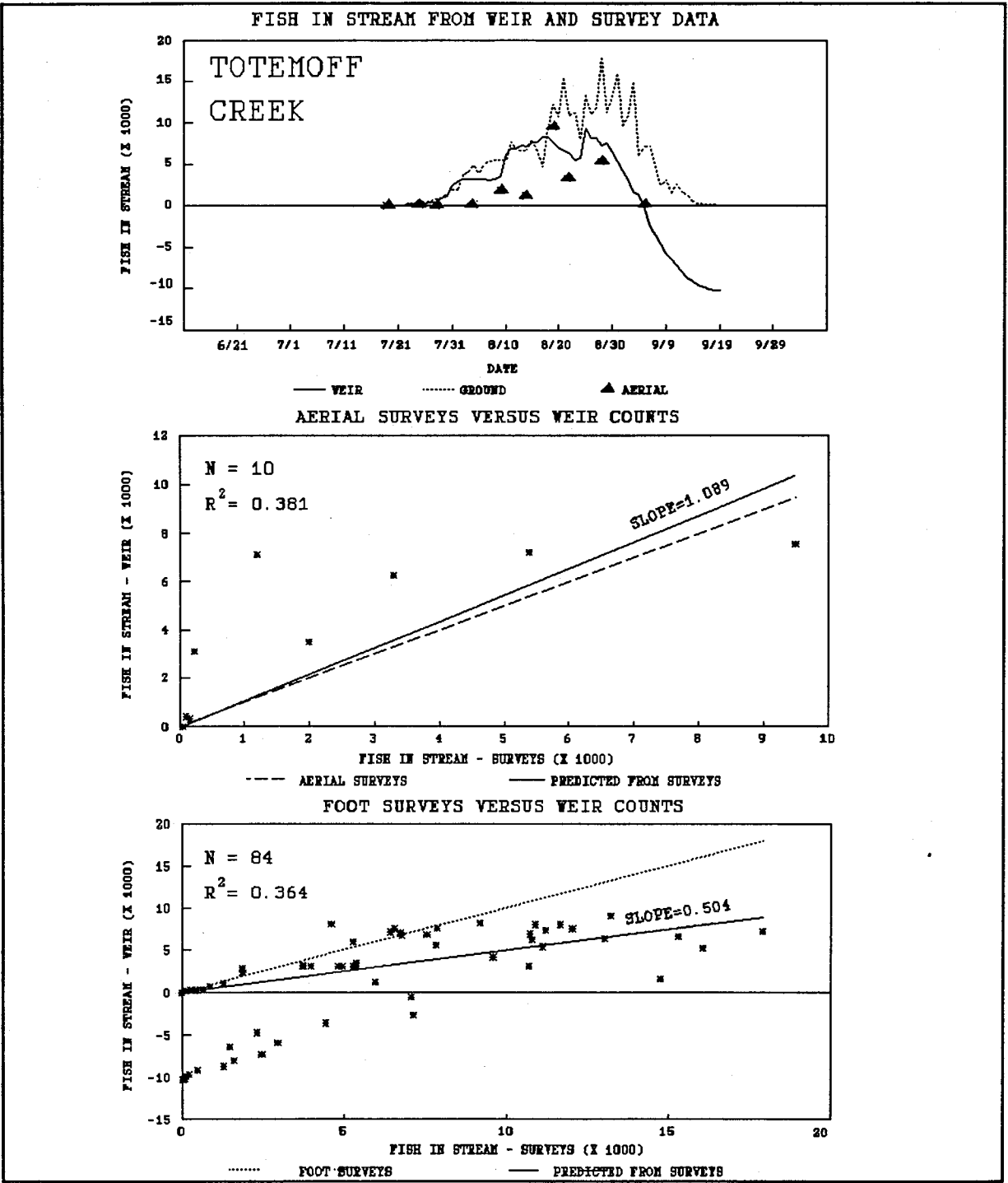
Figure 8. Daily numbers of fish in Totemoff Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

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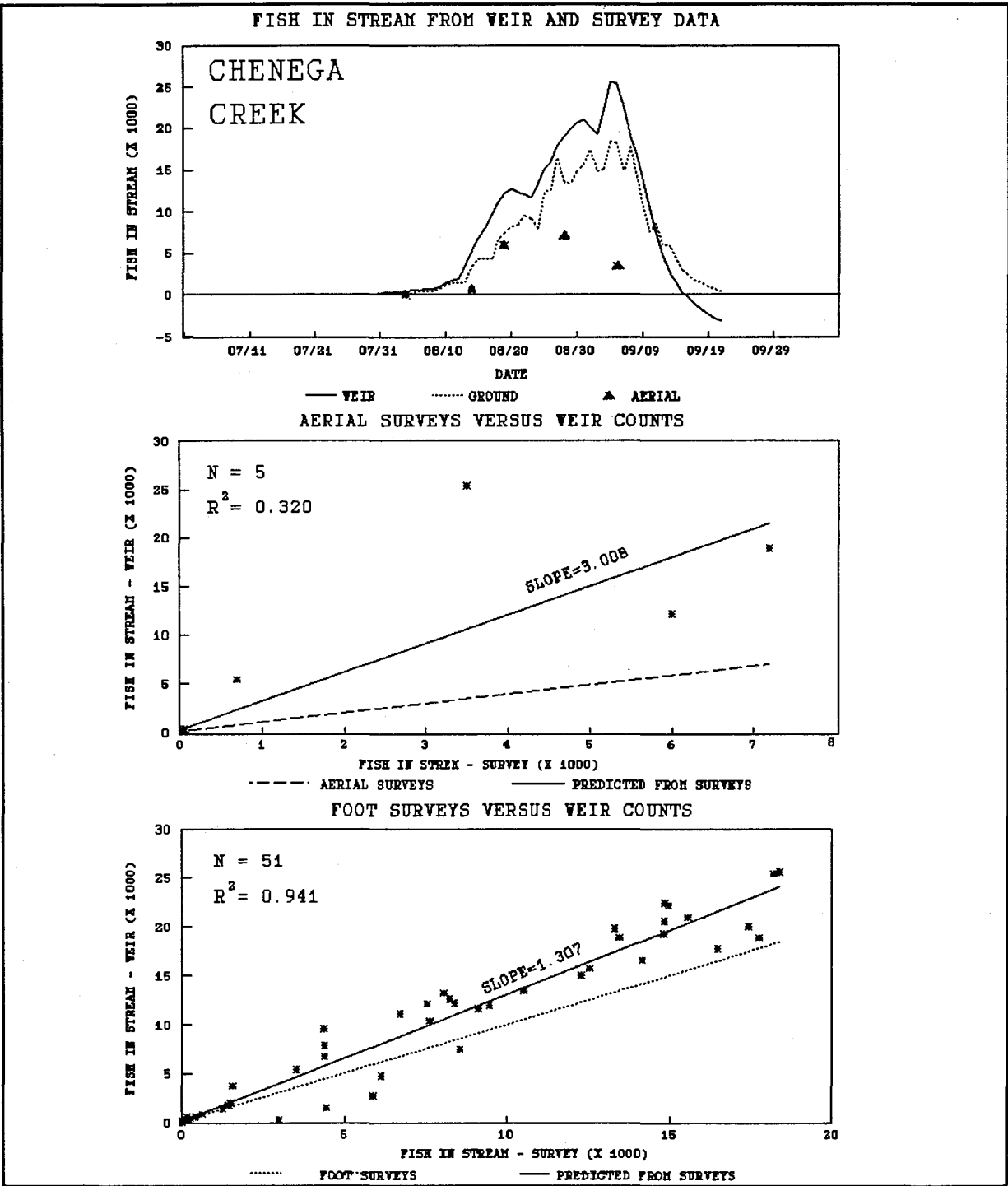
Figure 9. Daily numbers of fish in Chenega Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

27
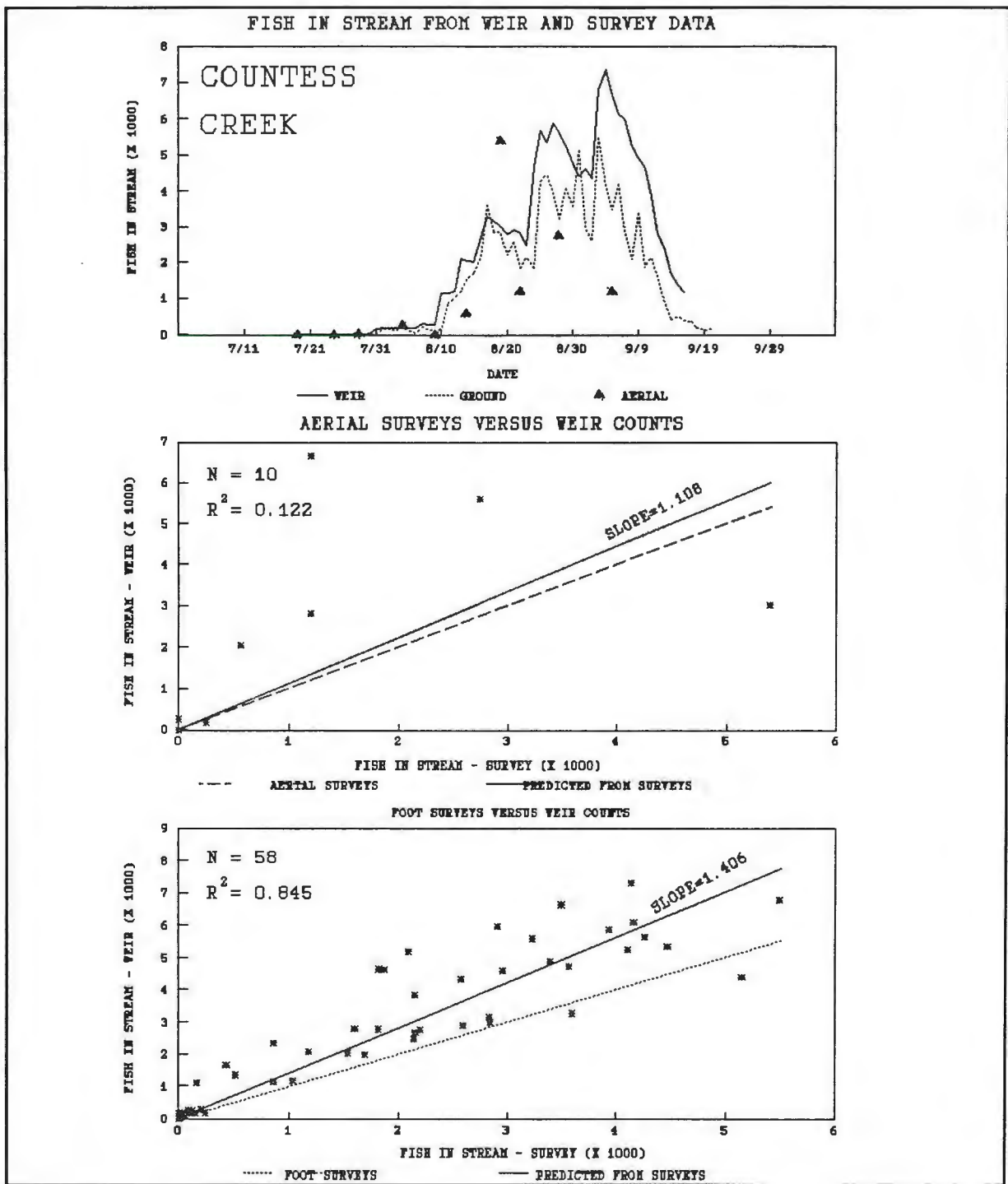
Figure 10. Daily numbers of fish in Countess Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

28
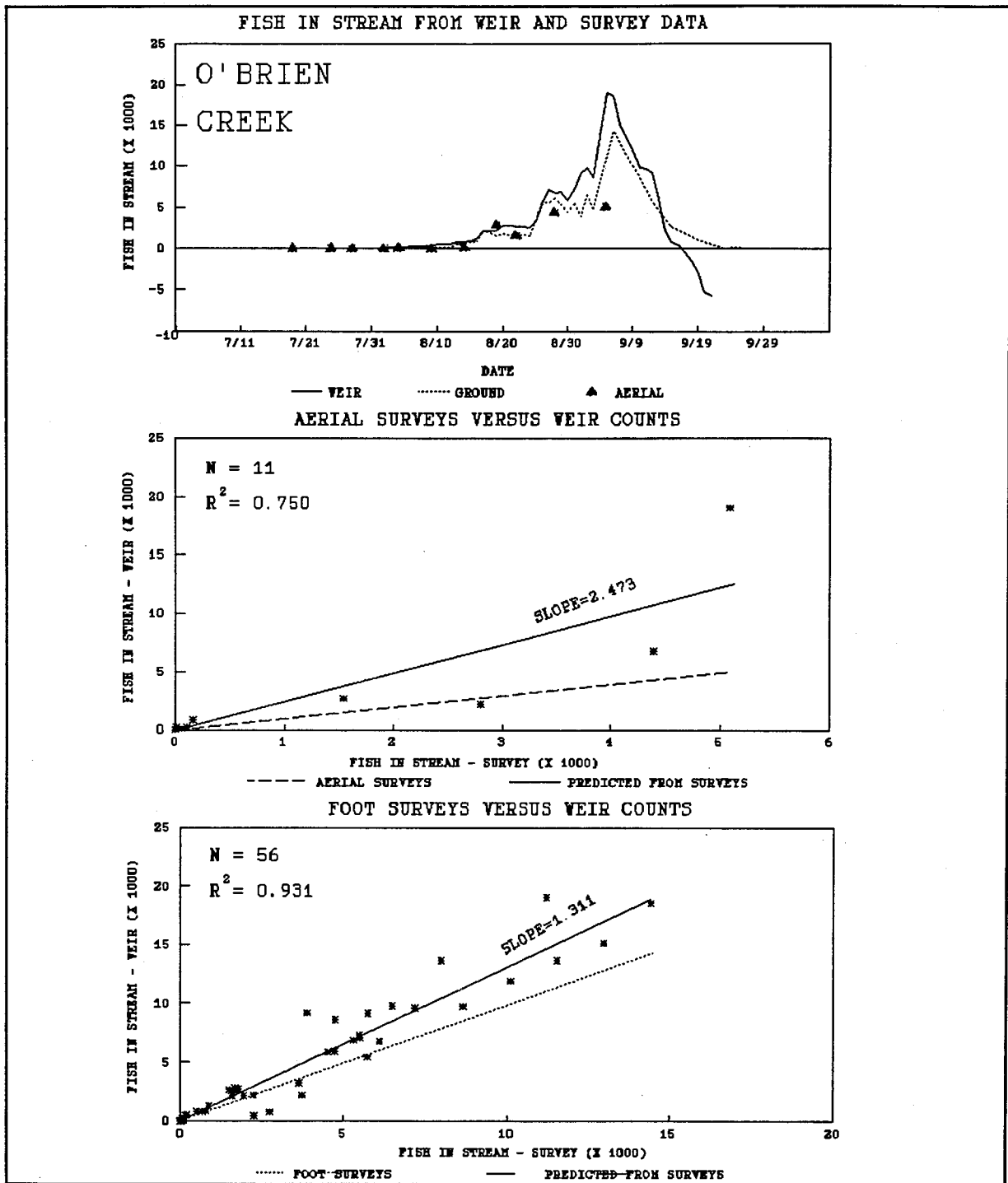
Figure 11. Daily numbers of fish in O'Brien Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

FISH IN STREAM FROM WEIR AND SURVEY DATA

AERIAL SURVEYS VERSUS WEIR COUNTS

FOOT SURVEYS VERSUS WEIR COUNTS
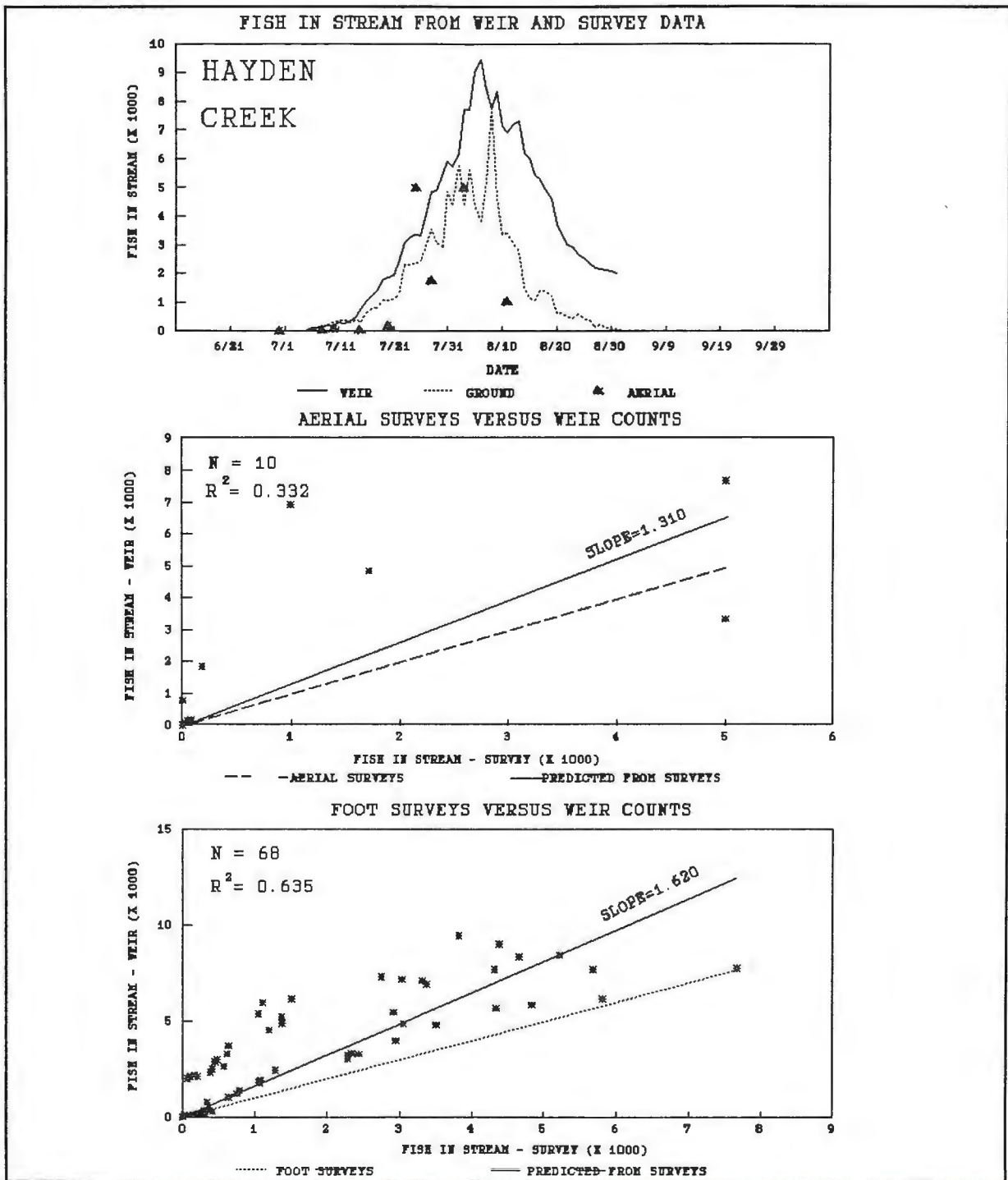
Figure 12. Daily numbers of fish in Hayden Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.
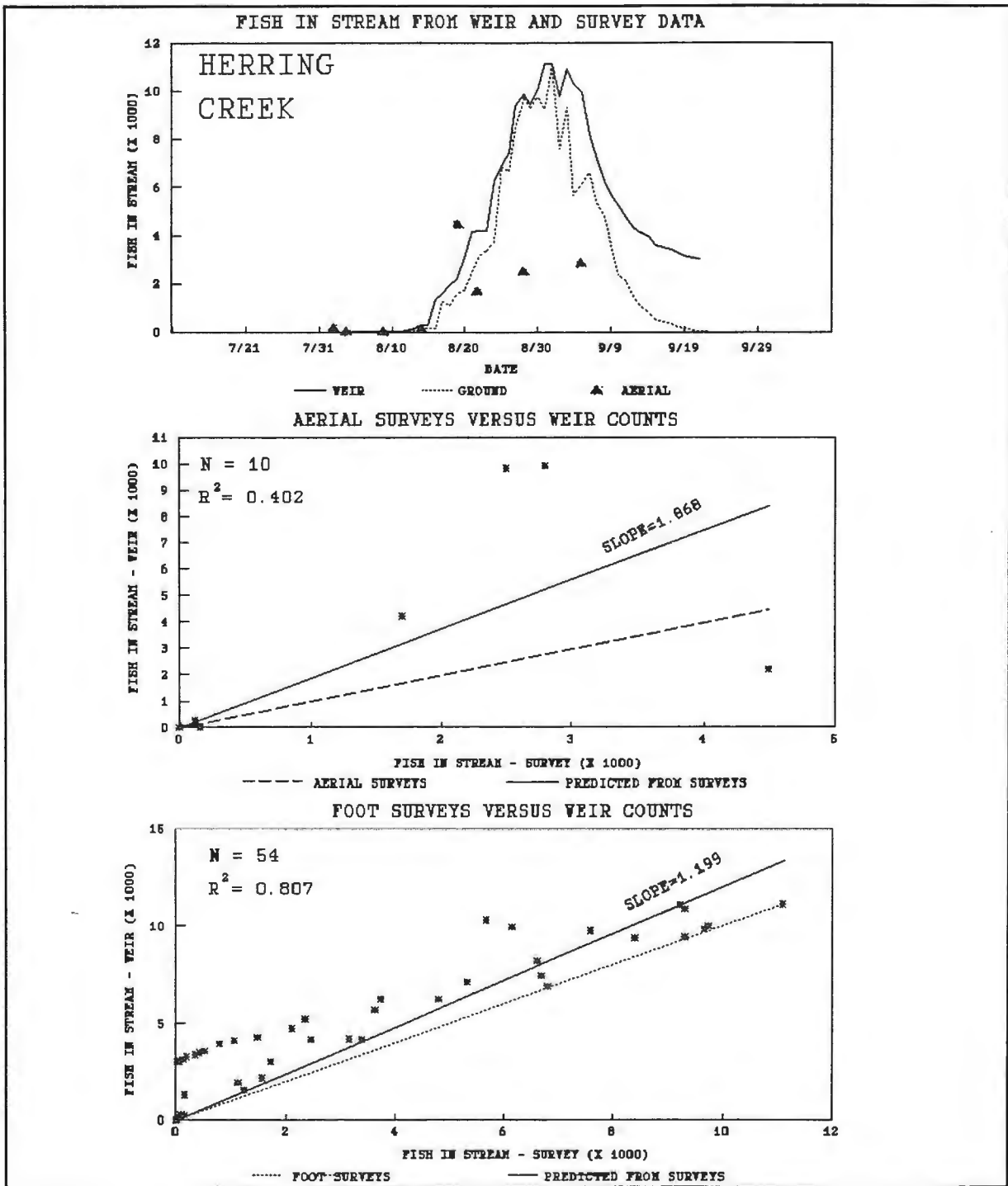
Figure 13. Daily numbers of fish in Herring Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.
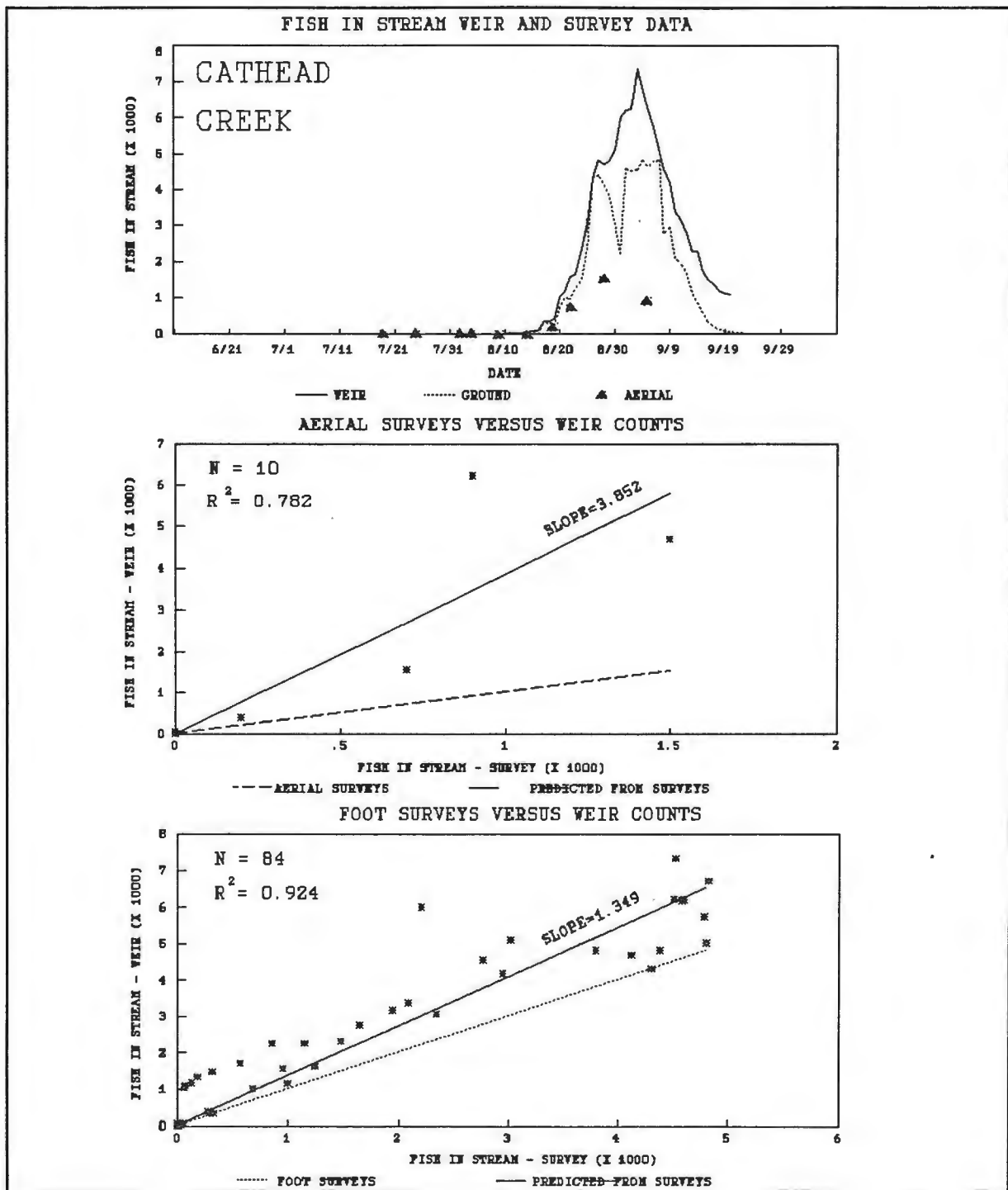
Figure 14. Daily numbers of fish in Cathead Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.
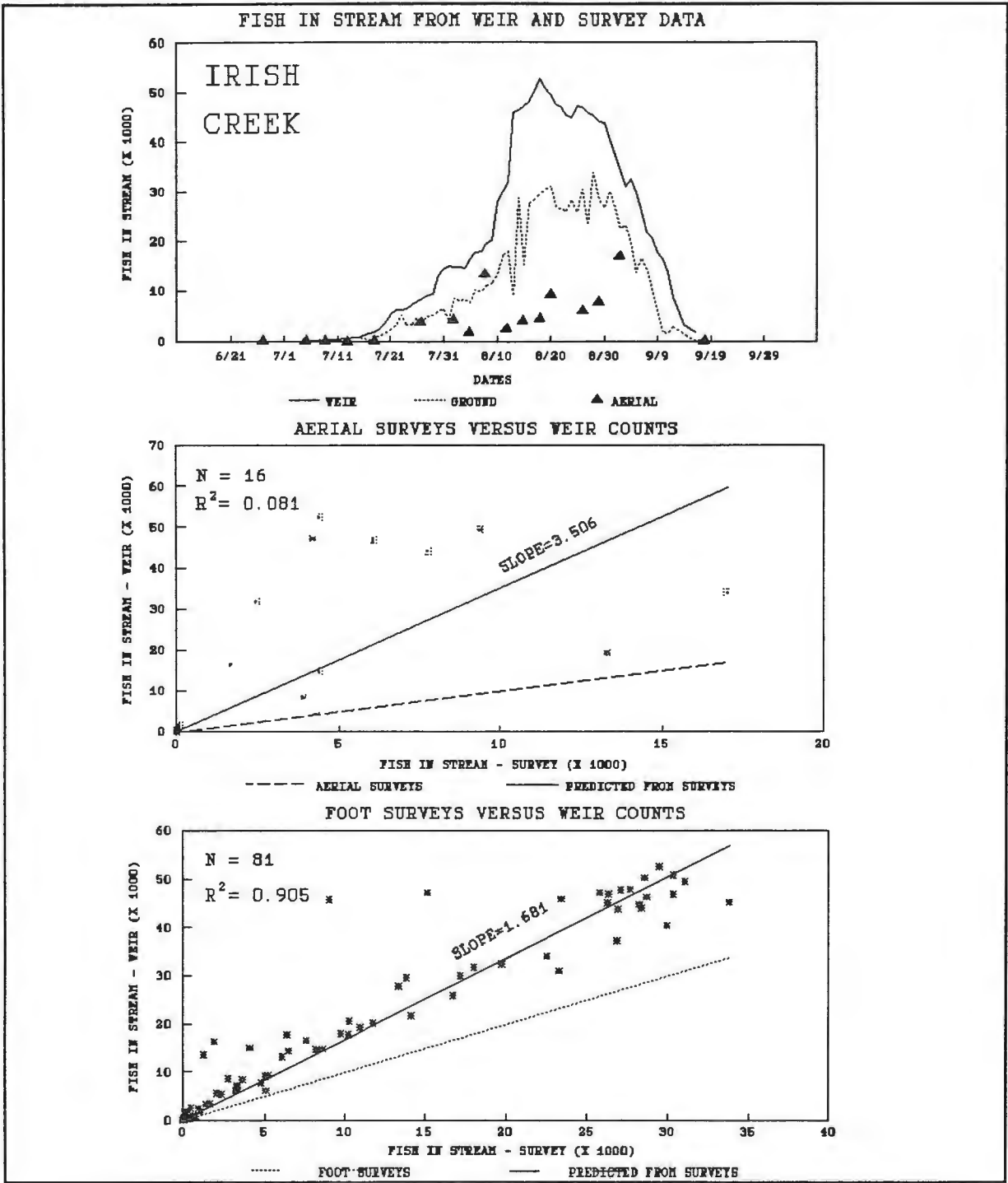
32
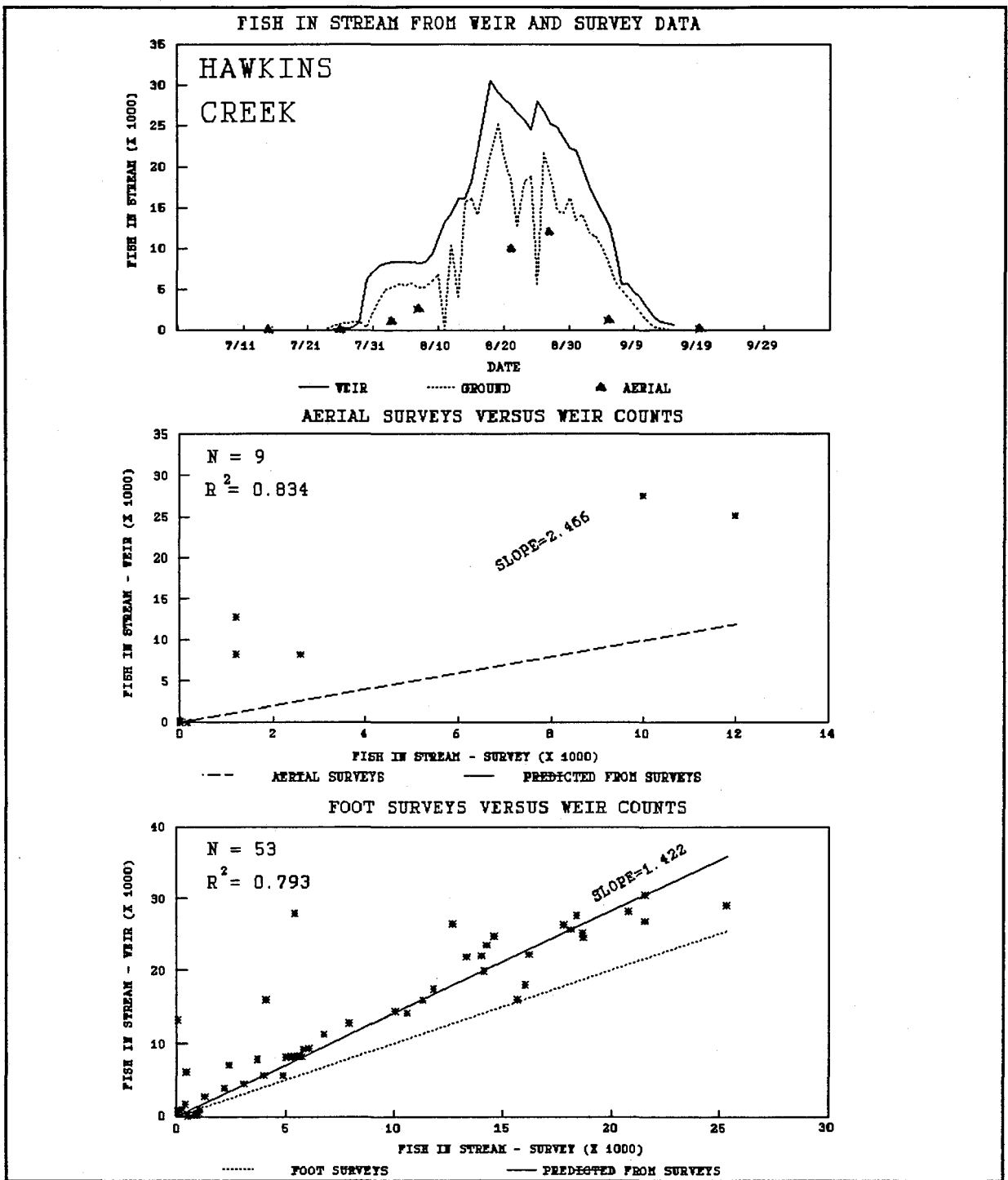
Figure 15. Daily numbers of fish in Hawkins Creek based on weir, ground survey, and aerial survey methods, 1991. Regressions of aerial and ground counts against concurrent counts from the weir are also shown.

Some of the error associated with estimating pink and chum salmon escapements from aerial survey data may be associated with using a stream life of 17.5 days. Results of studies by McCurdy (1984) and on five of eight streams surveyed for stream life in NRDA Study 1 in 1989 suggest stream life varies among streams and the 17.5 day estimate may be too large, especially for smaller streams. Results from 21 streams studied in 1990 by NRDA F/S Study 1 (Sharr et al. 1990) also indicate stream life is variable and shorter than 17.5 days for many streams in PWS.

Estimates Based on Tagging Data

Results of temporally stratified tagging studies in 1991 are summarized in Figure 5 and Appendix B. Approximately 30,000 tags were applied at 38 streams (Figure 2). Data entry for all streams is not complete and only results for weired systems have been summarized. At the weired sites 7,893 tags were applied. Weekly tagging strata ranged from three on small streams to as many as eight on large streams. Tag recoveries spanned nine weeks. Recoveries averaged 49.7% (3,925 total recoveries) and ranged from 20.7% to 78.7% across all streams and weekly strata (Appendix B.1.).

Stream life calculated solely on tag recovery data (Equation 3) ranged from 7.2 days to 21.9 days across all streams and weekly strata (Figure 16). Stream life estimates averaged across weekly strata for each stream ranged from 9.9 to 17.1 days and had a grand mean of 13.9 days (Table 2). This is slightly shorter than the 15.1 day average reported by Sharr et al (1990) using the same method on many of the same streams in 1990 and considerably shorter than Helle's (1964) estimate of 17.5 days which was made for the middle portion of the Olsen Creek return in eastern PWS. Stream life estimates for all streams and all but one weekly strata were shorter when adjusted for milling time at the stream mouth (Figure 16; Equation 4). Adjusted mean weekly stream life estimates ranged from 3.2 to 19.6 days across all strata and streams. Across all streams season average stream life estimates ranged from 6.8 to 13.9 days and had a grand mean of 9.8 days. Milling time at stream mouths ranged from 0.0 to 9.2 days across all weekly strata and streams. Season mean milling times across streams ranged from 1.9 to 6.1 days and had a grand mean of 4.1 days.

Weekly estimates of stream life unadjusted for milling time decreased significantly through time. Both Helle (1964) and McCurdy (1984) reported similar trends. Some of the decrease in the 1991 study can be ascribed to milling time which also decreased through the season. Adjusted estimates of stream life also declined

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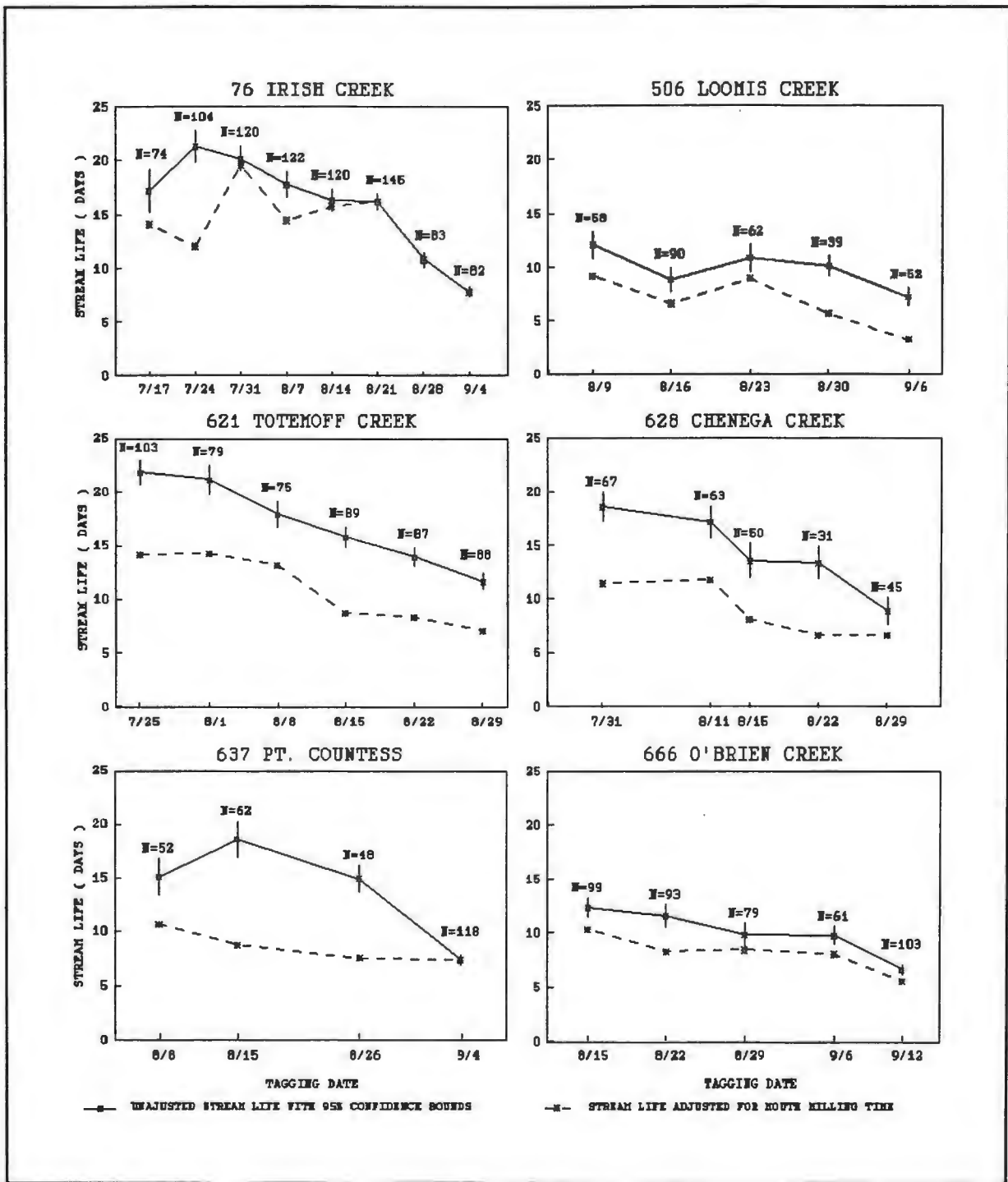
Figure 16. Weekly stream life estimates and 95% confidence bounds based on tagging studies for pink salmon in ten weired streams, 1991. Estimates adjusted for milling time are also shown.

677 HAYDEN CREEK

692 HERRING CREEK

699 CATHEAD CREEK

847 HAWKINS CREEK
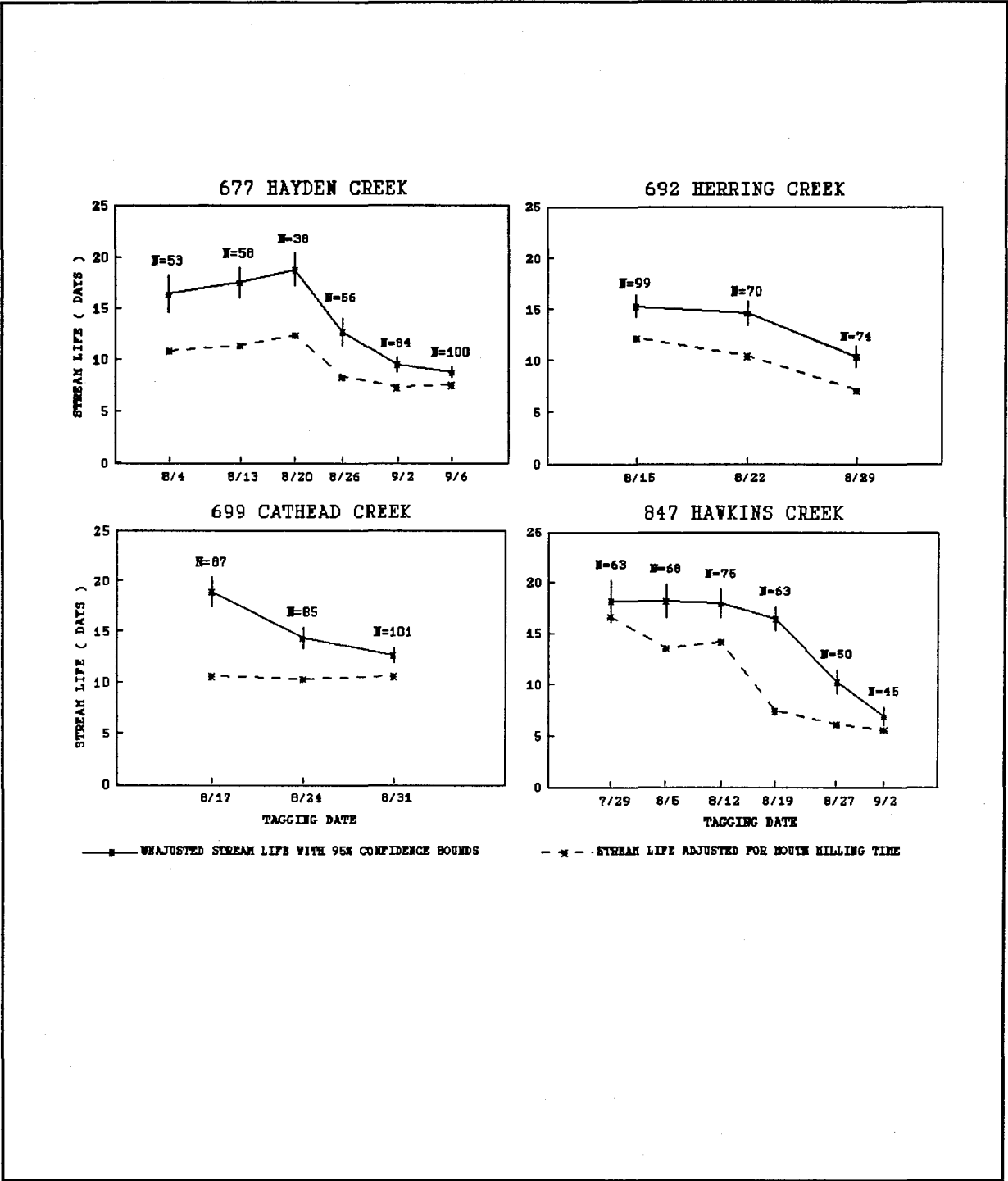
Figure 16. (continued).

significantly across the season for all but one stream (Cathead Creek, Figure 5). Mean adjusted stream life for fish tagged in all streams in the week ending 20 July was 14.1; days whereas, mean adjusted stream life was only 6.6 days for fish tagged in the week ending 7 September. Mean milling time increased slightly from the first to the second week of the study but from the week ending 21 July to the week ending 14 September declined from 8.4 days to 1.1 days. Seasonal decline in milling time was observed in all streams except Loomis Creek and Herring Creek (Appendix A).

Estimates Using Fish Days and Total Escapement

Estimates of stream life based on daily weir counts and daily counts of dead fish (Equation 5) and estimates based on daily counts of live and dead fish (Equation 6) are presented in Table 1. With the exception of Totemoff Creek, stream life estimates from weir data are larger than from ground survey data and in general correspond more closely to results from tagging. This is not surprising since negative bias associated with the ground counting method results in an estimate of fish days which is too low, hence a stream life estimate which is too low.

The stream life estimate from weir data at Totemoff Creek is only 3.4 days. The estimate from ground survey data of 9.1 days much more closely matches the 11 day estimate from tagging. These results tend to corroborate the "leaky weir" hypothesis for that stream. Low weir counts would result in an low estimate of fish days whereas the ground estimate of fish days may be fairly good.This suggests ground surveys of Totemoff Creek may have a fairly small negative bias.

Estimates From Run Timing

Estimates of stream life based on the difference between the mean dates of dead fish counts and passage of live fish through weirs (Equation 8) or the estimates of mean date of live fish counts on ground surveys (Equation 7) are presented in Table 1. With the exception of Herring Creek, stream life estimates from weir data are larger than from ground survey data and in general correspond more closely to results from tagging. The two estimates are indistinguishable at Herring Creek and very similar to the tagging estimate. Estimates based on run timing are based on relative counts between days. If counting errors at Totemoff Creek weir were independent of time, then the stream life estimate using the run timing method might be the best choice for that system in 1991.

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Total Escapement Estimates From Aerial Surveys

Pink salmon escapements were estimated using the geometric method (Equation 8) applied to aerial survey data for four streams in 1990 and 10 streams in 1991 (Table 2). All streams where estimates were made had weirs. Aerial data were adjusted using regression coefficients from aerial counts versus weir data for all streams except Totemoff Creek. Stream life values used in the estimates were based on fish days and total escapement through weirs for all streams but Totemoff Creek (Equation 5).

Totemoff adjustment coefficients for aerial counts in 1990 and 1991 were from aerial count to ground count regressions. The stream life estimate for Totemoff Creek was from ground survey fish days and carcass counts (Equation 6).

A total of 72,244 pink salmon were enumerated through four weirs in 1990. Escapements through the same weirs in 1991 totaled 159,748 fish. Aerial estimates of escapement to these four streams based on the geometric method (Equation 9) were negatively biased in both 1990 and 1991. Estimates which incorporated new stream life data and adjustment factors for aerial observer bias were more accurate than estimates using the traditional uncorrected survey data and a 17.5 day stream life for all streams. In 1990, adjusted estimates were 27.8% below the weir counts whereas the unadjusted traditional estimate was 40.8 % low. The traditional method performed more poorly in 1991 (-75.2%). Given the inflexibility of this method to changes in observer bias it is not surprising it performs poorly in the odd year when significant numbers of fish spawn in upstream areas and aerial observations are difficult. Conversely, the adjusted estimate improved to -17.1% in 1991 despite the increase in upstream spawners and a doubling of the number of fish to be estimated. Analyses for the other six weired streams provided similar results.

When all streams in the aerial survey program are categorized for adjustment factors and stream life values, the departure from the traditional escapement estimate can be quite significant. Stream life values and adjustment factors are now available for 20 streams in the 1990 return. The total escapement estimate for 209 streams in the aerial survey program increased from 1.3 million to 2.1 million fish when survey data were categorized and analyzed using these stream life and adjustment factor data.

The escapement estimate for all streams in the aerial survey program is incomplete pending final analysis of stream life data from streams which were not weired. However, an estimate of escapement using a traditional analysis has been completed and the results are compared to historic odd year trends (Figure 17). The mean odd year aerial escapement estimate in 209 streams surveyed annually by ADF&G since 1969 was 1.6 million The comparable aerial

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estimate for the 1991 escapement was almost 1.9 million fish (Figure 17). The sum of escapements to streams on the eastern side of Prince William Sound where commercial fishing effort was minimal after 15 July was slightly above average. Escapement to streams in the southwestern corner of the Sound were also above average and escapements on the large seaward islands in the Sound were considerable greater than average. Conversely, the sum of escapement for stocks along the north, and northwestern shores of the Sound were well below average.

The better than average performance of streams in the southwestern portion of the Sound in the face of very intense fish in that area for hatchery stocks is to a large extent attributable to harvest management strategies which were altered to protect wild stocks. Fishing in the Southwestern District was prohibited in areas which the weir, ground survey, and expanded aerial survey program results indicated escapement were below average. Restoration weirs at Countess Creek and Chenega Creek provided data which helped prompt management action which protected wild stocks in the southwestern PWS.

Hydrocarbon and Histopathology Analyses

Mussel samples from six of 118 sites sampled in 1989 had positive evidence of hydrocarbon contamination. Two sites where oil was visibly present in significant quantities during the oil survey conducted by NRDA Study 1 in 1989 and during the 1989 fry dig portion of NRDA Study 2 had mussel samples for which results were negative or inconclusive. Preliminary and incomplete results from 1990 mussel samples indicate definitive evidence for hydrocarbon contamination at two sites and inconclusive results for three others. One of the sites with positive results is the weired stream at Herring Bay and the other is a ground survey stream in Sleepy Bay. Two of the three sites with inconclusive results are also study sites for the current weir and ground survey program.

Restoration Strategies

Salmon stocks in Prince William Sound which were impacted by the Exxon Valdez Oil Spill are also heavily exploited in commercial, sport, and subsistence fisheries and can most effectively be restored through stock specific management practices designed to reduce exploitation on impacted stocks. The stocks in areas heavily impacted by the spill occur in mixed stock fisheries dominated by hatchery stocks and wild stocks from unaffected areas

PINK SALMON ESCAPEMENT INDEX
ODD YEARS 1969-1989 VERSUS 1991
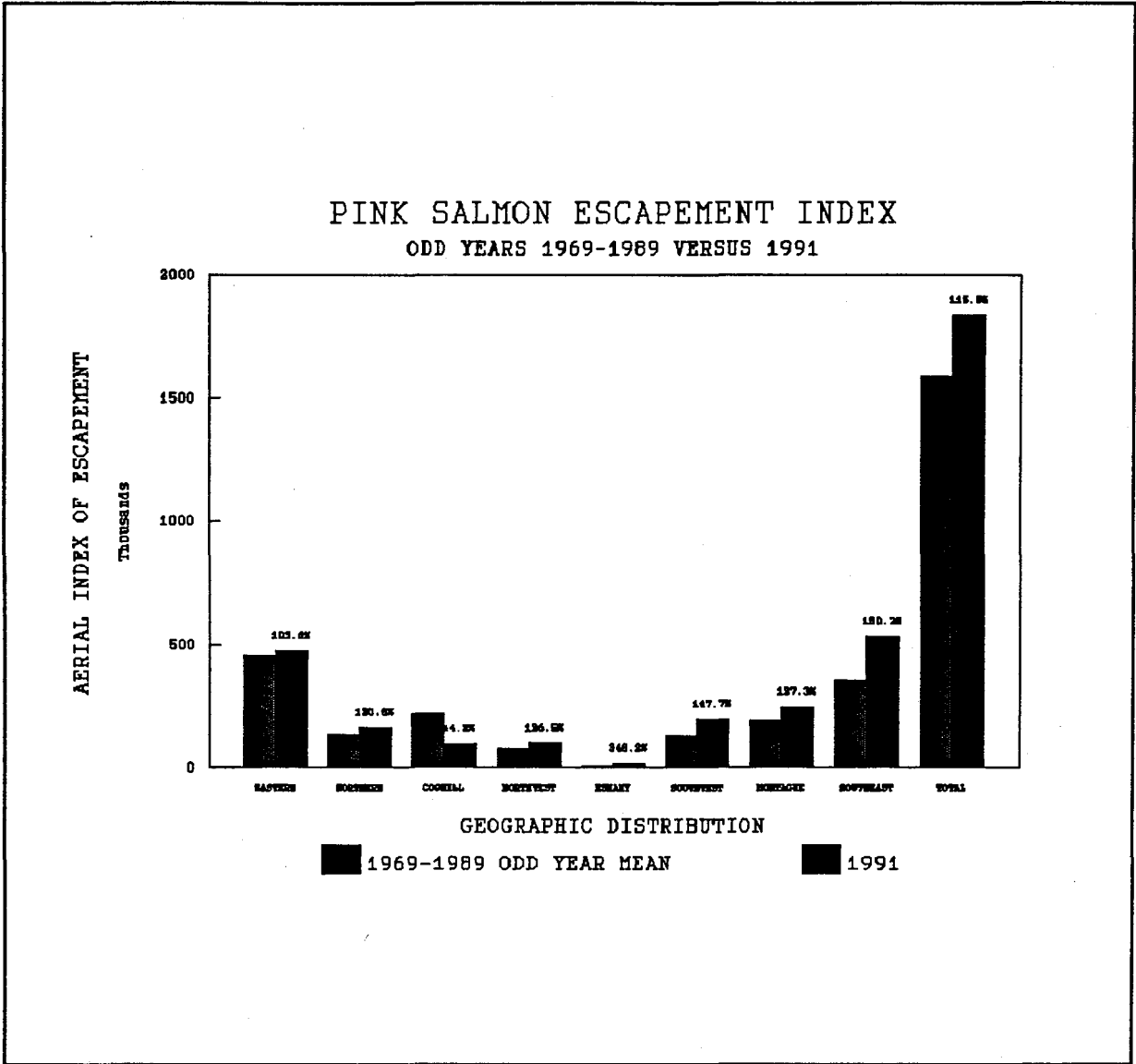
Figure 17 The relative size and distribution of 1991 pink salmon
escapements in Prince William Sound versus the average
for odd years from 1969 through 1989.

of the Sound. Restoration premised on stock specific management of the commercial fishery for reduced exploitation of impacted stocks will require the following:

1. Identification of impacted stocks through the NRDA process.
2. Determination of fisheries exploitation rates appropriate for facilitating the natural recovery of impacted stocks.
2. Accurate in-season escapement estimates for impacted and unimpacted wild stocks.
3. Accurate in-season estimates of the stock composition of the commercial catch by time and area.
4. Management action designed to reduce fishing effort on impacted stocks if results of escapement data and catch composition data indicate exploitation above levels desired to achieve restoration of the stock.The principal advantage of restoration strategies prefaced on more precise management are that the management framework is in place, the historic data base is sound, the research tools necessary for accurate escapement enumeration and catch stock composition estimates have been tested and established in the NRDA damage assessment arena, and regulatory mechanisms are all in place and well tested.

We have worked closely with the fisheries management and research staff of the Alaska Department of Fish and Game, Commercial Fisheries and FRED Divisions to develop a research and management package which will accomplish restoration objectives with minimal disruption of existing fisheries and fisheries management programs. Research projects have been proposed which are designed to provide the escapement estimates and catch stock composition estimates necessary for restoration predicated on improved management. A coded wire tagging and recovery project similar to NRDA F/S Study 3 is a key part of this package and will provide the catch stock composition estimates needed. An egg and fry sampling program has been suggested as an extension of NRDA Study F/S 2. In light of the demonstrated damages to this portion of the pink salmon life history in PWS the need for this program to monitor recovery is obvious.

The restoration process has already partially begun. Restoration Study 9 which resembles a scaled back version of NRDA F/S Study 1 was implemented in 1991. An expansion of the existing aerial survey program was also funded by the fishing industry. In it's first year, the program was used to implement area specific management which resulted in above average escapement to oil damaged portions of PWS despite very intense fish effort in surrounding waters.

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STATUS OF INJURY ASSESSMENT

Information to complete objectives 1 of this project, the determination of presence or absence of oil on intertidal habitat used by spawning salmon, was gathered during both the 1989 and 1990 field seasons. A survey of the distribution of oil contamination was completed for 441 Prince William Sound streams and included over half of the documented intertidal salmon spawning streams. The majority of streams which were not surveyed were located in portions of PWS unlikely to have received oil. Survey data have been entered on computers and preliminary summaries of the information were presented in the 1989 preliminary status report (Sharr et al. 1990). Mussel samples taken in 1989 from the intertidal zone at the mouths of 118 streams have been analyzed. Results corroborated categorization of streams as oiled and control in all but two instances. Analyses of mussel samples taken in 1990 in the mouths of 135 streams are only partially complete but continue to support our oiled and unoiled categories.

To meet objective 2, nearly all streams surveyed in 1989 and 1990 under objective 1 were photographed, the intertidal areas of oiled streams were mapped, and the type and extent of oil contamination were recorded. Results have also been forwarded to investigators in the coastal habitat studies.

Sampling to meet objective 3 was completed at the same 22 sites (12 oiled and 10 control) in 1990 and in 1991. Some of the histopathology results are now back from David Hinton's Laboratory at the University of California, Davis. The statistical analyses of the results are not complete.

The requirements for objective 4 were exceeded for both NRDA F/S Study 1 and for Restoration Study 9. Daily ground surveys within standardized intertidal and upstream zones were completed on 51 streams in 1991. Data have been entered for all surveys and preliminary analyses of the ground survey data from weired systems is partially complete. Analysis of tidal zone spawning distribution is still pending as are comparisons of variability of counts between and within replicate surveys for individual surveyors.

The requirements of objective 5 were met for both NRDA F/S Study 1 and Restoration Study 9. Seven NRDA weirs and three Restoration weirs were constructed and operated very successfully through the 1991 season. The restoration weirs in the southwestern portion of PWS were already provided data which was used inseason to justify altered harvest management strategies. Weired streams were among those included in aerial survey, ground survey, stream life, and egg and pre-emergent fry studies. The concurrent data from all these studies is unique and has provided the first opportunity in the 30 year history of the PWS survey program to assess the

accuracy of escapement estimates based on systematic survey and stream life data.

Objective 6 was related to objective 4 and was also met. In addition to the weir projects already described, a large set of paired ground and aerial observations (n=92) were made in 1990. These paired observations have been analyzed together with weir data. Estimates of escapement from aerial data were negatively biased with respect to estimates from weirs and ground survey data but negatively biased when compared to weir counts. Methods for improving aerial escapement estimates have been examined and when applied to 1990 data, removed more than 60% of the error which results from using traditional methods.

The requirements of objective 7 have been exceeded by both the NRDA and Restoration projects. Stream life studies were conducted on 48 streams in 1991. Three methods for estimating stream life using tagging data, weir counts, and daily counts of live and dead salmon have been investigated. A fourth method using only aerial counts is much more complex and is still under investigation. Analyses of 1991 data for stream life estimates are complete for 10 weired streams and underway for the remaining streams. All streams in the aerial survey index program have now been categorized as resembling at least one stream for which we have valid stream life estimates.

Objective 8 is nearly met pending final results from stream life studies on data from unweired systems in 1991. From preliminary results in 1991 it is apparent that bias correction factors for even and odd years are quite different and reflect differences in within stream spawner distributions between the two cycles. Analysis of historic odd year data will require completion of 1991 estimates of stream life and aerial bias for all 51 streams studied. A preliminary analysis of even year aerial data from 1990 has been completed. Using new stream life estimates and aerial bias correction factors, the 1990 escapement estimate was 2.1 million fish. This exceeds the estimate using traditional methods by 800,000 fish.

To meet objective 9, ground level and aerial photos were compiled for all of the 51 streams in the ground survey program and aerial photos are available for all 218 streams in the current ADF&G aerial survey program. Stream maps of the intertidal and lower upstream portions of 138 streams in the ground survey program in 1989 and 1990 and 51 streams in the 1991 NRDA and Restoration projects are complete and in most instances maps of streams in NRDA Study 2 have been annotated with information about spawner densities and distribution.

Objective number 10 was exceeded. Weir and ground survey crews recovered coded wire tags at the six weired streams where tags were originally applied and on 26 additional streams where no tags were applied. These data will provide a unique opportunity to

examine straying rates among wild stocks of pink salmon and between wild and hatchery stocks.

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APPENDIX A. DAILY WEIR DATA

IRISH CREEK WEIR

DAILY PASSAGE OF PINK SALMON
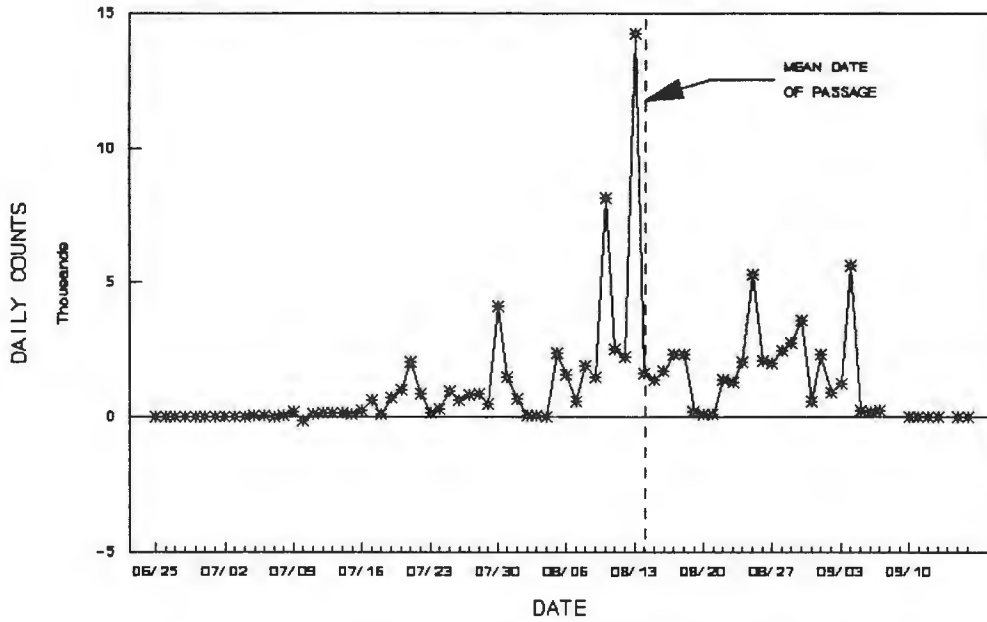
CUMULATIVE PASSAGE OF PINK SALMON
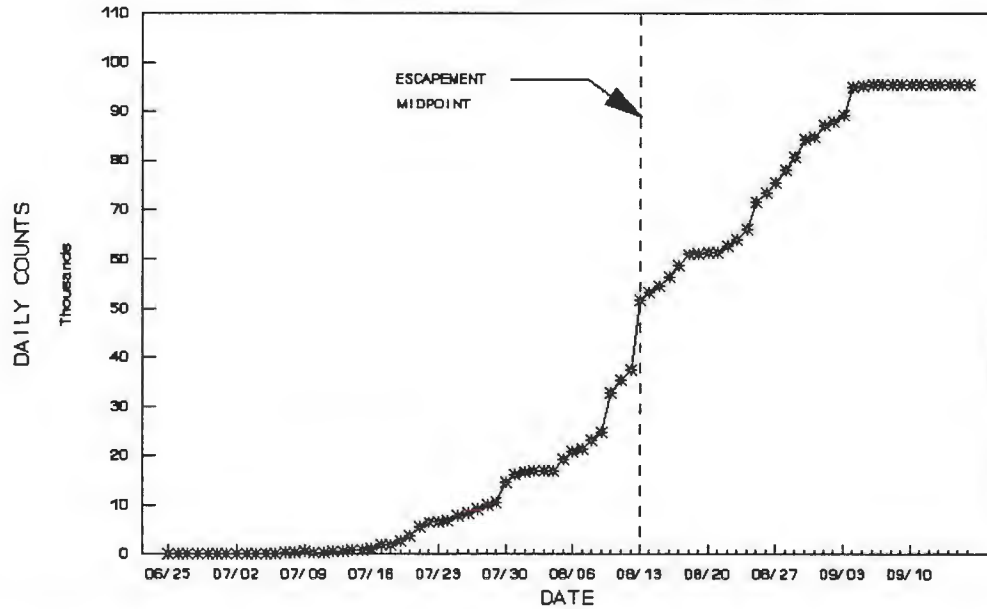
Appendix A.1.   Daily and cumulative escapements of pink salmon through the weir at Irish Creek, 1991.

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LOOMIS CREEK WEIR

DAILY PASSAGE OF PINK SLAMON
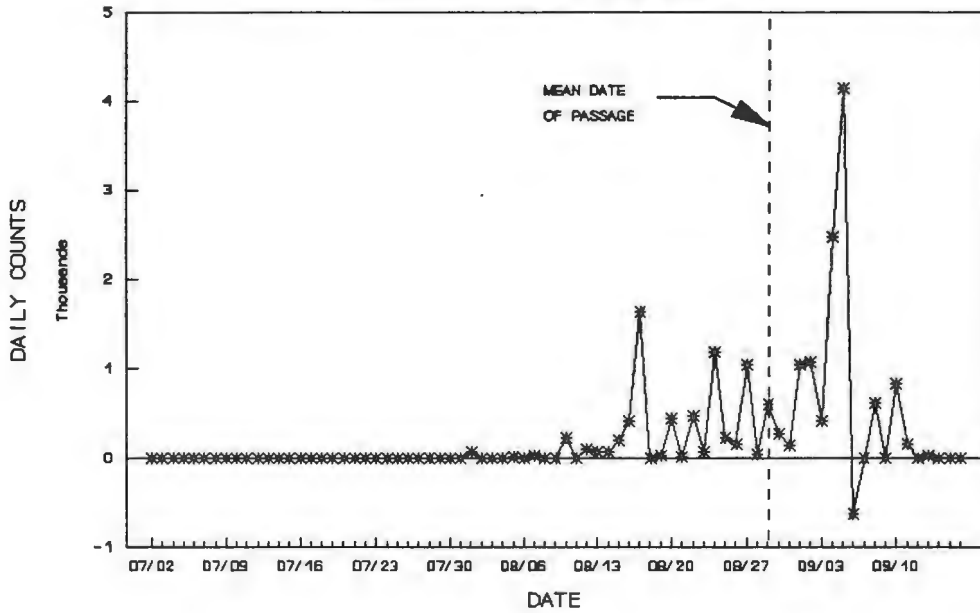
CUMULATIVE PASSAGE OF PINK SALMON
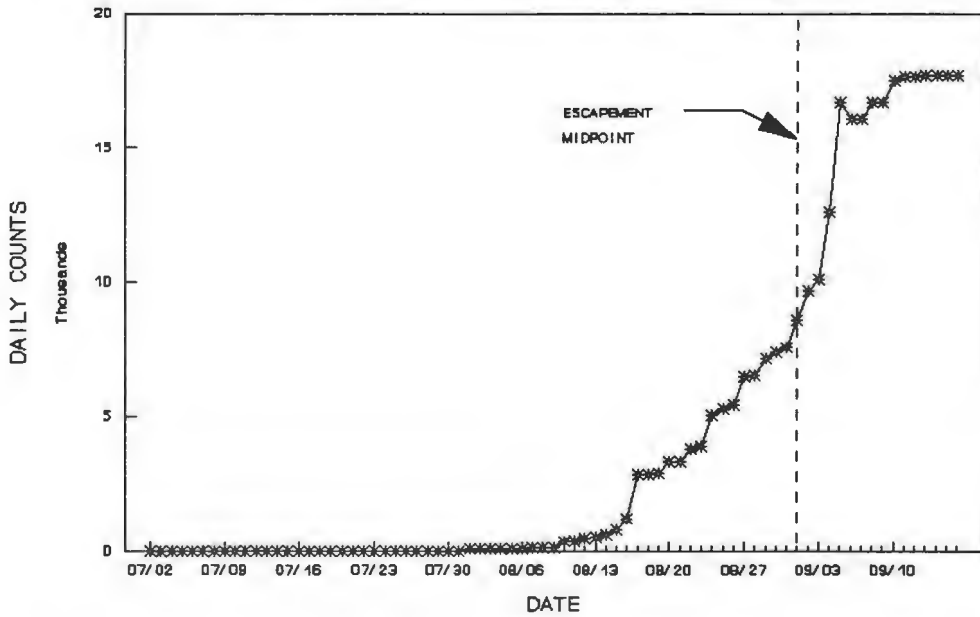
Appendix A.2.   Daily and cumulative escapement of pink salmon through the weir at Loomis Creek, 1991.

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Totemoff Creek Weir

DAILY PASSAGE OF PINK SALMON
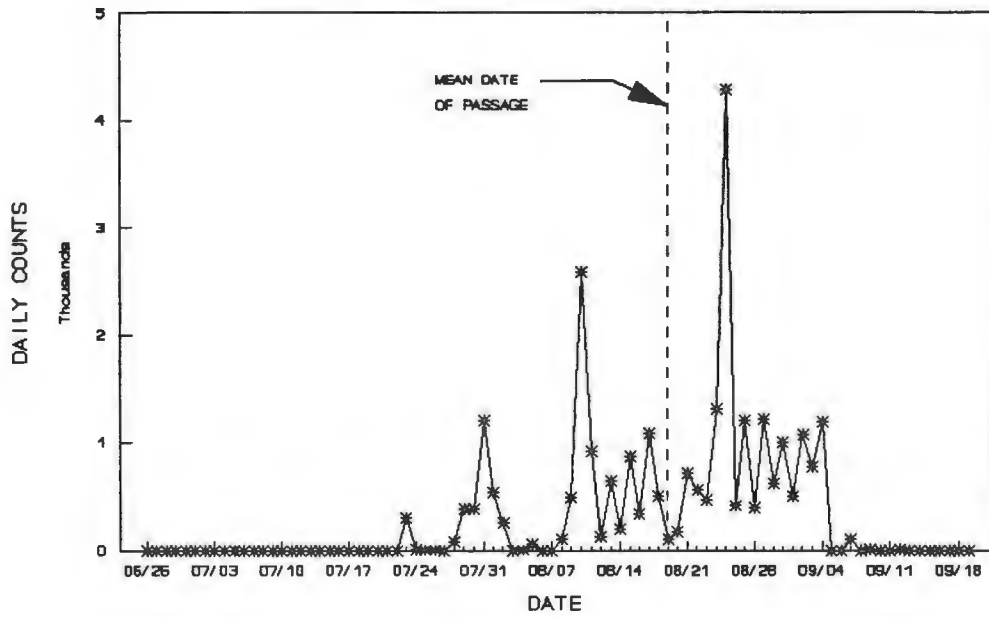
CUMULATIVE PASSAGE OF PINK SALMON
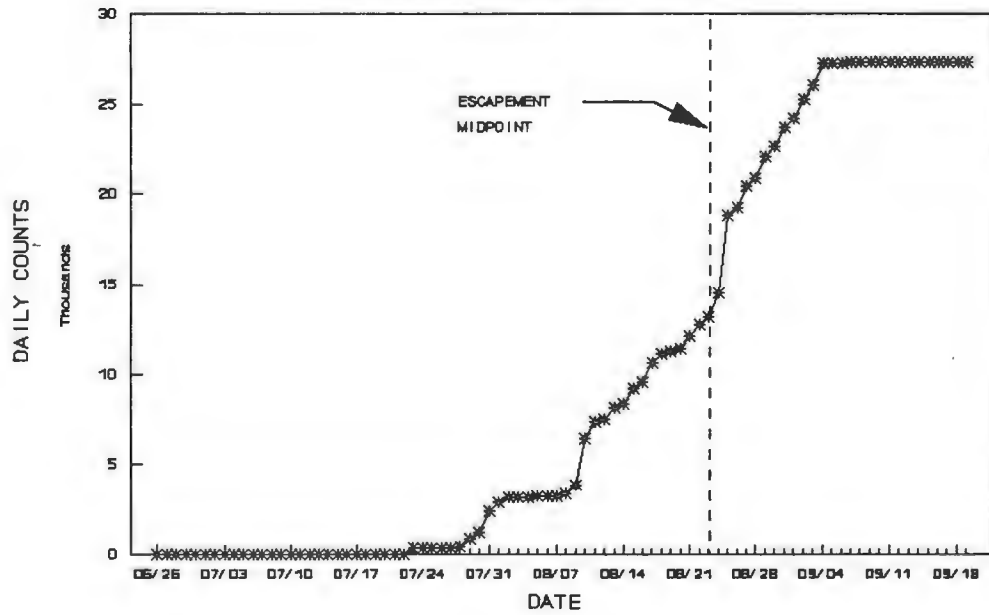
Appendix A.3. Daily and cumulative escapement of pink salmon through the weir at Totemoff Creek, 1991.

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Chenega Creek Weir

DAILY PASSAGE OF PINK SALMON
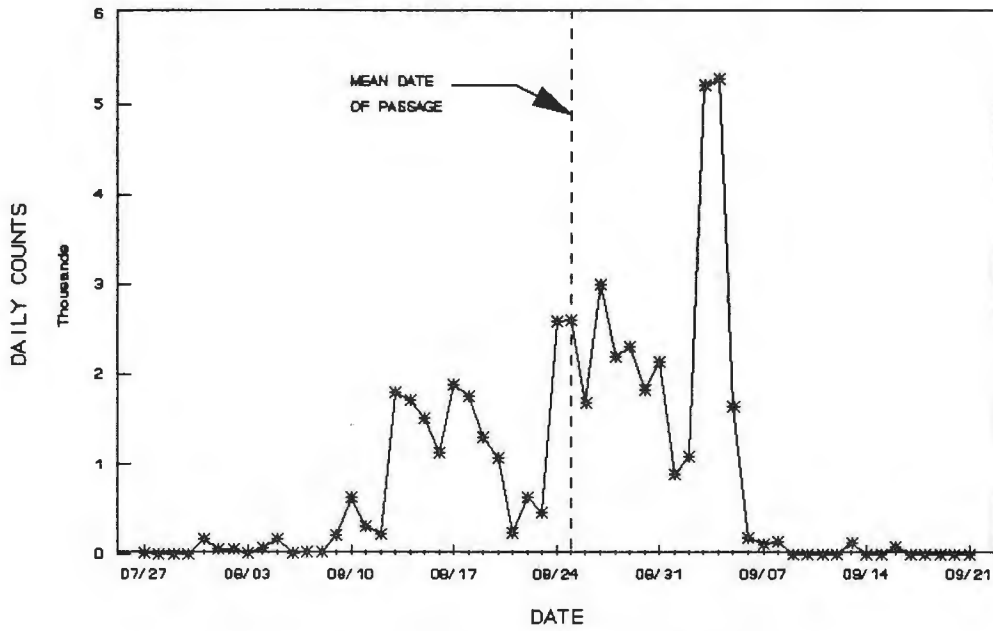
CUMULATIVE PASSAGE OF PINK SALMON
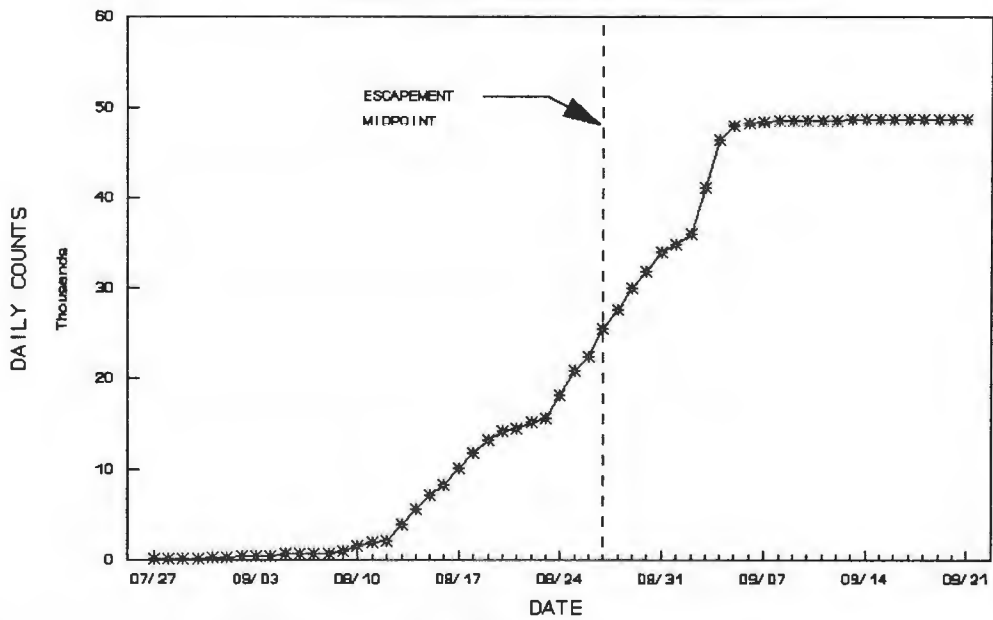
Appendix A.4. Daily and cumulative escapement of pink salmon through the weir at Chenega Creek, 1991.

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Pt. Countess Creek Weir
DAILY PASSAGE OF PINK SALMON
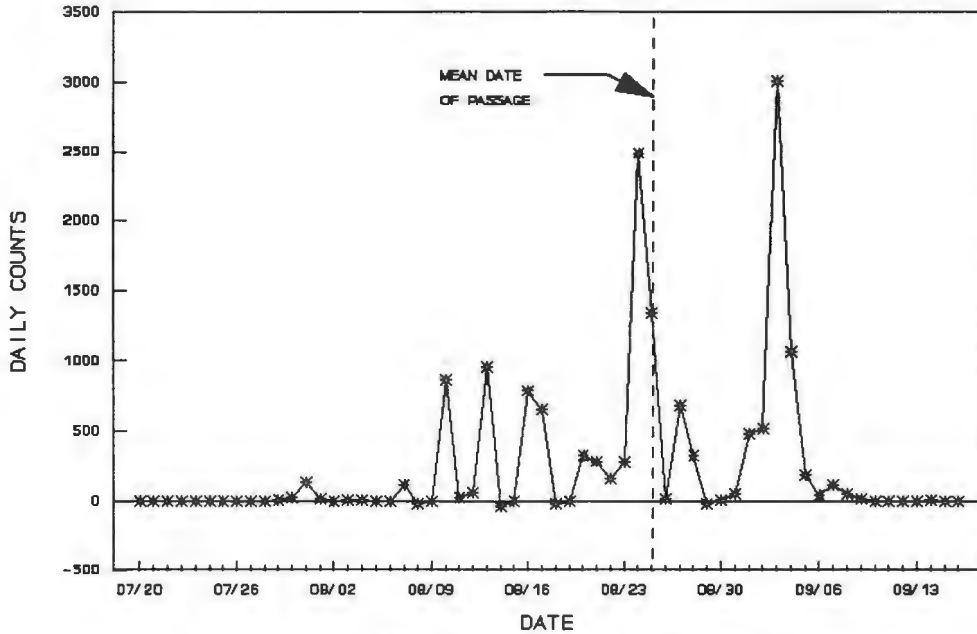
CUMULATIVE PASSAGE OF PINK SALMON
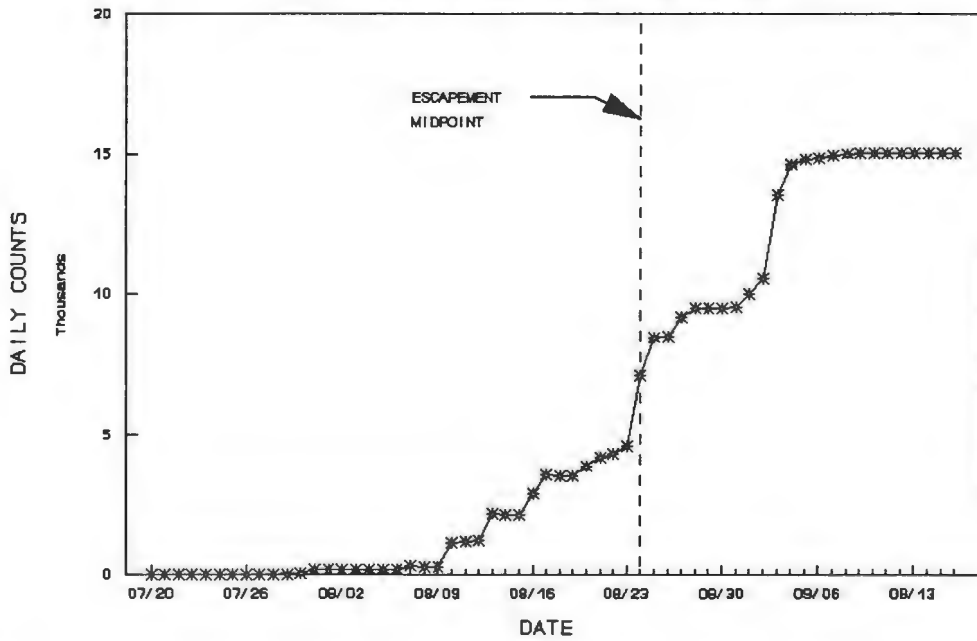
Appendix A.5. Daily and cumulative escapement of pink salmon through the weir at Countess Creek, 1991.

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O'Brien Creek Weir

DAILY PASSGE OF PINK SALMON
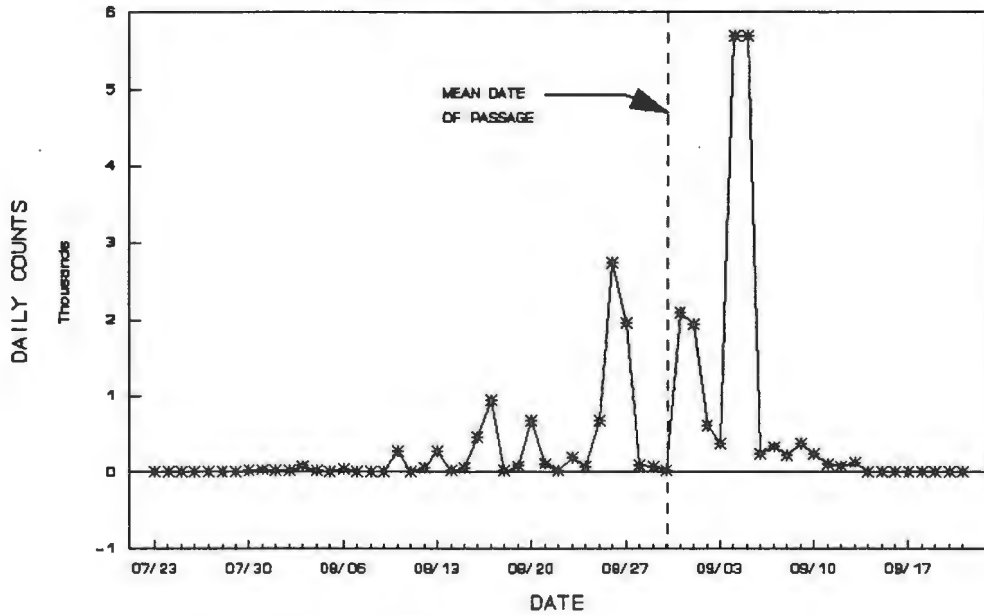
CUMLUATIVE PASSAGE OF PINK SALMON
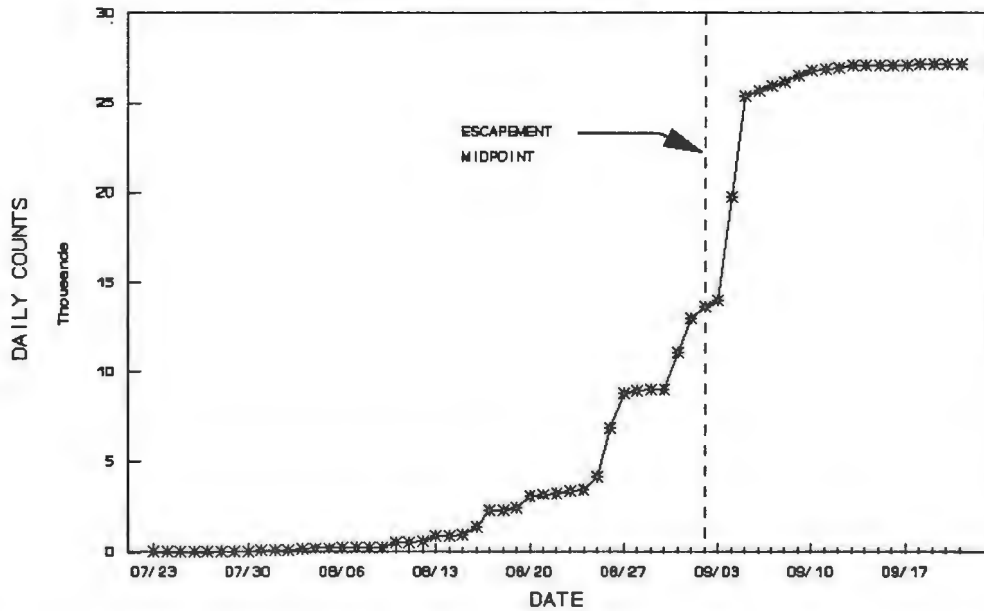
Appendix A.6. Daily and cumulative escapement of pink salmon through the weir at O'Brien Creek, 1991.

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Hayden Creek Weir

DAILY PASSAGE OF PINK SALMON
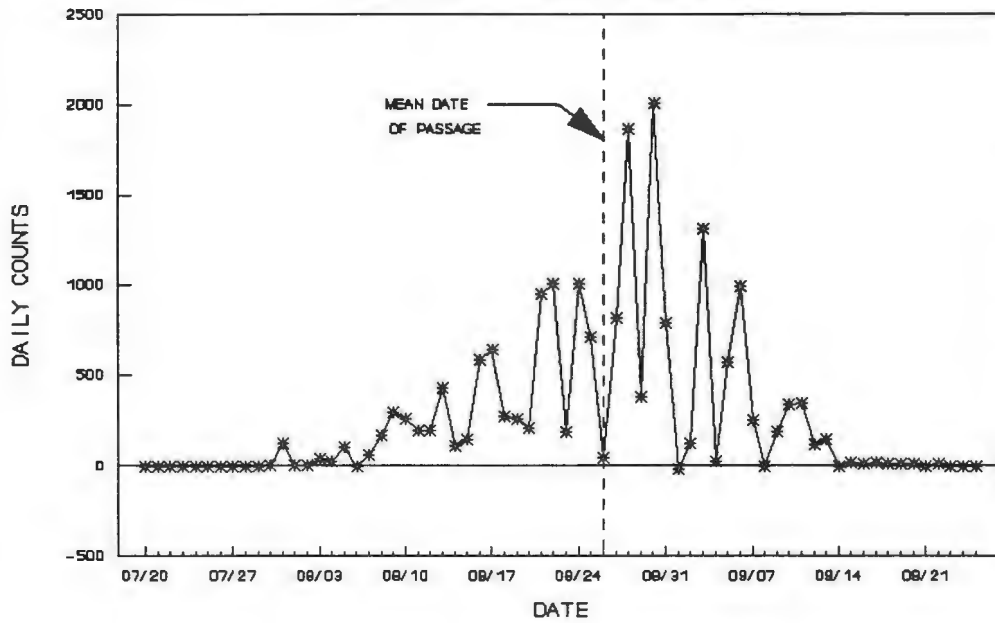
CUMULATIVE PASSAGE OF PINK SALMON
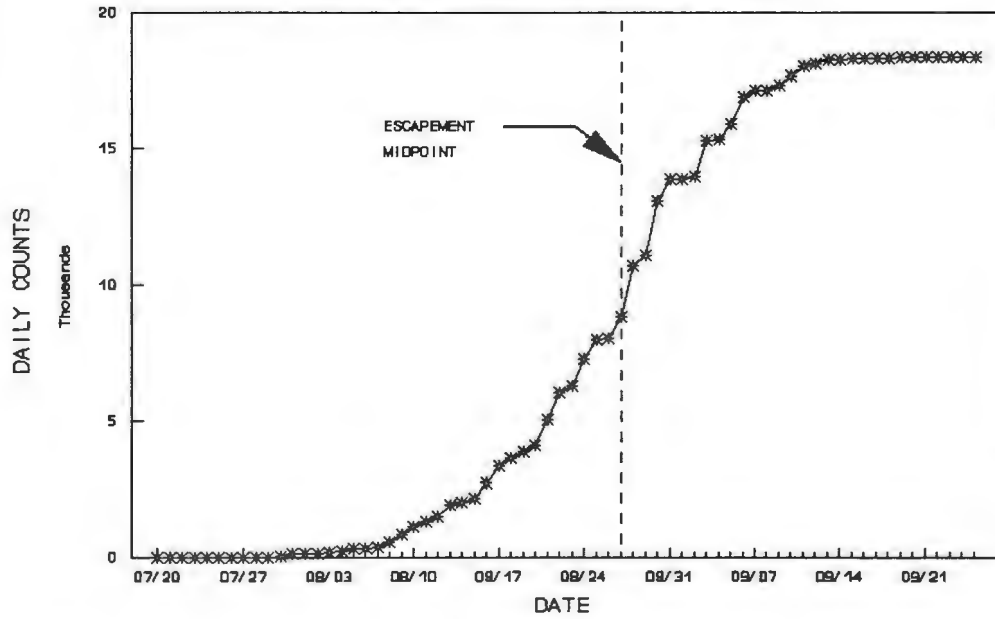
Appendix A.7. Daily and cumulative escapement of pink salmon through the weir at Hayden Creek, 1991.

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Herring Creek Weir

DAILY PASSAGE OF PINK SALMON

CUMULATIVE PASSAGE OF PINK SALMON
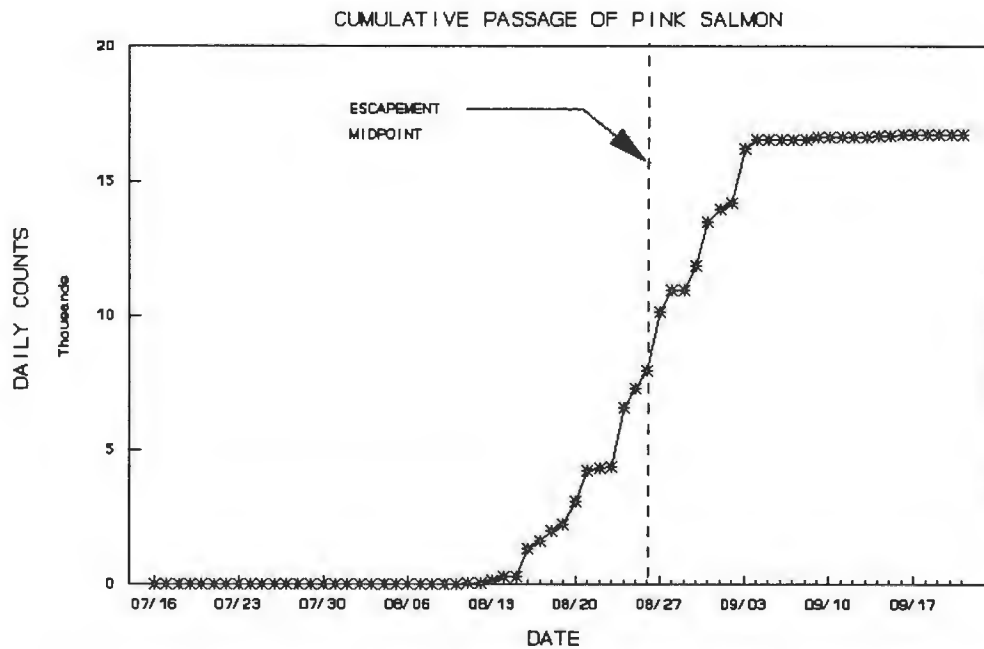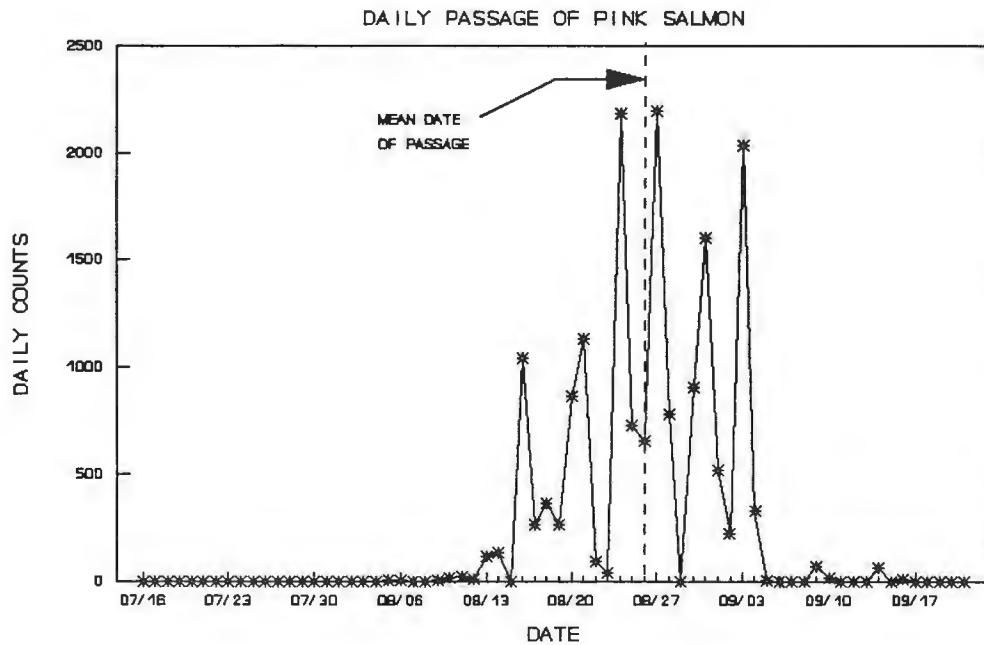
Appendix A.8. Daily and cumulative escapement of pink salmon through the weir at Herring Creek, 1991.

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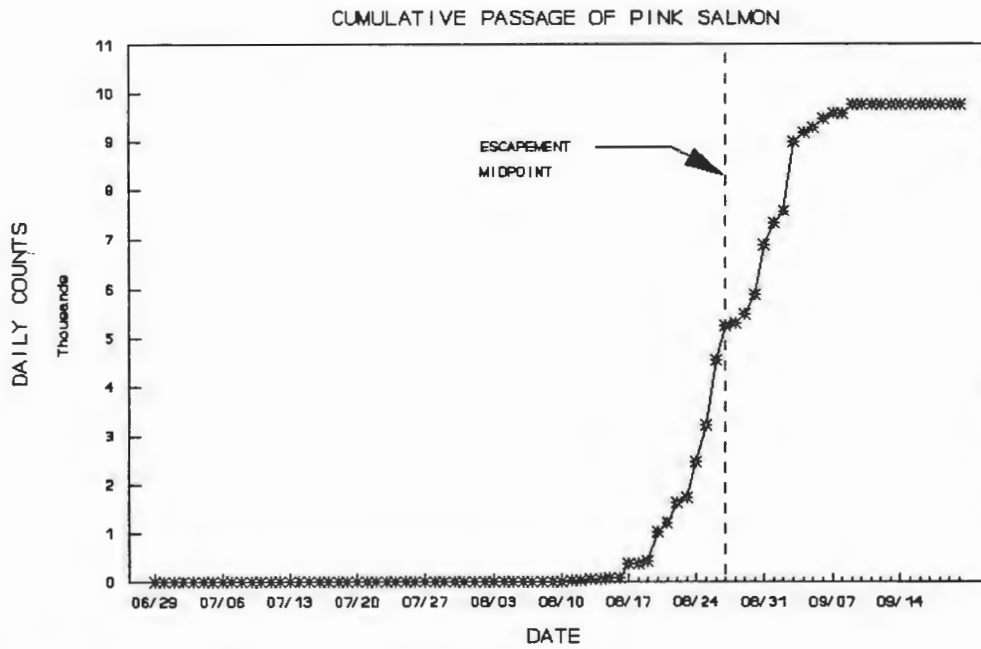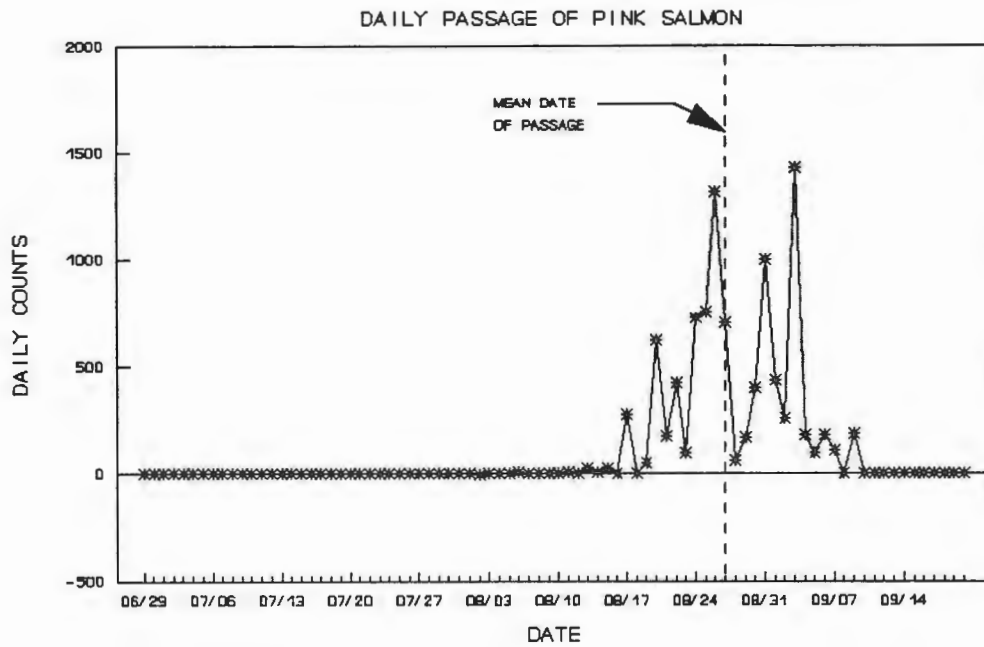
Appendix A.9. Daily and Cumulative escapement of pink salmon through the weir at Cathead Creek, 1991.

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Hawkins Creek Weir

DAILY PASSAGE OF PINK SALMON
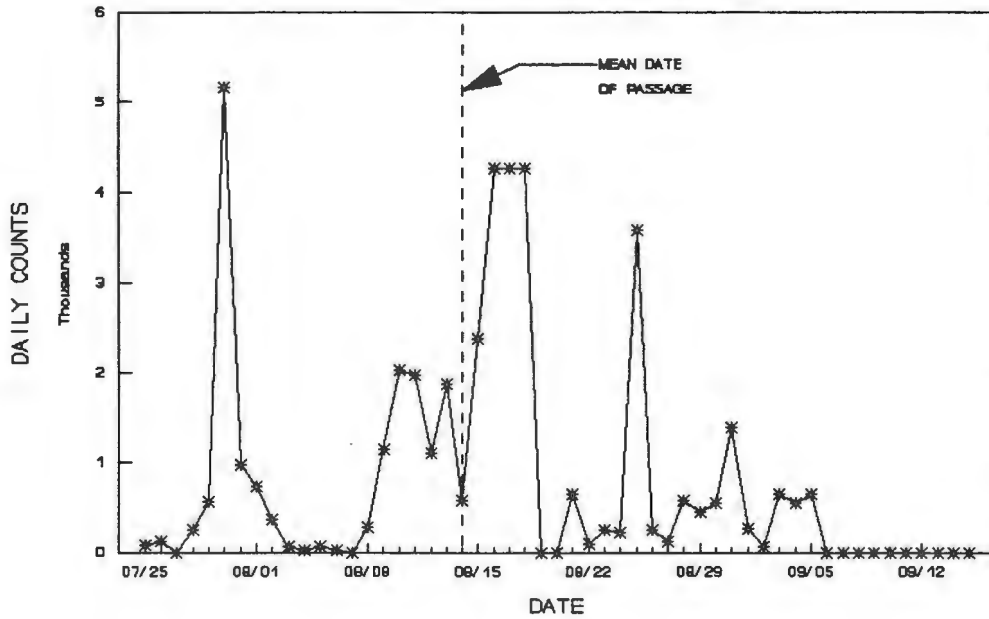
CUMULATIVE PASSAGE OF PINK SALMON
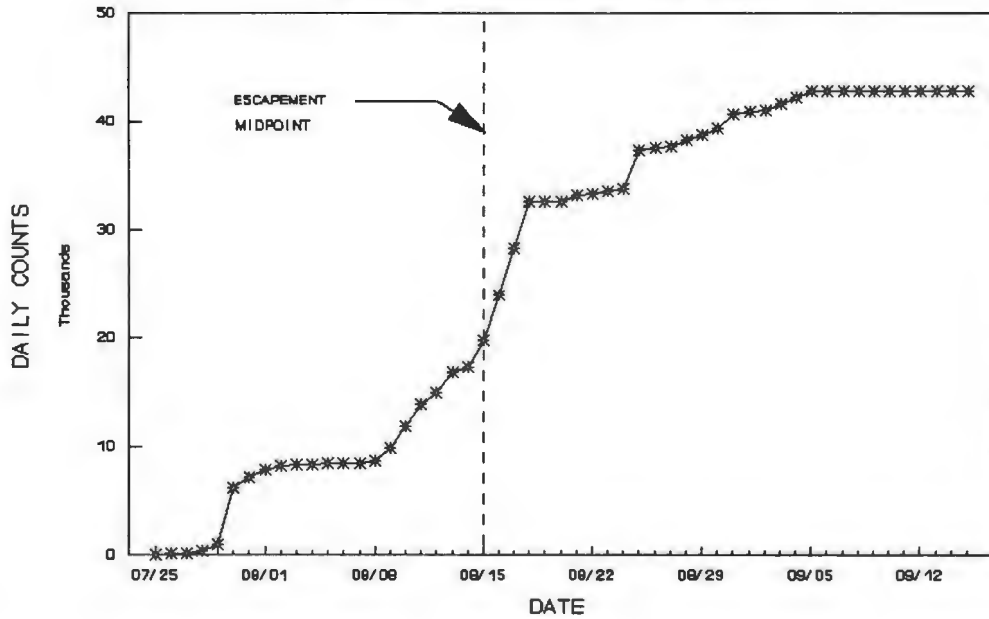
Appendix A.10. Daily and cumulative escapement of pink salmon through the weir at Hawkins Creek, 1991.

ESHAMY RIVER WEIR

DAILY PASSAGE OF SOCKEYE SALMON
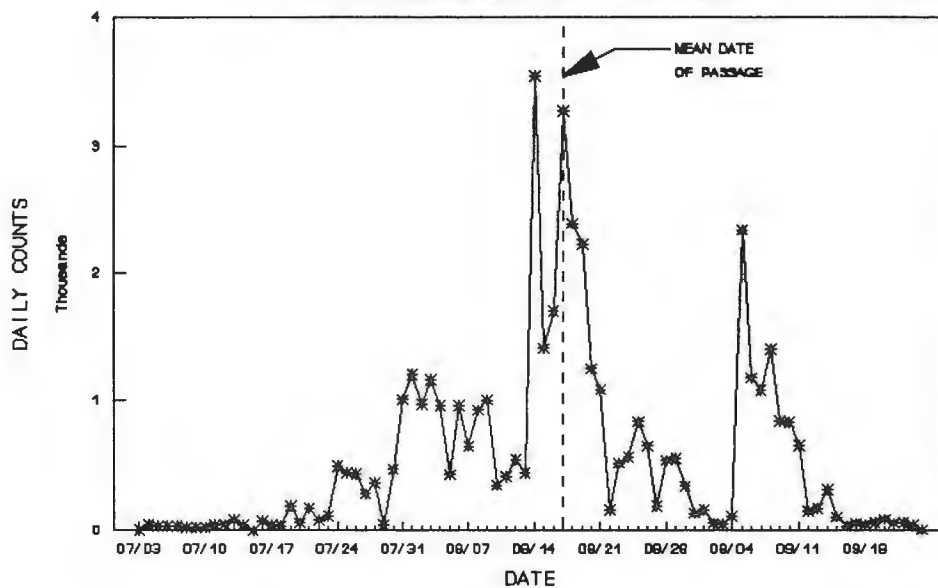
CUMULATIVE PASSAGE OF SOCKEYE SALMON
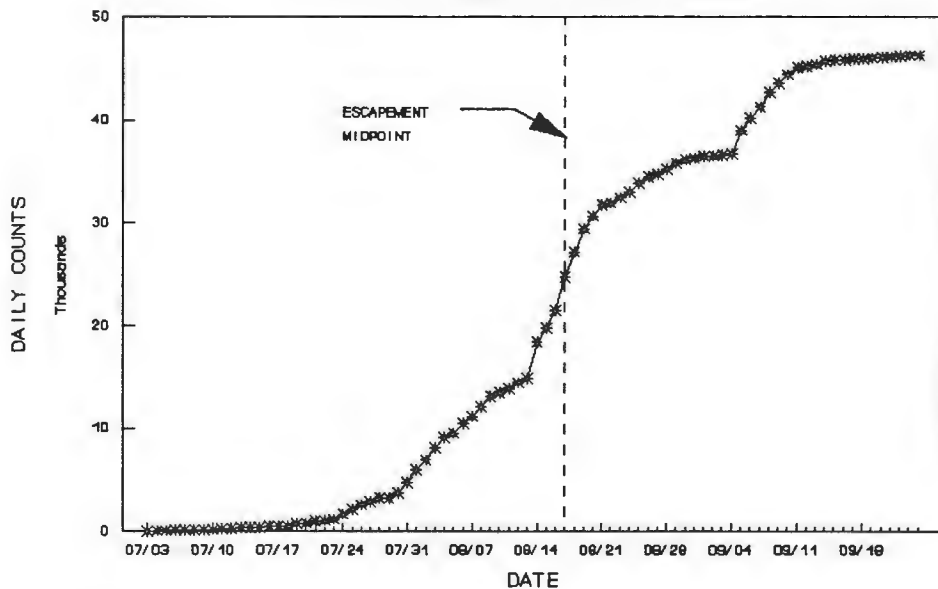
Appendix A.11. Daily and cumulative escapement of sockeye salmon through the weir at Eshamy River, 1991.

JACKPOT RIVER WEIR

DAILY PASSAGE OF SOCKEYE SALMON

CUMULATIVE PASSAGE OF SOCKEYE SALMON
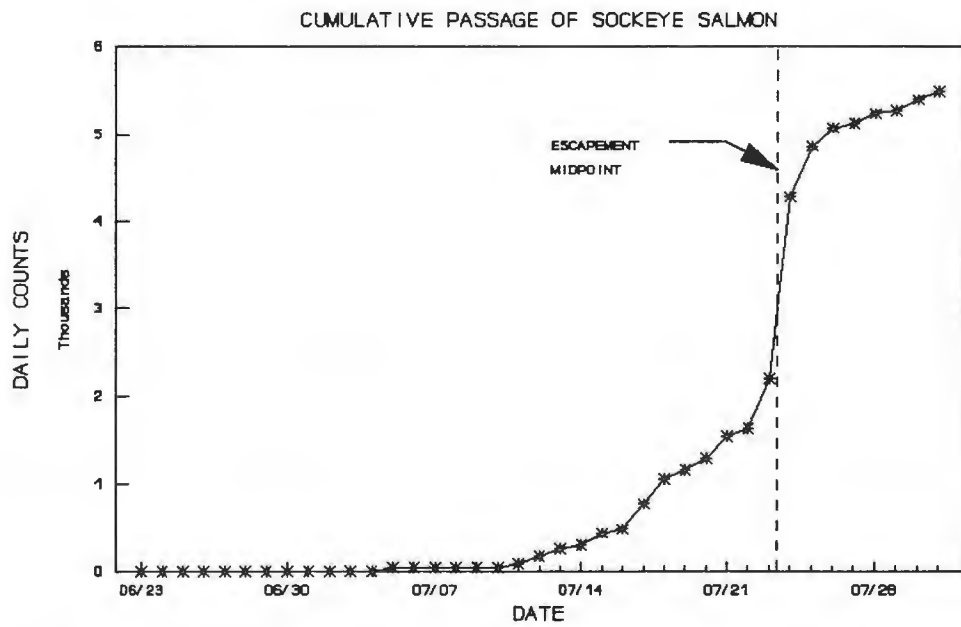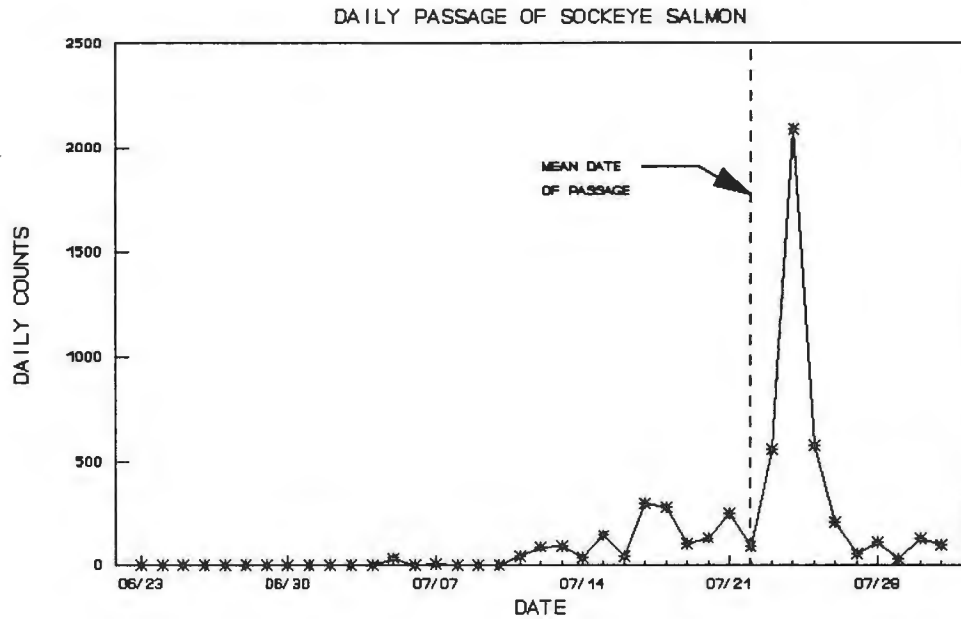
Appendix A.12. Daily and cumulative escapement of sockeye salmon
through the weir at Jackpot River, 1991.

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APPENDIX B. WEEKLY STREAM LIFE ESTIMATES

Appendix B.1. Mean weekly stream life estimates and their 95 % confidence intervals based on tagging studies at ten weired streams, 1991. Standard errors, errors of weekly estimates, 95 % confidence intervals around the estimates, and adjusted estimates based on estimated fish milling time at stream mouths are also shown.

| Stream Name | Tagging | | Recoveries | | Stream Life Statistics | | | | | | Mouth Milling Time | Adjusted Stream Life |
	Date	Number	Total	Percent	Mean	Std	Max	Min	Lower	Upper		
Irish Creek	07/17	198	74	37.4%	17.19	8.43	45	1	15.21	19.16	3.04	14.15
	07/24	200	104	52.0%	21.26	7.41	51	4	19.80	22.72	9.17	12.09
	07/31	200	120	60.0%	20.18	6.27	44	4	19.04	21.31	0.63	19.55 [1]
	08/07	200	122	61.0%	17.79	6.38	39	2	16.64	18.94	3.29	14.50
	08/14	200	120	60.0%	16.35	5.32	35	5	15.38	17.32	0.57	15.78 [1]
	08/21	200	145	72.5%	16.23	4.47	27	7	15.50	16.97	0.03	16.20 [1]
	08/28	150	83	55.3%	10.84	3.07	21	3	10.17	11.52	0.00	10.84 [1]
	09/04	150	82	54.7%	7.82	1.89	12	3	7.40	8.24	0.00	7.82
	Totals	1498	850	56.7%								
	Means	187	106	56.6%	15.96	5.40	34	4	14.89	17.02	2.09	13.87
Loomis Creek	08/09	150	58	38.7%	12.14	4.56	31	4	10.92	13.36	2.91	9.23
	08/16	148	90	60.8%	8.84	5.27	33	1	7.73	9.96	2.20	6.64
	08/23	150	62	41.3%	10.89	4.85	20	1	9.64	12.13	1.91	8.98
	08/30	150	39	26.0%	10.13	2.77	17	5	9.21	11.05	4.46	5.67
	09/06	150	52	34.7%	7.23	2.97	17	3	6.39	8.07	4.00	3.23
	Totals	748	301	40.2%								
	Means	150	60	40.3%	9.85	4.09	24	3	8.78	10.91	3.10	6.75
Totemoff Creek	07/25	150	103	68.7%	21.87	5.76	40	7	20.73	23.01	7.70	14.17
	08/01	150	79	52.7%	21.16	5.69	36	7	19.88	22.45	6.88	14.28
	08/08	150	75	50.0%	17.95	5.14	35	7	16.75	19.14	4.75	13.20
	08/15	150	89	59.3%	15.82	4.34	30	8	14.90	16.75	7.09	8.73
	08/22	149	87	58.4%	13.95	3.91	23	5	13.11	14.80	5.64	8.31
	08/29	150	88	58.7%	11.67	3.41	20	2	10.94	12.40	4.59	7.08
	Totals	899	521	58.0%								
	Means	150	87	58.0%	17.07	4.71	31	6	16.05	18.09	6.11	10.96
Chenega Creek	07/31	144	67	46.5%	18.60	5.44	34	6	17.26	19.94	7.16	11.44
	08/11	150	63	42.0%	17.17	5.75	32	6	15.71	18.63	5.39	11.78
	08/15	150	50	33.3%	13.56	5.50	27	2	11.97	15.15	5.47	8.09
	08/22	150	31	20.7%	13.35	4.05	21	2	11.85	14.86	6.71	6.64
	08/29	150	45	30.0%	8.87	4.04	16	1	7.64	10.10	2.26	6.61
	Totals	744	256	34.4%								
	Means	149	51	34.5%	14.31	4.95	26	3	12.89	15.74	5.40	8.91
Countess Creek	08/08	113	52	46.0%	15.12	5.93	31	5	13.44	16.79	4.46	10.66
	08/15	150	62	41.3%	18.63	6.40	32	3	16.99	20.27	9.90	8.73
	08/26	150	48	32.0%	14.94	4.17	24	3	13.71	16.17	7.40	7.54
	09/04	150	118	78.7%	7.32	2.44	12	1	6.87	7.77	0.00	7.32
	Totals	563	280	49.7%								
	Means	141	70	49.5%	14.00	4.73	25	3	12.75	15.25	5.44	8.56
O'Brien Creek	08/15	150	99	66.0%	12.39	4.43	24	4	11.50	13.29	2.01	10.38
	08/22	150	93	62.0%	11.63	4.94	30	1	10.61	12.66	3.29	8.34
	08/29	148	79	53.4%	9.90	4.59	23	1	8.86	10.94	1.40	8.50
	09/06	150	61	40.7%	9.80	3.22	17	2	8.97	10.64	1.73	8.08
	09/12	150	103	68.7%	6.63	2.21	14	2	6.19	7.07	1.00	5.63
	Totals	748	435	58.2%								
	Means	150	87	58.1%	10.07	3.88	22	2	9.23	10.92	1.89	8.19

1/ All fish tagged above the weir for these dates.

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Stream Name	Tagging		Recoveries		Stream Life Statistics						Mouth Milling Time	Adjusted Stream Life
	Date	Number	Total	Percent	Mean	Std	Max	Min	Lower	Upper		
Hayden Creek	08/04	143	53	37.1%	16.43	6.61	38	5	14.58	18.29	5.59	10.84
	08/13	150	58	38.7%	17.52	5.59	34	6	16.02	19.01	6.15	11.37
	08/20	150	38	25.3%	18.82	4.66	28	8	17.25	20.38	6.45	12.36
	08/26	150	56	37.3%	12.68	4.90	33	3	11.34	14.01	4.34	8.34
	09/02	150	84	56.0%	9.51	3.18	17	1	8.81	10.21	2.16	7.35
	09/09	150	100	66.7%	8.79	2.69	16	3	8.25	9.33	1.25	7.54
	Totals	893	389	43.6%								
	Means	149	65	43.5%	13.96	4.61	28	4	12.71	15.21	4.32	9.63
Herring Creek	08/15	150	99	66.0%	15.30	5.26	27	3	14.24	16.37	3.06	12.24
	08/22	150	70	46.7%	14.61	4.95	30	2	13.42	15.81	4.15	10.46
	08/29	150	74	49.3%	10.41	4.28	23	1	9.40	11.41	3.23	7.18
	Totals	450	243	54.0%								
	Means	150	81	54.0%	13.44	4.83	27	2	12.36	14.53	3.48	9.96
Cathead Creek	08/17	150	87	58.0%	18.89	6.58	34	4	17.47	20.30	8.33	10.56
	08/24	150	85	56.7%	14.31	4.65	23	0	13.29	15.32	4.00	10.31
	08/31	150	101	67.3%	12.67	3.56	22	2	11.96	13.38	2.09	10.58
	Totals	450	273	60.7%								
	Means	150	91	60.7%	15.29	4.93	26	2	14.24	16.34	4.81	10.48
Hawkins Creek	07/29	150	63	42.0%	18.14	8.10	50	4	16.09	20.20	1.56	16.58
	08/05	150	68	45.3%	18.16	6.68	33	4	16.53	19.79	4.65	13.52
	08/12	150	75	50.0%	17.89	5.88	32	3	16.53	19.26	3.73	14.16
	08/19	150	63	42.0%	16.43	4.39	29	7	15.31	17.54	9.00	7.43
	08/27	150	50	33.3%	10.22	3.95	19	2	9.08	11.36	4.09	6.13
	09/02	150	45	30.0%	6.91	2.79	15	3	6.06	7.76	1.31	5.61
	Totals	900	364	67.3%								
	Means	150	61	40.4%	14.63	5.30	30	4	13.27	15.99	4.06	10.57
Streams Combined by Week Ending Dates	07/20	198	74	37.4%	17.2	8.4	45.0	1.0	15.2	19.2	3.04	14.15
	07/27	350	207	59.1%	21.6	6.6	45.5	5.5	20.3	22.9	8.44	13.13
	08/03	644	329	51.1%	19.5	6.4	41.0	5.3	18.1	21.0	4.06	15.46
	08/10	1056	491	46.5%	16.4	5.9	34.1	4.7	14.9	17.8	4.43	11.96
	08/17	1548	829	53.6%	15.5	5.5	30.8	3.9	14.3	16.8	4.85	10.67
	08/24	1399	674	48.2%	14.5	4.5	25.7	3.7	13.3	15.6	4.58	9.89
	08/31	1498	663	44.3%	11.2	3.9	21.8	2.3	10.2	12.2	3.39	7.85
	09/07	900	442	49.1%	8.1	2.7	15.0	2.2	7.4	8.8	1.53	6.57
	09/14	300	203	67.7%	7.7	2.5	15.0	2.5	7.2	8.2	1.12	6.59
Totals		7893	3912	49.6%								
Mean of weeks		877	435	50.8%	14.6	5.1	30.4	3.4	13.4	15.8	3.9	10.7
Mean of streams		152	76	49.6%	13.9	4.7	27.1	3.3	12.7	15.0	4.1	9.8

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<u>STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT</u>
<u>DRAFT PRELIMINARY STATUS REPORT</u>

Project Title: INJURY TO SALMON EGGS AND PREEMERGENT FRY
                          IN PRINCE WILLIAM SOUND

Study ID Number: Fish/Shellfish Study Number 2

Lead Agency: State of Alaska, ADF&G;
                          Commercial Fish Division

Cooperating Agency(ies): Federal: USFS
                          State: DNR

Principle Investigator: Samuel Sharr

Assisting Personnel: Brian Bue
                          Steve Moffitt

Date Submitted: November 20th, 1991

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EXECUTIVE SUMMARY

This study is part of an integrated group of Natural Resource Damage Assessment Fish/Shellfish Studies (NRDA F/S Studies 1,2,3, and 4), being conducted to quantify damage to pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon stocks from the *M/V Exxon Valdez* oil spill. Each study will attempt to determine injury to salmon stocks at different stages in the life cycle. This project is designed to determine whether pink or chum salmon egg mortality or egg to preemergent fry survival in intertidal and upstream areas of Prince William Sound (PWS) was affected by oil contamination from the spill.

Wild stock pink and chum salmon play a major role in the PWS ecosystem. These salmon species not only provide a significant source of food for many fish, bird, and mammal species but also convey needed nutrients and minerals from the marine ecosystem to the estuary, freshwater stream, and terrestrial environments.

Up to 75% of the pink and chum salmon in PWS spawn in intertidal areas (Helle, Williamson, and Bailey 1964). These areas are highly susceptible to contamination from marine oil spills, and preemergent pink salmon fry are adversely affected by exposure to oil in seawater (Moles, Babcock, and Rice 1987). The *M/V Exxon Valdez* oil spill occurred just prior to the seaward migration of pink and chum salmon and impacted intertidal spawning areas in central and southwest PWS.

A significant increase in pink salmon egg mortality was found for oiled streams (p=0.047 with adjusted egg mortalities of 9% and 16%, p=0.038 with adjusted egg mortalities of 17% and 28%, and p=0.003 with adjusted egg mortalities of 20% and 43% for unoiled and oiled streams in 1989, 1990, and 1991 respectively). The greatest increase in mortality occurred at the highest intertidal zone (the "bathtub ring" of PWS).

No statistical differences in egg to preemergent fry survival were detected for the 1989 or 1990 brood years. This does not mean damages were not present; rather, it is indicative of insufficient power in sampling design or sampling levels to detect a difference.

Results are not available from fry histopathology, or mixed-function oxidase samples. However, results of the 1989 and 1990 mussel hydrocarbon studies from NRDA F/S Study 1 generally agree with visual observations of oil contamination from NRDA F/S Studies 1 and 2.

Determination of loss in adult salmon production cannot be made until data from NRDA F/S Studies 1,2,3, and 4 can be further analyzed.

OBJECTIVES

1. Estimate the density, by tide zone, of preemergent fry in 48 streams and eggs in 31 streams using numbers of live and dead eggs and fry.

2. Estimate egg mortality and overwinter survival of pink and chum salmon eggs in both oiled and unoiled streams.

3. Document hydrocarbon contamination of preemergent fry and mussels (*Mytilus sp.*) using tissue hydrocarbon analysis and eggs and preemergent fry using Mixed-Function Oxidase (MFO) and histopathology analysis.

4. Assess any loss in adult production from changes in overwinter survival using the results of NRDA F/S Studies 1,2,3, and 4.

5. Identify potential alternative methods and strategies for restoration of lost use, populations, or habitat where injury is identified.

INTRODUCTION

Wild salmon play a major role in Prince William Sound (PWS) marine and freshwater ecosystems while also contributing to the region's commercial fisheries. Migrating salmon fry are an important spring food source for various birds and fishes. Marine mammals prey on the ocean life stages of Pacific salmon while terrestrial mammals and birds, such as bears, river otters, eagles, and gulls depend on salmon for a large portion of their summer diet. Salmon also provide a pathway for transferring nutrients from marine ecosystems to near-shore and terrestrial communities. In recent years, commercial catches of wild salmon have ranged from 10.0 to 15.0 million pink salmon and from 0.8 to 1.5 million chum salmon.

About 75% of spawning pink and chum salmon in PWS use intertidal areas (Helle, Williamson, and Bailey 1964). Intertidal areas are very susceptible to contamination from marine oil spills. Oil contamination has adverse effects on pink salmon fry, especially in saltwater (Moles, Babcock, and Rice 1987). The 24 March 1989 spill from the *M/V Exxon Valdez* occurred immediately before the migration of PWS salmon fry, and oil contaminated many areas used by salmon for spawning and rearing.

Crude oil from the *M/V Exxon Valdez* moved counter clockwise around PWS and exited at the southwest corner. Since oiled streams were in southwestern PWS, overwinter survival work was generally confined to this area (Figure 1), although a few streams were also sampled on Montague Island and eastern PWS (Figure 2).

METHODS

Sample Sites

Egg Sampling

In 1989, the first year of the study, egg deposition sampling was completed on 31 streams from 27 September to 15 October (Figure 2). The streams were selected using the following criteria:

1. Adult salmon returns were expected to be large enough to indicate a high probability of success in egg and fry sampling.
2. Egg and fry sampling had been done in past years.
3. Streams that had low to no oil impact, i.e., controls, were selected near high oil impact streams as well as other parts of PWS to help account for variability in egg and fry survival due to different environmental conditions.

3
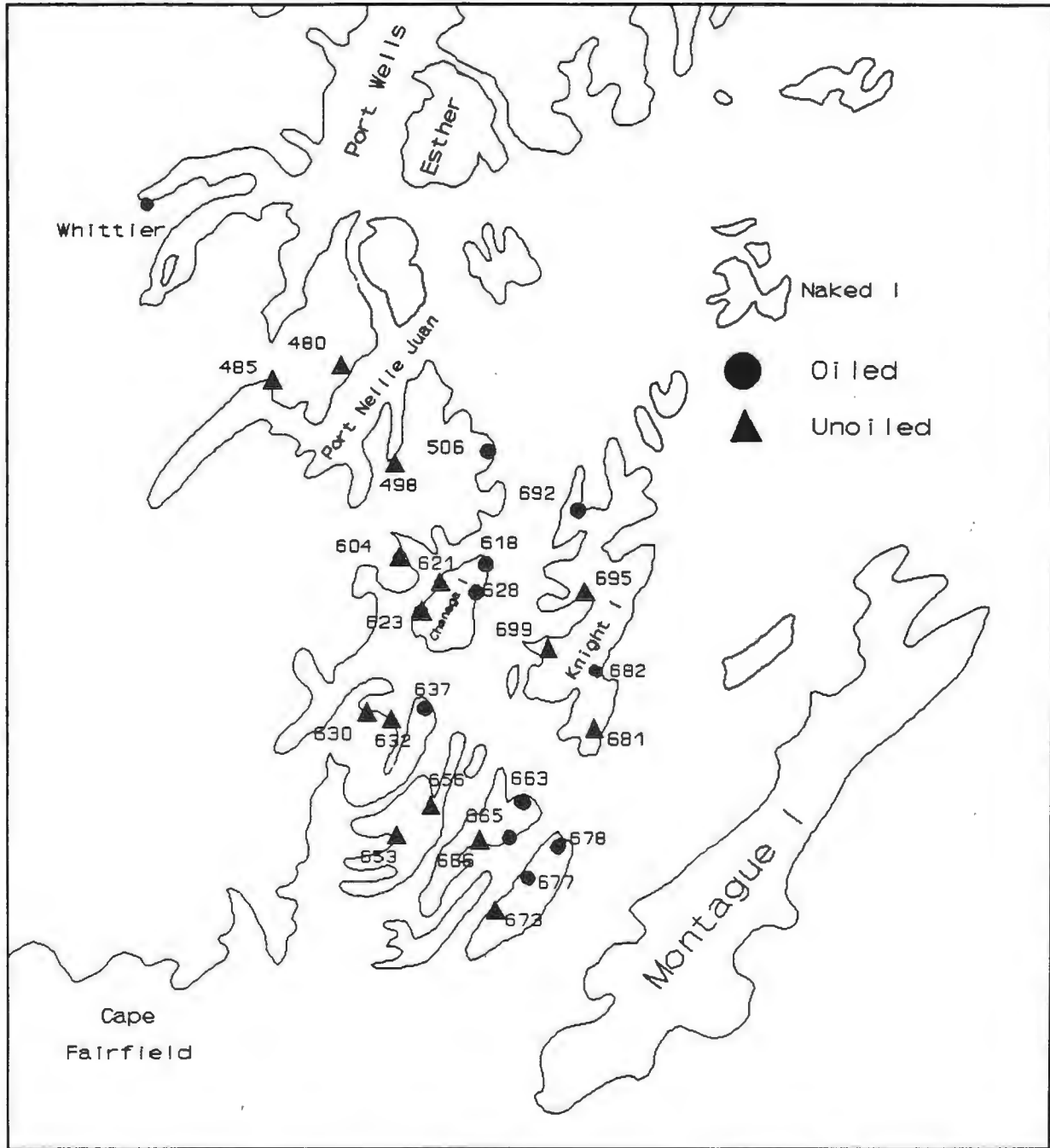
Figure 1. Specific streams sampled in southwestern Prince William Sound during 1989, 1990, and 1991 and their designations (oiled or unoiled) for egg mortality and overwinter survival analysis.

4
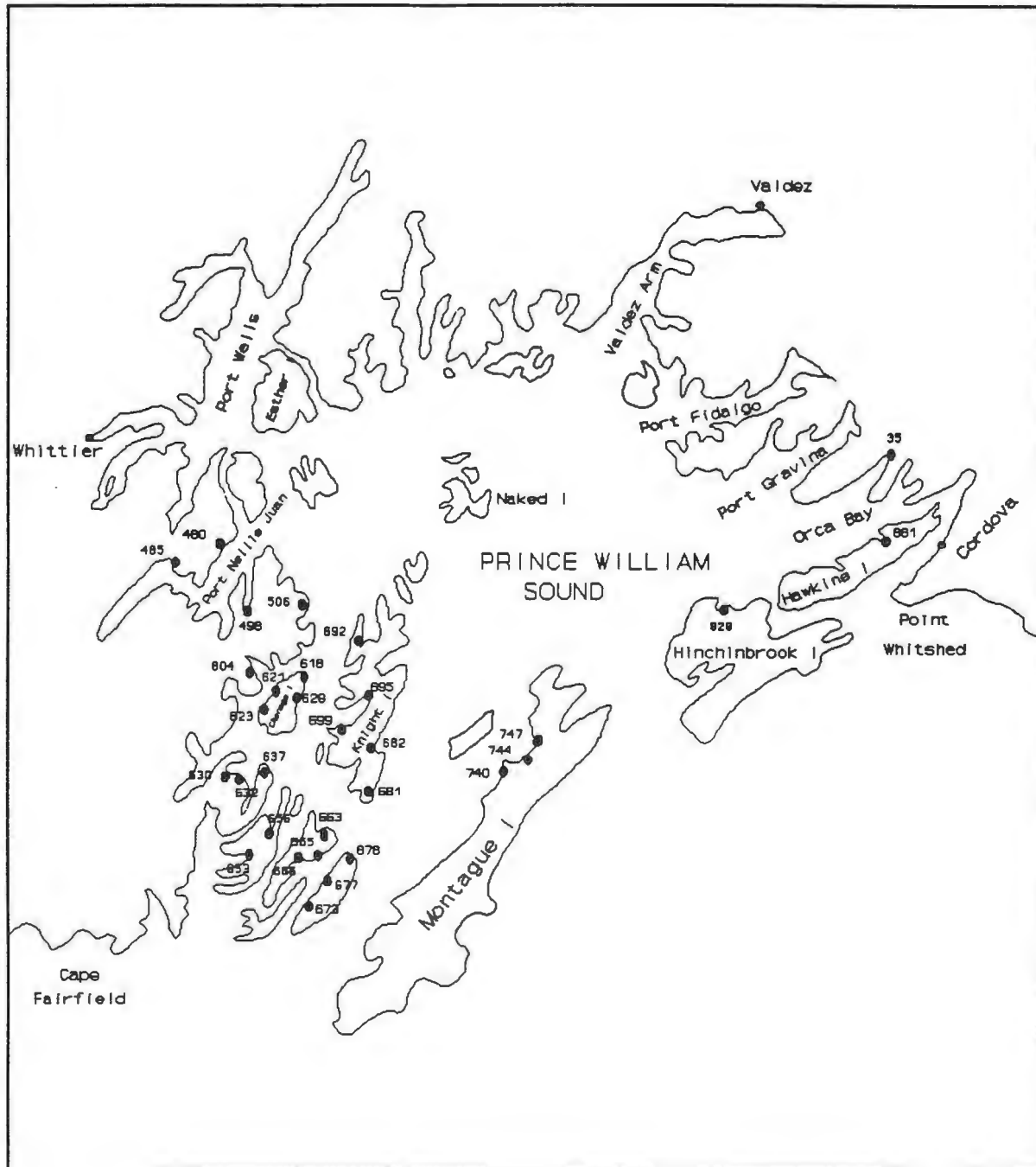
Figure 2. Streams examined by the 1989, 1990, and 1991 egg
surveys and the 1990 and 1991 fry surveys.

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In 1990 egg sampling was completed on 31 streams from 24 September to 18 October. These streams were also sampled for preemergent fry (by this study) and adult escapement (by NRDA F/S Study 1, Injury to salmon spawning areas in Prince William Sound).

In 1991 egg sampling was completed on 31 streams from 23 September to 12 October. These streams were also sampled for preemergent fry (by this study), and 16 of the 31 streams were sampled for adult escapement by NRDA F/S Study 1.

Preemergent Fry Sampling

In 1990 and 1991, 48 streams were sampled for preemergent fry. These included 25 streams historically sampled to forecast adult pink and chum salmon returns as well as 23 additional streams from the oil impact area. Sampling started on 15 March and was completed on 5 May 1990. Most streams (41) were sampled before 15 April, but snow and bay ice delayed sampling on a few (7). In 1991 sampling began on 15 March and was completed by 17 May. Most streams (37) were sampled before 15 April, but snow and ice delayed sampling on a few (11).

The 25 streams used for the adult return forecasting model have historically been sampled for the following reasons:

1. They contribute a large proportion of the wild return of pink and chum salmon to PWS.
2. They have significant spawning populations in both odd and even years.
3. They are representative of the spatial distribution of spawning escapement in PWS.
4. They are accessible for sampling in most years.

Sample Design

The methods used for both egg and preemergent fry sampling were based in part on those described by Pirtle and McCurdy (1977). Sampling was stratified by tide zone to control for possible differences in egg mortality or overwinter survival due to differences in salinity, temperature, predation, oiling, or a combination of these factors. Zone boundaries were established with a surveyor's level and stadia rod and staked prior to fry sampling. Four zones, three intertidal and one above tidal inundation were sampled, whenever possible, for each stream: 1.8 - 2.4 m, 2.4 - 3.0 m, 3.0 - 3.7 m above mean low water, and upstream of mean high tide (3.7 m). No sampling was done below the 1.8 - 2.4 m zone because survival was expected to be low (Helle, Williamson, and Bailey 1964). Upstream sample transects were often still within reach of

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extreme high tides (3.7 - 4.6 m) because ice and snow limit upstream sampling for preemergent fry in the spring.

Separate linear transects were established for each zone on the egg and preemergent fry surveys. Although most transects were 30.5 m long, some were shorter due to steep stream gradients. Transects were placed in riffle areas where spawning was observed during escapement surveys conducted for NRDA F/S Study 1. Transects ran diagonally across the river: fry survey transects started downstream against the right bank and moved upstream to the left bank while egg survey transects started downstream against the left bank and moved upstream to the right bank. This placement of egg and fry transects reduced sampling overlap and the influence of fall egg sampling on spring fry abundance. A map was drawn for each stream showing the tide zones and transect locations in relation to major landmarks. Each egg survey transect was marked with surveyor's flagging to assure that egg and fry survey transects would be in the same immediate area. This should result in a better estimate of egg to fry survival within each sample zone.

Fourteen circular digs, each 0.186 m^2, were systematically made along each transect. The sample size was a compromise between reducing variance and the practicality of conducting the study. Fewer digs were completed on narrow stream channels to avoid excessive sampling of the stream. Streams that split into two or more channels within a zone were sampled either by allocating digs among channels based on spawner distribution observed during NRDA F/S Study 1 or, where spawner distribution was unknown, by an equal allocation.

The following data were collected for each tide zone transect during both egg and fry sampling:

1. The sample date.
2. The sample tide zone.
3. The start and stop time for the tide zone transect.
4. Numbers and condition (live or dead) of fry and eggs by species for each dig.
5. A subjective estimate of the overall percent yolk sac absorption for fry in each dig.

Data were entered from "Rite in the Rain" books into a Lotus spreadsheet and an R:BASE database for editing and summarization.

Pink salmon eggs were separated from chum and coho (*O. kisutch*) salmon eggs by their smaller size. Chum salmon eggs were separated from coho salmon eggs by their greater development and different coloration. An egg was considered dead if it was opaque or discolored with concentrations of lipids. Pink salmon fry were differentiated from chum salmon fry by their smaller size and lack of parr marks. Sampling often killed fry (especially newly hatched

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fry), so fry were only considered dead if decomposition was evident.

<center>Data Analysis</center>

Egg and Preemergent Fry Densities

Densities of live eggs for stream i, zone j in m^2 were estimated by:

$$\hat{E}_{ij} = \frac{\Sigma\ LE_{ijk}}{0.186n_{ij}} \quad ,$$

where LE_{ijk} is the number of live eggs found in the kth dig, in stream i, zone j, and n_{ij} is the number of digs from stream i, zone j. Densities of dead eggs as well as dead and live fry were found using the same estimator with appropriate substitutions.

Fry densities have historically been used as an index of abundance in the adult return forecasting model. Stream area measurements completed during work on NRDA F/S Study 1 will allow density estimates to be expanded into an estimate of total number of eggs and fry in a given stream.

Egg Mortality and Overwinter Survival

Pink salmon egg mortalities were estimated for each stream using the following relationship:

$$\hat{M}_{ij} = \frac{\Sigma\ (DE_{eijk} + DF_{eijk})}{\Sigma\ (LE_{eijk} + DE_{eijk} + LF_{eijk} + DF_{eijk})} \quad ,$$

where DE_{eijk}, DF_{eijk}, LE_{eijk}, and LF_{eijk} are the number of dead eggs, dead fry, live eggs, and live fry for the kth dig from stream i, zone j, collected during the egg survey, respectively.

Pink salmon egg to preemergent fry survivals were estimated as:

$$\hat{S}_{ij} = \frac{(\Sigma\ LF_{fijk})\ /\ n_f}{\Sigma\ (LE_{eijk} + DE_{eijk} + LF_{eijk} + DF_{eijk})\ /\ n_e} \quad ,$$

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where LF_{fijk} is the number of live fry for the kth dig from stream i, zone j, collected during the fry survey, and n_e and n_f are the number of **digs** for stream i, zone j for the egg and fry surveys.

Differences in egg mortality and overwinter survival were examined using a mixed effects two-factor experiment with repeated measures on one factor (Neter, Wasserman, and Kutner, 1985):

$$Y_{ijk} = \ldots + O_i + Z_j + (OZ)_{ij} + S_{k(i)} + \epsilon_{(ijk)}.$$

The two treatments were extent of oiling, (O_i, 2 levels; oiled and unoiled), and height in the intertidal zone (Z_j, 4 levels; 2.1, 2.7, and 3.4 m above mean low water and upstream), both fixed effects. The data were blocked by stream ($S_{k(i)}$), a random effect nested within extent of oiling. The interaction of extent of oiling and height in the intertidal zone was also examined. The assumption of constant variance for error terms was tested using the F_{max}-test (Sokal and Rohlf, 1969) while normality of error terms was visually assessed using scatter plots, box plots, and normal probability plots. Arcsin square root, logit, log, and square root transforms were examined if the data indicated non-constant variances or non-normal error terms. Assumptions relating to a valid split-plot analysis of the repeated measures factor, zone, were also examined. Tests of homogeneity of between-treatment covariance matrices and the degree of sphericity of the pooled covariance matrix (Mauchly, 1940) were effected. Four contrasts (oil vs. unoiled for the 4 stream zones) and corresponding Bonferroni family confidence intervals ($\alpha = 0.10$ overall) were estimated if a significant difference due to oiling was detected. The SAS (SAS Institute Inc., 1991) General Linear Models Procedure was used to analyze the data.

Extent of oiling for the 1989, 1990, and 1991 analysis was based on visual observations of streams (NRDA F/S Studies 1 and 2) and hydrocarbon results of 1989 mussel samples (NRDA F/S Study 1) (Table 1). Six different groupings of oiled and unoiled streams were compared because visual observations and hydrocarbon results did not match for two streams (#506, Loomis Creek, and #681, Hogan Bay Creek). The following grouping was selected based on the evidence available:

1. Fifteen unoiled (control) streams including Hogan Bay Creek (streams 480, 485, 498, 604, 621, 623, 630, 632, 653, 656, 666, 673, 695, 699, and 681);

2. Ten known oiled streams including Loomis Creek (streams 618, 628, 637, 663, 665, 677, 678, 682, 692, and 506).

Streams 35, 740, 744, 747, 828, and 861 were left out of the analysis because they were not near the oiled streams.

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ble 1.   Samples collected from 31 PWS streams to document hydrocarbon contamination and results of analysis to date.

| | | Hydrocarbon Samples[abc] | | | | | Mixed Function Oxidase[bc] | | | |
| | | Mussels | | Fry | | | Fry Surveys | | Egg Surveys | |
No.	Stream Name	1989	1990	1989	1990	1991	1990	1991	1990	1991
35	Koppen Creek	NO	NO	X			X	X	X	X
480	Mink Creek	NO	NO	NO	X		X	X	X	X
485	W. Finger Creek	NO	NO	NO	X		X	X	X	X
498	McClure Creek	NO	NO				X	X	X	X
506	Loomis Creek	NO	NO?[d]		X	X	X	X	X	X
604	Erb Creek	NO	NO	NO			X	X	.X	X
618	Junction Creek	YES	NO				X	X	X	X
621	Totemoff Creek	NO	NO	X	X		X	X	X	X
623	Brizgaloff Creek	NO	NO		X		X	X	X	X
628	Chenega Creek		NO		X		X	X	X	X
630	Bainbridge Creek	NO	NO		X	X	X	X	X	X
632	Claw Creek	NO	NO		X		X	X	X	X
637	Pt. Countessss	YES	NO	X	X		X	X	X	X
653	Hogg Creek	NO	NO		X		X	X	X	X
656	Halverson Creek	NO	NO				X	X	X	X
663	Shelter Bay	YES	NO?		X		X	X	X	X
665	Bjorne Creek		NO?				X	X	X	X
666	O'Brien Creek	NO			X		X	X	X	X
673	Falls Creek	NO	NO	NO	X		X	X	X	X
677	Hayden Creek	YES	NO	NO	X		X	X	X	X
678	Sleepy Bay		YES		X			X	X	X
681	Hogan Bay	NO	NO				X		X	X
682	Snug Harbor	YES	NO	X	X		X	X	X	X
692	Herring Bay	YES	YES		X		X	X	X	X
695	Port Audrey	NO	NO	X	X		X	X	X	X
699	Cathead Bay	NO	NO	NO	X	X	X	X	X	X
740	Kelez Creek	NO	NO	NO	X		X	X	X	X
744	Wilby Creek	NO	NO				X	X	X	X
747	Cabin Creek	NO	NO		X		X	X	X	X
828	Cook Creek	NO	NO	NO			X	X	X	X
861	Bernard Creek	NO	NO	NO	X		X	X	X	X

[a]   A yes indicates oiling.
[b]   A blank indicates no sample was taken.
[c]   An X indicates that a sample was collected and analysis is pending.
[d]   A ? indicates borderline results.

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Assessment of Lost Adult Production

Lost production of adult pink salmon will be estimated using information obtained in this study along with estimates of total adult pink salmon production from NRDA F/S Studies 1, 3, and 28.

Documenting Hydrocarbon Contamination

Hydrocarbon Sampling

Samples used to determine hydrocarbon levels in preemergent fry were collected from intertidal stream channels during the 1989 (14 streams), 1990 (23 streams) and 1991 (3 streams) preemergent fry surveys (Table 1). Fry were dislodged from the stream gravel with a clam rake and caught in a stainless steel strainer pre-rinsed with dimethylchloride. Replicate samples of fry (approximately 10 grams each) were collected from each stream about 2.5 m above mean low water. Samples were collected when the tide was below the sampling area to avoid contamination by oil on the salt water surface. Captured fry were placed in glass jars topped with teflon lined lids, and then frozen. In 1989, glass jars and lids were pre-rinsed three times with dimethylchloride, dried, and kept in locked storage prior to use. In 1990 and 1991, pre-rinsed sample jars were obtained from a certified laboratory. Field blanks (jars opened at the site, closed, and frozen with the tissue samples) were collected at about every third stream. Chain of custody procedures were followed for all samples. Mussel samples were also collected for hydrocarbon analysis from most streams examined by NRDA F/S Study 1 in both 1989 and 1990 (Table 1).

Histopathology Sampling

Preemergent fry were collected from the intertidal channels of 22 streams during the spring of 1989 to assess possible damage from oil exposure. Captured fry were placed in glass jars containing Bouin's solution, topped with teflon lined lids, and frozen.

Mixed-Function Oxidase Sampling

Egg Sampling. Live and dead pink salmon eggs and fry were collected from 31 streams during the fall 1990 and 1991 egg surveys to test for mixed-function oxidase (MFO) (Table 1). Samples were collected, whenever possible, from all four tide zones of each stream. Live pink salmon eggs and fry were separated from dead eggs and fry for all the digs of a transect and randomly selected for MFO samples. Whenever possible, two samples of at least 50 live eggs and fry and one sample of at least 50 dead eggs and fry were collected and placed in 8 oz. jars containing a phosphate buffered, 10% formalin

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solution. Labels on each jar had the following information: sample number, stream number, stream name, stream location, latitude, longitude, tide zone, type of sample, collector, and sample date.

Preemergent Fry Sampling. Live pink or chum salmon fry were collected from 35 streams in 1990 and 31 streams in 1991 during the spring to test for MFO. Whenever possible, two samples of at least 20 fry were collected from each of the four tide zones within each stream. Live fry were retained from all the digs of a transect and randomly selected for MFO samples. Fry were placed in glass jars containing a phosphate buffered, 10% formalin solution. Labels on each jar had the following information: sample number, stream number, stream name, stream location, latitude, longitude, tide zone, type of sample, collector, and sample date.

RESULTS

Egg and Preemergent Fry Densities

Egg and Preemergent fry densities were summarized for the 1989, 1990, and 1991 egg surveys and the 1990 and 1991 fry surveys (appendices A.1, A.2, A.3, A.4, and A.5).

Egg Mortality and Overwinter Survival

Heteroscedastic variances were detected in the 1989 egg mortality data. Visual examination of the data suggested that the logit and arcsin square root transformations were appropriate. The arcsin square root transformation was used to stabilize the variance for the analysis for all three years of egg mortality data. Arcsin square root transformed data appeared to be normal for all three data sets.

The 1989 analysis indicated a statistically significant difference in egg mortality ($p=0.047$) between oiled and control streams (Figure 3). No significant zone effect ($p=0.61$) or oil by zone interaction ($p=0.86$) was evident. Examination of estimated contrasts indicated the differences in mortality were in the intertidal zones. The overall adjusted mean egg mortalities for the oiled and control streams were 0.164 and 0.087.

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1989 PWS Pink Salmon Egg Mortality
Adjusted Means and 90% Confidence Bounds
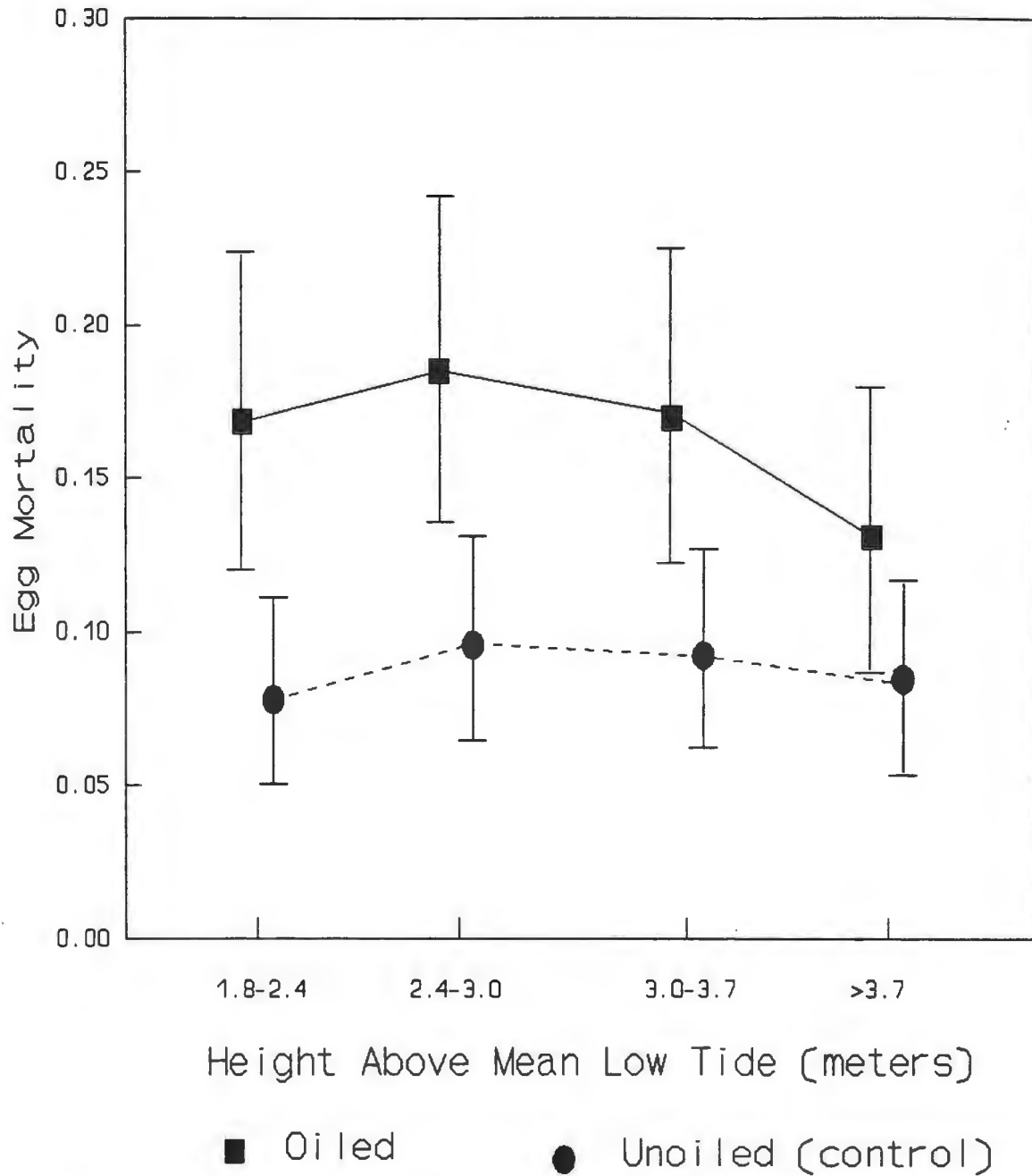
Figure 3   Adjusted mean mortality of 1989 pink salmon eggs by tide zone for oiled and control (unoiled) streams in Prince William Sound.

The 1990 egg mortality data also showed a statistically significant difference (p=0.038) between oiled and control streams (Figure 4). No significant zone effect or oil by zone interaction (p=0.148 and p=0.325) **was** observed. Estimated contrasts indicated the differences due to oiling were in the upper intertidal zone. The overall adjusted mean egg mortalities for the oiled and control streams were 0.282 and 0.170.

The 1991 egg mortality data indicated very significant differences between the oiled and control streams (p=0.003) (Figure 5). A significant zone effect (p=0.009) was evident although no oil by zone interaction was found (p=0.746). Estimated contrasts indicated differences due to oiling in all three intertidal zones as well as the upstream zone. The overall adjusted mean egg mortalities for the oiled and control streams were 0.430 and 0.197. The possibility that the differences in egg mortality across all tide zones are the result of sublethal oil effects are being investigated by NRDA F/S Study 1.

Egg to preemergent fry survival data were edited prior to analysis to remove values greater than 1.0 , i.e., overwinter survivals greater than 100%. While a test for heteroscedasticity of variances among oil by zone treatments for the 1989 and 1990 egg-to-fry survival data yielded insignificant F tests, visual examination of scatter plots of residuals suggested a need for some transformation. The data appeared normal after an arcsin square-root transformation.

The 1989 analysis of the egg-to-fry survival data indicated no significant effects of oil (p=0.58) (Figure 6). No significant zone by oil interaction was found (p=0.28), but a significant zone effect was observed (p=0.001).

Similar results were obtained for the 1990 egg-to-fry survival data (Figure 7). No significant oil or zone by oil effect was found (p=0.449, 0.79). A significant zone effect was observed (p=0.02).

Documentation of Hydrocarbon Contamination

No results are available for hydrocarbon analysis of preemergent samples fry collected in 1990 and 1991. The 1989 preemergent fry samples showed no contamination in the one stream analyzed where oil was visually evident (Table 1).

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1990 PWS Pink Salmon Egg Mortality

Adjusted Means and 90% Confidence Bounds
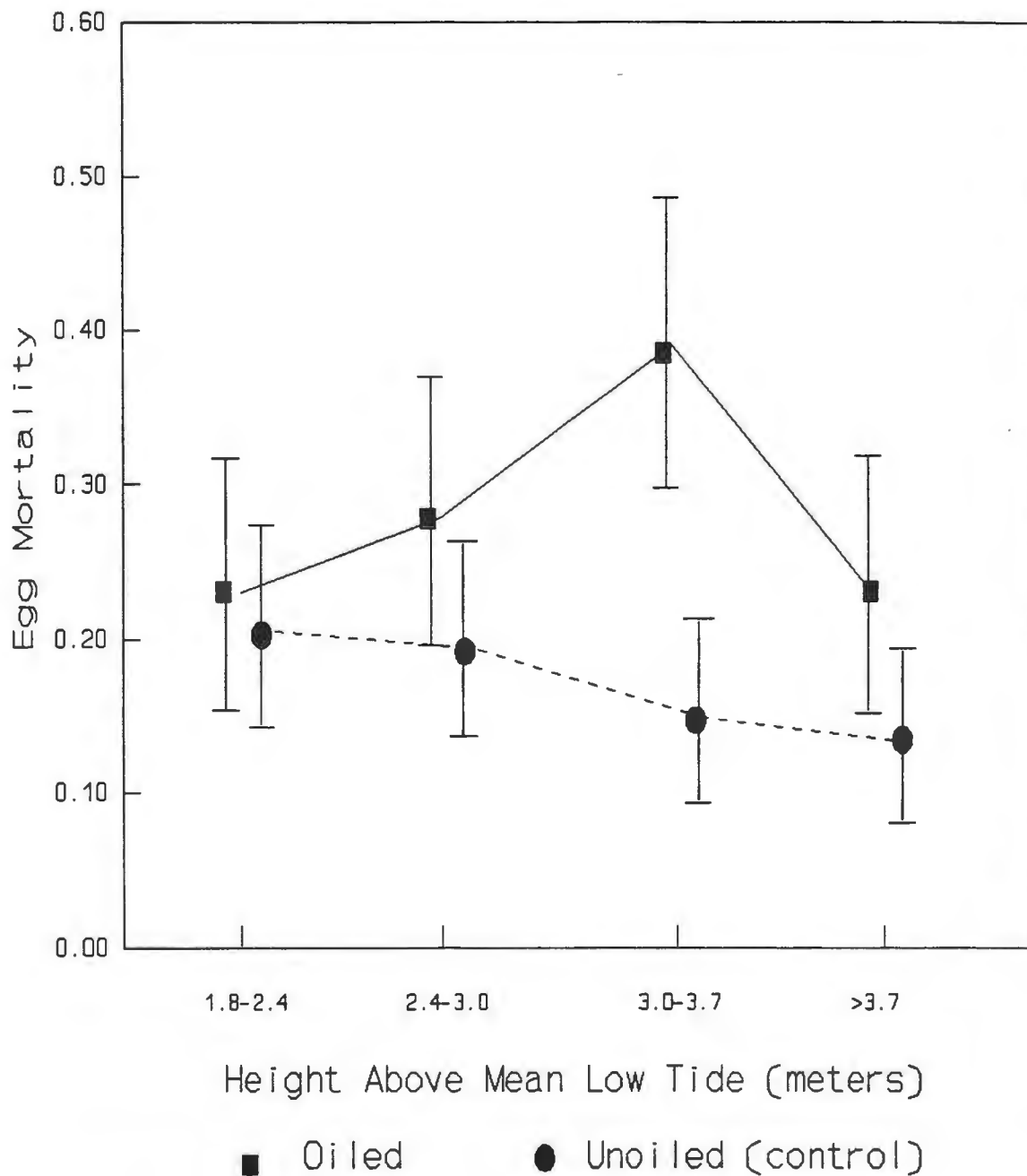
Figure 4   Adjusted mean mortality of 1990 pink salmon eggs by tide zone for oiled and control (unoiled) streams in Prince William Sound.

1991 PWS Pink Salmon Egg Mortality
Adjusted Means and 90% Confidence Bounds
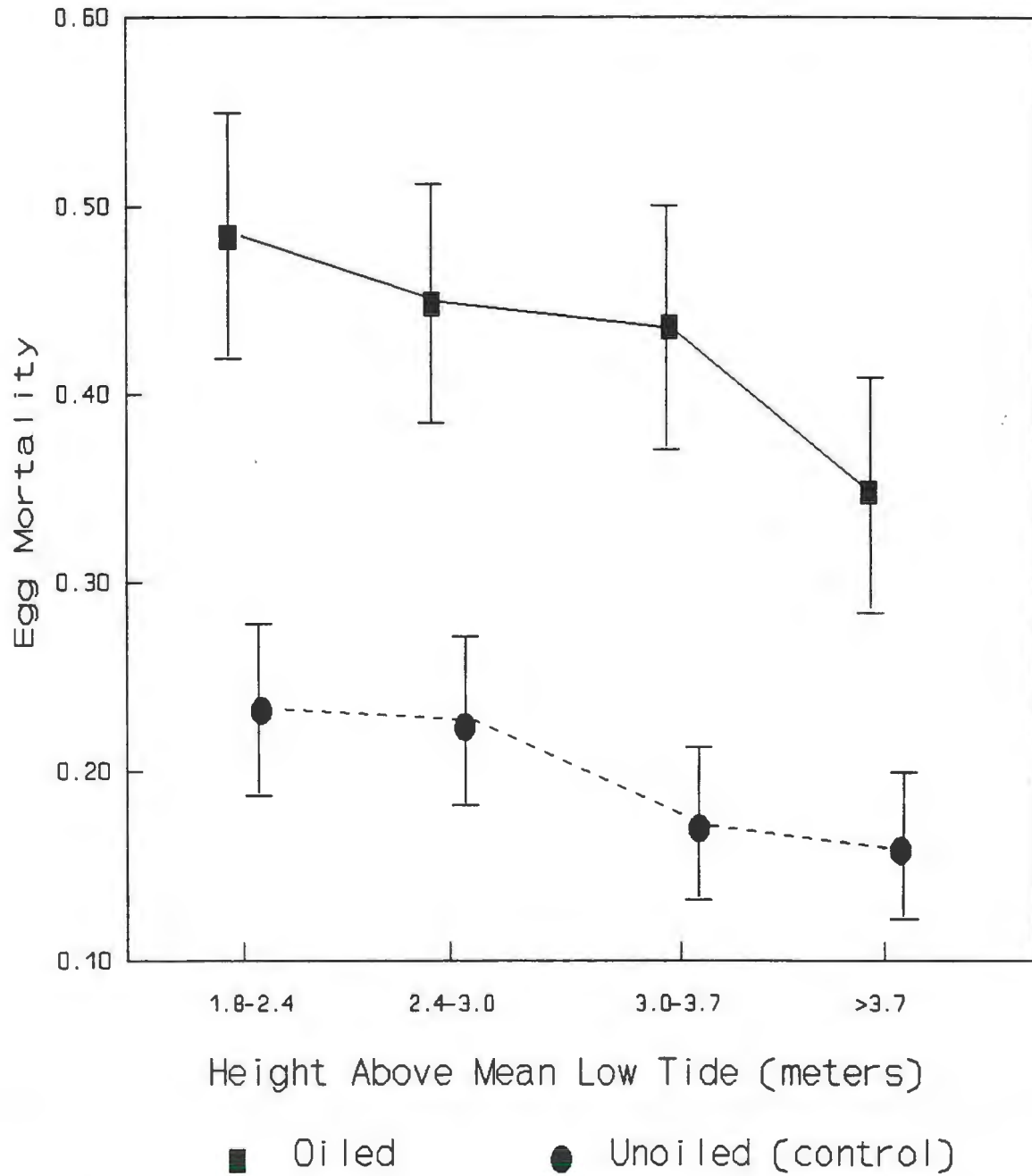
Figure 5 Adjusted mean mortality of 1991 pink salmon eggs by tide zone for oiled and control (unoiled) streams in Prince William Sound.

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1989-90 PWS Pink Salmon Egg to Fry Survival
Adjusted Means and 90% Confidence Bounds
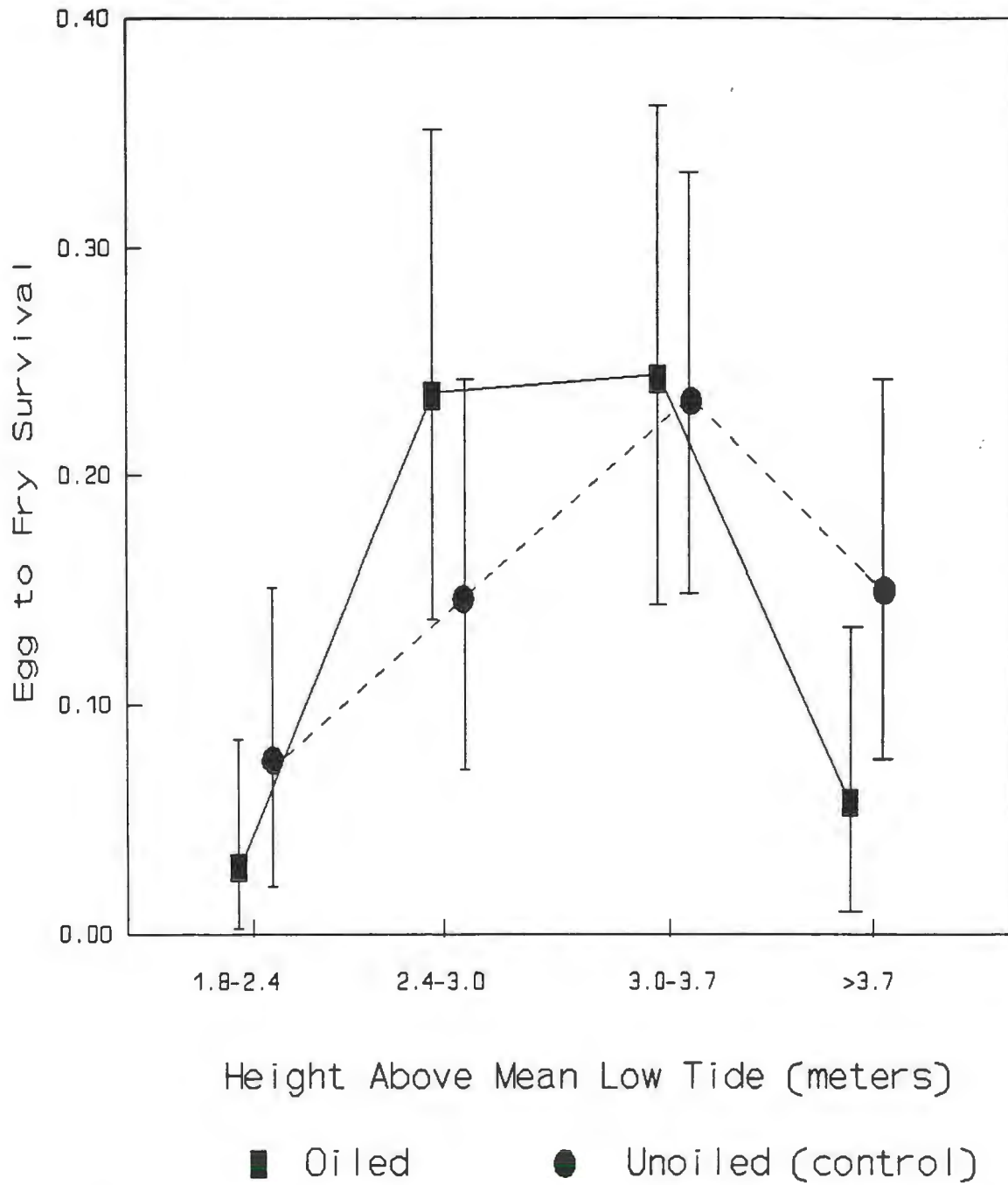
Figure 6   Pink salmon egg to preemergent fry adjusted survival means for oiled and control (unoiled) streams in Prince William Sound for the 1989 brood year.

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1990-91 PWS Pink Salmon Egg to Fry Survival
Adjusted Means and 90% Confidence Bounds
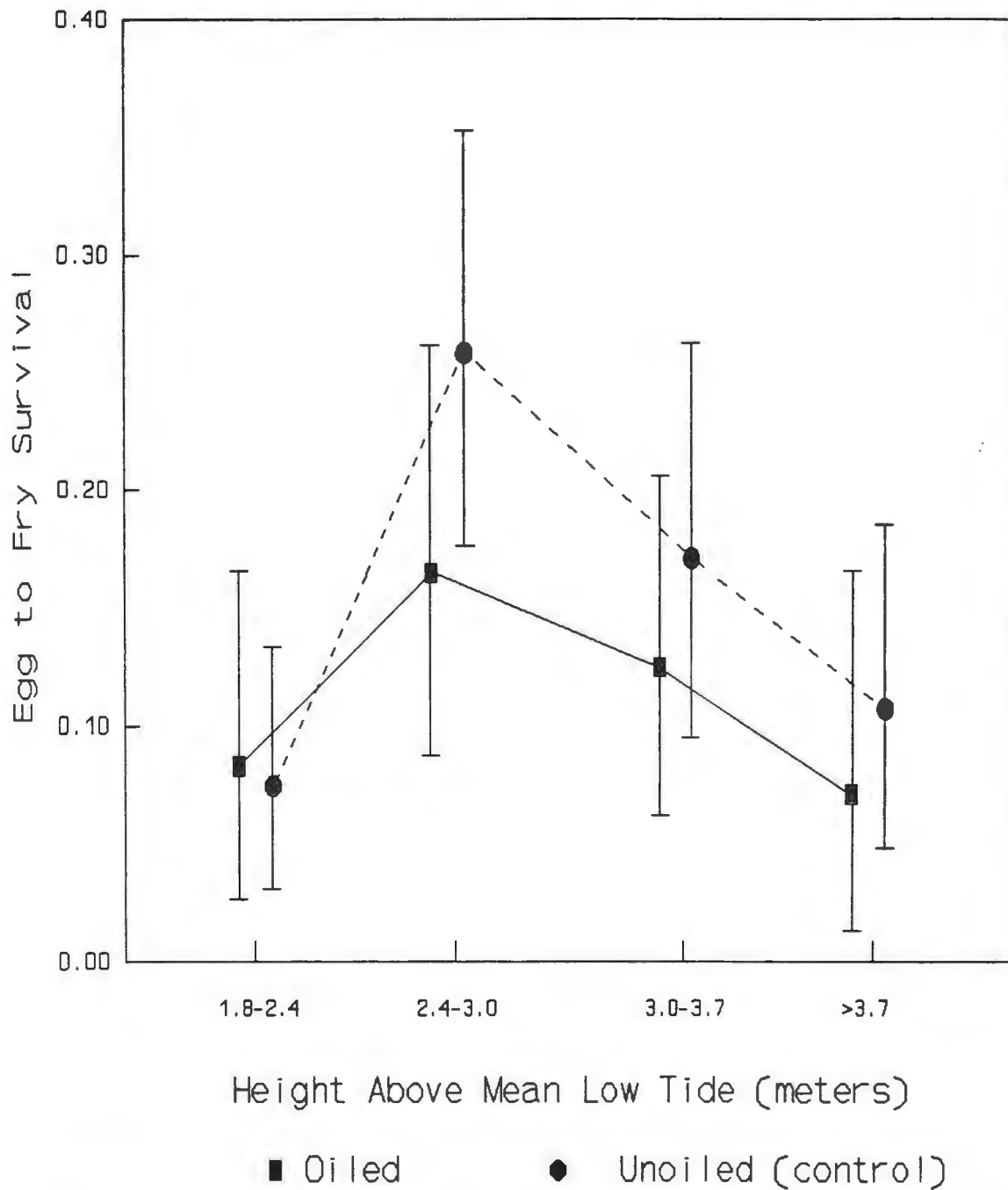
Figure 7   Pink salmon egg to preemergent fry adjusted survival means for oiled and control (unoiled) streams in Prince William Sound for the 1990 brood year.

Analysis for hydrocarbons in mussel samples collected in 1989 by NRDA F/S Study 1 showed positive contamination in six of the eight streams sampled where oil was visually evident (Table 1). Analysis of the 1990 mussel samples showed positive contamination in two and possible contamination in three of the ten streams where oil was visually evident in 1989 (Table 1).

STATUS OF INJURY ASSESSMENT

Egg and Preemergent Fry Densities

Densities of eggs and preemergent fry were used directly to assess injury from oiling. The data were used to determine egg mortality and overwinter survival.

Egg Morality and Overwinter Survival

The 1989 data showed a 7% difference in egg mortality between oiled and unoiled streams with the differences in the intertidal zones. The 1990 data showed a significantly higher egg mortality in the 3.0 to 3.7 m tide zone of oiled streams. The findings are consistent with visual documentation of oil impacts. In 1989, oil was visible throughout the intertidal zones with the heaviest deposits at mean high tide (3.7 m), while in 1990 oil was visible mostly at mean high tide.

In 1991 there were significant differences in egg mortality between oiled and unoiled streams in all the intertidal zones as well as the upstream zone. The largest difference in egg mortality was again in the highest intertidal zone. Differences in egg mortality between oiled and unoiled streams should not be expected in the upstream transects unless there were sublethal oil effects on the 1989 brood year. Seven of the ten oiled streams have upstream transects still within reach of extreme high tides. Results of adult spawner histopathology and cytological samples collected in 1991 by NRDA F/S Study 1 may help determine if the large differences in the 1991 egg mortalities were due to sublethal oil effects.

No difference in egg to preemergent fry survival between oiled and unoiled streams was found for the 1989 or 1990 brood years. This does not mean damages were not present; rather, it is indicative of insufficient power in sampling design or sampling levels to detect a difference.

Before final conclusions regarding oil damage can be made, the following are needed: hydrocarbon sample and coastal habitat study

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results indicating the extent of oiling, histopathology and cytological study results to examine possible sublethal oil effects, historical summary and analysis of egg and preemergent fry pre-spill data bases, and further egg and preemergent fry surveys for a post-spill data base.

Assessment of Lost Adult Production

Adult salmon production lost due to changes in spawning success cannot be assessed until the 1990 and 1991 catch and escapement data are evaluated. Measures of production generated by NRDA F/S Study 1 (wild stock escapement) and NRDA F/S Study 3 (allocation of the catch between wild and hatchery stocks using coded-wire tag results) will be needed. A loss in wild stock production could occur due to poor adult spawner escapement resulting in poor egg deposition, poor overwinter survival, poor early marine survival, or poor marine survival. Adult production losses due to oil damage may be hard to detect apart from natural variation without estimates of survival and extent of oil exposure at all life stages. NRDA F/S Studies 1,2,3, and 4 will provide the framework to assess whether lost production was attributable to oil injury or natural variation.

Documentation of Hydrocarbon Contamination

Results from histopathology samples collected during the 1989 fry survey and histopathology and MFO samples collected during the 1990 and 1991 egg and fry surveys are not available. Results from hydrocarbon samples collected by NRDA F/S Study 1 in 1989 generally agree with visual observations made immediately following the oil spill (NRDA F/S Studies 1 and 2); however, two streams with visible oil did not have contaminated mussel tissue samples in 1989. The 1990 hydrocarbon samples showed positive contamination at the two streams where oil was still visibly evident. Before making a final determination of which streams were oiled and the extent of oiling, further analysis of hydrocarbon samples needs to be done and other documentation of oil contamination needs to be summarized.

Restoration Strategies

Salmon stocks in PWS impacted by the *M/V Exxon Valdez* oil spill are also heavily exploited in commercial, sport, and subsistence fisheries and can most effectively be restored through stock specific management practices designed to reduce exploitation on impacted stocks. Impacted stocks occur in mixed-stock fisheries dominated by hatchery and wild stocks from unaffected areas of PWS.

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Restoration based on stock specific management of the commercial fishery for reduced exploitation of impacted stocks will require the following:

1. Identification of impacted stocks through the NRDA process.
2. Determination of fisheries exploitation rates appropriate for facilitating the natural recovery of impacted stocks.
2. Accurate in-season estimation of escapements to impacted and unimpacted wild stocks.
3. Accurate in-season estimation of the commercial catch stock composition by time and area.
4. Management action to reduce fishing effort on impacted stocks if the results of escapement and catch composition data indicate exploitation above levels desired to achieve restoration of the stock.

The advantages of restoration strategies based on more precise management are that the management framework is in place, the historic data base is sound, the research tools necessary for accurate escapement and catch stock-composition estimates have been tested and established in the NRDA arena, and regulatory mechanisms are in place and well tested.

We have worked closely with the fisheries management staff of the Alaska Department of Fish and Game, Commercial Fisheries Division, to develop a research and management package that will accomplish restoration objectives with minimal disruption of existing fisheries and fisheries management programs. Research projects exist or have been proposed that are designed to provide the escapement and catch stock-composition estimates necessary for restoration based on improved management. An escapement enumeration project similar to NRDA F/S Study 1, including an expanded aerial survey program, should provide the improved escapement enumeration needed. A coded wire tagging and recovery project similar to NRDA F/S Study 3 will provide the catch stock composition estimates needed.

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APPENDICES

APPENDIX A.1

Numbers of live and dead pink and chum salmon eggs and fry by
tide zone for the 1989 egg deposition survey

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Live	E/m²	SE	Pink Salmon Fry Dead	Live	Chum Salmon Eggs Dead	Live	E/m²	SE	Chum Salmon Fry Dead	Live	No. of Digs
35	Koppen Creek	10 15 89	9.0	30	455	3688	1415.93	249.68	0	0	289	940	360.89	187.01	0	39	14
			11.0	40	3390	8463	3249.19	708.75	0	3	519	624	239.57	93.50	0	69	14
			Upstream	60	2126	6085	2336.21	541.98	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		3845	12151	2332.56	408.73	0	3	808	1564	300.23	103.25	0	108	28
			Total Upstream		2126	6085	2336.21	541.98	0	0	0	0	.00	.00	0	0	14
480	Mink Creek	9 27 89	7.0	20	71	1169	448.81	218.66	1	0	33	272	104.43	55.87	0	311	14
			9.0	30	160	1138	436.91	213.75	0	0	458	606	232.66	132.15	0	75	14
			11.0	40	98	2597	997.06	335.25	0	1	22	60	23.04	16.47	0	1045	14
			Upstream	60	85	1311	503.33	165.56	0	2	15	11	4.22	4.22	0	156	14
			Total Intertidal		329	4904	627.60	153.06	1	1	513	938	120.04	48.84	0	1431	42
			Total Upstream		85	1311	503.33	165.56	0	2	15	11	4.22	4.22	0	156	14
485	W. Finger Creek	9 29 89	7.0	20	0	0	.00	.00	0	0	158	1255	481.83	188.28	0	54	14
			9.0	30	52	656	251.86	171.41	0	0	154	906	347.84	188.43	0	228	14
			11.0	40	13	3026	1161.77	355.42	0	0	100	629	241.49	181.62	0	993	14
			Upstream	60	65	2772	1064.25	340.35	0	5	0	0	.00	.00	0	0	14
			Total Intertidal		65	3682	471.21	150.10	0	0	412	2790	357.05	105.93	0	1275	42
			Total Upstream		65	2772	1064.25	340.35	0	5	0	0	.00	.00	0	0	14
498	McClure Creek	9 29 89	7.0	20	317	1355	520.22	148.50	0	1	22	0	.00	.00	0	0	14
			9.0	30	484	3119	1197.47	351.06	0	1	0	0	.00	.00	0	0	14
			11.0	40	843	6625	2543.53	498.04	0	210	0	0	.00	.00	0	0	14
			Upstream	60	61	1174	450.73	219.13	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		1644	11099	1420.41	242.53	0	212	22	0	.00	.00	0	0	42
			Total Upstream		61	1174	450.73	219.13	0	0	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
506	Loomis Creek	9 30 89	7.0	20	1094	2369	909.53	336.59	0	2	61	94	36.09	28.63	0	5	14
			9.0	30	2474	2929	1124.53	267.92	0	0	34	11	4.22	3.83	0	0	14
			11.0	40	1591	7250	2783.48	605.07	0	0	0	0	.00	.00	0	0	14
			Upstream	60	360	1688	1296.14	413.28	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		5159	12548	1605.85	274.51	0	2	95	105	13.44	9.72	0	5	42
			Total Upstream		360	1688	1296.14	413.28	0	0	0	0	.00	.00	0	0	7
604	Erb Creek	10 2 89	7.0	20	57	999	383.54	299.19	0	18	38	92	35.32	35.32	0	5	14
			9.0	30	83	1181	453.42	218.18	0	0	527	468	179.68	178.44	0	32	14
			11.0	40	842	2407	924.12	352.42	0	18	0	0	.00	.00	0	1	14
			Upstream	60	164	1876	720.25	356.23	0	95	0	1	.38	.38	0	23	14
			Total Intertidal		982	4587	587.03	170.37	0	36	565	560	71.67	60.37	0	38	42
			Total Upstream		164	1876	720.25	356.23	0	95	0	1	.38	.38	0	23	14
618	Junction Creek	10 2 89	7.0	20	422	1507	675.01	318.65	0	0	0	0	.00	.00	0	0	12
			9.0	30	274	1669	747.57	253.81	0	0	0	0	.00	.00	0	0	12
			11.0	40	305	1266	567.06	216.02	0	0	0	0	.00	.00	0	0	12
			Upstream	60	78	946	423.73	185.44	0	0	0	0	.00	.00	0	0	12
			Total Intertidal		1001	4442	663.22	149.77	0	0	0	0	.00	.00	0	0	36
			Total Upstream		78	946	423.73	185.44	0	0	0	0	.00	.00	0	0	12
621	Totemoff Creek	10 2 89	7.0	20	126	140	53.75	22.45	0	2	0	0	.00	.00	0	0	14
			9.0	30	242	2136	820.07	301.80	0	16	0	0	.00	.00	0	0	14
			11.0	40	828	2732	1048.89	318.37	0	176	0	0	.00	.00	0	0	14
			Upstream	60	432	788	302.54	155.02	0	3	0	0	.00	.00	0	0	14
			Total Intertidal		1196	5008	640.90	157.51	0	194	0	0	.00	.00	0	0	42
			Total Upstream		432	788	302.54	155.02	0	3	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
623	Brizgaloff Creek	10 3 89	7.0	20	13	507	194.65	109.97	0	1	0	0	.00	.00	0	0	14
			9.0	30	47	1960	752.50	348.45	0	0	0	0	.00	.00	0	0	14
			11.0	40	1083	2760	1059.64	356.86	0	191	0	0	.00	.00	0	0	14
			Upstream	60	1567	4335	1664.33	484.39	0	59	0	0	.00	.00	0	0	14
			Total Intertidal		1143	5227	668.93	175.21	0	192	0	0	.00	.00	0	0	42
			Total Upstream		1567	4335	1664.33	484.39	0	59	0	0	.00	.00	0	0	14
628	Chenega Creek	9 30 89	7.0	20	468	1898	728.70	327.18	0	0	0	0	.00	.00	0	0	14
			9.0	30	516	1687	647.69	228.87	0	1	0	0	.00	.00	0	0	14
			11.0	40	544	2814	1080.38	318.03	0	0	0	0	.00	.00	0	0	14
			Upstream	63	1509	7264	1394.43	217.01	0	50	2	39	7.49	6.71	0	0	28
			Total Intertidal		1528	6399	818.92	168.53	0	1	0	0	.00	.00	0	0	42
			Total Upstream		1509	7264	1394.43	217.01	0	50	2	39	7.49	6.71	0	0	28
630	Bainbridge Creek	10 3 89	7.0	20	1	206	79.09	53.90	0	0	0	0	.00	.00	0	0	14
			9.0	30	180	973	373.56	163.72	0	1	0	0	.00	.00	0	0	14
			11.0	40	159	3469	1331.85	238.65	0	184	0	0	.00	.00	0	0	14
			Upstream	60	725	5215	2002.19	499.42	0	18	0	0	.00	.00	0	1	14
			Total Intertidal		340	4648	594.83	127.03	0	185	0	0	.00	.00	0	0	42
			Total Upstream		725	5215	2002.19	499.42	0	18	0	0	.00	.00	0	1	14
632	Claw Creek	10 4 89	7.0	20	10	294	112.88	75.03	0	0	0	0	.00	.00	0	0	14
			9.0	30	38	242	92.91	66.98	0	0	0	0	.00	.00	0	0	14
			9.0	33	20	188	202.10	93.57	0	0	0	0	.00	.00	0	0	5
			11.0	40	146	6993	2684.81	665.86	0	16	0	0	.00	.00	0	0	14
			Upstream	60	67	1914	734.84	224.86	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		214	7717	882.53	261.22	0	16	0	0	.00	.00	0	0	47
			Total Upstream		67	1914	734.84	224.86	0	0	0	0	.00	.00	0	0	14

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m²	SE	Dead	Live	Dead	Live	E/m²	SE	Dead	Live	
637	Pt. Countess	10 4 89	7.0	20	1814	1429	548.63	216.74	0	0	0	0	.00	.00	0	0	14
			9.0	30	170	1828	701.82	141.31	0	0	0	0	.00	.00	0	0	14
			11.0	41	213	1270	975.18	357.34	0	0	0	0	.00	.00	0	0	7
			11.0	42	549	3272	2512.43	750.92	0	0	0	0	.00	.00	0	0	7
			Upstream	61	146	1201	922.20	240.16	0	0	0	0	.00	.00	0	0	7
			Upstream	62	311	2290	1758.39	574.29	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		2746	7799	998.09	188.74	0	0	0	0	.00	.00	0	0	42
			Total Upstream		457	3491	1340.29	320.73	0	0	0	0	.00	.00	0	0	14
653	Hogg Creek	10 5 89	7.0	20	10	1783	684.54	222.29	0	0	0	0	.00	.00	0	0	14
			9.0	31	5	269	180.73	140.33	0	0	0	0	.00	.00	0	0	8
			9.0	32	31	834	747.13	502.99	0	0	0	0	.00	.00	0	0	6
			11.0	40	20	2153	826.60	263.95	9	0	0	0	.00	.00	0	0	14
			Upstream	60	68	1952	749.43	330.38	0	4	0	0	.00	.00	0	0	14
			Total Intertidal		66	5039	644.87	137.67	9	0	0	0	.00	.00	0	0	42
			Total Upstream		68	1952	749.43	330.38	0	4	0	0	.00	.00	0	0	14
656	Halverson Creek	10 5 89	7.0	20	75	373	143.21	68.81	0	0	0	0	.00	.00	0	0	14
			9.0	30	737	1973	757.49	244.48	0	3	0	0	.00	.00	0	0	14
			11.0	40	600	3731	1432.44	427.74	0	26	0	0	.00	.00	0	0	14
			Upstream	60	296	5459	2095.87	387.87	0	180	0	0	.00	.00	0	0	14
			Total Intertidal		1412	6077	777.71	181.43	0	29	0	0	.00	.00	0	0	42
			Total Upstream		296	5459	2095.87	387.87	0	180	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
663	Shelter Bay	10 9 89	7.0	20	19	771	296.01	216.47	0	0	0	0	.00	.00	0	0	14
			9.0	30	81	840	376.25	197.23	0	0	0	0	.00	.00	0	0	12
			9.0	33	12	273	1467.38	.00	0	0	0	0	.00	.00	0	0	1
			11.0	40	1128	4315	1932.76	215.81	0	0	0	0	.00	.00	0	0	12
			Upstream	60	250	2149	962.57	261.05	0	0	0	0	.00	.00	0	0	12
			Total Intertidal		1240	6199	854.35	166.84	0	0	0	0	.00	.00	0	0	39
			Total Upstream		250	2149	962.57	261.05	0	0	0	0	.00	.00	0	0	12
665	Bjorne Creek	10 10 89	7.0	20	408	2359	905.69	273.16	0	0	0	0	.00	.00	0	0	14
			9.0	30	1147	3940	1512.68	389.82	0	0	0	0	.00	.00	0	0	14
			11.0	41	169	1180	906.07	304.36	0	0	0	0	.00	.00	0	0	7
			11.0	42	312	17	13.05	10.61	0	0	0	0	.00	.00	0	0	7
			11.0	43	119	360	161.25	100.56	0	0	0	0	.00	.00	0	0	12
			Upstream	60	554	4971	1908.51	311.59	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2155	7856	781.96	148.40	0	0	0	0	.00	.00	0	0	54
			Total Upstream		554	4971	1908.51	311.59	0	0	0	0	.00	.00	0	0	14
666	O'Brien Creek	10 11 89	7.0	20	173	1049	402.74	266.55	0	0	0	0	.00	.00	0	0	14
			7.0	23	85	316	141.54	117.81	0	0	0	0	.00	.00	0	0	12
			9.0	30	175	2655	1019.33	262.70	0	0	0	0	.00	.00	0	0	14
			11.0	40	223	3529	1354.88	308.95	0	1	0	0	.00	.00	0	0	14
			Upstream	60	63	712	546.71	275.24	0	0	0	0	.00	.00	0	0	7
			Upstream	63	360	1093	839.27	373.23	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		656	7549	751.41	141.08	0	1	0	0	.00	.00	0	0	54
			Total Upstream		423	1805	692.99	226.44	0	0	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
673	Falls Creek	10 10 89	7.0	21	24	560	376.25	155.94	0	0	0	0	.00	.00	0	0	8
			7.0	22	32	584	224.21	178.39	0	1	0	0	.00	.00	0	0	14
			9.0	30	53	2089	802.03	388.72	0	31	0	0	.00	.00	0	0	14
			11.0	40	80	1345	516.38	194.67	0	10	0	0	.00	.00	0	0	14
			Upstream	60	29	1757	674.56	227.60	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		189	4578	492.14	134.04	0	42	0	0	.00	.00	0	0	50
			Total Upstream		29	1757	674.56	227.60	0	1	0	0	.00	.00	0	0	14
677	Hayden Creek	10 10 89	7.0	21	151	1154	886.11	427.54	0	0	0	0	.00	.00	0	0	7
			7.0	22	27	774	594.32	200.03	0	1	0	0	.00	.00	0	0	7
			9.0	31	49	627	481.45	205.98	0	0	0	0	.00	.00	0	0	7
			9.0	32	66	834	640.39	214.32	0	7	0	0	.00	.00	0	0	7
			11.0	41	7	86	66.04	60.71	0	0	0	0	.00	.00	0	0	7
			11.0	42	103	274	210.39	171.97	0	0	0	0	.00	.00	0	0	7
			Upstream	61	4	19	14.59	9.44	0	0	0	0	.00	.00	0	0	7
			Upstream	62	26	142	109.04	109.04	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		403	3749	479.78	101.10	0	8	0	0	.00	.00	0	0	42
			Total Upstream		30	161	61.81	54.18	0	0	0	0	.00	.00	0	0	14
678	Sleepy Bay	10 9 89	7.0	20	13	381	170.66	82.37	0	0	0	0	.00	.00	0	0	12
			9.0	30	111	956	428.21	153.05	0	0	0	0	.00	.00	0	0	12
			11.0	40	231	1770	792.81	256.18	0	0	0	0	.00	.00	0	0	12
			Upstream	60	316	901	345.92	184.64	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		355	3107	463.89	109.09	0	0	0	0	.00	.00	0	0	36
			Total Upstream		316	901	345.92	184.64	0	0	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

| | | | | | Pink Salmon | | | | | | Chum Salmon | | | | | | |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	No. of Digs
681	Hogan Bay	10 11 89	7.0	20	186	2178	836.20	285.53	0	0	0	0	.00	.00	0	0	14
			9.0	31	141	1137	873.05	331.45	0	0	0	0	.00	.00	0	0	7
			9.0	32	432	2583	1983.38	563.56	0	0	0	0	.00	.00	0	0	7
			11.0	40	960	8167	3135.54	316.59	0	1	0	0	.00	.00	0	0	14
			Upstream	60	93	1290	495.27	201.47	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		1719	14065	1799.99	235.20	0	1	0	0	.00	.00	0	0	42
			Total Upstream		93	1290	495.27	201.47	0	1	0	0	.00	.00	0	0	14
682	Snug Harbor	10 11 89	7.0	20	350	1644	736.38	261.24	0	0	0	0	.00	.00	0	0	12
			9.0	30	1000	2658	1020.48	380.51	0	31	0	0	.00	.00	0	0	14
			11.0	40	477	4582	1759.16	395.91	0	27	0	0	.00	.00	0	0	14
			Upstream	60	134	1000	383.93	130.29	0	8	0	0	.00	.00	0	0	14
			Total Intertidal		1827	8884	1193.79	213.78	0	58	0	0	.00	.00	0	0	40
			Total Upstream		134	1000	383.93	130.29	0	8	0	0	.00	.00	0	0	14
692	Herring Bay	9 29 89	7.0	20	286	1887	724.47	332.80	0	0	0	0	.00	.00	0	0	14
			9.0	30	1163	2619	1005.51	398.40	0	0	0	0	.00	.00	0	0	14
			11.0	40	718	5044	1936.54	266.13	0	0	0	0	.00	.00	0	0	14
			Upstream	60	301	3841	1474.67	431.29	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2167	9550	1222.17	206.18	0	0	0	0	.00	.00	0	0	42
			Total Upstream		301	3841	1474.67	431.29	0	0	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
695	Port Audrey	10 1 89	7.0	21	29	288	221.14	148.90	0	0	0	0	.00	.00	0	0	7
			7.0	22	81	1958	1503.46	523.14	0	21	0	0	.00	.00	0	0	7
			9.0	31	190	432	331.71	122.87	0	0	0	0	.00	.00	0	0	7
			9.0	32	107	1662	1276.18	834.50	0	0	0	0	.00	.00	0	0	7
			11.0	40	1015	3821	1466.99	563.74	0	5	0	0	.00	.00	0	0	14
			Upstream	60	94	1669	640.78	231.96	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		1422	8161	1044.41	255.94	0	26	0	0	.00	.00	0	0	42
			Total Upstream		94	1669	640.78	231.96	0	0	0	0	.00	.00	0	0	14
699	Cathead Bay	10 1 89	7.0	20	137	814	312.52	155.10	0	0	222	0	.00	.00	0	0	14
			9.0	30	88	691	265.29	149.27	2	0	0	0	.00	.00	0	0	14
			11.0	40	118	999	383.54	219.54	0	0	0	0	.00	.00	0	0	14
			Upstream	60	59	737	282.96	154.55	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		343	2504	320.45	100.25	2	0	222	0	.00	.00	0	0	42
			Total Upstream		59	737	282.96	154.55	0	0	0	0	.00	.00	0	0	14
740	Kelez Creek	10 12 89	7.0	20	11	269	103.28	100.80	0	0	0	0	.00	.00	0	0	14
			9.0	30	85	944	362.43	122.33	0	0	0	0	.00	.00	0	0	14
			11.0	40	91	17	7.61	3.47	0	5	0	0	.00	.00	0	0	12
			11.0	43	114	1109	496.74	280.21	0	0	0	0	.00	.00	0	0	12
			Upstream	60	125	1334	512.16	249.34	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		301	2339	241.77	79.71	0	5	0	0	.00	.00	0	0	52
			Total Upstream		125	1334	512.16	249.34	0	0	0	0	.00	.00	0	0	14

Appendix A.1

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
744	Wilby Creek	10 13 89	7.0	20	20	587	225.37	123.77	0	0	0	0	.00	.00	0	0	14
			9.0	30	3	67	25.72	23.28	0	0	0	0	.00	.00	0	0	14
			11.0	40	3	44	33.79	22.03	0	0	0	0	.00	.00	0	0	7
			11.0	43	4	30	23.04	16.03	0	0	0	0	.00	.00	0	0	7
			Upstream	60	28	325	124.78	86.91	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		30	728	93.17	43.68	0	0	0	0	.00	.00	0	0	42
			Total Upstream		28	325	124.78	86.91	0	1	0	0	.00	.00	0	0	14
747	Cabin Creek	10 13 89	7.0	20	442	706	271.05	166.17	0	1	0	0	.00	.00	0	0	14
			9.0	30	147	2185	838.88	306.06	0	1	0	0	.00	.00	0	0	14
			11.0	40	1387	1752	724.38	218.79	0	0	0	0	.00	.00	0	0	13
			Upstream	60	406	1123	431.15	87.49	0	3	0	0	.00	.00	0	0	14
			Total Intertidal		1976	4643	608.69	139.80	0	2	0	0	.00	.00	0	0	41
			Total Upstream		406	1123	431.15	87.49	0	3	0	0	.00	.00	0	0	14
828	Cook Creek	10 13 89	7.0	20	0	3	1.15	.61	0	0	0	0	.00	.00	0	0	14
			9.0	30	603	1757	674.56	260.16	0	0	0	0	.00	.00	0	0	14
			11.0	41	39	739	567.45	363.52	0	0	0	1	.77	.77	0	0	7
			11.0	42	88	361	277.20	212.59	0	0	0	0	.00	.00	0	0	7
			11.0	43	111	96	86.00	81.72	0	0	0	0	.00	.00	0	0	6
			Upstream	60	881	4820	1850.54	386.40	0	257	0	0	.00	.00	0	1	14
			Upstream	100	1075	5297	2033.67	645.23	17	231	0	0	.00	.00	0	258	14
			Total Intertidal		841	2956	331.01	102.96	0	0	0	1	.11	.11	0	0	48
			Total Upstream		1956	10117	1942.10	369.43	17	488	0	0	.00	.00	0	259	28

1989 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Live	E/m²	SE	Fry Dead	Live	Chum Salmon Eggs Dead	Live	E/m²	SE	Fry Dead	Live	No. of Digs
861	Bernard Creek	10 14 89	7.0	20	209	826	317.13	113.03	0	1	0	0	.00	.00	0	0	14
			9.0	30	79	1229	471.85	180.74	0	2	0	0	.00	.00	0	0	14
			11.0	40	227	4481	1720.38	485.03	0	100	0	0	.00	.00	0	0	14
			Upstream	60	550	5736	2202.21	481.31	0	417	0	0	.00	.00	0	0	14
		Total Intertidal			515	6536	836.45	198.23	0	103	0	0	.00	.00	0	0	42
		Total Upstream			550	5736	2202.21	481.31	0	417	0	0	.00	.00	0	0	14

Prince William Sound Summary

					Dead	Live	E/m²	SE	Dead	Live	Dead	Live	E/m²	SE	Dead	Live	Digs
		Total Intertidal			37809	194731	791.14	34.13	12	1117	2637	5958	24.21	62.93	0	2857	1323
		Total Upstream			13408	85186	1015.24	62.93	17	1335	17	51	.61	79.07	0	439	451

APPENDIX A.2

Numbers of live and dead pink and chum salmon eggs and fry by
tide zone for the 1990 egg deposition survey

Appendix A.2

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs				Pink Salmon Fry		Chum Salmon Eggs				Chum Salmon Fry		No. of Digs
					Dead	Live	E/m²	SE	Dead	Live	Dead	Live	E/m²	SE	Dead	Live	
35	Koppen Creek	9 24 90	9.0	30	6107	1859	713.72	315.76	0	0	102	117	44.92	44.10	0	2	14
			11.0	40	7946	3209	1232.03	404.97	0	0	2	18	6.91	5.33	0	0	14
			Upstream	60	5205	1113	427.31	171.01	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		14053	5068	972.88	256.85	0	0	104	135	25.92	22.10	0	2	28
			Total Upstream		5205	1113	427.31	171.01	0	0	0	0	.00	.00	0	0	14
480	Mink Creek	9 25 90	7.0	20	1441	3886	1491.95	315.71	0	0	6	1	.38	.38	0	1	14
			9.0	30	450	3033	1164.46	342.57	0	18	303	188	72.18	38.61	0	170	14
			11.0	40	417	1979	759.79	241.95	0	70	20	110	42.23	38.98	0	31	14
			Upstream	60	350	3595	1380.22	436.57	0	7	79	314	120.55	96.21	0	181	14
			Total Intertidal		2308	8898	1138.73	176.95	0	88	329	299	38.26	18.42	0	202	42
			Total Upstream		350	3595	1380.22	436.57	0	7	79	314	120.55	96.21	0	181	14
485	W. Finger Creek	9 26 90	7.0	20	89	1694	650.38	189.82	0	0	29	344	132.07	120.26	0	0	14
			9.0	30	138	3827	1469.29	372.94	0	158	3	97	37.24	24.79	0	10	14
			11.0	40	302	4131	1586.01	456.04	0	14	44	929	356.67	199.37	0	110	14
			Upstream	60	710	2588	993.61	245.14	0	16	38	333	127.85	113.06	0	0	14
			Total Intertidal		529	9652	1235.23	211.46	0	172	76	1370	175.33	78.94	0	120	42
			Total Upstream		710	2588	993.61	245.14	0	16	38	333	127.85	113.06	0	0	14
498	McClure Creek	9 25 90	7.0	20	1769	1937	743.67	240.20	0	0	0	0	.00	.00	0	0	14
			9.0	30	3396	3460	1328.39	329.60	0	7	0	0	.00	.00	0	0	14
			11.0	40	3480	5665	2174.96	499.32	0	28	0	0	.00	.00	0	0	14
			Upstream	60	469	2702	1037.38	515.04	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		8645	11062	1415.67	228.80	0	35	0	0	.00	.00	0	0	42
			Total Upstream		469	2702	1037.38	515.04	0	0	0	0	.00	.00	0	0	14

Appendix A.2

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
506	Loomis Creek	9 30 90	7.0	20	1245	3377	1296.53	412.20	0	0	0	0	.00	.00	0	0	14
			9.0	30	4348	2627	1008.58	417.01	0	1	0	0	.00	.00	0	0	14
			11.0	40	3283	1350	518.30	218.33	0	0	0	0	.00	.00	0	0	14
			Upstream	60	1914	2487	954.83	278.59	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			8876	7354	941.14	209.50	0	1	0	0	.00	.00	0	0	42
		Total Upstream			1914	2487	954.83	278.59	0	0	0	0	.00	.00	0	0	14
604	Erb Creek	10 29 90	7.0	20	262	1043	800.88	492.89	0	0	0	0	.00	.00	0	0	7
			7.0	23	199	627	481.45	187.30	0	9	0	0	.00	.00	0	0	7
			9.0	30	2884	3930	1508.84	523.43	0	1	634	20	7.68	6.89	0	0	14
			11.0	40	845	1662	638.09	234.07	0	2	3	24	9.21	6.48	0	18	14
			Upstream	60	119	1302	499.88	275.21	0	1	0	0	.00	.00	0	0	14
		Total Intertidal			4190	7262	929.36	214.08	0	12	637	44	5.63	3.14	0	18	42
		Total Upstream			119	1302	499.88	275.21	0	1	0	0	.00	.00	0	0	14
618	Junction Creek	9 28 90	7.0	20	267	2268	1015.88	499.60	0	0	0	0	.00	.00	0	0	12
			9.0	30	151	1446	647.69	604.19	0	0	0	0	.00	.00	0	0	12
			11.0	40	1539	974	436.27	192.53	0	0	0	0	.00	.00	0	0	12
			Upstream	60	452	495	221.72	218.79	0	0	0	0	.00	.00	0	0	12
		Total Intertidal			1957	4688	699.94	264.41	0	0	0	0	.00	.00	0	0	36
		Total Upstream			452	495	221.72	218.79	0	0	0	0	.00	.00	0	0	12
621	Totemoff Creek	9 28 90	7.0	20	3195	3843	1475.44	390.40	52	16	0	0	.00	.00	0	0	14
			9.0	30	406	2494	957.52	304.48	0	7	0	0	.00	.00	0	0	14
			11.0	40	595	2673	1026.24	364.75	0	290	0	0	.00	.00	0	0	14
			Upstream	60	39	423	162.40	87.78	1	0	0	0	.00	.00	0	0	14
		Total Intertidal			4196	9010	1153.07	203.11	52	313	0	0	.00	.00	0	0	42
		Total Upstream			39	423	162.40	87.78	1	0	0	0	.00	.00	0	0	14

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
623	Brizgaloff Creek	9 27 90	7.0	20	1855	4747	1822.51	490.18	0	1	0	0	.00	.00	0	0	14
			9.0	30	1749	1694	650.38	280.76	0	0	9	2	.77	.77	0	0	14
			11.0	40	2585	4331	1662.79	589.98	0	0	2	0	.00	.00	0	0	14
			Upstream	60	3301	4220	1620.18	382.58	0	76	0	0	.00	.00	0	0	14
			Total Intertidal		6189	10772	1378.56	277.64	0	1	11	2	.26	.26	0	0	42
			Total Upstream		3301	4220	1620.18	382.58	0	76	0	0	.00	.00	0	0	14
628	Chenega Creek	9 29 90	7.0	20	169	276	105.96	68.65	0	0	0	0	.00	.00	0	0	14
			9.0	30	969	5465	2098.17	483.00	0	0	0	0	.00	.00	0	0	14
			11.0	40	1507	2066	793.20	212.71	0	0	0	0	.00	.00	0	0	14
			Upstream	60	989	7325	2812.28	483.73	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2645	7807	999.11	215.84	0	0	0	0	.00	.00	0	0	42
			Total Upstream		989	7325	2812.28	483.73	0	0	0	0	.00	.00	0	0	14
630	Bainbridge Creek	10 14 90	7.0	20	164	17	6.53	3.04	0	0	0	0	.00	.00	0	0	14
			9.0	30	780	3342	1283.09	336.75	13	342	0	0	.00	.00	0	0	14
			11.0	40	622	8727	3350.54	574.88	12	798	0	0	.00	.00	0	8	14
			Upstream	60	817	7867	3020.37	533.91	22	571	0	0	.00	.00	4	3	14
			Total Intertidal		1566	12086	1546.72	305.32	25	1140	0	0	.00	.00	0	8	42
			Total Upstream		817	7867	3020.37	533.91	22	571	0	0	.00	.00	4	3	14
632	Claw Creek	10 14 90	7.0	20	67	1665	639.24	316.57	0	261	0	0	.00	.00	0	0	14
			9.0	30	263	4038	1550.30	405.16	0	248	0	0	.00	.00	0	0	14
			11.0	40	260	7164	2750.46	587.23	0	639	0	0	.00	.00	0	0	14
			Upstream	60	0	0	.00	.00	0	1	0	0	.00	.00	0	0	7
			Total Intertidal		590	12867	1646.67	287.44	0	1148	0	0	.00	.00	0	0	42
			Total Upstream		0	0	.00	.00	0	1	0	0	.00	.00	0	0	7

Appendix A.2

1990 Prince William Sound Pink and Chum Salmon Egg Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
637	Pt. Countess	10 3 90	7.0	20	1793	3324	1276.18	350.33	0	0	0	0	.00	.00	0	0	14
			9.0	30	1400	4349	1669.71	452.30	0	37	0	0	.00	.00	0	0	14
			11.0	41	1777	3321	1275.03	252.80	0	8	0	0	.00	.00	0	0	14
			Upstream	61	368	2223	1706.95	374.09	0	7	0	0	.00	.00	0	0	7
			Upstream	62	251	577	443.05	147.24	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		4970	10994	1406.97	205.40	0	45	0	0	.00	.00	0	0	42
			Total Upstream		619	2800	1075.00	260.80	0	7	0	0	.00	.00	0	0	14
653	Hogg Creek	10 15 90	7.0	20	132	2044	784.75	311.12	0	185	0	0	.00	.00	0	0	14
			9.0	31	26	633	486.05	224.71	0	0	0	0	.00	.00	0	0	7
			9.0	32	9	214	164.32	158.14	0	2	0	0	.00	.00	0	0	7
			11.0	40	35	2553	980.17	557.03	0	299	0	0	.00	.00	0	0	14
			Upstream	60	517	1795	689.15	285.78	0	14	0	0	.00	.00	0	0	14
			Total Intertidal		202	5444	696.70	216.60	0	486	0	0	.00	.00	0	0	42
			Total Upstream		517	1795	689.15	285.78	0	14	0	0	.00	.00	0	0	14
656	Halverson Creek	10 15 90	7.0	22	100	774	297.16	131.06	0	75	0	0	.00	.00	0	0	14
			9.0	30	223	1473	565.53	186.32	0	1467	0	0	.00	.00	0	0	14
			11.0	40	590	5282	2027.91	381.32	0	659	0	0	.00	.00	0	0	14
			Upstream	60	1282	4639	1781.04	192.75	0	879	0	0	.00	.00	0	0	14
			Total Intertidal		913	7529	963.53	186.98	0	2201	0	0	.00	.00	0	0	42
			Total Upstream		1282	4639	1781.04	192.75	0	879	0	0	.00	.00	0	0	14
663	Shelter Bay	10 13 90	7.0	20	81	1223	547.80	439.44	0	0	0	0	.00	.00	0	0	12
			9.0	30	291	2287	1024.39	279.91	0	0	0	0	.00	.00	0	0	12
			11.0	40	629	3597	1611.16	547.42	0	0	0	0	.00	.00	0	0	12
			Upstream	60	148	1026	459.56	199.93	0	0	0	0	.00	.00	0	0	12
			Total Intertidal		1001	7107	1061.11	255.41	0	0	0	0	.00	.00	0	0	36
			Total Upstream		148	1026	459.56	199.93	0	0	0	0	.00	.00	0	0	12

Appendix A.2

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
665	Bjorne Creek	10 4 90	7.0	20	697	1255	481.83	455.22	0	0	0	0	.00	.00	0	0	14
			9.0	30	1957	2038	782.45	222.12	0	0	0	0	.00	.00	0	0	14
			11.0	40	1820	1718	659.59	222.53	0	16	0	0	.00	.00	0	0	14
			Upstream	60	1357	2271	871.90	313.52	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		4474	5011	641.29	180.89	0	16	0	0	.00	.00	0	0	42
			Total Upstream		1357	2271	871.90	313.52	0	0	0	0	.00	.00	0	0	14
666	O'Brien Creek	10 11 90	7.0	20	177	1275	489.51	180.17	0	0	0	0	.00	.00	0	0	14
			9.0	30	88	1239	475.69	144.09	0	4	0	0	.00	.00	0	0	14
			11.0	40	675	3579	1374.08	292.03	0	118	0	0	.00	.00	0	0	14
			Upstream	60	645	1607	616.97	237.17	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		940	6093	779.76	137.65	0	122	0	0	.00	.00	0	0	42
			Total Upstream		645	1607	616.97	237.17	0	1	0	0	.00	.00	0	0	14
673	Falls Creek	10 12 90	7.0	20	57	1299	498.72	264.89	0	183	0	0	.00	.00	0	0	14
			9.0	30	204	4995	1917.72	482.26	0	1399	0	0	.00	.00	0	0	14
			11.0	40	98	843	323.65	167.22	0	85	0	0	.00	.00	0	0	14
			Upstream	60	63	489	187.74	63.57	0	122	0	0	.00	.00	0	0	14
			Total Intertidal		359	7137	913.37	217.67	0	1667	0	0	.00	.00	0	0	42
			Total Upstream		63	489	187.74	63.57	0	122	0	0	.00	.00	0	0	14

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Live	E/m^2	SE	Pink Fry Dead	Live	Chum Salmon Eggs Dead	Live	E/m^2	SE	Chum Fry Dead	Live	No. of Digs
677	Hayden Creek	10 12 90	7.0	21	17	140	107.50	56.39	0	2	0	0	.00	.00	0	0	7
			7.0	22	59	300	230.36	137.78	0	45	0	0	.00	.00	0	0	7
			9.0	31	90	1340	1028.93	402.66	0	7	0	0	.00	.00	0	0	7
			9.0	32	247	1834	1408.25	510.01	0	340	0	0	.00	.00	0	0	7
			11.0	41	293	1049	805.48	514.65	0	0	0	0	.00	.00	0	0	7
			11.0	42	175	1683	1292.30	793.70	0	437	0	0	.00	.00	0	0	7
			Upstream	61	9	89	68.34	45.63	0	0	0	0	.00	.00	0	0	7
			Upstream	62	452	1361	1045.05	376.09	0	61	0	0	.00	.00	0	0	7
			Total Intertidal		881	6346	812.14	196.55	0	831	0	0	.00	.00	0	0	42
			Total Upstream		461	1450	556.70	226.86	0	61	0	0	.00	.00	0	0	14
678	Sleepy Bay	10 3 90	7.0	20	37	462	206.94	134.16	0	0	0	0	.00	.00	0	0	12
			9.0	30	117	141	63.16	49.29	0	0	0	0	.00	.00	0	0	12
			11.0	40	574	433	193.95	149.90	0	0	0	0	.00	.00	0	0	12
			Upstream	60	131	827	317.51	168.86	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		728	1036	154.68	67.93	0	0	0	0	.00	.00	0	0	36
			Total Upstream		131	827	317.51	168.86	0	0	0	0	.00	.00	0	0	14
681	Hogan Bay	10 13 90	7.0	20	60	201	77.17	59.62	0	1	0	0	.00	.00	0	0	14
			9.0	30	33	9	3.46	2.30	0	0	0	0	.00	.00	0	0	14
			11.0	40	207	1303	500.26	249.83	0	7	0	0	.00	.00	0	0	14
			Upstream	60	159	1489	571.67	297.39	0	10	0	0	.00	.00	0	0	14
			Total Intertidal		300	1513	193.63	90.23	0	8	0	0	.00	.00	0	0	42
			Total Upstream		159	1489	571.67	297.39	0	10	0	0	.00	.00	0	0	14

Appendix A.2

1990 Prince William Sound Pink and Chum Salmon Egg Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
682	Snug Harbor	10 16 90	7.0	20	1218	1438	552.09	183.71	0	234	0	0	.00	.00	0	0	14
			9.0	30	2208	2908	1116.46	313.72	0	63	0	0	.00	.00	0	0	14
			11.0	40	1289	5018	1926.55	455.81	0	894	0	0	.00	.00	0	0	14
			Upstream	60	616	4667	1791.79	525.22	3	1042	0	0	.00	.00	0	0	14
			Total Intertidal		4715	9364	1198.37	209.02	0	1191	0	0	.00	.00	0	0	42
			Total Upstream		616	4667	1791.79	525.22	3	1042	0	0	.00	.00	0	0	14
692	Herring Bay	9 30 90	7.0	20	394	954	366.27	166.44	0	0	0	0	.00	.00	0	0	14
			9.0	30	629	1563	600.08	237.54	0	1	0	0	.00	.00	0	0	14
			11.0	40	1089	3150	1209.38	285.44	0	0	0	0	.00	.00	0	0	14
			Upstream	60	564	1796	689.54	232.24	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2112	5667	725.24	143.47	0	1	0	0	.00	.00	0	0	42
			Total Upstream		564	1796	689.54	232.24	0	0	0	0	.00	.00	0	0	14
695	Port Audrey	9 29 90	7.0	21	119	1028	789.36	376.69	0	10	0	0	.00	.00	0	0	7
			7.0	22	83	625	479.91	250.55	4	20	0	0	.00	.00	0	0	7
			9.0	30	1863	2279	874.97	380.32	0	6	0	0	.00	.00	0	0	14
			11.0	40	908	1578	605.84	277.68	0	14	0	0	.00	.00	0	0	14
			Upstream	60	490	2434	934.48	388.78	1	9	0	0	.00	.00	0	0	14
			Total Intertidal		2973	5510	705.15	170.23	4	50	0	0	.00	.00	0	0	42
			Total Upstream		490	2434	934.48	388.78	1	9	0	0	.00	.00	0	0	14

Appendix A.2

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
699	Cathead Bay	10 1 90	7.0	20	381	3043	1168.29	384.33	0	39	603	0	.00	.00	0	0	14
			9.0	30	153	3160	1213.21	321.42	0	3	0	0	.00	.00	0	0	14
			11.0	40	183	2071	795.12	279.79	0	0	0	0	.00	.00	0	0	14
			Upstream	60	156	2437	935.63	453.45	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		717	8274	1058.88	188.84	0	42	603	0	.00	.00	0	0	42
			Total Upstream		156	2437	935.63	453.45	0	0	0	0	.00	.00	0	0	14
740	Kelez Creek	10 10 90	7.0	20	586	690	264.91	103.82	0	6	0	0	.00	.00	0	0	14
			9.0	30	101	849	325.96	172.58	0	8	0	0	.00	.00	0	0	14
			11.0	40	394	564	216.54	91.76	0	27	0	0	.00	.00	0	0	14
			Upstream	60	97	1242	476.84	192.23	0	6	0	0	.00	.00	0	0	14
			Total Intertidal		1081	2103	269.13	72.29	0	41	0	0	.00	.00	0	0	42
			Total Upstream		97	1242	476.84	192.23	0	6	0	0	.00	.00	0	0	14
744	Wilby Creek	10 9 90	7.0	20	79	36	13.82	3.77	0	0	0	0	.00	.00	0	0	14
			9.0	31	2	4	3.07	1.98	0	0	0	0	.00	.00	0	0	7
			9.0	32	174	236	181.21	175.86	0	13	0	0	.00	.00	0	0	7
			11.0	40	310	2777	1066.17	275.71	0	192	0	0	.00	.00	0	0	14
			Upstream	60	4	620	238.04	165.45	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		565	3053	390.71	120.18	0	205	0	0	.00	.00	0	0	42
			Total Upstream		4	620	238.04	165.45	0	0	0	0	.00	.00	0	0	14
747	Cabin Creek	10 9 90	7.0	20	1946	283	108.65	47.88	0	0	0	0	.00	.00	0	0	14
			9.0	30	620	447	171.62	108.06	0	0	0	0	.00	.00	0	0	14
			11.0	40	2477	1734	665.73	203.18	0	0	0	0	.00	.00	0	0	14
			Upstream	60	1133	1024	393.14	108.91	0	2	0	0	.00	.00	0	0	14
			Total Intertidal		5043	2464	315.33	85.75	0	0	0	0	.00	.00	0	0	42
			Total Upstream		1133	1024	393.14	108.91	0	2	0	0	.00	.00	0	0	14

1990 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
828	Cook Creek	10 18 90	7.0	20	26	625	239.96	137.98	0	0	0	0	.00	.00	0	0	14
			9.0	30	985	4226	1622.48	390.62	0	218	0	0	.00	.00	0	0	14
			11.0	40	235	3865	1483.88	429.81	0	168	0	0	.00	.00	0	0	14
			Upstream	60	157	1883	722.94	244.06	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		1246	8716	1115.44	217.00	0	386	0	0	.00	.00	0	0	42
			Total Upstream		157	1883	722.94	244.06	0	0	0	0	.00	.00	0	0	14
861	Bernard Creek	10 8 90	7.0	20	1429	990	380.09	148.23	0	1	0	0	.00	.00	0	0	14
			9.0	30	2466	1430	549.02	225.90	0	0	0	0	.00	.00	0	0	14
			11.0	40	1339	5019	1926.94	574.84	0	48	0	0	.00	.00	0	0	14
			Upstream	60	60	667	256.08	249.09	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		5234	7439	952.01	233.12	0	49	0	0	.00	.00	0	0	42
			Total Upstream		60	667	256.08	249.09	0	1	0	0	.00	.00	0	0	14
Prince William Sound Summary																	
			Total Intertidal		94198	217326	919.79	37.72	81	10251	1760	1850	7.83	63.94	0	350	1270
			Total Upstream		23024	69280	880.33	63.94	27	2826	117	647	8.22	76.98	4	184	423

APPENDIX A.3

Numbers of live and dead pink and chum salmon eggs and fry by
tide zone for the 1991 egg deposition survey

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Live	E/m²	SE	Fry Dead	Live	Chum Salmon Eggs Dead	Live	E/m²	SE	Fry Dead	Live	No. of Digs
35	Koppen Creek	9 23 91	9.0	30	2461	177	67.96	41.96	0	0	0	0	.00	.00	0	0	14
			11.0	40	5771	1492	572.82	226.06	0	0	66	68	26.11	26.11	0	0	14
			Upstream	60	6021	1748	671.11	215.98	0	0	1	0	.00	.00	0	0	14
			Total Intertidal		8232	1669	320.39	122.83	0	0	66	68	13.05	13.05	0	0	28
			Total Upstream		6021	1748	671.11	215.98	0	0	1	0	.00	.00	0	0	14
480	Mink Creek	10 9 91	7.0	20	46	726	278.73	113.40	0	0	0	0	.00	.00	0	0	14
			9.0	30	126	1880	721.79	232.12	0	2	6	60	23.04	23.04	0	81	14
			11.0	41	71	1017	780.91	448.64	2	108	0	0	.00	.00	0	0	7
			11.0	42	132	835	641.16	374.98	1	93	0	0	.00	.00	0	0	7
			Upstream	60	60	2291	879.58	266.30	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		375	4458	570.52	128.34	3	203	6	60	7.68	7.68	0	81	42
			Total Upstream		60	2291	879.58	266.30	0	0	0	0	.00	.00	0	0	14
485	W. Finger Creek	10 8 91	7.0	20	0	15	5.76	3.80	0	0	0	24	9.21	7.59	0	0	14
			9.0	30	172	5346	2052.48	726.28	0	1	8	599	229.97	223.78	0	34	14
			11.0	40	94	5546	2129.27	318.89	3	10	10	286	109.80	88.40	4	291	14
			Upstream	60	126	3855	1480.04	521.27	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		266	10907	1395.84	300.15	3	11	18	909	116.33	79.52	4	325	42
			Total Upstream		126	3855	1480.04	521.27	0	1	0	0	.00	.00	0	0	14
498	McClure Creek	10 8 91	7.0	20	402	1452	557.46	136.57	0	0	0	0	.00	.00	0	0	14
			9.0	30	813	4375	1679.69	415.97	0	3	0	0	.00	.00	0	0	14
			11.0	40	681	4695	1802.54	320.79	0	193	83	0	.00	.00	0	0	14
			Upstream	60	3238	5242	2012.55	552.92	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		1896	10522	1346.57	196.95	0	196	83	0	.00	.00	0	0	42
			Total Upstream		3238	5242	2012.55	552.92	0	1	0	0	.00	.00	0	0	14

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
506	Loomis Creek	10 9 91	7.0	20	520	830	318.66	108.99	0	0	0	0	.00	.00	0	0	14
			9.0	30	1299	2064	792.43	290.24	0	0	0	0	.00	.00	0	0	14
			11.0	40	2300	2150	825.45	300.55	0	0	0	0	.00	.00	0	0	14
			Upstream	60	557	1978	759.41	288.49	0	1	0	0	.00	.00	0	0	14
			Total Intertidal		4119	5044	645.51	144.96	0	0	0	0	.00	.00	0	0	42
			Total Upstream		557	1978	759.41	288.49	0	1	0	0	.00	.00	0	0	14
604	Erb Creek	10 10 91	7.0	20	222	3641	1397.88	357.08	0	31	0	0	.00	.00	0	0	14
			9.0	30	1825	6606	2536.23	417.38	0	1	103	22	8.45	8.04	0	16	14
			11.0	40	167	2633	1010.88	412.78	0	0	0	0	.00	.00	0	0	14
			Upstream	60	252	3688	1415.93	307.40	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2214	12880	1648.33	245.19	0	32	103	22	2.82	2.69	0	16	42
			Total Upstream		252	3688	1415.93	307.40	0	0	0	0	.00	.00	0	0	14
618	Junction Creek	10 1 91	7.0	20	28	9	4.03	1.77	0	0	0	0	.00	.00	0	0	12
			9.0	30	486	690	309.06	193.77	0	0	0	0	.00	.00	0	0	12
			11.0	40	822	1855	830.89	318.86	0	0	0	0	.00	.00	0	0	12
			Upstream	60	189	499	223.51	187.15	0	0	0	0	.00	.00	0	0	12
			Total Intertidal		1336	2554	381.33	133.85	0	0	0	0	.00	.00	0	0	36
			Total Upstream		189	499	223.51	187.15	0	0	0	0	.00	.00	0	0	12
621	Totemoff Creek	10 10 91	7.0	20	3892	4286	1645.52	490.60	0	1	0	0	.00	.00	0	0	14
			9.0	30	885	2166	831.59	291.60	0	2	0	0	.00	.00	0	0	14
			11.0	40	2065	5026	1929.63	373.30	4	451	1	0	.00	.00	0	0	14
			Upstream	60	648	4406	1691.59	452.49	0	154	0	0	.00	.00	0	0	14
			Total Intertidal		6842	11478	1468.91	233.31	4	454	1	0	.00	.00	0	0	42
			Total Upstream		648	4406	1691.59	452.49	0	154	0	0	.00	.00	0	0	14

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
623	Brizgaloff Creek	10 11 91	7.0	20	797	608	233.43	161.27	0	0	0	0	.00	.00	0	0	14
			9.0	30	820	2824	1084.21	321.96	0	0	0	0	.00	.00	0	0	14
			11.0	40	1926	3119	1197.47	427.35	0	0	0	0	.00	.00	0	0	14
			Upstream	60	2682	9093	3491.06	962.94	0	56	0	0	.00	.00	0	0	14
			Total Intertidal		3543	6551	838.37	193.71	0	0	0	0	.00	.00	0	0	42
			Total Upstream		2682	9093	3491.06	962.94	0	56	0	0	.00	.00	0	0	14
628	Chenega Creek	10 1 91	7.0	20	437	1169	448.81	249.08	0	1	0	0	.00	.00	0	0	14
			9.0	30	907	3979	1527.65	397.07	0	0	0	0	.00	.00	0	0	14
			11.0	40	1087	3910	1501.16	273.02	0	4	0	0	.00	.00	0	0	14
			Upstream	60	1059	6564	2520.11	424.66	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2431	9058	1159.21	193.02	0	5	0	0	.00	.00	0	0	42
			Total Upstream		1059	6564	2520.11	424.66	0	0	0	0	.00	.00	0	0	14
630	Bainbridge Creek	10 11 91	7.0	20	773	1010	387.77	162.10	0	0	0	0	.00	.00	0	0	14
			9.0	30	1632	4896	1879.71	458.31	0	0	0	0	.00	.00	0	0	14
			11.0	40	1440	8924	3426.18	486.41	0	210	0	0	.00	.00	0	0	14
			Upstream	60	1931	6384	2451.00	383.38	0	125	1	0	.00	.00	0	0	14
			Total Intertidal		3845	14830	1897.89	295.83	0	210	0	0	.00	.00	0	0	42
			Total Upstream		1931	6384	2451.00	383.38	0	125	1	0	.00	.00	0	0	14
632	Claw Creek	9 30 91	7.0	20	301	2600	998.21	273.88	0	0	0	0	.00	.00	0	0	14
			9.0	30	117	2145	823.53	326.98	0	0	0	0	.00	.00	0	0	14
			11.0	40	497	6728	2583.07	491.04	0	0	0	0	.00	.00	0	0	14
			Upstream	60	17	438	336.32	332.75	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		915	11473	1468.27	244.93	0	0	0	0	.00	.00	0	0	42
			Total Upstream		17	438	336.32	332.75	0	0	0	0	.00	.00	0	0	7

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
637	Pt. Countess	9 30 91	7.0	20	975	1143	438.83	146.57	0	0	0	0	.00	.00	0	0	14
			9.0	30	757	2619	1005.51	358.86	0	0	0	0	.00	.00	0	0	14
			11.0	41	269	444	340.93	224.42	0	0	0	0	.00	.00	0	0	7
			11.0	42	449	1448	1111.86	487.74	0	0	0	0	.00	.00	0	0	7
			Upstream	61	424	997	765.55	273.15	0	0	0	0	.00	.00	0	0	7
			Upstream	62	95	1284	985.93	523.58	0	0	0	0	.00	.00	0	0	7
			Total Intertidal		2450	5654	723.58	159.45	0	0	0	0	.00	.00	0	0	42
			Total Upstream		519	2281	875.74	285.33	0	0	0	0	.00	.00	0	0	14
653	Hogg Creek	9 28 91	7.0	20	702	4657	1787.96	382.49	0	0	0	0	.00	.00	0	0	14
			9.0	31	49	14	10.75	3.89	0	0	0	0	.00	.00	0	0	7
			9.0	32	79	477	366.27	249.29	0	0	0	0	.00	.00	0	0	7
			11.0	40	321	4439	1704.26	467.13	0	0	0	0	.00	.00	0	0	14
			Upstream	60	546	3876	1488.11	443.06	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		1151	9587	1226.91	231.25	0	0	0	0	.00	.00	0	0	42
			Total Upstream		546	3876	1488.11	443.06	0	0	0	0	.00	.00	0	0	14
656	Halverson Creek	9 29 91	7.0	22	91	2726	1046.59	291.54	0	0	0	0	.00	.00	0	0	14
			9.0	30	518	886	340.16	161.52	0	0	0	0	.00	.00	0	0	14
			11.0	40	1383	2360	906.07	186.91	0	0	0	0	.00	.00	0	0	14
			Upstream	60	858	4405	1691.21	423.96	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		1992	5972	764.27	133.06	0	0	0	0	.00	.00	0	0	42
			Total Upstream		858	4405	1691.21	423.96	0	0	0	0	.00	.00	0	0	14
663	Shelter Bay	9 27 91	7.0	20	10	6	2.69	2.69	0	0	0	0	.00	.00	0	0	12
			9.0	30	474	155	69.43	50.99	0	0	0	0	.00	.00	0	0	12
			11.0	40	3528	1941	869.41	310.90	0	0	0	0	.00	.00	0	0	12
			Upstream	60	718	957	428.66	211.08	0	0	0	0	.00	.00	0	0	12
			Total Intertidal		4012	2102	313.84	121.78	0	0	0	0	.00	.00	0	0	36
			Total Upstream		718	957	428.66	211.08	0	0	0	0	.00	.00	0	0	12

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
665	Bjorne Creek	9 27 91	7.0	20	316	116	44.54	37.30	0	0	0	0	.00	.00	0	0	14
			9.0	30	1610	188	72.18	26.49	0	0	0	0	.00	.00	0	0	14
			11.0	40	2738	941	361.28	135.06	0	0	0	0	.00	.00	0	0	14
			Upstream	60	3942	2060	790.89	290.83	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			4664	1245	159.33	51.47	0	0	0	0	.00	.00	0	0	42
		Total Upstream			3942	2060	790.89	290.83	0	0	0	0	.00	.00	0	0	14
666	O'Brien Creek	9 28 91	7.0	20	145	51	19.58	8.29	0	0	0	0	.00	.00	0	0	14
			9.0	30	508	451	173.15	95.22	0	0	0	0	.00	.00	0	0	14
			11.0	40	272	960	368.57	119.28	0	0	0	0	.00	.00	0	0	14
			Upstream	60	1037	2395	919.51	321.65	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			925	1462	187.10	54.47	0	0	0	0	.00	.00	0	0	42
		Total Upstream			1037	2395	919.51	321.65	0	0	0	0	.00	.00	0	0	14
673	Falls Creek	9 28 91	7.0	20	918	3417	1311.88	539.92	0	0	0	0	.00	.00	0	0	14
			9.0	30	1967	4095	1572.19	272.18	0	0	0	0	.00	.00	0	0	14
			11.0	40	1810	6742	2588.45	493.64	0	0	0	0	.00	.00	0	0	14
			Upstream	60	1254	5683	2181.87	487.93	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			4695	14254	1824.17	267.95	0	0	0.	0	.00	.00	0	0	42
		Total Upstream			1254	5683	2181.87	487.93	0	0	0	0	.00	.00	0	0	14

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
677	Hayden Creek	10 12 91	7.0	21	198	1284	985.93	392.75	0	0	0	0	.00	.00	0	0	7
			7.0	22	270	2081	1597.91	721.80	0	14	0	0	.00	.00	0	0	7
			9.0	31	258	1399	1074.23	632.32	0	0	0	0	.00	.00	0	0	7
			9.0	32	464	1443	1108.02	815.46	0	2	0	0	.00	.00	0	0	7
			11.0	41	473	994	763.25	311.92	0	0	0	0	.00	.00	0	0	7
			11.0	42	433	1933	1484.27	381.10	0	0	0	0	.00	.00	0	0	7
			Upstream	61	405	1195	917.59	389.06	0	0	0	0	.00	.00	0	0	7
			Upstream	62	547	1243	954.45	222.56	0	0	0	0	.00	.00	0	0	7
		Total Intertidal			2096	9134	1168.93	224.42	0	16	0	0	.00	.00	0	0	42
		Total Upstream			952	2438	936.02	215.38	0	0	0	0	.00	.00	0	0	14
678	Sleepy Bay	9 25 91	7.0	20	199	182	81.52	38.74	0	0	0	0	.00	.00	0	0	12
			9.0	30	1264	1245	557.66	187.91	0	0	0	0	.00	.00	0	0	12
			11.0	40	1335	688	308.17	99.82	0	0	0	0	.00	.00	0	0	12
			Upstream	60	1510	1027	460.01	167.56	0	0	0	0	.00	.00	0	0	12
		Total Intertidal			2798	2115	315.78	77.33	0	0	0	0	.00	.00	0	0	36
		Total Upstream			1510	1027	460.01	167.56	0	0	0	0	.00	.00	0	0	12
681	Hogan Bay	9 27 91	7.0	20	925	877	336.71	128.44	0	0	0	0	.00	.00	0	0	14
			9.0	30	1091	994	381.63	176.41	0	0	0	0	.00	.00	0	0	14
			11.0	40	3367	4681	1797.17	357.49	0	0	0	0	.00	.00	0	0	14
			Upstream	60	1340	1356	520.61	172.13	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			5383	6552	838.50	172.50	0	0	0	0	.00	.00	0	0	42
		Total Upstream			1340	1356	520.61	172.13	0	0	0	0	.00	.00	0	0	14

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

| | | | | | Pink Salmon | | | | | | Chum Salmon | | | | | | |
| | | | | | Eggs | | | | Fry | | Eggs | | | | Fry | | |
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	No. of Digs
682	Snug Harbor	9 26 91	7.0	20	1957	1073	411.96	126.56	0	5	0	0	.00	.00	0	0	14
			9.0	30	3663	3049	1170.60	364.15	0	0	0	0	.00	.00	0	0	14
			11.0	40	1677	1357	520.99	342.11	0	0	0	0	.00	.00	0	0	14
			Upstream	60	5256	3624	1391.36	255.17	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		7297	5479	701.18	175.54	0	5	0	0	.00	.00	0	0	42
			Total Upstream		5256	3624	1391.36	255.17	0	0	0	0	.00	.00	0	0	14
692	Herring Bay	10 7 91	7.0	20	1039	1864	715.64	207.85	0	0	0	0	.00	.00	0	0	14
			9.0	30	2336	3971	1524.58	316.70	0	0	0	0	.00	.00	0	0	14
			11.0	40	1084	3445	1322.63	253.02	0	0	0	0	.00	.00	0	0	14
			Upstream	60	748	3081	1182.88	406.45	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		4459	9280	1187.62	157.53	0	0	0	0	.00	.00	0	0	42
			Total Upstream		748	3081	1182.88	406.45	0	0	0	0	.00	.00	0	0	14
695	Port Audrey	10 2 91	7.0	20	286	1866	716.41	312.76	0	3	0	0	.00	.00	0	0	14
			9.0	31	342	1231	945.23	472.18	0	0	0	0	.00	.00	0	0	7
			9.0	32	77	348	267.21	133.71	0	0	0	0	.00	.00	0	0	7
			11.0	40	250	1620	621.96	447.37	0	7	0	0	.00	.00	0	0	14
			Upstream	60	170	1719	659.97	315.29	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		955	5065	648.20	195.85	0	10	0	0	.00	.00	0	0	42
			Total Upstream		170	1719	659.97	315.29	0	0	0	0	.00	.00	0	0	14

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs				Fry		Eggs				Fry		
					Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	
699	Cathead Bay	10 2 91	7.0	20	1781	2750	1055.80	393.55	0	0	0	0	.00	.00	0	0	14
			9.0	30	584	2226	854.63	267.57	0	0	0	0	.00	.00	0	0	14
			11.0	40	654	1719	659.97	180.79	0	0	0	0	.00	.00	0	0	14
			Upstream	60	679	2744	1053.50	470.50	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		3019	6695	856.80	167.41	0	0	0	0	.00	.00	0	0	42
			Total Upstream		679	2744	1053.50	470.50	0	0	0	0	.00	.00	0	0	14
740	Kelez Creek	9 25 91	7.0	20	373	349	133.99	81.34	0	0	0	0	.00	.00	0	0	14
			9.0	30	1340	1918	736.38	307.21	0	0	0	0	.00	.00	0	0	14
			11.0	40	1300	1557	597.78	142.67	0	0	0	0	.00	.00	0	0	14
			Upstream	60	308	2125	815.85	366.44	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		3013	3824	489.38	120.18	0	0	0	0	.00	.00	0	0	42
			Total Upstream		308	2125	815.85	366.44	0	0	0	0	.00	.00	0	0	14
744	Wilby Creek	9 25 91	7.0	20	873	76	29.18	21.37	0	31	0	0	.00	.00	0	0	14
			9.0	31	530	1074	412.34	167.37	0	0	0	0	.00	.00	0	0	14
			11.0	40	593	1885	723.71	320.70	0	0	0	0	.00	.00	0	0	14
			Upstream	60	150	681	261.46	153.30	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		1996	3035	388.41	125.88	0	31	0	0	.00	.00	0	0	42
			Total Upstream		150	681	261.46	153.30	0	0	0	0	.00	.00	0	0	14
747	Cabin Creek	9 24 91	7.0	20	377	127	48.76	23.41	0	0	0	0	.00	.00	0	0	14
			9.0	30	1927	1801	691.46	192.00	0	0	0	0	.00	.00	0	0	14
			11.0	40	585	1956	750.96	283.43	0	0	0	0	.00	.00	0	0	14
			Upstream	60	1018	1515	581.65	267.73	0	0	0	0	.00	.00	0	0	14
			Total Intertidal		2889	3884	497.06	122.11	0	0	0	0	.00	.00	0	0	42
			Total Upstream		1018	1515	581.65	267.73	0	0	0	0	.00	.00	0	0	14

Appendix A.3

1991 Prince William Sound Pink and Chum Salmon Egg Dig

					Pink Salmon						Chum Salmon						
					Eggs				Fry		Eggs				Fry		
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	E/m^2	SE	Dead	Live	Dead	Live	E/m^2	SE	Dead	Live	No. of Digs
828	Cook Creek	9 24 91	7.0	20	28	6	2.30	.74	0	0	0	0	.00	.00	0	0	14
			9.0	30	687	893	342.85	108.59	0	0	0	0	.00	.00	0	0	14
			11.0	41	713	744	571.29	237.97	0	0	0	0	.00	.00	0	0	7
			11.0	42	420	1265	971.34	590.63	0	0	0	0	.00	.00	0	0	7
			Upstream	60	2323	3533	1356.42	334.38	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			1848	2908	372.15	117.79	0	0	0	0	.00	.00	0	0	42
		Total Upstream			2323	3533	1356.42	334.38	0	0	0	0	.00	.00	0	0	14
861	Bernard Creek	9 23 91	7.0	20	22	1	.38	.38	0	0	0	0	.00	.00	0	0	14
			9.0	30	1977	895	343.62	228.03	0	0	0	0	.00	.00	0	0	14
			11.0	40	1944	1269	487.21	156.76	0	0	0	0	.00	.00	0	0	14
			Upstream	60	3298	2769	1063.10	308.40	0	0	0	0	.00	.00	0	0	14
		Total Intertidal			3943	2165	277.07	95.45	0	0	0	0	.00	.00	0	0	42
		Total Upstream			3298	2769	1063.10	308.40	0	0	0	0	.00	.00	0	0	14
Prince William Sound Summary																	
		Total Intertidal			95599	201836	854.23	35.38	10	1173	277	1059	4.48	76.17	4	422	1270
		Total Upstream			43406	94455	1205.93	76.17	0	338	2	0	.00	96.25	0	0	421

APPENDIX A.4

Numbers of live and dead pink and chum salmon eggs and fry by
tide zone for the 1990 preemergent fry survey

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs				Fry		
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
11	Humpy Creek	3 15 90	7.0	20	0	0	0	2	.83	.83	0	0	0	0	.00	.00	13
			9.0	30	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			11.0	40	375	0	0	196	75.25	72.78	0	0	0	0	.00	.00	14
			Upstream	60	2	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Upstream	63	5	0	0	0	.00	.00	0	0	0	0	.00	.00	10
			Total Intertidal		375	0	0	198	25.96	24.89	0	0	0	0	.00	.00	41
			Total Upstream		7	0	0	0	.00	.00	0	0	0	0	.00	.00	24
35	Koppen Creek	4 6 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			9.0	30	53	0	0	740	284.11	131.35	7	0	0	382	146.66	93.86	14
			11.0	40	427	0	5	2245	861.92	200.69	38	0	0	126	48.38	33.83	14
			Upstream	60	1040	0	13	1545	593.17	197.65	140	0	0	163	62.58	60.52	14
			Upstream	100	1246	0	1	211	81.01	52.17	0	0	0	0	.00	.00	14
			Total Intertidal		480	0	5	2985	573.01	130.16	45	0	0	508	97.52	49.86	28
			Total Upstream		2286	0	14	1756	337.09	111.75	140	0	0	163	31.29	30.30	28
52	Control Creek	4 5 90	7.0	20	1	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			9.0	30	103	0	0	409	157.03	51.85	0·	0	0	0	.00	.00	14
			9.0	33	41	0	0	100	44.79	30.52	0	0	0	0	.00	.00	12
			11.0	40	1227	0	3	1055	405.04	105.13	41	0	0	59	22.65	13.78	14
			Upstream	60	569	0	83	1356	520.61	126.65	7	0	0	0	.00	.00	14
			Total Intertidal		1372	0	3	1565	155.78	37.29	41	0	0	59	5.87	3.73	54
			Total Upstream		569	0	83	1356	520.61	126.65	7	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
80	Whalen Creek	4 5 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	466	0	3	122	46.84	26.48	0	0	0	0	.00	.00	14
			11.0	40	631	0	1	4	1.54	.88	0	0	0	0	.00	.00	14
			Upstream	60	581	0	0	16	6.14	1.68	1	0	0	1	.38	.38	14
			Total Intertidal		1097	0	4	126	16.13	9.26	0	0	0	0	.00	.00	42
			Total Upstream		581	0	0	16	6.14	1.68	1	0	0	1	.38	.38	14
89	Fish Creek	4 5 90	7.0	20	31	0	0	86	33.02	15.55	0	0	0	1	.38	.38	14
			9.0	30	69	0	0	351	134.76	48.96	29	0	0	97	37.24	21.39	14
			11.0	40	10	0	1	161	61.81	33.90	0	0	0	102	39.16	29.97	14
			Upstream	60	376	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		110	0	1	598	76.53	21.10	29	0	0	200	25.60	12.29	42
			Total Upstream		376	0	0	0	.00	.00	0	0	0	0	.00	.00	14
117	Indian Creek	4 4 90	7.0	20	14	0	0	2	.77	.52	0	0	0	0	.00	.00	14
			9.0	30	1386	0	304	27	10.37	4.59	14	0	0	0	.00	.00	14
			11.0	40	64	0	10	2425	931.03	273.36	22	0	3	743	285.26	158.22	14
			Upstream	60	160	0	235	913	350.53	140.75	9	0	154	369	141.67	80.46	14
			Total Intertidal		1464	0	314	2454	314.05	111.99	36	0	3	743	95.09	55.56	42
			Total Upstream		160	0	235	913	350.53	140.75	9	0	154	369	141.67	80.46	14
123	Gregorieff Creek	4 4 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	22	0	0	481	184.67	83.14	5	0	0	33	12.67	7.49	14
			11.0	40	28	0	15	58	22.27	15.19	0	0	0	0	.00	.00	14
			Upstream	61	5	0	47	2099	1611.73	706.43	0	0	0	56	43.00	30.88	7
			Upstream	62	1	0	6	753	289.10	121.55	0	0	0	22	8.45	8.04	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Live	Fry Dead	Live	F/m²	SE	Chum Salmon Eggs Dead	Live	Fry Dead	Live	F/m²	SE	No. of Digs
			Total Intertidal		50	0	15	539	68.98	30.34	5	0	0	33	4.22	2.61	42
			Total Upstream		6	0	53	2852	729.98	275.22	0	0	0	78	19.96	11.69	21
153	Stellar Creek	4 3 90	7.0	20	308	0	1	833	319.81	128.48	110	0	0	487	186.97	96.10	14
			9.0	30	13	0	24	1177	451.88	135.35	1	0	0	85	32.63	20.28	14
			11.0	40	75	0	4	1443	554.01	286.07	0	0	0	10	3.84	2.84	14
			Upstream	60	123	0	496	420	161.25	108.67	0	0	0	0	.00	.00	14
			Total Intertidal		396	0	29	3453	441.90	112.04	111	0	0	582	74.48	34.32	42
			Total Upstream		123	0	496	420	161.25	108.67	0	0	0	0	.00	.00	14
265	Unakwik Creek	4 3 90	7.0	20	0	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			9.0	32	1	0	0	836	641.93	384.43	0	0	0	0	.00	.00	7
			9.0	31	0	0	0	467	358.59	347.86	0	0	0	0	.00	.00	7
			11.0	42	0	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			11.0	41	0	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			Upstream	61	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			Upstream	62	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			Total Intertidal		1	0	0	1304	166.88	89.86	0	0	0	0	.00	.00	42
			Total Upstream		0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
276	Black Bear Creek	4 2 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	34	0	0	206	79.09	35.58	0	0	0	0	.00	.00	14
			11.0	40	778	0	1	1089	418.10	155.75	85	0	0	209	80.24	47.31	14
			Upstream	60	0	0	0	12	9.21	6.71	0	0	0	0	.00	.00	7
			Upstream	63	0	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			Total Intertidal		812	0	1	1295	165.73	59.16	85	0	0	209	26.75	16.48	42
			Total Upstream		0	0	0	12	4.61	3.47	0	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
322	Coghill River	4 2 90	5.0	10	8	0	2	60	23.04	13.59	0	0	0	0	.00	.00	14
			Upstream	120	15	0	1	267	71.76	37.83	0	0	0	0	.00	.00	20
			Upstream	123	325	0	72	3823	1027.43	170.65	0	0	0	0	.00	.00	20
			Upstream	124	286	0	44	6793	1825.62	266.44	0	0	0	0	.00	.00	20
			Total Intertidal		8	0	2	60	23.04	13.59	0	0	0	0	.00	.00	14
			Total Upstream		626	0	117	10883	974.94	140.05	0	0	0	0	.00	.00	60
421	Mill Creek	4 1 90	7.0	20	0	0	0	0	.00	.00	0	0	0	54	20.73	13.75	14
			9.0	30	0	0	0	0	.00	.00	0	0	0	1	.38	.38	14
			11.0	40	2	0	2	810	310.98	114.11	0	0	5	263	100.97	54.73	14
			Upstream	60	0	0	700	34	13.05	8.02	0	0	0	83	31.87	23.79	14
			Total Intertidal		2	0	2	810	103.66	43.59	0	0	5	318	40.70	19.56	42
			Total Upstream		0	0	700	34	13.05	8.02	0	0	0	83	31.87	23.79	14
430	Meacham Creek	4 1 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	59	0	0	81	31.10	20.32	0	0	0	0	.00	.00	14
			11.0	40	161	0	0	820	314.82	141.24	165	0	0	300	115.18	98.35	14
			Upstream	60	362	0	6	1675	643.08	197.92	0	0	0	0	.00	.00	14
			Total Intertidal		220	0	0	901	115.31	51.39	165	0	0	300	38.39	33.08	42
			Total Upstream		362	0	6	1675	643.08	197.92	0	0	0	0	.00	.00	14
455	Paulson Creek	4 1 90	7.0	20	0	0	0	51	19.58	18.76	0	0	0	1	.38	.38	14
			9.0	30	0	0	0	3	1.15	.61	0	0	0	0	.00	.00	14

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Pink Salmon Eggs Live	Pink Salmon Fry Dead	Pink Salmon Fry Live	Pink Salmon Fry F/m²	Pink Salmon Fry SE	Chum Salmon Eggs Dead	Chum Salmon Eggs Live	Chum Salmon Fry Dead	Chum Salmon Fry Live	Chum Salmon Fry F/m²	Chum Salmon Fry SE	No. of Digs
			11.0	40	9	0	2	243	186.59	61.59	9	0	0	302	231.89	103.41	7
			11.0	43	7	0	1	11	8.45	3.49	0	0	1	5	3.84	3.84	7
			Upstream	60	119	0	1	1177	451.88	171.81	1	0	0	104	39.93	24.96	14
			Total Intertidal		16	0	3	308	39.42	15.40	9	0	1	308	39.42	21.02	42
			Total Upstream		119	0	1	1177	451.88	171.81	1	0	0	104	39.93	24.96	14
480	Mink Creek	3 31 90	7.0	20	71	0	0	16	6.14	4.64	6	0	0	82	31.48	26.76	14
			9.0	30	1	0	0	0	.00	.00	48	0	0	0	.00	.00	14
			11.0	40	0	0	3	519	199.26	82.30	0	0	0	245	94.06	41.13	14
			Upstream	60	2	0	0	0	.00	.00	0	0	0	2	.77	.77	14
			Total Intertidal		72	0	3	535	68.47	30.45	54	0	0	327	41.85	17.08	42
			Total Upstream		2	0	0	0	.00	.00	0	0	0	2	.77	.77	14
485	W. Finger Creek	3 31 90	7.0	20	0	0	0	0	.00	.00	0	0	0	142	54.52	41.16	14
			9.0	30	22	0	0	4	1.54	1.19	6	0	0	223	85.62	80.30	14
			11.0	40	143	0	1	311	119.40	77.83	24	0	0	188	72.18	46.34	14
			Upstream	60	4	0	1	1014	389.30	130.11	0	0	0	0	.00	.00	14
			Total Intertidal		165	0	1	315	40.31	26.77	30	0	0	553	70.77	33.04	42
			Total Upstream		4	0	1	1014	389.30	130.11	0	0	0	0	.00	.00	14
498	McClure Creek	5 5 90	7.0	20	14	0	0	238	91.38	43.79	0	0	0	0	.00	.00	14
			9.0	30	483	0	0	931	357.44	113.92	0	0	0	0	.00	.00	14
			11.0	40	15	0	8	2682	1029.70	235.13	0	0	0	0	.00	.00	14
			Upstream	60	2	0	0	5	1.92	1.92	0	0	0	0	.00	.00	14
			Total Intertidal		512	0	8	3851	492.84	105.93	0	0	0	0	.00	.00	42
			Total Upstream		2	0	0	5	1.92	1.92	0	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
506	Loomis Creek	3 30 90	7.0	20	408	0	3	297	114.03	47.53	35	0	0	30	11.52	7.95	14
			9.0	30	556	0	2	732	281.04	80.19	32	0	0	0	.00	.00	14
			11.0	40	689	0	6	1146	439.98	136.79	5	0	0	0	.00	.00	14
			Upstream	60	57	0	1	28	21.50	14.41	0	0	0	38	29.18	28.29	7
		Total Intertidal			1653	0	11	2175	278.35	57.69	72	0	0	30	3.84	2.72	42
		Total Upstream			57	0	1	28	21.50	14.41	0	0	0	38	29.18	28.29	7
604	Erb Creek	3 22 90	7.0	20	0	0	0	4	1.54	.88	0	0	0	0	.00	.00	14
			9.0	30	0	0	0	2	.77	.52	0	0	0	0	.00	.00	14
			11.0	40	0	0	2	25	9.60	7.58	0	0	0	0	.00	.00	14
			Upstream	60	133	0	0	5	1.92	1.33	0	0	0	0	.00	.00	14
		Total Intertidal			0	0	2	31	3.97	2.56	0	0	0	0	.00	.00	42
		Total Upstream			133	0	0	5	1.92	1.33	0	0	0	0	.00	.00	14
618	Chenega SE	3 29 90	7.0	20	22	0	0	116	51.96	50.98	0	0	0	0	.00	.00	12
			9.0	30	14	0	3	656	293.83	179.44	0	0	0	0	.00	.00	12
			11.0	40	72	0	1	79	35.39	20.98	0	0	0	0	.00	.00	12
			Upstream	60	31	0	0	6	2.69	1.24	0	0	0	0	.00	.00	12
		Total Intertidal			108	0	4	851	127.06	63.96	0	0	0	0	.00	.00	36
		Total Upstream			31	0	0	6	2.69	1.24	0	0	0	0	.00	.00	12
621	Totemoff Creek	3 22 90	7.0	20	68	0	0	401	153.96	79.72	0	0	0	0	.00	.00	14
			9.0	30	134	0	0	1429	548.63	175.21	0	0	0	0	.00	.00	14
			11.0	40	147	0	2	1174	450.73	137.06	0	0	0	0	.00	.00	14
			Upstream	60	5	0	0	76	29.18	23.88	0	0	0	0	.00	.00	14
		Total Intertidal			349	0	2	3004	384.44	81.17	0	0	0	0	.00	.00	42

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
			Total Upstream		5	0	0	76	29.18	23.88	0	0	0	0	.00	.00	14
623	Brizgaloff Creek	4 11 90	7.0	20	1	0	0	4	1.54	.88	0	0	0	1	.38	.38	14
			9.0	30	34	0	0	545	209.24	119.74	5	0	0	39	14.97	14.97	14
			11.0	40	414	0	0	854	327.88	162.06	0	0	0	0	.00	.00	14
			Upstream	60	766	0	2	988	379.32	198.65	0	0	0	0	.00	.00	14
			Total Intertidal		449	0	0	1403	179.55	68.81	5	0	0	40	5.12	4.99	42
			Total Upstream		766	0	2	988	379.32	198.65	0	0	0	0	.00	.00	14
628	Chenega NE	3 29 90	7.0	20	9	0	0	27	10.37	5.39	0	0	0	0	.00	.00	14
			9.0	30	14	0	4	570	218.84	106.76	0	0	0	0	.00	.00	14
			11.0	40	20	6	2	816	313.29	166.00	0	0	0	0	.00	.00	14
			Upstream	63	16	3	0	121	46.46	29.69	0	0	0	0	.00	.00	14
			Upstream	60	408	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		43	6	6	1413	180.83	67.16	0	0	0	0	.00	.00	42
			Total Upstream		424	3	0	121	23.23	15.24	0	0	0	0	.00	.00	28
630	Bainbridge Creek	4 11 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	2	0	0	5	1.92	.91	0	0	0	0	.00	.00	14
			11.0	40	49	0	0	2831	1086.90	237.50	0	0	0	0	.00	.00	14
			Upstream	60	553	0	109	2364	907.61	266.88	0	0	0	0	.00	.00	14
			Total Intertidal		51	0	0	2836	362.94	111.15	0	0	0	0	.00	.00	42
			Total Upstream		553	0	109	2364	907.61	266.88	0	0	0	0	.00	.00	14
632	Claw Creek	3 28 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	33	37	0	0	671	300.55	109.17	0	0	0	0	.00	.00	12

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	
			11.0	40	10	0	4	687	263.76	105.30	0	0	0	0	.00	.00	14
			Upstream	60	21	0	1	131	50.29	41.33	0	0	0	0	.00	.00	14
			Total Intertidal		47	0	4	1358	135.17	40.36	0	0	0	0	.00	.00	54
			Total Upstream		21	0	1	131	50.29	41.33	0	0	0	0	.00	.00	14
637	Pt. Countess	3 21 90	7.0	20	69	0	0	2	.77	.52	0	0	0	0	.00	.00	14
			9.0	30	29	0	1	1088	417.71	219.43	0	0	0	0	.00	.00	14
			11.0	41	197	0	1	604	463.79	210.64	0	0	0	0	.00	.00	7
			11.0	42	410	0	0	627	481.45	274.20	0	0	0	0	.00	.00	7
			Upstream	62	79	0	0	7	5.38	2.35	0	0	0	0	.00	.00	7
			Upstream	61	136	0	0	905	694.91	339.55	0	0	0	0	.00	.00	7
			Total Intertidal		705	0	2	2321	297.03	95.33	0	0	0	0	.00	.00	42
			Total Upstream		215	0	0	912	350.14	189.08	0	0	0	0	.00	.00	14
653	Hogg Creek	3 21 90	7.0	20	3	0	0	170	65.27	44.62	0	0	0	0	.00	.00	14
			9.0	31	0	0	0	1	.77	.77	0	0	0	0	.00	.00	7
			9.0	32	0	0	2	398	305.61	215.44	0	0	0	0	.00	.00	7
			11.0	40	0	0	0	20	7.68	6.47	0	0	0	0	.00	.00	14
			Upstream	60	38	0	0	798	306.38	165.42	0	0	0	0	.00	.00	14
			Total Intertidal		3	0	2	589	75.38	40.29	0	0	0	0	.00	.00	42
			Total Upstream		38	0	0	798	306.38	165.42	0	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

| | | | | | | Pink Salmon | | | | | | | Chum Salmon | | | | | |
| | | | | | Eggs | | Fry | | | | Eggs | | | | Fry | | |
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	No. of Digs
656	Halverson Creek	4 26 90	7.0	20	19	0	0	59	22.65	14.52	0	0	0	0	.00	.00	14
			9.0	30	68	0	0	498	191.20	82.42	0	0	0	0	.00	.00	14
			11.0	40	63	0	1	2786	1069.63	296.18	0	0	0	0	.00	.00	14
			Upstream	60	995	0	0	1388	532.89	173.99	0	0	0	0	.00	.00	14
			Total Intertidal		150	0	1	3343	427.82	123.09	0	0	0	0	.00	.00	42
			Total Upstream		995	0	0	1388	532.89	173.99	0	0	0	0	.00	.00	14
663	Shelter Bay	3 27 90	7.0	20	0	0	0	42	16.13	13.84	0	0	0	0	.00	.00	14
			9.0	30	6	0	0	100	38.39	32.36	0	0	0	0	.00	.00	14
			11.0	40	412	0	8	3826	1468.91	433.70	0	0	0	0	.00	.00	14
			Upstream	60	446	0	0	6	2.69	1.40	0	0	0	0	.00	.00	12
			Total Intertidal		418	0	8	3968	507.81	176.86	0	0	0	0	.00	.00	42
			Total Upstream		446	0	0	6	2.69	1.40	0	0	0	0	.00	.00	12
665	Bjorne Creek	3 20 90	7.0	20	2	0	0	2	.77	.52	0	0	0	0	.00	.00	14
			9.0	30	465	0	1	215	82.54	49.52	0	0	0	0	.00	.00	14
			11.0	42	64	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			11.0	41	288	0	0	4	3.07	3.07	0	0	0	0	.00	.00	7
			11.0	43	2	0	0	28	12.54	11.58	0	0	0	0	.00	.00	12
			Upstream	60	1523	0	0	60	23.04	22.21	0	0	0	0	.00	.00	14
			Total Intertidal		821	0	1	249	24.78	13.59	0	0	0	0	.00	.00	54
			Total Upstream		1523	0	0	60	23.04	22.21	0	0	0	0	.00	.00	14

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	
666	O'Brien Creek	3 20 90	7.0	23	2	0	0	0	.00	.00	0	0	0	0	.00	.00	12
			7.0	20	5	0	0	53	20.35	17.97	0	0	0	0	.00	.00	14
			9.0	30	388	0	5	588	225.75	106.49	0	0	0	0	.00	.00	14
			11.0	40	528	0	2	1322	507.55	274.30	0	0	0	0	.00	.00	14
			Upstream	60	333	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			Upstream	63	480	0	0	6	4.61	2.47	0	0	0	0	.00	.00	7
		Total Intertidal			923	0	7	1963	195.39	79.48	0	0	0	0	.00	.00	54
		Total Upstream			813	0	0	6	2.30	1.35	0	0	0	0	.00	.00	14
673	Falls Creek	3 20 90	7.0	22	103	0	3	161	61.81	39.30	0	0	0	0	.00	.00	14
			7.0	21	0	0	0	4	3.07	1.60	0	0	0	0	.00	.00	7
			9.0	30	52	0	4	2384	915.29	230.66	0	0	0	0	.00	.00	14
			11.0	40	22	0	19	366	140.52	97.16	0	0	0	0	.00	.00	14
			Upstream	60	342	0	0	146	56.05	34.51	0	0	0	0	.00	.00	14
		Total Intertidal			177	0	26	2915	319.76	89.24	0	0	0	0	.00	.00	49
		Total Upstream			342	0	0	146	56.05	34.51	0	0	0	0	.00	.00	14
677	Hayden Creek	3 19 90	7.0	22	16	0	0	122	93.68	28.92	0	0	0	0	.00	.00	7
			7.0	21	1	0	0	4	3.07	1.60	0	0	0	0	.00	.00	7
			9.0	31	3	0	2	231	177.38	120.74	0	0	0	0	.00	.00	7
			9.0	32	7	0	5	282	216.54	97.92	0	0	0	0	.00	.00	7
			11.0	41	0	0	1	29	22.27	17.05	0	0	0	0	.00	.00	7
			11.0	42	6	0	3	283	217.30	135.70	0	0	0	0	.00	.00	7

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Live	Fry Dead	Live	F/m²	SE	Chum Salmon Eggs Dead	Live	Fry Dead	Live	F/m²	SE	No. of Digs
			Upstream	62	0	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			Upstream	61	0	0	0	1	.77	.77	0	0	0	0	.00	.00	7
		Total Intertidal			33	0	11	951	121.71	35.40	0	0	0	0	.00	.00	42
		Total Upstream			0	0	0	1	.38	.38	0	0	0	0	.00	.00	14
678	Sleepy Bay	3 19 90	7.0	20	1	0	0	4	1.79	1.01	0	0	0	0	.00	.00	12
			9.0	30	13	0	8	445	199.32	109.23	0	0	0	0	.00	.00	12
			11.0	40	23	0	2	60	26.88	11.44	0	0	0	0	.00	.00	12
			Upstream	60	29	0	0	4	1.54	.88	0	0	0	0	.00	.00	14
		Total Intertidal			37	0	10	509	76.00	38.52	0	0	0	0	.00	.00	36
		Total Upstream			29	0	0	4	1.54	.88	0	0	0	0	.00	.00	14
681	Hogan Bay	3 27 90	7.0	20	143	0	0	296	113.64	46.47	0	0	0	0	.00	.00	14
			9.0	31	200	0	0	2	1.54	1.54	0	0	0	0	.00	.00	7
			9.0	32	226	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			11.0	40	1232	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Upstream	60	459	0	0	0	.00	.00	0	0	0	0	.00	.00	14
		Total Intertidal			1801	0	0	298	38.14	17.26	0	0	0	0	.00	.00	42
		Total Upstream			459	0	0	0	.00	.00	0	0	0	0	.00	.00	14
682	Snug Harbor	3 19 90	7.0	20	46	0	0	115	44.15	21.68	0	0	0	0	.00	.00	14
			9.0	30	114	0	4	1181	453.42	217.50	0	0	0	0	.00	.00	14
			11.0	40	192	0	39	3153	1210.53	386.69	0	0	0	0	.00	.00	14
			Upstream	60	38	0	27	2139	821.22	339.27	0	0	0	0	.00	.00	14

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs				Fry		
					Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	
		Total Intertidal			352	0	43	4449	569.37	162.93	0	0	0	0	.00	.00	42
		Total Upstream			38	0	27	2139	821.22	339.27	0	0	0	0	.00	.00	14
692	Herring Bay	3 30 90	7.0	20	4	0	1	64	24.57	16.48	0	0	0	0	.00	.00	14
			9.0	30	212	0	5	351	134.76	52.55	0	0	0	0	.00	.00	14
			11.0	40	700	0	9	1749	671.49	189.22	0	0	0	0	.00	.00	14
			Upstream	60	183	0	16	2390	917.59	353.42	0	0	0	0	.00	.00	14
		Total Intertidal			916	0	15	2164	276.94	77.80	0	0	0	0	.00	.00	42
		Total Upstream			183	0	16	2390	917.59	353.42	0	0	0	0	.00	.00	14
695	Port Audrey	3 29 90	7.0	21	1	0	0	20	15.36	8.73	0	0	0	0	.00	.00	7
			7.0	22	51	0	0	523	401.59	240.19	0	0	0	0	.00	.00	7
			9.0	31	5	0	1	187	143.59	68.23	0	0	0	0	.00	.00	7
			9.0	32	1	0	0	118	90.61	60.56	0	0	0	0	.00	.00	7
			11.0	40	32	0	3	707	271.44	182.42	0	0	0	0	.00	.00	14
			Upstream	60	129	0	0	535	205.40	151.15	0	0	0	0	.00	.00	14
		Total Intertidal			90	0	4	1555	199.00	74.40	0	0	0	0	.00	.00	42
		Total Upstream			129	0	0	535	205.40	151.15	0	0	0	0	.00	.00	14
699	Cathead Bay	3 30 90	7.0	20	0	0	0	21	8.06	4.94	0	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | Fry | | | | Eggs | | | | Fry | | |
					Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	
			9.0	30	30	0	0	469	180.06	95.28	0	0	0	0	.00	.00	14
			11.0	40	11	0	0	474	181.98	61.04	0	0	0	0	.00	.00	14
			Upstream	60	232	0	1	512	196.57	185.58	0	0	0	0	.00	.00	14
			Total Intertidal		41	0	0	964	123.37	38.96	0	0	0	0	.00	.00	42
			Total Upstream		232	0	1	512	196.57	185.58	0	0	0	0	.00	.00	14
740	Kelez Creek	3 18 90	7.0	20	1	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	64	0	2	917	352.06	179.75	0	0	0	0	.00	.00	14
			11.0	40	75	0	2	37	14.21	13.40	0	0	0	0	.00	.00	14
			Upstream	60	69	0	17	23	8.83	6.14	0	0	0	0	.00	.00	14
			Total Intertidal		140	0	4	954	122.09	63.87	0	0	0	0	.00	.00	42
			Total Upstream		69	0	17	23	8.83	6.14	0	0	0	0	.00	.00	14
744	Wilby Creek	3 18 90	7.0	20	27	0	0	2	.77	.77	0	0	0	0	.00	.00	14
			9.0	30	1	0	0	47	18.04	11.16	0	0	0	0	.00	.00	14
			11.0	40	2	0	0	102	39.16	36.31	0	0	0	0	.00	.00	14
			Upstream	60	2	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		30	0	0	151	19.32	12.59	0	0	0	0	.00	.00	42
			Total Upstream		2	0	0	0	.00	.00	0	0	0	0	.00	.00	14
747	Cabin Creek	3 17 90	7.0	20	17	0	1	10	3.84	1.43	0	0	0	0	.00	.00	14
			9.0	30	313	0	2	362	138.98	38.84	0	0	0	0	.00	.00	14
			11.0	40	1353	0	66	387	148.58	71.86	0	0	0	0	.00	.00	14
			Upstream	60	134	0	61	126	48.38	23.12	0	0	0	0	.00	.00	14
			Total Intertidal		1683	0	69	759	97.13	28.50	0	0	0	0	.00	.00	42
			Total Upstream		134	0	61	126	48.38	23.12	0	0	0	0	.00	.00	14
749	Shad Creek	3 17 90	7.0	20	1	0	1	298	114.41	79.97	0	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | Fry | | | | Eggs | | | | Fry | | |
					Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	
			9.0	30	117	0	0	123	47.22	47.22	0	0	0	0	.00	.00	14
			11.0	40	0	0	1	2	.77	.52	0	0	0	0	.00	.00	14
			Upstream	60	381	0	8	543	208.47	113.30	0	0	0	0	.00	.00	14
			Total Intertidal		118	0	2	423	54.13	31.06	0	0	0	0	.00	.00	42
			Total Upstream		381	0	8	543	208.47	113.30	0	0	0	0	.00	.00	14
775	Pautze Creek	3 16 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	1	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			11.0	40	6	0	190	155	59.51	27.83	0	0	0	0	.00	.00	14
			Upstream	60	15	0	5	1660	637.32	279.67	0	0	0	0	.00	.00	14
			Total Intertidal		7	0	190	156	19.96	10.05	0	0	0	0	.00	.00	42
			Total Upstream		15	0	5	1660	637.32	279.67	0	0	0	0	.00	.00	14
815	Constantine Creek	3 23 90	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			8.0	23	62	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	64	0	0	165	63.35	58.89	4	0	0	15	5.76	4.99	14
			10.0	33	149	0	0	2	.77	.77	47	0	1	99	38.01	19.09	14
			11.0	40	261	0	0	2	.77	.52	0	0	0	0	.00	.00	14
			Upstream	80	160	0	0	712	273.36	122.92	0	0	0	0	.00	.00	14
			Upstream	90	19	0	0	112	43.00	40.95	0	0	0	0	.00	.00	14
			Upstream	100	100	0	0	678	260.30	106.95	0	0	0	0	.00	.00	14

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

| | | | | | | Pink Salmon | | | | | | | | Chum Salmon | | | | | |
| | | | | | Eggs | | Fry | | | | Eggs | | Fry | | | | Eggs | | Fry | |
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	Dead	Live	F/m²	SE	Dead	Live	Dead	Live	F/m²	SE	No. of Digs
			Upstream	120	42	0	0	50	19.20	19.20	0	0	0	0	.00	.00	14
			Total Intertidal		536	0	0	169	12.98	11.83	51	0	1	114	8.75	4.22	70
			Total Upstream		321	0	0	1552	148.96	44.09	0	0	0	0	.00	.00	56
828	Cook Creek	4 9 90	7.0	20	0	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			9.0	30	273	0	0	520	199.64	90.10	0	0	0	0	.00	.00	14
			11.0	43	24	0	0	74	66.29	65.22	0	0	0	0	.00	.00	6
			11.0	42	1	0	0	31	23.80	13.47	0	0	0	0	.00	.00	7
			11.0	41	0	0	0	20	15.36	6.58	0	0	0	1	.77	.77	7
			Upstream	60	390	0	0	178	68.34	43.56	0	0	7	0	.00	.00	14
			Upstream	100	68	0	4	1033	396.60	179.94	0	0	0	50	19.20	16.52	14
			Total Intertidal		298	0	0	646	72.34	29.43	0	0	0	1	.11	.11	48
			Total Upstream		458	0	4	1211	232.47	96.17	0	0	7	50	9.60	8.31	28
850	Canoe Creek	3 16 90	7.0	20	7	0	1	5	1.92	1.21	0	0	0	0	.00	.00	14
			9.0	30	87	0	1	354	135.91	83.99	0	0	0	0	.00	.00	14
			11.0	40	657	0	2	1151	441.90	165.44	0	0	0	0	.00	.00	14
			Upstream	60	256	0	16	2844	1091.89	446.27	0	0	0	0	.00	.00	14
			Total Intertidal		751	0	4	1510	193.24	66.82	0	0	0	0	.00	.00	42
			Total Upstream		256	0	16	2844	1091.89	446.27	0	0	0	0	.00	.00	14
861	Bernard Creek	3 16 90	7.0	20	0	0	1	1	.38	.38	0	0	0	0	.00	.00	14
			9.0	30	77	0	0	475	182.37	90.89	0	0	0	0	.00	.00	14
			11.0	40	194	0	7	1550	595.09	180.12	0	0	0	0	.00	.00	14
			Upstream	60	780	0	34	1280	491.43	132.04	0	0	0	0	.00	.00	14
			Total Intertidal		271	0	8	2026	259.28	76.24	0	0	0	0	.00	.00	42

Appendix A.4

1990 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs				Fry		
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
		Total Upstream			780	0	34	1280	491.43	132.04	0	0	0	0	.00	.00	14

Prince William Sound Summary

		Total Intertidal			20153	6	827	67400	176.72	10.72	738	0	10	4325	11.34	11.40	2050
		Total Upstream			15071	3	2008	43968	297.64	24.85	158	0	161	888	6.01	27.00	794

APPENDIX A.5

Numbers of live and dead pink and chum salmon eggs and fry by
tide zone for the 1991 preemergent fry survey

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

| Stream # | Stream Name | Date | Height in Tidal Zone | Loc | Pink Salmon | | | | | | Chum Salmon | | | | | | No. of Digs |
| | | | | | Eggs | | Fry | | | | Eggs | | Fry | | | | |
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
11	Humpy Creek	3 14 91	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	1	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			11.0	40	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Upstream	60	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		1	0	0	0	.00	.00	0	0	0	0	.00	.00	42
			Total Upstream		0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
35	Koppen Creek	4 7 91	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			9.0	30	243	0	27	3344	1283.86	243.00	16	0	0	59	22.65	13.41	14
			11.0	40	420	0	31	3669	1408.63	242.52	5	0	0	23	8.83	6.80	14
			Upstream	60	1404	0	0	34	13.05	13.05	66	0	0	0	.00	.00	14
			Total Intertidal		663	0	58	7013	1346.25	168.88	21	0	0	82	15.74	7.49	28
			Total Upstream		1404	0	0	34	13.05	13.05	66	0	0	0	.00	.00	14
52	Control Creek	3 15 91	7.0	20	12	0	0	10	3.84	1.64	0	0	0	0	.00	.00	14
			9.0	30	947	0	1	94	36.09	19.36	0	0	0	1	.38	.38	14
			11.0	40	158	0	0	449	172.38	109.99	0	0	0	2	.77	.52	14
			Upstream	60	1302	0	100	586	224.98	61.96	4	0	0	4	1.54	1.54	14
			Total Intertidal		1117	0	1	553	70.77	38.06	0	0	0	3	.38	.22	42
			Total Upstream		1302	0	100	586	224.98	61.96	4	0	0	4	1.54	1.54	14
80	Whalen Creek	3 27 91	7.0	20	168	0	0	176	67.57	25.55	0	0	0	0	.00	.00	14
			9.0	30	154	0	0	74	28.41	9.15	0	0	0	0	.00	.00	14
			11.0	40	2436	0	0	61	23.42	12.83	52	0	0	0	.00	.00	14
			Upstream	60	619	0	0	1	.38	.38	272	0	0	0	.00	.00	14
			Total Intertidal		2758	0	0	311	39.80	10.23	52	0	0	0	.00	.00	42
			Total Upstream		619	0	0	1	.38	.38	272	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
89	Fish Creek	3 26 91	7.0	20	13	0	0	191	73.33	36.71	0	0	0	0	.00	.00	14
			9.0	30	356	0	2	540	207.32	59.33	15	0	0	179	68.72	51.50	14
			11.0	40	424	0	0	61	23.42	12.93	27	0	0	5	1.92	1.92	14
			Upstream	60	109	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		793	0	2	792	101.36	26.06	42	0	0	184	23.55	17.48	42
			Total Upstream		109	0	0	0	.00	.00	0	0	0	0	.00	.00	14
117	Indian Creek	4 23 91	7.0	20	6	0	0	3	1.15	.61	0	0	0	3	1.15	.83	14
			9.0	30	31	0	0	1688	648.07	374.28	4	0	0	260	99.82	75.67	14
			11.0	40	254	0	0	71	27.26	20.33	19	0	0	2	.77	.52	14
			Upstream	60	13	0	0	533	204.63	98.69	54	0	0	650	249.55	102.76	14
			Total Intertidal		291	0	0	1762	225.49	130.50	23	0	0	265	33.91	25.66	42
			Total Upstream		13	0	0	533	204.63	98.69	54	0	0	650	249.55	102.76	14
123	Gregorieff Creek	3 27 91	7.0	21	9	0	0	61	23.42	13.70	1	0	0	0	.00	.00	14
			9.0	31	118	0	0	0	.00	.00	5	0	0	0	.00	.00	14
			11.0	41	371	0	58	201	77.17	44.24	0	0	0	53	20.35	10.86	14
			Upstream	61	38	0	2	1062	407.73	189.14	6	0	2	525	201.56	88.25	14
			Total Intertidal		498	0	58	262	33.53	15.88	6	0	0	53	6.78	3.83	42
			Total Upstream		38	0	2	1062	407.73	189.14	6	0	2	525	201.56	88.25	14
153	Stellar Creek	3 28 91	7.0	20	29	0	0	42	16.13	6.60	0	0	0	1	.38	.38	14
			9.0	30	46	0	0	261	100.21	66.36	20	0	0	17	6.53	5.72	14
			11.0	40	19	0	0	1186	455.34	181.03	51	0	0	1248	479.14	245.19	14
			11.0	43	118	0	1	357	137.06	34.01	283	0	24	927	355.90	92.53	14
			Upstream	60	7	0	10	457	175.46	38.52	0	0	25	440	168.93	47.46	14
			Total Intertidal		212	0	1	1846	177.18	52.64	354	0	24	2193	210.49	69.82	56
			Total Upstream		7	0	10	457	175.46	38.52	0	0	25	440	168.93	47.46	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
265	Unakwik Creek	3 28 91	7.0	20	0	0	0	1255	481.83	166.85	0	0	0	0	.00	.00	14
			9.0	31	9	0	0	402	308.68	249.80	0	0	0	0	.00	.00	7
			9.0	32	4	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			11.0	41	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			11.0	42	43	0	0	0	.00	.00	0	0	0	0	.00	.00	2
			Upstream	61	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			Upstream	62	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			Total Intertidal		56	0	0	1657	296.88	101.49	0	0	0	0	.00	.00	30
			Total Upstream		0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
276	Black Bear Creek	3 29 91	7.0	20	0	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			9.0	30	398	0	0	324	124.39	36.16	12	0	0	52	19.96	19.96	14
			11.0	40	882	0	0	1267	486.44	111.74	129	0	0	34	13.05	9.05	14
			Upstream	60	4	0	1	971	372.79	169.54	0	0	0	483	185.44	138.55	14
			Total Intertidal		1280	0	0	1592	203.74	49.95	141	0	0	86	11.01	7.24	42
			Total Upstream		4	0	1	971	372.79	169.54	0	0	0	483	185.44	138.55	14
322	Coghill River	3 29 91	5.0	10	0	0	0	0	.00	.00	0	0	0	16	6.14	4.94	14
			Total Intertidal		0	0	0	0	.00	.00	0	0	0	16	6.14	4.94	14
			Total Upstream		0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
421	Mill Creek	3 29 91	7.0	20	0	0	0	109	41.85	41.85	0	0	0	0	.00	.00	14
			9.0	30	51	0	0	497	190.81	79.24	1	0	0	277	106.35	94.63	14
			11.0	40	0	0	0	401	153.96	78.32	0	0	0	479	183.90	62.28	14
			Upstream	60	1	0	3	3	1.15	.83	0	0	0	0	.00	.00	14
			Total Intertidal		51	0	0	1007	128.87	39.93	1	0	0	756	96.75	38.67	42
			Total Upstream		1	0	3	3	1.15	.83	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
430	Meacham Creek	3 30 91	7.0	20	6	0	0	74	28.41	19.14	0	0	0	0	.00	.00	14
			9.0	30	748	0	0	136	52.21	49.34	1	0	0	0	.00	.00	14
			11.0	40	212	0	0	3018	1158.70	174.74	0	0	0	6	2.30	2.30	14
			Upstream	60	437	0	0	893	342.85	103.63	0	0	0	0	.00	.00	14
			Total Intertidal		966	0	0	3228	413.11	101.51	1	0	0	6	.77	.77	42
			Total Upstream		437	0	0	893	342.85	103.63	0	0	0	0	.00	.00	14
455	Paulson Creek	3 31 91	7.0	20	1	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	0	0	0	218	83.70	51.13	0	0	0	206	79.09	46.31	14
			11.0	40	6	0	0	435	334.02	72.28	0	0	0	76	58.36	54.86	7
			11.0	43	0	0	0	0	.00	.00	0	0	0	0	.00	.00	0
			Upstream	60	50	0	0	558	214.23	119.96	2	0	0	261	100.21	99.38	14
			Total Intertidal		7	0	0	653	100.28	32.05	0	0	0	282	43.31	21.74	35
			Total Upstream		50	0	0	558	214.23	119.96	2	0	0	261	100.21	99.38	14
480	Mink Creek	3 22 91	7.0	20	462	0	0	422	162.02	44.55	5	0	0	15	5.76	5.76	14
			9.0	30	369	0	1	501	192.35	97.75	19	0	0	58	22.27	20.63	14
			11.0	40	20	0	0	12	4.61	1.68	0	0	0	0	.00	.00	14
			Upstream	60	21	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			Total Intertidal		851	0	1	935	119.66	37.22	24	0	0	73	9.34	7.12	42
			Total Upstream		21	0	0	1	.38	.38	0	0	0	0	.00	.00	14
485	W. Finger Creek	3 22 91	7.0	20	2	0	0	98	37.63	20.55	0	0	0	8	3.07	1.76	14
			9.0	30	79	0	7	1862	714.88	277.51	5	0	13	106	40.70	27.52	14
			11.0	40	20	0	0	753	289.10	78.14	485	0	0	0	.00	.00	14
			Upstream	60	0	0	0	1397	536.35	212.73	0	0	0	33	12.67	10.77	14
			Total Intertidal		101	0	7	2713	347.20	103.61	490	0	13	114	14.59	9.42	42
			Total Upstream		0	0	0	1397	536.35	212.73	0	0	0	33	12.67	10.77	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
498	McClure Creek	4 30 91	7.0	20	76	0	1	256	98.29	43.43	0	0	0	0	.00	.00	14
			9.0	30	639	0	2	1348	517.54	249.34	0	0	0	0	.00	.00	14
			11.0	40	417	0	0	3341	1282.71	296.30	0	0	0	0	.00	.00	14
			Upstream	60	18	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		1132	0	3	4945	632.84	148.03	0	0	0	0	.00	.00	42
			Total Upstream		18	0	0	0	.00	.00	0	0	0	0	.00	.00	14
506	Loomis Creek	3 22 91	7.0	20	119	0	0	256	98.29	51.33	0	0	0	0	.00	.00	14
			9.0	30	906	0	22	1014	389.30	76.96	9	0	0	0	.00	.00	14
			11.0	40	1077	0	1	122	46.84	22.16	0	0	0	0	.00	.00	14
			Upstream	60	1513	0	1	55	21.12	7.27	0	0	0	0	.00	.00	14
			Total Intertidal		2102	0	23	1392	178.14	38.87	9	0	0	0	.00	.00	42
			Total Upstream		1513	0	1	55	21.12	7.27	0	0	0	0	.00	.00	14
604	Erb Creek	4 1 91	7.0	20	139	0	0	72	55.29	27.20	0	0	0	0	.00	.00	7
			7.0	23	17	0	0	42	32.25	14.51	0	0	0	0	.00	.00	7
			9.0	30	66	0	0	247	94.83	69.00	0	0	0	0	.00	.00	14
			11.0	40	0	0	0	33	12.67	4.28	0	0	0	0	.00	.00	14
			Upstream	60	61	0	0	4	1.54	1.19	0	0	0	0	.00	.00	14
			Total Intertidal		222	0	0	394	50.42	23.61	0	0	0	0	.00	.00	42
			Total Upstream		61	0	0	4	1.54	1.19	0	0	0	0	.00	.00	14
618	Junction Creek	3 20 91	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	12
			9.0	30	35	0	0	38	17.02	10.87	0	0	0	0	.00	.00	12
			11.0	40	62	0	0	868	388.79	195.46	0	0	0	0	.00	.00	12
			Upstream	60	26	0	0	71	31.80	21.29	0	0	0	0	.00	.00	12
			Total Intertidal		97	0	0	906	135.27	70.24	0	0	0	0	.00	.00	36
			Total Upstream		26	0	0	71	31.80	21.29	0	0	0	0	.00	.00	12

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon Eggs Dead	Eggs Live	Fry Dead	Fry Live	F/m²	SE	Chum Salmon Eggs Dead	Eggs Live	Fry Dead	Fry Live	F/m²	SE	No. of Digs
621	Totemoff Creek	3 21 91	7.0	20	138	0	0	216	82.93	37.97	0	0	0	0	.00	.00	14
			9.0	30	75	0	1	1077	413.49	157.14	0	0	0	0	.00	.00	14
			11.0	40	649	0	80	4040	1551.07	294.11	0	0	0	0	.00	.00	14
			Upstream	60	407	0	0	4	1.54	1.19	0	0	0	0	.00	.00	14
			Total Intertidal		862	0	81	5333	682.50	146.80	0	0	0	0	.00	.00	42
			Total Upstream		407	0	0	4	1.54	1.19	0	0	0	0	.00	.00	14
623	Brizgaloff Creek	4 17 91	7.0	20	400	0	0	79	30.33	13.28	0	0	0	0	.00	.00	14
			9.0	30	469	0	0	541	207.71	74.31	0	0	0	0	.00	.00	14
			11.0	40	805	0	0	1256	482.21	142.57	0	0	0	0	.00	.00	14
			Upstream	60	5415	0	1	367	140.90	49.32	0	0	0	0	.00	.00	14
			Total Intertidal		1674	0	0	1876	240.08	59.95	0	0	0	0	.00	.00	42
			Total Upstream		5415	0	1	367	140.90	49.32	0	0	0	0	.00	.00	14
628	Chenega Creek	3 19 91	7.0	20	18	0	0	8	3.07	2.30	0	0	0	0	.00	.00	14
			9.0	30	133	0	1	988	379.32	185.93	0	0	0	0	.00	.00	14
			11.0	40	121	2	5	422	162.02	73.94	0	0	0	0	.00	.00	14
			Upstream	60	1759	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		272	2	6	1418	181.47	69.37	0	0	0	0	.00	.00	42
			Total Upstream		1759	0	0	0	.00	.00	0	0	0	0	.00	.00	14
630	Bainbridge Creek	4 1 91	7.0	20	56	0	0	35	13.44	10.29	0	0	0	0	.00	.00	14
			9.0	30	310	0	0	427	163.94	62.63	0	0	0	0	.00	.00	14
			11.0	40	1137	0	28	295	113.26	54.25	0	0	0	0	.00	.00	14
			Upstream	60	616	0	36	3982	1528.80	316.73	0	0	0	0	.00	.00	14
			Total Intertidal		1503	0	28	757	96.88	28.85	0	0	0	0	.00	.00	42
			Total Upstream		616	0	36	3982	1528.80	316.73	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

| | | | | | | Pink Salmon | | | | | | Chum Salmon | | | | | |
| | | | | | Eggs | | Fry | | | | Eggs | | Fry | | | | |
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	No. of Digs
632	Claw Creek	4 11 91	7.0	20	4	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	118	0	7	2354	903.77	414.65	3	0	0	0	.00	.00	14
			11.0	40	163	0	15	3203	1229.72	257.93	0	0	0	0	.00	.00	14
			Upstream	60	161	0	0	92	70.64	47.24	0	0	0	0	.00	.00	7
			Total Intertidal		285	0	22	5557	711.16	178.33	3	0	0	0	.00	.00	42
			Total Upstream		161	0	0	92	70.64	47.24	0	0	0	0	.00	.00	7
637	Pt. Countess	3 19 91	7.0	20	34	0	0	12	4.61	2.69	0	0	0	0	.00	.00	14
			9.0	30	68	0	0	1490	572.05	184.22	0	0	0	0	.00	.00	14
			11.0	41	584	0	0	1216	466.86	162.99	0	0	0	0	.00	.00	14
			Upstream	61	304	0	0	2	1.54	1.54	0	0	0	0	.00	.00	7
			Upstream	62	375	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			Total Intertidal		686	0	0	2718	347.84	88.75	0	0	0	0	.00	.00	42
			Total Upstream		679	0	0	2	.77	.77	0	0	0	0	.00	.00	14
653	Hogg Creek	4 10 91	7.0	20	22	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	31	16	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			9.0	32	0	0	0	0	.00	.00	0	0	0	0	.00	.00	7
			11.0	40	107	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Upstream	60	427	0	2	431	165.47	151.17	0	0	0	0	.00	.00	14
			Total Intertidal		145	0	0	0	.00	.00	0	0	0	0	.00	.00	42
			Total Upstream		427	0	2	431	165.47	151.17	0	0	0	0	.00	.00	14
656	Halverson Creek	4 10 91	7.0	20	14	0	0	246	94.45	78.37	0	0	0	0	.00	.00	14
			9.0	30	28	0	0	607	233.04	110.77	0	0	0	0	.00	.00	14
			11.0	40	167	0	12	2790	1071.16	370.80	0	0	0	0	.00	.00	14
			Upstream	60	1287	0	0	1330	510.63	200.66	0	0	0	0	.00	.00	14
			Total Intertidal		209	0	12	3643	466.22	144.98	0	0	0	0	.00	.00	42
			Total Upstream		1287	0	0	1330	510.63	200.66	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
663	Shelter Bay	4 10 91	7.0	20	0	0	0	10	4.48	4.48	0	0	0	0	.00	.00	12
			9.0	30	0	0	0	0	.00	.00	0	0	0	0	.00	.00	12
			11.0	40	230	0	2	128	57.33	46.06	0	0	0	0	.00	.00	12
			Upstream	60	177	0	0	0	.00	.00	0	0	0	0	.00	.00	12
			Total Intertidal		230	0	2	138	20.60	15.61	0	0	0	0	.00	.00	36
			Total Upstream		177	0	0	0	.00	.00	0	0	0	0	.00	.00	12
665	Bjorne Creek	3 18 91	7.0	20	5	0	0	4	1.54	.88	0	0	0	0	.00	.00	14
			9.0	30	351	0	0	37	14.21	9.99	0	0	0	0	.00	.00	14
			11.0	40	240	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			Upstream	60	904	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		596	0	0	42	5.38	3.41	0	0	0	0	.00	.00	42
			Total Upstream		904	0	0	0	.00	.00	0	0	0	0	.00	.00	14
666	O'Brien Creek	3 19 91	7.0	20	5	1	0	3	1.15	.83	0	0	0	0	.00	.00	14
			9.0	30	1	1	0	836	320.96	121.96	0	0	0	0	.00	.00	14
			11.0	40	90	0	1	34	13.05	12.24	0	0	0	0	.00	.00	14
			Upstream	60	350	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		96	2	1	873	111.72	46.07	0	0	0	0	.00	.00	42
			Total Upstream		350	0	0	0	.00	.00	0	0	0	0	.00	.00	14
673	Falls Creek	3 18 91	7.0	20	3	0	0	143	54.90	22.36	0	0	0	0	.00	.00	14
			9.0	30	34	0	1	1941	745.21	152.30	0	0	0	0	.00	.00	14
			11.0	40	301	0	0	1359	521.76	209.52	0	0	0	0	.00	.00	14
			Upstream	60	63	0	0	3	1.15	.83	0	0	0	0	.00	.00	14
			Total Intertidal		338	0	1	3443	440.62	95.71	0	0	0	0	.00	.00	42
			Total Upstream		63	0	0	3	1.15	.83	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
677	Hayden Creek	3 18 91	7.0	21	19	0	1	591	453.80	130.84	0	0	0	0	.00	.00	7
			7.0	22	2	0	0	61	46.84	46.84	0	0	0	0	.00	.00	7
			9.0	31	0	0	0	542	416.18	177.38	0	0	0	0	.00	.00	7
			9.0	32	17	198	0	526	403.89	107.60	0	0	0	0	.00	.00	7
			11.0	41	2	7	0	103	79.09	39.46	0	0	0	0	.00	.00	7
			11.0	42	39	0	7	1068	820.07	338.50	0	0	0	0	.00	.00	7
			Upstream	61	162	0	0	172	132.07	105.58	0	0	0	0	.00	.00	7
			Upstream	62	15	0	0	1	.77	.77	0	0	0	0	.00	.00	7
			Total Intertidal		79	205	8	2891	369.98	77.38	0	0	0	0	.00	.00	42
			Total Upstream		177	0	0	173	66.42	53.89	0	0	0	0	.00	.00	14
678	Sleepy Bay	3 17 91	7.0	20	3	0	0	42	18.81	12.15	0	0	0	0	.00	.00	12
			9.0	30	2	0	0	70	31.35	21.78	0	0	0	0	.00	.00	12
			11.0	40	109	0	0	42	18.81	12.01	0	0	0	0	.00	.00	12
			Upstream	60	50	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		114	0	0	154	22.99	9.02	0	0	0	0	.00	.00	36
			Total Upstream		50	0	0	0	.00	.00	0	0	0	0	.00	.00	14
681	Hogan Bay	4 9 91	7.0	20	0	0	1	7	2.69	1.09	0	0	0	0	.00	.00	14
			9.0	30	2	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			11.0	40	50	0	0	0	.00	.00	5	0	0	0	.00	.00	14
			Upstream	60	314	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		52	0	1	7	.90	.41	5	0	0	0	.00	.00	42
			Total Upstream		314	0	0	0	.00	.00	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
682	Snug Harbor	3 16 91	7.0	20	151	0	0	288	110.57	37.66	0	0	0	0	.00	.00	14
			9.0	30	812	0	6	1288	494.50	193.60	0	0	0	0	.00	.00	14
			11.0	40	212	0	8	2022	776.30	257.42	0	0	0	0	.00	.00	14
			Upstream	60	3	0	1	2413	926.42	322.81	0	0	0	0	.00	.00	14
			Total Intertidal		1175	0	14	3598	460.46	113.71	0	0	0	0	.00	.00	42
			Total Upstream		3	0	1	2413	926.42	322.81	0	0	0	0	.00	.00	14
692	Herring Bay	3 21 91	7.0	20	18	0	0	913	350.53	132.14	0	0	0	0	.00	.00	14
			9.0	30	42	1	2	913	350.53	172.08	0	0	0	0	.00	.00	14
			11.0	40	204	0	0	346	132.84	90.86	0	0	0	0	.00	.00	14
			Upstream	60	258	0	27	1202	461.48	117.71	0	0	0	0	.00	.00	14
			Total Intertidal		264	1	2	2172	277.96	78.13	0	0	0	0	.00	.00	42
			Total Upstream		258	0	27	1202	461.48	117.71	0	0	0	0	.00	.00	14
695	Port Audrey	4 11 91	7.0	21	0	0	0	48	36.86	35.97	0	0	0	0	.00	.00	7
			7.0	22	0	0	0	108	82.93	28.46	0	0	0	0	.00	.00	7
			9.0	30	286	0	0	641	246.10	82.50	0	0	0	0	.00	.00	14
			11.0	40	52	0	8	616	236.50	161.99	0	0	0	0	.00	.00	14
			Upstream	60	45	0	2	537	206.17	161.66	0	0	0	0	.00	.00	14
			Total Intertidal		338	0	8	1413	180.83	61.05	0	0	0	0	.00	.00	42
			Total Upstream		45	0	2	537	206.17	161.66	0	0	0	0	.00	.00	14
699	Cathead Bay	3 31 91	7.0	20	124	0	0	164	62.96	23.86	0	0	0	0	.00	.00	14
			9.0	30	108	0	0	1179	452.65	201.27	0	0	0	0	.00	.00	14
			11.0	40	5	0	3	1500	575.89	134.66	0	0	0	0	.00	.00	14
			Upstream	60	11	0	0	248	95.21	65.44	0	0	0	0	.00	.00	14
			Total Intertidal		237	0	3	2843	363.84	86.16	0	0	0	0	.00	.00	42
			Total Upstream		11	0	0	248	95.21	65.44	0	0	0	0	.00	.00	14

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
740	Kelez Creek	4 2 91	7.0	20	45	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	6	0	0	326	125.16	58.87	0	0	0	0	.00	.00	14
			11.0	40	116	0	0	177	67.96	46.70	0	0	0	0	.00	.00	14
			Upstream	60	301	0	0	582	223.45	130.05	0	0	0	0	.00	.00	14
			Total Intertidal		167	0	0	503	64.37	25.70	0	0	0	0	.00	.00	42
			Total Upstream		301	0	0	582	223.45	130.05	0	0	0	0	.00	.00	14
744	Wilby Creek	4 2 91	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	31	1	0	0	162	62.20	27.64	0	0	0	0	.00	.00	14
			11.0	40	27	0	0	160	61.43	52.25	0	0	0	0	.00	.00	14
			Upstream	60	5	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		28	0	0	322	41.21	19.75	0	0	0	0	.00	.00	42
			Total Upstream		5	0	0	0	.00	.00	0	0	0	0	.00	.00	14
747	Cabin Creek	4 3 91	7.0	20	9	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	444	0	0	166	63.73	30.57	0	0	0	0	.00	.00	14
			11.0	40	1525	0	35	515	197.72	70.94	0	35	0	0	.00	.00	14
			Upstream	60	455	0	7	249	95.60	32.17	0	0	0	0	.00	.00	14
			Total Intertidal		1978	0	35	681	87.15	28.22	0	35	0	0	.00	.00	42
			Total Upstream		455	0	7	249	95.60	32.17	0	0	0	0	.00	.00	14
749	Shad Creek	3 23 91	7.0	20	32	0	0	163	62.58	39.16	0	0	0	0	.00	.00	14
			9.0	30	82	0	0	61	23.42	21.41	0	0	0	0	.00	.00	14
			11.0	40	137	0	0	2	.77	.52	0	0	0	0	.00	.00	14
			Upstream	60	622	0	48	2846	1092.66	261.54	0	0	0	0	.00	.00	14
			Total Intertidal		251	0	0	226	28.92	15.05	0	0	0	0	.00	.00	42
			Total Upstream		622	0	48	2846	1092.66	261.54	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Pink Salmon						Chum Salmon						No. of Digs
					Eggs		Fry				Eggs		Fry				
					Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	
775	Pautze Creek	4 3 91	7.0	20	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	2	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			11.0	40	0	0	0	2	.77	.77	0	0	0	0	.00	.00	14
			Upstream	60	0	0	0	704	270.29	183.45	0	0	0	0	.00	.00	14
			Total Intertidal		2	0	0	2	.26	.26	0	0	0	0	.00	.00	42
			Total Upstream		0	0	0	704	270.29	183.45	0	0	0	0	.00	.00	14
815	Constantine Creek	4 3 91	7.0	20	80	0	0	100	38.39	25.58	0	0	0	0	.00	.00	14
			8.0	23	51	0	0	452	173.54	122.51	0	0	0	1	.38	.38	14
			9.0	30	35	0	1	401	153.96	53.38	0	0	0	0	.00	.00	14
			10.0	33	101	0	6	232	89.07	28.40	32	0	0	144	55.29	47.55	14
			11.0	40	358	0	0	3	1.15	.61	0	0	0	0	.00	.00	14
			Upstream	80	0	0	0	14	5.38	5.38	27	0	1	338	129.77	82.50	14
			Upstream	90	0	0	7	0	.00	.00	2	0	0	0	.00	.00	14
			Upstream	100	21	0	0	0	.00	.00	8	0	0	26	9.98	9.58	14
			Upstream	120	0	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		625	0	7	1188	91.22	28.12	32	0	0	145	11.13	9.61	70
			Total Upstream		21	0	7	14	1.34	1.34	37	0	1	364	34.94	21.50	56
828	Cook Creek	4 18 91	7.0	20	0	0	0	1	.38	.38	0	0	0	0	.00	.00	14
			9.0	30	328	0	0	361	138.60	50.63	0	0	0	0	.00	.00	14
			11.0	41	0	0	0	1	.77	.77	0	0	0	0	.00	.00	7
			11.0	42	57	0	0	1	.77	.77	0	0	0	0	.00	.00	7
			Upstream	60	442	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			Total Intertidal		385	0	0	364	46.58	19.35	0	0	0	0	.00	.00	42
			Total Upstream		442	0	0	0	.00	.00	0	0	0	0	.00	.00	14

Appendix A.5

1991 Prince William Sound Pink and Chum Salmon Fry Dig

| | | | | | Pink Salmon | | | | | | Chum Salmon | | | | | | |
| | | | | | Eggs | | Fry | | | | Eggs | | Fry | | | | |
Stream #	Stream Name	Date	Height in Tidal Zone	Loc	Dead	Live	Dead	Live	F/m^2	SE	Dead	Live	Dead	Live	F/m^2	SE	No. of Digs
850	Canoe Creek	4 8 91	7.0	20	65	0	1	580	222.68	95.77	0	0	0	0	.00	.00	14
			9.0	30	1492	0	14	1925	739.06	189.31	0	0	0	0	.00	.00	14
			11.0	40	2392	0	1	1476	566.68	110.63	0	0	0	0	.00	.00	14
			Upstream	60	850	0	3	264	101.36	66.52	0	0	0	0	.00	.00	14
			Total Intertidal		3949	0	16	3981	509.47	84.70	0	0	0	0	.00	.00	42
			Total Upstream		850	0	3	264	101.36	66.52	0	0	0	0	.00	.00	14
861	Bernard Creek	3 14 91	7.0	20	117	0	0	0	.00	.00	0	0	0	0	.00	.00	14
			9.0	30	807	0	3	144	55.29	38.88	0	0	0	0	.00	.00	14
			11.0	40	125	0	0	6	2.30	1.22	0	0	0	0	.00	.00	14
			Upstream	60	103	0	20	295	113.26	107.12	0	0	0	0	.00	.00	14
			Total Intertidal		1049	0	3	150	19.20	13.26	0	0	0	0	.00	.00	42
			Total Upstream		103	0	20	295	113.26	107.12	0	0	0	0	.00	.00	14
Prince William Sound Summary																	
			Total Intertidal		30787	210	404	78254	212.54	11.95	1204	35	37	4258	11.56	12.87	1979
			Total Upstream		21525	0	271	22364	178.08	20.20	441	0	28	2760	21.98	21.32	675

<u>STATE/FEDERAL NATURAL RESOURCE DAMAGE ASSESSMENT</u>
<u>DRAFT PRELIMINARY STATUS REPORT</u>

Project Title: CODED-WIRE TAG STUDIES ON PRINCE
                                  WILLIAM SOUND SALMON

Study ID Number: Fish/Shellfish Study Number 3
                                  Restoration Study Number 8

Lead Agency: State of Alaska, ADF&G

Cooperating Agency(ies):   NOAA, UA
                                  State: DNR

Principal Investigator(s):   Samuel Sharr, Comm. Fish. Division
                                  Mark Willette, FRED Division

Assisting Personnel: Carol Peckham, Dan Sharp,
                                  Jodi Smith

Date Submitted: November 20, 1991

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EXECUTIVE SUMMARY

The study is part of an integrated group of Natural Resources Damage Assessment Fish/Shellfish Studies (NRDA F/S Studies 1,2,3,4, and 28) and Restoration Studies (8 and9), being conducted to quantify damage to wild Pacific salmon from the *MV Exxon Valdez* oil spill and restore damaged stocks to health. To determine how adult returns are affected, accurate appraisals of catch and spawning escapement are needed. NRDA F/S Study 3 is designed to estimate catch contributions and survival rates for both wildstock and hatchery salmon in oiled and unoiled areas of Prince William Sound (PWS). It is also designed to provide tags of known origin for recovery in NRDA F/S Study 4, Early Marine Salmon Injury Assessment. Restoration Study 8 integrates with NRDA F/S Study 3 as the tag application portion of the wildstock analyses and is summarized in this report.

Contribution of wild and hatchery pink salmon (*Oncorhynchus gorbuscha*) to the 1991 PWS commercial, cost recovery, special (discarded and donated pink salmon), and brood stock harvests were estimated from tagged fish released from 6 streams and 4 PWS hatcheries in 1990. Nineteen percent of the pink salmon harvest and 90% of the wildstock pink salmon carcasses in 46 selected streams were scanned for coded-wire tags. Out of 14,409 pink salmon heads sent to the Juneau Tag Lab, 8253 tags were recovered. The preliminary maximum estimate of wildstock contribution to the PWS pink salmon fishery is 6.8 million fish out of a total catch of 38.3 million fish (82% hatchery contribution). Estimated pink salmon survival, unadjusted for tag loss or tagging mortality, for the 6 tagged wildstock streams was 2.2%. Estimated maximum pink salmon survival for all hatcheries combined was 5.1%. The 1989 and 1990 hatchery average survival rates were 4.02% and 7.02%. Adjustment factors used in the hatchery contribution estimates ranged from 1.4 to 1.9.

Approximately 42% of the chum (*O. keta*), sockeye (*O. nerka*), coho (*O. kisutch*), and chinook (*O. tshawytscha*) salmon catch was scanned for tags, and 64, 4872, 1236, and 21 tags were recovered. Marine survival rates for these 4 species will be calculated as the many age classes return. Coho salmon brood stock sampling has just been completed and contribution estimates are incomplete.

Approximately 60,000 wild sockeye salmon in 3 streams and 319,400 wild pink salmon in 6 streams were tagged in 1991. Over 800,000 of the 535 million pink salmon fry and 473,000 hatchery produced chum, coho, sockeye, and chinook salmon released from PWS hatcheries in 1991 were also tagged.

Examination of the wild stock tagging data for differences in survival due to oiling is underway but not yet completed. Analysis of hatchery returns from oiled and unoiled areas is also being addressed.

OBJECTIVES

1. Estimate catch and survival rates of pink, chum, sockeye, coho, and chinook salmon released from five hatcheries in Prince William Sound; two hatcheries are in heavily oiled areas, and three are not.

2. Estimate survival rates of wild pink salmon from three streams with contaminated estuaries and three streams with uncontaminated estuaries using outmigration, catch, and escapement (provided by stream surveys).

3. Estimate survival rates of wild sockeye salmon from two watersheds with contaminated estuaries and one watershed with an uncontaminated estuary using outmigration, catch, and escapement (provided by operating weirs).

4. Provide marked salmon of known origin and oil exposure history for recovery by researchers studying early marine existence and migration of juvenile salmon (NRDA F/S Study 4).

5. Identify relevant injuries for which methods of restoring lost use, populations, and habitat must be developed.

INTRODUCTION

Wild pink salmon returns to Prince William Sound (PWS) have averaged 8 million fish since 1961. Hatchery produced pink salmon have been a significant component of the total return since 1985 and now average over 20 million fish. Hatchery fry have been tagged since 1986 to estimate contributions of wild and hatchery fish to the commercial catch and to estimate survival rates for release groups. Hatchery contribution estimates are necessary to estimate the wildstock catch and production. Estimates of catch and escapement for both wild and hatchery fish are needed to assess effects of oil and possible loss of production.

NRDA F/S Study 3 applies tags to all species of salmon produced at 6 hatcheries (Figure 1). Restoration Study 8 applies tags in wild sockeye salmon in 3 streams, and wild pink salmon in 6 streams (Figure 2). Results of the tagging and recovery are used to examine the relationship between oil exposure and survival rates and to document any loss of production. Pink salmon fry are produced at the Valdez Fisheries Development Association (VFDA) Solomon Gulch Hatchery and at three Prince William Sound Aquaculture Corporation (PWSAC) hatcheries: A.F. Koernig, W.H. Noerenberg, and Cannery Creek. The W.H. Noerenberg and Solomon Gulch hatcheries also produce chum and coho salmon. Chinook salmon are produced at the W.H. Noerenberg hatchery and sockeye salmon are produced at the Main Bay hatchery, which is also operated by PWSAC. The Ft. Richardson hatchery, a Fisheries Rehabilitation, Enhancement Department (FRED) facility, produces coho salmon smolts for release in Whittier and Cordova. Wild sockeye salmon were tagged at Jackpot, Coghill, and Eshamy Rivers. Wild pink salmon were tagged at Herring, Hayden, Loomis, Cathead, O'Brien, and Totemoff Creeks.

Tags were recovered at fish processing plants in Cordova, Valdez, Anchorage, Whittier, Kenai, and Kodiak. Recovery of tags from carcasses occurred at 6 wildstock pink salmon streams which had adult weirs and at 40 other streams surveyed as part of NRDA F/S 1. Broodstock scanning was conducted at all PWS hatcheries. A significant number of tags were recovered, allowing accurate contribution estimates and survival rates for hatchery and wildstock pink salmon in oiled and unoiled areas.

UNAKWIK
DISTRICT

Valdez

SG

CC

COGHILL
DISTRICT

Esther

BB

Bligh I

NORTHERN
DISTRICT

Whittier

WHN

EASTERN
DISTRICT

NORTHWEST
DISTRICT

Cordova

SOUTHEAST
DISTRICT

MB

MONTAGUE
DISTRICT

Hinchinbrook I

Knight I

AFK

Montague I

Cape
Fairfield

SOUTHWEST
DISTRICT

			SPECIES RELEASED				
			PINK	CHUM	COHO	SOCKEYE	CHINOOK
SG	=	SOLOMON GULCH	X	X	X		X
BB	=	BOULDER BAY ⭐	X				
CC	=	CANNERY CREEK	X				
WHN	=	WALLACE H. NOERENBERG	X	X	X		X
AFK	=	ARMIN F. KOERNIG	X				
MB	=	MAIN BAY				X	

⭐REMOTE RELEASE SITE FOR SOLOMON GULCH HATCHERY

Figure 1. Map of Prince William Sound fishing districts and hatcheries.

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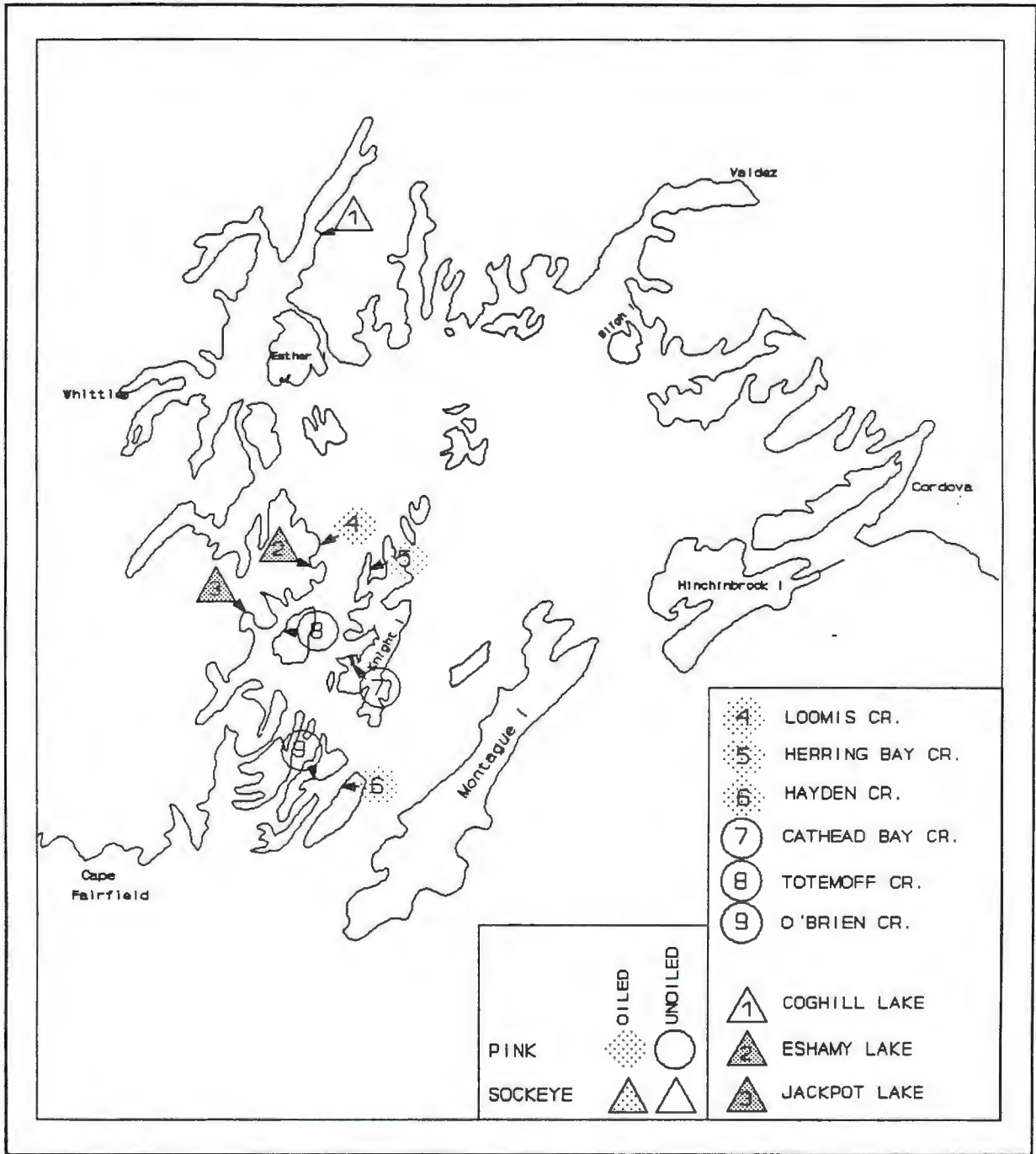
Figure 2.   Map of Prince William Sound pink and sockeye salmon weir sites.

METHODS

Tagging

Tag recovery rates vary by district, week, and processor (Peltz and Geiger 1988). Tagging goals are set to ensure tags can be recovered in sufficient numbers to estimate the contribution of each release group to each district, week, and processor stratum. This degree of precision is required to estimate differences in production for oiled and unoiled groups of wild salmon (when NRDA F/S 1, 2, 3, and 28 are synthesized). Hatchery release groups represent differences in fry treatment or timing (i.e., fed vs. unfed, early vs. late fry emergence). Tagging rates were held as constant as possible.

Tagging of Hatchery Stocks

Pink and chum salmon fry to be tagged were randomly selected as they emerged from incubators. Fry were then anesthetized in a 1 ppm solution of MS-222, adipose fin clipped, and tagged. A random sample of 20 clipped fish was graded for clip quality during each tagging shift. The proportion of bad clips was used to discount the daily release of tagged fish. Clipped fish were tagged and passed through a quality control device (QCD) to test for tag retention. Rejected fish were held and retested later in the day. If rejected a second time, they were killed to minimize the number of untagged but clipped fish in the release. Fry which retained tags were held overnight to determine short-term mortality. An overnight tag retention rate was estimated by randomly selecting 200 fish and testing them with the QCD before release into saltwater rearing pens. Tag placement was checked periodically but not quantified.

Methods of handling tagged fry prior to release differed slightly between PWSAC and VFDA facilities. Fry tagged at Solomon Gulch hatchery were held in freshwater incubators until all tagging within a single tag code was completed. They were then moved to saltwater pens. Fry tagged at PWSAC facilities were introduced into saltwater net pens once the initial 24 hour waiting period after tagging had passed. Tagged fry at all facilities were placed in small net pens suspended within the larger salt water rearing pens they represented for at least 3 days. This allowed tagged fry time to recover from tagging and handling before being mixed with their unmarked cohorts. By deducting both the short-term tagging and

saltwater rearing mortalities from the number tagged, the total number of fry with valid tags was estimated for each release group as:

$$T_{vt} = (T_t - M_{ot} - M_{sw}) (1 - L_{ot}) C ,$$

where
M_{sw} = saltwater rearing mortality,
T_t = total number of group t fish tagged,
M_{ot} = overnight mortality of tagged group t fish,
L_{ot} =overnight tag loss rate of group t fish,
C = good clip rate for group t fish.

Unmarked fry entering the salt water rearing pens were counted with fry counters at PWSAC hatcheries. At Solomon Gulch, the numbers of unmarked fry entering salt water net pens were estimated from counts of eggs loaded into incubators minus egg mortalities. Chum fry at Solomon Gulch Hatchery were transferred to salt water after emergence while those at W.H. Noerenberg Hatchery were reared in fresh water. At all facilities, fry mortalities in the large pens were estimated visually prior to release. Mortality rates determined from visual estimates were applied equally to tagged and untagged fish. The timing of hatchery releases was determined by the goals of the rearing experiment.

Sockeye, coho, and chinook salmon smolts were tagged using nearly identical methods as described for pink salmon fry tagging. The major differences were that full-length tags were used instead of half-length tags and fin clip inspections and discounting for poor clips were unnecessary because of the size of fish being tagged. After tagging, smolts were returned to freshwater before being transferred to either saltwater pens or remote release locations.

Tagging of Wild Stocks

In 1991, coded wire tags were applied to wild pink salmon at the same six streams examined in 1990 as part of NRDA Fish Study 3. Tags were also applied to the same three wild stocks of sockeye salmon examined in 1989 and 1990. Intertidal fry weirs, inclined-plane traps, and smolt weirs were used to capture and enumerate outmigrating juvenile salmon. A portion of the outmigration from each site was marked with an adipose fin clip and a coded wire tag was applied. Length, weight, and age information were collected to characterize the outmigration at each site. At Herring Creek, an upstream weir was operated in conjunction with an intertidal weir to separately enumerate and tag the pink fry production from both stream components.

Intertidal weirs were designed to provide a total enumeration of outmigrating pink salmon fry. Weirs were fished continuously and outmigration counts were summed for each low tide. Fry were counted

using electronic fry counters or by individually tallying fry using thumb counters. Each day, a random sample of fry were set aside for tagging. Of these, approximately 150 to 200 fry were measured and weighed to quantify size differences between creeks and within individual creeks over time. Fry to be tagged were anesthetized in an MS-222 solution, their adipose fin clipped, and injected with a half-length coded wire tag. Tagged fry were held for 24 hours to measure short term tag-loss and mortality rates. Each tagging day, a sample of 20 clipped fry were graded for fin clip quality to determine a good fin clip rate. Tag placement was also checked daily. After tag retention checks, fry were introduced into salt water net pens and held for up to 24 hours prior to release. The total number of fry with valid tags was estimated as:

$$T_{vt} = (T_t - M_{ot})\ (1 - L_{ot})\ C \quad ,$$

where
   T_t = total number of fish tagged from group t,
   M_{ot} = overnight mortality of tagged group t fish,
   L_{ot} = overnight tag loss rate of group t fish,
   C= good clip rate.

Tagging at each site was temporally stratified. The number of strata ranged from 3 to 5 depending on the magnitude and duration of the run. Tag codes for each stream were unique.

Smolts from wild stocks of sockeye salmon at Coghill, Eshamy, and Jackpot rivers were enumerated and a random sample were coded wire tagged. Inclined plane traps were used to capture smolt at all locations. A 1.22 m x 1.22 m fyke net was also used at the Eshamy weir. Smolts were anesthetized with an MS-222 solution and their adipose fins were clipped. Smolts were tagged and held for at least 24 hours to determine short term mortality and tag loss rates. The number of valid tags released was calculated the same as for pink salmon fry without discounting for bad fin clips.

1991 Tag Recovery

Commercial and Cost Recovery Harvests

Salmon delivered to sixteen land based processors and two floating processors were sampled for coded wire tags during the 1991 PWS fishery. All five species of salmon were sampled. Catches of salmon were scanned for coded wire tags by visual and tactile methods as the fish were off-loaded from tendering vessels. Each sample was from a specific tender, and the following data were recorded: sampler name, port, harvest type (i.e., commercial or cost recovery catch), catch date, delivery date, processor, tender

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or boat name, fishing district(s) where fish were caught, number of fish examined, number of fish with adipose fin clips found, identification numbers for fish heads recovered, and the quality of adipose clip on each recovered fish. District and subdistrict information for each tender load was obtained from tender crews, processor records, and fish tickets. Heads of clipped fish were frozen and sent to the ADF&G Coded-Wire Tag Processing Lab in Juneau along with sample data. The tag lab processed the heads, recording each head's tagcode when a tag was recovered. This information along with the information from the data sheets was entered into the Juneau tag lab database and sent to Cordova on a weekly basis to aid in-season editing and analysis.

Scanning commercial pink salmon catches for coded-wire tags involves visually selecting adipose clipped fish from a mixture of unclipped and clipped fish on a conveyor belt. Samplers select fish on the basis of whether they have a good view of the adipose fin region; negative sampling bias is possible by consistent exclusion of tagged fish. This possible sampling bias was tested by comparing the tag recovery rates of sampled fish to recovery rates in a complete census of the sampled load of fish.

Brood Stock Harvests

A technician was stationed at each of the 5 PWS hatcheries to scan the broodstock during egg take for all five species of salmon. After the salmon were manually spawned, technicians used visual and tactile methods to scan approximately 95% of the fish. When an adipose clipped fish was found, the head was removed and marked with a uniquely numbered cinch tag. Total number of fish scanned and total number of fin-clipped fish found were recorded on a daily basis. Heads and their corresponding data sheets were picked up weekly from each hatchery and returned to Cordova for editing and shipping to the Juneau Tag Lab.

Broodstock scanning is an important part of estimating hatchery contributions. Due to differential mortality between tagged and untagged fish as well as differential tag loss between release groups the tag expansion factor at release may no longer accurately reflect the tag expansion factor in the adult population. Theoretically, brood stock is 100% hatchery fish and representative of returns from each fry and smolt release group (Figure 3). Based on this assumption, tag recovery rates from brood stock can be used to adjust the initial tag expansions for each hatchery. Salmon sold for cost recovery are taken from terminal harvest areas directly in front of the hatcheries. Therefore, these fish are expected to be of primarily hatchery origin. Therefore, a similar analysis to that of the broodstock is performed for the cost recovery harvest.

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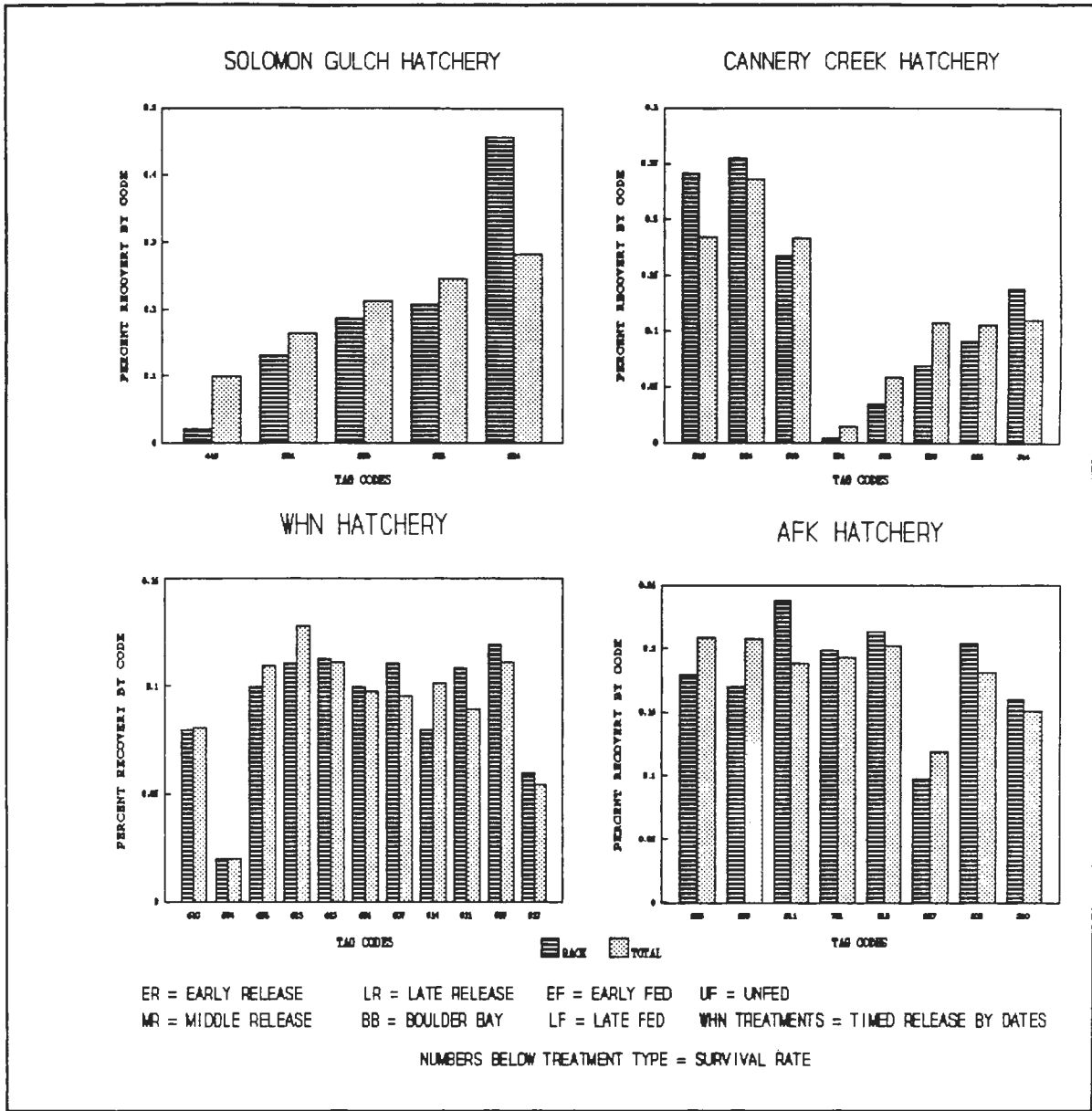
Figure 3.   Percent tags recovered in broodstock and total catch, 1991.

Wildstock Streams

Carcasses were scanned for coded-wire tags at the six tagged wildstock streams: Loomis, Cathead, Herring, Totemoff, O'Brien, and Hayden, and at an additional 40 streams surveyed as part of NRDA F/S 1. Only carcasses with a visible adipose region were counted. Heads were removed from the adipose clipped carcasses, soaked in a brine solution, and put into plastic bags. Total number of carcasses and total number of adipose clipped fish were recorded on a daily basis for each stream surveyed. Heads and their corresponding data sheets were picked up on a regular basis and returned to Cordova for editing and shipping to the Juneau tag lab.

Catch and Contribution

The 1986-87 tagging study indicated catch allocations for each hatchery should be stratified by district, week, and processor (Peltz and Geiger 1988). Processors tend to obtain fish from specific sub-areas within each district. In 1988, most fishing effort was restricted to terminal areas (close to the hatcheries) to prevent harvest of wild stocks. With this fishing pattern, it was not found necessary to stratify by processor when calculating the Solomon Gulch Hatchery contribution, presumably because tenders for each processor were in close proximity (Geiger and Sharr 1989). In 1989, fishing effort was again restricted to terminal areas due to the presence of oil in portions of PWS, but processor differences, though small, were found significant, suggesting that contribution estimates should be stratified by processor even when the fishery is conducted in terminal areas. The 1990 hatchery contribution estimates were therefore stratified by district, week and processor. Stratification differences have not yet been analyzed for the 1991 data and hatchery contribution estimates remain stratified by district, week, and processor.

Catches were obtained from summaries of fish sales receipts (fish tickets) issued to fishermen. The total hatchery contribution (C) to each harvest type is the sum over all release groups of theestimated contributions for each release group over all week, district, and processor strata:

$$\hat{C} = \Sigma_t \, \Sigma_i \, X_{ti} \, (\, N_i \, / \, S_i \, p_t) \quad ,$$

where
X_{ti}= number of group t tags recovered in ith strata,
N_i= number of fish caught in ith strata,
S_i= number of fish sampled in ith strata,
p_t= proportion of group t tagged.

A variance approximation which ignores covariance between release groups was calculated for sampled strata (Geiger 1988):

$$V(\hat{C}) = \Sigma_t \, \Sigma_i \, X_{ti} \, [\, (N_i \, / \, S_i \, p_t)^2 - (N_i \, / \, S_i \, p_t) \,].$$

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The average tag recovery rate for all processors in a week and district was used to estimate hatchery contribution in catches delivered to processors not sampled that district and week. Variances associated with unsampled strata are not calculated.

RESULTS

Previous Findings

In 1986, 625,000 of 200.5 million pink salmon fry released (1 out of 320) from 3 of the 4 Prince William Sound pink salmon hatcheries were tagged with half-length coded-wire tags and marked with adipose fin clips (Peltz and Miller 1988). These tags were recovered in 1987 by scanning catches at four processors and scanning the hatchery brood stock. Analysis of the 2,274 tag recoveries suggested the 3 hatcheries contributed approximately 10.2 million pink salmon to the total PWS harvest of 26.1 million pink salmon (Peltz and Geiger 1988). Survival of tagged hatchery stocks was approximately 6.3%.

In 1987, roughly 178,000 of the 60 million pink salmon fry released from Solomon Gulch hatchery were tagged, an average of 337 fish per tag. They were recovered by sampling commercial catches and hatchery brood stock in 1988. Approximately 300,000 pink salmon out of the total PWS commercial pink salmon catch of 11.8 million were attributed to Solomon Gulch returns. The survival rate for the stock was estimated at 0.5%.

Approximately 893,000 of the 521 million pink salmon fry released from all hatcheries in 1988 were tagged, an average of 583 fish per tag. Approximately 8,000 PWS pink salmon heads were sent to Juneau where 4,821 legible tags were removed and decoded. Tag expansions adjusted by tag recovery rates from brood stock collections yielded a maximum estimate of 20.3 million hatchery fish in the total harvest of 21.8 million fish which indicated a wildstock failure. Based on this estimate, survival of pink salmon from all hatcheries combined was 4.1%.

In 1989, over 1 million of the 506.6 million pink salmon fry released from PWS hatcheries were tagged, an average of 480 fish per tag. Approximately 182 thousand of the 3.68 million coho salmon smolts released from Solomon Gulch, Esther, and Ft. Richardson hatcheries, and 100 thousand of the 2.6 million sockeye salmon smolts released from the Main Bay hatchery were tagged. Over 8,500 tags were recovered in the 1990 season. The maximum catch contribution estimate was 36.5 million hatchery pink salmon out of a total catch of 45 million (8.5 million wildstock fish). The average survival rate for hatchery pink salmon stocks was 7.2%.

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1991 Tagging

Tagging of Hatchery Stocks

Total releases and number of tagged fish for each stock returning to the PWS fishery in 1991 are shown in Table 1. Tables 2 and 3 summarize tagging of hatchery and wild stocks in 1991. Efforts to maintain a constant tagging rate for hatchery produced pink salmon fry were successful with PWSAC hatcheries having a release to tagged ratio of approximately 600. Solomon Gulch was not as successful and had a lower tag ratio of 544.

Over 800,000 of the 535 million pink salmon released from PWS hatcheries were tagged, as were almost 473 thousand hatchery produced chum, coho, sockeye, and chinook salmon.

Tagging of Wild Stocks

Dates of operation and tagging results for the wild pink salmon fry and sockeye salmon smolt weirs are shown in Table 3. Timing and magnitude of pink salmon fry outmigrations for 1990 and 1991 are shown in Figures 4 and 5. Each pink salmon fry weir was at some time inoperable due to extremely high water or ice flows. Tide series outmigration sounts for times when the weirs were inoperable will be estimated using regression models of outmigrations on surrounding tide series. Over 319,000 wild pink salmon fry and approximately 60,000 wild sockeye salmon smolt were tagged.

1991 Tag Recovery

Twelve percent of the pink salmon common property catch was scanned for coded wire tags. Thirty percent of the cost recovery harvest, 7% of the special harvest and 93% of the pink salmon brood stock were scanned. Forty-two percent of the sockeye, chum, coho, and chinook catches were scanned. An average of 90% of the wildstock pink salmon carcasses at each surveyed stream was examined.Over 15,000 tags were recovered from almost 34,000 heads sent to the Juneau tag lab.

The preliminary unadjusted contribution estimate of the 6 tagged wildstock streams to the PWS pink salmon fishery is 47,077 fish. Survival rates ranged from .24% to 3.40% with an overall average of 2.2%. It appears that fry emigrating at the peak of outmigration timing had the highest survival rates (Table 4). This may be due to lessened effects of predation on larger groups of fry. Survival rates for the oiled streams (2.1%, 2.7%, 2.6%) were fairly consistent, while the survival rates for the unoiled streams

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Table 1. Hatchery tagged stocks returning to Prince William Sound in 1991.

Salmon Species	Hatchery	Year of Releas	Valid Tags[a]	Total Release[a]	Tag Ratio
Pink	A.F. Koernig	1990	193	113,844	590
	W.H. Noerenberg	1990	395	235,379	596
	Cannery Cr.	1990	240	143,663	599
	Solomon Gulch	1990	205	122,242	596
Chum	Main Bay	1986	120	5,109	42
	Main Bay	1987	110	76,537	696
	Solomon Gulch	1987	36	3,437	95
	Solomon Gulch	1989	28	2,921	104
Coho	W.H. Noerenberg	1989	101	2,600	26
	W.H. Noerenberg	1990	70	2,460	35
	Solomon Gulch	1989	31	980	32
	Solomon Gulch	1990	34	787	23
	Ft. Richardson	1989	51	100	2
	Ft. Richardson	1990	29	143	5
Sockeye	Main Bay	1988	42	309	7
	Main Bay	1989	100	2,645	26
	Main Bay	1990	141	2,747	19

[a] Thousands of fish.

Table 2. Coded wire tagging results for hatchery stocks released in Prince William Sound, 1991.

Salmon Species	Hatchery	Valid Tags[a]	Releases[a]	Tag Ratio	Tag Codes
Pink	A.F. Koernig	195	109,131	598	16
	W.H. Noerenberg	371	12,523	583	18
	Cannery Cr.	237	141,514	596	14
	Solomon Gulch	241	131,295	544	10
Chum	W.H. Noerenberg	178	77,949	459	4
	Solomon Gulch	20	1,736	87	2
Coho	W.H. Noerenberg	73	5,142	70	4
	Solomon Gulch	36	1,956	55	3
Sockeye	Main Bay	115	3,726	32	8
Chinook	W.H. Noerenberg	41	411	10	2

[a] Thousands of fish.

Table 3. Coded wire tagging results and dates of weir operation for wild stocks in Prince William Sound, 1991.

Salmon Species	Treatment	Stream	Date	Valid Tags[a]	Seaward Migration[a]	Tag Ratio
Pink	Control	Cathead Creek	4/18 - 5/25	40	158[b]	4
		O'Brien Creek	4/22 - 5/26	28	298[c]	10
		Totemoff Creek	4/17 - 5/24	43	734[d]	17
Pink	Oil	Hayden Creek	4/23 - 5/28	43	391[e]	9
		Herring Creek	4/13 - 6/3	43	399[d]	9
		Loomis Creek	4/18 - 6/1	45	211[e]	5
Sockeye		Eshamy River	4/4 - 6/25	21	683	33
		Jackpot Creek	4/14 - 6/1	5	20	4
		Coghill River	4/5 - 5/30	0	4	0

[a] Thousands of fish.
[b] Interpolated 5 days data.
[c] Interpolated 1 day data.
[d] Interpolated 3 days data.
[e] Interpolated 4 days data.
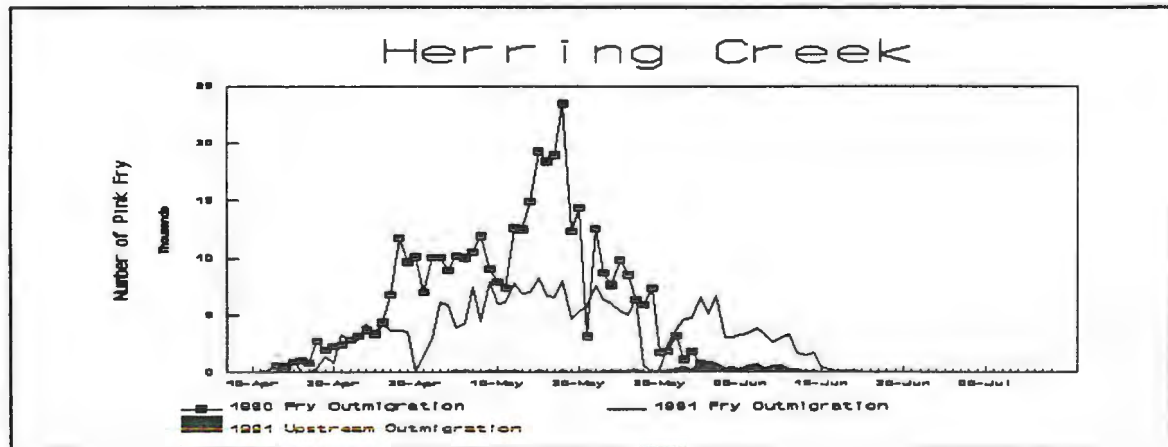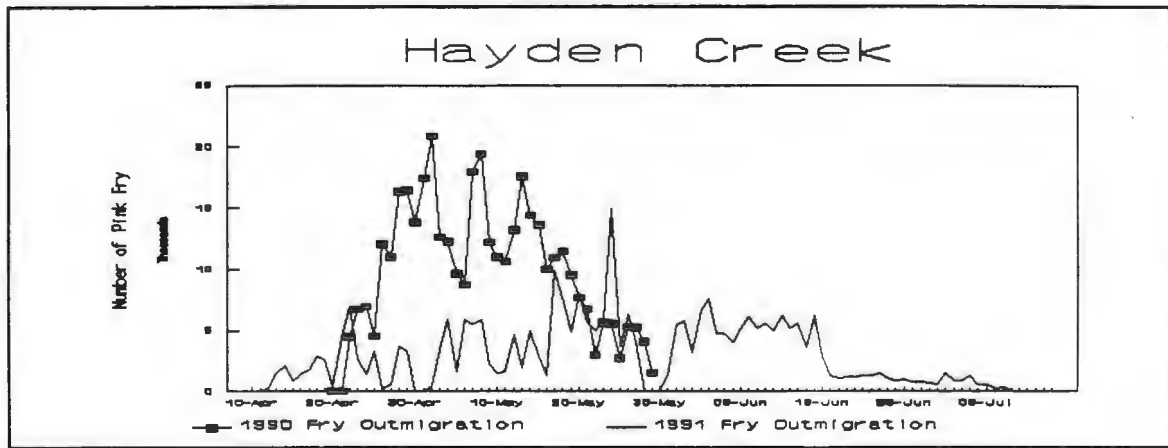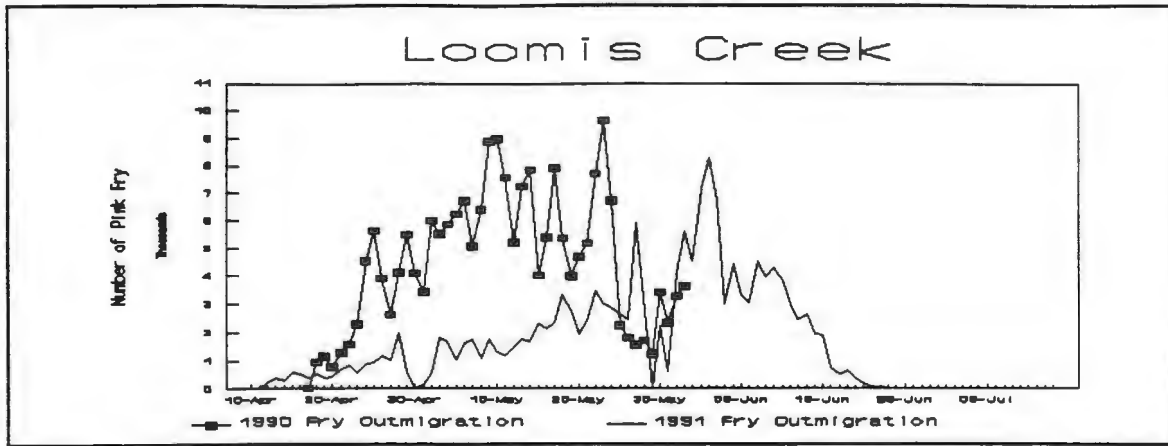
Figure 4.   Timing and magnitude of pink salmon fry outmigrations from three oiled streams in Prince william Sound

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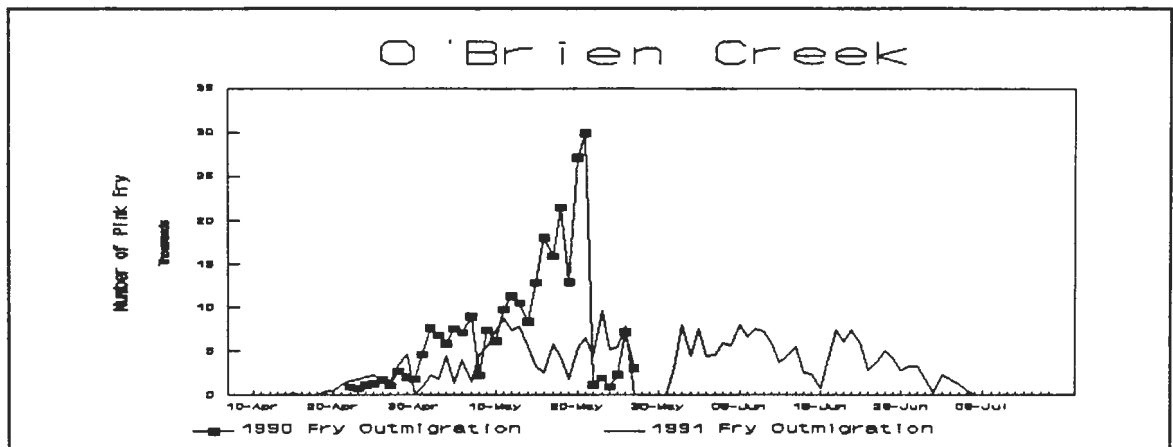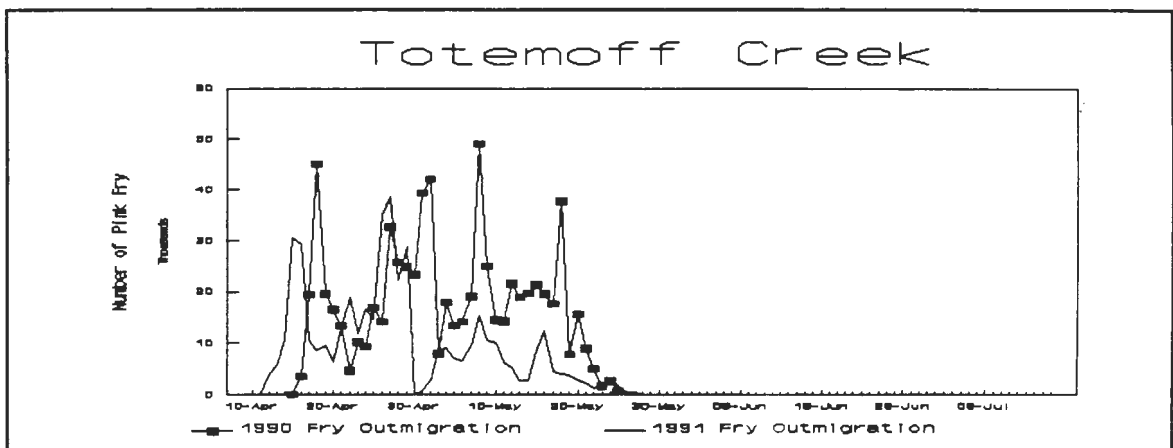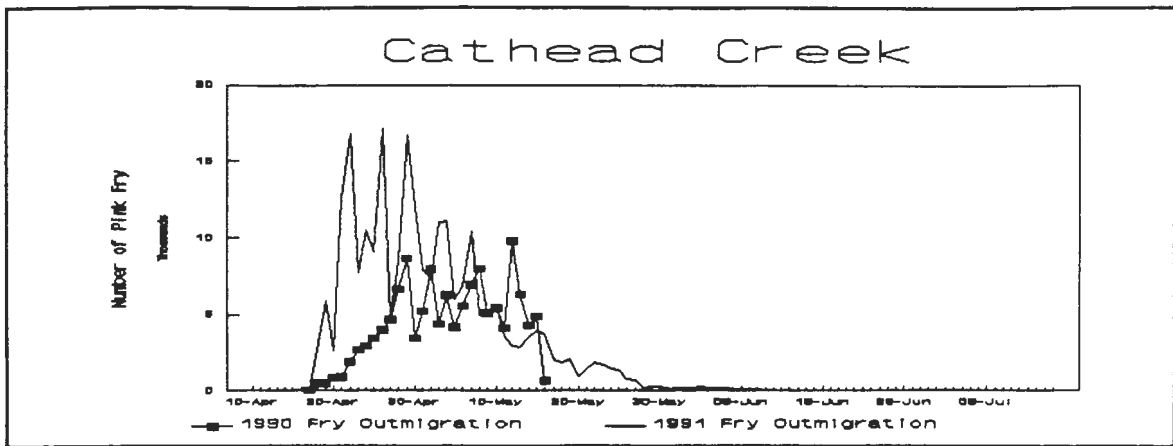
Figure 5. Timing and mignitude of 1990 and 1991 pink salmon fry outmigrations from three unoiled streams in Prince william Sound.

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Table 4. Recovery results for tagged wildstock pink salmon, 1991.

	WILDSTOCK STREAM	TAG CODE	TOTAL RELEASED	TOTAL TAGGED	TAG EXPANSION	TOTAL TAGS RECOVERED	TOTAL CONTRIBUTION	SURVIVAL RATE(%)
OILED	HAYDEN	802	275,233	30,574	9.002	154	7,457	2.71
		803	89,804	12,584	7.136	24	467	0.52
	HERRING	715	84,184	27,747	5.622	22	663	0.79
		801	309,229	14,974	11.144	193	10,004	3.24
	LOOMIS	707	130,586	27,132	4.812	219	4,396	3.37
		708	72,729	17,571	4.139	42	869	1.19
UNOILED	O'BRIEN	712	207,366	22,831	9.082	69	3,688	1.78
		711	82,342	5,358	15.368	1	197	0.24
	TOTEMOFF	713	440,358	25,457	17.298	189	10,881	2.47
		714	274,101	17,535	15.631	37	3,409	1.24
	CATHEAD	709	125,326	30,047	4.170	180	4,266	3.40
		710	29,051	9,617	3.020	35	780	2.68

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(1.34%, 2.0%,3.3%) varied. There was an apparent failure in the return of one O'Brien tagcode, 711, (one recovery) which influenced the overall O'Brien survival rate (Table 4). Some straying of hatchery and wildstock pinks is indicated by the 1991 tag recovery data (Table 5.). Tagged wildstock pink salmon were recovered in cost recovery and broodstock harvests as well as the common property fishery, and hatchery pinks were recovered in many of the wildstock streams. This suggests possible genetic mixing between and among the wild and hatchery pink salmon.

The preliminary estimate of maximum hatchery contribution to the 1991 catch of 37,037,118 pink salmon is 30,358,793 (6.7 million wild) with Solomon Gulch contributing 18%, W H Noerenburg 38%, A F Koernig 16%, and Cannery Creek 28% (Table 6). Figures 6 and 7 show contribution results stratified by district and week. Total hatchery contribution to each harvest type ranges from 80% (Common Property) to 92% (Broodstock) (Table 7). Pink salmon survival for all hatcheries combined is 5.2% (Figure 8). A. F. Koernig hatchery, located in a heavily oiled area, had the lowest survival rate (4.56%) of the 3 PWSAC hatcheries. Summary results for hatchery releases from 1987 through 1991 are listed in Table 8.

Tag expansion factors for 1990 releases from each hatchery were multiplied by adjustments between 1.38 and 1.92, based on tag recovery rates in cost recovery and brood stock samples. Tagging related mortality and tag loss may lower the incidence of tagged fish in hatchery returns and necessitate increasing tag expansion factors calculated for fry releases. Among adult returns, 100% of the fish in a hatchery broodstock are assumed to have originated from the releases at the hatchery. If no tag loss or tagging related mortality occur, the fraction of tagged fish in the broodstock should closely approximate the fraction observed in fry releases. Observed decreases in the fraction tagged are assumed to be related to tag loss or tagging related mortalities and a tag expansion factor calculated from tagging and release data are adjusted according to the tag rates observed in the broodstock. Tag rates in the broodstock were used to adjust tag expansions for AFK and WHN hatcheries in 1991, but not for Solomon Gulch and Cannery Creek hatcheries. At the latter 2 hatcheries, tag rates were much lower than those observed in fry releases, but were also much lower than those observed in hatchery cost recovery harvest. The low occurrence of tagged fish in these broodstocks relative to rates observed in the cost recvery harvests is puzzling. The problem could be related to sampling error (missed clips during scanning), but this seems unlikely since scanning procedures are uniform for all hatcheries. Low rates of tag occurrence may also be due to wildstock dilution of broodstock. Wild fish in the broodstock may originate from natural spawning regularly observed in streams adjacent to Solomon Gulch and Cannery Creek hatcheries. These streams also provide the hatcheries with water and provide olfactory cues to both hatchery and wild fish returning to these

Table 5. Tags recovered in wildstock streams by hatchery or stream of origin.

| RECOVERY STREAM | TAG ORIGIN | | | | | | | | | | TOTAL TAGS |
| | WILDSTOCK STREAM | | | | | | HATCHERY | | | | |
	LOOMIS	TOTEMOFF	O'BRIAN	HAYDEN	HERRING	CATHEAD	AFK	CCH	WHN	SGH	TAGS
LOOMIS	150	2	0	0	14	0	1	1	18	0	186
TOTEMOFF	3	108	0	0	4	8	1	1	6	0	131
O'BRIEN	0	1	26	3	1	3	10	0	5	1	50
HAYDEN	0	0	0	84	1	1	5	1	2	0	94
HERRING	2	0	0	1	54	1	1	0	3	0	62
CATHEAD	0	0	0	0	0	36	1	0	1	0	38
16949	0	0	0	0	2	3	0	0	1	0	6
500	0	0	0	0	1	0	0	0	0	0	1
507	0	1	0	0	0	0	0	0	0	0	1
508	2	3	0	0	20	2	3	0	2	0	32
510	1	4	0	0	1	2	0	2	4	0	14
511	0	1	0	0	3	2	0	1	1	0	8
515	0	0	0	0	1	0	0	0	2	0	3
516	2	1	1	0	2	0	0	0	5	0	11
601	0	1	0	0	2	1	1	0	4	0	9
602	0	1	0	0	1	1	0	1	1	0	5
604	1	11	0	0	1	5	0	0	2	0	20
612	0	1	0	0	0	0	0	0	0	0	1
618	1	0	0	1	3	0	1	0	1	0	7
623	0	3	1	0	0	3	1	1	2	0	11
628	0	0	0	0	1	1	1	2	2	0	7
636	1	0	0	0	0	0	0	0	0	0	1
665	0	0	0	1	3	0	3	0	1	0	8
670	0	0	0	1	0	1	1	0	0	0	3
673	0	0	1	2	0	0	1	1	0	0	5
678	0	0	0	0	0	0	1	0	0	0	1
695	0	0	0	1	2	2	0	1	0	0	6
697	0	0	0	0	0	1	0	0	1	0	2
76	0	0	0	0	0	0	1	0	0	2	3
80	0	1	0	0	0	0	0	1	0	0	2
93	0	0	0	0	0	0	0	0	0	3	3
94	0	1	0	0	0	0	0	0	0	0	1
TOTAL TAGS	163	140	29	94	117	73	33	13	64	6	732

Table 6. Summary of hatchery contributions to the PWS
         Fishery using tag expansions at release and
         adjustment factors calculated from the
         broodstock or cost recovery.

	Contribution	
	Unadjusted	Adjusted
SOLOMON GULCH HATCHERY		
Common Property	2,074,973	2,544,914
Cost Recovery	2,075,455	2,872,737
Special [1]	0	0
Broodstock	146,239	218,852
Total Return	4,296,667	5,636,503
Total Release	122,242,297	
Marine Survival	3.51	4.61
CANNERY CREEK HATCHERY		
Common Property	3,964,731	6,978,131
Cost Recovery	392,141	682,124
Special [1]	430,854	760,306
Broodstock	155,690	299,275
Total Return	4,943,416	8,719,836
Total Release	143,662,511	
Marine Survival	3.44	6.07
W.H. NOERENBERG HATCHERY		
Common Property	5,313,197	8,084,192
Cost Recovery	710,399	1,044,032
Special [1]	1,651,081	2,444,692
Broodstock	294,715	453,103
Total Return	7,969,392	12,056,019
Total Release	235,378,496	
Marine Survival	3.39	5.11
ARMIN F. KOERNIG HATCHERY		
Common Property	2,922,811	4,011,573
Cost Recovery	478,981	645,966
Special [1]	213,865	290,126
Broodstock	181,358	244,589
Total Return	3,797,015	5,192,254
Total Release	113,843,914	
Marine Survival	3.34	4.56

[1] Special includes the pink salmon that were discarded and
donated.

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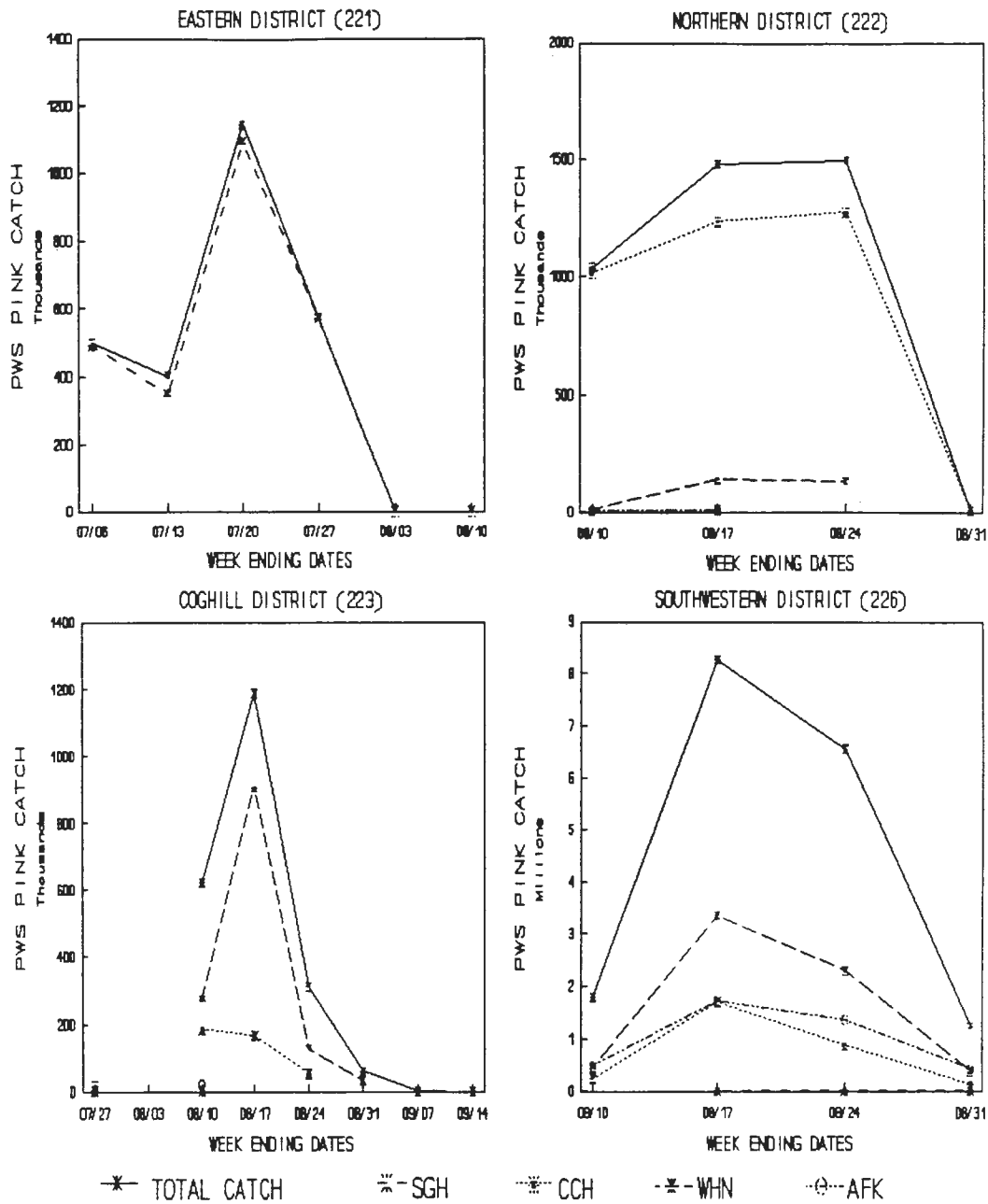
Figure 6. Hatchery contribution to the 1991 PWS pink salmon commercial fishery by district.

ALL DISTRICTS COMBINED (221-229)
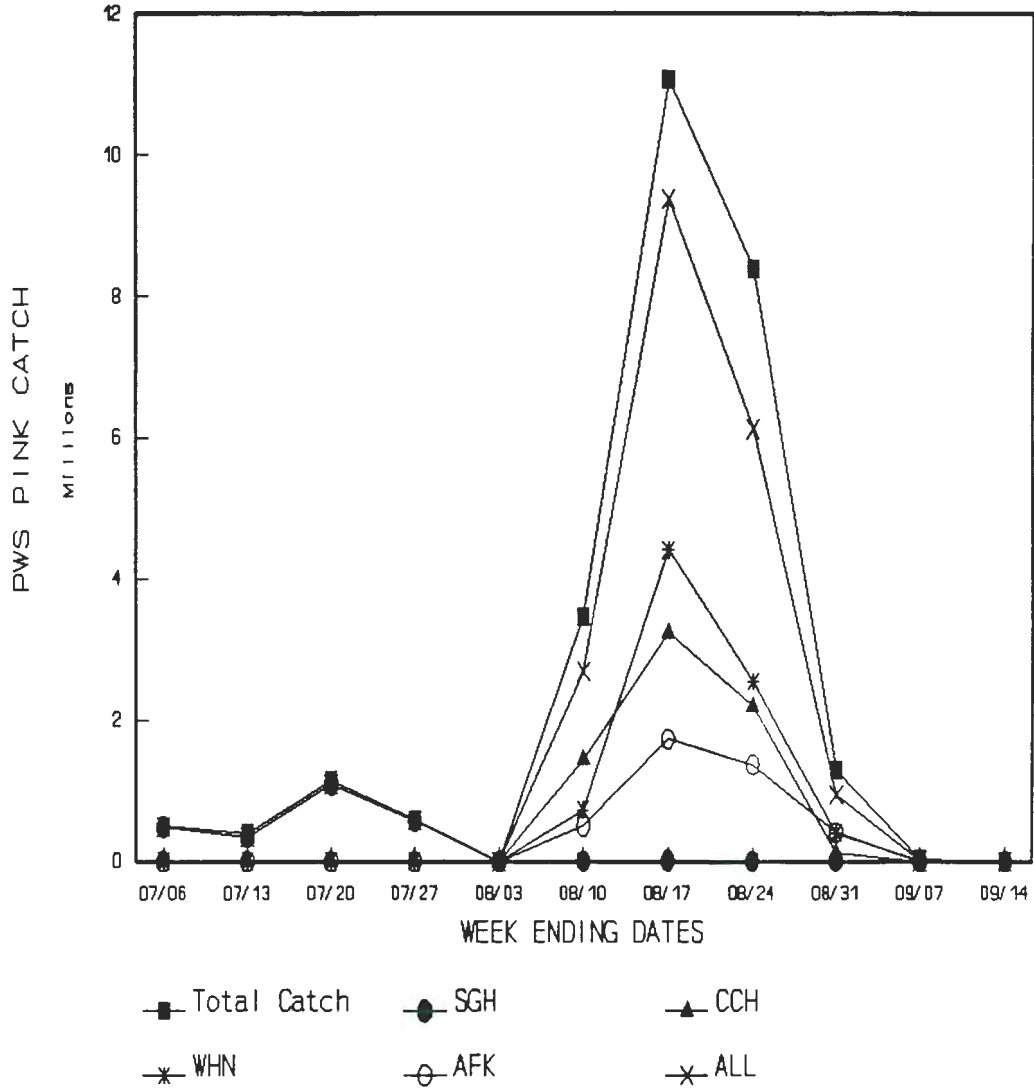
Figure 7. Total hatchery contribution to the 1991
PWS pink salmon commercial fishery for
all districts combined.

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Table 7. Total hatchery contribution (adjusted and unadjusted) to the Prince William Sound pink salmon fishery by harvest type.

HARVEST TYPE	TOTAL CATCH	CONTRIBUTION (UNADJUSTED)	PERCENT CONTRIBUTION	CONTRIBUTION (ADJUSTED)	PERCENT CONTRIBUTION
COMMON PROPERTY	26,894,679	14,275,712	53.08	21,618,810	80.38
COST RECOVERY	6,094,282	3,656,976	60.01	5,244,859	86.06
*SPECIAL	4,048,157	2,295,800	56.71	3,495,124	86.34
BROODSTOCK	1,317,708	778,002	59.04	1,215,819	92.27
TOTAL	38,354,826	21,006,490	54.77	31,574,612	82.32

Figure 8. Pink salmon survival rates by hatchery, tagcode, and treatment.

Table 8. Summary of results of coded wire tag studies on pink salmon in Prince William Sound, 1987-1991. Results of 1991 tag recoveries are preliminary.

Hatchery	Year	Releases[a]	Returns[a]	Survival Rate	Adjustment Factor[b]
A. F. Koernig	87	112,528	7,614	6.8	.96
	88				
	89	110,037	2,736	2.5	1.31
	90	160,487	7,159	4.5	1.56
	91	109,131	5,192	4.6	1.38
W. Noerenberg	87	34,437	3,032	8.8	1.18
	88				
	89	195,608	7,092	3.6	1.90
	90	159,714	14,833	9.3	1.26
	91	12,523	12,026	5.1	1.55
Cannery Cr.	87	56,200	2,123	3.8	2.22
	88				
	89	95,571	7,099	7.4	1.87
	90	58,970	3,245	5.5	1.87
	91	141,514	8,720	6.1	1.92
Solomon Gulch	87				
	88	130,827	300	.5	2.35
	89	60,000	3,405	2.6	1.15
	90	128,500	11,278	8.8	1.19
	91	131,295	5,636	4.6	1.50

[a] Thousands of fish.
[b] Adjusted for lost tags.

sites. In any case, tag rates in cost recovery harvest for these two hatcheries were much more consistent with rates observed at the time of fry release and were used to adjust the expansion factors. Given the high probability of at least some occurrence of wild fish in the cost recovery harvests as well, these expansion factor adjustments were probably too large.

STATUS OF INJURY ASSESSMENT

The major objective of this tagging study is to estimate differential survival of fish exposed to oil contaminated waters. Estimates of catch contributions and production from this study in conjunction with escapement (NRDA F/S 1), egg and fry survival (NRDA F/S 2), and early marine survival (NRDA F/S 4) will provide information on the extent of effects on each Pacific salmon life stage. The time frame depends on the life span of each species. Although still preliminary, we now have survival estimates for 1989, 1990, and 1991 hatchery produced pink salmon, as well as 1990 tagged wildstock pink salmon. We also have an extensive escapement database which will be modeled to determine whether differential production occurred between oiled and unoiled streams.(NRDA F/S 28)

Progress on each objective is as follows:

1.   Catch and survival rates of pink salmon released from four PWS hatcheries in 1988 were estimated from 1989 recoveries. The overall survival rate for pink salmon was 4.1%. Almost 1.4 million tagged pink, chum, sockeye, and coho salmon were released from five hatcheries in 1989. Over 8,500 of the pink salmon tagged in 1989 were recovered in 1990 providing an overall hatchery survival estimate of 7.2%. Marine survival of the other 4 species will be calculated as they return. Chum and sockeye salmon began returning in significant numbers in 1991, and recovery efforts will need to continue through 1993 to encompass the majority of adult returns from the 1989 release. Approximately 1.6 million tagged pink, chum, sockeye, and coho salmon were released from 5 hatcheries in 1990 along with over 265,000 wild sockeye and pink salmon. In 1991, 8253 pink salmon tags were recovered providing an overall hatchery survival rate of estimate of 5.13%. Chinook salmon tagged in 1990 will begin returning in 1993 and continue through 1995. Sockeye, chum, and coho salmon from the 1990 release will continue to return through 1994. In 1991, approximately 473,000 tagged pink, chum, sockeye, and coho salmon were released from the 5 hatcheries.

2.   Six streams (3 oiled and 3 unoiled) were selected for pink salmon fry tagging and estimation of seaward migrants in 1990 using information gathered in NRDA F/S 1 and 2. Over 240,000

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wild pink salmon were tagged at the 6 streams. These fish were recovered in the 1991 harvests and escapement surveys (NRDA F/S 1), providing survival rates and production estimates. The preliminary contribution estimate is 47,077 and the average survival rate was 2.2%. In 1991, 319,400 wild pink salmon were tagged at these same six streams.

3. Over 90,000 sockeye salmon smolts were tagged at Eshamy and Coghill Rivers in 1989. These fish will began returning in 1991. In 1990, 25 thousand tags were applied to sockeye salmon smolts in the Jackpot and Eshamy Rivers. Fish from the Coghill River were not tagged due to low smolt abundance. The sockeye salmon tagged in 1990 will begin returning in 1993. In 1991, approximately 60,000 tags were applied to sockeye salmon in the Eshamy, Jackpot, and Coghill Rivers. Weirs operated by ADF&G Commercial Fisheries and OSIAR Divisions are in place to monitor the escapements.

4. Almost 1.4, 1.6 million and 1.3 million Pacific salmon were tagged and released in 1989, 1990, and 1991 providing fish of known origin for NRDA F/S 4 (early marine life history) and this study.

5. The analysis of spatial trends in the recent and historic catch and escapement data suggest that alternative strategies for managing the commercial fleet may be the first and most effective step in restoring full production to PWS in the wake of the Exxon Valdez oil spill. A comprehensive escapement enumeration and stock identification projects, which are designed to improve the accuracy of current management strategies, have been proposed.

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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.

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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

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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.

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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.

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.

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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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<u>Objectives</u>

(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.

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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.

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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.

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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,

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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, **zoo**plankton 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 $^\circ$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 $^\circ$C. Kepshire's data was used to relate growth and temperature by

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$$G = 0.2141(T) + 1.2813 \tag{3}$$

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:

$$I_m = \frac{G - R}{A} \tag{4}$$

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)

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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≥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

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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

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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).

<u>Status of Injury Assessment</u>

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 ($4 - 14^{o}$ C) on the growth of pink salmon fry

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(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 n	1989 $\bar{x}$	1989 SE	1990 n	1990 $\bar{x}$	1990 SE	1991 n	1991 $\bar{x}$	1991 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.

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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.

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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	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					
BWO[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*BWO	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] BWO = 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					
BWO[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					
BWO	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					
BWO	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] BWO = 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					
BWO[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					
BWO	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] BWO = 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 ($^{\circ}$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
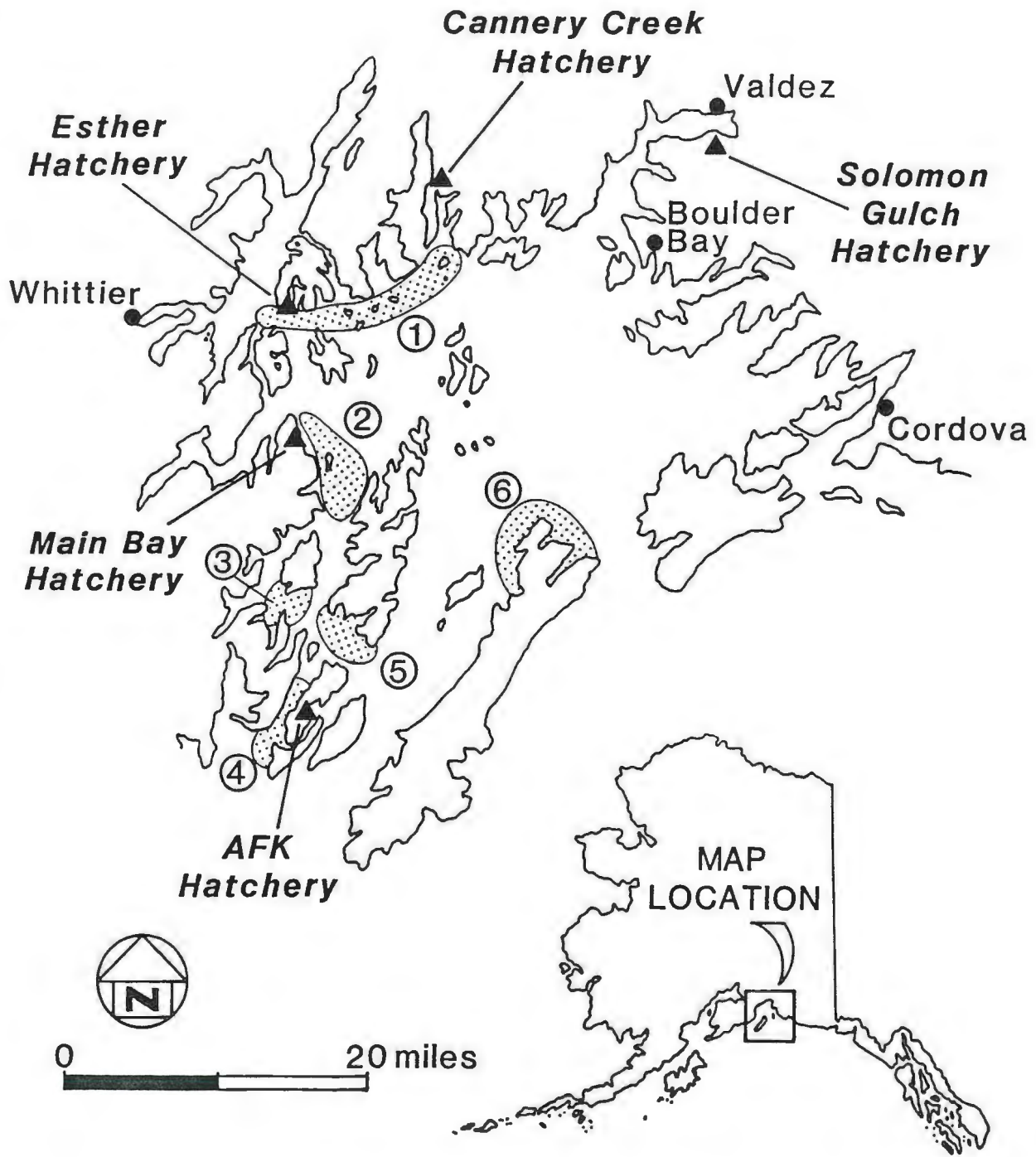
Figure 1: Six areas sampled for juvenile salmon in Prince William
Sound in 1989, 1990, and 1991.

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(a)

Ln(BW) = 0.012 R - 3.248   (p<.0001)

(b)

AGE = 0.995 INC + 3.534   (p<.0001)
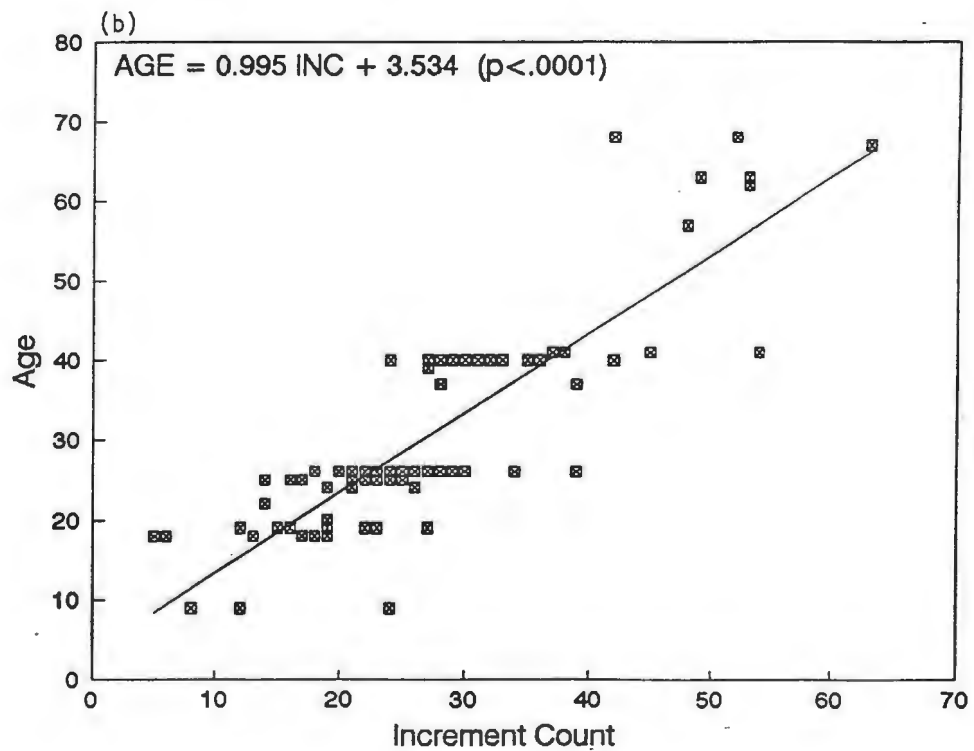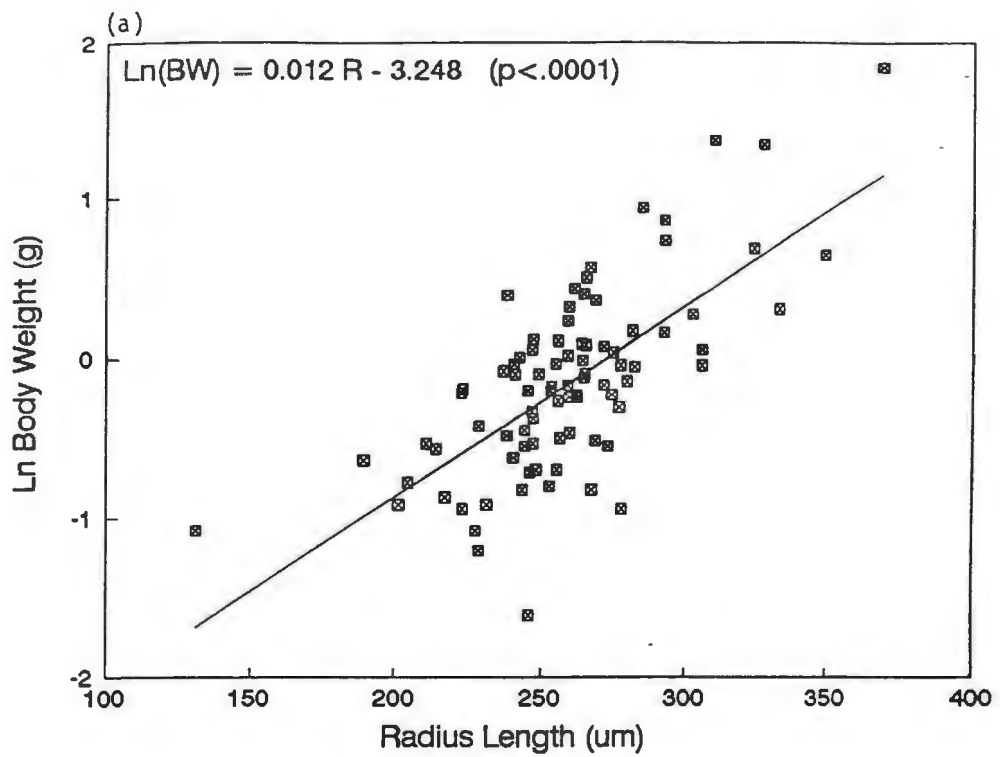
Figure 2: Regression of (a) ln(body weight) on otolith radius length and (b) fish age on otolith increment count. Data from the early-fed treatment group released from the Armin F. Koernig Hatchery in 1989.

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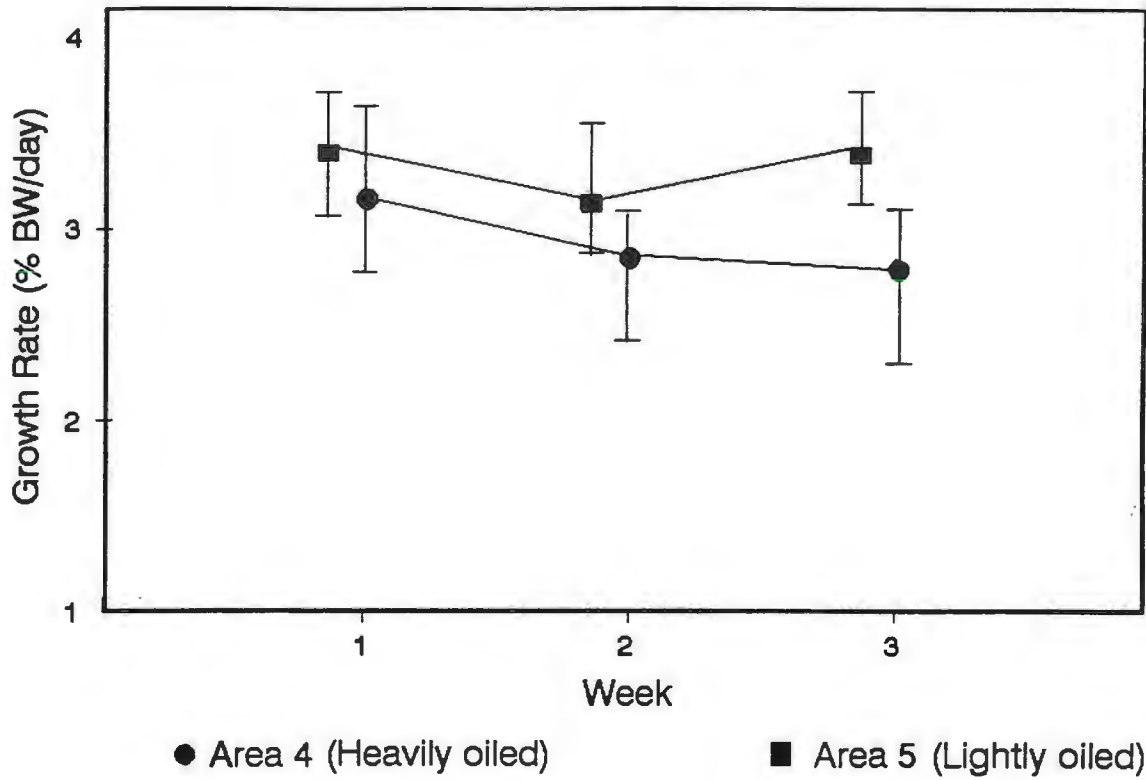
Figure 3: Back-calculated weekly mean growth rates obtained from otoliths with 95% confidence intervals. Data from the early-fed treatment group released from the Armin F. Koernig Hatchery in 1989.

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.
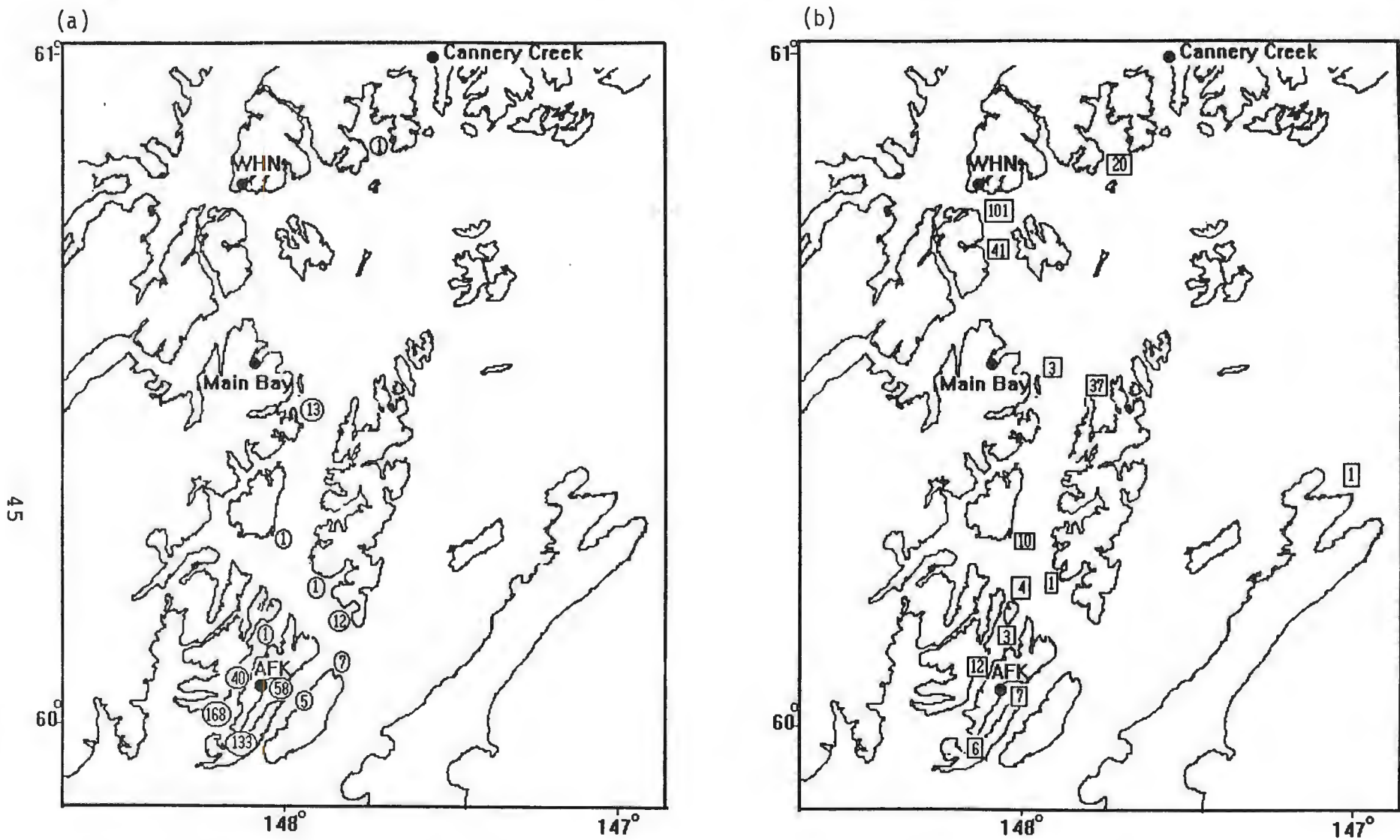
Figure 5: Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1990: (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.
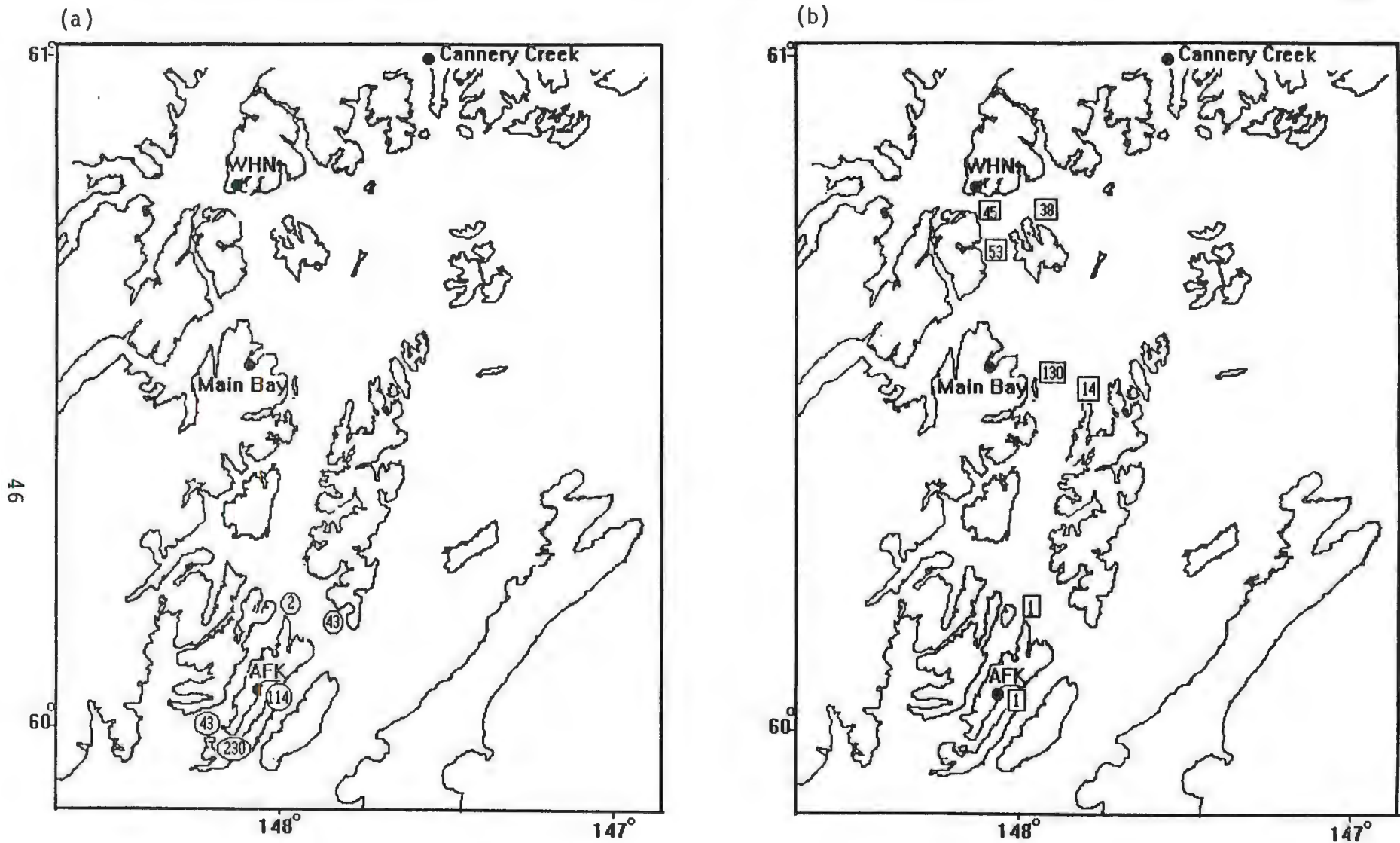
Figure 6: Geographic distribution of coded-wire tag recoveries in Prince William Sound in 1991. (a) fish released from the Armin F. Koernig Hatchery, (b) fish released from the Wally H. Noerenberg Hatchery. Enclosed values indicate the number of coded-wire tagged pink salmon recovered at each site.
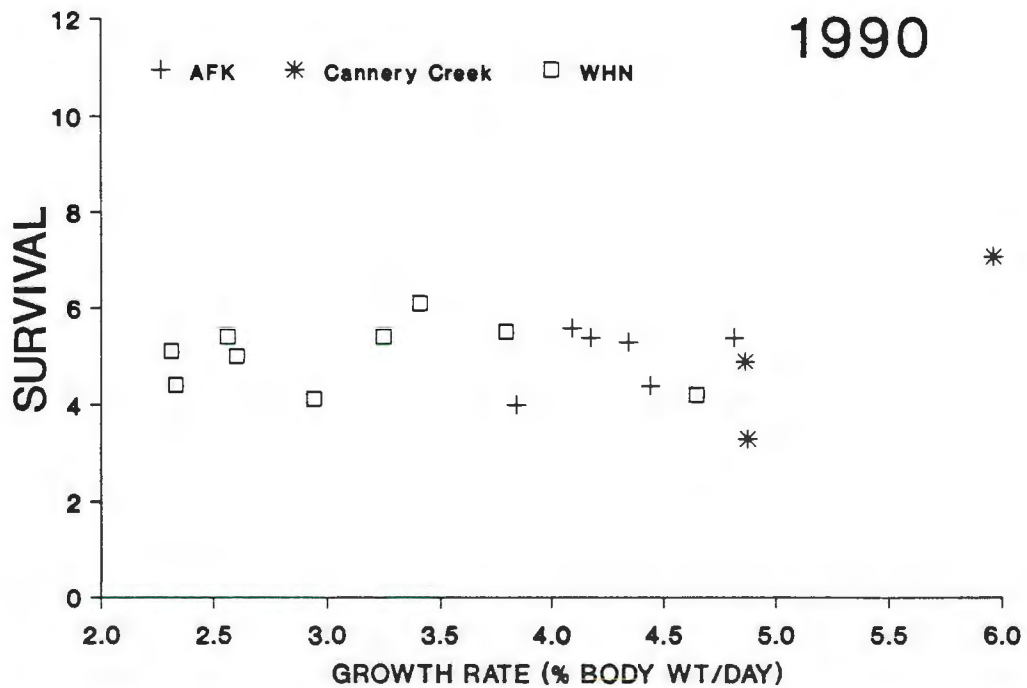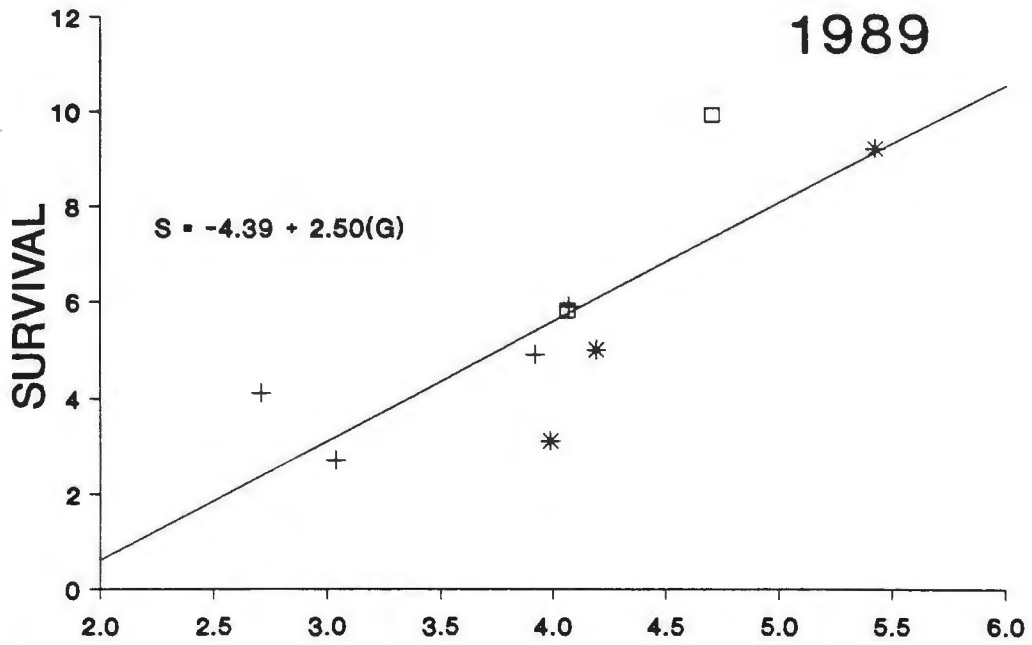
Figure 7. Relationship between fry-to-adult survival and mean growth rate by coded-wire tag code for pink salmon fry released into Prince William Sound in 1989 and 1990.

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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

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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 <u>a priori</u> 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

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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

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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).

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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 ($P > 0.100$). 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 ($P = 0.086$, 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 ($P = 0.003$) and ranks ($P = 0.004$, 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 ($P > 0.100$) 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 ($P = 0.023$) and time * habitat ($P = 0.055$) 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 ($P = 0.076$) and ranks ($P = 0.042$, Table 2.6). Although habitat was not significant ($P > 0.100$) 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 ($P = 0.096$), Ln catch ($P = 0.078$), ranks ($P = 0.035$, Table 2.5), frequency of occurrence (Table 2.7), and the non-parametric Wilcoxon test ($P = 0.030$, Table 2.4). In 1990 there

were no significant differences in pink salmon abundance between
oiled and non-oiled corridors ($P > 0.100$, 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 ($P = 0.014$) and ranks ($P = 0.027$, 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 ($P >
0.100$) between replicates of the same habitat type in 1990. In
1989, oil * habitat ($P = 0.022$) 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 ($P < 0.001$) 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 ($P <
0.050$, 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

2.9

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 (P = 0.017) and ranks (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
(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 (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).

2.11

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			1990		
		DF	F	Prob.	DF	F	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		

2.18

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.

Source	df	Rank transformation			Natural Log transformation		
		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)

Source	df	Rank transformation			Natural Log transformation		
		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 < $\underline{P}$ < 0.100
** = 0.010 < $\underline{P}$ < 0.050
*** = $\underline{P}$ < 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

Source	Bays			Corridors		
	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)						

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

2.22

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.

<div align="center">Probability</div>

Source	Bays			Corridors		
	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)						

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

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

Source	df	Rank transformation			Natural Log transformation		
		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)

Source	df	Rank transformation			Natural Log transformation		
		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		

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

2.28

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.

Source	1989			1990		
	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 < P < 0.100
** = 0.010 < P < 0.050
*** = 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		

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

2.30

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			

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

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

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

2.32

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. $\underline{P},x$ is the probability value for the tests of homogeneity of slopes for the pairs of regression lines shown. $\underline{P},w$ 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	$\underline{P},x$ ($\underline{P},w$)	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.

Area	1989			1990		
	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)
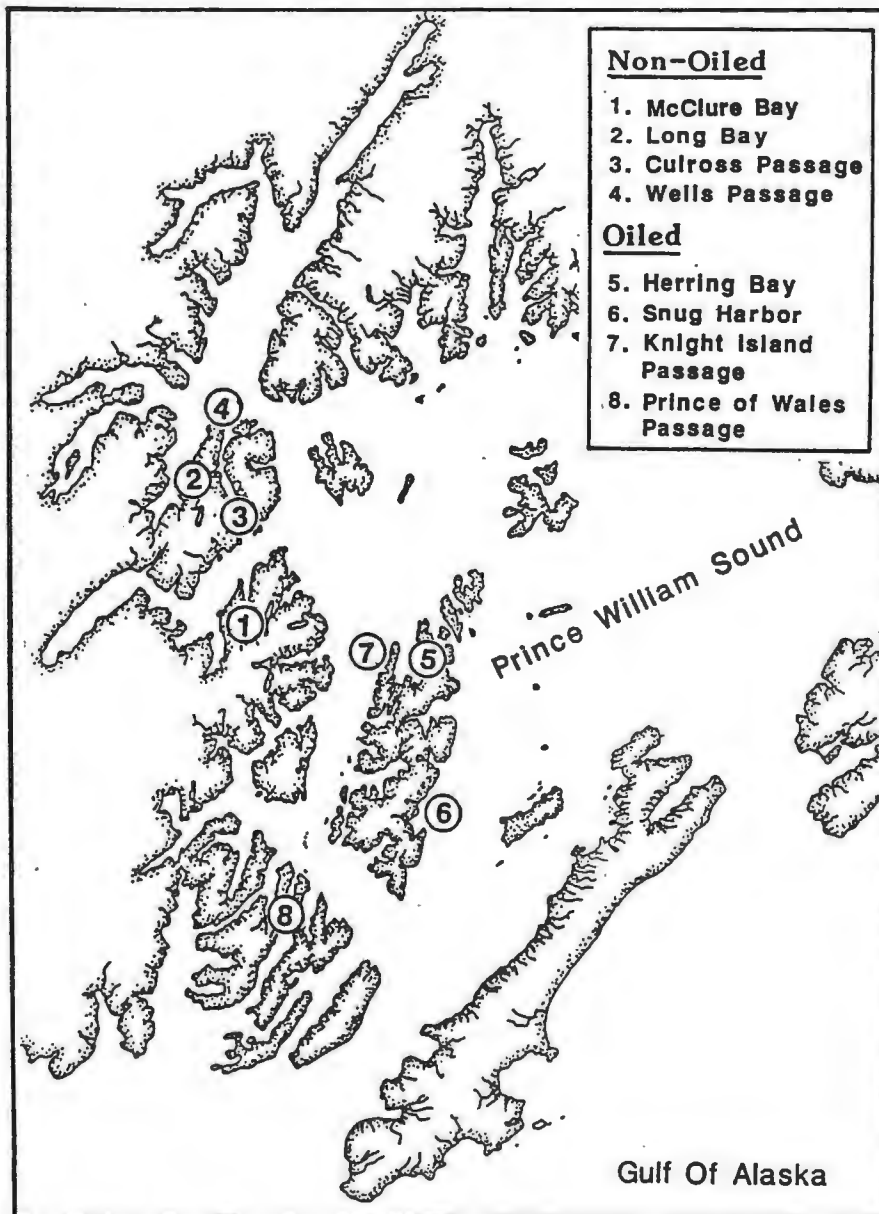
Fig. 2.1--Locations of oiled and non-oiled sampling locations for NMFS component of NRDA study F/S-4. Locations 1, 2, 5 and 6 were classified as embayments; locations 3, 4, 7 and 8 were classified as corridors.

2.38
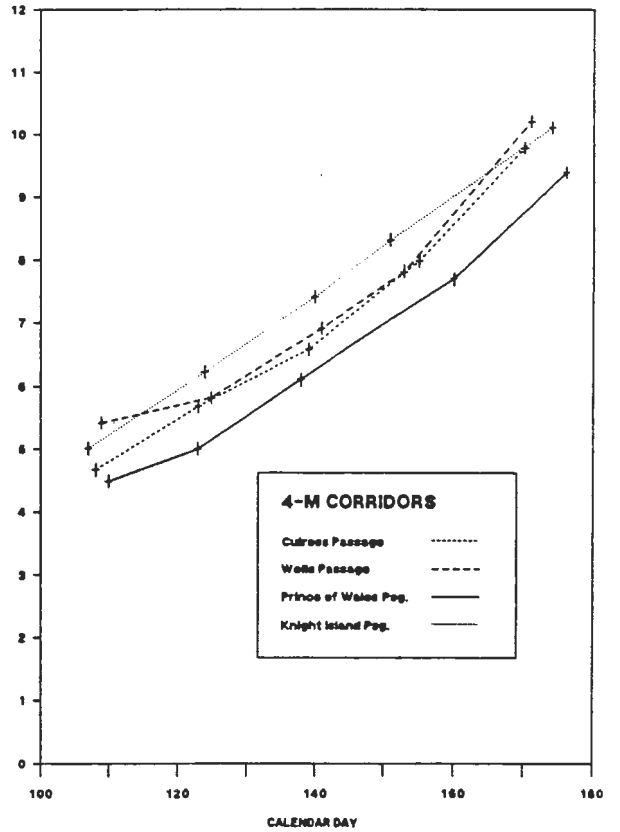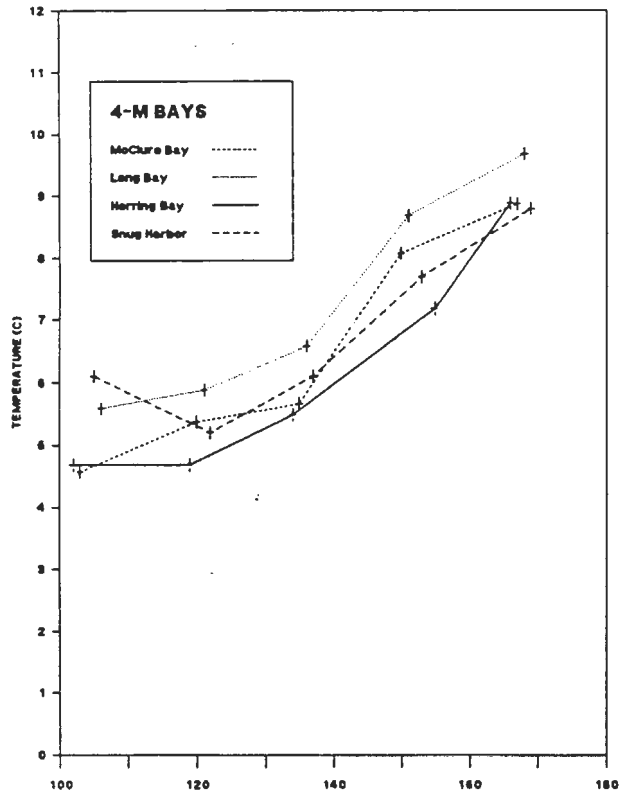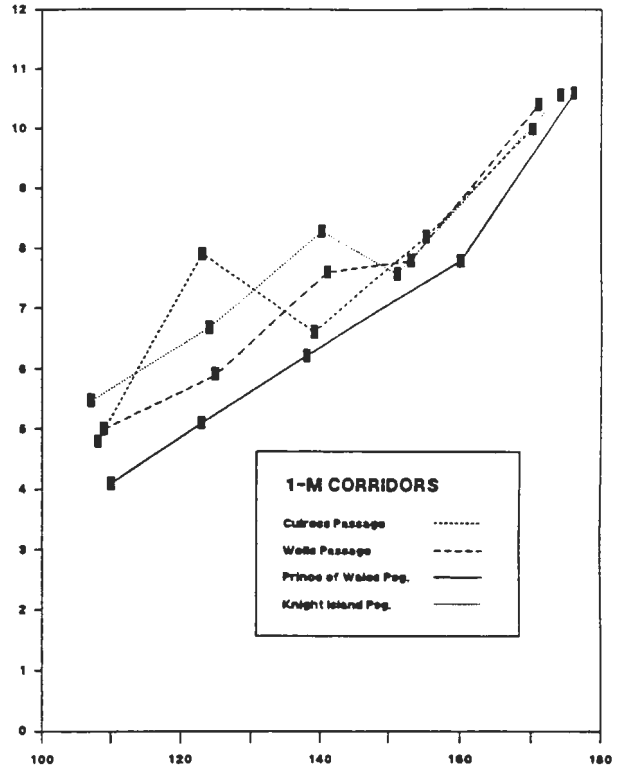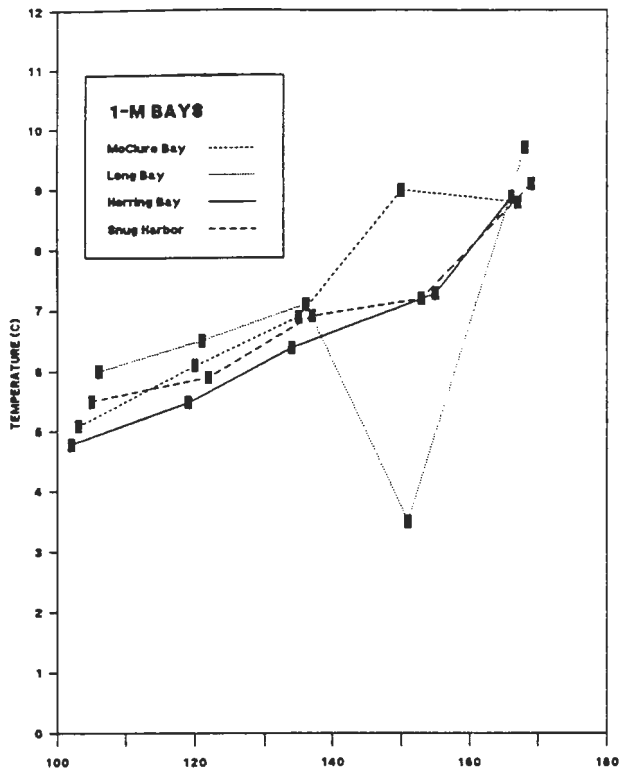
Figure 2.2. Temperatures at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1989. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.
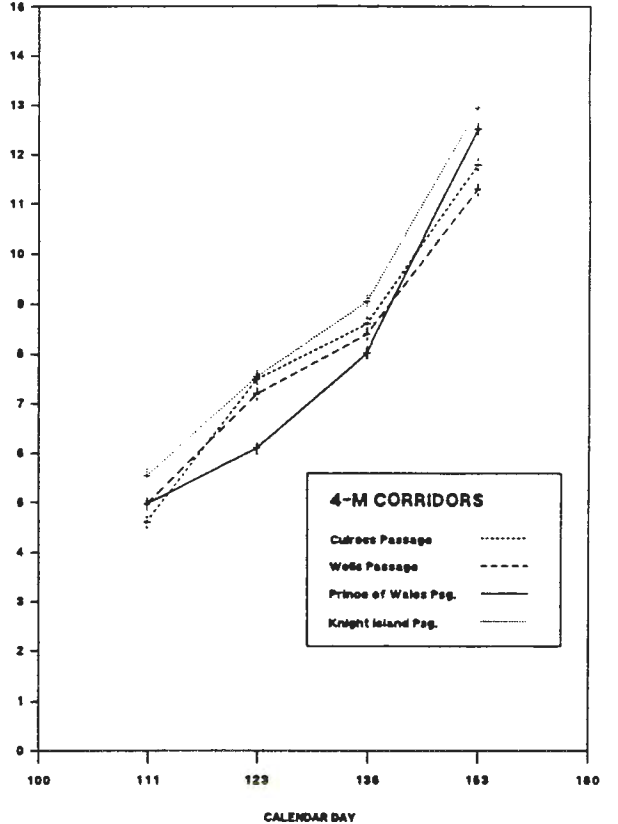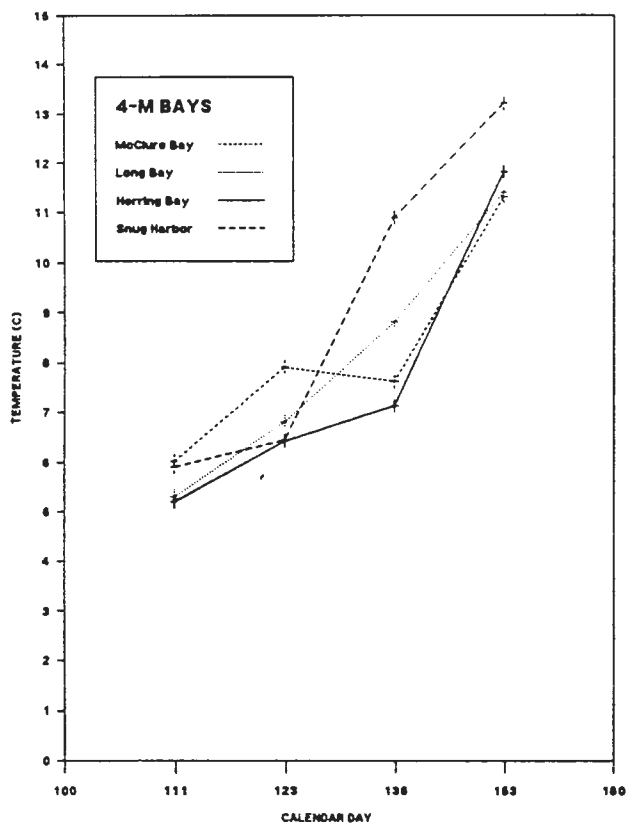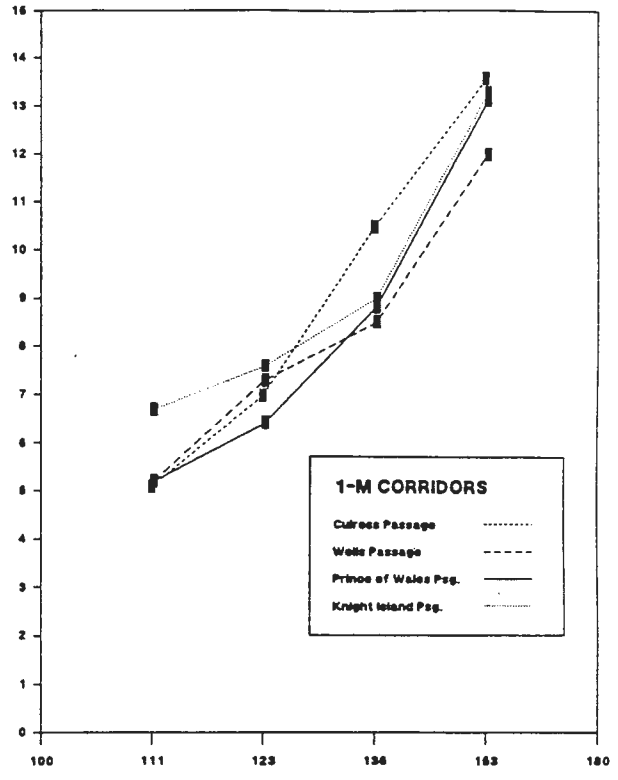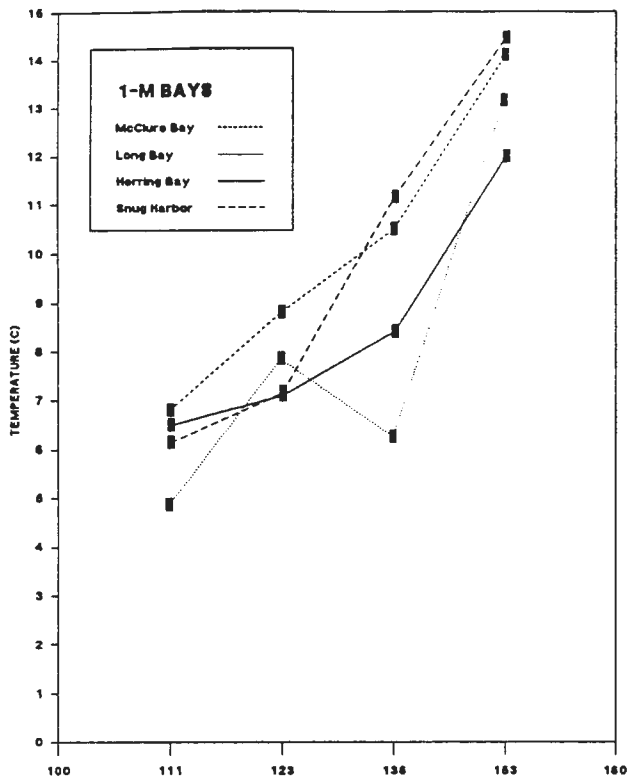
Figure 2.3. Temperatures at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1990. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.
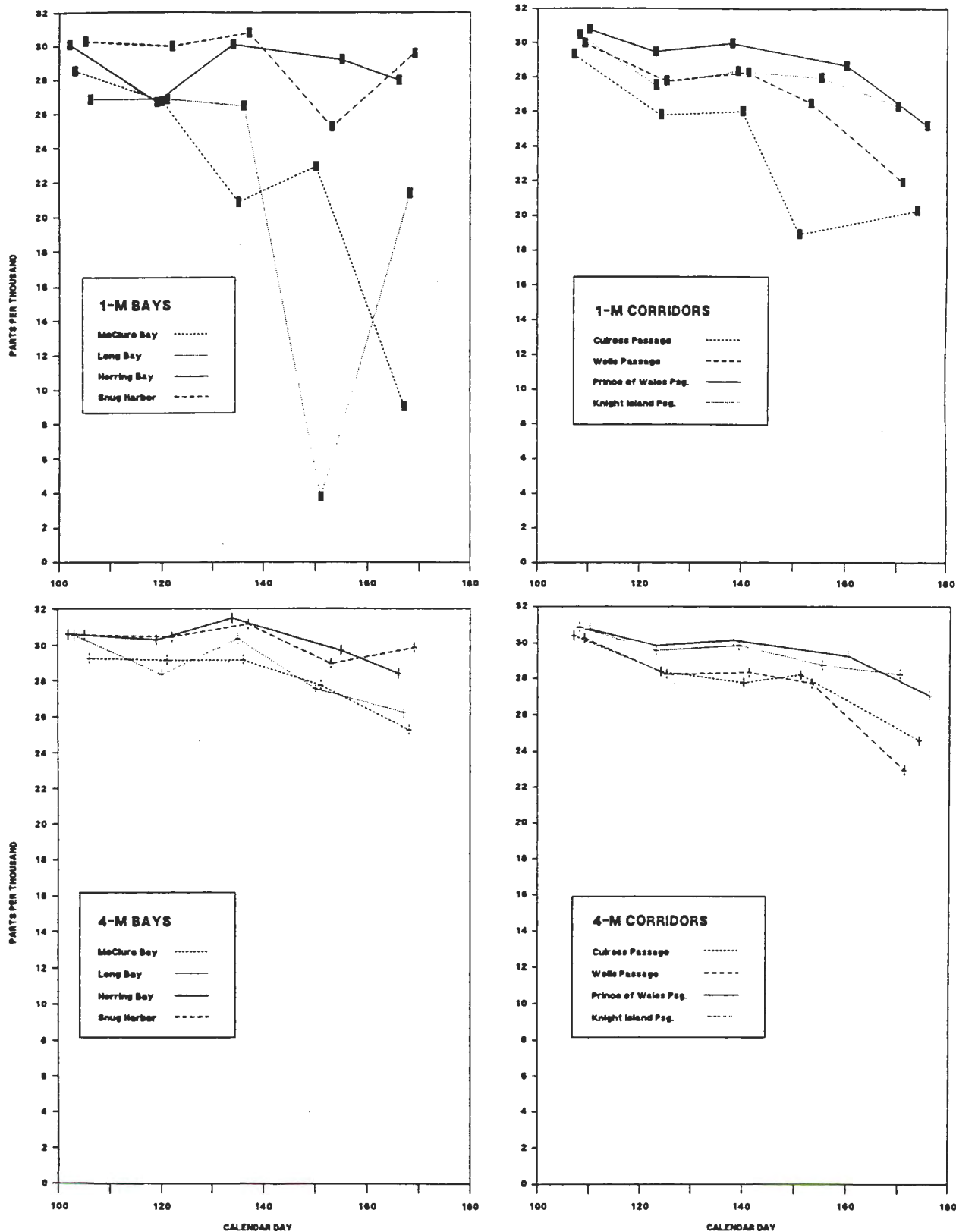
Figure 2.4. Salinities at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1989. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.
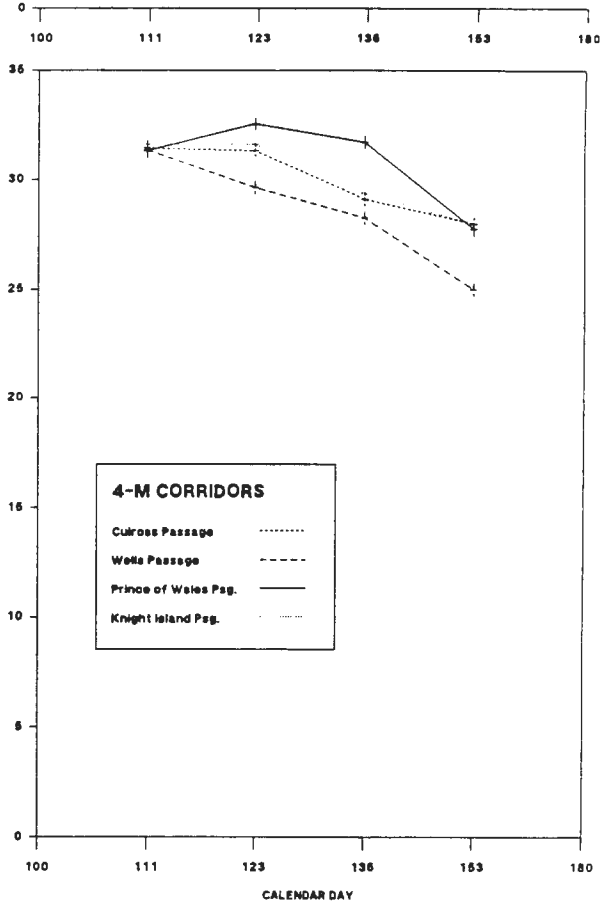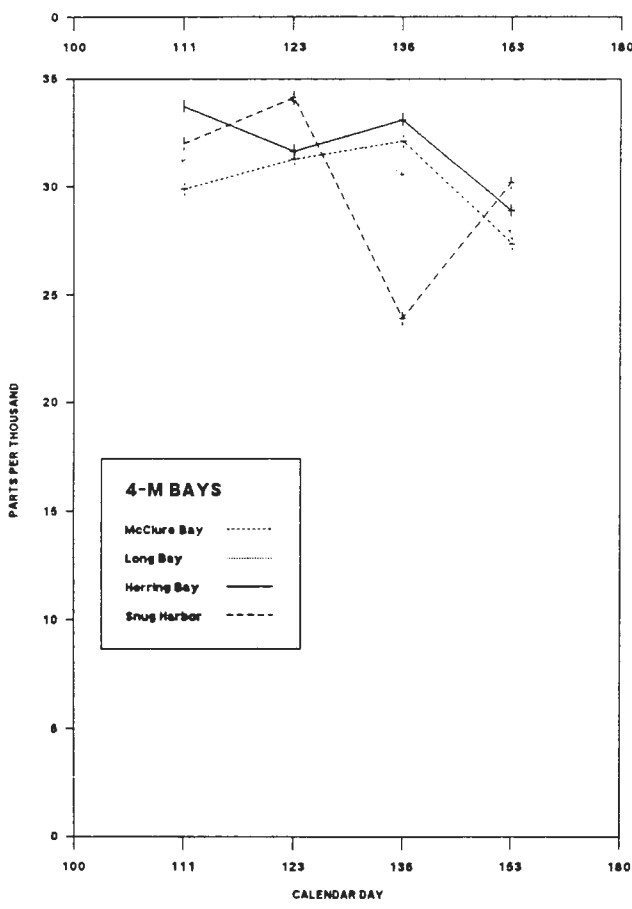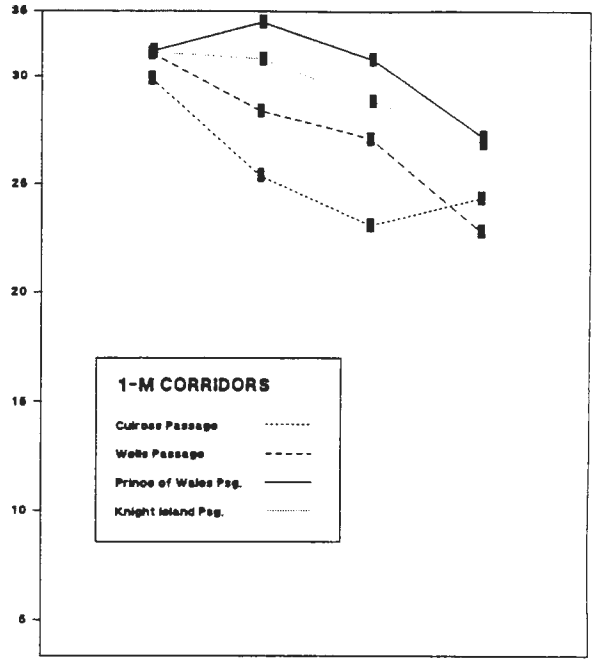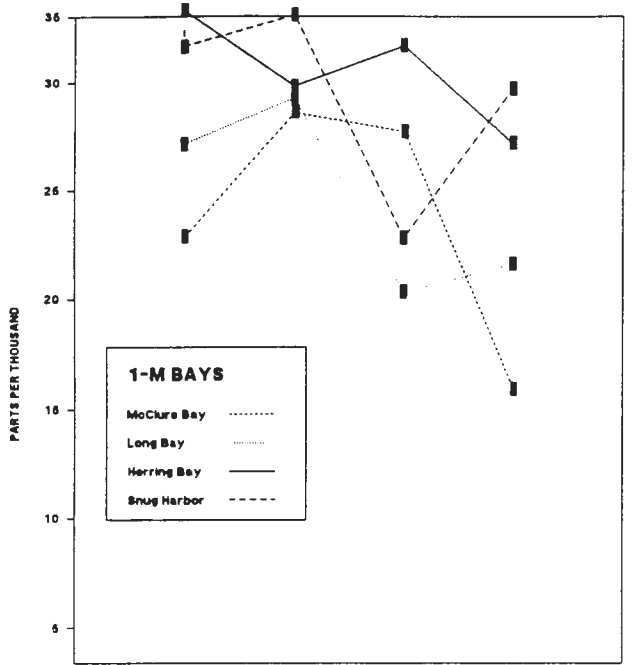
Figure 2.5. Salinities at 1-M and 4-M depths at eight sampling locations in Prince William Sound in 1990. McClure Bay, Long Bay, Culross Passage, and Wells Passage are non-oiled locations; Herring Bay, Snug Harbor, Prince of Wales Passage, and Knight Island Passage are oiled locations.

2.42
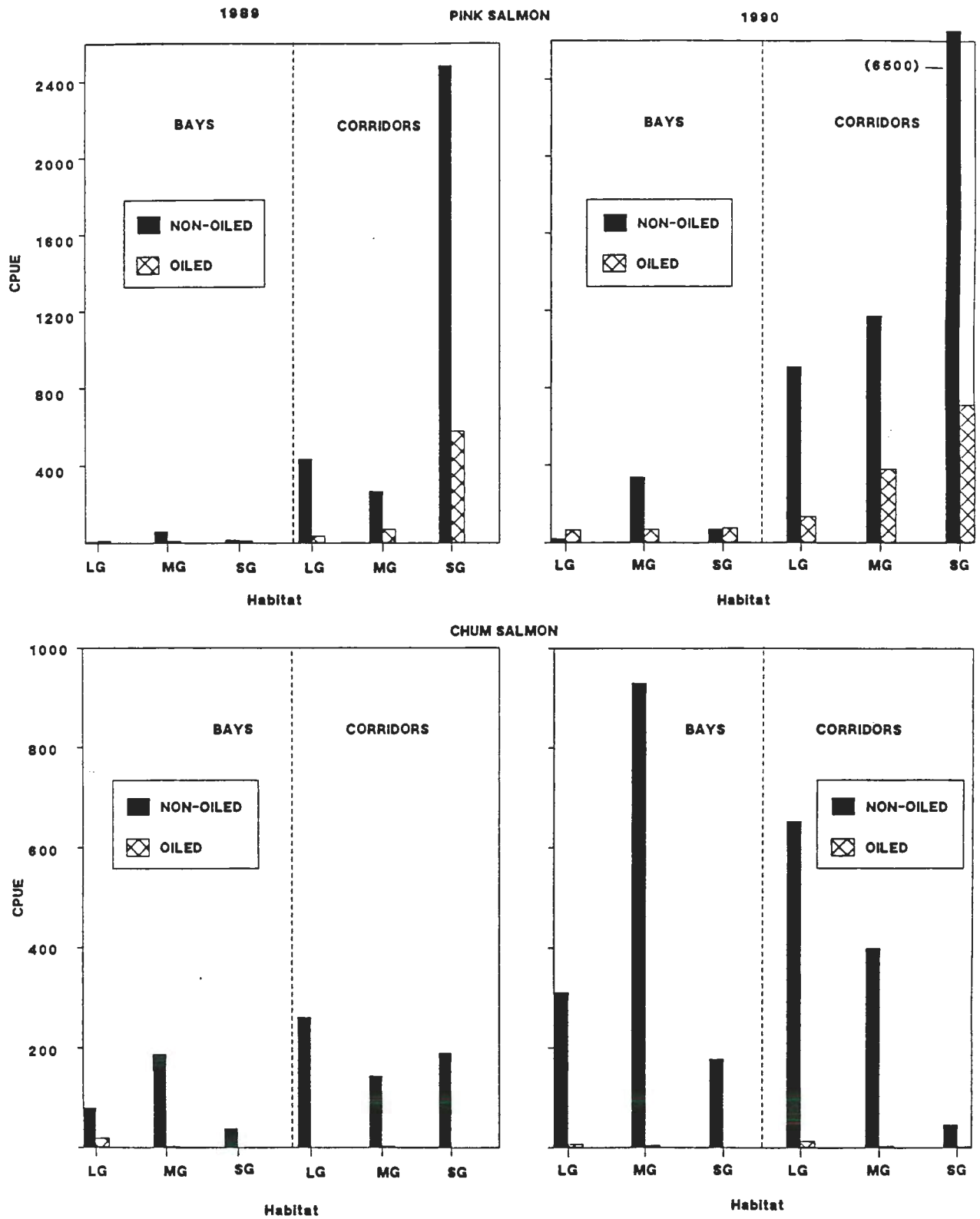
Figure 2.6. Systematic catch of juvenile pink and chum salmon by habitat type for oiled and non-oiled bays and corridors in Prince William Sound in 1989 and 1990. LG = low gradient; MG = medium gradient; SG = steep gradient.
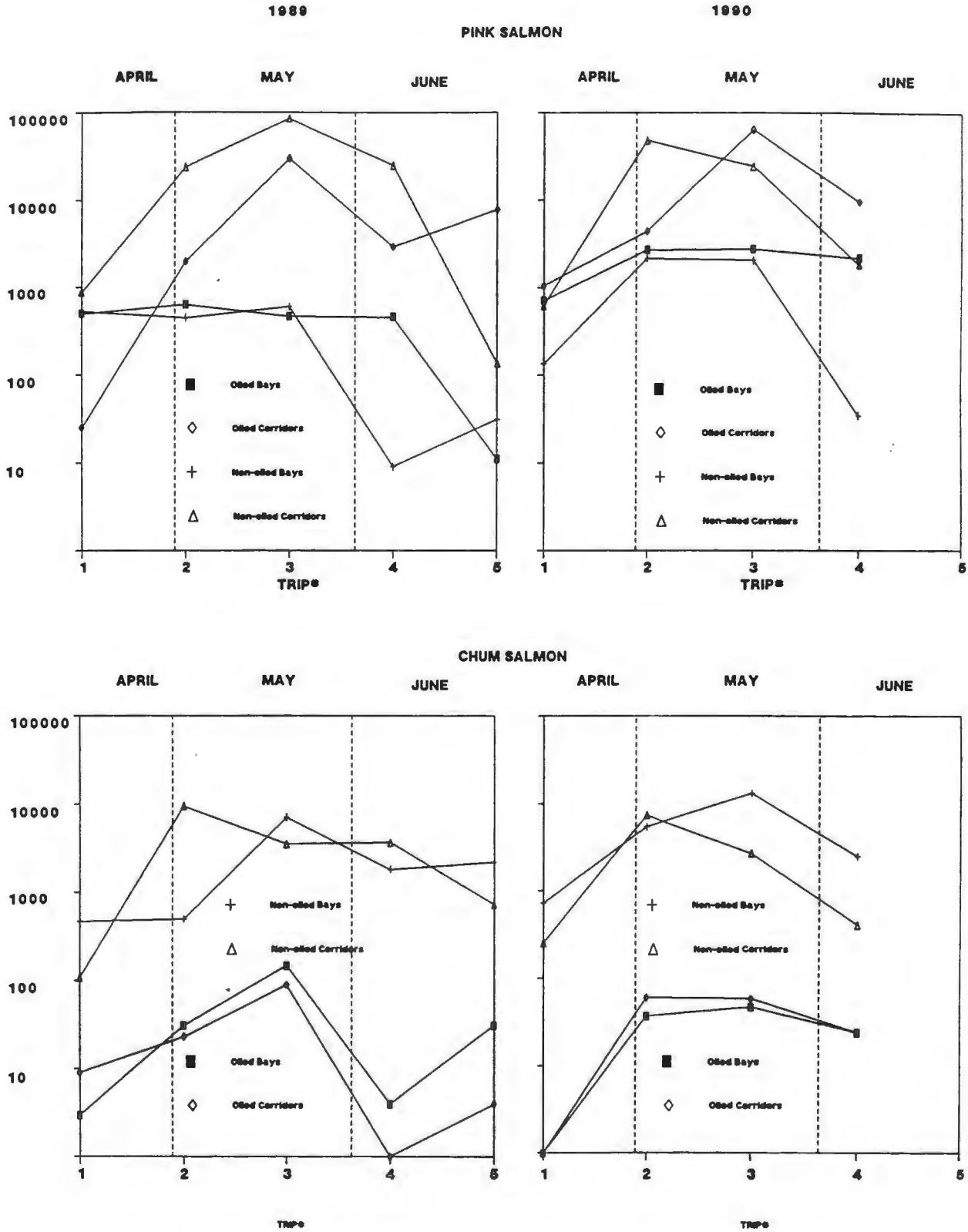
Figure 2.7. Numbers (in logarithmic scale) of juvenile pink and chum salmon captured by sampling period in Prince William Sound in April-June, 1989 and 1990. Fish captured in outer Snug Harbor are not included in the figure.
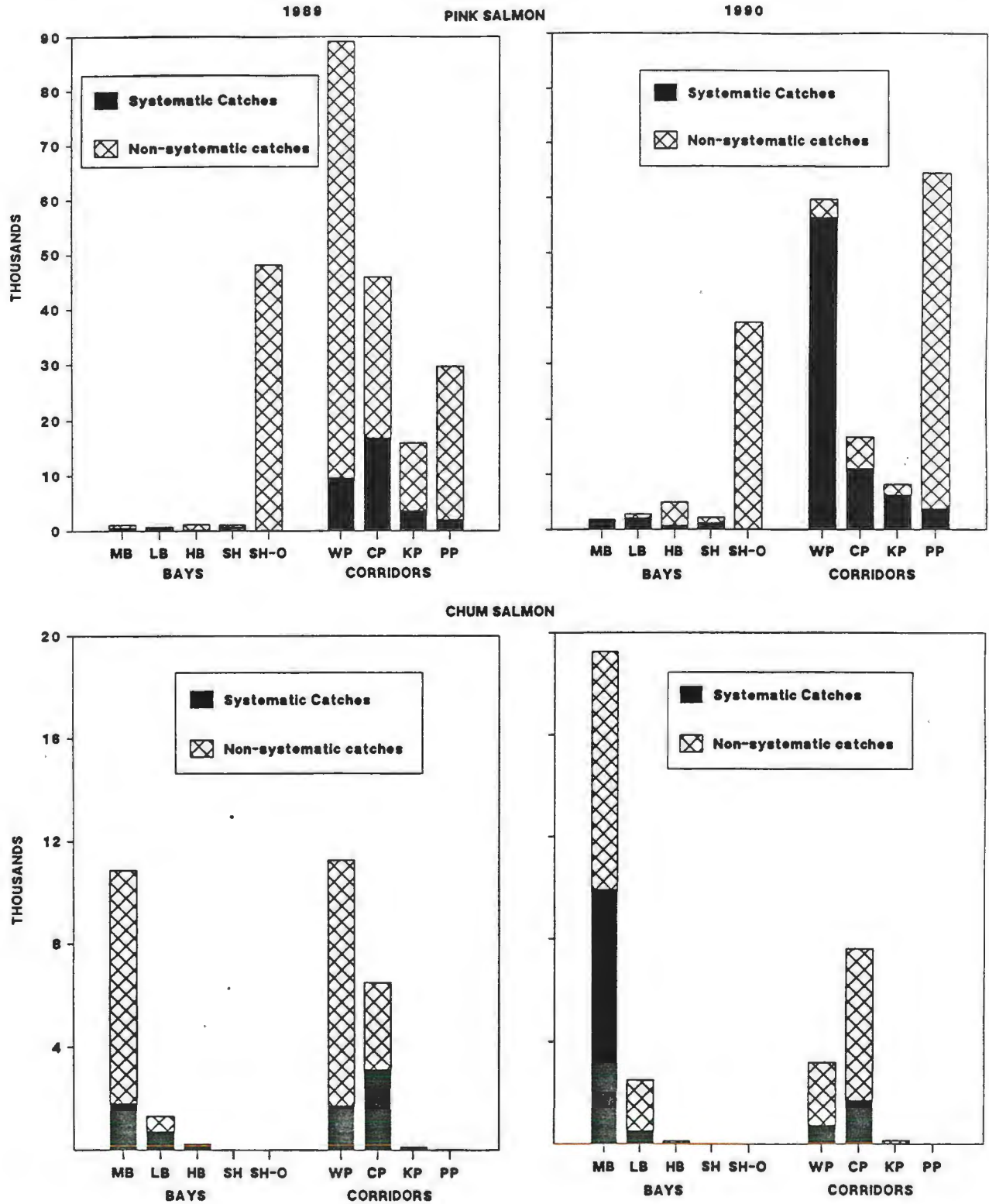
Figure 2.8. Total catch of juvenile pink and chum salmon at bay and corridor
sampling locations in Prince William Sound in 1989 and 1990. MB = McClure Bay;
LB = Long Bay; HB = Herring Bay; SH = Snug Harbor; SH-O = Snug Harbor, outer
bay; WP = Wells Passage; CP = Culross Passage; KP = Knight Island Passage;
PP = Prince of Wales Passage.

2.45
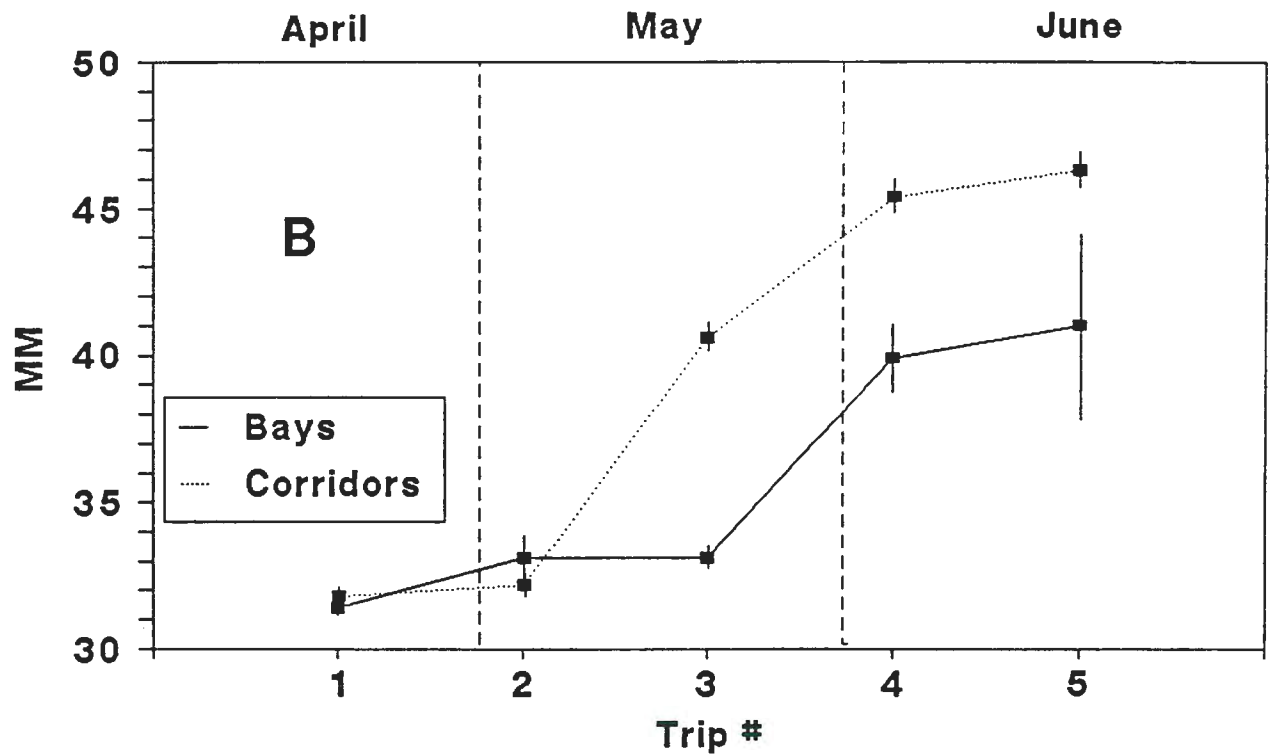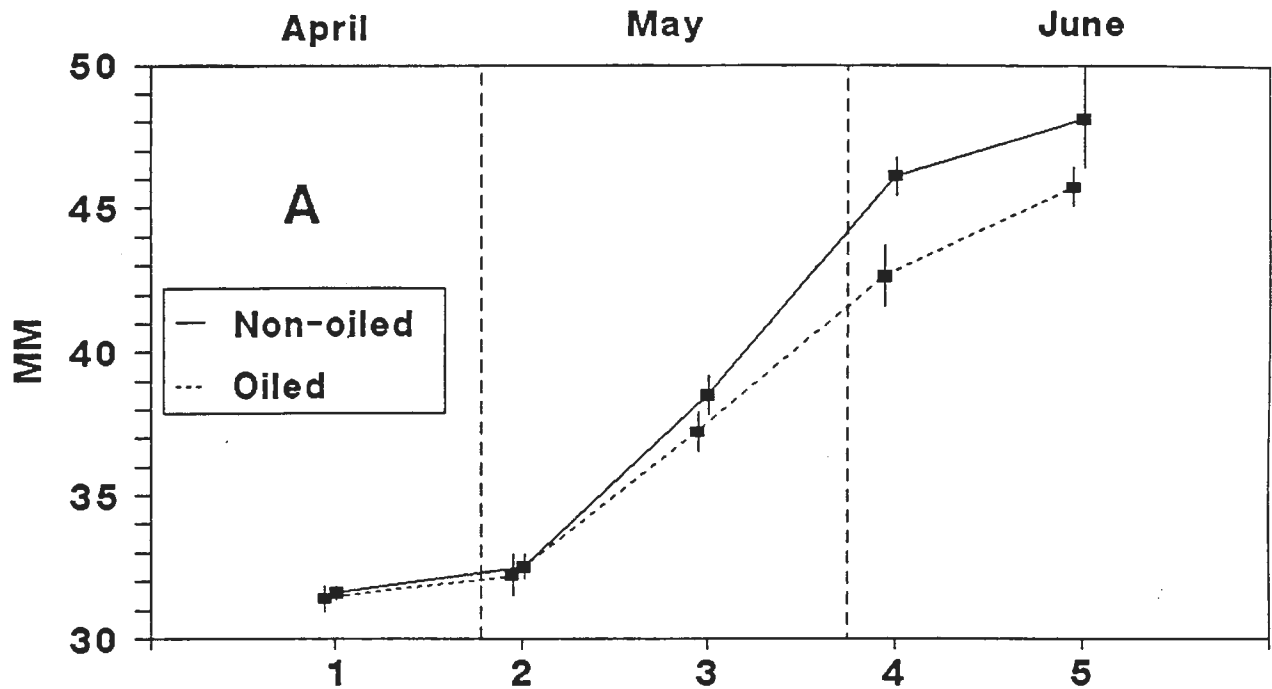
Figure 2.9. Mean fork length of juvenile pink salmon captured in Prince William Sound in 1989, pooled by oiled and non-oiled areas (A) and by bays and corridors (B). Vertical bars are 95% confidence intervals of the means.
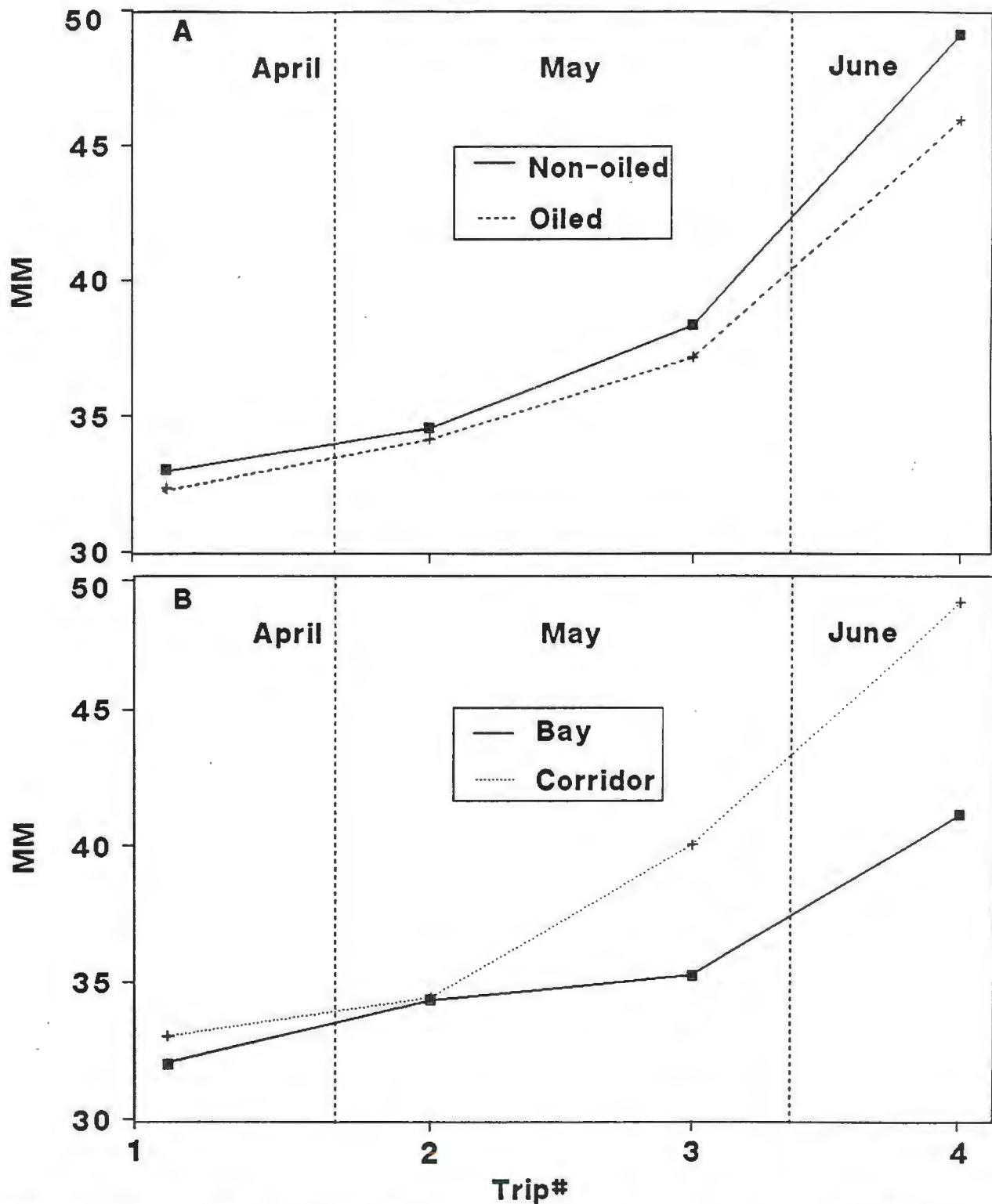
Figure 2.10. Mean fork lengths of pink salmon captured in Prince William Sound in 1990 in (A) oiled vs. non-oiled areas and (B) bays vs. corridors; 95% confidence intervals were all within 0.5 mm of the indicated means.
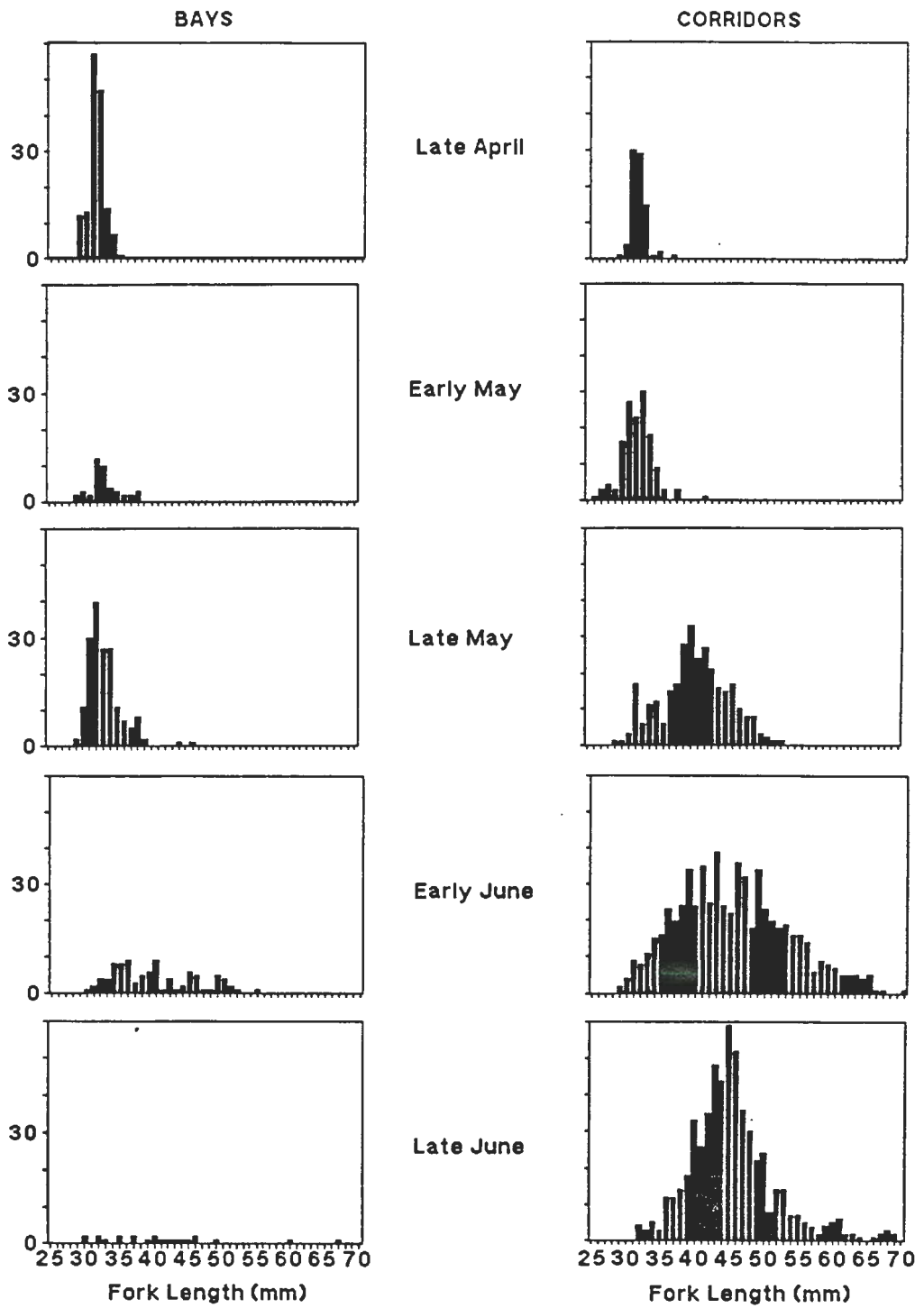
Figure 2.11. Histograms of fork lengths of juvenile pink salmon captured in Prince William Sound in 1989.

2.49
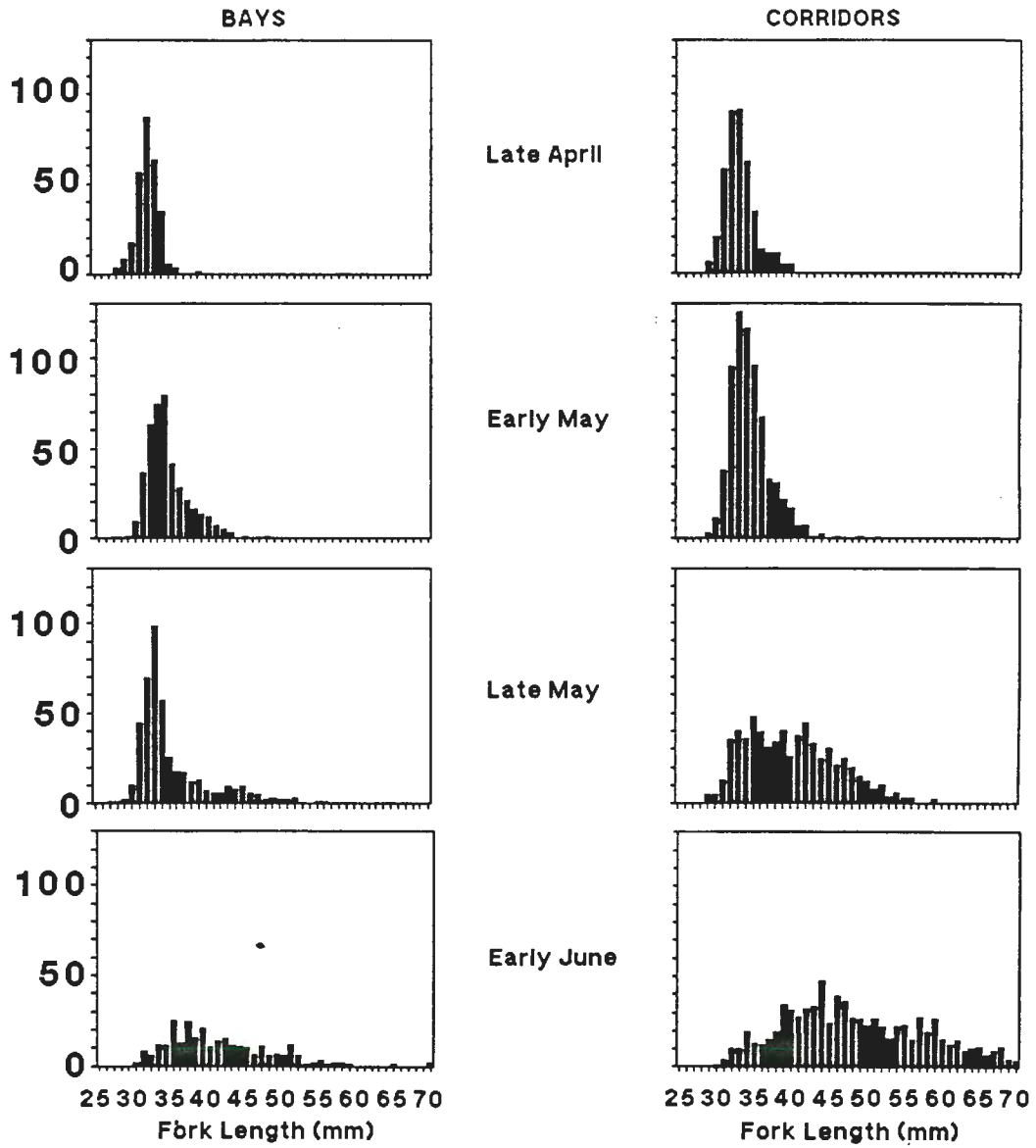
Figure 2.12. Histograms of fork lengths of juvenile pink salmon captured in Prince William Sound in 1990.
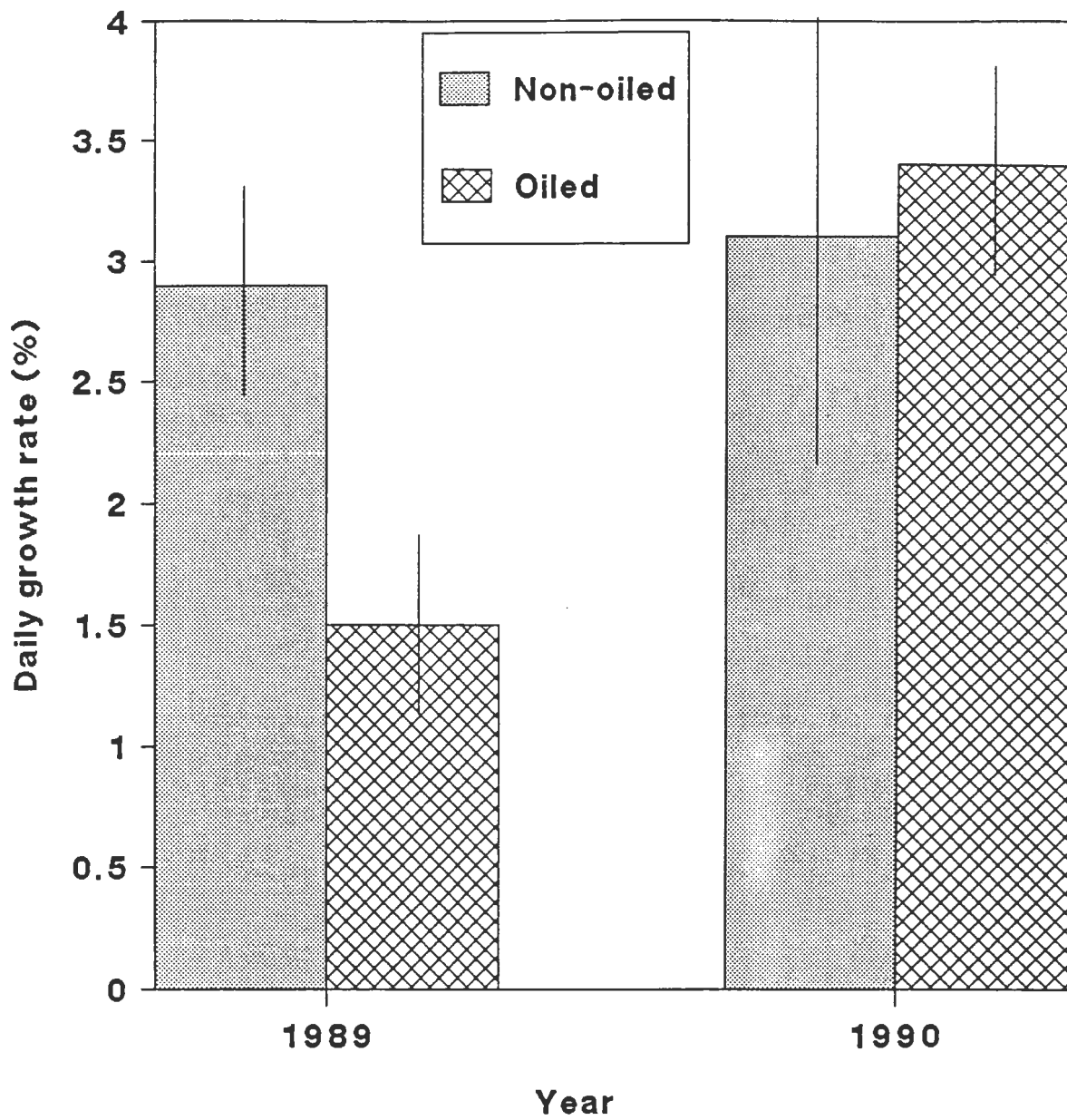
Figure 2.13. Apparent daily growth rate (%) and associated standard errors of juvenile pink salmon in corridor locations in Prince William Sound in 1989 and 1990.
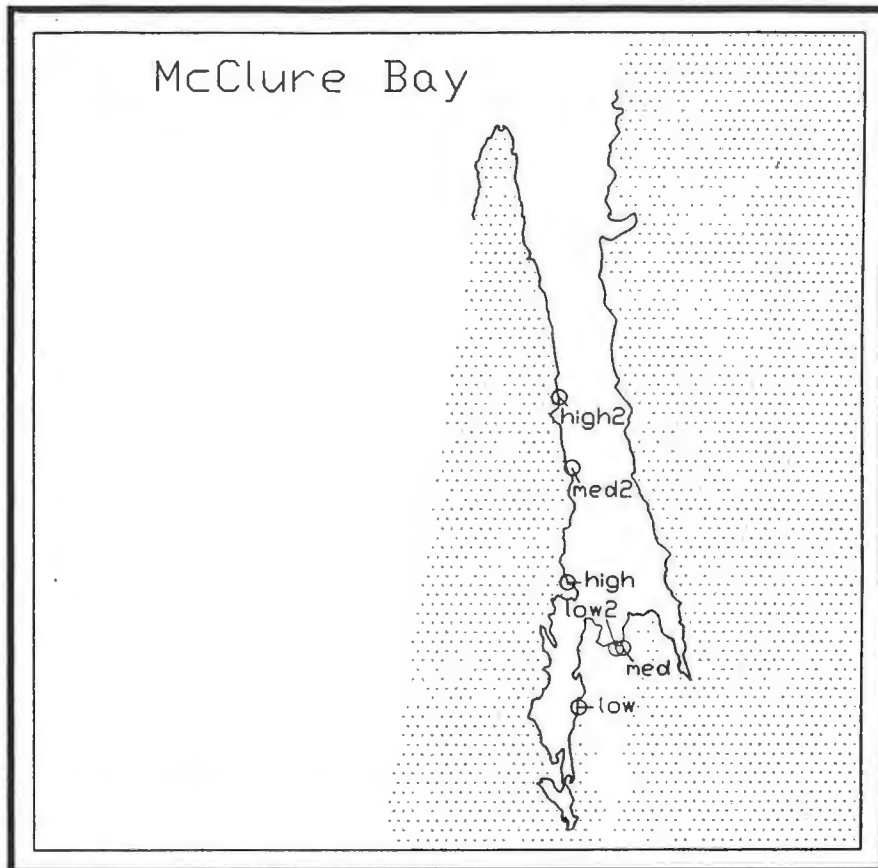
Appendix 2.1A. Systematic sampling sites at McClure Bay;
low = low gradient, med = medium gradient, and high =
steep gradient. Sites followed by the number 2 were
sampled only in 1990; all other sites were sampled in
both 1989 and 1990.
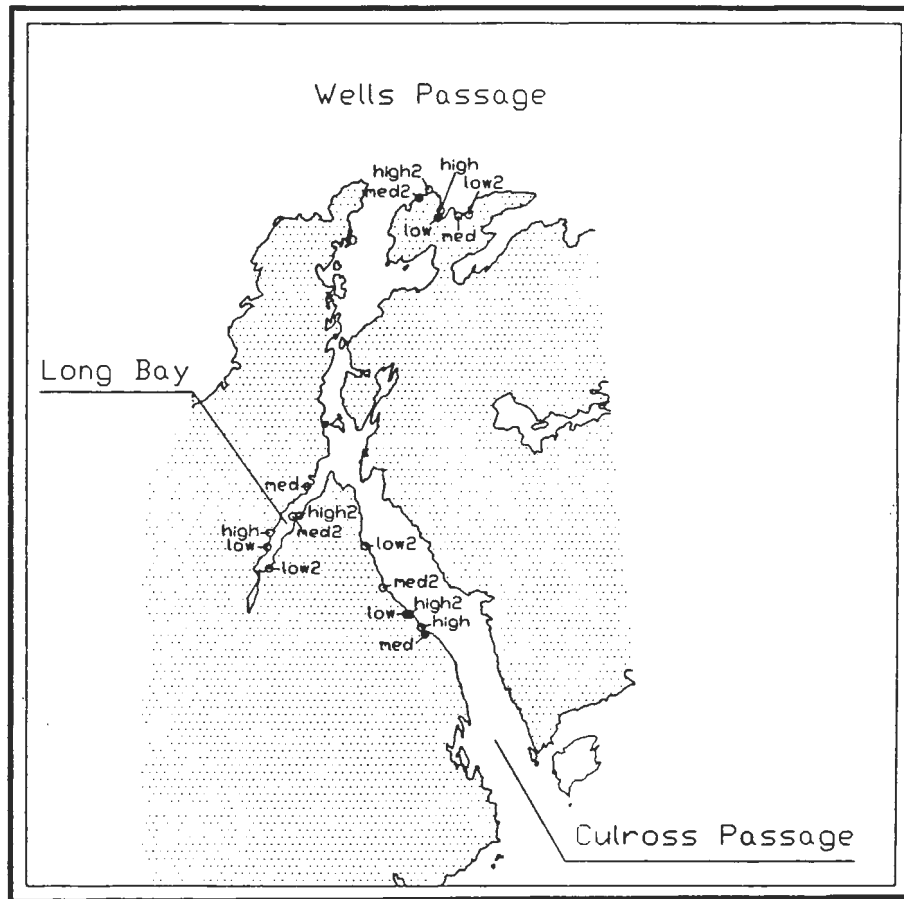
Appendix 2.1B. Systematic sampling sites at Long Bay,
Wells Passage and Culross Passage; low = low gradient,
med = medium gradient and high = steep gradient. Sites
followed by the number 2 were sampled only in 1990; all
other sites were sampled in both 1989 and 1990.
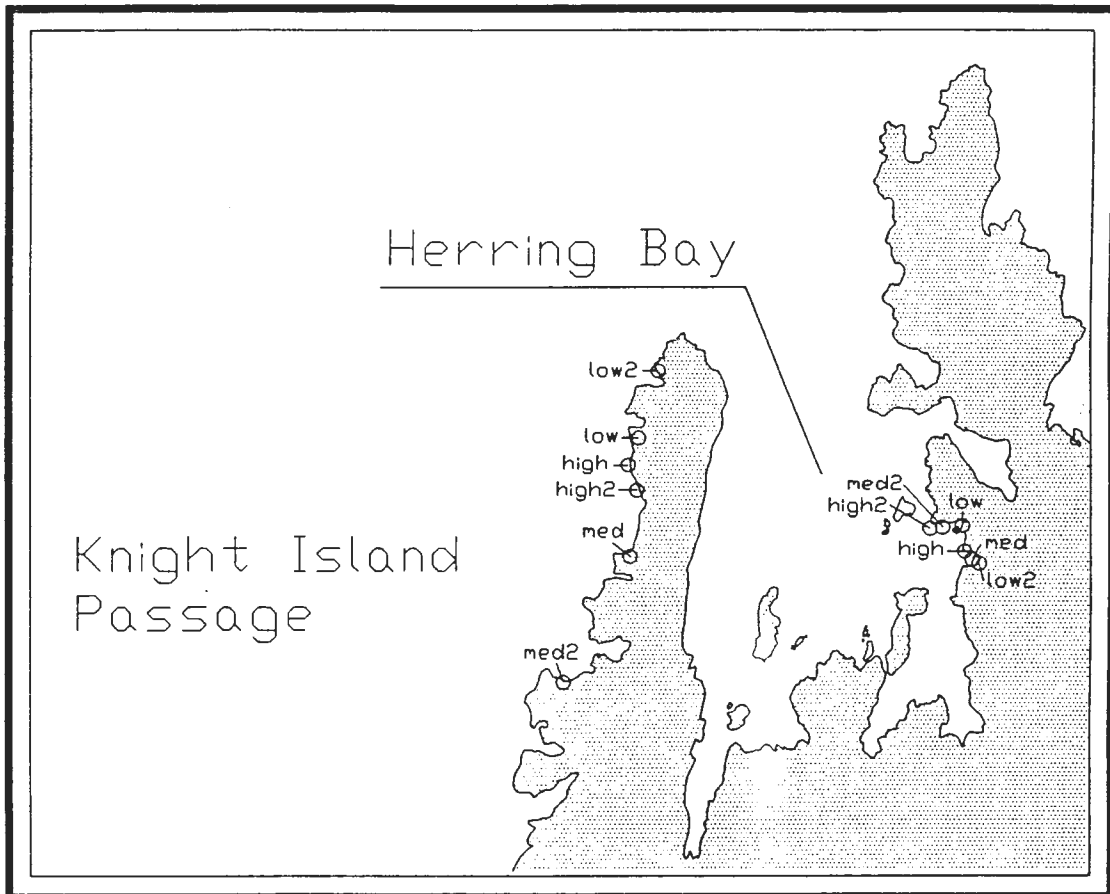
Appendix 2.1C. Systematic sampling sites in Herring Bay and Knight Island Passage; low = low gradient, med = medium gradient and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.
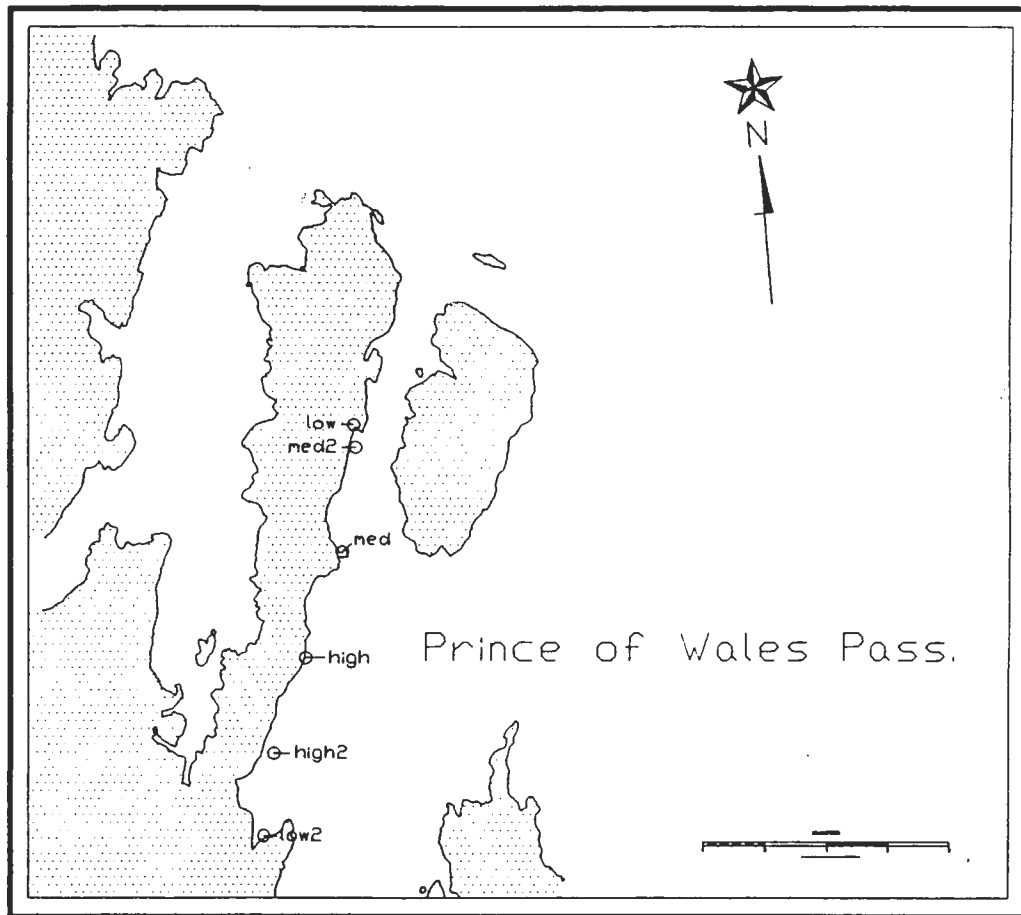
Appendix 2.1E. Systematic sampling sites in Prince of Wales Passage; low = low gradient, med = medium gradient, and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.
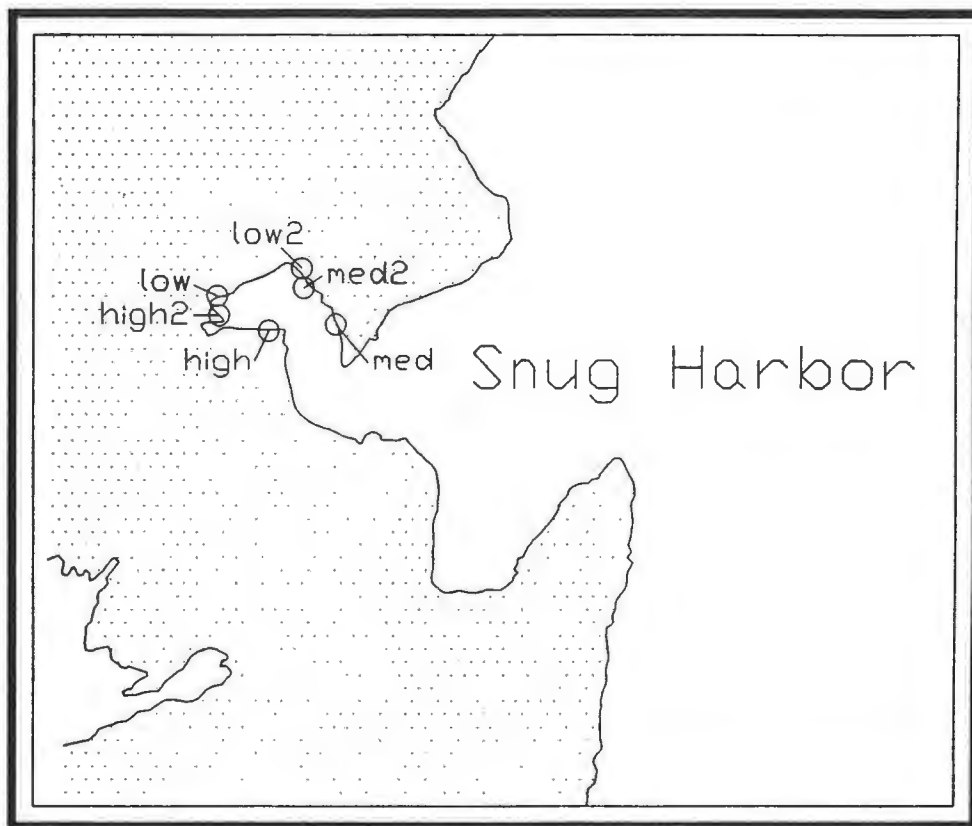
Appendix 2.1D. Systematic sampling sites in Snug Harbor; low = low gradient, med = medium gradient and high = steep gradient. Sites followed by the number 2 were sampled only in 1990; all other sites were sampled in both 1989 and 1990.

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

3.5

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

3.8

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

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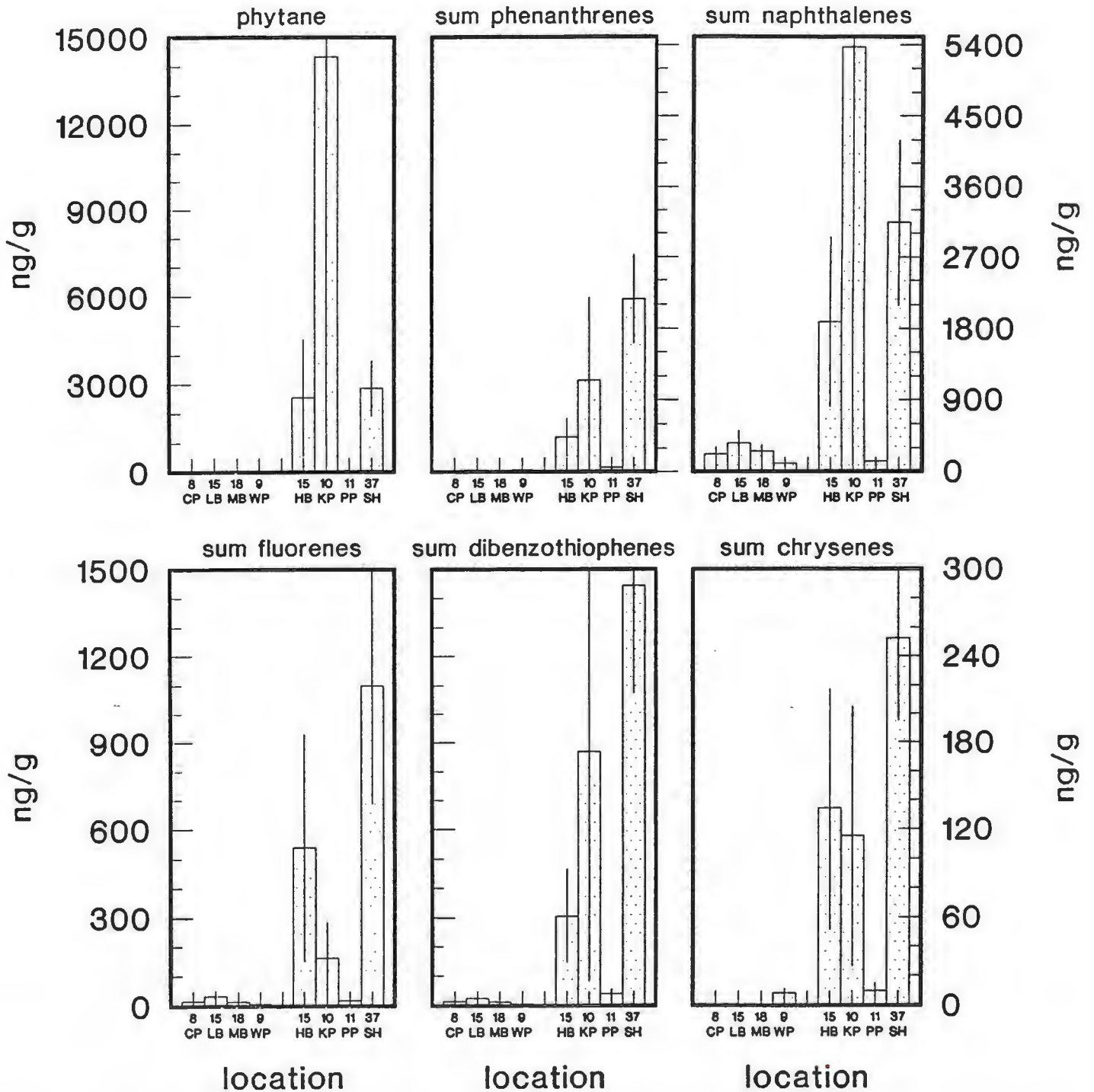
Figure 3.1--Concentrations of selected hydrocarbon analytes observed in sedi-
ments collected during 1989. Control sites are at the left of each graph
(CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage);
oiled sites are HB = Hering Bay, KP = Knight Island Passage, PP = Prince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

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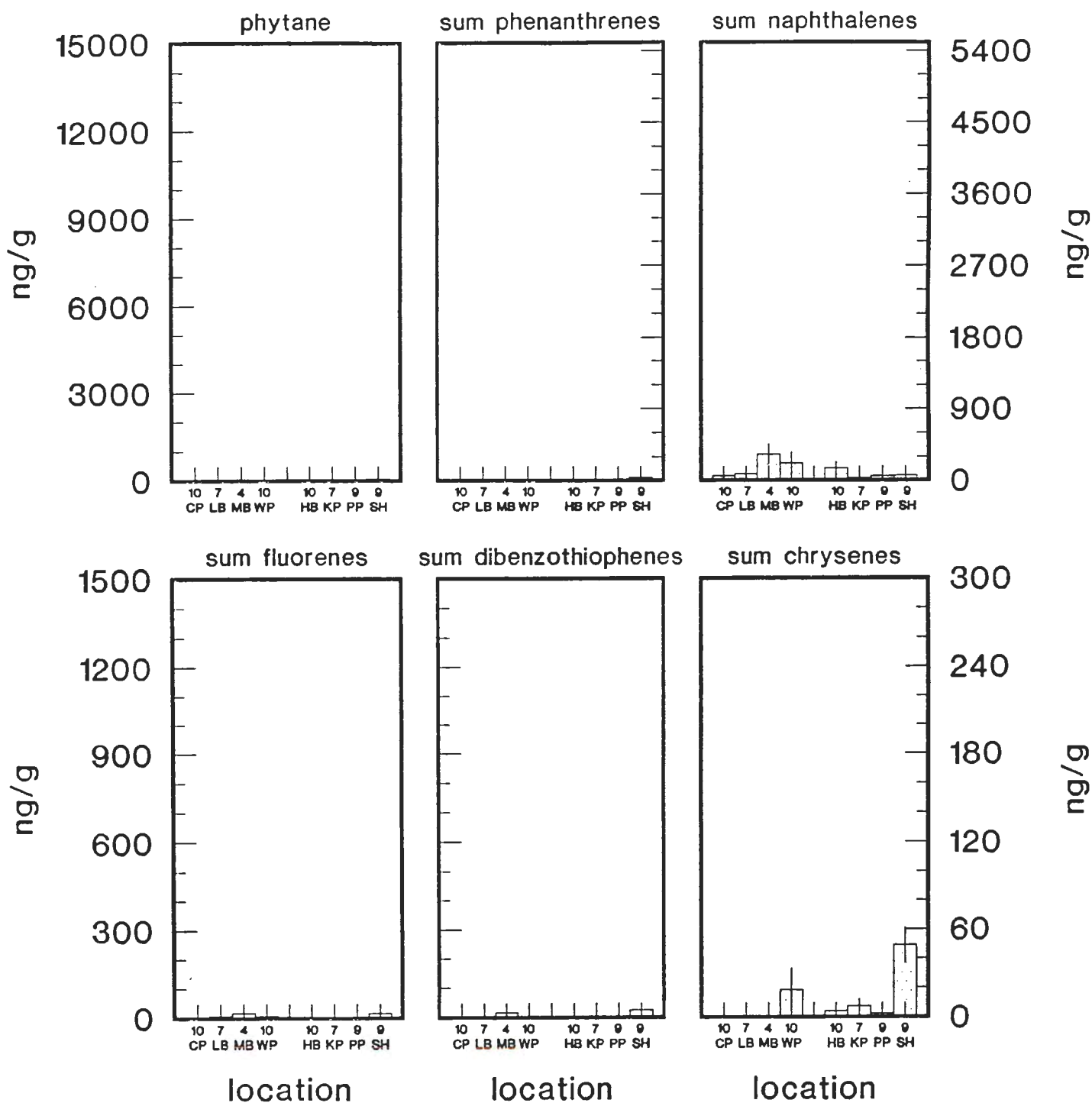
Figure 3.2--Concentrations of selected hydrocarbon analytes observed in sediments collected during 1990. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP = Prince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

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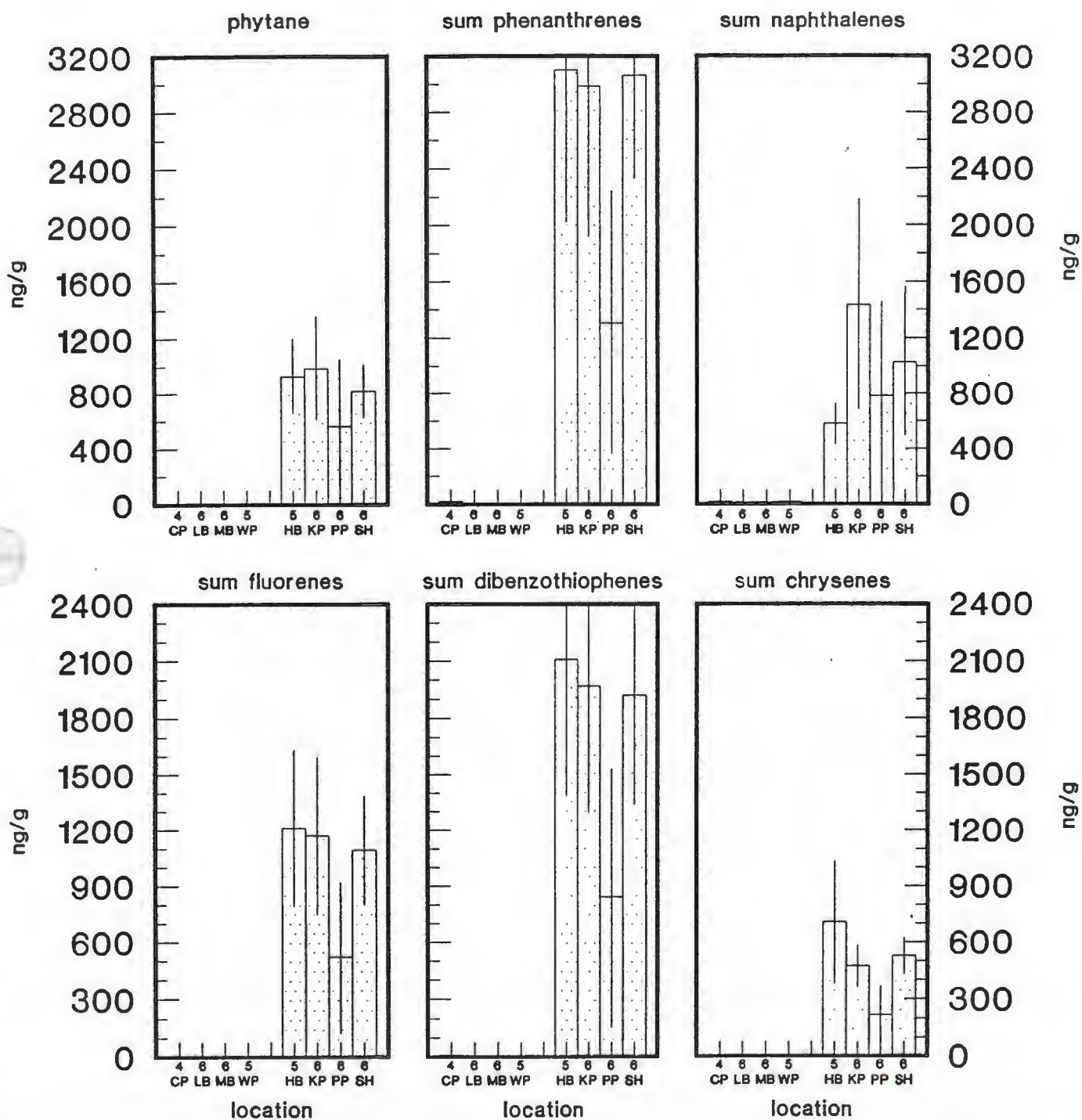
Figure 3.3--Concentrations of selected hydrocarbon analytes observed in mussel
tissues collected during 1989. Control sites are at the left of each graph
(CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage);
oiled sites are HB = Herring Bay, KP = Knight Island Passage, PP =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

Includes both positive Culross Passage observations

3.21

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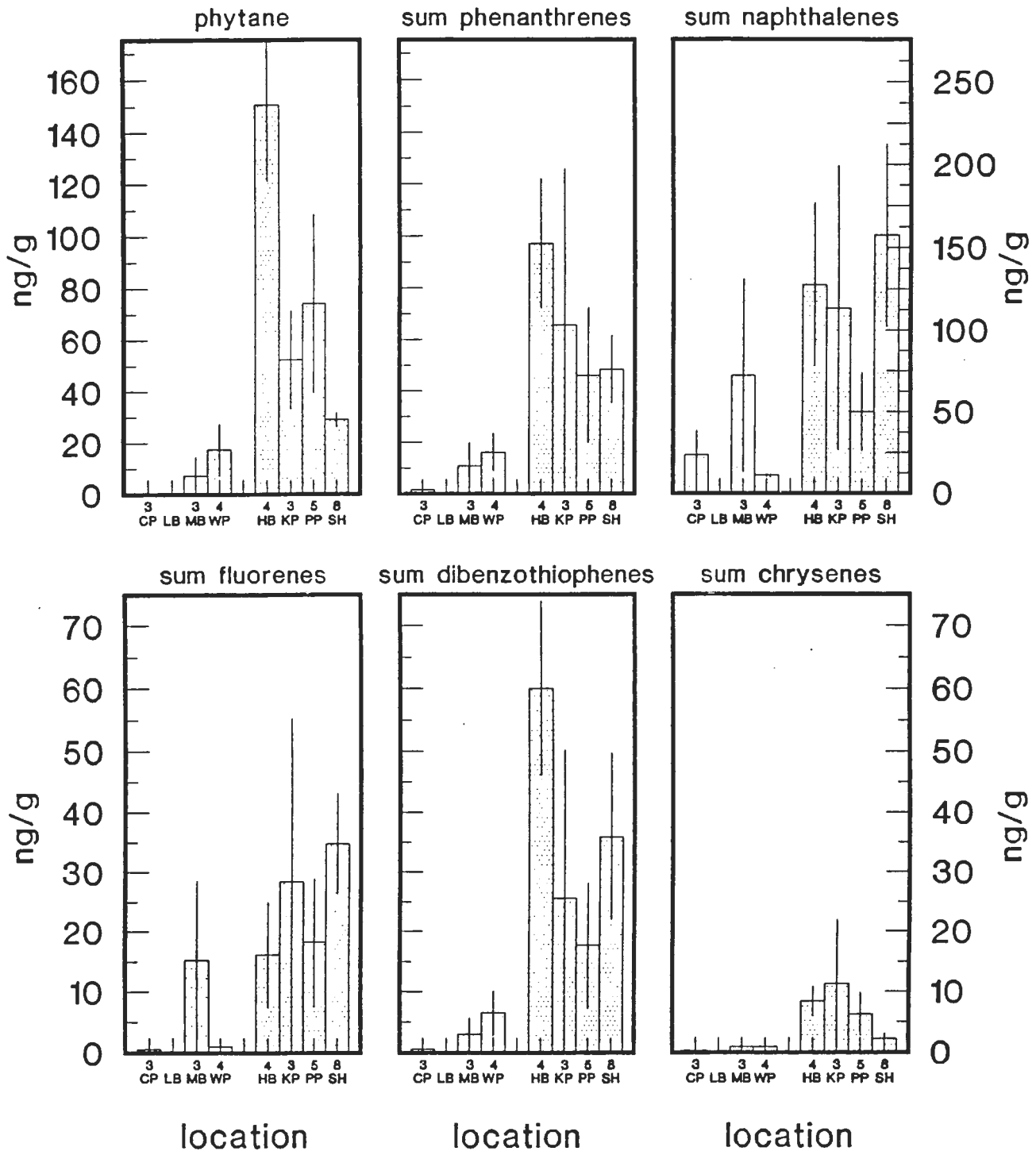
Figure 3.4--Concentrations of selected hydrocarbon analytes observed in juvenile pink salmon tissues collected during 1989. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island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

3.22

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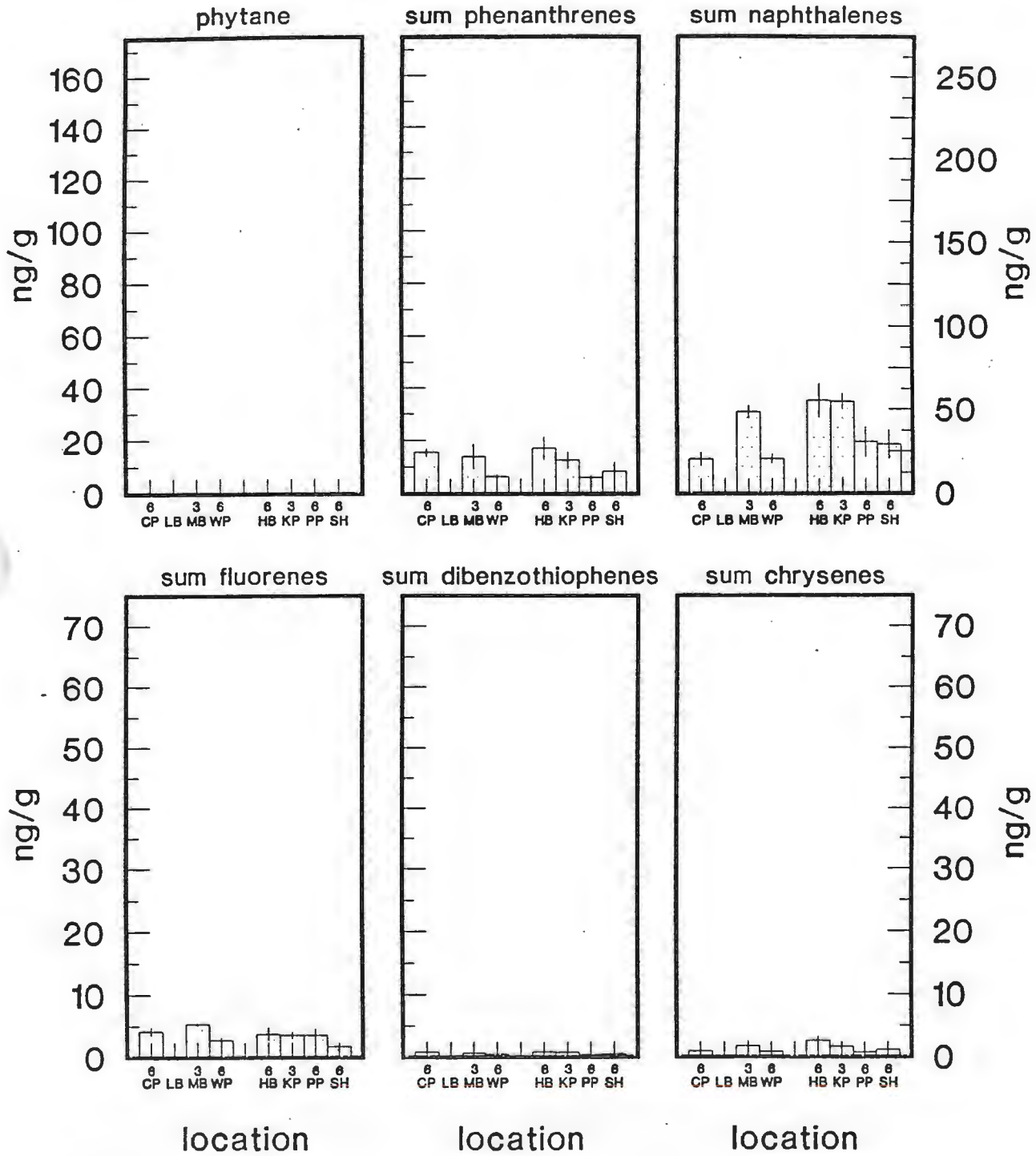
Figure 3.5--Concentrations of selected hydrocarbon analytes observed in juvenile pink salmon tissues collected during 1990. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island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

3.23
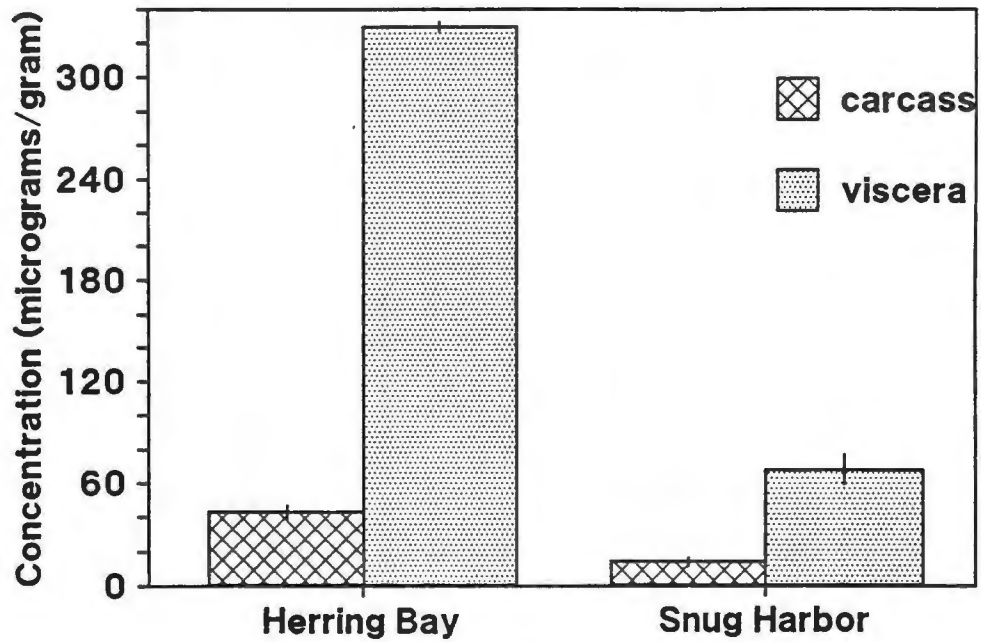
Figure 3.6--Concentrations of hydrocarbons in pink salmon fry
carcasses compared to concentrations in viscera. Error bars
are +1 standard error.
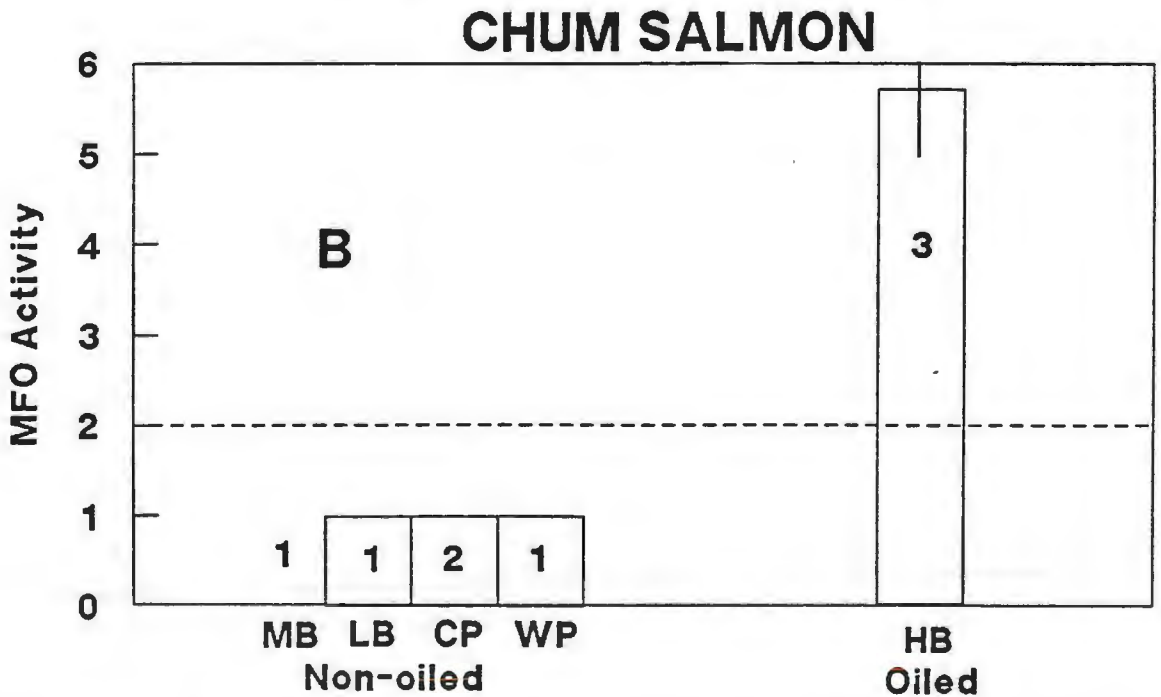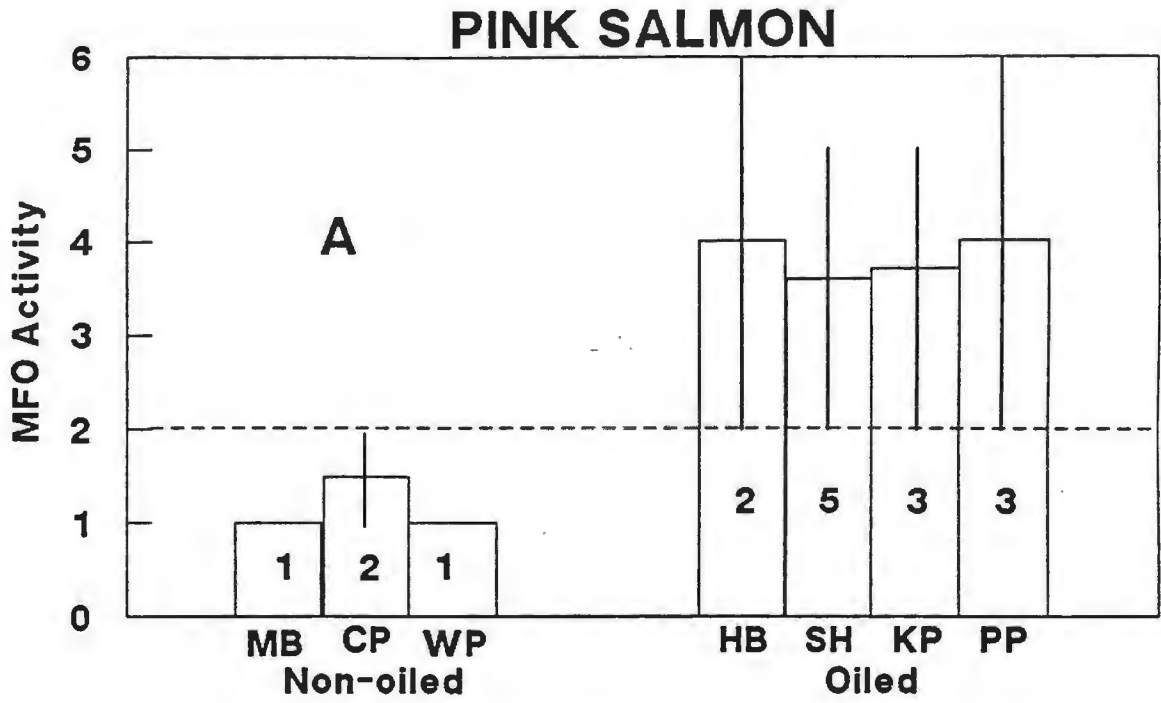
Figure 3.7. Mixed-function oxidase (MFO) levels observed in juvenile pink and chum salmon captured in nearshore marine waters of western Prince William Sound in 1989. Vertical bars show the range of MFO activity levels observed. The number shown with each bar is the number of samples analyzed for that 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.

3.25
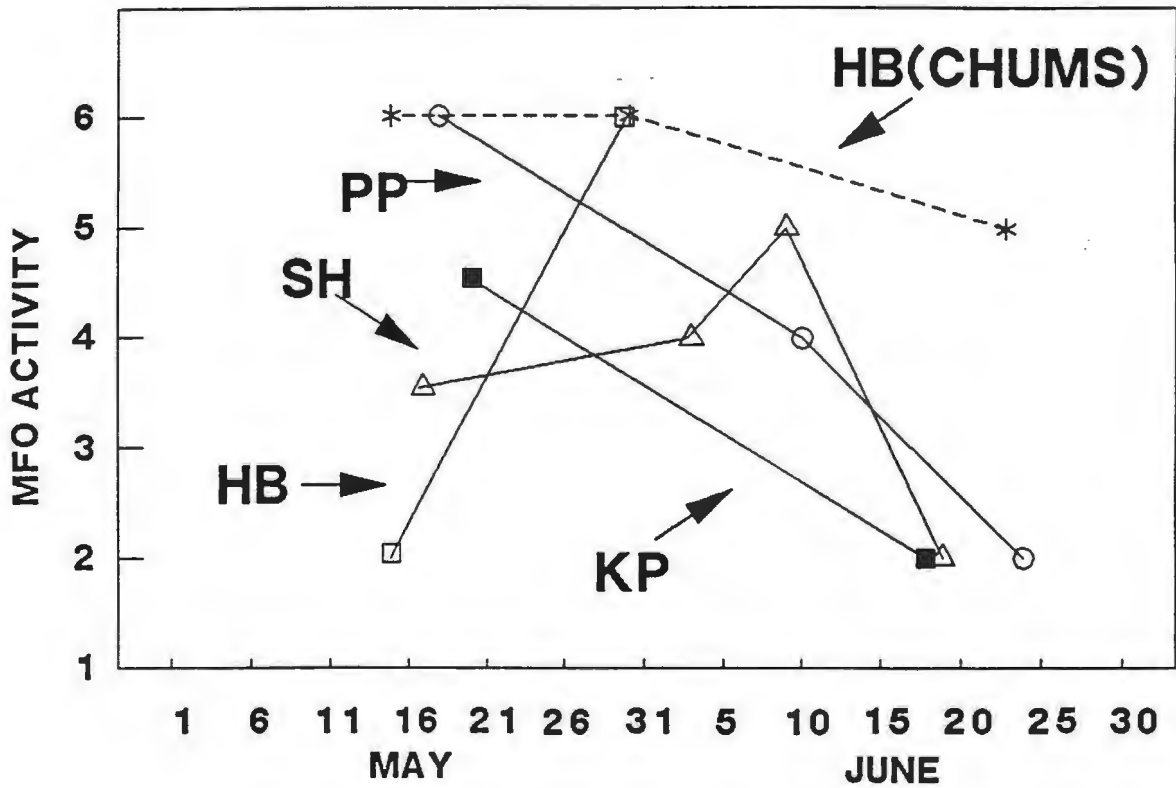
Figure 3.8. Mixed-function oxidase (MFO) activity in juvenile salmon sampled in nearshore marine waters in oiled areas of Prince William Sound in 1989. Solid lines are pink salmon; dashed line is chum salmon. HB = Herring Bay; SH = Snug Harbor; PP = Prince of Wales Passage; KP = Knight Island Passage.
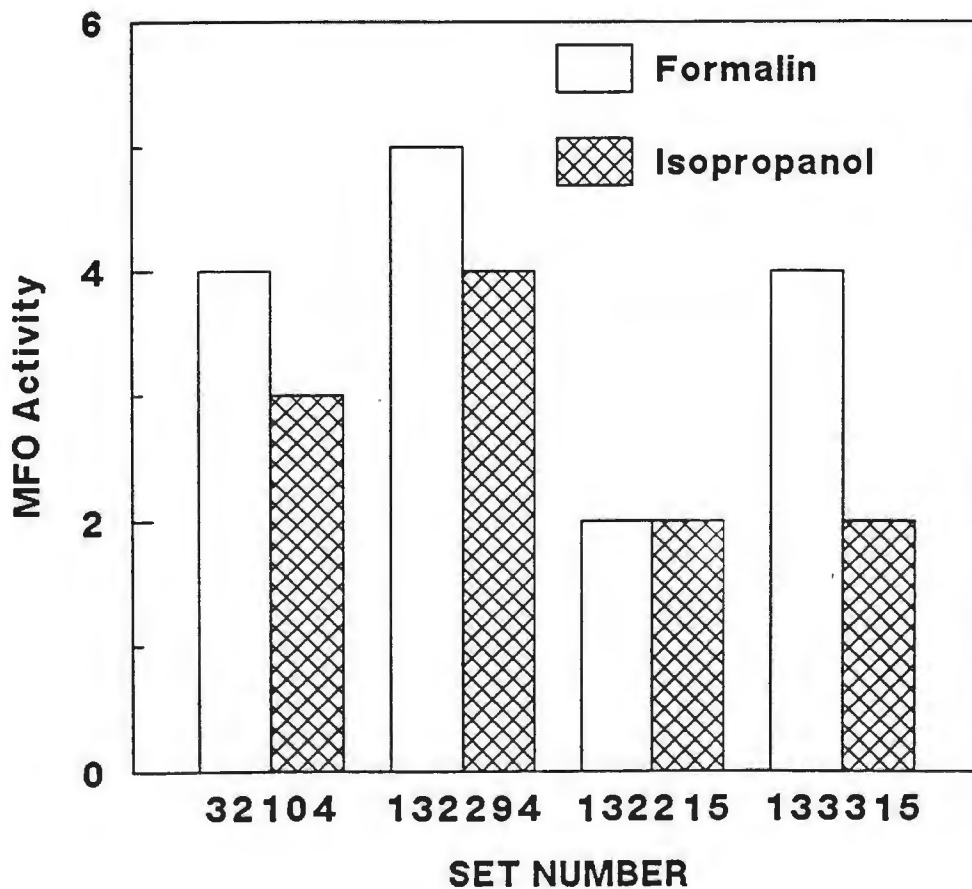
Figure 3.9. Comparison of MFO activity between subsamples of pink salmon juveniles collected in oiled areas of Prince William Sound in 1989. Comparisons are between subsamples of fish from the same set preserved in formalin or isopropanol.

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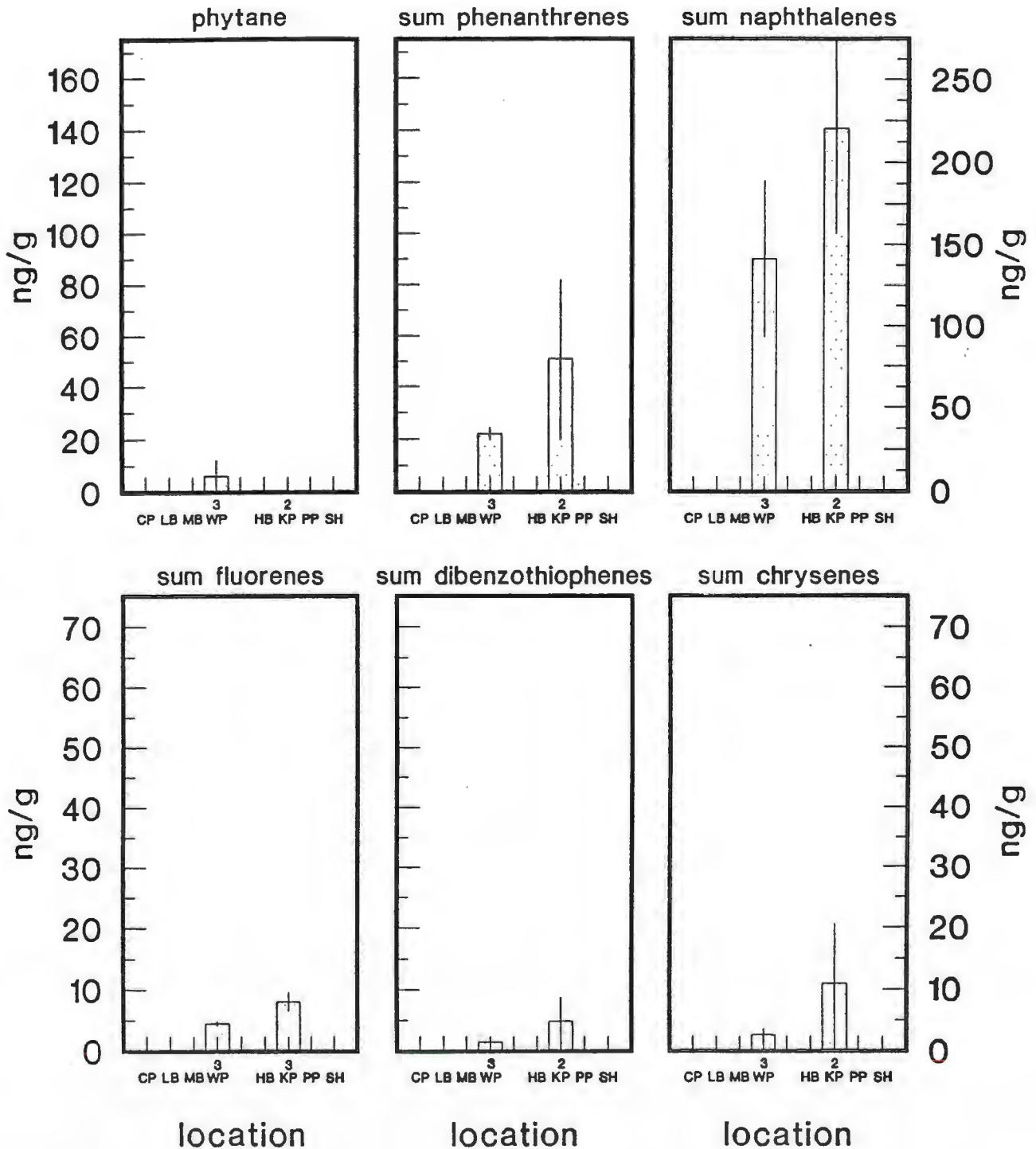
Figure 3.10--Concentrations of selected hydrocarbon analytes observed in CWT juvenile pink salmon tissues collected during 1989. Control sites are at the left of each graph (CP = Culross Passage, LB = Long Bay, MB = McClure Bay and WP = Wells Passage); oiled sites are HB = Herring Bay, KP = Knight Island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

4.2

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 (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 (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 (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

4.5

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. <u>Tisbe</u> comprised the largest proportion of the harpacticoid component with 47%, followed by <u>Harpacticus</u> and <u>Dactylopodia</u> at 27% and 11%, respectively. Chum salmon selected a greater biomass of <u>Tisbe</u> and less <u>Harpacticus</u> relative to their occurrence in the sled tows. Chum salmon also consumed <u>Dactylopodia</u> 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 ($\underline{P} > 0.1$). The correlation coefficients between zooplankton consumed and fish size were negative in both 1989 and 1990 (Figure 4.11); the r value was significantly ($\underline{P} < 0.05$) 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

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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

4.17

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

able 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
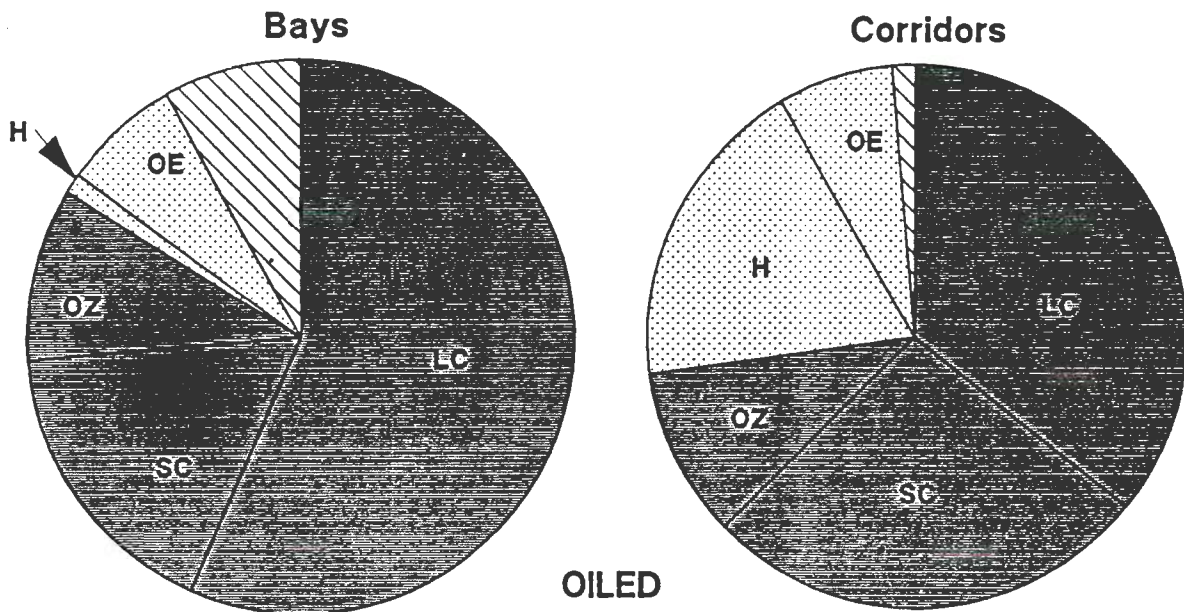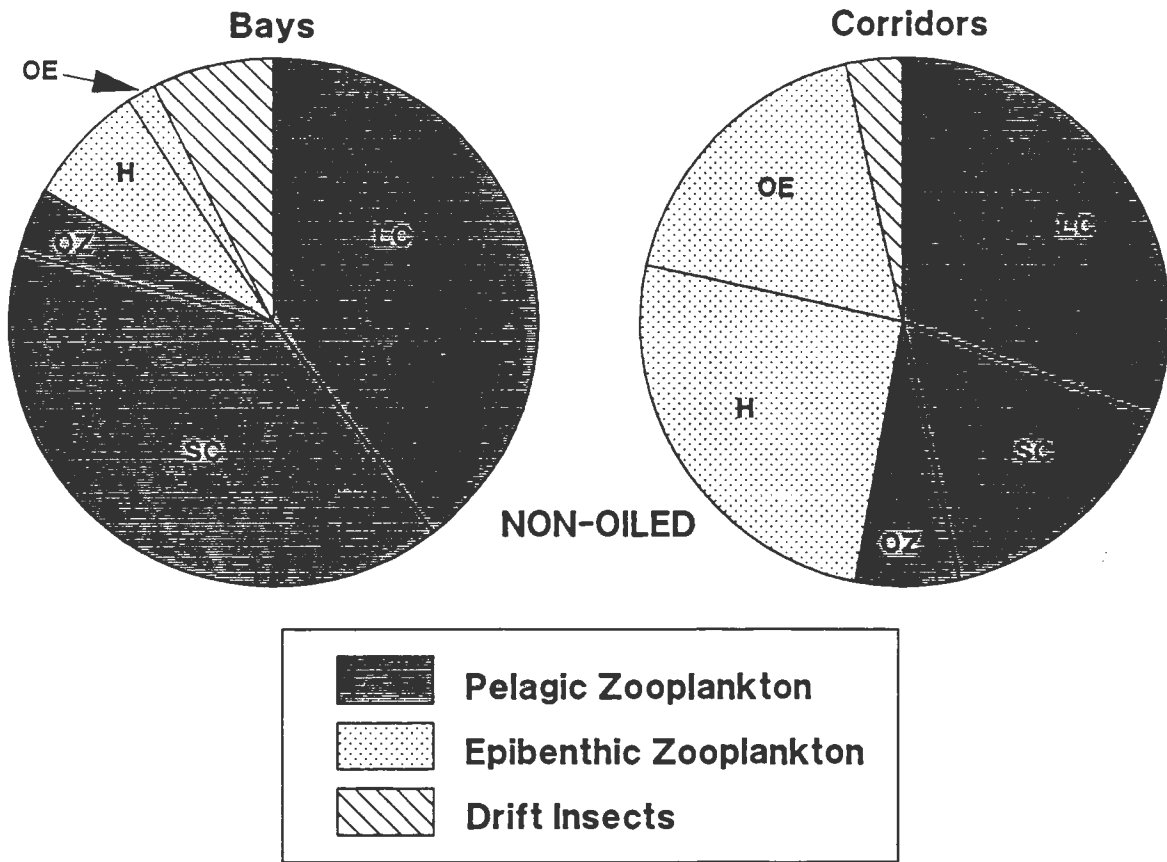
Figure 4.1. Prey percent dry weight from 397 pink salmon fry stomachs collected in Prince William Sound, Alaska, 1989. LC = Large Calanoids, SC = Small Calanoids, OZ = Other Zooplankton, H = Harpacticoids, OE = Other Epibenthic.
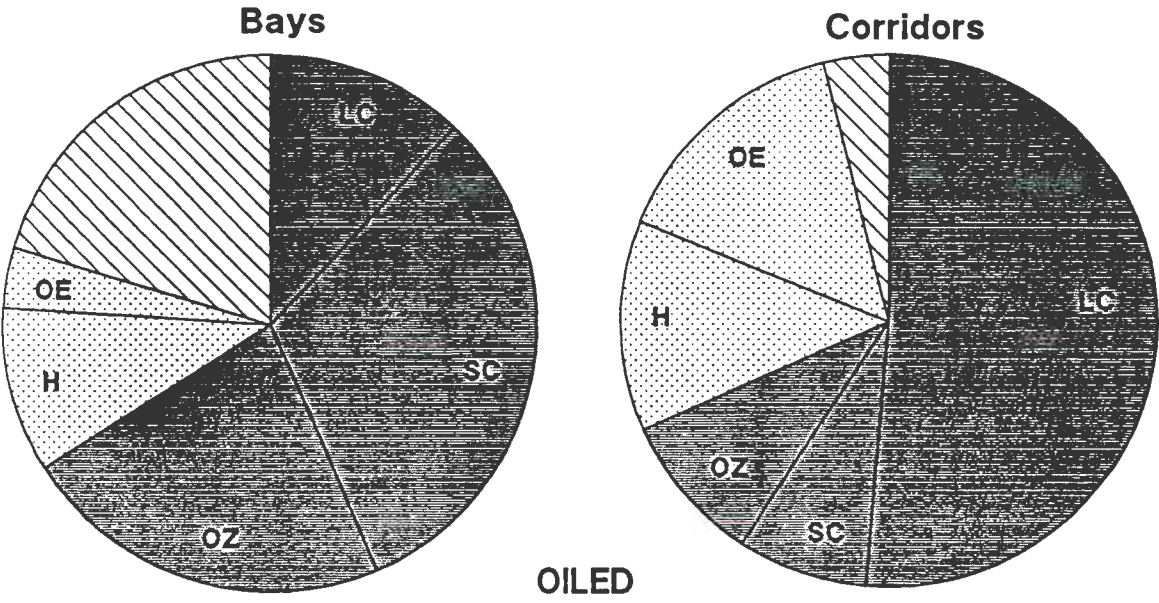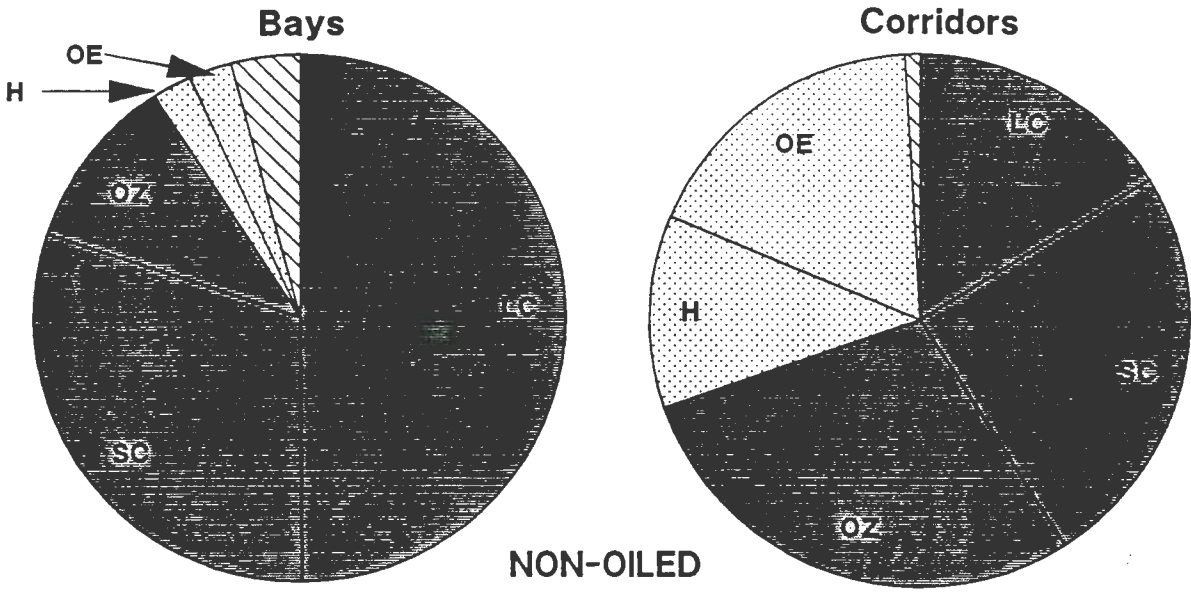
Figure 4.2. Prey percent dry weight from 595 pink salmon fry stomachs collected in Prince William Sound, Alaska, 1990. LC = Large Calanoids, SC = Small Calanoids, OZ = Other Zooplankton, H = Harpacticoids, OE = Other Epibenthic.
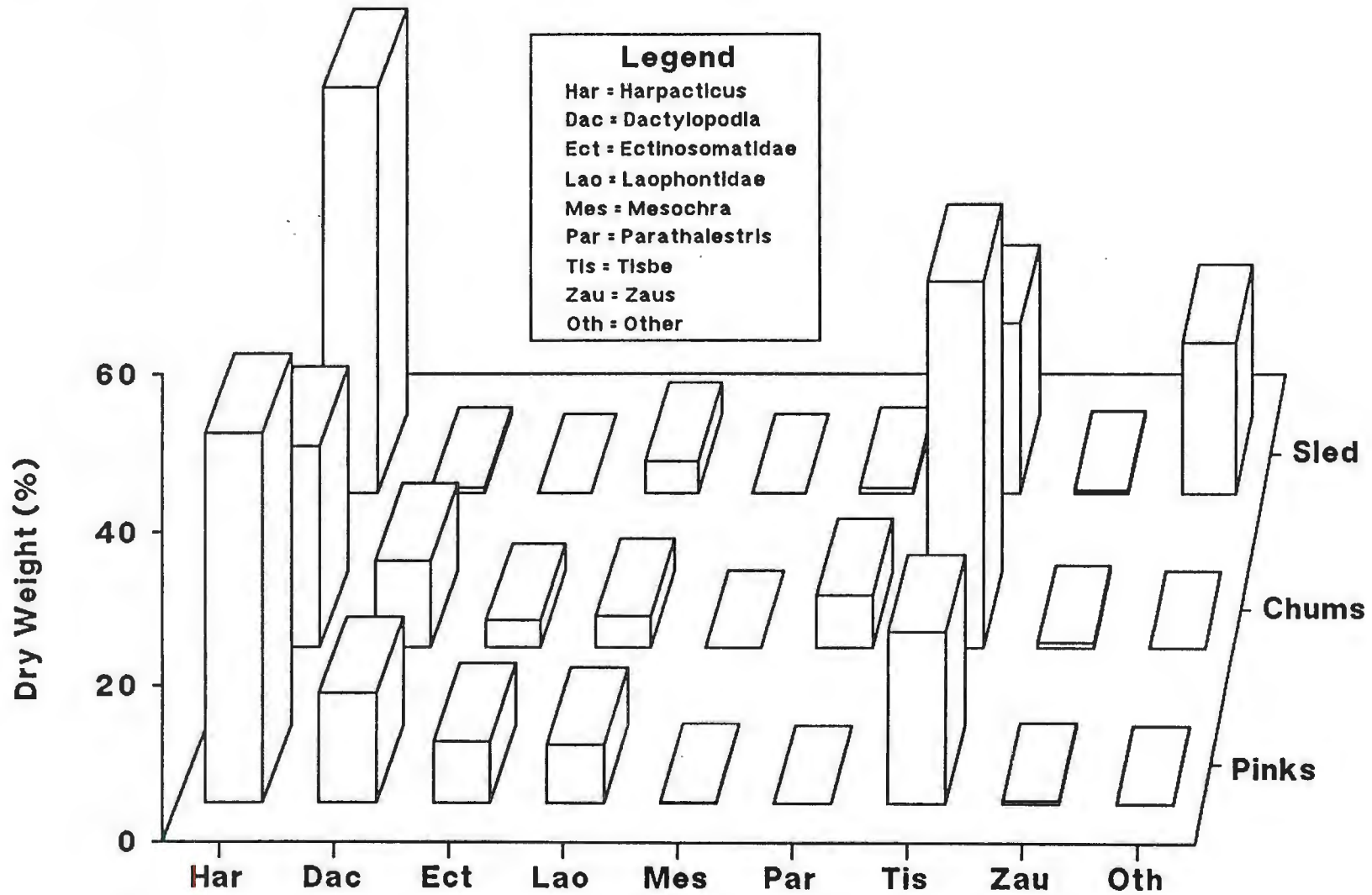
Figure 4.3. Harpacticoid composition of juvenile salmon diets and epibenthic environment in all locations of Prince William Sound, 1989.
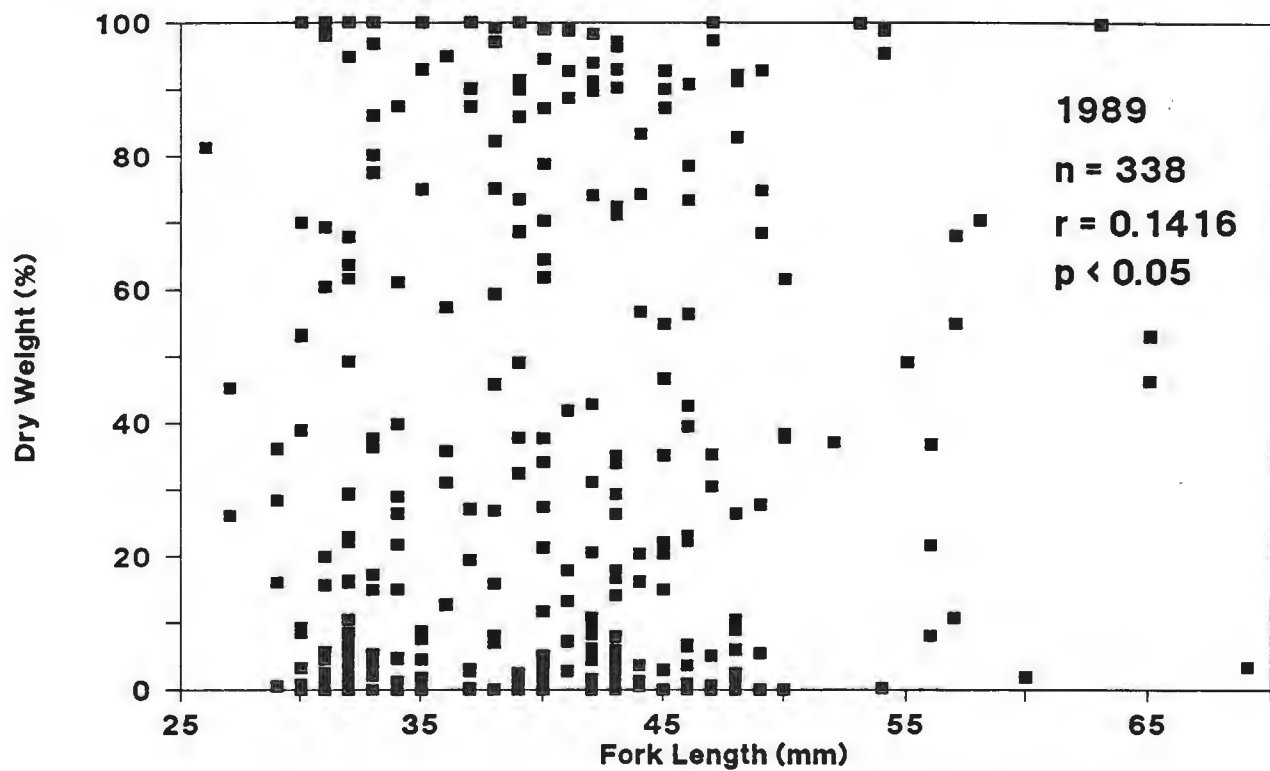
Figure 4.4. Relationship of biomass of epibenthic prey consumed to
size of juvenile pink salmon in all areas of Prince William Sound, 1989.
Number of fish (n) excludes those with empty stomachs. r = index
of association, p = probability of r being different from zero.
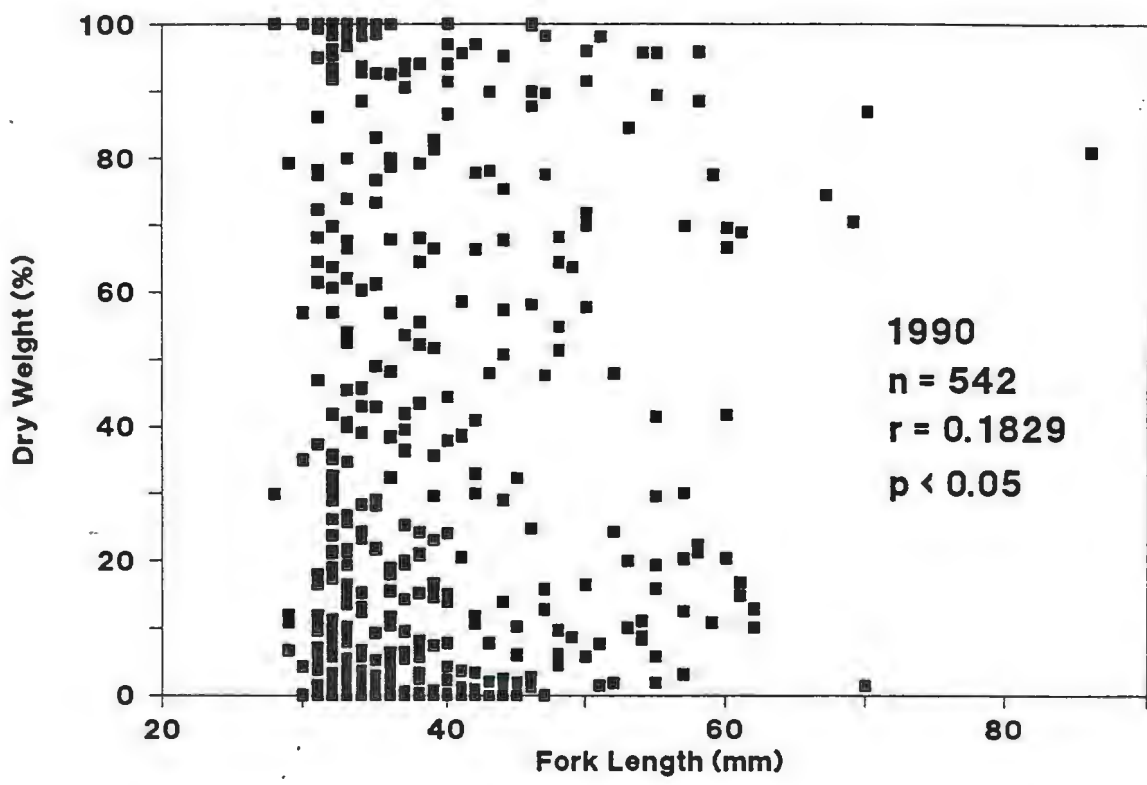
Figure 4.5. Relationship of biomass of epibenthic prey consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1990. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.
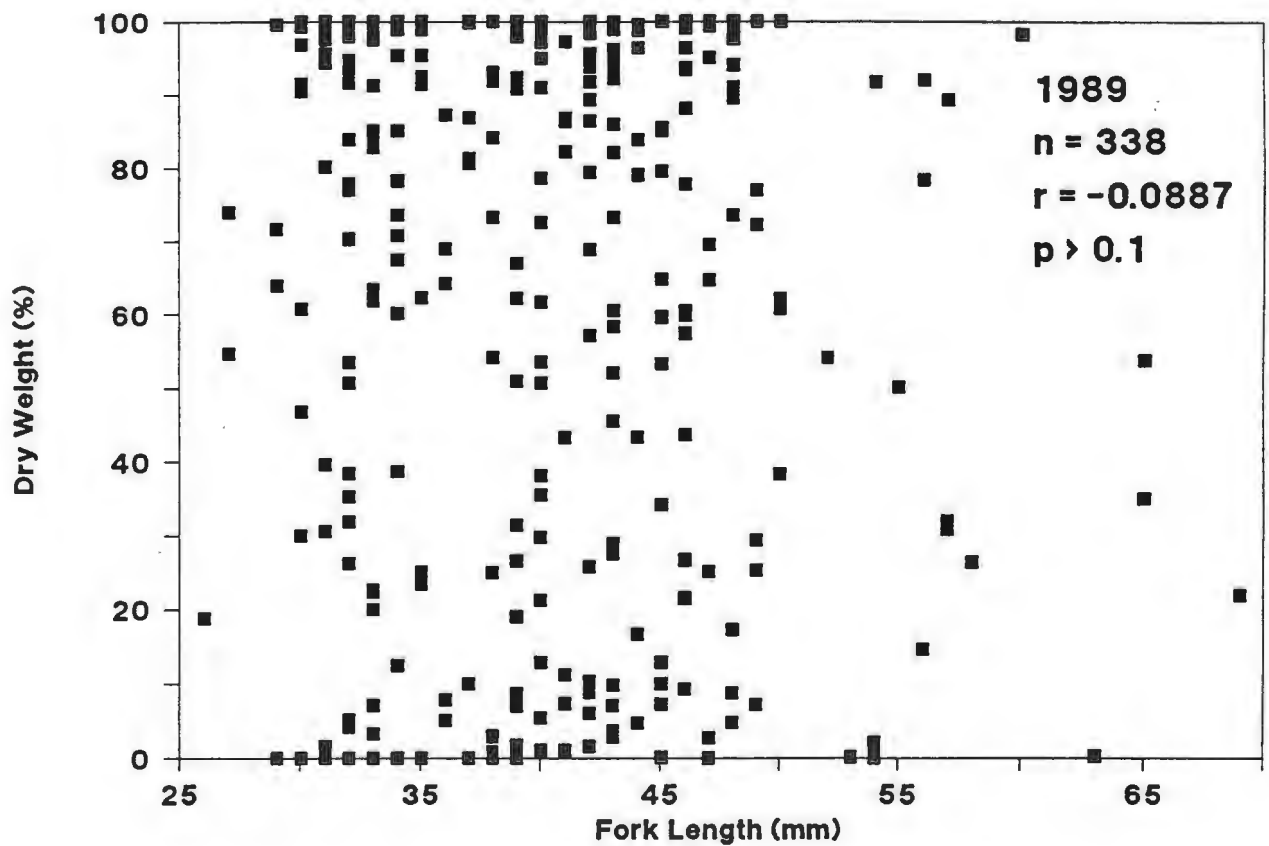
Figure 4.6. Relationship of biomass of pelagic zooplankton consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1989. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.
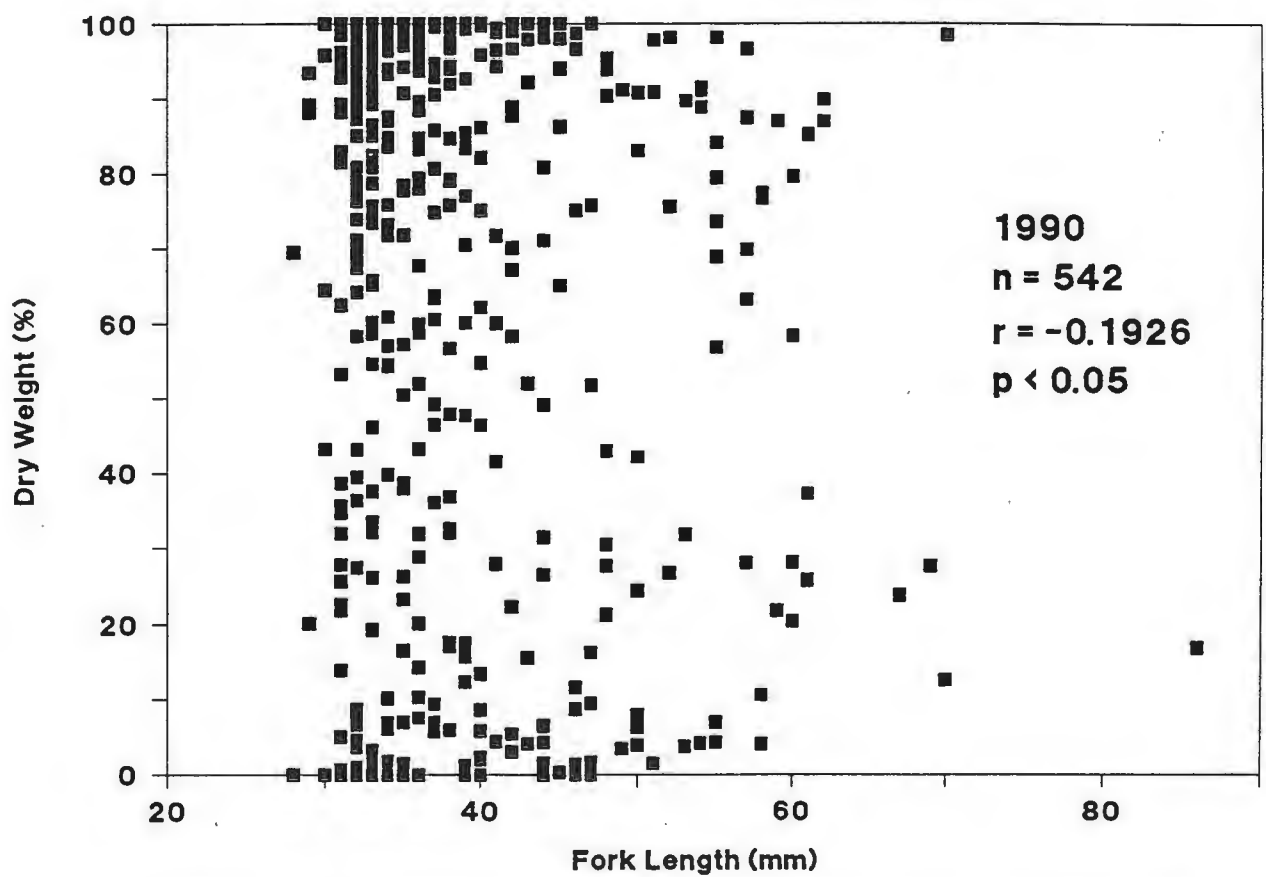
Figure 4.7. Relationship of biomass of pelagic zooplankton consumed to size of juvenile pink salmon in all areas of Prince William Sound, 1990. Number of fish (n) excludes those with empty stomachs. r = index of association, p = probability of r being different from zero.

4.33
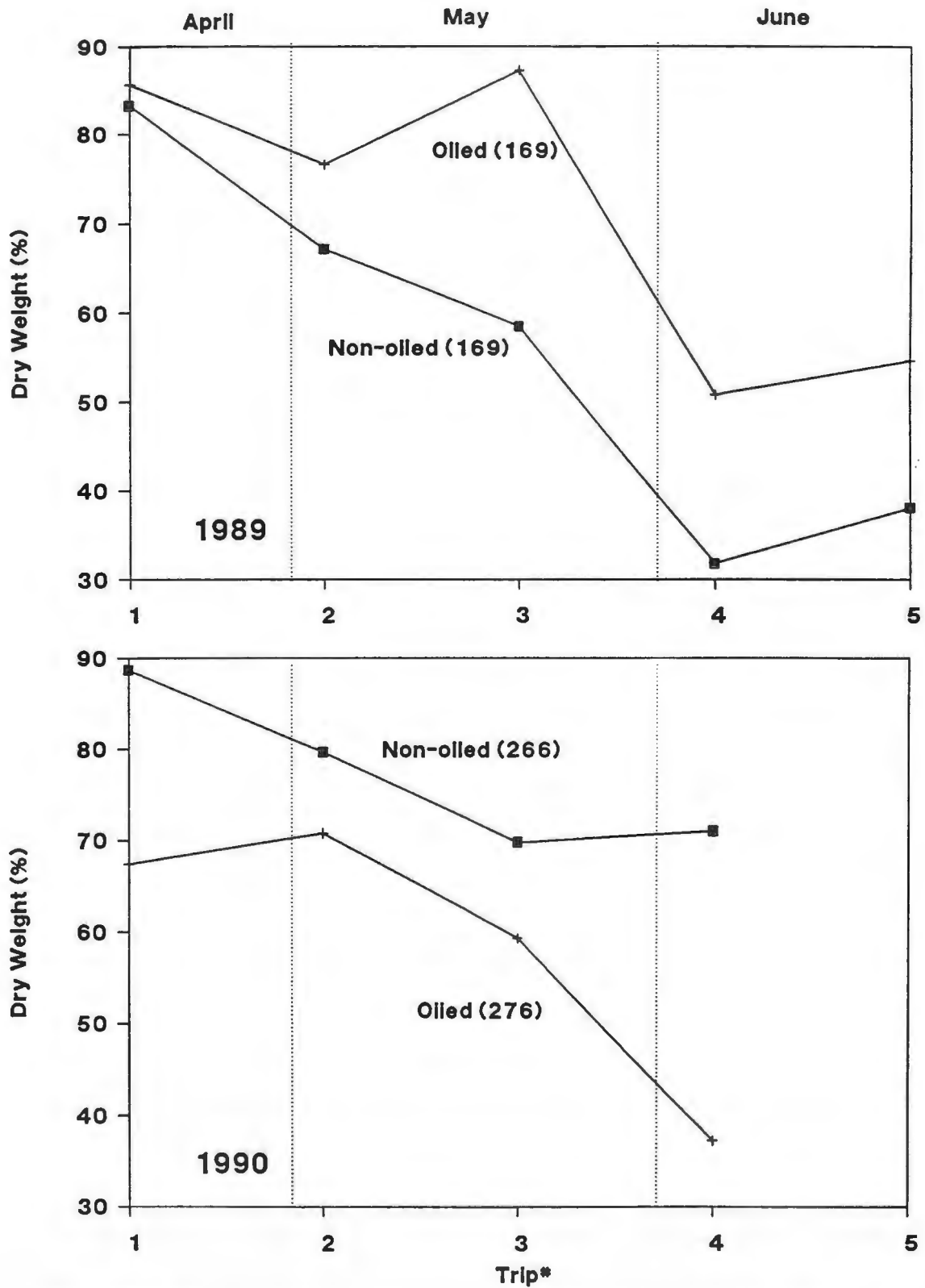
Figure 4.8. Average percent zooplankton consumed over time by pink salmon juveniles in oiled and non-oiled areas of Prince William Sound, 1989 and 1990. Numbers of fish in parentheses exclude those with empty stomachs.

4.34
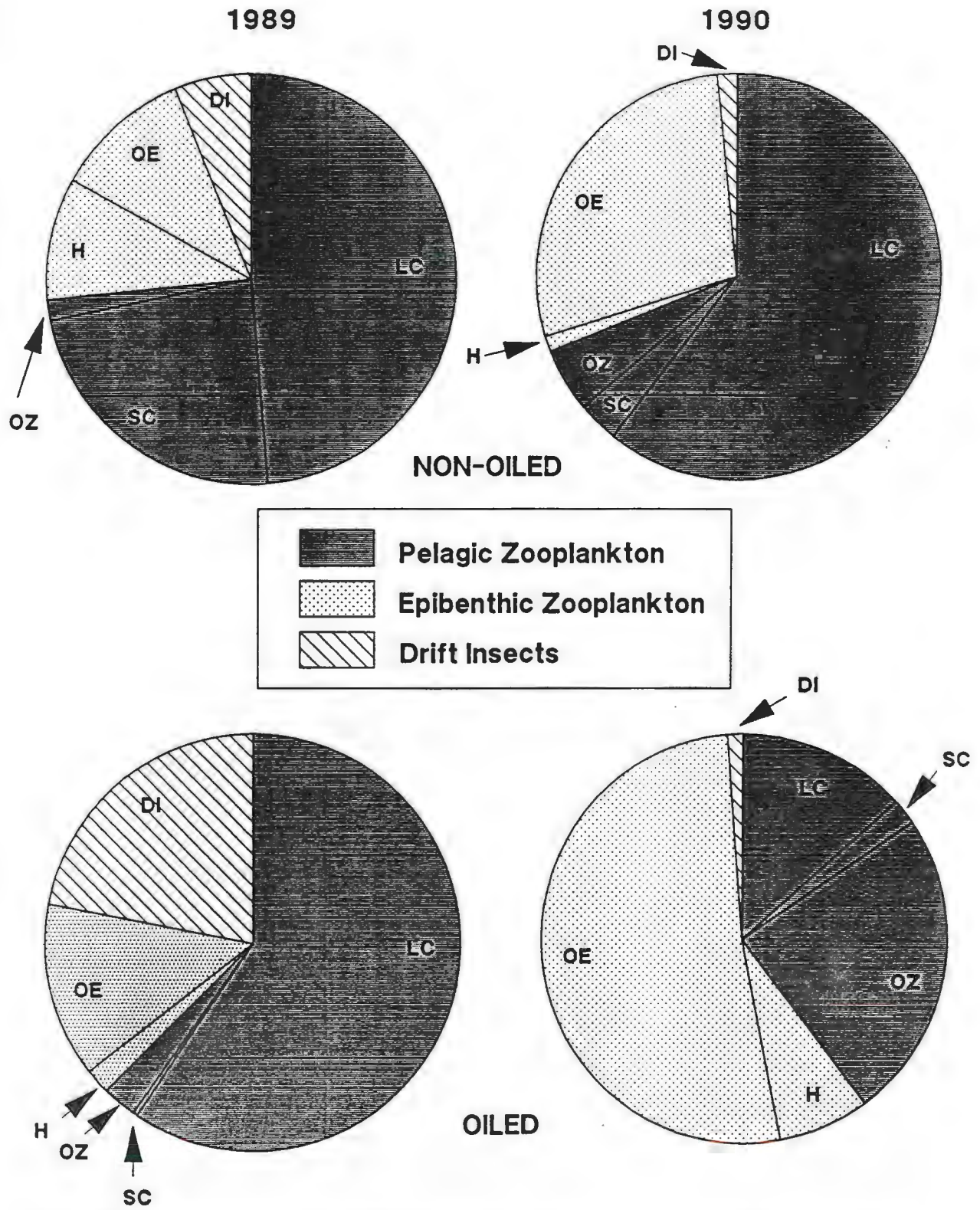
Figure 4.9. Prey percent dry weight from chum salmon fry stomachs collected in Prince William Sound, Alaska, in 1989 (n = 112) and 1990 (n = 136). LC = Large Calanoids, SC = Small Calanoids, OZ = Other Zooplankton, H = Harpacticoids, OE = Other Epibenthic, DI = Drift Insects.
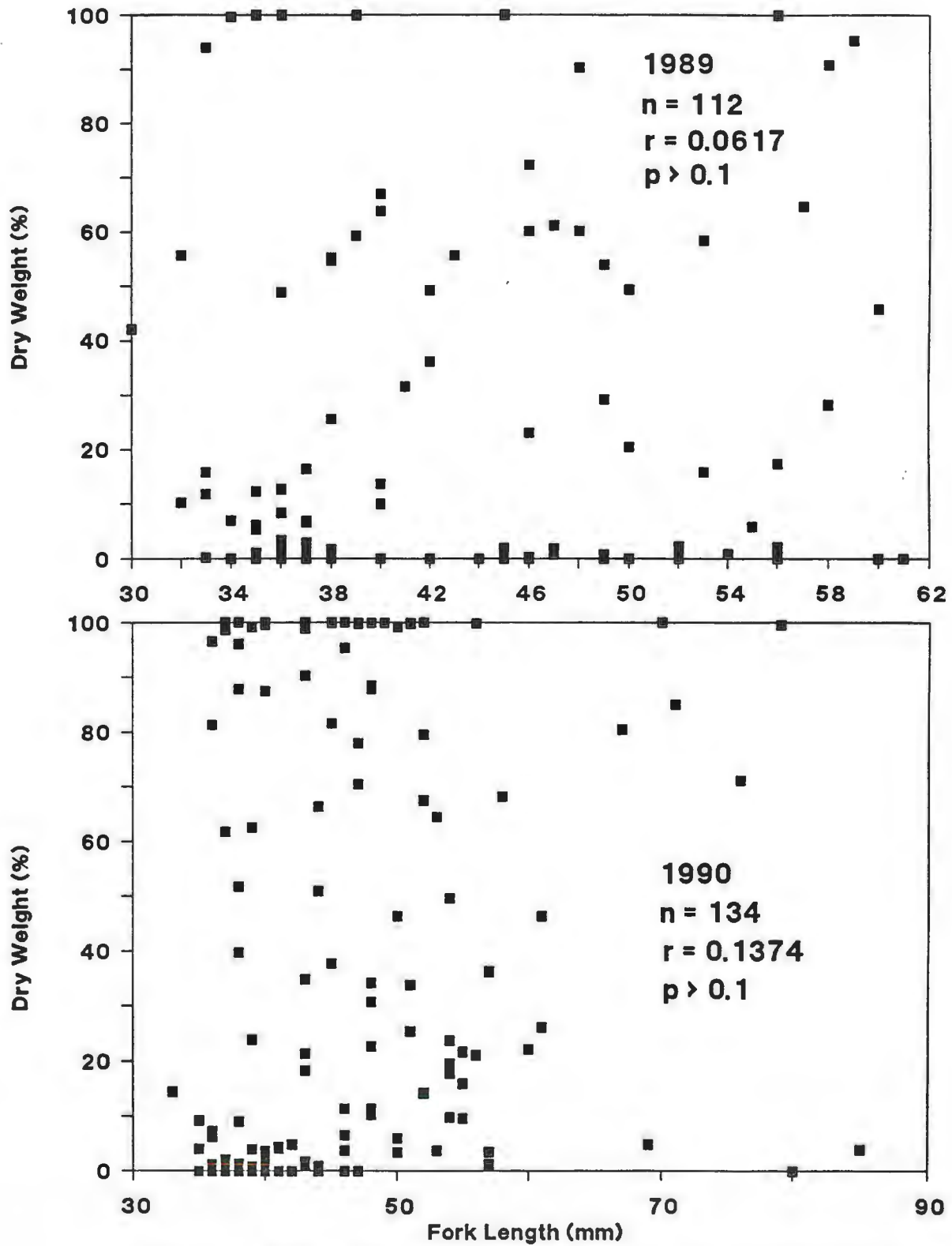
Figure 4.10. Relationship of biomass of epibenthos consumed to size of juvenile chum salmon in all areas of Prince William Sound, 1989 and 1990. Numbers of fish (n) exclude those with empty stomachs. r = index of association, p = probability of r being different from zero.
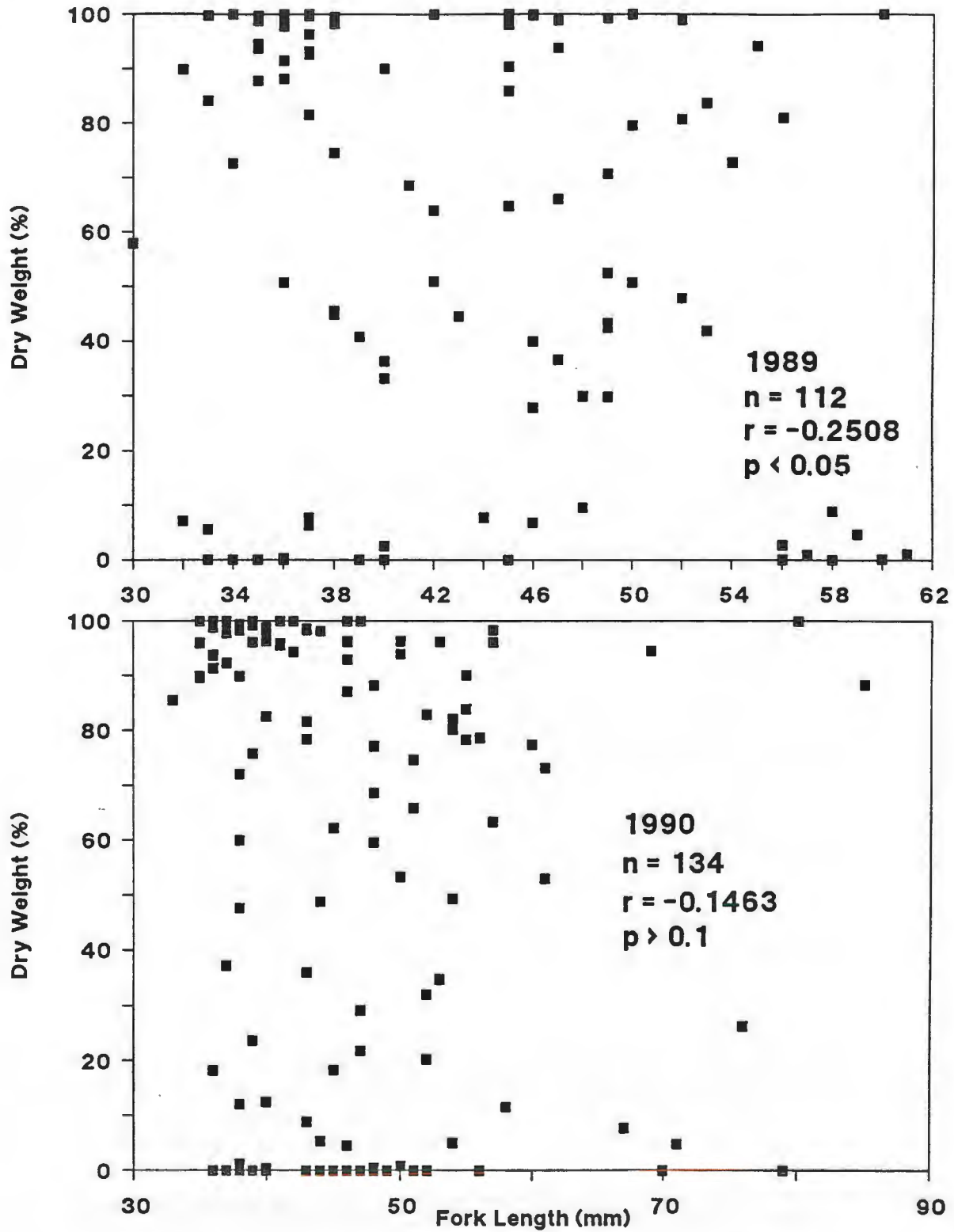
Figure 4.11. Relationship of biomass of zooplankton consumed to size of juvenile chum salmon in all areas of Prince William Sound, 1989 and 1990. Numbers of fish (n) exclude those with empty stomachs. r = index of association, p = probability of r being different from zero.
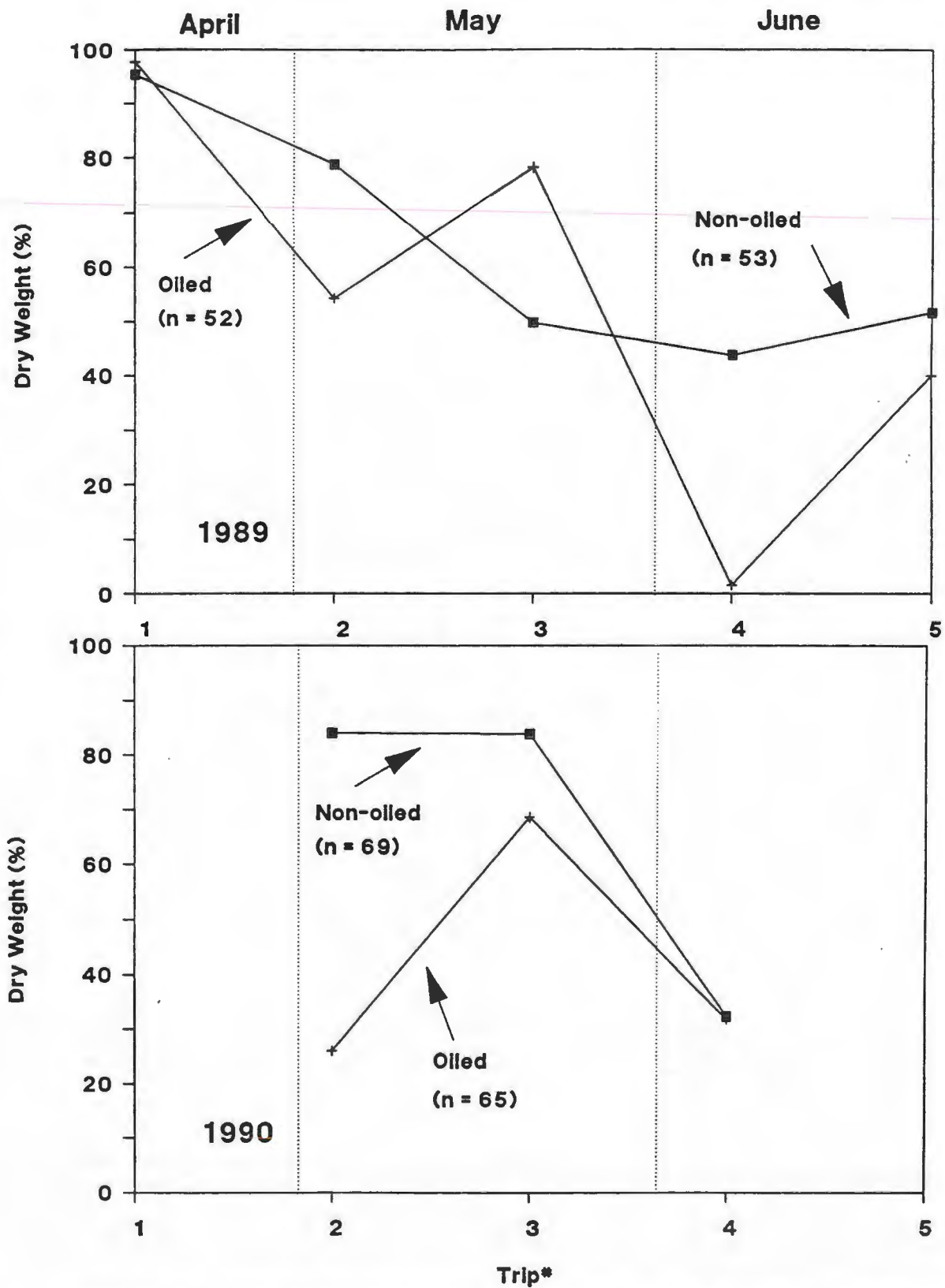
Figure 4.12. Average percent zooplankton consumed over time by chum salmon
juveniles in oiled and non-oiled areas of Prince William Sound, 1989 and 1990.
Numbers of fish (n) exclude those with empty stomachs.

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 <u>Harpacticus</u> genera only; Abundance of <u>Tisbe</u> genera only; Proportion of egg carrying female <u>Harpacticus</u> to all female adult <u>Harpacticus</u>; (5) Proportion of egg carrying female <u>Tisbe</u> to all female adult <u>Tisbe</u>; (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 $\underline{P} < 0.1$ 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.

<u>Meiofauna in experimentally contaminated sediments</u>.

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 $\underline{P}$-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 ($\underline{P}$ = 0.039) and Harpacticus uniremis alone ($\underline{P}$ = 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 ($\underline{P}$ = 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 ($\underline{P}$ = 0.205) or Tisbe sp. ($\underline{P}$ = 0.621, Table 5.24).

At Bay of Isles oil had a marginally significant effect on the abundance of harpacticoid copepods ($\underline{P}$ = 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 <u>Harpacticus</u> <u>sp.</u> (P = 0.217) or
<u>Tisbe</u> <u>sp.</u> (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 <u>Harpacticus</u> <u>sp.</u> (P = 0.234) or <u>Tisbe</u> <u>sp.</u> (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

5.12

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.

Time	Non-oiled locations		Oiled locations	
	$\bar{x}$	(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/m³) 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 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		Oiled locations	
	x̄	(SD)	x̄	(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		Oiled sites	
	$\bar{x}$	(SD)	$\bar{x}$	(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 < $\underline{P}$ < 0.100
** = 0.010 < $\underline{P}$ < 0.050
*** = $\underline{P}$ < 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 <u>Calanus marshallae</u>; <u>Calanus</u> sp.; <u>Eucalanus bungii</u>; <u>Heterorhabdus</u> sp.; <u>Neocalanus cristatus</u>; <u>Neocalanus plumchrus</u>; and adult female <u>Metridia pacifica</u>. 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.
<u>Small Calanoid Copepods</u>						
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			
<u>Large Calanoid Copepods</u>						
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			

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

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.

Time Period	Bay				Corridor			
	Non-oiled		Oiled		Non-oiled		Oiled	
	No.	(sd)	No.	(sd)	No.	(sd)	No.	(sd)
<u>1989</u>								
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)
<u>1990</u>								
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/m³) 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/m³) 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	Non-oiled locations			Oiled locations		
Period	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 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 < P < 0.100
** = 0.010 < P < 0.050
*** = 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		

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

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 m² 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 m² 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, <u>Harpacticus</u> <u>uniremis</u>, <u>Tisbe</u> <u>sp.</u>, and arcsine proportion of egg carrying females to total adult females of <u>Harpacticus</u> <u>uniremis</u> and <u>Tisbe</u> <u>sp.</u> 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

Non-oiled **Oiled**

Bays

Corridors

Small (< 2.6 mm)
Calanoid Copepods

Large (> 2.5 mm)
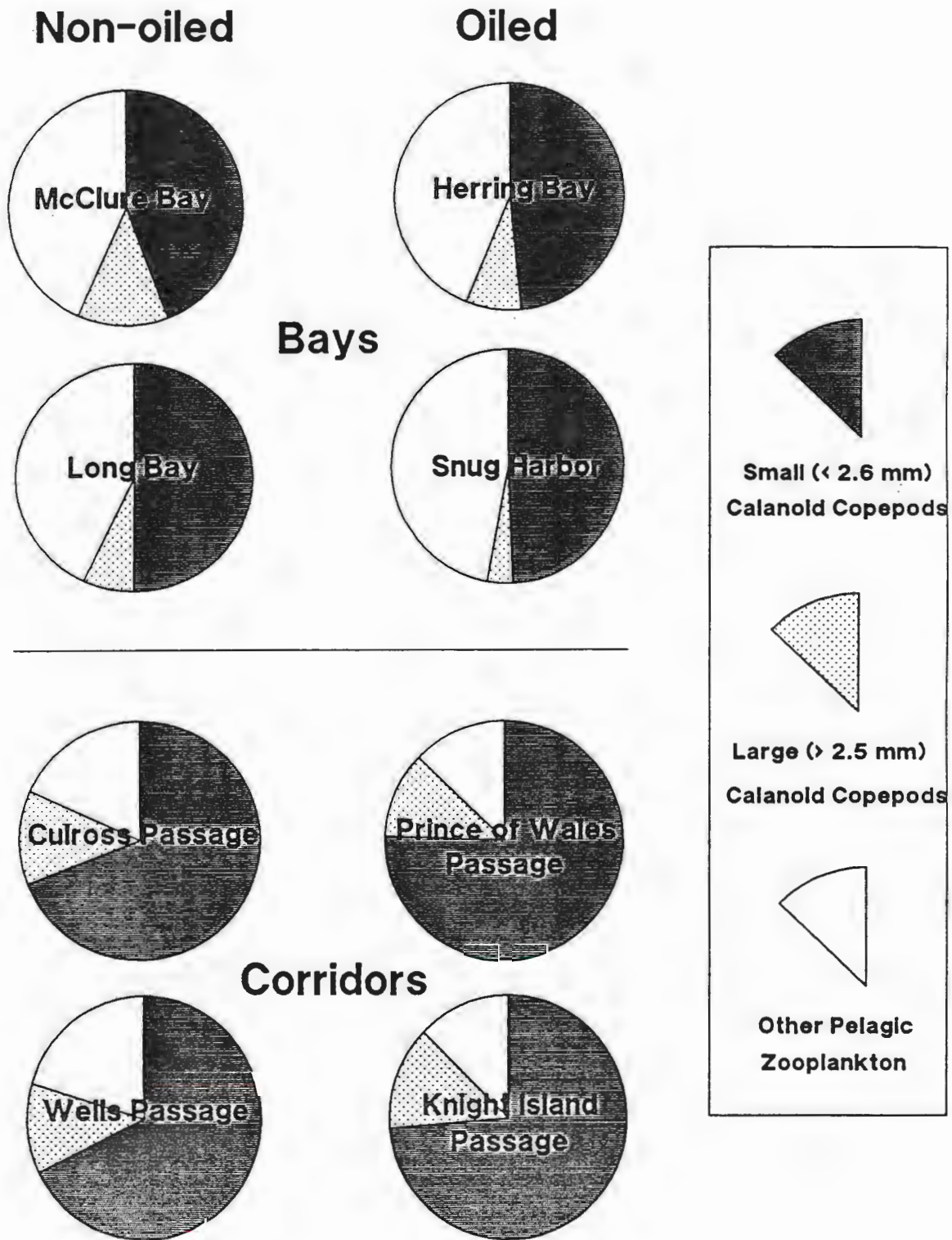Calanoid Copepods

Other Pelagic
Zooplankton

Figure 5.1. Relative abundance of pelagic zooplankton collected from four
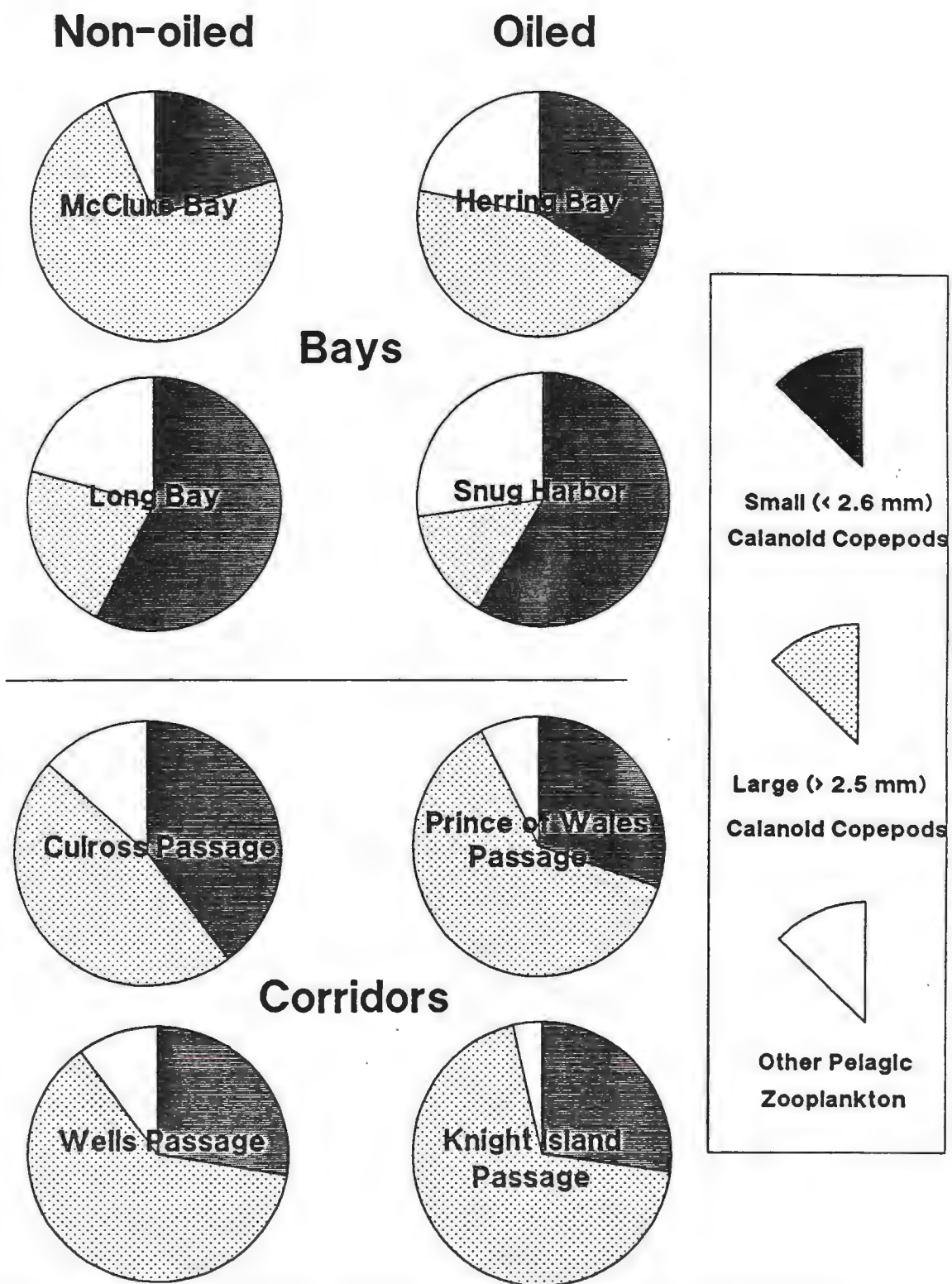pairs of oiled and non-oiled locations in Prince William Sound, April-June,
1989.

Non-oiled

Oiled

McClure Bay

Herring Bay

Bays

Long Bay

Snug Harbor

Culross Passage

Prince of Wales Passage

Corridors

Wells Passage

Knight Island Passage

Small (< 2.6 mm) Calanoid Copepods

Large (> 2.5 mm) Calanoid Copepods

Other Pelagic Zooplankton

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.
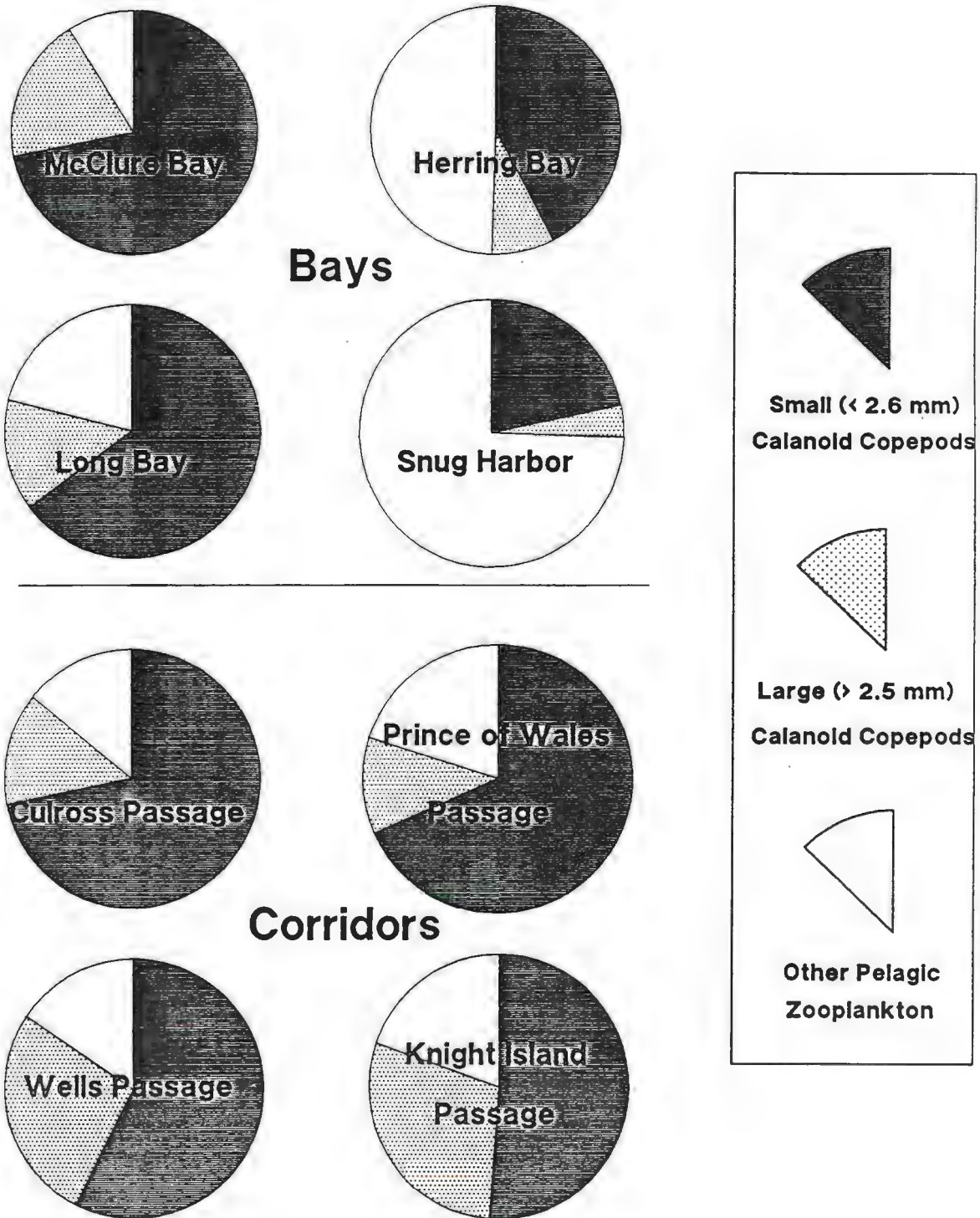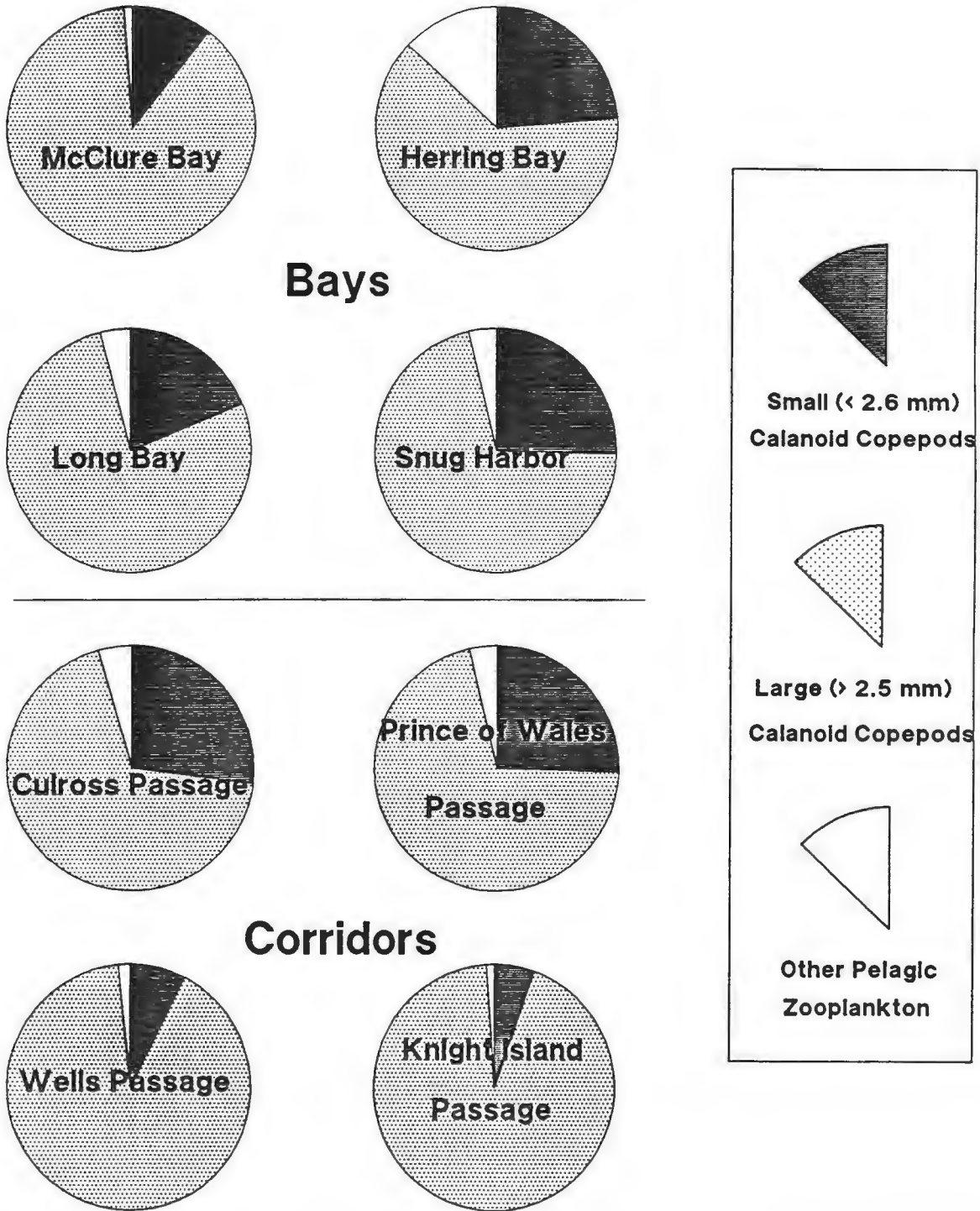
Figure 5.3. Relative abundance of pelagic zooplankton collected from four pairs of oiled and non-oiled locations in Prince William Sound, April–June, 1990.

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.
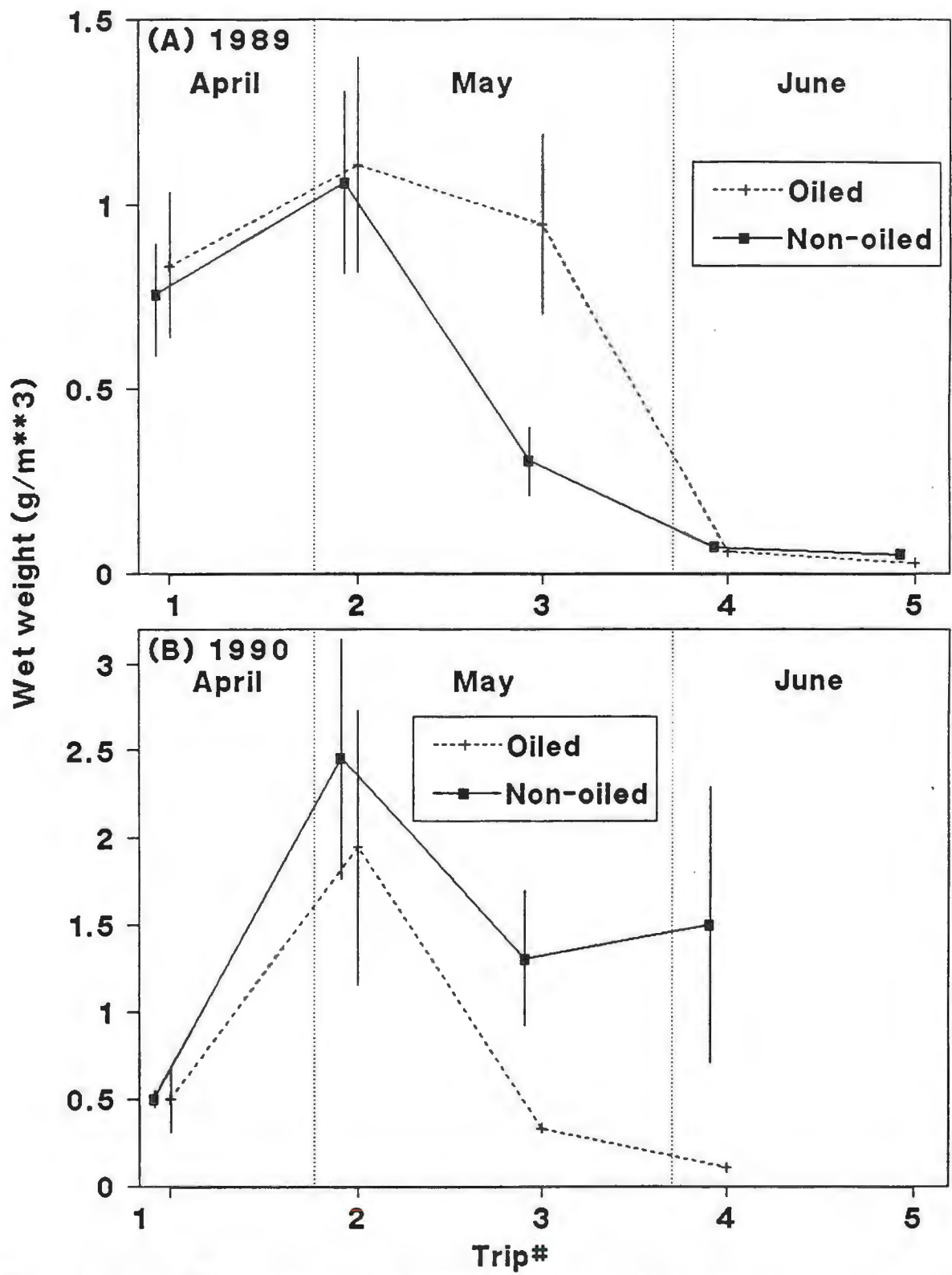
Figure 5.5. Biomass and standard errors of pelagic zooplankton in oiled and non-oiled areas of Prince William Sound in (A) 1989 and (B) 1990.
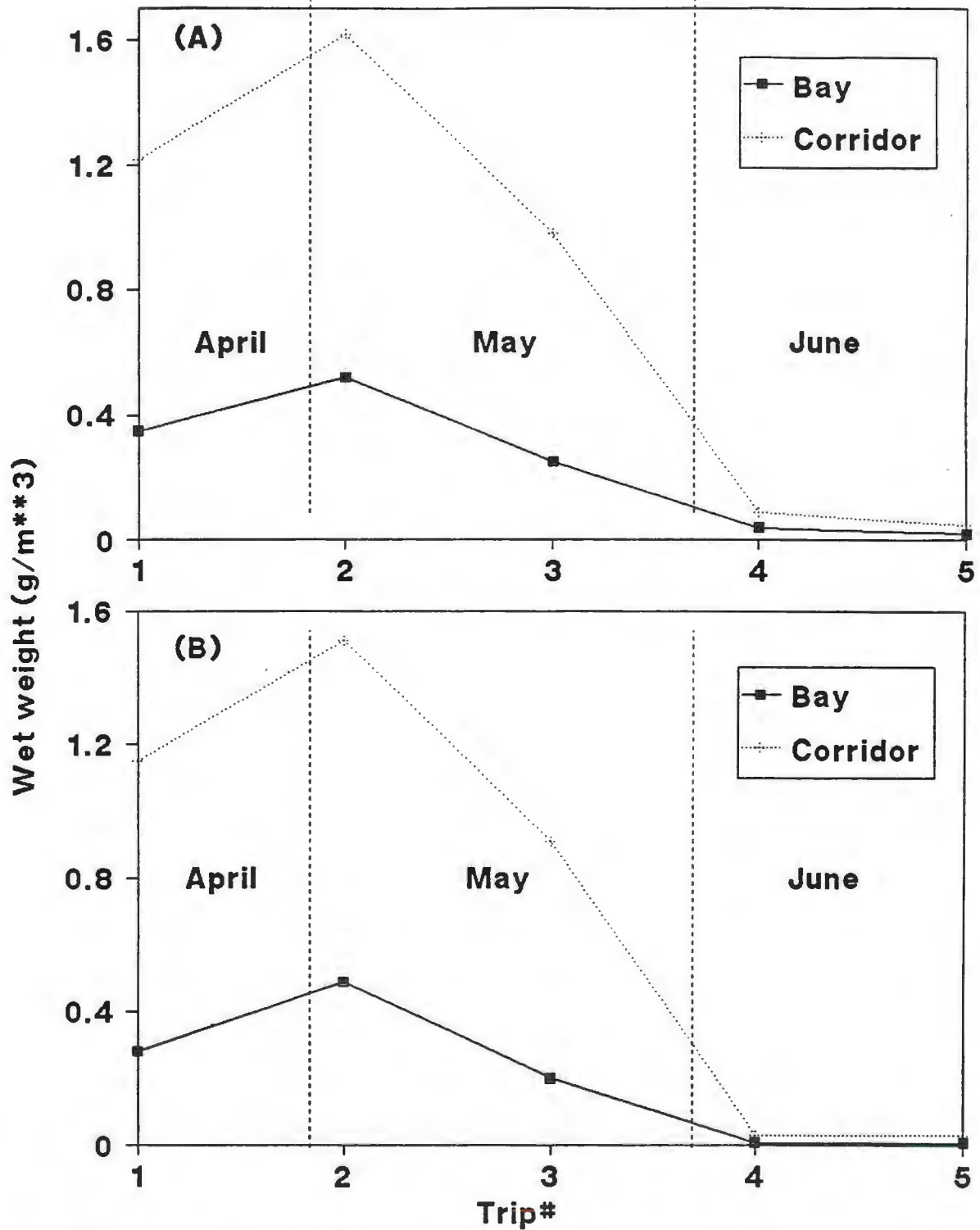
Figure 5.6. Biomass of (A) Pelagic zooplankton and (B) Calanoid copepods in Prince William Sound from April-June, 1989.
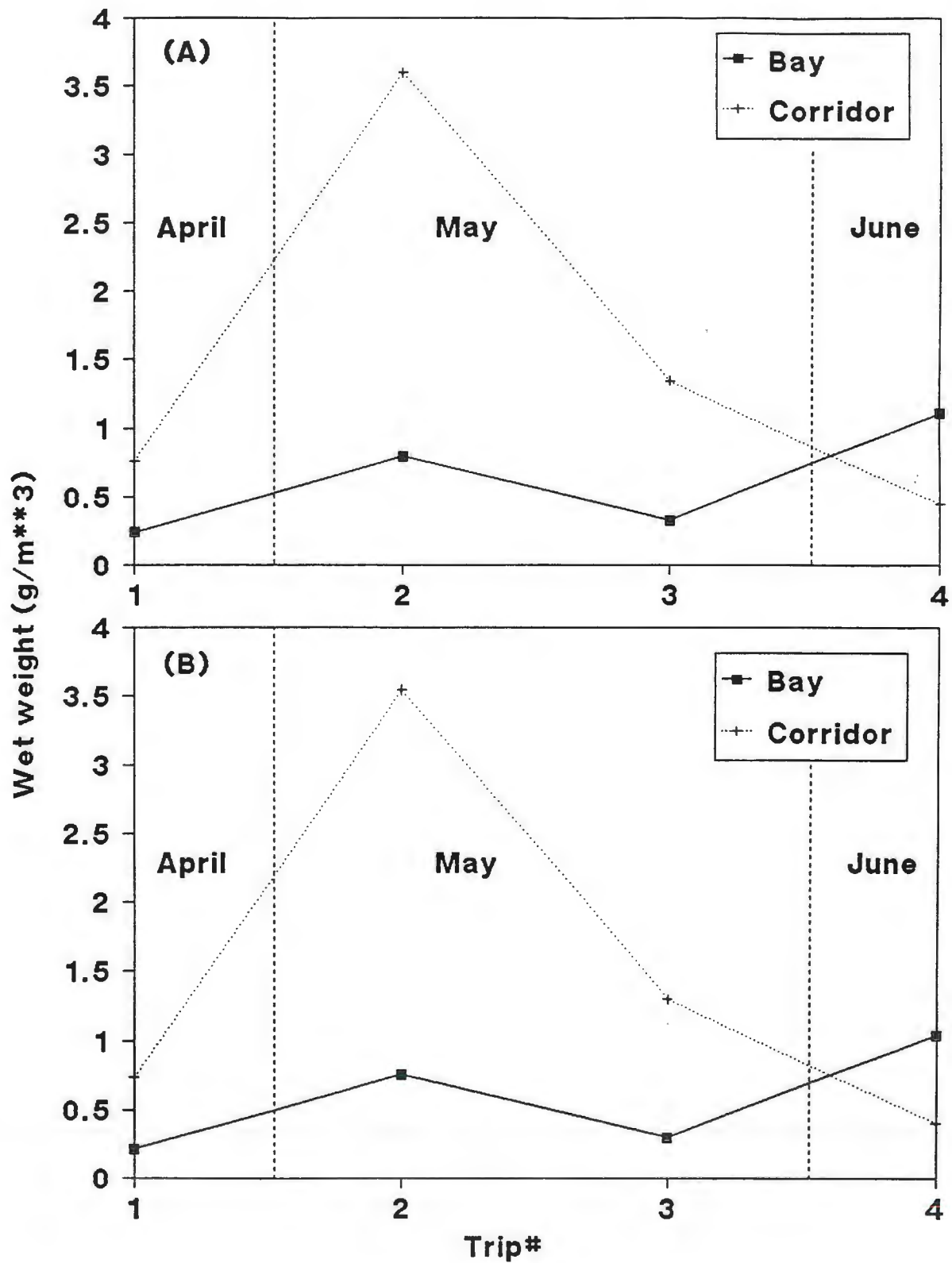
5.52

Figure 5.7. Biomass of (A) Pelagic zooplankton and (B) Calanoid copepods in Prince William Sound from April-June, 1990.
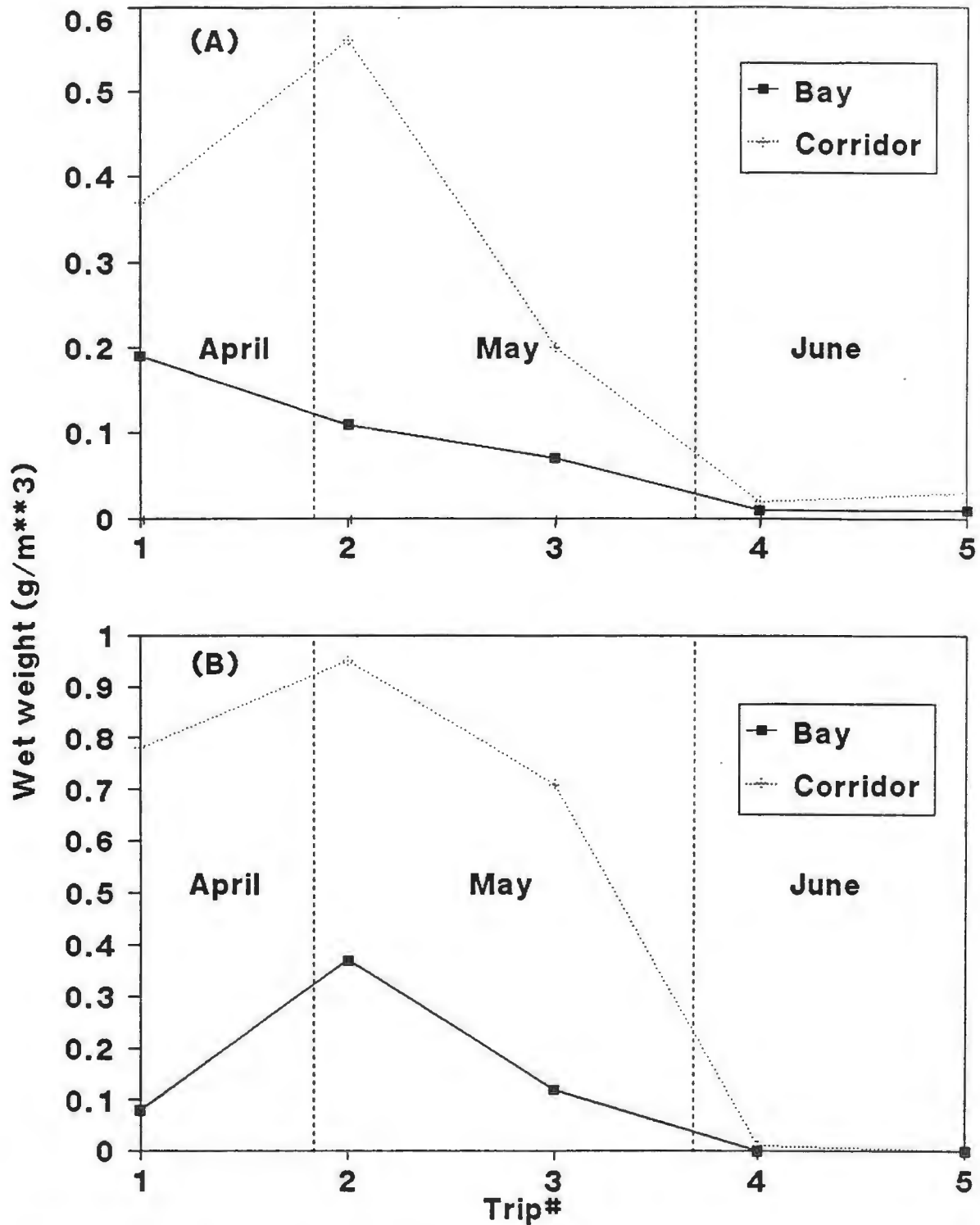
Figure 5.8. Biomass of (A) small (< 2.6 mm total length) and (B) Large (> 2.5 mm total length) calanoid copepods in Prince William Sound from April-June, 1989.
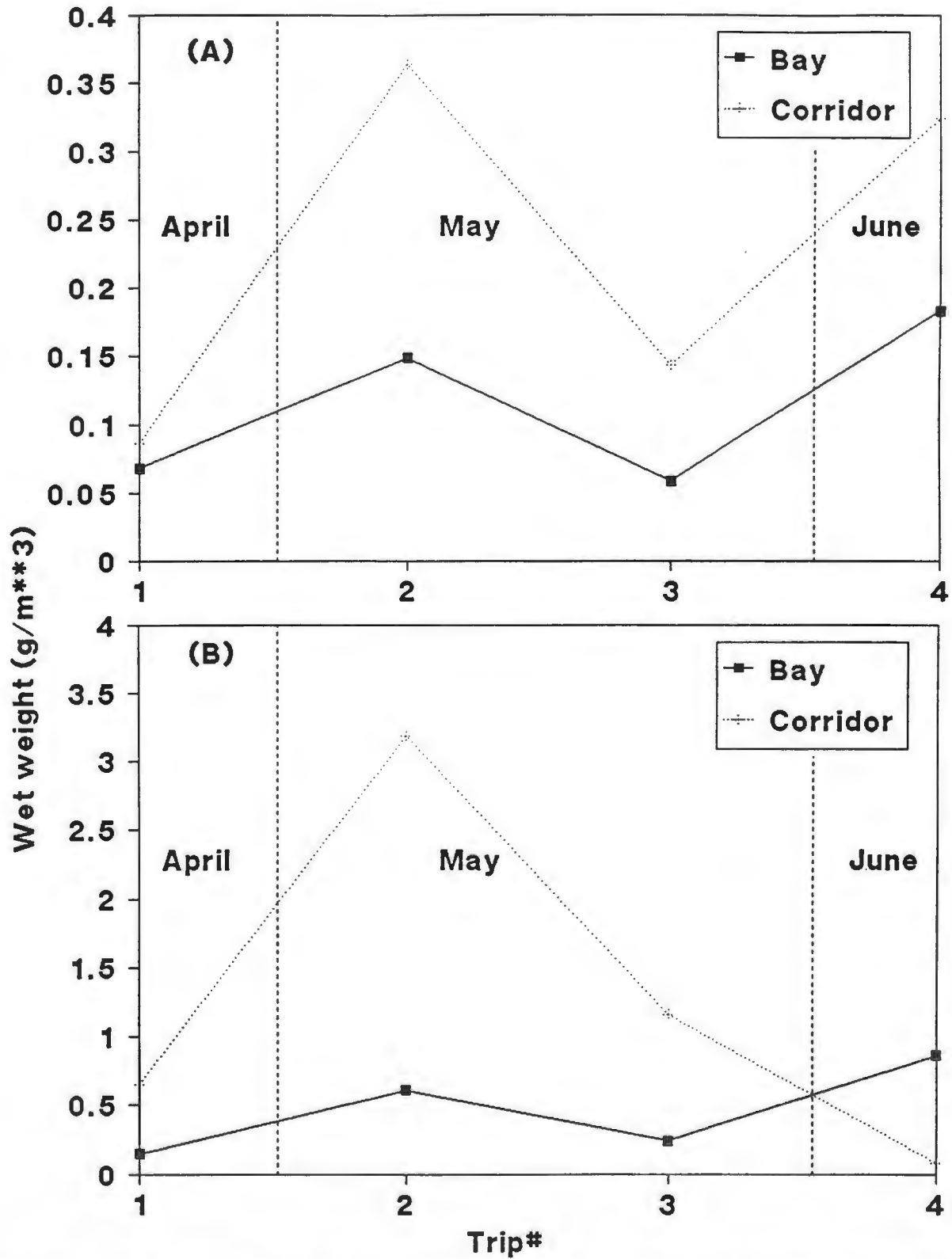
Figure 5.9. Biomass of (A) small (< 2.6 mm total length) and (B) Large (> 2.5 mm total length) calanoid copepods in Prince William Sound from April-June, 1990.

Non-oiled   **Oiled**

McClure Bay   Herring Bay

Bays

Long Bay   Snug Harbor

Epibenthic prey organisms (excluding harpacticoids)

Epibenthic non-prey organisms

Culross Passage   Prince of Wales Passage

Corridors

Harpacticoid copepods
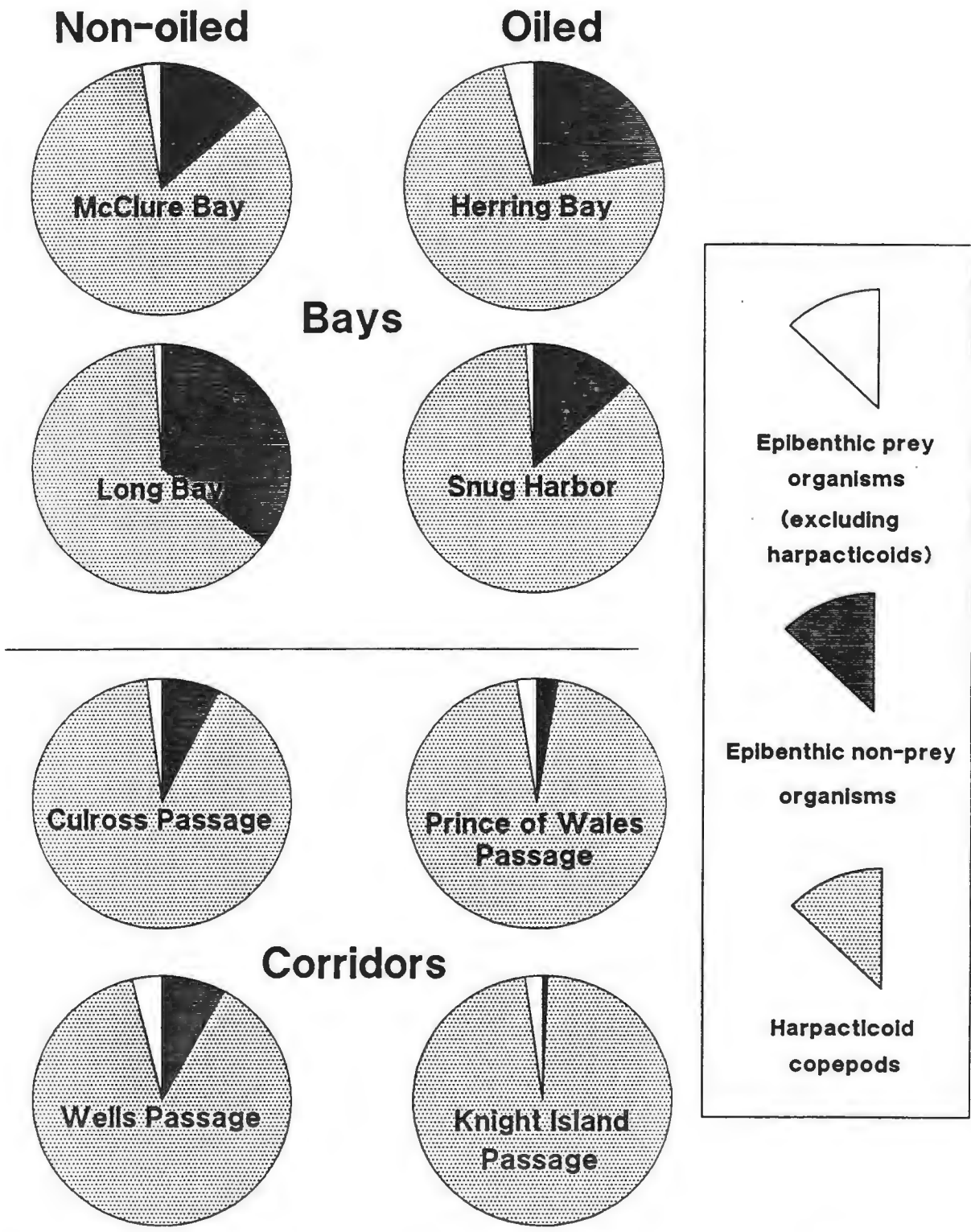
Wells Passage   Knight Island Passage

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.

5.56

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.
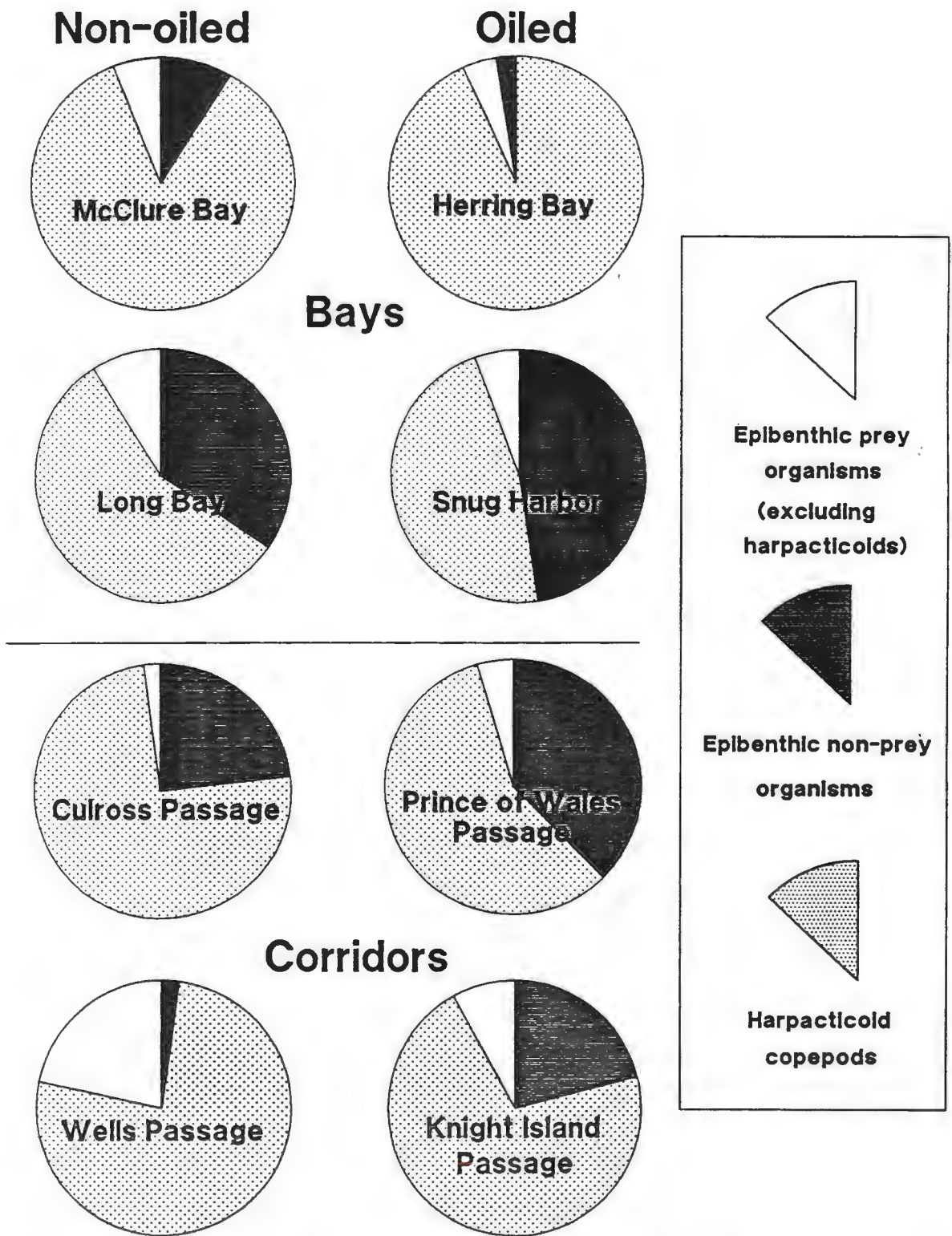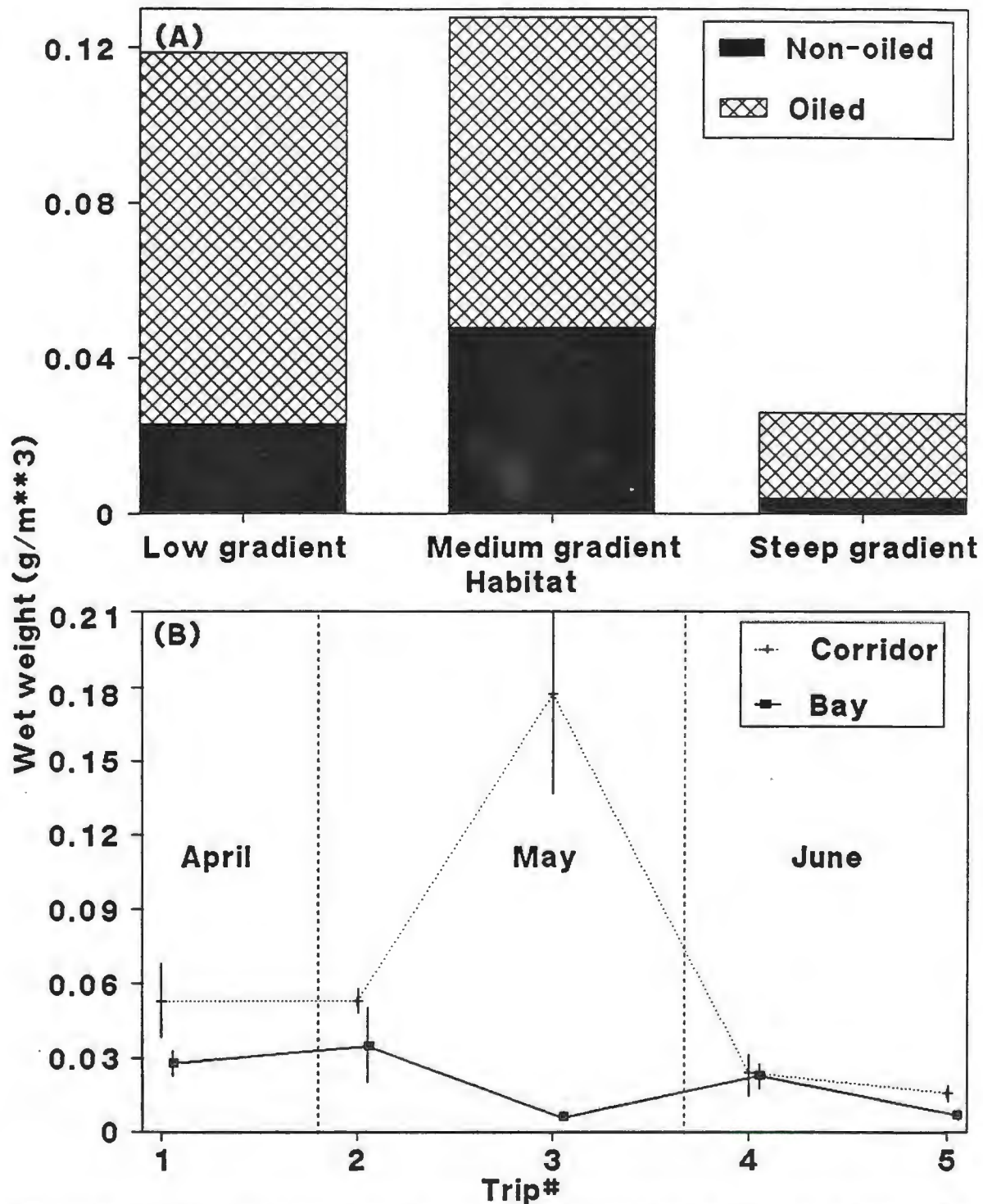
Figure 5.12. Harpacticoid copepod biomass in the systematic epibenthic sled samples in (A) oiled and non-oiled habitats, and (B) bays and corridors over time in Prince William Sound, April-June, 1989. Means in (b) are shown ± 1 standard error.
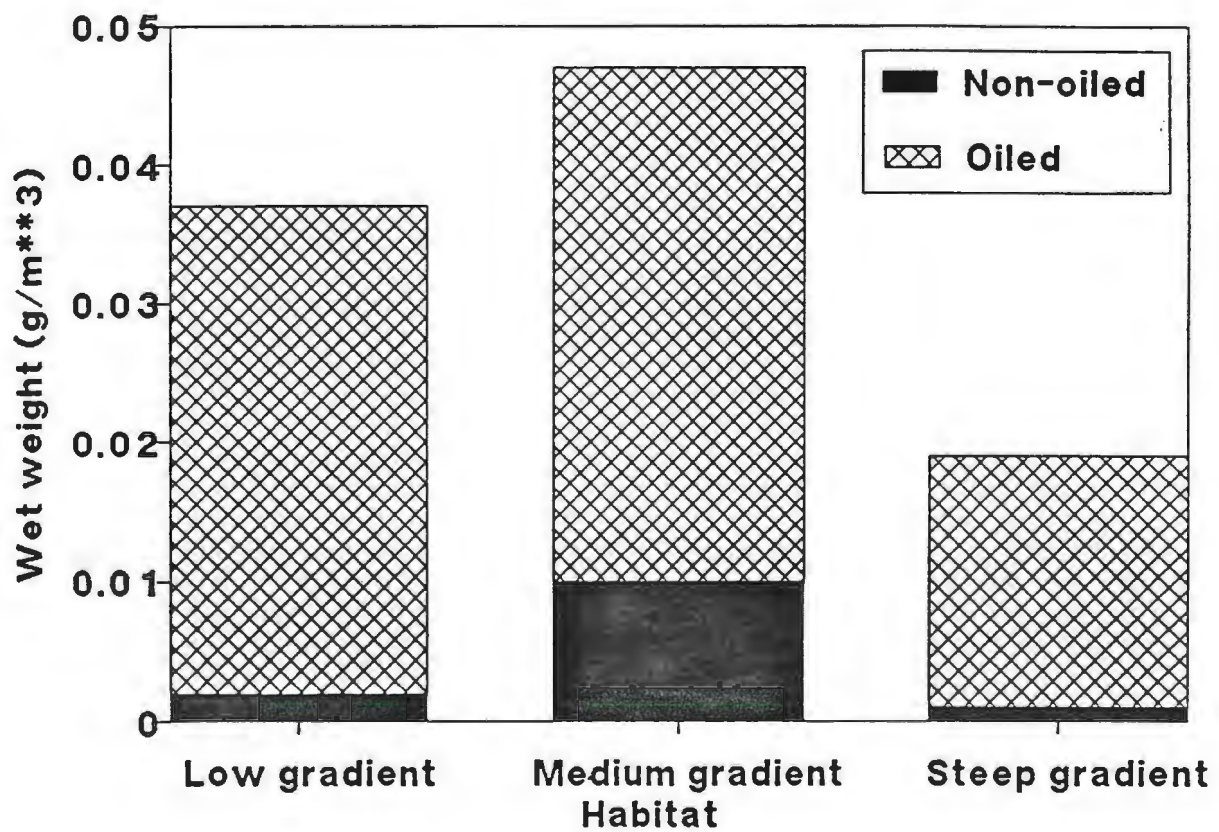
Figure 5.13. Harpacticoid copepod biomass in the tidal transect epibenthic sled samples from oiled and non-oiled habitats in bays of Prince William Sound, April-June, 1989.
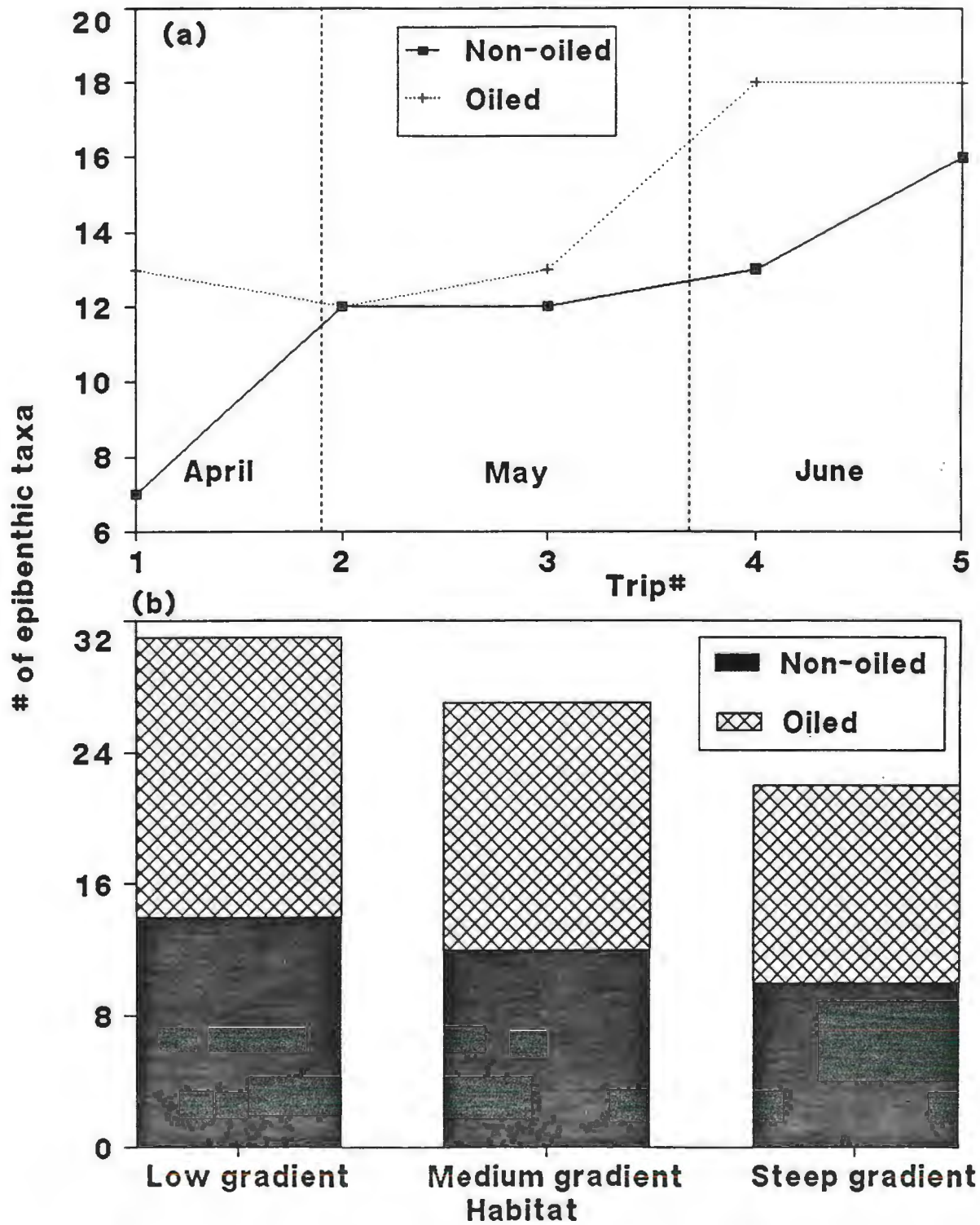
Figure 5.14. Number of epibenthic taxa captured in the systematic epibenthic sled samples in (a) oiled and non-oiled areas over time, and (b) oiled and non-oiled habitats in Prince William Sound, April-June, 1989.
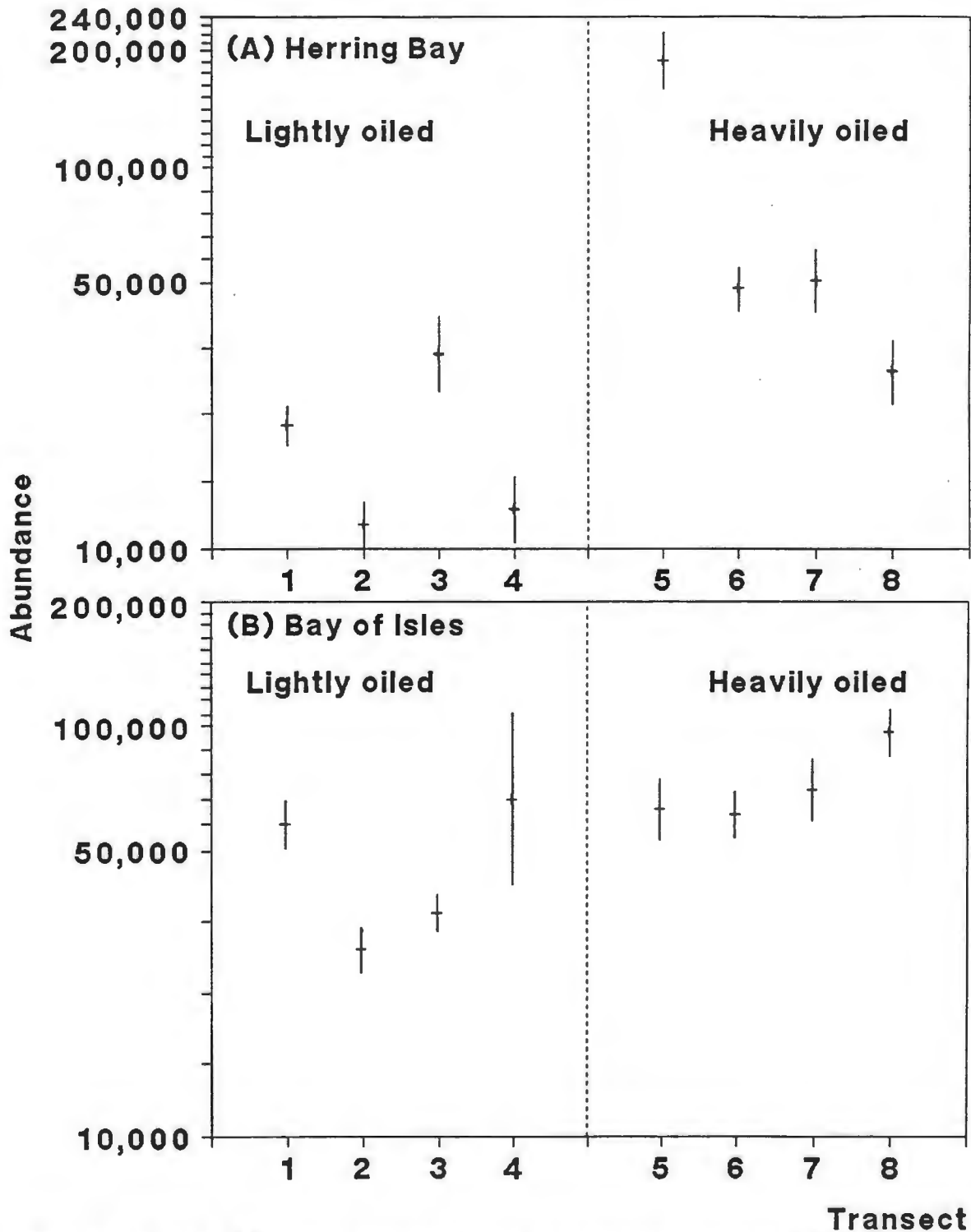
Figure 5.15. Mean numbers and standard errors (SE) of harpacticoid copepods sampled with the epibenthic pump along 4 lightly oiled and 4 heavily oiled transects in (A) Herring Bay in April, 1990, and (B) Bay of Isles in May, 1990, Prince William Sound.
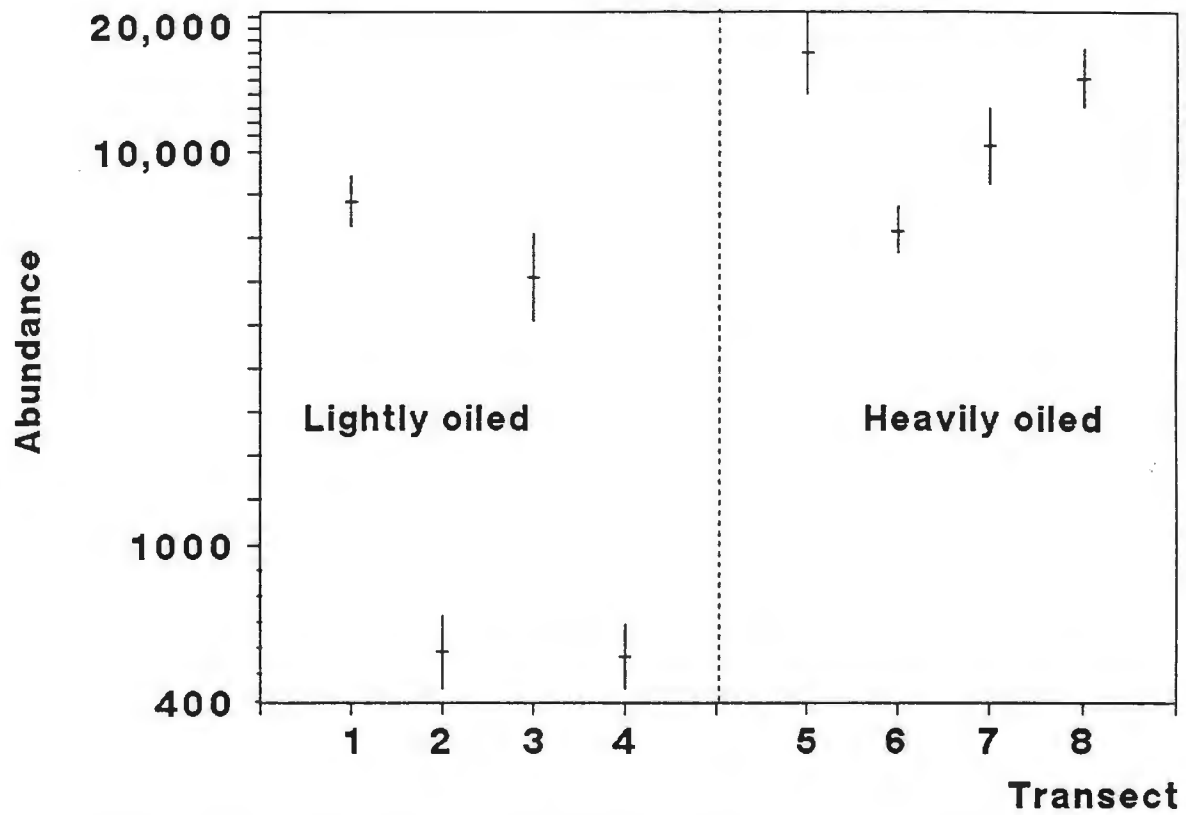
Figure 5.16. Mean numbers and standard errors (SE) of
Harpacticus uniremis sampled with the epibenthic pump
along 4 lightly oiled and 4 heavily oiled transects in Herring
Bay, Prince William Sound in April, 1990.

Meiofauna sediments, day 0
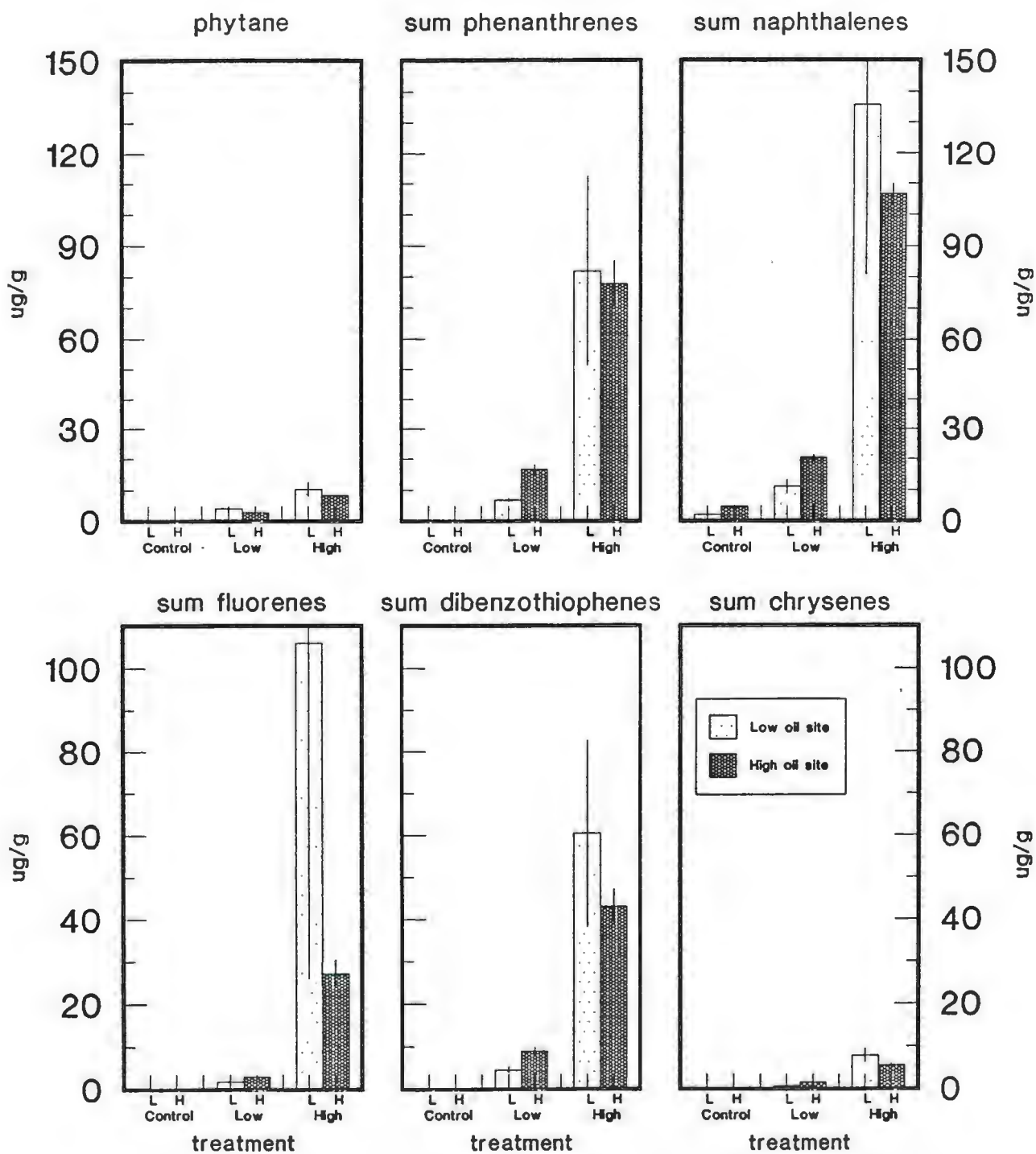
Figure 5.17. Summary characteristics of oil compounds contained in the sediments used in the meiofauna experiment. Control, low and high refer to sediment treatments buried at two discrete sites.
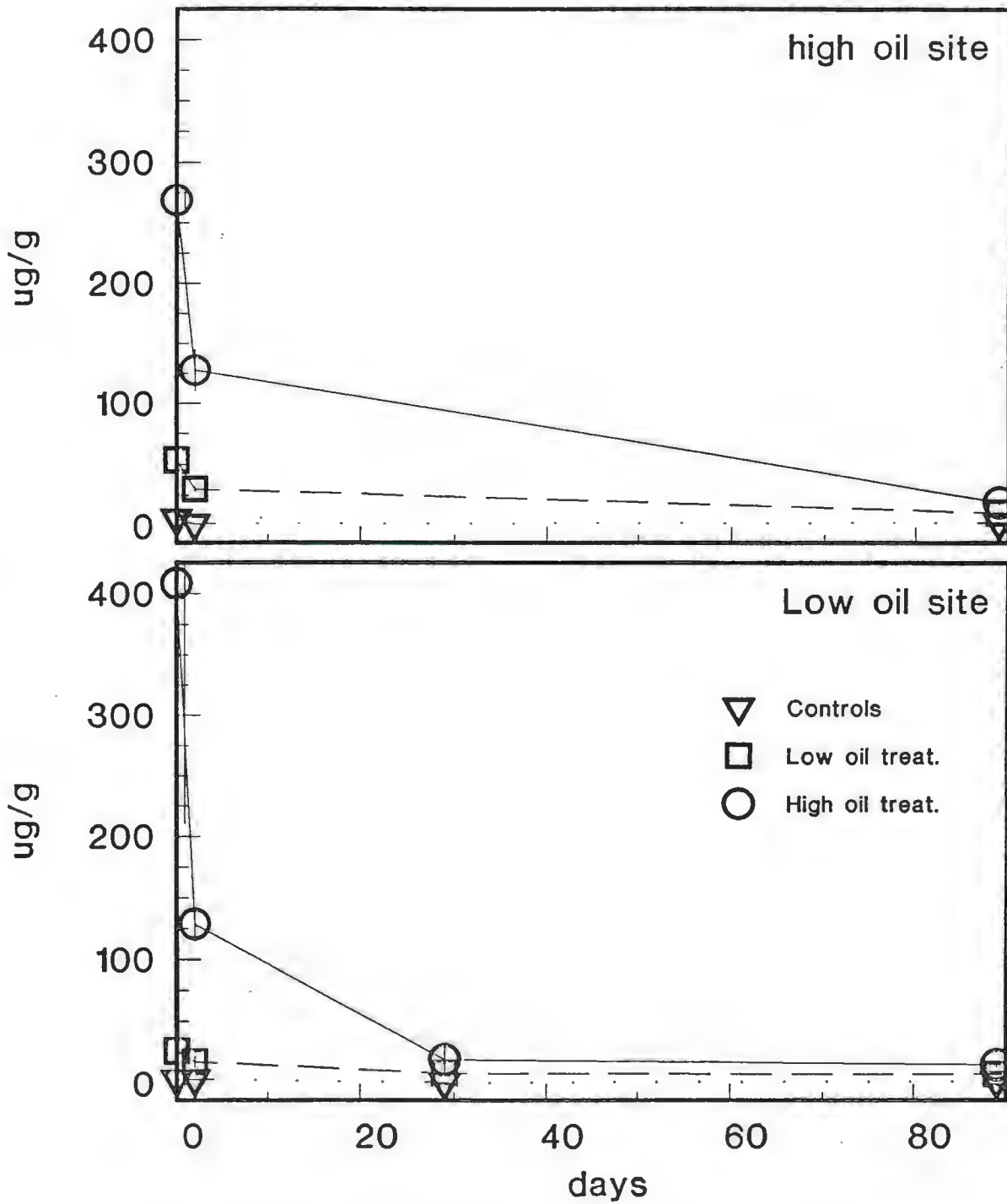
Figure 5.18. Aromatic hydrocarbon concentration (micrograms/gram) in treated meiofauna sediments over time.
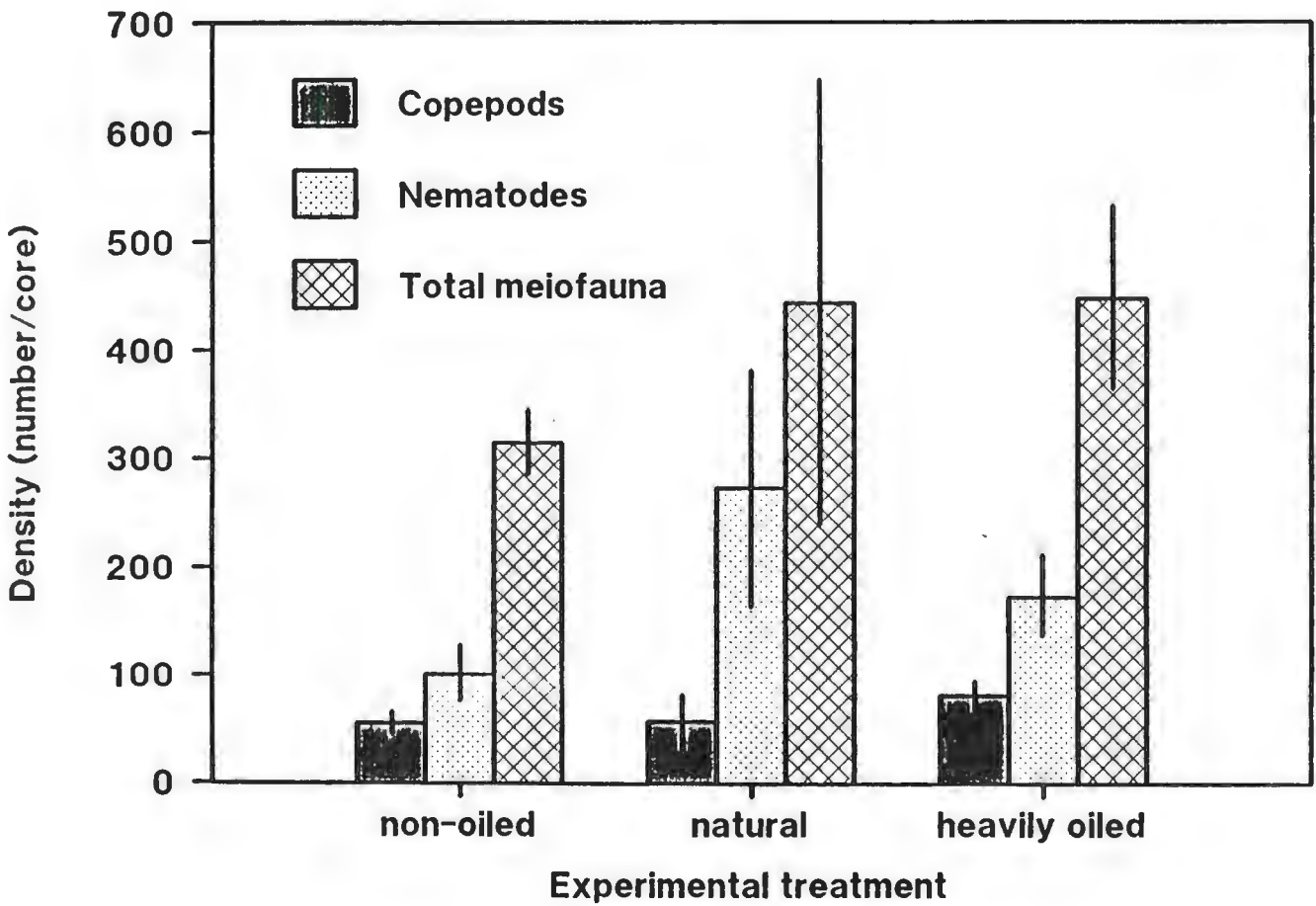
Figure 5.19. Preliminary densities of meiofauna in experimental treatments and natural sediments in a heavily oiled cove 29 d after the experiment began. Error bars are ±1 standard error.
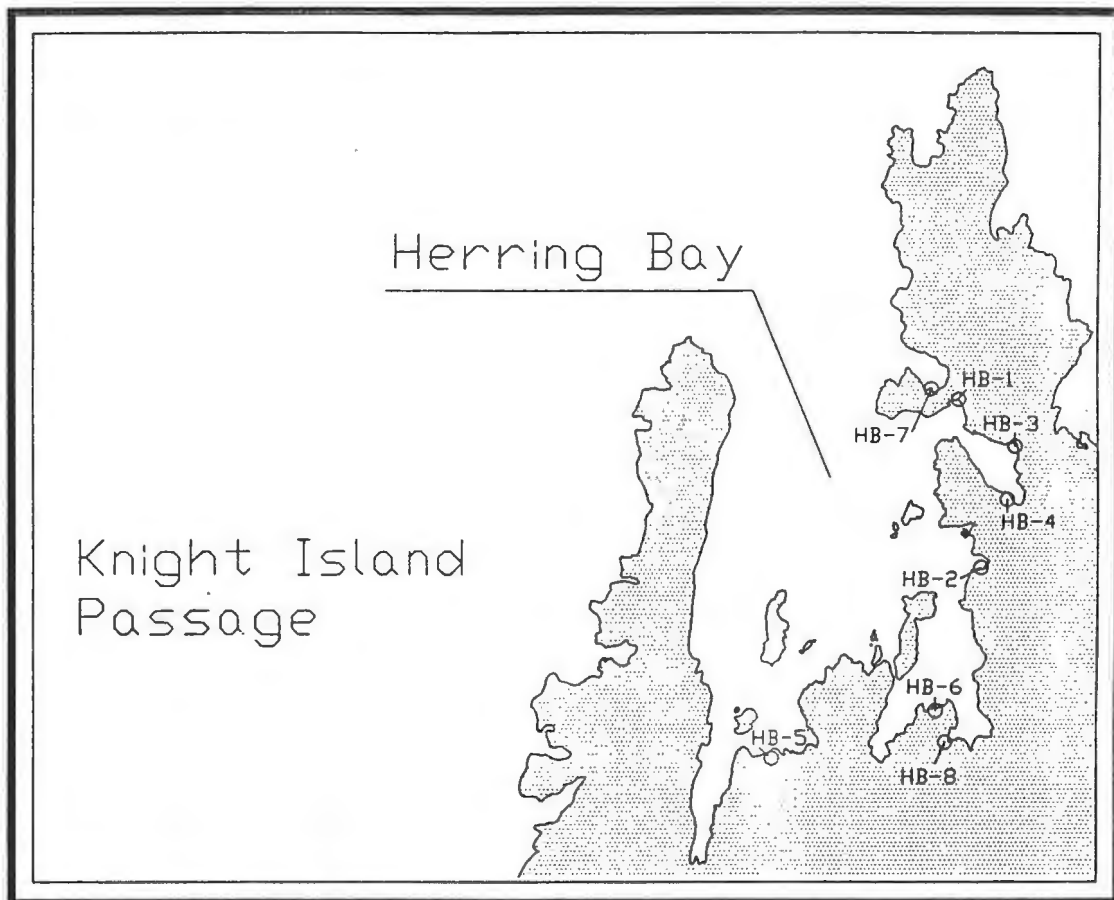
Appendix 5.1A. Locations of epibenthic pump transects in Herring Bay in 1990.
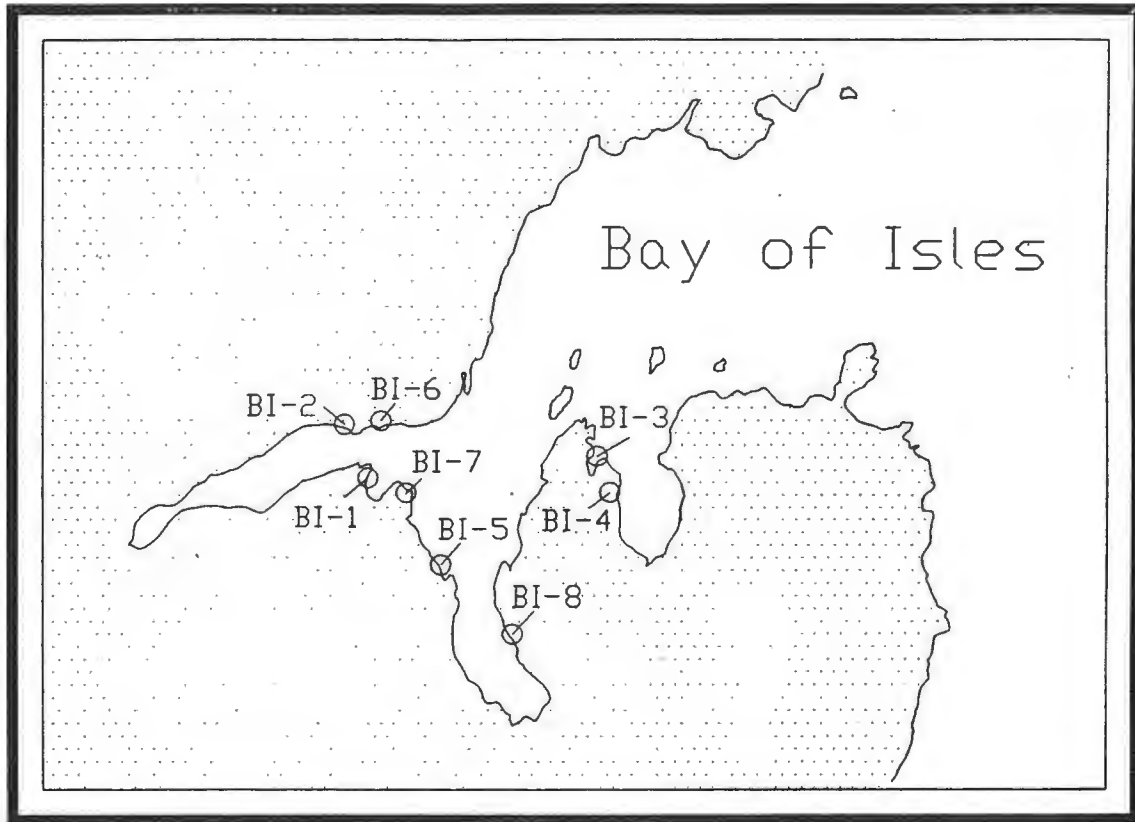
Appendix 5.1B. Location of epibenthic pump transects in Bay of Isles in 1990.

Herring Bay

Knight Island
Passage

HBH

HBL
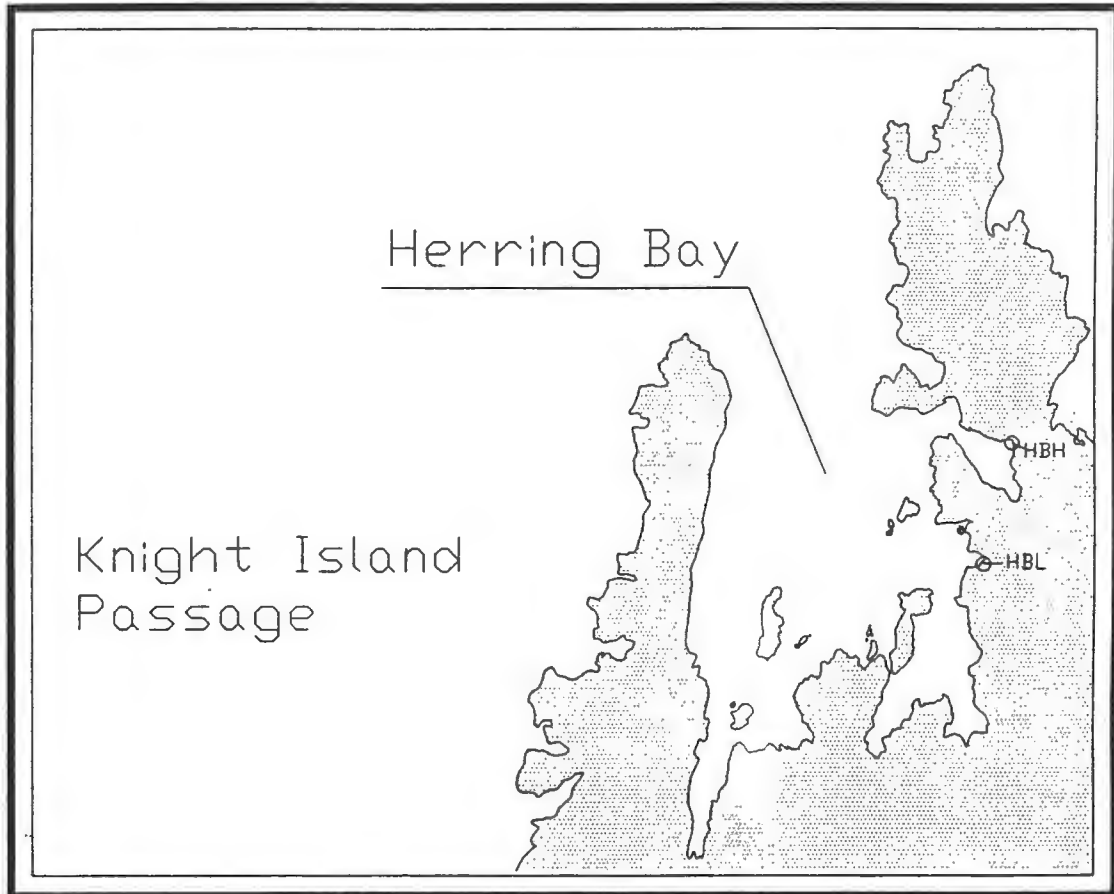
Appendix 5.1C. Sites where azoic sediments were buried to examine
meiofauna colonization. HBL = Lightly-oiled site; HBH = heavily-oiled
site.

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.
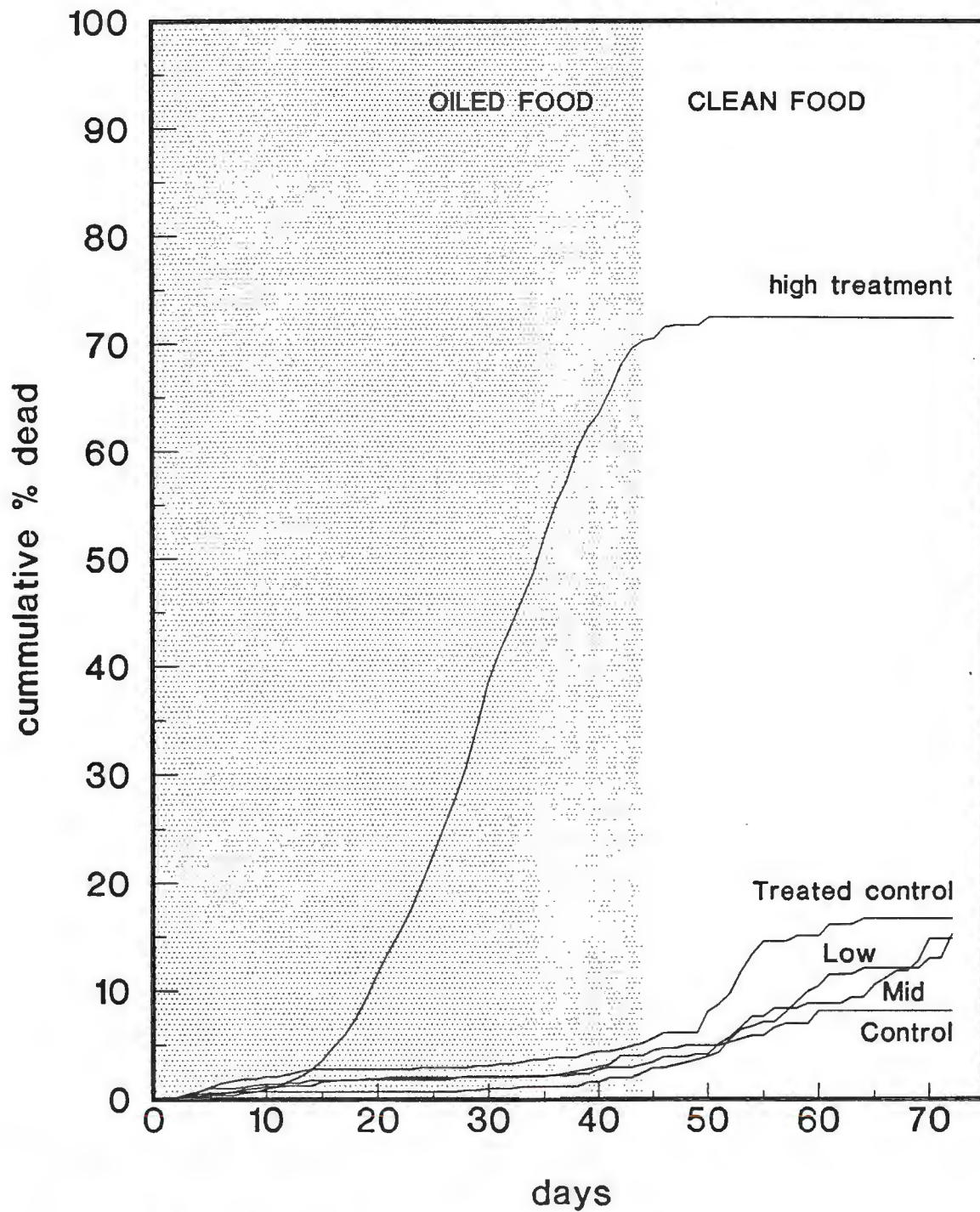
Figure 6.1--Cumulative fry mortality over time. Shaded region indicates period where fry received oiled food. For clarity, data from only 1 of 3 replicates is presented (replicate 3).
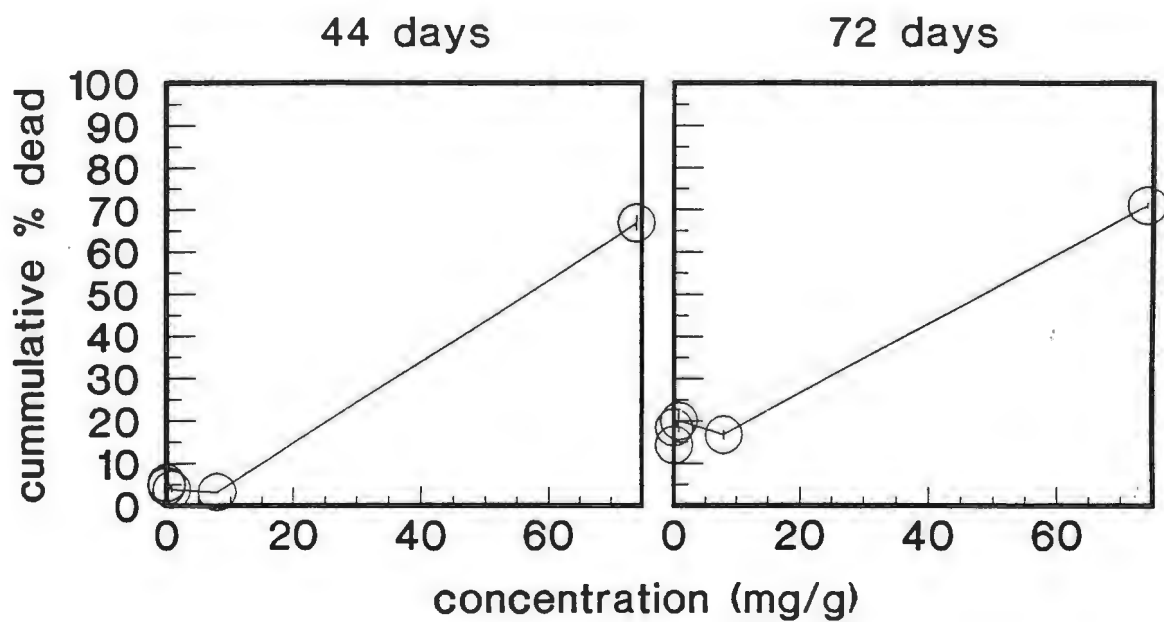
Figure 6.2--Cumulative fry mortality as a function of concentration, measured at the end of the uptake period (44 d) and at the end of the experiment (72 d). Error bars are $\pm$ 1 standard error.
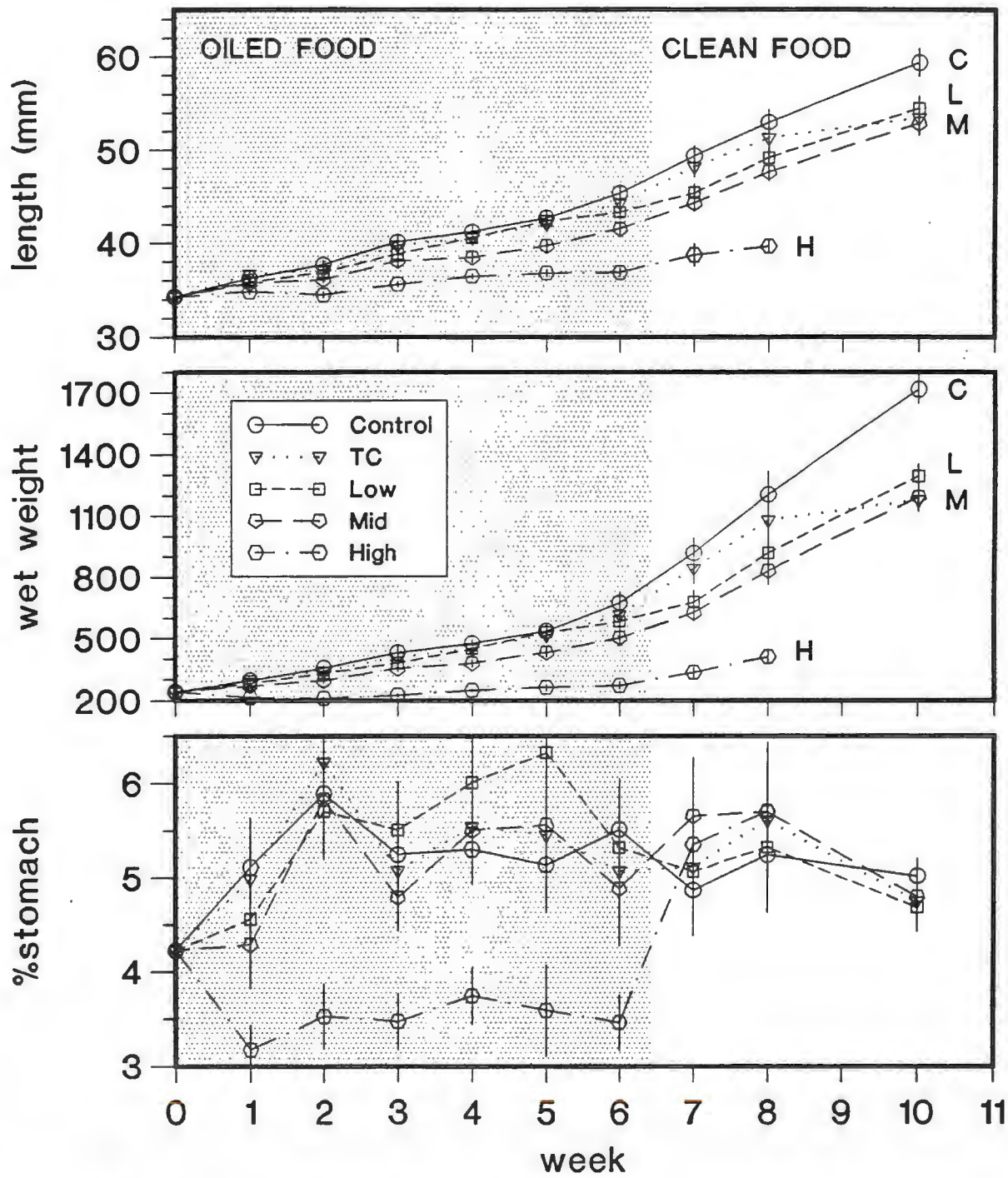
Figure 6.3--Time series showing changes in length, wet weight and % stomach weight. Error bars define the 95% confidence interval.
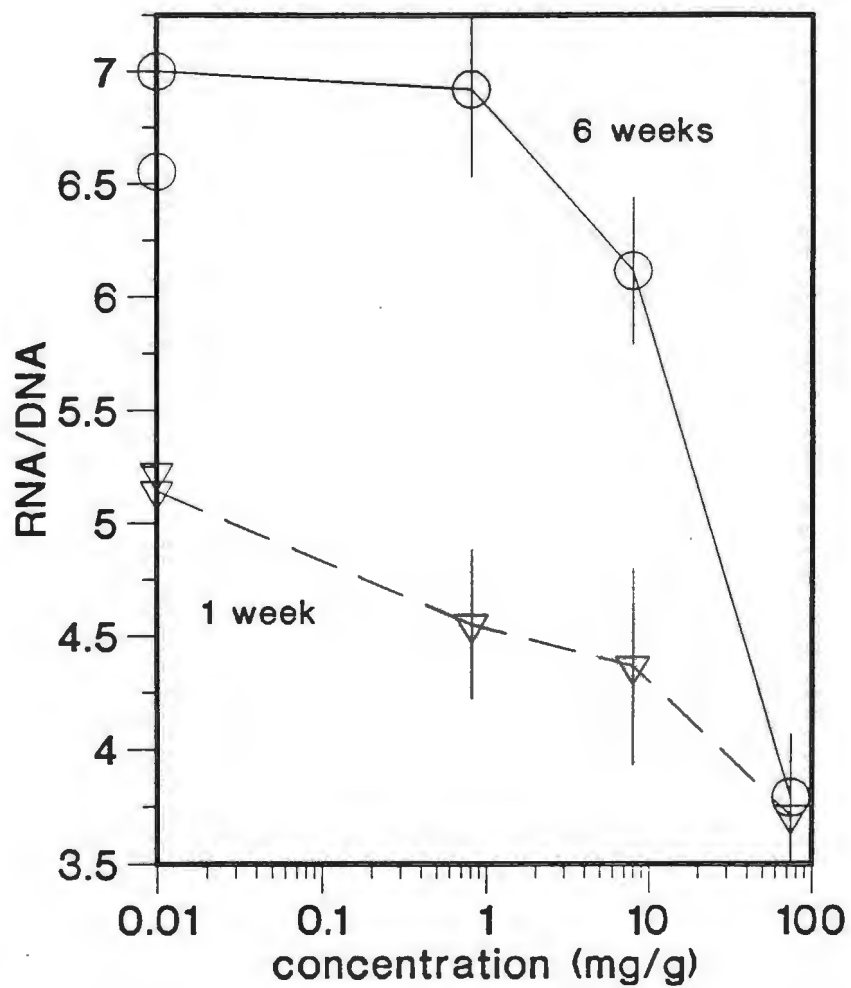
Figure 6.4--RNA/DNA ratios, measured 1 and 6 weeks after exposure, as a function of concentration. Error bars are ± 1 standard error.

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

7.3

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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