Sockeye Salmon Smolt Emigration Studies. Chignik Lakes System, 1998.

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

The Chignik sockeye smolt emigration project, implemented by the Alaska Department of Fish and Game under contract with the Chignik Regional Aquaculture Association, has completed five years of data collection through 1998. Smolt were trapped in the Chignik River with two rotary-screw traps in tandem, with an average trap efficiency estimate of 2.3%. From May 1 to July 1 over 450 thousand smolt were trapped, resulting in an estimate of 26 million smolt emigrating from the Chignik lakes. Most of these fish (74%) were age-2 smolt, and 25% were age-1. Smolt migrated from Chignik Lake most heavily during dark nights (50% - 90% cloud cover) with winds W/NW, that favored the downriver movement. Three large migration peaks occurred on the nights between May 15 to 20, with a total of 180 thousand smolt caught in the traps. This large migration indicates favorable food and survival conditions in the lakes. However, age-1 and age-2 smolt had similar average size and weight, suggesting that intraspecific competition may have been taking place, especially for age-2 smolt. Also, interspecific competition may have been present, as indicated by the large numbers of sticklebacks caught in the traps.

This study now has two years of adult return data from smolt that emigrated in 1994 and 1995. These data indicate that the smolt oceanic survival rate for those years was 23%. Applying this survival rate to the 1998 migration estimates yields an optimistic estimate of a 3.5 million sockeye salmon run for the year 2000. However, because this study only has one estimate of smolt survival, and because ocean conditions may be changing from those experienced by smolt in 1994 and 1995, run strength estimates must be considered as an index with limited forecasting power.

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) has completed five years (1994 –1998) of sockeye salmon smolt (*Oncorhynchus nerka*) studies in the Chignik lakes system with the support of the Chignik Regional Aquaculture Association (CRAA). At this point, we have two years of adult return data from smolt that emigrated in 1994 and 1995 and the first estimates of smolt-to-adult survival in Chignik. This new knowledge raises several questions and concerns. To further understand smolt production we need to explore the effects that changes in the freshwater habitat have on juvenile salmon, the pathways of energy transfer to fish, juvenile salmon bioenergetics, and how weather regime shifts affect the freshwater and marine survival of sockeye. In this line, the contribution of the smolt studies to the Chignik story is twofold; they are a prediction tool for future runs, and a measure of the nurturing potential of the freshwater rearing environment. Several questions affecting smolt production are currently being addressed by different groups (ADF&G, Natural Research Consultants, Fisheries Research Institute-University of Washington): (1) what changes are taking place in the Chignik lakes, (2) how are these changes affecting sockeye production and, ultimately, (3) what can be done about them to maintain production levels. Clues about the answers to this questions may be found in the strength and patterns of the annual smolt migration.

The annual Chignik smolt migration is the result of a complex set of adaptations that enable juvenile sockeye salmon to physiologically respond to environmental cues, find the lake outlet, and reach the ocean. Many of the changes during this process are directed towards a shift in the juvenile salmon osmoregulation, preparing the pre-smolt for the transition from hydrating conditions in freshwater to dehydrating conditions in seawater. Juvenile salmon attain the smolt stage at a certain size, during a specific season, under the influence of photoperiod and temperature. Smolting is stimulated by a daily rhythm of light. A period of short daylengths followed by long daylengths (between 10 and 14 h.) (Brünning 1973), is required before pre-smolts are stimulated. Temperature is also important for smolting, since it influences the attainment of the necessary body size and the development of the osmoregulatory capability necessary for a saltwater life. Thus, migration is controlled by a combination of temperature increase and temperature level during spring (3-4 ^{o}C), when a critical daylength is reached (Clarke and Hirano 1995). These environmental and physiological changes increase smolt stress levels. Smolt have high levels of hormones that induce stress. Those hormones may play a role stimulating the urge to migrate, but they also exacerbate the effects of stress if the fish encounter difficulties in their migration downriver. Careful handling of migrating smolt is essential to prevent stress-related mortality.

Once the smolt are prepared to migrate, they congregate in schools during the evening and move towards the lake outlet in the hours of darkness (Burgner 1962). In Chignik Lake, the migration movement is favored by onshore winds towards the lake outlet. The winds accumulate warmer surface waters at the outlet that increase stream temperatures and turbidity, stimulating migration (Hartman et al. 1967). This set of migratory behavioral adaptations are tuned to decrease mortality from predation.

The present document focuses on the 1998 sockeye smolt emigration from the Chignik lakes system. We trapped the smolt in the Chignik River (Figures 1, 2) about 2 km downriver from the lake outlet and 8.6 km upriver from the Chignik Lagoon, where the smolt spend an additional period of time adapting to salinity and growing (Phinney 1968). Our objectives were to (1) document the number of smolt emigrating from the lake system, (2) record the age and physical condition of the migrating smolt, (3) record environmental parameters associated with the migratory movement, and (4) continue building a smolt database to identify: smolt-to-adult survival, smolt lake of origin and, indirectly, measure productivity of the rearing environment.

Ongoing and Future Research

In addition to running the smolt project, we are currently working on two additional projects that involve historical data and smolt scales. We hope that these studies will provide a better understanding of the freshwater ecology of the sockeye salmon in the Chignik lakes system.

The first project is a comparison of scale pattern growth trends in historical (1964, 1965, 1967, 1970) and current (1995-1998) scales in the Chignik watershed. The objective of this study is to test whether changes in the Alec River flow and the sand spit formation in Black Lake (Figure 1) have affected the use of this lake as a rearing environment for fry from the Alec River and Fan Creek.

The second project involves smolt scale pattern analyses (SPA) from the 1994 and 1995 migrations to determine their lake of origin. This study is intended to answer the question of whether age-1 smolt are mostly of Black L. origin and age-2 smolt are mostly of Chignik L. origin. With this information, we would be able to estimate smolt survival by stock of origin, which will improve the accuracy of run forecasting and benefit stock management.

Water temperature is an essential factor in a fish's life, since it affects its metabolism and that of its prey. The timing of ice break-up in the lakes and the water temperatures subsequent to break-up determine the amount of new growth that juvenile salmon put on in early summer (Burgner 1987), and influences smolt migration. We have placed thermographs in Black L., Black River, Chignik L. and Chignik River to obtain a complete set of temperature measurements in the major bodies of water of the watershed. We will use the data to gain insight into smolt emigration timing, growth, and general lake temperature conditions.

A new set of biological samples will be collected during the 1999 season at the smolt trap site. ADF&G managers have expressed interest in also starting a coho smolt sampling program. Coho salmon numbers have been recorded as "by-catch" in past years. We will sample coho smolt trapped in the screw-traps for age, length, and weight measurements. In addition, we will also collect samples of stomach contents from sockeye smolt by stomach lavage (which does not require sacrificing the fish). This sampling will allow us to evaluate how much the smolt eat during migration and to determine the composition of their diet.

METHODS

Study Site and Trap Description

Emigrating sockeye smolt were captured daily in the Chignik River in 1998 with two rotary-screw traps (small and large) in tandem, from May 1 through July 1. Each trap consists of a stainless-steel cone mounted on two aluminum pontoons with 2 mm-mesh openings. The cone mouth diameter was 1.5 m on the small trap (placed inshore), and 2.4 m on the large trap (placed offshore), with one-half of each cone submerged. The center of the traps' cones were 5.9 m offshore for the small trap and 9.1 m for the large trap. The current propels an internal screw which rotates the cone at approximately 3-8 rpm during average water flow conditions. Fish are funneled through the cone into a 0.7 m^3 live-box on the downstream end of the trap. An aluminum fulcrum is utilized to maintain and adjust the traps position. Each trap was secured to the riparian vegetation with polypropylene line.

The traps were operated in a constricted section of the Chignik River downstream of a location referred to locally as the "King Hole". This site is 8.6 km upstream from Chignik Lagoon and 1.9 km downstream from the outlet of Chignik Lake (Figure 2). River width at this location is 46 m with an average depth of 2.2 m, and flow rate of 1.2 m/sec. The traps fished approximately 8-9% (3.9 m) of the river width.

The traps fished continuously (except during daily cleaning at 1200 h., <1 h.) from May 1 to June 7. At this time, high river flow and debris prevented continuous fishing, and the traps were raised from 1200 h. (noon) to 2330 h. on June 7 and 8. On June 9, a log stopped the large trap at 0415 h. For the next couple of days, the traps fished only at night. On June 12, traps returned to the continuous fishing schedule.

From July 3-30 the small trap was repositioned 4-5 m behind the adult counting weir (4.8 km upstream from Chignik Lagoon), approximately 35 m offshore from the North bank. However, catch from this time period is treated separately as it is not directly comparable to the catch of the two traps during May-June. The large trap was stored for the season.

Smolt Enumeration

Sockeye salmon smolt and incidental fish caught in the traps were enumerated daily. The traps were checked frequently during the night until 0500 h. to minimize trap induced mortality, and again at 1200 h. Sampling days extended from noon to noon on the date of the noon-to-midnight period.

Juvenile sockeye greater than 40 mm in length and with silver body coloration and eyes small relative to head size were considered smolt and were enumerated (Thedinga et al. 1994).

Age, Weight, and Length Sampling

In 1998, we sampled 70 sockeye smolt per day (5 days/week) for age, weight, and length, for a total of 2,652 smolt (Appendices C, D). To anesthetize the smolt prior to sampling, we used tricaine methanesulfonate (MS-222). Length (tip-of-snout to fork-of-tail) was measured to the nearest 1.0 mm, and weight to the nearest 0.1 g (OHAUS portable electronic balance). Scales removed from the preferred area (INPFC 1963) were mounted on a microscope slide for aging. After sampling, fish recovered in aerated water and were released downstream from the traps. We aged the scales with a microfiche reader (EYECOM 3000) under 36X or 60X magnification. Ages were recorded in European notation (Koo 1962).

Trap Efficiency Estimates

We conducted mark-recapture tests to estimate trap efficiency and total smolt emigration. We used two different approaches to estimate trap efficiency.

Originally (May 1 – June 9), smolt were collected from the traps and transferred to instream flow-through live-boxes. Smolt were retained from one to three days prior to marking, depending on smolt availability. An attempt was made to collect, mark, and release at least 1,000 sockeye smolt once a week, but 500 smolt were used when availability was low. Smolt were dyed in the evening (2100 h.) in an aerated Bismark Brown solution (1.9 g. dye to 57 L water for 30 minutes) (Ward and Verhoeven 1963; Lawler and Fitz-Earle 1968). Dyed smolt displayed a bright yellow/orange color in the fins. After marking, smolt were returned to the instream live-boxes and held for about 30 minutes to recover. At approximately 2230 h. (still light), dyed smolt were transported 1.3 km upstream from the traps (Figure 2), and released evenly across the stream channel. At each step of the dyeing process, dead or stressed smolts were counted and removed. Additionally, delayed mortality associated with marked fish was estimated, i.e., error associated with death of smolt upon release due to the handling and marking procedures (for methodology see Kaplan and Swanton 1997).

The original approach (used in the first part of this season and in previous smolt study years), does not take into account a series of behavioral traits that seem to influence smolt migration. In addition, the problem of fish fasting for a long period of time may affect fish condition and behavior and thus the mark-recapture tests. To solve these problems, we initiated a different approach starting June 10 to July 1.

The behavioral component of the new approach considers smolt activities just before and during migration. Smolt congregate in schools at the lake outlet. At some point during the dark hours of the night, particularly if the wind direction is appropriate (Hartman et al. 1967), the smolt schools begin to move downriver. A fraction of these fish is trapped by our rotary screw traps. To calculate the trap efficiency we run mark-recapture tests. The most accurate estimates of trap efficiency are those obtained from mark-recapture tests that minimize changes in smolt behavior. The goal is that the marked smolt should mix evenly with the population moving downriver, and must behave in the same way. To achieve this goal and minimize stress-related mortality, we need to (1) minimize retention of fish upon capture, (2) minimize time spent in the overall marking process, (3) release marked smolt into the migrating population, i.e., while the migration movement is taking place, during the dark hours, and (4) release smolt on the same date they were trapped.

This methodology differs from the previous one in that it eliminates the need for holding the fish from 1 –3 days prior to release, and therefore minimizes handling. It also eliminates the need for delayed mortality experiments, since no mortality has been observed using this method. In addition, migration patterns of the released fish are more likely to be natural, since the smolt are released the same night they were trapped, during dark hours, into the same migrating population they were originally part of, and after enduring as little stress as possible in the marking process.

This behaviorally-based method was used to estimate trap efficiency from June 10-July 1. Because this method emphasizes minimum fish handling and retention, the smolt necessary for the mark-recapture tests are counted at the trap site, transferred into the dye tub for 30 min., and transported in buckets to the release site (1.3 km upriver) where they are evenly distributed across the river channel. This method was repeated every three days (to allow for recapture of previously marked smolt), depending on smolt availability. Trap efficiency estimates increased in accuracy using this new approach (Appendix A) due to a higher number of recaptures over the original method.

Climate and Hydrology

Trap revolutions (rpm), water depth (cm), and daily climate observations, including air and water temperature (^{0}C), estimated cloud cover (%), and estimated wind velocity (mph) and direction were recorded daily at 1200 h. at the trap site. At this time, the traps were cleaned and adjusted to water level.

DATA ANALYSIS

Smolt Population Estimates

The Carlson et al. (*in review*) smolt population estimator was used for the 1998 Chignik Lakes smolt population estimates. This estimator has been used for previous years in the Chignik smolt project (Kaplan and Swanton 1997).

After release of dyed fish upstream, trap catches were examined for recaptures during the following three days. Recaptured smolt were recorded separately from unmarked fish and excluded from daily total catch to prevent double-counting. The variables used in the Carlson et al. (*in review*) smolt population estimator are:

h: stratum or period index (release event paired with a recovery period).
j: age index.
L: number of strata ($h = 1, 2, \ldots, L$).
M_h: number of marked releases in stratum h.
M: total number of marked releases ($= \Sigma M_h$).
m_h: number of marked recoveries in h.

u_h: number of unmarked smolt captured in *h*.
U_h: total population size of smolt in *h*, excluding marked releases and minus observed mortality.
U: total population size of smolt, excluding marked releases (= ΣU_h).
A_{jh}: number of age *j* smolt sampled in *h*.
A_h: number of smolt sampled in *h*.
θ_{jh}: proportion of age *j* smolt in *h*.
U_{jh}: total population size of age *j* smolt in *h*, excluding marked releases.
U_j: total population size of age *j* smolt, excluding marked releases (=ΣU_{jh}).

The approximately unbiased estimator of the total population within each stratum (U_h) is given as

$$\hat{U}_h = \frac{u_h(M_h+1)}{m_h+1}, \qquad (1)$$

with variance

$$v\left(\hat{U}_h\right) = \frac{(M_h+1)(u_h+m_h+1)(M_h-m_h)u_h}{(m_h+1)^2(m_h+2)}. \qquad (2)$$

The estimate of *U* is therefore

$$\hat{U} = \sum_{h=1}^{L} \hat{U}_h, \qquad (3)$$

with variance estimate

$$v\left(\hat{U}\right) = \sum_{h=1}^{L} v\left(\hat{U}_h\right). \qquad (4)$$

The 95% confidence intervals were estimated from:

$$\hat{U} \pm 1.96\sqrt{v(\hat{U})}, \qquad (5)$$

which assumes that $\hat{U}$ is asymptotically normally distributed.

To estimate the number of emigrating smolt by age class during each stratum *h*, the proportion of each age is first estimated as

$$\hat{\theta}_{jh} = \frac{A_{jh}}{A_h}, \qquad (6)$$

with estimated variance

$$v\left(\hat{\theta}_{jh}\right) = \frac{\hat{\theta}_{jh}\left(1-\hat{\theta}_{jh}\right)}{A_h} . \quad (7)$$

Within each stratum, the total population size by age class is estimated as

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh} , \quad (8)$$

with estimated variance ignoring the covariance term

$$v\left(\hat{U}_{jh}\right) = \hat{U}_h{}^2 v\left(\hat{\theta}_{jh}\right) + v\left(\hat{U}_h\right)\hat{\theta}_{jh}{}^2 . \quad (9)$$

Finally, the total population size of each age class among all strata is estimated as

$$\hat{U}_j = \sum_{h=1}^{L} \hat{U}_{jh} , \quad (10)$$

with estimated variance

$$v\left(\hat{U}_j\right) = \sum_{h=1}^{L} v\left(\hat{U}_{jh}\right) . \quad (11)$$

Condition factor for each smolt sampled was estimated using:

$$\hat{K} = \frac{W}{L^3} 10^5 , \quad (12)$$

where $\hat{K}$ is smolt condition factor, W is weight in grams, and L = length (tip-of-snout to fork-of-tail) in millimeters.

Adjustment of Population Estimates

Smolt population estimates from 1994 to May 1998 were adjusted to correspond to the new estimates of trap efficiency (June 1998). The new mark-recapture approach was repeated on four occasions during June (Appendix A), and trap efficiency estimates were always higher than those of the original method. The higher estimates result from a larger proportion of recaptures (Table 1). Therefore, to be able to compare previous and current smolt population estimates, we had to adjust the number of smolt recaptured to match the new trap efficiency estimates. This approximation was not simple. The traps have not been at the same location and/or distance from the shore every year, and leads to the traps had been used in the past (see Stopha and Barret 1994, Vania and Swanton 1996, Kaplan and Swanton 1997, Kaplan and Swanton 1998). Consequently, because trap efficiency is likely to have varied in different study years, we tried different approaches to recreate the trap efficiency observed using the new method. The number of recaptures were increased by one-third, by one-half, and doubled, and results compared. When the number of recaptures was increased by one-half, trap efficiency estimates approximated those observed using the new method, and therefore the increase of one-half for recaptures was chosen. In addition, increasing the number of recaptures had the advantage that the numbers generated depended on the actual recaptures for each trap/stratum/year, a reflection of trap location (Table 1).

RESULTS

Some of the following results include smolt data from 1996. Results that incorporate 1996 data have to be cautiously interpreted, since there is indication that some of the emigrating smolt had not been observed (see Discussion).

Adjusted estimates of efficiency were lower than the estimates for the 1998 strata 6-9, which were our index of efficiency (Table 1). The trap efficiency estimates increased following the pattern: 1994 < 1995 < 1996 ≤ 1997 = 1998 (strata 1-5) < 1998 (strata 6-9). From 1994 to 1997 the pattern is the same that was present with the original trap efficiency estimates.

Smolt emigration in 1998 was higher than in any of the other study years (Fig. 3, compare to Stopha and Barret 1994, Vania and Swanton 1996, Kaplan and Swanton 1997, Kaplan and Swanton 1998). The traps were in place by May 1, and large numbers of smolt were already being trapped (1,979 smolt, Appendices A, B), which indicates that some smolt had left the system before May 1. The flow of emigrating smolt did not decrease until late May, with three large migration peaks from May 15 to May 22. Several small migration peaks occurred before and after those dates, and the emigration continued until June 22, when low numbers of smolt were consistently trapped. Because we only have data since 1994, we don't know whether these large numbers of smolt are a periodical event or a punctual occurrence. In any case, it is remarkable that in 1998 more smolt were trapped (456,552) than in the four previous study years combined (424,351). Other species were also trapped in large numbers (Appendices A, E), especially sticklebacks. During July, the small trap caught a total of 1,066 smolt at its location behind the adult fish weir, less than in 1997 (13,504 smolt), indicating that most of the migration had taken place during previous months.

The estimated number of smolt that emigrated in 1998 (May 1 - July 1) is 26,398,449 (±3,854,506 S.E., Table 2). This number, although larger than estimates from other years, is not as large as the sum of the estimates from 1994-1997. This apparent discrepancy is the result of different trap efficiency estimates (Table 1). Traps had different efficiencies at different locations and/or distances from shore, and a low efficiency estimate results in a large number of smolt being estimated. In contrast to previous study years, mostly age-2 smolt (74%, Table 2) left the Chignik system in 1998. In past study years, the age-1 and age-2 components were similar. This is the first year we have observed that most of the emigrating smolt are of the same age (Fig. 4). Ages 0 and 3 smolt were scarce (Table 2).

Length frequency distributions of smolt sampled during May and June, 1998, were comparable (Fig. 5), although age-1 smolt were larger in May than in June (Appendix C). Average length for age-0 smolt was 45.2 mm (range: 40-52 mm) (Table 3). Average length for age-1 smolt was 69.7 mm (range: 65-75 mm). Average length for age-2 smolt was 72.4 mm (range: 58-120 mm), and average length for age-3 smolt was 83.6 mm (range: 67-104). Age-1 smolt in 1998 had the highest mean length and weight from the five study years (Table 3), but age-2 fish had the smallest size and weight yet recorded. Also, both age classes had low condition factors. In terms of length frequency distributions, 1998 was also different from previous study years. In the past, we found distinct distributions of smolt size by age for May and June (Stopha and Barret 1994, Vania and Swanton 1996, Kaplan and Swanton 1997, Kaplan and Swanton 1998), but in 1998 smolt ages-1 and -2 had similar average (and median) size, weight and condition factor (Table 3, Fig. 6). These data suggest that habitat and food resources in Chignik Lake were highly exploited by juvenile salmon. Length-weight relationships also showed that most smolt ages-1and -2 were in the range from 60-90 mm and from 2-5 g (Fig. 7).

Time series of weight, length and condition factor revealed differing patterns of migration in 1998 between smolt ages 1 and 2. In terms of timing, migration of both age groups peaked on May 15 (Fig. 4). However, larger and heavier age-1 smolt left the lakes in May, and their smaller counterparts left in June (Fig. 8). This pattern is particularly noticeable in the smolt condition factor, with age-1 being in the same or better condition than age-2 during May, and in lower condition during June. The age-2 smolt migration pattern differed from age-1. Age-2 smolt were heavier and had a higher condition factor during June than in May. Comparison of figures 4 and 8 shows that the majority of the smolt emigrated in May, in a group composed of good-condition age-1 and average-condition age-2 smolt. In June, the smolt leaving the lakes were small age-1 and large age-2 fish.

Time series of condition factors among the study years were very variable (Fig. 9). In 1994, age-1 smolt were in better condition than age-2 through the season, and both age-classes were in better condition in May than in June. The migration in 1994 took place evenly through the season (Stopha and Barret 1994). The 1995 smolt condition was better for age-2 than for age-1, and was higher during June, after most smolt had left in a large peak in May (Vania and Swanton 1996). In 1996 the condition patterns were not clear, although age-2 might have been in better condition than age-1. In 1997, age-2 smolt were in better condition than age-1, and condition improved in June. Most smolt had left in May (Kaplan and Swanton 1998).

Survival of smolt to the adult stage was different for ages-1 and -2. Mean smolt survival from brood year 1992 was 23% (Table 4). Only 13% of age-1 smolt returned as adults, compared to a 32% return of age-2 smolt. These age classes migrated in 1994 (age-1) and 1995 (age-2). It is interesting to note that age-1 smolt had a condition factor of 0.75 at time of migration (Table 3), and age-2 had a higher factor of 0.83. A better condition may be linked to the higher survival of age-2 from the 1995 migration. From brood year 1991, only 25% age-2 smolt (migration year 1994) returned as adults, and their condition factor was 0.75 (the same as for their age-1 counterparts). Therefore, the smolt that migrated in 1994 were in lower condition than the smolt that migrated in 1995 and their survival was also lower. However, age-2 had a higher percentage of survival than age-1 in the ocean conditions they encountered in 1994. Age-0 survival from brood year 1994 was very low (0.06%). Two brood years (1992 and 1994) had a similar number of migrating smolt produced per spawner (11 smolt/spawner), but inclusion of age-1 (1996 smolt migration year) in these calculations lowered the smolt/spawner proportion for brood year 1994.

Brood year 1993 had a very low (smolt/spawner = 3.69) smolt production due to the 1996 migration component (age-2), which is likely below the actual production (Table 4). Similarly, 21% smolt survival for age-1 in brood year 1993 is high due to the 1996 component of the brood table, and the estimate is probably inaccurate. Brood year 1995 had a record number of smolt produced per spawner (37.89) as indicated by the large migrations of 1997 and 1998.

DISCUSSION

The high level of smolt production in 1998 (resulting in large migrations) indicates favorable food and environmental conditions in the Chignik lakes system. The food abundance (and availability) was reflected in the survival and successful migration of large numbers of smolt and in the presence of large numbers of other fish species, especially sticklebacks.

Our calculations of smolt-to-adult survival indicate a rate of 23%, which is comparable to other published smolt survival estimates. Barnaby (1944) estimated a survival rate of 20% to 23% for smolt from the Karluk River, but these smolt were much larger than those from Chignik. In British Columbia (Hyatt and Stockner 1985), small smolt (1.2-3.4 g) had survival rates from 5% to 30%, depending on ocean conditions. Our estimates of 13% survival for age-1 and 25% survival for age-2 smolt are comparable to those found in a study of 12 Alaskan nursery lakes (Koenings et al. 1993). It has been hypothesized that ocean mortality rates are inversely related to the weight of the fish as they grow (Mathews and Buckley 1976), and survival is higher for older smolt (Barnaby 1944). However, other studies have shown that smolt length is more important for ocean survival than age (Koenings et al. 1993). In our case, the estimates of lower survival rate for age-1 than for age-2 smolt are justified, given the size difference between ages in the smolt that migrated in 1994 and 1995. In the future, it will be interesting to test the importance of age and size on survival for the 1998 smolt, since ages-1 and -2 were of similar sizes.

Age-2 smolt comprised 74% of the smolt that left the Chignik lakes in 1998. Their overall condition was 0.75, similar to the age-2 smolt from 1994. If we apply the 25% survival of the 1991 brood year (Table 4), about 5 million age-2 sockeye would be expected to return in the years 2000 (age-2.2) and 2001 (age-2.3). Similarly, from age-1 smolt (applying 13% survival, brood year 1992) we would expect a 0.7 million return (or lower, given their low condition factor of 0.75). In the best of scenarios (i.e., favorable ocean conditions and moderate predation/disease losses), the year 2000 total run (based on age composition of runs 1994 and 1995) might be as high as 3.5 million sockeye. Because ocean survival rates may differ in the next 2 or 3 years from those of the past few years, these estimates may be inaccurate and should be used cautiously. In addition, this estimate is based solely on smolt data, and not on sibling relationships, and should be considered an index indicating the potential for a relatively high adult return. The smolt that migrated in 1998 will enrich the year 2000 and 2001 runs, but the strength of those runs will also depend on the ocean environment those fish encounter, on the returns from the 1997 smolt migration, and on the number and condition of the smolt emigrating in 1999.

The results from the smolt project are the best estimates we have for smolt emigration in the Chignik system. But, because the timing of migration varies according to climatological conditions, a portion of the smolt may have been missed occasionally. For instance, in 1998, as early as May 1 we trapped 1,979 smolt, while in 1997, only 71 smolt were caught by May 3. Also, during July, only 1,066 smolt were trapped in 1998, but 13,504 smolt were trapped in 1997. We can assume that every year we miss a portion of the smolt that are emigrating too early or too late for our trap setup. These variations in timing are difficult to predict and add error to our calculations of survival, producing an overestimate of the actual survival. However, except for 1996, we are confident that we fished the traps during the migration peaks, and the variability in our estimates due to this source should be minimal.

There is disagreement between the 1996 smolt counts and indirect indicators of migration strength. In 1996, a remarkably low number of smolt left the Chignik lakes system (1,370 thousand) from May 6 – June 30. However, winter studies in the lakes (Ruggerone 1996) indicated an average abundance of fry. Water temperatures may have also been higher than average. A local observer indicated that Chignik L. froze late (Jan. 12) and the ice went out in April (Greg Ruggerone, NRC, pers. comm.). Water temperatures from Black L. indicate a warm period between April 12 and April 30 (Ruggerone 1996). Chignik L., a colder lake, probably did not warm-up until later in April, just before the traps were installed in the river. In that case, we may have missed a smolt migration peak a few days earlier. Further evidence in favor of a larger-than-recorded smolt migration in 1996 is the return of ages 1.2 and 2.2 in larger numbers than our smolt estimates can justify. Therefore, it appears that the smolt counts for 1996 were partial, i.e., only a portion (not necessarily the largest one) of the emigrating smolt population was estimated.

Several indicators suggest smolt competition occurred in Chignik L. during 1997 and 1998. The two major age classes had similar mean size and weight (Table 3, Fig. 6), and their condition factor was low (0.76). If competition was the cause of the similar growth between the two age classes, it had a stronger effect on age-2 smolt. Age-1 smolt were larger on average than in the past four years, but they were lean (low condition factor). Age classes-1 and -2 usually exhibit lacustrine habitat segregation, occupying the limnetic and littoral areas at different times through their development, which reduces competitive stress for food (Burgner 1991). Thus, if competition was taking place in the lake, there are two possible explanations for the large size of the age-1 smolt: (1) the age-1 smolt entered Chignik L. as fry and there was little competition for their food supply because juveniles from previous years were utilizing a different habitat, or (2) most of these fish were from Black L., and had a period of growth in their lake of origin before entering Chignik L. later in the season. In either case, most of the age-class 1 growth must have occurred during their early life stages. As these fry approximated in size the older sockeye in Chignik L., they may have competed with them for food and habitat preferences, thus limiting their weight gain. On the other hand, the age-2 smolt grew in Chignik L. among tens of millions of siblings from the same brood year. It is likely that the growth of this age-class was hampered by intraspecific competition from the moment they entered the lake as fry. It is also likely that the 1998 smolt were competing with large numbers of sticklebacks. Sticklebacks are a mixed blessing for sockeye: they have a beneficial effect by reducing dolly varden and coho predation, but they also compete for similar food resources (Burgner 1987, Ruggerone et al. 1992). The fact that both sockeye and sticklebacks were so abundant during this year, indicates favorable food and environmental conditions for different species of juvenile fish in the lakes. Thus, higher food availability must have been present for age-1 than for age-2 smolt early in their lacustrine life, and that advantage may be responsible for the similar migrating sizes of the two age-classes.

For a sockeye smolt, the time to leave the lake system depends on its general condition and on the weather pattern (Clarke and Hirano 1995). We observed in 1998, that the smolt emigrated from Chignik L. during dark nights (50%-90% cloud cover) with W/NW winds (from the lakes) (Appendix F), that blew downriver. These observations are in accordance with previous records of similar smolt behavior in Chignik Lake (Hartman 1967). Thus, wind direction and cloud cover could negatively affect the mark-recapture tests we use to determine trap efficiency if, for example, marked fish captured on dark nights with W/NW winds are released on clear nights with SE winds. By releasing the marked smolt the same night they are captured (as in the new methodology adopted) this risk is avoided; smolt are released in the same conditions under which they otherwise would be migrating.

The Chignik system has a set of nursery habitats for young sockeye. Unlike other systems, where smolt leave the lakes and enter the coastal waters and ocean feeding grounds, in Chignik, post-smolt take advantage of the extra nurturing available in the Chignik Lagoon. This estuary acts like a buffer between the freshwater and the saltwater ecosystems, with larger smolt occupying the pelagial zone and the smaller smolt in the littoral areas (Phinney 1968). Phinney (1968) concluded that the fish remain in the lagoon until they attain 80-100 mm, sometimes into September. Phinney (1968) also observed an increased tendency for the sockeye to remain in the lagoon for long periods when conditions were poor in the lakes. We observed a general pattern of size-at-migration during the five study years. In years when juvenile sockeye emigrated evenly through the season (May/June), competition for feeding opportunities in freshwater was probably high, and the smolt that remained until June were in a poorer condition than those that left earlier. However, when smolt emigrated in large peaks early in the season, competition in the lake may have decreased, thus allowing those smolt remaining in June to attain better condition than the early migrants. At some point, the smolt either stayed in the lake and probably gained a better general condition (at the expense of a longer growth period in the lagoon) or migrated to the lagoon (and perhaps encountered higher predation).

In summary, 1998 has been a record year of smolt emigration since ADF&G began the smolt migration project in 1994. Freshwater and weather conditions have been apparently beneficial for the egg-to-fry and fry-to-smolt survival, and there is a good prospect for future runs that incorporate sockeye salmon from this year's migration. Assuming ocean conditions similar to those of 1994 and 1995, up to a 23% smolt-to-adult survival could be expected. However, ocean temperatures, predation pressures, disease, catastrophic events, and food availability in the ocean grounds will have the last word on the survival and return of the 1998 smolt.

LITERATURE CITED

Barnaby, J.T. 1944. Fluctuations in abundance of red salmon, *Oncorhynchus nerka* (Walbaum), of the Karluk River, Alaska. Fish. Bull. Fish. Wildl. Serv. 50:237-296.

Brünning, E. 1973. The physiological clock. Springer-Verlag, New York. 258 p.

Burgner, R.L. 1962. Studies of red salmon smolts from the Wood River Lakes, Alaska. *In*: T.S.Y. Koo (ed.). Studies of Alaska red salmon. Univ. Wash. Publ. Fish. New Ser. 1.

Burgner, R.L. 1987. Factors influencing age and growth of juvenile sockeye salmon (*Oncorhynchus nerka*) in lakes. *In*: Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. H.D. Smith, L. Margolis, and C.C. Wood (eds.). Can. Spec. Publ. Fish. Aquat. Sci. 96.

Burgner, R.L. 1991. Life history of sockeye salmon (*Oncorhynchus nerka*). *In*: Pacific salmon life histories. C. Groot and L. Margolis (eds.). UBC Press, Vancouver.

Carlson, S.R., L.G. Coggins, Jr., and C.O. Swanton. *In Review*. A simple stratified design for mark-recapture estimation of salmon smolt runs. Alaska Fisheries Research Bulletin.

Clarke, W.C. and T. Hirano. 1995. Osmoregulation. *In*: Physiological ecology of pacific salmon. C. Groot, L. Margolis and W.C. Clarke (eds). UBC Press, Vancouver. 510 p.

Hartman W.L., W.R. Heard, and B. Drucker. 1967. Migratory behavior of sockeye salmon fry and smolts. J. Fish. Res. Board Can. 29:699-715.

Hyatt, K.D. and J.G. Stockner. 1985. Responses od sockeye salmon (*Oncorhynchus nerka*) to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42:320-331.

INPFC (International North Pacific Fisheries Commission). 1963. Annual Report 1961. Vancouver, British Columbia.

Kaplan, D.F. and C.O. Swanton. 1997. Chignik Lakes sockeye smolt abundance, age composition, and size characteristics, 1996. Alaska Department of Fish and Game, Commercial Fish Management and Development Division. Regional Information Report 4K97-28. Kodiak, AK.

Kaplan, D.F. and C.O. Swanton. 1998. Population estimates and biological attributes of the Chignik lakes sockeye salmon outmigration, 1997. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division. Regional Information Report 4K98-4. Kodiak, AK.

Koenings, J.P., H.J. Geiger and J.J. Hasbrouck. 1993. Smolt-to-adult survival patterns of sockeye salmon (*Oncorhynchus nerka*): Effects of smolt length and geographic latitude when entering the sea. Can. J. Fish. Aquat. Sci. 50:600-611.

LITERATURE CITED (Cont.)

Koo, T.S.Y. 1962. Age designation in salmon. *In*: Studies of Alaska red salmon. Univ. Wash. Publ. Fish. New Ser. 1.

Lawler, G.H. and M. Fitz-Earle. 1968. Marking small fish with stains for estimating populations in Heming Lake. Manitoba. J. Fish. Res. Board Can. 25:255-266.

Mathews, S.B. and R. Buckley. 1976. Marine mortality of Puget Sound coho salmon (*Oncorhynchus kisutch*).J. Fish. Res. Board Can. 33:1677-1684.

Phinney, D.E. 1968. Distribution, abundance and growth of postsmolt sockeye salmon in Chignik Lagoon, Alaska. MSc. Univ. of Washington. 159 p.

Ruggerone, G.T. 1996. Winter investigations of salmon in the Chignik lakes, Alaska, 1996. Report for the Chignik Regional Aquaculture Association by Natural Resources Consultants, Inc. Seattle, WA. 46 p.+ appendices.

Ruggerone, G.T. and D.E. Rogers. 1992. Predation on sockeye salmon fry by juvenile coho salmon in the Chignik lakes, Alaska: implications for salmon management. North Am. J. Fish. Mngmt. 12:87-102.

Stopha, M.E. and B.M. Barrett. 1994. Sockeye smolt and presmolt abundance, age composition, and condition, and the use of the parasite *Philomena oncorhynchi* as an inseason stock separation estimator for returning adult sockeye salmon, Chignik Lakes, 1994. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division. Regional Information Report 4K94-36. Kodiak, AK.

Thedinga, J.F., M.L. Murphy, S.W. Johnson, J.M. Lorenz, and K.V. Koski. 1994. Salmonid smolt yield determined with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries service, National Oceanic and Atmospheric Administration Technical Report. Juneau, AK.

Vania, T.D. and C.O. Swanton. 1996. Chignik Lakes sockeye smolt abundance, age composition, and size characteristics, 1995. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division. Regional Information Report 4K96-22. Kodiak, AK.

Ward, F.J. and L.A. Verhoeven. 1963. Two biological stains as markers for sockeye salmon fry. Trans. Am. Fish. Soc. 94:379-383.

Table 1. Comparison of marked sockeye salmon smolt recaptures in Chignik River using the original data and the adjusted data (see Methods section), and trap efficiency estimates for both methods. Framed area (strata 6 - 9) corresponds to the actual measurement of trap efficiency using the behaviorally-based mark-recapture approach.

				No. of Recaptures		Efficiency Estimate	
Year	Stratum	Catch	Marked	Original	Adjusted	Original	Adjusted
1994	1	3,810	471	3	4	0.64	0.85
	2	7,770	1,315	6	9	0.46	0.68
	3	12,354	2,472	16	24	0.65	0.97
	4	11,615	1,682	7	10	0.42	0.59
	5	3,044	2,011	10	15	0.50	0.75
	6	6,046	2,063	12	18	0.58	0.87
	7	6,645	3,090	10	15	0.32	0.49
	8	9,311	3,219	14	21	0.43	0.65
1995	1	14,532	1145	9	13	0.79	1.14
	2	33,833	944	6	9	0.64	0.95
	3	14,791	1147	10	15	0.87	1.31
	4	5,233	864	8	12	0.93	1.39
	5	3,905	1315	24	36	1.83	2.74
	6	2,089	782	5	7	0.64	0.90
1996	1	16,789	1,502	18	27	1.20	1.80
	2	7,906	2,788	31	46	1.11	1.65
1997	1	6,361	1,057	15	22	1.42	2.08
	2	27,252	1,468	13	19	0.89	1.29
	3	100,931	1,559	14	21	0.90	1.35
	4	78,209	4,026	47	70	1.17	1.74
	5	40,645	4,056	36	54	0.89	1.33
	6	5,969	947	14	21	1.48	2.22
	7	5,311	1,172	15	22	1.28	1.88
1998	1	18,370	1,020	16	24	1.57	2.35
	2	74,965	1,031	17	25	1.65	2.42
	3	183,513	1,053	9	13	0.85	1.23
	4	64,290	640	6	9	0.94	1.41
	5	44,906	1,510	22	33	1.46	2.19
	6	52,460	1,008	24	24	2.38	2.38
	7	8,608	1,019	25	25	2.45	2.45
	8	2,194	505	16	16	3.17	3.17
	9	7,105	1,020	32	32	3.14	3.14

Table 2. Sockeye salmon smolt population estimates by age class for the Chignik Lakes system, 1994-1998, adjusted by revised trap efficiency estimates. (-) Age-classes not present in samples.

		Emigrating Smolt						95% C.I.	
Year		Age-0.	Age1.	Age-2.	Age-3.	Total	S.E.	Lower	Upper
1994	No.	-	5,060,477	3,006,964	-	8,067,441	800,982	6,497,517	9,637,365
	%	-	63.0	37.0	-	100			
1995	No.	514,812	1,991,470	3,633,286	-	6,139,569	1,045,019	4,091,332	8,187,805
	%	8.4	32.5	59.1	-	100			
1996	No.	54,597	815,993	496,358	3,407	1,370,355	179,067	1,019,383	1,721,327
	%	4.0	59.5	36.2	0.2	100			
1997	No.	359,150	7,604,583	9,366,098	83,435	17,413,267	1,679,593	14,121,265	20,705,268
	%	2.1	43.7	53.7	0.5	100			
1998	No.	75,560	5,790,587	20,374,245	158,056	26,398,449	3,834,506	18,882,817	33,914,080
	%	0.4	24.8	73.8	0.9	100			

Table 3. Summary of mean length, weight, and condition factor by age class of emigrating sockeye salmon smolt sampled from the Chignik River, 1994-1998. (a) indicates standard errors below precision level of measurement (0.1 g).

Emigration Year	Age	N	Mean Length (mm)	S.E.	Mean Weight (g)	S.E.	Condition Factor	S.E.
1994	0	0						
1995	0	286	45.7	0.20	0.7	a	0.74	0.01
1996	0	83	47.9	0.50	0.9	a	0.76	0.02
1997	0	154	46.3	0.30	0.8	a	0.82	0.01
1998	0	13	45.2	1.06	0.7	a	0.70	0.03
1994	1	1,722	66.6		2.3	a	0.75	
1995	1	1,275	60.2	0.30	2.0	a	0.80	0.01
1996	1	935	66.9	0.30	2.4	a	0.76	0.01
1997	1	1,393	64.7	0.40	2.5	a	0.80	0.00
1998	1	608	71.5	0.38	3.0	a	0.76	0.00
1994	2	1,096	77.4		3.6	a	0.75	
1995	2	1,009	75.1	0.20	3.5	a	0.83	0.01
1996	2	429	79.5	0.40	4.1	a	0.79	0.01
1997	2	765	83.4	0.30	4.7	a	0.80	0.00
1998	2	1,917	72.4	0.13	3.0	a	0.76	0.00
1994	3	0						
1995	3	0						
1996	3	3	100.3	5.50	8.4	a	0.81	0.07
1997	3	12	87.3	1.34	5.2	a	0.77	0.02
1998	3	20	83.6	3.39	5.5	0.99	0.81	0.02

Table 4. Sockeye salmon spawner escapement and estimated number of smolt produced by brood year from both lakes (Black L. and Chignik L.), smolt produced per spawner, and adult return per smolt emigrating from the system (a measure of survival). Numbers in parentheses are migration years. Numbers in framed areas (italics) have an important 1996 (migration year) component (see Results and Discussion). (-) Data not available.

Brood	Total	Smolt Produced			Total	Smolt/	Smolt Survival			
Year	No. Spawners	age-0.	age-1.	age-2.	Smolt	Spawner	age-0.	age-1.	age-2.	mean
1991	1,040,098	-	-	3,006,964 *(94)*	-	-	-	-	0.25	-
1992	766,603	-	5,060,477 *(94)*	3,633,268 *(95)*	8,697,152	11.35	-	0.13	0.32	0.23
1993	697,377	-	1,991,470 *(95)*	496,358 *(96)*	2,571,263	*3.69*	-	*0.21*		
1994	964,354	514,812 *(95)*	815,993 *(96)*	9,366,098 *(97)*	10,854,959	*11.23*	0.0006			
1995	739,920	54,597 *(96)*	7,604,583 *(97)*	20,374,245 *(98)*	28,033,425	37.89				
1996	735,112	359,150 *(97)*	5,790,587 *(98)*							
1997	775,618	75,560 *(98)*								
1998	701,128									

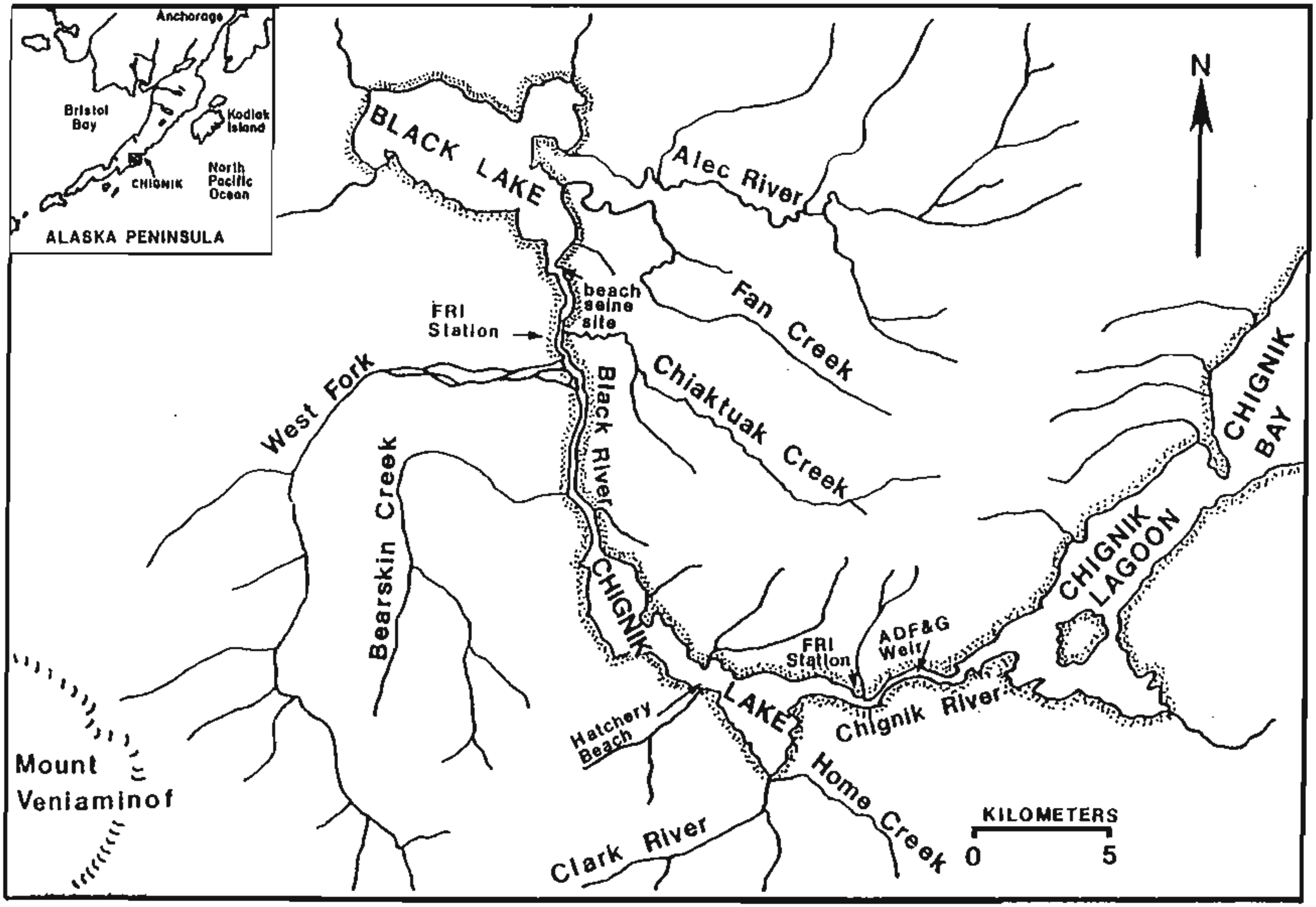

Figure 1. Map of the Chignik watershed with inset of western Alaska.

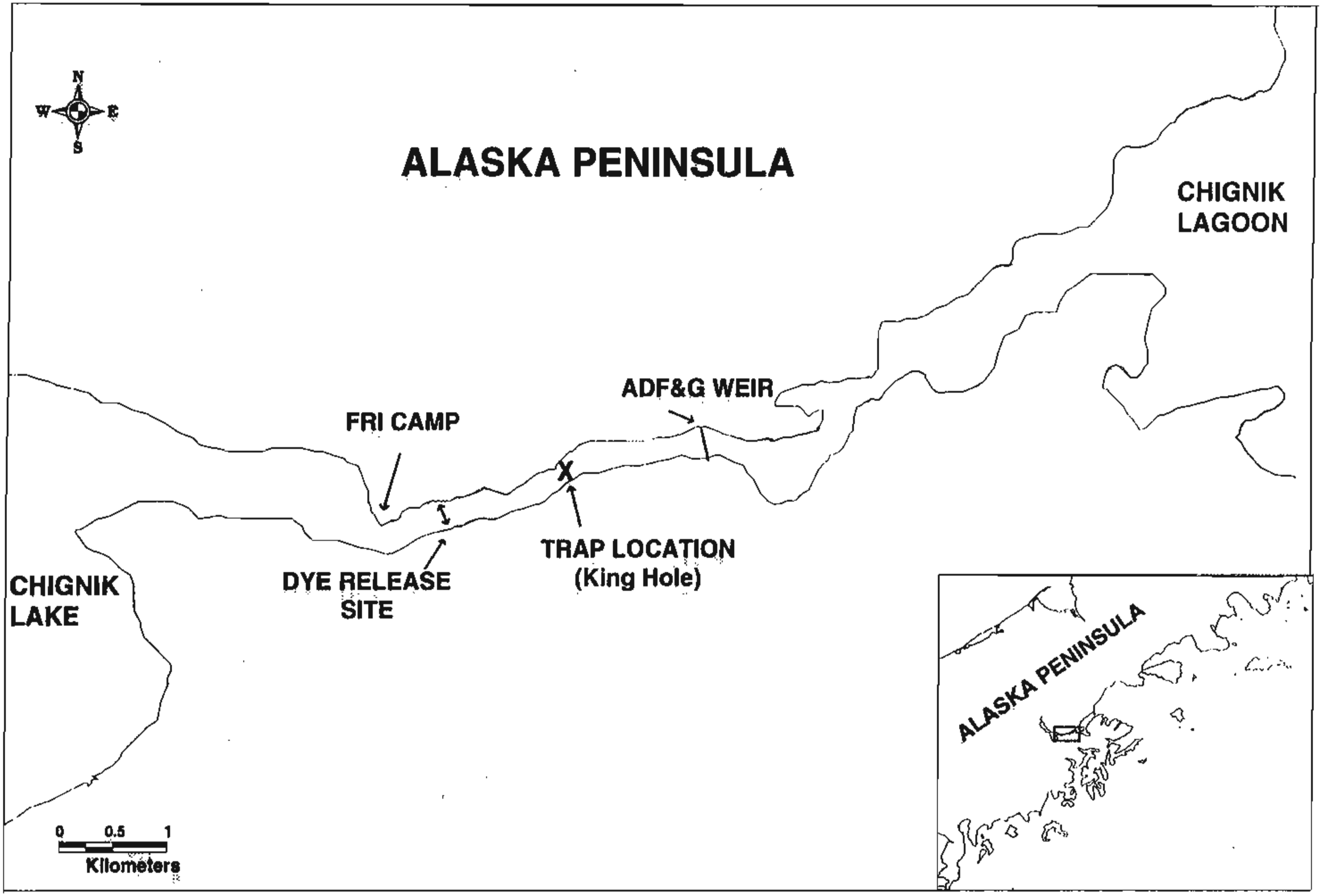

Figure 2. Location of rotary-screw trap, and release site of marked fish on the Chignik River, 1998, Alaska.

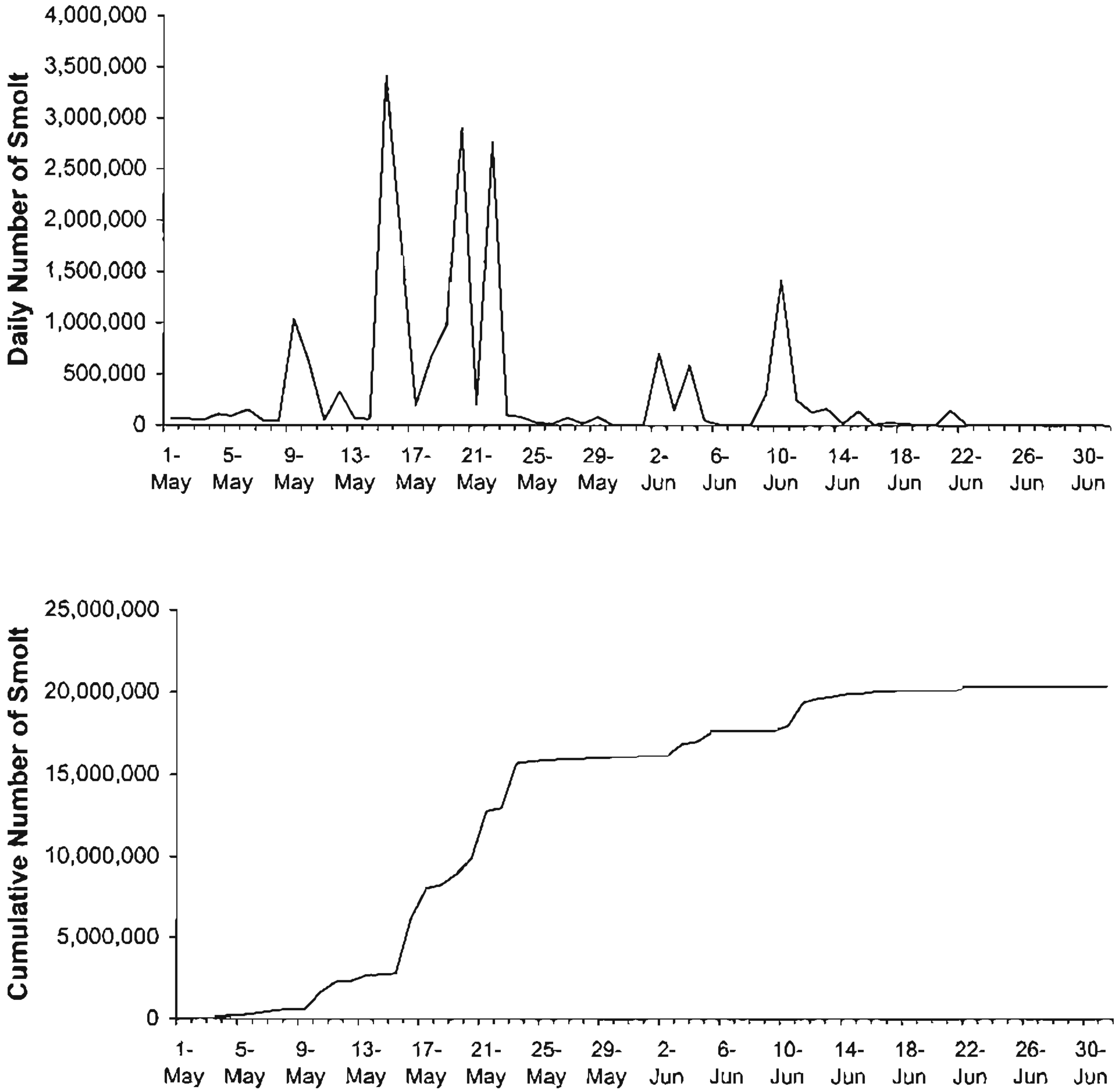

Figure 3. Estimated number of sockeye salmon smolt emigrating from the Chignik lakes, by day and cumulative, for May-June 1998.

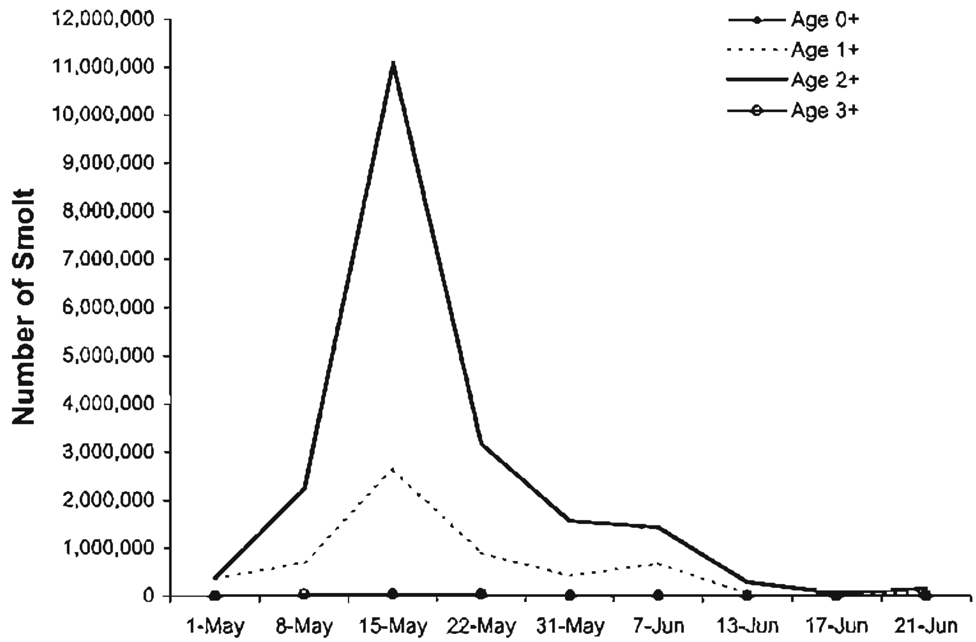

Figure 4. Estimated number of sockeye salmon smolt leaving the Chignik lakes by statistical period and by age-class, 1998.

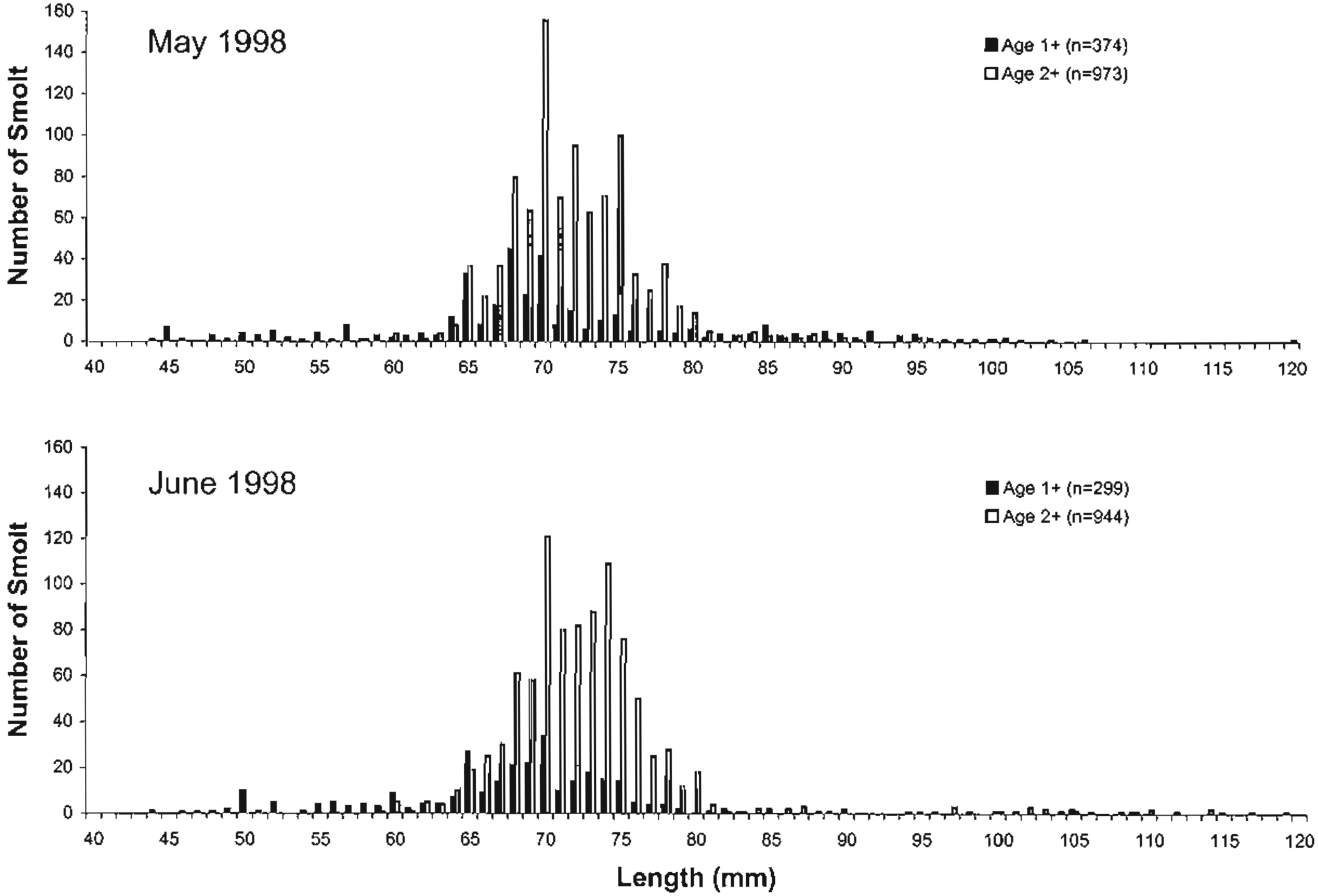

Figure 5. Sockeye salmon smolt length frequency distributions during May and June, 1998, for the Chignik River.

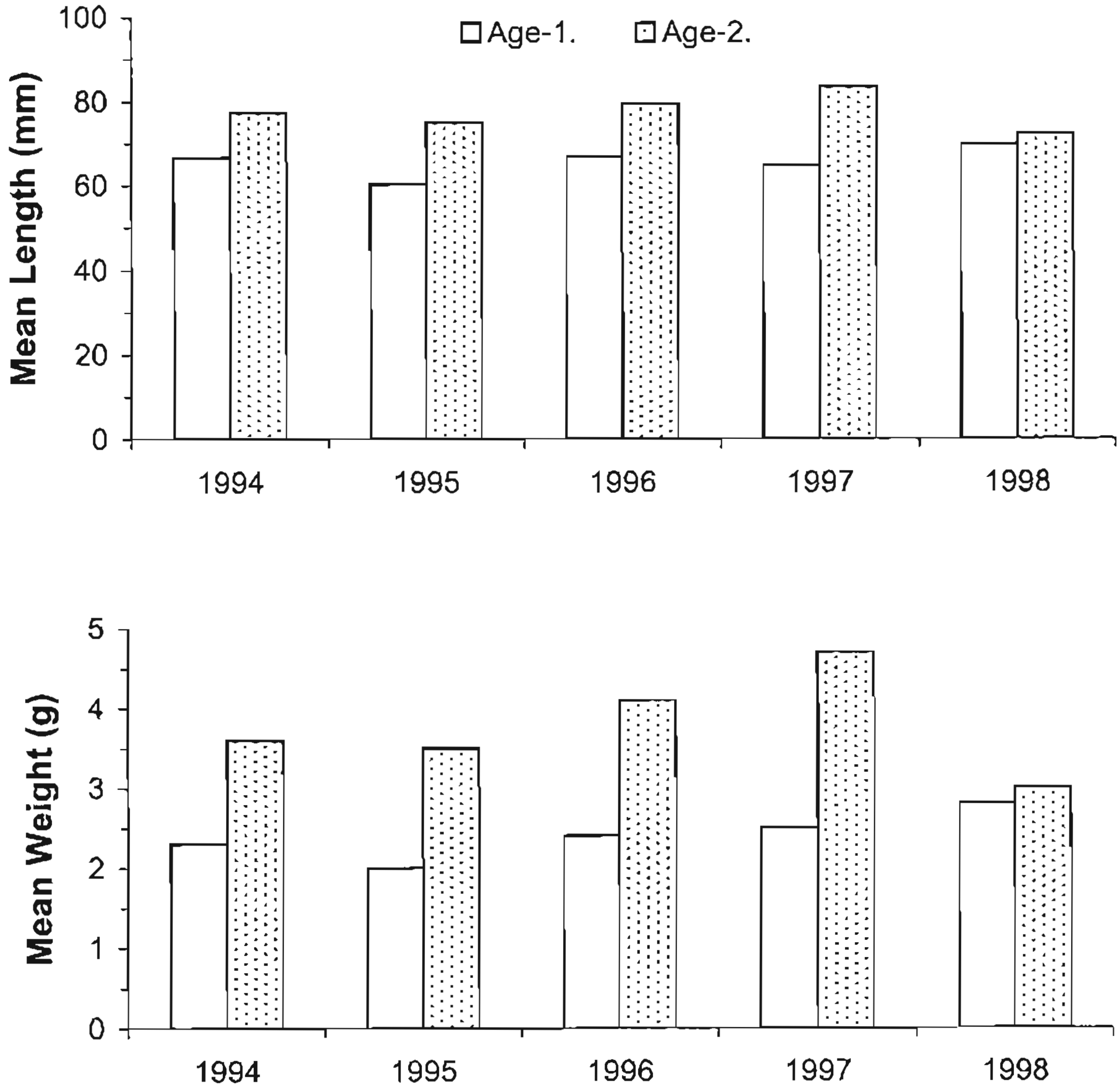

Figure 6. Mean length and weight of emigrating Chignik sockeye salmon smolt by age-class in the five study years, 1994-1998.

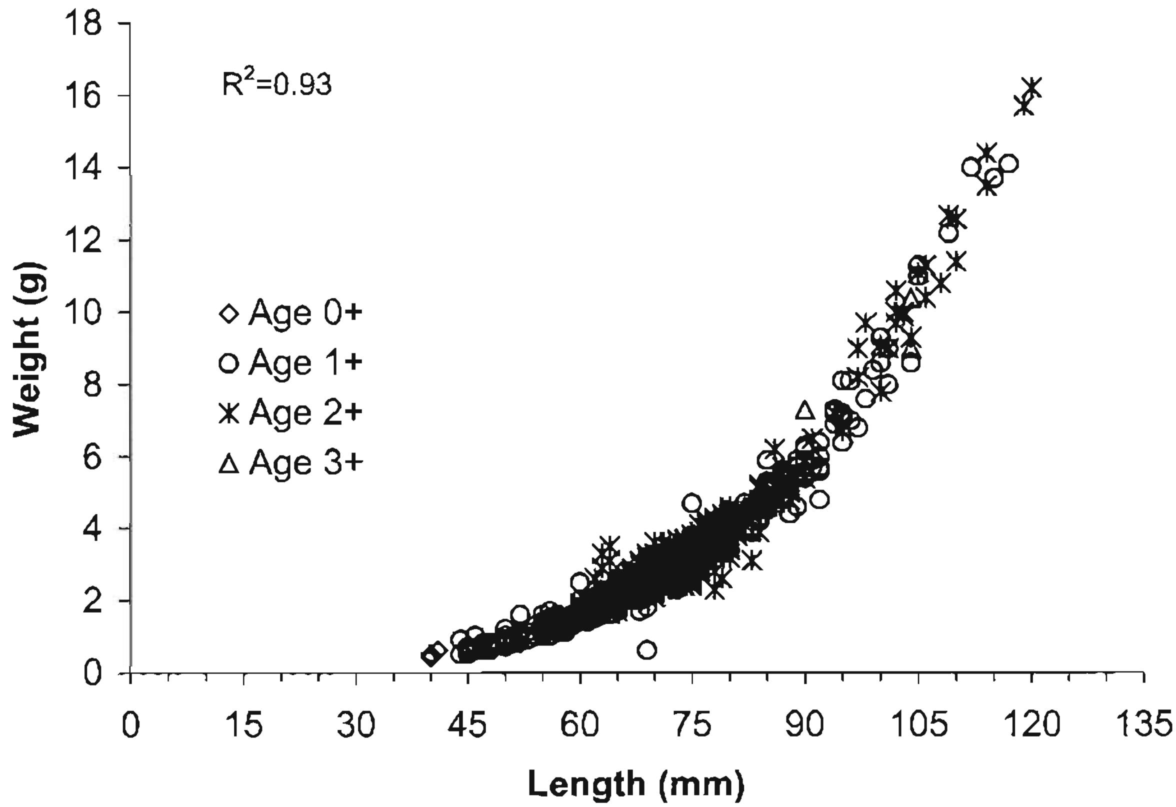

Figure 7. Length-weight relationships of sockeye salmon emigrating from the Chignik Lakes during May-June, 1998, including all the age classes present in the samples.

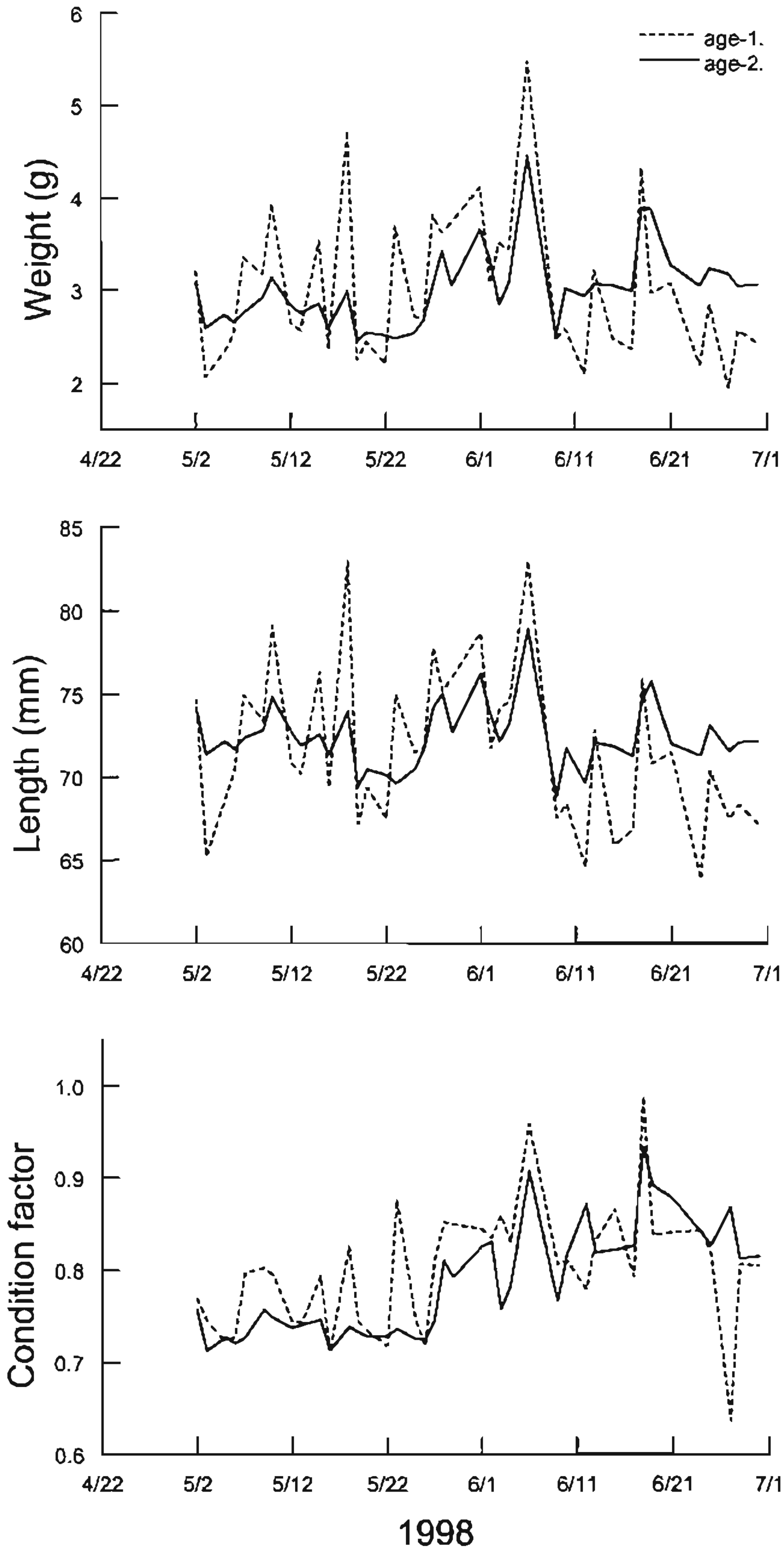

Figure 8. Length, weight and condition factor of sockeye salmon smolt emigrating in 1998 from the Chignik lakes.

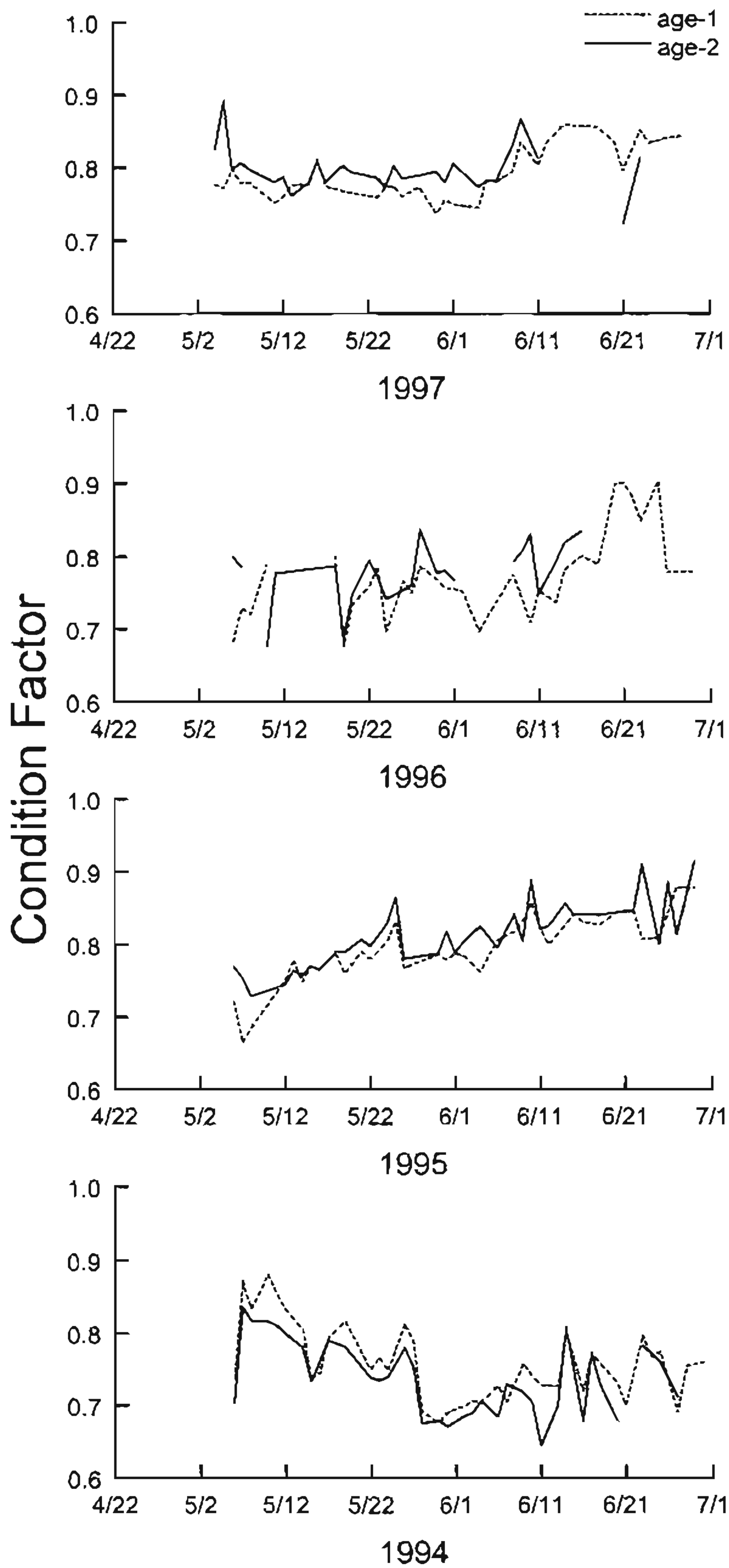

Figure 9. Condition factor of sockeye salmon smolt emigrating from the Chignik lakes from 1997 to 1994.

APPENDIX

Appendix A. Number of sockeye salmon smolt caught with rotary-screw traps by day in 1998 in the Chignik River. Results from mark-recapture tests and by-catch of non-target species. Dates are 24 h. periods from noon to noon. Framed area (10-Jun - 1-Jul) indicates the change in methodology that increased trap efficiency estimates. Original data, no corrections have been applied to trap efficiency estimates.

	Catch		Trap Efficiency Test			Incidental Catch[1]								
Date	Daily	Cum.	Marked	Recovered	Rate %	SoF	coho	chnk	DV	SB	SC	PW	PS	SF
1-May	1,979	1,979				388	6	0	6	1,526	40	0	4	9
2-May	2,089	4,068				226	7	0	17	2,120	44	1	2	3
3-May	1,436	5,504				569	6	0	9	1,712	41	0	0	1
4-May	3,376	8,880				794	16	0	16	3,875	57	0	0	8
5-May	3,017	11,897	1,020	16	1.57	428	13	0	18	2,051	54	0	0	21
6-May	4,942	16,839				670	39	0	38	7,803	97	0	2	33
7-May	1,531	18,370				300	11	0	7	3,884	24	0	0	7
8-May	1,315	19,685				236	9	0	11	3,237	21	0	0	2
9-May	35,185	54,870				130	5	0	7	4,620	0	0	0	0
10-May	20,959	75,829				558	8	0	7	4,345	12	0	1	0
11-May	1,717	77,546	1,031	17	1.65	207	7	0	6	1,230	24	0	1	11
12-May	11,345	88,891				130	9	0	3	7,700	21	0	0	0
13-May	2,419	91,310				333	8	0	7	6,085	45	0	0	0
14-May	2,025	93,335				257	10	0	7	5,185	36	0	0	21
15-May	61,630	154,965				370	5	0	4	5,700	11	0	0	0
16-May	32,693	187,658				100	0	0	2	6,450	9	0	0	0
17-May	3,559	191,217				435	29	0	16	5,387	67	0	0	6
18-May	12,136	203,353	1,053	9	0.85	630	18	0	22	11,182	56	0	0	6
19-May	17,629	220,982				265	4	0	1	7,710	22	0	0	0
20-May	52,318	273,300				190	2	0	4	5,965	15	0	1	3
21-May	3,548	276,848				385	5	0	10	5,888	41	0	1	2
22-May	56,098	332,946				430	3	0	7	5,500	11	0	0	0
23-May	2,020	334,966				555	8	0	8	7,114	23	1	1	0
24-May	1,616	336,582				720	4	0	4	4,809	71	0	0	15
25-May	494	337,076	640	6	0.94	273	17	0	9	317	45	0	3	1
26-May	399	337,475				463	17	0	5	1,486	40	0	0	5
27-May	1,565	339,040				189	17	0	19	3,216	62	0	1	16
28-May	392	339,432				157	14	0	8	735	51	1	2	13
29-May	1,706	341,138				187	4	0	4	544	33	0	2	12
30-May	141	341,279				91	5	0	9	106	18	0	1	0
31-May	102	341,381				431	7	0	11	2,466	50	1	2	5

-Continued-

	Catch		Trap Efficiency Test			Incidental Catch[a]								
Date	Daily	Cum.	Marked	Recovered	Rate %	SoF	coho	chnk	DV	SB	SC	PW	PS	SF
1-Jun	237	341,618				0	0	0	0	0	0	0	0	0
2-Jun	20,877	362,495				120	10	0	8	276	24	0	0	13
3-Jun	4,473	366,968	1,510	22	1.46	255	14	0	16	2,124	37	0	0	22
4-Jun	17,452	384,420				90	7	0	14	2,393	4	0	0	16
5-Jun	1,446	385,866				55	16	11	20	2,154	19	0	0	11
6-Jun	319	386,185				105	11	15	16	2,743	32	0	1	21
7-Jun	251	386,436				160	13	19	15	1,597	31	0	1	5
8-Jun	97	386,533				19	4	17	9	35	11	0	4	3
9-Jun	7,473	394,006				90	7	29	16	105	46	0	4	0
10-Jun	35,174	429,180	1,008	24	2.38	0	0	0	0	0	0	0	0	0
11-Jun	6,217	435,397				164	35	14	21	113	64	0	1	11
12-Jun	3,248	438,645				280	18	18	16	3,485	26	1	0	13
13-Jun	4,189	442,834	1,019	25	2.45	270	21	11	16	2,544	48	0	0	18
14-Jun	477	443,311				236	16	27	13	4,685	33	0	0	0
15-Jun	3,654	446,965				302	22	21	22	2,985	46	0	2	7
16-Jun	288	447,253				303	16	27	13	3,552	29	0	4	3
17-Jun	1,065	448,318	505	16	3.17	296	19	33	15	3,844	36	1	1	9
18-Jun	564	448,882				245	21	60	26	4,475	55	0	1	4
19-Jun	329	449,211				345	12	27	13	7,055	26	0	4	5
20-Jun	236	449,447				186	20	38	13	2,904	50	0	4	0
21-Jun	4,881	454,328	1,020	32	3.14	300	20	57	24	5,287	52	0	4	4
22-Jun	661	454,989				133	16	28	14	1,075	23	0	2	3
23-Jun	254	455,243				107	14	51	10	652	39	0	1	1
24-Jun	227	455,470				115	17	47	14	3,505	30	0	8	0
25-Jun	205	455,675				115	12	49	9	4,341	40	0	1	0
26-Jun	64	455,739				105	7	33	10	2,090	20	0	0	1
27-Jun	133	455,872				125	16	60	14	2,497	27	0	1	0
28-Jun	122	455,994				171	18	79	10	4,150	61	0	1	0
29-Jun	112	456,106				60	10	27	14	3,160	20	0	5	1
30-Jun	91	456,197				97	14	90	1	2,346	28	0	4	0
1-Jul	355	456,552				80	17	20	7	1,800	22	0	3	2
Total	456,552		8,806	167	1.96	15,946	739	888	704	206,120	2,098	6	78	371

[a]SoF=sockeye fry, coho=coho, chnk=chinook, DV=Dolly Varden,SB=Stickleback, SC=Sculpin, PW=Pigmy Whitefish, PS=Pond Smelt, SF=Starry Flounder

Appendix B. Number of sockeye salmon smolt caught by trap, by day, Chignik River, 1 May - 1 July, 1998.

	Small Trap		Large Trap		Combined		Percent Total	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
1-May	363	363	1,616	1,616	1,979	1,979	22	78
2-May	367	730	1,722	3,338	2,089	4,068	21	79
3-May	435	1,165	1,001	4,339	1,436	5,504	43	57
4-May	583	1,748	2,793	7,132	3,376	8,880	21	79
5-May	378	2,126	2,639	9,771	3,017	11,897	14	86
6-May	737	2,863	4,205	13,976	4,942	16,839	18	82
7-May	350	3,213	1,181	15,157	1,531	18,370	30	70
8-May	206	3,419	1,109	16,266	1,315	19,685	19	81
9-May	4,001	7,420	31,184	47,450	35,185	54,870	13	87
10-May	1,990	9,410	18,969	66,419	20,959	75,829	10	90
11-May	309	9,719	1,408	67,827	1,717	77,546	22	78
12-May	1,403	11,122	9,942	77,769	11,345	88,891	14	86
13-May	395	11,517	2,024	79,793	2,419	91,310	20	80
14-May	461	11,978	1,564	81,357	2,025	93,335	29	71
15-May	7,101	19,079	54,529	135,886	61,630	154,965	13	87
16-May	5,924	25,003	26,769	162,655	32,693	187,658	22	78
17-May	404	25,407	3,155	165,810	3,559	191,217	13	87
18-May	1,103	26,510	11,033	176,843	12,136	203,353	10	90
19-May	1,218	27,728	16,411	193,254	17,629	220,982	7	93
20-May	3,604	31,332	48,714	241,968	52,318	273,300	7	93
21-May	306	31,638	3,242	245,210	3,548	276,848	9	91
22-May	5,351	36,989	50,747	295,957	56,098	332,946	11	89
23-May	228	37,217	1,792	297,749	2,020	334,966	13	87
24-May	282	37,499	1,334	299,083	1,616	336,582	21	79
25-May	91	37,590	403	299,486	494	337,076	23	77
26-May	69	37,659	330	299,816	399	337,475	21	79
27-May	150	37,809	1,415	301,231	1,565	339,040	11	89
28-May	100	37,909	292	301,523	392	339,432	34	66
29-May	136	38,045	1,570	303,093	1,706	341,138	9	91
30-May	38	38,083	103	303,196	141	341,279	37	63
31-May	24	38,107	78	303,274	102	341,381	31	69
1-Jun	32	38,139	205	303,479	237	341,618	16	84
2-Jun	2,752	40,891	18,125	321,604	20,877	362,495	15	85
3-Jun	382	41,273	4,091	325,695	4,473	366,968	9	91
4-Jun	1,583	42,856	15,869	341,564	17,452	384,420	10	90
5-Jun	178	43,034	1,268	342,832	1,446	385,866	14	86
6-Jun	36	43,070	283	343,115	319	386,185	13	87
7-Jun	28	43,098	223	343,338	251	386,436	13	87
8-Jun	8	43,106	89	343,427	97	386,533	9	91
9-Jun	464	43,570	7,009	350,436	7,473	394,006	7	93
10-Jun	1,643	45,213	33,531	383,967	35,174	429,180	5	95
11-Jun	784	45,997	5,433	389,400	6,217	435,397	14	86
12-Jun	202	46,199	3,046	392,446	3,248	438,645	7	93
13-Jun	310	46,509	3,879	396,325	4,189	442,834	8	92

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Appendix B. (page 2 of 2)

	Small Trap		Large Trap		Combined		Percent Total	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative	Small	Large
14-Jun	93	46,602	384	396,709	477	443,311	24	76
15-Jun	150	46,752	3,504	400,213	3,654	446,965	4	96
16-Jun	65	46,817	223	400,436	288	447,253	29	71
17-Jun	65	46,882	1,000	401,436	1,065	448,318	7	94
18-Jun	85	46,967	479	401,915	564	448,882	18	82
19-Jun	43	47,010	286	402,201	329	449,211	15	85
20-Jun	20	47,030	216	402,417	236	449,447	9	91
21-Jun	139	47,169	4,742	407,159	4,881	454,328	3	97
22-Jun	33	47,202	628	407,787	661	454,989	5	95
23-Jun	39	47,241	215	408,002	254	455,243	18	82
24-Jun	35	47,276	192	408,194	227	455,470	18	82
25-Jun	17	47,293	188	408,382	205	455,675	9	91
26-Jun	7	47,300	57	408,439	64	455,739	12	88
27-Jun	7	47,307	126	408,565	133	455,872	6	94
28-Jun	13	47,320	109	408,674	122	455,994	12	88
29-Jun	26	47,346	86	408,760	112	456,106	30	70
30-Jun	15	47,361	76	408,836	91	456,197	20	80
1-Jul	5	47,366	350	409,186	355	456,552	1	99
Total	47,366		409,186		456,552		16	84

Appendix C. Length, weight and condition factor for sockeye salmon smolt by freshwater age, trapped in the Chignik River, 1998. (a) indicates standard errors below precision level of measurement (0.1 g).

			Length		Weight		Condition	
Age	Week	N	Mean	S.E.	Mean	S.E.	Mean	S.E.
0	3-May	4	41.5	1.50	0.5	a	0.69	0.04
0	10-May	1	52	0.00	0.8	a	0.57	0.00
0	24-May	2	45.5	0.50	0.7	a	0.74	0.03
0	14-Jun	1	41	0.00	0.6	a	0.87	0.00
0	21-Jun	3	47.7	0.33	0.8	a	0.74	0.02
0	28-Jun	2	47.5	0.50	0.6	a	0.61	0.03
Total		13	45.2	1.06	0.7	a	0.7	0.03
1	1-May	31	74.7	1.47	3.2	0.23	0.73	0.01
1	3-May	122	70.6	0.83	2.7	0.12	0.72	0.00
1	10-May	62	74.1	1.20	3.17	0.19	0.73	0.00
1	17-May	61	70.38	1.18	2.74	0.20	0.74	0.01
1	24-May	70	74.63	1.28	3.37	0.19	0.76	0.01
1	31-May	68	76.37	1.37	3.9	0.31	0.8	0.01
1	7-Jun	58	67.05	0.64	2.42	0.08	0.79	0.01
1	14-Jun	44	71.11	1.51	3.26	0.34	0.83	0.01
1	21-Jun	51	67.59	0.97	2.56	0.12	0.72	0.03
1	28-Jun	41	67.51	0.96	2.48	0.11	0.79	0.02
Total		608	71.48	0.38	2.98	a	0.76	0.00
2	1-May	38	74.2	0.95	3.1	0.13	0.74	0.01
2	3-May	189	72.2	0.35	2.8	a	0.72	0.00
2	10-May	241	72.7	0.32	2.8	a	0.73	0.00
2	17-May	250	70.5	0.24	2.6	a	0.73	0.00
2	24-May	255	72.8	0.35	2.9	a	0.74	0.00
2	31-May	256	74.6	0.42	3.4	a	0.79	0.00
2	7-Jun	202	70.7	0.40	2.6	0.10	0.71	0.02
2	14-Jun	211	73.4	0.56	3.4	0.12	0.83	0.00
2	21-Jun	199	72.1	0.29	3.2	a	0.84	0.01
2	28-Jun	76	72.1	0.39	3.1	a	0.81	0.01
Total		1,917	72.4	0.13	3	a	0.76	0.00
3	3-May	2	89.5	14.50	6	3.00	0.76	0.04
3	10-May	3	83	5.13	4.4	0.83	0.74	0.01
3	24-May	5	72.8	1.56	3	0.21	0.77	0.02
3	31-May	2	107	25.00	12.7	8.30	0.86	0.06
3	7-Jun	2	77.5	0.50	3.7	a	0.81	0.03
3	14-Jun	5	88.2	4.45	6.3	1.18	0.88	0.04
3	21-Jun	1	71	0.00	3	a	0.84	0.00
Total		20	83.6	3.39	5.5	0.99	0.81	0.02

Appendix D. Mean length, weight, and condition factor by age class and date of sockeye salmon smolt captured in the Chignik River, July, 1998.

		Length (mm)			Weight (g)			Condition		
Age	Week	N	Mean	S.E.	N	Mean	S.E.	N	Mean	S.E.
0	9-Jul	1	42	0	1	0.7	0	1	0.94	0
0	13-Jul	1	42	0	1	0.7	0	1	0.94	0
Total		2	42	0	2	0.7	0	2	0.94	0
1	9-Jul	15	72.9	1.78	15	3.6	0.21	15	0.92	0.03
1	13-Jul	35	60.9	0.84	35	2.5	0.14	35	1.1	0.06
1	21-Jul	33	60.2	1	33	2.1	0.1	33	0.92	0.01
1	27-Jul	28	64.4	1.53	28	2.6	0.21	28	0.95	0.02
Total		111	63.2	0.72	111	2.6	0.09	111	0.98	0.02
2	9-Jul	5	74.8	1.59	5	3.5	0.26	5	0.83	0.05
2	13-Jul	3	72	1.15	3	3.3	0.03	3	0.9	0.04
Total		8	73.8	1.15	8	3.4	0.16	8	0.86	0.03

Appendix E. Number of sockeye salmon smolt caught with the small rotary-screw trap in Chignik River in July 1998.

	Catch		Incidental Catch[a]								
Date	Daily	Cum.	SoF	coho	chnk	DV	SB	SC	PW	PS	SF
3-Jul	13	13	0	0	1	0	4	0	0	0	0
4-Jul	48	61	0	0	4	0	130	0	0	0	0
5-Jul	92	153	0	0	0	0	85	0	0	0	0
6-Jul	22	175	0	2	0	0	127	0	0	0	0
7-Jul	81	256	1	0	0	0	80	0	0	1	0
8-Jul	68	324	5	3	0	1	60	0	0	2	0
9-Jul	46	370	5	1	0	0	45	0	0	0	0
10-Jul	87	457	5	1	0	0	37	0	0	0	0
11-Jul	29	486	3	1	2	0	37	0	0	0	0
12-Jul	55	541	3	0	3	1	25	0	0	1	0
13-Jul	22	563	2	0	0	0	25	0	0	0	0
14-Jul	120	683	4	5	5	0	34	0	0	6	0
15-Jul	37	720	1	0	0	0	12	0	0	1	0
16-Jul	14	734	2	0	0	0	15	0	0	0	0
17-Jul	38	772	2	2	1	1	15	0	0	3	0
18-Jul	41	813	1	2	1	1	11	0	0	0	0
19-Jul	3	816	0	5	0	0	3	0	0	0	0
20-Jul	1	817	0	3	0	1	12	0	0	0	0
21-Jul	24	841	0	4	2	0	50	0	0	4	0
22-Jul	9	850	0	1	1	0	12	0	0	1	0
23-Jul	17	867	0	4	0	1	10	0	0	0	0
24-Jul	7	874	0	5	1	1	12	0	0	0	0
25-Jul	21	895	0	5	1	0	12	0	0	2	0
26-Jul	12	907	2	2	1	0	17	0	0	1	0
27-Jul	36	943	0	3	0	0	15	0	0	1	0
28-Jul	58	1001	0	4	0	0	11	0	0	2	0
29-Jul	36	1037	0	1	0	0	17	0	0	2	0
30-Jul	22	1059	0	1	2	0	15	0	0	4	0
31-Jul	7	1066	0	2	5	0	4	0	0	1	0
Total	1,066		36	57	30	7	932	0	0	32	0

[a] SoF=sockeye fry, coho=coho, chnk=chinook, DV=Dolly Varden,SB=Stickleback, SC=Sculpin, PW=Pigmy Whitefish, PS=Pond Smelt, SF=Starry Flounder

Appendix F. Daily climatological observations at the screw-traps location in the Chignik River, 1998.

Date	Time	Air (^oC)	Water (^oC)	Cloud* Cover %	Wind* Dir	Vel.* (Mph)	Stream Gauge (cm)	Trap Revolutions (rpm) Large	Trap Revolutions (rpm) Small	Comments
1-May	1300	7	5	80	NW	5	25	4.75	5	Traps started fishing at 1300 hrs.
2-May	1200	6.5	5	50	NW	5	25	4.5	5	Scattered. 2500 broken
3-May	1210	5	5	40	NW	5-10	26	4.5	5	1500 broken; light rain.
4-May	1215	4	4	100	SE	10-15	26	4.75	5	3-500 solid; rain.
5-May	1205	7	5	50	SE	0-5	26	5	5.25	1500 broken.
6-May	1215	5	4.5	80	NW	10-15	27	5	5.25	700 broken; rain.
7-May	1205	9	5	70	NW	5	27	5	5.25	1500 broken.
8-May	1210	7	5	80	NW	5-10	27	5	5.25	2000 broken.
9-May	1210	9	5	90	NW	5	27.5	5.25	5.75	1200 solid.
10-May	1205	7	5	50	NW	10	28	5.5	5.75	2000 broken.
11-May	1205	6	5	100	SE	0-5	28	5.25	5.25	2000 solid.
12-May	1205	7	5	100	NW	10	28	5.5	5.25	800 solid.
13-May	1200	7.5	5.5	100	NW	5	27	5.25	5.5	1600 solid.
14-May	1200	8	5	100	NW	5	26	5	5.25	1200 solid.
15-May	1215	6	5	100	NW	15	26	5	5.25	600 solid.
16-May	1215	7	5	60	NW	5-10	27	5	5.5	2000 broken.
17-May	1205	10.5	6	70	SE	15	28	5	5.5	1500 broken.
18-May	1210	6	5	100	NW	10	29.5	5.5	6	1200 solid.
19-May	1300	8	5.5	70	NW	5	30	5.75	6.25	1500 broken.
20-May	1220	9.5	5.5	10	NW	5-10	29.5	5.75	6.25	2000 broken.
21-May	1205	9.5	6	10	variable	10	29	5.5	6	Clear and visibility unlimited (CAVU)
22-May	1250	6	5.5	95	NW	20-25	29	5.5	6	800 broken.
23-May	1205	5.5	5	30	NW	25-30	28	5.5	6	1500 broken.
24-May	1210	10	6.5	40	SE	5	27.25	5	5.25	3000 broken.
25-May	1200	10	6	50	SE	10	27	5	6	1000 broken.
26-May	1215	13	7.5	90	SE	15	26.5	5	5.25	1500 broken.
27-May	1215	8.5	6	75	NW	5	29	5.5	6	2500 broken.
28-May	1215	8	5.5	90	SE	10	31	6	6.5	2500 broken.
29-May	1205	8.5	6.5	100	SE	5-10	31	6.25	6.75	1000 solid.
30-May	1230	8	6.5	100	NW	5	33	6.5	7	800 solid.
31-May	1200	9	7	10	NW	15	34	6.75	7.25	CAVU

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Appendix F. (page 2 of 3)

Date	Time	Air (°C)	Water (°C)	Cloud* Cover %	Wind* Dir	Vel.* (Mph)	Stream Gauge (cm)	Trap Revolutions (rpm) Large	Small	Comments
1-Jun	1205	7.5	6.5	50	NW	15	35	7.25	8	300 broken.
2-Jun	1215	10	7	30	SE	5-10	36	7	7.5	CAVU
3-Jun	1200	8	7	100	SE	5-10	36	7.25	7.75	1800 solid.
4-Jun	1215	9.5	7	100	SE	20	37	7.25	8	500 solid.
5-Jun	1205	9	7	90	SE	0-5	39	7.75	8.5	2500 broken.
6-Jun	1215	9	7	60	SE	10-15	39	8.25	9	2000 broken.
7-Jun	1200	9	7	90	SE	25-30	>>	8.25	9.25	1000 broken (barely). Water depth above gauge.
8-Jun	1230	8	7	100	NW	10	>>	9	10.75	1500 solid. Water depth above gauge.
9-Jun	1215	8.5	7	70	NW	10-15	>>	10.25	11	3000 broken. Water depth above gauge.
10-Jun	1230	6	7	100	SE	5	>>	10	11	500 solid. Water depth above gauge.
11-Jun	1230	9	7	70	NW	10-15	>>	9.75	10.75	2500 broken. Water depth above gauge.
12-Jun	1200	10	8	40	NW	10	>>	9.25	9.5	3500 broken. Water depth above gauge.
13-Jun	1200	7.5	7	100	SE	5-10	>>	9.25	10.25	1000 solid. Water depth above gauge.
14-Jun	1200	8.5	7.5	90	NW	5	58	9	10	2000 broken.
15-Jun	1200	8.5	7.5	90	SE	5	55	8.5	9.75	2000 broken.
16-Jun	1200	10	8.5	0	NW	10	51	8.5	9.5	CAVU
17-Jun	1200	10	9	0.0	SE	10	51	8.25	9.5	CAVU
18-Jun	1215	7.5	8.5	100	SE	10	47	8.25	9.5	200 solid.
19-Jun	1205	7	8	80	NW	15-20	47	8.25	9.75	2000 broken.
20-Jun	1215	8	8	60	NW	5	47	8.25	9.75	2000 broken.
21-Jun	1230	7.5	8.5	70	calm	-	47	8	9.25	3000 broken.
22-Jun	1200	8.5	8	100.0	SE	10	46	8	9.25	200 solid.
23-Jun	1210	7.5	8.5	60	NW	25-30	46	8.25	9.75	1000 broken.
24-Jun	1230	10	9.5	20	NW	10	48	8.25	8.75	3500 broken. Water depth above gauge.
25-Jun	1215	10.5	10	100	NW	5-10	46	8.25	9.5	500 solid.
26-Jun	1205	10	9.5	100	NW	5	48	8.5	9.5	2500 solid.
27-Jun	1210	10	10	100	NW	5-10	48	8	9.25	400 solid.
28-Jun	1200	11	10	20	NW	10	47	8	9.25	CAVU
29-Jun	1150	11	10	90	SE	0-5	45	8.25	9	Slightly broken.
30-Jun	1150	13	10	40	SE	0-5	45	8	-	3000 broken.
1-Jul	1200	12.5	10	40	SE	10	44	-	-	2500 broken.
2-Jul	900	12	10	100	SE	25	-	-	-	200 solid. Large trap out for the season.

-Continued-

Appendix F. (page 3 of 3)

Date	Time	Air (°C)	Water (°C)	Cloud* Cover %	Wind* Dir	Vel.* (Mph)	Stream Gauge (cm)	Trap Revolutions (rpm) Large	Small	Comments
3-Jul	-	-	-	-	-	-	-	-	-	Small trap moved to adult weir site.
4-Jul	1200	-	-	100	-	-	-	-	-	Light drizzle.
5-Jul	1235	-	-	100	NW	15	-	-	-	Light drizzle.
6-Jul	1230	13.5	11.5	90	-	-	-	-	-	
7-Jul	1345	15	12	100	-	-	-	-	-	
8-Jul	1215	15	12.5	90	-	-	-	-	-	
9-Jul	1235	15	-	100	SW	10	-	-	-	Occasional drizzle.
10-Jul	1252	15	12	85	-	-	-	-	-	
11-Jul	1220	15	12	50	NW	20	-	-	-	
12-Jul	1205	-	-	7	nw	25	-	-	-	
13-Jul	1152	-	-	0	calm	-	-	-	-	CAVU
14-Jul	1150	-	-	90	-	5	-	-	6.75	
15-Jul	1200	-	-	85	SW	15	-	-	6.75	
16-Jul	1205	-	-	90	-	10	-	-	6.5	
17-Jul	1200	-	-	60	SW	5-10	-	-	7	
18-Jul	1220	-	-	100	NE	5-10	-	-	6.5	Light rain.
19-Jul	1220	-	-	100	NE	25-30	-	-	6.5	Rain.
20-Jul	1215	-	-	100	NE	15-25	-	-	6	Drizzle. Fog.
21-Jul	1220	-	-	100	NE	5	-	-	6.5	
22-Jul	1220	-	-	100	SW	5-10	-	-	6.75	Drizzle.
23-Jul	1225	-	-	100	calm	-	-	-	6.5	
24-Jul	1210	-	-	100	NE	5	-	-	7	
25-Jul	1210	-	-	90	calm	-	-	-	6	
26-Jul	1225	-	-	60	variable	5	-	-		
27-Jul	1330	-	-	80	calm	-	-	-	6.5	
28-Jul	1340	-	-	80	calm	-	-	-	6	
29-Jul	1220	-	-	100	NE	10-15	-	-	5.5	Drizzle.
30-Jul	1210	-	-	50	NE	20	-	-	6	
31-Jul	1200	-	-	10	NE	25	-	-	6	

* Based on observer estimates.