Chapter 2

95320A Salmon Growth and Mortality

Exxon Valdez Oil Spill
Restoration Project Annual Report

Sound Ecosystem Assessment: Salmon Growth and Mortality

Restoration Project 95320A
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 94320A. An annual report was issued in 1994 by Willette, M., G. Carpenter, E. Debevec, under the title Sound Ecosystem Assessment: Salmon Growth and Mortality. The project effort was continued under Restoration Project 95320A, the subject of this annual report. In 1996, this project will be merged with project 96320E. 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 four sites during three sampling periods in both May and June. Total zooplankton biomass and the abundance of large calanoid copepods was significantly greater in offshore than nearshore habitats. This result indicates that the growth potential for juvenile pink salmon may be greater offshore when growth is limited by low food abundance nearshore. When this condition occurs juvenile salmon may face a trade off between growth and predation risk, because the abundance of predatory fish is at times much greater in offshore habitats. Several lines of evidence indicate that significant mortality may have occurred among an early group of relatively small juvenile salmon released from the Wally H. Noerenberg Hatchery prior to the middle of June, 1994. Fry-to-adult survival was an order of magnitude greater for a late (mid-June) release of relatively large fry compared to an early release of much smaller fish. Recoveries of coded-wire tagged fry indicated that these two groups of fish were mixed together in lower Knight Island Passage after the middle of June. Several biological characteristics were not significantly different between the two groups after they were mixed together. Finally, relative abundances of the early-release group in purse seine catches declined exponentially, consistent with an instantaneous mortality rate assuming equal mortality between the early- and late-release groups after they were mixed together. High mortality among the early-release group largely caused the failure of the 1995 pink salmon return to the Wally H. Noerenberg Hatchery. High mortality among juvenile pink salmon prior to the middle of June may have been the cause of weak returns of both wild and hatchery-reared pink salmon in western Prince William Sound in 1995.

Key Words: *Exxon Valdez*, pink salmon, *Oncorhynchus gorbuscha*, migration, food consumption, diet composition, growth, mortality, coded-wire tagging.

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Table of Contents

List of Tables

List of Tables

List of Figures

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 daily foraging times of juvenile pink salmon, (2) estimate prey abundance and composition in nearshore nursery habitats utilized by juvenile pink salmon, (3) estimate the diet composition of juvenile pink salmon, and (4) estimate the size composition and mean growth rate of juvenile pink salmon. Diel feeding studies were conducted at 4 sites during 3 time periods in May and June. Juvenile salmon were sampled with a purse seine and tow net every three hours during a 24-hour period in nearshore and offshore habitats at each site. Four thousand and six hundred juvenile pink and chum salmon were collected to estimate size composition, condition, daily foraging times and the proportion of the diet comprised of large calanoid copepods. Preliminary estimates of foraging time and daily food consumption have been made for four sites. Daily foraging time and food consumption increased by a factor of 2 and 6 between May and June, respectively. An additional 1,800 samples of fish (<150mm FL) from seven species were collected to estimate species/size composition of nearshore fish assemblages. Stomach contents analysis will be conducted on a portion of these samples to examine diet overlap among species under project 95163 Forage Fish Influence on Recovery of Injured Species'. Coded-wire tagged juvenile salmon released from the Wally H. Noerenberg (WHN) Hatchery were sampled in June to estimate growth rate. Mean growth rate was significantly different (P=.010) among three treatment groups, but not different from the mean growth of juvenile salmon in 1994. Zooplankton samples were collected every three hours at each site to test for differences in plankton abundance between nearshore and offshore habitats. Total zooplankton biomass and the abundance of large calanoid copepods was significantly greater (P<.05) in offshore than in nearshore habitats. Laboratory studies have shown that the feeding rate of juvenile pink salmon is about 3 times greater when feeding on large rather than small calanoid copepods. In the present study, large calanoid copepods were 3 times more abundant offshore than nearshore in June. This result indicates that the growth potential for juvenile pink salmon may be greater offshore when growth is

limited by low food abundance nearshore. When this condition occurs juvenile salmon may face a trade off between growth and predation risk, because the abundance of predatory fish is at times much greater in offshore habitats.

Several lines of evidence indicate that significant mortality may have occurred among an early group of relatively small juvenile salmon released from the WHN hatchery prior to the middle of June in 1994. High mortality among this early-release group largely caused the failure of the 1995 pink salmon return to the WHN Hatchery. Fry-to-adult survival was an order of magnitude greater for a late release of relatively large fry (1.5 g) compared to the early release of much smaller fish (.30 g). Recoveries of CWT fry indicated that these two groups of fish were mixed together in lower Knight Island Passage after the middle of June. Several biological characteristics were not significantly different between the two groups after they were mixed together. Finally, relative abundances of the early-release group in purse seine catches declined exponentially, consistent with an instantaneous mortality rate assuming equal mortality between the early and late groups after they were mixed together. Several alternative hypotheses were examined to evaluate the possible causes of these observations. High mortality among juvenile pink salmon prior to the middle of June, 1994 may have also been the cause of weak returns of wild pink salmon in western PWS in 1995.

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.

Recruitment to adult salmon populations is 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 a higher mortality, because they are vulnerable to predators for a longer time than fast-growing individuals (Parker 1971; Healey 1982; West and Larkin 1987). Low returns of hatchery-produced salmon in 1992 and 1993 indicates that the run failures were likely caused by processes occurring during the early marine period. 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 relationship between juvenile growth and mortality changed dramatically for pink salmon released in 1992 suggesting a change in predation rate.

In FY95 this project focused on the relationship between the daily foraging time of juvenile pink salmon and predation risk (Walters and Juanes 1993). Juvenile salmon spend much of their time in nearshore nursery habitats (Cooney et al. 1978) 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 1994). 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 increased foraging time and predation risk.

Coded-wire tagged fish have played a major role in tracking the migration, growth and mortality of juvenile salmon in this study. During the past decade, five salmon hatcheries have been established within PWS. These facilities, operated by private non-profit corporations, released approximately 500 million juvenile pink salmon in 1995. Approximately one million of these fish were marked with a coded-wire tag (CWT). Several aspects of this project would not have been feasible without the CWT program. 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 (Figure 1).

This project will provide data needed to test several of the following predator\prey hypotheses posed by SEA investigators.

I. Walleye pollock and seabirds are the principal predators on juvenile salmon during the first 30 days of marine residence. After the initial 30 days, walleye pollock, herring, and adult salmon are the principal predators.

Sub-hypotheses:

I-1. *The juvenile salmon consumption rate of seabirds and age 1+ walleye pollock is greater than for all other predators combined during the initial 30 days of marine residence.*

I-2. *The juvenile salmon consumption rate of age 1+ walleye pollock, herring, and salmon is greater than for all other predators combined after the initial 30 days of marine residence.*

II. The rate of predation on juvenile salmon and other age 0 fish is strongly affected by the timing and duration of the macrozooplankton bloom modulated by ocean temperatures during the early marine period. During the macrozooplankton bloom, predators largely consume large calanoid copepods and predation on age-0 fish is low. As the abundance of macrozooplankton declines, predators switch to age 0 fish. Predation on age 0 fish is also size dependent; predation risk being substantially less for fish greater than approximately 60 mm FL. The survival of juvenile pink salmon and other age-0 fish therefore depends largely on their growth rate prior to reaching a size of approximately 60 mm FL and the coincident timing of the decline of the macrozooplankton bloom. Ocean temperature during this period is also critical, because the growth of juvenile pink salmon is largely temperature dependent.

Sub-hypotheses:

II-1. *The proportion of predator diets comprised of juvenile salmon and other age-0 fish is inversely related to the proportion of the diet comprised of large calanoid copepods.*

II-2. *The juvenile salmon consumption rate is greater when the abundance of large calanoid copepods is low.*

II-3. *Greater than 75% of the juvenile salmon consumed by predators are less than 60 mm FL.*

II-4. *Growth rates of juvenile salmon are positively related to ocean* *temperature and the proportion of the diet comprised of large calanoid copepods.*

II-5. *The survival of pink salmon to the adult stage is positively related to growth rate before the fish reach 60 mm FL.*

III. The carrying capacity of PWS for juvenile salmon is determined by the availability of predation refuges that are both temporally and spatially limited. Temporal limitation of the predation refuge for juvenile salmon results from seasonal inshore movements of predators. Foraging time of juvenile salmon and thus predation risk is inversely related to interannual and seasonal changes in prey density and composition. Increased juvenile salmon density leads to longer juvenile salmon foraging times and increased predation risk.

Sub-hypotheses:

III-1. *The abundance of fish predators increases substantially from May to June in nearshore nursery habitats occupied by juvenile salmon.*

III-2. *The seasonal increase in fish predator abundance in nearshore nursery habitats is related to ocean temperature structure.*

III-3 *Zooplankton abundance and the abundance of large calanoid copepods is greater offshore (outside of predation refuge) than nearshore (within predation refuge).*

III-4. *The daily foraging time of juvenile salmon is inversely related to total prey density and the proportion of large calanoid copepods in the diet.*

III-5. *The daily foraging time of juvenile salmon is positively related to juvenile salmon abundance.*

III-6. *The juvenile salmon consumption rate of predators is positively related to the daily foraging time of juvenile salmon.*

IV. Predation on wild salmon fry is greater when wild fry are mixed with larger hatchery-reared fry in nearshore nursery habitats. Behavioral responses of predators lead to predator aggregations and greater predation rates in areas of high juvenile salmon abundance. Predators select smaller wild fry in mixed schools of wild and hatchery salmon.

Sub-hypotheses:

IV-1. *Predator abundance is positively related to juvenile salmon abundance.*

IV-2. *Wild salmon fry are smaller than hatchery-reared fry in nearshore nursery habitats.*

IV-3. *The ratio of wild to hatchery salmon in predator stomachs is greater than the ratio of wild to hatchery salmon in nearby nearshore nursery areas.*

V. Spatial patterns of adult pink salmon production in Prince William Sound are determined by the distribution of age 1+ walleye pollock and macrozooplankton during the early marine period.

Objectives:

Original objectives in detailed project description for 95320A:

1. Estimate the daily foraging time of juvenile pink salmon at 16 study sites in PWS.

2. Estimate the relative abundance of juvenile pink salmon at 16 study sites in PWS.

3. Estimate prey abundance and composition in nearshore nursery habitats utilized by juvenile pink salmon and in adjacent offshore areas at 16 study sites in PWS.

4. Estimate diet composition of juvenile pink salmon at 16 study sites in PWS and collect juvenile fish stomach samples for project 95163 (Forage Fish).

5. Estimate the size composition and condition of untagged juvenile pink salmon at 16 study sites in PWS.

6. Estimate the growth rate of juvenile CWT salmon recovered at 16 study sites in PWS.

7. Conduct preliminary tests of predator\prey hypotheses.

Objective added as result of new information obtained in FY95:

8. Evaluate differences in fry-to-adult survival, biological characteristics and relative

abundance of small early-fed and large late-fed juvenile salmon released in 1994 from the Wally H. Noerenberg Hatchery.

Methods:

The study design in FY95 focused on diel patterns of feeding and movements of juvenile salmon and their predators. 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. 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. The 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 (Figure 2).

Objective 1:

The daily foraging time of juvenile pink salmon was estimated from diel feeding periodicity studies conducted at each of 16 nearshore study sites. Each site consisted of an approximately 3000 m long segment of shoreline. Juvenile salmon sampling was conducted at 3-hour intervals throughout a 24-hour period at each site. A small-mesh purse seine (70 m length) was used to sample juvenile pink salmon in nearshore nursery habitats where the fish were aggregated. In offshore habitats, juvenile pink salmon were sampled with a tow net (3m x 4m) deployed from a 6 m long aluminum skiff. Samples of untagged juvenile pink salmon (n=100) were preserved in 10% buffered formaldehyde solution.

Stomach contents analysis was conducted later in the laboratory on a random subsample of 15 individuals. Fish showing signs of regurgitation were not included in the subsample. Whole body wet weight was measured to an accuracy of 0.01 g. Total stomach contents weight was measured to an accuracy of 0.1 mg. The proportion of the diet comprised of large calanoid copepods (>2.5 mm), small calanoid copepods (<2.5 mm), and 'other prey' was visually estimated. Large calanoid copepods in each stomach were enumerated. Stomach fullness was expressed as the ratio of stomach contents weight and whole body weight.

The daily foraging time of juvenile pink salmon at each site was estimated by examining changes in stomach fullness by time of day. Temperature-specific gastric evacuation rate was estimated from data provided by Bailey et al. (1975). Expected stomach fullness assuming no feeding was estimated for each sampling time from stomach fullness during the previous sampling time reduced by gastric evacuation. If measured stomach fullness was greater than expected it was assumed that the fish were feeding during the interval between sampling times. Food consumption during the interval between sampling times was estimated from the difference between expected stomach fullness and measured stomach fullness. Daily food consumption was estimated from the sum of food consumption during the intervals between sampling times. In cases where data was not available for all 7 sampling times within a day, daily food consumption and foraging time was estimated by extrapolating the results obtained during the period sampled to the entire 24-hour period. Stomach data from all stations sampled during each time period were pooled in the analysis.

Objective 2:

The relative abundance of juvenile pink salmon was estimated at each study site from visual surveys of nearshore nursery habitats. Relative abundance from visual surveys was described as low (=1), medium (=2) or high (=3). Relative abundance in offshore areas adjacent to nearshore nursery habitats was estimated by catch per net set in purse seines (1 cm stretch mesh; 20m x 240m) and catch per hour in tow nets (3m x 4m). Purse seines were fished by holding a hook into the direction of the prevailing current for 20 min. Tow nets were fished for approximately one-half hour along a transect 100m from shore.

Objective 3:

Zooplankton samples were collected every three hours during daylight with a 0.5 m ring net (243 um mesh) at two stations nearshore and two stations offshore at each of the 16 study sites. Nearshore stations were located in areas inhabited by juvenile salmon. Offshore stations were approximately two kilometers from the shore in water generally exceeding 200 m depth. Of the 228 samples collected, 179 were 20 m vertical tows and 48 were 10 m vertical tows. Ten meter vertical tows were only taken at nearshore stations when the bottom depth was less than 20 m. All samples were preserved in 10% buffered formaldehyde solution for later laboratory analysis.

In the laboratory, a vacumn pump was used to remove excess water from each sample. The sample was placed on a 100 um filter and the pump operated for 1 minute. Total sample wet weight was measured to an accuracy of 0.1 mg. The sample was then washed into a graduated beaker and subsampled with a Stimple pipette. Large calanoid copepods (>2.5 mm), small calanoid copepods (<2.5 mm), and 'other zooplankters' were enumerated in each subsample. A sufficient volume was subsampled to obtain a minimum count of 100 large calanoid copepods. The total wet weight of animals in each category was estimated from the product of abundance and average wet weight (Coyle et al. 1990). Biomass (g m^{-3}) and abundance (no.m^{-3}) were estimated for each taxonomic group in both nearshore and offshore habitats at each site.

Objective 4:

The field sampling design and laboratory procedures described in objective 1 were used to estimate diet composition of juvenile pink salmon at each study site. Whenever possible, samples of other juvenile fishes (forage fish) were collected along with samples of juvenile salmon. These juvenile salmon and forage fish samples were provided to project 95163 (Forage Fish) for a later more detailed diet analysis. A paired comparison of diet overlap among various species of juvenile fishes occupying nearshore habitats will be conducted under project 95163.

Objective 5:

The size composition and condition of juvenile pink salmon at each study site was estimated from samples of untagged juvenile pink salmon (n=60) collected as described in objective 1. Fork length was measured to the nearest 0.5 mm and total body wet weight to the nearest 0.01 g. Each fish was blotted dry before weighing. Condition of juvenile pink salmon was examined to evaluate feeding and growth conditions at each site. The relationship between body weight (W) and length (L) was described by

$$W = a\,L^{b} \tag{1}$$

where a is the condition factor and b is the slope of the linear-transformed model (Ricker 1975). All juvenile pink salmon collected at each site were pooled to estimate the parameters of the model.

Objective 6:

In 1995, approximately one million CWT juvenile pink salmon were released from four hatcheries in PWS. Juvenile salmon were sampled as described in objective 1 to obtain CWT juvenile salmon for estimation of growth rate. A portable tube CWT detector was used to isolate CWT juvenile salmon from untagged fish in purse seine catches. Only about one fish in a thousand were coded-wire tagged on average, so a large number of juvenile salmon were captured to obtain an adequate sample of CWT salmon. When a large number of fish were caught, the total number of fish in the catch was estimated volumetrically. Live fish were placed in a volumetric beaker with a known volume of water. The displacement volume of the fish was calculated by subtraction. The number of beakers of live fish in the total catch was recorded. Total number of fish in the catch was estimated from the number of beakers and the number of fish per displacement volume.

Individual CWT juvenile salmon were placed in pre-weighed vials and frozen. The vials were weighed later on shore when accuracies of 0.01 g were obtained. Fork length was measured to the nearest 0.05 mm. Methods developed by the ADF&G CWT Laboratory for extracting and interrogating CWTs were employed. An exponential model was used to estimate growth rates (G_i) of individual CWT juvenile salmon, i.e.

$$G_l = \frac{\ln(W_c) - \ln(W_r)}{t_c - t_r} \quad (2)$$

where W_c is the weight of the fish at capture, W_r is the mean weight at release of the fish in a specific tag-code group, t_c is the date at capture, and t_r is the mean date at release.

Objective 7:

Sub-hypotheses I-1 & I-2.

See DPD for project 95320E.

Sub-hypotheses II-1 through II-3.

See DPD for project 95320E.

Sub-hypothesis II-4.

A bioenergetics model will be used to examine the effects of ocean temperature and diet composition on the growth of juvenile pink salmon (Willette et al. 1994). Holling (1966) developed a model to estimate the feeding rate of invertebrates in relation to prey density, i.e.,

$$I_f = \frac{\gamma\, p\, U}{1 + \gamma\, p\, U\, h} \quad (3)$$

where I_f is the feeding rate (g sec^{-1}), γ is the cross-sectional area of the reactive field (cm^2), p is the prey density (g cm^{-3}), U is the swimming speed (cm sec^{-1}), and h is the prey handling time (sec g^{-1}). This model was successfully used by Ware (1975, 1978) to estimate the feeding rate of fish. To account for prey that are attacked but not captured, equation (3) will be multiplied by the prey capture success rate. A prey capture success rate of 85% is typical for juvenile fishes (Ware 1972). The distance from which a fish will approach prey is called the reactive distance (Ware 1972). This distance is a function of fish size (Ware 1978) and prey size (Ware 1972). Data provided by Ware (1972) was used to estimate a regression equation relating reactive distance to fish length and prey length, i.e., $d_r = 0.29\ L_f^{1.1} + 3.3\ L_p$ (r=.98, P=.005), where d_r is the reactive distance (cm), L_f is total fish length (cm) and L_p is prey length (mm) (Willette et al. 1994). Given d_r, the cross-sectional area of the reactive field (γ) is πd^2_r. Bailey et al. (1975) estimated that pink salmon swim at 11 to 20 cm sec^{-1} when feeding in currents. In the present study, an average swimming speed of 15 cm sec^{-1} will be assumed, because juvenile pink salmon are often observed feeding while swimming in currents. For a 1 g pink salmon, this is approximately the critical swimming speed, i.e. 3.0 body lengths per second. Parsons and LeBrasseur (1973) estimated the feeding rates of juvenile pink salmon in tanks at different prey densities. Their data have not be used to estimate feeding rates directly, because the prey densities used 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.

Estimates of daily food consumption will be obtained from equation 3 using prey composition data obtained from stomach contents analyses of juvenile pink salmon in PWS (Willette et al. 1994). It will be assumed that light levels in PWS are adequate for feeding for twenty hours each day. The daily food consumption will be estimated using handling times for large and small copepods (Parsons and LeBrasseur 1973). Handling times for small copepods will be used for all prey items other than large copepods. The analysis will be conducted using data collected in 1989, 1990, 1991, 1993, 1994, and 1995, because estimates of prey density by taxonomic group are available for these years (Wertheimer et al. 1993, Willette et al. 1994).

Daily growth will be estimated by a simple mass balance equation, i.e.

$$G = a\,I - R \tag{4}$$

where G = growth rate (cal day^{-1}), I = food consumption (cal day^{-1}), R = total metabolism (cal day^{-1}), and a = assimilation coefficient. An assimilation coefficient (a) of 0.86 will be used (Ware 1975). Total metabolism (R) is composed of feeding metabolism, standard metabolism, active metabolism, and migration metabolism (Brett and Groves 1979). Brett and Glass (1973) estimated the active metabolism (including standard 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). Data provided by Brett and Glass (1973) will be used to estimate temperature-specific active metabolic rates for a 1 g pink salmon. Feeding metabolism is a function of the rate 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 (i.e. ~0.16, Ware 1975). Feeding metabolism will be added to active metabolism after an initial estimate of food consumption. Migration metabolism will not be included in total metabolism, because active metabolism has been estimated while the fish were swimming at the critical speed. The model will be validated by comparing predicted growth to measured growth of coded-wire tagged juvenile pink salmon in PWS.

Sub-hypothesis II-5.

The relationship between juvenile growth rate and fry-to-adult survival was evaluated from recoveries of CWT juveniles and adults. Restoration project 95320B (Pink Salmon Coded-wire Tag Recovery) provided data on survival rates of CWT pink salmon released in 1994. Analysis of covariance was used to test for differences in the intercept and slope of the regression model between years (1989-1994). Mean growth and survival for each tag code group were used in the analysis. The independent variable was release year with mean growth rate of juvenile salmon as a covariate. Only juvenile salmon less than 60 mm FL at capture were included in the analysis .

Sub-hypotheses III-1 & III-2.

See DPD for project 95320E.

Sub-hypothesis III-3.

Analysis of variance was used to test for differences in total zooplankton biomass (g m^{-3}), and the abundance of large calanoid copepods (no. m^{-3}), small calanoid copepods, and 'other' zooplankters between nearshore and offshore habitats. Zooplankton biomass and composition was estimated as described in objective 3. The analysis was conducted using data from both 10 and 20m vertical net tows, and only data from 20 m vertical net tows. Analysis of variance was also used to test for differences the abundance of large copepods in nearshore habitats at three levels of current speed (<.10 m sec^{-1}, .10 m sec^{-1} > and < .20 m sec^{-1}, and >.20 m sec^{-1}). This analysis was conducted to determine if periodic tidal mixing causes large calanoid copepods to be pulsed into nearshore habitats. Current speed estimates were obtained from tide programs provided by NOAA.

Sub-hypotheses III-4 & III-5.

Multiple linear regression analysis will be used to examine the relationship between the daily foraging time of juvenile salmon and prey density, the proportion of large calanoid copepods in the diet, ocean temperature, and the abundance of juvenile salmon. The daily foraging time of juvenile salmon, prey density, diet composition, juvenile salmon abundances will be estimated as described in objectives 1, 2, 3, and 4. Data from each diel study conducted at nearshore sampling sites will be used as the sample unit in the analysis.

Sub-hypothesis III-6.

Regression analysis will be employed to examine the relationship between juvenile salmon consumption rate and the daily foraging time of juvenile salmon. The juvenile salmon consumption rate will be obtained from project 95320E. The daily foraging time of juvenile salmon will be estimated as described in objective 1. Data from each diel study conducted at nearshore sampling sites will be used as the sample unit in the analysis.

Sub-hypothesis IV-1.

Analysis of variance was used to test for a relationship between the abundance of fish predators and the abundance of juvenile salmon. Catch per unit effort in trawl, purse seine and fixed gear was used as an index of predator abundance in offshore, nearshore pelagic, and nearshore benthic habitats at each site. The abundance of juvenile salmon was estimated as described in objective 2.

Sub-hypotheses IV-2 and IV-3.

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

Objective 8:

In 1995, estimates of survival to adult became available for pink salmon released in 1994. A striking difference in survival of early and late groups released from the Armin F. Koernig and WHN hatcheries prompted an examination of possible causes. The distribution of the two groups of fish were visually compared on maps indicating the location of recovery of CWT juveniles. An analysis of variance was conducted to test for differences in growth, length-adjusted body weight (condition), and length between the two groups. Only data from CWT juveniles were used in this analysis. Growth rate of the early release group was estimated for the period when the two groups of fish were mixed together (after the middle of June). The body weight of the early release group in mid-June was used as an initial weight to calculate growth after that time. The relative abundance of each group was estimated from the number of CWT juveniles recovered in each net set expanded by the appropriate tagged-to-untagged ratio. An analysis of variance was conducted to test for differences in the relative abundance of the two groups after the middle of June. The dependent variable in the analysis was the natural logarithm of catch per net set. Two instantaneous mortality rates were calculated for the early release group for the initial 45 days of marine residence (i.e. prior to the release of the late group) assuming (1) equal mortality for the early and late release groups after the middle of June, and (2) constant mortality for the early release group throughout the marine lifestage and differential mortality between the early and late release groups after the middle of June. The instantaneous mortality of the early release group under assumption #1 was estimated by

$$\frac{z_{ij} = z_i t_i + z_j t_j}{t_{ij}} \qquad (5)$$

$$z_i = x\ z_j$$

where z_{ij} is the instantaneous mortality for the entire fry-to-adult lifestage, z_i is the instantaneous mortality during the initial 45 days of marine residence, t_i is the duration of the initial period (45 days), z_j is the instantaneous mortality after the initial 45 day period, t_j is the duration of the period after the initial 45 days, t_{ij} is the duration of the entire fry-to-adult stage, and x is a constant. Changes in relative abundance of the early release group were modelled using these two assumed instantaneous mortality rates, i.e

$$N_t = N_o e^{-zt} \qquad (6)$$

where N_t is the population size at time t, N_o is the initial population size, and z is the instantaneous mortality rate. Estimated and simulated changes in the relative abundance of the early release group were visually compared.

Results:

The 1995 release of juvenile salmon from the WHN Hatchery began on April 29 and continued until June 14. During this time period, approximately 168 million juvenile pink salmon averaging .24-.35 g were released (Figure 3). About 300,000 of these fish carried a CWT. The last release occurred on June 14 when 7 million juvenile pink salmon averaging 1.0 g swam out of two net pens at the WHN Hatchery. This group of relatively large juveniles was released to test the hypothesis that mortality is size dependent.

Objective 1:

Four thousand and six hundred juvenile pink and chum salmon were collected to estimate daily foraging times at sixteen sites in western PWS. Stomach sample processing was initiated in December, 1995. Approximately 40% of these samples have been laboratory analyzed to date. Preliminary estimates of daily foraging time were developed for 4 sites from which sufficient data was available. Stomach fullness differed significantly by time of day ($P<.001$) at each of the 4 sites (Figure 4). Daily food consumption was relatively low in early May and increased by a factor of 6 by early June (Table 1). Daily foraging times increased by a factor of two between early May and early June (Table 1). A more comprehensive analysis will be conducted when all data is available.

Objective 2:

The relative abundance of juvenile salmon varied considerably among sixteen sites sampled in western PWS (Table 2). There was no apparent relationship between the relative abundance of juvenile salmon in nearshore and offshore habitats. In offshore habitats, catch per net set in purse seines and tow nets did not appear to be related. Further analyses will be conducted when acoustic data from project 95320N becomes available.

Objective 3:

Mean total zooplankton biomass ranged from 0.3 to 1.8 g m^{-3} and varied significantly ($P<.001$) among sixteen sites sampled in western PWS (Table 3). The mean abundance of large calanoid copepods (no. m^{-3}), small calanoid copepods, and 'other' zooplankters also varied significantly ($P<.001$) among the sixteen sites sampled in 1995 (Table 3).

Objective 4:

Four thousand and six hundred juvenile pink and chum salmon were collected at sixteen sites in western PWS to estimate diet composition. Stomach sample processing was initiated in December, 1995. Approximately 40% of these samples have been laboratory analyzed to date. Analyses of these data will be conducted when all data becomes available. An additional 1,513 samples of various species of forage fish were collected for later stomach contents analysis by the NMFS, Auke Bay Laboratory under project 96163 (Table 4).

Objective 5:

Juvenile pink salmon increased in length from 32 mm in early May to 59 mm in the middle of June (Table 5). Analysis of covariance indicated significant differences (P<.001) in condition among the six sites for which data is presently available.

Objective 6:

Two hundred and sixty four juvenile CWT pink salmon were recovered during June in western PWS. Growth rates of juvenile pink salmon differed significantly among three treatment groups (P=.011) and were similar to growth rates observed in 1994 (Table 6).

Objective 7:

Sub-hypothesis II-4.

An analysis has not yet been conducted to determine if the growth of juvenile pink salmon was likely limited by low food abundance. Diet composition data for juvenile salmon collected in 1995 is not yet fully from the laboratories. Work on this and other components of data analysis will continue in July after the 1996 field season.

Sub-hypothesis II-5.

Analysis of covariance indicated significant differences (P<.0001) among years in the slope of the relationship between juvenile growth and fry-to-adult survival (Willette et al. 1995). The slope of the growth-survival relationship was significantly different (P<.0001) from zero in all years, except 1991 (P=.1470) and 1992 (P=.1986). For fry released from the WHN Hatchery in 1994, the slope of the growth-survival relationship was again not significantly different (P=.1904) from zero (Figure 5).

Sub-hypothesis III-3.

A total of 230 vertical ring net samples were collected to test for differences in zooplankton biomass and species composition between nearshore and offshore habitats. Forty nine of these samples were 10 m vertical net tows taken in nearshore habitats where bottom depth was less than 20 m. The remainder were 20 m vertical net tows. When all samples were included in the analysis, the total zooplankton biomass was significantly greater offshore than nearshore in both May (P=.003) and June (P=.001). When all samples were included in the analysis, the abundance of large copepods was significantly greater offshore than nearshore in both May (P=.005) and June (P=.004). When only 20 m vertical net tows were included in the analysis, the total zooplankton biomass was still significantly greater offshore than nearshore in May (P=.024) and June (P=.007). When only 20 m vertical net tows were included in the analysis, the abundance of large copepods was still significantly greater offshore than nearshore in May (P=.063) and June (P=.006). The abundance of large copepods was approximately 50% greater in offshore habitats in May and 3 times greater in June (Tables 7 & 8). There was generally no relationship between tidal current speed and zooplankton biomass or abundance. However, the abundance of 'other' zooplankters was significantly greater (P=.038) at intermediate current speeds relative to both low and high current speeds in May (Table 9). It is not clear what mechanism if any may have caused this difference.

Sub-hypothesis III-4 & III-5.

An analysis has not yet been conducted to examine the relationship between the daily foraging time of juvenile pink salmon and environmental conditions. Diet composition data for juvenile salmon collected in 1995 is not yet fully from the laboratories. Work on this and other components of data analysis will continue in July after the 1996 field season.

Sub-hypothesis III-6.

An analysis has not yet been conducted to examine the relationship between the daily foraging time of juvenile pink salmon and juvenile salmon consumption rates. Work on this and other components of data analysis will continue after the 1996 field season.

Sub-hypothesis IV-1.

The relative abundance of juvenile salmon was not significantly related to catch of predatory fish per unit effort in trawl gear (P=.3148), seine gear (P=.9238), or fixed gear (P=.8646, Table 10) Trawl catch per unit effort was marginally significantly related to sampling site (P=.0974), but no site effect was detected for the other gear types. Further analyses will be conducted when data from project 95320N becomes available.

Objective 8:

Survival to adult in 1995 was an order of magnitude greater for a late release of large fry compared to an early release of small fry at the WHN Hatchery (Table 11). Recoveries of coded-wire tagged juvenile salmon indicated that these two groups of fish were mixed together in southwest PWS after the middle of June (Figure 6). Comparison of several biological characteristics between these two groups indicated no difference in growth (P=.247) or length-adjusted body weight (P=.351) after the fish were mixed together (Table 12);

although, length was slightly less for the late release group compared to the early release group (Table 12). After the middle of June, catch per unit effort of coded-wire tagged fry was roughly equal for these two groups despite the fact that 235,000 tags had been applied to the early-release group and only 20,000 tags to the late-release group (Figure 7). These results suggest that significant mortality may have occurred among the early release group prior to the middle of June, 1994. Assuming equal mortality for the early and late release groups after the middle of June, the instantaneous mortality rate (z) of the early release group prior to the middle of June was estimated to be -.0846. The instantaneous mortality rate for the early release group (assuming constant mortality throughout the marine lifestage) was estimated to be -.0133. Comparison of simulated and estimated changes in relative abundance (catch per unit effort) support the conclusion that significant mortality may have occurred among the early release group prior to the middle of June, 1994 (Figure 8).

Discussion:

Greater zooplankton biomass and abundances of large calanoid copepods in offshore habitats (Tables 7 & 8) indicates that the growth potential for juvenile pink salmon may be greater offshore when growth is limited by low food abundance nearshore. Willette et al. (1994) found that growth rates of juvenile pink salmon may be limited by low food abundance when zooplankton biomass is less than 0.10 g m^{-3} and water temperature exceeds 10° C. When growth is limited by low food abundance in nearshore habitats, juvenile salmon may face a trade off between growth and predation risk, because the abundance of predatory fish is at times much greater in offshore habitats (Willette et al. 1995b, Walters and Juanes 1993). The abundance of large calanoid copepods likely has a strong effect in determining whether juvenile salmon are food limited, because the feeding rate of juvenile pink salmon is approximately 3 times greater when the fish consume large rather than small calanoid copepods (Parsons and LeBrasseur 1973). Preliminary estimates of daily food consumption and foraging times suggest that juvenile pink salmon may not have been food limited in nearshore habitats in May when foraging times were approximately 12 hours per day (Table 1). This is consistent with earlier estimates of daily foraging times in May which were based on estimated feeding rates and maximum daily ration (Willette et al. 1994). Further analyses will be conducted to evaluate when low food abundance may have limited the growth of juvenile pink salmon in nearshore habitats. We will also examine how the timing of food limitation in nearshore habitats may coincide with apparent offshore movements of fry and seasonal changes in predator abundances.

Several lines of evidence indicate that significant mortality may have occurred among the early group released from the WHN hatchery prior to the middle of June, 1994. Fry-to-adult survival was an order of magnitude greater for the late release of relatively large fry compared to the early release of much smaller fish (Table 11). Recoveries of CWT fry indicated that these two groups of fish were mixed together in lower Knight Island Passage after the middle of June (Figure 6). Several biological characteristics were not significantly different between the two groups after they were mixed together (Table 12). Finally, relative abundances of the early-release group in purse seine catches declined exponentially, consistent with an instantaneous mortality rate assuming equal mortality between the early and late groups after they were mixed together. Several alternative hypotheses must be examined to evaluate the possible causes of these observations: (1) the mortality of the early-release group was high in some area within their overall distribution after the middle of June, (2) high condition (energetic content) among the late-release group caused lower mortality compared to the early-release group after the middle of June, and (3) the apparent exponential decline in relative abundance of the early-release group was due to sampling error.

It seems unlikely that the mortality of the early-release group was high in some area within their overall distribution after the middle of June. In 1994, shoreline surveys were conducted in Knight Island Passage to collect samples of CWT juvenile salmon. Each survey typically began in the lower reaches of the passage below the area where fry from the WHN Hatchery had last been observed. The sampling effort then moved northward toward WHN Hatchery recovering CWT fry as they were encountered. The overall sampling effort moved southward in the passage as the main body of fry from WHN Hatchery moved south. After the middle of June, sampling effort was focused in southern PWS. Thus, it is possible that the bulk of the late-release group was not mixed with the early-release group and was distributed more in northern PWS. If so, higher mortality among the early-release group could be due to higher predation in southern PWS. However, mid-water trawl sampling indicated very low abundances of walleye pollock and squid in both northern and southern PWS in early July (Willette et al. 1995b). Also, catch per net set for the early-release group abruptly declined several weeks prior to the middle of June (Figure 8).

High condition (energetic content) among the late-release group may have caused lower mortality compared to the early-release group after the middle of June. Sequential measurements of carbon-nitrogen ratios of juvenile pink salmon indicated that condition declined rapidly after release (See chapter 95320I, Confirming food web dependencies). These measurements were made on fish from the early-release group. The initial high condition of fish upon release was likely due to a period of feeding in net pens. Measurements of energy content were not made for the late release of large fry from the WHN Hatchery. However, it is likely that the condition of these fish was very high after more than 45 days of net pen feeding. In the present study, the condition of the early and late release groups was estimated from measurements of whole body wet weight (Table 11). This method of estimating condition may not be adequate for describing the energy content of fish due to differences in water content of tissues (Brett et al. 1969). Several studies have shown that predation rate is related to the condition of juvenile salmon (Bams 1967, Hatfield and Anderson 1972, Sylvester 1972, Ginetz & Larkin 1976, Olla and Davis 1989, Olla et al. 1992, Gadomski and Hall-Griswold 1992). Future studies should focus on condition-dependent predation on juvenile pink salmon.

It does not appear that the exponential decline in catch per net set of juvenile pink salmon from the early-release group was due to sampling error. In the present study, juvenile salmon were sampled with a small-mesh purse seine operated from a skiff. As juvenile pink salmon approach 60-70 mm in length, they tend to move offshore and deeper in the water column (Hoar 1976, Cooney et al. 1978). In the present study, the relative abundance of the early-release group declined abruptly between early and late May, 1994 (Figure 8). Over this same time interval, the mean length of the early-release group increased from 38 to 42 mm (Willette et al. 1995a). It seems unlikely that this relatively small increase in mean length could account for the observed magnitude of the decline in catch per net set for the early-release group. It is possible that a significant number of fish from the early-release group moved out of our study area. However, previous juvenile CWT recovery surveys (1989-1991) conducted over a broader area documented that the majority of juvenile pink salmon released from WHN Hatchery typically move southward into Knight Island Passage (Willette et al. 1994).

High mortality among the early-release group largely caused the failure of the 1995 pink salmon return to the WHN Hatchery. Low survival of early-release groups and high survival of late-release groups was also observed at the Armin F. Koernig (AFK) Hatchery in southwest PWS (Table 11). The return of pink salmon to the AFK Hatchery also failed in 1995. Comparison of percent deviation of district-specific wild pink salmon escapement from the sound-wide mean indicates that wild pink salmon returns may have also been weak in western PWS in 1995 (Figure 9). These results suggest that high mortality among juvenile pink salmon prior to the middle of June may have been the cause of weak returns of both wild and hatchery-reared pink salmon in western PWS in 1995.

Conclusions:

1. Greater zooplankton biomass and abundances of large calanoid copepods in offshore habitats indicates that the growth potential for juvenile pink salmon may be greater offshore when growth is limited by low food abundance nearshore.

2. Several lines of evidence indicate that significant mortality may have occurred among an early group of juvenile pink salmon released from the WHN hatchery prior to the middle of June, 1994.

3. High mortality among early-release groups of juvenile pink salmon largely caused the failure of the 1995 pink salmon return to the WHN Hatchery. Low production of wild and hatchery-reared pink salmon throughout western PWS in 1995 may have been caused by high mortality of juveniles prior to the middle of June, 1994.

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Table 1: Estimated daily food consumption and foraging time for juvenile pink salmon at four sites in western Prince William Sound, 1995.

Date	Description	Temp. (deg. C)	Daily Food Consumption (%BW)	Foraging Time (hours)
5/8-5/9	W. Esther	6.0	4.8	9
5/9-5/10	S. Esther	6.0	4.5	12
5/30-5/31	Esther Pt.	7.0	28.0	24
6/1-6/2	Tipping Pt.	7.0	31.5	24

Table 2: Relative abundance of juvenile pink salmon in nearshore and offshore habitats at sixteen study sites in western Prince William Sound, 1995. Catch per net set in purse seines (PS) and tow nets (TN) was used as a measure of relative abundance in offshore habitats.

Date	Site	Description	Relative Abundance		
			Nearshore	Offshore (PS)	Offshore (TN)
5/3-5/4	501	Esther Pt.	high	157.2	-
5/5-5/6	506	Tipping Pt.	low	1.5	-
5/8-5/9	525	W. Esther Is.	moderate	1430.8	-
5/9-5/10	526	S. Esther Is.	high	1.9	-
5/11-5/12	501	Esther Pt.	high	0.9	-
5/13-5/14	525	W. Esther Is.	moderate	0.6	-
5/15-5/16	506	Tipping Pt.	low	0.2	-
5/17-5/18	502	Hodgkin Pt.	high	0.5	-
5/30-5/31	501	Esther Pt.	high	0.3	5.8
6/1-6/2	506	Tipping Pt.	moderate	3.6	5.5
6/3-6/4	525	W. Esther Is.	moderate	39.7	-
6/5-6/6	502	Hodgkin Pt.	moderate	575.3	4.0
6/8-6/9	506	Tipping Pt.	low	0.4	3.1
6/9-6/10	504	NE Culross	high	27.3	3.2
6/11-6/12	505	SE Culross	high	79.4	3.9
6/13-6/14	509	Herring Pt.	low	178.9	2.8

Table 3: Mean total zooplankton biomass (g m^{-3}) and mean abundance of large calanoid copepods (g m^{-3}), small calanoid copepods, and 'other' zooplankters at sixteen study sites in western Prince William Sound, 1995.

Date	Site	Description	n	Total	Lg. Cop.	Sm. Cop.	Other
5/3-5/4	501	Esther Pt.	20	.41	122	676	133
5/5-5/6	506	Tipping Pt.	8	.58	88	3255	157
5/8-5/9	525	W. Esther Is.	8	.33	78	1446	161
5/9-5/10	526	S. Esther Is.	11	.98	272	4340	386
5/11-5/12	501	Esther Pt.	15	.47	89	2381	209
5/13-5/14	525	W. Esther Is.	8	.47	103	1922	162
5/15-5/16	506	Tipping Pt.	6	.48	106	2873	397
5/17-5/18	502	Hodgkin Pt.	11	.44	48	3493	402
5/30-5/31	501	Esther Pt.	11	.69	123	5148	541
6/1-6/2	506	Tipping Pt.	1	1.79	115	12116	1077
6/3-6/4	525	W. Esther Is.	12	.50	49	3495	586
6/5-6/6	502	Hodgkin Pt.	3	.54	23	3598	366
6/8-6/9	506	Tipping Pt.	4	.38	37	1855	459
6/9-6/10	504	NE Culross	16	.72	24	3726	580
6/11-6/12	505	SE Culross	14	.28	21	2618	370
6/13-6/14	509	Herring Pt.	11	.53	29	1601	330

Table 4: Number of samples collected for later stomach contents analysis under project 96163 'Forage Fish Influence on Recovery of Injured Species.

Site	Date	Greenling	Wolfish	Herring	Tom Cod	Pollock	Capelin	Sandlance	Stickleback
521	5/2			21			48		
501	5/3						56		
506	5/5			36		12	12		
525	5/8	5					12		
526	5/9								23
501	5/12								93
525	5/13						35		12
506	5/16	20					24		10
502	5/17	24		12					51
517	5/26							12	
528	5/27	12		48				12	
501	5/30	36					24		96
506	6/1	9	13	12			24	30	
525	6/3					47			24
502	6/5	17					12		
506	6/8	2						13	
504	6/9	14	15			71			12
505	6/12				12	151	36		
509	6/13	54	2	11		171			
521	6/14	12							
Total		205	30	140	12	452	283	67	321

Table 5: Mean length, body weight, and condition of juvenile pink salmon collected at sixteen study sites in western Prince William Sound, 1995.

Date	Site	Description	Length (mm)	Weight (g)	Condition
5/3-5/4	501	Esther Pt.	32.0	.20	3.22
5/5-5/6	506	Tipping Pt.	32.7	.21	2.47
5/8-5/9	525	W. Esther Is.	32.5	.20	1.81
5/9-5/10	526	S. Esther Is.	34.6	.26	2.85
5/11-5/12	501	Esther Pt.	33.5	-	-
5/13-5/14	525	W. Esther Is.	36.1	-	-
5/15-5/16	506	Tipping Pt.	36.1	-	-
5/17-5/18	502	Hodgkin Pt.	39.5	-	-
5/30-5/31	501	Esther Pt.	40.6	.50	3.18
6/1-6/2	506	Tipping Pt.	48.9	.90	1.95
6/3-6/4	525	W. Esther Is.	43.3	-	-
6/5-6/6	502	Hodgkin Pt.	49.2	-	-
6/8-6/9	506	Tipping Pt.	53.1	-	-
6/9-6/10	504	NE Culross	52.0	-	-
6/11-6/12	505	SE Culross	54.4	-	-
6/13-6/14	509	Herring Pt.	58.9	-	-

Table 6: Mean growth (%BW day^{-1}) of coded-wire tagged juvenile pink salmon released from four hatcheries in Prince William Sound, 1989-1994.

Hatchery	Treatment	1989	1990	1991	1992	1993	1994	1995
AFK	Early Fed	3.77 (39)	4.30 (133)	3.12 (146)	4.13 (159)	4.41 (12)	4.59 (7)	-
	Direct Release	2.56 (22)	3.81 (50)	3.08 (13)	4.14 (32)	4.11 (5)	4.74 (7)	-
	Late Fed	2.16 (36)	3.35 (20)	3.12 (18)	5.14 (14)	6.11 (37)	4.62 (24)	-
WHN	Early Fed	4.12 (24)	3.96 (80)	3.38 (148)	4.43 (3)	4.57 (2)	4.26 (162)	4.21 (181)
	Direct Release	3.89 (9)	3.65 (12)	2.80 (19)	4.04 (1)	4.49 (1)	-	4.37 (27)
	Late Fed	9.19 (5)	7.09 (11)	2.09 (15)	-	6.84 (10)	-	3.37 (56)
CCH	Early Fed	5.64 (6)	4.76 (17)	3.08 (18)	-	-	5.25 (9)	4.21 (1)
	Direct Release	4.00 (8)	4.61 (8)	-	-	4.12 (1)	-	-
	Late Fed	3.87 (10)	5.29 (54)	2.80 (4)	4.48 (3)	6.84 (4)	5.92 (56)	-
SGH	Early Fed	5.60 (6)	6.53 (1)	-	-	2.22 (2)	4.32 (30)	-
	Direct Release	-	-	-	-	-	4.61 (24)	-
	Late Fed	5.10 (1)	2.50 (5)	-	-	-	-	-

AFK - Armin F. Koernig Hatchery
WHN - Wally H. Noerenberg Hatchery
CCH - Cannery Creek Hatchery
SGH - Solomon Gulch Hatchery

Table 7: Tests for differences in mean total zooplankton biomass and the abundance of large copepods, small copepods, and other zooplankters between nearshore and offshore stations during May and June. All stations used in analysis.

Month	Variable	Mean Nearshore	Mean Offshore	P-value
May	total biomass	.46	.65	.003
	abdn. lg. copepods	95	159	.005
	abdn. sm. copepods	1967	2020	.908
	abdn. other zoops.	219	223	.933
June	total biomass	.48	.74	.001
	abdn. lg. copepods	31	80	.004
	abdn. sm. copepods	3687	4291	.309
	abdn. other zoops.	529	605	.306

Table 8: Tests for differences in mean total zooplankton biomass and the abundance of large copepods, small copepods, and other zooplankters between nearshore and offshore stations during May and June. Only 20 m vertical net tows.

Month	Variable	Mean Nearshore	Mean Offshore	P-value
May	total biomass	.49	.65	.024
	abdn. lg. copepods	106	159	.063
	abdn. sm. copepods	1599	2020	.303
	abdn. other zoops.	194	223	.481
June	total biomass	.45	.69	.007
	abdn. lg. copepods	22	74	.006
	abdn. sm. copepods	2993	3868	.117
	abdn. other zoops.	480	602	.126

Table 9: Tests for differences in mean total zooplankton biomass and the abundance of large copepods, small copepods, and other zooplankters among 3 levels of current speed (low: <10 m sec-1, medium: >.10 m sec-1 and < .20 m sec-1, and high: >.20 m sec-1) during May and June. Only 20 m vertical net tows.

Month	Variable	Low	Medium	High	P-value
May	total biomass	.34	.60	.48	.196
	abdn. lg. copepods	103	118	86	.496
	abdn. sm. copepods	1151	2261	1994	.420
	abdn. other zoops.	136	293	193	.038
June	total biomass	.43	.45	.45	.989
	abdn. lg. copepods	45	19	17	.163
	abdn. sm. copepods	2301	3498	2908	.497
	abdn. other zoops.	337	484	446	.817

Table 10: Mean catch per unit effort of potential predatory fish at sixteen study sites in western Prince William Sound, 1995.

Site	Relative Fry Abund.	n	Gear Type Trawl	Seine	Fixed
Tipping Pt.	low	3	24.0	7.7	1.6
Herring Pt.	low	1	6.7	176.3	1.6
Hodgkin Pt.	moderate	1	42.7	42.9	2.8
Tipping Pt.	moderate	1	58.0	7.7	2.0
W. Esther Is.	moderate	1	46.7	147.4	2.3
Esther Pt.	high	3	47.9	73.3	2.2
Hodgkin Pt.	high	1	3.2	125.7	2.2
NE Culross	high	1	33.7	24.0	2.6
SE Culross	high	1	146.9	225.2	2.0
S. Esther Is.	high	1	32.8	47.6	1.4
Statistical Significance (P)			.315	.923	.865

Table 11: Survival to adult of the early-fed and late-fed groups released from the Wally H. Noerenberg Hatchery in 1994.

Hatchery	Release Date	Length (mm) at Release	Number Released (millions)	Survival to Adult (%)
AFK	early May	30	84.8	.36
AFK	early June	50	7.0	7.21
WHN	early May	33	154.7	.38
WHN	early June	55	7.7	22.12

Table 12: Biological characteristics of the early-fed and late-fed groups released from the Wally H. Noerenberg Hatchery and recovered after mid-June, 1994.

Characteristic	Treatment Group		P-value
	Early-fed	Late-fed	
Growth Rate (% $BWday^{-1}$)	4.86	5.19	.247
Length-adj. Body Weight (g)	1.60	1.57	.351
Length (mm)	84.6	78.8	.002

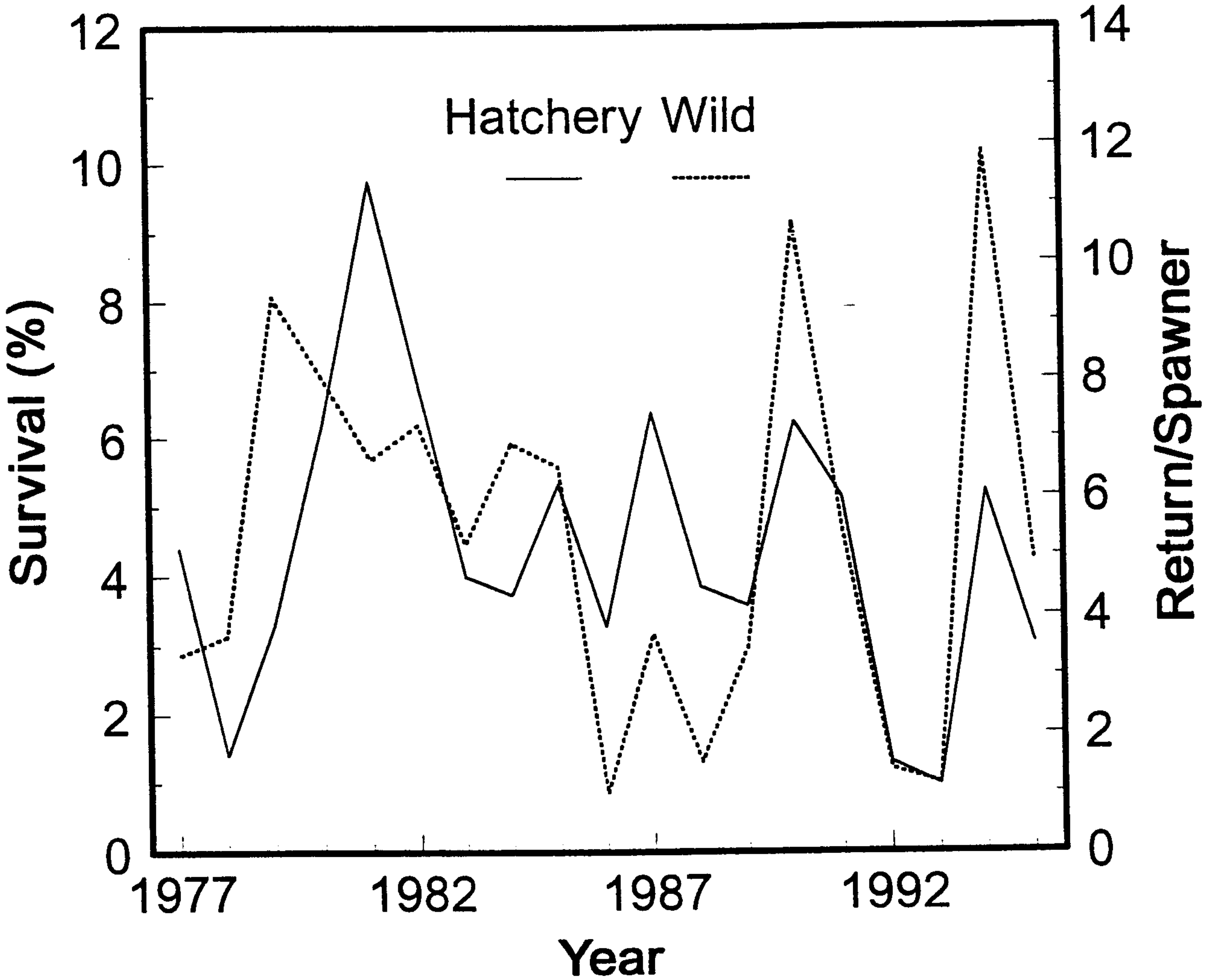


Figure 1: Survival of hatchery-reared pink salmon and return per spawner of wild pink salmon in Prince William Sound, 1977-1995..

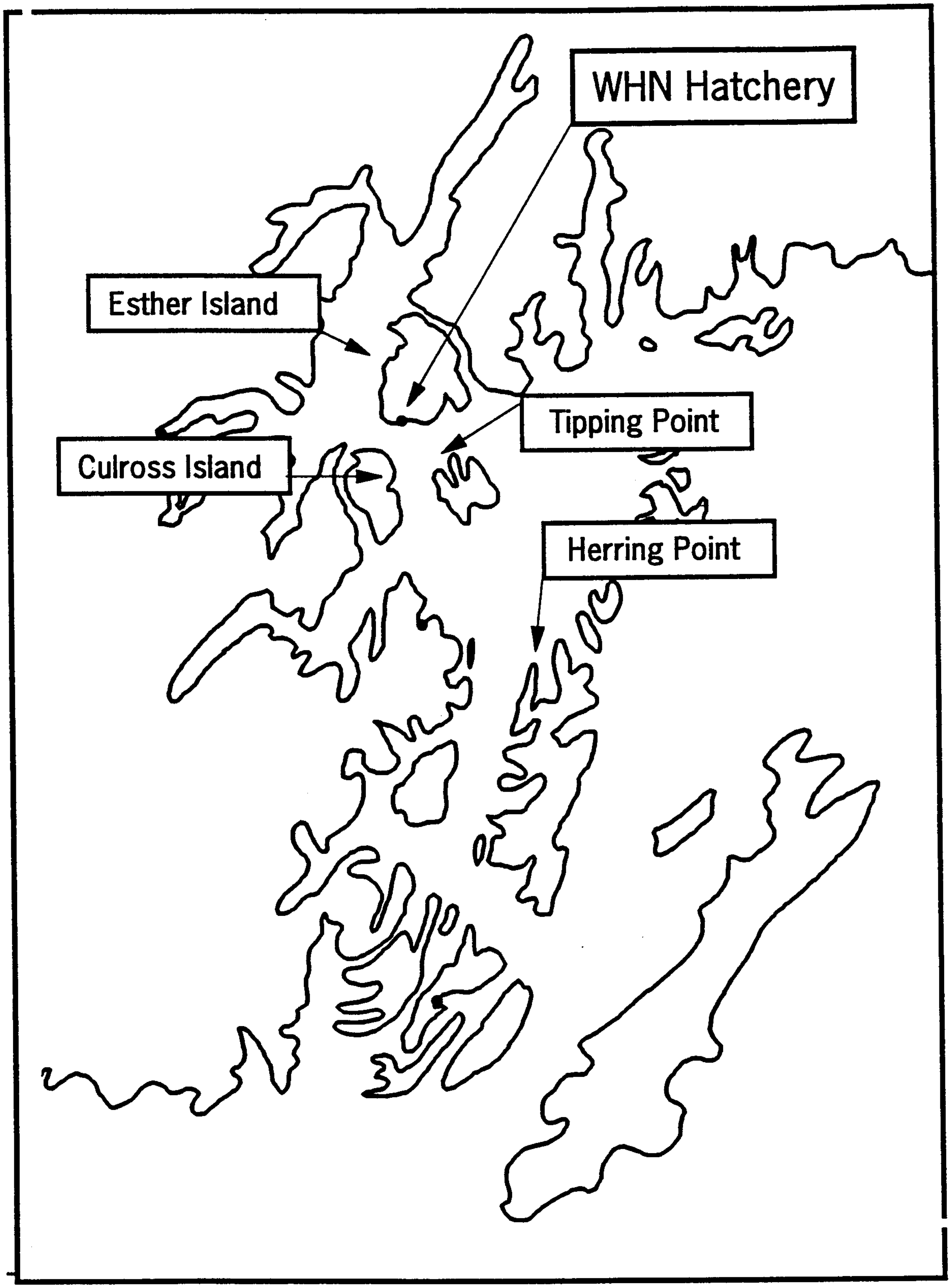


Figure 2: Study sites in western Prince William Sound.

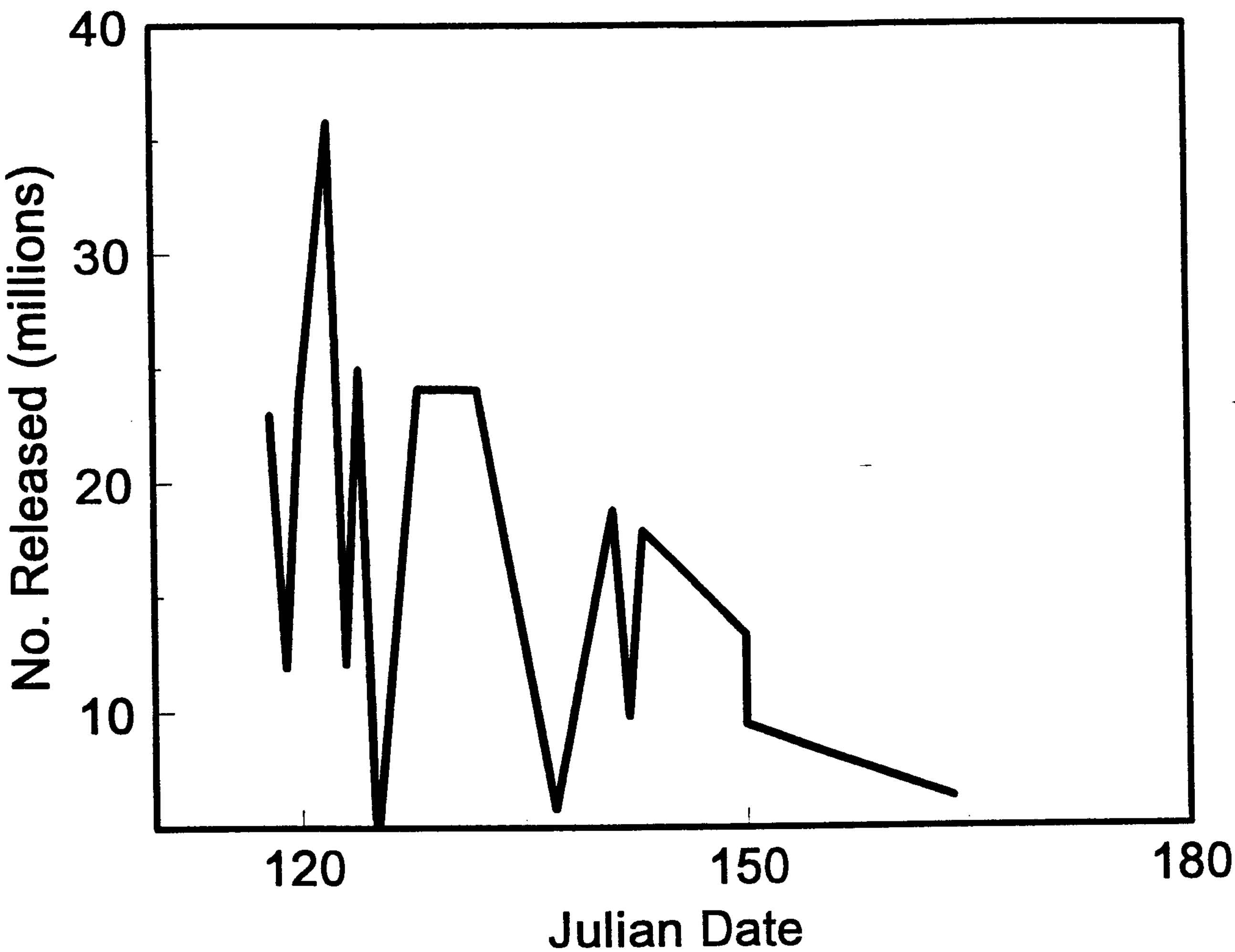


Figure 3: Timing of releases of juvenile pink salmon from the Wally H. Noerenberg Hatchery in 1995.

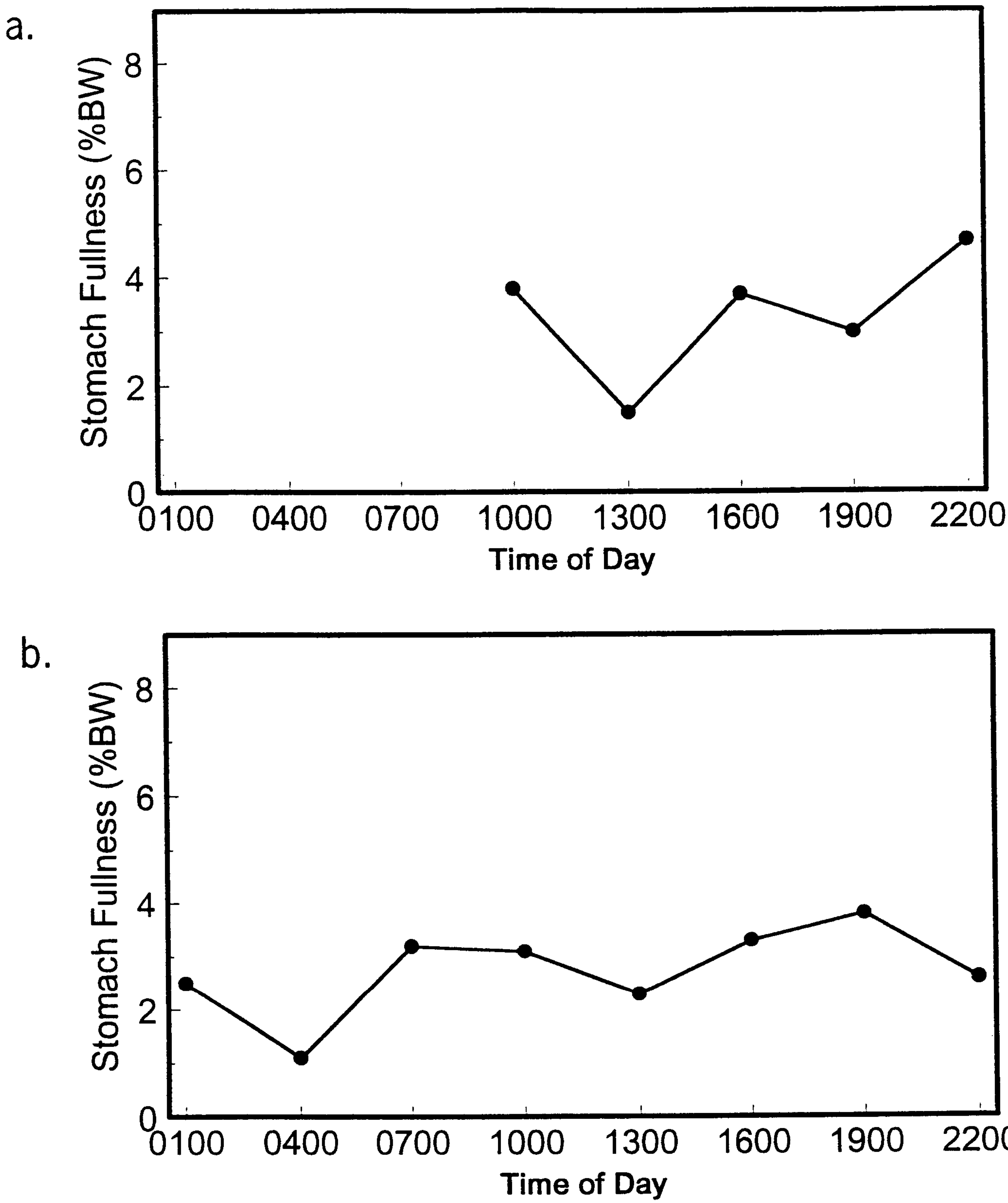
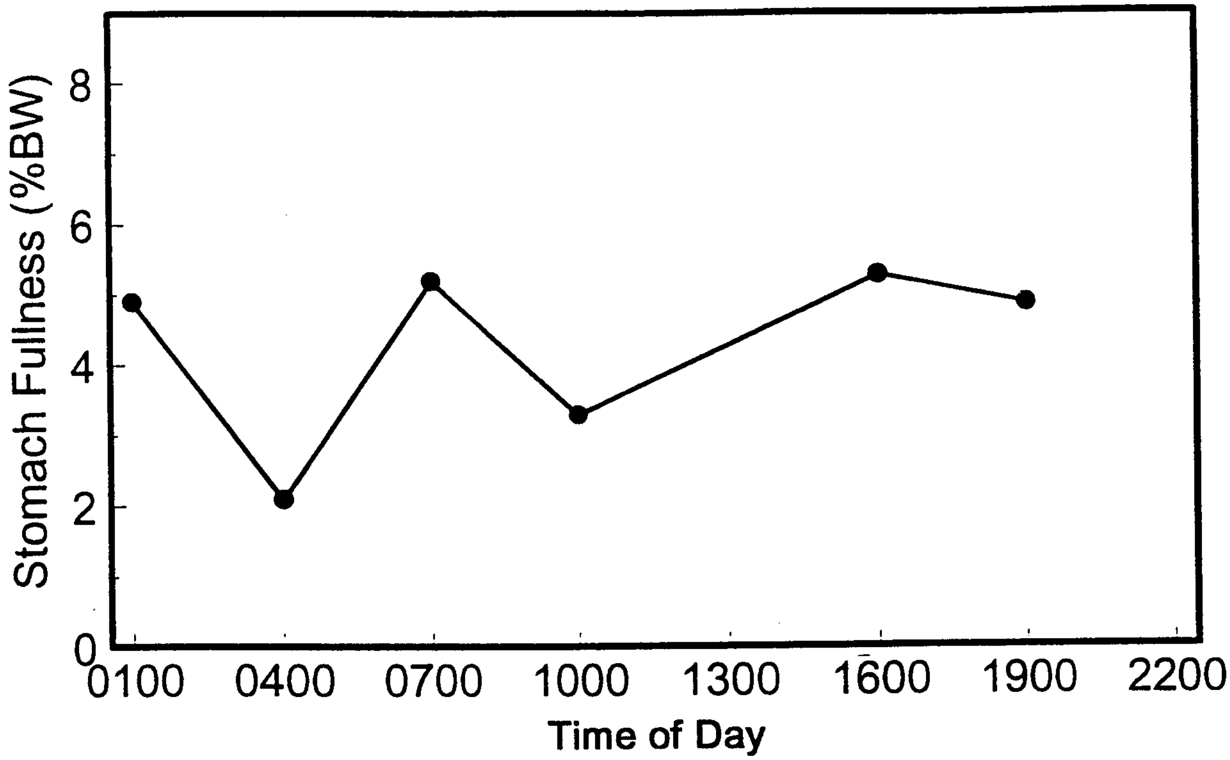


Figure 4: Stomach fullness of juvenile pink salmon sampled along the (a) west coast of Esther Island (May 8-9) and (b) south coast of Esther Island (May 9-10).

c.



d.

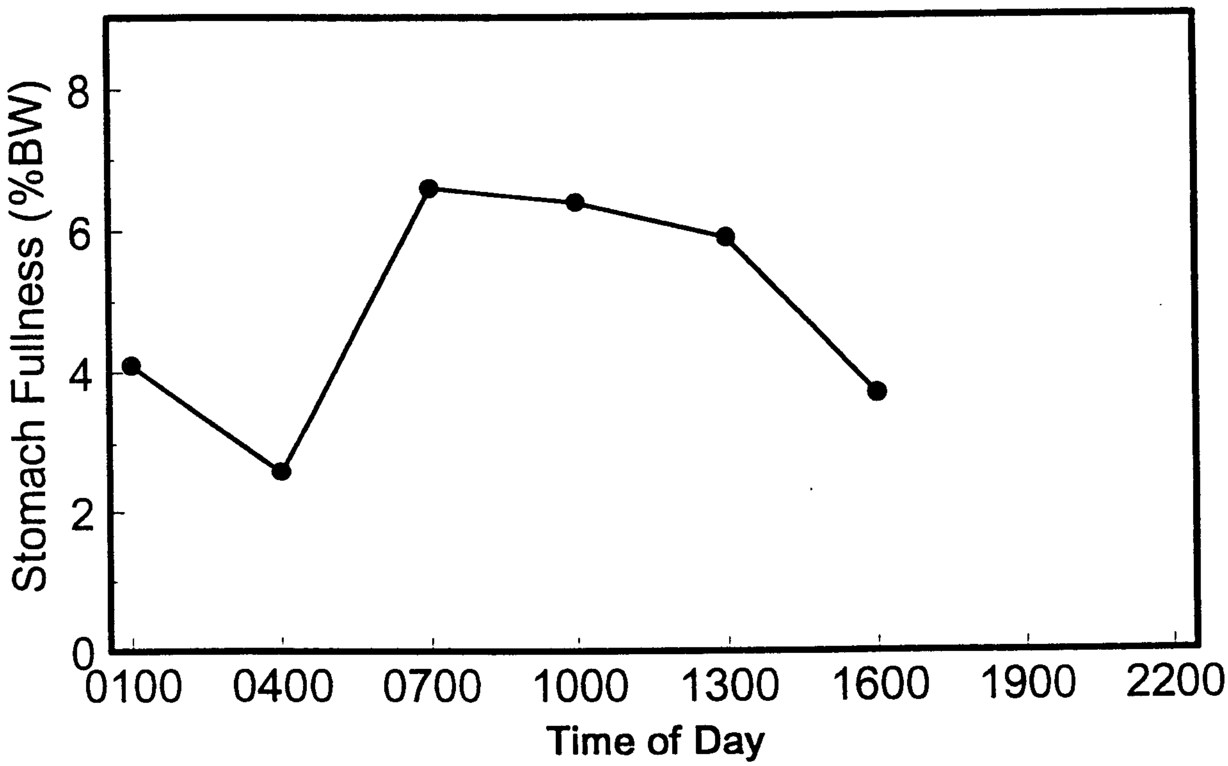


Figure 4: Stomach fullness of juvenile pink salmon sampled (c) near Esther Point (May 30-31)and (d) near Tipping Point (June 1-2).

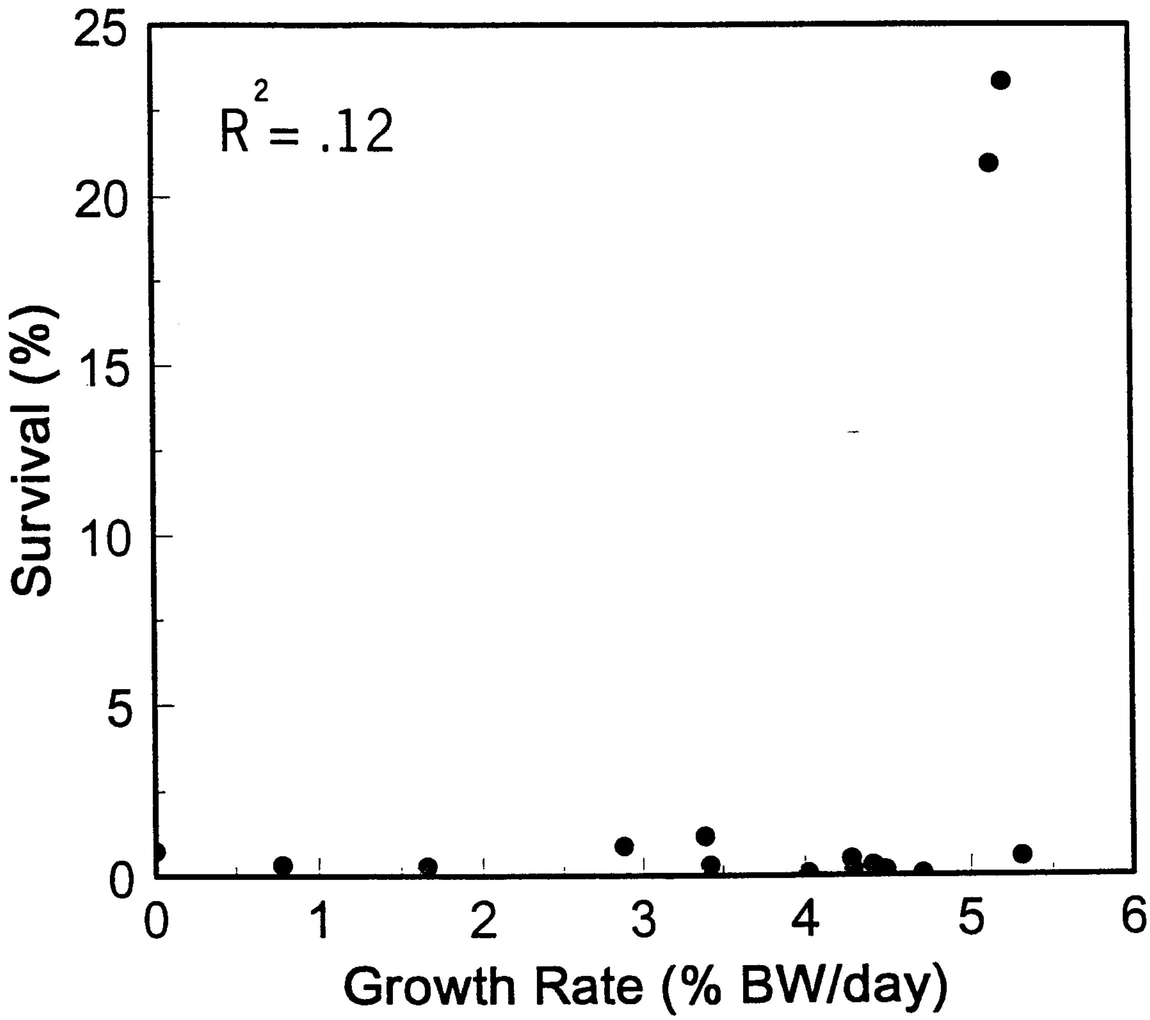


Figure 5: Relationship between growth rate of juvenile pink salmon and survival to adult for fish released from the Wally H. Noerenberg Hatchery in 1994.

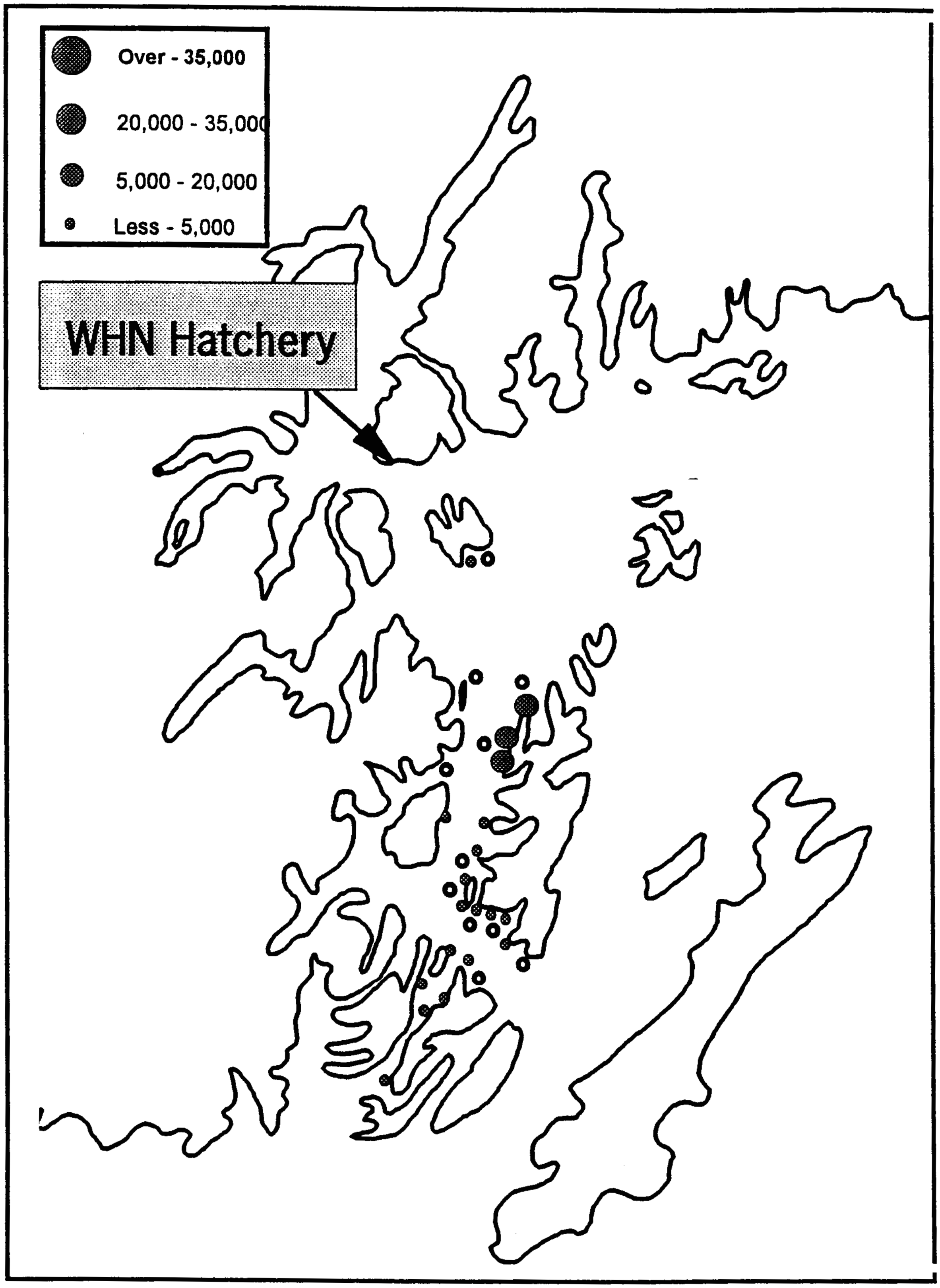


Figure 6: Distribution of the early and late groups released from the Wally H. Noerenberg (WHN) Hatchery and recovered in late June and early July, 1994. Solid circles indicate the early release group and open circles indicate the late release group.

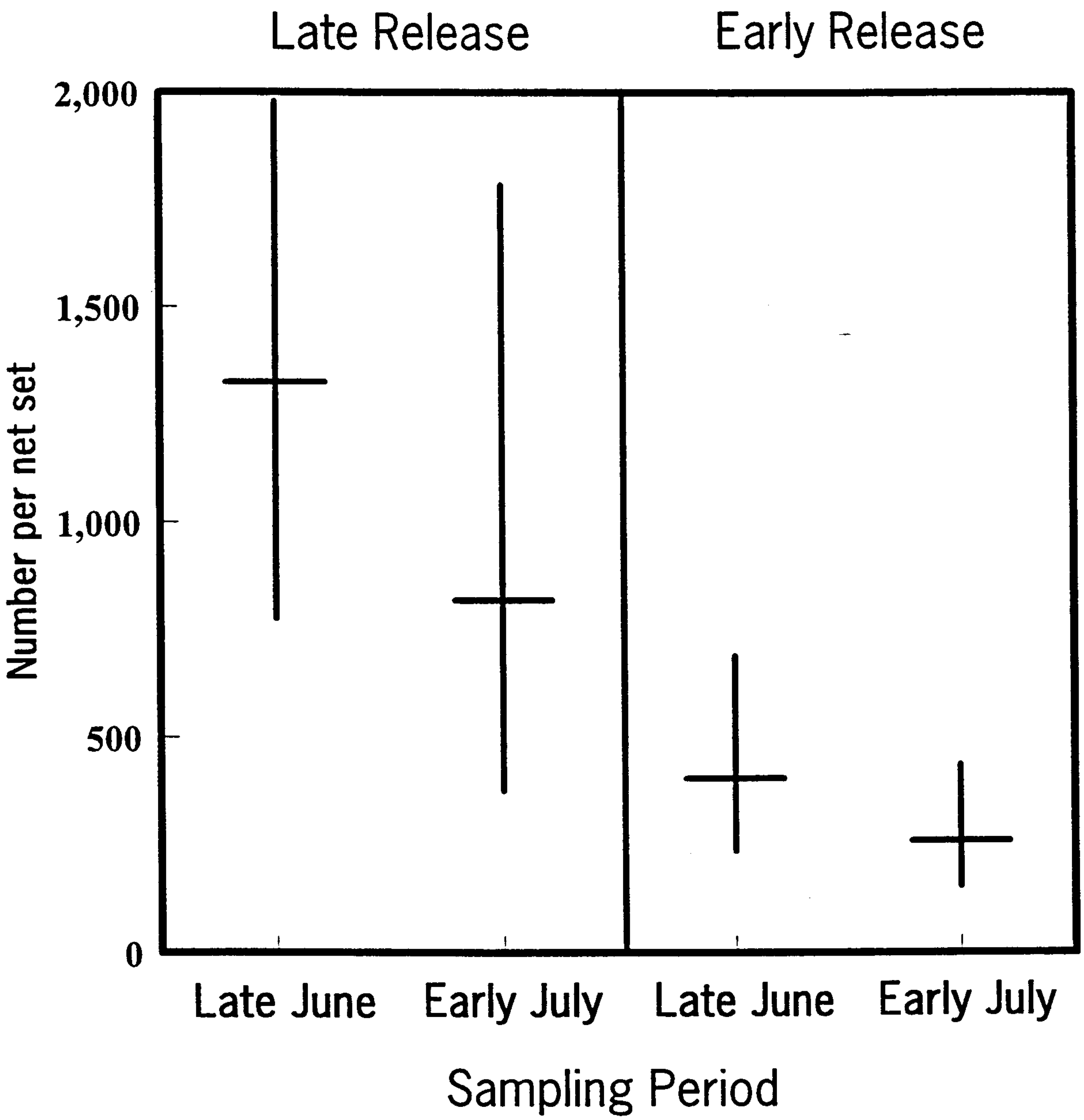


Figure 7: Comparison of catch per net set of juvenile pink salmon for the early and late groups released from the Wally H. Noerenberg Hatchery in 1994.

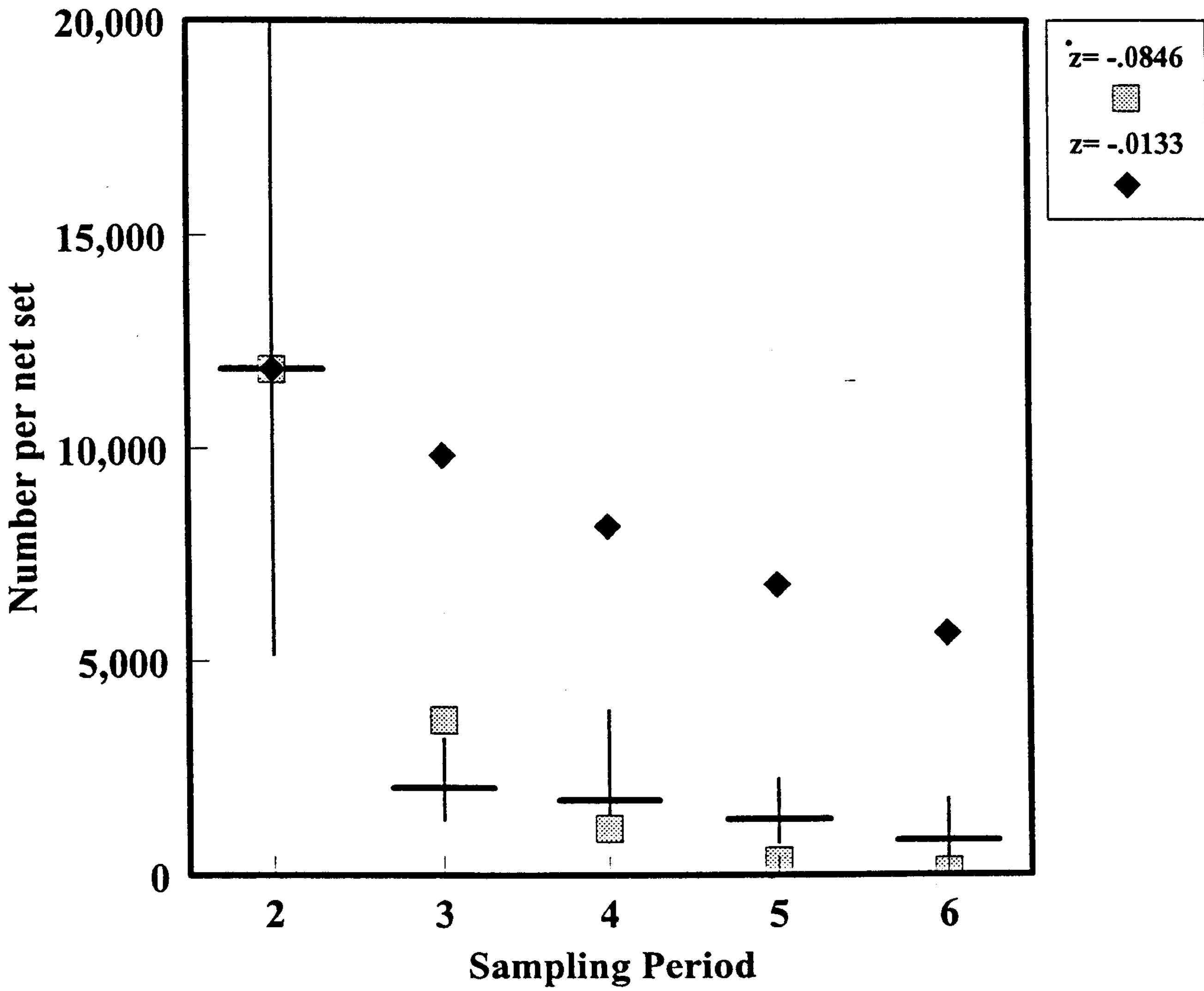


Figure 8: Estimated catch per net set of juvenile pink salmon from the early group released from the Wally H. Noerenberg Hatchery in 1994 and simulated relative abundance at two assumed levels of instantaneous mortality.

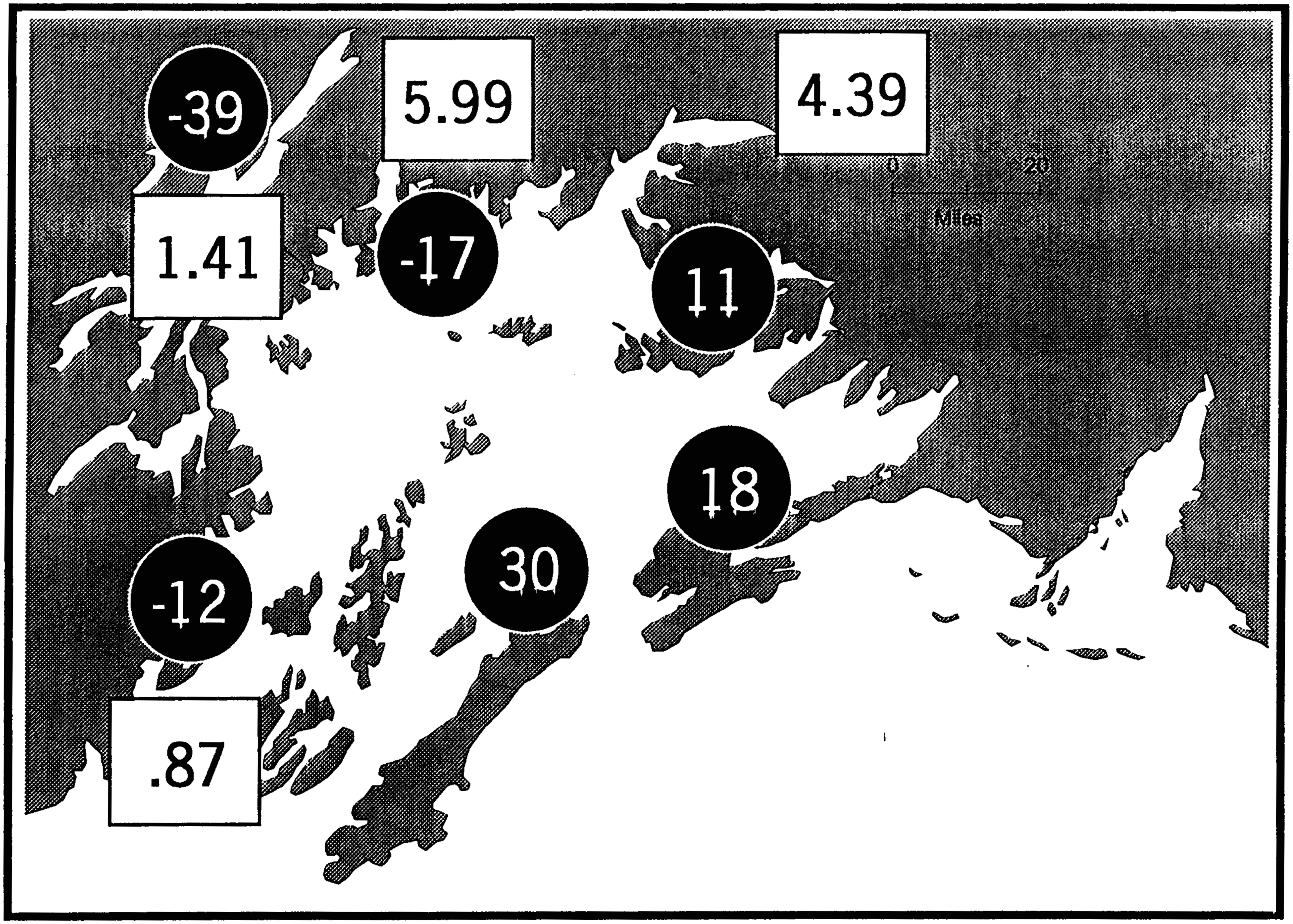


Figure 9: District-specific pink salmon escapement deviations from the sound-wide mean (circles) and survival of pink salmon returning to four hatcheries (squares) in Prince William Sound, 1995.