Chapter 3

95320E Juvenile Salmon and Herring Integration

Exxon Valdez Oil Spill
Restoration Project Annual Report

Sound Ecosystem Assessment: Juvenile Salmon & Herring Integration

Restoration Project 95320E
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil spill Trustee Council Restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: This project was initiated under Restoration project 94320E. An annual report was issued in 1994 by Willette, M., E. Debevec, Jay Johnson under the title Sound Ecosystem Assessment: Salmon Predation. The project effort was continued under Restoration Project 95320E, the subject of this annual report. In 1996, this project will be merged with project 96320A. A final report will be prepared for both projects in FY98.

Abstract: This project is a component of the Sound Ecosystem Assessment program. The project collected data needed to test several hypotheses related to predator-prey interactions affecting the mortality of pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound. Diel studies were conducted at sixteen study sites during four sampling periods in both May and June, 1995. As in 1994, Age 3+ pollock and herring were found to be important predators on juvenile pink salmon in pelagic habitats. However, sampling with various kinds of fixed gear revealed that age 1-2 pollock, tomcod and benthic fishes (greenlings and sculpins) may be important predators on juvenile salmon in nearshore habitats. It was also apparent that significant interannual variability occurs in seasonal patterns of fish predator abundance and diet composition. We were somewhat surprised to find that the strength of tidal currents in narrow passages may affect the distribution, feeding rate, and diet composition of age 3+ pollock. A period of peak tidal range in mid-May was related to a marked decline in pollock catch per effort in the 0-40m layer, a sharp reduction in stomach fullness, and a shift in diet composition from large copepods to pteropods. Analysis of coded-wire tag data from the 1995 pink salmon return indicated that survival to adult was related to tidal range at the time fry were released from the Wally H. Noerenberg Hatchery in 1994. This result suggests that our observations of pollock distribution and feeding related to tidal range may have important ramifications for pink salmon survival.

Key Words: *Exxon Valdez*, pink salmon, *Oncorhynchus gorbuscha*, Pacific herring, *Clupea pallasi*, walleye pollock, *Theragra chalcogramma*, Pacific tomcod, *Microgadus proximus*, mortality, predation, food habits.

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Executive Summary

This project is a component of the Sound Ecosystem Assessment (SEA) program. SEA is a multi-disciplinary effort to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of pink salmon and herring production in Prince William Sound (PWS). Pink salmon runs to PWS failed in 1992 and 1993, and herring biomass dropped sharply in 1993. These run failures have drastically affected the economy of the PWS region which is largely based on the salmon and herring resources. This project collected data needed to test several hypotheses related to predator-prey interactions affecting the mortality of pink salmon (*Oncorhynchus gorbuscha*) in PWS. Several other projects within SEA also contribute to this hypothesis testing effort. These hypotheses include the following concepts (1) predation on juvenile salmon and other age 0 fish is inversely related to the abundance of large calanoid copepods, (2) predation risk is related to the daily foraging times of juvenile salmon, and (3) spatial patterns of adult pink salmon production are related to the distribution of large calanoid copepods and walleye pollock during the early marine period. This project was designed to achieve the following objectives: (1) estimate the juvenile salmon consumption rate of fish predators at 16 study sites in northwest PWS, (2) estimate the species/size composition of fish predators at 16 study sites in northwest PWS, (3) conduct preliminary tests of predator/prey hypotheses, (4) examine the relationship between the abundance and diet composition of walleye pollock and tidal range, and (5) estimate the proportion of the diet comprised of juvenile herring as well as total annual consumption of herring for several important fish predators in PWS.

Diel studies were conducted at four study sites during each of four time periods in northwest PWS. Each nearshore study site consisted of an approximately 3000 m long segment of shoreline. Fish sampling was generally conducted at 4 stations located along 3-4 transects perpendicular to the shoreline every 3 hours throughout a 24-hour period. Four vessels were employed to sample fish predators. An approximately 25 m vessel sampled fish in offshore areas using a mid-water wing trawl. Two purse seine vessels sampled fish in the upper 20 m of the water column in nearshore areas with bottom depths greater than 20 m. In nearshore areas shallower than 20 m, variable mesh sinking gill nets, hoop traps, and fyke nets were used to sample fish predators.

As in 1994, age 3+ pollock and herring were found to be important predators on juvenile pink salmon in pelagic habitats. However, sampling with various kinds of fixed gear revealed that age 1-2 pollock, Pacific tomcod and benthic fishes (greenlings and sculpins) may be important predators on juvenile salmon in nearshore habitats. It was also apparent that significant interannual variability occurs in seasonal patterns of fish predator abundance and diet composition. We were somewhat surprised to find that the strength of tidal currents in narrow passages may affect the distribution, feeding rate, and diet composition of age 3+ pollock. A period of peak tidal range in mid-May was related to a marked decline in pollock catch per effort in the 0-40m layer, a sharp reduction in stomach fullness, and a shift in diet

composition from large copepods to pteropods. Analysis of coded-wire tag data from the 1995 pink salmon return indicated that survival to adult was related to tidal range at the time fry were released from the Wally H. Noerenberg Hatchery in 1994. This result suggests that our observations of pollock distribution and feeding related to tidal range may have important ramifications for pink salmon survival.

Introduction:

This project is a component of the Sound Ecosystem Assessment (SEA) program. SEA is a multi-disciplinary effort to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of pink salmon and herring production in Prince William Sound (PWS). Pink salmon runs to PWS failed in 1992 and 1993, and herring biomass dropped sharply in 1993. These run failures have drastically affected the economy of the PWS region which is largely based on the salmon and herring resources. In 1992, pink salmon returns were low in Kodiak, Lower Cook Inlet, and PWS, but pink salmon returns in 1993 were low only in PWS. Low returns of hatchery-produced salmon in both years indicates that the failures were likely caused by processes occurring during the juvenile lifestage. Damage assessment studies on juvenile pink salmon in PWS have demonstrated that growth during the juvenile lifestage is related to survival to adult (Willette et al. 1994). Growth rates of juvenile salmon were estimated in 1991 and 1992 after the fish were released from hatcheries. Juvenile growth and ocean temperatures were low in PWS during the early marine period in 1991. However, in 1992 juvenile growth and ocean temperatures were near average; although, zooplankton abundance was very low. The growth of juvenile fishes is believed to be related to survival, because slow-growing individuals are vulnerable to predators for a longer time (Parker 1971; Healey 1982; West and Larkin 1987). The growth and mortality rates of juvenile salmon released into PWS in 1992 suggests that a change in predation rate may have contributed to the observed run failures.

This is a multi-year project designed to test several hypotheses regarding mechanisms that may regulate predation on juvenile salmon and other age-0 fish in PWS. Regulation of prey population size by a predator requires that prey mortality rate increase with prey population size (i.e density-dependent mortality; Holling 1959). Intense predation immediately after ocean entry may have contributed to poor survival of relatively large release groups of hatchery-reared coho salmon (Bayer 1986, Olla and Davis 1989, Pearcy 1992). Learned behavior or response to environmental cues may cause predators to aggregate in areas where prey are consistently abundant (Ware 1971, Godin 1978). Alternatively, predation on a prey population may increase when the preferred prey of potential predators is not available (Werner and Hall 1974, Ringler 1979, Winfield et al. 1983). In the northern Gulf of Alaska, predators such as juvenile walleye pollock (Armstrong and Winslow 1968) that prefer macrozooplankton (Clausen 1983, Dwyer et al. 1987, Bailey 1989) may switch to age-0 fish when macrozooplankton abundance is low. Macrozooplankton abundance was very low in PWS in 1992 indicating that predators may have switched to juvenile salmon.

The daily foraging time of juvenile salmon and other age-0 fish may be related to predation risk (Walters and Juanes 1993). Juvenile salmon spend much of their time in nearshore nursery habitats (Cooney et al. 1981) that likely provide a refuge from predation. This behavior is common among juvenile fish, and often juveniles must move out of the predation refuge to feed in areas where food abundance is greater (Helfman 1993). The amount of time spent feeding is likely related to food abundance and particularly the abundance of large calanoid copepods (Parsons and LeBrasseur 1973, Willette et al. 1994). High abundances of juvenile salmon or other age-0 fish may also lead to competition and increased foraging time and predation risk.

This project will provide data needed to test several of the predator\prey hypotheses posed by SEA investigators (See chapter 95320A, Salmon Growth and Mortality).

Objectives:

Original objectives in detailed project description for 95320E:

1. Estimate the juvenile salmon consumption rate of fish predators at 16 study sites in northwest PWS.
2. Estimate the species/size composition of fish predators at 16 study sites in northwest PWS.
3. Conduct preliminary tests of predator/prey hypotheses.

Objectives added as result of new information obtained in FY95:

4. Examine the relationship between the abundance and diet composition of walleye pollock and tidal range.
5. Estimate the proportion of the diet comprised of juvenile herring as well as total annual consumption of herring for several important fish predators in PWS.

Methods:

This study examined the relationship between the daily foraging time of juvenile pink salmon and predation risk modulated by changes in prey abundance and juvenile salmon abundance. This approach required sampling at a number of sites exhibiting a range of both prey abundance and juvenile salmon abundance. Four nearshore study sites were sampled in western PWS during each of four time periods. In FY95, we also sampled at three sites thought to be juvenile herring rearing areas during each of two time periods in southeast PWS (Figure 1). The large releases of juvenile salmon from the Wally H. Noerenberg (WHN) Hatchery provide an opportunity to investigate processes regulating the growth and mortality of juvenile pink salmon. Comparison of survival rates of hatchery-reared salmon and return per spawner of wild salmon suggests that similar mortality processes may be affecting both groups (See chapter 95320A, Salmon Growth and Mortality). Results from the first year of this project indicate that similar process-oriented studies may not be feasible in areas of much lower juvenile salmon abundance due to difficulties in measuring juvenile salmon consumption rates of fish predators (Willette et al. 1995b).

Objective 1:

Identification of the principal fish predators on juvenile salmon requires estimation of the juvenile salmon consumption rate for each potential predator species. Fish biomass, food consumption rate (daily ration), and diet composition must be estimated for each potential predator species to estimate juvenile salmon consumption rate. Project 95320N estimated fish biomass using hydroacoustic techniques. Project 95320E estimated predator species/size composition, food consumption rate, and diet composition.

Diel studies were conducted at four study sites during each of four time periods in northwest PWS. Each nearshore study site consisted of an approximately 3000 m long segment of shoreline. Fish sampling was generally conducted at 4 stations located along 3-4 transects perpendicular to the shoreline every 3 hours throughout a 24-hour period (Figure 2). Four vessels were employed to sample fish predators. An approximately 25 m trawl vessel sampled fish in offshore areas using a 40 m x 28 m mid-water wing trawl equipped with a net sounder. The cod end of the trawl was lined with 1.5 cm stretch-mesh web to retain small specimens. Each tow was made approximately 1 km offshore parallel to the shore in the upper 40 m of the water column. At the first 4 study sites, a pair trawl (30 m x 30 m; codend 1.5 cm stretch mesh) was also used to sample fish in the upper 40 m of the water column. The pair trawl was fished using two approximately 15 m vessels working in tandem. Data from the pair trawl was used to evaluate the selectivity of the mid-water trawl. Two purse seine vessels sampled fish in the upper 20 m of the water column in nearshore areas with bottom depths greater than 20 m (stations 2-3). Each seiner fished a small-mesh purse seine (250 m x 30 m, 1.5 cm stretch mesh web) holding a hook with the seine open in the direction of the prevailing current for 20 minutes. In nearshore areas shallower than 20 m, variable mesh sinking gill nets (150 m, 1.5 cm to 10 cm stretch mesh), hoop traps (1.5 m diameter, 1.5 cm stretch mesh), and fyke nets (1.5 m diameter, 1.5 cm stretch mesh in codend) were used to sample fish predators. These gear were deployed from an approximately 6 m aluminum skiff at the station nearest to shore (station 1) along each transect. A hotel boat provided room and board for field sampling crews. All sample processing was conducted on board the hotel boat by a single processing crew.

Processing of fish samples from each net set occurred in two stages following procedures outlined by Livingston (1989) and Dwyer et al. (1987). If less than 300 fish were captured, all fish in the catch were enumerated by species. If a large number of fish were caught, species composition was estimated from a random sample of 300 individuals. Fish greater than 150 mm FL were processed differently than those less than 150 mm FL.

Fish less than 150 mm FL were identified to the lowest possible taxonomic level. A sample of 30 individuals from each species was preserved in 10% buffered formaldehyde for later analysis of stomach contents under project 95163 (Forage Fish Influence on Recovery of Injured Species). The purpose of these studies is to examine diet overlap among forage fish.

For large fish (greater than 150 mm FL), a randomly selected sample (n=60) from each net set and each species was taken. The stomach was excised, placed in a cloth bag, and preserved in 10% buffered formaldehyde for later analysis of stomach contents. Fish showing evidence of regurgitation were not included in the sample. Fork length was measured to the nearest millimeter. Weight was measured to the nearest gram when conditions permitted. Sex and sexual maturity was recorded. Later in the laboratory, total stomach contents wet weight was measured to the nearest .01 gram. Invertebrate prey in the gut were generally identified to the family level. Fish in the gut were identified to the lowest possible taxonomic level, enumerated, and measured to the nearest millimeter. The proportion of total stomach contents in each taxonomic group was visually estimated. Stomach fullness was expressed as a proportion of fish body weight. In cases where distinct size classes occurred within species, stomach contents analysis was conducted for each size class as described above. Size related shifts in diet toward piscivory have been noted in several species of gadoid fishes, including Pacific cod (*Gadus macrocephalus*) (Livingston 1989), walleye pollock (*Theragra chalgogramma*) (Dwyer et al. 1987), Atlantic cod (*Gadus morhua*) (Daan 1973), Pacific whiting (*Merluccius productus*) (Livingston 1983), and silver hake (*Merluccius bilinearis*) (Langton 1982).

Techniques developed by Mehl and Westgard (1983) were used to develop at preliminary order-of-magnitude estimate the juvenile salmon consumption rate of pelagic pollock in northwest PWS in 1994, i.e.

$$C_i = DR \times B_i \times P_i \tag{1}$$

where C_i is the consumption (grams) of juvenile salmon by pollock during each ten-day sampling period (i), DR is the daily ration (% body weight per day), B_i is the biomass (grams) of pollock during sampling period (i), and P_i is the proportion by weight of juvenile salmon in pollock stomachs during sampling period (i). Acoustic biomass estimates for pelagic pollock were provided by project 95320N. No biomass data was available for the first sampling period in late April, so the biomass estimate from early May was used. Target strength and net catch data indicated that the majority of pelagic pollock were age 3+ fish greater than 40 cm in length. It was assumed that the daily ration of these age 3+ pollock was 0.6 % body weight per day (Lang et al. 1991). Lang et al. (1991) estimated daily ration from annual growth increments of pollock in the eastern Bering Sea and gross growth conversion efficiency. Comparison of size-at-age for pollock in the eastern Bering Sea and PWS indicated that the growth rates of the two stocks were similar.

An analysis of variance was conducted to test for differences in the mean percent of predator diets comprised of juvenile salmon among four time periods in May and June, 1995. Data were arcsin square root transformed prior to conducting the test (Zar 1984). Due to small sample sizes, Pacific cod (*Gadus macrocephalus*) and Pacific tomcod (*Microgadus proximus*) were pooled in the analysis, as well as, several species of sculpins and greenlings (*Hemilepidotus hemilepidotus, Myxocephalus verrucosus, Hexagrammos decagrammus, Hexagrammos octogrammus, Blepsias bilobus*). All specimens were initially included in the analysis to examine changes in diet for the population within each taxonomic group as a whole. The analysis was also conducted with only specimens found to consume juvenile salmon included. This was done to examine whether individual predators were targeting juvenile salmon. The percent frequency of occurrence of juvenile salmon in predator diets was also calculated to determine the proportion of the population within each taxonomic group that was consuming juvenile salmon. An analysis of variance was conducted to test for differences in mean stomach fullness of juvenile salmon predators among four time periods. Data were arcsin square root transformed prior to conducting the test (Zar 1984). Finally, an analysis of variance was conducted to test for changes in the mean catch per net set of juvenile salmon predators among four time periods. This was done to evaluate differences in the relative abundance of fish predators over time. Data were generally square-root transformed prior to conducting the test. However, trawl data was expressed as natural-logarithm of catch per hour of tow.

Objective 2:

The species/size composition of the fish predators in each study area was estimated from net samples collected as described in objective 1. Species/size composition data from net samples will be used by the Nearshore Fish component of SEA to estimate the species/size composition of hydroacoustic targets. As much as possible, net sampling was paired with hydroacoustic sampling for this purpose. On board each sampling vessel, all fish were identified to the lowest possible taxonomic level. If a large number of fish were caught, species composition was estimated from a random sample of 300 individuals. Length was measured for a randomly selected subsample (n≈60) from each species in the catch.

Objective 3:

Sub-hypothesis I-1.

The juvenile salmon consumption rate of age 1+ walleye pollock during the initial 30 days of marine residence was estimated as described in objective 1. An estimate of the juvenile salmon consumption rate of seabirds was obtained from the project 95320Y. The two estimates were summed to evaluate the relative magnitude of juvenile salmon consumption by these two taxonomic groups.

Sub-hypothesis I-2.

Deferred until FY96 when abundance estimates will be available for herring and adult salmon.

Sub-hypothesis II-1.

An analysis of covariance was conducted to test for a relationship between the mean proportion of the diet comprised of large calanoid copepods and the mean proportion of the diet comprised of age-0 fish at each sampling site. Analysis of covariance was also used test for a relationship between the mean proportion of the diet comprised of large calanoid copepods and the mean abundance of large calanoid copepods at each sampling site. Regression analysis was employed to estimate the parameters of the relationships. Diet composition was estimated as described in objective 1. Diet proportions were arcsin square root transformed (Zar 1984). Methods used to collect and analyze zooplankton samples are described in chapter 95320A (Salmon growth and mortality). Only fish species found to consume juvenile salmon in 1995 were used in the analysis.

Sub-hypothesis II-2.

Analysis of variance was employed to test for differences in the mean proportion of juvenile salmon in predator diets in relation to the mean relative abundance (low: $<50\ m^{-3}$, moderate: $>50\ m^{-3}$ and $<100\ m^{-3}$, and high: $>100\ m^{-3}$) abundance of large calanoid copepods at each sampling site. Methods used to collect and analyze zooplankton samples are described in chapter 95320A (Salmon growth and mortality). Diet composition was estimated as described in objective 1. Diet proportions were arcsin square root transformed. Only fish species found to consume juvenile salmon in 1995 were used in the analysis.

Sub-hypothesis II-3.

The proportion of juvenile salmon less than 60 mm FL was estimated from measurements of juvenile salmon in predator stomachs. Chi-square analysis was conducted to test for a difference in length frequencies between juvenile salmon found in predator stomachs and those captured alive during each sampling period. The length frequency proportions for the live fry were subtracted from the length frequency proportions for the prey fry in each length interval to evaluate the nature of selectivity.

Sub-hypotheses II-4 and II-5.

See chapter 95320A, Salmon Growth and Mortality.

Sub-hypothesis III-1.

Analysis of variance was employed to test for differences in catch per unit effort of predators in nearshore nursery habitats during four sampling periods in May and June, 1995. Only fish species known to consume juvenile salmon were included in the analysis. Net set was used as the sample unit in the analysis.

Sub-hypothesis III-2.

Deferred until FY96 when ocean temperature, acoustic and net catch data will be integrated.

Sub-hypotheses III-3 through III-5.

See chapter 95320A, Salmon Growth and Mortality.

Sub-hypothesis III-6.

Deferred until FY96 when estimates of daily foraging time of juvenile salmon will be available (See chapter 95320A, Salmon growth and mortality).

Sub-hypothesis IV-1.

See chapter 95320A, Salmon Growth and Mortality.

Sub-hypotheses IV-2 and IV-3.

Deferred until FY96 when otolith thermal marked juvenile pink salmon will be released from all PWS hatcheries.

Hypothesis V.

Deferred until FY96 when the spatial pattern of adult pink salmon production from the 1995 outmigration will be known.

Objective 4:

The relationship between tidal range and seasonal changes in the relative abundance of pollock in nearshore and offshore habitats was examined in a time series plot. Catch per hour of tow in mid-water trawl gear was used to estimate changes in relative abundance of pollock in offshore habitats. The mid-water trawl was generally fished in the upper 40 m of the water column. Catch per net set in purse seines and fixed gear was used to estimate changes in relative abundance of pollock in nearshore habitats. Catch per effort data were natural-logarithm transformed. Tide data was obtained from software provided by NOAA. A regression analysis was conducted to estimate the parameters of the relationship between tidal range and natural logarithm of pollock catch per hour of tow in offshore habitats. Seasonal changes in pollock stomach fullness and diet composition were examined in time series plots. Methods used to estimate stomach fullness and diet composition are described under objective 1. Finally, a regression analysis was conducted to estimate the parameters of the relationship between tidal range and fry-to-adult survival for juvenile pink salmon released from the WHN Hatchery in 1994. The tidal range on the date of fry release was the independent variable in the analysis.

Objective 5:

The percent of the diet comprised of juvenile herring was estimated from analyses of stomach contents of fish predators as described under objective 1. Estimates were derived for northwest and southwest PWS in 1994 and northwest and southeast PWS in 1995. The sites sampled in southeast PWS in 1995 were thought to be rearing areas for herring. The other sites were selected primarily to examine predation processes affecting juvenile salmon. Equation 1 was used to estimate the annual consumption of herring by pollock, arrowtooth flounder (*Atheresthes stomias*), and Pacific cod in PWS. Biomass estimates for these fish predators were obtained from a bottom trawl survey conducted in PWS in 1989. The proportion of the diet comprised of herring for these fish predators was obtained from Yang (1993), and estimates of daily ration were obtained from Lang et al. (1991).

Results:

Objective 1:

Prelimnary estimates of consumption of juvenile salmon by walleye pollock indicated that approximately 5 million salmon may have been consumed prior to the middle of June, 1994 (Table 1). Assuming that all of the juvenile salmon consumed were from the WHN Hatchery, this total consumption accounts for about 3% of the 153 million juveniles released from WHN Hatchery.

The mean percent of the diet comprised of juvenile salmon increased significantly (P<.001) over time for age 1-2 pollock and decreased significantly (P=.041) over time for age 3+ pollock (Table 2). There was a marginally significant decrease (P=.063) in the mean percent of the diet comprised of juvenile salmon for nearshore benthic fish (Table 2). When only specimens consuming juvenile salmon were included in the analysis, there were no significant differences in the mean percent of the diet comprised of juvenile salmon for any of these fish predators (Table 3). The mean percent of the diet comprised of juvenile salmon was greater than 50% for cod, age 1-2 pollock, dolly varden trout, and nearshore benthic fish (Table 3). The percent frequency of occurrence of juvenile salmon in the diet was greatest for age 1-2 pollock, sockeye salmon, and dolly varden trout (Table 4). Significant differences in mean stomach fullness were detected for 5 out of 8 taxonomic groups found to consume juvenile salmon (Table 5). Mean stomach fullness of age 1-2 pollock was greater during early June (P<.001) when the percent of juvenile salmon in the diet was high. Stomach fullness of age 3+ pollock and nearshore benthic fish generally increased from early May to mid-June (Table 5). Significant differences in mean catch per net set over time were detected for herring and adult chum salmon (Table 6). Total consumption of juvenile salmon by these fish predators will be estimated in FY96 when acoustic biomass estimates will be available.

Objective 2:

Five of the eight taxonomic groups found to consume juvenile salmon exhibited length modes at about 20 cm (Figure 3). Age 3+ pollock, sockeye salmon, and chum salmon were the only taxonomic groups that generally exceeded 40 cm in length.

Objective 3:

Sub-hypothesis I-1.

Losses of juvenile salmon prior to the middle of June, 1994 may have exceeded 100 million (See chapter 95320A, Salmon growth and mortality). An estimated 2.7-5.9 million juvenile salmon may have been consumed by seabirds near the WHN Hatchery in 1995 (See chapter 95320Y, Variation in local predation rates on hatchery-released fry). Seabirds numbered in the hundreds near the WHN Hatchery in 1995. However, in 1994 we observed perhaps thousands of seabirds (mostly kittiwakes) apparently feeding on fry near the WHN Hatchery. Thus, seabird consumption of juvenile salmon in 1994 may have been as much as ten times greater than in 1995. Pelagic walleye pollock may have consumed approximately 5 million juvenile salmon prior to the middle of June, 1994 (Table 1). However, this is likely a minimum estimate because pollock biomass in the 0-5 m layer and 125-400 m layers was not estimated. In addition, pollock daily ration may be greater if pollock are glut feeding at the surface then descending to depth (Clark and Green 1990). Also, we did not assess pollock biomass or feeding in nearshore areas less than 10 m in deep in 1994. At the present time, data are not sufficient to reject Sub-hypothesis I-1.

Sub-hypothesis II-1.

Results from an analysis of covariance indicated that the intercept and slope of the relationship between the proportion of the diet comprised of age-0 fish and the proportion of the diet comprised of large calanoid copepods was significantly different (P=.001) among the seven species of fish predators included in the analysis. Examination of the parameters of the relationship for each fish species indicated that the proportion of the diet comprised of age-0 fish was significantly related to the proportion of the diet comprised of large calanoid copepods for herring (P<.001) and age 1-2 pollock (P<.001, Table 7). The proportion of the diet comprised of large calanoid copepods was significantly related to the mean abundance of large calanoid copepods at each sampling site for herring, age 1-2 pollock and age 3+ pollock (Table 8). This result supports the hypothesis that herring and age 1-2 pollock switched to feeding on age-0 fish when densities of large calanoid copepods declined. However, for age 3+ pollock other alternative prey were consumed after the seasonal decline in copepod abundance (Figure 9).

Sub-hypothesis II-2.

The mean relative abundance of large copepods at each sampling site was not significantly related to the proportion of the diet comprised of juvenile salmon for any of the seven species of fish predators included in the analysis (Table 9). This result taken in conjunction with those described under sub-hypothesis II-1 indicates that consumption of juvenile salmon may not be correlated with consumption of age-0 fish in general. This may be because juvenile salmon occupy habitats very near to shore. Predators in these nearshore habitats may experience a different set of alternative prey densities compared to the mean conditions in the area. This is because juvenile salmon occur in dense schools in nearshore habitats, and zooplankton layers in offshore habitats may be disrupted nearshore due to frictional boundary processes (See chapter 95320A: Salmon growth and mortality).

Sub-hypothesis II-3.

The length frequencies of juvenile salmon found in predator stomachs and juvenile salmon captured alive in nearshore nursery habitats were significantly different in the first (P=.001), second (P=.001), third (P=.013), and fourth (P=.005) sampling periods. The length frequency differences indicated that predators generally selected smaller juvenile salmon in all sampling periods (Figure 4). Of the total number of juvenile salmon consumed, 100% were less than 60 mm FL in the first and second time periods (Figure 4). During the third and fourth time periods, 85% were less than 60 mm FL. These results support the hypothesis that predation risk is substantially less for juvenile salmon greater than 60 mm FL. However, we did not sample after the middle of June in 1995 when the mean length of the fry population exceeded 60 mm FL.

Sub-hypothesis III-1.

There were no significant differences in catch per net set for cod, age 1-2 pollock, age 3+ pollock, dolly varden trout, or nearshore benthic predators during four sampling periods in May and June, 1995. Significant differences in mean catch per net set among sampling periods were detected for herring and adult chum salmon (Table 6). No clear seasonal increase in herring catch per net set was detected. This result contrasts with apparent seasonal changes in fish abundance in 1994 (Willette et al. 1995b). These difference in seasonal patterns of abundances may be related to differences in ocean temperature between 1994 and 1995 (Figures 5 & 6). At the present time, we must reject the hypothesis that fish abundances increase substantially from May to June. Rather, it appears that there is significant interannual variability in the timing of these events.

Objective 4:

In 1995, approximately sixty percent of the variance in pollock catch per effort was related to tidal range in offshore habitats of northwest PWS (Figure 7). A peak in tidal range in the middle of May corresponded with a marked decline in pollock catch in offshore habitats. However, pollock catch in nearshore habitats declined only slightly during the period of peak tidal range. Stomach fullness and diet composition of pollock was also apparently related to tidal range. During the period of peak tidal range, stomach fullness declined (Figure 8). Prior to the period of peak tidal range in mid-May, pollock diets were comprised primarily of large calanoid copepods (Figure 9). During the period of peak tidal range, the proportion of the diet comprised of amphipods and euphausiids increased considerably. After the period of peak tidal range, pollock switched to feeding primarily on pteropods. Consumption of euphausiids peaked again in mid-June coincident with another increase in tidal range and decline in pollock catch. Consumption of age-0 fish was apparently not related to changes in tidal range (Figure 9). However, the proportion of the diet comprised of juvenile salmon declined during the period of peak tidal range. In 1994, survival to adult was significantly related to tidal range on the date each group of fry was released from the WHN Hatchery (Figure 10).

Objective 5:

The percent of the diet comprised of herring was generally very low in both northwest and southwest PWS in 1994 (Table 10). However, 47% of the diet of dolly varden trout was comprised of herring. A similar pattern was observed in 1995 in northwest PWS (Table 11). However, at herring rearing areas in southeast PWS, the percent of the diet comprised of herring was much greater (Table 11). Length frequencies of herring in net catches and those found in predator stomachs indicated that predators likely select juvenile herring less than 170 mm SL (Figure 11). The percent of the diet comprised of herring in southeast PWS was similar to that reported by Yang (1993) for both Pacific cod and pollock (Tables 11 & 12). Estimated annual consumption of herring was greatest for arrowtooth flounder (Table 12).

Discussion:

Sampling with fixed gear in nearshore habitats in 1995 revealed several additional fish species that may be important predators on juvenile salmon. In 1994, fish predators were sampled with a mid-water trawl and purse seines. Age 3+ pollock, herring, adult pink salmon, and dolly varden trout appeared to be important predators on juvenile salmon in 1994 (Willette et al. 1995b). Fixed gear sampling in 1995 consisted of sinking gillnets, hoop traps, and fyke nets deployed on the bottom in nearshore habitats. These gear captured a greater number of age 1-2 pollock, tomcod and a variety of nearshore benthic fishes than was obtained in 1994. The proportion of the diet comprised of juvenile salmon was relatively high for age 1-2 pollock and tomcod (Table 2). Nearshore benthic fish may have consumed a relatively large number of juvenile salmon during early May (Tables 2 & 3). When only individuals found to consume juvenile salmon were included in the analysis, the proportion of the diet comprised of juvenile salmon was relatively high for all three of these taxonomic groups. This result indicates that these fish may at times target juvenile salmon. Bakshtanskiy (1964) concluded that juvenile pollack (*Pollachius virens*) and cod (*Melanogrammus morhua morhua*) were important predators on juvenile pink and chum salmon in the White Sea. He observed that juvenile pink and chum salmon were at times driven from nearshore nursery habitats by large schools of juvenile pollack and cod. We observed a similar event in late May when a large school of juvenile pollock appeared at night and apparently drove juvenile salmon offshore.

Diet data indicated apparent high consumption of juvenile salmon by age 1-2 pollock at that study site (Table 2). The proportion of the diet comprised of juvenile salmon was relatively low for age 3+ pollock and herring (Table 2); however, these species appear to be relatively abundant compared to the other taxonomic groups and their total consumption of juvenile salmon may be high (Tables 4 & 6). Bakshtanskiy (1964, 1965) concluded that predation by herring largely determined survival of juvenile pink and chum salmon in the Barents Sea and White Sea. Dolly varden trout appeared to be an important predator on juvenile salmon in both 1994 and 1995 (Willette et al. 1995b). The juvenile salmon consumption rate of each of these fish predators must be estimated to determine the relative importance of each group. Relative abundance or biomass estimates are needed for each taxonomic group to achieve this objective. It is difficult to accurately assess the relative abundance of the each taxonomic group from net catches due to differences in gear selectivity. Herring were caught primarily in purse seines, age 3+ pollock primarily in a mid-water trawl, and age 1-2 pollock, tomcod and nearshore benthic fish in fixed gear. More detailed analyses of acoustic data and application of video techniques (Collins et al. 1991, Irvine et al. 1991, DeMartini and Ellis 1995) are needed to estimate the relative abundance of each group.

Seasonal changes in fish abundance were very different in 1995 compared to 1994. In 1994, age 3+ pollock were relatively abundant in the 0-40 m layer in offshore habitats in late April and May. In early June, age 3+ pollock abundance in the 0-40 m layer declined, and abundances of herring, salmon, dolly varden trout, etc. increased markedly in nearshore habitats (Willette et al. 1995b). In 1995, catch per effort of age 3+ pollock was not significantly different among four sampling periods (Table 6). Catch per effort of herring was significantly different among sampling periods, but there was not a clear seasonal increase in abundance (Table 6). These differences in seasonal patterns of abundance may be related to differences in ocean temperature between the two years. In 1994, a substantial increase in fish catch in nearshore habitats coincided with a sharp increase in ocean temperature in early June (Figure 5). Ocean temperatures were slightly higher in May and lower in June in 1995 compared with 1994 (Figures 5 & 6). Rogers et al. (1986) noted a substantial seasonal increase in fish species diversity and density in Prince William Sound. In winter, fish distributions shifted further offshore and deeper in the water column (Rogers et al. 1986). Seasonal migrations of fish into deeper water in winter and shallow water in summer are well known (Trout 1957, Alverson 1960, Jean 1964, Heeseen 1983). These seasonal shifts in distribution may be related to temperature, light or food abundance (Laevastu and Hela 1970). Seasonal changes in the vertical distribution and activity patterns of cod have been related to seasonal stratification of the water column (Clark and Green 1990). In the present study, a more detailed analysis of fish distribution and water column structure is needed.

Seasonal changes in the distribution and diet composition of age 3+ pollock appear to be related to food abundance. In May 1994, age 3+ pollock fed primarily on large calanoid copepods in the upper 40m of the water column (Willette et al. 1995b). During June 1994, consumption of large copepods declined, pollock catches in the 0-40m layer declined, and consumption of age-0 fish increased (Willette et al. 1995b). The decline in consumption of large copepods in June coincided with a decline in the biomass of late-stage *Neocalanus spp.*

in the upper 50 m of the water column (Cooney 1995). Increased consumption of age-0 fish coincided with increased net catches of age-0 pollock in all gear types (Willette et al. 1995). In 1995, a different pattern was evident. Age 3+ pollock fed primarily on large copepods in early May, switched to feeding on pteropods in June, and abundances in the 0-40m layer did not decline (Figure 9). It is apparent that choice of pelagic habitats by pollock is strongly affected by the density of zooplankton in the upper layers of the water column. Prey selection is likely a function of the relative profitabilities of alternative prey (Charnov 1976, Mittelbach 1981, Osenberg and Mittelbach 1989). Apparently, large copepods such as *Neocalanus spp.* are not the only zooplankton species that may occur in sufficient densities for profitable exploitation by age 3+ pollock.

Distribution, feeding rate, and diet composition of age 3+ pollock was apparently affected by tidal range in northwest PWS in 1995. During a period of high tidal range in mid-May, pollock catches in the 0-40m layer declined, stomach fullness declined, and diet composition shifted from predominately large copepods to amphipods and euphausiids (Figures 7-9). After the period of high tidal range, pollock catches increased, stomach fullness increased, and diet composition shifted to predominantly pteropods. Cooney (pers. comm.) postulated that these changes may be related to the effect of turbulence caused by strong tidal currents that disrupts zooplankton layers in narrow passages. Such effects may reduce local zooplankton densities to the extent that pollock can no longer profitably feed on zooplankton. Yoshida (1994) found that pelagic pollock feed mainly on macrozooplankton during summer in the central Bering Sea. Measurements of gill rakers indicated that large pollock had the ability to feed on prey greater than 2 mm. However, analysis of stomach contents indicated that pelagic pollock fed mainly on prey greater than 4 mm (Yoshida 1994). These results suggest that pelagic pollock may filter feed, but some prey selection is also evident. The decline in pollock catches in the 0-40m layer during the period of peak tidal range suggests that pollock may (1) migrate out of narrow passages, (2) migrate to depth, or (3) migrate into nearshore habitats during spring tides. Pollock catches in nearshore habitats also declined slightly during the spring tides suggesting that pelagic pollock did not move nearshore. The diets of the few pollock that were sampled during the spring tides indicated increased consumption of amphipods and euphausiids (Figure 9). This result suggests that at least some pollock may have migrated to depth where euphausiids typically occurred in dense layers. Increased survival of juvenile salmon during periods of peak tidal range is consistent with our observations of decreased pollock abundances in the surface layer (Figure 10). This result may support the hypothesis that age 3+ pollock are important predators on juvenile salmon; however, some other processes may also function to increase juvenile salmon survival during periods of high tidal range. Further study is needed to reveal the mechanisms behind these observations as well as any consequences for juvenile salmon survival.

Conclusions:

1. Age 1-2 pollock, tomcod and benthic fishes (greenlings and sculpins) may be important predators on juvenile salmon in nearshore habitats.
2. Seasonal patterns of abundance of fish predators and diet composition exhibited significant interannual variability.
3. Distribution, feeding rate, and diet composition of age 3+ pollock is apparently affected by tidal range in northwest PWS.
4. Survival to adult was related to tidal range at the time fry were released from the WHN Hatchery in 1994.

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Table 1: Preliminary estimates of juvenile salmon consumption by walleye pollock in northwest Prince William Sound, 1994.

Sampling Period	Pollock Biomass (kg)	% Diet Juv. Salmon	Juv. Salmon Consumption
Late April	590,399	4.74	2 ,956,380
Early May	590,399	.96	1,495,247
Late May	802,722	.05	118,452
Early June	460,771	.11	94,229
Total			4,664,308

Table 2: Mean percent of diet comprised of juvenile salmon for several fish taxonomic groups during four time periods in northwest Prince William Sound, 1995. Cod includes both Pacific cod and tomcod. Benthic fishes include various species of sculpin and greenlings. Statistical test for changes in the mean diet percentage comprised of juvenile salmon among time periods. All specimens included in the analysis.

Date	Pacific Herring	Cod	Pollock (age 1-2)	Pollock (age 3+)	Sockeye Salmon	Chum Salmon	Dolly Varden	Benthic Fishes
5/3 - 5/9	.11	2.78	0	.23	33.3	0	0	2.27
5/11-5/17	.01	3.33	0	.01	0	.05	0	.04
5/30 - 6/3	0	.57	14.74	.12	0	.11	12.42	.35
6/8-6/13	.10	4.74	1.38	.01	0	.75	1.45	.72
P-value	.327	.863	<.001	.041	.374	.171	.141	.063

Table 3: Mean percent of diet comprised of juvenile salmon for several fish taxonomic groups during four time periods in northwest Prince William Sound, 1995. Cod includes both Pacific cod and tomcod. Benthic fishes include various species of sculpin and greenlings. Statistical test for changes in the mean diet percentage comprised of juvenile salmon among time periods. Only specimens consuming juvenile salmon included in the analysis.

Date	Pacific Herring	Cod	Pollock (age 1-2)	Pollock (age 3+)	Sockeye Salmon	Chum Salmon	Dolly Varden	Benthic Fishes
5/3 - 5/9	28.7	100.0	-	14.8	100.0	-	-	54.6
5/11-5/17	21.2	100.0	-	1.7	-	2.1	-	4.6
5/30 - 6/3	-	100.0	87.9	26.2	-	6.2	64.8	23.3
6/8-6/13	29.1	77.7	94.0	20.5	-	13.5	63.8	86.8
P-value	.629	.681	.553	.309	-	.470	.776	.154

Table 4: Percent frequency of occurrence of juvenile salmon in the diets of several fish taxonomic groups during four time periods in northwest Prince William Sound, 1995. Cod includes both Pacific cod and tomcod. Benthic fishes include various species of sculpin and greenlings.

Date	Pacific Herring	Cod	Pollock (age 1-2)	Pollock (age 3+)	Sockeye Salmon	Chum Salmon	Dolly Varden	Benthic Fishes
5/3 - 5/9	.39	4.17	0	1.24	33.33	0	0	3.85
5/11-5/17	.04	2.56	0	.57	0	2.56	0	.72
5/30 - 6/3	0	1.41	16.0	.33	0	1.15	16.67	1.75
6/8-6/13	.19	7.58	3.6	.13	0	4.23	4.20	.75
Sample size	5,017	399	872	4,966	17	382	225	638

Table 5: Mean stomach fullness (% body weight) for several fish taxonomic groups found to prey on juvenile salmon during four time periods in northwest Prince William Sound, 1995. Cod includes both Pacific cod and tomcod. Benthic fishes include various species of sculpin and greenlings. Statistical test for changes in the mean stomach fullness among time periods.

Date	Pacific Herring	Cod	Pollock (age 1-2)	Pollock (age 3+)	Sockeye Salmon	Chum Salmon	Dolly Varden	Benthic Fishes
5/3 - 5/9	1.66	1.89	1.81	.91	.21	.35	.90	2.06
5/11-5/17	.42	1.39	.89	.98	.10	.09	.81	2.13
5/30 - 6/3	.44	1.29	1.22	1.13	.52	.72	1.40	2.62
6/8-6/13	.64	.98	.53	1.24	.15	.39	1.82	3.18
P-value	<.001	.106	<.001	.001	.347	<.001	.622	.037

Table 6: Mean catch per net set for several fish taxonomic groups found to consume juvenile salmon during four time periods in northwest Prince William Sound, 1995. Cod includes both Pacific cod and tomcod. Benthic fishes include various species of sculpin and greenlings. Data for age 3+ pollock includes only fish caught in mid-water and pair trawls (catch per hour of tow).

Date	Pacific Herring	Cod	Pollock (age 1-2)	Pollock (age 3+)	Sockeye Salmon	Chum Salmon	Dolly Varden	Benthic Fishes
5/3 - 5/9	25.6	1.4	3.7	36.6	1.0	1.5	1.0	1.4
5/11-5/17	308.7	1.4	3.8	17.1	1.0	3.4	1.0	1.3
5/30 - 6/3	48.4	1.4	18.0	33.1	1.0	11.3	2.5	1.5
6/8-6/13	466.8	2.2	6.0	27.0	1.0	3.3	2.2	1.4
P-value	<.001	.246	.115	.154	-	.002	.533	.157

Table 7: Parameters of the relationship between the mean proportion of the diet comprised of age-0 fish and the mean proportion of the diet comprised of large calanoid copepods at each study site for seven fish species found to consume juvenile salmon in 1995.

Fish Species	Intercept	Slope	P-value
Herring	.85	-.49	<.001
Cod	.82	-.02	.951
Pollock (age 1-2)	1.22	-.87	<.001
Pollock (age 3+)	.31	.02	.856
Chum Salmon	.63	1.94	.409
Dolly Varden	.92	.64	.852
Benthic Fish	.56	-1.18	.241

Table 8: Parameters of the relationship between the mean proportion of the diet comprised of large calanoid copepods and the mean abundance of large calanoid copepods at each study site for seven fish species found to consume juvenile salmon in 1995.

Fish Species	Intercept	Slope	P-value
Herring	.44	.002	.040
Cod	.06	.001	.146
Pollock (age 1-2)	.30	003	.039
Pollock (age 3+)	.27	.002	.056
Chum Salmon	.03	0	.894
Dolly Varden	.02	0	.710
Benthic Fish	.03	0	.747

Table 9: Mean proportion of the diet comprised of juvenile salmon at three levels of relative abundance of large calanoid copepods at each study site for seven fish species found to consume juvenile salmon in 1995.

	Rel. Abundance Large Copepods			
Fish Species	low	moderate	high	P-value
Herring	.02	.02	.07	.835
Cod	2.77	25.00	25.00	.520
Pollock (age 1-2)	13.70	1.61	0	.152
Pollock (age 3+)	.12	.06	.11	.786
Chum Salmon	.56	.10	.04	.485
Dolly Varden	5.53	15.03	.82	.381
Benthic Fish	.72	1.20	.57	.916

Table 10: Mean percent of the diet comprised of juvenile herring for four species of fish predators in northwest and southwest Prince William Sound, 1994.

Fish Species		Number	% Herring
NW PWS	Herring	1,370	.004
	Tomcod	55	.03
	Pollock	2,367	.61
	Chum Salmon	101	.25
	Dolly Varden	57	47.57
SW PWS	Herring	862	.027
	Tomcod	28	0
	Pollock	516	3.04
	Chum Salmon	13	0
	Dolly Varden	45	2.04

Table 11: Mean percent of the diet comprised of juvenile herring for three species of fish predators in northwest and southeast Prince William Sound, 1995.

Fish Species		Number	% Herring
NW PWS	Pacific cod	22	0
	Kelp Greenling	54	0
	Pollock	4,788	.22
SE PWS	Pacific cod	41	54.32
	Kelp Greenling	10	94.68
	Pollock	220	16.05

Table 12: Estimated annual consumption of herring by several important fish predators in Prince William Sound.

Fish Species	Biomass (mt)	Daily Ration (% BW)	% Herring in Diet	Total Consumption (mt)
Pollock	4,788	.01	20	6,426
Arrowtooth flounder	49,842	.01	9	14,899
Pacific cod	1,195	.01	37	1,452

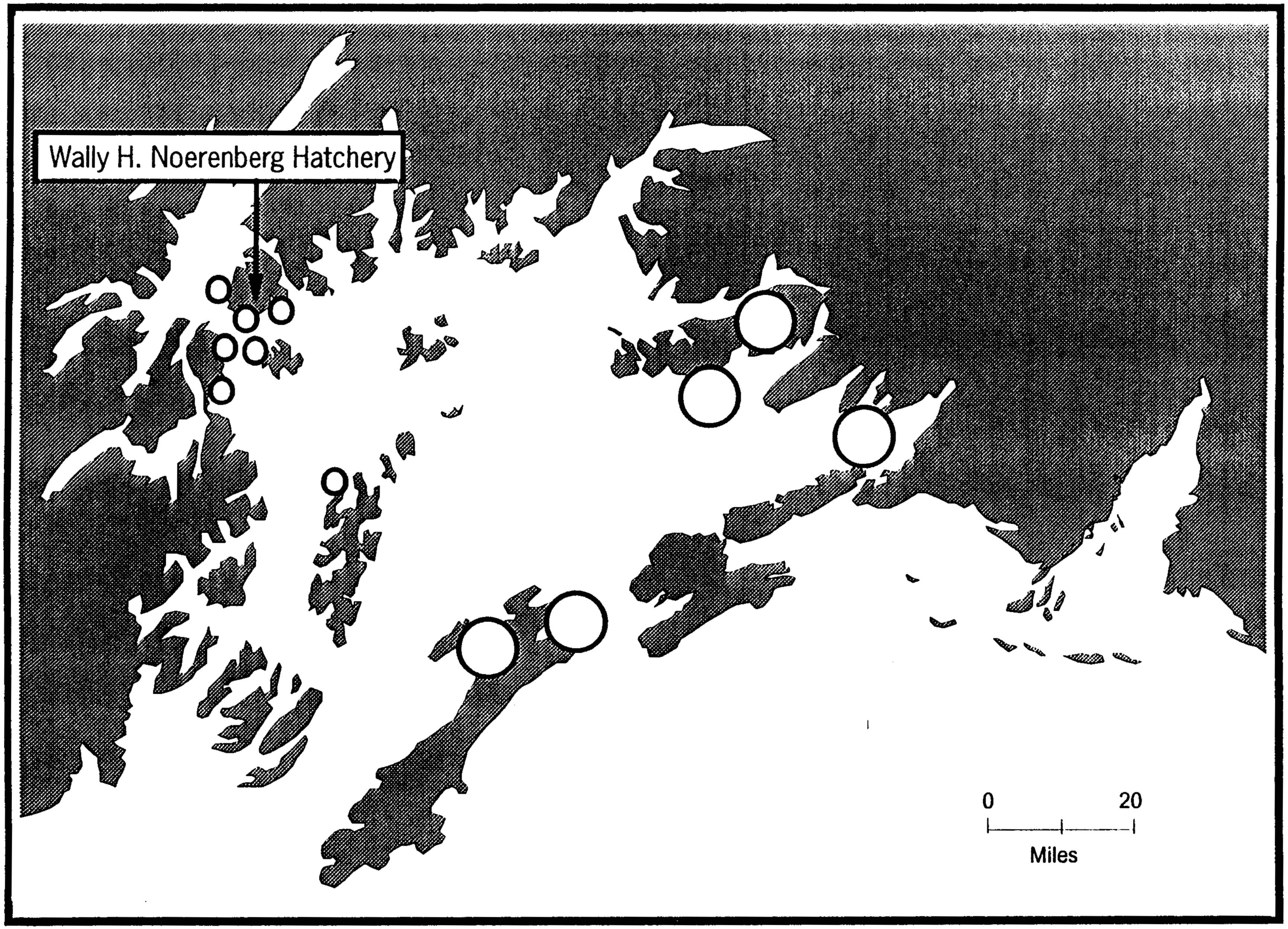


Figure 1: Study sites sampled primarily for juvenile salmon (small circles) and juvenile herring (large circles) in Prince William Sound, 1995.

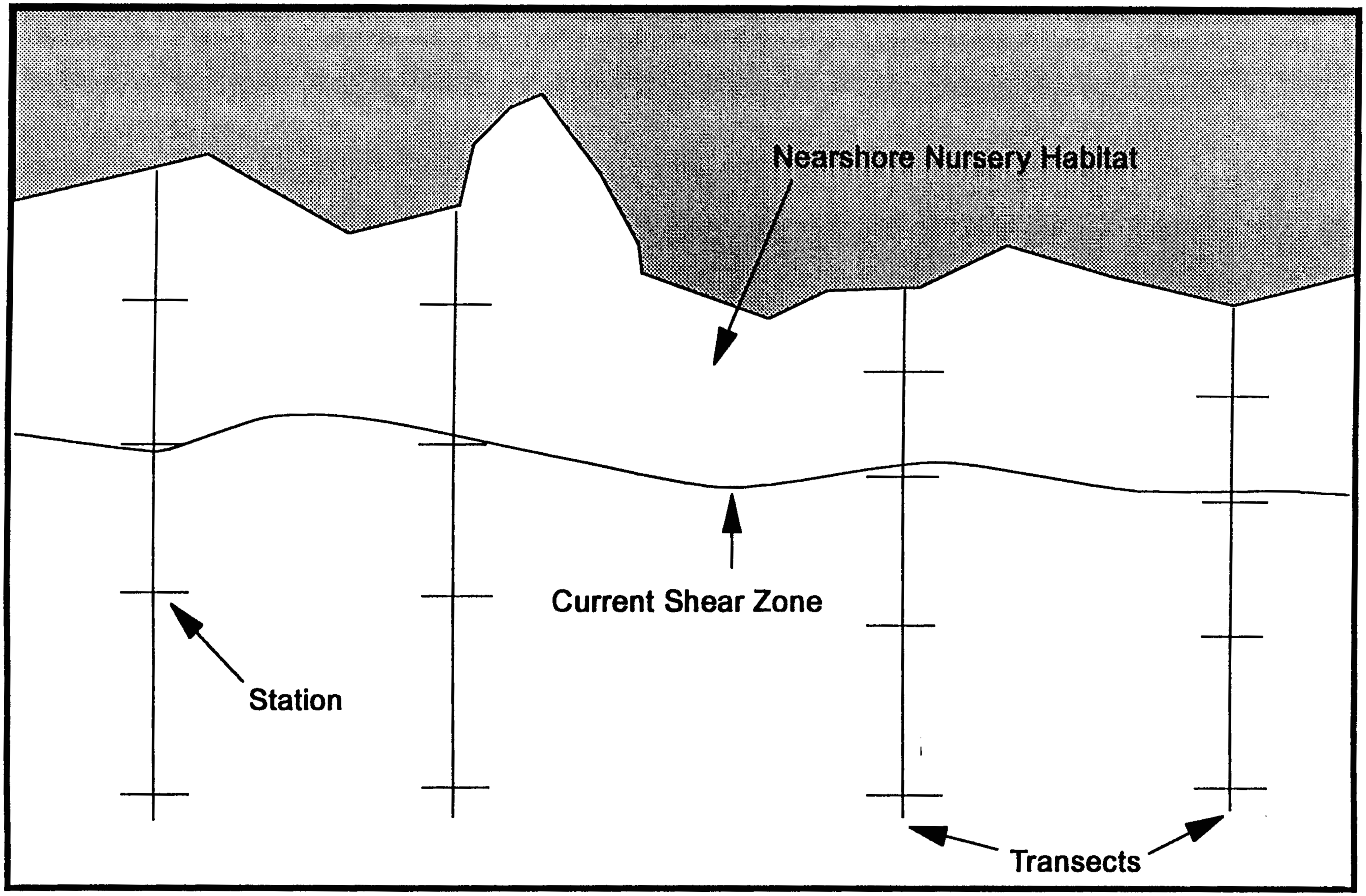


Figure 2: Spatial design for sampling juvenile salmon and their predators and prey at 16 study sites in northwest Prince William Sound in 1995. Each study site was approximately 3000 m in length. Stations were located approximately 100 m apart.

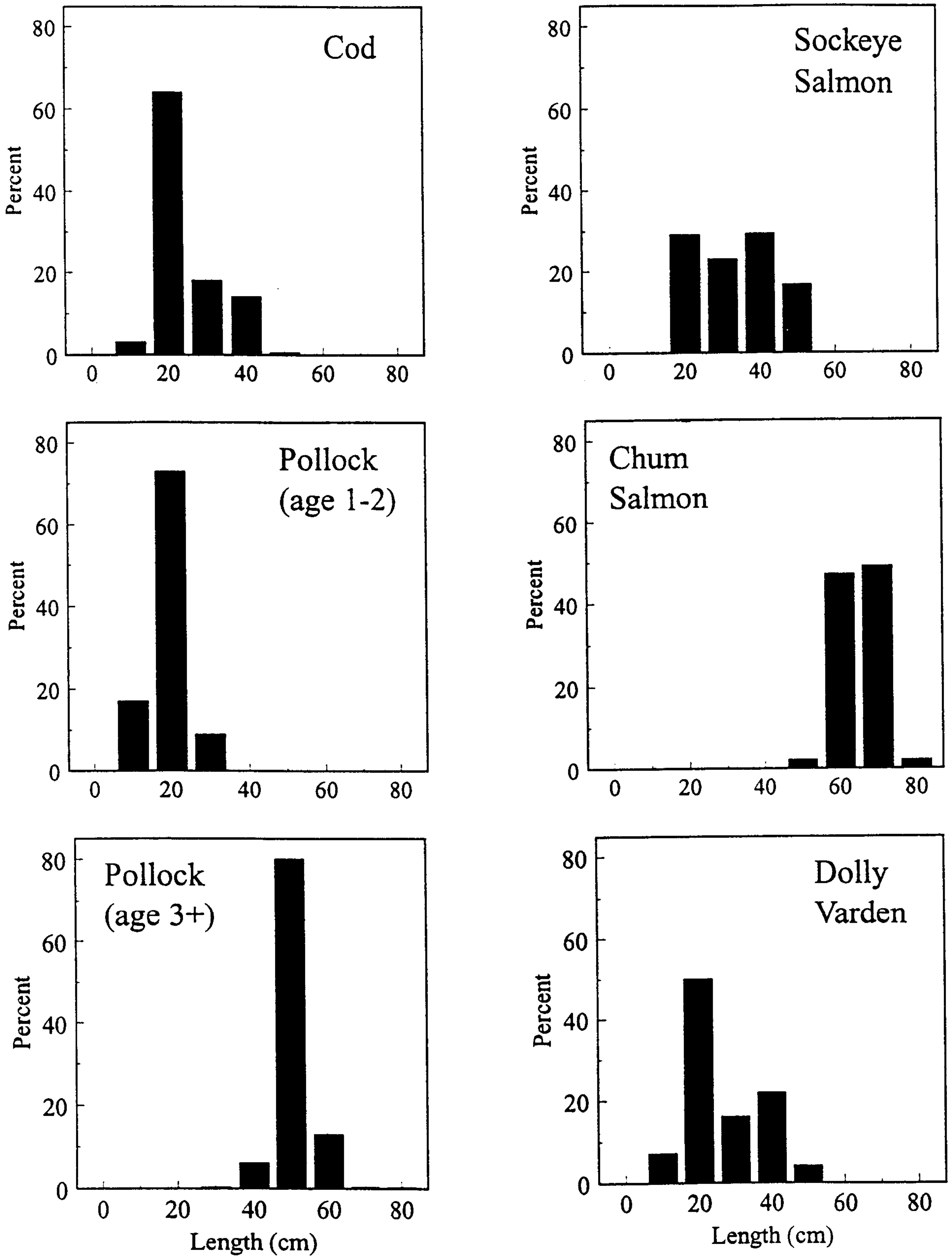
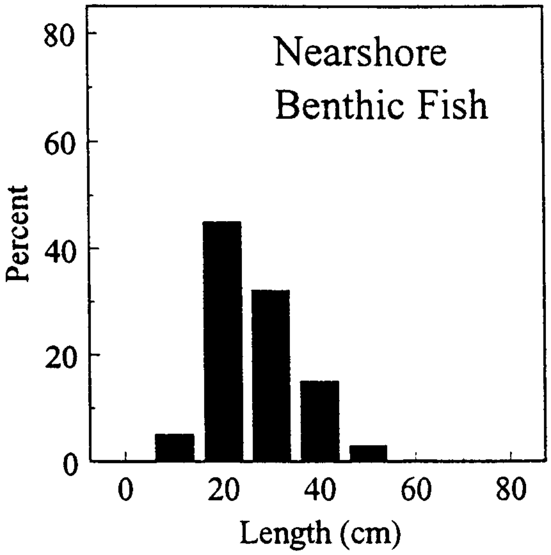


Figure 3: Length frequencies for several fish species found to consume juvenile salmon in northwest Prince William Sound, 1995.



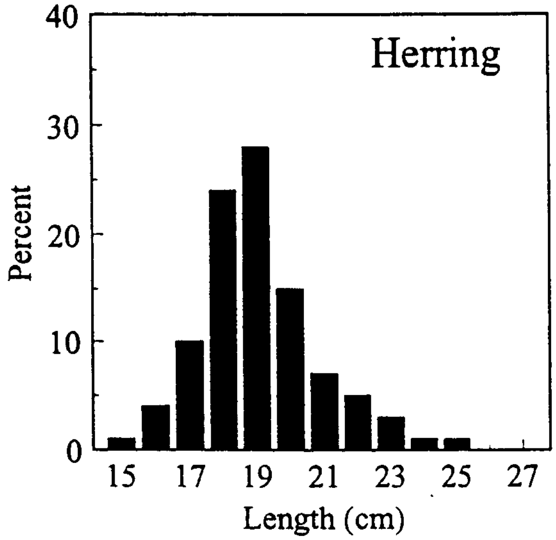


Figure 3: Length frequencies for several fish species found to consume juvenile salmon in northwest Prince William Sound, 1995.

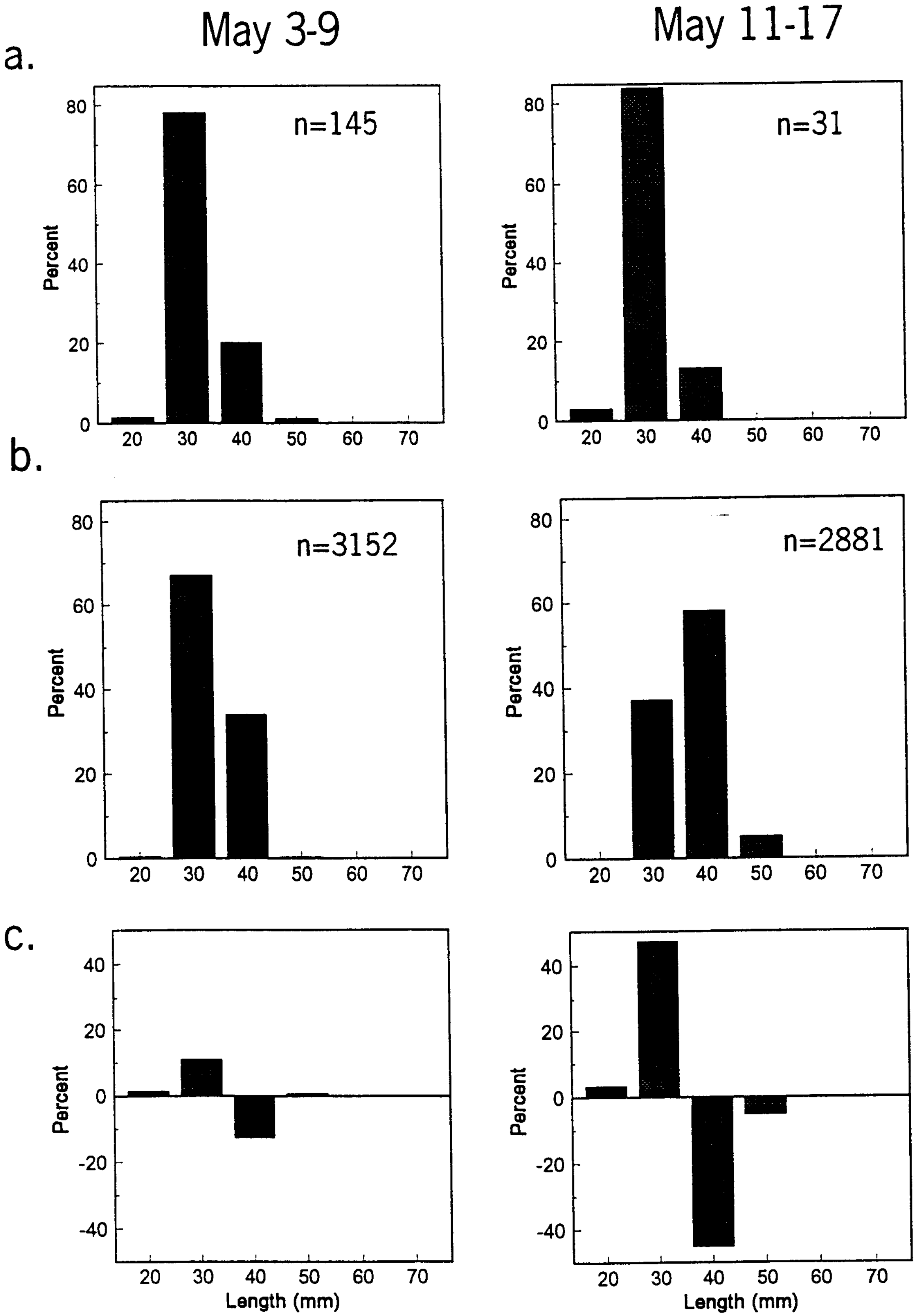
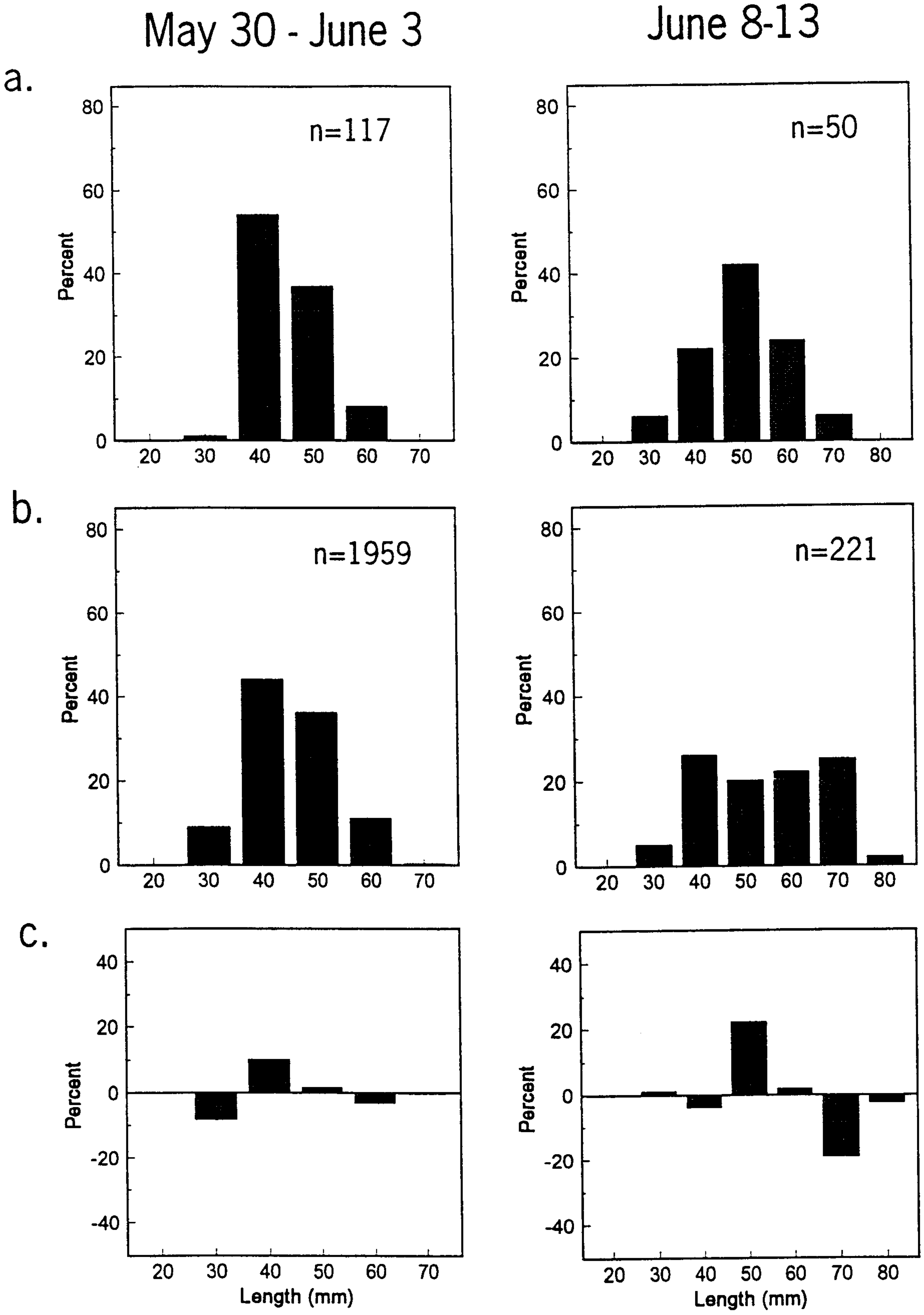


Figure 4: Length frequency of juvenile salmon (a) found in the stomachs of fish predators, (b) captured alive in nearshore habitats, and (c) percent frequency difference.



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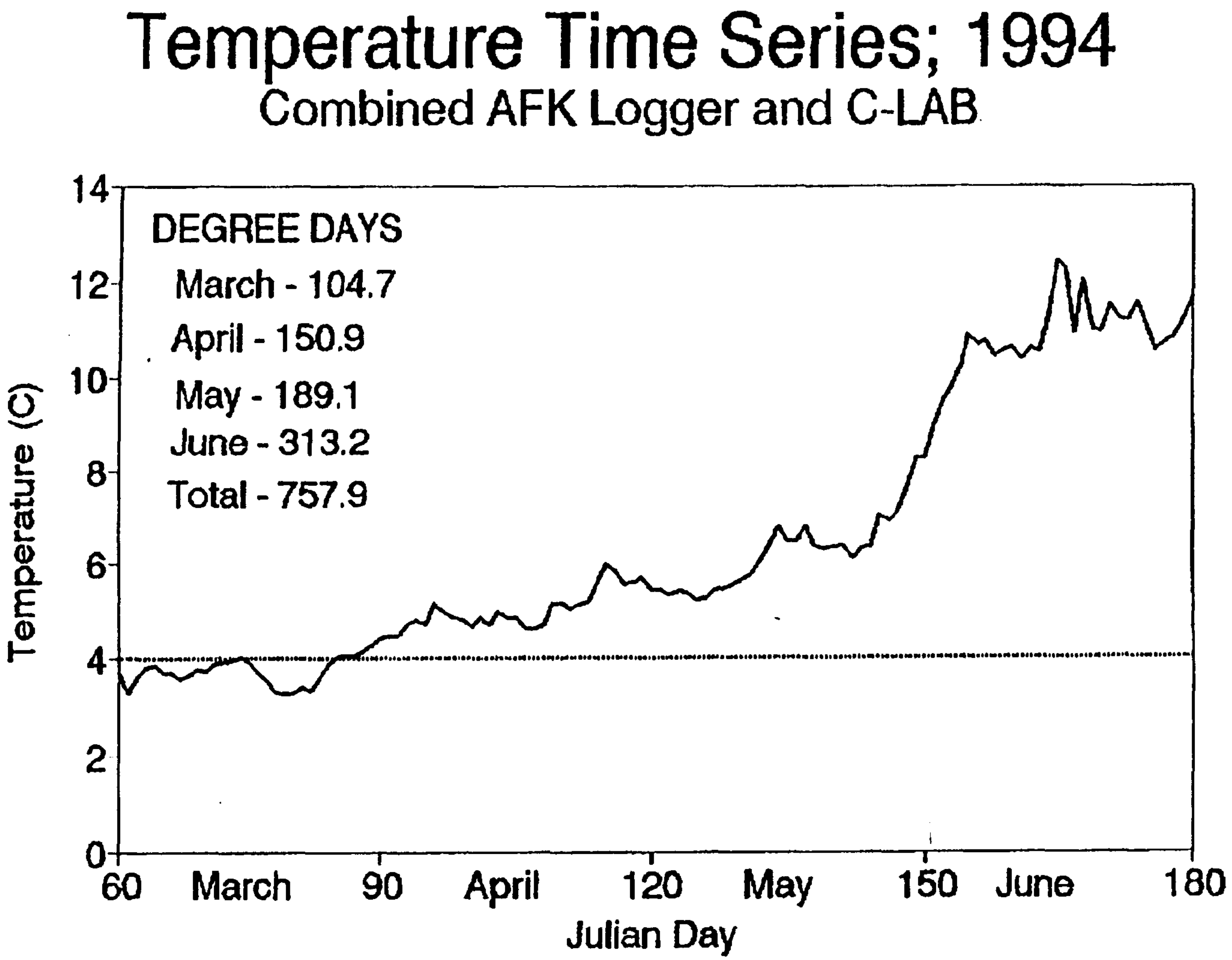


Figure 5: Seasonal changes in ocean temperature at two stations in Prince William Sound, March-June 1994. Data provided by the Prince William Sound Aquaculture Corporation and project 95320-H.

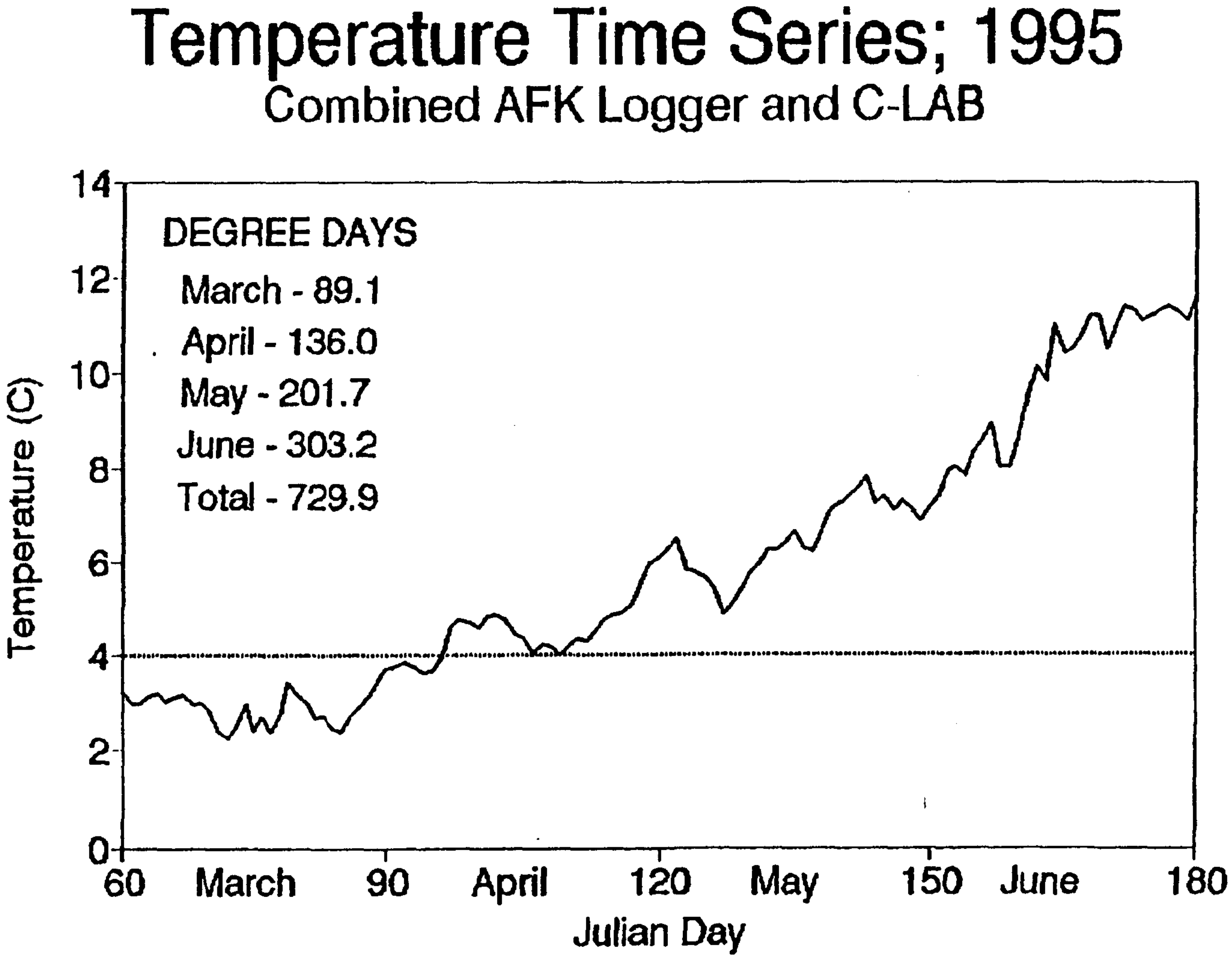


Figure 6: Seasonal changes in ocean temperature at two stations in Prince William Sound, March-June 1995. Data provided by the Prince William Sound Aquaculture Corporation and project 95320-H.

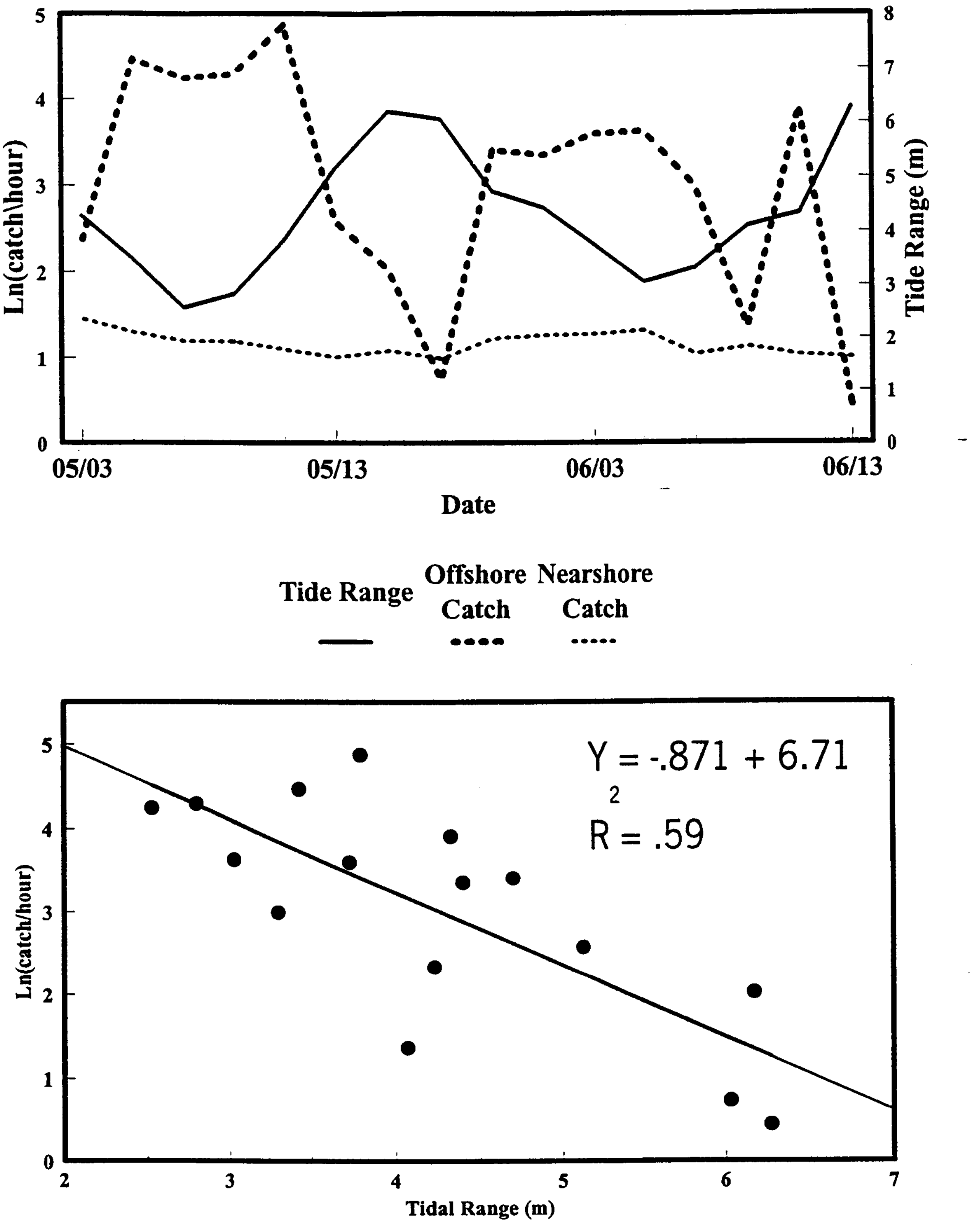


Figure 7: (a) Seasonal changes in tidal range and catch per effort of walleye pollock in nearshore and offshore habitats, and (b) relationship between tidal range and natural logarithm of catch per effort of walleye pollock in northwest Prince William Sound, 1995.

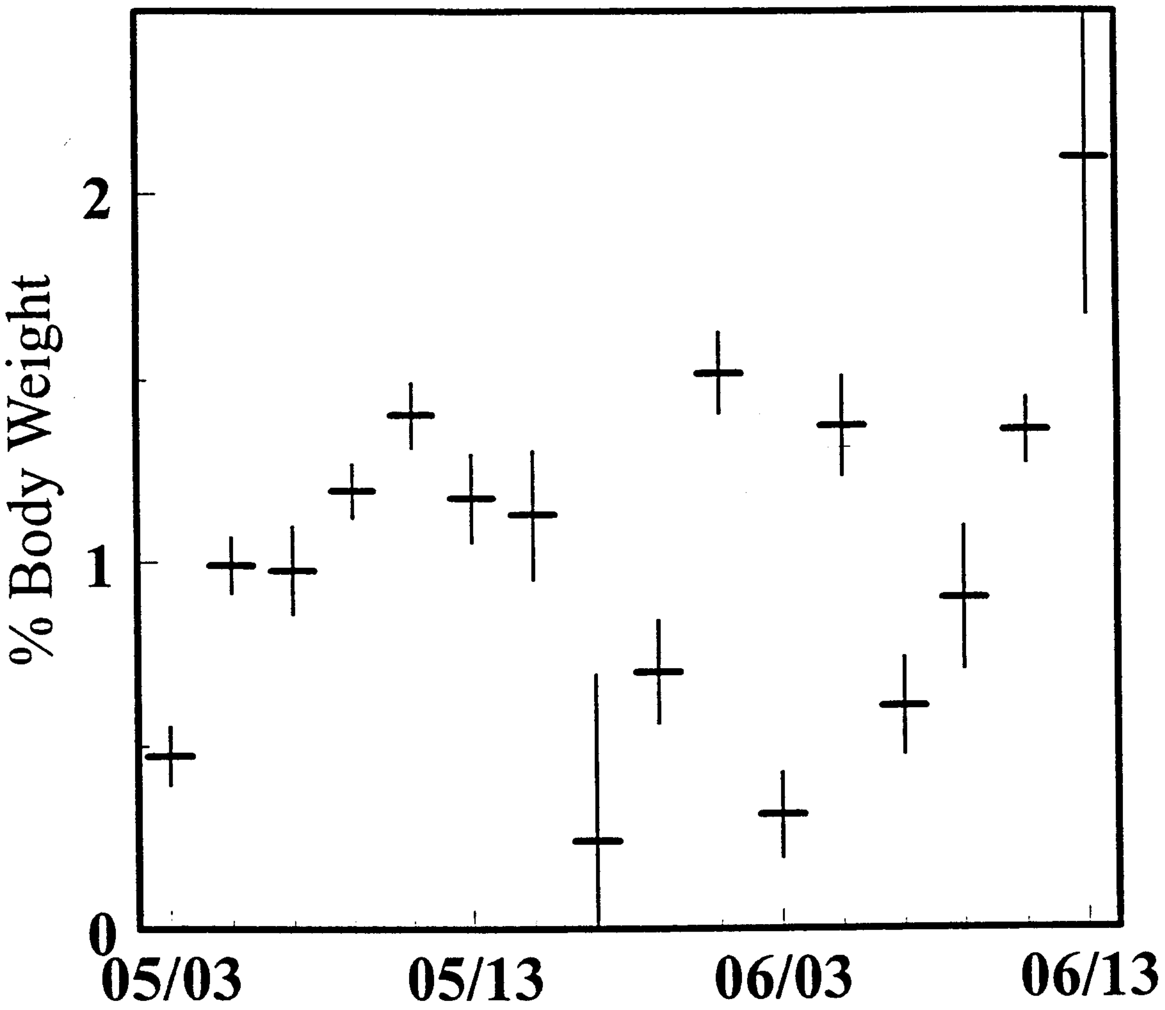


Figure 8: Seasonal changes in stomach fullness (% body weight) of walleye pollock in northwest Prince William Sound, 1995.

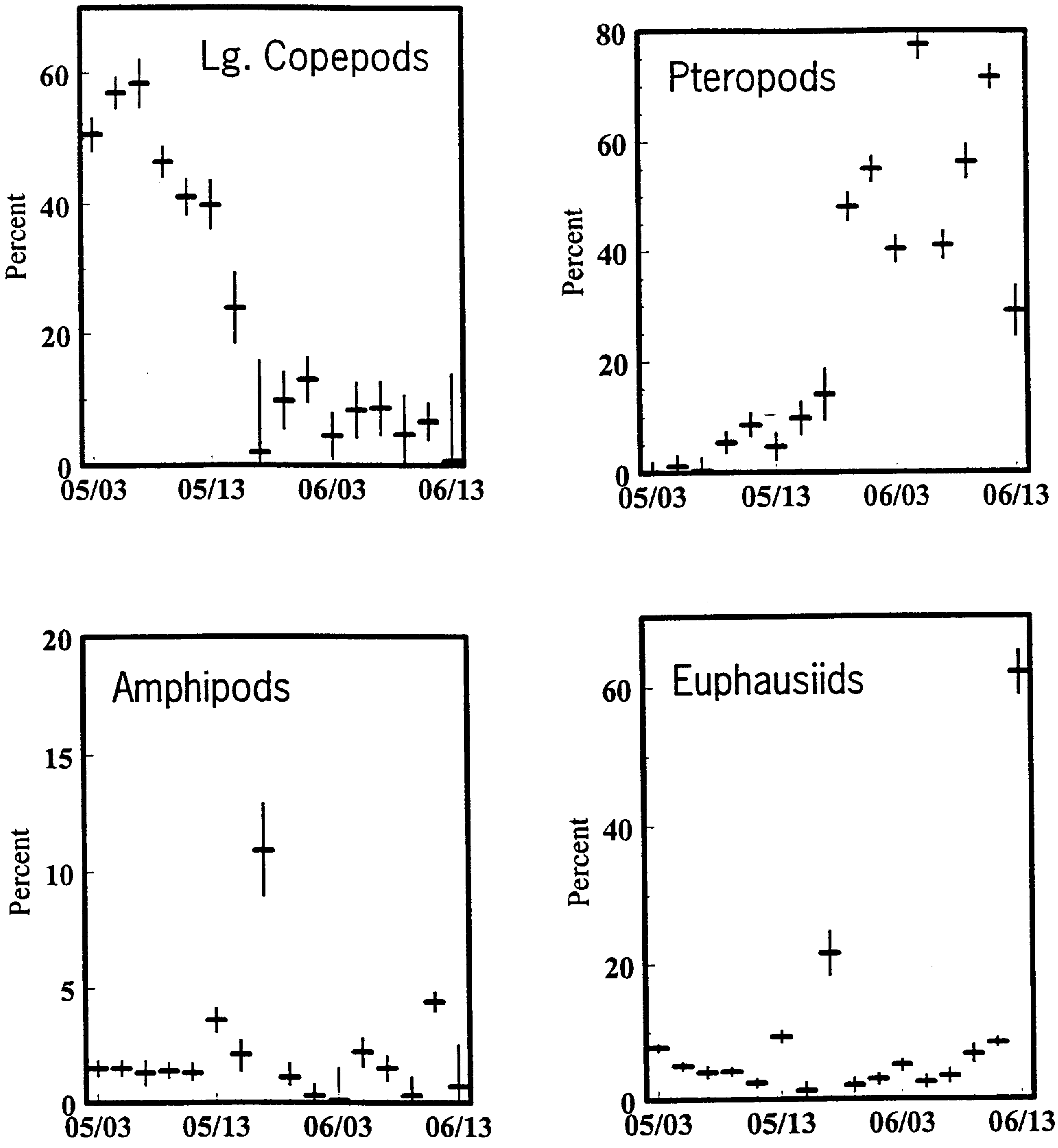
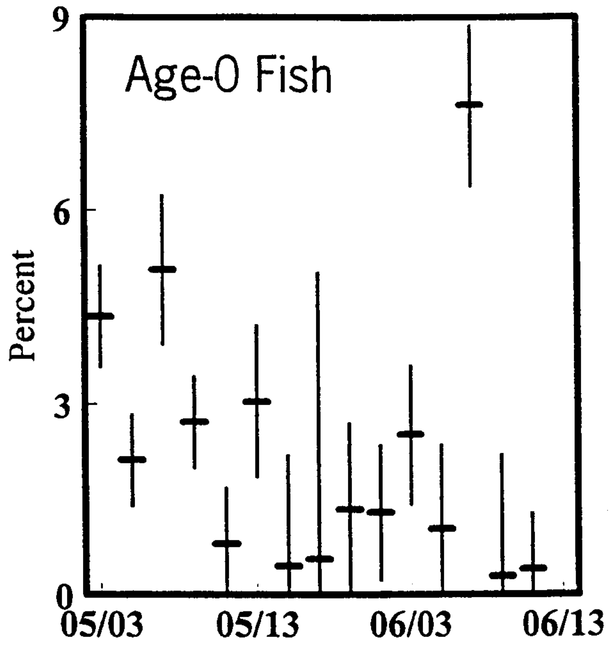


Figure 9: Seasonal changes in diet composition of walleye pollock in northwest Prince William Sound, 1995.



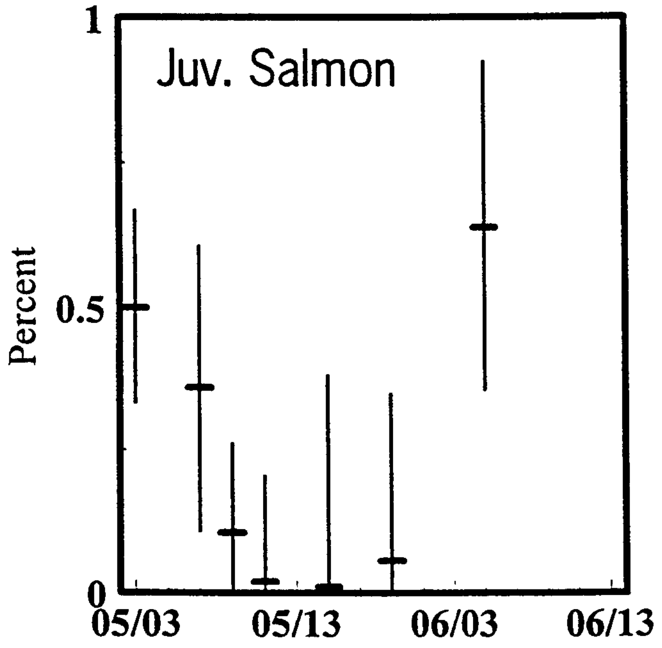


Figure 9: Seasonal changes in diet composition of walleye pollock in northwest Prince William Sound, 1995.

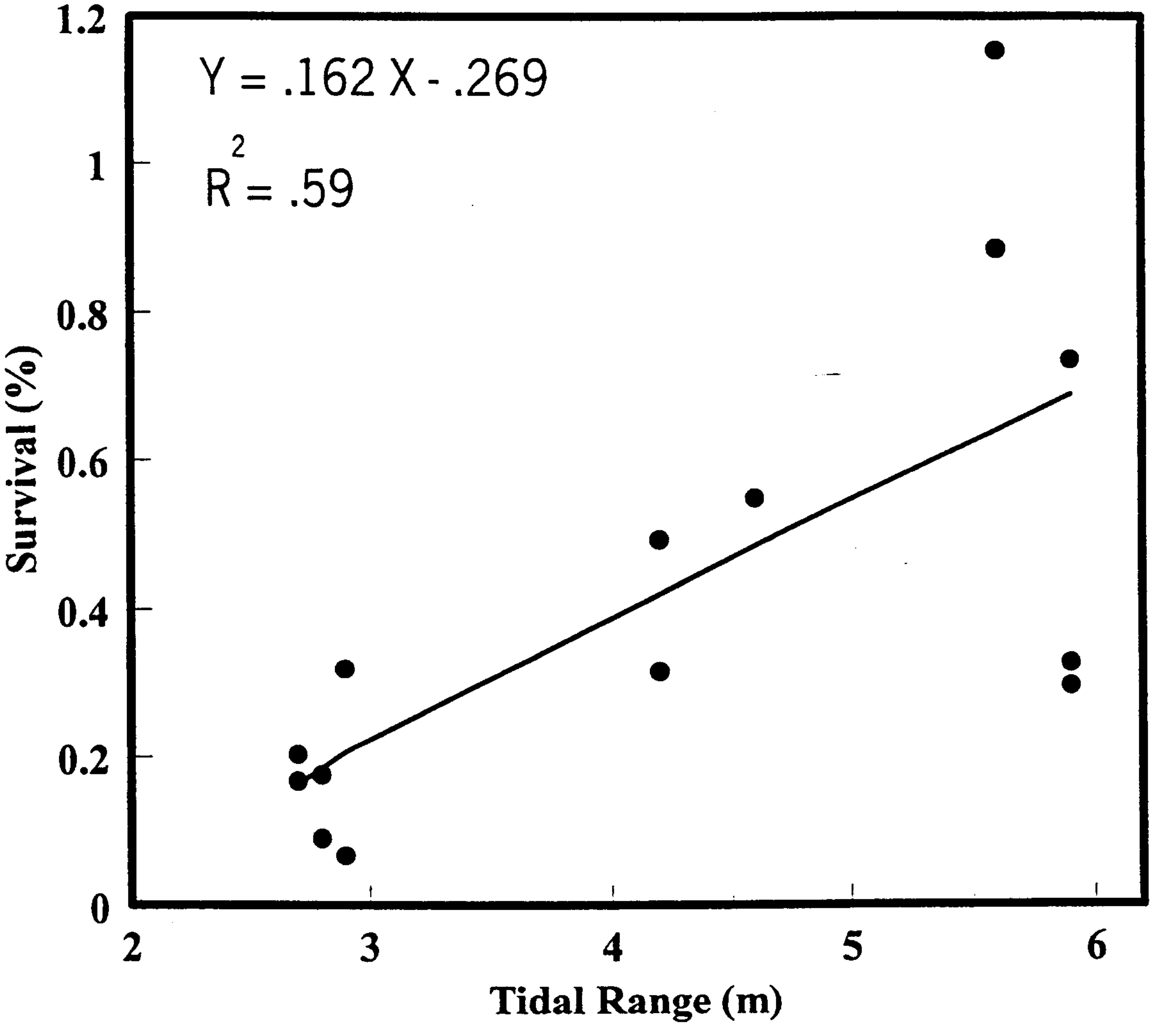


Figure 10: Relationship between tidal range and survival to adult for juvenile salmon released from the Wally H. Noerenberg Hatchery, 1994.

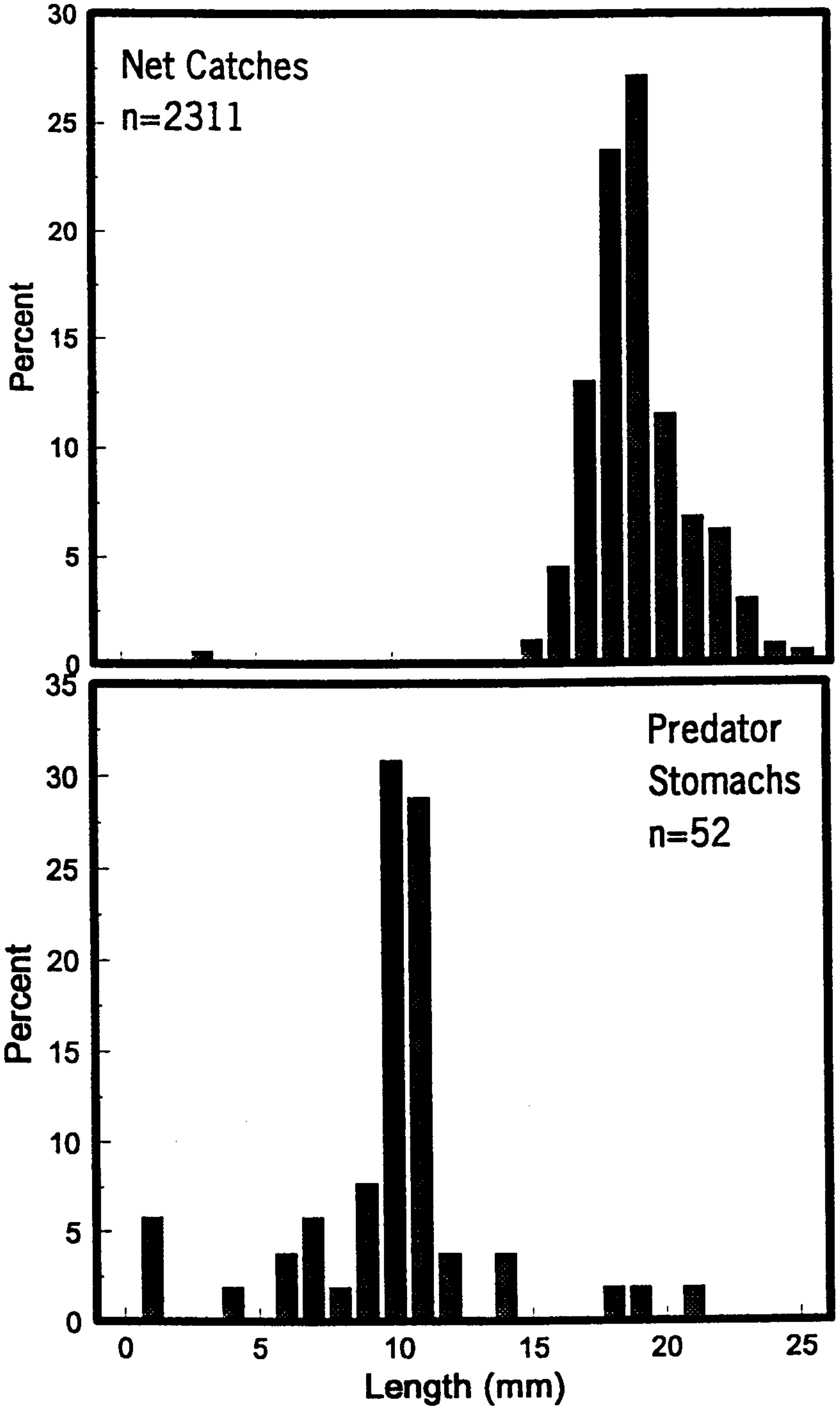


Figure 11: Length frequencies of herring from net catches and herring in stomachs of fish predators in May and June, Prince William Sound, 1995.