Exxon Valdez Oil Spill
Restoration Project Final Report

Sockeye Salmon Overescapement (Kodiak Island Component)

Restoration Project 96258A-2
Final Report

Charles O. Swanton

Alaska Department of Fish and Game
Division of Commercial Fisheries
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<u>Study History</u>: This investigation was initiated with a detailed study plan that subsequently became Fish/Shellfish Study Number 27. The initial research plan 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) titled Sockeye Salmon Overescapement. Subsequent studies focused on restoration efforts which consisted of continued monitoring of the affected populations with an interim ADF&G Regional Information Report (No. 5J95-15) published by Schmidt et al. (1995). The data collected from Kodiak Archipelago sockeye populations were included in these reports while publications focused solely upon Kodiak Island sockeye data with limited analyses have also been generated: Barrett et al. (1993a, 1993b); Swanton and Nelson (1995); Swanton et al. (1996). The following final report includes data, analyses, and conclusions specific to the Kodiak Archipelago sockeye salmon populations.

<u>Abstract</u>: The impacts of large escapements on sockeye salmon (*Oncorhynchus nerka*) systems with freshwater production constrained by limitations on lake rearing capacity were substantiated with empirical data for several Alaskan stocks. As a result of the *Exxon Valdez* oil spill, Red and Akalura lakes on Kodiak Island received escapements that were 2X the upper end of the escapement goals. Data collected were macrozooplankton biomass, species composition and size structure along with abundance and size of rearing fry and smolt. Two sockeye salmon systems, Upper Station and Frazer lakes, were used as controls. Zooplankton density and biomass decreased at both Red and Akalura lakes when fry from the 1989 brood year were present, however only the decrease for Akalura Lake sockeye was statistically significant. Rearing fry population estimates for both study lakes were deemed of low utility owing to numerous instances where they were less then subsequent smolt population estimates. Sockeye smolts from the 1989-1991 brood years exhibited increased percentages of age-2 fish alluding to the rearing environment having been impacted by heightened foraging of rearing fry. These results although not definitive, suggest that a depression in the rearing environment was caused by the 1989 escapement event and persisted through 1992.

<u>Key Words</u>: Akalura Lake, density dependence, escapement, Kodiak Island, limnology, *Oncorhynchus nerka,* overescapement, rearing fry, Red Lake, smolt production, smolt to adult survival, zooplankton.

Project Data: Project data may be made available via contact with the principal investigator. Current contact information: Charles O. Swanton, Alaska Department of Fish and Game, Fairbanks, Alaska, charles_swanton@fishgame.state.ak.us.

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EXECUTIVE SUMMARY

Sockeye salmon studies were funded by the *Exxon Valdez* Oil Spill (EVOS) Trustee Council beginning in 1989 and continued until 1996. These studies focused on data collection and analysis of limnological parameters, macrozooplankton populations and sockeye salmon fry, smolt and adults. There were four study lakes: two that had received excessive levels of escapement (Red and Akalura lakes) and two lakes (Upper Olga and Frazer) that served as control systems.

It is apparent that the 1989 escapement event resulted in high abundance of fry and smolts; these juvenile fish had a negative impact on macrozooplankters in both the Red and Akalura lakes (decreased biomass, density, and size). Effects were also evident with decreases in size of rearing juveniles and shifts to older age at smolting of fish from the 1989 brood year. There were problems with population estimates of both rearing fry and smolt owing to uncorrected bias that warrant further attention.

INTRODUCTION

During 1989 numerous commercial salmon harvest opportunities (surplus production beyond escapement objectives) were foregone within the Kodiak commercial salmon fishery management area owing to the *Exxon Valdez* oil spill. Commercial fishing was severely curtailed due to oiling of nearshore marine fishing areas. Sockeye salmon escapements into several Kodiak Island lakes were twice the targeted escapement goals (e.g. Red Lake 768,000 fish and Akalura 116,000), while adjacent lake systems experienced escapements that were close to desired levels.

Initially (1990-1992) this study was founded upon previous sockeye salmon work that had defined freshwater production parameters for each affected system. Seminal to quantifying potential lost adult sockeye salmon production and perturbations to the freshwater rearing environment were the Kodiak lakes being characterized as rearing limited (Koenings and Burkett 1987). This determination allowed for enhanced monitoring of lake limnology, and smolt production, coupled with existing run reconstruction programs.

The potential deleterious effects of excessive sockeye salmon escapements (overescapement) on freshwater production parameters was first documented for Frazer Lake on Kodiak Island (Kyle et al. 1988). An initial escapement goal of 400,000 spawners (based on spawning habitat; Blackett 1979), when attained for two consecutive years, caused depletion of macrozooplankton biomass and reduction in smolt size, smolt-to-adult survival (SAS) and adult returns. The freshwater density-dependent affects demonstrated at Frazer Lake have been partially substantiated by other investigators (Koenings and Burkett 1987; McDonald et al. 1987; Edmundson et al 1993; Koenings and Kyle 1996; Kyle 1996). The results of these efforts confirmed the compensatory relationship within sockeye salmon spawner-recruit relationships and solidified the overescapement concept. The Frazer Lake case has formed the foundation of the research efforts reported herein, regarding the effects of large escapement events on Kodiak Archipelago sockeye salmon.

During 1993-1996 (from brood years 1991-1995) smolt abundance estimates and size-at-age data, in concert with macrozooplankton biomass and species composition, suggested that sockeye production remained depressed for the Red and Akalura lake systems following the 1989 brood year. The 1990 brood year from Red Lake elicited a 7-fold decrease in smolts as compared to the 1989 brood year while for Akalura, smolt production from the 1989 and 1990 brood years decreased by 3-fold (Swanton and Nelson 1995). Commensurate with reductions in smolt numbers from both of these systems were also marked reductions in zooplankton densities within both lakes that, following 1992, showed favorable increases suggesting that intervention (artificial nutrient enrichment) would be unnecessary. Field data collection on these sockeye stocks continued through 1996, chronicling what appeared to be natural recovery from the 1989 escapement event. The following represents data collection, final analyses, and conclusions based upon data obtained during both the injury assessment and restoration phases of this research.

OBJECTIVES

The following objectives were developed for addressing impacts of overescapement on sockeye salmon production:

1. measure the biological attributes (numbers and size at age) of juveniles in nursery lakes of Kodiak Island;
2. determine effects on smolt production and subsequent adult returns caused by large escapements resulting from fishery closures after the EVOS. Catalog and quantify changes in rearing capacity of selected nursery lakes which were either affected or unaffected by the oil spill. Data employed for evaluating changes include:
    a. physical and chemical limnological parameters, zooplankton populations;
    b. abundance, age, and growth of juveniles and smolts; and,
3. identify potential alternative methods and strategies for restoration of lost use, populations, or habitat where injury is identified.

METHODS

STUDY LOCATION

The Kodiak commercial salmon fishery management area spans the entire Kodiak Archipelago from Shuyak Island to the Trinity Islands (southern boundary) inclusive of the Alaska Peninsula from the northern boundary at Cape Douglas to Kilokak Rocks (Figure 1). This area is comprised of seven districts and 52 sections with five species of pacific salmon commercially harvested. There are 39 documented systems that support sockeye salmon populations of various sizes, of which four systems (Karluk, Ayakulik-Red River, Upper Station, and Frazer) generate greater than 85% of the area wide production (Swanton and Nelson 1996).

Red Lake located on the southwest end of Kodiak Island is 6.4 km long with a surface area of 8.4 km^2 and volume of $208x10^6$ m^3 (Honnold 1993). The Upper Station system is comprised of two adjoining lakes: Upper (7.9 km^2 surface area) and Lower Olga (6.1 km^2 surface area; Swanton 1992). These lakes are physically and productively dissimilar. Upper Olga is larger in surface area, 7m higher in elevation while Lower Olga Lake resembles Akalura Lake with a 4.9 km^2 surface area, mean depth of 9.9m and elevation of 17m above sea level. Frazer Lake (14.6 km long and 1.6 km wide) is second in overall size to Karluk Lake on Kodiak Island with a surface area of 6.7 km^2 and volume of $557x10^6m^3$ (Blackett 1979).

LIMNOLOGICAL ASSESSMENT

Limnological sampling was conducted annually at the four study lakes from May to September. Data were collected at two locations at each lake (4-6 week interval) throughout the season. Data collected included water temperature, dissolved oxygen, light penetration, water chemistry, and zooplankton biomass and species composition. Specific sampling methodology and data processing procedures are described in Kyle (1994), Edmundson et al. (1994), and Honnold et al. (1996).

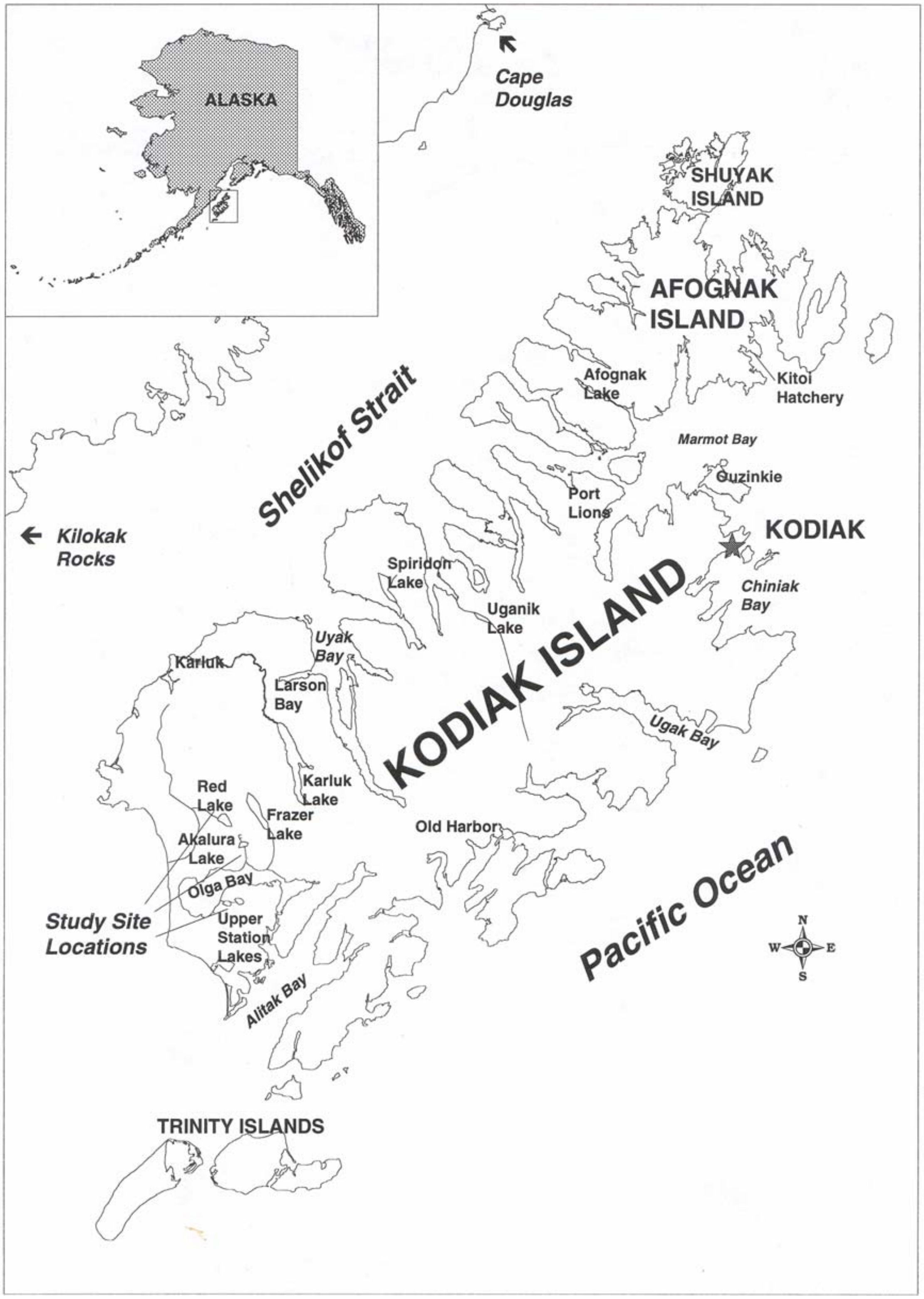


Figure 1.-Location of Red, Akalura, Upper Station, and Frazer lakes on the southern end of Kodiak Island.

Juvenile Sockeye Salmon Assessment

Hydroacoustic and Townet Surveys

Hydroacoustic surveys conducted annually between September-October were performed at Red (1990-91), Akalura (1990-91, and 1995), Upper Station (1990-91), and Frazer (1985-1996) lakes to estimate sockeye salmon rearing fry populations and distribution. The Upper Station Lake (control) was replaced with Frazer Lake after the 1993 season because of budget constraints.

A detailed description of instrumentation, electronic settings, and specific methods employed can be found in Honnold (1993) and Edmundson et al. (1994). Each lake area was divided into three strata (A-C), and two to four transects per strata (depending upon lake size) were randomly selected; assessments were conducted during darkness (Hansson 1993; Appenzeller and Leggett 1995) along six to twelve transects orthogonal to the lake shore.

Since 1990, townet surveys of all study lakes were conducted between 21 September and 6 October for indexing relative sockeye fry abundance and size at age characteristics. The percentage of sockeye fry captured versus threespine stickleback (*Gasterosteus aculeatus*) was used to apportion total fish population estimates generated from hydroacoustic surveys. The townet employed during 1990-94 measured 2m X 2m at the entrance and 7.5 m long and was constructed of variable mesh (3.8 cm, 1.3 cm, and 0.6 cm) knotless nylon. Surveys conducted after 1995 were completed using a monofilament net with identical dimensions. All tows were completed at a depth of ~9.1 m for a duration of 10-35 min. Catch from each tow was sorted, counted, and recorded by species, except when more than 200 stickleback were captured for a tow (Swanton et al. 1996).

Littoral Zone Beach Seining

At Red Lake, four shoal sites selected during 1992 (Barrett et al. 1993) were sampled weekly (~May-June) using a beach seine measuring 15 m X 2 m with 6 mm stretch mesh. The attendant catch was recorded by species with total length (TL) recorded for sockeye fry captured.

Sockeye Smolt Trap Locations and Site Characteristics

The Red Lake sockeye smolt enumeration site was located approximately 1.6 km downstream of the lake outlet where a single Canadian Fan Trap (Ginetz 1977) was deployed in 1990 (Barrett et al. 1993). During 1991-1996 two traps were operated (~6 May – 30 June) in tandem, the second trap was a modified incline plane trap (Todd 1994). The traps were connected together with an inverted V-shaped structure constructed of perforated plate; trap capture widths were 1.5 m and 2.0 m. During 1992 a total smolt enumeration weir located 30 m downstream of the traps was operated (Barrett et al. 1993a). Including the trap and attached leads, the effective capture width represented ~35% of the overall stream width.

The Akalura Lake smolt site was located ~5.6 km downstream of the lake outlet and 0.4 km from the ocean. A single Canadian fan trap was operated (4 May-30 June 1990-1995; Swanton et al. 1996) which spanned 4 m or 31% of the wetted stream width. A total smolt weir was operated in concert with the smolt trap during 1996 (Coggins 1997).

Upper Station was initially selected as a control system for overescapement studies; after the 1993 season, Frazer Lake became the control. The smolt trapping site was located 1.2 km downstream from the outlet of Lower Olga Lake. A single modified incline plane trap with perforated plate leads was operated annually from 4 May through approximately 9 August 1990-1993 (Barrett et al. 1993b). General site characteristics included water velocity greater than 0.3m/sec, average stream depth of 0.4 m, and a trap capture width of 4.5 m (39% of the stream width).

Frazer Lake replaced Upper Station as the control system during 1994. During preceding years two smolt traps, an incline plane and permanent concrete trap were operated below the barrier falls; however trap catches were treated as abundance indices not total smolt estimates (Barrett 1988). For the 1994 season the incline plane trap was moved above the falls 76m upstream of the fish pass facility (Swanton et al. 1996). The trap capture width including perforated plate leads was 5m or 20% of the total stream width.

Sockeye Salmon Smolt Enumeration and Sampling

Typically all smolt traps were inspected every 30 to 45 minutes from 2130 to 0400 h and during daylight hours every 3-4 h. Inspections consisted of enumeration and release of all catch by species, except when age-weight-length (AWL) or trap efficiency trials were scheduled. Fish species identification was made using visual examination of external characteristics (McConnell and Snyder 1972; Trautman 1973).

Smolt enumeration was completed using direct visual counts; the exception being use of a catch-weight approach when catches within a 3 h period exceeded $\geq$ 10,000 smolts (Barrett et al. 1993b). All catches were recorded by sampling day which extended from noon to noon.

At each location, up to 70 sockeye salmon smolts were sampled daily for AWL data 5 days per week. To alleviate sampling bias, all fish in the live-box were mixed prior to sampling. Each sampled fish was anesthetized with MS-222 and a preferred area scale smear removed (INPFC 1963); fish weights (to 0.1 g) and lengths (to nearest 1.0 mm) were also recorded.

Smolt Trap Catch Efficiency

Smolt trap capture efficiency was estimated using mark-recapture trials scheduled on a weekly basis. At all sites except Frazer Lake, about 500 smolts were marked and released about 1 km upstream of the trap site. At Frazer Lake, historical indices of trap capture efficiencies were low $\leq$ 0.5 % and a sample size of 1,000 marked fish was targeted. The mark-recapture process consisted of obtaining a random sample (preferably smolts captured in a single night), transport to a release site, and immersion in a 1,267 ppm Bismark Brown Y-dye solution for 1 h (Ward and Verhoeven 1963; Lawler and Fitz-Earle 1968), and placing them in an instream recovery live box for 1-1.5 h. After recovery, fish were released evenly across the stream channel at about 2200hrs. Smolts exhibiting signs of stress or abnormal behavior were destroyed. All trap catches were inspected for marked fish for a minimum of three successive nights after being liberated.

Sampling for Adult Age Composition

Sockeye salmon catches by district (if open to fishers) are sampled for age (scales) during commercial fishery openings on a weekly basis (ADF&G 1995). The sample size for a particular area is 600 scales per week, which enables all age classes to be simultaneously estimated at α=0.05, within $\pm$ 4.0% of the true proportions (Thompson 1987). Catch data (numbers of fish) by species and area are extracted from the statewide ADF&G fish ticket (harvest receipt) database.

Weekly, sockeye salmon escapements are sampled for age (scales), length, and sex composition at the Ayakulik, Upper Station and Frazer weirs (ADF&G 1995). Samples are collected using a live box trap positioned upstream of the weir with attempts made to collect a 240 fish sample within two consecutive days from June-August (Swanton and Nelson 1995). The escapement sample size allows for simultaneously estimating all age classes at $\boldsymbol{\alpha} = 0.10$ within +- 6.5% of the true proportions (Thompson 1987). The Akalura sockeye system is sampled at reduced intensity with a desired sample size of 480 fish from each of the early and late run components.

Run Reconstruction

With five major wild stocks and numerous fishing areas, assignment of annual commercial sockeye catches to stock of origin has been a decade in development. Long standing run reconstruction programs using scale pattern analysis (Frazer and Upper Station early run; Swanton 1992) and a system-specific freshwater age class (Karluk early and late runs and late run Upper Station; Barrett and Nelson 1994) have been established but require intensive catch and escapement age sampling efforts and post season analysis. Run reconstruction for the Red River stock is less refined being based upon mark-recapture results from a study conducted during 1981-82 (Tyler et al. 1986). Commercial catch apportionment for the Akalura Lake system has been completed using scale pattern analysis for several years; however most of the brood table data has been derived by applying harvest rates from the late run Upper Station sockeye stock (Swanton 1992; Sagalkin and Swanton 2000).

DATA ANALYSIS

Limnology

Analysis of variance (GLM; Snedecor and Cochran 1980) with lake as a random effect and salmon escapement as a fixed effect was employed to test for significant differences in zooplankton density and size. We used only *Bosmina* and *Cyclops* density and size estimates that were log-transformed for response variables. The initial analysis of variance employed all pertinent data pooled across lakes whereby an observation within a year represented a replicate. Subsequent analyses were run for both Red and Akalura lakes independent of both the control systems and of each other to elucidate the effect of escapement level (as surrogate for actual fry densities) on zooplankton. All data were back-transformed for calculating arithmetic means of both zooplankton density and size.

Hydroacoustic Fish Population Estimates

Estimates were derived from interpretation of hydroacoustic tapes adhering to procedures outlined in Kyle (1990) and Honnold (1993). Fish density estimates and associated variances were computed by combining adjacent transects within strata following Bazigos (1976) and Kyle (1990). Population estimates by strata were then summed for the overall system population estimate. Variances and 95% confidence intervals were generated using the approach outlined in Thorne (1983).

Smolt Population Estimation

During the initial stages of this investigation smolt population estimates and associated variances were generated employing formulas forwarded by Rawson (1984). After detecting errors in several of Rawson's estimators a change was made to using a population estimator subsequently published by Carlson et al. (1998). In brief, sockeye salmon smolt population estimates and accompanying error estimates for a two-site situation were generated by: $\tilde{N}_h = \dfrac{n_h M_h}{m_h}$, which is essentially the Peterson estimator with *h* designating stratum. Further definition of terms, distributional and bias concerns are addressed in Carlson et al. (1998). The approximately unbiased variance estimator from Seber (1970) is:

$$v(\hat{N})_h = \frac{(M_h + 1)(n_h + 1)(M_h - m_h)(n_h - m_h)}{(m_h + 1)^2 (m_h + 2)}.$$

Therefore, the approximately unbiased stratum estimators are $\hat{N}_h$ and v($\hat{N}_h$) with total smolt abundance estimated as: $\hat{N} = \sum_{h=1}^{L} \hat{N}_h$;

the variance as $v(\hat{N}) = \sum_{h=1}^{L} (\hat{N}_h)$; and,

the approximate 95% confidence intervals as $\hat{N} \pm 1.96\sqrt{v(\hat{N})}$. Numerous other data treatments and analyses (tests of consistency, bootstrapping, marked fish survival and sample size) are detailed and discussed in Carlson et al. (1998).

Preseason Run Forecasts
The relationship between smolt numbers at age and subsequent adult returns by ocean age was examined using standard linear regression models to evaluate potential utility for preseason run forecasting. These relationships are affected by both smolt to adult survival and the proportion of a particular smolt age class that returns after one, two, or three years of ocean residence.

Stock-Recruitment and Escapement Goal Evaluation
As a component of the overall study, adult production relationships and system specific escapement goals extant during this study were verified. A suite of models including constant, density independent (linear) and density dependent (non-linear Ricker Curve; Ricker 1954) cast in either additive or multiplicative error form were fit to available data. Model selection was achieved using Bayesian Information Criteria (BIC; Adikison et al. 1996). Bootstrap procedures as recommended by Hilborn and Walters (1992) were employed to estimate variance and 95% CI bounds around Ricker curve parameter estimates and the optimum spawning escapement (S_{MSY}).

RESULTS

LIMNOLOGICAL ASSESSMENT

During the period 1986-1996 limnological surveys provided: 38 samples from Red Lake, 52 from Akalura Lake, 36 for Upper Olga Lake, and 69 from Frazer Lake (Table 1). Limnological

Table 1.–Limnological stations and sampling frequency for Red, Akalura, Upper Station and Frazer lakes, 1985-1996.

Lake	Year	Sampling Stations	Frequency	Lake	Year	Sampling Stations	Frequency
Red				**Upper Station**			
	1986	2	1		1985	2	5
	1987-89	no data	0		1986	2	5
	1990	2	5		1987-89	no data	0
	1991	2	5		1990	2	5
	1992	2	5		1991	2	5
	1993	2	6		1992	2	6
	1994	4	6		1993	3 [a]	6
	1995	4	6		1994	0	0
	1996	2	4		1995	2	4
		Total:	38		1996	0	0
						Total:	36
Akalura				**Frazer**			
	1986	3	2		1986	2	6
	1987	1	5		1987	2	6
	1988	1	3		1988	2	9
	1989	1	4		1989	2	9
	1990	2	6		1990	2	9
	1991	2	6		1991	2	7
	1992	2	6		1992	2	6
	1993	2	5		1993	2	5
	1994	4	5		1994	4	4
	1995	4	6		1995	4	4
	1996	2	4		1996	4	4
		Total:	52			Total:	69

[a] One sampling station was in lower Upper Station Lake.

parameters from these lakes showed no anomalies (outside the ranges observed from Alaskan oligotrophic lakes) regarding general water chemistry parameters, nutrients or chlorophyll *a*. There were no consistent trends in parameter values detected at either Red or Akalura lakes which received high escapements relative to Upper Station and Frazer lakes viewed as controls within this study (Schmidt et al. 1995; Schrof et al. 2000; Appendix A1-A6).

The zooplankton biomass by taxa has been summarized for the years 1986-1996 for each of the subject lakes; when available data collected prior to 1986 was included for comparison. Like other sockeye salmon-producing systems in northern climes, preferred prey of rearing sockeye salmon fry are confined largely to copepods (*Cyclops*) and cladocerans (*Bosmina and Daphnia*) while including species that are tolerant of saline intrusion (*Eurytemora*).

An overall assessment of the cladoceran and copepod contributions (animals/m^2) to total macrozooplankton ranged from approximately 75% Copepoda and 25% Cladocera for the Red and Upper Station systems (averaged 1986-1996) to 46% and 31% for Akalura and Frazer lakes (Figure 2). The system specific data depicts that densities of *Bosmina* are greatest for the Akalura and Frazer system followed by *Cyclops* (Frazer Lake) and *Eurytemora* for Akalura during 1986-1996 (Figure 3). The Red and Upper Station Lakes densities were highest for *Cyclops* and *Bosmina* during 1986-1996.

Biomass (mg m^2) of these macrozooplankton groups depicted that copepods dominated (greater than 80%) all systems except Frazer Lake where cladocerans averaged 59% (Figure 4). When viewed by system and year, *Cyclops* and *Bosmina* dominated within Frazer Lake, while *Bosmina* followed by *Eurytemora* and *Epischura* were the primary copepods within Akalura lake (Figure 5). For Red and Upper Station Lakes *Cyclops* was resoundingly the primary zooplankton in biomass.

Pooled data, incorporating data from all four lakes with the response variable of log transformed density of *Bosmina,* resulted in a significant relationship (P=0.012). This suggests a depensitory affect induced by the rearing fry levels on density was realized. The pooled results should be viewed with caution as data for Red Lake zooplankton size were unavailable (Table 2). A second pooled lake model with *Bosmina* size employed as the response variable was also statistically significant (P=0.006) further substantiating that at least for *Bosmina* size decreased as fry rearing numbers increased. The influential data points regarding size were derived from Akalura Lake (Table 3) while estimates from Upper Station and Frazer Lake were used as contrasting data (Tables 4-5).

The macrozooplankton trends for Red Lake suffer from a lack of pre-1989 data but do have several years data (1993-1996) after the fry rearing from 1989 event were vacant from the system (Table 2). Focusing on *Bosmina* and *Daphnia*, the 1990 and 1991 density and biomass estimates appear to be about one half of the mean levels. Specifically, *Cyclops a*nd *Bosmina* densities were 57% and 58% respectively of the average as were total densities of all macrozooplankters, *Daphnia* densities showed no decline during 1990-1991. The GLM constructed for Red Lake *Bosmina* density was not significant (P=0.64) nor was the model using densities of *Cyclops* (P=0.55). There were no size measures for the macrozooplankters from Red Lake collected.

The trends for Akalura Lake were markedly different for *Bosmina* and *Cyclops* with decreases in density (No/m^2) of 44% and 56% (1987-1996 mean compared to 1990-92 average; Table 3).

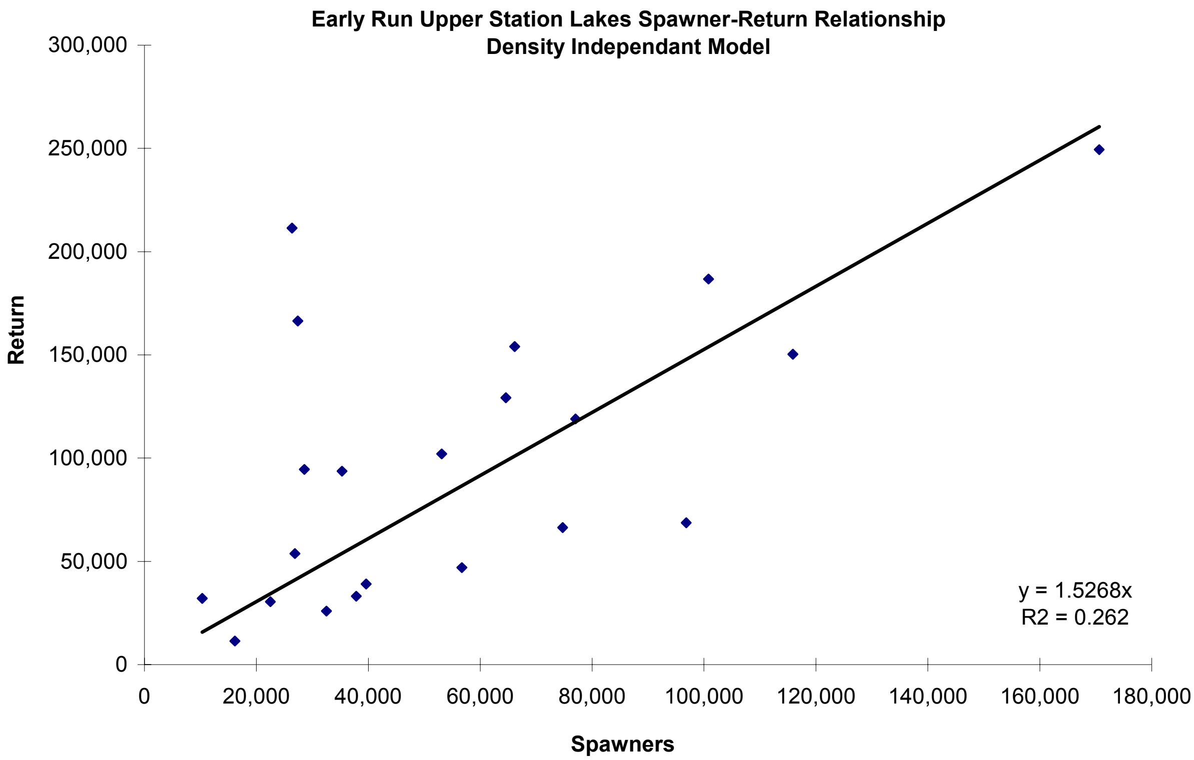


Figure 2.-Contribution of cladocerans and copepods to the total macrozooplankton density (animals m^2) for each of the study lakes. Data are averaged for the May through October period for each year sampled.

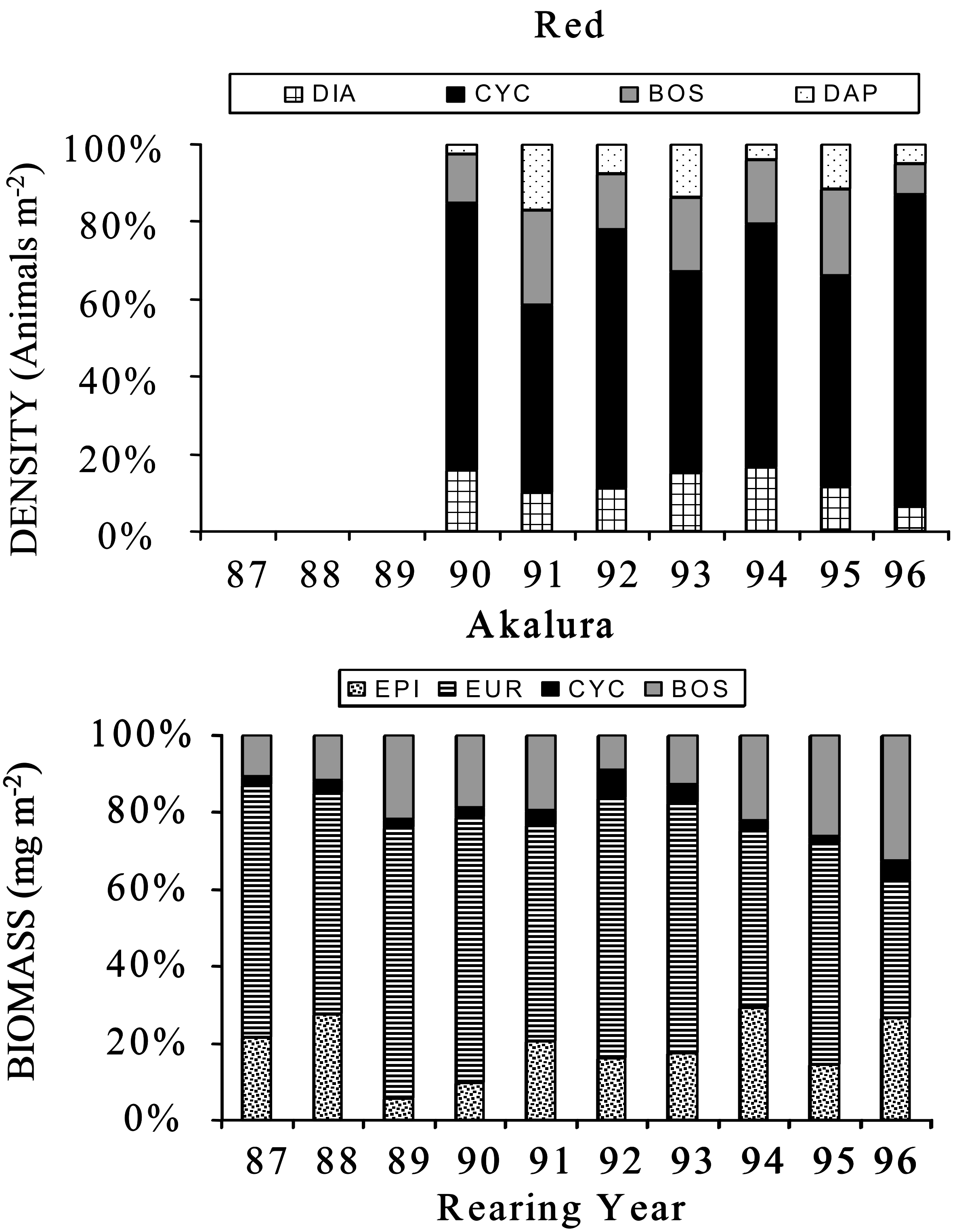


Figure 3.-Percentage relative density of the macrozooplankton taxa *Bosmina* (BOS), *Cyclops* (CYC), *Daphnia* (DAP), *Diaptomus* (DIA), *Epischura* (EPI), and *Eurytemora* (EUR) in each of the study lakes. Data are averaged for the May through October period for each year sampled.

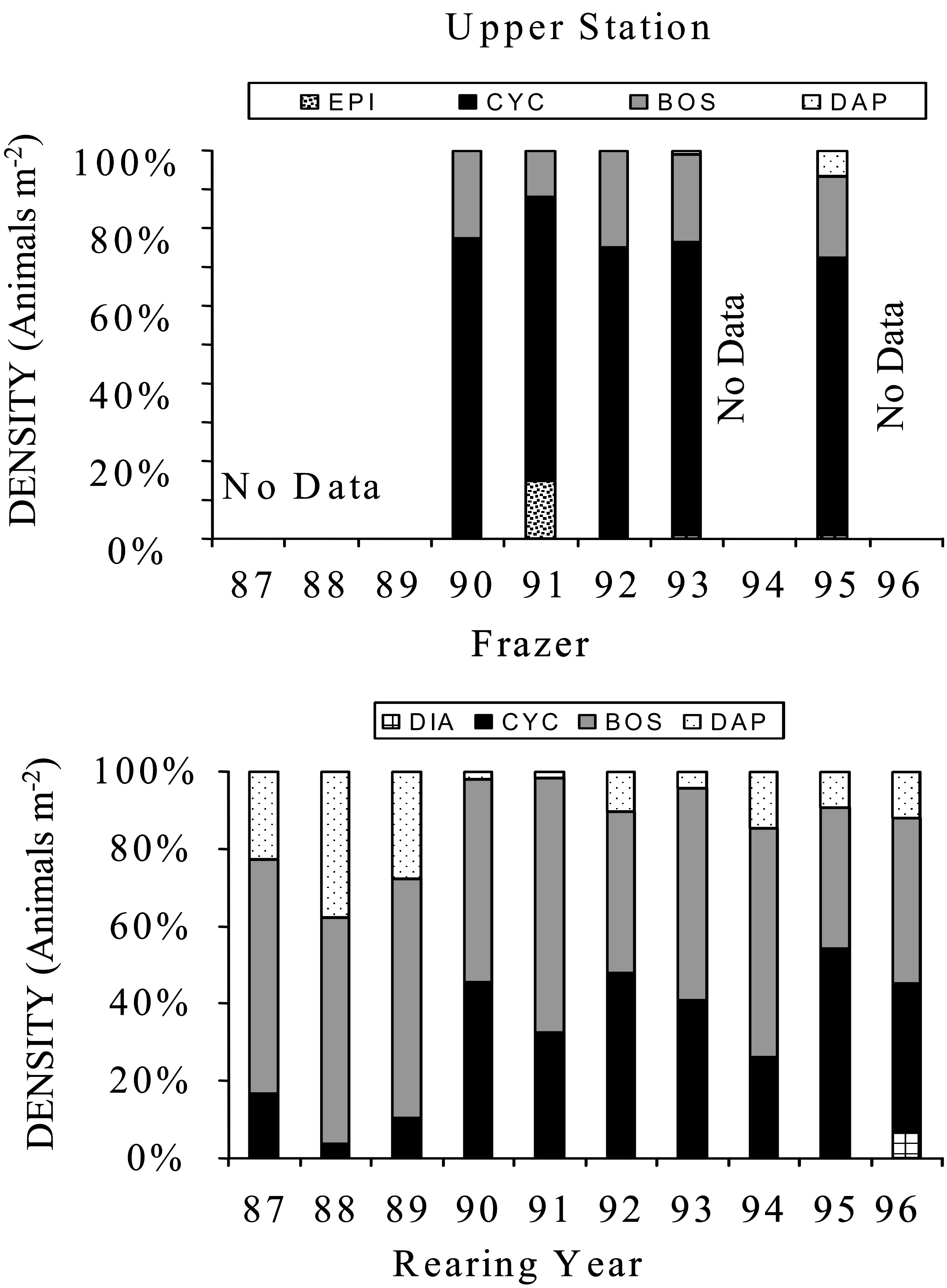


Figure 3.-Continued.

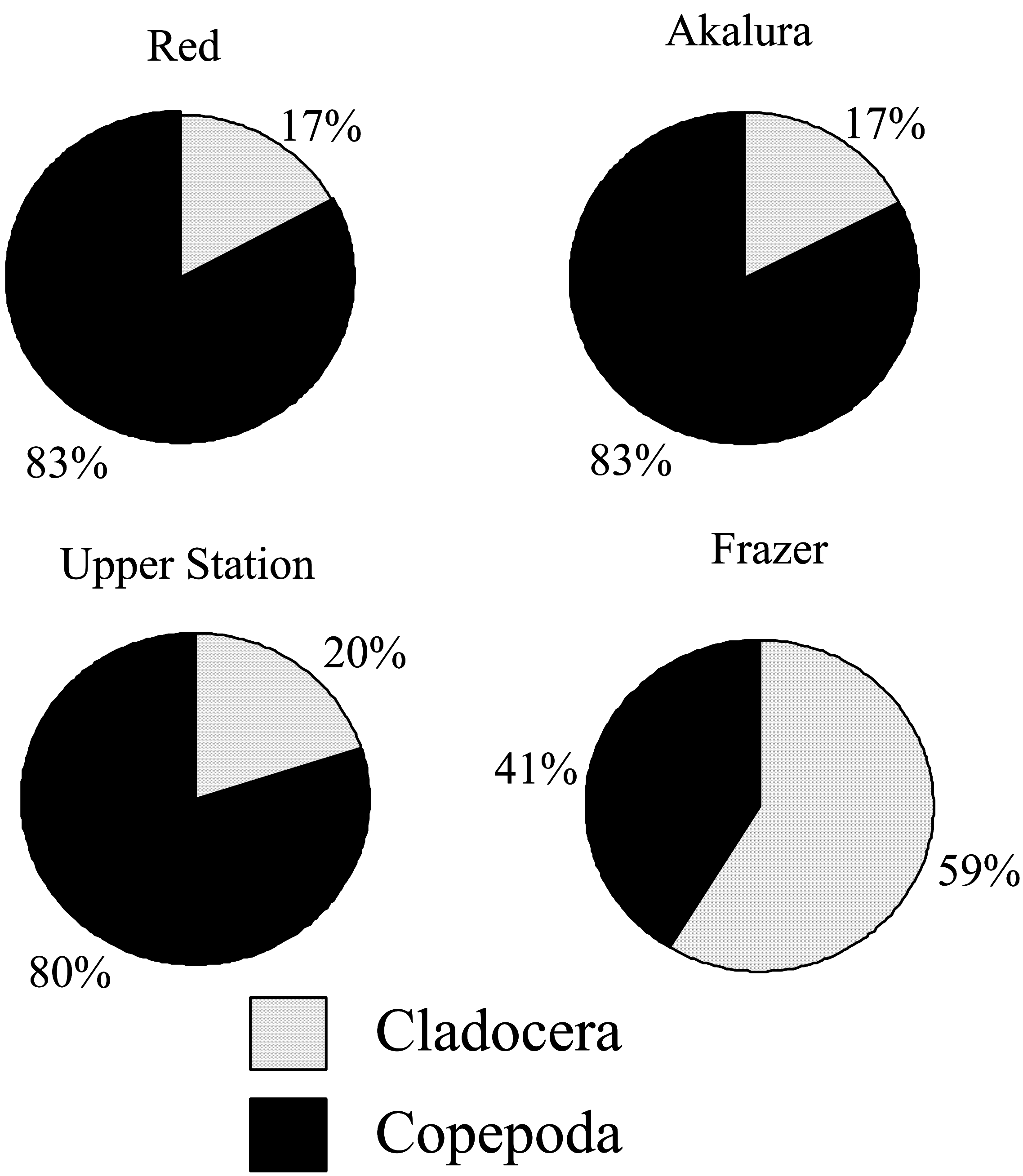


Figure 4.-Contribution of cladocerans and copepods to the total macrozooplankton biomass (mg m^{-2}) for each of the study lakes. Data are averaged for the May through October period for each year sampled.

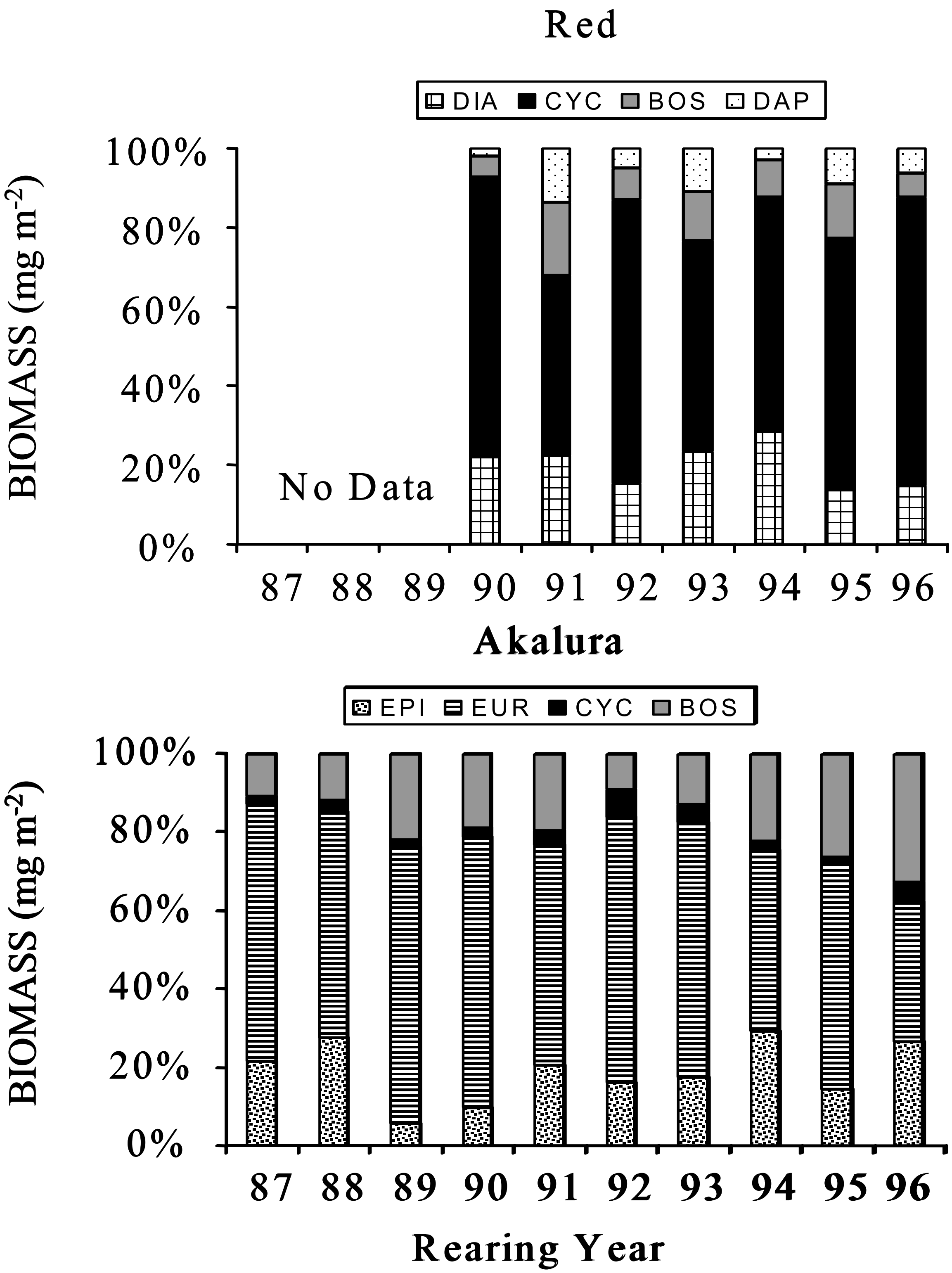
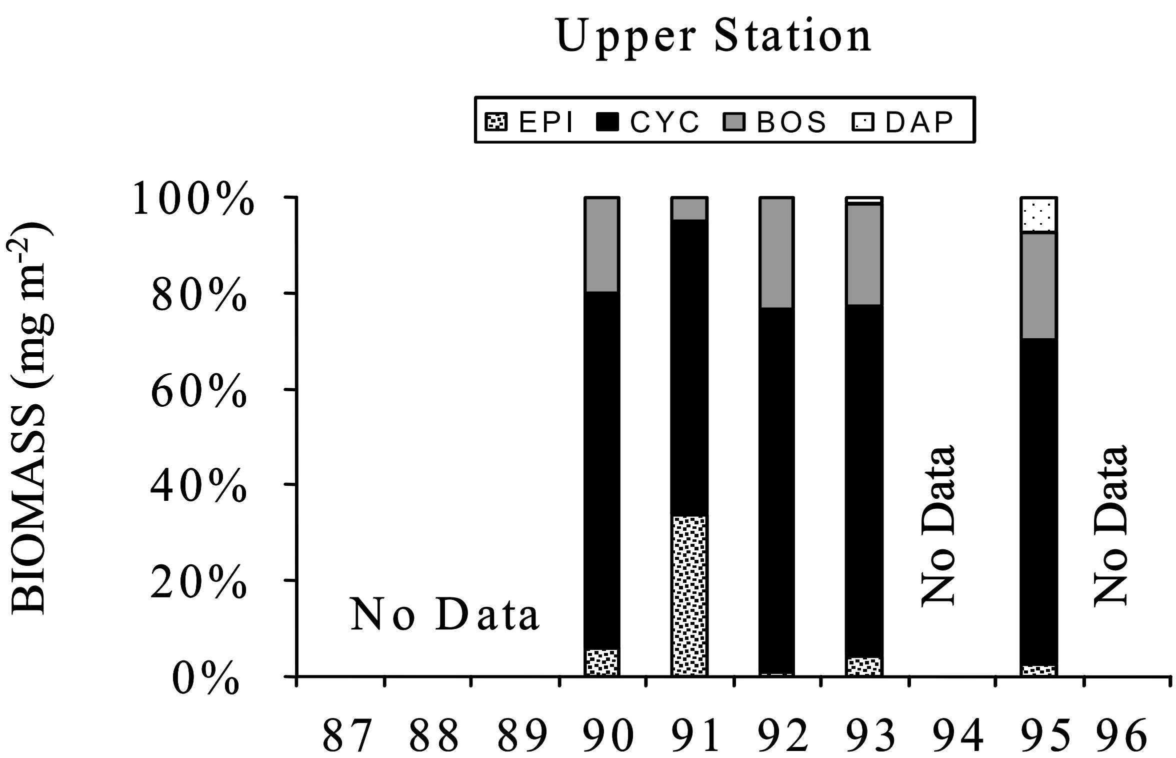


Figure 5. Percentage relative biomass of the macrozooplankton taxa *Bosmina* (BOS), *Cyclops* (CYC), *Daphnia* (DAP), *Diaptomus* (DIA), *Epischura* (EPI), and *Eurytemora* (EUR) in each of the study lakes. Data are averaged for the May through October period for each year sampled.



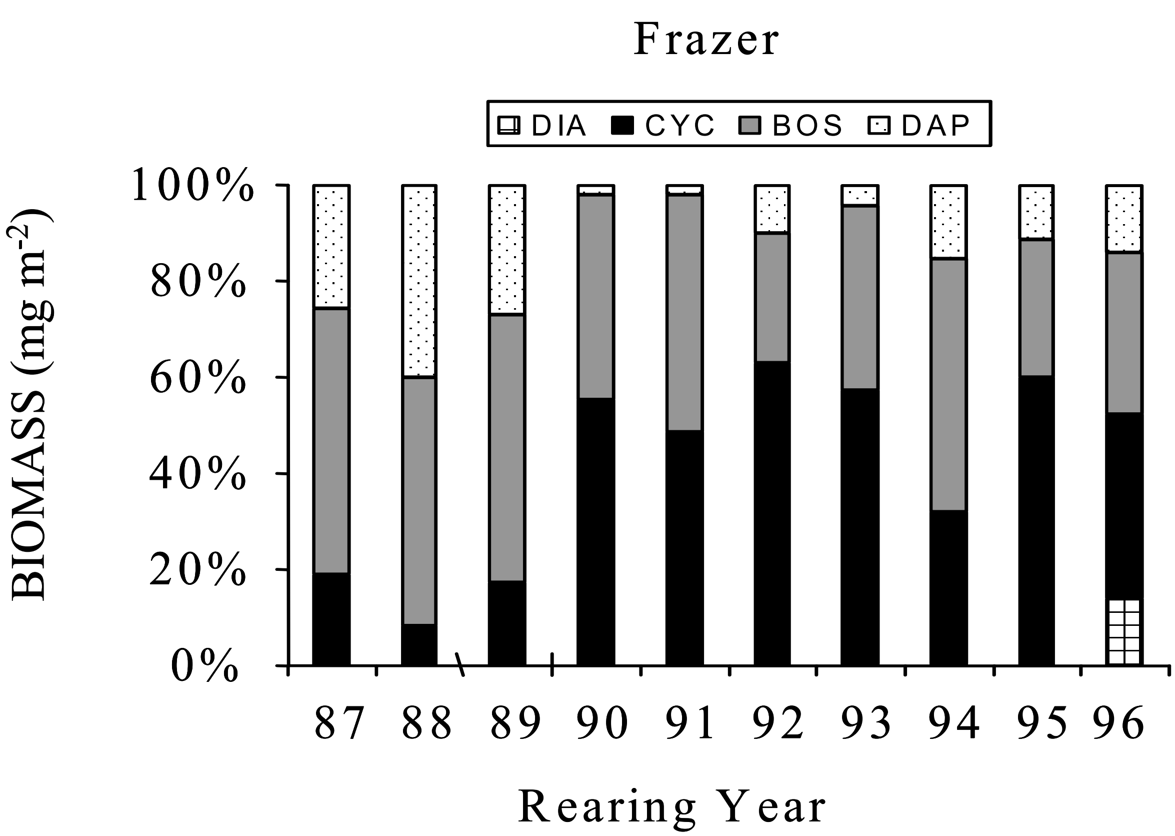


Figure 5.-Continued

Table 2.–Red Lake zooplankton species composition, density, and biomass, 1990-1996.

Year	*Diaptomus*		*Cyclops*		*Bosmina*		*Daphnia*		Total	
	Density (No. m^{-2})	Biomass (mg m^{-2})	Density (No. m^{-2})	Biomass (mg m^{-2})	Density (No. m^{-2})	Biomass (mg m^{-2})	Density (No. m^{-2})	Biomass (mg m^{-2})	Density (No. m^{-2})	Biomass (mg m^{-2})
90	70,674	222	303,026	715	55,573	54	11,519	19	440,792	1,010
91	23,587	98	115,139	198	57,946	80	40,364	59	237,036	435
92	85,612	393	516,432	1,828	113,279	202	57,281	132	772,604	2,555
93	74,642	247	256,878	558	92,954	129	68,471	117	492,945	1,051
94	50,779	197	189,424	413	50,270	67	12,275	20	302,748	697
95	125,753	412	597,951	1,878	245,401	412	125,443	267	1,094,548	2,969
96	48,721	202	587,786	995	57,345	84	36,958	87	730,810	1,368
Mean	**68,538**	**253**	**366,662**	**941**	**96,110**	**147**	**50,330**	**100**	**581,640**	**1,441**

This same trend was also reflected when viewing biomass where decreases of 45% and 54% were realized. Size (mm) also decreased by approximately 20% (1990-1992) when compared to a mean using 1987-1996 estimates. The statistical test using log density of *Bosmina* was significant (P=0.036) relative to escapement level for Akalura Lake as was size (P=0.006). Additional statistical tests for *Cyclops* were also significant for both density (P=0.021) and size (P=0.019). This confirms that there were significant decreases in both density (No/m^2) and size (mm) for these macrozooplankters within Akalura Lake.

JUVENILE AND SMOLT POPULATION ESTIMATES AND SIZE-AT-AGE CHARACTERISTICS

During 1990-92, juvenile fish abundance indices (derived from townet surveys) and fry population estimates (using hydroacoustic gear) were developed for Red, Akalura, and Upper Station lakes and are detailed in Honnold (1993). Rearing fish population estimates from all study systems ranged from 1.9 million fish (1996) to 12.5 million fish (1993; Table 6). Companion townet surveys completed for each of the lakes depicted low numbers of sockeye relative to stickleback. Most rearing fry were age-0 and age-1 with exceptions being found from Akalura and Red lakes. The age and size attribute data from rearing fry captured from all lakes except Frazer, were compromised due to improper preservation, so data reporting is limited (Table 7).

Sockeye salmon smolts typically begin emigrating during early to mid-May with most runs terminating by late June (Swanton et al. 1995, 1996; Barrett et al. 1993a, 1993b), an exception being the Upper Station Lakes sockeye smolt emigration which usually lasts through early August. This phenomenon is attributed to a large age-0 component (>30% of the total estimate in some years) coupled with this system having a bimodal run similar to Chignik Lakes (Kaplan and Swanton 1997). Smolt population estimates for all systems ranged from 65,000 (Akalura 1993) to 8.8 million fish (Frazer 1995).

Although length, weight, and condition factor varied by system over time, there were no obvious trends relating escapement magnitude to rearing fry indices, smolt population numbers, nor size at age for any of the study lakes during this investigation.

Red Lake

A rearing fish population estimate of 7.23 million (95% CI 6.0-8.4 million) was estimated in 1990; townet surveys indicated only 1.4% of the estimate were sockeye (20 sockeye fry) relative to 98.6% stickleback (1,452 fish; Table 6). Application of this ratio to the juvenile fish population estimate generated a sockeye fry estimate of 101,188 fish, compared to 7.1 million stickleback. In 1991, a total fish estimate of 9.4 million fish was generated with townet results depicting 6.7% were sockeye (0.63 million sockeye fry).

Size at age data for townet samples were not available for 1990, while data from 1991 and 1993 are founded upon alcohol preserved samples and therefore biased (Billy 1982). The 1991 spring fry samples (n=34) were 35% age-0, 18% age-1, with the balance (47%) being age-2, whereas fry captured during the fall were 30% age-0, and 70% age-1, fry increasing in length by 22 mm and weight by 2.2 g (Tables 6-7). Fall townet catches in 1992 and 1994 shifted from being dominated by age-0 (68%) in 1992 to age-1, (91%) in 1994 with the size attributes depicting somewhat stable growth. There were only 4 fall fry captured in 1993 prohibiting comparison with other years.

Table 3.–Akalura Lake zooplankton species composition, density, biomass, and size characteristics, 1987-1996.

Year	*Epischura*			*Eurytemora*			*Cyclops*		
	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)
87	41,242	198	0.99	108,386	601	0.97	16,242	18	0.57
88	25,035	97	0.95	45,471	204	0.85	7,741	10	0.63
89	10,152	18	0.71	49,662	216	0.84	6,403	7	0.56
90	2,854	22	0.81	34,348	157	0.58	4,565	5	0.39
91	4,450	22	0.68	12,485	61	0.60	3,776	4	0.39
92	2,981	9	0.61	7,095	38	0.63	2,913	4	0.45
93	7,813	27	0.60	22,491	101	0.57	5,772	7	0.39
94	16,723	75	1.00	23,298	119	0.92	6,702	6	0.53
95	15,010	51	0.91	45,023	201	0.85	4,895	5	0.61
96	15,444	52	0.93	13,483	70	0.95	7,774	10	0.61
Mean	**14,170**	**57**	**0.82**	**36,174**	**177**	**0.78**	**6,678**	**8**	**0.51**

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Table 3.– Page 2 of 2.

Year	*Bosmina*			*Chydorinae*			Total	
	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)	Density (No. m^{-2})	Biomass (mg m^{-2})
87	122,452	98	0.30	743	1	--	289,065	916
88	59,934	42	0.28	0	0	--	138,181	353
89	80,912	67	0.30	266	0	--	147,395	308
90	53,318	43	0.20	528	0	0.26	95,613	227
91	27,757	21	0.20	354	0	--	48,822	108
92	5,559	5	0.20	209	0	0.24	18,757	56
93	25,510	20	0.20	967	1	0.24	62,553	156
94	76,037	57	0.29	0	0	--	122,760	257
95	124,546	92	0.29	514	0	0.25	189,988	349
96	82,523	64	0.29	743	1	0.29	119,967	197
Mean	**65,855**	**51**	**0.26**	**432**	**0**	**0.26**	**123,310**	**293**

Table 4.–Upper Station (Olga Lakes) zooplankton species composition, density, biomass, and size characteristics, 1990-1995.

Year	*Epischura* Density (No. m^{-2})	*Epischura* Biomass (mg m^{-2})	*Epischura* Size (mm)	*Cyclops* Density (No. m^{-2})	*Cyclops* Biomass (mg m^{-2})	*Cyclops* Size (mm)	*Bosmina* Density (No. m^{-2})	*Bosmina* Biomass (mg m^{-2})	*Bosmina* Size (mm)
90	3,318	49	1.33	321,576	604	0.69	95,329	164	0.29
91	77,820	487	1.02	376,849	882	0.85	62,799	70	0.35
92	804	11	1.45	410,753	884	0.78	137,208	275	0.46
93	7,095	56	1.19	575,872	923	0.68	173,554	274	0.41
95	6,668	37	--	490,751	937	--	144,871	316	--
Mean	**19,141**	**128**	**1**	**435,160**	**846**	**1**	**122,752**	**220**	**0**

Year	*Daphnia* Density (No. m^{-2})	*Daphnia* Biomass (mg m^{-2})	*Daphnia* Size (mm)	Total Density (No. m^{-2})	Total Biomass (mg m^{-2})
90	186	0.3	0.61	420,409	817
91	0	0	--	517,468	1,439
92	0	0	--	548,765	1,170
93	7,418	15	0.68	763,939	1,268
95	44,819	100	--	687,109	1,390
Mean	**10,485**	**23**	**1**	**587,538**	**1,217**

Table 5.–Frazer Lake zooplankton species composition, density, biomass, and size characteristics, 1985-1996.

Year	*Epischura*			*Cyclops*			*Bosmina*		
	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)	Density (No. m^{-2})	Biomass (mg m^{-2})	Size (mm)
85	40	0	0.70	1,512	3	0.78	121,746	145	0.36
86	38	0	--	3,431	7	0.73	66,766	83	0.37
87	95	0	0.96	13,175	23	0.70	47,676	67	0.39
88	0	0	--	5,725	19	0.94	92,281	118	0.37
89	0	0	--	15,731	40	0.84	94,708	128	0.38
90	74	0	0.82	50,756	106	0.77	58,587	82	0.39
91	228	0	0.64	55,012	112	0.76	111,598	114	0.34
92	8	0	1.24	133,548	395	0.91	117,044	169	0.39
93	213	1	0.95	120,295	242	0.76	161,651	164	0.33
94	93	1	1.04	49,801	94	0.73	114,400	156	0.38
95	0	0	--	59,089	85	0.65	39,823	41	0.34
96	21,762	63	--	126,668	171	--	140,040	151	--
Mean	**1,879**	**5**	**1**	**52,895**	**108**	**1**	**97,193**	**118**	**0**

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Table 5.–Page 2 of 2.

Year	*Daphnia* Density (No. m^{-2})	*Daphnia* Biomass (mg m^{-2})	*Daphnia* Size (mm)	Total Density (No. m^{-2})	Total Biomass (mg m^{-2})
85	42,255	65	0.60	165,553	213
86	27,516	42	0.60	97,751	132
87	18,028	31	0.64	78,974	121
88	59,256	92	0.61	157,262	229
89	42,142	62	0.59	152,581	230
90	2,136	4	0.65	111,553	192
91	2,969	5	0.62	169,807	231
92	28,677	63	0.71	279,277	627
93	12,654	18	0.59	294,813	425
94	28,145	45	0.61	192,439	296
95	10,404	16	0.60	109,316	142
96	39,306	62	--	327,776	447
Mean	**26,124**	**42**	**1**	**178,092**	**274**

Table 6.–Juvenile sockeye salmon estimates based on fall townet catch, species composition, and hydroacoustic total fish population estimates for Red, Akalura, Upper Station and Frazer lakes, 1990-1996.

			Total Fish Estimates				Sockeye Estimates			
		Sockeye			95% C. I.				95% C. I.	
Lake System	Year	Composition	Estimate	Variance	Low	High	Estimate	Variance	Low	High
Red	1990	1.4%	7,227,742	3.4E+11	6,084,898	8,370,586	101,188	6.7E+07	85,189	117,188
	1991	6.7%	9,430,782	2.2E+12	6,523,690	12,337,874	631,862	9.9E+09	437,087	826,638
Akalura	1990	5.3%	3,950,101	1.6E+11	3,156,377	4,743,825	209,355	4.6E+08	167,288	251,423
	1991	1.3%	3,171,881	7.6E+09	3,001,016	3,342,746	41,234	1.3E+06	39,013	43,456
	1995	12.7%	3,637,001	1.7E+11	2,828,888	4,445,114	461,899	2.7E+09	359,269	564,529
Upper	1990	30.5%	3,843,823	5.7E+10	3,375,889	4,311,757	1,172,366	5.3E+09	1,029,646	1,315,086
Station	1991	9.7%	3,987,459	8.0E+10	3,433,098	4,541,820	386,784	7.5E+08	333,011	440,557
Frazer	1990	76.8%	7,434,331	6.2E+11	5,891,056	8,977,606	5,709,566	3.7E+11	4,524,331	6,894,801
	1991	75.3%	8,320,947	4.3E+11	7,035,715	9,606,179	6,265,673	2.4E+11	5,297,893	7,233,453
	1992	18.0%	8,340,877	1.8E+12	5,711,313	10,970,441	1,501,358	5.8E+10	1,028,036	1,974,679
	1993	6.3%	12,519,826	1.8E+11	11,688,285	13,351,367	788,749	7.1E+08	736,362	841,136
	1994	0.4%	9,069,751	2.2E+11	8,150,448	9,989,054	36,279	3.5E+06	32,602	39,956
	1995	0.4%	3,927,893	1.2E+11	3,248,943	4,606,843	15,712	1.9E+06	12,996	18,427
	1996	16.8%	1,948,829	2.5E+09	1,850,831	2,046,827	327,403	7.1E+07	310,940	343,867

Table 7.–Age, mean length (mm), weight (g), and condition factor by age class for juvenile sockeye salmon captured by townetting at Red, Akalura, Upper Station, and Frazer lakes, 1990-1996.

		Age-0					Age-1				
Lake System	Year	n	%	Length	Weight	Condition	n	%	Length	Weight	Condition
Red	1991 [a]	12	35.3	29	0.2	0.83	6	17.6	69	2.4	0.74
	1991 [b]	27	29.7	51	1.2	0.85	64	70.3	81	4.4	0.81
	1992 [c]	69	68.1	69	2.6	0.79	37	31.9	97	8.2	0.84
	1993 [d]	1	25.0	63	2.3	0.92	3	75.0	79	5.1	1.01
	1994	6	7.4	60	1.4	0.65	74	91.4	85	4.4	0.72
Akalura	1991 [a]	3	6.8	29	0.2	0.79	24	54.5	50	1.0	0.78
	1991 [b]	54	36.7	52	1.4	0.95	93	63.3	74	3.8	0.93
	1995	43	49.5	61	2.7	1.14	44	50.5	82	6.0	1.10
Upper Station	1991 [a]	4	30.8	31	0.3	0.87	2	15.4	73	3.3	0.87
	1991 [b]	116	72.5	56	1.7	0.85	44	27.5	91	7.0	0.91
	1992	213	77.5	67	2.9	0.89	62	22.5	90	8.4	1.03
Frazer	1990	64	61.5	50	1.5	1.19	40	38.5	77	5.2	1.15
	1991	54	53.5	50	1.2	0.92	47	46.5	70	3.4	0.95
	1992	51	24.8	64	2.9	1.05	132	64.1	87	6.5	1.00
	1993 [d]	22	91.7	66	1.6	0.58	2	8.3	97	5.0	0.55
	1994	2	100.0	68	1.7	0.54	0	0.0			
	1995	2	100.0	53	1.6	1.07	0	0.0			
	1996	6	5.8	44	1.0	1.17	95	91.3	58	2.2	1.08

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Table 7.–Page 2 of 2.

Lake System	Year		Age-2 N	%	Length	Weight	Condition
Red	1991	[a]	16	47.1	95	6.0	0.69
	1991	[b]					
	1992	[c]					
	1993	[d]					
	1994		1	1.2	103	7.7	0.70
Akalura	1991	[a]	17	38.6	68	2.4	0.74
	1991	[b]					
	1995						
Upper Station	1991	[a]	7	53.8	109	10.4	
	1991	[b]					
	1992						
Frazer	1990						
	1991						
	1992		23	11.1	91	7.5	0.99
	1993	[d]					
	1994						
	1995						
	1996		3	2.9	80	5.4	1.05

[a] Spring samples – alcohol preservation.
[b] Fall samples – alcohol preservation.
[c] Average of two fall sample dates.
[d] Alcohol preservation of samples.

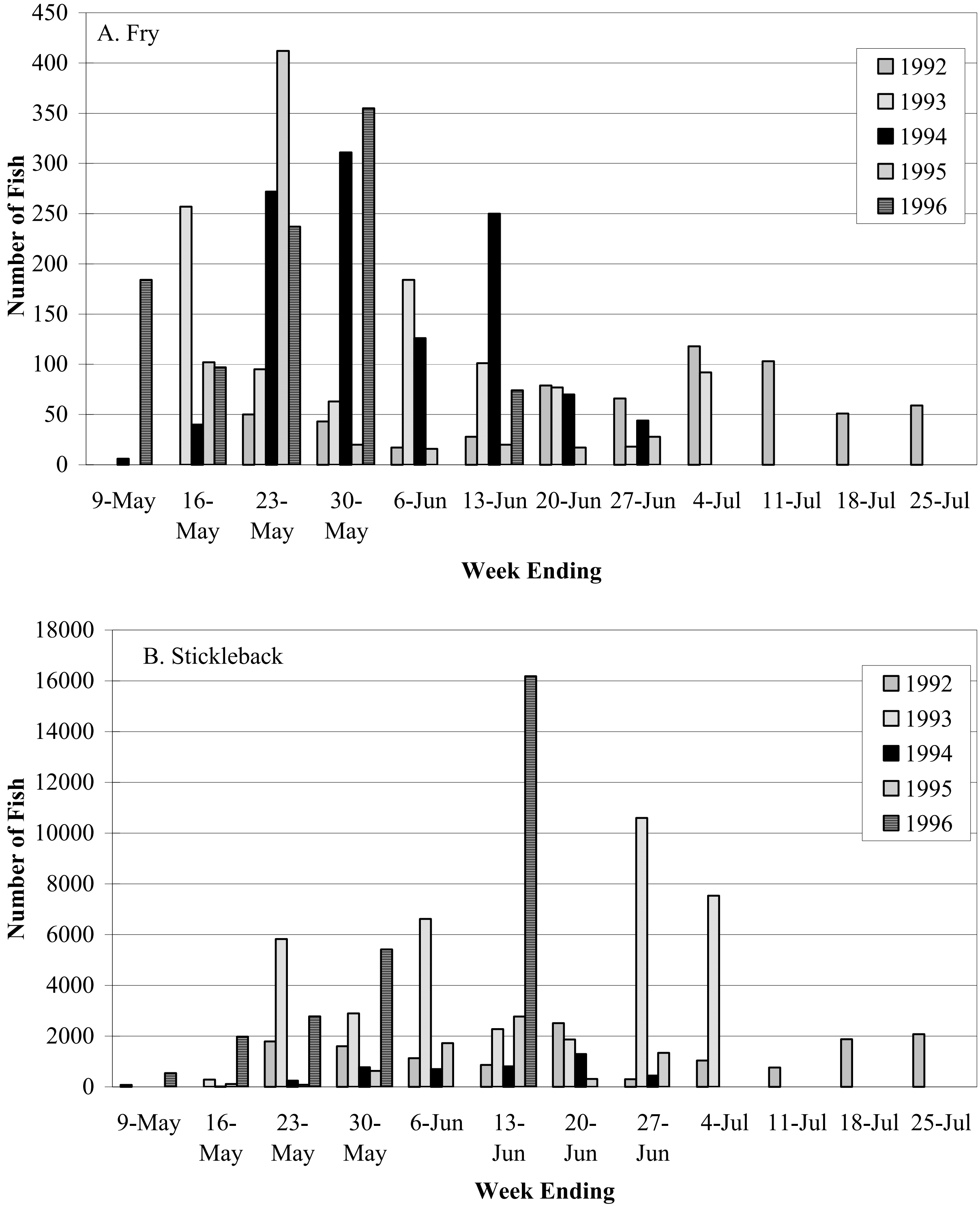


Figure 6.-Numbers of sockeye salmon fry (A) and threespine stickleback (B) captured in littoral zone beach seining, Red Lake 1992-1996.

Catches of sockeye salmon fry and stickleback from Red Lake littoral zone sampling during 1992-96 peaked during late May for sockeye and for stickleback about mid-June (Figure 6). The largest catches were observed during 1994-96 and for all years stickleback catches were generally an order of magnitude larger than for sockeye.

Annual smolt outmigrations from Red Lake (1990 through 1996) varied from 270,700 (1991) to 1,343,862 (1992; Table 8; Appendix B1). The brood year smolt emigrations ranged from 205,083 (1990) to 1,530,296 smolts (1989; Table 9). The largest outmigration was from the 1989 BY escapement of 761,101 adults while the smallest occurred for BY 1990 (escapement of 350,000; Figure 7).

The average length and weight of age-1 smolts varied from 86 to 106 mm and 5 g – 10 g; age-2 fish ranged from 99 mm t 112 mm and 7.6 g – 12.1 g; and age-3, fish (small sample size) from 113 mm to 122 mm and 9.0-15.4 g (Figure 8). The range in smolt condition factor by age class was 0.79-0.94 (age-1), 0.76-0.88 (age-2) and 0.77-0.87 for age-3 smolts.

Akalura Lake

There is general agreement between age-1 fry and subsequent age-2 smolts after 1992 with an average increase in length of 30 mm and weight of 6g (Swanton et al. 1995, 1996). As a result of preservation problems, no age or size data were available for fry in 1990. There were 54 fry collected during May 1991 of which 6.8% were age-0, 54% age-1 and 39% age-2 fish. Comparatively these fish were smaller at age then those from Red Lake. Fall surveys conducted in October 1991 yielded 37% age-0 and 63% age-1 with size at age being 52 mm and 1.4 g for age-0 and averaging 74 mm and 3.8 g for age-1 fry (Table 7). In 1995, the fall survey captured 87 fry, 50% were age-0 and 50% age-1; these fry were about 10 mm and 2 g larger than the rearing fall fry sampled in 1991.

The estimated annual sockeye smolt outmigrations (1992-96) ranged from 65,366 (1993) to 454,759 (1990; Table 10; Appendix B2). The brood year estimates varied from 68,681 (1990 BY) to 339,615 (1988 BY; Table 11; Figure 9). Contrary to the Red Lake smolt data, the 1989 BY escapement did not produce a commensurately large smolt outmigration; however the 1990 BY did follow suit with the smallest observed smolt emigration for this system. The hydroacoustic sockeye fry estimates were substantially lower than the subsequent smolt outmigrations pointing to there being substantial bias in the fry estimates, the smolt population estimates, or both.

Ranges in length and weight of sockeye salmon smolts by age were 62-88 mm and 2.2-6.3g (age-1), 86-93 mm and 3.9-7.3 g (age-2), and 86-99 mm and 4.9-9.5 g (age-3) (Figure 10). Average condition factors varied from K=0.75 to 0.91 for all age classes. Rearing sockeye fry estimates relative to smolt outmigrations and also size at age showed similar discrepancies as were observed for Red Lake.

Upper Station

Total fish population estimates during 1990-91 from hydroacoustic data were 3.8 and 3.9 million fish. Townet catches of rearing sockeye fry were 174 and 397 juveniles which translated into rearing sockeye fry population estimates of 1.1 million fry (95% CI 1.0 to 1.3 million; 1990) and 0.39 million (95% CI 0.33 to 0.44 million) in 1991 (Table 6).

Table 8.-Estimated number of sockeye salmon smolt outmigrating from Red Lake by year and age class, 1990-1996.

Smolt Outmigration Year	Number and Relative Percent of Smolt by Age Class 1.	2.	3.	Total Population Estimate	SE	95% CI Lower	Upper
1990	274,434	389,336	4,241	668,011	67,643	535,431	800,591
	41.1%	58.3%	0.6%		***76,329***	***548,316***	***848,656***
1991	123,920	109,633	37,147	270,700	20,407	230,701	310,699
	45.8%	40.5%	13.7%		***20,384***	***235,973***	***315,199***
1992	31,915	1,343,862	17,243	1,393,020	83,868	1,228,639	1,557,401
	2.3%	96.5%	1.2%		***84,087***	***1,246,133***	***1,574,617***
1993	328,698	170,907	62,514	562,118	33,961	495,554	628,682
	58.5%	30.4%	11.1%		***34,837***	***501,618***	***640,848***
1994	41,359	509,409	2,261	553,030	21,645	510,605	595,454
	7.5%	92.1%	0.4%		***20,970***	***514,207***	***598,556***
1995	17,361	324,299	9,943	351,603	32,548	287,810	415,396
	4.9%	92.2%	2.8%		***32,561***	***293,900***	***419,215***
1996	735,953	233,991	17,669	987,612	61,248	867,565	1,107,659
	74.5%	23.7%	1.8%		***64,867***	***878,312***	***1,130,527***

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

Table 9.-Adult sockeye salmon escapement and estimated smolt outmigration from Red Lake by brood year and age class, 1986-1995.

Brood Year	Escapement	Smolt Numbers by Age and Percent 1.	2.	3.	Total
1986	318,135	[a]	[a]	4,241	[b]
1987	261,913	[a]	389,336	37,147	426,483 [b]
1988	291,774	274,434 68.4%	109,633 27.3%	17,243 4.3%	401,310
1989	768,101	123,920 8.1%	1,343,862 87.8%	62,514 4.1%	1,530,296
1990	371,282	31,915 15.6%	170,907 83.3%	2,261 1.1%	205,083
1991	374,859	328,698 38.8%	509,409 60.1%	9,943 1.2%	848,050
1992	344,184	41,359 10.8%	324,299 84.6%	17,669 4.6%	383,327
1993	286,170	17,361	233,991	[c]	251,351 [b]
1994	380,181	735,953	[c]	[c]	[b]
1995	317,832	[c]	[c]	[c]	[b]

[a] Smolt migration not monitored.

[b] Incomplete brood year data.

[c] Smolt of this age class have not outmigrated.

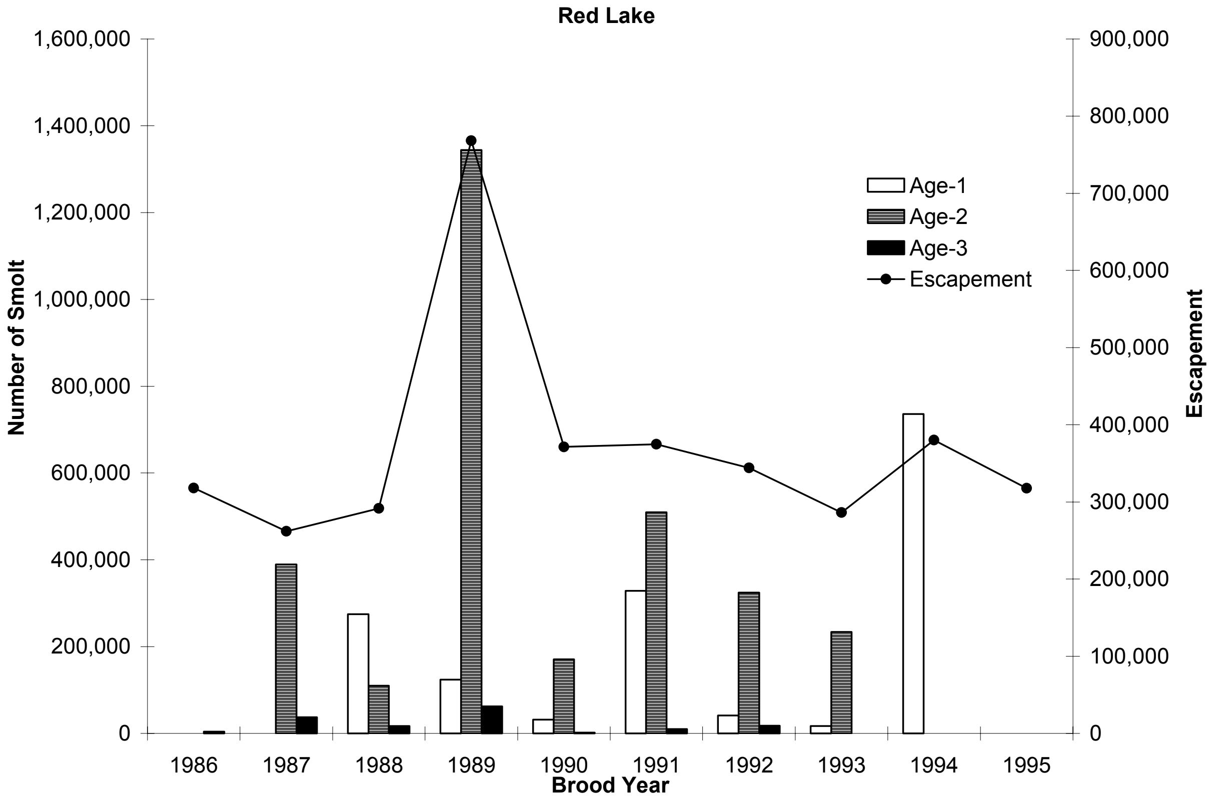


Figure 7.-Relationship between Red Lake parent year escapement and subsequent smolt production by age class for brood years 1987-1993.

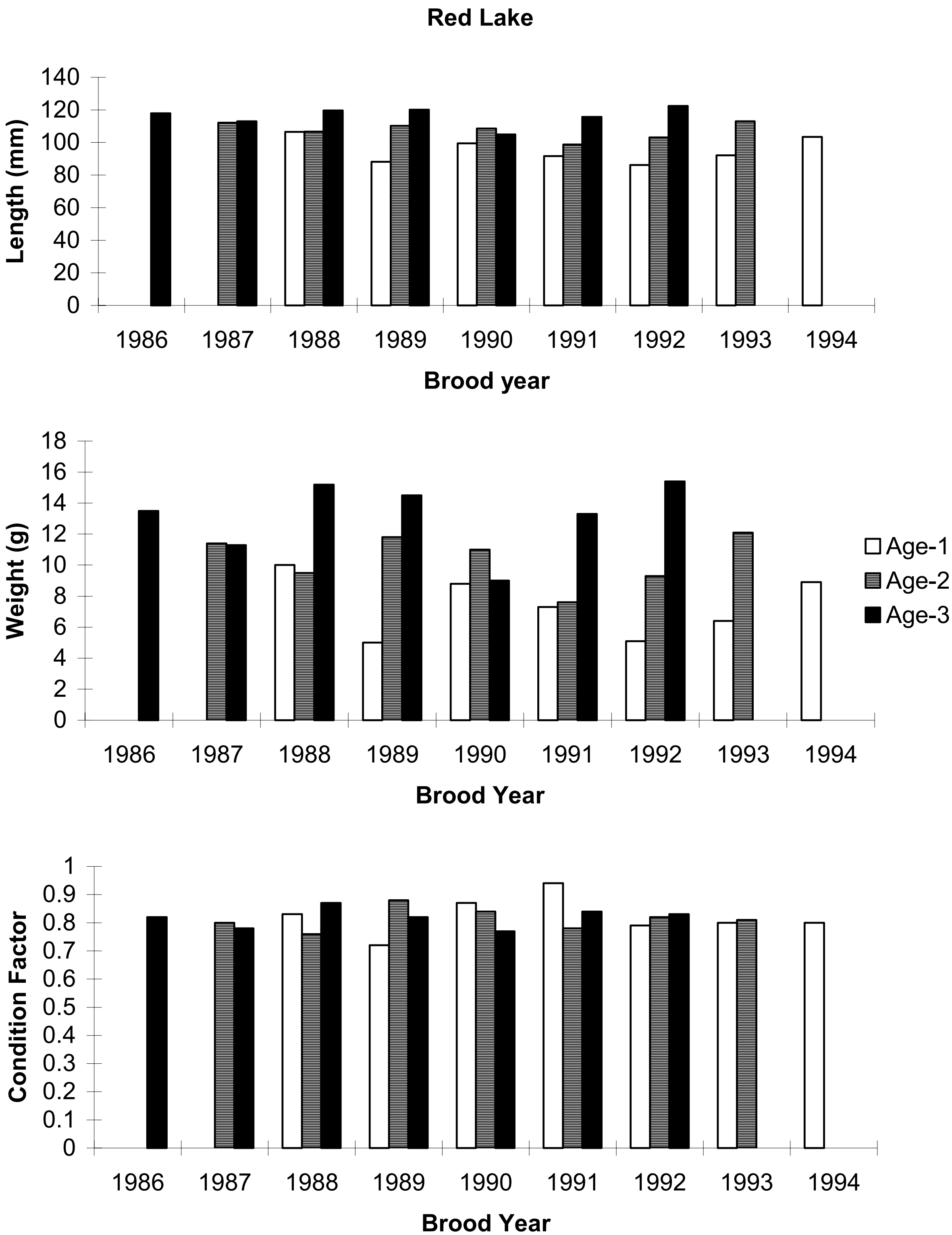


Figure 8.-Red Lake sockeye salmon smolt length, weight, and condition factor by age class and brood year, 1986-1994.

Table 10.-Estimated number of sockeye salmon smolts outmigrating from Akalura Lake by year and age class, 1990-1996.

Smolt Outmigration Year	Number and Relative Percent of Smolt by Age Class 0.	1.	2.	3.	4.	Total Population Estimate	SE	95% CI 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%				

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

b. The 1996 smolt outmigration was enumerated via a counting weir. Estimates of precision are not available.

Table 11.-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
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	270,867	8,561	80	339,615[b]
			17.7%	79.8%	2.5%	0.0%	
1989	116,029	0	8,172	180,557	5,624	0	194,354
			4.2%	92.9%	2.9%	0.0%	
1990	47,181	0	2,173	57,512	8,996	0	68,681
			3.2%	83.7%	13.1%	0.0%	
1991	44,189	21	2,150	91,296	268	0	93,736
			2.3%	97.4%	0.3%	0.0%	
1992	63,269	0	71,495	71,187	1,416	[c]	144,099[b]
			49.6%	49.4%	1.0%		
1993	30,692	128	60,654	228,766	[c]	[c]	[b]
1994	13,681	0	15,639	[c]	[c]	[c]	[b]
1995	2,010	0	[c]	[c]	[c]	[c]	[b]

[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.

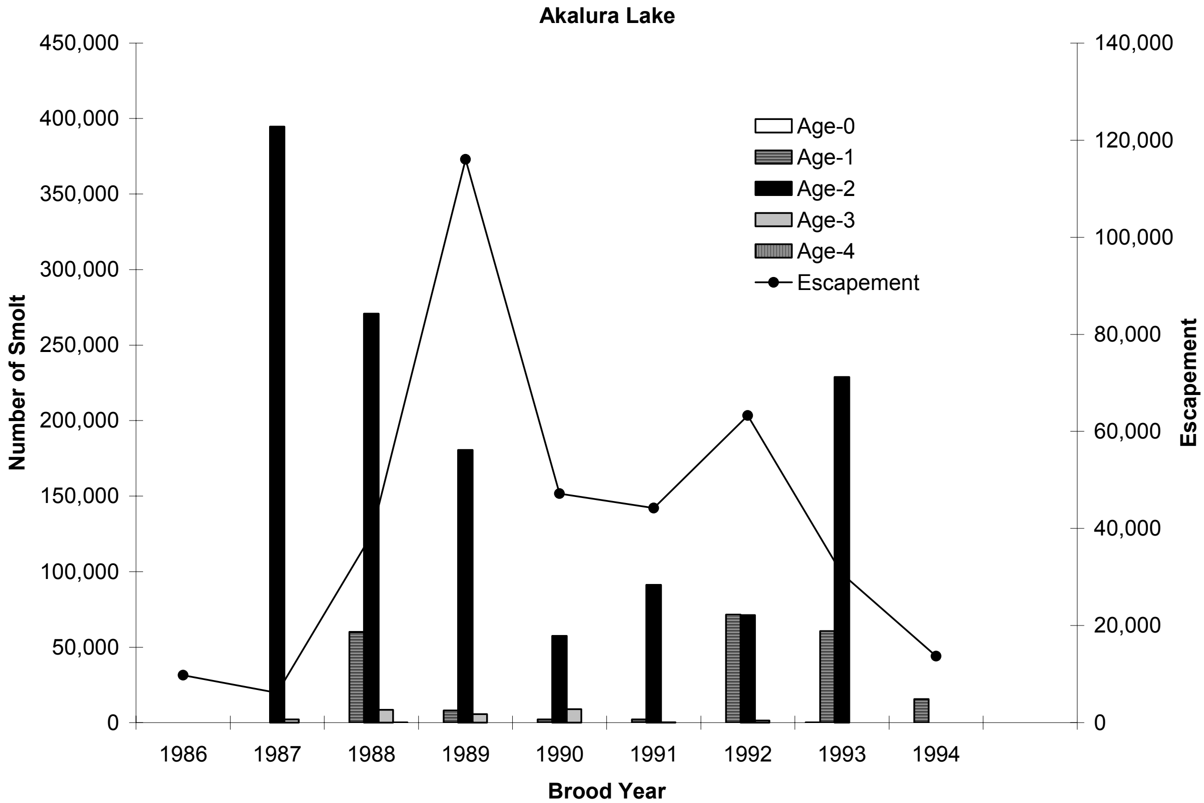


Figure 9.-Relationship between parent year escapement and subsequent smolt production by age class for Akalura Lake sockeye salmon, brood years 1986-1994.

The 1991 spring (8 May) townet catch was only 14 rearing fry of which 31% were age-0 with an average length of 31 mm and 0.3 g; age-1 fish represented 15% of the catch, and age-2 54% (Table 7). Age and size attributes from the 1991 fall surveys (N=160) were 72% age-0 averaging 56 mm and 1.7 g; and age-1 fry (28%) with mean length 91 mm and mean weight of 7.0 g. The fall 1992 age composition was similar to that of 1991, 77% age-0 and 23% age-1; length increased by ~10 mm and weight by 1.0 g for age-0 fry and were static for age-1 fish.

The range of estimated smolt outmigration for this system was 2.1 to 6.6 million fish during 1990-93 (Table 12; Appendix B3). There were four years of smolt data collected and only the 1989 BY was completely reconstructed (Table 13; Figure 11); assuming that age-3 smolts made up a small component of the 1990 BY then by comparison the 1990 BY was substantially less than 1989.

The average length and weight of sockeye smolts ranged from about 55 to 61 mm and 1.5 g to 2.1 g (age-0), age-1 fish length ranged from 81 mm to 93 mm and 4.9 g to 7.9 g, and for age-2 smolts, 100-111 mm and 8.3-11.7 g. The few age-3 smolts sampled were similar to age-2 smolts both in length and weight (Figure 12). Condition factors ranged from 0.8 to 0.9 for all years and age classes.

The relationship between rearing sockeye fry estimates and subsequent smolt outmigrations appear to be more realistic than for either Red or Akalura lakes. Additionally, size at age comparisons for the one year's data that are available point to fall fry to age-1 growth as realistic when compared to data available for sockeye fry. Smolt growth being about 30 mm in length and 4 g in weight over the winter conforms to post-1991 data collected from Red Lake.

Frazer Lake

Total fish population estimates generated using hydroacoustic data have ranged from a low of 1.9 million fish in 1996 to greater than 12.5 million (95% CI 11.7 to 12.3 million) during 1993. Estimates have averaged over seven million fish annually during 1990-94 (Table 6). The rearing sockeye fry percentages from townet surveys conducted during this study varied from 1.0% to 75% with an apparent declining trend since 1991 (Table 6). Rearing sockeye salmon fry estimates were 6.2 million (95% CI 5.3 to 7.2 million) in 1991, declining to 1.5 million in 1992 and again during 1993 to 0.79 million fry. The decreased rearing fry estimates are directly tied to extremely low townet catches.

The dominant age classes of rearing fry captured were age-0 during 1990 and 1993, with age-1 fry being dominant in 1991-92, and 1996. The size of age-0 fish ranged from 44 mm and 1.0 g (1996) to 64 mm and 2.9 g during 1992 (Table 7). The age-1 fry ranged in size from 58 mm and 2.2 g during 1996 to 87 mm and 6.5 g in 1992. In 1993-94 sockeye smolts were found to have very low condition coefficients which could be attributed to measurement error; however, K values from other years approached or exceeded 1.0.

During 1991-96 annual estimated smolt emigrations have ranged from 3.8 million (1996) to 8.8 million (1995) fish (Table 14; Appendix B4). The largest smolt outmigration was 10.2 million fish resulting from a parent escapement of 360,373 adults (Table 15; Figure 13) of which approximately 33% were age-3 fish.

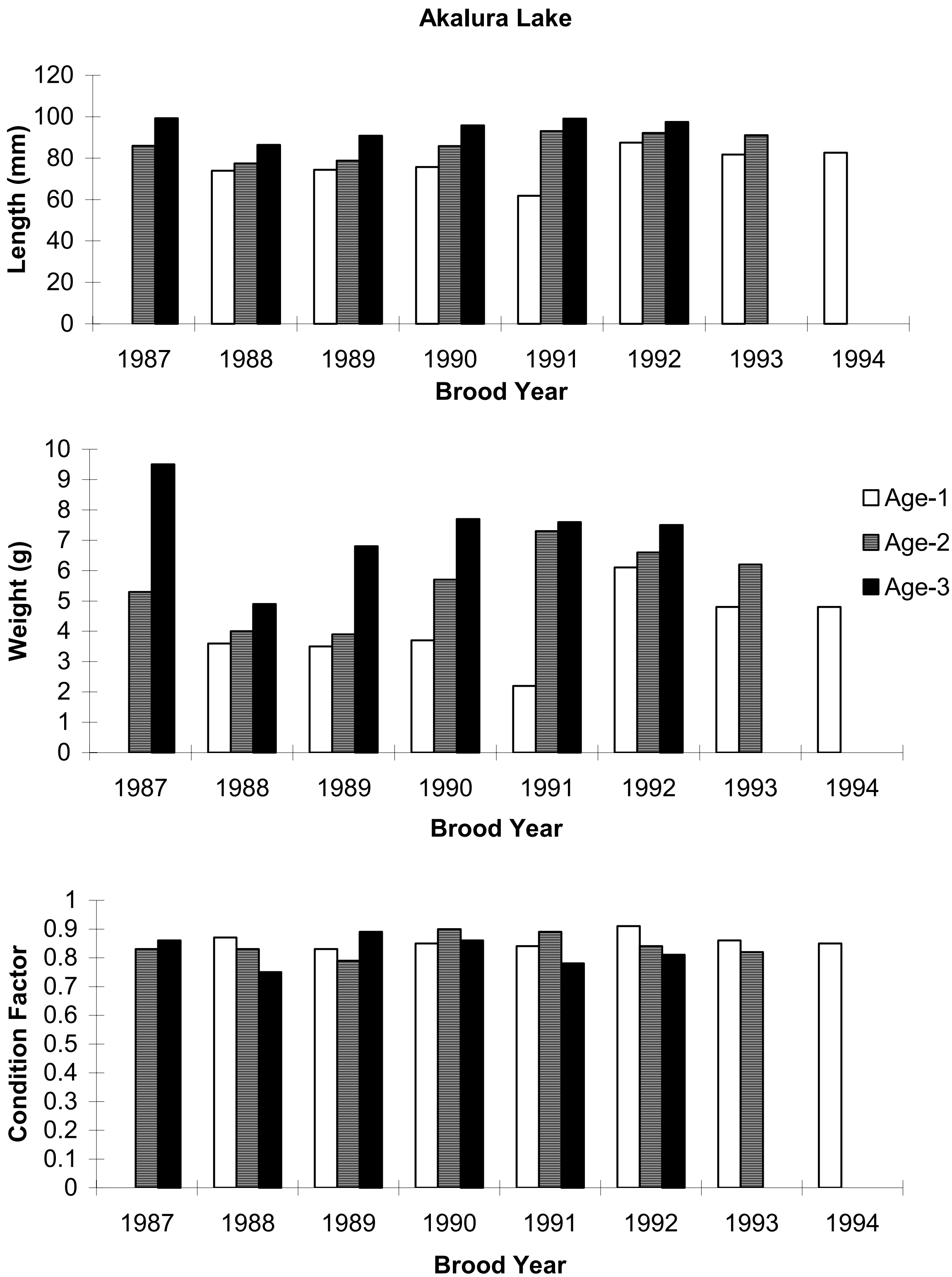


Figure 10.-Akalura Lake sockeye smolt length, weight and condition factor by age class and brood year, 1986-1994.

Table 12.-Estimated number of sockeye salmon smolt outmigrating from Upper Station lakes by year and age class, 1990-1993.

Smolt Outmigration Year	Number and Relative Percent Of Smolt by Age Class				Total Population Estimate	SE	95% CI	
	0.	1.	2.	3.			Lower	Upper
1990	5,188,222	156,344	1,171,183	54,581	6,570,331	881,065	4,843,443	8,297,219
	79.0%	2.4%	17.8%	0.8%		***1,018,105***	***5,066,571***	***8,924,036*** [a]
1991	1,730,763	200,531	222,037	15,637	2,168,968	263,019	1,653,451	2,684,485
	79.8%	9.2%	10.2%	0.7%		***296,221***	***1,704,019***	***2,832,030***
1992	1,870,009	43,823	222,668	1,065	2,137,565	193,335	1,758,628	2,516,502
	87.5%	2.1%	10.4%	0.0%		***209,146***	***1,790,761***	***2,595,910***
1993	3,187,854	620,651	502,347	13,163	4,324,015	294,599	3,746,601	4,901,429
	73.7%	14.4%	11.6%	0.3%		***304,345***	***3,831,942***	***5,015,391***

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

Table 13.-Adult sockeye salmon escapement and estimated smolt outmigration from Upper Station lakes by brood year and age class, 1986-1993.

Brood Year	Escapement	Smolt Numbers by Age and Percent 0.	1.	2.	3.	Total
1986	466,385	[a]	[a]	[a]	54,581	54,581 [b]
1987	232,195	[a]	[a]	1,171,183	15,637	1,186,820 [b]
1988	306,560	[a]	156,344	222,037	1,065	379,445 [b]
1989	286,288	5,188,222	200,531	222,668	13,163	5,624,584
		92.2%	3.6%	4.0%	0.2%	
1990	254,446	1,730,763	43,823	502,347	[a]	2,276,933 [b]
1991	292,886	1,870,009	620,651	[a]	[a]	2,490,660 [b]
1992	218,143	3,187,854	[a]	[a]	[a]	3,187,854 [b]
1993	222,381	[a]	[a]	[a]	[a]	

[a] Smolt migration not monitored.

[b] Incomplete brood year data.

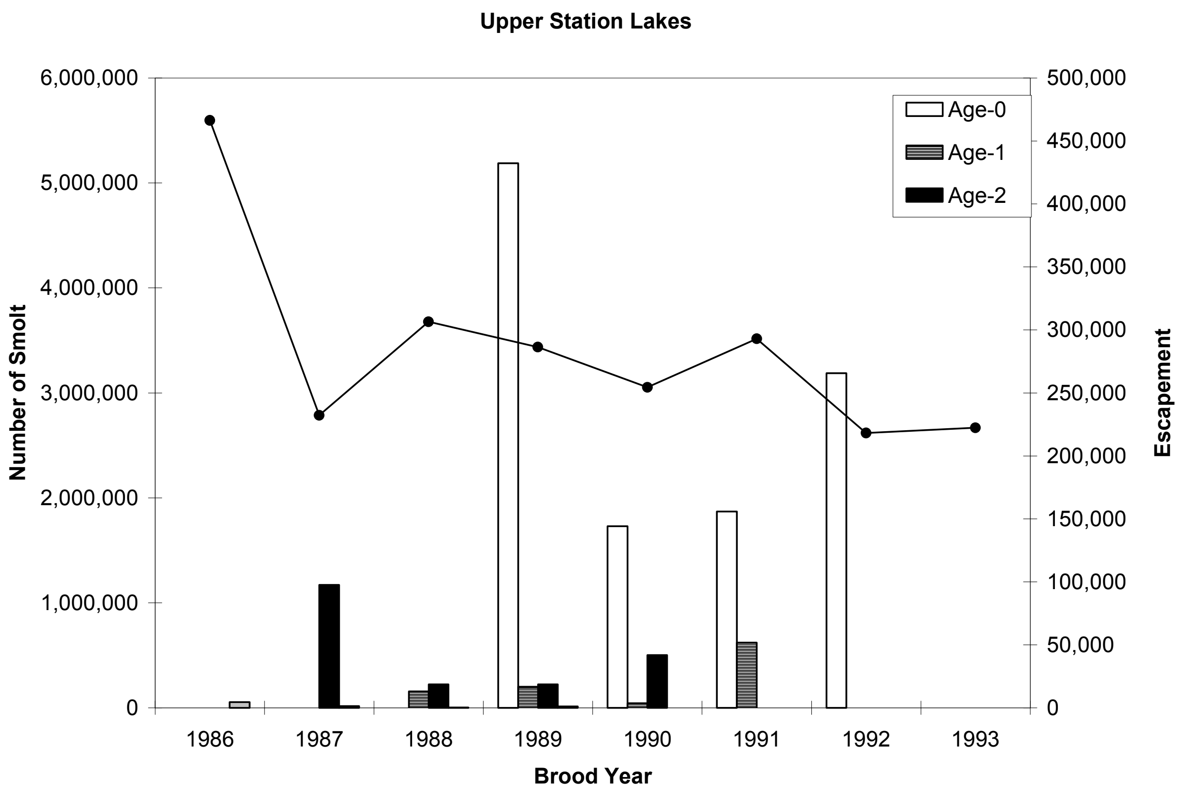


Figure 11.-Relationship between sockeye salmon parent year escapement and subsequent smolt production by age class for Upper Station lakes, brood years 1986-1993.

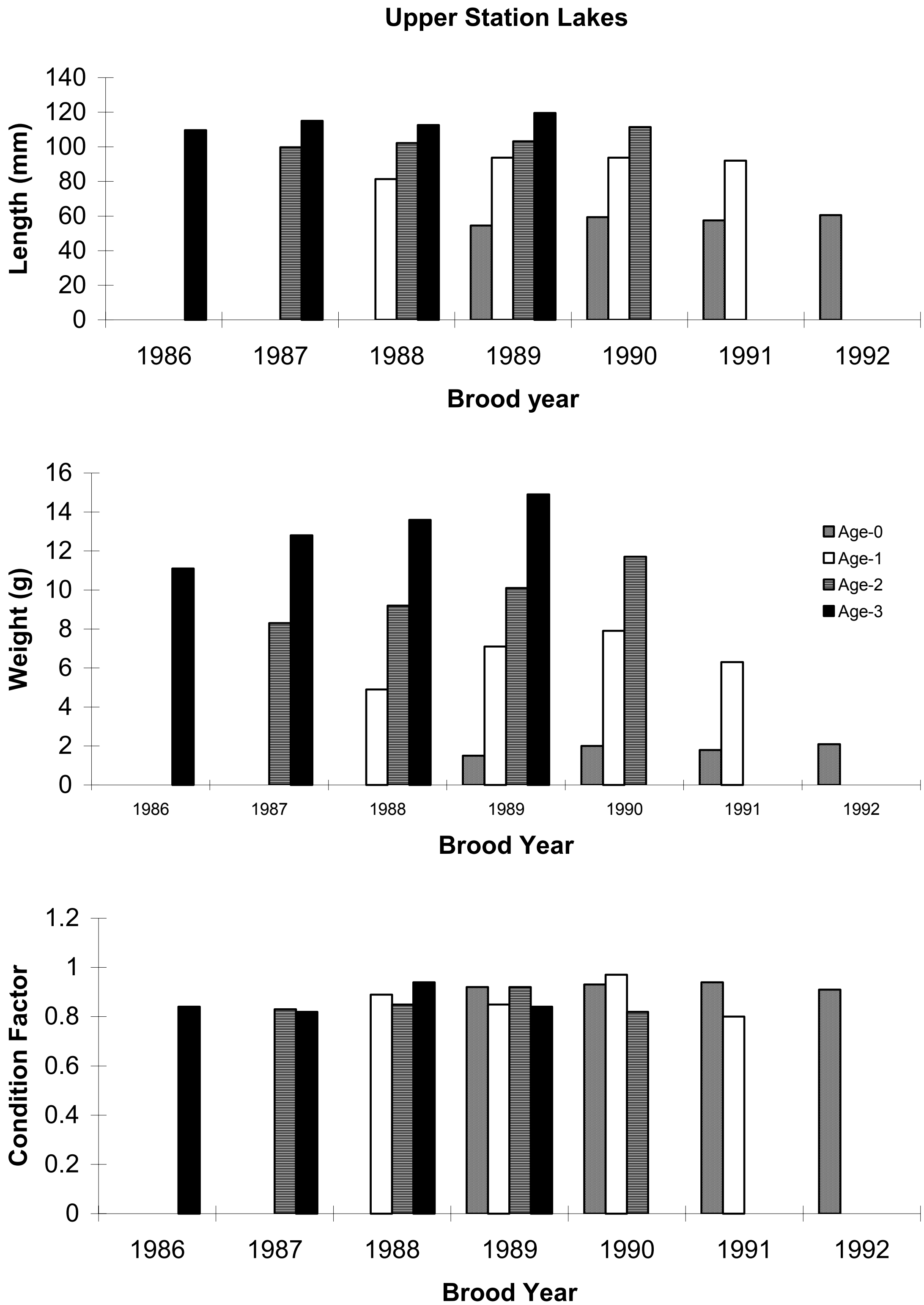


Figure 12.-Upper Station lakes sockeye salmon smolt length, weight, and condition factor by age class and brood year, 1986-1992.

Smolt length and weight statistics by age class ranged from 86 to 91 mm and 5.2 – 6.2 g (age-1), 83 to 103 mm and 5.2 g – 8.3 g for age-2 fish, and 91 mm – 121 mm and 7.2 g to 15.7 g for age-3 smolts (Figure 14). Condition factors ranged from 0.73 to 0.94 for all years and age classes sampled.

Smolt to Adult Survival (SAS) and Preseason Forecasting
As mentioned previously, both smolt and adult return estimates are likely biased owing to violations of either mark-recapture or run reconstruction assumptions. The smolt to adult survival relationships may be erroneous, however are reported, as predictive smolt to adult relationships were an objective of the original study plan.

Estimates of SAS varied from 2% to nonsensical values greater than 300% among all brood years, age classes and study lakes (Table 16). There were numerous SAS estimates from the Red and Upper Station sockeye stocks that were greater than 100% and therefore biased. The SAS estimates from Akalura and Frazer with the exception of age-1 (1989 BY; ~344% SAS deemed an outlier) were within empirical ranges from other Alaskan sockeye salmon stocks so the analyses were performed. The linear regression analyses between smolt length and SAS for the Akalura and Frazer systems both independently and combined (Figure 15) resulted in a significant negative relationship between smolt length and SAS for both the Akalura data and pooled Akalura-Frazer data (P=0.02 and P=0.01). Analyses performed only on smolt length and SAS with the Frazer data resulted in an insignificant relationship.

Overall, the suitability of using smolt and adult return data to develop preseason forecasts showed promise in explaining some of the variability in adult return but all of the relationships suffer from small sample sizes. These apparent relationships have the likelihood of becoming spurious as additional data points are added.

Considering the forecasting relationship employed for Red Lake sockeye salmon, two of the nine relationships were significant ($P \leq 0.10$; Table 17; Figure 16). Both of these relationships predicted returning two ocean fish and the age-3.2 forecast in particular explained a majority of the variability in return ($r^2 = 0.90$). These apparent relationships are suspect because they encompass data points with smolt to adult ratios greater than 100%.

Two of nine relationships assembled using Akalura data were also significant at $\alpha = 0.10$ (Table 17**;** Figure 17). The number of age-1 emigrating smolts explained about 71% of the variability in the number of age-1 adult returns, while age-2 smolt numbers explained 84% of variability in age-2.2 adult return.

The Upper Station run forecast relationship was constructed by pooling both the early and late run brood table data since emigrating smolts could not be segregated by temporal component. Three of twelve regressions were significant ($P \leq 0.10$) and were able to explain between 81% data point at the high end of the smolt-adult return spectrum, thus heavily influencing the regressions statistics.

The Frazer Lake forecasting regressions generated four significant relationships out of eight constructed (Figure 19). Similar to Upper Station, the Frazer models contained a single very influential data point that dominated the fit of the regressions and prompted formulating a second set of relationships with the potential outlier removed.

Table 14.-Estimated number of sockeye salmon smolt outmigrating from Frazer Lake by year and age class, 1991-1996.

Smolt Outmigration Year	Number and Relative Percent of Smolt by Age Class				Total Population Estimate	SE	95% CI	
	1.	2.	3.	4.			Lower	Upper
1991	1,940,906	2,870,690	6,905	0	4,818,501	1,077,978	2,705,664	6,931,337
	40.3%	59.6%	0.1%	0.0%		***1,186,633***	***3,172,021***	***7,820,482***
1992	82,415	4,978,109	305,253	0	5,365,777	624,657	4,141,448	6,590,106
	1.5%	92.8%	5.7%	0.0%		***679,871***	***4,257,624***	***6,870,418*** [a]
1993	22,221	4,046,434	3,364,676	966	7,434,298	1,397,839	4,694,534	10,174,062
	0.3%	54.4%	45.3%	0.0%		***1,611,530***	***5,121,858***	***11,390,654***
1994	673,765	4,450,246	537,478	0	5,661,489	344,992	4,985,306	6,337,672
	11.9%	78.6%	9.5%	0.0%		***352,368***	***5,059,556***	***6,433,932***
1995	53,410	8,684,874	85,492	0	8,823,777	551,775	7,742,298	9,905,256
	0.6%	98.4%	1.0%	0.0%		***551,595***	***7,878,816***	***10,022,259***
1996	57,487	3,480,272	282,845	0	3,820,604	268,297	3,294,742	4,346,466
	1.5%	91.1%	7.4%	0.0%		***275,331***	***3,360,404***	***4,411,103***

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

Table 15.-Adult sockeye salmon escapement and estimated smolt outmigration from Frazer Lake by brood year and age class, 1986-1995.

Brood Year	Escapement	Smolt Numbers by Age and Percent 1.	2.	3.	4.	Total
1986	126,529	[a]	[a]	[a]	0	[b]
1987	40,544	[a]	[a]	6,905	0	[b]
1988	246,704	[a]	2,870,690	305,253	966	3,177,110 [b]
1989	360,373	1,940,906	4,978,109	3,364,676	0	10,283,692
		18.9%	48.4%	32.7%	0.0%	
1990	226,960	82,415	4,046,434	537,478	0	4,666,327
		1.8%	86.7%	11.5%	0.0%	
1991	190,358	22,221	4,450,246	85,492	0	4,557,959
		0.5%	97.6%	1.9%	0.0%	
1992	185,825	82,415	8,684,874	282,845	[c]	8,581,171 [b]
		1.0%	95.7%	3.3%		
1993	178,391	53,410	3,480,272	[c]	[c]	[b]
1994	206,071	57,487	[c]	[c]	[c]	[b]
1995	196,362	[c]	[c]	[c]	[c]	

[a] Smolt migration not monitored.
[b] Incomplete brood year data.
[c] Smolt of this age class have not outmigrated.

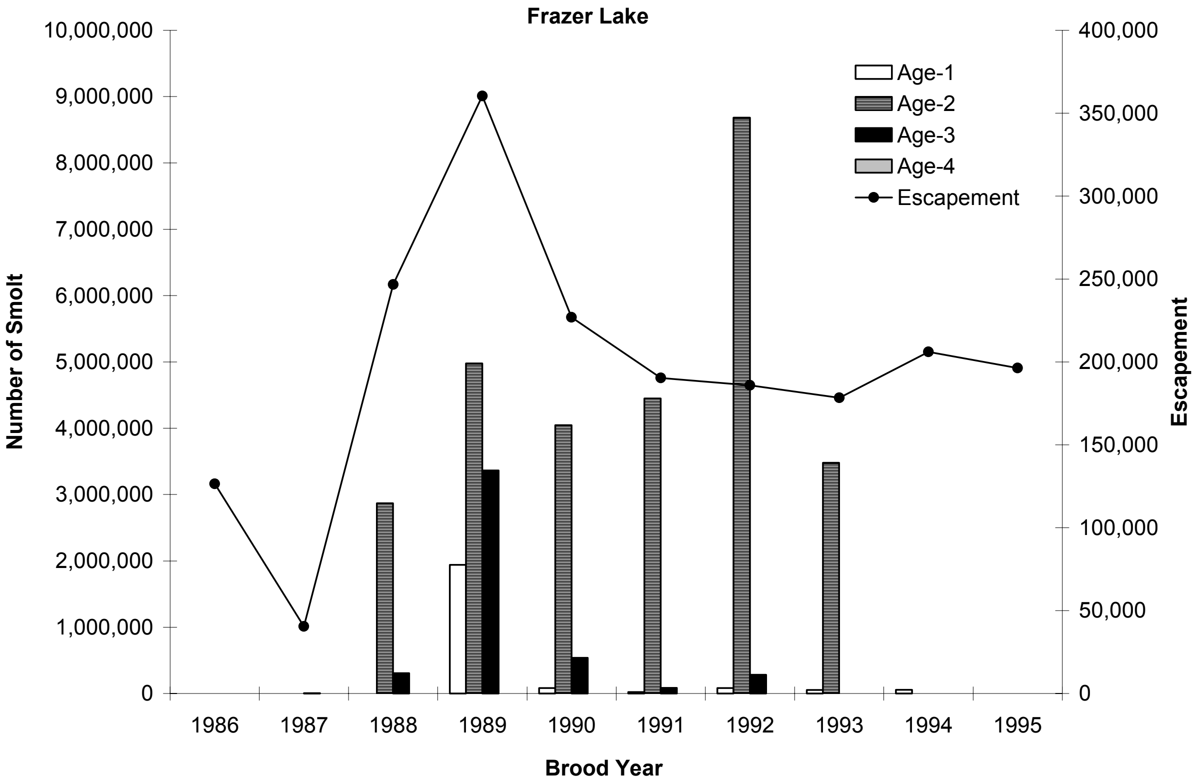


Figure 13.-Relationship between parent year escapement and subsequent smolt production by age class for Frazer Lake sockeye salmon, brood years 1986-1994.

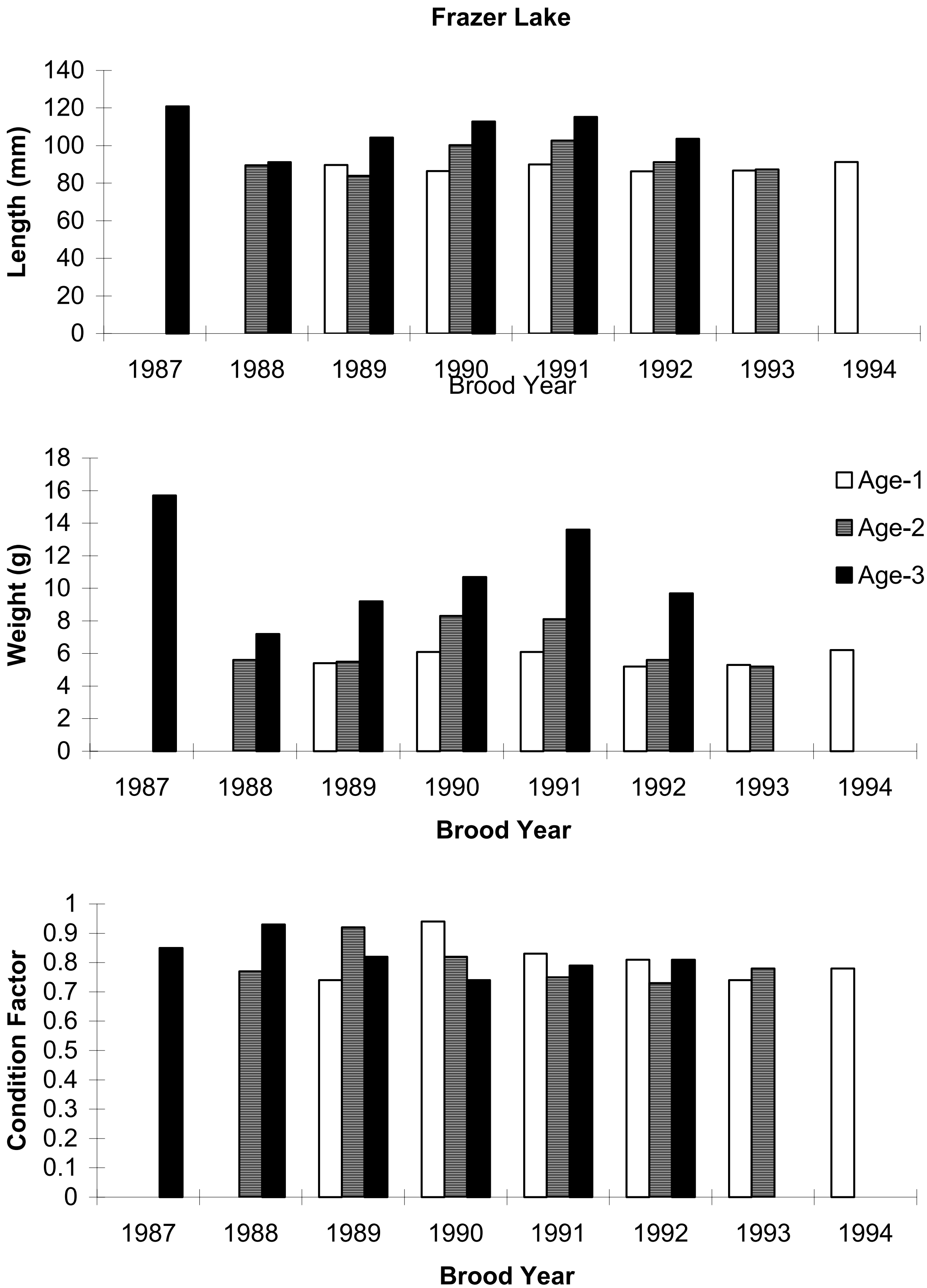


Figure 14.-Frazer Lake sockeye salmon smolt length, weight, and condition factor by age class and brood year, 1986-1994.

and 94% of the variability in adult return (Figure 18). Each regression contained an influential

Table 16.-Smolt to adult survival estimates (SAS) for Red, Akalura, Upper Station and Frazer lakes by brood year and age class, 1986-1992.

Lake System	Brood Year	Age 0.			Age 1.			Age 2.			Age 3.		
		Smolt	Adult	SAS	Smolt	Adult	SAS	Smolt	Adult	SAS	Smolt	Adult	SAS
Red Lake	1986	[a]									4,241	5,967	141%
	1987							389,336	672,472	173%	37,147	37,870	102%
	1988				274,434	146,565	53%	109,633	156,739	143%	17,243	18,880	109%
	1989				123,920	47,186	38%	1,343,862	594,125	44%	62,514	105,791	169%
	1990				31,915	63,681	200%	170,907	512,405	300%			
	1991				328,698	561,590	171%						
Akalura Lake	1986	[a]									0	232	---
	1987							394,652	102,545	26%	2,181	434	20%
	1988				60,107	9,560	16%	270,867	45,677	17%	8,561	278	3%
	1989				8,172	28,128	344%	180,557	60,153	33%	5,624	98	2%
	1990				2,173	1,174	54%	57,512	2,444	4%			
	1991				2,150	1,484	69%						
Upper Station Lakes	1986										54,581	3,676	7%
	1987							1,171,183	192,100	16%	15,637	15,974	102%
	1988				156,344	150,157	96%	222,037	128,913	58%	1,065	2,703	254%
	1989	5,188,222	261,503	5%	200,531	153,554	77%	222,668	331,597	149%	13,163	308	2%
	1990	1,730,763	176,272	10%	43,823	68,298	156%	502,347	379,786	76%			
	1991	1,870,009	241,320	13%	620,651	216,089	35%						
	1992	3,187,854	89,403	3%									
Frazer Lake	1987	[a]									6,905	986	14%
	1988							2,870,690	282,960	10%	305,253	28,637	9%
	1989				1,940,906	497,198	26%	4,978,109	686,306	14%	3,364,676	191,829	6%
	1990				82,415	52,706	64%	4,046,434	624,469	15%			
	1991				22,221	4,380	20%						

[a] Insufficient data to estimate smolt-to-adult survival.

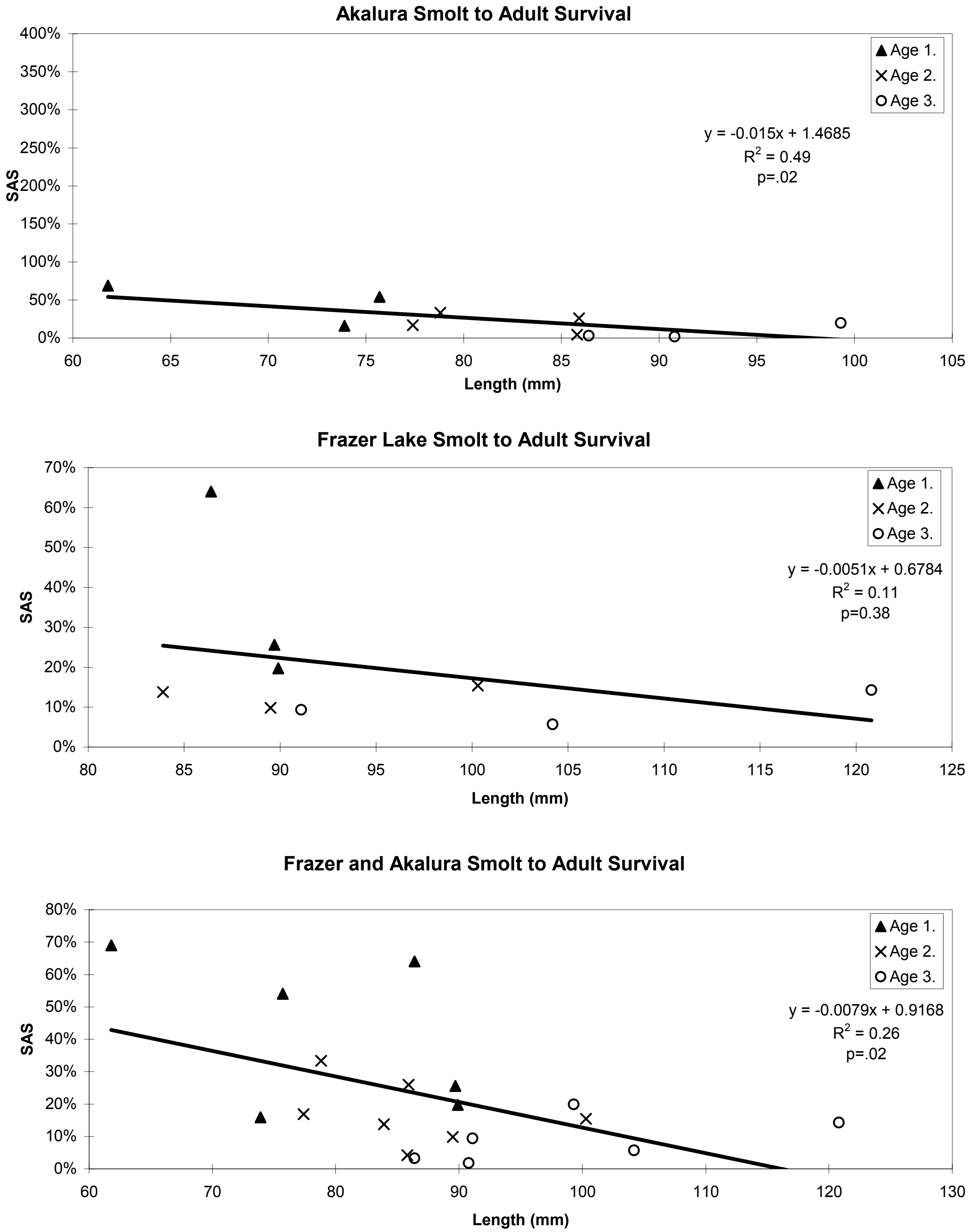


Figure 15.-Simple linear regressions of sockeye salmon smolt to adult survival (SAS) on smolt length for Akalura and Frazer lakes smolt, and Akalura-Frazer pooled by age class.

Table 17.-Simple linear regression relationships using smolt outmigration estimates by freshwater age class to predict adult returns for Red, Akalura, Upper Station, and Frazer lakes.

System	Independent variable	Dependent Variable	Regression Statistics				
			Slope	Intercept	r^2	p value	n
Red	Age 1. smolt	Age 1.1	0.04	-206	0.51	0.11	6
		Age 1.2	0.34	10746	0.69	0.08	5
		Age 1.3	0.89	-34981	0.48	0.31	4
	Age 2. smolt	Age 2.1	0.02	12545	0.36	0.21	6
		Age 2.2	0.08	266291	0.10	0.61	5
		Age 2.3	0.10	157276	0.18	0.58	4
	Age 3. smolt	Age 3.2	0.82	4834	0.90	0.01	5
		Age 3.3	0.87	-14248	0.75	0.33	3
Akalura	Age 1. smolt	Age 1.1	0.01	30	0.72	0.07	5
		Age 1.2	0.00	5596	0.00	0.97	5
		Age 1.3	0.07	3354	0.17	0.59	4
	Age 2. smolt	Age 2.1	0.06	1409	0.08	0.65	5
		Age 2.2	0.27	-20713	0.84	0.03	5
		Age 2.3	0.01	2171	0.03	0.84	4
	Age 3. smolt	Age 3.1	-0.01	54	0.49	0.19	5
		Age 3.2	0.00	202	0.01	0.88	5
		Age 3.3	-0.01	80	0.08	0.72	4
Upper Station	Age 0. smolt	Age 0.1	0.00	6317	0.28	0.47	4
		Age 0.2	0.03	-11941	0.87	0.07	4
		Age 0.3	-0.02	159713	0.21	0.54	4
	Age 1. smolt	Age 1.1	0.01	1030	0.52	0.28	4
		Age 1.2	0.10	52093	0.64	0.20	4
		Age 1.3	0.11	38673	0.81	0.10	4
	Age 2. smolt	Age 2.1	-0.01	12742	0.16	0.60	4
		Age 2.2	-0.06	246609	0.06	0.76	4
		Age 2.3	0.02	23840	0.10	0.68	4
	Age 3. smolt	Age 3.1	-0.01	305	0.45	0.33	4
		Age 3.2	-0.04	5923	0.02	0.86	4
		Age 3.3	0.03	-287	0.94	0.03	4
Frazer	Age 1. smolt	Age 1.1	0.01	1486	0.97	0.002	5
		Age 1.2	0.17	3095	0.999	0.0003	4
	Age 2. smolt	Age 2.1	0.01	-24738	0.65	0.10	5
		Age 2.2	0.08	21187	0.65	0.20	4
	Age 3. smolt	Age 3.1	0.002	102	0.97	0.02	4
		Age 3.2	0.04	-9	0.99	0.004	4

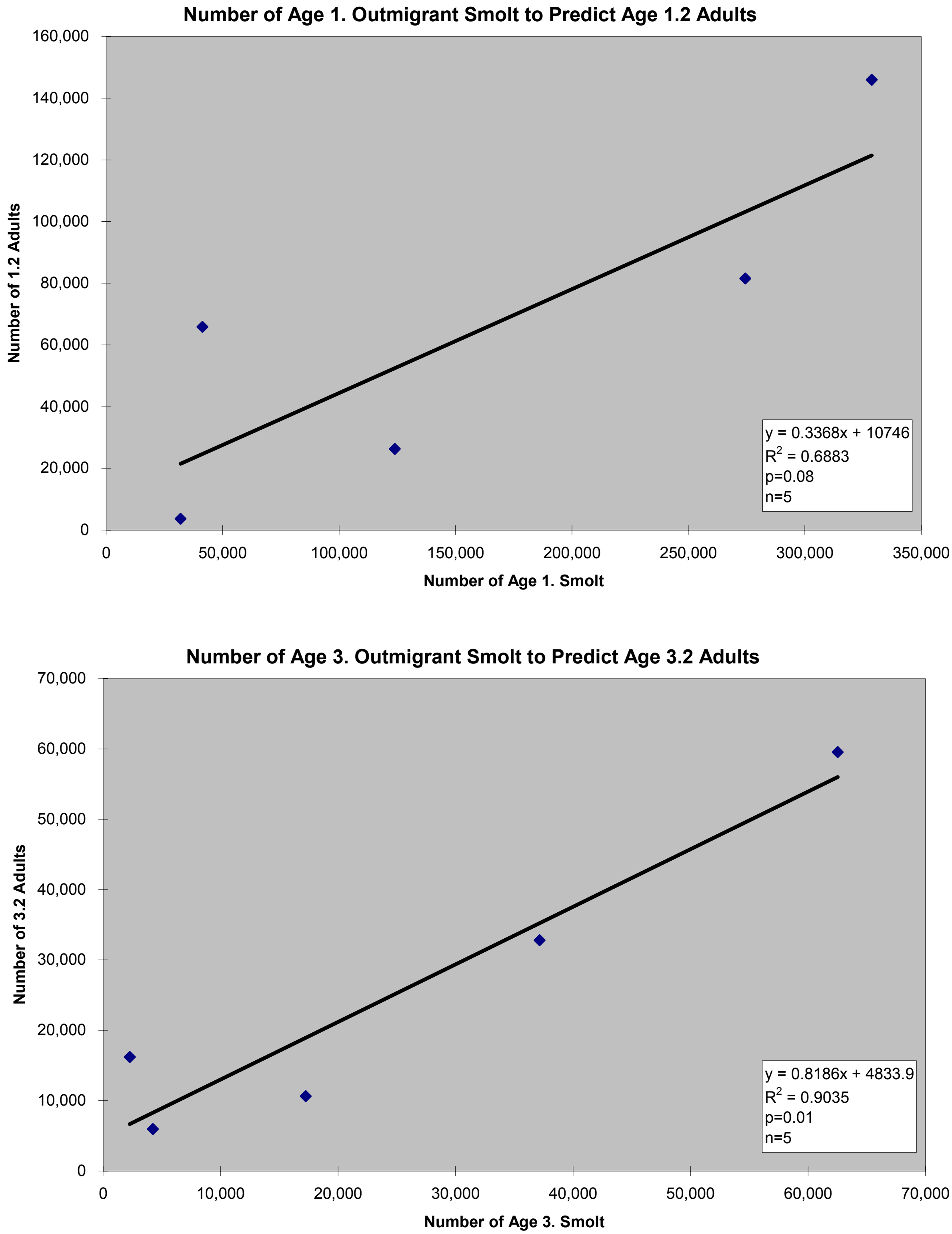
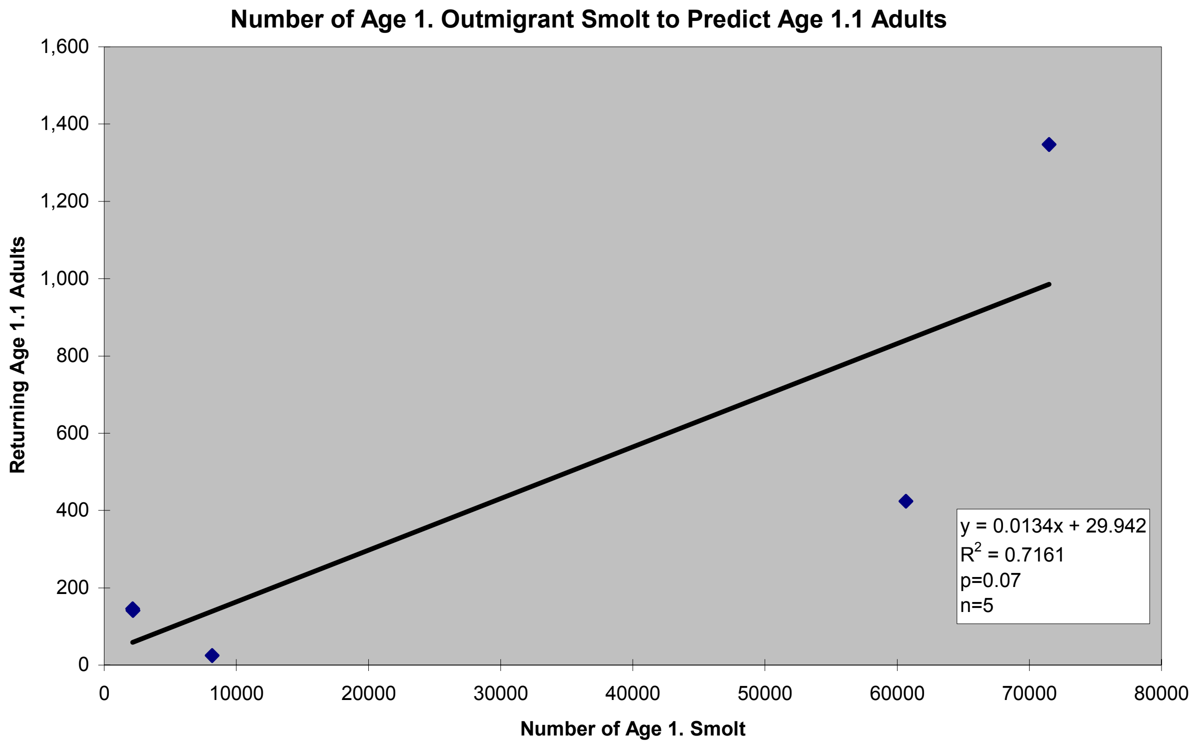


Figure 16.-Significant simple linear regressions of age-1 and age-3 sockeye smolts for predicting adult returns for Red Lake sockeye salmon.



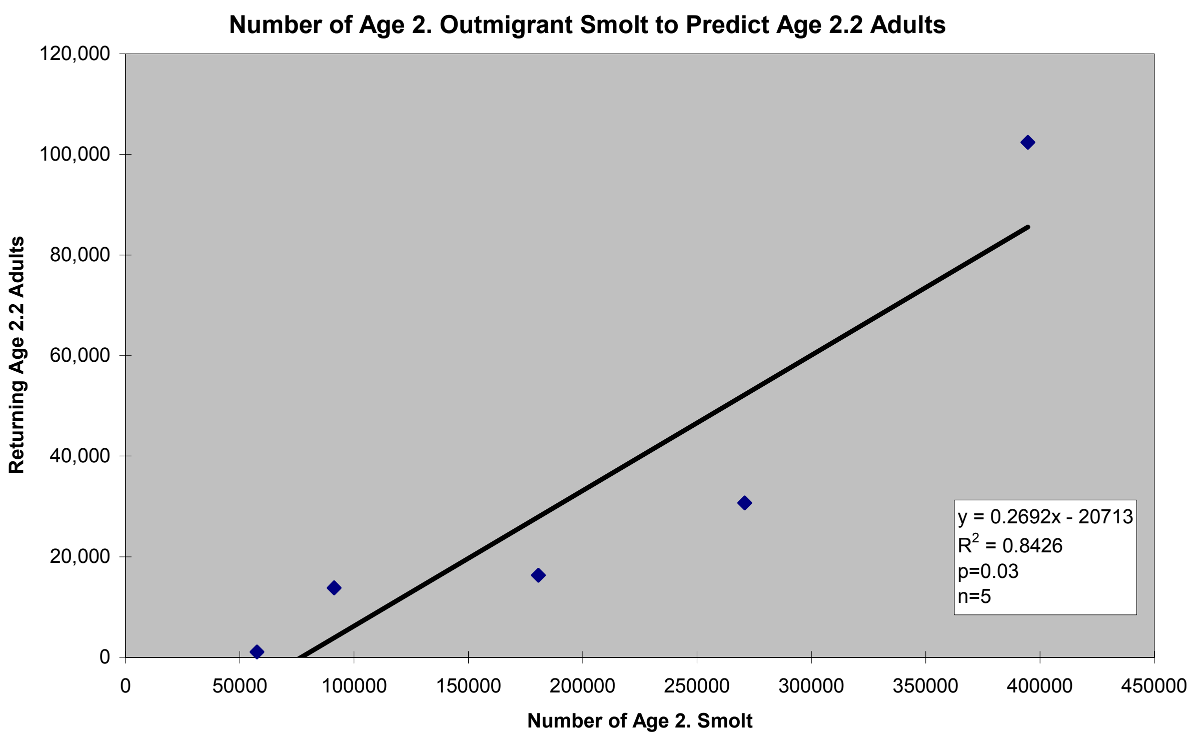


Figure 17.-Significant regressions of age-1 and age-2 Akalura Lake sockeye salmon smolts for predicting adult returns.

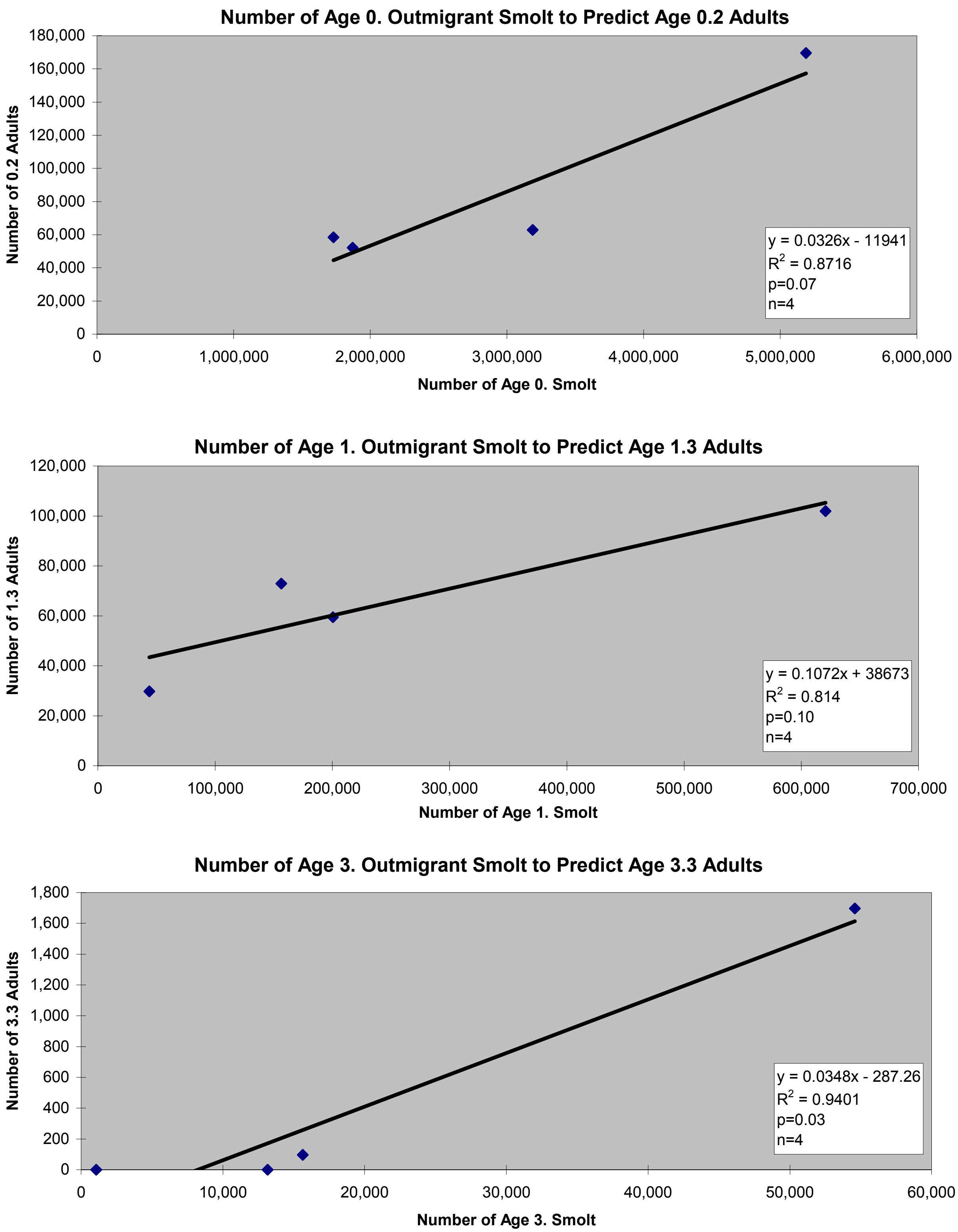


Figure 18.-Significant simple linear regressions of age-0, age-1, and age-2 smolts (early and late runs pooled) for predicting adult returns to the Upper Station lakes.

Stock Recruit Models

The relationship between spawners and returns was evaluated for Red Lake, early and late Upper Station and the Frazer Lake sockeye stocks; the Akalura system had an insufficient time series of data (Appendix C1). The density independent model best fit the Red Lake and late run Upper Station data based upon the BIC (Figures 20-23). Also, when Ricker curves were fit to these data sets, the density dependent parameter was not significantly different from zero suggesting a density independent relationship. Generally, these relationships are poor at high escapement levels.

The control system (Frazer Lake) spawner-return relationship was best represented by a Ricker model with multiplicative error structure (Figure 19). The variance and 80% CI range for the Ricker parameters conform well with estimates derived from both linear and bootstrap procedures. This analysis provides an estimate of S_{MSY} of 116,909 spawners (80% CI range 85,077-211,330; Appendix C2**).**

DISCUSSION

MACROZOOPLANKTON COMMUNITY AND GRAZING EFFECTS

In comparing the Kodiak sockeye salmon systems within this investigation to the 29 Alaskan systems reviewed within Kyle (1996) both the Red and Akalura lakes would rank in the upper half in terms of secondary production while Frazer Lake ranked 23rd. The macrozooplankton data presented for the study lakes elude to the Red and Akalura systems being more productive and therefore resilient to the potential affects of overgrazing. This comparison points to both these systems being better than average in terms of secondary production, and certainly more productive then either the Upper Station or Frazer Lake systems.

The influence of heightened planktivorous grazing can be inferred from two potential data sources, abrupt changes in species composition (shift from cladocera to copepod species) or decreases in size of the available zooplankters for sockeye forage. However there are other factors such as the presence of competing species (stickleback), changes in zooplankton behavior, reproductive capacity, or nutrient cycling (Schindler 1992; Gliwicz 1994; Kyle 1996). These confounding factors aside, for Red Lake the overall density and biomass of the primary zooplankters exhibited decreases that were not statistically significant but did decrease and then increase once fry from the 1989 escapement outmigrated as smolts. Unfortunately, size data were unavailable for this system. There was no apparent affect of cropping down of *Daphnia*, which were in low numbers throughout the study period. For Akalura Lake, the overall density of zooplankters showed a marked decrease during 1990-1992 as did both size and density metrics for *Eurytemora* and *Cyclops*. The density of *Bosmina* exhibited a decrease but no companion size reduction was evident.

SMOLT POPULATION ESTIMATE BIAS

All mark-recapture estimators require that assumptions be met to assure unbiased abundance estimates are obtained. Given the mark-recapture techniques employed in this study, the following assumptions must hold true among strata: (1) the population is closed; (2) all smolts have identical capture probabilities; (3) probability of capture is constant; (4) marks are not lost between release and recovery; (5) all marked smolts are reported on recover; and (6) all marked smolts are either recovered or pass by the recapture site (Carlson et al. 1998). In practice the

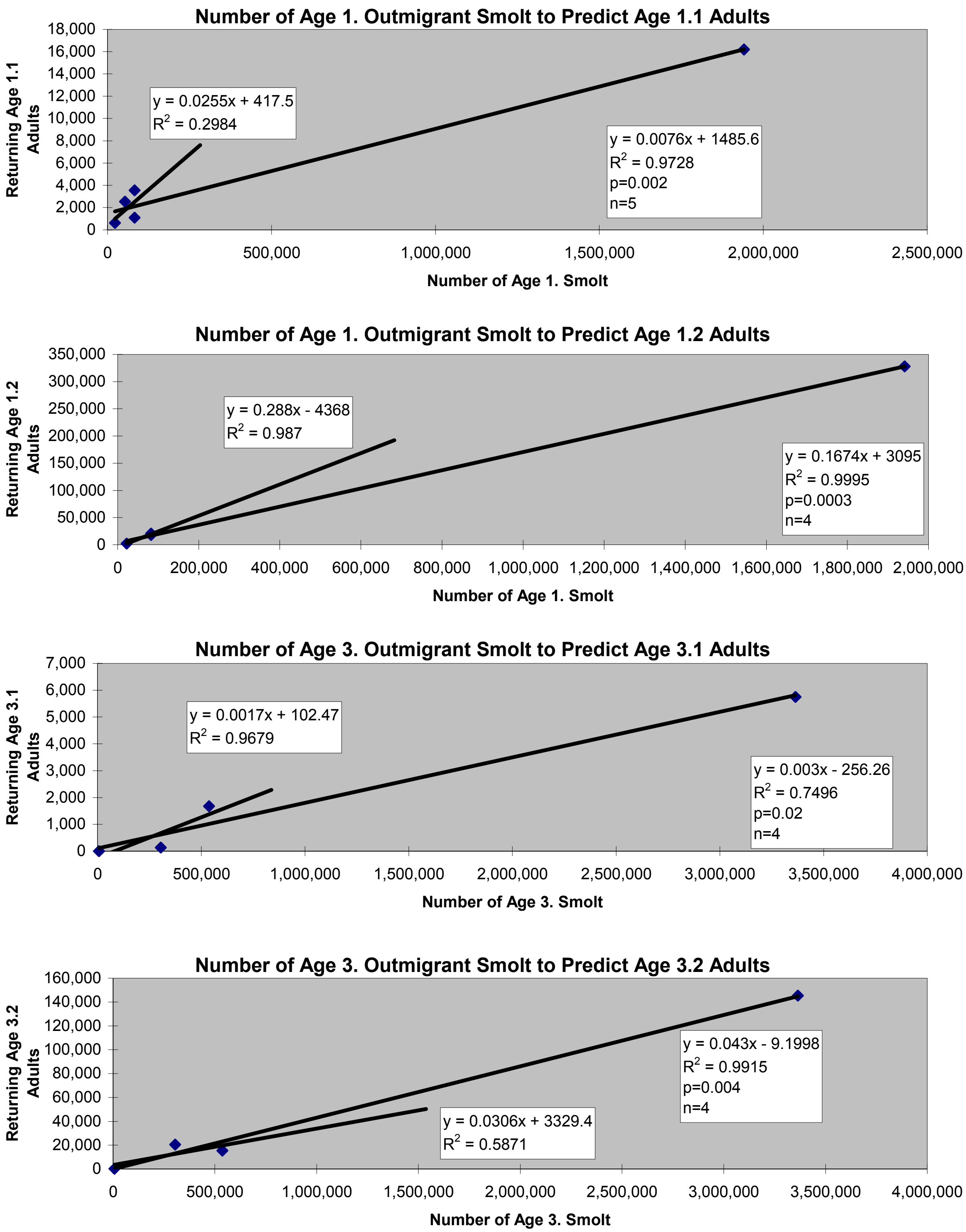


Figure 19.-Significant simple linear regressions of age-1 and age-3 Frazer Lake sockeye salmon smolts for predicting adult returns.

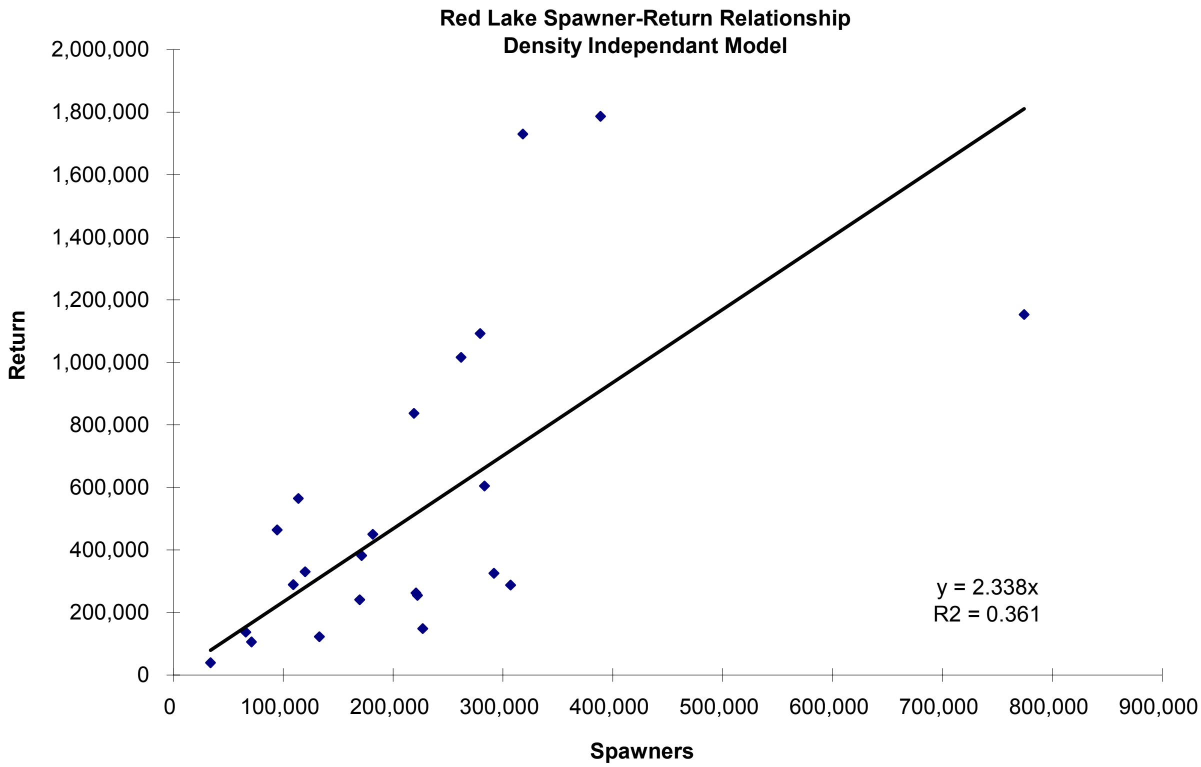


Figure 20.-Red Lake sockeye salmon spawner-return relationship using a density independent model.

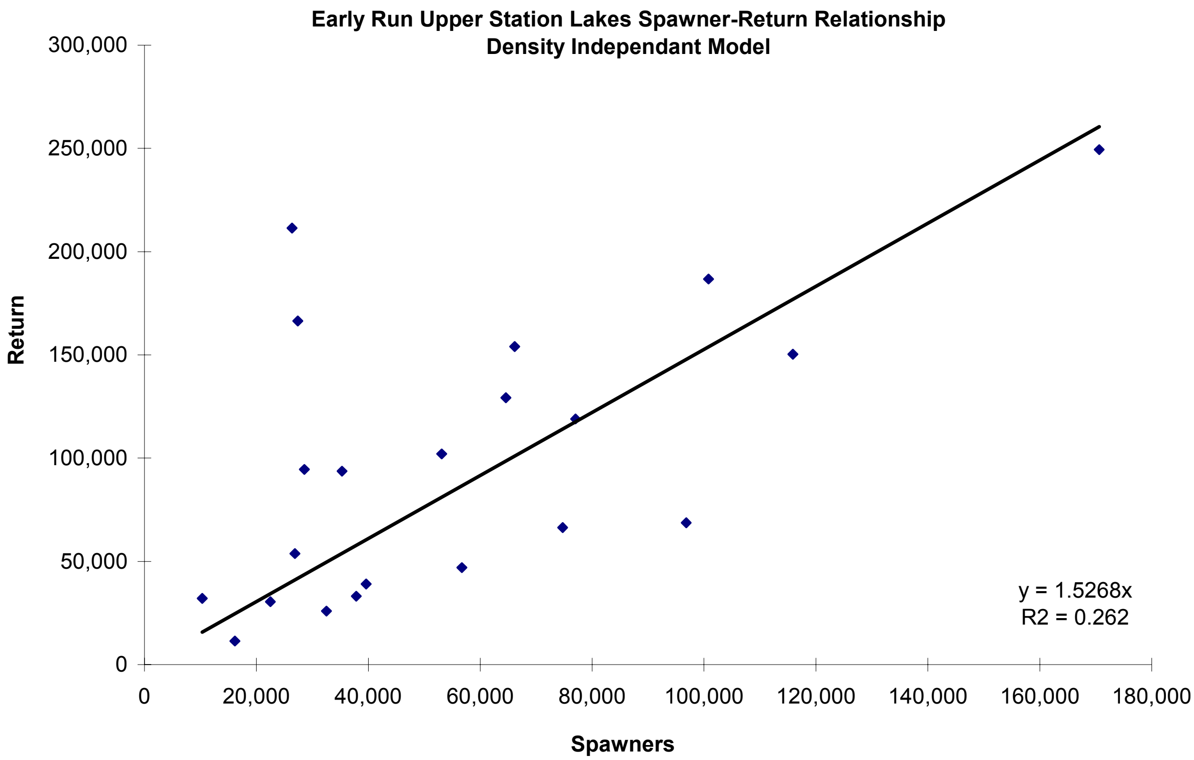


Figure 21.-Upper Station lakes early run sockeye salmon spawner-return relationship using a density independent model.

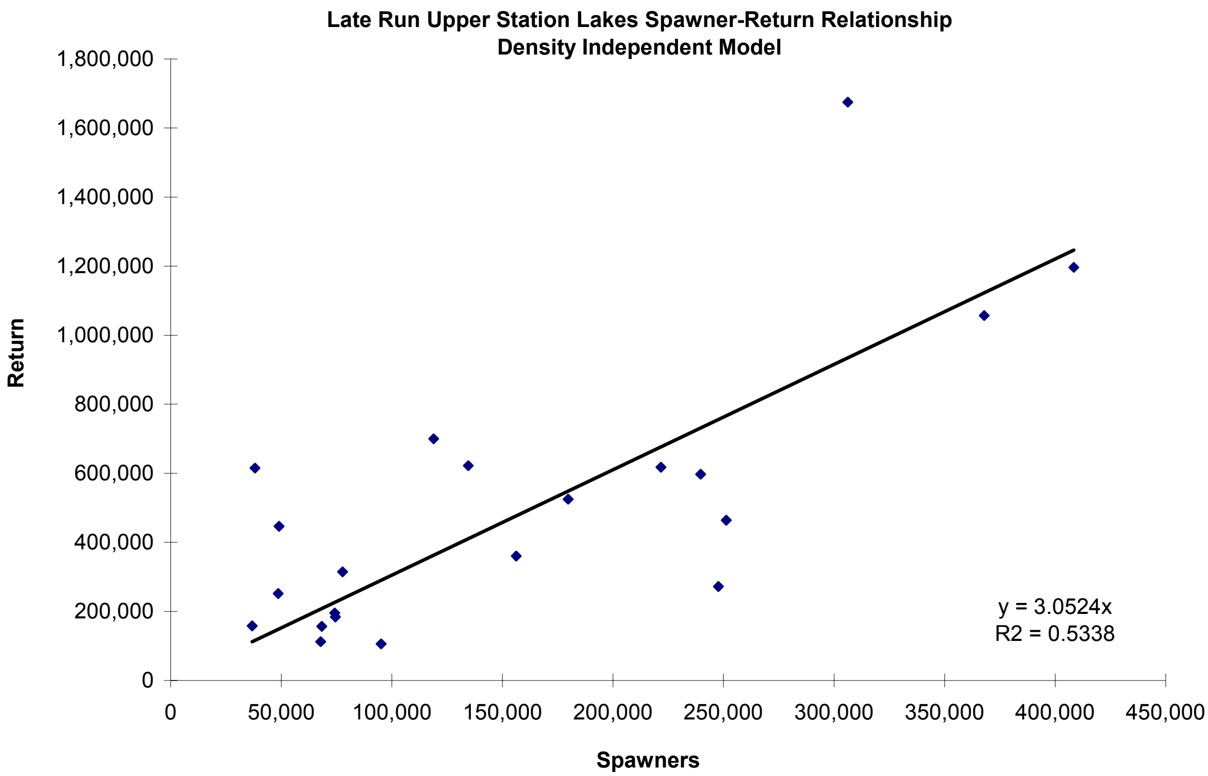


Figure 22.-Upper Station lakes late run sockeye salmon spawner-return relationship using a density independent model.

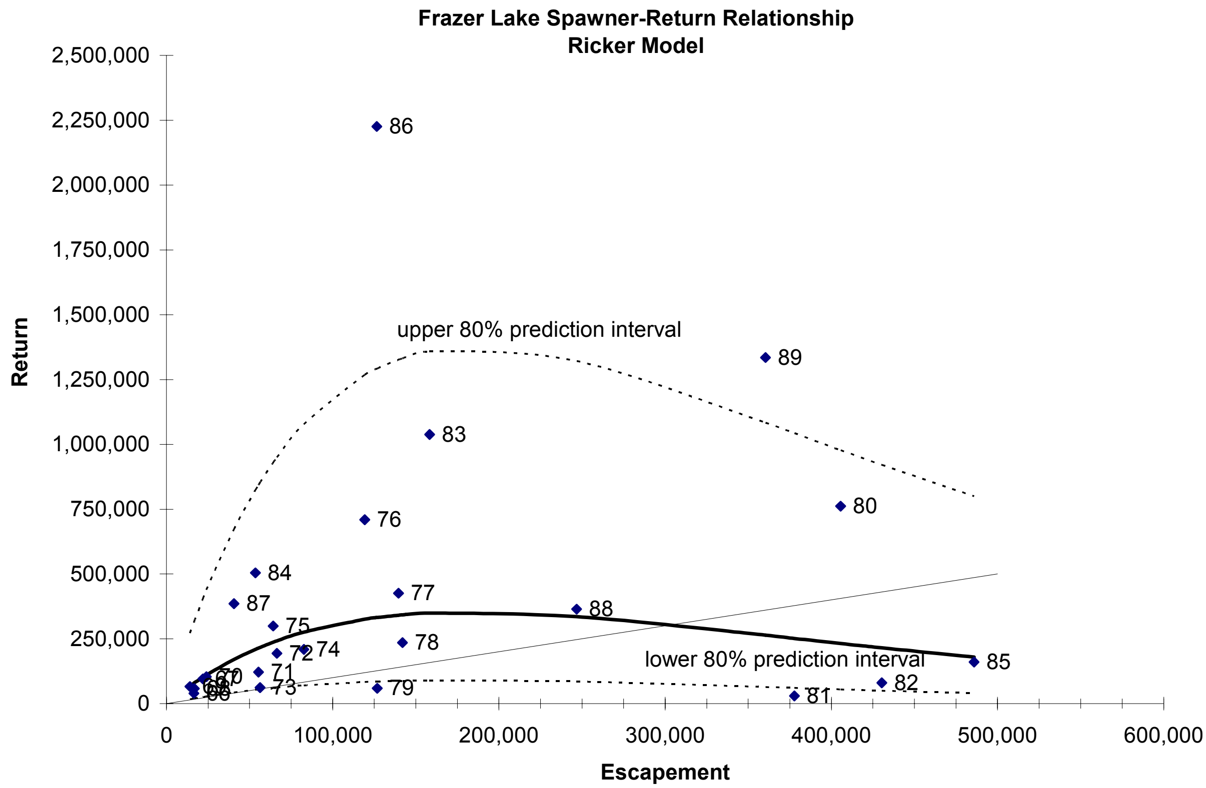


Figure 23.-Frazer Lake sockeye salmon spawner-return relationship using a Ricker curve, with 80% prediction intervals depicted.

most likely assumptions to be violated are 1 and 2, which are directly related to the fate of marked fish. As an example if marked fish experience a higher mortality rate owing to stress or predation the population estimate becomes positively biased (violation of 1 and 2); conversely, if marked fish are stressed resulting in increased trap catch vulnerability this results in a negatively biased estimate. Although it is nearly impossible to evaluate which, if any, of these assumptions have been violated in conjunction with a mark-recapture trial, several experiments were conducted to evaluate dye marked fish detectability and delayed mortality as potential mechanisms which could violate particular assumptions. Additionally, a smolt weir was operated in conjunction with mark-recapture trials to evaluate efficiency and bias in the smolt population estimates at Red Lake during 1992 and at Akalura Lake during 1996-97.

DYE DECTECTABILITY AND DELAYED MARKING MORTALITY

The detectability of bismark brown Y-dye was evaluated at the Red Lake site in 1995 (Swanton et al. 1996). This experiment along with a similar one conducted at Chignik Lake (ADF&G, *unpublished data*) revealed that marked fish were identified at a rate greater than 99% under field conditions similar to those encountered during normal smolt mark-recapture procedures. This suggests that it is unlikely that violation of assumption 5 was experienced.

Experiments to detect delayed mortality associated with the dye-marking process were conducted at Red Lake in 1995 (Swanton et al. 1996) and at both the Red and Akalura sites during 1996 (Coggins and Sagalkin 1999). These experiments revealed a significant difference ($p < 0.005$ for both Red and Akalura lakes) between mortality rates of marked and unmarked smolts. However the differential mortality rate varied widely among year, site, and replicates (0.4% - 42.5%) such that a standard dye mortality rate was not estimated. This variability is not surprising however, given that water temperature and handling are known to be influential on the process (Ward and Verhoeven 1963; Jessop 1973). Consequently, delayed marking mortality was a likely source of bias due to violation of assumptions 1 and 2.

SMOLT WEIR EVALUATION

Spanning a 26 d period at Red Lake in 1992 the relative error of mark-recapture derived smolt population estimates compared to the known smolt emigration derived from weir counts was approximately 11% (Barrett et al. 1993a). The actual smolt outmigration being 1,314,013 was within the 95% confidence interval of the population estimate (point estimate 1,179,712; (95% CI 1,029090 to 1,330,333).

At Akalura Lake during 1996 mark-recapture population estimates were made in concert with a total smolt weir operation spanning a 39 d period. This evaluation revealed a relative error of 38% between the population estimate (277,908 smolts; 95% CI 248,426 – 307,390) and known smolt emigration (201,437 fish). The discrepancy is possibly due to marked smolt experiencing higher mortality from predation or possibly from marking (assumption 1 and 2 violations). Dolly Varden *Salvelinus malma* occur in large numbers in Akalura Creek and were observed actively feeding downstream from the site where marked smolt were released. Additionally, Dolly Varden captured at the weir and smolt trap were observed regurgitating sockeye smolts.

A similar evaluation program was conducted again in 1997 over a 44 d period (Coggins and Sagalkin 1999) and resulted in 193,064 fish counted through the weir with a companion population estimate of 206,453 fish (95% CI 187,675 to 225,232). This translated into a relative error of 7%. However, from the 1996 experiments it was recognized that the dye marking mortality was possibly biasing the estimates, the study design implemented in 1997 had been modified to account for delayed marking mortality. Following Thedinga et al. (1994), 100 marked smolts were held in an instream live box and monitored over a 5 d period concurrent with each marking event. The observed delayed marking mortality rates ranged from 0% to 6% and were then used to adjust numbers of marked fish available for capture. This approach resulted in an adjusted smolt population estimate of 200,977 (95% CI 182–219 thousand) which equates to a relative error of 4%.

As is apparent from evaluations at both the Red and Akalura sites, the magnitude and direction of bias in smolt abundance estimates is unpredictable without diligent attention to the underlying assumptions. Since evaluation of assumptions 1 and 2 were not rigorously conducted at any of the study sties, smolt population estimates with the exception of Red Lake (1992) and Akalura (1996) could be biased by an unknown amount.

Red Lake

The population estimates of juvenile sockeye in the fall of 1990 and 1991 (101,000 and 632,000) do not correspond with resulting smolt population estimates (Honnold 1993). The 1991 and 1992 sockeye smolt estimates were 263,500 and 1,420,000 respectively (Barrett et al. 1993). The total fish population estimates were 7.2 million and 9.4 million which are mostly three spine stickleback which substantiates the bias associated with the hydroacoustic fry estimates.

The reasons for this are likely to be: 1) errors in duration beam analysis techniques; 2) the fall fry were not detected (near-boundary distribution) by the hydroacoustic gear; 3) errors in mark-recapture estimates of the smolt migration; 4) species composition bias as result of net avoidance during townet surveys; or 5) a combination of the above factors (Kyle 1990; Honnold 1993).

The potential sources of error in the duration in-beam technique include estimates of boat speed and establishing a counting threshold and making insonification counts (Kyle 1990). As a component of the 1991 hydroacoustic surveys, fish distribution in areas where acoustic gear is ineffective was investigated and found to be minimal (Honnold 1993). The smolt population estimation technique at Red Lake was evaluated with a total enumeration weir count in 1992 and found to have minimal error (Barrett et al. 1993). One of the most evident sources of error in hydroacoustic estimation of fish populations in lakes is the bias associated with species apportionment and cohort composition (Kyle 1990), it is likely that the identified bias could be attributed to these factors as well.

Unfortunately, the loss of samples due to inadequate preservation technique in 1990 preclude a complete analysis of size for comparing all age classes by brood years, however a partial comparison can be made. Age-1 sockeye fry from the 1989 parent year that were rearing in the lake in May of 1991 averaged 69 mm in length and 2.4 g in weight. By October, these fry average 81 mm and 4.4 g. These sizes were derived from preserved (alcohol) samples and likely showed shrinkage (Honnold 1993). Sockeye smolt preserved in formalin (25-180 days) may result in ~2% loss of weight and ~5% loss of length (Billy 1981). Alcohol preservation in the case of Red Lake fry appears to have enhanced shrinkage. Initial results of live weights and lengths compared to preserved weights and lengths from ADF&G data indicate ~20% weight loss for preserved fish (P. Shields, ADF&G, CFMDD, Soldotna, personal communication). The loss of length (< 2%) appears less than weight. Correcting for shrinkage results in a fry size of 70 mm and 3.0 g in May, and 82 mm and 5.5 g in October. The age-1 fall fry sampled (unpreserved) in 1992 (BY 1990) averaged 92 mm and 7.4 g (24 September), and 102 mm and

9.0 g (23 September), or a 35% to 64% increase in weight. This suggests that the age-1 fry from BY 1989 reared under conditions that limited growth, whereas, the age-1 fry from the subsequent BY reared under more favorable conditions. There were few sockeye fry sampled (N=4) for age and size in 1993 to make comparison to previous years; however, in 1994, the size of both age-0 and age-1 juveniles declined substantially compared to 1992. Smolt from each respective BY (1992 and 1993) did not exhibit this trend (Swanton et al. 1996).

Akalura Lake
Fall population estimates of juvenile sockeye in 1990 (209,350) and 1991 (44,380) were similar to Red Lake (Honnold 1993); low compared to the subsequent spring smolt estimates in 1991 (310,000) and 1992 (193,200). However, the fry estimate in 1995 (462,000) was higher than the following smolt emigration estimate (281,000, 1996; Coggins and Sagalkin 1999) and, not did not include fish that had delayed migration for an additional year. Based upon field observations and the hydroacoustic targets, fish were observed near the surface and were evenly distribution in the pelagic area of the lake. This antidotal data regarding near surface distribution of fish may have caused the underestimation of fall fry populations in 1990 and 1991. Townet catch and near-surface distribution bias may have had less affect on the 1995 hydroacoustic survey, resulting in higher juvenile sockeye estimates. However, the high fall fry-to-smolt survival may be suspect as a majority (88% in 1996; Coggins and Sagalkin 1999)of smolt reside two years in the lake; thus, the age-0 fall fry (1995) would likely hold-over until age-2. The number of age-0 sockeye fry (~50%) of the total estimate based on age composition of townet catch would be 231,000. However, about 875,000 age-0 fall fry would be expected based on escapement (1994), and employing standard survival estimates (Honnold and Edmundson 1993). The underestimation of fall fry in 1995 would explain this discrepancy; however, high mortality may have occurred in the first year of freshwater residence.

The age-1 fall fry sampled n October of 1991 was produced in 1989 when excessive escapement occurred (Honnold 1993). The average size of fry was 75 mm and 4.7 g (correcting for shrinkage), and had a condition coefficient of 0.90. Also, the weight of age-1 smolts for brood years 1988-1990 appeared relatively stable (Barrett et al. 1993). The high escapement appeared to have had minimal effect on juvenile sockeye size. Both age-0 and age-1 juveniles were substantially larger in 1995 than prior years indicating favorable rearing conditions.

Upper Station Lake

Population estimates of juvenile sockeye (1990 and 1991) were substantially different (1,171,200 and 387,000, respectively) and lower than the following years smolt estimates (2,445,000 and 2,395,000, respectively; Honnold 1993). Again, underestimation of fall fry was likely to have occurred.

This lake, as the control lake, did not receive a high escapement in 1989. The size of age-1 and age-2 smolts did not exhibit large changes for the brood years 1988-1990 (Barrett et al. 1993). Similarly, fall fry sizes for brood years 1989 and 1990 remained static.

Frazer Lake
Frazer Lake replaced Upper Station Lake as the control system in 1993 (Swanton et al. 1996). Fall sockeye fry estimates have been considerably less than subsequent smolt estimates since 1992. Fall fry estimates were greater than the following spring smolt estimates in 1990 and 1991, however, if accurate, they would indicate smolt survival was in excess of 80%. As with the other lakes, there appears to be negative bias in the fall fry estimates. Also, sockeye

juveniles are generally distributed below five meters in depth and off shore in the lake; thus, minimizing the potential for bias associated with hydroacoustic estimates. Again townet species apportionment is assumed to be the cause.

The utility of using townet catch proportions in conjunction with total fish abundance to estimate juvenile sockeye appears minimal for all four lakes discussed. Frazer Lake total fish estimates, however, may provide an index for predicting subsequent smolt abundance (Figure 6). Preliminary data indicate a positive (although weak) relationship between total fish abundance estimates and subsequent smolt estimates ($r^2 = 0.50$; $P = 0.08$). Further scrutiny of the data is needed to assess development of such an index.

The size of age-1 and age-2 smolts has generally remained stable; however, some reduction in size was noted in 1995 (Swanton et al. 1996). Similarly, fall fry sizes exhibited little variation from 1990-1993 with the exception in 1992 when average sizes were larger. Townet catches were poor in 1994-1995; thus sample sizes were too small to provide reliable size data. Samples in 1996, when townet catches were larger, (N=104) indicate a reduction in size for all fall fry; however, fry remained robust as reflected by the K values > 1.0.

There were observed decreases in length, weight, and age at smolting that occurred as a result of the 1989 escapement event at Red Lake, whereas none were evident at Akalura or either of the control systems. For Red Lake a disproportionate number of smolts held over and emigrated as age-2, and both length and weight of age-1 smolts were smaller than for other brood years. The weight of both age-1 and age-2 smolts decreased after 1989 however condition factor remained relatively static. This disparity between the two systems that experienced excessive adult escapement could be attributed to the Akalura system having a greater forage base per rearing fry capacity and thus not as susceptible to short term excessive fry loadings.

Smolt to Adult Survival

The thesis that smolt to adult survival is partially a function of smolt size has been a long-standing premise (Forester 1954; Ricker 1962). Recently, there have been additions to this body of work that expanded and updated the data to include Alaskan sockeye stocks that are the result of outplanting fry into barren lakes (Koenings and Burkett 1987) and stratification of data by latitude (Koenings et al. 1993). The precept has held that larger smolts have higher smolt to adult survival (SAS). The data for Alaskan systems suggest that for age-1 and age-2 smolts averaging between 90-140 mm that SAS ranges from 30-50% (Koenings and Burkett 1987) which is also substantiated by data presented by Koenings et al. (1993). The smolts emigrating from Red Lake should have, based on length, and experienced 20-30% smolt to adult survival for age-1 and age-2 smolts from the 1989 and 1990 brood years. The 1989 brood year smolts had estimated SAS values of 38% and 44% for age-1 and age-2 smolts respectively, whereas the 1990 brood year smolts exhibited highly biased SAS values in excess of 100%.

The SAS estimates for Akalura Lake smolts were 33% for age-2 smolts and 344% for age-1 smolts from the 1989 BY, and 4% and 54% for these age classes from the 1990BY. The low SAS for age-2 fish (1990 BY) can not be attributed to diminished size as these smolts averaged 80 mm. Unrealistic SAS values were also realized for the Upper Station system for both age-1 and age-2 smolts. However, smolt to adult survival estimates generated for sockeye smolts from the Frazer Lake system ranged from 14% to 64% for the 1989-1990 brood years which are well within survival estimates reported within the literature.

It is apparent that there were periods of high trap avoidance possibly coupled with unaccounted for mortality of marked smolts for all systems studied except for Frazer Lake. There are indications that these sources of bias could be linked to smolt size during some years (avoidance and marked fish mortality).

VERIFICATION OF BIOLOGICAL ESCAPEMENT GOALS

The existing escapement goals for the four systems investigated within this report during 1989 were 200-300,000 sockeye for Red Lake, 40-60,000 at Akalura, 200-275,000 for Upper Station, and 140-200,000 sockeye for Frazer Lake. The realized escapements for these systems during 1989 were 768,000 fish for Red Lake (156% over the upper end of the goal), 116,000 for Akalura (93% greater then the upper end of the goal), and for the Upper Station and Frazer systems escapements of 286,000 and 360,000, respectively (Prokopowich et al 1997). The analyses conducted for the Frazer system using a Ricker spawner-recruit model confirmed the existing escapement goal, whereas the analyses performed for Red Lake and Upper Station failed to confirm the existence of a compensatory response. The plausible explanation for this is that these systems have been managed adhering to a fixed escapement goal policy for 30 years. This scenario only allows for escapement overages to occur infrequently and therefore provides minimal contrast to spawner-recruit analyses and verifying compensation.

Return data from the 1988-1990 Broods from Red Lake showed poor overall adult production (about 500,000 fish less) then what average production had been for the brood years 1985-1987 and 1991. Brood year production for Akalura Lake sockeye for 1989 did not show any such dichotomy, while Frazer Lake 1989 Brood year adult production was 4X greater than the 1988 brood year and about 2X the production from the 1990 BY. During the years 1980-1982 escapements into the Frazer system averaged 400,000 per year and subsequent production of adults was approaching replacement levels. It is hypothesized that a large-scale collapse of the forage base for this system was averted owing to lower levels of escapement (158,000 and 54,000) that occurred during 1983-84 (Kyle et al 1988). It was however evident that these large consecutive escapements were cause for declines in zooplankton biomass, species composition and size, coupled with decreased size at age for emigrating sockeye smolts. There were similar observations made with zooplankton biomass, decreased size of smolts and also a shift in age of smolting from age-1 to age-2 for both the Red and Akalura systems. This shift in smolt age could also be evidence for interannual brood year interaction that may have occurred within these systems.

CONCLUSIONS

It is apparent that the 1989 escapement event did have a negative impact upon both the Red and Akalura lake sockeye salmon stocks which was demonstrated by decreased biomass, density and size (where data was available) of macrozooplankters. Effects were also evident with decreases in size of rearing fry, shifts (in the case of Red Lake sockeye) in smolt age for the 1989 brood year, and reduced adult returns owing to a reduction in smolt numbers. It is hypothesized that these systems are plastic enough in their capacity to sustain one or even several years of high consecutive escapements without resounding collapse of both the forage base, rearing fry, or subsequent smolt numbers or size. It is unfortunate that smolt population estimates were not verified earlier in this study so that additional years of unbiased sockeye smolt population estimates and SAS could have been obtained.

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APPENDIX A

Appendix A1.-Summary of mean water chemistry parameters from Red, Akalura, Upper Station, and Frazer lakes 1985-1996.

Lake	Year	Conduct-ivity (mmhos cm^{-1})	pH (units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Iron (mg L^{-1})	Total - P (mg L^{-1})	Total filter-able - P (mg L^{-1})
RED	90	55.1	7.3	15.5	0.7	5.7	19	10.3	5.0
RED	91	60.8	7.1	15.4	1.0	5.0	39	13.3	7.7
RED	92	59.4	7.0	15.0	0.8	4.2	14	14.9	6.3
RED	93	63.8	7.0	15.7	1.2	6.2	79	19.4	12.2
RED	94	62.3	6.9	15.4	0.9	4.4	29	16.7	8.3
RED	95	61.1	7.0	16.3	1.0	4.5	27	10.5	5.6
RED	96	54.2	7.2	15.1	0.8	4.8	23	13.7	6.0
AKALURA	87	50.4	6.8	14.0	2.0	6.4	102	17.6	6.8
AKALURA	88	54.0	6.7	13.7	0.7	8.3	31	12.1	5.7
AKALURA	89	60.0	7.0	13.8	1.4	8.4	141	11.0	5.2
AKALURA	90	59.3	7.2	14.9	1.0	6.8	272	11.4	3.4
AKALURA	91	58.0	7.1	14.0	1.5	7.1	64	11.8	6.1
AKALURA	92	56.9	6.9	14.8	1.4	5.6	87	16.0	5.2
AKALURA	93	59.4	6.9	15.0	1.4	6.5	71	14.1	6.7
AKALURA	94	59.2	6.9	14.2	3.9	5.6	70	13.7	5.2
AKALURA	95	59.6	6.8	15.1	1.7	5.2	177	12.3	4.1
AKALURA	96	59.6	7.2	16.6	1.0	7.4	62	11.3	5.1
USTA	90	45.6	6.9	9.0	0.5	8.6	24	6.8	4.7
USTA	91	46.6	6.9	8.8	1.1	9.7	23	10.5	4.1
USTA	92	45.7	6.9	8.4	0.6	5.8	24	8.4	3.7
USTA	93	48.4	6.9	9.3	1.1	3.2	30	10.8	4.7
USTA	95	na[\1]	na	na	na	na	na	na	na
FRAZER	85	47.8	6.9	13.4	1.0	8.4	16	6.3	2.2
FRAZER	86	47.9	6.9	13.4	0.5	8.4	10	5.3	2.9
FRAZER	87	46.9	6.8	13.6	0.4	7.9	20	5.2	4.5
FRAZER	88	46.9	6.9	12.2	0.7	8.2	22	7.9	4.7
FRAZER	89	50.6	7.1	13.5	0.7	7.4	15	9.6	4.3
FRAZER	90	50.6	7.1	14.1	0.8	5.3	39	5.9	3.0
FRAZER	91	52.6	7.1	13.1	0.9	6.9	25	5.4	3.5
FRAZER	92	52.3	7.1	13.1	0.7	6.3	12	5.1	2.6
FRAZER	93	53.6	6.8	13.0	0.8	5.0	13	5.2	3.4
FRAZER	94	55.3	6.9	13.6	0.6	5.4	12	6.3	2.1
FRAZER	95	50.4	6.7	13.3	1.2	7.3	22	5.2	2.0
FRAZER	96	53.6	6.8	14.0	0.5	6.6	14	5.0	2.3

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Lake	Year	Filterable reactive - P (mg L^{-1})	Total particulate - P (mg L^{-1})	Total - N (mg L^{-1})	Total Kjeldahl - N (mg L^{-1})	Ammonia (mg L^{-1})	Nitrate + nitrite (mg L^{-1})	Reactive silicon (mg L^{-1})	Particulate organic - C (mg L^{-1})
RED	90	2.0	5.3	153	131	2.5	21.8	136	255
RED	91	4.5	5.6	133	115	12.3	18.1	101	197
RED	92	3.0	8.6	147	135	7.1	12.4	212	294
RED	93	8.3	7.2	215	149	15.1	66.6	252	247
RED	94	4.5	8.5	178	162	6.1	15.9	147	273
RED	95	2.3	4.8	150	141	2.4	8.5	192	243
RED	96	1.9	7.7	164	161	8.2	3.0	104	266
AKALURA	87	2.5	10.8	258	229	6.9	28.8	292	517
AKALURA	88	2.3	6.4	184	164	16.2	20.4	325	386
AKALURA	89	2.3	5.9	166	146	8.0	20.5	394	265
AKALURA	90	1.5	7.9	193	167	15.8	25.6	384	438
AKALURA	91	3.0	5.7	178	159	12.0	19.0	283	412
AKALURA	92	2.3	10.8	166	161	7.0	4.9	779	409
AKALURA	93	4.1	7.4	204	196	9.4	7.9	636	371
AKALURA	94	3.6	8.5	277	261	21.0	15.9	877	562
AKALURA	95	1.6	8.1	211	183	20.8	27.5	573	328
AKALURA	96	2.2	6.2	167	164	12.3	3.0	268	312
USTA	90	2.4	2.1	110	93	4.6	17.4	95	264
USTA	91	1.6	6.4	128	124	7.8	4.0	247	307
USTA	92	1.6	4.8	129	122	3.6	7.1	253	395
USTA	93	1.7	6.1	157	149	2.9	7.5	239	347
USTA	95	na	na	na	na	na	na	na	na
FRAZER	85	2.0	4.1	135	91	12.0	44.9	2342	129
FRAZER	86	2.2	2.4	141	82	9.9	59.3	2313	42
FRAZER	87	2.9	0.6	166	88	11.5	77.5	2204	98
FRAZER	88	2.9	3.2	171	98	10.4	73.0	1811	132
FRAZER	89	2.6	5.3	179	120	4.9	59.2	1853	na
FRAZER	90	1.2	2.9	110	66	6.3	43.8	1664	198
FRAZER	91	2.2	1.9	144	99	6.8	45.1	992	154
FRAZER	92	1.3	2.5	174	113	5.2	60.7	1421	169
FRAZER	93	2.1	1.8	158	101	4.1	56.8	1792	150
FRAZER	94	1.5	4.3	161	102	4.3	59.1	1928	136
FRAZER	95	1.4	3.2	166	95	2.8	70.9	2215	163
FRAZER	96	1.6	2.8	146	116	3.5	29.3	2136	134

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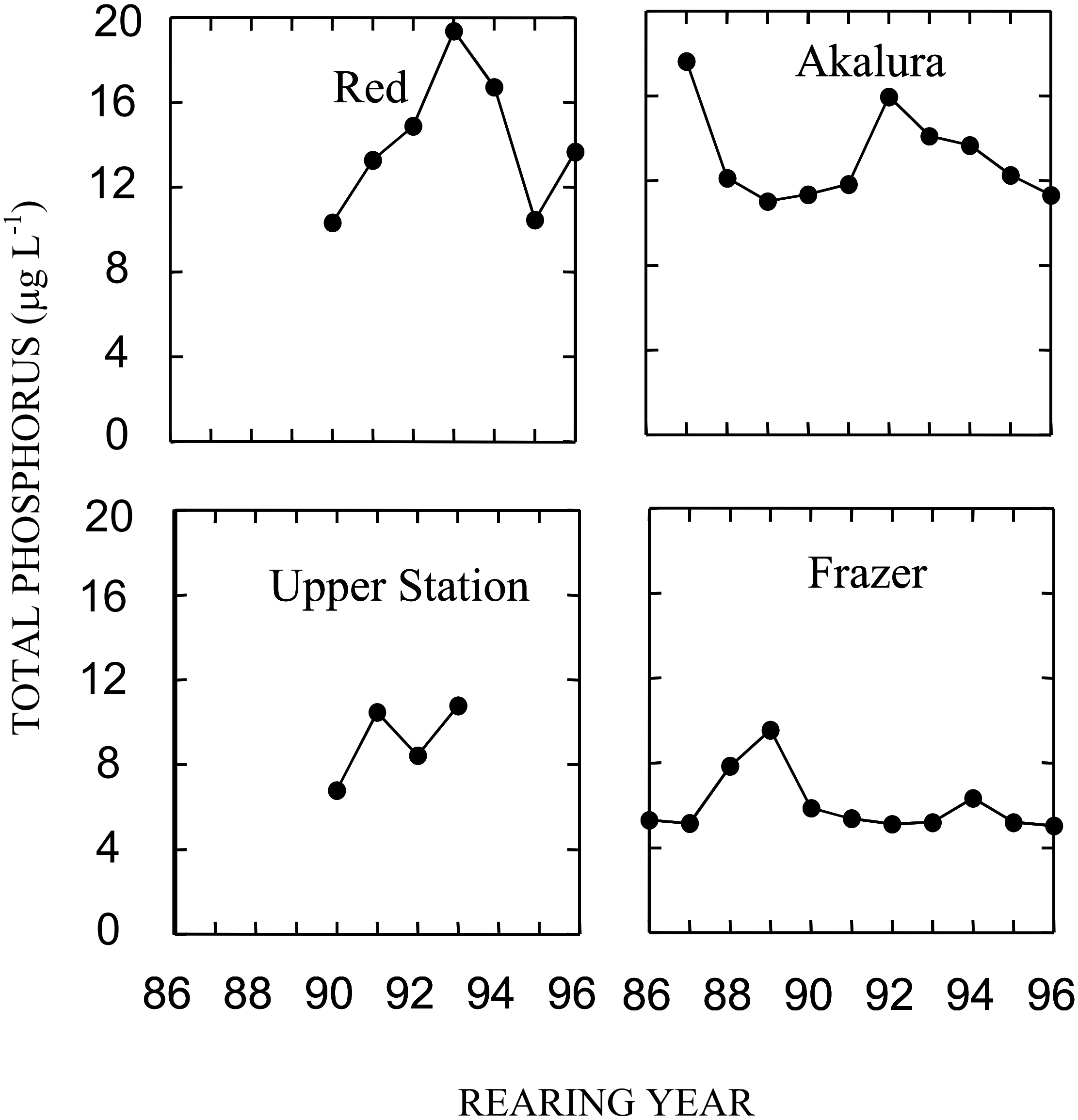
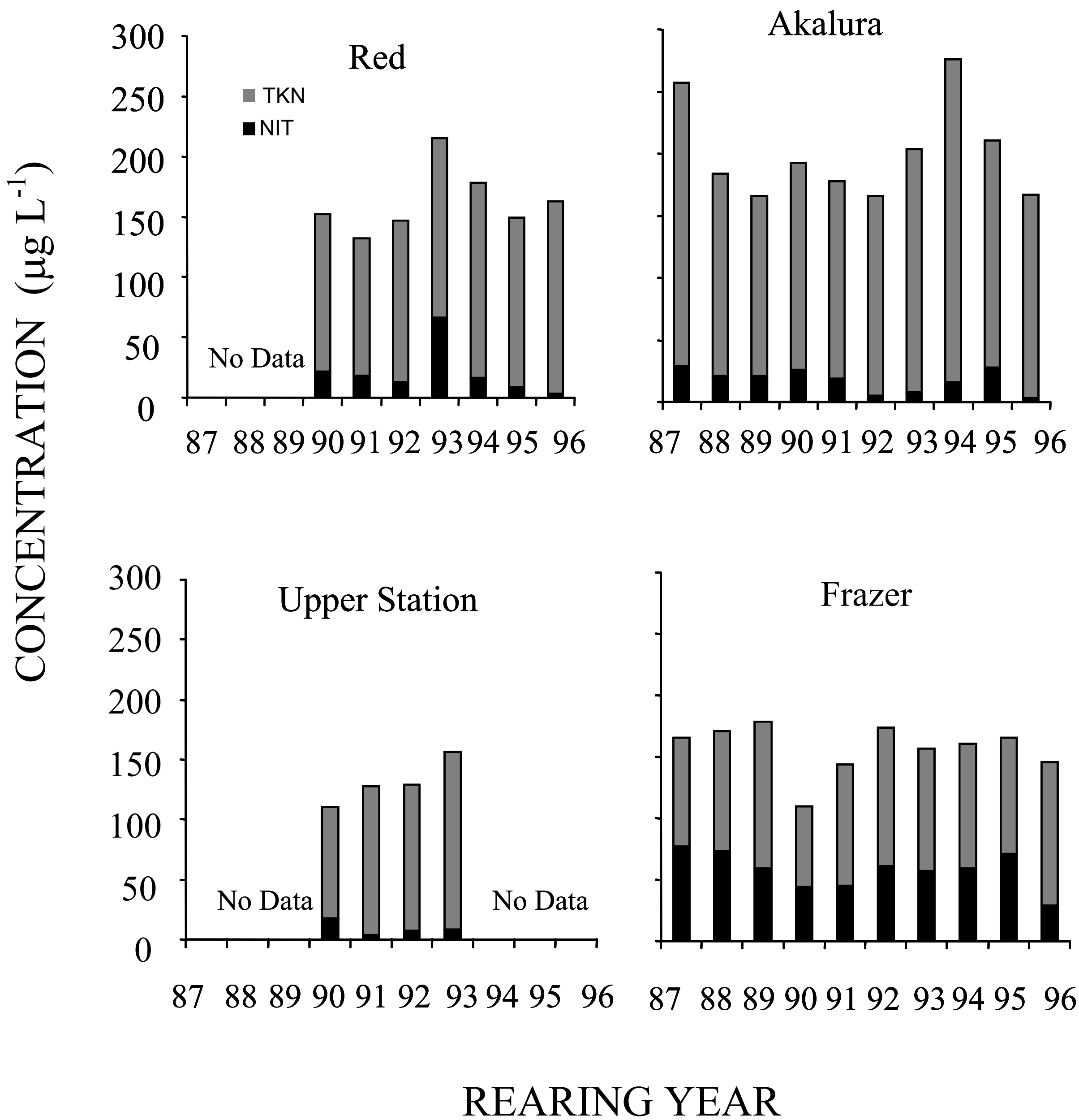
Lake	Year	Chloro-phyll *a* (mg L^{-1})	Total macro-zooplankton density (Nr. m^{-2})	Total macro-zooplankton biomass (mg m^{-2})
RED	90	2.3	440,792	1,010
RED	91	2.3	237,036	435
RED	92	1.7	772,604	2,555
RED	93	2.9	492,945	1,051
RED	94	3.7	302,748	697
RED	95	3.4	1,094,548	2,969
RED	96	0.7	730,810	1,368
AKALURA	87	6.0	289,065	916
AKALURA	88	3.5	138,181	353
AKALURA	89	4.2	147,395	308
AKALURA	90	4.1	95,613	227
AKALURA	91	4.3	48,822	108
AKALURA	92	3.3	18,757	56
AKALURA	93	4.9	62,553	156
AKALURA	94	5.9	122,760	257
AKALURA	95	4.9	189,988	349
AKALURA	96	1.3	119,967	197
USTA	90	1.7	420,409	817
USTA	91	2.0	517,468	1,439
USTA	92	1.5	548,765	1,170
USTA	93	2.3	763,939	1,268
USTA	95	na	687,109	1,390
FRAZER	85	1.1	165,553	213
FRAZER	86	0.6	97,751	132
FRAZER	87	1.1	78,974	121
FRAZER	88	0.8	157,262	229
FRAZER	89	1.3	152,581	230
FRAZER	90	1.9	111,553	192
FRAZER	91	1.5	169,807	231
FRAZER	92	1.4	279,277	627
FRAZER	93	1.7	294,813	425
FRAZER	94	0.7	192,439	296
FRAZER	95	1.9	109,316	142
FRAZER	96	0.5	109,316	142

1/na = not available

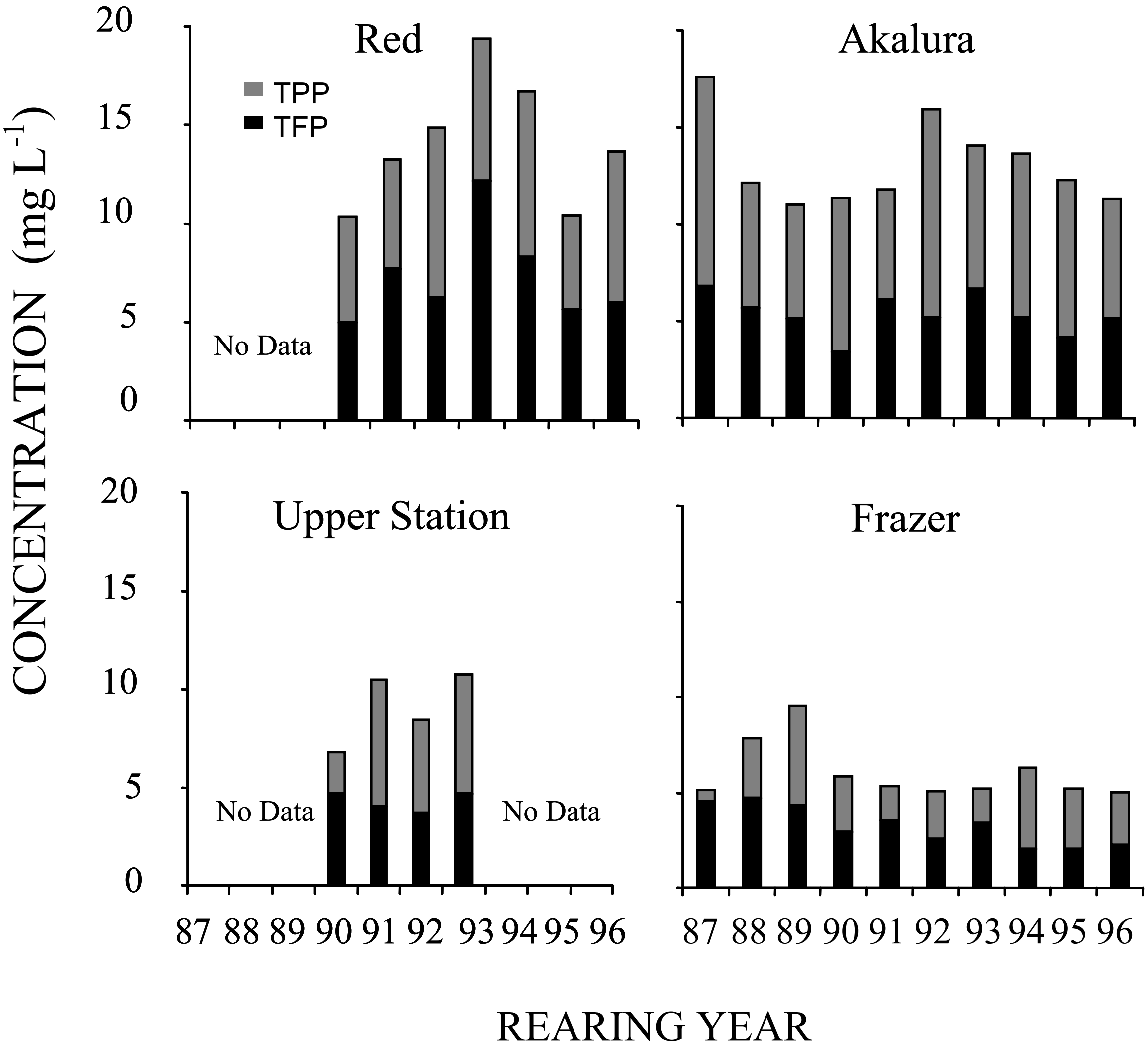
Appendix A2.-Mean chlorophyll a concentration for the 1-m stratum in the four study lakes, 1086-1996. Data are shown fro the May through October period in each year.



Appendix A3.-Total Kjeldahl nitrogen (TKN) and nitrate-N (NIT) concentration in the four study lakes, 1987-1996. Data are shown fro the 1-m stratum during the May through October period in each year.



Appendix A4.-Total filterable phosphorus (TFP) and calculated particulate phosphorus (TPP) concentration in the four study lakes, 1987-1996. Data are shown for the 1-m stratum during the May through October period in each year.



Appendix A5.-Mean temperature (degrees Celsius) of the 1-m stratum for the 4 study lakes.

LAKE	DATE	JULIAN	TEMP (°C)
RED	05/20/90	1235	6.0
RED	06/21/90	1267	9.0
RED	07/19/90	1295	13.8
RED	08/23/90	1330	12.8
RED	09/28/90	1366	9.5
RED	05/16/91	1596	4.0
RED	06/11/91	1622	7.3
RED	07/07/91	1648	12.8
RED	08/05/91	1677	12.8
RED	09/17/91	1720	11.0
RED	10/11/91	1744	9.0
RED	05/12/92	1958	4.4
RED	06/01/92	1978	8.0
RED	06/30/92	2007	10.0
RED	08/10/92	2048	13.8
RED	09/11/92	2080	10.5
RED	10/08/92	2107	7.8
RED	05/17/93	2328	5.8
RED	06/13/93	2355	9.8
RED	07/13/93	2385	13.0
RED	08/19/93	2422	13.3
RED	09/21/93	2455	10.0
RED	10/15/93	2479	8.5
RED	05/16/94	2692	5.0
RED	06/14/94	2721	8.9
RED	07/18/94	2755	12.0
RED	08/17/94	2785	15.0
RED	09/22/94	2821	9.8
RED	10/22/94	2851	6.7
RED	05/16/95	3057	5.0
RED	06/22/95	3094	9.7
RED	07/27/95	3129	12.7
RED	08/13/95	3146	11.3
RED	09/13/95	3177	12.9
RED	10/03/95	3197	10.5
RED	05/20/96	3427	4.7
RED	06/27/96	3465	9.9
RED	08/08/96	3507	12.9
RED	09/19/96	3549	10.3
AKALURA	05/26/87	145	7.0
AKALURA	07/28/87	208	16.0

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LAKE	DATE	JULIAN	TEMP (^{o}C)
AKALURA	09/28/87	270	11.0
AKALURA	06/06/88	522	11.0
AKALURA	08/09/88	586	14.0
AKALURA	09/30/88	638	10.5
AKALURA	05/10/89	860	7.0
AKALURA	06/26/89	907	12.0
AKALURA	09/02/89	975	13.0
AKALURA	10/05/89	1008	10.5
AKALURA	04/29/90	1214	4.6
AKALURA	05/24/90	1239	9.3
AKALURA	06/19/90	1265	11.0
AKALURA	07/20/90	1296	15.5
AKALURA	08/21/90	1328	14.0
AKALURA	09/28/90	1366	12.5
AKALURA	05/16/91	1596	7.8
AKALURA	06/11/91	1622	11.0
AKALURA	07/07/91	1648	15.0
AKALURA	08/05/91	1677	14.5
AKALURA	09/10/91	1713	13.0
AKALURA	10/22/91	1755	7.5
AKALURA	05/12/92	1958	7.4
AKALURA	06/01/92	1978	11.0
AKALURA	06/30/92	2007	11.5
AKALURA	08/10/92	2048	15.3
AKALURA	09/11/92	2080	11.8
AKALURA	10/06/92	2105	8.1
AKALURA	05/07/93	2318	8.5
AKALURA	06/13/93	2355	12.3
AKALURA	07/13/93	2385	15.5
AKALURA	08/19/93	2422	15.0
AKALURA	09/21/93	2455	11.0
AKALURA	05/16/94	2692	7.5
AKALURA	06/14/94	2721	11.9
AKALURA	07/18/94	2755	13.6
AKALURA	08/17/94	2785	17.3
AKALURA	09/26/94	2825	10.9
AKALURA	05/16/95	3057	7.3
AKALURA	06/28/95	3100	13.0
AKALURA	07/27/95	3129	14.6
AKALURA	08/13/95	3146	13.0
AKALURA	09/13/95	3177	13.8
AKALURA	10/03/95	3197	11.5

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Appendix A5.-Page 3 of 5.

LAKE	DATE	JULIAN	TEMP (^{o}C)
AKALURA	05/20/96	3427	10.6
AKALURA	06/27/96	3465	11.7
AKALURA	08/08/96	3507	15.0
AKALURA	09/19/96	3549	11.5
USTA	05/21/90	1236	5.3
USTA	06/22/90	1268	8.0
USTA	07/18/90	1294	12.8
USTA	08/20/90	1327	13.0
USTA	10/03/90	1371	10.0
USTA	05/16/91	1596	3.5
USTA	08/06/91	1678	14.1
USTA	09/12/91	1715	11.0
USTA	10/11/91	1744	8.5
USTA	05/07/92	1953	3.6
USTA	06/01/92	1978	7.3
USTA	07/06/92	2013	9.8
USTA	08/10/92	2048	14.3
USTA	09/08/92	2077	11.0
USTA	10/06/92	2105	7.7
USTA	05/06/93	2317	3.5
USTA	06/07/93	2349	7.0
USTA	07/07/93	2379	10.5
USTA	08/19/93	2422	14.0
USTA	09/21/93	2455	10.5
USTA	10/15/93	2479	9.0
USTA	05/18/95	3059	3.6
USTA	06/25/95	3097	10.4
USTA	08/18/95	3151	12.0
USTA	09/29/95	3193	15.2
FRAZER	05/21/87	140	4.5
FRAZER	06/09/87	159	7.3
FRAZER	06/30/87	180	7.3
FRAZER	07/24/87	204	10.5
FRAZER	08/17/87	228	12.3
FRAZER	09/08/87	250	12.3
FRAZER	10/09/87	281	8.8
FRAZER	11/23/87	326	4.5
FRAZER	05/16/88	501	3.8
FRAZER	06/06/88	522	6.1
FRAZER	06/23/88	539	8.5
FRAZER	07/15/88	561	11.8
FRAZER	08/09/88	586	12.0
FRAZER	09/03/88	611	11.8

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Appendix A5.-Page 4 of 5.

LAKE	DATE	JULIAN	TEMP (^oC)
FRAZER	09/30/88	638	8.9
FRAZER	05/10/89	860	3.5
FRAZER	06/05/89	886	5.5
FRAZER	06/26/89	907	8.8
FRAZER	07/20/89	931	12.8
FRAZER	09/02/89	975	11.5
FRAZER	10/05/89	1008	9.3
FRAZER	04/29/90	1214	3.9
FRAZER	05/26/90	1241	6.0
FRAZER	06/17/90	1263	7.8
FRAZER	07/02/90	1278	10.5
FRAZER	07/25/90	1301	12.5
FRAZER	08/17/90	1324	12.0
FRAZER	10/02/90	1370	9.0
FRAZER	10/30/90	1398	5.8
FRAZER	05/12/91	1592	3.5
FRAZER	06/05/91	1616	5.5
FRAZER	06/29/91	1640	8.8
FRAZER	07/19/91	1660	11.8
FRAZER	08/02/91	1674	12.5
FRAZER	08/02/91	1674	12.5
FRAZER	08/21/91	1693	12.3
FRAZER	09/17/91	1720	10.1
FRAZER	05/07/92	1953	3.7
FRAZER	06/01/92	1978	7.0
FRAZER	06/22/92	1999	9.0
FRAZER	07/13/92	2020	11.3
FRAZER	08/09/92	2047	13.3
FRAZER	09/01/92	2070	10.8
FRAZER	09/23/92	2092	9.3
FRAZER	05/04/93	2315	4.0
FRAZER	06/15/93	2357	9.5
FRAZER	07/26/93	2398	14.3
FRAZER	08/09/93	2412	11.0
FRAZER	10/13/93	2477	9.0
FRAZER	06/02/94	2709	7.3
FRAZER	07/17/94	2754	11.0
FRAZER	08/25/94	2793	12.0
FRAZER	08/30/94	2798	12.0
FRAZER	10/11/94	2840	8.6
FRAZER	05/18/95	3059	5.0
FRAZER	07/05/95	3107	12.2
FRAZER	08/08/95	3141	12.0

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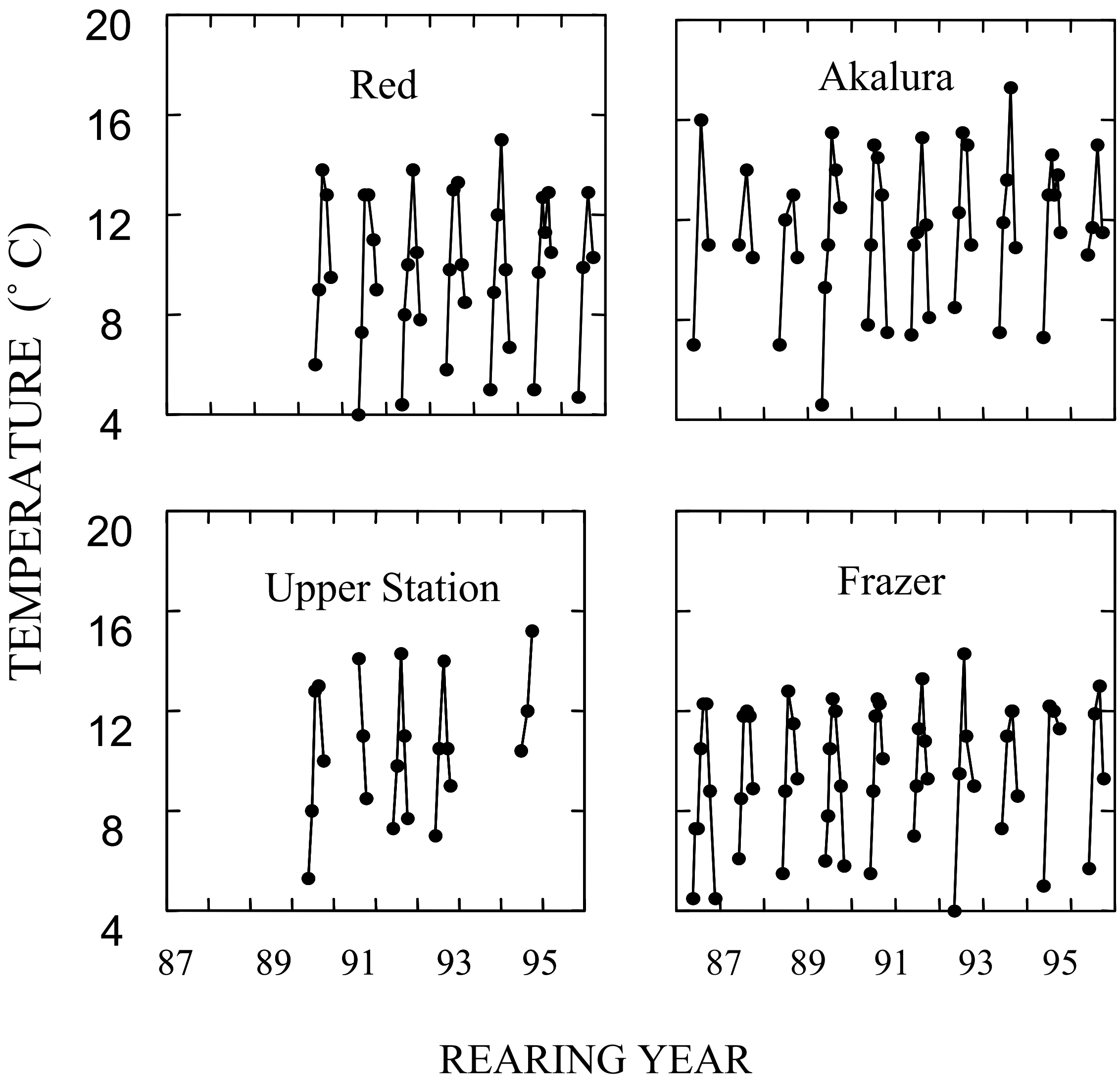
LAKE	DATE	JULIAN	TEMP (^oC)
FRAZER	09/27/95	3191	11.3
FRAZER	05/28/96	3435	5.7
FRAZER	07/16/96	3484	11.9
FRAZER	08/27/96	3526	13.0
FRAZER	09/27/96	3557	9.3

Appendix A6.-Temperature of the 1-m stratum during the May through October period in the study lakes. Data are the average of two station measurements for each year sampled.



APPENDIX B

Appendix B1.-Estimated number of sockeye salmon smolt outmigrating from Red Lake by strata, age class, and year, 1990-1996.

				Age-1				Age-2				Age-3			
		Stratum Dates		Population		95% CI		Population		95% CI		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1990	1	5/7	6/2	453	252	0	948	88,042	21,745	45,422	130,662	2,153	722	739	3,567
1990	2	6/3	6/10	9,859	3,242	3,505	16,213	54,971	15,863	23,880	86,062	896	575	0	2,023
1990	3	6/11	6/15	16,421	3,495	9,570	23,271	58,728	11,270	36,639	80,818	773	411	0	1,579
1990	4	6/16	6/20	129,548	24,729	81,079	178,017	107,328	20,675	66,805	147,851	419	426	0	1,255
1990	5	6/21	6/25	47,626	9,468	29,069	66,183	29,003	6,059	17,128	40,878	0	0	0	0
1990	6	6/26	7/2	70,527	21,288	28,803	112,251	51,264	15,613	20,662	81,866	0	0	0	0
	Total			**274,434**	**34,309**	**207,188**		**389,336**	**39,489**	**311,937**	**466,735**	**4,241**	**1,096**	**2,092**	**6,390**
1991	1	5/6	5/28	0	0	0	0	15,350	2,407	10,633	20,067	19,724	3,016	13,812	25,636
1991	2	5/29	6/3	42	43	0	127	7,260	1,863	3,609	10,911	3,190	863	1,498	4,881
1991	3	6/4	6/9	3,887	1,010	1,909	5,866	40,008	6,909	26,467	53,549	10,852	2,189	6,561	15,143
1991	4	6/10	6/15	10,782	1,730	7,392	14,172	24,535	3,471	17,732	31,337	2,310	581	1,172	3,448
1991	5	6/16	6/23	82,463	12,979	57,024	107,902	20,134	3,647	12,985	27,282	1,071	505	82	2,060
1991	6	6/24	7/7	26,745	2,944	20,975	32,515	2,346	397	1,567	3,125	0	0	0	0
	Total			**123,920**	**13,459**	**97,541**	**150,298**	**109,633**	**9,083**	**91,831**	**127,435**	**37,147**	**3,902**	**29,499**	**44,796**
1992	1	5/4	5/24	47	47	0	139	11,597	1,879	7,914	15,281	2,198	458	1,299	3,096
1992	2	5/25	5/29	895	636	0	2,142	110,083	10,647	89,215	130,950	4,027	1,374	1,334	6,721
1992	3	5/30	6/5	4,421	2,581	0	9,480	412,641	43,319	327,737	497,546	7,369	3,356	791	13,947
1992	4	6/6	6/12	1,824	1,834	0	5,419	558,275	65,688	429,526	687,024	3,649	2,607	0	8,759
1992	5	6/13	6/19	10,253	2,788	4,789	15,717	174,298	18,440	138,156	210,441	0	0	0	0
1992	6	6/20	6/30	14,475	2,687	9,208	19,741	76,968	11,304	54,813	99,124	0	0	0	0
	Total			**31,915**	**5,042**	**22,032**	**41,797**	**1,343,862**	**82,317**		**1,505,204**	**17,243**		**8,442**	**26,043**

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				Age-1				Age-2				Age-3			
		Stratum Dates		Population		95% CI		Population		95% CI		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1993	1	5/4	5/19	20	20	0	58	1,370	189	1,000	1,740	3,444	351	2,756	4,133
1993	2	5/20	5/24	433	254	0	930	18,035	2,413	13,305	22,764	20,920	2,712	15,606	26,235
1993	3	5/25	5/29	4,016	1,518	1,040	6,992	95,376	14,527	66,903	123,849	37,648	6,657	24,600	50,697
1993	4	5/30	6/5	121,094	16,674	88,413	153,775	51,040	8,010	35,339	66,740	500	504	0	1,488
1993	5	6/6	6/12	93,856	11,104	72,092	115,621	2,769	923	960	4,577	0	0	0	0
1993	6	6/13	6/19	62,196	6,571	49,316	75,075	725	369	3	1,448	0	0	0	0
1993	7	6/20	6/30	47,083	4,778	37,718	56,448	1,593	423	763	2,423	0	0	0	0
	Total				**21,673**	**286,219**	**371,176**	**170,907**	**16,800**	**137,980**	**203,834**	**62,514**	**7,215**	**48,373**	**76,654**
1994	1	5/4	5/22	120	56	11	230	7,531	1,012	5,547	9,516	96	50	0	193
1994	2	5/23	5/28	617	438	0	1,475	105,182	8,675	88,179	122,184	617	438	0	1,475
1994	3	5/29	6/4	8,513	2,598	3,422	13,605	219,027	16,598	186,496	251,559	1,548	1,097	0	3,698
1994	4	6/5	6/11	9,693	1,721	6,320	13,067	85,300	6,720	72,128	98,472	0	0	0	0
1994	5	6/12	6/18	9,249	1,553	6,205	12,293	71,381	5,471	60,657	82,105	0	0	0	0
1994	6	6/19	6/27	13,167	1,454	10,318	16,016	20,988	2,033	17,002	24,973	0	0	0	0
	Total			**41,359**	**3,799**	**33,914**	**48,805**	**509,409**		**468,719**	**550,100**	**2,261**	**1,182**		**4,578**
1995	1	5/7	5/26	154	59	37	271	5,436	549	4,360	6,513	1,189	187	823	1,555
1995	2	5/27	6/3	182	129	0	435	29,143	2,929	23,403	34,884	2,451	514	1,443	3,459
1995	3	6/4	6/10	869	621	0	2,086	115,951	14,329	87,866	144,036	3,474	1,284	958	5,990
1995	4	6/11	6/19	10,963	2,636	5,796	16,131	159,142	26,533	107,137	211,147	2,829	1,098	677	4,981
1995	5	6/20	6/28	5,193	672	3,875	6,511	14,627	1,523	11,641	17,612	0	0	0	0
	Total			**17,361**	**2,794**	**11,883**		**324,299**	**30,340**		**383,766**	**9,943**	**1,776**	**6,463**	**13,423**
1996	1	5/1	5/23	711	192	335	1,087	7,570	1,059	5,494	9,646	3,597	576	2,467	4,726
1996	2	5/24	5/29	14,251	2,753	8,854	19,647	59,314	7,686	44,249	74,379	6,162	1,663	2,904	9,421
1996	3	5/30	6/4	71,042	10,983	49,515	92,569	64,038	10,059	44,323	83,753	4,503	1,611	1,346	7,660
1996	4	6/5	6/10	293,974	34,918	225,534	362,413	45,895	8,818	28,611	63,178	2,481	1,771	0	5,953
1996	5	6/11	6/18	277,711	34,067	210,940	344,482	42,582	7,788	27,317	57,848	926	931	0	2,751
1996	6	6/19	6/27	78,264	10,964	56,776	99,753	14,592	2,707	9,286	19,897	0	0	0	0
	Total			**735,953**		**635,470**	**836,436**	**233,991**	**17,525**	**199,642**	**268,339**	**17,669**	**3,114**	**11,565**	**23,772**

Appendix B2.-Estimated number of sockeye salmon smolt outmigrating from Akalura Lake by strata, age class, and year, 1990-1996.

				Age-0				Age-1			
		Stratum Dates		Population		95% CI		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1990	1	5/4	5/20	0	0	0	0	2,982	2,152	0	7,200
1990	2	5/21	5/27	0	0	0	0	2,724	906	949	4,499
1990	3	5/28	6/1	0	0	0	0	13,961	2,403	9,250	18,672
1990	4	6/2	6/10	0	0	0	0	27,545	4,921	17,901	37,190
1990	5	6/11	6/26	0	0	0	0	12,895	1,702	9,558	16,231
				0	**0**	**0**	**0**	**60,107**	**6,192**	**47,971**	**72,243**
1991	1	5/4	5/17	0	0	0	0	7,032	1,994	3,125	10,940
1991	2	5/18	5/31	0	0	0	0	517	266	0	1,039
1991	3	6/1	7/1	0	0	0	0	623	178	274	972
	Total			**0**	**0**	**0**	**0**		**2,019**	**4,215**	**12,130**
1992	1	5/1	5/11	0	0	0	0	354	253	0	849
1992	2	5/12	5/18	0	0	0	0	1,443	524	416	2,471
1992	3	5/19	5/26	0	0	0	0	37	26	0	88
1992	4	5/27	6/2	0	0	0	0	126	74	0	270
1992	5	6/3	7/1	21	21	0	63	213	71	74	352
	Total			**21**	**21**	**0**		**2,173**	**591**	**1,014**	**3,332**
1993	1	5/1	5/19	0	0	0	0	521	325	0	1,158
1993	2	5/20	5/23	0	0	0	0	491	227	45	936
1993	3	5/24	5/26	0	0	0	0	222	226	0	665
1993	4	5/27	6/1	0	0	0	0	143	101	0	341
1993	5	6/2	6/19	0	0	0	0	774	143	495	1,054
	Total			**0**	**0**	**0**		**2,150**	**489**	**1,191**	**3,109**
1994	1	5/4	5/30	0	0	0	0	256	103	53	459
1994	2	5/31	6/5	0	0	0	0	7,675	1,425	4,883	10,468
1994	3	6/6	6/12	0	0	0	0	35,239	3,674	28,038	42,441
1994	4	6/13	6/20	128	93	0	311	22,738	4,014	14,871	30,605
1994	5	6/21	6/27	0	0	0	0	5,586	1,419	2,805	8,367
	Total			**128**	**93**	**0**	**311**	**71,495**	**5,802**	**60,123**	
1995	1	5/4	5/11	0	0	0	0	164	75	17	311
1995	2	5/12	5/18	0	0	0	0	1,474	329	829	2,120
1995	3	5/19	5/28	0	0	0	0	2,612	501	1,630	3,593
1995	4	5/29	6/4	0	0	0	0	2,854	565	1,746	3,962
1995	5	6/5	6/10	0	0	0	0	26,474	4,898	16,875	36,074
1995	6	6/11	6/16	0	0	0	0	22,280	4,230	13,990	30,571
1995	7	6/17	6/27	0	0	0	0	4,795	927	2,978	6,612
	Total			**0**	**0**	**0**	**0**		**6,590**	**47,738**	**73,570**
1996	1	4/26	5/2	0	0	0	0	0	0	0	0
1996	2	5/3	5/9	0	0	0	0	895	335	239	1,552
1996	3	5/10	5/16	0	0	0	0	4,294	1,333	1,681	6,908
1996	4	5/17	5/23	0	0	0	0	624	194	243	1,005
1996	5	5/24	5/30	0	0	0	0	3,468	603	2,285	4,650
1996	6	5/31	6/6	0	0	0	0	2,842	463	1,936	3,749
1996	7	6/7	6/13	0	0	0	0	3,017	75	2,869	3,165
1996	8	6/14	6/20	0	0	0	0	498	6	487	509
	Total			**0**	**0**	**0**	**0**	**15,639**	**1,585**		**18,745**

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-				Age-2				Age-3			
		Stratum Dates		Population		95% CI		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1990	1	5/4	5/20	351,905	55,571	242,986	460,823	0	0	0	0
1990	2	5/21	5/27	9,535	3,071	3,515	15,554	0	0	0	0
1990	3	5/28	6/1	15,257	2,611	10,140	20,374	0	0	0	0
1990	4	6/2	6/10	16,262	3,029	10,324	22,199	0	0	0	0
1990	5	6/11	6/26	1,693	293	1,120	2,267	0	0	0	0
	Total			**394,652**	**55,800**	**285,284**	**504,019**	**0**	**0**	**0**	**0**
1991	1	5/4	5/17	203,432	21,734	160,833	246,032	1,005	717	0	2,409
1991	2	5/18	5/31	48,867	6,525	36,077	61,656	646	300	59	1,234
1991	3	6/1	7/1	18,568	3,388	11,929	25,208	530	159	217	842
	Total			**270,867**	**22,944**	**225,896**		**2,181**	**793**		**3,735**
1992	1	5/1	5/11	76,214	7,507	61,500	90,928	6,203	1,176	3,898	8,509
1992	2	5/12	5/18	71,633	6,941	58,029	85,237	1,985	621	768	3,201
1992	3	5/19	5/26	7,704	767	6,201	9,208	184	60	66	302
1992	4	5/27	6/2	17,170	2,011	13,228	21,112	168	86	0	335
1992	5	6/3	7/1	7,836	934	6,006	9,667	21	21	0	63
	Total			**180,557**	**10,490**	**159,998**	**201,117**	**8,561**	**1,334**		**11,176**
1993	1	5/1	5/19	4,524	2,570	0	9,561	2,162	1,246	0	4,605
1993	2	5/20	5/23	7,218	2,065	3,170	11,265	1,822	606	634	3,010
1993	3	5/24	5/26	20,210	4,408	11,570	28,851	1,110	540	52	2,169
1993	4	5/27	6/1	19,243	1,870	15,577	22,908	499	192	122	876
1993	5	6/2	6/19	6,317	815	4,719	7,915	30	22	0	73
	Total			**57,512**	**5,871**	**46,005**	**69,019**	**5,624**	**1,500**	**2,684**	**8,564**
1994	1	5/4	5/30	13,593	2,083	9,511	17,676	4,641	786	3,101	6,181
1994	2	5/31	6/5	52,798	4,885	43,222	62,373	4,187	1,023	2,181	6,192
1994	3	6/6	6/12	23,268	2,687	18,002	28,534	169	169	0	500
1994	4	6/13	6/20	1,542	408	742	2,341	0	0	0	0
1994	5	6/21	6/27	95	71	0	233	0	0	0	0
	Total			**91,296**	**5,966**	**79,602**		**8,996**	**1,301**	**6,446**	**11,546**
1995	1	5/4	5/11	9,013	1,035	6,985	11,041	98	58	0	211
1995	2	5/12	5/18	17,807	2,154	13,585	22,030	170	100	0	366
1995	3	5/19	5/28	19,224	2,683	13,966	24,482	0	0	0	0
1995	4	5/29	6/4	12,777	1,839	9,171	16,382	0	0	0	0
1995	5	6/5	6/10	11,868	2,453	7,061	16,675	0	0	0	0
1995	6	6/11	6/16	499	223	63	935	0	0	0	0
1995	7	6/17	6/27	0	0	0	0	0	0	0	0
	Total			**71,187**	**4,728**	**61,920**	**80,455**	**268**	**115**	**42**	**494**
1996	1	4/26	5/2	5	0	5	5	0	0	0	0
1996	2	5/3	5/9	43,356	358	42,655	44,057	128	128	0	378
1996	3	5/10	5/16	114,231	1,512	111,268	117,194	1,288	740	0	2,738
1996	4	5/17	5/23	20,657	194	20,276	21,038	0	0	0	0
1996	5	5/24	5/30	34,214	603	33,032	35,397	0	0	0	0
1996	6	5/31	6/6	15,810	463	14,903	16,716	0	0	0	0
1996	7	6/7	6/13	487	75	339	635	0	0	0	0
1996	8	6/14	6/20	6	6	0	17	0	0	0	0
	Total			**228,766**	**1,742**	**225,351**	**232,180**	**1,416**	**751**	**0**	**2,888**

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				Age-4			
		Stratum Dates		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper
1990	1	5/4	5/20	0	0	0	0
1990	2	5/21	5/27	0	0	0	0
1990	3	5/28	6/1	0	0	0	0
1990	4	6/2	6/10	0	0	0	0
1990	5	6/11	6/26	0	0	0	0
	Total			**0**	**0**	**0**	**0**
1991	1	5/4	5/17	0	0	0	0
1991	2	5/18	5/31	0	0	0	0
1991	3	6/1	7/1	0	0	0	0
	Total			**0**	**0**	**0**	**0**
1992	1	5/1	5/11	0	0	0	0
1992	2	5/12	5/18	0	0	0	0
1992	3	5/19	5/26	0	0	0	0
1992	4	5/27	6/2	0	0	0	0
1992	5	6/3	7/1	0	0	0	0
	Total			**0**	**0**	**0**	**0**
1993	1	5/1	5/19	80	72	0	222
1993	2	5/20	5/23	0	0	0	0
1993	3	5/24	5/26	0	0	0	0
1993	4	5/27	6/1	0	0	0	0
1993	5	6/2	6/19	0	0	0	0
	Total				**72**	**0**	**222**
1994	1	5/4	5/30	0	0	0	0
1994	2	5/31	6/5	0	0	0	0
1994	3	6/6	6/12	0	0	0	0
1994	4	6/13	6/20	0	0	0	0
1994	5	6/21	6/27	0	0	0	0
	Total			**0**	**0**	**0**	**0**
1995	1	5/4	5/11	0	0	0	0
1995	2	5/12	5/18	0	0	0	0
1995	3	5/19	5/28	0	0	0	0
1995	4	5/29	6/4	0	0	0	0
1995	5	6/5	6/10	0	0	0	0
1995	6	6/11	6/16	0	0	0	0
1995	7	6/17	6/27	0	0	0	0
	Total			**0**	**0**	**0**	**0**
1996	1	4/26	5/2	0	0	0	0
1996	2	5/3	5/9	0	0	0	0
1996	3	5/10	5/16	0	0	0	0
1996	4	5/17	5/23	0	0	0	0
1996	5	5/24	5/30	0	0	0	0
1996	6	5/31	6/6	0	0	0	0
1996	7	6/7	6/13	0	0	0	0
1996	8	6/14	6/20	0	0	0	0
	Total			**0**	**0**	**0**	**0**

Appendix B3.-Estimated number of sockeye salmon smolt outmigrating from Upper Station Lakes by strata, age class, and year, 1990-1993.

				Age-0				Age-1			
		Strata Dates		Population		95% CI		Population		95% CI	
Year	STRATUM	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1990	1	5/3	5/27	0	0	0	0	26,122	11,719	3,154	49,091
1990	2	5/28	6/2	0	0	0	0	17,050	2,853	11,458	22,642
1990	3	6/3	6/7	0	0	0	0	29,553	5,691	18,398	40,708
1990	4	6/8	6/11	0	0	0	0	4,707	1,604	1,563	7,851
1990	5	6/12	6/17	0	0	0	0	15,598	4,281	7,207	23,990
1990	6	6/18	6/22	0	0	0	0	10,771	1,547	7,740	13,802
1990	7	6/23	6/29	5,013	1,621	1,836	8,190	42,014	10,510	21,413	62,614
1990	8	6/30	7/7	54,644	10,924	33,232	76,056	8,896	2,351	4,287	13,504
1990	9	7/8	7/14	3,627,479	756,871	2,144,012	5,110,945	0	0	0	0
1990	10	7/15	7/28	1,501,087	369,688	776,498	2,225,675	1,633	1,681	0	4,929
	Total			**5,188,222**	**842,404**	**3,537,110**	**6,839,334**	**156,344**		**121,284**	**191,405**
1991	1	5/6	6/1	0	0	0	0	2,369	508	1,374	3,364
1991	2	6/2	6/9	0	0	0	0	10,516	1,822	6,945	14,087
1991	3	6/10	6/19	0	0	0	0	128,128	21,693	85,609	170,646
1991	4	6/20	6/28	0	0	0	0	26,366	5,240	16,095	36,637
1991	5	6/29	7/6	3,137	743	1,681	4,593	6,798	1,439	3,976	9,619
1991	6	7/7	7/12	559,359	129,772	305,005	813,713	16,697	6,485	3,987	29,408
1991	7	7/13	7/19	578,972	147,100	290,656	867,288	8,411	4,023	526	16,297
1991	8	7/20	7/27	539,624	160,964	224,135	855,114	1,104	1,150	0	3,358
1991	9	7/28	8/5	49,671	11,913	26,322	73,019	142	146	0	429
	Total			**1,730,763**	**254,030**	**1,232,865**	**2,228,662**		**23,734**	**154,013**	**247,048**
1992	1	5/4	5/21	0	0	0	0	360	291	0	929
1992	2	5/22	5/27	0	0	0	0	6,823	2,128	2,651	10,995
1992	3	5/28	6/2	0	0	0	0	3,305	705	1,923	4,687
1992	4	6/3	6/8	0	0	0	0	5,921	1,257	3,456	8,386
1992	5	6/9	6/17	0	0	0	0	9,285	1,391	6,558	12,011
1992	6	6/18	6/27	502	172	166	839	12,009	1,731	8,617	15,402
1992	7	6/28	7/7	631,798	142,706	352,094	911,501	6,119	3,344	0	12,673
1992	8	7/8	7/15	588,240	116,869	359,177	817,303	0	0	0	0
1992	9	7/16	7/22	349,977	36,155	279,113	420,841	0	0	0	0
1992	10	7/23	7/29	249,311	22,359	205,488	293,134	0	0	0	0
1992	11	7/30	8/9	50,181	4,521	41,320	59,042	0	0	0	0
				1,870,009		**1,498,896**	**2,241,122**	**43,823**		**34,463**	**53,182**
1993	1	5/10	5/17	0	0	0	0	8,145	1,319	5,560	10,730
1993	2	5/18	5/22	0	0	0	0	23,746	5,443	13,077	34,415
1993	3	5/23	5/27	0	0	0	0	71,274	12,008	47,739	94,810
1993	4	5/28	6/1	0	0	0	0	169,560	49,658	72,229	266,890
1993	5	6/2	6/6	0	0	0	0	158,135	25,195	108,753	207,517
1993	6	6/7	6/14	0	0	0	0	91,774	18,100	56,298	127,249
1993	7	6/15	6/21	15,911	2,444	11,120	20,702	55,570	6,323	43,176	67,964
1993	8	6/22	6/29	199,808	16,569	167,332	232,284	24,908	4,009	17,051	32,766
1993	9	6/30	7/5	405,363	41,264	324,485	486,241	7,424	3,375	809	14,040
1993	10	7/6	7/15	1,793,232	262,079	1,279,557	2,306,907	3,667	3,702	0	10,924
1993	11	7/16	7/25	444,840	41,211	364,066	525,614	6,447	2,492	1,563	11,331
1993	12	7/26	8/1	206,255	16,397	174,117	238,393	0	0	0	0
1993	13	8/2	8/9	122,445	8,946	104,911	139,979	0	0	0	0
	Total			**3,187,854**	**269,659**	**2,659,323**	**3,716,385**	**620,651**	**60,756**	**501,569**	**739,732**

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				Age-2				Age-3			
		Strata Dates		Population		95% CI		Population		95% CI	
Year	STRATUM	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1990	1	5/3	5/27	595,919	224,150	156,586	1,035,253	27,755	12,337	3,575	51,935
1990	2	5/28	6/2	74,119	9,751	55,007	93,231	3,315	970	1,415	5,216
1990	3	6/3	6/7	49,188	9,117	31,319	67,057	2,024	730	592	3,456
1990	4	6/8	6/11	133,607	27,347	80,007	187,207	5,793	1,847	2,172	9,414
1990	5	6/12	6/17	192,381	37,028	119,806	264,956	11,699	3,494	4,850	18,548
1990	6	6/18	6/22	21,377	2,773	15,942	26,813	658	244	179	1,137
1990	7	6/23	6/29	36,046	9,085	18,239	53,852	477	356	0	1,176
1990	8	6/30	7/7	59,409	11,808	36,266	82,552	2,859	1,090	723	4,995
1990	9	7/8	7/14	9,137	9,323	0	27,410	0	0	0	0
1990	10	7/15	7/28	0	0	0	0	0	0	0	0
	Total				**229,906**	**720,567**	**1,621,799**	**54,581**	**13,064**	**28,976**	**80,186**
1991	1	5/6	6/1	10,556	2,005	6,626	14,487	1,080	267	557	1,602
1991	2	6/2	6/9	15,711	2,630	10,556	20,865	1,014	298	429	1,598
1991	3	6/10	6/19	162,226	26,642	110,008	214,444	12,399	3,997	4,564	20,234
1991	4	6/20	6/28	20,199	4,104	12,155	28,243	1,079	453	191	1,968
1991	5	6/29	7/6	3,595	831	1,967	5,223	65	67	0	196
1991	6	7/7	7/12	8,349	4,181	153	16,544	0	0	0	0
1991	7	7/13	7/19	1,402	1,445	0	4,234	0	0	0	0
1991	8	7/20	7/27	0	0	0	0	0	0	0	0
1991	9	7/28	8/5	0	0	0	0	0	0	0	0
	Total			**222,037**	**27,529**	**168,080**	**275,993**		**4,043**		**23,562**
1992	1	5/4	5/21	27,849	15,796	0	58,809	600	432	0	1,446
1992	2	5/22	5/27	77,732	19,778	38,967	116,496	244	251	0	736
1992	3	5/28	6/2	22,404	3,651	15,247	29,560	0	0	0	0
1992	4	6/3	6/8	42,998	6,740	29,788	56,208	141	142	0	420
1992	5	6/9	6/17	35,138	4,459	26,399	43,878	80	81	0	238
1992	6	6/18	6/27	11,959	1,724	8,580	15,339	0	0	0	0
1992	7	6/28	7/7	4,589	2,836	0	10,148	0	0	0	0
1992	8	7/8	7/15	0	0	0	0	0	0	0	0
1992	9	7/16	7/22	0	0	0	0	0	0	0	0
1992	10	7/23	7/29	0	0	0	0	0	0	0	0
1992	11	7/30	8/9	0	0	0	0	0	0	0	0
	Total			**222,668**	**27,025**	**169,700**	**275,637**	**1,065**	**526**	**35**	**2,095**
1993	1	5/10	5/17	33,938	3,952	26,192	41,683	1,358	449	477	2,238
1993	2	5/18	5/22	60,407	12,365	36,172	84,643	2,916	1,230	506	5,327
1993	3	5/23	5/27	130,832	19,471	92,670	168,995	2,929	1,728	0	6,316
1993	4	5/28	6/1	190,429	55,496	81,658	299,200	5,217	2,988	0	11,074
1993	5	6/2	6/6	50,043	9,890	30,659	69,427	0	0	0	0
1993	6	6/7	6/14	20,335	4,508	11,500	29,170	268	272	0	801
1993	7	6/15	6/21	10,686	1,878	7,005	14,368	475	339	0	1,139
1993	8	6/22	6/29	2,707	1,223	310	5,105	0	0	0	0
1993	9	6/30	7/5	2,970	2,114	0	7,113	0	0	0	0
1993	10	7/6	7/15	0	0	0	0	0	0	0	0
1993	11	7/16	7/25	0	0	0	0	0	0	0	0
1993	12	7/26	8/1	0	0	0	0	0	0	0	0
1993	13	8/2	8/9	0	0	0	0	0	0	0	0
	Total			**502,347**	**61,278**	**382,242**	**622,452**	**13,163**	**3,717**	**5,876**	**20,449**

Appendix B4.-Estimated number of sockeye salmon smolt outmigrating from Frazer Lake by strata, age class, and year, 1991-1996.

				Age-1				Age-2			
		Stratum Dates		Population		95% CI		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1991	1	5/11	5/26	535,908	220,751	103,237	968,579	671,672	275,573	131,548	1,211,795
1991	2	5/27	6/2	113,443	26,381	61,736	165,151	155,389	35,370	86,063	224,714
1991	3	6/3	6/10	1,087,095	387,726	327,152	1,847,037	1,605,295	568,772	490,502	2,720,089
1991	4	6/11	6/20	154,418	42,113	71,877	236,960	254,281	68,243	120,526	388,037
1991	5	6/21	7/11	50,042	8,381	33,616	66,468	184,052	27,223	130,696	237,409
	Total			**1,940,906**		**1,060,864**	**2,820,948**	**2,870,690**	**637,253**		**4,119,705**
1992	1	5/6	5/16	4,428	3,218	0	10,736	208,115	120,006	0	443,327
1992	2	5/17	5/20	1,893	1,334	0	4,507	148,264	60,663	29,364	267,164
1992	3	5/21	5/26	20,845	10,792	0	41,998	1,238,184	330,922	589,577	1,886,791
1992	4	5/27	6/3	21,903	7,457	7,288	36,519	1,029,464	138,214	758,566	1,300,363
1992	5	6/4	6/11	21,656	10,290	1,488	41,825	1,653,077	409,260	850,928	2,455,225
1992	6	6/12	6/18	6,374	2,864	761	11,987	322,328	80,163	165,207	479,448
1992	7	6/19	6/26	3,094	1,495	163	6,025	178,665	59,477	62,090	295,240
1992	8	6/27	7/11	2,222	1,341	0	4,850	200,012	81,546	40,183	359,842
	Total			**82,415**		**48,335**	**116,495**	**4,978,109**			**6,105,408**
1993	1	5/6	5/18	0	0	0	0	18,674	8,646	1,727	35,620
1993	2	5/19	5/25	0	0	0	0	212,620	73,101	69,343	355,897
1993	3	5/26	6/2	0	0	0	0	1,875,292	598,728	701,786	3,048,798
1993	4	6/3	6/8	0	0	0	0	1,314,872	419,748	492,166	2,137,578
1993	5	6/9	6/20	22,221	12,588	0	46,894	624,977	279,735	76,697	1,173,257
	Total			**22,221**	**12,588**		**46,894**	**4,046,434**			**5,587,664**
1994	1	5/6	5/18	2,120	1,533	0	5,126	243,851	40,227	165,006	322,696
1994	2	5/19	5/25	12,279	5,174	2,138	22,420	474,784	58,512	360,100	589,468
1994	3	5/26	6/1	23,398	11,985	0	46,889	1,924,521	238,835	1,456,403	2,392,638
1994	4	6/2	6/8	82,325	19,705	43,704	120,946	1,070,225	140,176	795,481	1,344,969
1994	5	6/9	6/15	330,677	50,270	232,148	429,206	688,166	93,424	505,055	871,278
1994	6	6/16	6/22	123,156	15,465	92,844	153,467	28,251	4,711	19,017	37,485
1994	7	6/23	6/28	99,809	21,824	57,034	142,585	20,447	5,062	10,526	30,369
	Total			**673,765**	**61,673**	**552,886**	**794,644**	**4,450,246**			**5,039,907**
1995	1	5/11	5/17	0	0	0	0	2,480,978	329,992	1,834,193	3,127,763
1995	2	5/18	5/24	8,518	8,572	0	25,319	2,955,773	368,492	2,233,528	3,678,018
1995	3	5/25	5/31	4,504	3,211	0	10,797	779,109	82,606	617,201	941,017
1995	4	6/1	6/7	20,970	10,705	0	41,952	1,751,022	204,122	1,350,942	2,151,102
1995	5	6/8	6/14	9,760	4,090	1,743	17,777	553,058	60,383	434,707	671,408
1995	6	6/15	6/27	9,658	2,152	5,440	13,877	164,935	19,123	127,455	202,415
	Total			**53,410**	**14,824**	**24,355**	**82,465**	**8,684,874**			**9,753,359**
1996	1	5/9	5/12	0	0	0	0	253,497	22,787	208,834	298,160
1996	2	5/13	5/18	4,067	4,093	0	12,089	1,289,322	161,693	972,404	1,606,240
1996	3	5/19	5/25	3,270	2,337	0	7,852	479,115	57,192	367,019	591,211
1996	4	5/26	6/1	36,006	12,534	11,440	60,573	1,087,393	170,154	753,891	1,420,896
1996	5	6/2	6/9	13,418	4,133	5,318	21,519	356,706	43,203	272,027	441,385
1996	6	6/10	6/23	725	202	329	1,121	14,238	2,107	10,109	18,368
	Total			**57,487**	**14,016**	**30,017**	**84,958**				**3,963,395**

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				Age-3				Age-4			
		Stratum Dates		Population		95% CI		Population		95% CI	
Year	Stratum	Start	End	Estimate	SE	Lower	Upper	Estimate	SE	Lower	Upper
1991	1	5/11	5/26	0	0	0	0	0	0	0	0
1991	2	5/27	6/2	0	0	0	0	0	0	0	0
1991	3	6/3	6/10	5,633	5,966	0	17,327	0	0	0	0
1991	4	6/11	6/20	0	0	0	0	0	0	0	0
1991	5	6/21	7/11	1,272	756	0	2,754	0	0	0	0
	Total			**6,905**	**6,014**	**0**	**18,692**	**0**	**0**	**0**	**0**
1992	1	5/6	5/16	82,360	47,954	0	176,350	0	0	0	0
1992	2	5/17	5/20	25,867	11,202	3,911	47,824	0	0	0	0
1992	3	5/21	5/26	133,407	42,042	51,005	215,809	0	0	0	0
1992	4	5/27	6/3	10,952	5,089	978	20,926	0	0	0	0
1992	5	6/4	6/11	43,312	16,347	11,273	75,352	0	0	0	0
1992	6	6/12	6/18	8,195	3,380	1,570	14,820	0	0	0	0
1992	7	6/19	6/26	1,160	771	0	2,672	0	0	0	0
1992	8	6/27	7/11	0	0	0	0	0	0	0	0
	Total			**305,253**	**67,065**	**173,806**	**436,700**	**0**	**0**	**0**	**0**
1993	1	5/6	5/18	120,091	53,683	14,872	225,309	966	703	0	2,345
1993	2	5/19	5/25	580,703	193,810	200,836	960,570	0	0	0	0
1993	3	5/26	6/2	1,811,723	578,994	676,895	2,946,551	0	0	0	0
1993	4	6/3	6/8	727,164	239,005	258,714	1,195,614	0	0	0	0
1993	5	6/9	6/20	124,995	58,377	10,577	239,413	0	0	0	0
	Total			**3,364,676**	**660,462**	**2,070,172**	**4,659,181**	**966**	**703**	**0**	**2,345**
1994	1	5/6	5/18	162,214	27,815	107,697	216,731	0	0	0	0
1994	2	5/19	5/25	165,765	25,261	116,253	215,277	0	0	0	0
1994	3	5/26	6/1	93,594	25,608	43,402	143,785	0	0	0	0
1994	4	6/2	6/8	100,222	22,304	56,507	143,937	0	0	0	0
1994	5	6/9	6/15	14,895	6,892	1,387	28,404	0	0	0	0
1994	6	6/16	6/22	441	444	0	1,312	0	0	0	0
1994	7	6/23	6/28	347	354	0	1,041	0	0	0	0
	Total			**537,478**	**51,116**	**437,291**	**637,665**	**0**	**0**	**0**	**0**
1995	1	5/11	5/17	43,399	18,486	7,166	79,632	0	0	0	0
1995	2	5/18	5/24	8,518	8,572	0	25,319	0	0	0	0
1995	3	5/25	5/31	2,252	2,261	0	6,684	0	0	0	0
1995	4	6/1	6/7	26,213	12,029	2,636	49,790	0	0	0	0
1995	5	6/8	6/14	3,253	2,321	0	7,802	0	0	0	0
1995	6	6/15	6/27	1,857	854	184	3,530	0	0	0	0
	Total			**85,492**	**23,899**	**38,651**	**132,334**	**0**	**0**	**0**	**0**
1996	1	5/9	5/12	33,428	7,032	19,645	47,211	0	0	0	0
1996	2	5/13	5/18	105,749	23,890	58,925	152,572	0	0	0	0
1996	3	5/19	5/25	60,503	11,773	37,428	83,577	0	0	0	0
1996	4	5/26	6/1	79,214	20,447	39,138	119,291	0	0	0	0
1996	5	6/2	6/9	3,355	1,970	0	7,216	0	0	0	0
1996	6	6/10	6/23	597	179	245	948	0	0	0	0
	Total			**282,845**	**34,362**	**215,495**	**350,195**	**0**	**0**	**0**	

APPENDIX C

Appendix C1.-Estimated return by system, brood year, and age class for Red, Akalura, Upper Station, and Frazer Lakes, 1985-1994.

Lake System	Brood Year	AGE 0.1	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	2.4	3.3	Total Return [a]
Red	1985	0	0	61,345	3,903	365,489	18,971	0	589,731	513,314	0	0	229,750	4,276	0	0	1,786,779
	1986	0	0	4,480	38,326	571,371	6,489	0	506,463	365,644	0	0	231,471	5,967	0	0	1,730,211
	1987	0	0	12,991	15,380	173,341	13,602	0	103,512	317,142	0	0	341,728	32,807	0	5,063	1,015,566
	1988	0	0	2,822	3,351	81,584	2,832	0	62,159	126,124	0	0	27,783	10,655	0	8,225	325,535
	1989	0	0	2,571	5,565	26,297	29,189	0	18,318	310,379	0	0	254,557	59,553	0	46,238	752,667
	1990	0	0	1,028	8,047	3,618	14,638	0	59,035	295,167	0	0	202,600	16,202	[a]	[a]	600,335 [d]
	1991	0	640	22,371	17,118	145,925	36,123	0	393,294	482,178	0	[a]	[a]	[a]	[a]	[a]	1,097,649 [d]
	1992	0	4,591	2,578	9,900	65,889	24,694	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	107,652 [d]
	1993	0	0	3,093	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	3,093 [d]
	1994	0	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	0 [d]
Akalura	1985	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	0	0	0 [d]
	1986	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	37	20,257	232	0	0	20,526 [d]
	1987	[b]	[b]	[b]	[b]	[b]	[b]	0	7,762	102,390	0	141	141	260	14	174	110,882 [d]
	1988	[b]	[b]	[b]	0	2,558	306	0	6,974	30,699	0	28	14,671	278	0	0	55,515 [d]
	1989	[b]	[b]	25	0	17,129	43,866	0	10,533	16,283	28	442	5	22	0	48	88,378 [d]
	1990	[b]	0	141	0	396	202	0	636	1,097	0	0	1,145	281	[a]	[a]	3,898 [d]
	1991	0	0	146	0	866	1,867	0	472	13,809	80	[a]	[a]	[a]	[a]	[a]	17,238 [d]
	1992	0	0	1,347	0	7,729	695	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	9,770 [d]
	1993	0	0	424	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	424 [d]
	1994	0	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	0 [d]
Upper [e] Station	1985	2,313	564,233	1,962	312,640	37,238	34,840	0	47,473	266,787	0	578	88,184	6,773	0	64	1,363,086
	1986	1,449	72,450	7,633	94,830	343,176	6,546	678	152,087	535,096	60	18	25,969	1,919	6	1,697	1,243,614
	1987	0	70,150	541	114,843	14,926	3,976	0	17,779	135,412	27	225	52,712	15,851	0	96	426,537
	1988	0	9,239	216	27,863	76,665	1,852	0	72,937	115,742	387	339	11,319	2,316	0	0	318,874
	1989	401	169,607	1,529	91,353	92,558	19,177	142	59,467	251,877	308	0	60,543	0	0	0	746,962
	1990	1,432	58,489	4,482	115,907	34,022	11,142	444	29,794	357,490	0	0	11,154	361	[a]	[a]	624,717 [d]
	1991	6,744	52,217	8,116	182,199	105,991	12,095	160	101,982	844,602	31	[a]	[a]	[a]	[a]	[a]	1,314,137 [d]
	1992	4,965	62,827	1,331	21,611	64,882	16,194	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	171,810 [d]
	1993	5,405	46,684	6,293	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	58,382 [d]
	1994	1,417	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	1,417 [d]

-continued-

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Lake	Brood	AGE															Total
System	Year	0.1	0.2	1.1	0.3	1.2	2.1	0.4	1.3	2.2	3.1	1.4	2.3	3.2	2.4	3.3	Return [a]
Frazer	1985	0	0	192	0	16,502	4,399	0	49,290	53,978	151	0	22,578	9,032	1,595	2,694	160,412
	1986	0	1,393	67,475	0	727,658	40,794	0	230,893	972,290	0	0	168,815	9,129	0	8,584	2,227,031
	1987	0	0	1,787	1,851	3,019	26,596	0	3,902	187,581	0	0	159,822	104	156	882	385,701
	1988	0	0	1,886	0	21,073	7,793	0	30,096	210,586	133	0	64,565	20,510	16	7,994	364,652
	1989	0	0	16,191	208	327,929	12,847	0	153,078	373,277	5,752	0	300,182	145,325	0	40,752	1,375,541
	1990	0	0	1,096	0	18,217	12,986	0	33,393	400,750	1,678	0	210,733	15,341	[a]	[a]	694,194 [d]
	1991	0	0	621	0	2,031	57,463	0	1,728	330,817	302	[a]	[a]	[a]	[a]	[a]	392,961 [d]
	1992	0	0	3,545	0	20,512	78,168	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	102,225 [d]
	1993	0	0	2,529	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	2,529 [d]
	1994	0	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	0 [d]

[a] Return is the sum of catch and escapement.

[b] These age classes have not yet returned.

[c] Run reconstruction was not performed for these brood year/age class combinations.

[d] Incomplete brood year return data.

[e] Upper Station Lakes data is the sum of the early and late runs.

Appendix C2.-Ricker parameter estimates for Frazer Lake Sockeye Salmon (1969-1989).

Parameter	Linearized Form	Bootstrap
a=ln(a)	1.7	1.6
se(a)	0.30	0.23
cv(a)	18%	14%
low 95%	1.0	1.2
upp95%	2.3	2.1
b	5.5E-06	5.4E-06
se(b)	1.4E-06	1.7E-06
cv(b)	26%	31%
low 95%	2.5E-06	1.75E-06
upp95%	8.4E-06	8.52E-06
S_{MSY}	116,909	137,087
se(S_{MSY})	---	115,636
cv(S_{MSY})	---	84%
low 80%	---	85,077
upp 80%	---	211,330