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SUSITNA RIVER SOCKEYE SALMON FRY STUDIES, 1994 AND 1995

Bruce E. King

and

Stanley C. Walker

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AUTHORS

Bruce E. King is a Research Project Leader for the Alaska Department of Fish and Game, Sport Fish Division, Region II, Upper Cook Inlet, 34828 Kalifornsky Beach Road Suite B, Soldotna, AK 99669.

Stanley C. Walker is an FWTIII for the Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, 34828 Kalifornsky Beach Road Suite B, Soldotna Alaska.

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ABSTRACT

Studies were conducted in 1994 and 1995 on Susitna River drainage lakes that contained rearing sockeye salmon fry (*Oncorhynchus nerka*). Data reported includes acoustic estimates of pelagic zone fish populations, and species composition and morphological characteristics of the enumerated fish. Sticklebacks (*Gasterosteus sp*) were the predominant species in four of the sampled lakes. Pelagic fish were present in densities ranging from 0.0383 to 1.6450 per m^2 of lake surface area, and ranged in mean length from 27 to 85 mm. Sockeye salmon fry ranged in mean length from 37 to 85 mm. Sticklebacks and sockeye salmon fry could not be separated acoustically using target strength. There were also inconsistencies in the results from tow netting, as conducted in this study, with regard to the reliability of apportioning acoustic targets to species. The two predominantly sockeye salmon fry rearing lakes, Judd and Chelatna, experienced declines in fry size with concomitant increases in population size. The 1995 sockeye salmon fry size in Judd Lake remained low after a 75% reduction of fish numbers from the previous year.

Key words: Sockeye salmon fry, *Oncorhynchus nerka*, acoustic estimates, tow netting, stickleback, *Gasterosteus sp*

INTRODUCTION

The Susitna River watershed comprises 49,210 km^2, and originates in the mountains of the Alaska Range about 145 km south of Fairbanks. It flows southwesterly from the Alaska Range for approximately 400 km before entering upper Cook Inlet west of Anchorage (Figure 1). There are three major tributaries within the drainage, and numerous sockeye salmon nursery lakes (Figure 2). The largest tributaries are the Yentna, Chulitna and Talkeetna Rivers. Most of the sockeye salmon (*Oncorhynchus nerka*) production within the Talkeetna drainage is thought to come from Larson and Stephan Lakes (Table 1). Numerous small lakes contribute to sockeye salmon production in the Chulitna drainage, and Byers Lake is thought to have the greatest potential. The Yentna drainage has at least 12 lakes known to support sockeye salmon, of which four, Chelatna, Shell, Hewitt, and Judd, are thought to have the majority of the production potential. The lower main-stem of the Susitna River contains six primary lakes supporting sockeye salmon. Sockeye salmon spawning and rearing were also documented in side sloughs and the main-stem of the Susitna River (Thompson et al. 1986).

Numerous salmon investigations were previously conducted in the drainage, but much of the work was limited in scope and duration. Various lakes within the drainage were visited sporadically in the 1950's and 1960's by United States Fish and Wildlife Service (USFWS) and Alaska Department of Fish and Game (ADF&G) personnel to collect salmonid juvenile and adult data, and lake limnology information. These early data were the result of short site visits during which gillnets, seines, and other equipment were used to sample juveniles. Adult spawner counts were primarily the product of aerial surveys. These data were unpublished, and are currently archived in the ADF&G Soldotna office.

Beginning in the 1970's, attempts were made to monitor the sockeye salmon escapement entering selected tributaries, and to estimate total escapement into the Susitna drainage. Escapement into the Talachulitna River was monitored using counting towers near the confluence of the Talachulitna and Skwentna Rivers from 1972 to 1974 (Barrett 1975). A fish wheel was used in conjunction with the counting tower in 1973 and 1974 to obtain age, weight and length (AWL) information. Salmon escapement into the Fish Lakes system of the Yentna drainage was also enumerated in 1974 by means of a weir installed in Quig Creek above Lower Fish Lake (Barrett 1975). The Susitna River mark-and-recapture population estimate conducted in 1974 and 1975 was part of an effort to estimate juvenile and adult anadromous fish populations in the upper Susitna between Devil's Canyon and the confluence of the Susitna and Chulitna Rivers. These studies were part of the pre-authorization investigation for the proposed Susitna Hydroelectric Project (Barrett 1974, Friese 1975). Sockeye and chum salmon were tagged in the vicinity of river mile 26, near the site of the old town of Susitna Station. Tag recovery fish wheels were operated at the confluence of the Talachulitna and Skwentna Rivers, on the Yentna River one mile above the Lake Creek confluence, and at a site on the Susitna River approximately 8 km upstream of the town of Talkeetna. A tagging program was also conducted the same summers in the upper reaches of the Susitna River between the Chulitna River confluence and Portage Creek. The results of these studies indicated that the majority of sockeye salmon in the Susitna basin were produced in the Yentna and Skwentna drainages (Namtvedt et al. 1978).

Escapement into Shell Creek was enumerated by ADF&G using a weir from 1973 to 1975 (Barrett 1973, 1975 and Friese 1978). The weir also provided a recapture location for fish tagged as part of the Susitna Hydroelectric Project. Later studies of Shell Lake conducted by Cook Inlet Aquaculture Association (CIAA) consisted of adult escapement and smolt enumeration in 1987, and escapement counts which occurred in conjunction with beaver dam modification activities along the outlet stream starting in the summer of 1983 (Marcuson 1987b).

Anadromous and resident fish populations of the mainstem Susitna River were investigated from 1981 to 1985 as part of the Environmental Impact Assessment (EIA) for a revised Susitna Hydroelectric project. Salmon escapement reports produced as part of the EIA, and all known historical escapement data dating from 1951, were summarized by Hoffman and Crawford (1986).

The smolt migration from Larson Lake, a tributary of the Talkeetna River, was enumerated in 1982 by ADF&G, and again in 1984 by the CIAA. These data were part of a five year lake enrichment program which also included adult sockeye salmon enumeration (Marcuson 1984, 1985, 1986, 1987a, 1988).

The use of acoustic equipment to monitor salmon escapement began with an unsuccessful attempt in the mid- 1970's by ADF&G to enumerate adults returning to the Lake Creek-Chelatna Lake drainage (Namtvedt et al 1978). Chelatna Lake was also investigated by CIAA, in cooperation with ADF&G, between 1983 and 1988 as a candidate for enhancement by nutrient enrichment (Fandrei 1994). The initial investigations suggested that the lake could produce more adult sockeye salmon without enrichment. The final enhancement plan was revised to include fry stocking, and continuation of studies to define the factors limiting adult production. The program for 1988 consisted of limnological surveys and adult enumeration. From 1989 to the present, the program included limnological surveys, smolt and adult enumeration, spawning area identification and stocking of up to two million fry. The numbers of fry released in 1994 and 1995 were 1,330,000 and 1.81 million respectively (Fandrei 1994 and pers comm). All fry in each year were thermally banded to determine their contribution to the smolt migration and adult return.

CIAA also investigated Judd and Hewitt Lakes as potential brood stock for Chelatna Lake. These investigations included the installation of weirs to enumerate adult spawning populations (Schollenberger 1989). The Judd Lake weir was abandoned after 1989 when bacterial kidney disease (BKD) was detected in the sockeye salmon population (Schollenberger 1989). Adult sockeye salmon escapement enumeration at Hewitt Lake was discontinued after the 1990 season because escapement to Chelatna Lake reached levels sufficient to meet egg collection goals (Schollenberger 1991).

Adult salmon escapements into the Susitna River were monitored at Susitna Station (mile 26) from 1976 to 1980. An average of 216,000 sockeye salmon (range of 94,000 to 340,000) was counted annually at the site (Davis and King 1996). Changes in the Susitna River bottom characteristics at that sonar location precluded continuation of the project after 1980. Because no other site suitable for the existing counting equipment was found in the mainstem, the project was moved to the Yentna River, the largest tributary in the Susitna River drainage.

From 1985 to the present, the Yentna River daily sonar counts have been used as an indicator of the sockeye salmon escapement into the Susitna River drainage. These counts are also used to manage the Upper Cook Inlet drift and set net fisheries. The average Yentna River sockeye salmon escapement from 1986-1995 was 101,000 (Davis and King 1996). The peak escapement of 141,700 occurred in 1993, and the lowest escapement (52,300) occurred in 1988. The sockeye salmon escapement bound for the Yentna River was thought to be approximately 50% of the total Susitna River sockeye salmon escapement based on data collected during the Susitna Hydroelectric Project, and ongoing stock separation studies (D. Waltemeyer, pers. comm., ADF&G, Soldotna AK).

Tarbox and Kyle (1989) estimated the sockeye salmon production potential within the Susitna River drainage based on preliminary measurements of euphotic volume of twenty-four lakes known to rear sockeye salmon. Their preliminary analysis indicated that lakes in the Chulitna region have the smallest cumulative lake surface area and the lowest amount of adult production potential (Table 1). Conversely, lakes in the Yentna region have the largest cumulative lake surface area and the highest amount of adult production potential. The majority of the production potential in the Yentna region was attributed to Chelatna Lake. They also suggested that the historical average sockeye salmon production from the drainage was similar to the sum of the individual euphotic volume production estimates from the 24 lakes. However, examination of historical spawner estimates indicated that there were some lakes in which escapements were considerably less than that arrived at by calculating the euphotic volume.

In early 1993, ADF&G received $150,000 in Capital Improvement Project (CIP) funding to study sockeye salmon production in the Susitna River drainage. This funding was intended to finance the initial year of a five-year study to determine if the current sockeye salmon escapement goal for the Susitna River was providing maximum sustained yield.

The goal of the first year of the study was to evaluate fish population and lake limnological parameters in nine major sockeye salmon nursery lakes (Kyle et al. 1994). These lakes were selected based on geographic location and production potential, and range in elevation from 37 to 560 m, and in size from 325 to 2,740 acres (Appendix A). Weir sites for adult and smolt enumeration were also identified at each lake.

No additional funds were allocated to this project after 1993, so the remaining funds were used in 1994 and 1995 to continue acoustic and townet studies on selected lakes. Because the parent year escapement of the age-0. fry populations examined in 1993 was the third lowest and 1994 the highest in the history of the Yentna River sonar project, the range of contributing spawning escapements provided an opportunity to evaluate key lakes at potentially minimum and maximum spawner contributions. We therefore repeated the acoustic surveys and townetting on several lakes in 1994 to document the results of these diverse escapements on sockeye salmon fry production. Sampling at Byers Lake was discontinued because it had the lowest potential productivity of the lakes examined in 1993. Redshirt Lake, which had marginal salmonid production in 1993 and an advanced invasion of pike, was also not sampled a second year. Stephan Lake, which was not sampled in 1993 due to inclement weather, was included in 1994.

In 1995, remaining CIP funds were used to continue acoustic and townet sampling of Chelatna, Judd and Hewitt Lakes. Chelatna Lake was continued because it had the largest euphotic volume of the Susitna drainage lakes, and in combination with ongoing limnological work and adult enumeration programs, provided a complement of the projects necessary for base level analysis of carrying capacity. Judd Lake was included because it was the most productive lake in the drainage, and the sockeye salmon fry population was relatively free of competition from other species. Hewitt Lake was selected because of good sockeye salmon fry production in a multi-species competitive situation.

The objectives of the project in 1994 and 1995 were to:

1) Estimate the numbers by species of fish inhabiting the pelagic zone of each lake. In 1995, this included estimation of the density of fish in the top 3 m of the water column;
2) Collect age-weight-length (AWL) data from sockeye salmon fry;
3) In 1995 only, examine the difference in fish species and size using two different trawls;
4) Compare target strength data to length data to determine the possibility of separating species using target strength only.

METHODS

Acoustic Surveys

Acoustic surveys were conducted between late August and early October each year. A survey consisted of recording data along transects perpendicular to the longitudinal axis of the lake. Each lake was divided into equidistant transects, with the interval between calculated to provide approximately 20 transects. Interval distances at Judd Lake were considered short enough that only 10 transects were necessary. Recording of acoustic data began 30 minutes after sunset.

A *BioSonics*[1] model-105 echosounder system with a 6/15° dual-beam transducer was used for the surveys. Returning voltages were recorded using a *Sony* digital audio tape (DAT) recording system, and a *BioSonics* model-115 chart recorder. The pulse width was set at 0.4 ms and the pulse repetition rate at 5 pulses sec^{-1}. The surveys were conducted using a 5 m raft powered by a 15 hp outboard motor. The transducer was deployed 1 m below the lake surface, and speed along the transect was approximately 2 m sec^{-1}.

No estimates of the near surface component of the population were made in 1993 and 1994 because the transducer was deployed downward and towed at a depth of approximately 1 m. Data collected in the 1-2 m immediately below the transducer were not processed because of uncertainty of results in the near-field (Urick 1983). Down- and side-looking transects were run on each of the lakes surveyed in 1995. The side-looking surveys in Hewitt and Chelatna lakes consisted of two transects parallel to the longitudinal axis of the lake. Because of the small size and circular shape

[1] Use of a company's name does not constitute product endorsement

of Judd Lake, the side-looking survey was run in three slightly curved transects, with the transducer looking toward the middle of the lake. These data were used to estimate fish density in the upper 3 m of water column.

The side-looking transducer was deployed on an aluminum frame mounted on the side of the raft at a depth of approximately 2 m. The mount was adjustable around its vertical axis for aiming with respect to direction of boat travel. It was also adjustable for tilt with regard to the vertical axis. The ability to adjust tilt allowed adjustment of the distance at which the sonar beam intersected the water surface. Aiming was checked by deploying a target 2 m below the surface and collecting returning echoes from various ranges out to approximately 75 m. Equipment settings and data recording methods were the same as those used for down-looking data collection.

Analysis of the recorded data from the down-looking surveys was conducted by Dr. Richard Thorne of *BioSonics, Inc.*, under a State of Alaska contract. Fish densities were low enough in most surveys to employ echo-counting techniques (Thorne 1983) for the population estimates. This method used by-stratum sample volumes estimated by the duration-in-beam technique (Nunnallee and Mathisen 1972; Nunnallee 1980; Thorne 1988). Resultant fish densities were determined for each depth interval along thirds of each transect. Fish densities (no. m^{-3}) for each depth interval were summed to determine the total area fish density (no. m^{-2}) for each one-third transect. The total population estimate was obtained by multiplying the area representing each one-third transect by the mean transect fish density, and summing all transect population estimates. Population estimates of Hewitt, Judd and Larson Lakes in 1994, and Hewitt and Judd Lakes in 1995, were derived using a combination of echo integration and echo counting. This modification was necessary because of high target densities encountered in portions of these lakes. Equipment calibration information and data collection parameters are listed in Appendix B.

Analysis of tapes from the 1995 side-looking surveys used the *BioSonics* ESP target strength and integration software. Dual-beam data recorded on tape were processed through a *BioSonics, Inc.* Model 281 Echo Signal Processor (ESP). A returning echo was accepted as a valid target if the amplitude was below a minimum bottom threshold of 7- 9,000 mV and above the counting threshold of 100 mV. Single targets were separated from multiple targets if the pulse width was within 20% of the transmitted pulse width at -6 dB and -18 dB. The maximum half-angle selected for data processing was 4^0. Data were stratified in 1 m increments for analysis starting 2 m in front of the transducer. The manufacturers' target strength processing program entitled ESPTS was then used to compute the mean target strength and average backscattering cross section for each 1-m depth interval. These computations were made using individual echoes which met the single target criteria. Estimates of fish density were made for each transect by echo integration using the *BioSonics, Inc.* ESP Model 221 echo integrator. Correction from the 40 log(R) setting used during data collection to the 20 log(R) used for data processing was accomplished by adjusting the B constant value for each depth stratum. Equipment calibration information and parameters for data collection and analysis are listed in Appendix B.

The echo integrator compiled data in one minute sequences along each transect and sent outputs to computer files for further reduction using the manufacturers' echo integration post-processing program entitled ESPCRNCH. We then calculated the distance at which the effective beam intersected the lake surface, using mean target strengths and the angle above or below the horizontal at which the transducer was aimed. A density estimate for the near surface component was then selected from the echo integration output using the 1 m stratum with the largest sample volume which occurred prior to the effective beam width intersection with the surface. The chosen density estimate was expanded by the lake surface area and 3 m depth interval to estimate the number of fish in the near-surface waters. The number of fish in the near surface stratum was added to the number estimated by the down-looking survey to arrive at a total population estimate for the lake.

Larson Lake 1993 and 1994, and Hewitt Lake 1994 and 1995 target strength frequency distributions and length frequency distributions of sockeye salmon fry and stickleback (*Gasterosteus sp.*) were compared to assess whether these species could be separated based on a bimodal distribution of target strengths. All data for comparing target strengths were collected using a 100- 150 mV threshold since it was necessary to use processing thresholds which were as low as possible, but still provided a minimum signal-to-noise ratio of three to one. We examined the resulting target strength distributions to determine if truncation of small targets resulted. Before making the comparison of length frequencies of sockeye salmon fry and sticklebacks, each species' contribution to the total population estimate was weighted by using their proportions in the tow net catches. Histograms of the target strengths measured for each of these lake surveys were compared to those of lengths to look for bimodal distribution.

Townet Studies

Townetting was conducted in conjunction with the acoustic surveys to determine species of acoustically-counted fish, and to measure age and size of juvenile sockeye salmon and sticklebacks. The net used was a midwater trawl with a mouth opening of 4 m by 2 m, and a length of 10 m. Mesh size decreased from 7.6 cm at the mouth to 0.3 cm at the cod end. The trawl was towed between two 5 m rafts at approximately 1-2 m sec^{-1}, and the tows ranged from near surface to 15 m deep. A minimum of 3 tows of at least 30-min. duration was conducted in each lake. All captured fish were identified and enumerated at the end of each tow. All sockeye salmon fry and a representative sample of other fish species were preserved in a 10% buffered formalin solution. The minimum sample size for each lake was 300 sockeye salmon fry. Fork length (nearest 1 mm), weight (nearest 0.1 g), and scales (for age determination) were collected from a random sample of sockeye salmon fry after 15 days in preservative. Lengths were also measured from a minimum of 100 fish of other species captured in each lake.

The predominance of age-0. sockeye salmon fry, and their small size in 1993 and 1994 townet catches, raised the possibility that the townet sampling was biased toward younger, smaller fish. We reviewed adult and juvenile age-class data for lakes surveyed in this project to look for differences that might indicate townet bias. Sampling of adult sockeye salmon at Hewitt Lake by CIAA in 1990 found that 20% of the returning adults for that year had out-migrated as age-2. smolt (Schollenberger 1991). An ADF&G genetics project in 1992 found 72% of the sampled adults had left Hewitt Lake as age-2. smolt (Davis and King 1992). The CIAA investigation of Judd Lake in 1989 found 19% of the adults had smolted at age-2., and genetic sampling in 1992 found 70% of the adults sampled had left as age-2. smolt (Schollenberger 1989). For the years 1984 through 1988, age-1. smolt constituted 90% or more of the migration from Larson Lake in four of the five years. In the remaining year (1984) age-2. and age-3. smolt comprised 94% of the migration (Marcuson 1985-1988). Genetic sampling in 1992 found 25% of the adults sampled had smolted at age 2. (Davis and King 1992). Age-0. and age-1. smolt comprised 99% or more of the migration from Chelatna Lake for the years 1989 through 1995 (Fandrei 1994 and pers comm.). Adults that had smolted as age-2. juveniles made up approximately 3% of the return to Chelatna in 1994 and 5% in 1995 (Fandrei 1994 and pers comm.). Genetic sampling in 1992 found 33% of the adults sampled had smolted as age-2. (Davis and King 1992). In 1987, 86% of the smolt enumerated in Shell Creek were age-1., 11% were age-2. and 3% were age-3. (Marcuson 1987). Adult returns from 1973 through 1975 were from 86% to 99% fish that had smolted at age-1. (Friese 1978). In 1986, 78% of the adult return was from age-1. smolt and 22% from age-2. (Marcuson 1987). The 1992 genetic sample from Shell Lake was 67% adults from age-1. and 33% from age-2. smolt (Davis and King 1992). The historical investigations revealed a variety of age classes in some years.

We also observed a bias in tow net results in similar studies of Russian River salmon production (King et al. in press). We therefore attempted to evaluate net selectivity by collecting additional samples from each lake surveyed in 1995 using a larger mid-water trawl. The large trawl dimensions were a 6.1 m by 3.1 m opening, 15 m long, with the same gradation of mesh size from mouth to cod end as that of the small (4x2 m) trawl. Deployment and operation of both trawls was identical. A minimum of one 30 minute tow was made on each lake with a target sample size of 300 sockeye salmon fry. Time permitting, additional tows were made if minimum sample size was not met.

Length frequencies of the catch from the two mid water trawls were compared using the student's t-test to determine if there was a significant ($P=0.05$) difference in mean lengths of the sockeye salmon fry. Data were analyzed by age class using formulas for both equal and unequal variance. Criteria from (Zar 1984) were used to determine the appropriate formula for each sample tested. Species and age class proportions from the small trawl catches were applied to the total acoustic targets to arrive at the sockeye salmon fry population estimates in all lakes for all years.

RESULTS

1993

Results of the 1993 studies were reported by Kyle et al. (1994). For this report, raw acoustic data from Larson Lake were initially reprocessed to calculate target strength using a 300 mV (-68 dB), threshold. The resulting mean target strength was –58 dB (Table 2). The target strength frequency distribution indicated a substantial reduction in the number of echoes smaller than -67 dB. Since this may have reflected a loss of targets due to the processing threshold, we repeated the procedure using a 100 mV (-77 dB) threshold. The second run resulted in a mean target strength of –59 dB and a similar precipitous drop-off in numbers of echoes at -67 dB. However, since the smallest target strengths were 10 dB larger than the threshold, we concluded that the collected data adequately represented the size of the smallest fish available to the acoustic gear. The resulting target strength frequency distribution was only slightly bimodal (Figure 3).

Townetting in Larson Lake resulted in a catch of 267 sockeye salmon fry (Kyle et al. 1994; Table 3). The predominant age class of sockeye salmon fry was age-0. (Table 4), with a mean length of 55 mm. The only other fish captured by the townet were sticklebacks, with lengths which ranged from 17 to 49 mm, and averaged 28 mm. Mean length of the sockeye fry sampled was approximately double that of stickleback, and there was a bimodal distribution of length frequencies.

1994

The total number of fish detected by the acoustic gear ranged from 163,479 in Stephan Lake to 3,871,308 in Hewitt Lake (Table 5). Fish density per stratum was highest in Hewitt Lake (0.1693 fish m^{-3}) and lowest in Stephan Lake (0.0057 fish m^{-3}). Sockeye salmon fry density per stratum was highest in Judd (0.0880 fry m^{-3}), and lowest in Stephan (0.0013 m^{-3}) Lakes. Density of all fish, and sockeye salmon fry, standardized to square meter of surface area was also highest in Judd Lake and lowest in Stephan Lake. The majority of fish in all of the lakes was observed at depths less than 15 m during the surveys (Figures 4-6), and density in three of the six lakes was highest in the first measurable stratum.

Townet catches ranged from 17 fish at Stephan Lake to 2,622 at Hewitt Lake (Table 3). The sockeye salmon fry percentage of the total catch ranged from 16.9 % at Shell Lake to 95.9% in Chelatna Lake. Non-salmonid catches were predominantly sticklebacks in Judd (9.7%), Hewitt (76.1%), and Larson (3.4%) Lakes. Other non-salmonid species included sculpin (*Cottus sp.*) in Stephan and Shell Lakes, dolly varden or arctic char (*Salvelinus sp.*), arctic grayling (*Thymallus arcticus*), and chinook salmon (*Oncorhynchus tshawytscha*) in Stephan Lake, and whitefish (*Prosopium sp.*) in Chelatna Lake. Proportions of the total catch by species and AWL data from Stephan Lake were not considered reliable because of insufficient sample size. Based on the proportion of sockeye salmon fry in the tow net catches, the estimated populations of this species were 367,469 in Shell Lake, 520,270 in Larson Lake, 925,748 in Hewitt Lake, 1,036,661 in Judd Lake, 2,825,504 in Chelatna Lake, and 38,466 in Stephan Lake (Table 5.)

Age-0. juveniles comprised 97.6 % of the sockeye salmon fry caught in Judd Lake, 99.7% in Hewitt Lake and 100% in the remaining four lakes (Table 3). Mean lengths of age-0. fry ranged from 39 mm in Judd Lake to 56 mm in Stephan Lake (Table 4). Mean weights ranged from 0.8 g in Judd Lake to 2.8 g in Shell Lake. Mean lengths of sticklebacks ranged from 27 mm in Larson Lake to 34 mm in Hewitt Lake.

Weighted length frequency distributions from Larson Lake fish were bimodal, with mean lengths of 54 and 27 mm, for sockeye salmon fry and stickleback (Figure 7). As in 1993, the disproportionate numbers of each species in the estimate masked the magnitude of the differences in the length frequency distributions of the two species. The weighted length frequency distribution for Hewitt

Lake shows two size classes of sticklebacks overlapping two size classes of sockeye salmon fry (Figure 8).

Target strength data from Larson Lake were first processed using a 300 mV (-69 dB) threshold, resulting in a mean target strength of –52 dB (Table 2). The target strength frequency distribution indicated a substantial reduction in the number of echoes smaller than -67 dB. Although the smallest target strengths were 2 dB larger than the threshold, there appeared to be some loss of targets due to the 300 mV threshold. We repeated the procedure using a 150 mV (-75 dB threshold), since the 100 mV threshold used in 1993 did not provide the 3:1 signal to noise ratio desired for this analysis. The second run resulted in a mean target strength of -54 dB and a similar drop-off in numbers of echoes at -73 dB. We could not conclude from these results that the threshold was sufficient to allow processing of fish echoes from the smallest fish available to the gear. The final mean target strength in 1994 was approximately 5 dB larger than the previous fall. The target strength frequency distribution indicated at least three overlapping modes, none sufficiently separated to delineate from the others (Figure 7).

The analysis of Hewitt Lake data resulted in a mean target strength of –52 dB when a processing threshold of 300 mV (-69 dB) was used. No -69 dB targets were identified. A second analysis of the data using a threshold of 100 mV (-77 dB) resulting in a mean target strength of –53 dB with less than 0.5% of the targets at or less than -69 dB. The small percentage and distribution of echoes in the smallest target strength increments indicated that the data collection and processing thresholds used for this analysis were sufficient to measure the smallest fish available to the equipment. There were no distinguishable modes in the target strength frequency distribution (Figure 8).

1995

The total number of fish detected acoustically ranged from 271,729 in Judd Lake to 3,571,547 in Chelatna Lake (Table 5). Fish density per stratum was highest in Hewitt Lake (0.0651 fish m^{-3}) and lowest in Judd Lake (0.0112 fish m^{-3}). Sockeye salmon fry density per stratum was highest in Chelatna Lake, (0.0247 fry per m^{-3}) and lowest in Judd Lake (0.0012 m^{-3}). When density was standardized to numbers of fish m^{-2} of surface area, sockeye salmon fry had the lowest density in Hewitt Lake and the highest in Chelatna Lake. The majority of the fish in all lakes were found in the top 15 m (Figure 9), although fish were more evenly distributed in the water column in Judd Lake than previously observed.

Density estimates for the near surface stratum (0-3 m) derived from side-looking surveys were completed only for Chelatna and Hewitt lakes. The near surface density in both lakes was approximately 20% of that of the first measurable stratum in the down-looking survey data. The near surface stratum contributed 118,454 fish to the Hewitt Lake and 29,704 fish to the Chelatna Lake population estimates. We were unable to process side-looking data collected for Judd Lake because of excessive noise.

A threshold of 300 mV (-69 dB) was initially used to process the Hewitt Lake data. This resulted in a mean target strength of –51 dB and an apparent truncation of the target strength frequency distribution (Table 2). Processing the data with a 100 mV (-77dB) threshold resulted in a mean target strength of –53 dB, and a distribution of target strengths that indicated that some fish were missed because of the initial processing threshold.

The weighted length frequency distribution for sockeye salmon fry was overlapped by a bimodal length frequency distribution of sticklebacks, despite an 11 mm difference in mean length between the species (Figure 10). The distribution of target strengths, while somewhat extended on the small end, had no visible modes.

Townet sampling at Hewitt and Judd Lakes in 1995 resulted in a catch of at least 300 sockeye salmon fry with each of the trawls fished (Table 2). Only 12 sockeye salmon fry were caught at Chelatna Lake with the small trawl towed for a total of 240 minutes. The larger trawl was not used because of motor failure on one of the inflatable boats. The catch at Hewitt Lake was 51.8% sockeye salmon fry in the large trawl and 11.0% sockeye salmon in the small trawl. The catch at Judd Lake was approximately 99% sockeye salmon fry in both trawls.

Age-0. sockeye salmon fry comprised at least 99% of the catch of both trawls at Hewitt Lake, and 94% at Judd Lake (Table 4). Disregarding the small sample collected at Chelatna Lake, the mean length of age-0. fry was largest from the large trawl catch from Hewitt lake (43 mm) and smallest from the large trawl catch in Judd Lake (37 mm). Mean length of sticklebacks for both trawls at Hewitt Lake was smaller than in 1994 (small net mean = 28 mm; large net mean = 32 mm).

Comparison of the length frequencies of the catches from the two mid-water trawls revealed that the large trawl caught age-0. fry with a mean length that was approximately 2 mm greater than the small trawl in Hewitt Lake, but smaller by approximately 1 mm in Judd Lake (Table 6). These means were sufficiently different (Hewitt Lake $p<0.000$; Judd Lake $p= 0.0161$) to reject the hypothesis that mean lengths were independent of trawl size used for capture (Figures 11 and 12). The large trawl caught larger (approximately 1 mm) age-1. fry in Judd Lake. The hypothesis that the means of the catches were equal was accepted ($p=0.2746$) for Judd Lake age-1. fry.

DISCUSSION

One-half of the lakes examined in this study contained a large population of sticklebacks. We did not find any reference in the literature for target strengths of fish in the size range of the smallest sticklebacks in our townet catches (<20 mm). However MacLennan and Simmonds (1992) reported target strengths of krill (28-40 mm) and euphasids (11-19 mm) in the -74 to -95 dB range, and Urick (1983) discussed copepod target strengths of -80 dB for specimens as small as 3 mm. We used processing thresholds that varied from of -75 to -77 dB, and discovered that in at least one of the two years of the study, the minimum processing threshold did not completely process all fish targets in lakes (Hewitt and Larson) where the smallest sticklebacks were captured. Using the results of townet catches to determine the proportion of each species in the lakes overestimated the proportion of the smaller size species (stickleback), since this species was fully available to the townet but not the acoustic equipment.

Regardless of the threshold used for processing, we found that there was no bimodal distribution of the target strength of returning echoes that might allow separation of sockeye salmon fry and sticklebacks. The disproportionate numbers of one species masked the differences in their target strength frequency distributions. We did observe a 5 dB increase in mean target strength from 1993 to 1994 in Larson Lake, suggesting an approximate doubling of size of the average target in the second year. These data were consistent with the change in the predominant species from sticklebacks (96.4% of the total; mean length = 28 mm) in 1993 to sockeye salmon fry (97.6% of the total; mean length = 54 mm) in 1994.

A second factor influencing the ability to totally enumerate fish populations in the study lakes was the distribution of fish in near surface waters. We found that the highest fish density was observed in the first measurable stratum in seven of the 17 surveys conducted in 1993 and 1994. Previous techniques used in UCI (Tarbox and Brannian 1995) assumed a near surface density equal to or less than that of the first measurable strata in down looking surveys. This assumption, if applied to our survey data, would add significant numbers of fish to the total estimates for nearly one-half of the lakes. Our side looking surveys in 1995 revealed densities of fish that were approximately 20% of the density in the next stratum, and added 9.2% and 0.8% to the pelagic fish estimates in Hewitt and Chelatna Lakes.

The estimate of fish inhabiting the near surface waters during the 1995 fall fry surveys was a first attempt to apply newly developed data collection and analysis techniques. There was no concern for correct quantity and spacing of transects. Considering the variability of fish densities in the down-looking transects, our side-looking transects were probably not sufficient to accurately measure the true numbers of fish in this stratum. The technique did however appear to be successful.

Target densities measured in numbers per m^2 of lake surface area varied dramatically between lakes and between years within lakes. In Larson and Shell Lakes, two of the multi-species lakes, lack of data from the near surface waters made these changes difficult to assess. In Judd Lake, we also were unable to determine if changes in numbers per m^2 from 1993 to 1994 were real or a function of near surface distribution. However, since we did estimate the near surface component in 1995, the reduction in fish density from the previous year reflected a significant loss which could not be attributed to bias in the estimation technique.

Hewitt Lake experienced a significant decline in numbers in 1995 compared to the two previous years. Since the 1995 estimate included the near-surface component, the decline from the previous years was also a result of fluctuations in the fish population. This lake contained two length cohorts of *Gasterosteus sp*, which typically has a 3-year life span (McPhail and Lindsey 1970). The annual variation in the numbers and mean length of this species may be indicative of the relative success of different age classes. However, we do not know how the dynamics of stickleback populations affects the success of sockeye salmon fry rearing.

Several problems were apparent from examination of the townet results. In lakes where both sockeye salmon fry and stickleback were found, the sockeye salmon proportion varied between years, and in one of two lakes, between the two trawls used. These data indicated that fish target apportionment problems exist in multispecies lakes where the species of interest is a fraction of the total population. An extensive townet program designed to sample a variety of temporal and depth strata may be necessary for accurate estimation of the true proportion of sockeye salmon fry in these lakes. These problems will require significant effort to solve, and until methods and analysis techniques are perfected, estimates of sockeye salmon fry are suspect.

Sockeye salmon fry were the numerically dominant species in Judd Lake in all three years. Although the sockeye salmon fry proportion of the trawl catch varied between years, there was no variation in the sockeye salmon fry proportion between the 2 trawls used in 1995. The annual proportions of sockeye salmon fry in the catch appeared to be a true measure of the actual species proportions in the lake, however an expanded trawl program would likely be necessary to provide the level of precision necessary for future productivity studies.

Comparison of historic age-class data, and age composition data from our studies revealed differences in age structure in all of the lakes. Without looking at adult returns from measured fry populations over a period of years, we cannot draw conclusions about the predominance of age-0. sockeye salmon fry in this study. Our evaluation of the adult data does, however, demonstrate the variability in the age structure of rearing populations present in these lakes in previous years.

Declines in sockeye salmon fry mean lengths were observed in all lakes from 1993 to 1995. These declines were significant in 4 of the five lakes. In the two lakes where we were relatively confident of the accuracy of the sockeye salmon fry population estimates, Chelatna and Judd, the size declines accompanied increases in total fish numbers. The mean lengths in Judd and Hewitt Lakes in 1995, while in some cases statistically different between the two trawl types, were similar enough to speculate that the statistical results were a function of sample size, and that the samples reasonably represented the population of age-0. fry. This conclusion was reinforced by the fact that the larger mean did not necessarily result from the larger trawl. Differences were likely a result of trawl program sample design.

Sockeye salmon fry size at Shell, Larson and Chelatna Lakes was within the bounds of this species in the other Cook Inlet rearing lakes (Tarbox and Brannian 1995, Todd and Kyle 1996, King et al. *in press*, King et al. 1994). Judd and Hewitt Lake fall fry sizes were among the smallest seen in UCI lakes. The lengths and weights were comparable to fall fry found in Crescent Lake in 1994 and 1995, where sockeye salmon total returns have declined for several years (unpublished data, ADF&G, Soldotna). We do not however, have adequate data to assess the ramifications of fry size on the success of smolt production in these systems.

Mean weight of age-0. fry in the lakes where sockeye salmon fry were the predominant species decreased each fall throughout the study period. In Chelatna Lake, the decrease in mean weight was accompanied by an increase in total number of fish and a net increase in fish biomass of approximately one-third from 1993 to 1995. Judd Lake sockeye salmon fry mean weights also decreased as the numbers of fish increased between 1993 and 1994. The net result of the 30%

decrease in mean weight and 400% increase in numbers was a twofold increase in biomass in 1994. However, there was not a corresponding increase in mean weight in 1995 when the numbers returned to the 1993 level. The result was about one-half the fish biomass present in 1993 when the numbers were the same as 1995.

PROJECT SUMMARY

This study began in 1993 in an effort to determine if the current production of individual lakes that contribute to the Susitna River sockeye salmon total return was at levels estimated by the euphotic volume of the lakes (Kyle et al. 1994). In theory, the known major rearing lakes should produce approximately 1 million adults, or about the average total return attributed to this drainage in the past. In order to achieve our objective, we needed to determine if we could successfully enumerate and describe the juvenile fish populations currently inhabiting the lakes. We could then evaluate the production potential of the Susitna Basin lakes by assessing key biological and limnological parameters that would indicate excessive use or underutilization of the rearing area.

The age-0. sockeye salmon fry rearing in 1993 were from a 1992 escapement estimate of 66,000 adults in the Yentna River. The escapement into the Yentna River was estimated to represent a total Susitna River drainage escapement of 132,000, or approximately one-third less than the minimum escapement goal of 200,000. Thus, the 1993 fry reared under conditions that should have provided low intraspecific competition. In contrast, the 1993 Yentna River adult sockeye salmon escapement was the highest on record (141,694), resulting in a total Susitna River escapement estimate that approached the upper end of the goal. Examination of the fry populations in 1994 should have revealed evidence of an overall increase in production, given relatively constant spawner distribution.

The limnological sampling conducted in 1993, and the historical information suggested that some of the lakes were more productive than others, and the zooplankton community in some lakes had undergone changes (Kyle et al. 1994). The ranking of trophic status based on limnological parameters revealed that the more shallow systems such as Whiskey and Red Shirt lakes were more productive. However, because of their relatively shallow depth, the zooplankton forage base, which is the major food source for rearing sockeye salmon fry, was relatively small. In contrast, Stephan Lake, which also is shallow relative to the other lakes, was second to Larson Lake in zooplankton biomass. High nutrient and chlorophyll a concentrations, which are consistent with a high standing stock (biomass) of zooplankton, suggest that this lake may have a relatively long water resident time. The most significant change in zooplankton, based on the limited historical data, was in Chelatna Lake. This glacially-influenced lake was the most oligotrophic of the eight lakes surveyed in 1993, and since 1990 the zooplankton biomass has been consistently less than the years 1984-1989. Also, the zooplankton structure changed from the dominance of *Diaptomus* to *Cyclops*. The reason(s) for these changes in the zooplankton community of Chelatna Lake is largely unknown, however, the dramatic decrease in zooplankton biomass may affect the ability of this lake to support sockeye salmon fry.

Although the size of age-0. fry in Shell, Larson, and Chelatna Lakes declined during the study years, mean lengths were similar to other Upper Cook Inlet rearing lakes where overwinter survival has been documented as generally adequate. Evidence in the historical age data from these lakes suggests a periodic adjustment to the populations' inability to reach adequate size for smolting after one winter. We do not know the frequency or impact on production of these events, but by itself, fry size did not suggest that production was maximized or spawner limited. The small fry sizes in Judd and Hewitt Lakes could have been due to high intraspecific competition; however, except for small size *Bosmina* in Hewitt Lake, the zooplankton community did not reflect this condition. Again, the limited duration of this study, and lack of zooplankton data after 1993, did not provide adequate data to assess the ramifications of fry size on the success of smolt production in these lakes.

Changes in density and total sockeye salmon fry biomass were observed in Chelatna and Judd Lakes between years. In Chelatna Lake, a decrease in fish size, and change in zooplankton species accompanied increases in biomass. In Judd Lake, the high densities in 1994 resulted in an increase in total fish biomass over the previous fall, at the expense of mean fry weight. A mean fry weight increase did not accompany the subsequent substantial reduction in numbers in 1995. These trends in both lakes may be indicative of rearing limitations based on food availability.

Clearly, there were some technical problems in estimating sockeye salmon fry populations in lakes dominated by sticklebacks. Inability to measure all of the targets, and variations in the species composition of the townet catches, resulted in questionable estimates in lakes where sockeye salmon fry represent only a fraction of the total fish. However, except for Shell Lake, the lakes where stickleback appeared to be the predominant species (Larson and Hewitt) had historical adult returns expected from the range of sockeye salmon fry estimates in this study and the adult estimate generated by the euphotic volume measurements. In the absence of additional data, particularly adult spawner numbers, it was not possible to determine the response of Shell and Hewitt Lakes to dramatically different Yentna River adult sockeye salmon escapements in 1992 and 1993, or to determine the interspecific competitive advantages of variable sockeye salmon fry population levels.

In other lakes, such as Judd and Chelatna, accurate estimates were possible because the size of the smallest targets was well above the processing threshold and the proportion of sockeye salmon fry in the trawl catches was high. Our data does point out that there are still technical issues that need to be resolved. Townetting programs in these lakes would have to be expanded to insure accuracy, and estimates of near surface fish must adequately represent spatial differences in distribution. Despite these uncertainties, we did detect major changes in the sockeye salmon fry populations between years.

Fry density in Judd and Chelatna Lakes was comparable to that measured in other UCI sockeye salmon fry rearing lakes. Chelatna Lake production is similar to that of Skilak Lake in years of highest production in the latter lake (Table 7). Both are glacial lakes with similar light penetration. There has been a recent decline in fall fry size and change in the zooplankton population in Chelatna Lake, but the adult spawning escapement, fish biomass in the lake in the fall, and smolt numbers increased annually. These data appear consistent with a lake approaching carrying capacity. This conclusion was arrived at by using smolt counts, and average overwinter and marine survival rates, to compare anticipated adults from current fry estimates to the number of adults predicted by the euphotic volume. In addition, the recent counts of spawners to Chelatna Lake, combined with ADF&G's best estimate of the exploitation rate on Susitna bound stocks, is consistent with both estimates (euphotic volume and fall fry) of the production from this lake.

Judd Lake in 1994 had the highest sockeye salmon fry density of any UCI lake measured between 1993 and 1995. This included Upper Russian Lake, commonly thought to be one of the most productive sockeye salmon fry rearing lakes in UCI. Our best estimate of the adult production from fall fry numbers indicates that in two of the three years production was probably well below expected, and the third year, 1994, well above. These data may indicate that on average the production is near capacity, but additional work is necessary to confirm this conclusion.

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Table 1. Potential sockeye salmon production based on euphotic volume for lakes within the four geographical regions of the Susitna River drainage.

Geographical region	Lake	Surface area (acres)	Adult production (number)	Adult production expressed as percent of the grand total
Chulitna	Byers	368	37,200	3.8%
	Swan	385	11,000	1.1%
	Spink	252	23,500	2.4%
	Bunco	106	1,600	0.2%
	Total	1,111	73,300	7.6%
Mainstem	Caswell	159	13,700	1.4%
	Trapper	1,188	16,800	1.7%
	Fish	132	10,600	1.1%
	Sucker	273	8,300	0.9%
	Red Shirt	1,272	69,500	7.2%
	Neil	115	7,600	0.8%
	Total	3,139	126,500	13.0%
Talkeetna	Larson	437	45,100	4.6%
	Stephan	899	63,700	6.6%
	Total	1,336	108,800	11.2%
Yentna	Chelatna	3,906	363,574	37.5%
	Trinity	308	19,300	2.0%
	Whiskey	271	23,600	2.4%
	Fish Creek	111	9,000	0.9%
	Shell	1,293	90,265	9.3%
	Puntilla	90	8,800	0.9%
	Eightmile	115	5,600	0.6%
	Movie	110	6,700	0.7%
	Lockwood	233	11,000	1.1%
	Judd	316	59,500	6.1%
	Hewitt	697	60,600	6.2%
	Red Salmon	113	3,400	0.4%
	Total	7,563	661,339	68.2%
	Grand Total	13,149	969,939	100.0%

Source: Tarbox and Kyle (1989)

tab1.xls

Table 2. Target strength distribution for various hydroacoustic data processing thresholds used for Susitna River drainage lakes.

	Processed at 300 mV.[1]				Processed at 100 mV.[1]				Processed at 150 mV.[1]	
	Number of targets					Number of targets				Number of targets
Target	Larson		Hewitt		Target	Larson	Hewitt		Target	Larson
strength[2]	1993	1994	1994	1995	strength[2]	1993	1994	1995	strength[2]	1994
-79	0	0	0	0	-79	0	0	0	-79	0
-77	0	0	0	0	-77	0	5	9	-77	0
-75	0	0	0	0	-75	0	14	66	-75	1
-73	0	0	0	0	-73	0	9	87	-73	70
-71	0	0	0	0	-71	0	29	122	-71	86
-69	4	1	0	0	-69	8	43	140	-69	127
-67	106	64	12	7	-67	167	82	201	-67	211
-65	261	124	41	53	-65	412	119	248	-65	284
-63	403	263	96	156	-63	671	193	326	-63	425
-61	511	419	239	287	-61	787	327	427	-61	564
-59	606	666	315	446	-59	713	376	561	-59	735
-57	603	857	481	625	-57	612	485	653	-57	861
-55	462	868	712	875	-55	462	712	876	-55	868
-53	393	912	807	1014	-53	393	807	1015	-53	912
-51	329	981	908	1010	-51	329	908	1007	-51	981
-49	113	1098	772	902	-49	113	772	901	-49	1098
-47	46	1039	512	817	-47	46	512	814	-47	1039
-45	9	723	269	690	-45	9	269	691	-45	723
-43	6	244	101	527	-43	6	101	527	-43	244
-41	5	50	40	270	-41	5	40	268	-41	50
-39	6	15	15	86	-39	6	15	86	-39	15
-37	4	6	1	17	-37	4	1	15	-37	6
-35	1	3	1	2	-35	1	1	2	-35	3
-33	0	1	0	2	-33	0	0	1	-33	1
-31	0	2	0	2	-31	0	0	2	-31	2
-29	0	0	0	0	-29	0	0	0	-29	0
-27	0	0	0	0	-27	0	0	0	-27	0
-25	0	0	0	0	-25	0	0	0	-25	0
-23	0	0	0	0	-23	0	0	0	-23	0
-21	0	0	0	0	-21	0	0	0	-21	0
Population mean target strength	-58	-52	-52	-51	Population mean target strength	-59.00	-53	-53	Population mean target strength	-54

[1]Data collected with 100 mV. threshold

[2]Shaded valued is approximate dB equivalent of processing threshold

table 2.xls

Table 3. Summary of the number of fish caught during townetting in the Susitna River drainage lakes.

Lake	Towing minutes	Number of fish: Sockeye	Stickle-back	Sculpin	D. Varden	Grayling	Chinook	Whitefish	Total	Percent Sockeye
1995										
Chelatna										
small net	240	12	0	0	0	0	0	0	12	100.0
large net	[1]									
Hewitt										
small net	155	380	3,076	0	0	0	0	0	3,456	11.0
large net	25	592	551	0	0	0	0	0	1,143	51.8
Judd										
small net	195	303	4	0	0	0	0	0	307	98.7
large net	60	453	8	0	0	0	0	0	461	98.3
1994										
Stephan	170	4	0	7	2	3	1	0	17	23.5
Chelatna	440	117	0	0	0	0	0	5	122	95.9
Judd	119	791	85	0	0	0	0	0	876	90.3
Hewitt	45	627	1,995	0	0	0	0	0	2,622	23.9
Larson	307	207	5	0	0	0	0	0	212	97.6
Shell	282	82	397	5	0	0	0	0	484	16.9
1993										
Byers	297	109	11	4	4	1	0	0	129	84.5
Chelatna	490	68	0	0	0	0	0	7	75	90.7
Hewitt	75	620	3,680	0	0	0	0	0	4,300	14.4
Judd	262	369	86	0	1	0	0	0	456	80.9
Larson	351	267	7,110	0	1	0	0	0	7,378	3.6
Red Shirt	263	6	5,675	1	0	0	0	0	5,682	0.1
Shell	252	19	1,275	2	0	0	1	0	1,297	1.5

[1] No large net tows made due to motor failure

tab3.xls

Table 4. Sockeye salmon and stickleback age, length, and weight data collected from Susitna River drainage lakes.

	Age-0. sockeye salmon										Age-1. sockeye salmon										Stickleback				
			Length (mm)				Weight (g)						Length (mm)				Weight (g)					Length (mm)			
Lake	N	%	Min	Max	Mean	SD	Min	Max	Mean	SD	N	%	Min	Max	Mean	SD	Min	Max	Mean	SD	N	Min	Max	Mean	SD
1995																									
Chelatna																									
small net	12	100.0	34	71	56	12.59	0.4	4.7	2.4	1.53	0	-	-	-	-	-	-	-	-	-	0	-	-	-	-
large net	0	-	-	-	-	-	-	-	-		0	-	-	-	-	-	-	-	-	-	0	-	-	-	-
Hewitt																									
small net	298	99.3	26	64	40	6.08	0.1	3.1	0.8	0.38	2	0.7	70	74	72	2.83	3.8	5.2	4.5	0.00	116	20	49	28	5.03
large net	299	99.7	28	63	43	6.17	0.2	2.8	0.9	0.40	1	0.3	63	63	63	-	2.8	2.8	2.8	-	90	24	57	32	4.81
Judd																									
small net	282	94.0	27	58	38	5.69	0.2	1.8	0.6	0.28	18	6.0	53	65	57	3.68	1.0	2.9	2.0	1.40	0	-	-	-	-
large net	283	94.3	27	62	37	5.88	0.2	2.1	0.6	0.29	17	5.7	50	66	58	4.87	1.3	3.0	2.2	0.52	0	-	-	-	-
1994																									
Chelatna	116	100.0	42	74	56	6.69	1.2	5.7	2.6	0.92	0	-	-	-	-	-	-	-	-	-	0	-	-	-	-
Hewitt	297	99.7	27	62	40	7.63	0.2	3.9	1.1	0.71	1	0.3	64	64	64	0.00	3.2	3.2	3.2	0.00	100	18	57	34	11.14
Judd	290	97.6	26	58	39	6.37	0.1	2.7	0.8	0.45	7	2.4	56.0	65	62	3.66	2.3	3.7	3.1	0.50	75	29	59	39	6.16
Larson	165	100.0	44	70	54	5.27	0.7	4.3	2.1	0.64	0	-	-	-	-	-	-	-	-	-	5	20	33	27	4.17
Shell	36	100.0	41	69	55	6.43	1.0	4.3	2.8	0.81	0	-	-	-	-	-	-	-	-	-	100	14	49	32	7.07
Stephan	4	100.0	39	68	56	11.51	0.9	3.8	2.5	1.16	0	-	-	-	-	-	-	-	-	-	0	-	-	-	-
1993																									
Chelatna	65	98.5	34	82	62	9.90	0.5	8.1	3.3	1.53	1	1.5	73	-	-	-	4.9	-	-	-	0	-	-	-	-
Hewitt	596	97.2	29	69	49	7.63	0.2	4.1	1.4	0.65	17	2.8	66	82	82	5.02	3.2	6.7	6.7	1.05	154	20	58	28	4.76
Judd	329	91.9	27	65	46	6.47	0.2	2.9	1.2	0.48	29	8.1	57	72	64	3.14	2.1	4.4	3.1	0.46	67	16	51	34	9.57
Larson	249	98.0	37	75	55	7.14	0.6	5.2	2.1	0.83	5	2.0	65	75	68	3.79	3.4	5.2	4.0	0.66	293	17	43	28	5.77
Redshirt	4	66.6	80	89	85	3.34	6.8	8.4	7.7	0.61	2	33.3	74	81	78	3.50	4.8	6.4	5.6	0.80	113	22	47	32	5.79
Shell	13	100.0	55	72	63	5.50	2.1	4.7	3.3	0.81	0	-	-	-	-	-	-	-	-	-	121	24	51	34	6.10
Byers	97	100.0	49	86	64	6.68	1.3	8.0	3.5	1.18	0	0.0	-	-	-	-	-	-	-	-	11	28	60	52	9.67

tab4.xls

Table 5. Population estimates and densities of all pelagic fish and sockeye salmon fry in the Susitna River drainage lakes.

Lake	Total estimated targets	Estimated no. sockeye fry	Peak density: No. of fish m^{-3}	Peak density: No. of sockeye m^{-3}	Peak density: Depth (m below transducer)	Mean surface density: Fish m^{-2}	Mean surface density: Sockeye m^{-2}
1995							
Hewitt[1]	1,276,892	140,399	0.0651	0.0072	5-10	0.5150	0.0566
Judd[1]	271,729	267,014	0.0112	0.0012	5-10	0.1931	0.1898
Chelatna[1]	3,571,547	3,571,547	0.0247	0.0247	4-8	0.2254	0.2254
1994							
Shell	2,168,964	367,469	0.0957	0.0162	2-5	0.4991	0.0846
Larson	532,837	520,270	0.0311	0.0304	9-13	0.3135	0.3061
Hewitt	3,871,308	925,748	0.1693	0.0405	5-10	1.6450	0.3934
Judd	1,148,060	1,036,661	0.0975	0.0880	2-5	0.8434	0.7616
Chelatna	2,946,252	2,825,504	0.0370	0.0355	1.5-5	0.1954	0.1874
Stephan	163,479	38,466	0.0057	0.0013	4-8	0.03836	0.0090
1993							
Redshirt	1,025,012	1,082	0.0519	0.0001	1-4	0.2320	0.0002
Shell	1,354,520	19,843	0.0230	0.0003	5-10	0.2542	0.0037
Larson	269,064	9,737	0.0207	0.0007	2-4.5	0.1576	0.0057
Hewitt	3,100,714	447,080	0.2055	0.0296	1-5	1.4140	0.2039
Judd	343,378	277,865	0.0249	0.0202	5-10	0.2861	0.2315
Byers	107,995	91,252	0.0084	0.0071	5-9	0.0749	0.0633
Chelatna	2,230,970	2,022,746	0.0080	0.0073	4-8	0.1407	0.1276

[1]Estimated total targets and estimated sockeye salmon fry includes fish estimated near surface.

tab5.xls

Table 6. Results of student's t-test on Susitna River drainage sockeye fry caught in two sizes of mid-water trawls, 1995.

		Small trawl			Large trawl							
	Age	N	Mean	V	N	Mean	V	T-stat	V	T-crit	P_{2tail}	H_0[1]
Hewitt Lake	0	298	40	37	299	43	38	-4.8615	595	1.964	0.0000	Reject
Judd Lake	0	282	38	32	283	37	35	2.4136	563	1.9642	0.0161	Reject
Judd Lake	1	18	32	14	17	35	24	-1.129	30	2.0423	0.2746	Accept

[1] H_0 Mean of small net = Mean of large net

tab6.xls

Table 7. Densities of pelagic fish in selected lakes of upper Cook Inlet.

	Numbers of fish per m^2 of lake surface area		
Lake	1993	1994	1995
Chelatna[a]	0.1276	0.1874	0.2254
Judd[a]	0.2315	0.7616	0.1898
Hewitt[b]	1.4140	1.6450	0.5150
Larson[b]	0.1576	0.3135	
Shell[b]	0.2542	0.4991	
Upper Russian[a]		0.5240	0.2440
Skilak[a]	0.3410	0.0967	0.0793
Tustumena[a]	0.0489	0.0424	0.0357
Kenai[a]	0.0785	0.0531	0.0260
Crescent[a]			0.0440

[a]Lakes with predominantly sockeye salmon fry. Densities are sockeye fry only.
[b]Lakes with mixed species popolations. Densities are all fish species combined.

tab7.xls

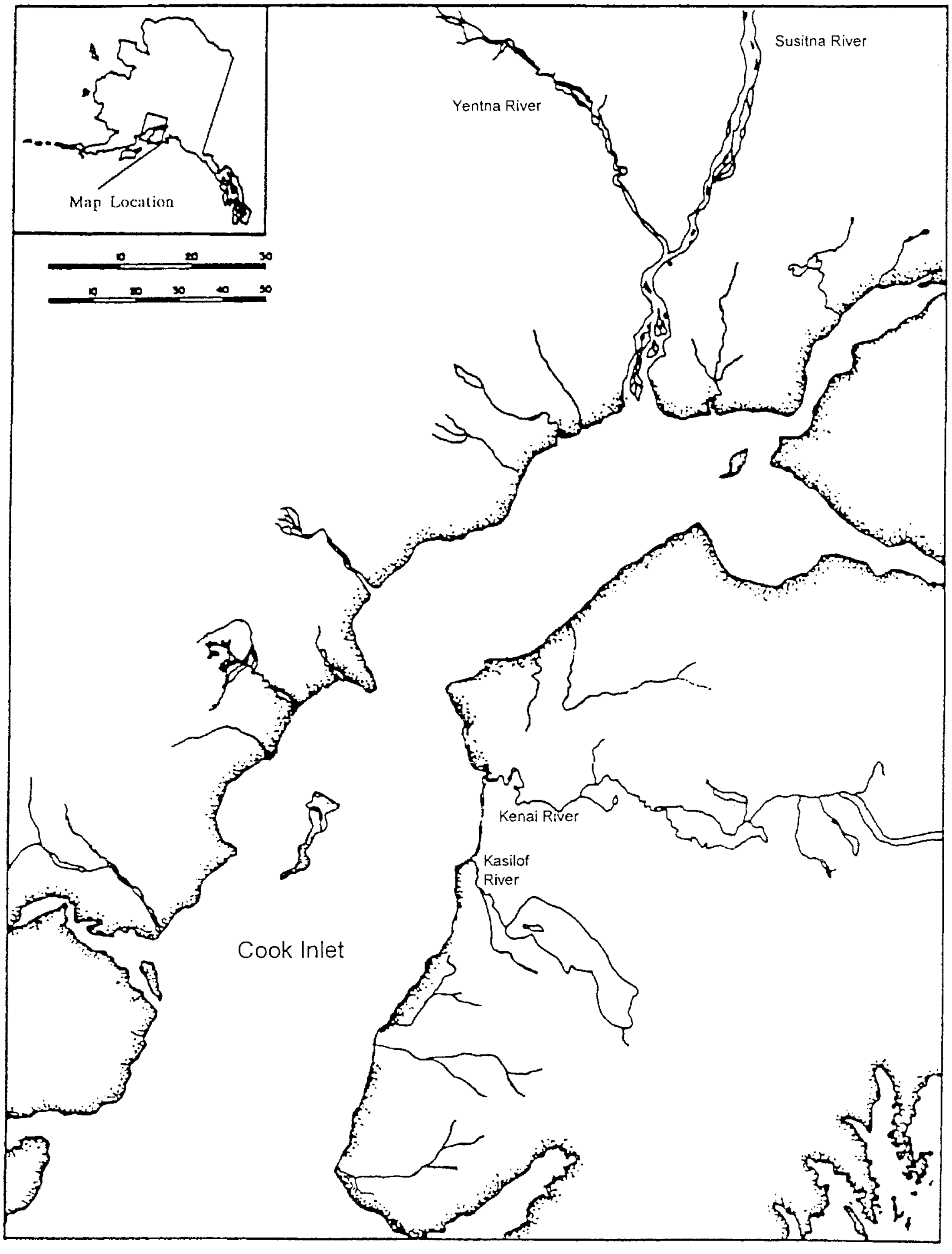


Figure 1. Map of Upper Cook Inlet, Alaska showing locations of the Kenai, Kasilof, Susitna and Yentna Rivers.

fig1.pre

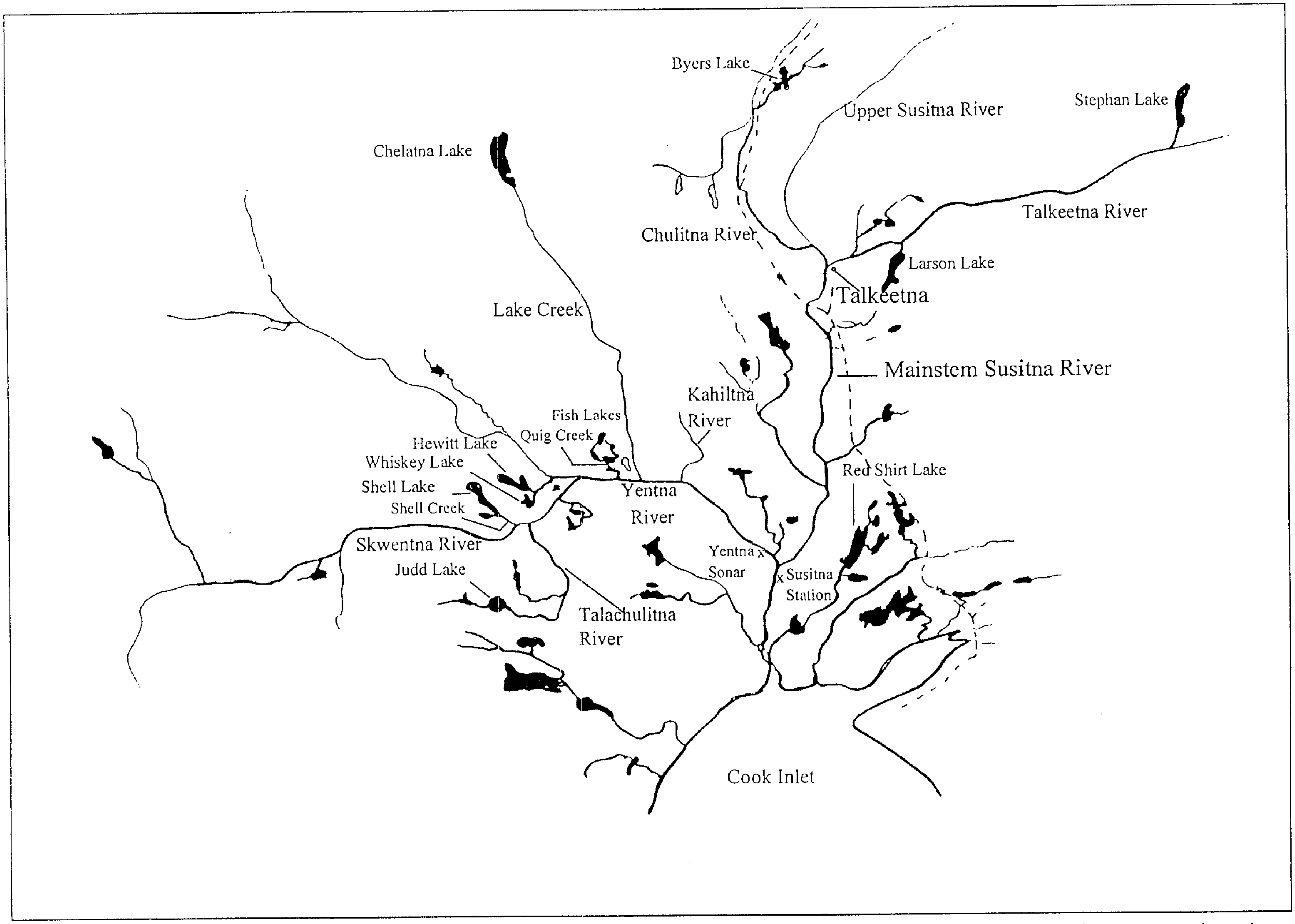


Figure 2. Major tributaries of the Susitna River, Alaska showing the locations of current and historical sockeye salmon research projects.

susitna.pre

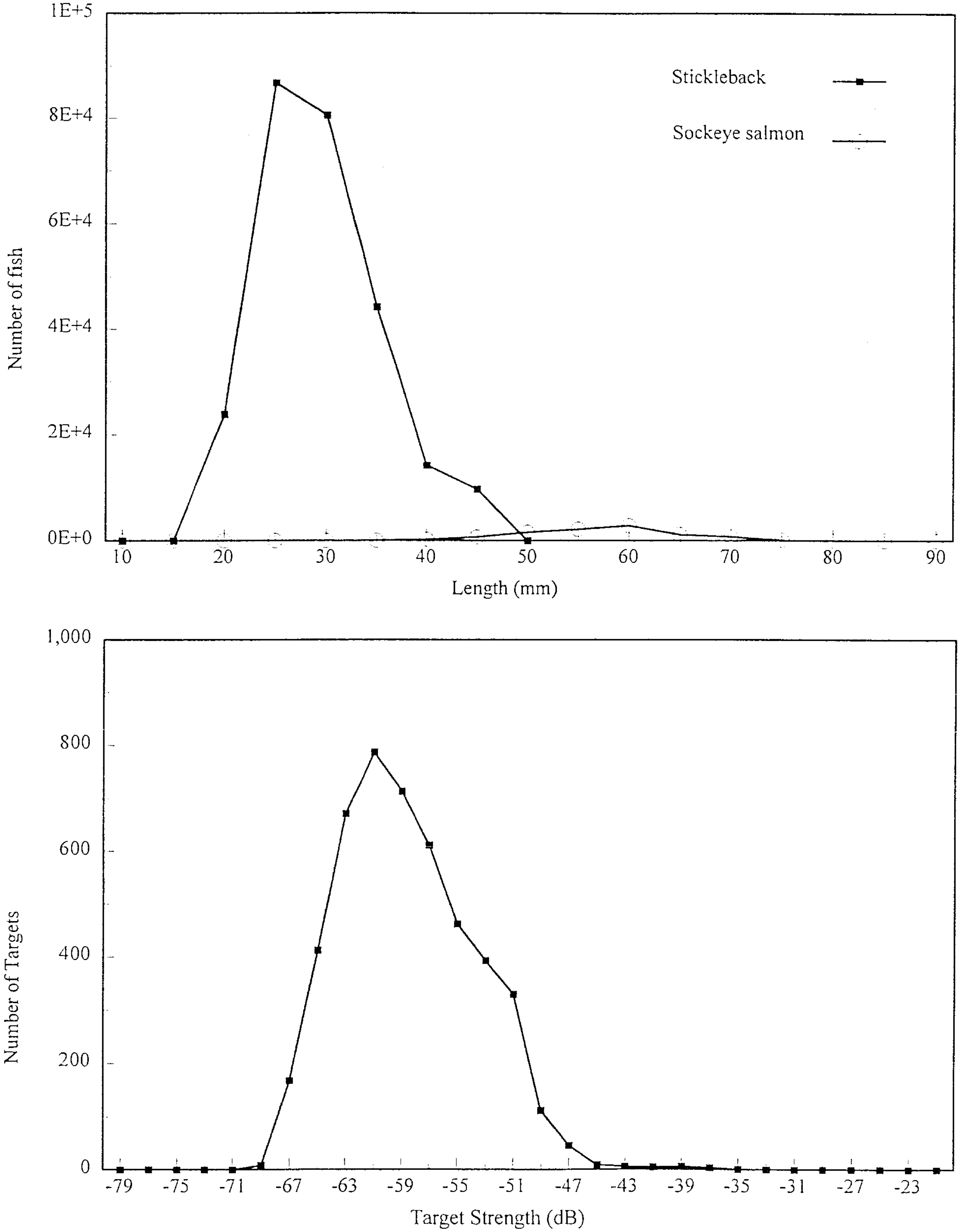


Figure 3. Larson Lake 1993 weighted length frequencies,(top) and target strength frequencies.

fig3.pre

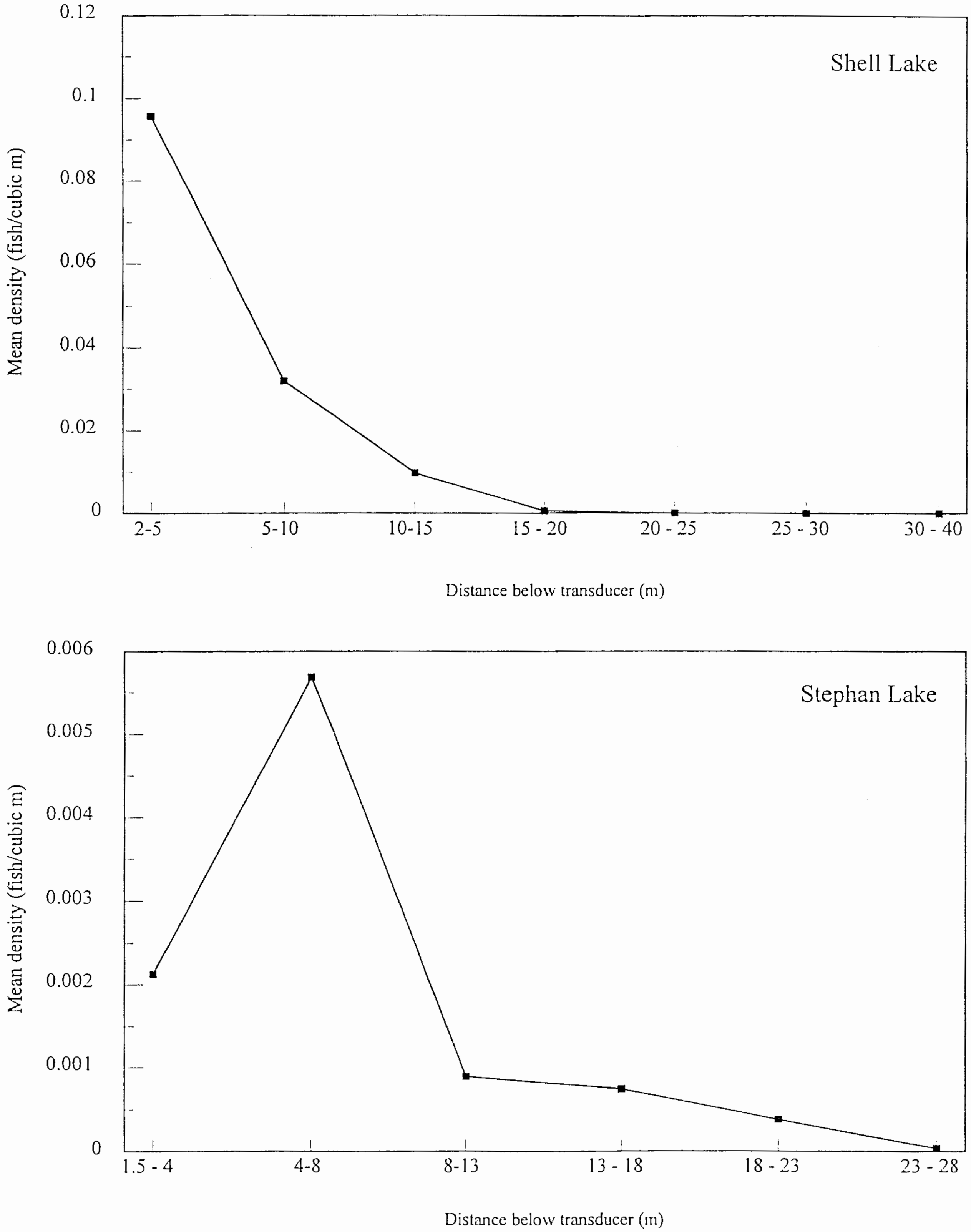
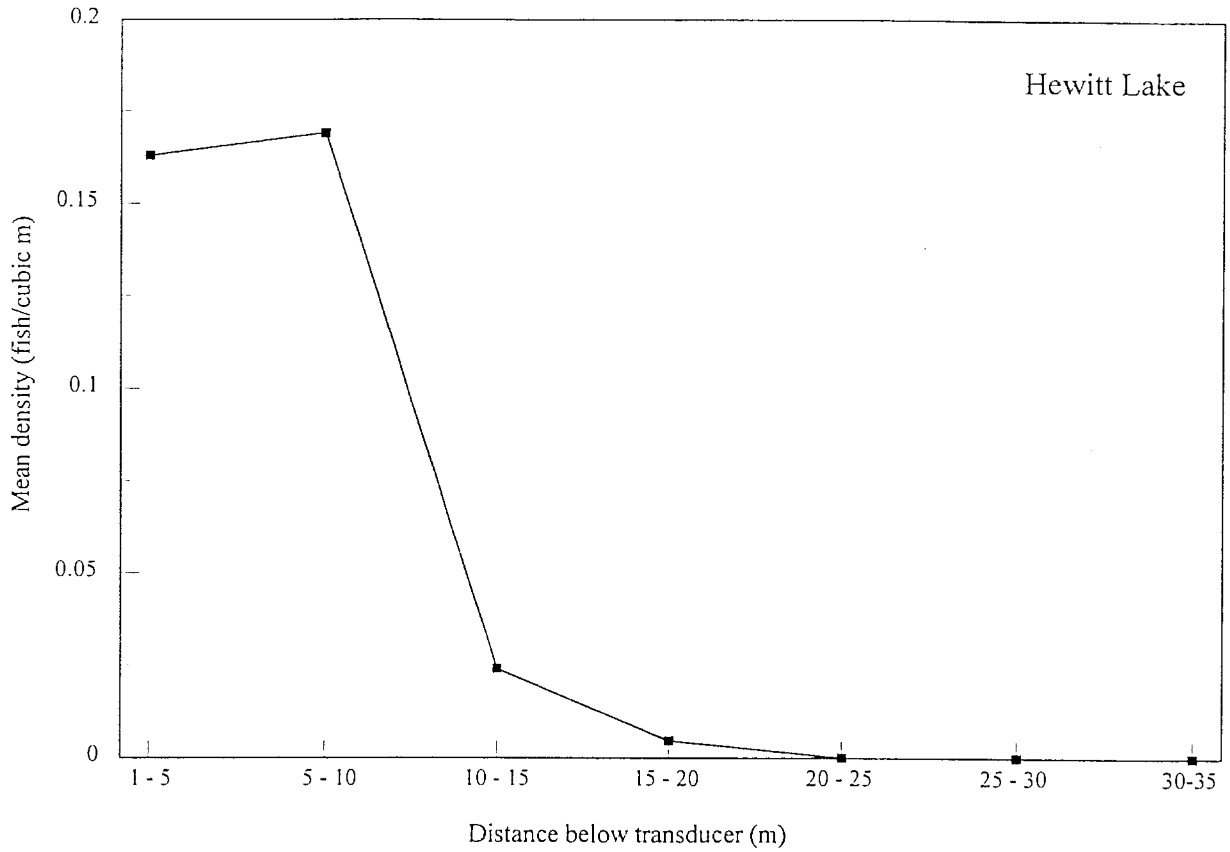


Figure 4. Mean density by depth stratum (all transects combined) for Shell Lake (top) and Stephan Lake in 1994.

fig4.pre



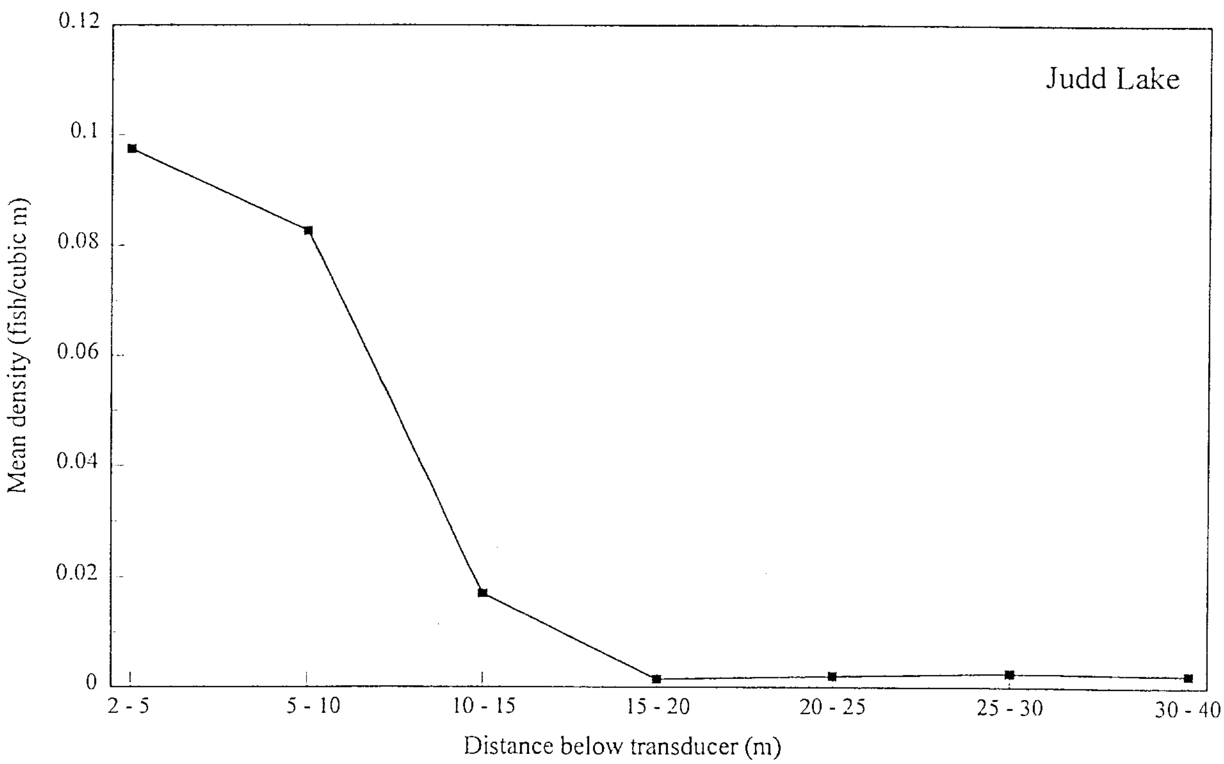


Figure 5. Mean density by depth stratum (all transects combined) for Hewitt Lake (top) and Judd Lake in 1994.

fig5.pre

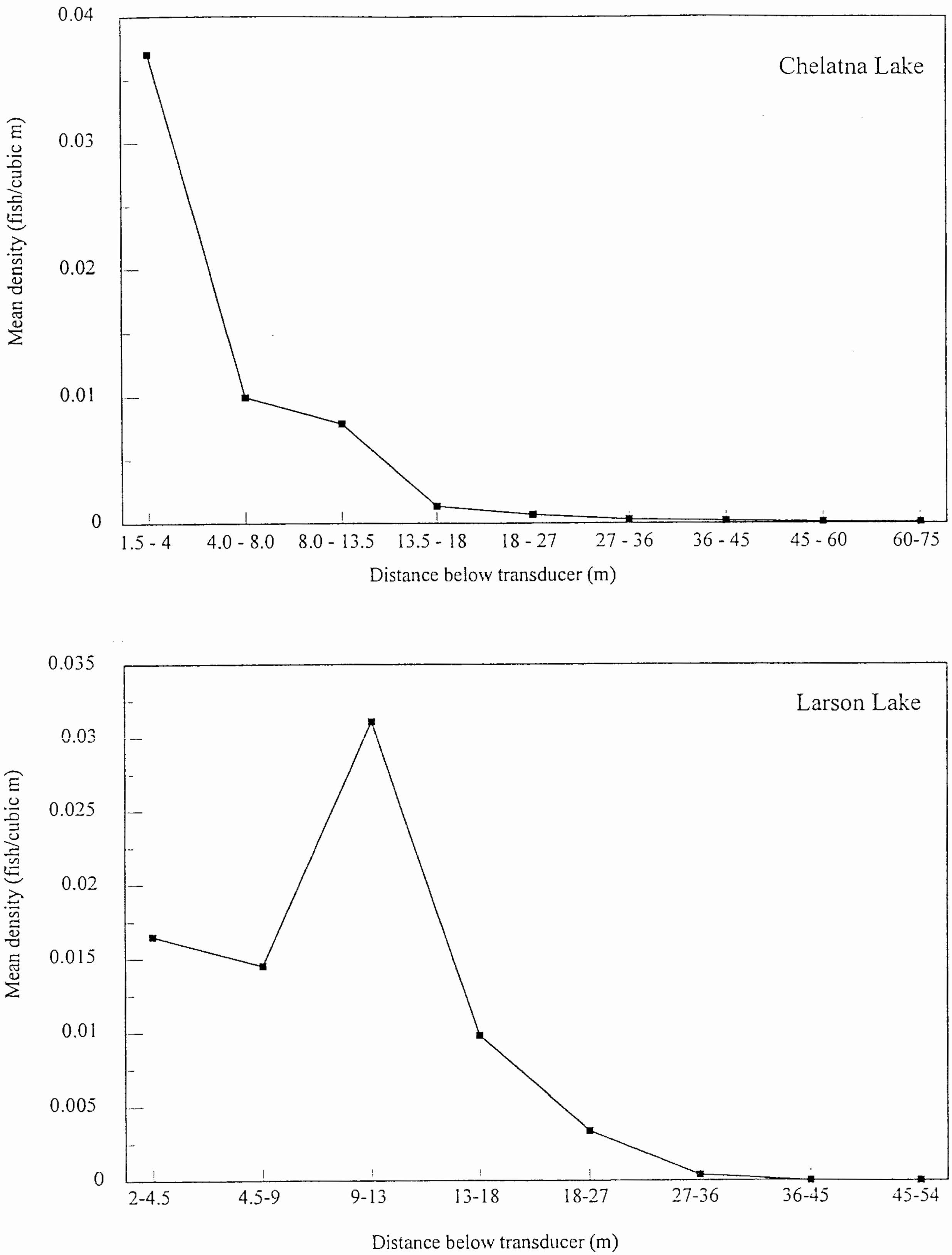


Figure 6. Mean density by depth stratum (all transects combined) for Chelatna Lake (top) and Larson Lake in 1994.

fig6 pre

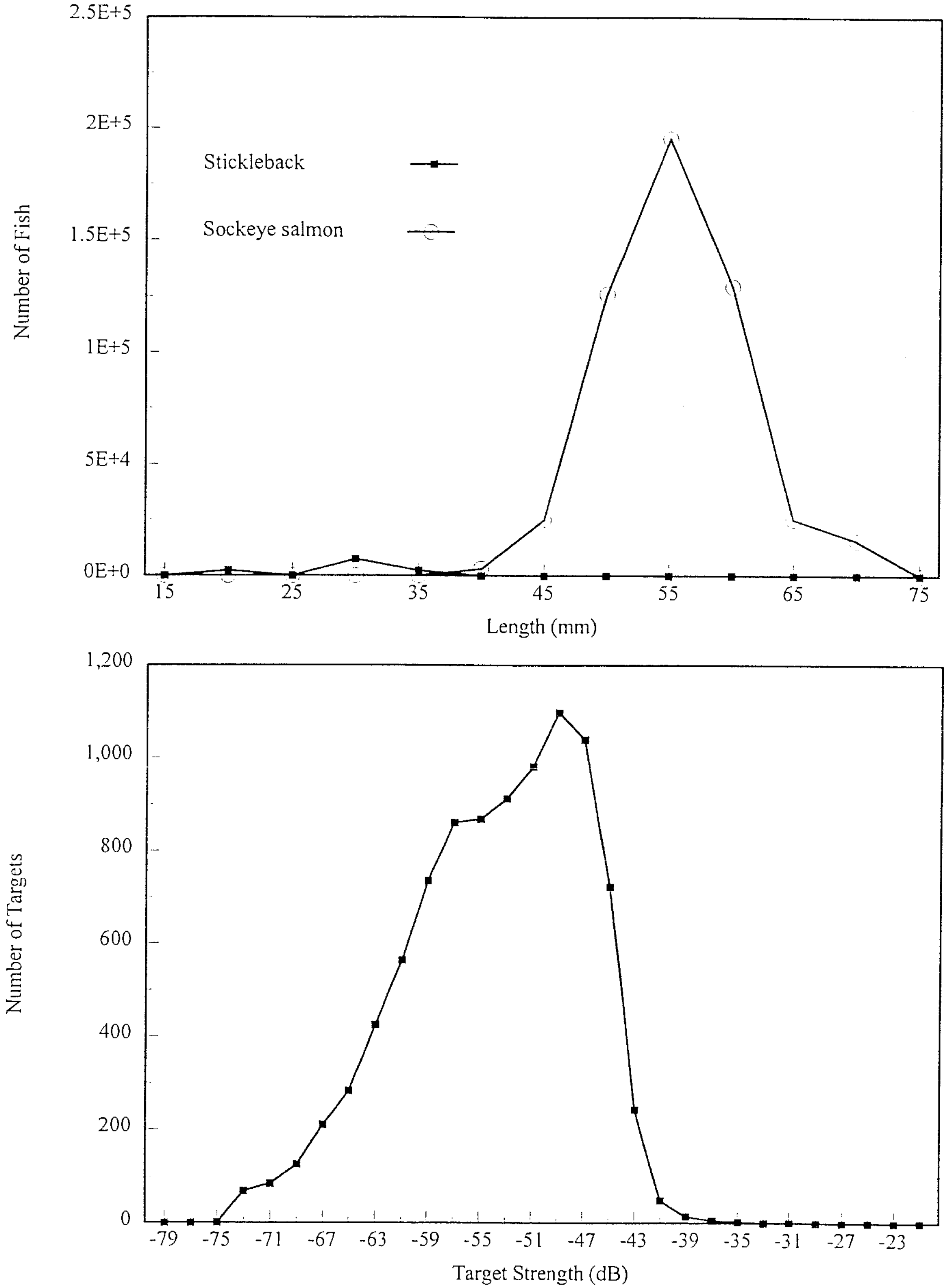


Figure 7. Larson Lake 1994 weighted length frequencies, (top) and target strength frequencies.

fig7.pre

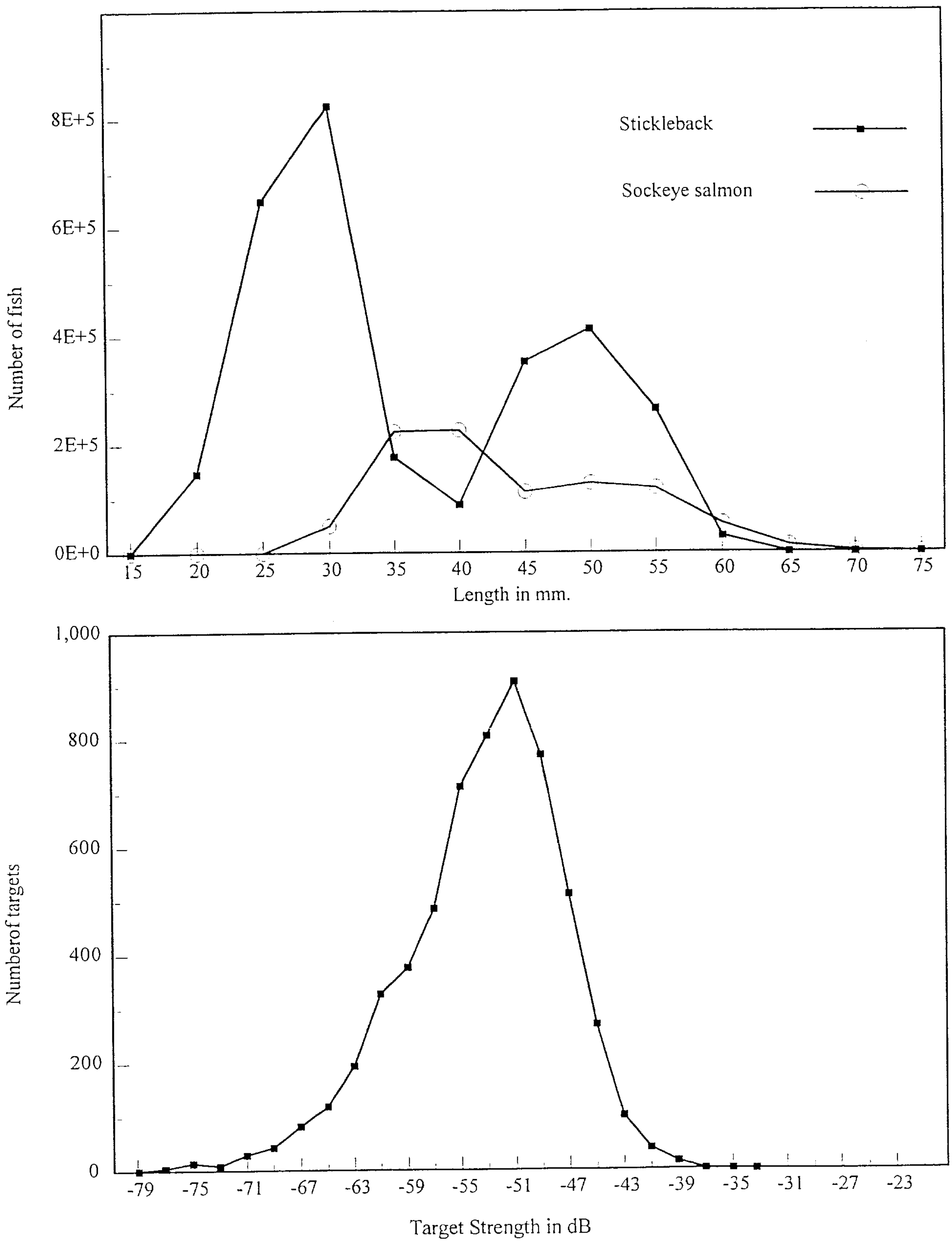


Figure 8. Hewitt Lake 1994 weighted length frequencies,(top) and target strength frequencies

fig8.pre

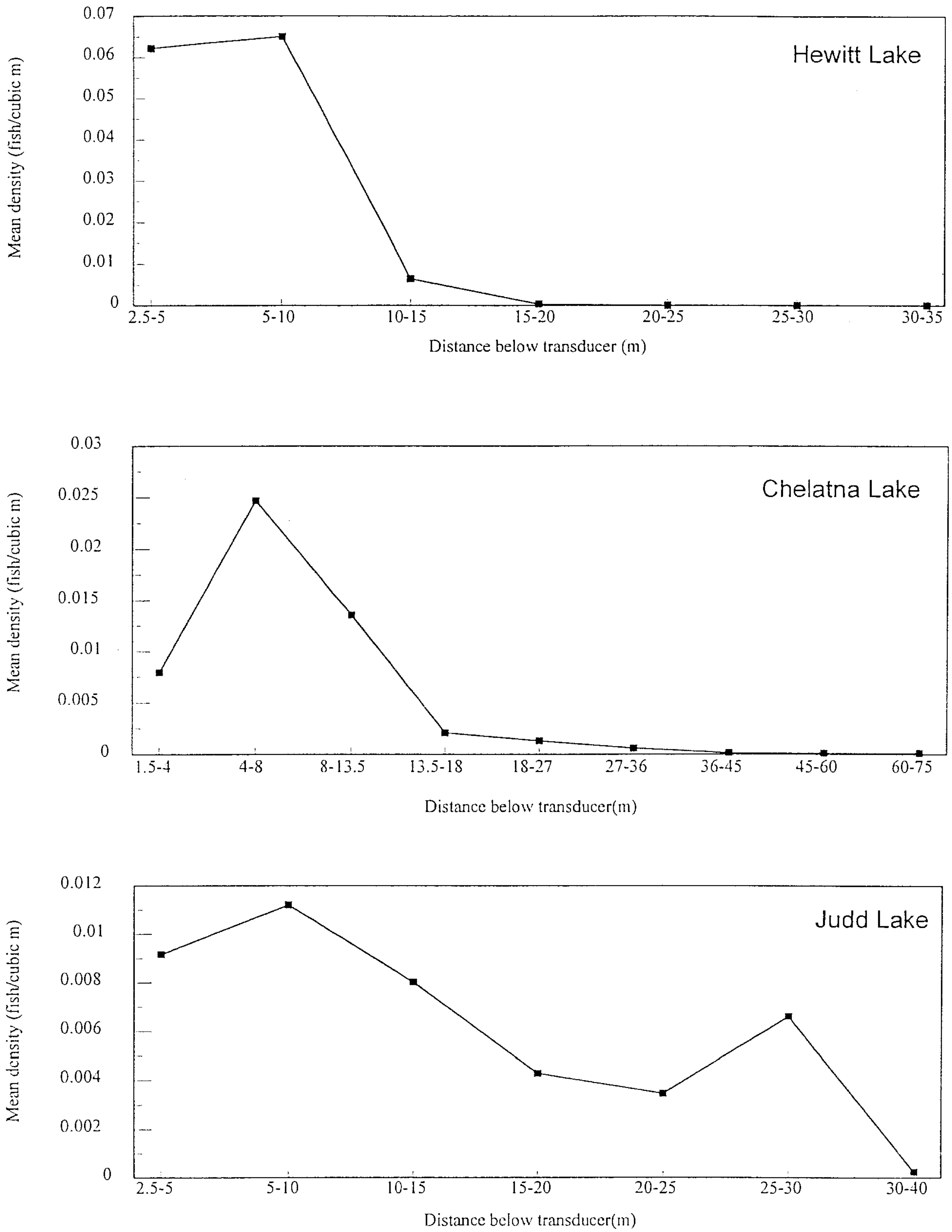


Figure 9. Mean density by depth stratum for Hewitt (top), Chelatna (middle) and Judd Lakes in 1995.

fig9 pre

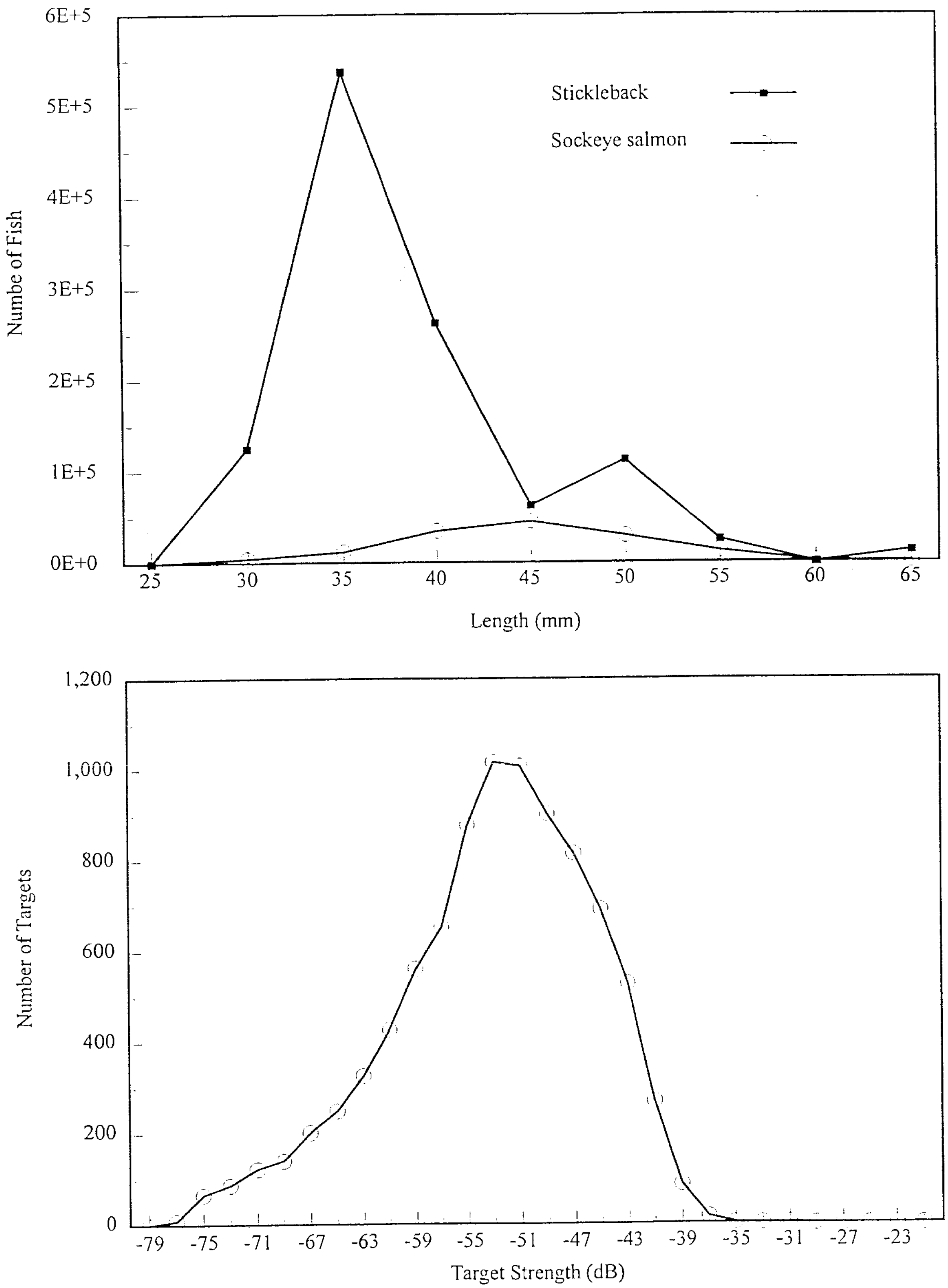


Figure 10. Hewitt Lake 1995 weighted length frequencies, (top) and target strength frequencies.

fig10.pre

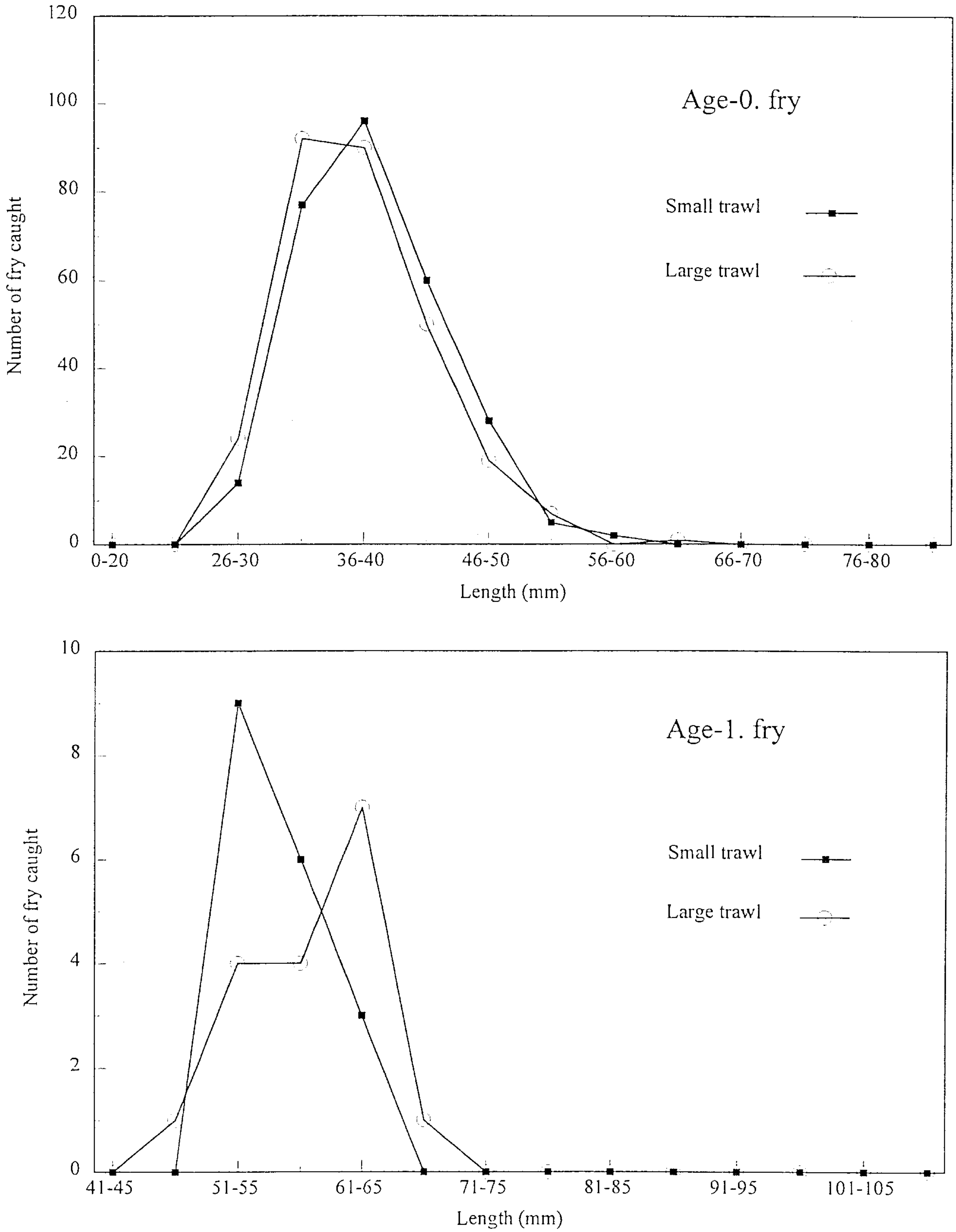


Figure 11. Length of sockeye fry (age-0. top) captured with two trawl sizes in Judd Lake, 1995.

fig11.pre

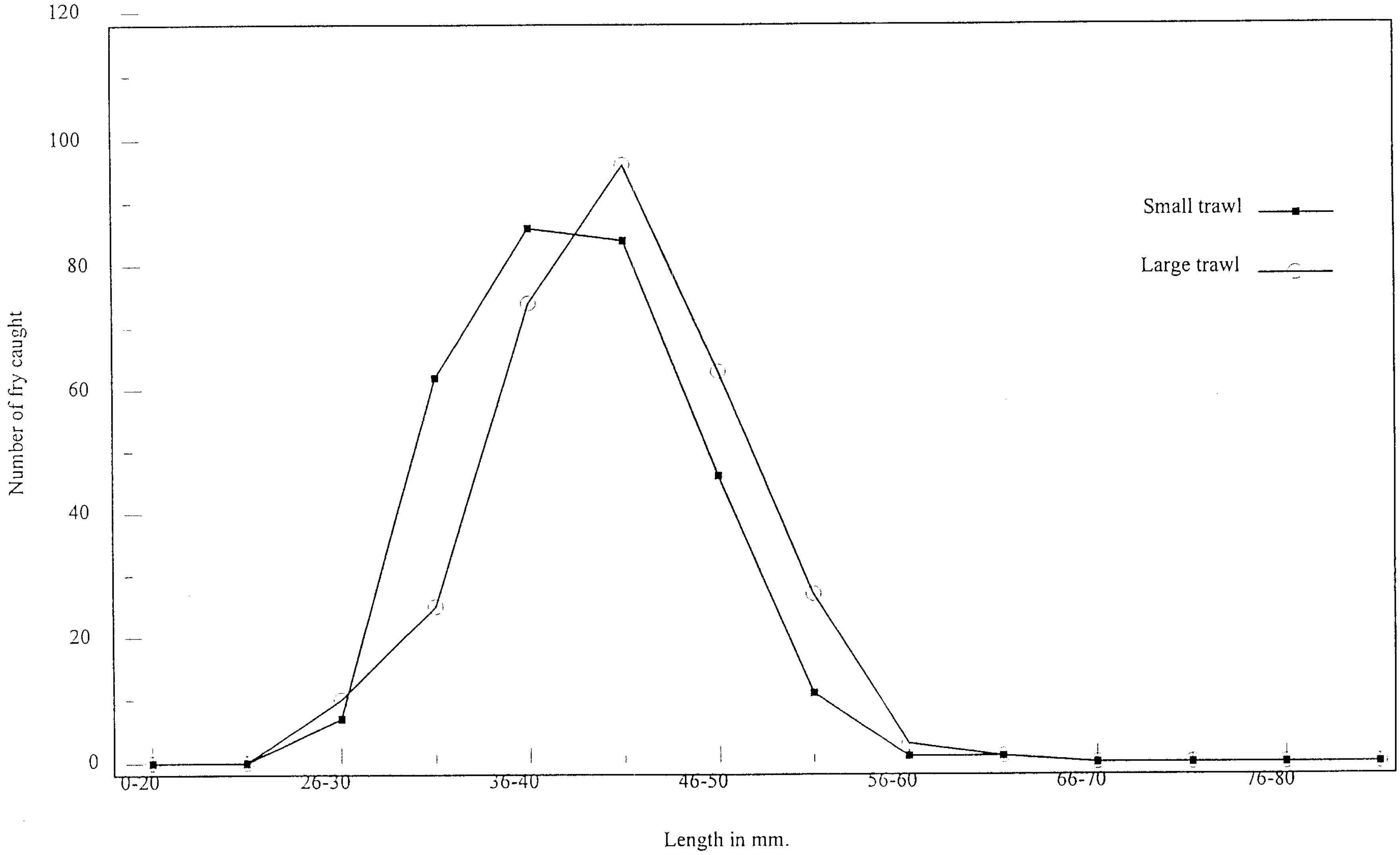
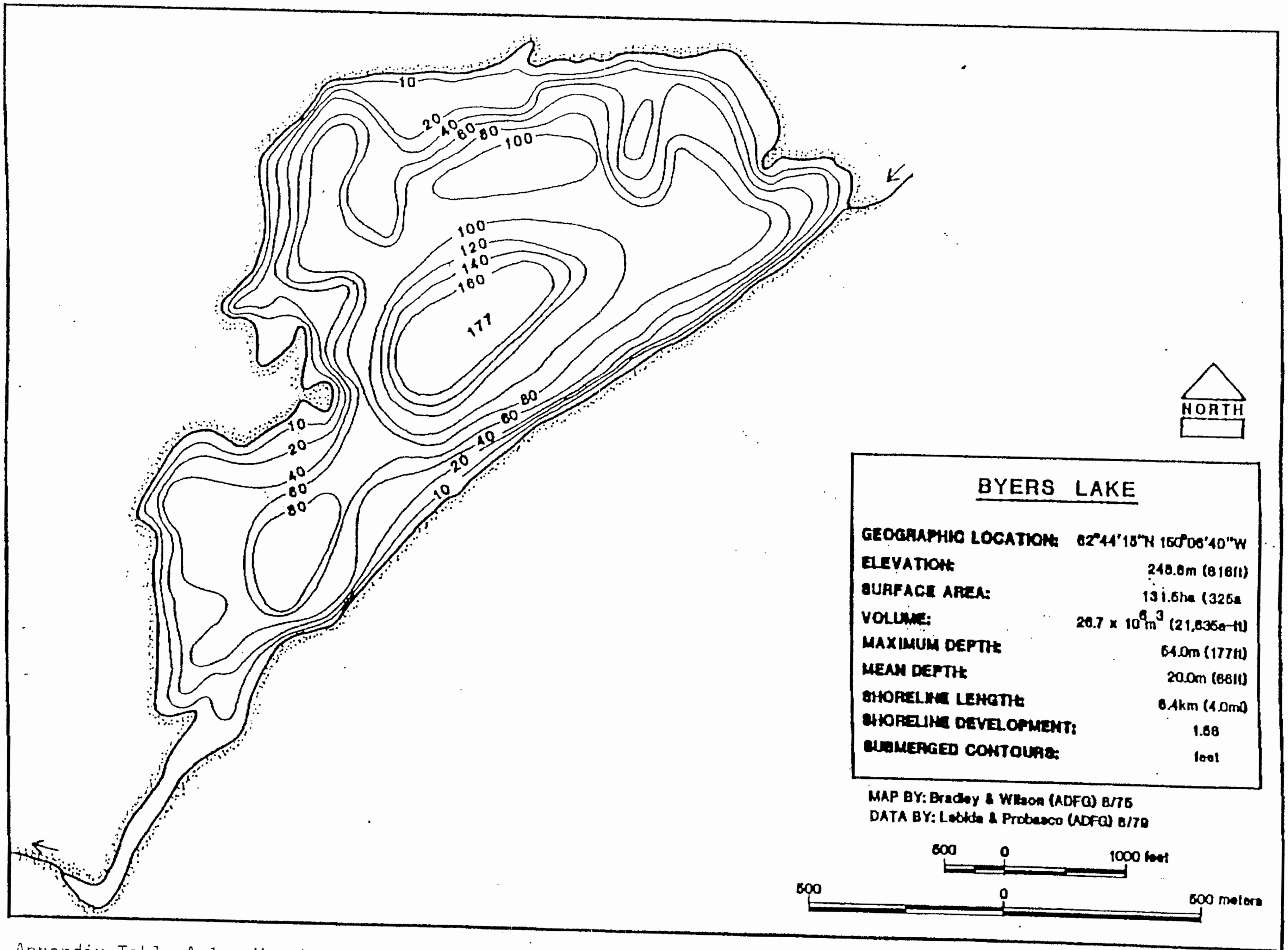


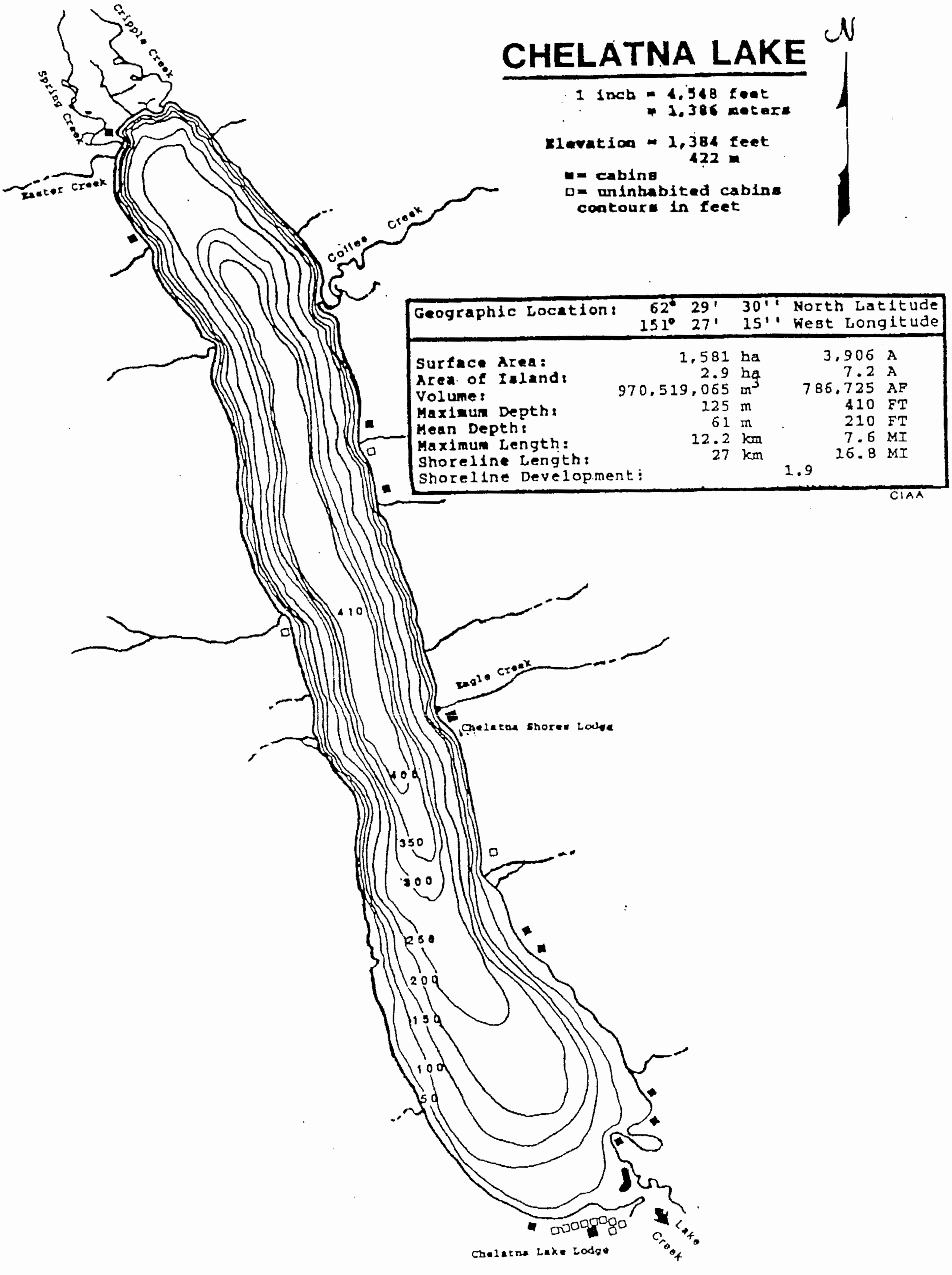
Figure 12. Lengths of age-0. sockeye fry captured with two trawl sizes in Hewitt Lake, 1995.

fig12.pre

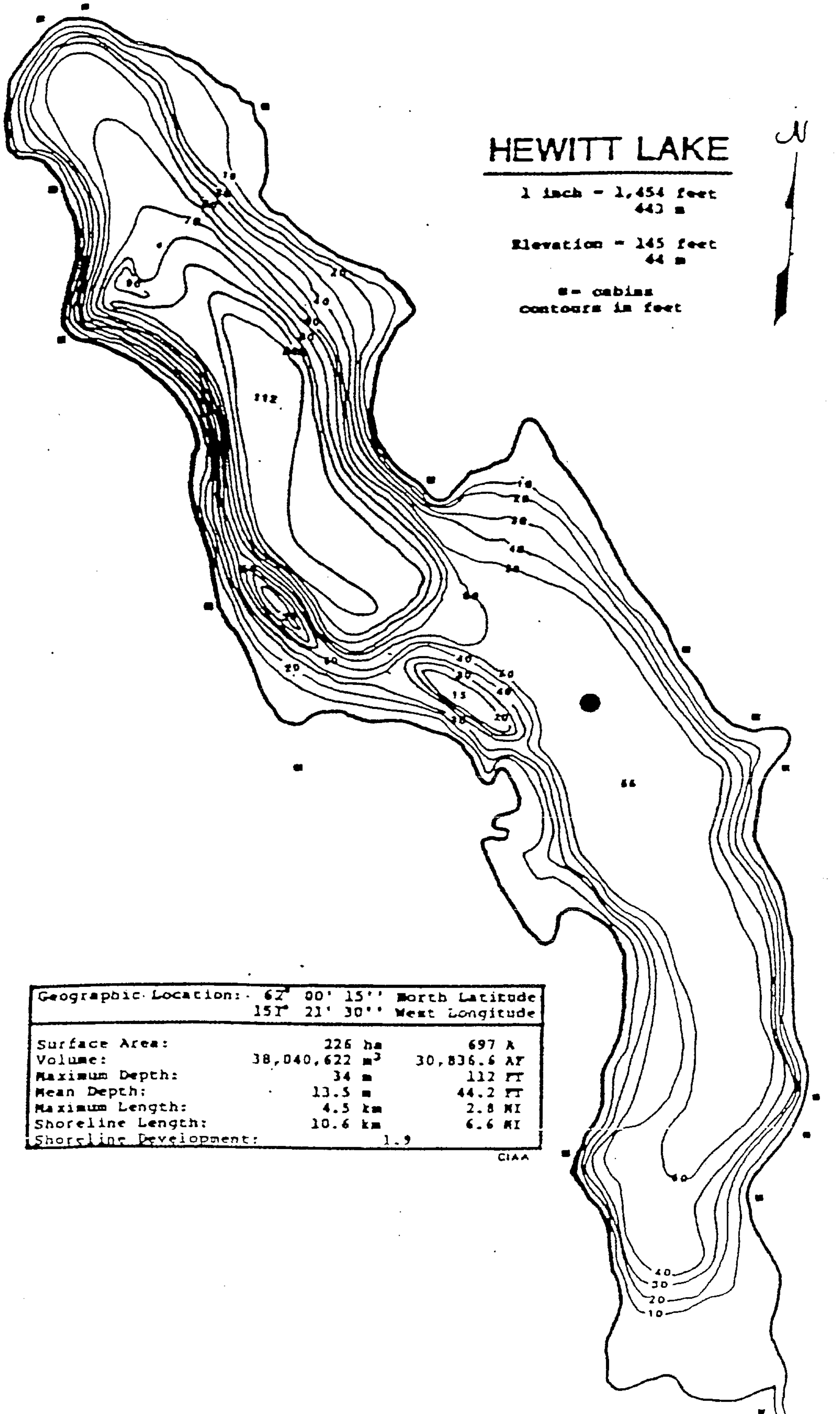
APPENDIX A



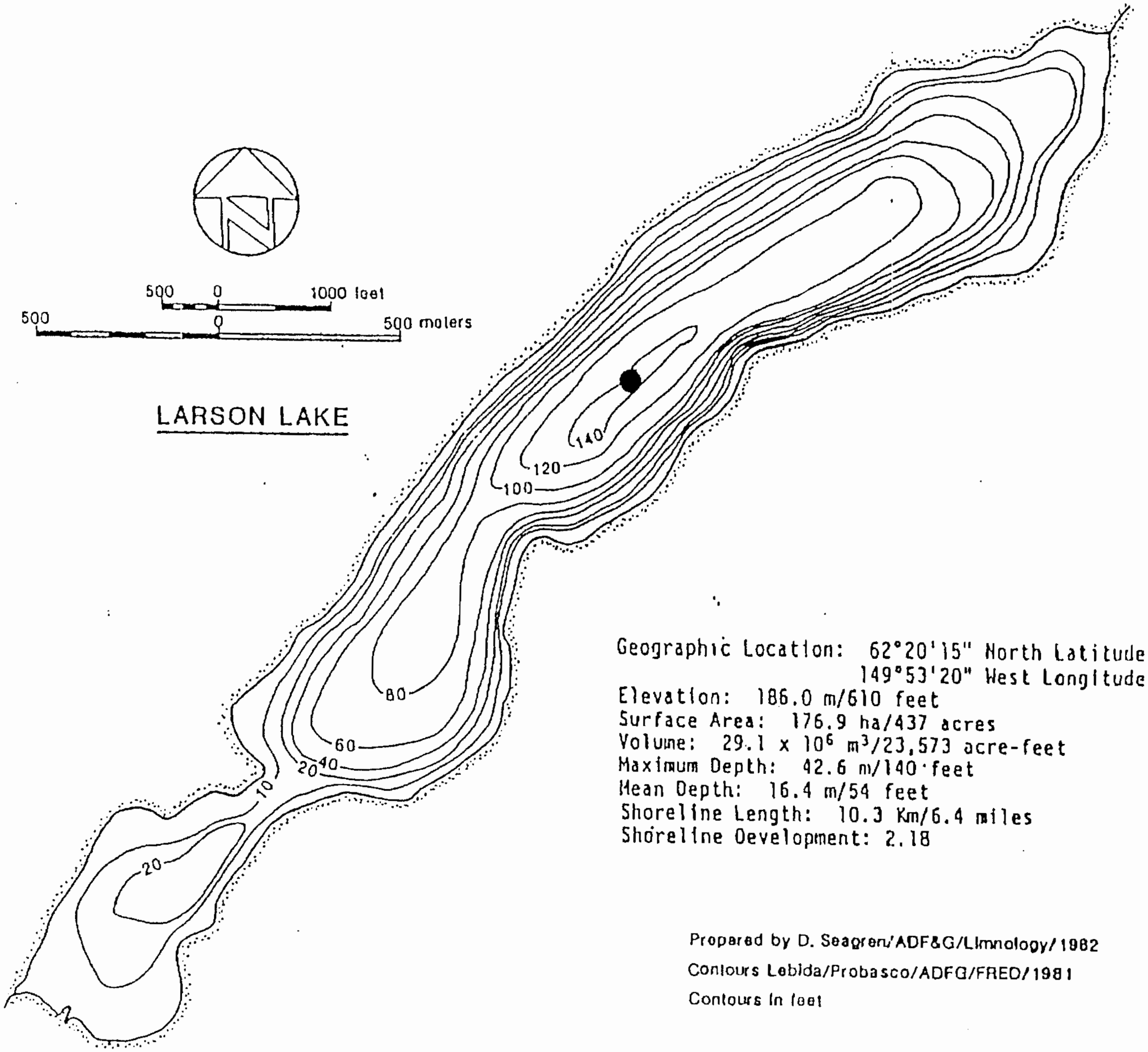
Appendix Table A.1. Morphometric map of Byers Lake



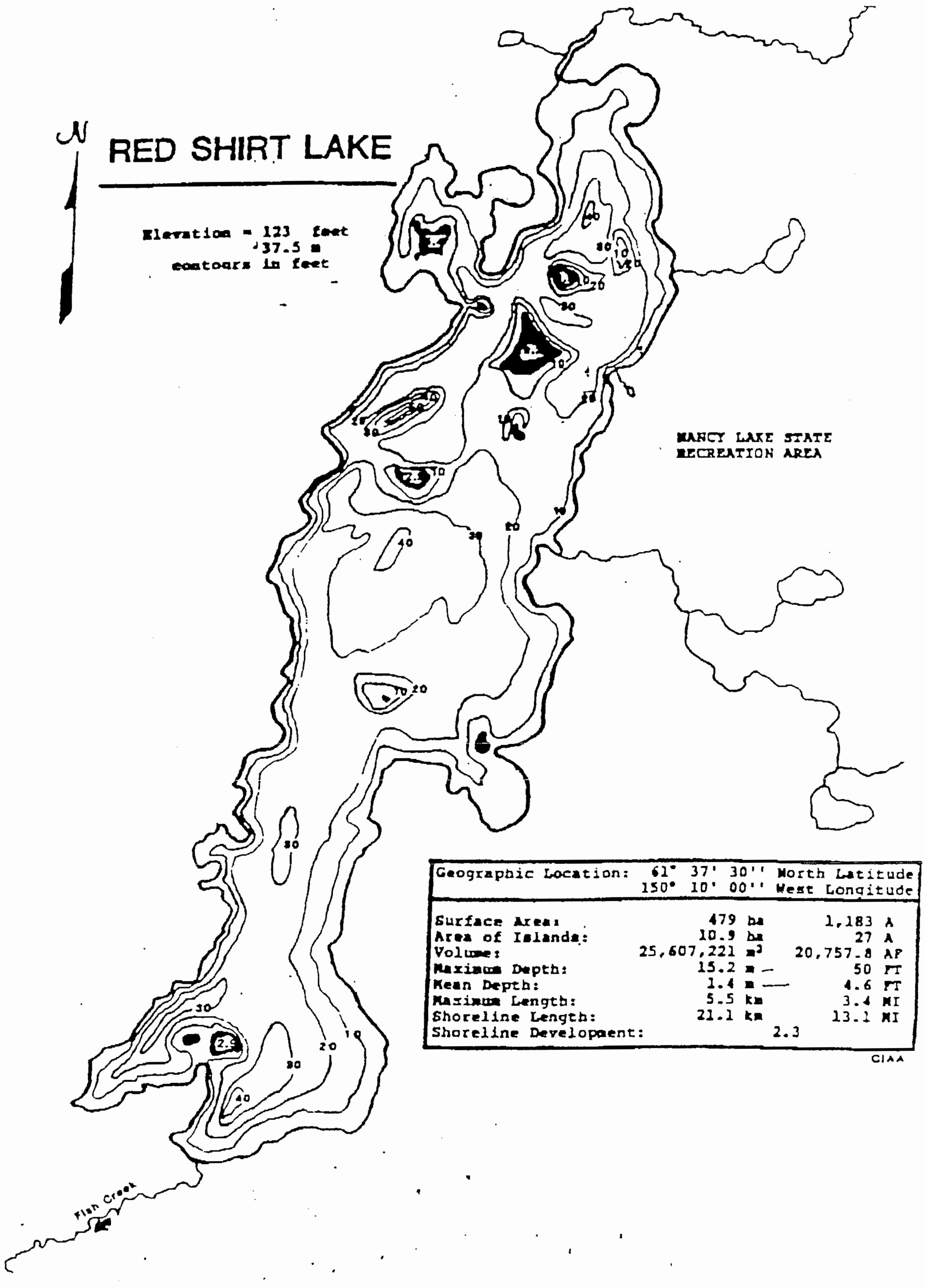
Appendix Table A.2. Morphometric map of Chelatna Lake.



Appendix Table A.3. Morphometric map of Hewitt Lake.

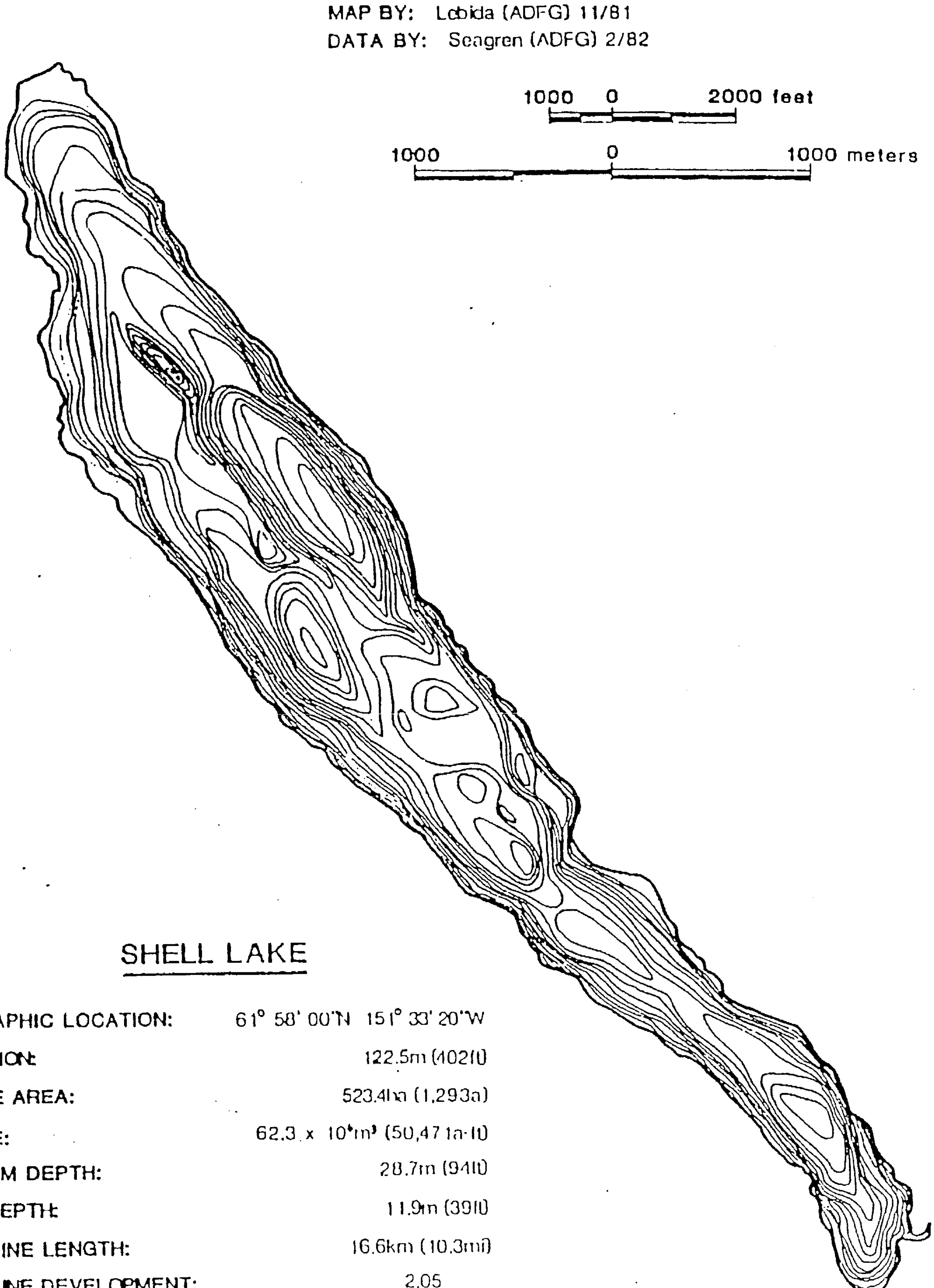


Appendix Table A.4. Morphometric map of Larson Lake.



Geographic Location:	61° 37' 30'' North Latitude			
	150° 10' 00'' West Longitude			
Surface Area:	479	ha	1,183	A
Area of Islands:	10.9	ha	27	A
Volume:	25,607,221	m^3	20,757.8	AF
Maximum Depth:	15.2	m	50	FT
Mean Depth:	1.4	m	4.6	FT
Maximum Length:	5.5	km	3.4	MI
Shoreline Length:	21.1	km	13.1	MI
Shoreline Development:	2.3			

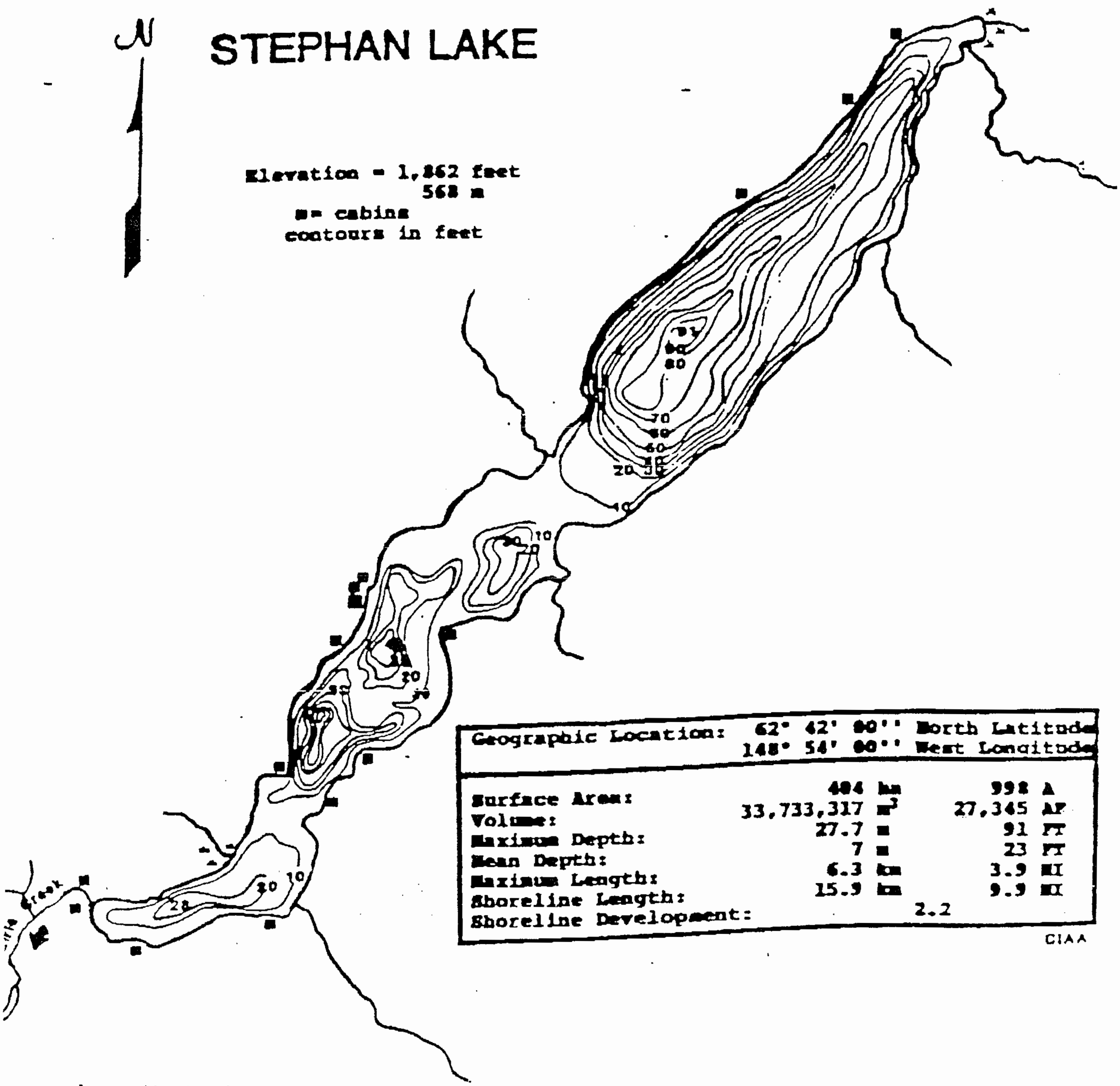
Appendix Table A.5. Morphometric map of Red Shirt Lake.



SHELL LAKE

GEOGRAPHIC LOCATION:	61° 58' 00"N 151° 33' 20"W
ELEVATION:	122.5m (402ft)
SURFACE AREA:	523.4ha (1,293a)
VOLUME:	62.3 x 10^6m^3 (50,471a-ft)
MAXIMUM DEPTH:	28.7m (94ft)
MEAN DEPTH:	11.9m (39ft)
SHORELINE LENGTH:	16.6km (10.3mi)
SHORELINE DEVELOPMENT:	2.05
SUBMERGED CONTOURS:	feet

Appendix Table A.6. Morphometric map of Shell Lake.



Appendix Table A.7. Morphometric map of Stephan Lake.

APPENDIX B

Appendix B1. Calibration and processing parameters for collections and analysis of target strength/length frequency comparisons for Larson Lake 1993 and Hewitt Lake 1994 surveys.

Sounder	Receiving sensitivity (dB/mP@ Im.)	Channel 1	40 log R=	-125.917 dB
			20 log R=	-137.962 dB
		Channel 2	40 log R=	-125.704 dB
			20 log R=	-136.989 dB
	Source level (dB/mP@im.)			217.805 dB
	TVG crossover			2.578 m.
	Receiver gain			6 dB
Transducer	Beam width		narrow	6 degrees
			wide	15 degrees
	Wide beam dropoff	A"coefficient		1.5138 dB
		B"coefficient		0.5678 dB
	Beam pattern factor	avg. squared value		1.49E-03
Dual beam processor	Correction multiplier	narrow beam		1.000 (0dB)
		wide beam		0.976 (dB)
	Threshold			
	'target strength collection			100 mV
	'ESPTS processing			300 mV(-68.325dB)
	'narrow beam			300 mV(-68.325dB)
	'wide beam			300 mV
	'bottom			7000 mV
	Integration file collection			
	Ei processing			
	'narrow beam			300 mV(-68.325dB)
	'wide beam			300 mV(-68.325dB)
	Maximum half angle			4
	Pulse width criteria	-18dB	Maximum	0.96 mS
		-6dB	Minimum	0.28 mS
		-6dB	Maximum	0.52 mS
	Bottom window			2 m
	Start depth			2 m
Echo Integrator		depth	B constant value	
		2-7m.	0.3282	
		7-12m.	0.0736	
		12-17m.	0.0316	
		17-22m.	0.0175	
		22-27m.	0.0111	
		27-32m.	0.0076	
		32-37m.	0.0056	
		37-42m.	0.0043	
		42-47m.	0.0034	
		47-52m.	0.0027	

Appendix B2. Calibration and processing parameters for collection and analysis of target strength/length frequency comparisons for Larson Lake 1994 survey.

Sounder	Receiving sensitivity (dB/mP@ lm.)	Channel 1	40 log R=	-125.917 dB
			20 log R=	-137.962 dB
		Channel 2	40 log R=	-125.704 dB
			20 log R=	-136.989 dB
	Source level (dB/mP@im.)			217.805 dB
	TVG crossover			2.578 m.
	Receiver gain			6 dB
Transducer	Beam width		narrow	6 degrees
			wide	15 degrees
	Wide beam dropoff	A" coefficient		1.5138 dB
		B" coefficient		0.5678 dB
	Beam pattern factor	avg. squared value		1.49E-03
Dual beam processor	Correction multiplier	narrow beam		1.000 (0dB)
		wide beam		0.976 (dB)
	Threshold			
	'target strength collection			100 mV
	'ESPTS processing			300 mV(-68.325dB)
	'narrow beam			300 mV(-68.325dB)
	'wide beam			300 mV
	'bottom			9000 mV
	Integration file collection			
	Ei processing			
	'narrow beam			300 mV(-68.325dB)
	'wide beam			300 mV(-68.325dB)
	Maximum half angle			4
	Pulse width criteria	-18dB	Maximum	0.96 mS
		-6dB	Minimum	0.28 mS
		-6dB	Maximum	0.52 mS
	Bottom window			2 m
	Start depth			2 m
Echo Integrator		depth	B constant value	
		2-7m.	0.3282	
		7-12m.	0.0736	
		12-17m.	0.0316	
		17-22m.	0.0175	
		22-27m.	0.0111	
		27-32m.	0.0076	
		32-37m.	0.0056	
		37-42m.	0.0043	
		42-47m.	0.0034	
		47-52m.	0.0027	

Appendix B3. Calibration and processing parameters for collection and analysis of target strength/length frequency comparisons for Hewitt Lake 1995 survey.

Sounder	Receiving sensitivity (dB/mP@ lm.)	Channel 1	40 log R=	-126.68 dB
			20 log R=	-125.06 dB
		Channel 2	40 log R=	-126.93 dB
			20 log R=	-124.87 dB
	Source level (dB/mP@im.)			217.63 dB
	TVG rossover			12.053 m.
	Receiver Gain			6 dB
Transducer	Beam width		narrow	6 degrees
			wide	15 degrees
	Wide beam dropoff	A" coefficient		1.919 dB
		B" coefficient		0.424 dB
	Beam pattern factor	avg. squared value		1.01E-03
Dual beam processor	Correction multiplier	narrow beam		1.000 (0dB)
		wide beam		1.029 (dB)
	Threshold			
	Target strength collection			100 mV
	'ESPTS processing			300 mV(-67.4dB)
	'narrow beam			300 mV(-67.4dB)
	'wide beam			300 mV
	'bottom			9000 mV
	Integration file collection			
	Ei processing			
	'narrow beam			300 mV(-67.4dB)
	'wide beam			300 mV(-67.4dB)
	Maximum half angle			4
	Pulse width criteria	-18dB	Maximum	0.96 mS
		-6dB	Minimum	0.28 mS
		-6dB	Maximum	0.52 mS
	Bottom window			2 m.
	Start depth			2 m.
Echo Integrator		depth	B constant value	
		2-7m.	6.9169	
		7-12m.	1.5520	
		12-17m.	0.6619	
		17-22m.	0.3684	
		22-27m.	0.2333	
		27-32m.	0.1610	
		32-37m.	0.1177	
		37-42m.	0.0898	
		42-47m.	0.0732	
		47-52m.	0.0572	
		52-57m.	0.0472	
		57-62m.	0.0396	

Appendix B4. Calibration and processing parameters for collection and analysis of hydroacoustic data from 1995 Hewitt and Chelatna Lakes sidelooking surveys.

Sounder	Receiving sensitivity (dB/mP@1m.)	Channel 1	40 log R=	-126.68 dB
			20 log R=	-125.06 dB
		Channel 2	40 log R=	-126.93 dB
			20 log R=	-124.87 dB
	Source level (dB/mP@im.)			217.63 dB
	TVG crossover			12.053 m.
	Receiver Gain			6 dB
Transducer	Beam width		narrow	6 degrees
			wide	15 degrees
	Wide beam dropoff	A" coefficient		1.919 dB
		B" coefficient		0.424 dB
	Beam pattern factor	avg. squared value		1.01E-03
Dual beam processor	Correction multiplier	narrow beam		1.000 (0dB)
		wide beam		1.029 (dB)
	Threshold			
	Target strength collection			100 mV
	'ESPTS processing			Hewitt 650 mV - Chelatna 500 mV
	'narrow beam			650 mV - Chelatna 500 mV
	'wide beam			300 mV
	'bottom			9000 mV
	Integration file collection			
	Ei processing			
	'narrow beam			Hewitt 650 mV - Chelatna 500 mV
	'wide beam			650 mV - Chelatna 500 mV
	Maximum half angle			4
	Pulse width criteria	-18dB	Maximum	0.96 mS
		-6dB	Minimum	0.32 mS
		-6dB	Maximum	0.48 mS
	Bottom window			1 m.
	Start depth			1 m.
Echo Integrator		Stratum	B constant value	
		1-2m	6.9169	
		2-3m	1.5520	
		3-4m	0.6662	
		4-5m	0.3684	
		5-6m	0.2333	
		6-7m	0.1610	
		7-8m	0.1177	
		8-9m	0.0898	
		9-10m	0.0707	
		10-11m	0.0572	
		11-12m	0.0472	
		12-13m	0.0396	
		13-14m	0.0337	
		14-15m	0.0290	
		15-16m	0.0252	
		16-17m	0.0222	
		17-18m	0.0196	
		18-19m	0.0175	
		19-20m	0.0157	
		20-21m	0.0157	