Exxon Valdez Oil Spill
Restoration Project Final Report

Akalura Lake Sockeye Salmon Restoration

Restoration Project 97251
Final Report

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October 1999

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Study History: Restoration Project 97251 continues the efforts initiated in 1990 with Fish/Shellfish Study Number 27, which concluded in 1996. The study coupled parallel investigations on Kenai/Skilak Lakes in Cook Inlet with Red and Akalura Lakes on Kodiak Island. A final report on F/S No.27 was published by D.C. Schmidt and K.E. Tarbox within the Fisheries Rehabilitation, Enhancement and Development Report series (No.136) entitled Sockeye Salmon Overescapement. Subsequent studies focused on restoration efforts essentially continuing field data collection and population monitoring with an interim ADF&G Regional Information Report (No. 5J95-15) published by Schmidt, D.C. et al. 1995. Studies conducted on Kodiak Island lakes have been included in these reports, however reports solely on Kodiak's data collection and limited data analyses have also been prepared: Barrett et al. 1993a, 1993b; Swanton et al. 1995 and 1996; Swanton et al. (*In review*). The following final report includes data, analyses, and conclusions relative only to Akalura Lake investigations.

Abstract: This report documents the final year of sockeye salmon (*Oncorhynchus nerka*) smolt investigations at Akalura Lake on Kodiak Island. Smolt production from Akalura Lake continues to appear depressed relative to pre-oil spill conditions with a total outmigration estimate of 193,750 fish during 1997. The 1997 season marks the fifth consecutive year in which adult sockeye escapement was below the minimum escapement goal of 40,000 fish. However, the increasing trend in smolt per adult productivity in recent years as well as smolt size and age composition suggests that rearing conditions have improved. Furthermore, the 1998 forecasts based on smolt outmigrations indicate a fairly robust run. Finally, this report summarizes evaluations of mark-recapture population estimation methods completed during 1996 and 1997, including consideration of delayed dye mortality effects.

Key Words: Akalura Lake, escapement, Kodiak Island, mark-recapture population estimation, *Oncorhynchus nerka*, smolt production, sockeye salmon.

Project Data: The data collected in this and previous years' investigations include: sockeye smolt mark-recapture data, sockeye smolt age, weight, and length data, scale samples, climate data, weir counts of adult and smolt passage, and escapement age composition. All data currently resides in computerized data files (Excel and R:BASE) and in slide collections maintained by the Alaska Department of Fish and Game, Kodiak, AK. Contact Nick Sagalkin or Patti Nelson @ Alaska Department of Fish and Game, Division of Commercial Fisheries, 211 Mission Road, Kodiak, AK 99615, 907-486-1848.

Citation:

Coggins, L.G., Jr., and N.H. Sagalkin. 1998. Akalura Lake sockeye salmon restoration, *Exxon Valdez* Oil Spill Restoration Final Report (Restoration Project 97251), Alaska Department of Fish and Game, Division of Commercial Fisheries, Kodiak, Alaska.

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EXECUTIVE SUMMARY

Sockeye salmon smolt studies funded by the Exxon Valdez Oil Spill (EVOS) Trustee Council began in 1990 and continued through 1996 to evaluate the effects of sockeye salmon overescapements in Red and Akalura Lakes (Barrett et al. 1993a, 1993b; Swanton et al. 1995 and 1996). This report documents an additional year of study in 1997 authorized by the EVOS Trustee Council to further evaluate the recovery of sockeye salmon smolt production from Akalura Lake.

Based on the numbers of sockeye smolt counted leaving Akalura during 1997 (193,750 fish) relative to pre-oil spill production, it appears that the recovery of Akalura Lake from the overescapement event is not yet complete. Additionally, 1997 marks the fifth consecutive year that the lower bound escapement goal was not reached for adult sockeye returning to Akalura Lake. However, the health of the lake environment appears to be improving considering the increasing trend in smolt per adult productivity in recent years as well as the size of smolt and the lower proportion of older age smolt counted during 1997. Furthermore, based on smolt numbers observed during 1996, the 1998 run is forecast to be relatively strong.

During 1996 and 1997, evaluations of mark-recapture methods of smolt population estimation were conducted at Akalura Lake using concurrent total weir counts and mark-recapture estimation trials. Although these investigations have increased our understanding of estimating smolt, they have also highlighted biases with our trap-efficiency estimation methods that require further study. Finally, in combination with a new smolt estimator detailed by Carlson et al. *(In review)*, the effects of delayed dye marking mortality are evaluated.

INTRODUCTION

In 1989, crude oil spilled from the M/V *Exxon Valdez* contaminated many of the traditional salmon fishing grounds within the Kodiak Management Area (KMA; Barrett and Monkiewicz 1989). This contamination resulted in the closure or severe restriction of salmon fisheries area-wide, and sockeye salmon escapement goals were consequently exceeded (overescapement) in several systems including Afognak, Akalura, Frazer, and Red Lakes.

The 1989 Akalura escapement was 116,000 compared to the 40,000 to 60,000 goal (Barrett et al. 1993a). Sockeye salmon production has been demonstrated to be linked to lake fertility (Koenings and Burkett 1987) and the excessive Akalura escapement in 1989 likely caused a decline in freshwater productivity (Edmundson et al. 1994, Schmidt et al. 1993). Previous studies have documented that excessive escapements may lead to changes in zooplankton species composition and biomass by overloading the lake with too many juvenile sockeye salmon fry. These changes can reduce overwinter sockeye salmon fry survival, extend freshwater rearing for additional years, and affect multiple brood years (Kyle et al. 1988).

Swanton et al. (1996) documented a steady decrease in the number of outmigrating smolts at Akalura between 1990 and 1993. Smolt outmigrating population size increased in 1994 and 1995 compared to the 1993, however they remained well below levels observed in 1990 and 1991. Coincident with the decrease in smolt abundance, Barrett et al. (1993b) found that smolt size in Akalura Lake had also declined. Furthermore, they documented a shift toward older age classes and poor growth of outmigrating smolt. In a follow-up study conducted in 1994-1995, smolt production continued to lag behind pre-oil spill averages; however, the shift to older age classes observed between 1990 and 1993 was less prevalent (Swanton et al. 1996).

An additional year of study was conducted at Akalura Lake during 1997 in response to poor escapements of 2,010 and 7,898 fish during 1995 and 1996, respectively. Prior to the 1997 study beginning, it was determined that a smolt outmigration of less than 200,000 fish along with failure to meet the lower bound of the biological escapement goal of 40,000 again during 1997 would constitute continued injury to this system and trigger a rehabilitation effort.

It was recognized prior to the 1996 study that due to the small size of Akalura Creek and the typical number of outmigrant smolt, it would be possible to conduct a complete census of the smolt outmigration via a weir. Additionally, mark-recapture estimates could be made concurrently with the census in order to evaluate mark-recapture methods. Therefore, beginning in 1996 and continuing through 1997, a nearly complete census count of outmigrating smolt was conducted, and mark-recapture estimates were compared to census counts.

Juvenile sockeye are most vulnerable to predation during smolt migrations from the lake to sea (Groot and Margolis 1991). Potential impact by bird and fish predators on juvenile salmon in Alaskan systems inspired early efforts of predator control (Meacham and Clark 1979; Petry 1942). Predator control programs were discontinued when their value was questioned (DeLacy and Morton 1943). However, the reduced abundance of the smolt population at Akalura may make them more sensitive to predation effects. The primary fish predator on outmigrating smolts at Akalura is the Dolly Varden (*Salvelinus malma*). Therefore, abundance and length of Dolly Varden was also estimated.

This report documents the results of the 1997 study along with the mark-recapture evaluation completed in 1996.

Objectives

1. Estimate the abundance-at-age of sockeye smolt emigrating from Akalura Lake during 1997.

2. Estimate the age, weight, and length of sockeye smolt emigrating from Akalura Lake during 1997.

3. Estimate smolt outmigration with standard mark-recapture methods while concurrently conducting a smolt outmigration census via a weir during 1996 and 1997.

4. Enumerate the abundance and estimate the mean length of downstream migrant Dolly Varden (*Salvelinus malma*) greater than 250mm in length via the weir for as long as practicable during 1997.

METHODS

Smolt Trap and Weir Descriptions

During 1997, a single Canadian fan trap was operated from 30 April through 12 June approximately 5.6 km downstream of the Akalura Lake outlet (Figure 1). The trap was equipped with a flow through livebox measuring 1.5 m long, 1 m wide, and 0.8 m high. Perforated-plate leads were attached to the trap opening extending 1.3 m towards the left stream bank and 1.9 m to the right bank (Figure 2). The lead to the right bank was attached to the stream bank and prohibited smolt passage on this side of the trap. The leads and trap opening spanned approximately 30% of the stream width. Additionally, a second trap (referred to as the weir) was installed and fitted with leads spanning the remaining portion of the stream. Collectively, the weir and trap captured 100% of outmigrant smolt. References made to weir catches throughout the remainder of this document are the sum of the weir and trap catches, or the total smolt outmigration. Due to the near completion of the smolt outmigration by June 12, the trap was removed and the right bank lead of the weir extended fully to the right bank. This weir configuration continued to enumerate smolt until June 25.

The 1997 trap/weir configuration was modified slightly from the 1996 configuration because it was suspected that the right bank weir lead may have been influencing trap efficiency excessively during 1996 (Figure 2).

Smolt Enumeration

Smolt enumeration was completed by individual species counts as fish were removed from the liveboxes; an exception was when smolt capture rates exceeded the crew's ability (> 10,000 fish per hour) to hand tally fish and a catch-weight method was instituted. The catch-weight method was conducted by transferring the catch by dip net to a small mesh basket attached to a spring scale suspended over the stream by an A-frame support; each dip net load was individually weighed, with fish immediately released into the stream downstream of the traps. Approximately every tenth dip net load was sampled to determine species count by weight. This entailed counting by species a dipnet load of fish into a water filled container, transferring the catch to a netted basket suspended from a scale for weighing, and then releasing the fish downstream of the trap site. All catch-weights were recorded to the nearest 0.1 kg. Species identification was made by visual examination of external characteristics (McConnell and Snyder 1972; Trautman 1973).

All catch data were recorded by sampling day which extended from noon to noon and was identified by the calendar day of the noon to midnight period.

Age, Weight, and Length Sampling

Up to 70 sockeye salmon smolt were sampled daily for age, weight, and length (AWL), five days a week (dependent upon smolt availability). To minimize bias, all fish in the live-box were stirred immediately before being removed for sampling. Each sampled fish was anesthetized with MS-222 and a scale smear from the preferred area (INPFC 1963) was removed and mounted on a standard microscope slide for ageing. Smolt weight was recorded to the nearest 0.1 g using a digital balance and tip-of-snout to fork-of-tail length (TL) was recorded to the nearest 1.0 mm. After sampling, all smolt were revived and released downstream of each trap site. Scale ageing was conducted using a microfiche reader equipped with a 42X lens. All ages were recorded in European notation (Koo 1962).

Weekly up to 100 Dolly Varden greater than 250 mm in total length were sampled for length data. The 250 mm length restriction was subjectively determined to be the minimum size of effective sockeye smolt predators. Fish were captured either incidentally in smolt traps or by hook and line.

Mark-Recapture Experiments

Trap efficiency was estimated at least weekly dependent upon smolt availability. The procedure (referred to as a dye test) involved releasing up to 500 dyed smolt about 1 km upstream of the trap location in a low velocity water flow area (<0.5 m/sec). The dye tests were scheduled so that the release time was approximately 2200 hrs. Smolts used for dye tests were collected from the trap within three days and often within one day of each test. An instream covered flow through live box with perforated sides was used to hold the smolts prior to upstream transport. Transport was performed using backpacks and 19 L plastic buckets equipped with battery-powered aerators. At the release sites, smolts were placed into instream live boxes and held for about 30 minutes before transfer into a continuously-oxygenated dye solution of 1.9 g Bismark Brown Y dye to 57 L of water for another 30 minutes. After dyeing, the smolt were held for about 60 minutes in an instream perforated live box with lid, and then placed in water filled 19 L buckets for release across the stream channel. At each step in the process, the smolt were counted, and those that behaved abnormally were destroyed. Following the release of dyed fish, the liveboxes were checked for three or more days for recoveries. All recaptures were recorded separately from the unmarked fish catch and were not included in the daily trap or weir catch totals.

Delayed Mortality Estimation

Experiments conducted at both Red and Akalura Lakes demonstrated a significant difference in mortality rates between dyed and un-dyed smolt (Swanton et al. 1996; Swanton et al. *In review*). In order to adjust for this potential bias in mark-recapture estimates of the smolt outmigration, delayed mortality of dyed fish was estimated concurrent with each dye test (Carlson et al. *In review*; Thedinga et al. 1994). To accomplish this, an additional 100 smolt were dyed along with the smolt to be released. Smolt used for the mortality experiment were handled identically to those released, except never released. The smolt were held in a covered instream flow through live box and checked daily for 5 days; mortalities were recorded and removed from the live box.

Climate Observations

Air and stream temperatures (°C), stream height (cm), percent cloud cover, wind velocity, and wind direction were recorded at approximately 1800 hr. or 0800 hr.

DATA ANALYSIS

SMOLT POPULATION ESTIMATION

The following variables are defined in the development of the smolt population estimator (Carlson et al. *In review*):

- 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 ($= \Sigma U_h$).
- 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 ($=\Sigma U_{jh}$).

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

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

The 95% confidence intervals were estimated two separate ways each detailed in Carlson et al. (*In review*). The first was to use the standard formula

$$\hat{U} \pm 1.96\sqrt{v(\hat{U})}. \tag{5}$$

which assumes that $\hat{U}$ is asymptotically normally distributed. The second was to use a parametric bootstrap procedure assuming the hypergeometric distribution.

To adjust the strata abundance estimates for delayed mortality, an estimate of mark-survival is first calculated as:

$$\hat{S}_h = {a_h}/{A_h}, \tag{6}$$

where $\hat{S}_h$ is the estimated mark survival, a_h is the remaining number of live fish with marks, and A_h is the initial number of marked smolt held. The estimated number of marked smolt available for recapture in stratum h is

$$\hat{M}_h = M_h \hat{S}_h, \tag{7}$$

Finally, substituting $\hat{M}_h$ in place of M_h in equations 1-5 provides population estimates adjusted for delayed mortality.

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

$$\hat{\theta}_{jh} = \frac{A_{jh}}{A_h}, \tag{8}$$

with estimated variance

$$v(\hat{\theta}_{jh}) = \frac{\hat{\theta}_{jh}(1-\hat{\theta}_{jh})}{A_h}. \tag{9}$$

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

$$\hat{U}_{jh} = \hat{U}_h \hat{\theta}_{jh}, \tag{10}$$

with estimated variance ignoring the covariance term

$$v(\hat{U}_{jh}) = \hat{U}_h^2 v(\hat{\theta}_{jh}) + v(\hat{U}_h)\hat{\theta}_{jh}^2. \tag{11}$$

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

$$\hat{U}_j = \sum_{h=1}^{L} \hat{U}_{jh}, \tag{12}$$

with estimated variance

$$v(\hat{U}_j) = \sum_{h=1}^{L} v(\hat{U}_{jh}). \tag{13}$$

Condition factor for each smolt sampled was estimated using:

$$\hat{K} = \frac{W}{L^3} 10^5, \tag{14}$$

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

RESULTS

Smolt and Dolly Varden Outmigrations

A total of 193,750 sockeye salmon smolt were counted through the weir during 1997; the majority of which were age-2. fish (92%) from the 1994 brood year (Tables 1-2; Figure 3; Appendices A.1 and A.2). Most smolt outmigrated during the time period 3 - 30 May with peak age-2. outmigration occurring during the week beginning 10 May, and peak age-1. outmigration during the week beginning 24 May (Figure 4).

During 1997, average sockeye smolt length varied from 58 mm (age-0.) to 92 mm (age-3.) with corresponding weights of 1.7 g and 6.3 g for age-0. and age-3. fish, respectively (Table 3). The average size of age-1. smolt emigrating from the 1993-1995 brood years (82 mm and 4.8 g) was approximately 7 mm longer and 1 g heavier than the average size of age-1 smolts from the 1988-92 brood years (75 mm and 3.8 g; Figure 5). Similarly, the average size of age-2. smolts from the 1992-94 brood years (92 mm and 6.4 g) was over 7 mm longer and 1 g heavier than the average size of age-2. smolt from the 1987-91 brood years (84 mm and 5.2 g).

A total of 14,093 Dolly Varden greater than 250 mm were counted through the weir from 30 April through 31 May 1997 when adult weir operations precluded the continued enumeration of Dolly Varden (Figure 6). Interestingly, the outmigration pattern of Dolly Varden is similar to the smolt outmigration, though approximately 5-7 days earlier. The average length of outmigrating Dolly Varden was 345 mm (95% CI 201 mm - 489 mm) from a sample size of 427 fish. Dolly Varden were observed regurgitating smolt during sampling as well as actively feeding on smolt both above and below the weir.

Examination of the ratios of smolt produced from brood year escapement (smolts/adult) indicates a substantial drop in lake productivity associated with the 1989 overescapement event relative to the 1988 brood year (Table 2). This low productivity ratio strongly suggests damage from the overescapement event that has persisted through the 1992 brood year. However, the increasing smolt per adult productivity evident from the 1993 - 1995 brood years imply that this system is recovering.

Smolt Trap Evaluation

The overall estimated smolt outmigration differed from the true outmigration by 71,195 (relative error 35%) in 1996 and 13,389 (unadjusted for dye mortality; relative error 7%) or 7,990 (adjusted for dye mortality; relative error 4%) in 1997 (Table 4). In 1996, trap efficiency was under-estimated in all time strata except the first resulting in over-estimates of smolt outmigration in strata 2-6, and an under-estimate of smolt outmigration in stratum 1 (Table 4; Figure 7). During 1997, trap efficiency estimates were generally less biased than in 1996 with substantial differences occurring in only the third and fifth strata. In turn both unadjusted and adjusted smolt outmigration estimates were not significantly different from true outmigration (within the confidence bounds) for strata 1, 2, 4, and overall. Because delayed dye mortality estimates were minor, ranging from 0% to 6%, adjusted and unadjusted smolt outmigration estimates differed little.

With the exception of the first stratum in 1996, smolt outmigration estimates tend to be positively biased due to negatively biased estimates of trap efficiency. This was particularly true during 1996 in strata 2-6, but also evident in 1997 for strata 3 and 5.

Climate Observations

Climate data collected during 1997 are reported in Appendix A.3.

DISCUSSION

Overescapement Impacts

Overall, smolt production at Akalura Lake continues to appear depressed relative to pre-oil spill levels (brood years 1987-88). The 1997 smolt outmigration was 22% less than observed in 1996 (245,821 smolt) and a 12% decrease from the 1990-96 average (220,357 smolt). There are many causal mechanisms that could explain this response including continued damage to primary and secondary production within the lake, competition with stickleback (*Gasterosteus aculeatus*) within the lake, a large predator population (Dolly Varden), or low brood year escapements. The excessive 1989 escapement did not appear to initially impact the macrozooplankton community; based on size and composition of lake zooplankters in 1990 (Edmundson et al. 1994). However, subsequent zooplankton biomass decreased by 50% in 1991 and continued to be depressed in 1992. Decreases in zooplankton biomass coincided with a shift in the age composition of outmigrating smolts (Barrett et al. 1993b). Changes in smolt age composition have also been linked to poor growth of age-2. and age-3. smolt, further suggesting lack of food (Barrett et al. 1993b).

A total of 14,093 Dolly Varden > 250 mm were counted outmigrating from Akalura Lake during 1997. Prior to statehood, the U. S. Fish and Wildlife Service (FWS) periodically captured and destroyed Dolly Varden at many salmon producing systems on Kodiak Island (Hungerford 1931, 1934; Turner 1936; Culbertson 1938; Ferrandini 1939; Petry 1942). These efforts reported annual catches of Dolly Varden from Akalura Lake ranging between 6,387 and 34,734. Based on this historic data, the numbers of Dolly Varden observed during 1997 do not appear excessively large. However, this observation is confounded by the fact that the catches reported in FWS reports were possibly due to fishing efforts over the entire season and composed of fish of all lengths.

Signs of Recovery

Continued assessments of secondary production in 1994 and 1995 suggest that the zooplankton community in Akalura Lake recovered sufficiently to recommend targeting the upper bound escapement goal of 60,000 (Edmundson et al. 1994). Edmundson et al. (1994) also suggested that competition among sockeye and stickleback could potentially limit sockeye production; however the effects of this competition would likely be apparent only when zooplankton biomass is depressed. The increased ratio of smolt/adult production from the 1993-1995 brood years and the large smolt size and low proportion of age-3. smolts observed during the 1996-1998 outmigrations, support this recommendation and suggest that freshwater productivity is continuing to improve.

Smolt Estimation

This project led to the development of a refined smolt estimator along with the dye mortality adjustment proposed by Carlson et al. (*In review*). Comparisons of smolt estimates with weir counts and mark detectability experiments have given area staff insight into smolt outmigration estimates. However, as is apparent in the 1996 evaluation presented in this paper, all sources of estimation bias have not been removed. For example, during 1996 the true smolt population within each strata, as measured by the weir, fell outside the 95% confidence interval of the estimate generated by the trap efficiency, mark-recapture technique. Several sources of error may have affected trap efficiencies observed in 1996 and to some degree in 1997. Trap efficiencies are estimated by recapturing marked fish collected at the smolt trap. Thus, if there are differences in vulnerability between the outmigrating population and the trapped population, the true trap efficiency will not be estimated. This could occur if, for example, a particular age class is more capable of avoiding the trap than other age classes (e.g., King et al. 1994). Predation of marked fish by Dolly Varden or avian predators may violate some of our assumptions about mark-recapture. Furthermore, it is possible that behavior of marked fish is altered thereby affecting trap efficiencies. Smolt may become "trap-shy" (Krebs 1989) or stressed if they are not released as part of the same outmigrating diel population (Alicia Perez personal communication). It is also possible that the magnitude of the outmigrating smolt population affects the bias of the trap efficiency. For example, in 1996 all estimates were positively biased, except during stratum 1 which had the highest smolt population. Similarly, in 1997 the estimator tended to be positively biased during slower outmigration and negatively biased during higher strata. This is likely due to the fact that it is more difficult to observe all marked fish during very high outmigration. In particular, if outmigation numbers get too large, numbers are estimated (to prevent overcrowding) using weights and it becomes more difficult to observe marked fish. Since the estimates during 1997 were much closer to the true values it is also possible that the modification made to the trap in 1996 helped correct most of the bias. However, since the study was limited to two years it is difficult to make any conclusive judgements.

While a detailed run reconstruction program is not in place for Akalura Lake, escapement data and the assumption of an exploitation rate allows the estimation of total run. Assuming that fish returning to Akalura Lake were exploited at a rate of 50% during the last 5 years (1993-1997), the total runs have ranged between approximately 4,000 (1995) and 62,000 (1993). However, even if these estimated runs were allowed to completely escape into Akalura Lake, the lower bound escapement goal would have been exceeded only in 1993.

CONCLUSIONS

Although trapping methods vary, smolt enumeration (mark-recapture) and subsequent smolt population estimation (Carlson estimator) methods presented in this report have been adopted in most of Kodiak's smolt research projects. While there are further refinements necessary (e.g., better trap efficiency testing), comparisons of estimates to true smolt outmigration indicate that estimates are close to the true population.

This study supports previous research on sockeye salmon overescapement, overgrazing and subsequent diminished production (e.g., Kyle et al. 1988). While increased escapements provide increased nutrient loading, there are system limits beyond which excess fish do not necessarily equate to increased production. These results further provide evidence that overescapements affect multiple brood years by altering multiple (juvenile) year classes and suppressing secondary production through overgrazing. Recovery from such interactions requires time in order to rebuild the forage base and reduce the overall population of juvenile salmon rearing in the lake. In consequence, escapement goals, particularly post-overescapement, should be viewed in relation to the forage base (macrozooplankton) of a system.

Trends in the ratio of smolt production to brood year escapement strongly indicate damage to the productivity of Akalura Lake as a result of the 1989 overescapement event. Furthermore, improved smolt production ratios in recent years suggest that this system is in recovery. Now is the time to capitalize on the lake's rearing potential by ensuring adequate escapements. Euphotic volume estimates of Akalura Lake (45.1×10^6 m^3) suggest a potential smolt production from 486,864 to 1,239,700. Using the average (863,282 smolt) and a conservative smolt to adult survival of 10%, allows for production of approximately 80,000 adult sockeye salmon. Edmundson et al. (1994) similarly calculated an estimated production of 100,000 adult sockeye salmon based upon 2,300 adults per euphotic volume. Allowing for a 50% harvest rate will result in an escapement of 40,000-50,000 adults.

Based on a conservative estimate of smolt-to-adult survival (10%; Koenings et al. 1993) and an exploitation rate of 50%, the adult run to Akalura Lake during 1998 should be approximately 30,000 fish of which 15,000 fish will escape to spawn. This level of escapement would be an improvement over escapements observed since 1993 (excluding 1997), but it is still far below the lower bound escapement goal of 40,000.

It is likely that over time sockeye production will rebound to pre-oil spill levels given continued significant escapements. However, the continued monitoring of this system's productivity is essential so that appropriate rehabilitation efforts, changes in fishery management, or both can be evaluated to hasten the recovery of the Akalura sockeye run.

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Table 1. Estimated number of sockeye salmon smolt outmigrating from Akalura Lake by year and age class, 1990-1997.

Smolt Outmigration Year	Number and Relative Percent of Smolt by Age Class					Total Population Estimate	SE	95% CI	
	0.	1.	2.	3.	4.			Lower	Upper
1990	0	60,107	394,652	0	0	454,759	56,896	343,243	566,275
	0.0%	13.2%	86.8%	0.0%	0%		*61,043*	*363,054*	*590,669* [a]
1991	0	8,172	270,867	2,181	0	281,220	23,741	234,688	327,752
	0.0%	2.9%	96.3%	1%	0%		*24,426*	*237,050*	*333,251*
1992	21	2,173	180,557	8,561	0	191,313	11,098	169,560	213,066
	0.0%	1.1%	94.4%	4.5%	0%		*11,067*	*170,497*	*214,448*
1993	0	2,150	57,512	5,624	80	65,366	7,104	51,443	79,289
	0.0%	3.3%	88.0%	8.6%	0%		*7,045*	*52,862*	*79,763*
1994	128	71,495	91,296	8,996	0	171,915	9,569	153,159	190,671
	0.1%	41.6%	53.1%	5.2%	0%		*9,839*	*154,112*	*192,359*
1995	0	60,654	71,187	268	0	132,110	9,339	113,806	150,414
	0.0%	45.9%	53.9%	0.2%	0%		*9,882*	*115,939*	*154,980*
1996	0	15,639	228,766	1,416	0	245,821	[b]		
	0.0%	6.4%	93.1%	0.6%	0%				
1997	196	14,874	178,680	0	0	193,750	[b]		
	0.1%	7.7%	92.2%	0.0%	0.0%				

[a] Italicized standard error and confidence intervals from bootstrapping methods.

[b] The 1996 and 1997 smolt outmigrations were enumerated via a counting weir. Estimates of precision are not available.

Table 2. Adult sockeye salmon escapement and estimated smolt outmigration from Akalura Lake by brood year and age class, 1985-1995.

Brood Year	Escapement	Smolt Numbers by Age and Percent 0.	1.	2.	3.	4.	Total	Smolts/Adult
1985	[d]	[a]	[a]	[a]	[a]	0	[b]	
1986	9,800	[a]	[a]	[a]	0	0	[b]	
1987	6,116	[a]	[a]	394,652	2,181	0	[b]	
1988	38,618	[a]	60,107 17.7%	270,867 79.8%	8,561 2.5%	80 0.0%	339,615 [b]	8.8
1989	116,029	0	8,172 4.2%	180,557 92.9%	5,624 2.9%	0 0.0%	194,354	1.7
1990	47,181	0	2,173 3.2%	57,512 83.7%	8,996 13.1%	0 0.0%	68,681	1.5
1991	44,189	21	2,150 2.3%	91,296 97.4%	268 0.3%	0 0.0%	93,736	2.1
1992	63,269	0	71,495 49.6%	71,187 49.4%	1,416 1.0%	0	144,099 [b]	2.3
1993	30,692	128	60,654	228,766	0	[c]	289,548 [b]	9.4
1994	13,681	0	15,639	178,680	[c]	[c]	194,319 [b]	14.2
1995	2,010	0	14,874	[c]	[c]	[c]	14,874 [b]	7.4
1996	7,898	196	[c]	[c]	[c]	[c]	[b]	
1997	18,140							

[a] Smolt migration not monitored.
[b] Incomplete brood year data.
[c] Smolt of this age class have not outmigrated.
[d] Akalura weir not operated in 1985.

Table 3. Length, weight, and condition factor of Akalura Lake sockeye salmon smolts, 1997.

		Length (mm)			Weight (g)			Condition		
Age	Stat Week	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error	Sample Size	Mean	Standard Error
0	23	6	57.5	2.1	6	1.6	0.2	6	0.8	0.0
0	24	3	61.7	3.4	3	1.9	0.4	3	0.8	0.0
0	25	1	50.0	--	1	1.1	--	1	0.9	--
Total		10	58.0	1.8	10	1.7	0.2	10	0.8	0.0
1	19	1	91.0	--	1	6.3	--	1	0.8	--
1	20	8	85.6	1.8	8	5.0	0.4	8	0.8	0.0
1	21	5	80.2	1.0	4	3.8	0.1	4	0.8	0.0
1	22	78	81.3	0.4	78	4.4	0.1	78	0.8	0.0
1	23	116	82.0	0.5	116	4.7	0.1	116	0.8	0.0
1	24	115	84.3	0.5	115	5.1	0.1	115	0.8	0.0
1	25	38	75.1	1.7	38	3.8	0.3	38	0.9	0.0
Total		361	81.9	0.3	360	4.7	0.1	360	0.8	0.0
2	19	225	93.2	0.3	225	6.5	0.1	225	0.8	0.0
2	20	338	91.1	0.2	338	6.0	0.0	338	0.8	0.0
2	21	201	91.3	0.3	172	6.2	0.1	172	0.8	0.0
2	22	271	92.3	0.3	271	6.5	0.1	271	0.8	0.0
2	23	39	90.4	1.0	39	6.2	0.2	39	0.8	0.0
2	24	19	95.5	0.8	19	7.4	0.2	19	0.9	0.0
2	25	1	87.0	--	1	5.5	--	1	0.8	--
Total		1094	91.9	0.1	1065	6.3	0.0	1065	0.8	0.0

Table 4. Comparison of the true and estimated trap efficiency and smolt outmigration during 1996 and 1997. The 1997 estimates are both unadjusted and adjusted for estimated delayed dye mortality.

		Date		Trap Efficiency		Estimated	Smolt Outmigration			
								95% C.I. [b]		
Year	Stratum	Starting	Ending	Estimated	True [a]	dye mortality	Estimated	Lower	Upper	True [a]
1996	1	5/10	5/15	28.7%	19.5%	[d]	76,815	66,481	87,149	113,864
	2	5/16	5/22	15.3%	32.5%		52,919	42,268	63,569	25,074
	3	5/23	5/28	6.0%	11.4%		59,833	39,350	80,316	32,404
	4	5/29	6/4	13.1%	36.7%		62,068	48,569	75,567	22,497
	5	6/5	6/11	10.5%	29.3%		18,485	13,885	23,085	6,728
	6	6/12	6/17	10.1%	29.8%		2,512	1,730	3,295	870
	Total			14.2%	22.1%		272,632	243,583	301,680	201,437
1997 **(Unadjusted)**	1	4/30	5/11	20.5%	21.9%	4%	63,991	53,782	76,128	60,511
	2	5/12	5/19	20.4%	18.3%	0%	74,161	63,407	88,317	83,265
	3	5/20	5/26	16.6%	23.9%	6%	40,709	33,642	48,616	28,504
	4	5/27	6/2	18.3%	20.0%	0%	19,501	16,392	23,121	17,978
	5	6/3	6/12	6.0%	17.7%	6%	8,092	5,743	11,462	2,806
	Total			16.3%	20.4%		206,453	188,885	225,080	193,064
1997 **(Adjusted)**	1	4/30	5/11	21.4%	21.9%	4%	61,499	51,531	73,143	60,511
	2	5/12	5/19	20.4%	18.3%	0%	74,161	62,926	87,391	83,265
	3	5/20	5/26	17.6%	23.9%	6%	38,283	31,724	47,369	28,504
	4	5/27	6/2	18.3%	20.0%	0%	19,501	16,248	23,409	17,978
	5	6/3	6/12	6.3%	17.7%	6%	7,610	5,488	10,890	2,806
	Total			16.9%	20.4%		201,054	183,361	220,318	193,064

[a] True smolt outmigration is the number of smolt counted through the weir, and true trap efficiency is the quotient of the total strata trap catch and the total strata weir count x 100.

[b] Confidence intervals in 1996 were estimated assuming a normal distribution, and confidence intervals for 1997 data were estimated using boostrap techniques.

[c] Starting and ending dates were established based on mark-recapture trials.

[d] Dye mortality trials to adjust smolt outmigration estimates; estimates were not conducted in 1996.

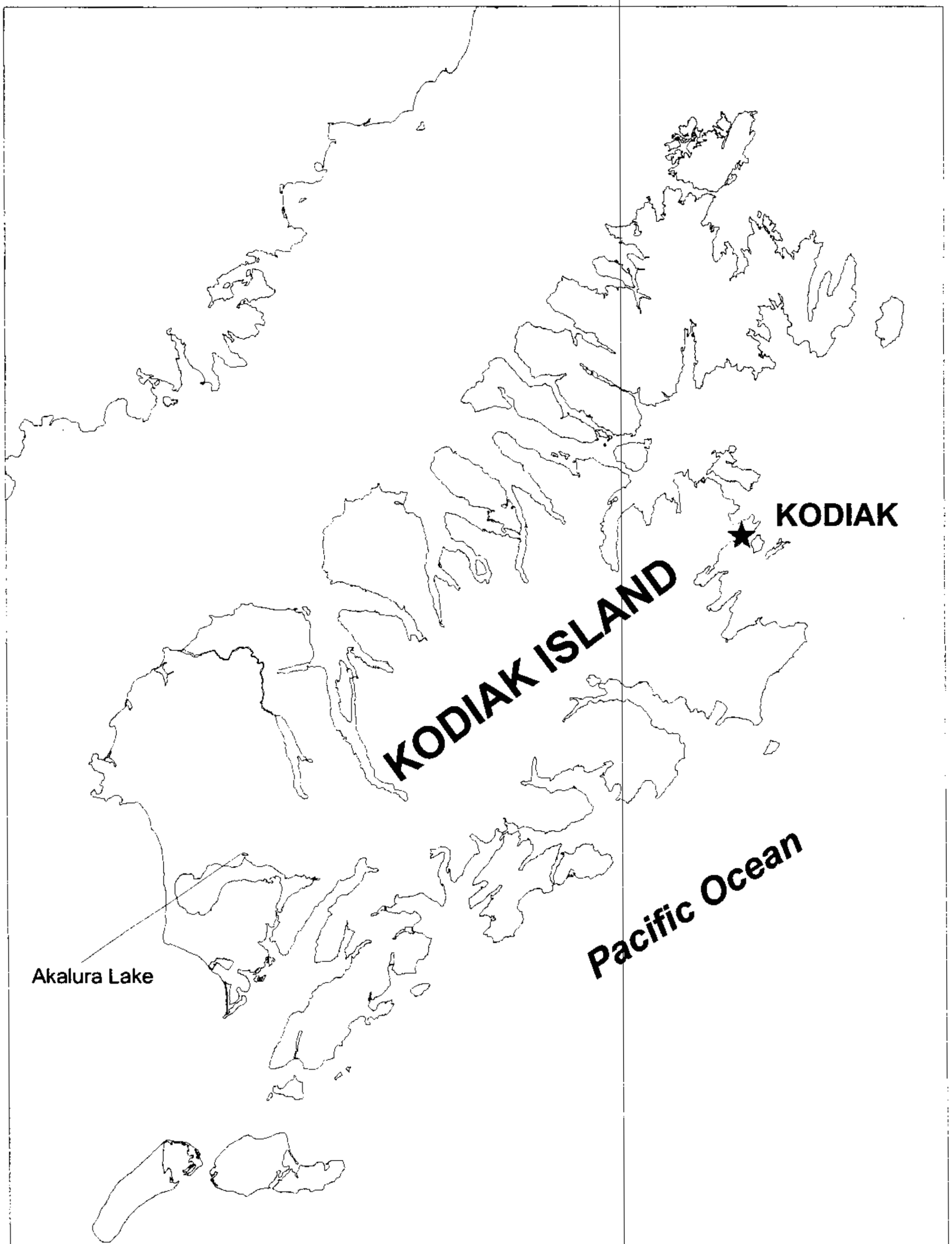

Figure 1. Map depicting location of Akalura Lake, Kodiak Island, Alaska.

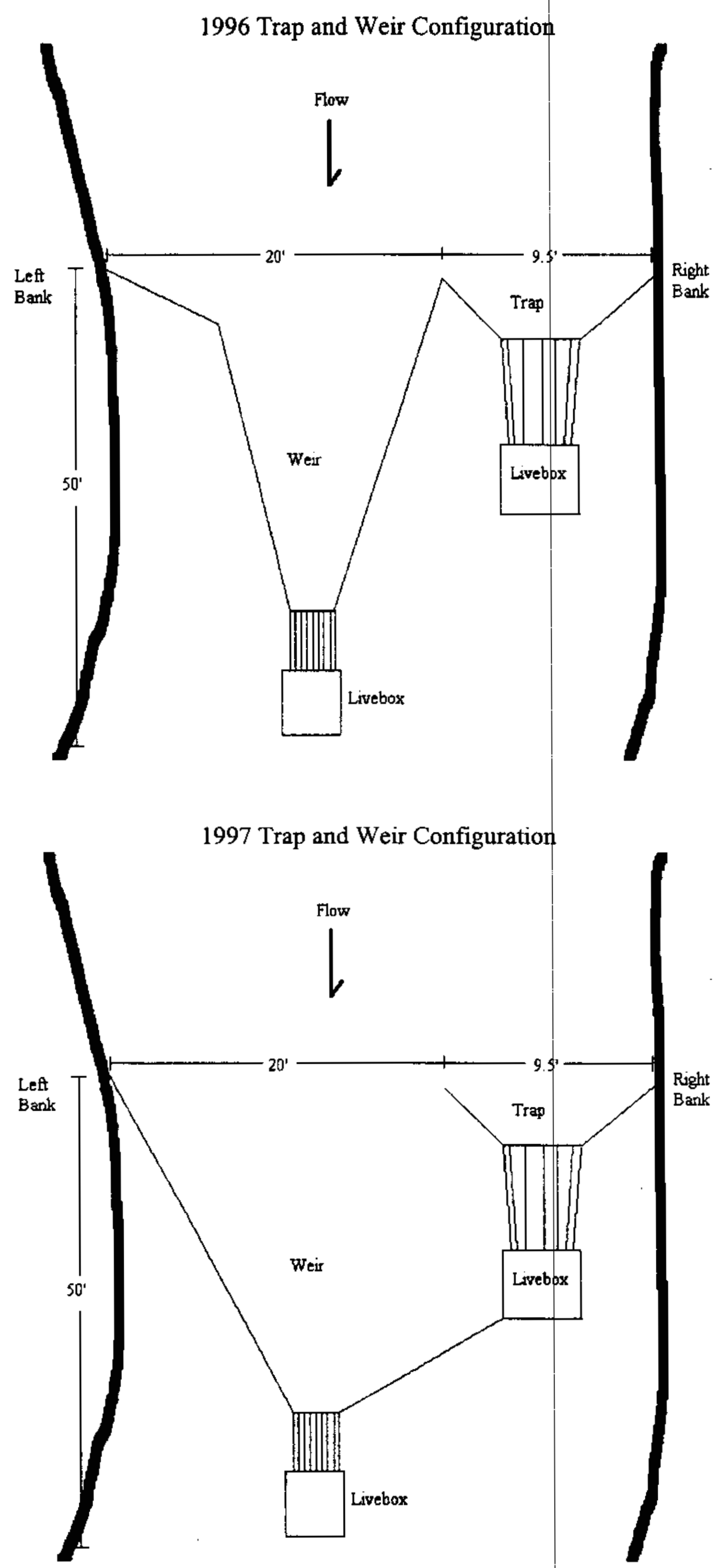

Figure 2.Trap and weir configurations at Akalura Lake, 1996 and 1997.

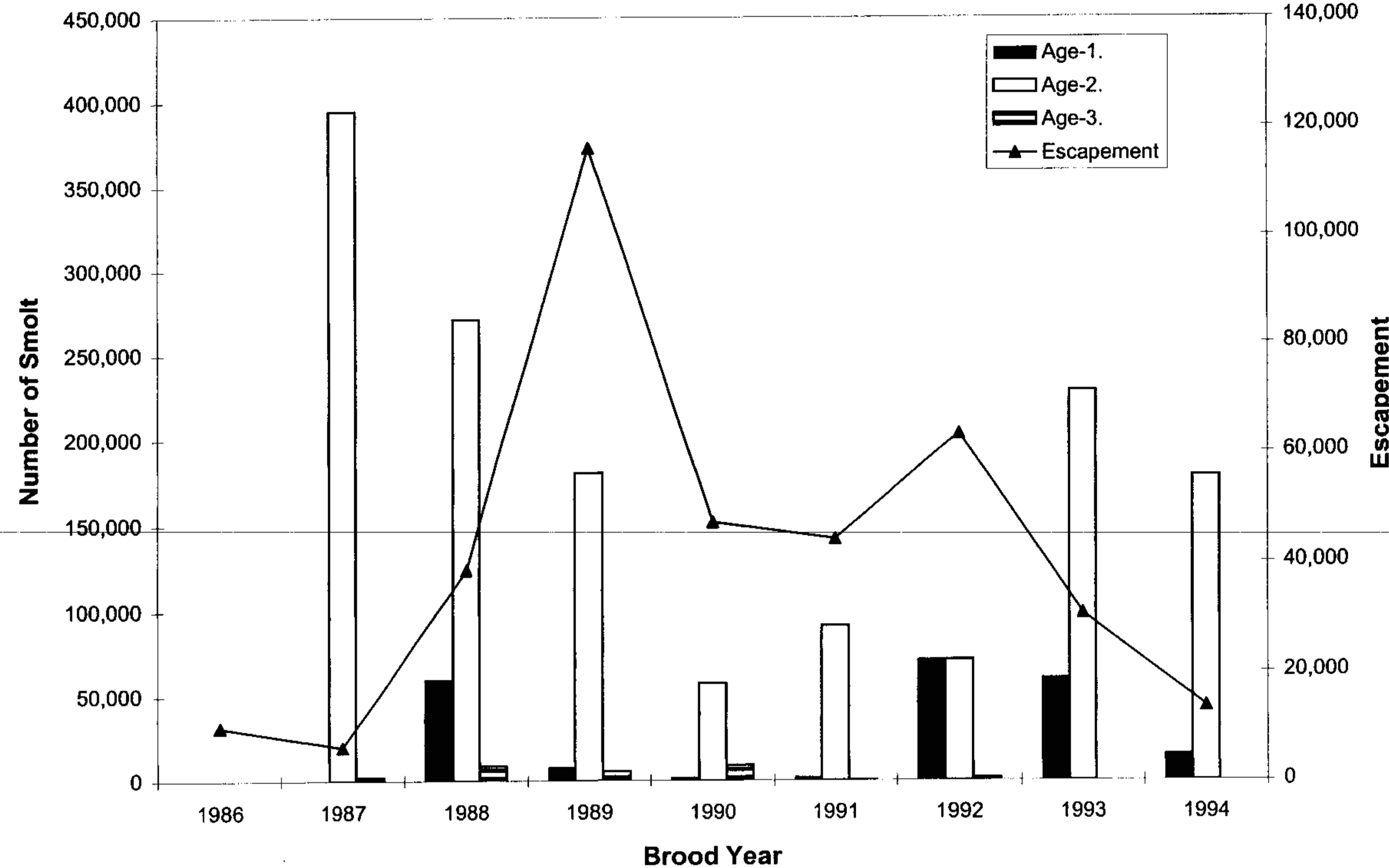

Figure 3. Sockeye salmon escapement and smolt production by age class and brood year, 1986-1994.

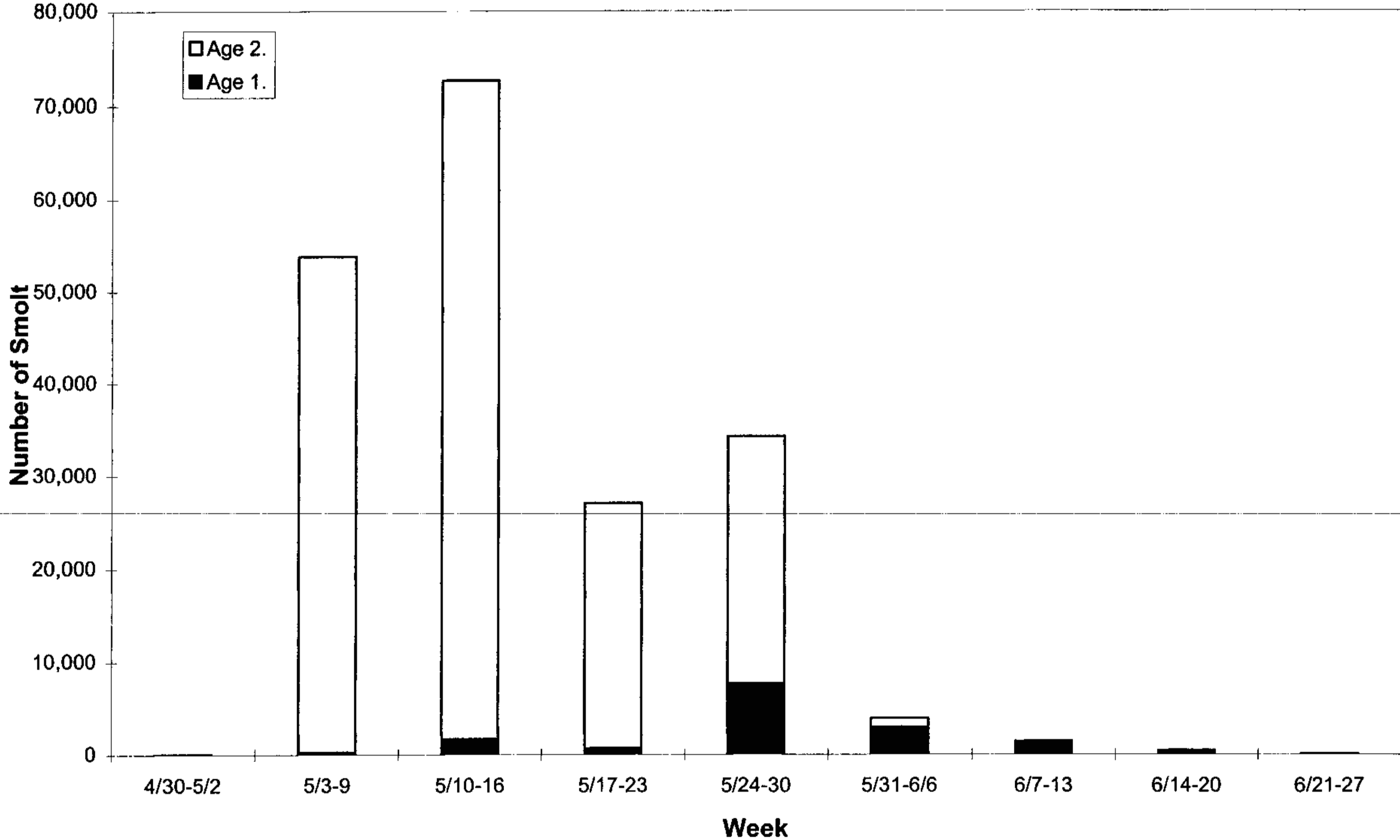

Figure 4. Sockeye salmon smolt outmigration timing by age class, Akalura Lake, 1997.

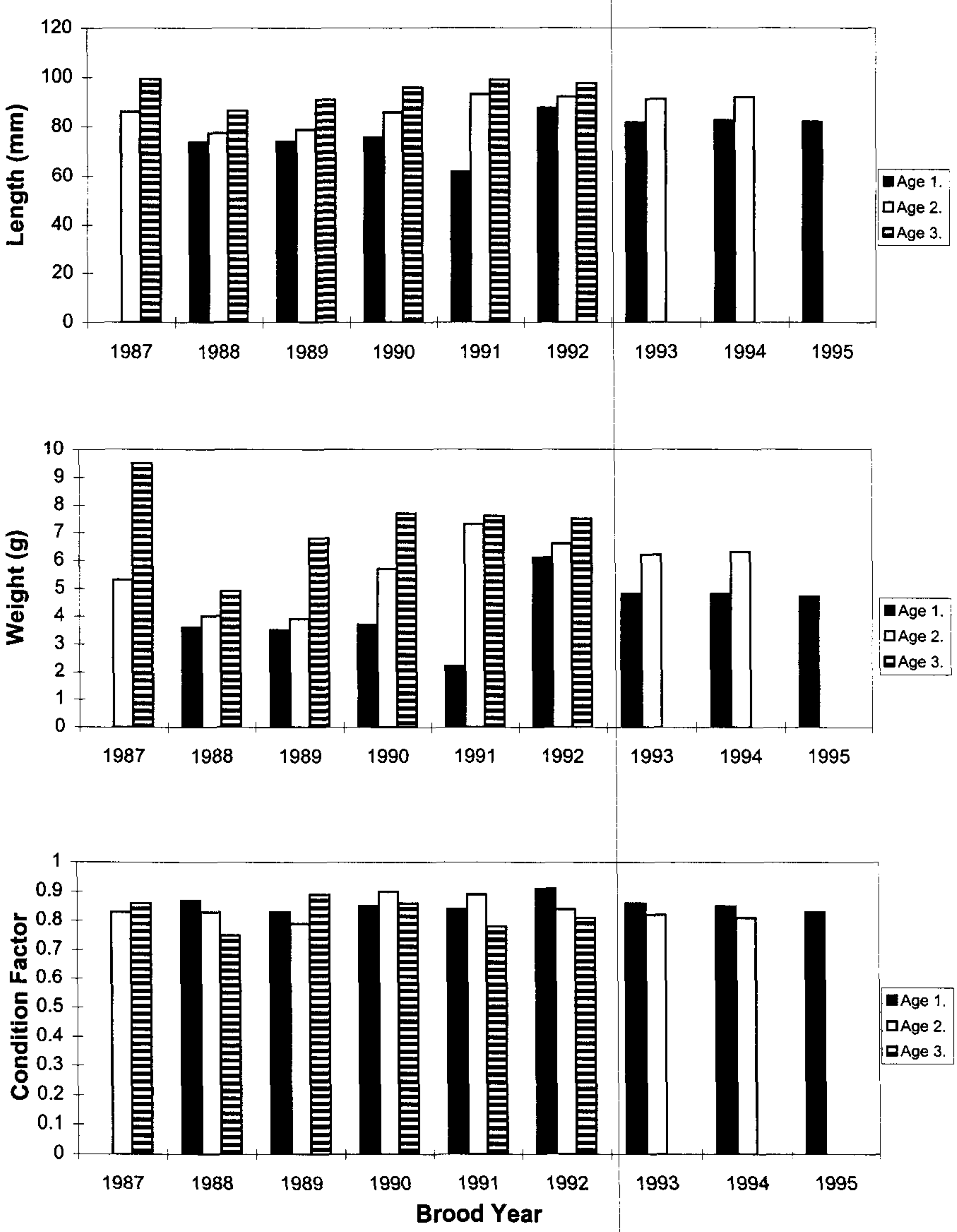

Figure 5. Mean length, weight, and condition factor of sockeye smolts from Akalura Lake, brood years 1987-1995.

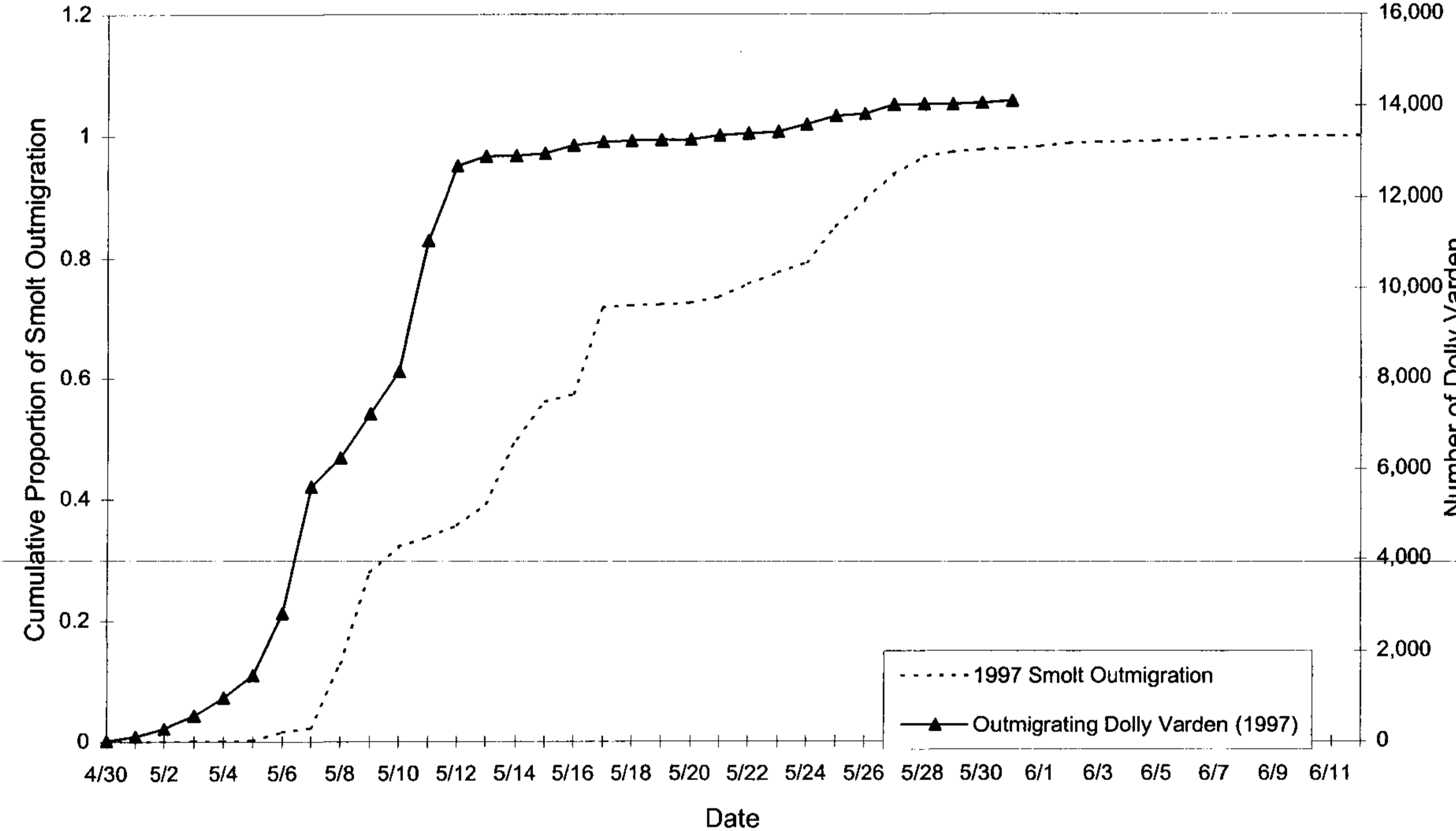

Figure 6. Cumulative proportion of sockeye salmon outmigration and cumulative number of outmigrant Dolly Varden by day, Akalura Lake, 1997.

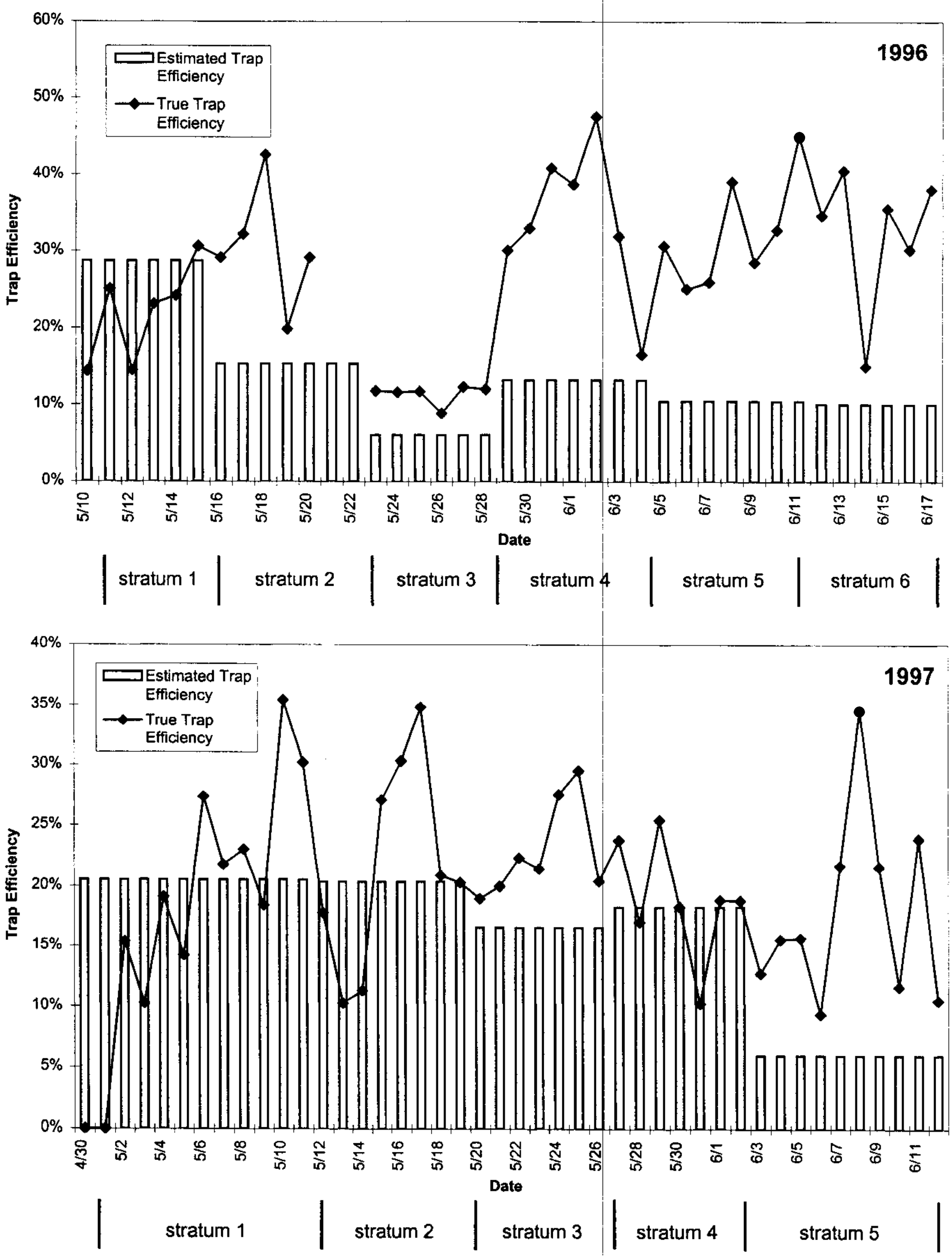

Figure 7. True and estimated trap capture efficiencies at Akalura Lake during 1996 and 1997.

APPENDIX A

Appendix A.1. Estimated number of sockeye salmon smolt outmigrating from Akalura Lake by temporal strata, age class, and year, 1996-1997.

				Age-0				Age-1				Age-2				Age-3			
		Stratum Dates		Population [b]		95% CI		Population [b]		95% CI		Population [b]		95% CI		Population [b]		95% CI	
Year	Stratum [a]	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1996	1	4/26	5/2	0	0	0	0	0	0	0	0	5	0	5	5	0	0	0	0
1996	2	5/3	5/9	0	0	0	0	895	335	239	1,552	43,356	358	42,655	44,057	128	128	0	378
1996	3	5/10	5/16	0	0	0	0	4,294	1,333	1,681	6,908	114,231	1,512	111,268	117,194	1,288	740	0	2,738
1996	4	5/17	5/23	0	0	0	0	624	194	243	1,005	20,657	194	20,276	21,038	0	0	0	0
1996	5	5/24	5/30	0	0	0	0	3,468	603	2,285	4,650	34,214	603	33,032	35,397	0	0	0	0
1996	6	5/31	6/6	0	0	0	0	2,842	463	1,936	3,749	15,810	463	14,903	16,716	0	0	0	0
1996	7	6/7	6/13	0	0	0	0	3,017	75	2,869	3,165	487	75	339	635	0	0	0	0
1996	8	6/14	6/20	0	0	0	0	498	6	487	509	6	6	0	17	0	0	0	0
Total				0	0	0	0	15,639	1,585	12,533	18,745	228,766	1,742	225,351	232,180	1,416	741	0	2,868
1997	1	4/30	5/2	0	0	0	0	0	0	0	0	21	0	21	21	0	0	0	0
1997	2	5/3	5/9	0	0	0	0	238	237	0	703	53,536	237	53,071	54,001	0	0	0	0
1997	3	5/10	5/16	0	0	0	0	1,681	587	530	2,832	71,003	587	69,852	72,154	0	0	0	0
1997	4	5/17	5/23	0	0	0	0	656	290	88	1,224	26,352	290	25,784	26,920	0	0	0	0
1997	5	5/24	5/30	0	0	0	0	7,648	763	6,152	9,144	26,572	763	25,076	28,068	0	0	0	0
1997	6	5/31	6/6	151	60	33	269	2,918	143	2,637	3,199	981	137	713	1,249	0	0	0	0
1997	7	6/7	6/13	32	18	0	68	1,223	46	1,133	1,313	202	43	118	286	0	0	0	0
1997	8	6/14	6/20	11	11	0	33	434	16	403	465	11	11	0	33	0	0	0	0
1997	9	6/21	6/25	2	2	0	6	76	3	71	81	2	2	0	6	0	0	0	0
Total				198	68	70	322	14,874	1,044	12,828	16,920	178,680	1,043	176,636	180,724	0	0	0	0

[a] Strata defined by statistical week.

[b] Population estimates derived from weir counts.

Appendix A.2. Akalura Lake sockeye salmon smolt catch, trap efficiency estimates, and weir catches, 1997

Date	Daily Trap Catch	Released	Recovered	Estimated Trap Efficiency	Weir Catch
4/30	0				1
5/1	0				7
5/2	2				13
5/3	15				146
5/4	13				68
5/5	37				260
5/6	569				2,076
5/7	248	487	68	20.5%	1,138
5/8	4,204		32		18,232
5/9	5,886		0		31,854
5/10	1,639				4,626
5/11	631				2,090
5/12	782				4,387
5/13	1,384				13,486
5/14	4,269	550	38	20.4%	37,669
5/15	2,377		70		8,764
5/16	504		4		1,662
5/17	5,699				16,359
5/18	125				598
5/19	69				340
5/20	105				553
5/21	349				1,745
5/22	874	519	32	16.6%	3,913
5/23	750		37		3,500
5/24	663		16		2,404
5/25	2,346		1		7,940
5/26	1,724				8,449
5/27	1,594				6,699
5/28	1,133	530	45	18.3%	6,645
5/29	305		47		1,199
5/30	162		5		884
5/31	90				880
6/1	117				620
6/2	198				1,051
6/3	45				353
6/4	52				334
6/5	50	520	9	6.0%	319
6/6	46		13		493
6/7	89		5		410
6/8	105		1		304
6/9	67		3		310
6/10	10				86

-Continued-

Appendix A.2. (page 2 of 2)

Date	Daily Trap Catch	Released	Recovered	Estimated Trap Efficiency	Weir Catch
6/11	22				92
6/12	11				105
6/13	Trap				150
6/14	Pulled				157
6/15					51
6/16					109
6/17					46
6/18					42
6/19					17
6/20					34
6/21					13
6/22					16
6/23					20
6/24					21
6/25					10
6/26					Weir
6/27					Pulled
Total	39,360	2,606	426	16%	193,750

Appendix A.3. Daily climatological observations, water temperature, and water depth monitored at the Akalura field station, 1997.

Date	Time	Temperature		Cloud	Wind		Stream Gauge	Comments
		Air (°C)	Water (°C)	Cover %	Direction	Speed (MPH)	(cm)	
5/1	18:00	10	6	100	SE	10	45	
5/2	18:00	10	6	30	SE	20	45	
5/3	18:00	16	8	30	NW	10-15	45	
5/4	18:00	13	10	60	SE	5	45	
5/5	18:00	14	8	65	SE	10	44	
5/6	18:00	12	9	25	S	5-10	44	
5/7	18:00	11	9	75	SE	5	44	
5/8	18:00	13	9	90	SE	5	44	
5/9	18:00	10	9	100	S	5	44	Weather changing rapidly
5/10	18:00	11	9	90	SE	15	44	
5/11	18:00	7	8	100	SE	25	44	
5/12	18:00	7	7	100	NW	15	47	rain
5/13	18:00	7	8	100	S	15	45	
5/14	18:00	7	7	75	VAR	10	47	
5/15	18:00	11	8	100	SE	10	47	
5/16	18:00	7	7	100	SE	10	48	
5/17	18:00	8	7	50	SW	10	48	
5/18	18:00	8	9	95	SE	25-30	48	
5/19	18:00	8	8	100	SE	5	48	
5/20	18:00	12	8	100	VAR	5	48	
5/21	18:00	9	8	50	VAR	10	48	
5/22	18:00	15	11	0	N	5	48	
5/23	18:00	16	12	0	VAR	5	47	
5/24	18:00	13	11	0	S	5	47	
5/25	18:00	17	13	0	CALM	CALM	47	
5/26	18:00	18	14	0	NW	5	47	
5/27	18:00	17	15	40	NE	10	46	
5/28	18:00	17	13	100	NE	10	46	
5/29	18:00	11	12	80	SE	15-20	45	
5/30	18:00	14	13	80	CALM	CALM	45	
5/31	18:00	14	14	0	SW	5	44	
6/1	18:00	13	13	0	S	5	44	
6/2	18:00	17	14	95	CALM	CALM	44	rain
6/3	18:00	13	14	95	S	5	44	
6/4	18:00	15	14	100	N	5	45	
6/5	18:00	15	14	100	CALM	CALM	45	
6/6	18:00	15	12	65	SW	10	45	
6/7	18:00	13	14	80	CALM	CALM	43	
6/8	18:00	13	13	95	S	10	42	
6/9	18:00	12	13	100	CALM	CALM	42	
6/10	18:00	13	14	100	NE	5	42	

-Continued-

Appendix A.3. (page 2 of 2)

Date	Time	Temperature		Cloud	Wind		Stream Gauge	Comments
		Air (°C)	Water (°C)	Cover %	Direction	Speed (MPH)	(cm)	
6/11	18:00	11	13	100	S	5	42	
6/12	18:00	11	13	100	SE	10	42	
6/13	18:00	11	13	75	S	15	42	
6/14	18:00	10	12	100	SE	25	43	
6/15	18:00	13	14	75	S	5	42	
6/16	18:00	10	13	100	CALM	CALM	42	
6/17	18:00	12	14	40	S	15	42	
6/18	8:00	9	12	90	NW	5	41	
6/19	8:00	9	12	0	CALM	CALM	41	
6/20	8:00	10	12	100	CALM	CALM	41	
6/21	8:00	9	13	0	N	<5	42	
6/22	8:00	11	13	0	CALM	CALM	41	
6/23	8:00	12	13	100	CALM	CALM	40	
6/24	8:00	10	13	100	CALM	CALM	40	
6/25	8:00	11	13	100	CALM	CALM	40	
6/26	8:00	14	14	50	N	<5	40	
6/27	8:00	12	14	0	NW	<5	39	
6/28	8:00	13	14	0	CALM	CALM	39	rain
6/29	8:00	11	14	15	CALM	CALM	39	rain
6/30	8:00	13	15	100	VAR	5	39	