TUSTUMENA LAKE PROJECT REPORT: SOCKEYE SALMON INVESTIGATIONS 1994

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REGIONAL INFORMATION REPORT NO. 5J95-12

Alaska Department of Fish and Game
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The 1994 adult sockeye salmon *Oncorhynchus nerka* escapement into Tustumena Lake based on sonar counts in the Kasilof River was estimated at 204,525. The hatchery contribution of adult sockeye salmon in the escapement for 1994 was 9,103 (4.5% contribution rate). An estimated 31,236 hatchery-produced fish contributed to the total Tustumena Lake sockeye salmon return for 1994.

A total of 12.5 million sockeye salmon juveniles were estimated in Tustumena Lake based on a hydroacoustic/townet survey conducted in September of 1994. The age composition of sockeye salmon fry collected in September of 1994 was 80.7% age-0 and 19.3% age-1. The mean size of age-0 fry was 64 mm and 2.6 g, which was larger than all previous years (since 1980) except 1993.

The estimated number of sockeye salmon smolts that emigrated Tustumena Lake in 1994 was 9.1 million. The daily peak emigration occurred on 1 June when an estimated 1.3 million smolts emigrated. The smolt population was comprised of 7.4 million (80.7%) age-1 smolts and 1.8 million (19.3%) age-2 smolts. The mean size of age-1 smolts was 72 mm and 2.8 g. The number of hatchery-produced smolts in 1994 was estimated at 363,000, or 4.0% of the total emigration.

Limnological surveys in 1994 indicated a higher seasonal mean water temperature, lower concentrations of key nutrients (phosphorus and nitrogen), and higher algal biomass (chlorophyll *a*). Mild weather conditions (sunny days, warm temperatures) resulted in a longer growing season and a higher assimilation rate of nutrients such as total phosphorus into phytoplankton growth. This condition most likely contributed to the 3.5-fold higher density of *Diaptomus* in 1994 compared to the mean during 1980-1993. Warmer weather, and in particular, greater algal biomass peaks were probably responsible for the larger numbers of *Diaptomus* and the relatively larger size fall fry.

KEY WORDS: sockeye, fry stocking, smolt and adult production, glacial lake, limnology

INTRODUCTION

The Tustumena Lake sockeye salmon *Oncorhynchus nerka* investigation project was initiated in 1981 to assess juvenile and adult sockeye salmon populations relative to the effects of stocking hatchery fry. The primary goals of this project are to determine in-lake factors affecting productivity and to assess the stocking program relative to averting negative impacts to the natural production of sockeye salmon.

Initially, the working hypothesis of sockeye salmon production in Tustumena Lake was that this system operated in a typical density-dependent fashion, where the variability in smolt production (juvenile-rearing success) is related to fluctuations in freshwater trophic levels (Foerster 1944; Johnson 1965; Brocksen et al. 1970; Koenings and Burkett 1987; Kyle et al. 1988). However, if juvenile fish density is not sufficient to challenge the limnetic forage base, and trophic-level responses become uncoupled from fish density, observed trophic changes may be correlated to environmental variables (density-independent). In Tustumena Lake, Kyle (1992) reported that trophic-level responses were inconsistent with unconditional density-dependent sockeye salmon production. A preliminary analysis in Tustumena Lake suggests that sockeye salmon production is density-independent, as environmentally dependent variables were responsible for a majority of the annual variation in the production of wild age-1 smolts (Koenings et al. 1988).

This report summarizes fisheries and limnological data collected during 1994. This information is used to assess the fry stocking project through monitoring juvenile and adult sockeye salmon production and changes in limnological parameters in Tustumena Lake. Sockeye salmon investigations in Tustumena Lake have been on-going since 1980. In 1974 sockeye salmon eggs were first taken from Glacier Flats Creek. Since then, sockeye salmon eggs have been taken each year from Glacier Flats Creek, Bear Creek, or both, and fry have been stocked in Tustumena Lake (with the exception of 1994, when the fry were infected with IHN-virus and destroyed) at levels ranging from 6-17 million. Previous years of information on this project are reported in federal-aid (Anadromous Fish Conservation) annual reports (1987-1992), in a summary report for years 1980-1991 by Kyle (1992), and in an annual report by Todd and Kyle (1994).

Study Site Description

Tustumena Lake (60° 10' N, 150° 55' W) is located on the Kenai Peninsula, approximately 25 km south of Soldotna, Alaska. This lake has a surface area of 294.5 km^2 (73,942 acres), a mean and maximum depth of 24 m and 320 m, and is approximately 40-km long and 8-km wide (Figure 1). Tustumena Lake is fed by clearwater as well as glacial creeks that originate in the Harding Icefield. The lake outlet (Kasilof River) drains into Cook Inlet over a watershed area of 1,376 km^2. Tustumena Lake lies within the Kenai National Wildlife Refuge and project activities are regulated under a special use permit issued each year to the Alaska Department of Fish and Game (ADF&G) by the United States Fish and Wildlife Service (FWS). The Cook Inlet Aquaculture Association (CIAA) collects eggs at Bear Creek on Tustumena Lake for the fry stocking project in Tustumena Lake and for stocking fry in other lakes in Cook Inlet.

All 5 species of Pacific salmon are found in the Tustumena Lake system, though sockeye salmon predominate. Sockeye salmon escapements have been estimated in the Kasilof River by sonar since 1968. Annual escapements have ranged from a low of 40,000 in 1973 to a high of 505,000 in 1985 (King and Tarbox 1991). The estimated commercial fishing exploitation rate of sockeye salmon bound for the Kasilof River has ranged from 50% to 85%. Sockeye salmon returning to the Tustumena Lake system are a major contributor to the total Cook Inlet sockeye salmon harvest.

METHODS

Adult Hatchery Contribution

The contribution of hatchery-produced fish to the Tustumena Lake sockeye salmon escapements in 1994 was estimated from respective hatchery smolt data and the corresponding return of adults by age class. The adult sockeye salmon age composition is determined from data collected at the Kasilof River sonar/fishwheel site, operated each year by ADF&G. As not all hatchery released fingerlings were marked, the total number of hatchery-produced sockeye salmon in the escapement was computed from: 1) the corresponding years of release, 2) the number of fingerlings released, and 3) the number of fingerlings marked. The contribution rate of hatchery-produced sockeye salmon in the total return (escapement and harvest) was determined by making the assumption that the same ratio of hatchery-to-wild fish estimated in the escapement also occurred in the commercial, personal-use and sport catches of Tustumena Lake sockeye salmon. No spawning escapement surveys were conducted in 1994, but CIAA conducted an escapement count during the egg take at Bear Creek.

Hydroacoustic/Townet Surveys

A hydroacoustic survey was conducted on 21 September 1994 to estimate the number and distribution of sockeye salmon fingerlings rearing in Tustumena Lake. Hydroacoustic surveys were comprised of recording data along 9 transects perpendicular to the longitudinal axis of the lake (Figure 2). The lake was divided into 3 areas, and 3 transects per area were selected randomly. Recording of down-looking acoustic data along the transects was done at night because juvenile sockeye salmon in this lake are more dispersed during darkness. A Magellan NAV 5000A GPS (Global Positioning System) receiver was used to maintain transect course. A BioSonics model-105 echosounder system with a 6/15° dual-beam transducer was used for the survey. Fish signals were recorded electronically using a Sony digital audio tape recording system and on paper using a BioSonics model-115 chart recorder.

Analysis of the recorded hydroacoustic tapes was conducted by Dr. Richard Thorne of BioSonics, Inc., under a State of Alaska contract. Fish densities were low enough to allow the use of echo-counting techniques (Thorne 1983) for the population estimate. The number of echoes from fish targets were counted in 10-min increments along the 9 transects and in 5 depth intervals. Sampling volumes were estimated by the duration-in-beam technique (Nunnallee and Mathisen 1972; Nunnallee 1980; Thorne 1988). For each depth interval and 10-min increment, fish densities (no./m^3) were summed to determine the total areal fish density (no./m^2) for each transect. Mean fish densities were weighted by time, since end-of-transect increments were usually less than 10 min. A mean areal fish density and an associated variance was computed from the 3 transects per area (Kyle 1990). The total population estimate was obtained by multiplying the lake area representing each transect by the mean transect fish density, and summing all transect population estimates. Transect variances were summed and a 95% confidence interval for the total fish population estimate was calculated.

Townetting was conducted in conjunction with the hydroacoustic surveys to determine species of acoustically-counted fish, and to determine age and size of juvenile sockeye salmon. Townetting procedures consisted of using a 3 x 3-m net pulled at a speed of approximately 1.0-1.25 m/sec. As the fish in Tustumena Lake are located relatively near the surface during both night and day, surface net tows were conducted during the day on 26 and 29 September 1994. Unlike previous years, all captured juvenile sockeye salmon were sampled fresh for individual snout-to-fork lengths (nearest 1.0 mm) and weights (nearest 0.1 g). This was done in 1994 because the fry were analyzed for lipid content as part of the comparative investigations of overescapement on the Kenai River (Schmidt et al. 1995). A scale smear was taken from each fish, and ages were determined with the use of a microfiche reader.

Smolt Enumeration and Sampling

One inclined-plane smolt trap (Todd 1994) was placed in the Kasilof River on 9 May and operated through 24 June 1994; an anchor cable holding the trap in place broke so the trap was pulled earlier than normal. The trap measured 1.5 m wide by 1 m in height, and was 3.8 m long. Each day, captured smolts were either individually enumerated and released, or when the daily smolt numbers exceeded 7,000, the number of smolts were estimated using a biomassing technique. This biomassing procedure entailed weighing 100 individual sockeye salmon smolts every other day to obtain a mean smolt weight, which was divided by the total weight of the sockeye salmon smolts caught to estimate the number of smolts.

The population estimate of sockeye salmon smolts migrating from Tustumena Lake was made using weekly trap efficiencies determined through a mark-and-recapture procedure (Rawson 1984). During each week in May and June 900 sockeye salmon smolts were dyed and released upstream of the traps to estimate trap efficiency. The enumerated smolts were placed in an aerated transport tank containing a dye solution (1 g of Bismarck Brown Y dye to 30 L of water), and remained in the dye for 30 minutes during transport to the release location, approximately 2 km upstream. The dyed smolts were placed in a live box in the river to recover and assess handling mortality prior to release. Dyed smolts recaptured in the trap were enumerated and released. Weekly migrations were estimated from the recovery of stained smolts to determine trap catch efficiency. The percentage of the total migration comprising age-1 and age-2 smolts was estimated for each weekly period using scales obtained from samples collected that week. This percentage was then applied to the estimated total smolt migration for the weekly period to obtain estimates of the number of migrating smolts for each age class (Flagg et al. 1984).

The number of hatchery-produced sockeye salmon smolts migrating each year was estimated from the proportion of marked-to-unmarked smolts recovered during sampling by weekly periods (up to 4,500 smolts per day were observed for missing ventral fins), and the expansion of the estimated marked smolts by the percentage marked for that respective release year (Reed 1981). In addition, the number of hatchery smolts produced each year was adjusted by a differential mark-mortality factor of 1.5 after Flagg et al. (1987).

Every other day through the peak of the smolt emigration, a random sample of 50 sockeye salmon smolts was sampled for age and size. After the emigration peaked, the smolts were sampled twice weekly. The smolts were anesthetized in a solution of MS-222 and measured for snout-to-fork length (nearest millimeter) and weight (nearest 0.1 g). A scale smear was taken from each of the sampled smolts and read with the use of a microfiche reader to determine age.

Limnological Surveys

Limnology sampling was conducted once every 3 weeks during the ice-free period at 3 stations representing each basin of the lake (Figure 1). Chemical and biological samples were analyzed according to standard limnology procedures (Koenings et al. 1987). Dissolved oxygen (DO) and temperature profiles (taken at 1 m intervals from the surface to 5 m, then at 5-m intervals to 50 m or the bottom at Station A) were recorded at each station using a Yellow Springs Inc. model-57 temperature/DO meter. Water samples for nutrient and general water-quality analysis were taken from depths of 1 m and 50 m at Stations B and C, and 1 m and 25 m at Station A. The 1% incident light level (euphotic zone depth) was measured using an International Light submersible photometer. Zooplankton were collected with a 0.5-m diameter zooplankton net of 153 μm mesh down to 50 m at Stations B and C and at the bottom at Station A (approximately 30 m). Zooplankton from each station were preserved in a 10%-buffered formalin solution for species identification, enumeration, and sizing (Koenings et al. 1987). Two additional zooplankton stations were sampled on each sample trip; one midway between Stations A and B (Station E), and one midway between Stations B and C (Station D), down to 50 m each.

RESULTS AND DISCUSSION

Adult Hatchery Contribution

In 1994, the estimated number (and percentage) of hatchery fish in the total escapement was 9,103 (4.4%), which was lower than the mean for 1984-1993 (Table 1). During 1984-1993, the average number of hatchery fish in the escapement was an estimated 65,451, which represented 26.6% of the average Kasilof River sonar count.

The estimated commercial harvest of Tustumena Lake sockeye salmon was 484,107 in 1994 (Randall Davis, ADF&G, Soldotna, personal communication). Using the hatchery contribution rate of 4.5%, an estimated 21,547 hatchery-produced sockeye salmon were harvested in the commercial fishery (Table 1). In addition, an estimated 586 hatchery-produced sockeye salmon were caught in the personal-use subsistence and sport fisheries in 1994 (Jeff Fox, ADF&G, Soldotna, personal communication). Thus, of the total return of sockeye salmon to Tustumena Lake in 1994, an estimated 31,236 fish were hatchery-produced.

The relatively low return of hatchery-produced sockeye salmon in 1994 in part can be attributed to a lowered stocking level (beginning in 1988); however, apparently other factors are involved. That is, using the historical average fry-to-smolt and smolt-to-adult survivals suggests that from a 6 million fry stocking level, 135,000 adults should be produced. Other factors affecting hatchery adult production include excessive fry transport mortality and/or underestimation of hatchery production. A dramatic decline in the contribution of smolt produced from the fry stocking first occurred in 1990. In the fry transports of 1989 and 1990, the fry appeared to be stressed due to warm ambient water temperature during transport. Thus, the hatchery-produced adults (age 1.3 and age 2.2; the predominant age classes) that returned in 1994 were exposed to stress conditions during the 1990 fry transport. The procedure for estimating hatchery smolt production has been followed since the inception of the smolt monitoring program. Since 1990, hatchery adult production as been based on the contribution percentage of hatchery smolts and the corresponding escapement, harvest. This was different from previous years (1984-1989) when weirs and personnel were in place to observe marked hatchery fish. In addition, this change was initiated because of the change in fry transport technique (starting in 1986) from ground stocking of fry in the creeks to aerial stocking. Aerial stocking increases the chance of weak imprinting to release sites, and has resulted in a decline in hatchery smolt survival (Kyle 1992).

Hydroacoustic/Townet Surveys

An estimated 12.5 ± 2.8 million juvenile sockeye salmon fry were rearing in Tustumena Lake during late September 1994 (Table 2). The highest fish density (153 per 10^3 m^2) was observed near the south shore of transect 7 (Figure 2). Transects 1-3 located in the eastern portion of the lake where there is a major glacial input usually have the lowest fish densities in the fall, and this was the case in 1994 in which fish densities were generally $<$25 per 10^3 m^2.

Townetting in the fall of 1994 resulted in a catch of 394 juvenile sockeye salmon, which comprised 97% of the total catch (Table 3). The percentages of age-0 and age-1 fry were similar in 1994 compared to the 1980-1993 means of 80.2% and 17.8%, respectively (Table 4). Age-0 fish comprised 80.7% of the total number of juvenile sockeye salmon caught, and averaged 64 mm and 2.6 g in size (Table 4). The remaining sockeye salmon juveniles (19.3%) were age-1 fish which averaged 83 mm and 5.5 g in size. The mean size of fry for both age classes were considerably larger than the 1980-1993 mean; however, in previous years (except 1992) the size was based on formalin-preserved fish. Although the 1994 fry size were based on fresh samples compared to formalin-preserved samples used in past years, recent analysis indicates less than 5% difference in length and weight between these 2 types of samples (Pat Shields, ADF&G, Soldotna, personal communication). The larger sizes of both the age-0 and age-1 fry in the fall reflect relatively good summer growing conditions and the likelihood of relatively higher overwinter survival.

Smolt Enumeration and Sampling

In 1994, an estimated 9,139,022 ± 2,088,334 sockeye salmon smolts emigrated Tustumena Lake during 9 May-24 June (Table 5). During the course of the migration 3 peaks occurred; the first peak during 22-25 May, the largest peak during 30 May-4 June when 3.4 million smolts emigrated, and the third peak extending from 7-15 June (Figure 3). Peak emigration timing in 1993 and 1994 were similar when approximately the same number of smolts emigrated, but was approximately one week earlier than the previous 4 years (1989-1992) when the emigrations were smaller (Figure 3). On 1 June 1994 an estimated 97,000 smolts were caught, and based on a 7.3% capture rate the daily emigration was estimated at 1.3 million (Table 5). The 1994 migration consisted of 81% age-1 and 19% age-2 smolts that averaged 72 mm and 2.8 g, and 86 mm and 4.9 g, respectively (Table 6). The mean size of smolts in 1994 were larger than the mean during 1981-1993, and there was a higher percentage (18% higher) of age-1 smolts compared to the mean during 1981-1993 (Table 6). Based on the weekly age compositions, an estimated 7,375,600 of the total 1994 smolt migration comprised age-1 smolts and 1,763,400 comprised age-2 smolts (Table 7). Finally, a total of 363,000 hatchery-produced smolts (4.0% of the total) emigrated Tustumena Lake in 1994, which was similar percentage compared to 1991-1993. In 1994, of the hatchery-produced smolts, the majority (344,000) were age-1 (Table 8).

Limnological Surveys

Eight limnological surveys were conducted on Tustumena Lake during 1994. The first survey was earlier in the season (approximately 2 weeks) than previous years, and the last fall survey was also 2-4 weeks earlier than in previous years. In 1994 the seasonal mean epilimnetic (1 m) concentrations of corrected total phosphorous (CTP) and ammonia were lower at all 3 stations than for the station means during 1980-1993 (Table 9). Total nitrogen (Kjeldahl nitrogen plus nitrate + nitrite) was lower (3-13%) at the 3 stations compared to the 1980-1993 means, but because of lower CTP values in 1994, the atomic ratio of total nitrogen (TN) to CTP was higher (13-23%) than the means at all stations. In addition, seasonal mean chlorophyll *a* concentrations (algal biomass) were similar to the historical averages (1980-1993) for each station; however, peak concentrations were 1.2-1.7 times higher in 1994 and could reflect lower grazing by zooplankton, good environmental conditions (e.g., sunlight and temperature), or a combination of the two. In 1994, weather conditions were relatively mild that resulted in many sunny days. The seasonal mean water temperature was higher, and the date of heat maximum was later (2-3 weeks) than the means for 1980-1993. These conditions were probably responsible for a higher assimilation rate of nutrients such as phosphorus into phytoplankton growth (e.g., peak algal biomass) which provides more food for zooplankton, the primary source of food for juvenile sockeye salmon.

In 1994, the seasonal mean *Diaptomus* biomass was about 3 times higher and the seasonal mean density was about 3.5 times higher for all stations (A, B and C) combined compared to that for 1980-1993 (Table 10). *Cyclops* seasonal mean biomass and density for all 3 stations combined was similar to that for 1980-1993; however, at Station C both biomass and density were proportionately less (about 30%) compared to that for 1980-1993. Seasonal mean *Diaptomus* biomass and density were 2 times and 4 times higher, respectively at station D in 1994 than the 1990-1993 mean. At station E the *Diaptomus* density was 1.5 times higher in 1994 than the 1990-1993 mean. The *Cyclops* biomass and density were both higher 1.5 and 2 times, respectively at station D, and similar at station E than the 1990-1993 means.

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Table 1. Estimated number and percentage of hatchery-produced sockeye salmon in the escapement and total return for Tustumena Lake in 1994, and comparison to the mean for 1984-1993.

	1994	Mean 1984-1993
Kasilof River sonar count (escapement)	204,525	234,057
Estimated number and (%) of hatchery-produced fish in the escapement\a	9,103 4.5%	65,451 26.6%
Estimated commercial fishing exploitation rate\b	69.6%	73.9%
Estimated commercial harvest\b	484,107	732,332
Estimated number of hatchery-produced fish commercially caught\c	21,547	206,286
Estimated number of fish caught in personal-use (dipnet and gillnet) and sport fisheries\b	13,173	20,791
Estimated number of hatchery-produced fish in personal-use fisheries	586	6,022
Estimated number of hatchery-produced fish in the total return	31,236	277,759

\a Hatchery produced fish estimates are from smolt-to-adult return survival rates.
\b Exploitation rate and catch and harvest figures are preliminary.
\c Hatchery-produced fish in commercial harvest is percent hatchery fish in the escapement times the commercial harvest.

Table 2. Densities and population estimates of juvenile fish rearing in Tustumena Lake by transect based on the 21 September 1994 hydroacoustic survey, and comparison to the means for 1981-1993.

Transect	Mean fish density (no./10^3 m^2)	Area ($X\ 10^3\ m^2$) transect	Area ($X\ 10^3\ m^2$) total	Weighted mean fish density (no./10^3 m^2)	Variance	Fish population	Variance
1	3.77	40,168					
2	2.70	37,637	107,270	6.7	3.12E+01	716,141	3.6E+11
3	15.72	29,465					
4	26.16	21,482					
5	33.21	29,566	90,637	36.8	6.26E+01	3,336,813	5.1E+11
6	45.29	39,589					
7	86.12	39,627					
8	67.73	41,553	105,293	80.2	1.07E+02	8,446,092	1.2E+12
9	92.02	24,113					
Total	372.719	303,200			Total	12,499,045	2.05E+12
					95% confidence interval (+/-)	2,808,962	
					Mean 1981-1993	10,525,000	

Table 3. Summary of fish caught in net tows during September of 1994 in Tustumena Lake.

Date	Tow no.	Tow duration (minutes)	Basin	Depth	Sockeye age-0	Sockeye age-1	Sockeye total	Stickleback
26 Sept	1	60	C	Surf	51	16	67	1
26 Sept	2	60	B	Surf	22	4	26	
29 Sept	5	50		Surf	99	22	121	9
				Total	121	26	147	9
26 Sept	3	60	A	Surf	51	5	56	1
26 Sept	4	30		Surf	15	5	20	1
29 Sept	6	60		Surf	80	24	104	
				Total	146	34	180	2
	Total	320		Total	318	76	394	12
				Percent	80.7%	19.3%		
						Percent	97.0%	3.0%

Table 4. Mean size and age composition of juvenile sockeye salmon fry caught in net tows by basin during 1994 in Tustumena Lake, and comparison to the mean for 1980-1993.

	Age-0						Age-1					
Basin	Sample size	Age comp. %	Mean length (mm)	S.D.	Mean weight (g)	S.D.	Sample size	Age comp. %	Mean length (mm)	S.D.	Mean weight (g)	S.D
A	146	81.1%	65	4.78	2.5	0.56	34	18.9%	84	3.17	5.4	0.47
B	121	82.3%	64	5.36	2.5	0.59	26	17.7%	82	2.41	5.4	0.57
C	51	76.1%	64	4.48	2.7	0.53	16	23.9%	81	2.93	5.6	0.51
Total	318						76					
Mean 1994		80.7%	64	5.02	2.6	0.57		19.3%	83	3.03	5.5	0.52
Mean 1980-1993		82.2%	56		2.0			17.8%	76		4.9	

Table 5. Daily and seasonal population estimates of sockeye salmon smolts emigrating Tustumena Lake, 1994.

Date	No. Rel.	No. Recov.	Unmarked Fish Caught (1000s)	Est. Migration	95% Conf. Int. lower	95% Conf. Int. upper
10-May	902	74	0.784	9,675	7,492	11,857
11-May	902	74	1.593	19,658	15,322	23,994
12-May	902	74	0.918	11,328	8,789	13,868
13-May	902	74	1.959	24,175	18,865	29,485
14-May	902	74	1.082	13,352	10,376	16,328
15-May	902	74	1.716	21,176	16,513	25,840
16-May	950	104	1.894	17,449	14,226	20,672
17-May	950	104	1.580	14,556	11,854	17,259
18-May	950	104	1.798	14,556	11,854	17,259
19-May	950	104	1.686	15,533	12,655	18,411
20-May	950	104	2.771	25,529	20,853	30,205
21-May	950	104	7.731	71,224	58,330	84,118
22-May	950	104	32.392	298,422	244,671	352,173
23-May	889	58	44.299	689,940	520,879	859,001
24-May	889	58	22.422	349,214	263,589	434,839
25-May	889	58	28.378	441,976	333,636	550,317
26-May	889	58	7.465	116,264	87,684	144,845
27-May	889	58	2.230	34,731	26,117	43,346
28-May	889	58	2.045	31,850	23,941	39,759
29-May	889	58	6.170	96,095	72,453	119,737
30-May	891	66	9.454	129,420	99,687	159,152
31-May	891	66	40.684	556,939	429,330	684,548
01-Jun	891	66	96.979	1,327,584	1,023,543	1,631,624
02-Jun	891	66	40.310	551,819	425,383	678,256
03-Jun	891	66	36.957	505,919	389,990	621,847
04-Jun	891	66	21.895	299,729	231,006	368,453
05-Jun	891	66	7.076	96,866	74,586	119,146
06-Jun	884	75	8.779	104,738	82,239	127,236
07-Jun	884	75	20.128	240,137	188,677	291,597
08-Jun	884	75	26.255	313,235	246,139	380,331
09-Jun	884	75	46.369	553,205	434,780	671,630
10-Jun	884	75	31.544	376,335	295,742	456,928
11-Jun	884	75	21.636	258,128	202,819	313,437
12-Jun	884	75	22.007	262,554	206,299	318,810
13-Jun	899	57	11.302	181,183	136,285	226,081
14-Jun	899	57	16.684	267,463	201,238	333,687
15-Jun	899	57	20.837	334,040	251,358	416,721
16-Jun	899	57	11.775	188,766	141,994	235,538
17-Jun	899	57	3.300	52,903	39,714	66,092
18-Jun	899	57	0.833	13,354	9,942	16,766
19-Jun	899	57	0.849	13,610	10,135	17,086
20-Jun	900	67	3.901	53,125	40,951	65,300
21-Jun	900	67	3.579	48,740	37,562	59,919
22-Jun	900	67	2.790	37,995	29,259	46,732
23-Jun	900	67	1.817	24,745	19,019	30,470
24-Jun	900	67	2.187	29,783	22,913	36,654
Totals	6,315	501	680.84	9,139,022	7,050,688	11,227,356

Table 6. Size and age of Tustumena Lake sockeye salmon smolts by sample period, 1994.

Sample period	Sample size	Age class	Percent comp.	Mean length (mm)	S.D.	Mean weight (g)	S.D.
10 - 15 May	127	1	85%	72.0	3.68	2.9	0.45
	23	2	15%	86.5	3.19	4.9	0.61
16 - 22 May	126	1	84%	75.0	3.98	2.9	0.45
	24	2	16%	87.5	4.00	4.8	0.66
23 - 29 May	133	1	89%	71.5	3.22	2.7	0.41
	17	2	11%	86.0	4.03	4.7	0.70
30 May - 05 Jun	123	1	82%	72.0	3.49	2.8	0.44
	27	2	18%	86.0	4.02	4.9	0.72
06 - 12 Jun	70	1	70%	75.0	4.15	2.7	0.45
	30	2	30%	85.0	3.54	4.9	0.53
13 - 19 Jun	84	1	84%	69.5	3.58	2.8	0.45
	16	2	16%	93.0	4.96	5.1	0.91
20 -26 Jun	74	1	74%	75.5	3.59	3.2	0.47
	26	2	26%	88.0	4.83	5.2	0.85
Weighted mean (1994)	737	1	81%	72.4	3.60	2.8	0.44
	163	2	19%	86.4	3.95	4.9	0.67
Mean (1980-1993)		1	63%	69.0		2.7	
		2	36%	82.7		4.5	

Table 7. Population estimate (in thousands) of sockeye salmon smolts emigrating Tustumena Lake by age and sample period, 1994.

		Age-1			Age-2		
Sample period		Migration Estimate	95% Conf. Interval		Migration Estimate	95% Conf. Interval	
10-May	15-May	84.1	74.8	93.5	15.2	5.9	24.6
16-May	22-May	384.1	332.1	436.1	73.2	21.1	125.2
23-May	29-May	1560.6	1348.6	1772.6	199.5	-12.5	411.5
30-May	05-Jun	2844.0	2486.6	3201.4	624.3	266.9	981.7
06-Jun	12-Jun	1475.8	1290.1	1661.6	632.5	446.8	818.2
13-Jun	19-Jun	883.1	760.3	1005.9	168.2	45.4	291.0
20-Jun	26-Jun	143.8	124.1	163.6	50.5	30.8	70.3
	Total	7375.6	6900.8	7850.4	1763.4	1288.6	2238.2
	Percent	80.7%			19.3%		

Table 8. Estimated number of hatchery-produced sockeye salmon smolts emigrating Tustumena Lake, 1994.

Release Location	Year released	Number released (1000s) \a	Number marked (1000s)	Mark type \b	Number of marks recovered	Est. no. hatchery smolts (1000s)
		Age 2				
Bear Creek	1992	162.0	162.0	RV	4	19
Bear Creek	1992	5,900.0				
Subtotal		6,062.0	162.0			
		Age 1				
Bear Creek	1993	161.5	161.5	RV	80	344
Bear Creek	1993	5,839.0	5839.0			
Subtotal		6,000.5	6000.5			
Grand total		12,062.5	6,162.5			363

\a All fry were aerial-dropped.
\b RV = right ventral.

Table 9. Limnological characteristics within the epilimnion (1 m) of Tustumena Lake during 1994, and comparison to the means for 1980-1993.

Parameter	Station A		Station B		Station C	
	1994	Mean 1980-93	1994	Mean 1980-93	1994	Mean 1980-93
Turbidity (NTU)	40	39	43	41	41	41
Seasonal mean water temp. (C)	10.5	8.9	8.9	8.4	7.8	7.2
Date of 1 m water at 4 C	5/11	5/19	5/20	5/28	5/26	6/6
Date of heat max. (C)	8/18	7/30	8/18	7/23	8/18	7/25
Euphotic zone depth (m)	1.6	1.3	1.4	1.3	1.4	1.2
Total phosphorus (μg/L)	32.7	45.4	35.0	47.7	37.2	48.4
NTP (μg/L) \a	22.3	31.0	23.8	32.6	25.4	33.1
CTP (μg/L) \b	6.2	8.4	6.6	8.8	7.0	8.9
Total nitrogen (μg/L)	149	153	136	156	149	153
Total Kjeldahl nitrogen (μg/L)	64.1	60.0	57.6	59.9	54.8	54.0
Ammonia (μg/L) \c	1.7	4.3	1.7	3.4	1.7	3.2
Nitrate + Nitrite (μg/L)	84.5	92.9	78.6	95.8	94.0	99.1
Atomic ratio (TN:CTP)	52.7	40.8	45.5	39.8	46.9	38.5
Silicon (μg/L)	2,294	2,311	2,163	2,247	2,131	2,258
Alkalinity (mg/L $CaCO_3$)	13	14	13	14	13	14
pH units	6.8	7.0	6.8	6.9	6.7	6.9
Chlorophyll *a* (seasonal mean)	0.59	0.55	0.48	0.45	0.45	0.38
Chlorophyll *a* (seasonal peak)	1.52	1.24	1.82	1.06	1.60	1.21

\a Total phosphorus corrected for turbidity (NTP) = -0.224 + 0.688 TP (ug/L).
\b Total phosphorus corrected for turbidity and inorganic particulate phosphorus (CTP) = 0.0701 + 0.249 NTP.
\c Detection limit for ammonia is 1.7; a value of 1.7 is entered to compute means.

Table 10. Summary of zooplankton seasonal mean density (no./m^2) and biomass (mg/m^2) within Tustumena Lake during 1994, and comparison to historical means.

Taxa	Station A		Station B		Station C		Station D		Station E	
	1994	Mean 1980-93	1994	Mean 1980-93	1994	Mean 1980-93	1994	Mean 1990-93	1994	Mean 1990-93
Diaptomus density	29,012	7,542	12,980	8,512	33,404	5,619	40,138	10,096	11,356	8,081
Cyclops density	30,256	32,962	31,224	34,426	26,240	37,780	57,325	44,739	37,831	37,646
Diaptomus biomass	116	38	45	32	112	25	112	57	46	43
Cyclops biomass	86	81	79	78	67	89	172	96	110	93

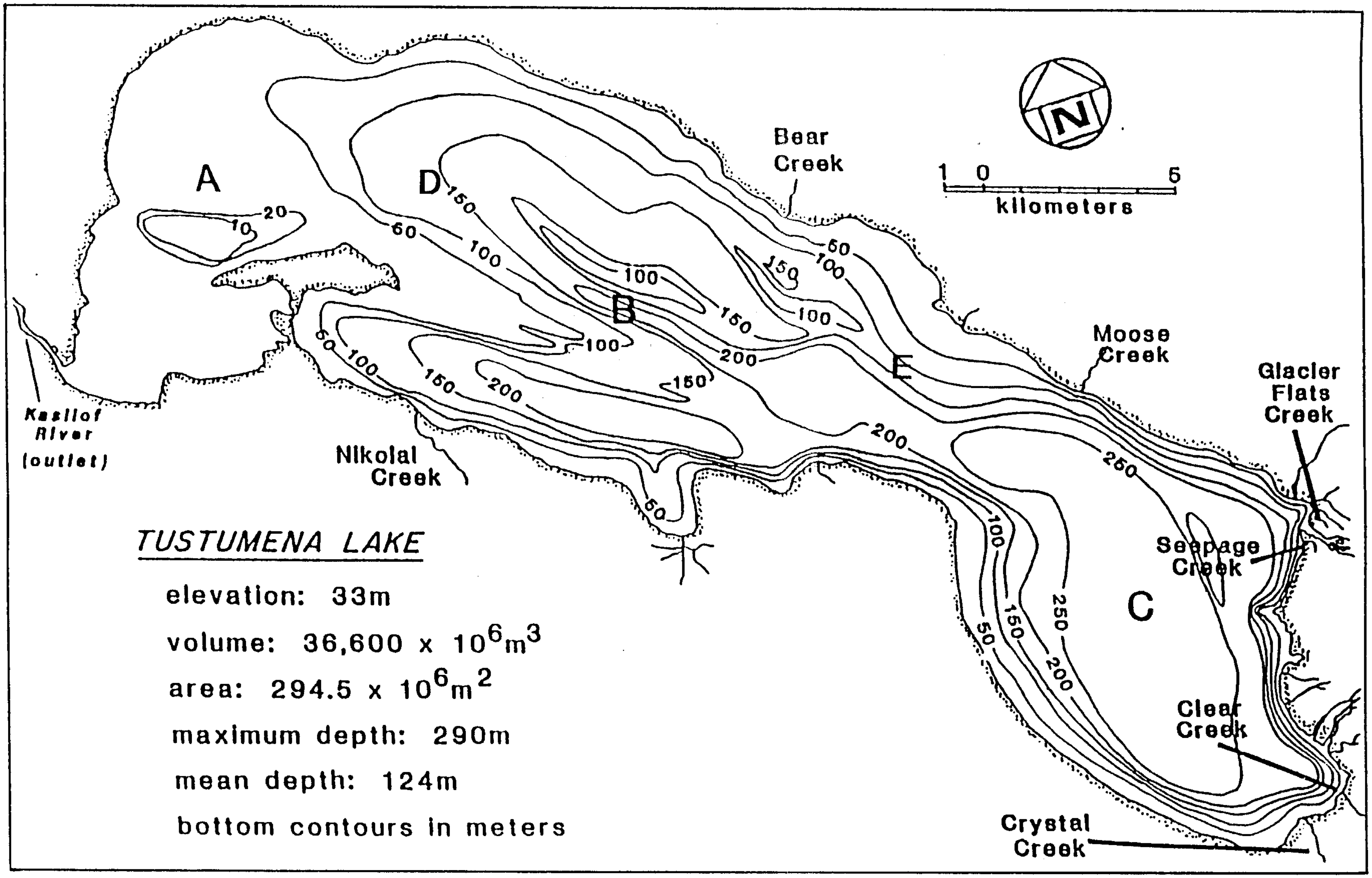

Figure 1. Morphometric map of Tustumena Lake showing the location of limnological sample stations, and the seven major salmon-producing tributaries.

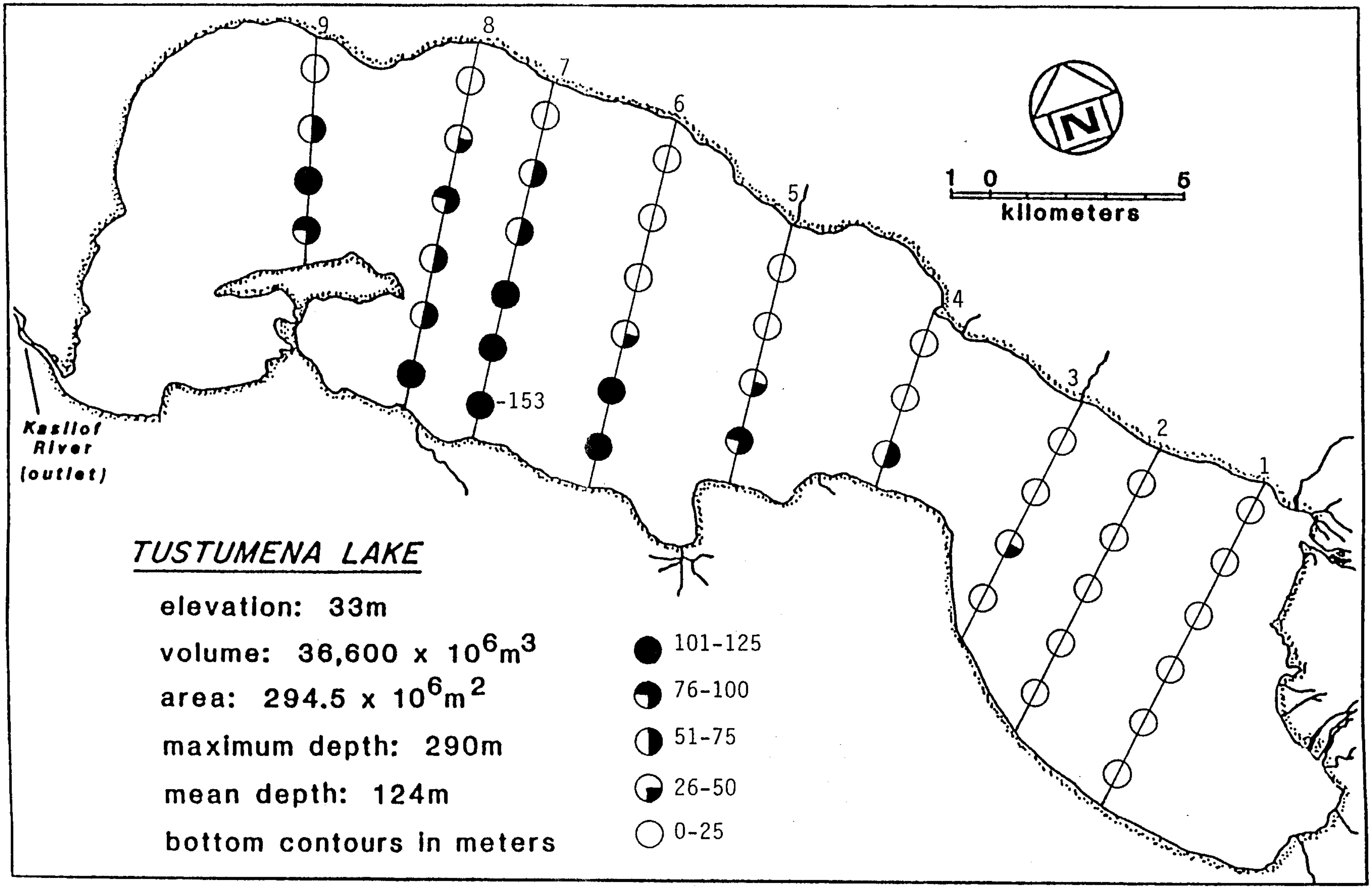

Figure 2. Map of Tustumena Lake showing the 9 transects used during the 1994 hydroacoustic surveys, and the distribution of juvenile sockeye salmon density (no./1000 m^2) for the 21 September 1994 hydroacoustic survey.

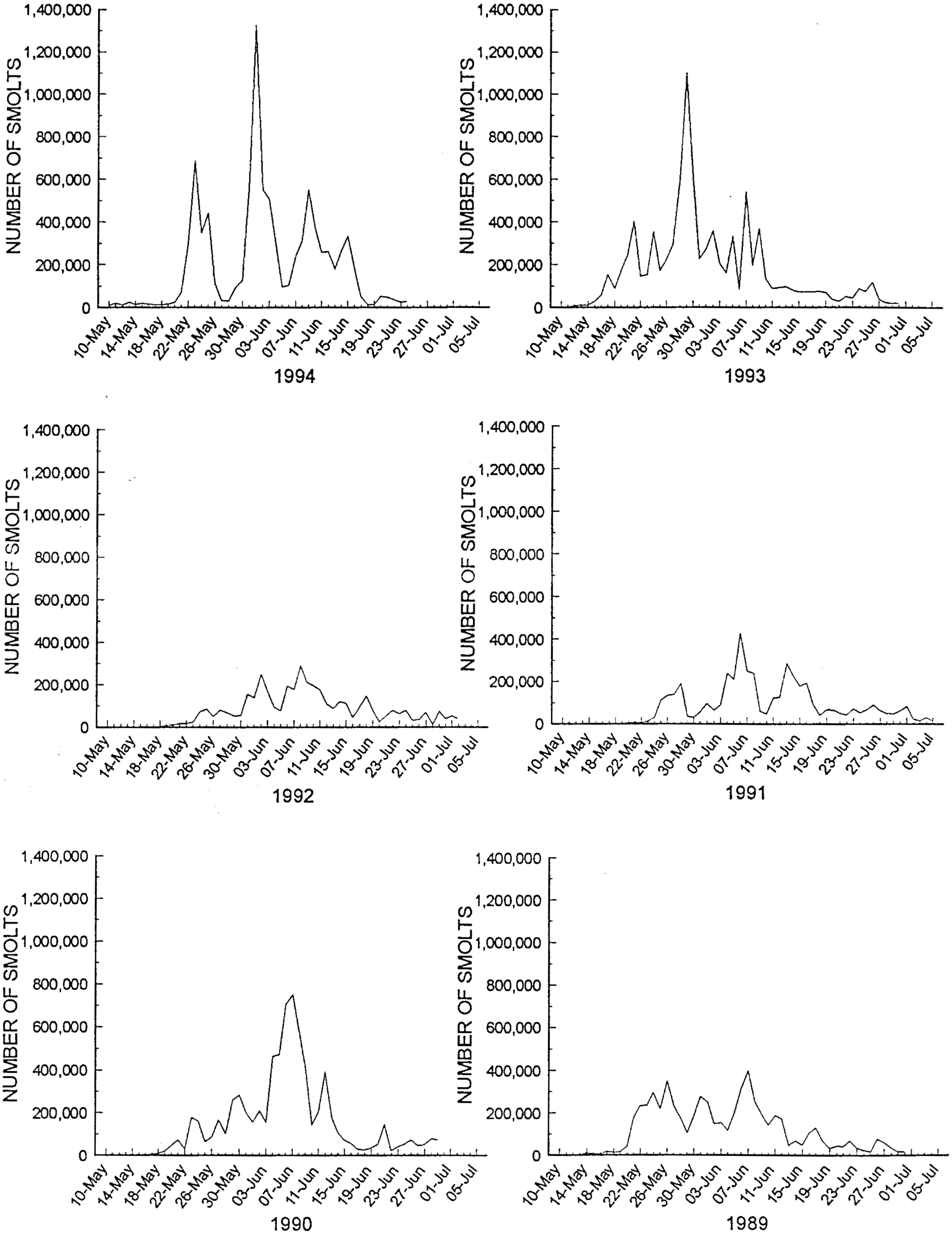

Figure 3. Migration timing for sockeye salmon smolts emigrating Tustumena Lake in 1994, and comparison through 1989.