CHAPTER 1

94320-A Juvenile Salmon Growth and Mortality

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Exxon Valdez Oil Spill
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Sound Ecosystem Assessment: Salmon Growth and Mortality

Restoration Project 94320A
Final Report

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Abstract

This project tracked the migration of juvenile salmon through Prince William Sound, estimated juvenile salmon growth, and collected samples of co-occurring species for analysis of diet overlap. Recovery of these coded-wire tagged (CWT) fish played a major role in tracking the migration and growth of juvenile salmon. Approximately, 1.2 million juvenile pink salmon were captured and scanned for CWTs in western PWS during the 1994 season. About, 1,200 CWTs were recovered from these fish indicating that roughly 60% of these fish were of hatchery origin. Pacific sandlance and age 0 gadids was a common co-occurring species in nearshore net catches after the beginning of June. The mean length of the early-fed juvenile salmon released from the Wally H. Noerenberg Hatchery exceeded 60 mm after the middle of June, 1994. The mean length of the late-fed group did not exceed 60 mm until after July 9. Results from project 94320E indicated that predation risk was substantially less for juvenile salmon greater than 60 mm, and that predator abundance in nearshore areas increased after the beginning of June. Prolonged exposure to high predator abundance may lead to reduced survival among juvenile salmon entering the ocean late in the season. Results from analysis of variance indicated significant differences in the growth of juvenile pink salmon among years ($P < .0001$), hatcheries ($P < .0001$), and treatment groups ($P < .0001$). Juvenile growth in 1993 was the highest measured in the five years since 1989. Comparison of migration rates of early-fed CWT groups released early (April 25-28) and late (May 3-11) indicated higher migration rates for the later release groups. This result suggests that competition for food among successive release groups may led to increased migration rate. As predation by adult walleye pollock was apparently high in offshore areas of the passages in PWS in late April and May (See final report for 94320E), increased migration out of nearshore predation refuges may lead to decreased survival.

Diet composition data is presently available for 2,152 fish specimens (<150 mm FL) from eleven species. Mean stomach fullness of Pacific herring was significantly greater ($P < .0100$) in August-Sept. than in April-July. Stomach fullness of walleye pollock was significantly greater ($P = .0001$) in June-July than in August-September. There was no difference in stomach fullness of pink salmon among any sampling periods. However, stomach fullness of chum salmon was significantly lower ($P = .0001$) in June-July than in April-May or August-September. Although no statistical tests were performed, there were some apparent differences in diet composition among the eleven fish species and three sampling periods examined. Large copepods were apparently a dominant prey item for all fish species examined in April-May. The apparent dominance of large copepods was diminished somewhat among the fish species examined in June-July. By August-Sept., all fish species examined apparently consumed a broader range of prey items.

Analysis of covariance indicated significant differences ($P < .0001$) among years in the slope of the relationship between juvenile growth and fry-to-adult survival. The slope of the growth-survival relationship was significantly different ($P < .0001$) from zero in all years, except 1991 ($P = .1470$) and 1992 ($P = .1986$). The growth-survival relationship was different ($P = .0011$) for the early-fed and late-fed treatment groups with the slope for the early-fed group being greater than for the late-fed group four out of five years.

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 fish, and marine bird and mammal production in Prince William Sound (PWS). Pink salmon runs to PWS failed in 1992 and 1993. These salmon run failures have drastically affected the economy of the PWS region which is largely based on the salmon 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 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.

This project tracked the migration of juvenile salmon through PWS, estimated juvenile salmon growth, and contributed to studies of carrying capacity of the Sound. The project complemented other components of SEA by providing essential data needed to improve our understanding of the mechanisms regulating ecosystem function.

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 salmon in 1994. Approximately one million of these fish were marked with a coded-wire tag (CWT). Recovery of these CWT fish played a major role in tracking the migration and growth of juvenile salmon.

This project was designed to achieve the following six objectives in 1994.

1. Estimate the growth rate and condition of juvenile CWT salmon in PWS in 1994, and test for differences in growth rate among years (1989-1994).

2. Describe the migration of juvenile salmon through PWS, estimate migration rate, and provide inseason data to other SEA researchers.

3. Estimate diet composition of juvenile pink salmon in PWS in 1994, test for differences in diet composition among years (1989-1992, 1994), and collect juvenile fish stomach samples for project 94163 (Forage Fish).

4. Determine if the growth rate of juvenile salmon was likely limited by low food abundance in 1994.

5. Test for differences in the relationship between juvenile salmon growth and fry-to-adult survival among years (release years 1989-1993).

6. Develop techniques to estimate the mortality of juvenile salmon in PWS and the Gulf of Alaska.

Methods:

Objective 1:

Juvenile pink salmon were collected using a 40 m long purse seine deployed from a 6 m long aluminum skiff. Sampling began the first week of May and extend to mid-July. An approximately 25 m long vessel provided logistical support to the field crew enabling them to track the juvenile salmon migration and obtain samples of fry from a large area. Juvenile salmon were located from visual surveys of nearshore nursery habitats. A portable tube CWT detector was used to isolate CWT juvenile salmon from untagged fish in the catch. Approximately one fish in a thousand were coded-wire tagged on average. As a result, a large number of juvenile salmon must be captured to obtain an adequate sample of CWT salmon. All CWT salmon were retained for later analysis of growth. 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. 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 number of beakers and number of fish per displacement volume. Water temperature at 1 m depth was measured at all sample sites using a thermistor.

A stratified-random sampling design was employed to estimate the growth rate of juvenile pink salmon in PWS (Cochran 1977). Strata were established based upon recovery date (May, June), hatchery, and treatment group. Previous studies of juvenile pink salmon growth in PWS have shown that growth sometimes differs among these groups (Willette 1994). An analysis of gain in precision was used to identify strata that can be combined. Three treatment groups receiving different feeding regimes at the hatcheries were employed: (1) an early-fed group composed of individuals released during high zooplankton abundance after 1-2 weeks of feeding in net pens, (2) a direct-release group released during high zooplankton abundance after only 2-5 days of feeding, and (3) a late-fed group released during declining zooplankton abundance and increasing temperatures after 1-2 weeks of feeding.

Approximately 12 treatment groups were released from all four pink salmon hatcheries in PWS in 1994. Therefore, it was likely not possible to meet each of the sampling objectives for each of the treatment groups. The following criteria (listed in order of priority) were employed in making sampling decisions in the field:

1) Recover a minimum of 100 tagged fish from each treatment group.
2) Recover fish from each treatment group in at least three different areas during a single sampling period.
3) Recover fish from each treatment group during at least three different sampling periods.

Coded-wire tags were extracted and interrogated as they were recovered in the field. This approach enabled specific treatment groups to be targeted. More than one tag code is typically applied to each treatment group. Methods developed by the ADF&G CWT Laboratory for extracting and interrogating CWTs were employed. Damage to the fishes' head was kept to a minimum when dissecting CWTs. The remains of the head and the body were placed in a pre-weighed vial and frozen. The vials were weighed later on shore when accuracies of .01 g were obtained. An exponential model was used to estimate growth rates (G_i) of individual CWT juvenile salmon, i.e.

$$G_i = \frac{\ln(W_c) - \ln(W_r)}{t_c - t_r} \qquad (1)$$

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. Analysis of covariance was used to test for differences in growth rate among years. Recovery site was used as the sample unit in the analysis. A nested model was used with hatchery and treatment group nested within years and with julian date (of recovery) as a covariate.

Condition of CWT juvenile salmon was examined to evaluate feeding and growth conditions. The relationship between body weight (W) and length (L) was described by

$$W = a\, L^b \qquad (2)$$

where a is the condition factor and b is the slope of the linear-transformed model (Ricker 1975). Analysis of covariance was used to test for differences in the intercept and slope of the linear-transformed model between years. Samples from all hatcheries, treatment groups, and months (May, June) were pooled in the analysis. The slope of the regression (b) was used as a measure of the condition of juvenile CWT pink salmon in different years.

Objective 2:

Immediately after the juvenile salmon were released from the Wally H. Noerenberg (WHN)

Hatchery, the sampling crew began surveys of nearshore habitats in western PWS. The sampling crew started surveying at a distance from the hatchery and moved toward it until juvenile salmon are encountered. They then continued on to the WHN Hatchery sampling CWT juvenile salmon along the way. This was done five times during the period from May 1 through July 20. Information on juvenile salmon distribution was radioed to other SEA program researchers focused on salmon predation.

An analysis was conducted to determine the migration rate and distribution of the early-fed group released from the WHN Hatchery by sampling period. The early-fed WHN group comprised the majority of the CWT recoveries in western PWS in 1994. The number of early-fed WHN juvenile salmon recovered at various sites was summed. The tagged-to-untagged ration (1/600) was applied to estimate the total number of hatchery-origin salmon. Maps were then prepared indicating the distribution of these fish during each sampling period.

The migration rate (km day^{-1}) was calculated by measuring the distance from WHN Hatchery to the site where the CWT fish were recovered. The difference in days from release to recovery was determined for each CWT juvenile salmon. The frequency distributions of migration rate were compared between all CWT fish recovered in May and in June/July. Similar distributions were compared only for CWT fish recovered at the leading edge of the migration. Finally, migration rate frequencies were compared between CWT fish released early (April 25-28) and late (May 3-11) and recovered in May and in June/July. This was done to examine the effect of the accumulation of successive early-fed release groups near the hatchery on migration rate.

Objective 3:

Stomach contents analysis was used to estimate diet composition of juvenile salmon, examine diet overlap among juvenile fishes, and determine if the growth rate of juvenile salmon was likely limited by low food abundance. A stratified-random sampling design was employed to estimate diet composition of juvenile salmon. Strata were established based upon date (May, June), area (Figure 1), and habitat type (shallow bay, moderate slope, steep slope adjacent to current). Site was used as the sample unit in the analysis. Samples of untagged juvenile pink salmon (n=15) were collected between 1500 and 2100 hours from approximately 12 randomly selected sites within each strata. Samples were preserved in 10% buffered formaldehyde solution. Whenever possible, samples of other juvenile fishes (forage fish) were collected along with samples of juvenile salmon. These samples were provided to project 94163 (Forage Fish) for stomach contents analysis. This approach allowed for a paired comparison of diet overlap among various species of juvenile fishes in PWS (see Project 94163 DPD).

Stomach contents analysis was conducted later in the laboratory. Fish showing signs of regurgitation were not be included in the sample. Prey items in the gut were identified to the lowest possible taxonomic level and enumerated. Prey biomass in each category was estimated by the product of prey abundance and average prey wet weight (Coyle et al. 1990). Total stomach contents weight was measured to an accuracy of 0.1 mg. Diet composition was expressed as a proportion of total stomach contents weight. Stomach fullness was expressed as a proportion of fish body weight.

A main-effects analysis of variance was conducted for each fish species to test for differences in stomach fullness among sampling periods. Least-squares mean stomach fullness was estimated for each sampling period, and multiple comparisons tests were conducted. A chi-square analysis was conducted to examine differences in diet composition among eleven species of fish during three sampling periods. Diet composition for each fish species was expressed as a proportion of total prey abundance in each prey category for all samples combined. A more detailed analysis of this data will be conducted during the next several months to determine the degree of diet overlap among various fish species and test for differences in diet composition of juvenile salmon among years.

Objective 4:

A simple bioenergetics model was used to evaluate whether the growth of juvenile pink salmon was likely limited by low prey density in 1994 (Willette 1994). The model estimated the time required for a 1 g pink salmon to obtain a maximum daily ration composed of either large or small copepods at specific temperatures and prey densities (Brett and Groves 1979). The time required to obtain a ration composed of mixed prey was estimated from diet composition data and model estimates of feeding times required for large and small copepods, respectively. It was assumed that approximately twenty hours is available for feeding in PWS during May and June. Feeding times in excess of twenty hours indicate that the fish may not have acquired the daily ration. Holling (1966) developed a model to estimate the feeding rate of invertebrates in relation to prey density, i.e.,

$$I_f = \frac{\gamma\, p\, U}{1 + \gamma\, p\, U\, h} \tag{3}$$

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) was 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 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} was 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 were not 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. The inverse feeding rate (I^{-1}) was used to estimate the time required for a fish to obtain the maximum daily ration.

The maximum daily ration was estimated by a simple mass balance equation, i.e.

$$I_c = \frac{G + R}{A} \qquad (4)$$

where I_c = food consumption (cal day^{-1}), G = growth rate (cal day^{-1}), R = total metabolism (cal day^{-1}), and A = assimilation coefficient. The temperature-specific growth rate (G) at maximum ration was estimated from a regression equation relating temperature to the growth of juvenile CWT pink salmon in PWS (Willette 1994). An assimilation coefficient (A) of 0.86 was 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) were 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 was added to active metabolism after an initial estimate of food consumption. Migration metabolism was not be included in total metabolism, because active metabolism has been estimated while the fish were swimming at the critical speed.

Objective 5:

The relationship between juvenile growth and fry-to-adult survival was evaluated from recoveries of CWT juveniles and adults. Restoration project 94194 (Pink Salmon Coded-wire Tag Recovery) provided data on survival rates of CWT pink salmon released in 1993. A weighted analysis of covariance was used to test for differences in the slope of the growth-survival relationship among years. The number of CWT juvenile salmon obtained to estimate mean growth was used as a weighting factor in the analysis. Further, a common intercept term was used for all years. Tag-code groups were used as the sample unit in the analysis.

We also tested for differences in the growth-survival relationship between the early-fed and late-fed treatment groups. This was done because the date of release for these two treatment groups differs by nearly one month. It was expected that differences in ocean temperature, prey abundance, and predator abundance may result in differences in the growth-survival relationship between these two groups. A weighted analysis of covariance was used to test for differences in the slope of the growth-survival relationship among treatment groups. The number of CWT juvenile salmon obtained to estimate mean growth was used as a weighting factor in the analysis. Further, a common intercept term was used for all years and treatment groups. Tag-code groups were used as the sample unit in the analysis. An extra sum-of-squares F-test was used to test for differences in the growth-survival relationship between the early-fed and late fed treatments (Neter et al. 1980).

Objective 6:

A feasibility study was conducted to develop a technique to estimate the mortality of pink salmon in PWS and the Gulf of Alaska. This element of the SEA program is intended to determine if year-class success is established in PWS. The project will employ a technique developed by Parker (1968). In 1995, pit tags will be applied to large juvenile pink salmon (total length > 100 mm) captured near the southwest entrances to PWS. At about 100-125 mm in length, juvenile pink salmon migrate from bays and passages into the coastal zone adjacent to the Gulf of Alaska (Royce et al. 1968). If possible, pink salmon of primarily hatchery origin will be tagged, because in this case recovery of tagged adults will be greatly simplified. If wild fish are tagged, the tag recovery program will need to scan wild fish in hundreds of streams in PWS - greatly increasing the cost of the program.

The feasibility study conducted in 1994 determined if large juvenile pink salmon of primarily hatchery origin can be captured near the southwest entrances to PWS in large numbers. In early July, a purse seine vessel used an approximately 250 m x 20 m (11/16 " stretch mesh) purse seine to capture juvenile salmon. The vessel and gear were provided by the Salmon Predation component of the SEA program. The number of CWT fish in the catch were estimated by passing the fish through a portable tube CWT detector. The total number of fish in the catch were estimated volumetrically (see objective 1). The proportion of hatchery-origin fish in the catch were estimated assuming a tag-to-untagged ratio of 1 in 600.

Results:

Approximately, 1.2 million juvenile pink salmon were captured and scanned for CWTs in western PWS during the 1994 season (Table 1). About, 1,200 CWTs were recovered from these fish (Table 2). All tags have been deciphered. Approximately, one in 600 juvenile pink salmon were tagged at the four pink salmon hatcheries in PWS in 1994. Given this tagged-to-untagged ratio, about 60% of the juvenile pink salmon captured in western PWS were of hatchery origin. Pacific sandlance was a common co-occurring species with juvenile salmon in nearshore net catches after the beginning of June (Table 1). A substantial proportion of the fish in the 'other' category in table 1 were age 0 gadids.

Objective 1:

The juvenile pink salmon in the early-fed treatment group released from the WHN Hatchery grew to nearly 100 mm in length by the middle of July (Figure 1). By the middle of June, the mean length of this group exceeded 60 mm. The late-fed treatment groups released from all hatcheries in PWS did not exceed 60 mm until the middle of July (Figure 2).

Results from analysis of covariance indicated significant differences in juvenile growth (Figure 3) among years ($P<.0001$), hatcheries ($P<.0001$), and treatment groups ($P<.0001$). Although all interaction terms were also significant in the model, it was clear that the majority of the variability in juvenile growth was associated with the main effects in the model. Multiple comparison tests indicated that growth was significantly different for all pairwise comparisons between years ($P<.0001$), except 1990 and 1992 ($P=.1410$). All pairwise comparisons between treatment groups were significant ($P<.0001$). All pairwise comparisons between hatcheries were significant ($P<.0001$), except juvenile growth was not different ($P=.1166$) between the A.F. Koernig and W.H. Noerenberg hatcheries.

An analysis of covariance of juvenile growth was also conducted for the A.F. Koernig Hatchery alone, because data was available for all treatment groups and years. The results were very similar to that obtained for all hatcheries combined (Figure 4). Multiple comparison tests indicated that growth was significantly different for all pairwise comparisons between years ($P<.0100$), except 1990 and 1992 ($P=.2100$), and 1989 and 1991 ($P=.0690$). All pairwise comparisons between treatment groups were significant ($P<.0500$).

Comparisons of condition of juvenile CWT pink salmon among years have not yet been conducted.

Objective 2:

The 1994 release of the WHN early-fed CWT group began on April 25 and continued until May 11. During this time period, approximately 153 million juvenile salmon averaging .22 - .24 g were released. About 250,000 of these fish carried a CWT. During the first sampling period in early May, these fish were clustered within 10 km of the WHN Hatchery (Figure 5). By late May, they had travelled nearly 50 km to Point Nowell and Herring Bay along northern Knight Island Passage. During the early June survey, WHN early-fed juveniles were found as far south as northern Prince of Wales Passage, and few remained within 10 km of the WHN Hatchery. By early July, this group of fish was absent from northern PWS and was distributed primarily in the southern entrances to the Sound, 90 km from the WHN Hatchery.

Comparison of frequency distributions of migration rates indicated no apparent difference in migration rate between all early-fed CWTs recoveries and fish at the leading edge (Figure 6). However, migration rates in May were apparently greater than in June/July (Figure 6). Juvenile CWT salmon released early (April 25-28) apparently migrated more slowly than fish released late (May 3-11; Figure 7).

Objective 3:

Diet composition data is presently available for 2,152 fish specimens (<150 mm FL) from eleven species. Approximately, 200 additional specimens remain to be analyzed for stomach contents. It is anticipated that these samples will be completed by the middle of April.

Least-squares mean stomach fullness of Pacific herring was significantly greater ($P<.0100$) in August-Sept. than in April-July (Table 4). Stomach fullness of Pacific cod and Pacific tomcod was not significantly different between June-July and August-Sept. However, the stomach fullness of walleye pollock was significantly greater ($P=.0001$) in June-July than in August-Sept. (Table 4). There was no difference in stomach fullness of pink salmon among any sampling periods. However, stomach fullness of chum salmon was significantly lower ($P=.0001$) in June-July than in April-May or August-Sept.(Table 4). There were no differences in stomach fullness of capelin or Pacific sandlance between sampling periods.

Although no statistical tests were performed, there were some apparent differences in diet composition among the eleven fish species and three sampling periods examined. Large copepods were apparently a dominant prey item for all fish species examined in April-May (Table 5). The apparent dominance of large copepods was diminished somewhat among the fish species examined in June-July (Table 6). Prey items in the 'other' category were apparently important in the diets of both Pacific tomcod and chum salmon during June-July. By August-Sept., all fish species examined apparently consumed a broader range of prey items (Table 7). Larvaceans were a notable addition to the diet of many species during this time period.

More detailed analyses will be conducted over the next several months to examine diet overlap among fish species and differences in diet composition of pink salmon among years.

Objective 4:

An analysis has not yet been conducted to determine if the growth of juvenile pink salmon was likely limited by low food abundance in 1994. Diet composition data for juvenile salmon collected in PWS in 1994 was only recently available from the laboratories. Work on this and other components of data analysis will continue in July after the 1995 field season.

Objective 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. The slope of growth-survival relationship (Figure 8) was significantly different ($P < .0001$) from zero in all years, except 1991 ($P = .1470$) and 1992 ($P = .1986$). The growth-survival relationship was different ($P = .0011$) for the early-fed and late-fed treatment groups with the slope for the early-fed group being greater than for the late-fed group four out of five years (Figure 9).

Objective 6:

Sampling with a small mesh purse seine (250 m x 20 m) operated from a purse seine vessel in the southwest passages of PWS indicated that large juvenile pink salmon (> 100 mm) of primarily hatchery origin could not be captured in large numbers (Table 8). The mean length of juvenile pink salmon in net catches ranged from 65 to 73 mm. The estimated percent of hatchery-origin ranged from 51-83%. Sampling was terminated when it became apparent that large juveniles were not being caught in large numbers. Sampling with a small mesh purse seine (40 m x 10 m) operated from a skiff did result in recovery of several hundred large juvenile pink salmon (> 100 mm) over a period of about one month. However, the proposed tagging study would likely require recovery and tagging of 10 to 20 thousand large juveniles.

Discussion:

The results from the present study indicated that the mean length of the early-fed juvenile salmon released from the WHN Hatchery exceeded 60 mm after the middle of June, 1994 (Figure 1). The mean length of the late-fed group did not exceed 60 mm until after July 9, 1994 (Figure 2). Stomach contents of predators in western PWS indicated that predation risk was substantially less for juvenile salmon greater than 60 mm (See final report for 94320E). Also, the abundance of potential fish predators increased substantially in nearshore areas after June 1. Over all hatcheries and years, the growth of the late-fed group has generally been greater than the early-fed or direct release groups (Figure 3). Yet, the slope of the growth-survival relationship for the late-fed group is significantly lower than for the early-fed group. These results are consistent with the hypothesis that the relatively low survival of the late-fed group is caused by elevated predation rates later in the season. The survival of these two treatment groups will be compared in 1995 after the fish return as adults.

Comparison of migration rates of the early-fed CWT groups released early (April 25-28) and late (May 3-11) suggests that competition for food among successive release groups may affect migration rate. Simenstad et al. (1980) concluded that the migration rate of juvenile chum salmon in Hood Canal was greater when food abundance was low. Predation by adult walleye pollock was apparently high in offshore areas of the passages in PWS in late April and early May (See final report for 94320E). It also appeared that the nearshore habitats occupied by juvenile salmon during the initial 30 days of marine residence provide a refuge from predation, because predator abundances were low in these habitats prior to the beginning of June (See final report for 94320E). As the abundance of juvenile salmon in the nearshore refuges increases with successive releases, juveniles may leave the refuge to seek food elsewhere. Over all sampling periods, approximately 40% of the juvenile pink salmon scanned for CWTs in 1994 were wild. Competition for food in nearshore predation refuges may be primarily among juvenile salmon during May. Pacific sandlance and age 0 gadids were common co-occurring species in nearshore habitats but only in June and July (Table 1). The proposed study design for 1995 will focus on the tradeoff between foraging and predation risk (Walters and Juanes 1993). Otolith marked hatchery salmon (Project 94320C) will provide a valuable tool for examining these tradeoffs for both wild and hatchery salmon.

Results from a study designed to evaluate the feasibility of tagging juvenile pink salmon as they were exiting PWS indicated that large juvenile pink salmon of primarily hatchery origin could not be captured in large numbers. This element of SEA was intended to determine if year-class success is established in PWS. Parker (1968) employed this technique to partition the marine mortality of pink salmon between the nearshore and offshore lifestages. In the present study, large numbers of juvenile salmon were captured in nearshore habitats at approximately 60 mm FL. Catch per effort in small-mesh purse seines was lower later in the season after the fish moved offshore. This may be due to larger fish escaping the net or a decrease in average school size after the juveniles move offshore. As this component of SEA may contribute significantly to our understanding of mortality processes, further analyses of existing data will be conducted to identify opportunities for tagging juveniles at approximately 60 mm FL.

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Table 1: Total number of fish caught by species for the Salmon Growth and Mortality project, 1994.

Month	No. Sets	Total Catch: Pink	Chum	Sockeye	Sandlance	Other
May	19	206,705	2,978	6	32	68
June	61	636,664	23,998	2,868	3,478	3,938
July	46	355,979	182	990	3,332	11,081

Table 2: Total number of coded-wire tags recovered by species for the Salmon Growth and Mortality project, 1994.

Month	Total Number of CWT's Recovered: Pink	Chum	Sockeye	Coho
May	263	3	0	0
June	378	60	17	0
July	551	30	6	0

Table 3: 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
A. F. Koernig	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)
W. H. Noerenberg	Early Fed	4.12 (24)	3.96 (80)	3.38 (148)	4.43 (3)	4.57 (2)	4.26 (162)
	Direct Release	3.89 (9)	3.65 (12)	2.80 (19)	4.04 (1)	4.49 (1)	-
	Late Fed	9.19 (5)	7.09 (11)	2.09 (15)	-	6.84 (10)	-
Cannery Creek	Early Fed	5.64 (6)	4.76 (17)	3.08 (18)	-	-	5.25 (9)
	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)
Solomon Gulch	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)	-	-	-	-

Table 4: Least-squares mean stomach fullness (% BW) for eleven species of fish (<150 mm FL) collected in western Prince William Sound during three sampling periods, 1994.

Fish Species	April-May	June-July	August-Sept.
Pacific herring	.73	0.51	1.37
Pacific cod	-	1.68	1.84
Pacific tomcod	-	4.90	2.14
Walleye pollock	-	4.44	0.85
Sockeye salmon	-	0.27	-
Pink salmon	2.02	1.39	2.05
Chum salmon	2.30	1.43	2.07
Northern smoothtongue	0.46	-	-
Capelin	0.26	-	0.53
Pacific sandlance	-	2.80	1.84
Threespine stickleback	1.05	-	-

Table 5: Summary of diet composition (% total prey abundance) for eleven fish species (< 150 mm) collected in western Prince William Sound in April-May.

Fish Species	Fish Larvae	Harpc. Copepod	Large Copepod	Small Copepod	Larvacean	Other
Pacific herring	0.31	0.04	80.72	2.15	1.25	15.53
Pacific cod	-	-	-	-	-	-
Pacific tomcod	-	-	-	-	-	-
Walleye pollock	-	-	-	-	-	-
Sockeye salmon	-	-	-	-	-	-
Pink salmon	0.20	0.92	42.87	16.98	0.37	38.66
Chum salmon	7.57	1.12	32.66	0.82	24.42	33.41
Northern smoothtongue	0.36	0.00	35.64	13.82	31.64	18.55
Capelin	4.73	0.00	68.56	7.58	3.03	16.10
Pacific sandlance	-	-	-	-	-	-
Threespine stickleback	2.61	0.00	73.28	7.06	12.94	4.12

Table 6: Summary of diet composition (% total prey abundance) for eleven fish species (<150 mm) collected in western Prince William Sound in June-July.

Fish Species	Fish Larvae	Harpc. Copepod	Large Copepod	Small Copepod	Larvacean	Other
Pacific herring	0.02	0.01	65.36	3.69	2.86	28.07
Pacific cod	0.06	12.13	50.16	5.01	0.16	32.48
Pacific tomcod	4.71	0.00	1.18	0.00	0.00	94.12
Walleye pollock	0.43	0.14	89.66	1.29	0.14	8.33
Sockeye salmon	0.00	0.00	60.00	0.00	0.00	40.00
Pink salmon	0.03	0.08	35.47	18.64	5.05	40.73
Chum salmon	0.68	0.13	5.56	2.88	7.35	83.40
Northern smoothtongue	-	-	-	-	-	-
Capelin	-	-	-	-	-	-
Pacific sandlance	0.02	0.03	26.70	18.33	0.54	54.37
Threespine stickleback	-	-	-	-	-	-

Table 7: Summary of diet composition (% total prey abundance) for eleven fish species (<150 mm) collected in western Prince William Sound in August-September.

Fish Species	Fish Larvae	Harpc. Copepod	Large Copepod	Small Copepod	Larvacean	Other
Pacific herring	0.01	0.01	33.12	16.35	26.32	24.20
Pacific cod	0.00	30.07	47.06	0.00	0.00	22.88
Pacific tomcod	0.57	1.03	11.25	4.91	70.53	11.71
Walleye pollock	0.03	0.02	31.19	20.97	12.21	35.58
Sockeye salmon	-	-	-	-	-	-
Pink salmon	0.49	0.01	14.17	0.01	84.64	0.69
Chum salmon	0.05	0.00	8.86	0.01	58.39	32.68
Northern smoothtongue	-	-	-	-	-	-
Capelin	0.00	0.00	47.35	12.52	33.20	6.94
Pacific sandlance	0.00	0.00	49.54	26.41	21.49	2.56
Threespine stickleback	-	-	-	-	-	-

Table 8: Summary of results from study to determine feasibility of capturing large juvenile salmon in the southwest passages of Prince William Sound.

Set No.	Date	Total Juv. Pink	Total CWT	Est. Prop. Hatchery	Mean Length
9430245	July 7	45	0	0	-
9430248	July 7	12,036	50	83	67.2
9430250	July 8	1,560	4	51	72.7
9430252	July 8	13,248	38	57	66.0
9430254	July 9	1,332	5	75	65.0
9430256	July 9	5,830	17	58	73.1
9430259	July 9	3,780	7	37	69.1

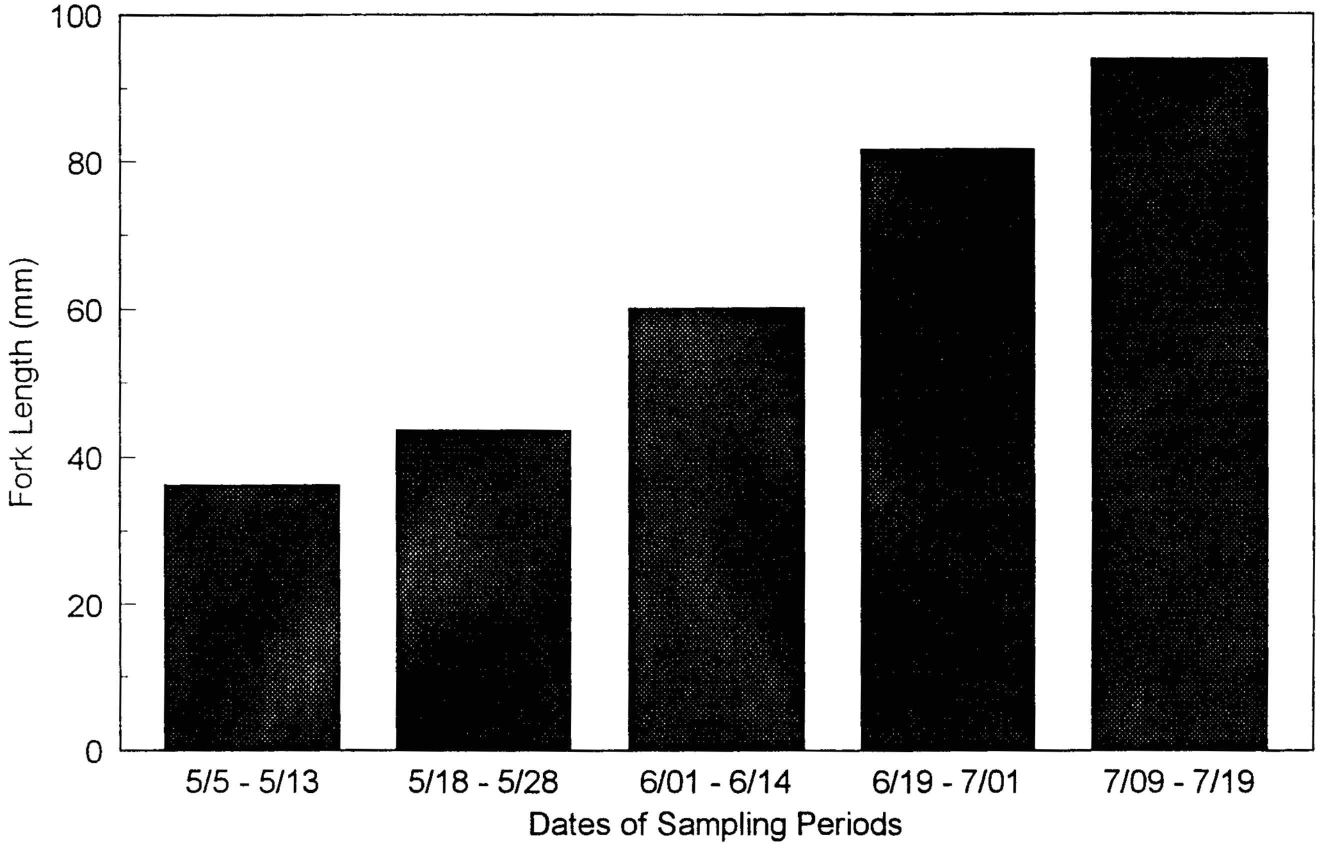


Figure 1: Average length of recovered early fed CWT pink salmon from WHN Hatchery, 1994.

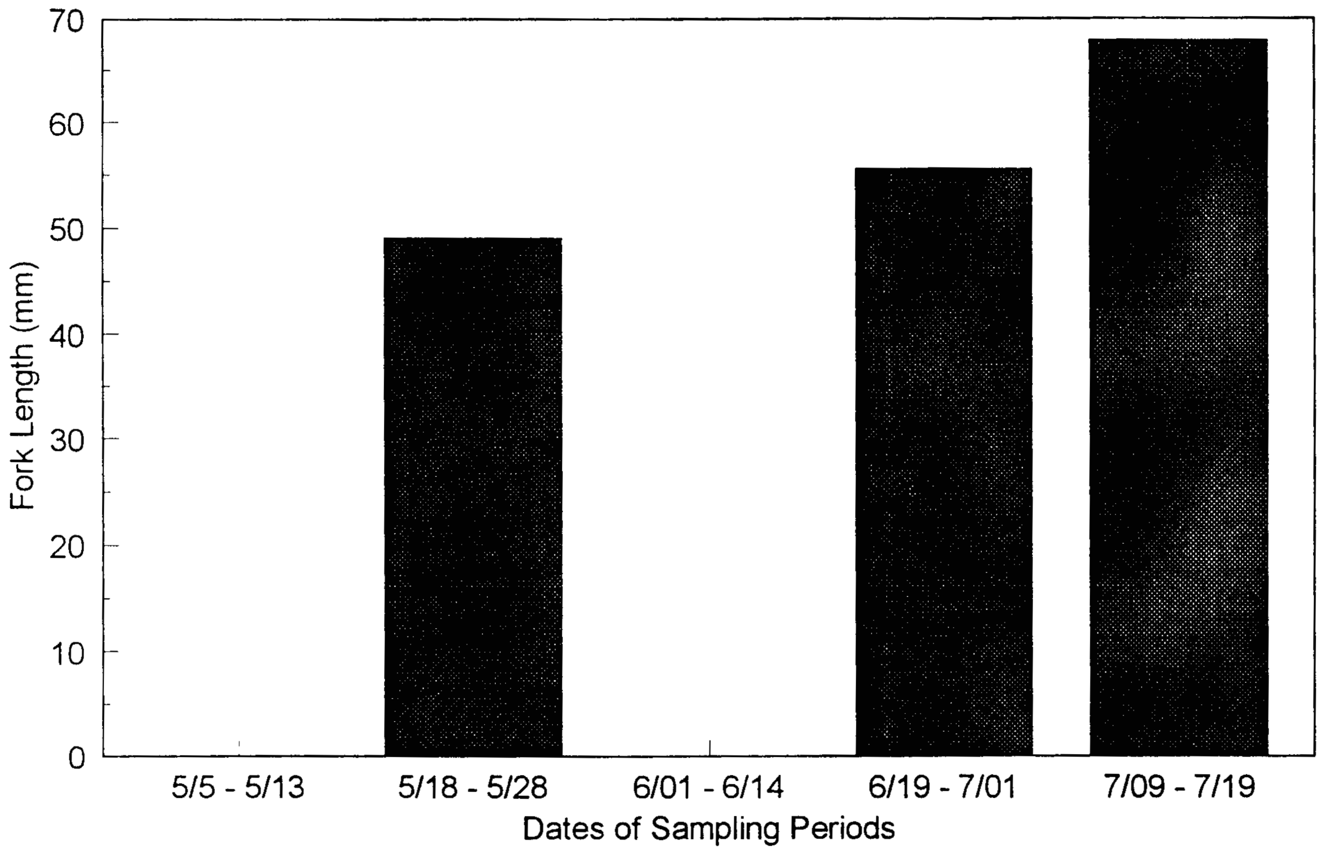


Figure 2: Average length of recovered late fed CWT pink salmon from all Hatcheries, 1994.

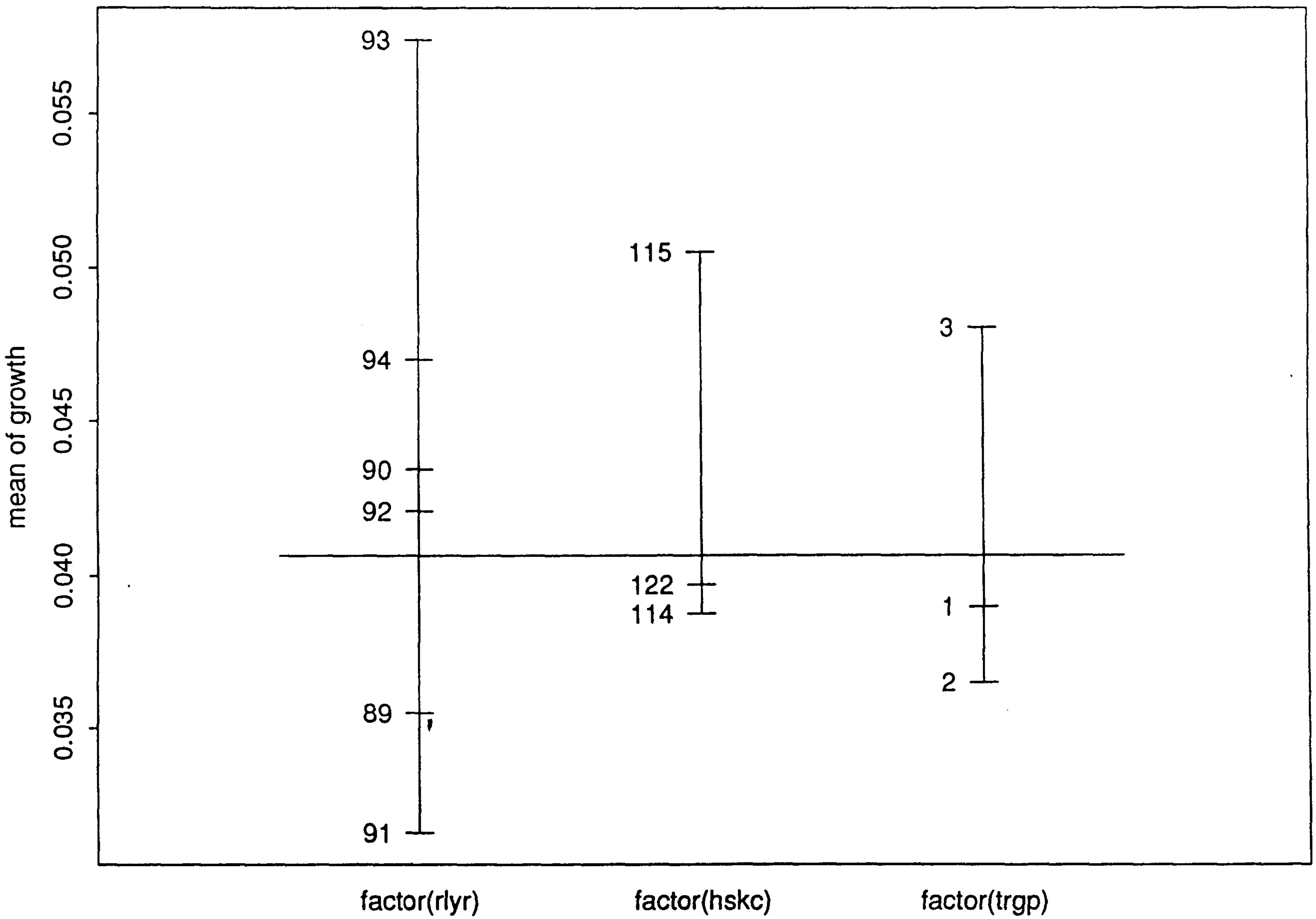


Figure 3: Comparison of mean growth of juvenile coded-wire tagged pink salmon by release year (rlyr), hatchery (hskc), and treatment group (trgp). Hatchery codes: 114 = Armin F. Koernig Hatchery, 115 = Cannery Creek Hatchery, and 122 = Wally H. Noerenberg Hatchery. Treatment group codes: 1 = early fed, 2 = direct release, and 3 = late fed.

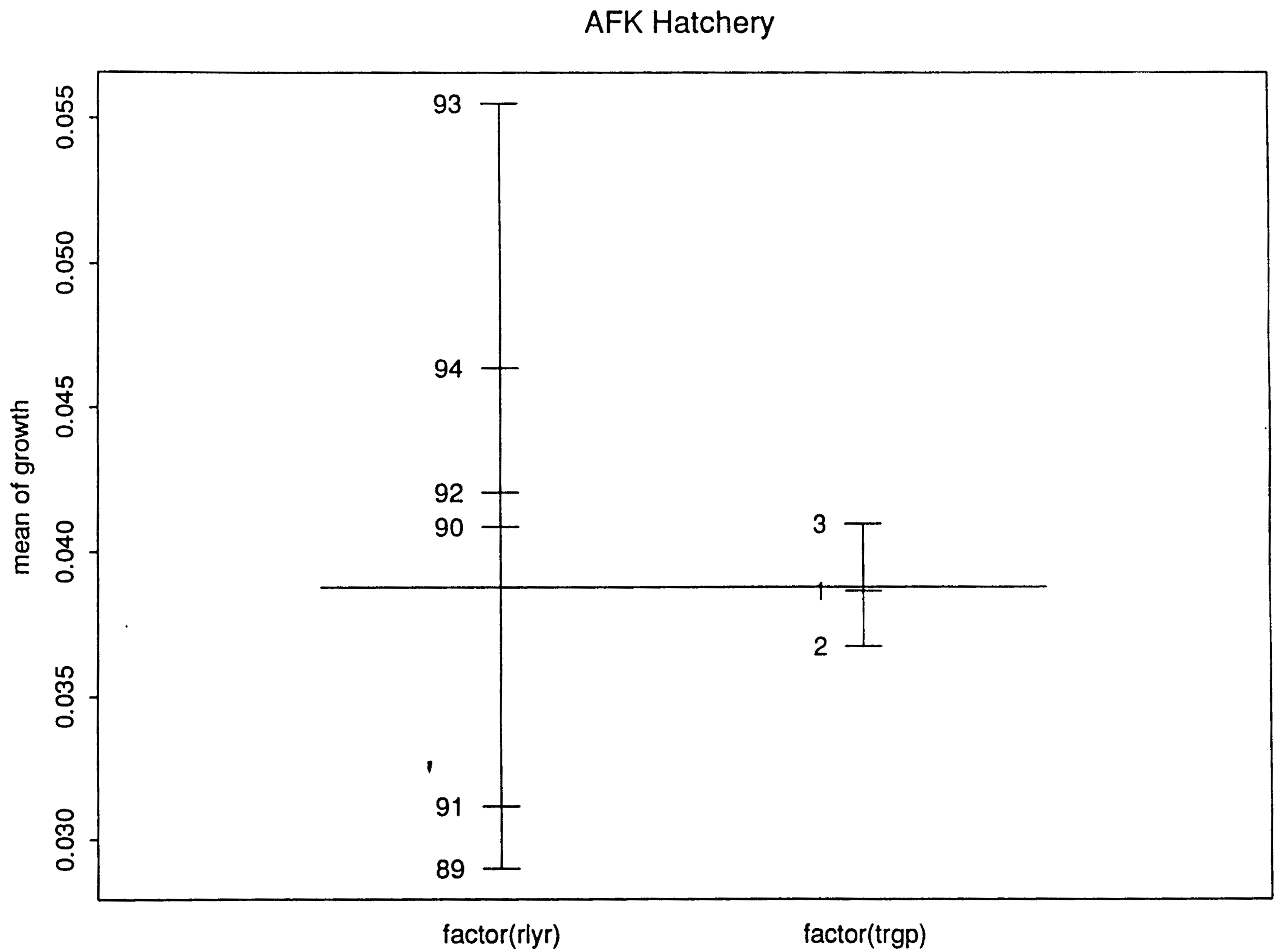


Figure 4: Comparison of mean growth of juvenile coded-wire tagged pink salmon from the Armin F. Koernig Hatchery by release year (rlyr) and treatment group (trgp). Treatment group codes: 1 = early fed, 2 = direct release, and 3 = late fed.

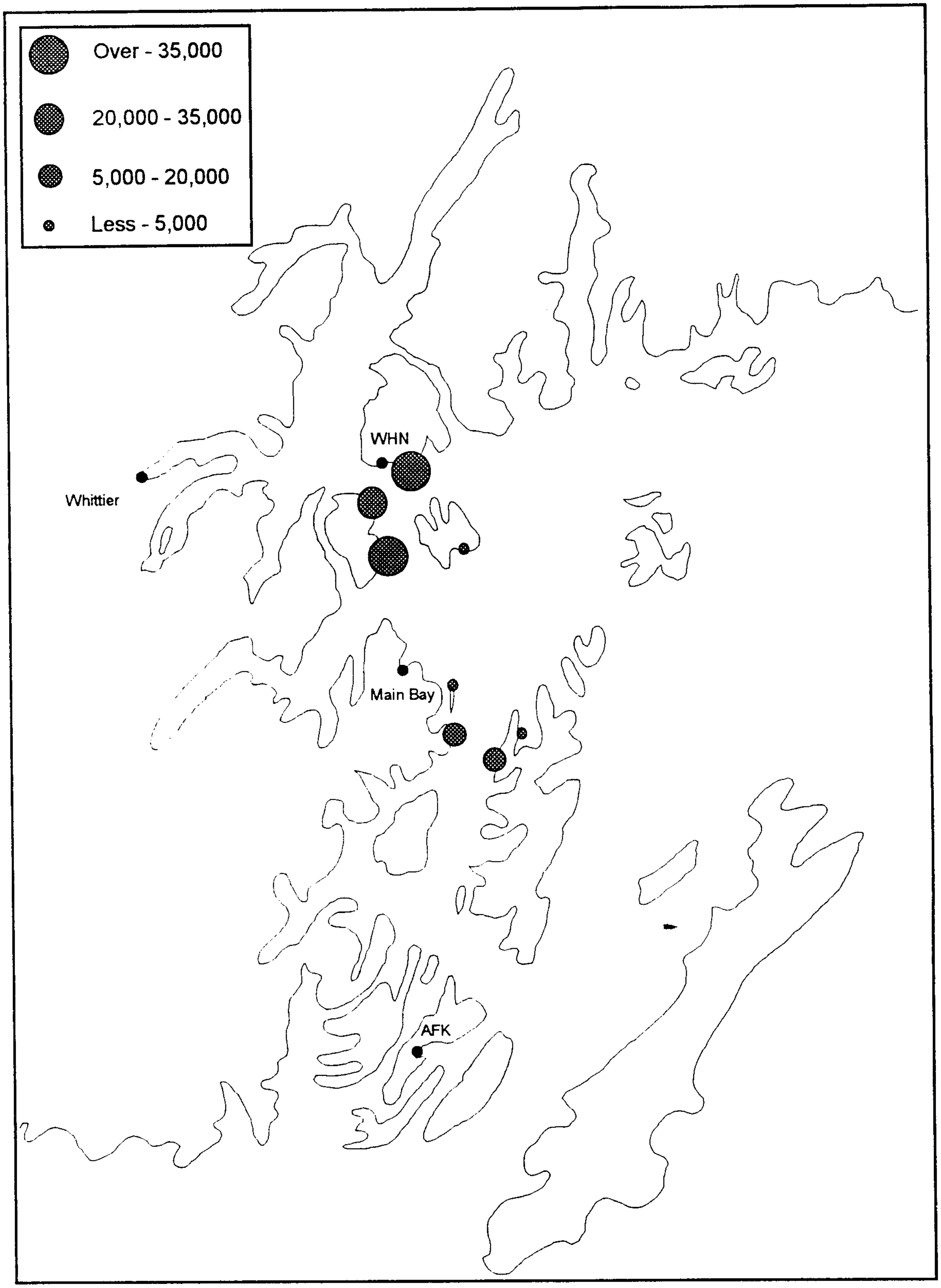


Figure 5: Estimated distribution of early fed pink salmon from WHN hatchery based on CWT recoveries May 5- 27, 1994.

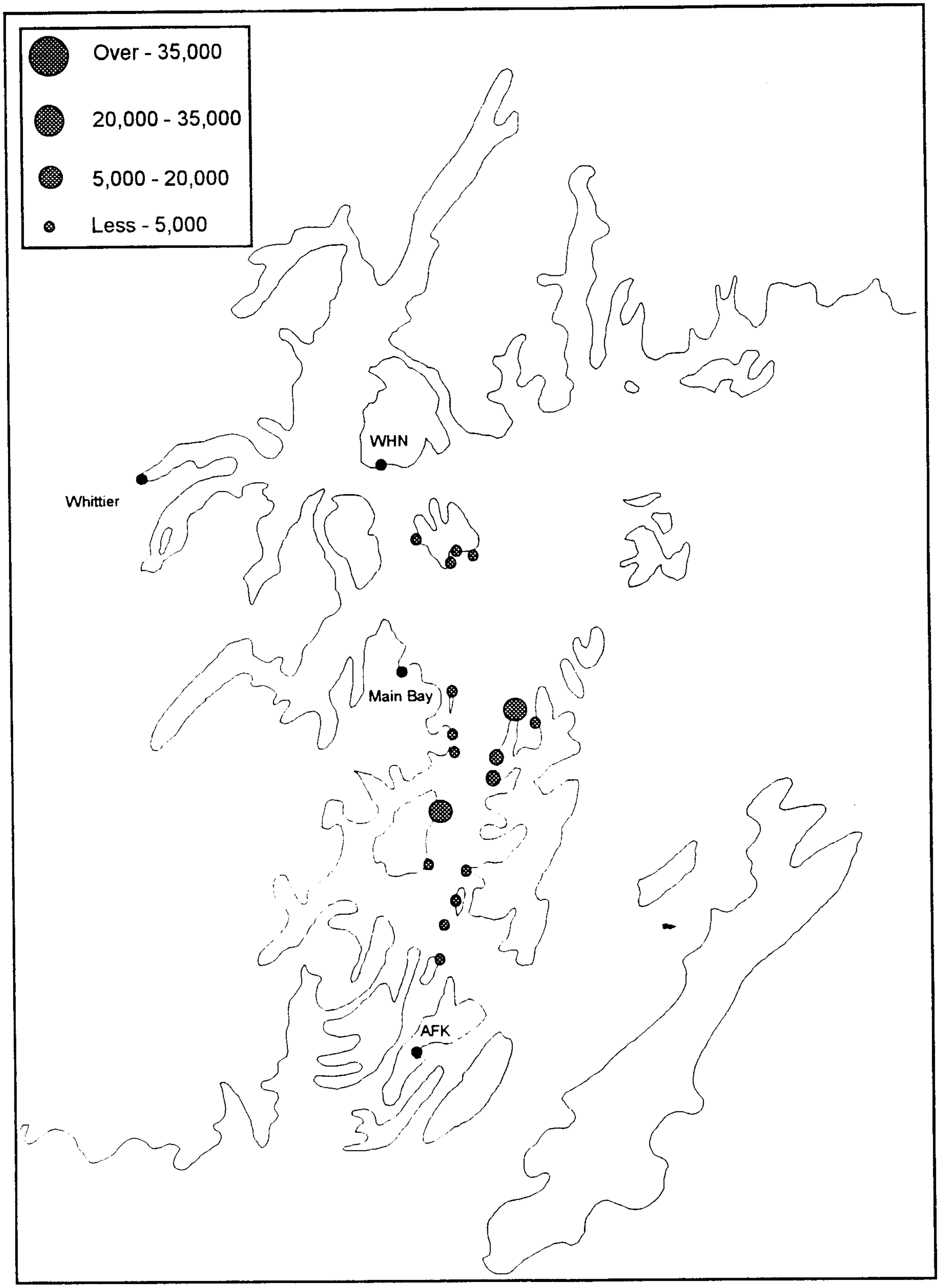


Figure 5: Estimated distribution of early fed pink salmon from WHN hatchery based on CWT recoveries June 2 - 14, 1994.

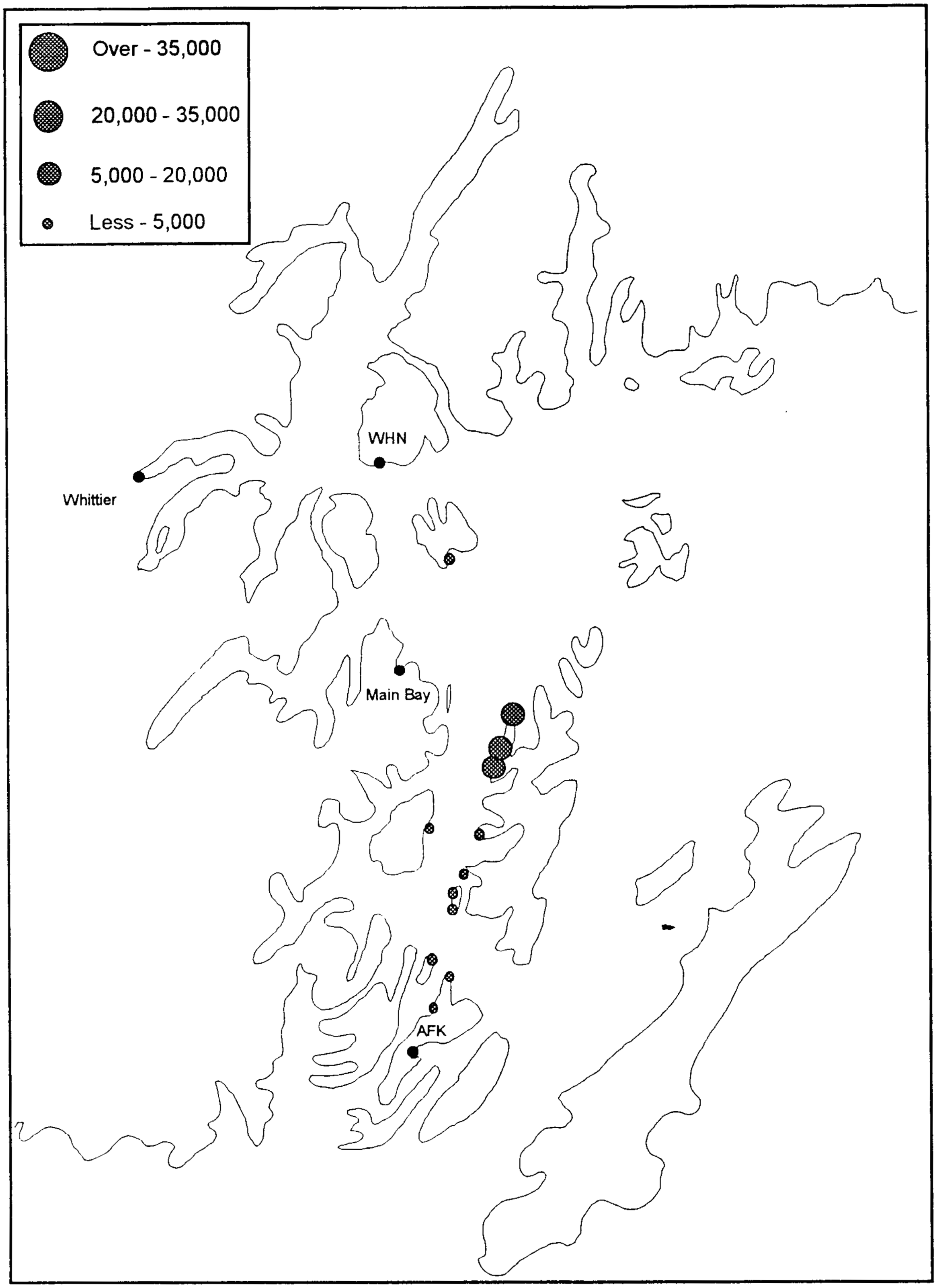


Figure 5: Estimated distribution of early fed pink salmon from WHN hatchery based on CWT recoveries June 22 - July 1, 1994.

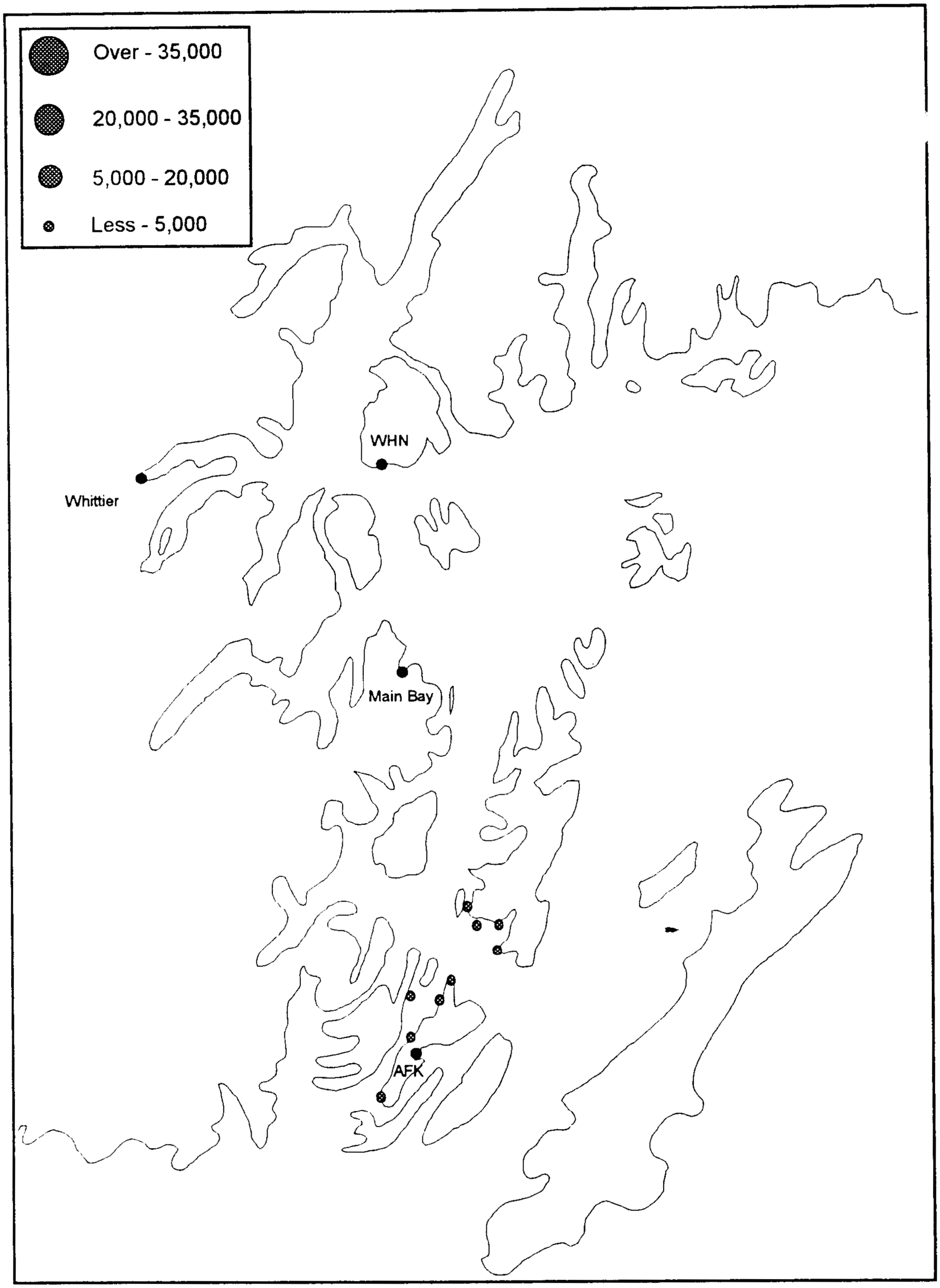


Figure 5: Estimated distribution of early fed pink salmon from WHN hatchery based on CWT recoveries July 7 - 18, 1994.

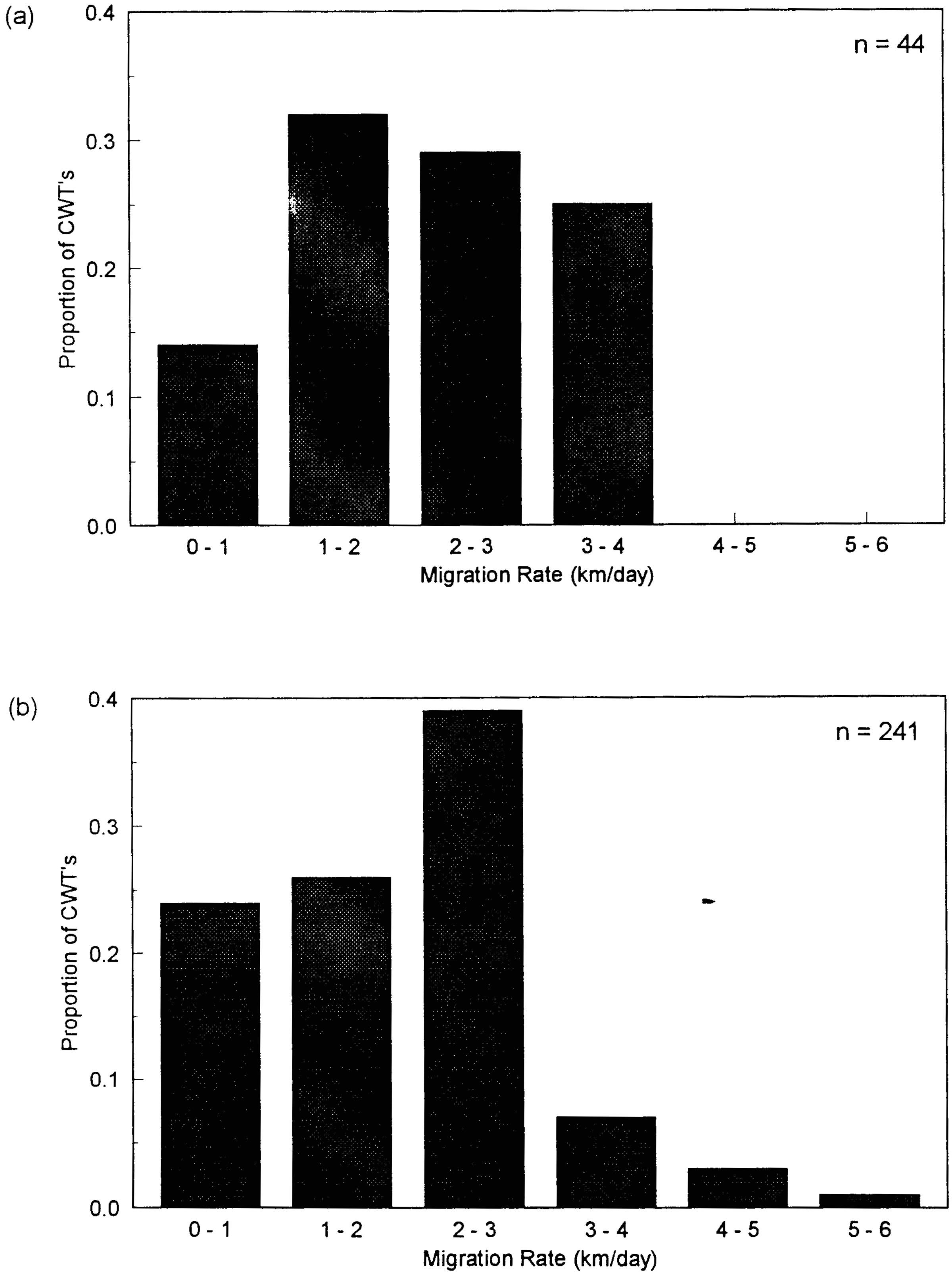


Figure 6 : Migration rates of WHN early fed CWT pink fry recovered (a) at the leading edge and (b) from all sets, May, 1994.

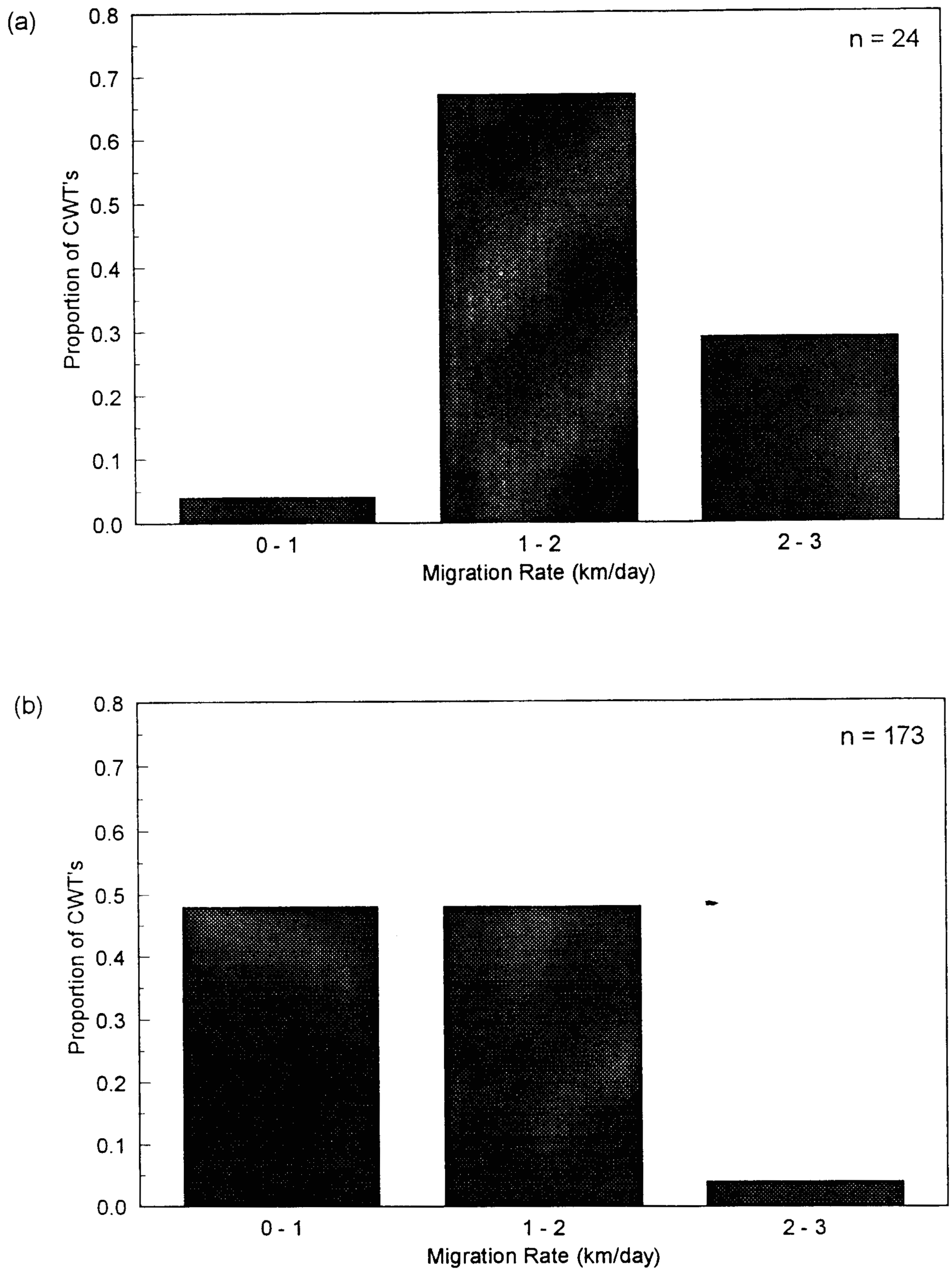


Figure 6: Migration rates of WHN early fed CWT pink fry recovered (a) at the leading edge and (b) from all sets, June and July, 1994.

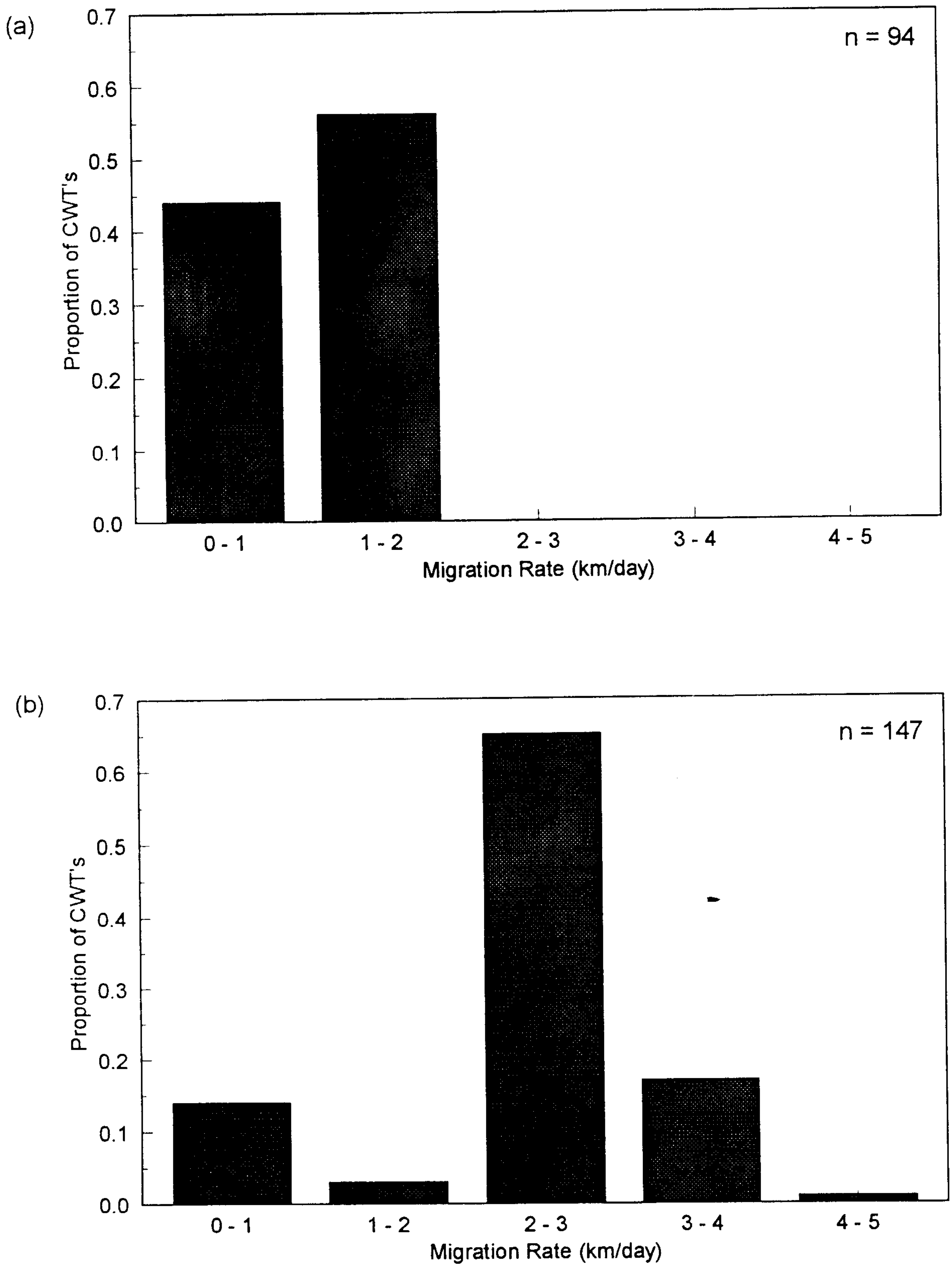
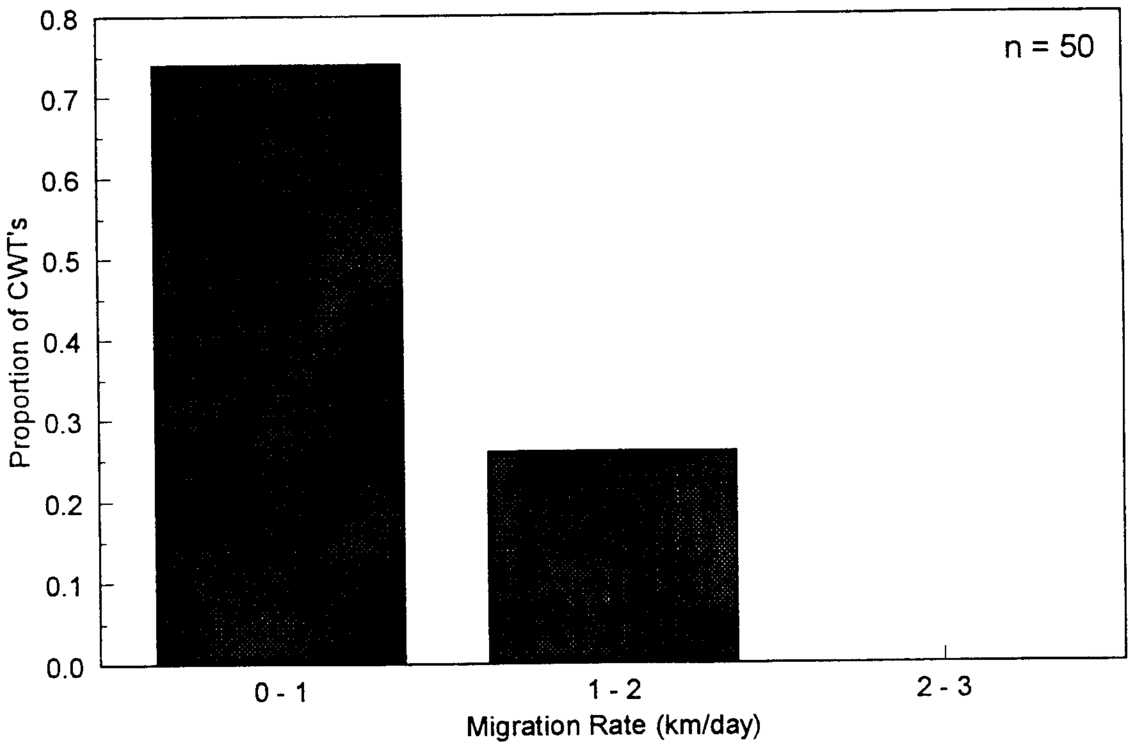


Figure 7: Migration rates of WHN early fed CWT pink fry released between (a) April 25 - 28 and (b) May 3 - 11, recovered during May, 1994.

(a)



(b)

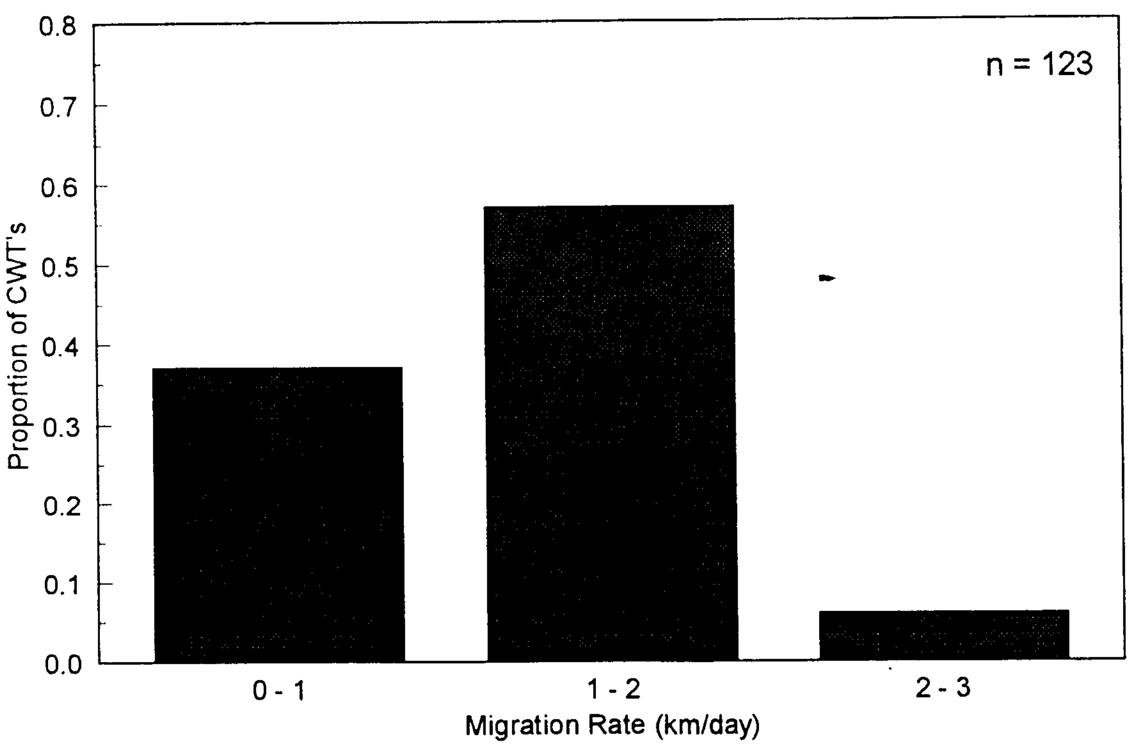


Figure 7: Migration rates of WHN early fed CWT pink fry released between (a) April 25 - 28 and (b) May 3 - 11, recovered during June and July, 1994.

Weighted regression of survival on growth and year using a common intercept term

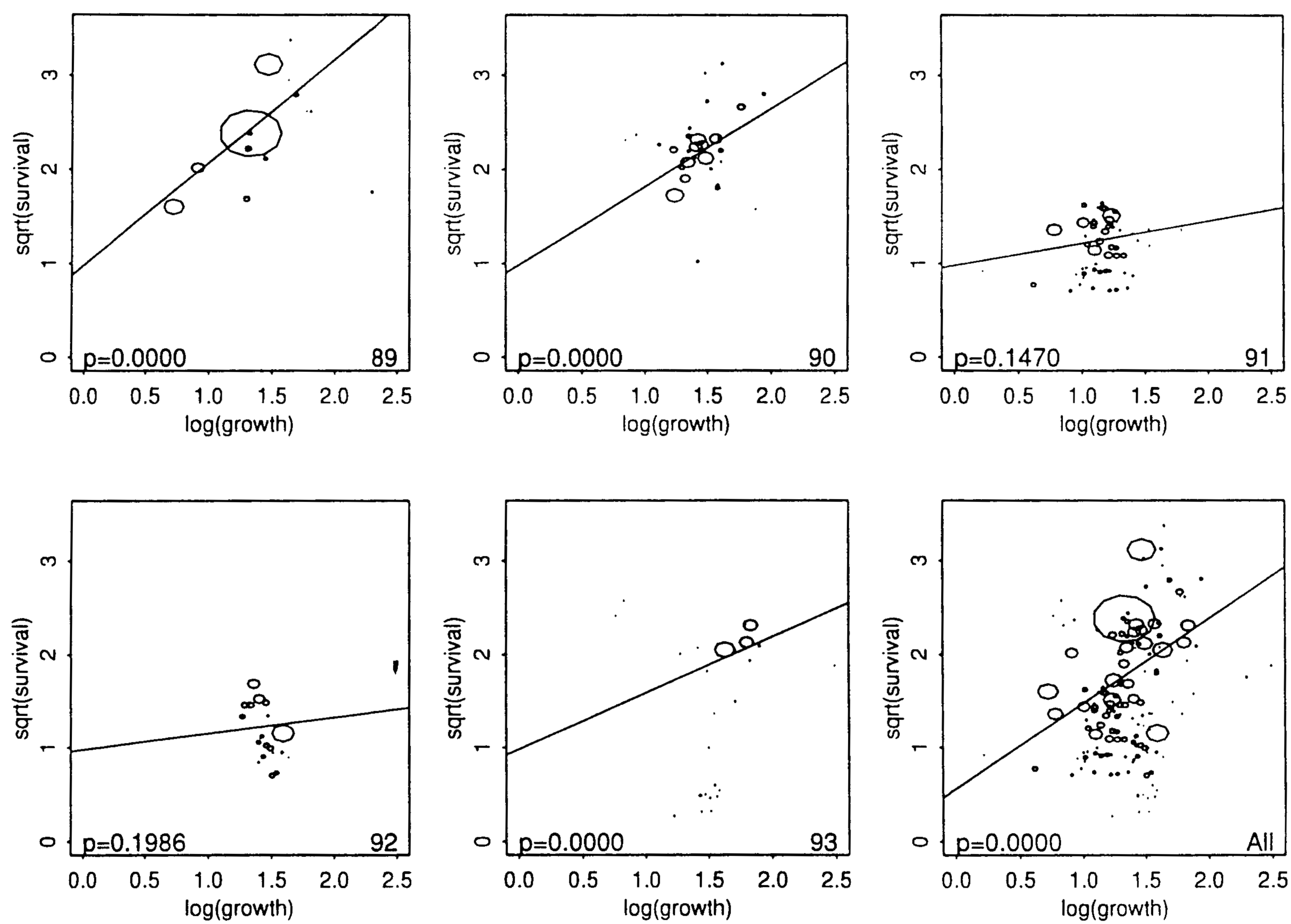


Figure 8: **Relationship between mean growth of juvenile coded-wire tagged pink salmon and fry-to-adult survival by release year. The size of circles indicates the sample size obtained for estimation of mean growth.**

Weighted regression of survival on growth, year, and treatment within year using a common intercept term

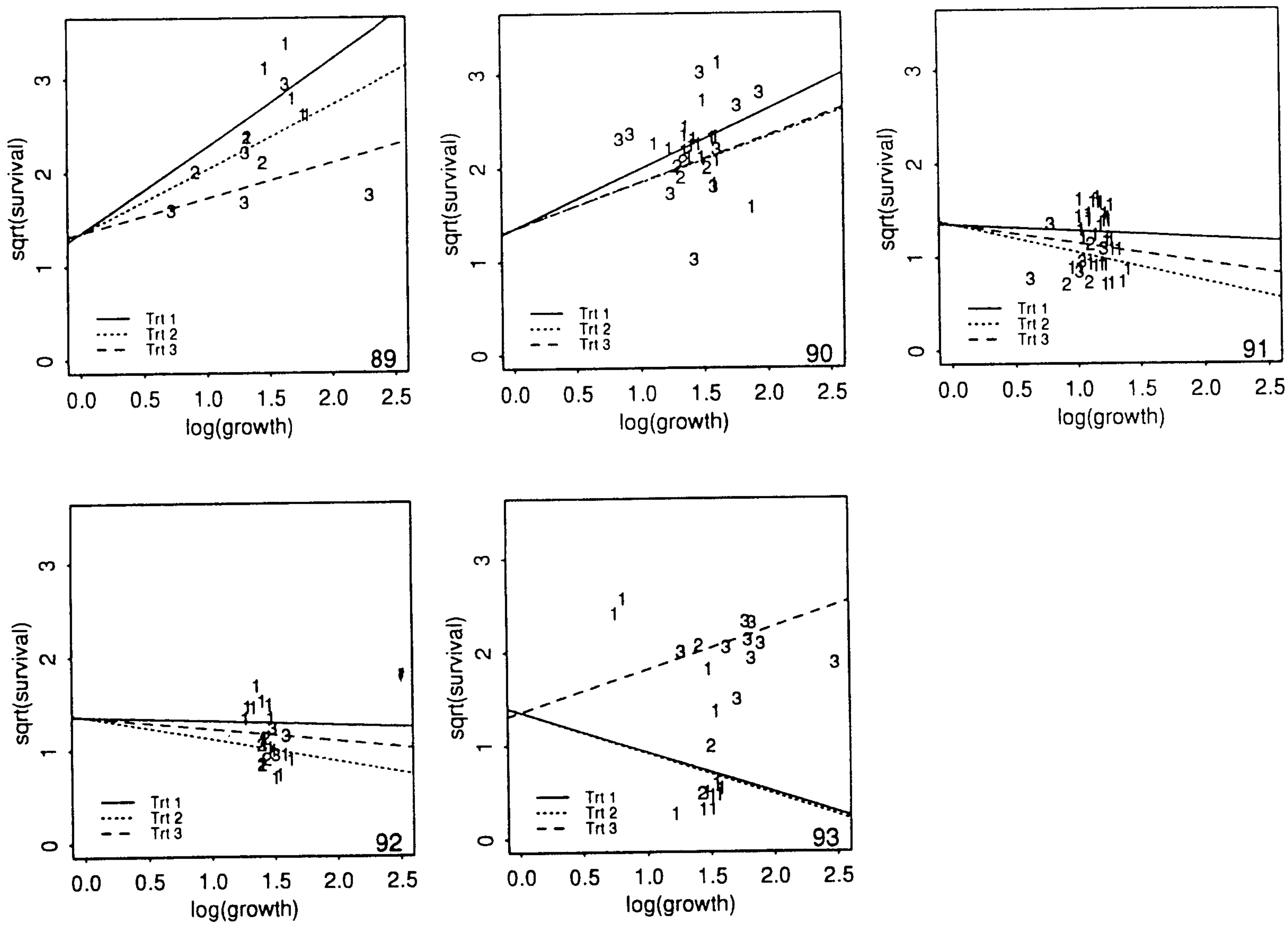


Figure 9: Relationship between mean growth of juvenile coded-wire tagged pink salmon and fry-to-adult survival by release year and treatment group.