Sockeye Salmon Overescapement: 1993 Annual Report on Kenai River and Kodiak Investigations

Exxon Valdez Oil Spill
Restoration Project 930002

By

D. C. Schmidt
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REGIONAL INFORMATION REPORT NO 5J95-15

Alaska Department of Fish and Game
Division of Commercial Fisheries
Management and Development
P. O. Box 25526
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EXECUTIVE SUMMARY

This status report is the fourth in a series describing progress of studies on the effect of overescapement on sockeye salmon *Oncorhynchus nerka* production from selected major rearing lakes impacted by the Exxon *Valdez* oil spill. Large escapements of sockeye salmon can result in the over abundance of juvenile salmon rearing in lakes. By exceeding the rearing capacity, the forage base (zooplankton community) can be altered through changes in species, size composition, and biomass (Koenings and Burkett 1987; Kyle et al. 1988; Koenings and Kyle 1991). In some sockeye salmon systems, escapements of two to three times normal levels have caused major changes in the ability of a nursery lake to support juveniles as evidenced by changes in abundance, size, and age structure of migrating sockeye salmon smolts. These alterations to nursery lakes can be sustained and adversely affect productivity in succeeding years. This report provides an update on studies of the 1989 overescapement event caused by the presence of oil on the fishing grounds in Cook Inlet and the Kodiak area.

In 1993, a major decrease in smolt abundance from the Kenai River system continued with poor overwintering survival as the primary cause. Projected returns from the 1993 smolt production will fail to meet current escapement goals established for this system. Smolt production in 1993 from Red Lake (located on Kodiak Island) was modest. Smolt production remains very low for this system. Akalura Lake also produced a low number of smolt in 1993 and continued to show a decreasing trend in production, suggesting over-cropping of the zooplankton population.

Analysis of lipid content of fall juveniles from Skilak and Kenai lakes in 1992 indicated a decrease in total fat content, in addition the juveniles were smaller compared to Tustumena Lake. Further, Tustumena Lake fall fry growth in 1993 responded positively to favorable rearing conditions during the summer of 1993, while the fall fry in Skilak and Kenai lakes were much smaller, indicating continued availability of food resources. Further analysis of the zooplankton data in Skilak Lake indicates that the basins with the highest summer density of fish had a high rate of cropping on ovigerous calanoid copepods, while in Tustumena Lake these zooplankton increased in abundance. A pilot restoration project has been recommended for 1995 using net enclosures to test the effects of fish density on the plankton community, and to assess if adding nutrients would facilitate recovery of this system. In addition, to further test the hypothesis that overwintering mortality is caused by starvation of poor conditioned fish, we recommend conducting a laboratory test on the effects of starvation of sockeye salmon fry from glacial lake stocks on the Kenai Peninsula.

ABSTRACT

This report provides results of continuing studies on the effects of large sockeye salmon *Oncorhynchus nerka* escapements in the Kenai River system and in Red and Akalura lakes on Kodiak Island. The number of smolt migrating from the Kenai River decreased from 30 million in 1989 to less than 500,000 in 1992 and 1993. Decreased overwintering survival of age-0 juvenile sockeye salmon rearing in Skilak and Kenai lakes continued through the 1992-1993 winter. In contrast, in Tustumena Lake (a nearby glacial system used as a control), smolt production in 1993 was the third highest in the past 13 years, but received only average escapements (~150,000) in recent years. Juvenile sockeye salmon caught in the fall from Skilak and Kenai lakes were about half the size of those caught in Tustumena Lake, and had less lipid content compared to juveniles in Tustumena Lake. The increased size of Tustumena Lake fall fry in 1993 presumably resulted from the mild (sunny and warm) weather conditions that produced an increase in overall zooplankton density. Selective cropping on ovigerous copepods in the lower basin of Tustumena Lake was quite evident, and demonstrated that sockeye salmon fry preferred this organism. The number of smolt migrating from Red and Akalura lakes on Kodiak Island, which received high escapements, have varied since monitoring, but in 1993 a substantial decrease occurred.

Key Words: *Oncorhynchus nerka,* over-escapement, glacial, zooplankton, diel vertical migration, foraging

INTRODUCTION

Following the Exxon *Valdez* oil spill (EVOS) in 1989, the presence of oil in the waters of traditional fishing areas in the Gulf of Alaska resulted in the closure of many commercial fisheries. This closure resulted in the escapement of large numbers of sockeye salmon *Oncorhynchus nerka* into several nursery lakes systems. Investigations of the impact of large escapements on future production were initiated in 1990. Specifically, these investigations assessed impacts to the production and ecology of major sockeye salmon rearing lakes on the Kenai Peninsula and Kodiak Island (Figures 1 and 2).

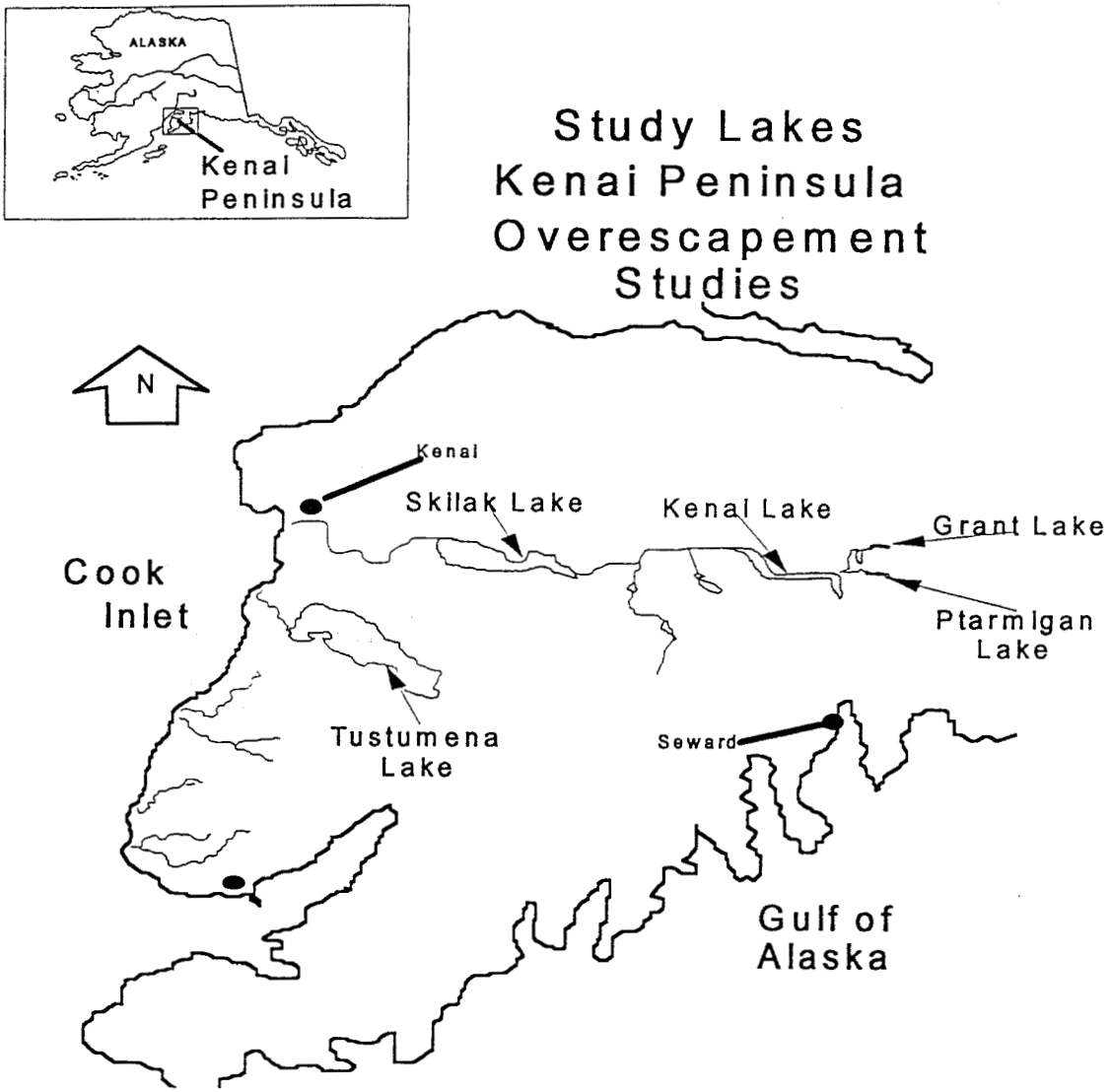

Figure 1. Location of study lakes of the Kenai River drainage, Kenai Peninsula, Alaska.

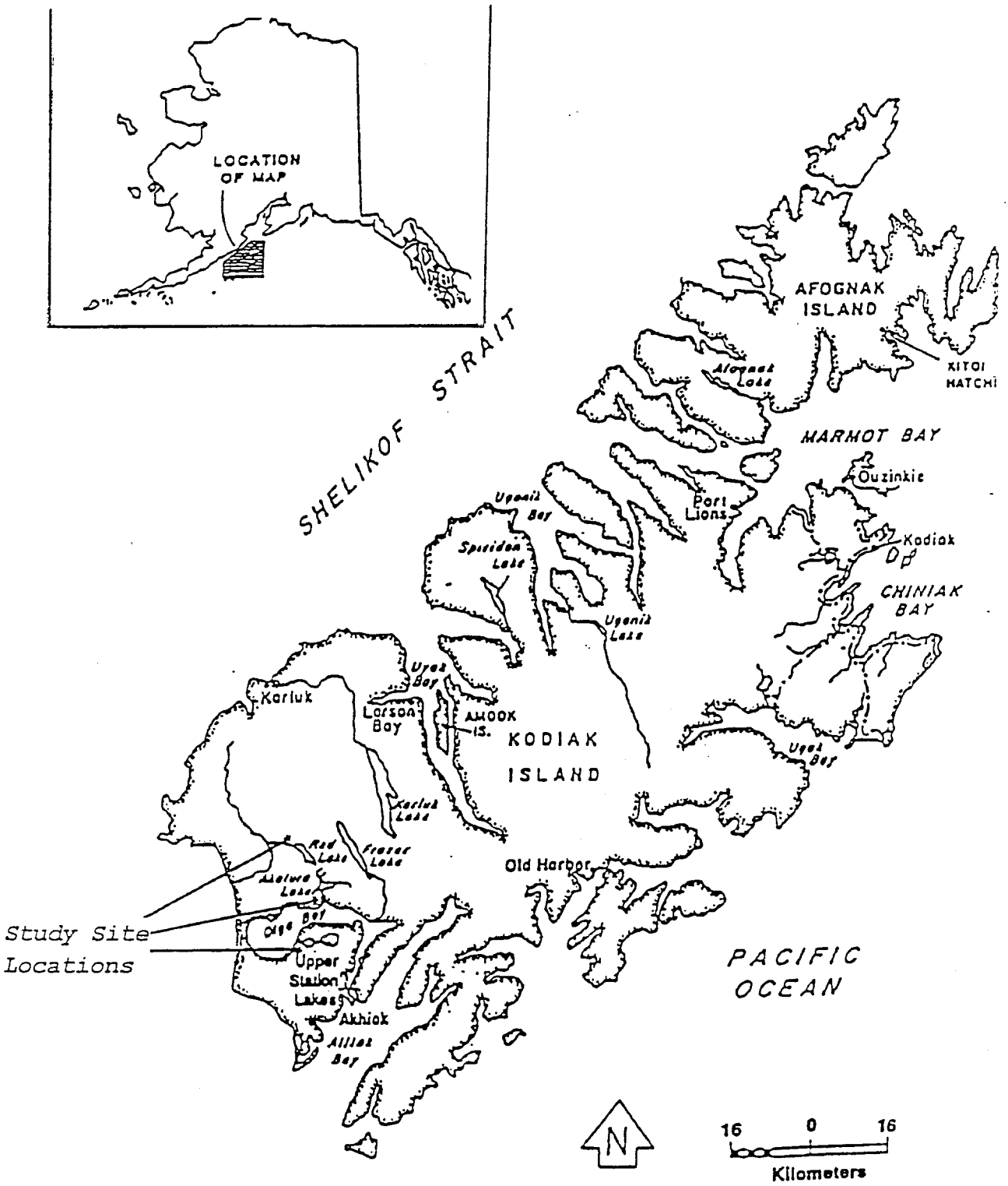

Figure 2. Location of Red, Akalura, and Upper Station lakes on the southern end of Kodiak Island.

In 1989, the sockeye salmon escapement into Red Lake was 768,000 and in Akalura Lake was 116,000, which was more than twice the escapement goals for these lake systems. However, not all southern Kodiak Island lakes received higher-than-average escapements. For example, Upper Station Lake adjacent to Red Lake received an escapement of 286,000 sockeye salmon in 1989, which was reasonably close to the 200,000 to 275,000 goal. The major sockeye-producing lakes on the Kenai Peninsula are glacially influenced and have produced large runs of sockeye salmon over the past decade. The highest escapements occurred in three consecutive years from 1987 to 1989. Escapements of sockeye salmon during these three years were approximately double those of previous years, and double the Alaska Department of Fish and Game's escapement goal of 550,000 adults.

The first three years of study (1990-1992) were designed to characterize the population parameters of sockeye salmon smolts resulting from escapements before and during 1989, when oil on the fishing grounds curtailed fishing. Smolt sizes, ages, and numbers reflect the density-dependent effects of escapements consistent with established goals, and thus help to establish pre-impact conditions. The limnological assessment characterized the rearing conditions during the initial impact of large numbers of rearing fish and the effects of large nutrient additions to the lakes from salmon carcasses. Because high densities of planktivorous fish can exert top-down control over lower trophic levels, measurable ecosystem changes within the affected lakes are expected to occur. For example, major forage items within the zooplankton community may be reduced or eliminated, prey item body-sizes may be reduced, and preferred food items may be replaced by forms resistant to predation. Kyle et al. (1988) found that large sockeye salmon escapements into Frazer Lake on Kodiak Island resulted in subsequent reductions in smolt size that was correlated to a depressed zooplankton community. The resulting reduction in the number of outmigrant smolt from the affected Kenai and Kodiak systems may foretell a major collapse of the commercial, sport and subsistence fisheries on effected stocks of salmon in Cook Inlet and on Kodiak Island.

In 1991 we reported the first indication of major decreases in smolt production from Red Lake on Kodiak Island and from the Kenai River. In 1993, we continued to assess the cause of decline in smolt production through fish and limnological investigations. Density-dependent mechanisms may decrease production whereby predation exhausts or alters the availability of the food resources. This reduction in food resources may subsequently lead to decreased survival. Alternatively, climatic variation, such as extended winters could be a primary or an associated cause of poor survival. Although measuring the magnitude of decline in fish production is a high priority, assessment of changes in nutrient concentrations and the zooplankton community provide information to determine the feasibility of rehabilitation programs to restore lost productivity. Our investigations include the examination of prey (zooplankton) availability for sockeye salmon fry in five glacial lake systems on the Kenai Peninsula and three clearwater lakes on Kodiak Island that have had various densities of sockeye salmon fry recruited to the pelagic environment. Our studies attempt to link measurements of the food supply in these lakes with the fall condition and survival of juvenile sockeye salmon. These data also are essential to determine if production changes in fish are related to density rather than climatic or other non-density dependent factors.

Objectives

The following objectives of this study are required to assess impacts of overescapement on the production of sockeye salmon.

1. Measure critical biological attributes (number, age, size) of juvenile sockeye salmon in nursery lakes of the Kenai Peninsula and Kodiak Island.

2. Determine effects on smolt production and subsequent adult returns caused by large escapements resulting from fishery closures after the EVOS. These effects will be inferred by studying the changes in the rearing capacity of selected nursery lakes which were either affected or unaffected by the oil spill. Data used for these inferences include:

a. abundance, age, and growth of juveniles and smolts
b. nutrient concentrations, plankton population characteristics, and physical and chemical parameters.

Although not included in the original study plan, the collected data inherently provide an opportunity to examine the feasibility of restoration methods.

This report provides interim results as to changes that occurred in the biological, physical, and chemical properties during the course of this investigation, and includes findings of other pertinent investigations for comparative purposes. We provide preliminary analyses of some of these data with the intent of determining if existing monitoring programs are adequate to measure the biological responses and provide evidence as to the cause of observed changes.

METHODS

Adult Sockeye Salmon Escapement

Escapements of sockeye salmon were estimated by weirs at Red, Upper Station, and Akalura lakes. Escapements into the Kenai and Kasilof rivers were estimated by sonar counters using fish wheels for capturing samples of the escapement for species apportionment, sex ratios, and size data (King and Tarbox 1991). Weir and sonar counts are used in conjunction with commercial catch data to manage the sockeye salmon fisheries of Cook Inlet and Kodiak. Spawners in the Kenai River were estimated by subtracting the sport harvest above the counting site from the sonar count. In addition, the Kenai River spawner estimates were further adjusted by removing escapement estimates from the Russian River and Hidden Lake (weir counts). Kasilof River sport harvest is considered negligible; therefore spawner counts were equivalent to the number counted by sonar (minus the number used for egg takes). Adult scales were collected for age analysis from the fishery and fish collection devices near the sites where escapements were enumerated.

Sockeye Salmon Smolt Enumeration and Sampling

Estimates of migrating sockeye salmon smolt (with 95% confidence intervals) were made for each lake based on a mark-recapture technique (Rawson 1984). In general, this technique consisted of marking a sample (based on catch efficiency) of smolt each week with Bismark Brown dye and releasing them upstream to determine weekly trap efficiencies. This efficiency rate was then applied to estimate the total smolt outmigration. Because of low catch of sockeye salmon smolt in the Kenai River during 1993, trap efficiencies were estimated using a bootstrap method based on previous years of trap efficiency (King et al. 1994). Detailed methods of sampling are available in Barrett et al. (1993a) for the Kodiak lakes, in King et al. (1991) for the Kenai River, and in Kyle (1992) for the Kasilof River. Smolt were sampled for size and age, and were compared by broodyear. In addition, subsamples of smolt from the Kodiak lakes were taken and sent to the University of Alaska in Fairbanks to determine the relative levels of marine (N^{15}) versus terrestrial nitrogen from selected Kodiak Island systems. These samples were taken to determine the effects of carcass-derived nutrients in maintaining the productivity of Red Lake. Analysis of these samples will be reported in a later progress report.

Juvenile Sockeye Salmon Abundance and Sampling

For Skilak, Kenai, and Tustumena lakes, juvenile (in-lake) sockeye salmon abundance, size and age were estimated by conducting hydroacoustic/townet surveys. For Red, Upper Station, Frazer, and Akalura lakes some hydroacoustic surveys were conducted, but because of biased (low) catches of fry in these clearwater lakes used to identify hydroacoustic signals, only townetting was done in subsequent years for samples of fall fry size. Fry lengths and weights were measured after preservation in 10% buffered formalin. Occasionally, frozen or unpreserved fry were measured; however, preserved samples were corrected for shrinkage (Honnold 1993). In 1992, hydroacoustic surveys were conducted only on the Kenai Peninsula lakes. Detailed survey methods are documented for the Kenai River lakes in Tarbox and King (1992), for Tustumena Lake in Kyle (1992), and for the Kodiak Island lakes in Honnold (1993). Freshwater growth and age of juvenile sockeye salmon from all study systems were determined from scale and otolith measurements made either by direct visual analysis of scales or for otoliths with an optical pattern recognition system. Additional collection of hydroacoustic data and analysis was done in 1992 to determine the vertical distribution of sockeye salmon juveniles in Skilak, Kenai, and Tustumena lakes in an effort to further understand potential limitations to sockeye production. One of the hydroacoustic transects used for the 1991 fall survey in Skilak Lake was used in May of 1992 to determine diel changes in the distribution of fry. Multiple recording of hydroacoustic data from this transect was obtained from twilight through darkness. In addition, sampling at alternative depth strata using a closing-net system was deployed in the summer and fall of 1993 to provide fry size and age data at different depths and areas of Skilak Lake.

As overwintering appears to be the time period of high mortality for juvenile sockeye salmon in lakes of the Kenai River system, in 1992 we began taking samples of fry in the fall and spring for measurement of lipid content. Lipid analyses were conducted by the Palmer Laboratory of the University of Alaska, using methods described by Randall (1974). We statistically compared crude fat content of sockeye salmon fry collected in September 1992 between Kenai, Skilak, and Tustumena lakes. Analyses were also conducted to evaluate temporal patterns of fat content in fry collected in Skilak Lake in August, September, November, and December 1992. The fry were obtained by townetting and were assumed to represent a random sample of each population. Two approaches to the statistical analyses were used. First, mean fat content (g) was directly compared among sample groups using a one-way ANOVA model followed by pairwise comparisons; this analysis did not take into account or adjust for size differences of fry between the populations. Second, mean fat content was compared among the sample groups using wet weight as a covariant (ANCOVA model); this analysis adjusted for size differences between the groups. A homogeneity-of-slopes test was performed before final model specification for either separate or equal slopes. The ANCOVA approach is similar to comparing percent fat among the groups. However, we did not analyze percent fat due to technical problems with dry weight measurements as reported by the contracting laboratory. Statistical tests were conducted at the $p = 0.05$ significance level. Finally, the diet selectivity for age-0 fall fry was determined by calculating electivity indices (Ivlev 1961). Electivity values range from -1 (no selectivity) to +1 (strong selectivity).

Limnological Sampling

Limnological sampling has been conducted on Tustumena Lake (the control lake for the Kenai River lakes) since 1981 at three stations (Kyle 1992). Two stations were sampled from Skilak and Kenai lakes from 1986-1989, and beginning in 1990 three stations were used to collect limnological parameters. Zooplankton data were collected from Skilak Lake at five stations in 1990, 10 in 1991, and three in 1992. Zooplankton samples from Kenai Lake were collected at three stations during 1990-1993. Limnological data were collected from three stations in Red Lake, two stations in Akalura Lake, and two stations in Upper Station Lake. Samples were collected at about three-week intervals on each lake during May through October. All limnological parameters were analyzed at the

State of Alaska's Limnology Laboratory located in Soldotna. Analytical procedures followed standardized laboratory and quality assurance methods of Koenings et al. (1987).

The vertical distribution of zooplankton in 1992 was monitored from two locations in Skilak Lake during daylight hours on May 19, June 8, July 1, July 30, August 26, September 25 and October 27. Night samples were collected on May 19, June 11, July 17, August 6, September 2, October 8, October 12, and October 27. Vertical distribution of zooplankton in Tustumena Lake during 1992 was sampled at a single location during daylight hours on October 7 and October 26, and during the night of October 7. Vertical zooplankton samples were collected from one location in Kenai Lake during daylight hours on August 21, September 28, and November 11, and during the night on October 12 and November 11 of 1992. In 1993, zooplankton samples were taken from 10-m depth intervals near Station A on Skilak Lake during four periods over 24 hours approximating mid day, dusk, night, and dawn. Sampling was conducted on June 3 and 4, July 15 and 16, and October 14 and 15. In addition, all three stations on Skilak Lake were sampled for vertically integrated zooplankton samples on April 26, May 22, June 21, July 13, August 10, August 26, September 22, October 22, and December 1 of 1993.

A closing net was used to collect samples to characterize the vertical distribution of zooplankton. The net is constructed of 153-μm Nitex mesh with a 0.5-m mouth and a 200-ml collection bucket. Essentially, this netting procedure is identical to the methods used for collecting water column zooplankton samples used for biomass estimates. The net is vertically lowered to the desired depth as measured with a tow line marked in 1-m increments. After vertically retrieving a 5- or 10-m tow, the line is sharply jerked to trigger the closing mechanism at the opening of the net. Triggering this mechanism causes the net to fold over on itself stopping any further collection of zooplankton. After the collection bucket is thoroughly rinsed, the release mechanism is reset and the net lowered to the depth at which collection had previously been halted. An optical plankton counter (OPC) from Focal Technologies Ltd. was deployed to measure vertical distribution of zooplankton in Skilak Lake. We are in the process of evaluating whether the OPC provides an adequate index of copepod biomass by comparison with net tows. These results will be reported after an additional field season of data collection.

RESULTS AND DISCUSSION

Kenai River System Investigations

Adult Return and Escapement

During 1987-1989, the Kenai River received escapements two-three fold higher than the mid-point of the desired range of escapement (Figure 3). The 1989 high escapement was due to closure of the fishery in Cook Inlet as a consequence of the Exxon *Valdez* oil spill. In Tustumena Lake, an adjacent sockeye system located south of the Kenai River, escapements did not exceed the escapement goal during this same time period (Figure 4), and as it also is a glacial system, it was selected as a control for the Kenai River system. To assess whether the Kenai River lakes (Skilak and Kenai) were spawning limited we evaluated the relationship between fall age-0 fry abundance and potential egg deposition (PED).

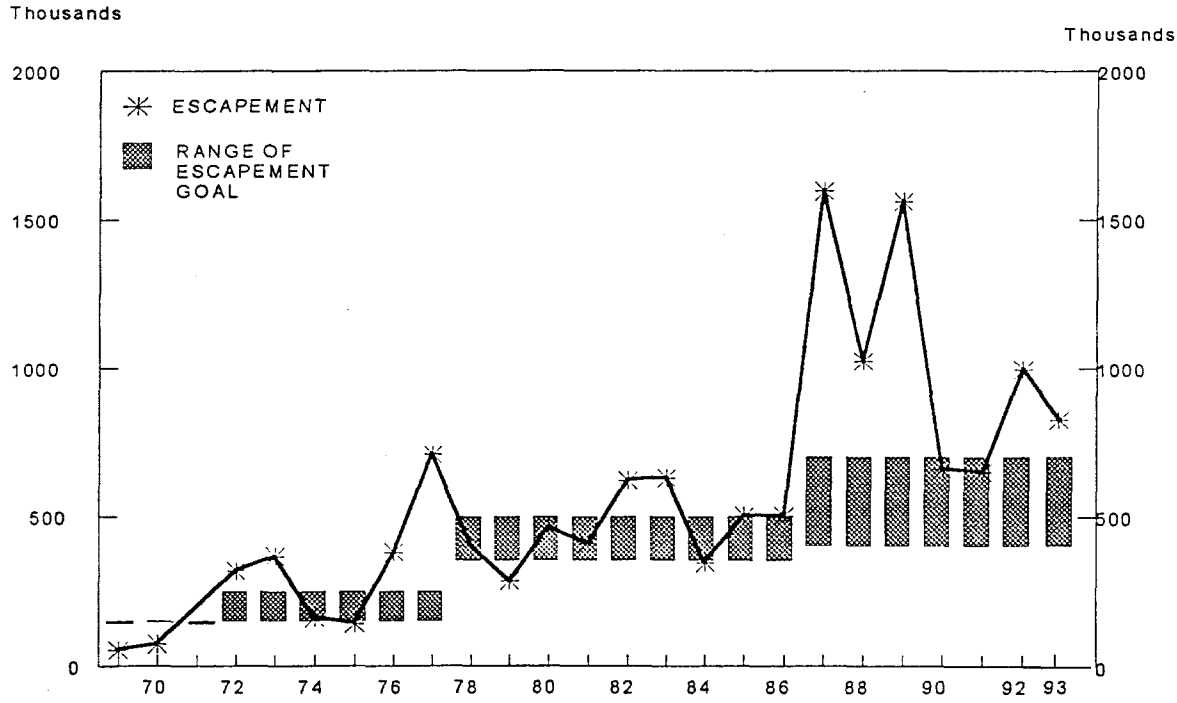

Figure 3. Summary of sockeye salmon escapements and historical escapement goal ranges for the Kenai River. Escapements represent sonar counts at mile 19 of the Kenai River.

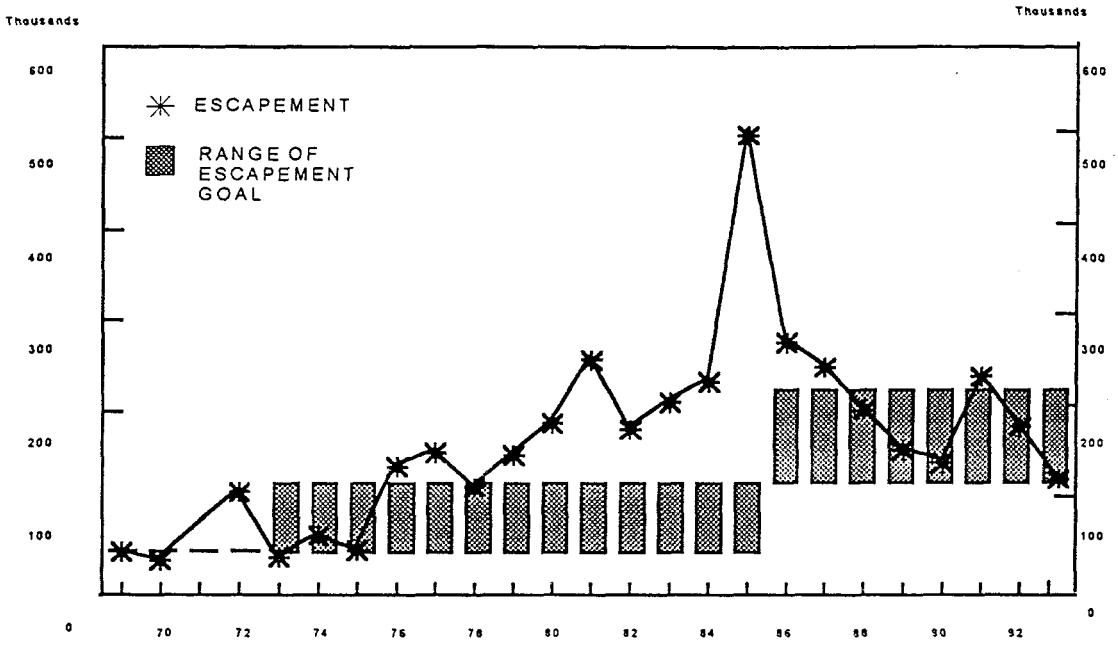

Figure 4. Summary of sockeye salmon escapements and historical escapement goal ranges for the Kasilof River. Escapements represent sonar counts at mile 11 of the Kasilof River.

We found that during 1985 through 1992 a significant, positive relationship existed between PED and the number of age-0 sockeye salmon fry rearing in the fall; thus suggesting that fall fry production is primarily a function of escapements (Figure 5). In this relationship fall fry abundance estimate errors were assumed to be random, uncorrelated, and unbiased; thus, they were absorbed in the model error term (Neter et al. 1989). Fall fry counts (dependent variable) were based on combined estimates from the two lakes (1986-1993) and egg counts (independent variable) were estimated by multiplying the number of mainstem female spawners by 3,500 for the corresponding broodyears (1985-1992). Two models were applied; one with and one without the y-intercept (constant) term. The first model (constant included) gave the maximum possible R^2 within the range of egg counts and provided a way to test the constant. The 0-intercept model adhered to the biological requirement of including the origin. Cook's D statistic and studentized residuals were used to evaluate influential points and the Durbin-Watson statistic was used to test for residual autocorrelation in the sequential data. Both models had significant slopes ($p<0.05$), although the model with the constant accounted for 50.3% of the variation in fall fry abundance, while the 0-intercept model accounted for only 39% of the variation. The Durbin-Watson statistic indicated no residual autocorrelation ($r = -.029$; $p>0.05$).

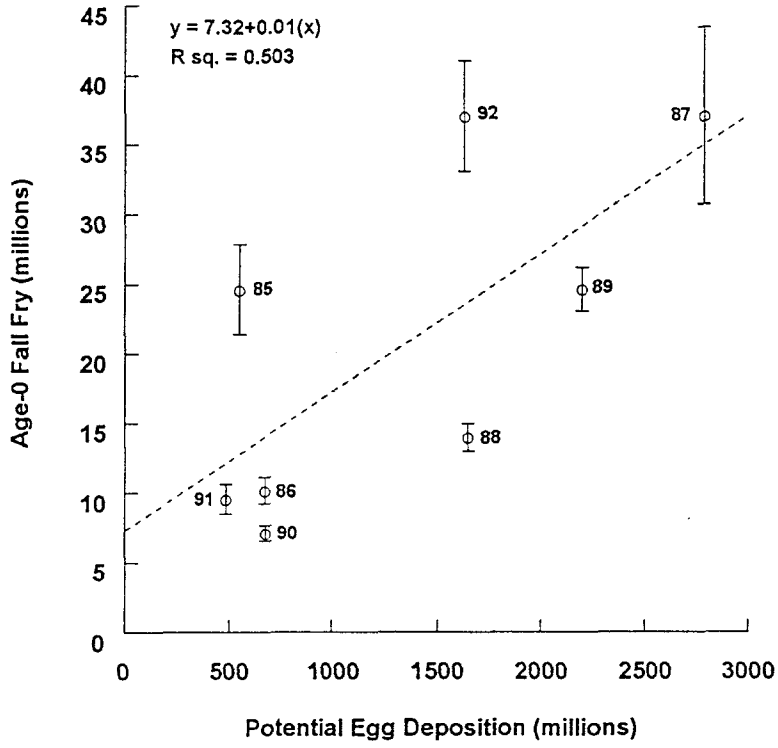

Figure 5. Relationship between the number of age-0 fall fry and potential egg deposition in Kenai and Skilak lakes during 1985-1992. Vertical bars represent standard error of fry estimates. Two models were used to assess this relationship: one with the constant term shown above ($y = 7.32 + 0.010x$; $R^2 = .50$; $p<0.05$), and one without the constant ($y = 0.014x$; $R^2 = .39$; $p<0.05$).

Smolt Abundance, Size, and Age

Detailed results of smolt investigations are presented by King et al. (1994) for the Kenai River smolt investigations, and in Todd and Kyle (1994) for the Kasilof River smolt investigations. The smolt production in the Kenai River has decreased dramatically from over 30 million for broodyear 1987 to less than 300,000 for broodyear 1990 (Table 1). However, for Tustumena Lake smolt production for this time period remained quite stable (Tables 3-5). These data indicate major decreases in smolt production for broodyears 1990 and 1991 in the Kenai River system, but not in the Tustumena Lake/Kasilof River system. In addition, a shift of Kenai River smolt age composition from age-1 to age-2 occurred in 1992 (Table 2), which did not occur in Tustumena Lake/Kasilof River (Table 4), and an increase in mean weight of age-2 smolt was evident. Most likely, these changes reflected smolt from the Russian River and other minor systems in the smolt samples obtained from the lower Kenai River. The low number of smolt produced from Kenai and Skilak lakes caused these minor systems to be major contributors to sockeye salmon smolt production in the Kenai River watershed.

Table 1. Sockeye salmon smolt production by age class and broodyear for the Kenai River, 1986-1993.

Brood Year	Spawning Escapement	Total Number of Smolt Produced Age-1	Age-2	Age-3	Total
1986	422,000	[a]	115,000[b]	16,000	
1987	1,408,000	24,416,000[b]	5,807,000[b]	1,000	30,224,000
1988	910,000	5,249,000[b]	431,000[b]	0	5,680,000
1989	1,379,000	2,776,000[b]	312,000[c]	0	3,088,000
1990	519,000	253,000[c]	33,000[c]	[d]	284,000
1991	431,000	735,000[c]	[d]		
1992	798,000				
1993	814,000				

[a] No data collected.

[b] Includes Hidden Lake migration not thought to be captured by the inclined plane traps.

[c] Includes Hidden Lake and Moose River migration not thought to be captured by inclined plane traps.

[d] Will not migrate as smolt until 1994.

Table 2. Sockeye salmon smolt age composition for the Kenai River, 1989-1993. Percentages do not represent production from Hidden Lake and Moose River.

Smolt Year	Smolt Age Composition (%) Age-0	Age-1	Age-2	Age-3	n
1989	0	99.7	0.3	0	3,567
1990	0	46.7	53.1	0.2	3,422
1991	0	86.1	13.9	0	3,741
1992	0	17.3	82.7	0	981
1993	8.5	88.5	3.0	0	1,200

Table 3. Sockeye salmon escapement and smolt production for Tustumena Lake, 1981-1993.

Brood Tustumena	Spawner Escapement	Number of Smolt and Percent Hatchery Contribution				
		Age-1x1000	% Hatchery	Age-2 x1000	% Hatchery	Total x1000
1981	256,625	6,817	40.7	2,869	20.6	9,686
1982	180,239	11,390	36.3	4,001	7.7	15,391
1983	210,270	12,580	27.8	2,223	11.1	14,803
1984	231,685	5,268	30.2	3,540	31.1	8,808
1985	505,049	1,074	59.2	2,549	17.0	3,623
1986	275,963	2,056	52.0	3,009	10.2	5,065
1987	249,246 [a]	3,109	30.3	3,521	3.0	6,630
1988	204,000	3,916	2.0	2,335	1.0	6,251
1989	158,206	2,400	7.0	2,012	1.3	4,412
1990	144,136	2,107	7.5	1,833	3.3	3,940
1991	238,269	7,189	6.3			
1992	184,178					
1993	149,939					

[a] Because of sonar failure, escapement estimates were based on stream surveys and spawning stream weir counts above Tustumena Lake.

Table 4. Sockeye salmon smolt age composition for the Kasilof River, 1983-1993.

Smolt Year	Age Composition (%)		
	n	Age-1	Age-2
1983	1,163	84	16
1984	1,192	80	20
1985	1,263	76	24
1986	1,348	70	30
1987	1,635	23	77
1988	1,275	45	55
1989	1,125	51	49
1990	1,150	53	47
1991	1,018	51	49
1992	1,150	56	44
1993	942	80	20

Table 5. Sockeye salmon smolt length (mm) for the Kasilof River, 1983-1993.

Smolt	Age-1			Age-2		
Year	L (mm)	n	S. D.	L (mm)	n	S. D.[a]
1983	70	712	3.8	83	451	5..4
1984	73	1,005	3.5	85	187	4.4
1985	70	981	2.8	84	282	5.4
1986	69	983	3.9	84	365	5.1
1987	64	412	6.1	77	1,223	4.8
1988	68	623	4.0	78	652	4.5
1989	66	609	4.4	81	516	4.5
1990	69	683	4.4	82	467	4.2
1991	68	529	3.5	80	489	3.2
1992	74	594	3.8	87	556	4.7
1993	71	755	3.5	82	187	4.2

[a]S. D. = 1 standard deviation.

Juvenile Abundance, Size, Age, and Lipid Content

Juvenile sockeye salmon abundance in Kenai and Skilak lakes generally reflected adult escapements (Figure 6). Has mentioned above, smolt production has declined markedly since 1989. In contrast, no such decrease in smolt production for the same time period is evident from the Kasilof River system (Figure 7), which did not receive excess escapement in 1989. This decrease in smolt production in Skilak Lake resulting from poor overwinter survival during the winter of 1991-1992 was verified by a hydroacoustic/townet survey conducted in May of 1992. A single transect sampled in May of 1992 indicated juvenile sockeye salmon densities that were less than 10% of those observed during the fall of 1991 in the same area. This is approximately the decline observed from the 1990 fall fry to 1991 smolt during the previous year's investigation (Schmidt and Tarbox 1993).

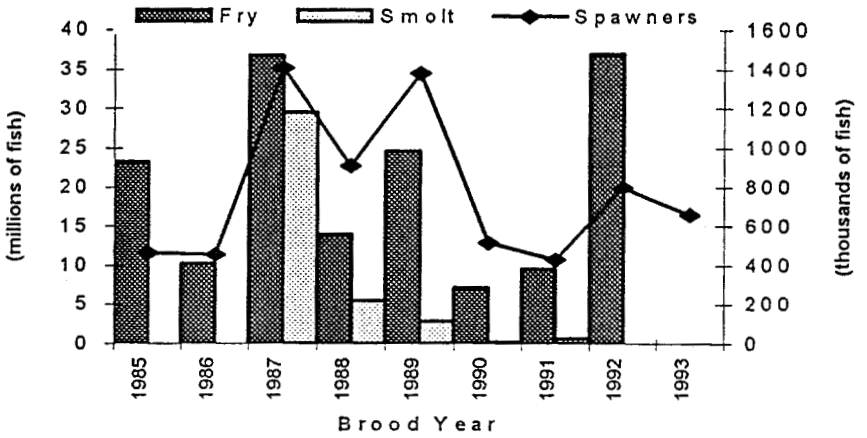

Figure 6. Interannual variation in sockeye salmon escapement by broodyear and the production of smolt and fall fry for Kenai and Skilak lakes, 1985-1993.

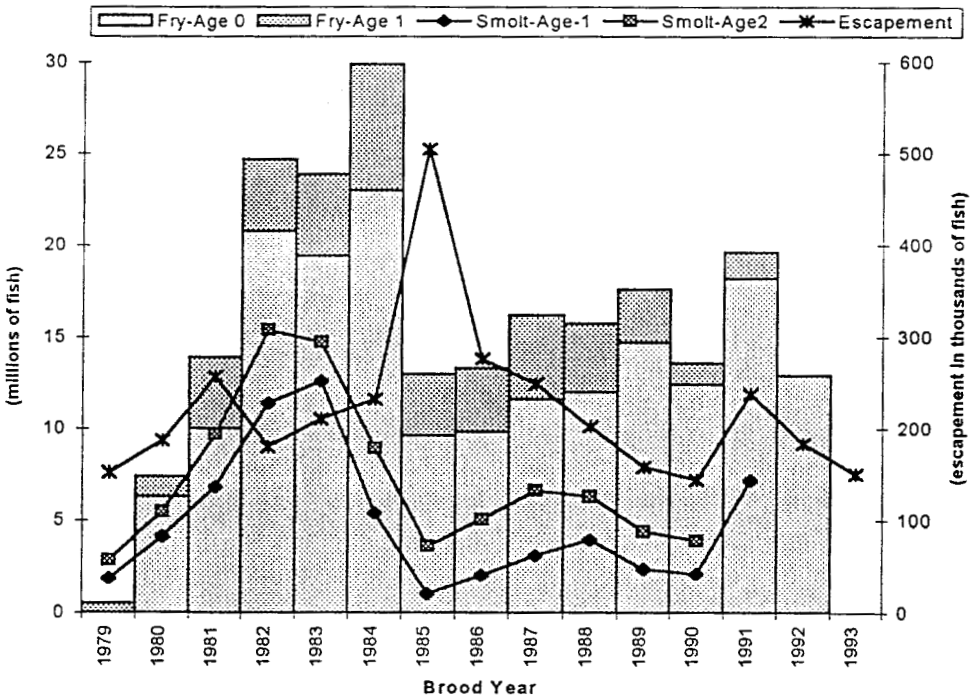

Figure 7. Interannual variation in sockeye salmon escapement by broodyear and the production of fall fry and smolt for Tustumena Lake, 1979-1993.

Fall fry length and weight data from Skilak, Kenai, and Tustumena lakes are presented in Table 6. The Skilak and Kenai lake fall fry are generally smaller than in Tustumena Lake. No trend in mean weight over the time series was evident for Skilak and Kenai lakes. Further investigations of juvenile sockeye salmon growth in these lakes are planned, and will be compared to historic samples if sampling procedures are determined to be unbiased.

The lipid content of age-0 juvenile sockeye salmon collected in the fall of 1992 from Tustumena, Skilak, and Kenai lakes differed significantly in mean fat content, although the magnitude of differences was higher for the unadjusted (ANOVA) means compared to the adjusted (ANCOVA) means (Figure 8). This is because Tustumena Lake fry were heavier wet weights (2.0 g) than Skilak Lake fry (1.6 g), which were somewhat heavier than Kenai Lake fry (1.4 g).

Table 6. Age and size of fall sockeye salmon fry in the three Kenai Peninsula study lakes.

		Age-0						Age-1					
Lake			Length			Weight			Length			Weight	
	Year	(n)	(mm)	S. D.	(n)	(g)	S. D.	(n)	(mm)	S. D.	(n)	(g)	S. D
Skilak	1986	15	57		a			8	74				
	1988	109	50	5.3	109	0.9	0.4						
	1989	136	50	3.3	136	1.2	0.3	126	64	6	126	2.8	0.7
	1990	928	49	4.3	290	1.3	0.3	34	72.8	3.3	20	4.0	0.4
	1991	863	51	4.9	286	1.5	0.5	55	73.8	3.8	14	4.7	0.5
	1992	883	54	6	883	1.8	0.6	10	89	3	10	7.0	0.8
	1993	3,652	49	5	3,652	1.2	0.4	55	75	5	55	4.5	0.9
Kenai	1986	227	52		227			2	77				
	1989	38	48	4.5	38	1.0	0.2	56	64	4.6	56	2.5	0.6
	1990	1,484	52	4.6	1,484	1.5	0.4	62	69.4	4.2	22	3.6	0.6
	1991	1,364	53.5	6.5	1,364	2.0	0.6	40	75.9	4.8	15	5.5	1
	1992	1,492	56	7.3	1,492	2.0	0.8	12	78	10	12	5.6	1.7
	1993	2,969	45	4	2,969	1.0	0.2	4	68	1	4	3.3	0.5
Tustumena	1980	222	59	6.1	222	2.3	0.7	20	80	3.5	20	5.7	0.7
	1981	197	55	5.1	197	1.6	0.4	21	73	4.6	21	3.8	0.7
	1982	194	54	5.1	194	1.8	0.5	17	74	3.9	17	4.	0.9
	1983	562	60	6.1	562	2.5	0.7	55	80	5.0	55	5.8	1.1
	1984	388	61	4.6	388	2.5	0.6	186	79	3.7	186	5.3	0.8
	1985	173	56	5.6	173	2.1	0.6	52	78	5.0	52	5.6	1.2
	1986	156	50	6.4	156	1.3	0.5	92	73	4.5	92	4.1	0.7
	1987	143	53	5.9	143	1.8	0.6	50	71	3.8	50	4.2	0.6
	1988	303	55	5.3	303	1.8	0.5	89	75	3.6	89	4.5	0.6
	1989	47	52	5.7	47	1.9	0.6	18	74	4.6	18	5.1	0.9
	1990	200	57	5.5	200	1.5	0.4	50	75	2.9	50	3.4	0.5
	1991	202	57	5.4	202	2.0	0.5	47	78	6.5	47	5.1	1.2
	1992	323	59	4.4	323	2.0	0.4	21	79	4.1	21	4.52	0.7
	1993	417	63	6.7	417	2.9	0.8	46	81	3.0	46	6.18	0.7

[a]Missing values indicate no data available; S. D. = 1 standard deviation.

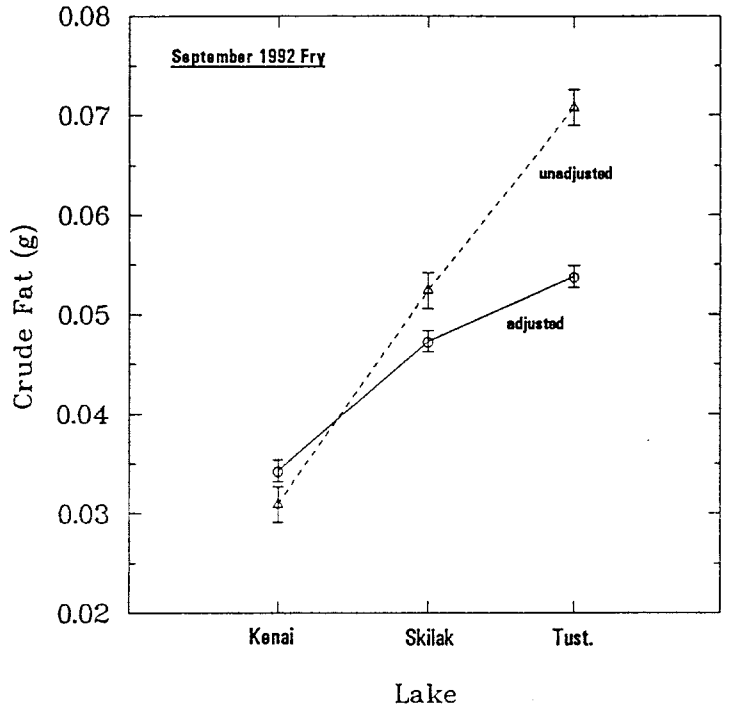

Figure 8. Results of statistical comparison of the mean fat content of age-0 sockeye salmon fry collected in Kenai, Skilak, and Tustumena lakes. Vertical bars represent standard error. Unadjusted means are from the ANOVA analysis and adjusted means are from the ANCOVA analysis.

Temporal differences in fat content of age-0 fry in Skilak Lake were evident (Figure 9) and the pattern of results differed between the two approaches (ANOVA versus ANCOVA). Again, this is attributable to the difference in wet weight of fry collected in August (1.3 g), September (1.6 g), November (2.1 g), and December (1.8 g). Fat content per fry (unadjusted means) increased significantly until November, after which a significant decrease occurred in December to a level slightly higher than September. Weight-adjusted fat content increased significantly ($p<0.05$) from August to September, after which no changes were detected. These data indicate the Kenai River lakes have significantly decreased fat reserves when compared with Tustumena Lake and that the available fat per fish in Skilak Lake begins declining after September.

Finally, sampling of juvenile sockeye salmon distribution in Skilak Lake during 1993 indicated near-surface schooled aggregations during the day (pers. comm. Tom Carlson, Battele NW, Inc.). The schools dispersed at dusk and were generally not apparent from downward looking sonar. Contrary to earlier inferences from downward looking sonar (Schmidt and Tarbox 1993), diel vertical migration (DVM) of juvenile sockeye salmon in Skilak Lake may not occur. That is, the dusk and night dispersions from near-surface schools provided the appearance of DVM with down-looking deployment of the hydroacoustical gear. However, this phenomenon does

not affect population estimates obtained by the hydroacoustic sampling because it was conducted during the night in Skilak Lake. These types of fry aggregations were not observed in Tustumena Lake.

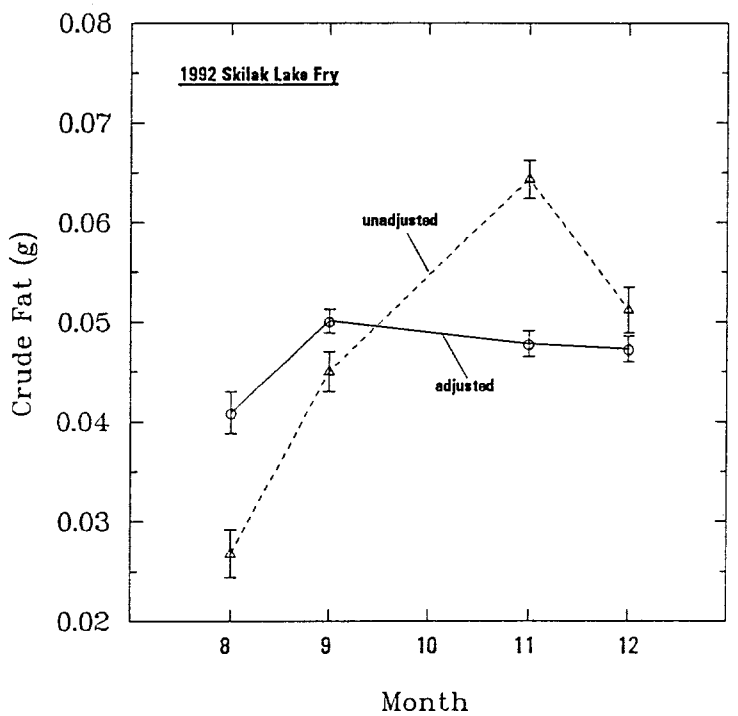

Figure 9. Results of statistical comparison of the mean fat content of age-0 sockeye salmon fry collected in August through December of 1992 in Skilak Lake. Vertical bars represent standard error. Unadjusted means are from the ANOVA analysis and adjusted means are from the ANCOVA analysis.

Limnological Assessment and Fry Diet Selectivity

As noted in previous progress report (Schmidt and Tarbox 1993), the standing crop (biomass) of zooplankton in Skilak Lake had changed only modestly, as did the water-quality parameters. Figure 10 illustrates seasonal fluctuations of turbidity measurements in Skilak Lake during the past few years. Note that turbidity values in 1986 are of comparable magnitude to the most recent years. This relatively short time series does not afford more detailed analysis relating to growth or survival of Skilak Lake fry. The seasonal temperature profiles of Skilak and Tustumena lakes appear more similar to each other in any given year then they do to themselves among years (Figure 11).

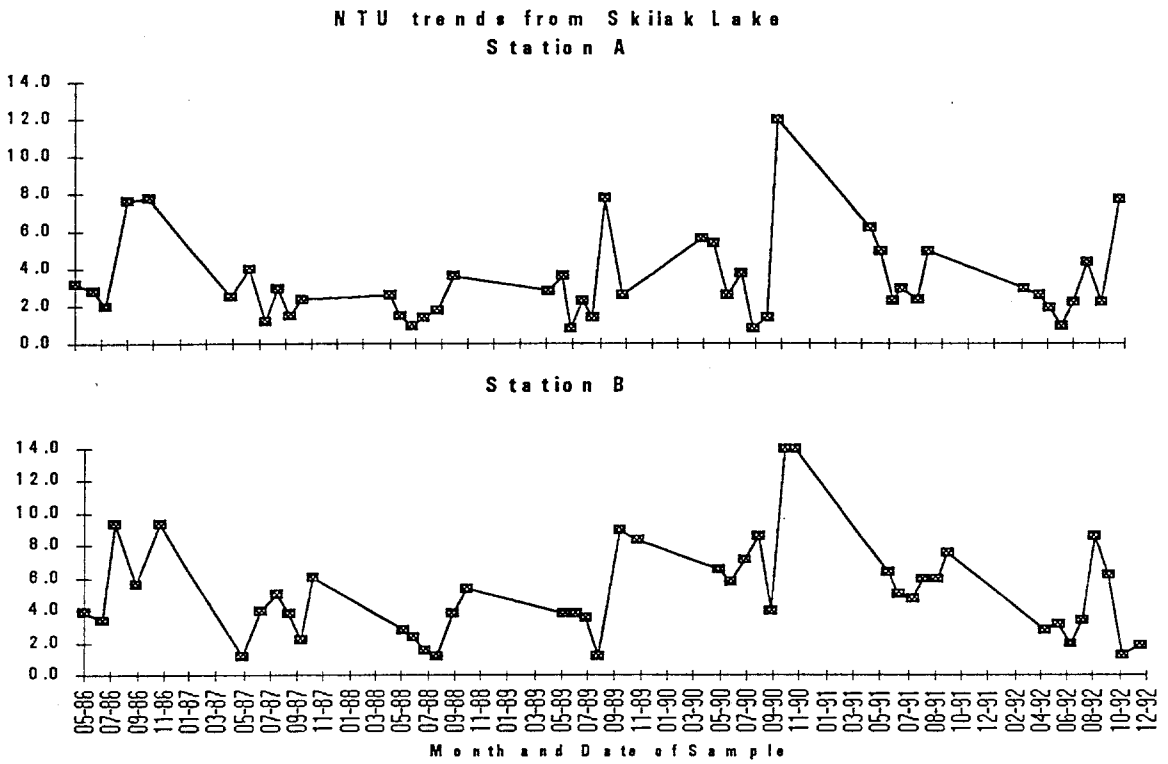

Figure 10. Measurements of turbidity (NTU) at Stations A and B of Skilak Lake during 1986-1992.

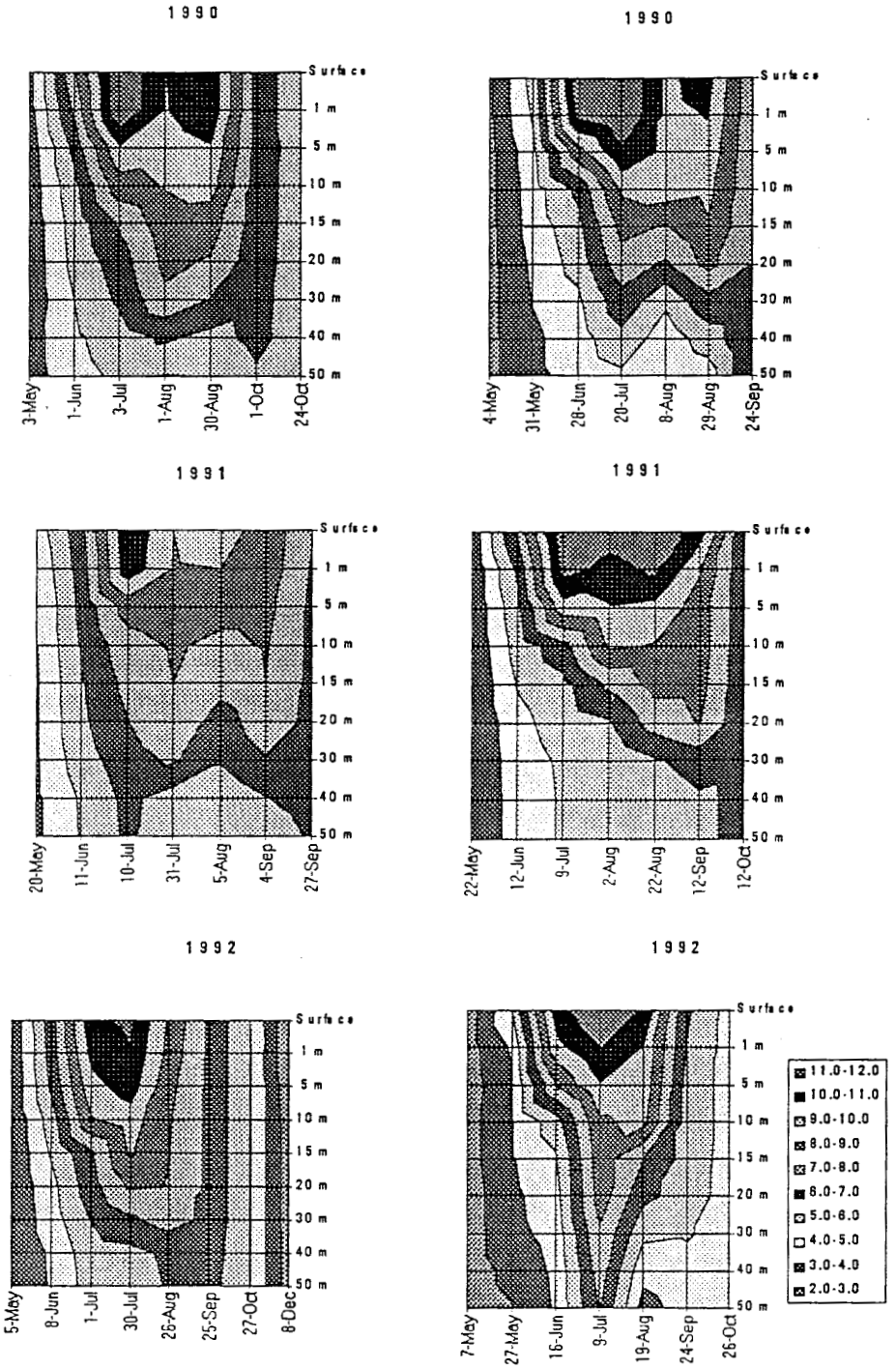

Figure 11. Temperature profiles for Skilak Lake (left) and Tustumena Lake (right) during 1990-1992. Contours represent 1° C intervals.

Zooplankton biomass of the two dominant copepod species during 1986-1993 in Skilak Lake is presented in Figure 12. Note that *Cyclops* had an apparent increase in abundance in 1993, although little overall change in trend is apparent. In Tustumena Lake, we observed an increase in the 1993 total copepod abundance and a corresponding increase in fall fry weights, resulting in the largest fall fry weights recorded over that past 14 years of sampling (Table 6). This increase was not observed in Skilak Lake (Table 6), suggesting that density-dependent mechanisms may regulate fall fry size in Skilak Lake but are of lesser importance in Tustumena Lake.

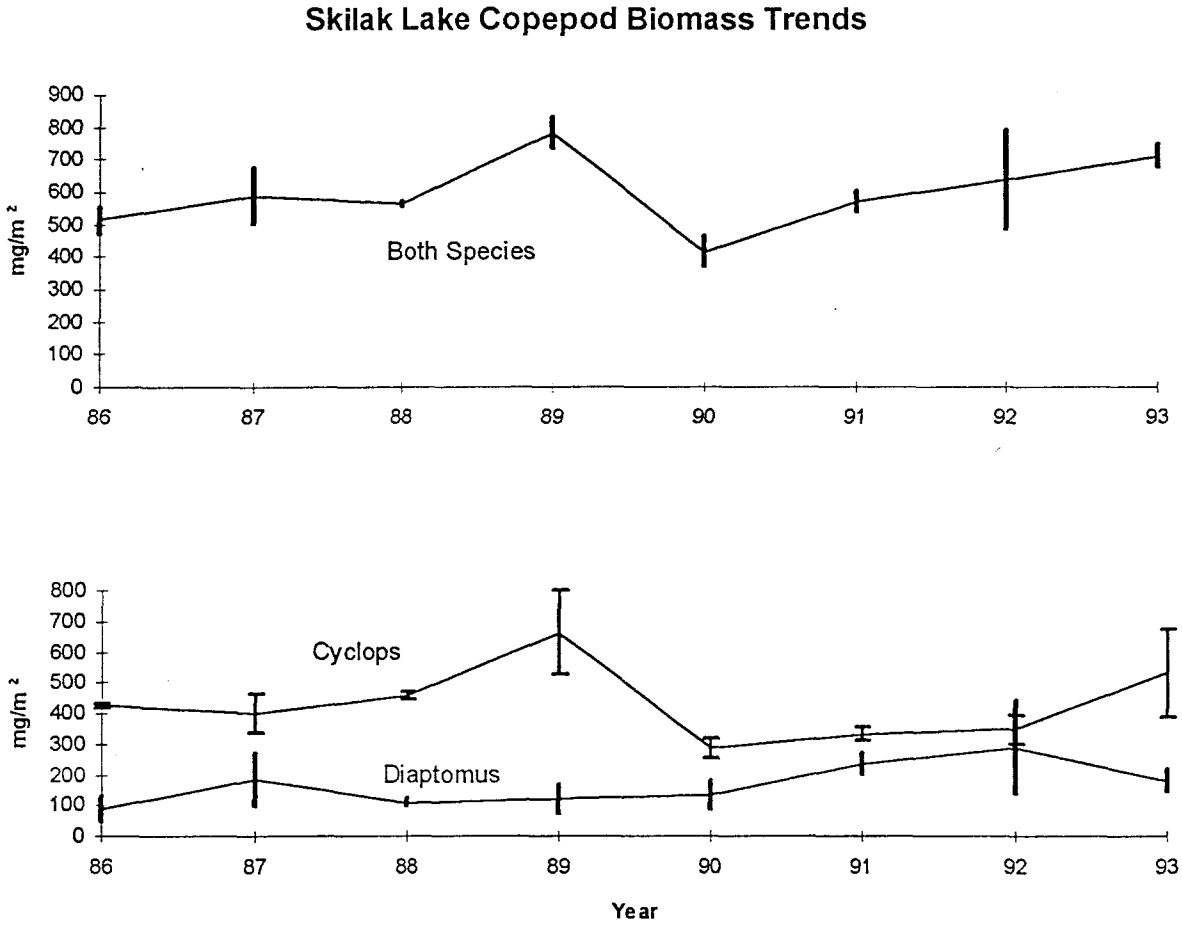

Figure 12. Interannual variation in zooplankton biomass in Skilak Lake. Error bars represent standard error.

A summary of zooplankton densities and fall juvenile sockeye salmon densities in Skilak and Tustumena lakes is presented in Table 7. This summary indicates that only in 1993 has the biomass of zooplankton per fall fry in Tustumena Lake exceeded that of Skilak Lake. This is relative to the finding that the size of fall fry in Tustumena Lake was larger in 1993 compared to other years, and Skilak Lake fry are typically smaller (Table 6).

Table 7. Comparison of copepod biomass and fall density of juvenile sockeye salmon in Tustumena and Skilak lakes. Copepod biomass reflect the seasonal mean biomass and fall fry densities were estimated by hydroacoustics.

	Copepod biomass						Fall sockeye density[a]		Copepod biomass/fall fry	
	mg m^{-2}						fry m^{-2}		mg fry^{-1}	
Year	Skilak	S. E.	n[b]	Tustumena	S. E.	n	Skilak	Tustumena	Skilak	Tustumena
1986	514	46	2	115	13	3	0.22	0.056	2,370	2,062
1987	586	28	2	100	23	3	0.09	0.045	6,426	2,242
1988	565	6	2	75	10	3	0.31	0.051	1,805	1,472
1989	783	257	2	90	18	3	0.22	0.056	3,554	1,599
1990	417	55	5	74	5	5	0.23	0.062	1,833	1,186
1991	571	40	10	165	15	5	0.07	0.052	8,418	3,181
1992	637	191	3	110	9	5	0.09	0.051	7,428	2,136
1993	710	134	3	204	29	5	0.34	0.049	2,082	4,198

[a] Standard error of fall fry density estimates are <25% of the mean.
[b]Indicates number of sample stations

We used multiple regression analysis to develop a model to predict survival of age-0 fall fry to smolt in Tustumena Lake. Fry-to-smolt survival (FSS) was computed as the percent of outmigrating age-1 and age-2 smolt from the age-0 fry cohort. Independent variables available for selection in the model included: seasonal mean zooplankton density and biomass (ZD, ZB), seasonal mean density of ovigerous copepods (ED; square-root transformed), previous years' mean density of ovigerous copepods (EDL; square-root transformed); proportion of ovigerous copepods (PE), summer (July-August) density of copepods (ZDSU), fall (September-October) density of copepods (ZDF), following years' spring copepod density (ZDSL), October (only) copepod density (ZD10), September (only) ovigerous copepod density (ED9; square-root transformed), October ovigerous copepod density (ED10; square-root transformed), average fall fry weight (FW), fall fry condition (FC; after LeCren 1951), total fall fry abundance (FAT), total fall fry biomass (FBT), and finally, abundance and biomass of age-1 fall fry (F1A and F1B). Maximum R^2 and stepwise regression procedure were used to initially select a subset of models, each with up to three independent variables. Prospective models were subjected to several diagnostic procedures (Belsley et al. 1980). Collinearity among the independent variables was assessed using condition indices and variance proportions. The Durbin-Watson statistic was used to test for autocorrelation among years. Outliers and influential points were identified using leverage values, studentized residuals, and Cook's D statistic. the model with the highest R^2 that also satisfies the diagnostic criteria was chosen and evaluated based on theoretical aptness.

Several models provided adequate results; however, the best single variable that predicted FSS was ED10 (R^2 = .673). ED10 and EDL provided the best 2-variable model (R^2 = .772). The model that accounted for most of the variation (81.6%) was a model consisting of three variables: ED10 (October copepod egg densities), F1A (abundance of age-1 fry), and FC (fall fry condition) (Figure 13). These models will be refined in the future and will be used as a surrogate to sockeye salmon production in Skilak and Kenai lakes when more information on these two lakes are collected in future years.

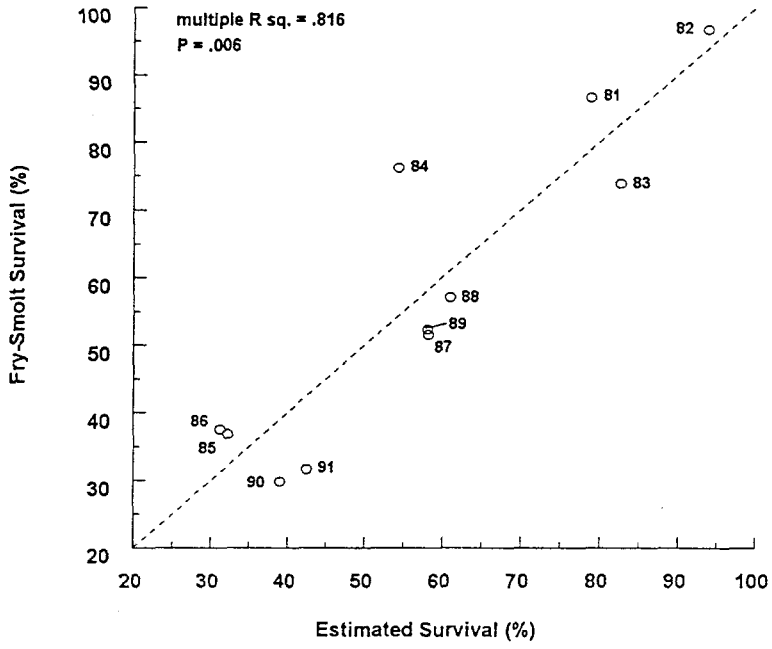

Figure 13. Multivariate model predicting age-0 fall fry-to-smolt survival in Tustumena Lake. Plot of estimated versus actual values from the regression equation FSS = 1.0912(ED10) - 5.008(F1A) + 52.2(FC) - 1.69. The variable F1A is in thousands of fry and ED10 is square-root transformed. Points are labeled by rearing year for fall fry.

In 1993, we further examined the spatial and temporal availability of zooplankton, and the selectivity of zooplankton prey in Skilak Lake. Earlier studies by Yanusz (1989) indicate that sockeye salmon actively feed on copepods in nearby Tustumena Lake, but have a high selectivity against copepods in clearwater lakes which had both cladocerans and copepods present. The electivity indices of fry sampled during August and September of 1993 in Skilak Lake from the three areas indicate that in general, non-ovigerous *Cyclops* were selected against while ovigerous individuals and non-ovigerous *Diaptomus* were highly selected for (Table 8). In July, at the two stations sampled, non-ovigerous *Cyclops* were selected while non-ovigerous *Diaptomus* were not. Samples taken during the fall of 1992 and 1987, indicated a similar trend. The 1987 data were limited to 18 preserved fish that were recently examined for diet. As these are the only samples available prior to the decline in Kenai River smolt production, they may provide insight as to changes that may have occurred. Table 9 illustrates the large variation in diet between samples collected in 1987 and samples collected in 1992 and 1993. The large change in diet corresponds with the shift in electivity indices illustrated in Table 8. These data are consistent with the hypothesis of a density-dependent decrease in food availability being a major contributor to the decreased fall condition and overwintering survival of Skilak Lake fry. However, because of the limited sample, and the lack of spatial or temporal measurements of variation in 1987, these results should be interpreted with caution.

Also in 1993, we measured the relative density of the two copepod taxa and the ovigerous component of the populations with regard to spatial and seasonal variations (Figure 14). Tarbox and Brannian (1993) indicated a general trend of decreasing fry abundance in October, from west to east (corresponding to stations A, C, and B of Appendix A in Schmidt and Tarbox (1993)). Only non-ovigerous *Cyclops* followed this pattern (Figure 14).

Table 8. Ivlev's electivity index for food selection by age-0 sockeye fry from different time and area strata within Skilak Lake in 1987, 1992, and 1993.

Sample Date(s)	Location	Non - ovigerous *Cyclops*	Non - Ovigerous *Diaptomus*	Ovigerous *Cyclops*	Ovigerous *Diaptomus*	Total Ovigerous Copepods[a]
All 1993	All locations	0.00	0.02	0.03	0.89	
September	Station A	-0.13	0.97	0.64	1.00	
	Station C	-0.06	0.78	0.53	1.00	
	Station B	-0.07	0.80	0.61	1.00	
	All locations	-0.09	0.89	0.59	1.00	
August	Station A	-0.11	0.67	0.25	0.96	
	Station C	-0.25	0.75	0.32	1.00	
	Station B	-0.27	0.83	0.52	0.99	
	All locations	-0.23	0.77	0.42	0.98	
July	Station A	0.09	-0.69	-0.22	0.28	
	Station C	0.20	-0.79	-0.49	0.56	
	Station B	Not Sampled				
	All locations	0.18	-0.79	-0.47	-0.19	
Oct.-Nov. 1992[b]	Station C	-0.08	0.43	-0.12	0.96	
	Station A	-0.11	0.62	0.28	0.93	
	Station B	-0.10	0.54	0.19	0.93	
Sept. 1987[c]	Station A	-0.73	0.89	[a]	[a]	0.87
Oct. 1987	Station A	-0.74	0.88			0.96
Sept.- Oct. 1987	Station A	-0.73	0.89			0.89

[a]Ovigerous copepods were not segregated into separate taxa in 1987. Data reflect all ovigerous copepods.

[b]Fish stomach samples were taken from near Station C only in 1992. Electivity indices were calculated using these stomach samples compared with zooplankton samples from all three stations.

[c]Fish stomach samples were taken near Station A only in 1987. Zooplankton samples were taken from Station A during September and October. Electivity indices were calculated using the Station A data for stomach with parallel zooplankton data from September, October and both months combined.

Table 9. Comparison of zooplankton taxa found in sockeye salmon fry of Skilak Lake in 1987, 1992, and 1993.

		1987	1992	1993
Non-ovigerous *Cyclops*	%	9%	69%	83%
	Average no./fry	24.6	150.0	184.6
	S. E. average no./fry	6.3	14.0	33.0
Ovigerous *Cyclops*	%	2%	1%	4%
	Average no./fry	5.8	3.0	8.7
	S. E. average no./fry	1.8	0.4	1.9
Non-ovigerous *Diaptomus*	%	52%	21%	8%
	Average no./fry	145.1	45.4	17.8
	S. E. average no./fry	35.9	4.5	4.4
Ovigerous *Diaptomus*	%	37%	9%	5%
	Average no./fry	102.5	19.0	10.5
	SE average no./fry	24.9	2.6	2.6
Chydoridae	%		0.05	1.78
Bosmina	%			0.01
Harpactacoid	%			0.02
Number of fry sampled		17	63	123
Mean Fry Length	(mm)	64	57	50
S. D.	(mm)	6.8	6.7	9.2
Mean Fry Weight	(g)	2.6	1.7	1.5
S. D.	(g)	.96	.68	.98

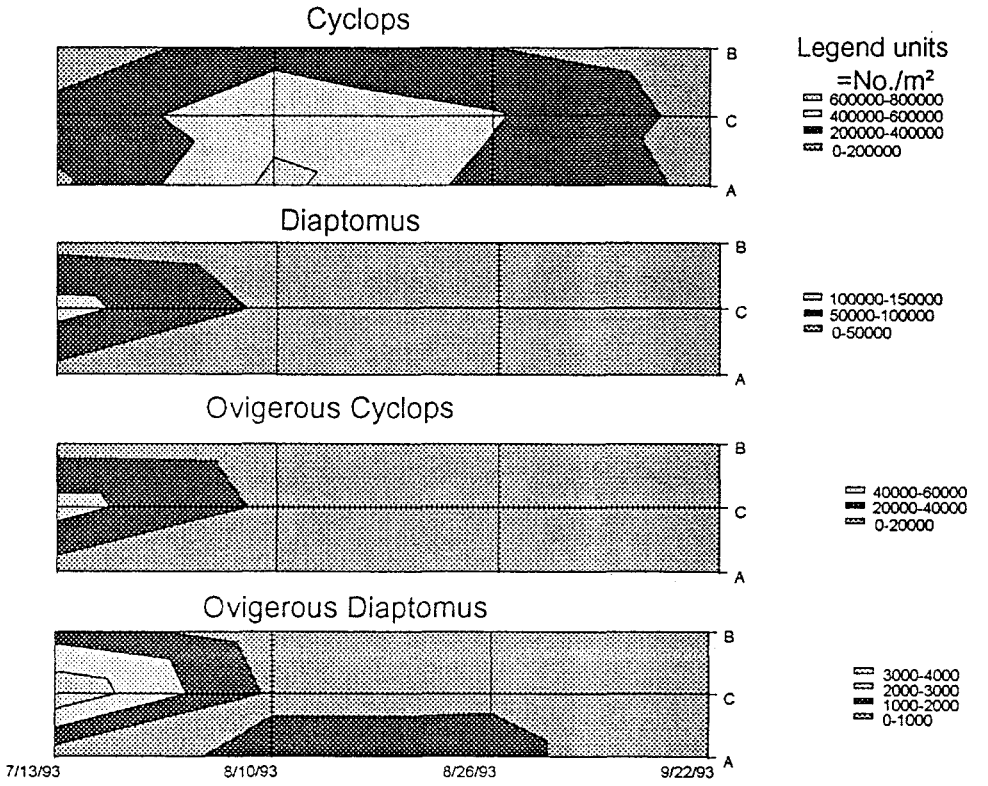

Figure 14. Zooplankton distribution in Skilak Lake during 1993. Station B is located on the east end of Skilak Lake, station C near the center, and station A near the west end of the lake.

Because of the differences observed in the DVM of zooplankton among the Kenai Peninsula lakes in 1992 (Schmidt and Tarbox 1993), we intensified sampling in 1993. We measured DVM of *Cyclops*, *Diaptomus* and ovigerous cohorts (Figures 15, 16, and 17 respectively) over a 24-hour period during June, July, and October. Non-ovigerous *Cyclops* were at high abundance in June and July and maintained minimal indication of DVM (Figure 15). *Diaptomus* were much less abundant and demonstrated a much stronger propensity to avoid the surface during daylight (Figure 16). The ovigerous cohorts were found in adequate numbers for analysis only during July (Figure 17). The ovigerous cohorts demonstrated the highest degree of DVM of all the groups. This inferred DVM from the differences in daylight and dark vertical distribution is consistent with the seasonal electivity values listed in Table 8. Only in July, when *Cyclops* was abundant and near the surface, did we observe a positive electivity for this taxa. At all other times and areas, *Diaptomus* and the ovigerous cohorts were highly selected for by feeding fry. The spatial densities (Figure 14) were also consistent with these electivity and DVM patterns. The low abundance of the forms that had the highest positive electivity values correspond with the highest density of fish, suggesting either cropping or horizontal migration from the high fish density areas.

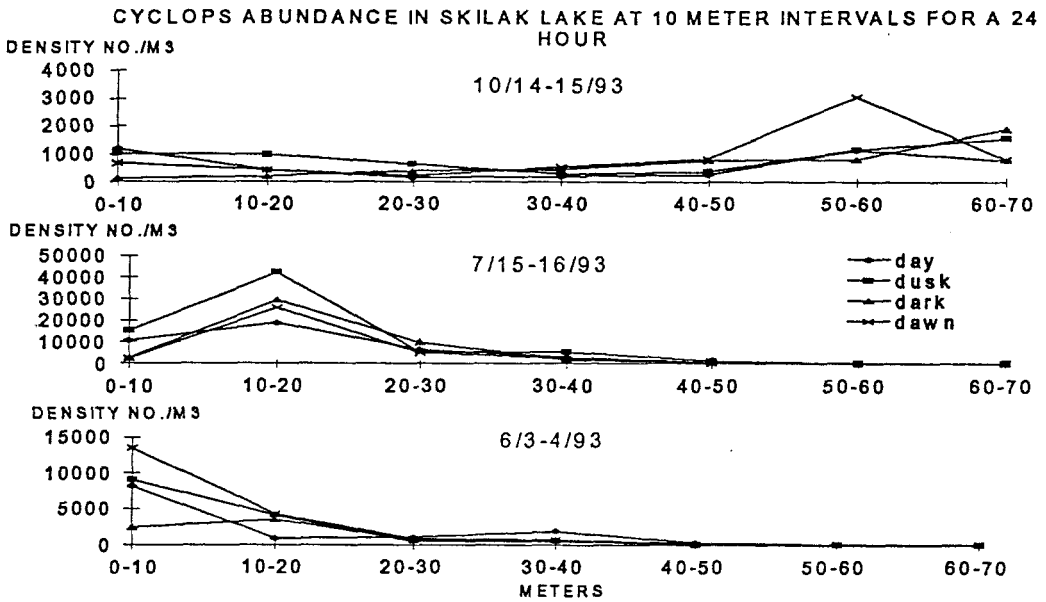

Figure 15. Diel variation in density of *Cyclops* in Skilak Lake by 10-m depth intervals during the summer of 1993.

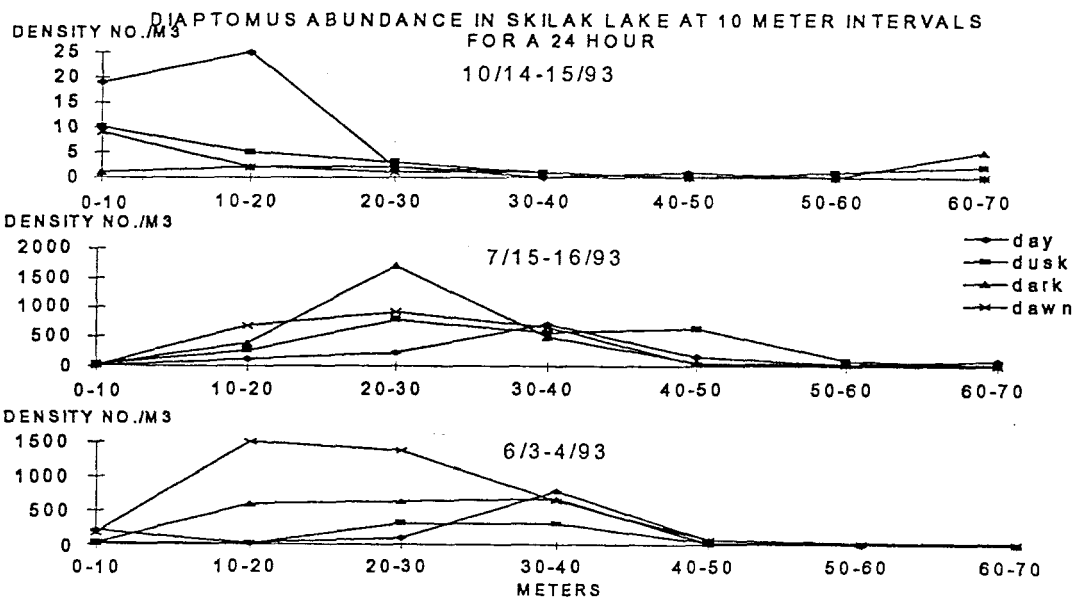

Figure 16. Diel variation in density of *Diaptomus* in Skilak Lake by 10-m depth intervals during the summer of 1993.

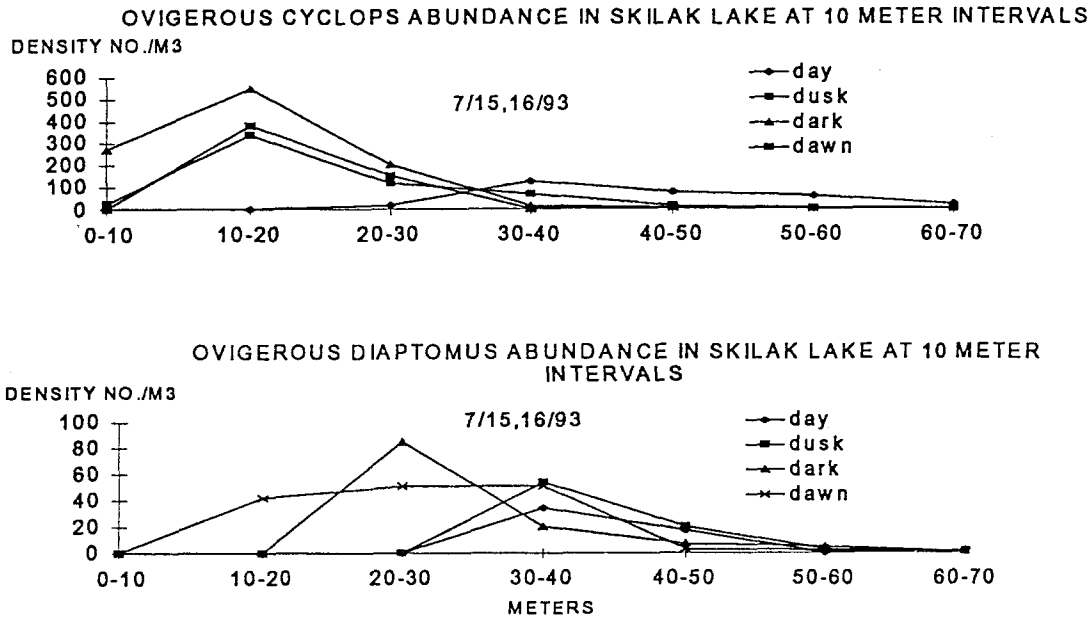

Figure 17. Diel variation in density of ovigerous copepod in Skilak Lake by 10-m depth intervals during the summer of 1993.

To further illustrate this point, Figure 18 illustrates all of the vertical distribution data on *Cyclops* collected during 1992 and 1993. Although DVM is present throughout all periods, only during June and July of 1993 was there a strong indication of surface orientation of *Cyclops*. *Diaptomus* demonstrated a stronger tendency for daylight surface avoidance throughout most periods (Figure 19) while the ovigerous cohorts of *Cyclops* and *Diaptomus* consistently displayed major differences in surface orientations between daylight and night (Figures 20 and 21).

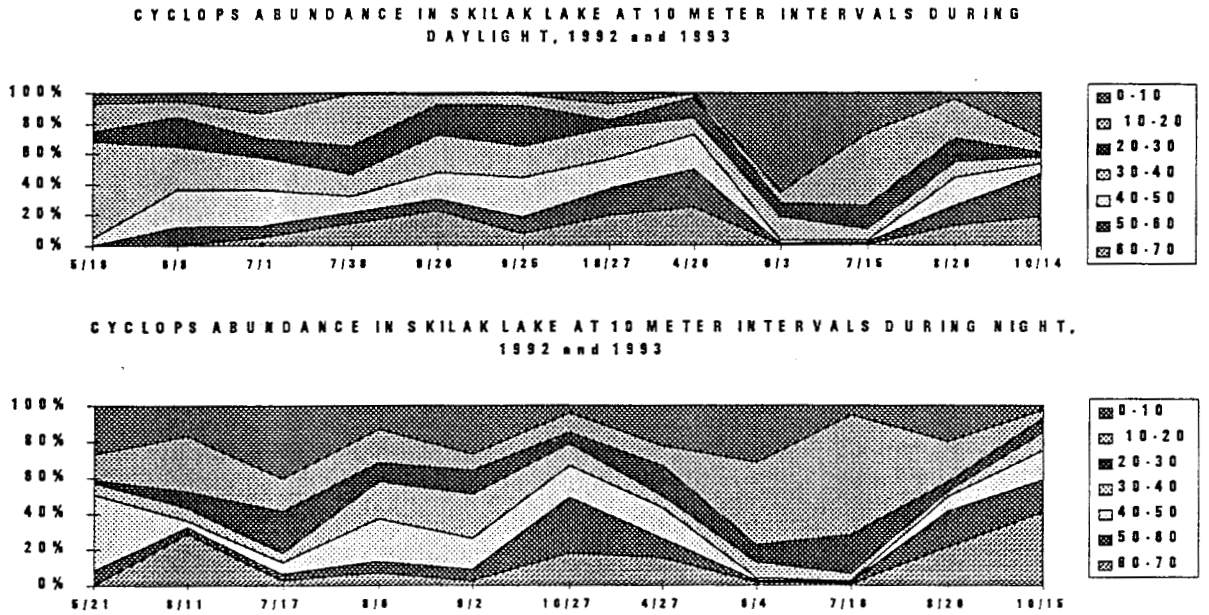

Figure 18. Relative abundance of *Cyclops* in Skilak Lake by 10-m depth intervals in Skilak Lake during daylight and night from 1992 through 1993.

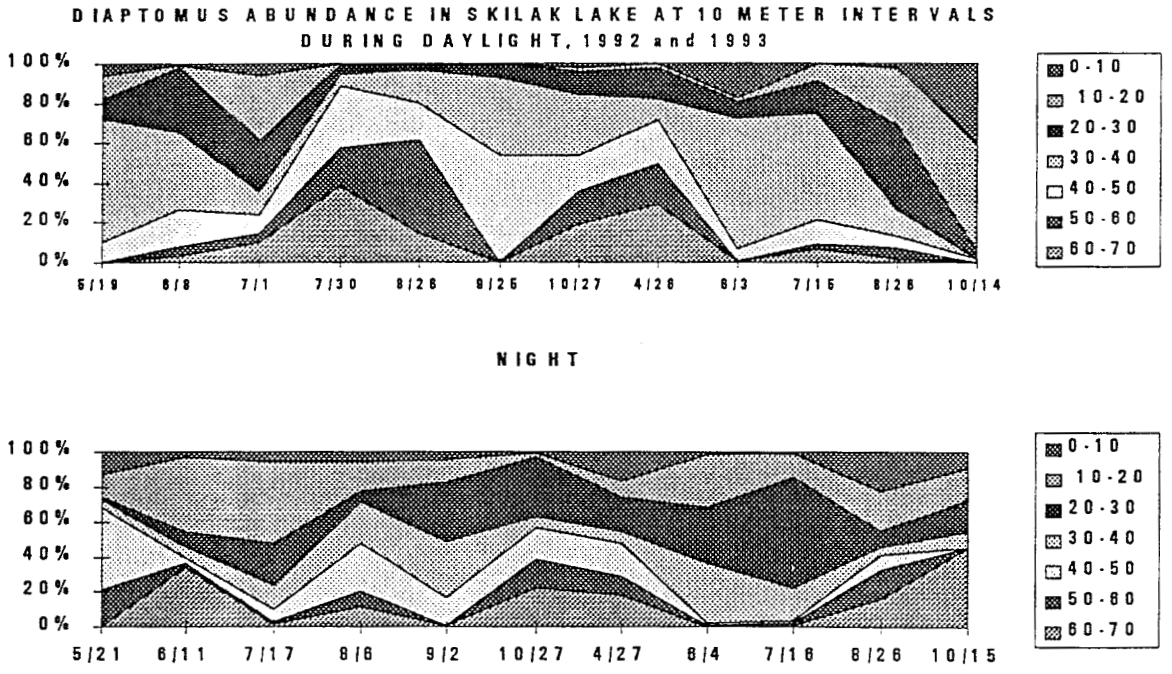

Figure 19. Relative abundance of *Diaptomus* in Skilak Lake by 10-m depth intervals during daylight and night from 1992 through 1993

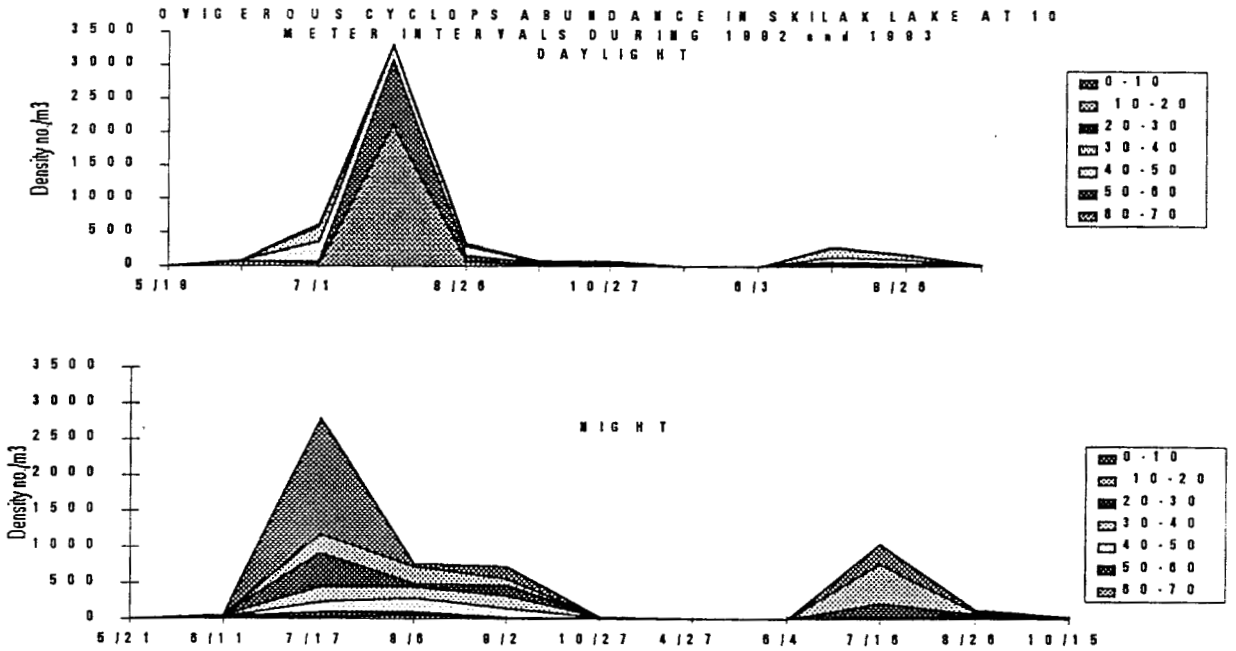

Figure 20. Density of ovigerous *Cyclops* in Skilak Lake by 10-m depth intervals during daylight and night from 1992 through 1993.

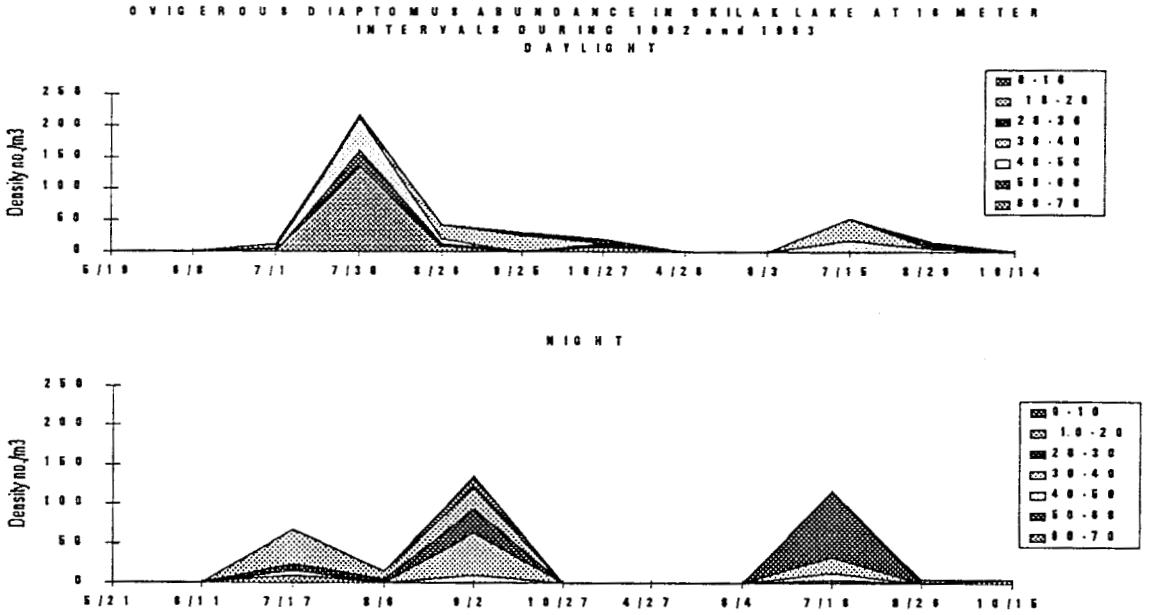

Figure 21. Density of ovigerous *Diaptomus* in Skilak Lake by 10-m depth intervals during daylight and night from 1992 through 1993.

In summary, the small sample of preserved fish from 1987 analyzed for stomach content provided the first direct evidence of dietary change before the large escapements of 1987-1989. The horizontal (station differences) and vertical spatial differences in zooplankton abundance throughout the season and throughout the diel cycle in Skilak Lake during 1993 corresponded with electivity indices. The zooplankton forms which had the highest electivity also demonstrated the most DVM, and were least abundant at the sampling stations where fish were the most abundant. In Tustumena Lake, favorable weather conditions during the summer of 1993 resulted in higher density (relative to other recent years) and a near-surface distribution of *Cyclops*, and the size of fall fry were larger. In contrast, the 1993 mean size of fall fry in Skilak Lake was the second smallest recorded since 1988, which reflects poor rearing conditions, and could continue to result in poor overwinter survival.

Kodiak Lake Investigations

The following sockeye salmon information on Kodiak lakes was taken from Barrett et al. (1993b), and condensed for this report.

Smolt Abundance, Size, and Age

Red Lake - In 1993, an estimated 583,985 ± 147,819 sockeye salmon smolt migrated from Red Lake, which was ~25% less than the 1990-1992 average (Table 10 and Table 11). Age-1 smolt from the 1991 broodyear (BY) were most abundant (52% of the total), followed by age-2 smolt (33%), and age-3 smolt (15%). While fewer total smolt outmigrated in 1993 than the 1990-1992 average, age-1 and age-3 smolt numbers were greater than the previous three years. The average length and weight of smolt in 1993 were within the range observed for the 1990-1992 period (Table 18 and Table 19). The age-3 smolt that migrated in 1993 completes production from the 1989 BY. The total number of sockeye salmon smolt produced from the 768,000 escapement of 1989 is an estimated 1.6 million fish (Table 11). This represents a 4-fold increase in smolt compared to the estimate for the 1988 BR, and a 7-fold increase over the 1990 BY (based upon age-1 and age-2 numbers). While the Red Lake smolt estimates should be considered relative indices (at least for BY's 1987 and 1988), it is apparent that the 1990 BY responded poorly to the 1989 overescapement event by extending freshwater rearing time and producing relatively few age-1 and age-2 smolt.

Table 10. Sockeye salmon smolt estimates by age and smolt year for Red Lake, 1986-1993.

		Age Class				95 % CI	
Smolt Year		Age-1	Age-2	Age-3	Total	Low	High
1990	#	240,500	493,026	6,427	739,954	402,905	1,077,004
	%	32.5	66.6	0.0	100.0		
1991	#	105,467	119,849	38,184	263,500	178,221	348,782
	%	40.0	45.5	14.5	100.0		
1992	#	29,482	1,365,082	25,792	1,420,356	1,117,748	1,722,965
	%	2.1	96.1	1.8	100.0		
1993	#	303,462	193,884	86,644	583,985	436,166	731,804
	%	52.0	33.2	14.8	100.0		

Table 11. Sockeye salmon smolt production and escapement by broodyear for Red Lake, 1986-1993

		Number of Smolt (by Age)			
Brood Year	Escapement	Age-1	Age-2	Age-3	Total[a]
1986	318,135	b		6,427	6,427
1987	261,913		493,026	38,184	531,210
1988	291,774	240,500	119,849	25,792	386,143
1989	768,101	105,467	1,365,082	86,642	1,557,191
1990	371,282	29,482	193,882		223,366
1991	374,859	303,462			303,462
1992	344,184				
1993	286,170				

[a]Smolt production for some broodyears is missing or incomplete
[b]Missing data indicates not available.

Upper Station Lake - The sockeye salmon smolt outmigration from Upper Station Lake in 1993 was estimated at 3,462,058 ± 741,406, which was about 16% lower than the 1990-1992 average (Table 12 and Table 13). As in previous years (1990-1992), age-0 smolt dominated (73%) the outmigration. The mean size of smolt in 1993 was larger than previous years, except for age-1 smolt which were about average compared to other years (Table 18 and Table 19). The 1988-1990 BY production of age-1 and age-2 smolt has been relatively stable, averaging about 0.5 million. The 1991 BY smolt production appears strong, having produced an estimated 0.2 million more smolt than the 1990 BY. While age-1 and age-2 smolt are common to both the early and late Upper Station sockeye salmon runs, age-0 smolt are exclusive to the late run (Roche 1992). For BY's 1989-1992, the production of age-0 smolt averaged 3.0 million, and ranged from 1.9 to 5.5 million.

Table 12. Sockeye salmon smolt estimates by age and smolt year for Upper Station Lake, 1986-1993.

		Age Class					95% CI	
Smolt Year		Age-0	Age-1	Age-2	Age-3	Total	Low	High
1990	#	5,511,473	241,181	1,591,424	58,682	7,402,762	3,962,768	10,842,756
	%	74.4	3.3	21.5	0.8	100.0		
1991	#	1,959,424	224,621	245,673	15,388	2,445,106	1,258,660	3,527,829
	%	80.1	9.2	10.1	0.6	100.0		
1992	#	1,950,244	80,238	362,990	1,444	2,394,916	1,511,502	3,278,334
	%	81.4	3.3	15.2	0.1	100.0		
1993	#	2,528,937	568,342	354,833	9,946	3,462,058	2,720,652	4,203,464
	%	73.0	16.4	10.3	0.3	100.0		

Table 13. Sockeye salmon smolt production and escapements by broodyear for Upper Station Lake, 1986-1993.

				Number of Smolt (by Age)				
		Escapement						
Brood Year	Early	Late	Total	Age-0	Age-1	Age-2	Age-3	Total[a]
1986	100,163	366,222	466,385	b		58,682	56,682	
1987	75,921	156,274	232,195			1,591,424	15,389	1,606,813
1988	58,913	247,647	306,560		241,181	245,673	1,444	488,298
1989	64,582	221,706	286,288	5,511,473	244,621	362,990	9,946	6,129,030
1990	56,159	198,287	254,446	1,959,423	80,238	354,833		2,394,494
1991	50,026	242,860	292,886	1,950,244	568,342			2,518,586
1992	19,076	199,067	218,143	2,528,937				2,528,937
1993	34,852	187,529	222,381					

[a]Smolt production for some broodyears is missing or incomplete.
[b]Missing data indicates not available

Akalura Lake - The 1993 sockeye salmon smolt migration estimate for Akalura Lake was 88,873, ± 52,930, which was a 4-fold decrease compared to the average for 1990-1992 (Table 14). Age-2 smolt were the most abundant comprising 82% of the estimate, and although age-3 smolt represented only 14% of the 1993 estimate, numerically they were more abundant than in the 1990-1992 smolt outmigrations. In 1993, age-1 smolt averaged about 14 mm less and 1.7 g less than the average during 1990-1992 (Table 18 and Table 19). The average size of age-2 and age-3 smolt in 1993 was within the range of averages for 1990-1992 (Table 18 and Table 19). In 1993, the age-1 smolt scale pattern was atypical in that there was no annulus present. Scales from the 1993 age-1 smolt showed about 3-5 circuli per scale. The absence of a scale annuli was likely due to starvation extending beyond the 1992-1993 winter into the spring of 1993. As reported by Bilton and Robins (1971), annuli development occurs after food depravation and not during starvation periods. While it is possible that the BY 1991 young-of-year fish did not reach scale development stage until after the 1992-1993 winter, it is unlikely. Rudimentary sockeye scale development occurs at about 38 mm (Clutter and Whitesel 1956), and smaller fish would probably have insufficient fat reserves to successfully overwinter. In addition, the age-2 and age-3 smolt scales had minimal, if any plus growth, which suggests that the 3-5 circuli present on the age-1 smolt scales were circuli developed from the 1992 summer and fall rearing and not from spring growth in 1993. Finally, the 1987 and 1988 BY's produced about a 2-fold increase in the number of smolt compared to the 1989 BY (Table 15). Also, the 1990 BY (indicated by the number of age- 1 and age-2 smolt) produced relatively few smolt (about 50% less) compared to the 1989 BY. Thus, Akalura Lake has shown a steady decline in smolt production and a shift in age composition to fewer age-1 and more age-3 smolt.

Table 14. Sockeye salmon smolt estimates by age and smolt year for Akalura Lake, 1986-1993.

		Age Class					95 % CI	
Smolt Year		Age-1	Age-2	Age-3	Age-4	Total	Low	High
1990	#	66,460	408,330	0	0	474,790	318,734	630,846
	%	14.0	86.0	0.0	0.0	100.0		
1991	#	9,086	299,591		0	309,928	237,981	381,875
	%	2.9	96.7	0.04	0.0	100.0		
1992	#	1,921	182,963	8,315	0	193,199	153,765	232,638
	%	2.9	96.7	4.3	0.0	100.0		
1993	#	3,259	73,062	12,315	238	88,873	35,943	141,802
	%	3.7	82.3	13.9	0.1	100.0		

Table 15. Sockeye salmon smolt production and escapements by broodyear for Akalura Lake, 1986-1993.

		Number of Smolt (by Age)				
Brood Year	Escapement	Age-1	Age-2	Age-3	Age-4	Total[a]
1986	9,800	b		0	0	
1987	6,116		408,330	1,251	0	40,582
1988	38,618	66,460	299,591	8,315	238	374,604
1989	116,029	9,086	182,963	12,315		204,364
1990	47,181	1,921	73,062			74,983
1991	44,189	3,259				3,259
1992	63,269					
1993	30,692					

[a]Smolt production for some broodyears is missing or incomplete.
[b]Missing data indicates not available.

Frazer Lake - The 1993 Frazer Lake sockeye salmon smolt outmigration was estimated at 9,789,057 ± 6,479,172 million smolt, which is ~33% more than the estimates in 1991 and 1992 (Table 16). Age-2 and age-3 smolt equally dominated the emigration, which was markedly different than in the previous two years. That is, in 1991 age-1 smolt comprised 40% and age-2 smolt comprised 59% of the emigration, whereas in 1992 age-2 comprised 89% of the total population. In 1993, all age classes of smolt were similar in size compared to previous years (Table 18 and Table 19). The 1989 BY escapement produced an estimated 12.9 million smolt from an escapement of 360,000. The 1988 and 1990 BY escapements produced less than half as many smolt from escapements that were only 22% and 28% less than the 1989 BY escapement. In addition, age-1 smolt production from the 1991 BY is quite low relative to other years. Thus, based on results of recent sampling, age-1 smolt production has substantially decreased, whereas age-2 smolt numbers appear to be more stable and age-3 smolt abundance has increased.

Table 16. Sockeye salmon smolt estimates by age and smolt year for Frazer Lake, 1986-1993.

		Age Class					95% CI	
Smolt Year		Age-1	Age-2	Age-3	Age-4	Total	Low	High
1991	#	2,552,835	3,777,426	3,786	0	6,334,047	2,128,460	10,539,634
	%	40.3	59.6	0.1	0	100.0		
1992	#	108,489	5,739,150	557,584	0	6,405,222	2,649,678	10,160,766
	%	2.9	89.6	8.7	0	100.0		
1993	#	23,496	5,077,865	4,687,084	612	9,789,057	3,309,885	16,268,229
	%	0.2	51.9	47.9	0	100.0		

Table 17. Sockeye salmon smolt production and escapements by broodyear for Frazer Lake, 1986-1993.

		Number of Smolt (by Age)				
Brood Year	Escapement	Age-1	Age-2	Age-3	Age-4	Total[a]
1986	126,529	b		0		
1987	40,544			3,786	0	3,786
1988	246,704		3,777,426	557,584	612	4,335,622
1989	360,373	2,552,835	5,739,150	4,687,083		12,979,068
1990	226,960	108,489	5,077,866			5,186,355
1991	190,358	23,496				23,496
1992	185,825					
1993	178,391					

[a]Smolt production for some broodyears is missing or incomplete

[b]Missing data indicates not available.

Table 18. Mean length of sockeye salmon smolt by age and smolt year for the Kodiak Island study lakes, 1990-1993.

		Smolt Fork Length (mm)														
		Age-0			Age-1			Age-2			Age-3			Age-4		
System	Smolt Year	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE
Red Lake																
	1990	0			342	106.5	0.2	1,052	111.8	0.3	20	117.9	1.9	0		
	1991	0			1,135	88.2	0.1	977	106.7	0.3	407	113.0	0.3	0		
	1992	0			85	99.5	0.9	1,667	110.2	0.2	63	119.7	1.4	0		
	1993	0			1,409	91.7	0.1	516	108.6	0.5	397	120.1	0.6	0		
Akalura																
	1990	0			577	73.9	0.3	748	85.9	0.2	0			0		
	1991	0			41	77.2	2.0	1,382	77.5	0.2	22	97.3	4.0	0		
	1992	1	59.0		25	75.7	1.0	2,014	78.8	0.1	61	86.4	0.6	0		
	1993	0			74	61.8	1.2	992	85.8	0.2	94	90.8	0.7	2	101.5	2.5
Upper Station																
	1990	939	54.5	0.2	325	81.4	0.4	1,539	99.7	0.2	74	109.7	0.8	0		
	1991	1,622	59.3	0.2	658	94.0	0.4	947	102.3	0.3	72	115.0	1.1	0		
	1992	1,813	57.5	0.1	477	93.7	0.4	1,841	103.3	0.2	8	112.6	2.3	0		
	1993	2,311	60.5	0.1	1,113	92.0	0.2	853	111.4	0.4	27	119.6	2.5	0		
Frazer																
	1990	0			574	84.2	0.2	553	104.3	0.2	44	113.0	1.6	0		
	1991	0			746	89.7	0.2	1,344	89.5	0.2	4	120.8	9.1	0		
	1992	0			49	86.4	1.1	2,951	83.9	0.1	191	91.1	0.5	0		
	1993	0			8	89.9	0.5	682	100.3	0.1	913	104.2	0.2	3	121.3	9.4

Table 19. Mean weight of sockeye salmon smolt by age and smolt year for the Kodiak Island study lakes, 1990-1993.

	Smolt Weight (g)														
	Age-0			Age-1			Age-2			Age-3			Age-4		
System Smolt Year	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE	N	Mean	SE
Red Lake															
1990	0			341	10.0	>0.1	1,050	11.0	>0.1	20	13.0	0.1	0		
1991	0			1,135	5.0	0.0	977	9.5	0.1	407	11.3	0.1	0		
1992	0			85	8.8	0.3	1,666	11.8	0.1	63	15.2	0.6	0		
1993	0			1,409	7.3	>0.1	517	11.0	0.1	395	14.5	0.2	0		
Akalura															
1990	0			577	3.6	<0.1	749	5.3	<0.1	0			0		
1991	0			41	4.3	0.5	1,382	4.0	0.0	22	8.9	1.2	0		
1992	1	1.5		25	3.7	0.3	2,007	3.9	0.0	61	4.9	0.1	0		
1993	0			74	2.2	0.1	992	5.7	0.0	94	6.8	0.2	2	10.1	0.5
Upper Station															
1990	937	1.5	0.1	324	4.9	0.1	1,538	8.3	0.1	74	11.1	0.2	0		
1991	1,622	2.0	0.0	660	7.1	0.1	946	9.3	0.1	71	12.8	0.4	0		
1992	1,813	1.8	0.0	477	7.9	0.1	1,841	10.1	0.0	8	13.6	1.2	0		
1993	2,311	2.1	0.1	1,113	6.3	0.1	852	11.7	0.1	27	14.9	0.9	0		
Frazer															
1990	0			574	4.5	0.0	552	9.0	0.1	44	12.2	0.7	0		
1991	0			745	5.4	0.0	1,343	5.6	0.0	4	15.7	3.9	0		
1992	0			49	6.1	0.2	2,947	5.5	0.0	194	7.2	0.1	0		
1993	0			8	6.1	0.2	684	8.3	0.0	899	9.2	0.0	2	17.7	5.1

Juvenile Size and Age

In 1993, townet surveys were done in Red and Frazer lakes to compare the size of juvenile sockeye salmon rearing in each lake. A total of 51 juvenile sockeye salmon from Red Lake and 24 from Frazer Lake were caught by tow net during 1993 (Table 20).

Table 20. Summary of fish caught by townet in Red and Frazer lakes in 1993.

Lake	Date	Tow no.	Tow duration (min)	Tow depth (m)	Catch Sockeye	Catch Stickleback
Red	26-Sep	1	20	10	21	99
	26-Sep	2	21	10	7	69
	26-Sep	3	21	10	13	257
	27-Sep	4	17	18	10	23
				Total	51	448
Frazer	22-Sep	1	20	10	3	106
	22-Sep	2	20	10	12	104
	23-Sep	3	20	18	5	86
	23-Sep	4	22	18	0	5
	23-Sep	5	21	18	3	66
	23-Sep	6	21	10	1	28
				Total	24	395

In addition, 448 stickleback in Red Lake and 395 in Frazer Lake were caught during the surveys. In both lakes, the majority of the catch was age-0 sockeye fry. The mean size of age-0 sockeye fry caught in Red Lake was 49 mm and 0.9 g, while in Frazer Lake the fry averaged 65 mm and 1.5 g (Table 21).

Table 21. Age and mean size of fish caught by townet in Red and Frazer lakes in 1993.

Lake	Age	No. Sampled	Length (mm) Mean	Length (mm) S. D.	Weight (g) Mean	Weight (g) S. D.
Red	0	44	49	6.9	0.9	0.4
	1	7	81	7.1	4.9	1.0
Frazer	0	22	65	5.6	1.5	0.4
	1	2	97	7.0	6.1	1.1

The 1993 mean size of fall age-0 sockeye fry in Red Lake was the smallest ever recorded since 1990 (Schmidt and Tarbox 1993). This fact and the finding of larger size age-0 sockeye fry in nearby Frazer Lake, indicates a higher intraspecific competition for food by sockeye juveniles in Red Lake.

Limnological Assessment

Limnological parameters from four Kodiak Island lakes pertinent to the oilspill studies were collected in 1993 (Appendix A). As in previous years, during 1993 no unusual values (outside the range for oligotrophic lakes in Alaska) for general water-quality parameters, nutrients, or chlorophyll *a* were detected. Specifically, no consistent trends in these parameters were apparent in Red and Akalura lakes that received high escapements in 1989 compared to nearby Upper Station and Frazer lakes that did not receive overly large escapements.

The zooplankton biomass by taxa for these four lakes systems since 1986 is provided in Figure 22. As reported in Schmidt and Tarbox (1993), the preferred prey of sockeye fry (cladocerans) in Red Lake apparently demonstrated a density-dependent response to the large escapement of 1989, as indicated by a 5- to 10-fold decrease in *Bosmina* and *Daphnia* in 1990 compared to 1986. In 1991, the total biomass decreased further despite the lower escapement in 1990 (371,000), but the majority of smolt produced from the 1989 BY held over an additional year and were rearing in the lake during 1991. In 1992, both *Bosmina* and *Daphnia* increased dramatically and the total biomass increased to ~2,500 mg m^{-2}; the highest recorded to date. This increase was most likely the result of reduced predation pressure as the majority of smolt produced from the high escapement of 1989 migrated, and the escapement in 1991 was ~375,000. Unexpectedly, in 1993 the total zooplankton biomass decreased to about the 1990 level. The major drop in overall production due to *Cyclops*. Although the 1993 zooplankton biomass was similar to the 1990 level, there was a substantially higher number of cladocerans in 1993. The 1992 escapement of 345,000 sockeye salmon that produced the age-0 fry rearing in 1993 was similar to that in 1991, yet the zooplankton biomass in 1993 was about 2.5 times lower. An explanation for the lower biomass in 1993 is that a high proportion of the fry produced from the 1991 escapement may have held over for an additional year of rearing.

As Schmidt and Tarbox (1993) indicated, the zooplankton biomass in Upper Station Lake varied substantially between stations and in species composition compared to Red Lake. The 1993 biomass for this lake showed similar trends as previous years. Akalura Lake does not show any trends in biomass or species composition related to the large 1989 sockeye salmon escapement. The species composition of this system is also quite different from that observed in Red Lake. The zooplankton community of Red Lake is more comparable to that of Frazer Lake (Figure 22), and in the future this lake will be more suitable as a control to evaluate zooplankton changes in Red Lake. Frazer Lake was treated with nutrients to increase the forage base during 1988-1992. In 1993, when no nutrients were added to Frazer Lake, the zooplankton biomass decreased (compared to 1992) despite similar escapements the previous three years. This response was similar to that observed in Red Lake when escapements were also nearly equivalent for the last three years, and suggests either increased predation pressure, or lower zooplankton production, possibly due to diminished environmental conditions.

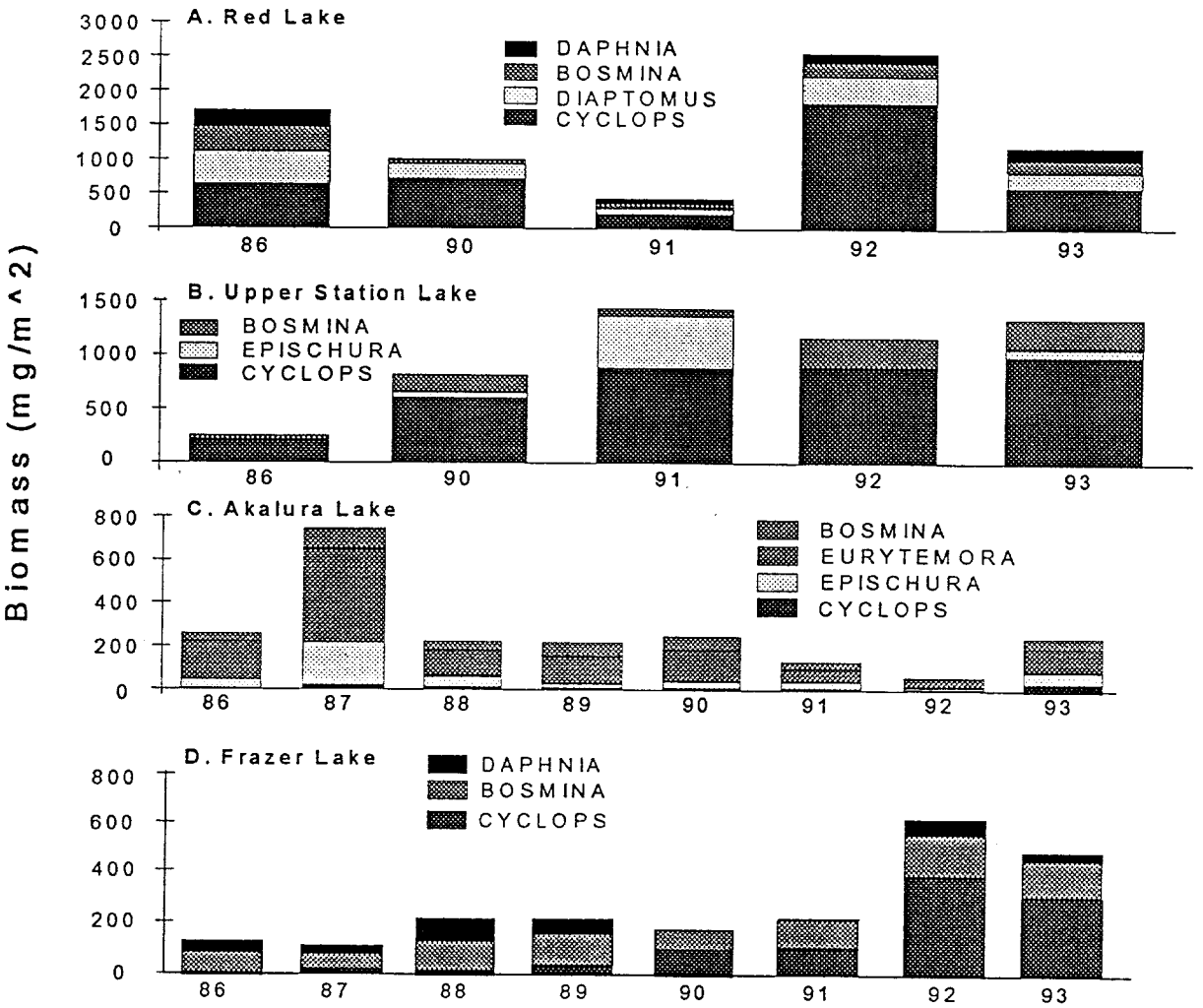

Figure 22. Interannual variation in seasonal mean zooplankton biomass for the Kodiak Island study lakes, 1986-1993.

STATUS OF INJURY ASSESSMENT

The 1993 studies have provided additional insight about plausible reason(s) for the collapse of sockeye salmon smolt production within the Kenai River system and from Red Lake on Kodiak Island. The Kenai River smolt production has decreased over time and major reductions in adult returns from these smolt years are likely. Fall fry data coupled with limited sampling in the spring of 1992 provide support for the contention that overwintering mortality of fry in the lake is primarily responsible for the collapse. The 1993 fall data indicate high abundance and small size of juvenile sockeye salmon in Skilak Lake. In contrast, Tustumena Lake produced record-size fall fry in 1993, and had high zooplankton densities, suggesting that fish survival are most likely caused by density-independent factors. Survival of these two populations would be expected to be different, given the pre-winter condition. As other factors may compound overwinter survival such as length of winter and availability of zooplankton in the spring, forecasts future smolt production from these systems would have a high degree of uncertainty.

More detailed studies of zooplankton behavior, abundance, and distribution in Skilak Lake in 1993 suggests DVM may decline with increased abundance (and presumably increased competition for food), at least for *Cyclops*. The electivity of the feeding habits of fry from limited pre-overescapement samples is consistent with the hypothesis of reduced availability of copepods in Skilak Lake. The DVM patterns in 1993 were consistent with spatial abundance and electivity indices of fry collected from the same time and areas. Because the current study approach provides only correlative data, we are recommending that in 1995, a net-enclosure study be initiated to determine the effect of altering sockeye salmon fry densities, coupled with nutrient additions, on growth of juvenile sockeye salmon. These studies will provide a basis for determining the feasibility of restoration activities to facilitate recovery of Skilak Lake sockeye salmon. These investigations will be coupled with the ongoing monitoring of fry populations and characteristics, and overwintering survival to smolt in Skilak and Tustumena lakes, in addition to monitoring the zooplankton communities.

Smolt production from Red and Akalura lakes continue to be depressed. The decline in fall fry size and zooplankton density from Akalura Lake suggests density-based affects continue. As the zooplankton density (forage base) in Akalura Lake during 1993 increased, we should expect an improvement in growth and survival of sockeye salmon juveniles. The nutrient status of Akalura Lake indicate that this system is not nutrient deficient and would not benefit from a nutrient enrichment program (Edmundson et al. 1994). The zooplankton community in Red Lake appears to have recovered from the high 1989 escapement. Improved recruitment of juveniles to this lake through maintaining adequate escapements should allow this system to restore naturally. Continued smolt monitoring until restoration is completed is recommended.

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APPENDIX A

Appendix Table 1. General water-quality parameters, metals, nutrient concentrations, and algal pigments within the 1-m stratum and hypolimnion of Akalura Lake, 1993.

Date	Station	Depth (m)	Sp. Cond. (umhos/cm)	pH (Units)	Alkalinity (mg/L)	Turbidity (NTU)	Color (Pt Units)	Calcium (mg/L)	Magnesium (mg/L)	Iron (ug/L)	Total-P (ug/L)	Total filterable-P (ug/L)	Filterable reactive-P (ug/L)	Total Kjeldahl-N (ug/L)	Ammonia (ug/L)
5/17/93	1	1	59	6.8	14.5	1.3	8	4.7	1.7	64	15.8	5.0	1.9	187.9	1.5
5/17/93	1	17	59	6.8	14.5	1.8	8	3.7	1.7	93	18.3	3.6	1.2	210.7	3.5
5/17/93	2	1	59	6.8	14.5	1.6	9	3.7	1.7	70	14.2	3.8	1.2	188.0	0.5
5/17/93	2	13	58	6.8	15.0	1.5	8	4.7	1.7	80	14.0	3.2	0.9	186.3	1.7
6/15/93	1	1	59	6.9	15.0	2.0	ND	4.8	1.7	32	ND\a	ND	ND	174.9	2.6
6/15/93	1	16	62	6.5	15.0	2.0	8	4.8	1.7	366	15.9	6.6	3.8	203.4	48.1
6/15/93	2	1	61	6.8	15.0	2.0	10	5.0	1.5	50	11.4	7.2	4.3	176.4	1.6
6/15/93	2	13	60	6.6	14.0	1.7	5	5.0	1.5	81	13.0	3.4	1.6	156.2	2.6
7/13/93	1	1	59	6.8	15.0	0.8	3	4.8	1.7	46	12.4	4.4	2.7	191.8	4.5
7/13/93	1	16	63	6.6	17.0	1.0	3	4.8	1.7	167	13.7	9.3	4.7	203.5	39.3
7/13/93	2	1	59	6.9	15.0	1.7	3	4.8	1.7	168	12.1	4.2	2.9	195.0	4.5
7/13/93	2	14	61	6.4	15.0	1.5	3	4.8	1.7	336	14.6	7.7	4.0	225.2	74.1
8/19/93	1	1	59	6.8	15.0	0.7	3	5.0	1.4	48	14.1	7.2	4.9	202.0	6.2
8/19/93	1	16	64	6.3	17.0	3.0	3	5.0	1.4	780	33.0	4.5	3.3	335.6	129.5
8/19/93	2	1	60	6.9	15.5	1.0	3	5.0	1.4	76	12.8	4.2	1.8	192.7	4.5
8/19/93	2	14	64	6.3	16.0	2.1	3	5.0	1.4	630	28.4	4.9	3.8	288.2	92.1
9/21/93	1	1	59	6.9	15.0	1.2	3	4.9	1.3	72	18.0	5.0	2.5	218.2	34.8
9/21/93	1	17	59	6.9	15.0	1.4	3	4.9	1.3	98	19.2	5.7	2.8	222.9	35.9
9/21/93	2	1	60	6.9	15.0	1.2	3	4.9	1.3	88	20.1	11.8	6.5	231.5	33.7
9/21/93	2	13	60	6.8	15.0	1.3	3	4.9	1.3	96	18.4	5.7	3.0	215.2	40.4
1-m stratum seasonal mean			59	6.8	14.9	1.3	5	4.8	1.5	76	14.5	5.9	3.2	198.2	10.2
Hypolimnetic seasonal mean			61	6.6	15.4	1.7	5	4.8	1.5	273	18.9	5.5	2.9	224.7	46.7

ND = suspected contamination of sample for these parameters; not used for seasonal mean values.

Appendix Table 2. General water-quality parameters, metals, nutrient concentrations, and algal pigments within the 1-m stratum and hypolimnion of Frazer Lake, 1993.

Date	Station	Depth (m)	Sp. Cond. (umhos/cm)	pH (Units)	Alkalinity (mg/L)	Turbidity (NTU)	Color (Pt Units)	Calcium (mg/L)	Magnesium (mg/L)	Iron (ug/L)	Total-P (ug/L)	Total filterable-P (ug/L)	Filterable reactive-P (ug/L)	Total Kjeldahl-N (ug/L)	Ammonia (ug/L)
5/4/93	1	1	53	6.9	13.0	0.4	11	5.0	0.6	12	4.8	5.3	3.2	84.5	0.5
5/4/93	1	23	52	7.0	13.0	0.4	4	5.0	0.6	18	5.0	4.2	2.6	121.1	<1.7
5/4/93	3	1	53	7.0	13.0	0.4	4	5.0	0.6	14	6.0	1.8	1.9	88.2	<1.7
5/4/93	3	50	121	6.9	13.0	0.4	6	5.0	1.9	24	6.2	5.2	2.2	117.3	2.6
6/15/93	1	1	51	6.8	12.0	0.9	12	5.0	1.5	27	4.4	3.8	2.3	92.0	0.5
6/15/93	1	23	52	6.5	12.0	1.0	6	5.0	1.5	21	4.5	2.3	1.8	77.7	2.6
6/15/93	3	1	51	6.6	12.0	1.3	5	5.0	1.5	28	4.6	3.1	2.0	100.2	1.6
6/15/93	3	50	64	8.2	19.0	1.9	5	8.0	1.5	23	3.7	2.4	1.9	77.8	6.7
7/26/93	1	1	55	6.7	14.0	0.6	3	4.1	2.2	7	4.0	2.9	2.0	100.3	6.0
7/26/93	1	25	55	6.4	15.0	1.4	3	5.1	2.2	12	6.5	3.1	2.1	111.7	13.6
7/26/93	3	1	56	6.5	12.0	0.7	3	5.1	2.2	3	4.6	2.0	1.4	109.5	7.0
7/26/93	3	50	56	6.5	15.0	0.6	2	5.1	2.2	3	6.5	2.5	1.4	107.2	14.6
9/9/93	1	1	57	6.7	13.5	0.5	3	5.0	1.6	11	6.5	3.3	1.7	117.0	7.0
9/9/93	1	25	63	7.0	16.0	0.3	3	7.0	1.6	10	4.9	3.1	1.4	96.5	21.6
9/9/93	3	1	57	6.8	14.0	0.5	3	5.0	1.6	10	6.0	3.9	2.2	136.0	7.0
9/9/93	3	50	57	6.7	13.5	0.3	3	5.0	0.8	6	4.8	3.2	1.7	96.6	20.0
10/13/93	1	1	51	6.9	13.0	1.5	3	4.5	1.7	4	5.7	3.0	1.2	92.0	3.8
10/13/93	1	25	52	6.9	13.5	0.4	3	4.5	1.7	3	5.9	2.6	1.4	90.5	4.9
10/13/93	3	1	52	6.9	13.0	0.8	3	4.5	1.7	9	5.4	4.8	2.8	87.5	7.0
10/13/93	3	50	52	6.8	13.5	3.0	3	5.0	0.7	22	5.7	2.9	1.5	88.2	8.6
1-m stratum seasonal mean			54	6.8	13.0	0.8	5	4.8	1.5	13	5.2	3.4	2.1	100.7	3.9
Hypolimnetic seasonal mean			62	6.9	14.4	1.0	4	5.5	1.5	14	5.4	3.2	1.8	98.5	9.4

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