FRED Reports

Summary of Acoustically-Derived Population Estimates and Distributions of Juvenile Sockeye Salmon *(Oncorhynchus nerka)* in 17 Lakes of Southcentral Alaska, 1982-1987

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June 1990

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

ABSTRACT

During 1982-1987, 54 hydroacoustic surveys were conducted on 17 lakes in southcental Alaska to estimate populations of rearing juvenile sockeye salmon (*Oncorhynchus nerka*), and to determine their nighttime vertical and horizontal rearing distributions. Population estimates of sockeye salmon juveniles ranged from 40,000 to over 18 million, the 95% confidence intervals ranged between ±3-58% of the mean population estimate, and averaged ±17% for the 54 surveys. Except for a few surveys, the horizontal distributions of fish along transects were quite uniform. Vertical fish distributions, in most of the surveys, were consistent with other investigations; sockeye salmon juveniles were distributed in the upper to middle part of the water column at night. No significant differences ($p<0.05$) in vertical or horizontal distributions were found during immediate re-run of transects or whole lake series. Finally, there are a variety of sources for potential error in the hydroacoustic/townet technique to assess limnetic populations of juvenile sockeye salmon. The most evident source of potential error in the surveys was the bias in townet catches relative to representing all age groups of juvenile sockeye salmon (cohorts), and to a lesser extent, in representing limnetic fish species. In 35 of 46 surveys that were sampled by townet for species composition, juvenile sockeye salmon represented over 80% of the population.

INTRODUCTION

Determining the number and condition of juvenile sockeye salmon in lakes is essential in regard to assessing fry recruitment, growth, survival, distribution patterns, and fish interactions with other trophic levels. As part of the evaluation of lake-fertilization and lake-stocking projects, the Limnology Section of the Alaska Department of Fish and Game (ADF&G), Division of Fisheries, Rehabilitation, Enhancement, and Development (FRED) intiated the use of acoustical techniques in 1982 to determine juvenile sockeye salmon abundance and distribution.

Echosounders have been employed to study fish distribution and relative abundance since the mid-1930's (Thorne 1983). Since the mid-1960's, the understanding and application of acoustical principles have dramatically advanced. Combining these new advancements with recent improvements in echosounders, signal recorders, and automated signal processors, have resulted in a wide variety of successful applications of acoustic techniques to determine fish population estimates; especially for juvenile sockeye salmon (Thorne and Woodey 1970; Croker 1973; Nunnallee 1980; Brannian et al. 1981; Burczynski and Johnson 1986).

The purpose of this report is to present a summary of juvenile sockeye salmon population estimates and nightime rearing distributions based on acoustic/townet surveys of 17 lakes in southcentral Alaska. In addition, this report serves as a reference to how acoustical surveys were conducted during 1982-1987 by the FRED Limnology Section, and the acoustical data processing and analyses used to estimate juvenile fish populations. Finally, sources of error associated with acoustical estimation of fish populations in lakes are discussed.

METHODS

Hydroacoustic Instrumentation-- The data acquistion system utilized during the 1982-1983 surveys comprised of four components: 1) a Simrad® EY-M echosounder; 2) a Sony TCD cassette tape recorder; 3) a Tektronix 214 oscilloscope and; 4) a fin-mounted narrow beam (nominal 11°) transducer. The Simrad EY-M echosounder has an operating frequency of 70 kHz and is designed for portable applications. A 10-kHz output frequency allowed recording of hydroacoustic data on a magnetic cassette tape recorder in the analog format. The output frequency of the echosounder is near the high end of the response scale for most of the cassette recorders, and therefore it was neccessary to use high-quality, metallic recording tape. Calibration signals were

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measured with the oscilloscope and were recorded on tape at the beginning and end of each transect to check for system drift. Fish signals were recorded both on tape and on the build-in paper chart recorder of the Simrad EY-M.

During the 1984-1987 surveys, a BioSonic 105 echosounding system was used. This echosounder is also designed for portable use, and has components similar in function to that of the Simrad EY-M system. However, the BioSonic echosounder and the video cassette recording (VCR) system are more stable and flexible. In addition, because of a higher operating frequency, this system is more suited for freshwater fishery assessment. The BioSonic echosounder has a frequency of 420 kHz and was used in conjuction with either a single-beam (nominal 6°) or dual-beam (nominal 6°/15°) transducer mounted in a towed body. The transmission of sound waves from the BioSonic sounder is more selectable than the Simrad EY-M; the pulse width ranges between 0.2-1.6 ms, and the ping rate selection ranges between 0.2-30 pings/sec. The recording system used with the BioSonic system comprised of a Sony SL-2000 VCR, a Sony PCM-F1 digital audio processor, and a BioSonic 171 recorder interface. This recording system is superior to others, especially compared to the analog cassette system, in that the dynamic range is at least 70 dB greater. A BioSonics 115 paper chart recorder was also used to record fish signals. Finally, calibration signals were measured with a Tektronix 214 oscilloscope, and because of the stability of the BioSonic sounder; calibrations were recorded only at the beginning and at the end of each survey.

Hydroacoustic Data Acquisition-- The receiver gain for surveys conducted with the Simrad EY-M echosounder was usually set at 8, and the ping rate at 3 pings/sec. The pulse width of the Simrad EY-M is fixed at 0.6 m/sec. System calibration signals were also recorded at setting 8 and ranged between 1.8-2.0 volts (peak-peak) at 50 ms. All surveys were conducted with the time-varied-gain (TVG) set at 40 log (R). System settings for surveys conducted with the BioSonic echosounder were +12 dB receiver gain, 5 pings/sec, 0.4 ms pulse width, and 40 log (R) TVG. The calibrator control was set at 20 dB at a gain setting of +12 dB to produce a calibration signal close to 10 volts (peak-peak) at 5 ms.

Basically, a lake survey comprised of recording hydroacoustic data along at least six transects orthogonal to the longitudinal axis of the lake, and chosen to equally represent all lake areas and basins. In the 1982-1983 surveys, and in the larger lakes (Karluk, Frazer, Tosina, Tazlina, Klutina, Summit and Crescent), only one transect series was completed (recording hydroacoustic data along all transects only once). However, beginning in 1984, two transect runs on the smaller lakes were usually conducted (individual transects were immediately re-run). In 1987, all transects of six smaller lakes were sampled once as a series before starting a second series on the same night to evaluate vertical and horizontal fish migration between transect series (distributional changes within a survey). All acoustic surveys were done during the darkest period of night, when juvenile sockeye salmon are normally distributed in the upper to middle part of the water column (Narver 1970; McDonald 1973; Eggers 1978; Simpson et al. 1981; Nunnallee 1983; Burczynski and Johnson 1986; Levy 1987). Transecting speed was fixed at 1.5 m/sec, and was measured three times per transect with the use of a Marsh-McBirney flow meter. Flashing strobe lights were placed at both ends of each transect to assist in maintaining transect course.

Hydroacoustic Data Analysis-- All recorded hydroacoustic tapes were analysed under State of Alaska contract with Dr. Richard Thorne of BioSonics, Inc. (formerly of the Fisheries Research Institute of the University of Washington). The analysis procedures he used to compute fish population estimates are described in the following three sections.

Echo Counting: Echo counting was done when the densities of fish and occurrence of multiple targets were relatively low. This technique involves visual counting of targets displayed on a storage oscilloscope in numerous depth strata. The number of depth strata is dictated by the density of targets, as each strata has to be sufficiently narrow enough to allow the analyst to visually discriminate and count targets. This method is more tedious than echo-integration procedures, but, in lakes with low fish densities is more accurate (Thorne 1983).

The first step in echo counting is the determination of a minimum counting threshold to eliminate problems of background noise and side-lobe detections. The counting threshold was established on target amplitudes and noise levels, and was approximately 30 dB below the largest targets. The echosounder 40 log (R) TVG correction for range losses allows the counting threshold to be equivalent for a constant target strength at all depths.

The next step in the echo-counting procedure is determining the beam dimension or the sampling volume of insonified water. Sampling volumes were measured by the duration-in-beam method (Nunnallee and Mathisen 1972; Saville 1977; Nunnallee 1980; Thorne 1988). This method is based on the premise that the number of times each target is detected in the water column is proportional to the area of detectability at a given depth. This premise allows the use of the following formula to compute the radius of the cross-sectional area of the sampling cone Nunnallee 1980):

$$r = \frac{4 \times s \times \bar{e}}{\pi P_r}$$

where s = boat speed (m/sec)

$\bar{e}$ = mean number of echoes per target

P_r = pulse repitition rate of echosounder.

After the sampling area was computed, fish targets over the counting threshold were recorded for each depth strata. Fish counts by depth strata were made along each transect in increments (usually 1-5 minutes) depending on transect duration. Beginning in 1984, fish densities were computed for one-third subsections of every transect to evaluate horizontal distribution. Fish density was computed for each transect increment using the following empirical formula (Nunnallee 1980):

$$FD = \frac{10^3 \times I_t}{V_{eff} \times P}$$

where FD = fish density (fish/10^3 m^3)

I_t = total insonification count for a depth strata for each transect increment

Veff. = effective sample volume per pulse (m^3/pulse)

P = number of pulses in a given depth strata for each increment.

Echo Integration: Echo integration is an automated, signal-processing technique that is used when targets are too dense and cannot be individually counted (high number of multiple targets). The integration procedure is based on the premise that the output of an integrator is directly proportional to the squared mean number of detected signals from an echosounder (Thorne 1971).

Of the 54 hydroacoustic surveys conducted during 1982-1987, 19 (35%) required integration analysis. For those surveys, the recorded hydroacoustic data were integrated using a BioSonics 120 series echo integrator. In all cases, the integrator output was scaled empirically (linear regression technique) to echo counts made in a variety of areas (different locations and depths) in which fish densities were low enough (Nunnallee 1983). The correlation coefficient for the regression between echo counts and integration values usually exceeded 0.90. As in the echo-counting method, beginning in 1984, fish densities were computed for selected depth strata for all transects, and by one-third subsections of each transect.

Population Estimates: When two estimates of density per transect were obtain (replication of transects), fish densities (no./m^3) for each depth strata and transect increment were summed to determine total areal fish density (no./m^2) for each transect. A mean fish density ($\overline{D}$; no./10^3 m^2) and an associated variance (VAR) for each transect replicate were then computed using the following formulae after Thorne (1982):

$$\overline{D} = \sum_{k=1}^{R} L_{ik} \times D_{ik} \div \sum_{k=1}^{R} L_{ik}$$

$$VAR\ \overline{D} = \sum_{k=1}^{R} L_i \times (D_{ik} - \overline{D}_i)^2 \div (R-1) \sum_{k=1}^{R} \times L_{ik}$$

where R = replicates

D_{ik} = fish density (no./10^3 m^2 of transect *i* for replicate *k*

L_{ik} = length of transect *i* for replicate *k*.

Next, the fish population estimate for each depth stratum (N_s) was computed by extrapolation of mean fish density ($\overline{D}$; fish/10^3 m^2) by volume stratum (V_s), and the N_s variance computed:

$$N_s = V_s \times \overline{D}$$

$$VAR\ N_s = (V_s)^2 \times VAR\ \overline{D}$$

Finally, the total fish population estimate (N_t) and variance were computed by summation of the products of N_s and VAR N_s, and the 95% confidence interval ($CI_{.95}$) computed:

$$CI_{.95} = \sqrt{VAR\ N_t} \times 1.96$$

If only one transect series was conducted, the fish densities and variances were computed by collapsing adjacent transects into a strata (Bazigos 1976), using the following formulae:

$$\overline{WD_{si}} = \frac{(MD_i \times L_i) + (MD_{ai} \times L_{ai})}{L_s}$$

where $\overline{WD_{si}}$ = weighted mean fish density of strata *i* (no./10^3 m^2)

MD_i = mean fish density of transect *i* (no./10^3 m^2)

MD_{ai} = mean fish density of adjacent transect *i* (no./10^3 m^2)

L_i = length of transect *i*

L_{ai} = length of adjacent transect i

L_s = length of strata

and

$$VAR\ \overline{WD_{si}} = \frac{[(MD_i - \overline{WD_{si}})^2 \times L_i] + [(MD_{ai} - \overline{WD_{si}})^2 \times L_{ai}]}{L_s}$$

$$WA_{si} = \frac{(A_i \times L_i) + (A_{ai} \times L_{ai})}{L_s}$$

where WA_{si} = weighted area of strata i (10^3 m^2)

A_i = area of transect i (10^3 m^2)

A_{ai} = area of adjacent transect i (10^3 m^2).

Fish population estimates for each strata were computed by multiplying WA_{si} by WD_{si}. Total fish population estimates were computed by summing strata population estimates, and the strata population estimate variances. The variance and 95% confidence intervals for the total fish population estiumates were calculated using the following formulae after Thorne (1982):

$$Var\ FP_{si} = (WA_{si})^2 \times \overline{WD_{si}}$$

where VAR FP_{si} = variance of the total fish population for strata i, and

$$CI_{.95} = \sqrt{VAR\ FP_{si-n}} \times 1.96$$

where VAR FP_{si-n} = sum of all (i-n) fish population strata variances.

Townet catches were used to compute the juvenile sockeye salmon population estimates. This was accomplished by multiplying the composition of juvenile sockeye salmon in the combined net tows by the total fish population estimate. Transect/strata variances and the 95% confidence interval for the juvenile sockeye salmon population estimates were computed using the following formulae after (Thorne 1982):

$$VAR\ SP_{t/si} = (SC)^2 \times VAR\ FP_{si-n}$$

where VAR $SP_{t/si}$ = variance of juvenile sockeye salmon population for transect/strata *i*

SC = juvenile sockeye salmon percent composition

and

$$CI_{.95} = \sqrt{VAR\ SP_{t/si-n}} \times 1.96$$

where VAR $SP_{t/si-n}$ = sum of all (*i-n*) juvenile sockeye salmon population transect/strata variances.

Townet Sampling-- Townetting was utilized as a ground-truth technique to interpret the recorded hydroacoustic data. In addition to species composition, townetting provided age composition (and size - not reported here) of juvenile sockeye salmon. The townet technique used was similar to that described by Gjernes (1979). The townet measured 2 m x 2 m at the mouth, and was 7.5 m in length. The body of the net was constructed of three different mesh sizes (stretch measure) of knotless nylon (3.8 cm, 1.3 cm, 0.6 cm), and the cod-end was constructed of 0.3-cm (stretch measure) knotless nylon. Ten-meter bridles were attached to the corners of each side of the net and were attached to a 75-m tow line. The townet was held open at the top by a 10-cm diameter, 2.2-m long, sealed plastic pipe filled with polyurethane foam, and at the bottom by a 5-cm diameter, 2.2-m long, 16-kg steel pipe. Towing depth was maintained by attaching a 1.3-cm diameter polypropylene rope (the length of desired towing depth) to 0.5-m diameter floats tied to each side of the top float bar. The two surface floats provided extra buoyancy to the upper float bar, aided in keeping the upper float bar horizontal, and provided a visual indication that the net bridle was not tangled.

Finally, net tows were usually duplicated respective to length and location. Because of the shortage of daylight, and the need to minimize net avoidance, towing was usually conducted on the night following the hydroacoustic survey. Most tows were of 30-min duration (at fishing depth), and conducted at a speed of 1.0 m/sec at mid-depths where high concentrations of acoustic targets were observed. Fish samples were stored in 15%

neutralized formalin. Ages of juvenile sockeye salmon were determined from scale smears (mounted on glass slides) using a microfische projector.

RESULTS AND DISCUSSION

Horizontal Distributions-- In general, fish were distributed quite equally along the transects of most surveys, and there appeared to be a fairly consistent horizontal pattern of fish distribution between early- and late-fall of most surveys (Figures 1-7). For example, in the 1984 July survey of Packers Lake, the middle subsection of all transects comprised 41% of the total horizontal distribution, while in October of the same year, 36% of the total was distributed in the middle subsection (Figure 5B). In August and October 1985, the middle subsection comprised 45% and 44% respectively, of the total horizontal distribution in Packers Lake; and in July and September 1986, the middle subsection contained 32% and 45% of the total fish density, respectively. Similarly, in Leisure Lake, the distribution in the middle subsection during early- and late-fall surveys was consistent (Figure 1A). In 1985, during the August and October surveys, the middle subsection comprised 32% and 40% respectively, of the total density of fish distributed across all transects. In 1986, during the August and October surveys, the middle subsections made up 39% and 33% respectively, of the total fish density in Leisure Lake.

Contrary to the above, there were substantially fewer numbers of fish in the middle transect third of some surveys at Tokun and Frazer Lakes. For example, in the 1985 and 1986 August surveys at Tokun Lake, the middle subsection comprised 18% and 19% respectively, of the total fish density (Figure 1B). In September of 1986 and August of 1987, fish were more uniformally distributed, as the percentage of fish density in the middle subsection increased to 27% and 26%, respectively. Similarly, in the August and September surveys of 1986 on Frazer Lake, the middle subsection contained 17% and 18% respectively, but ranged from 25-37% for all other surveys (Figure 2B).

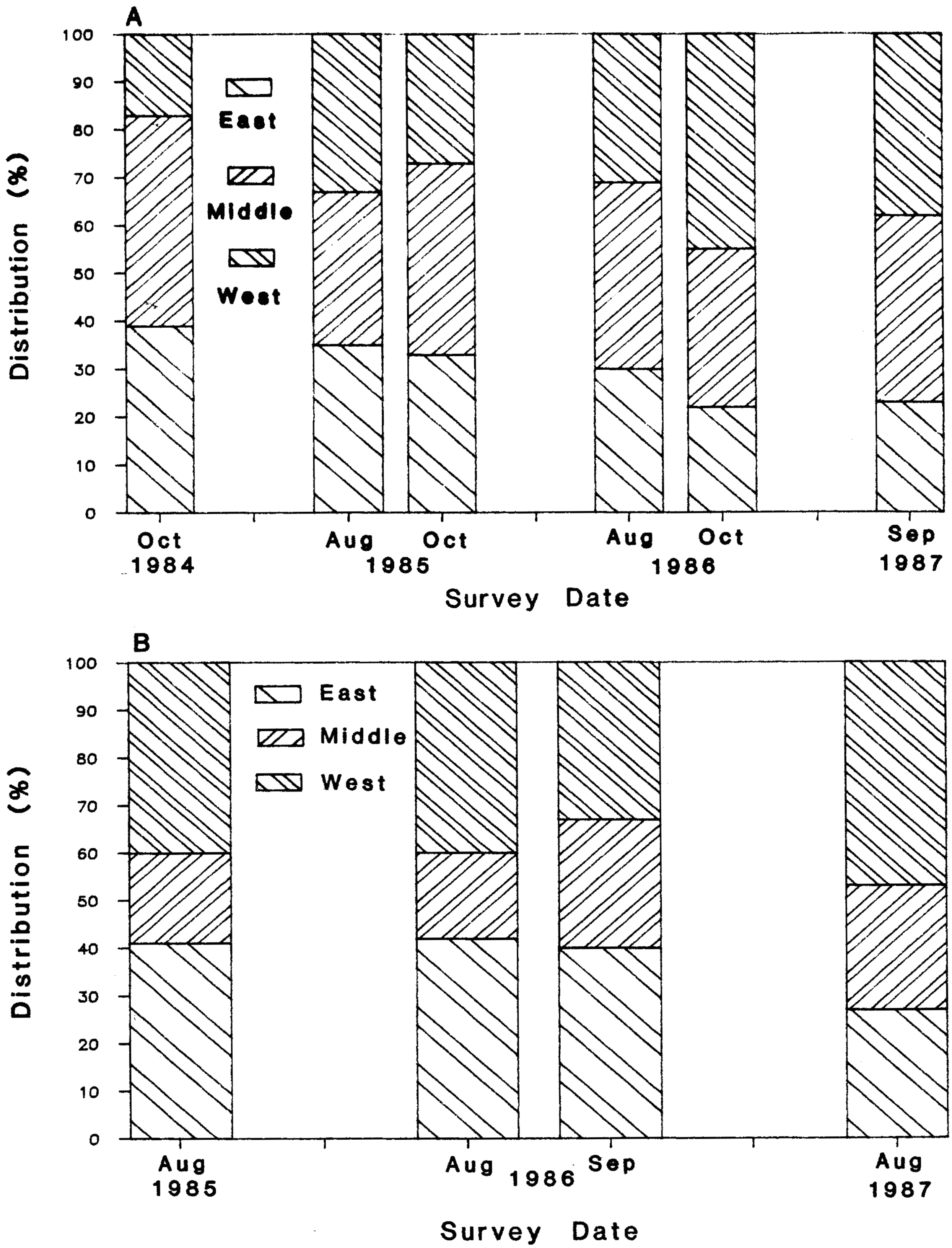


Figure 1. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for surveys conducted at Leisure Lake (A) and Tokun Lake (B).

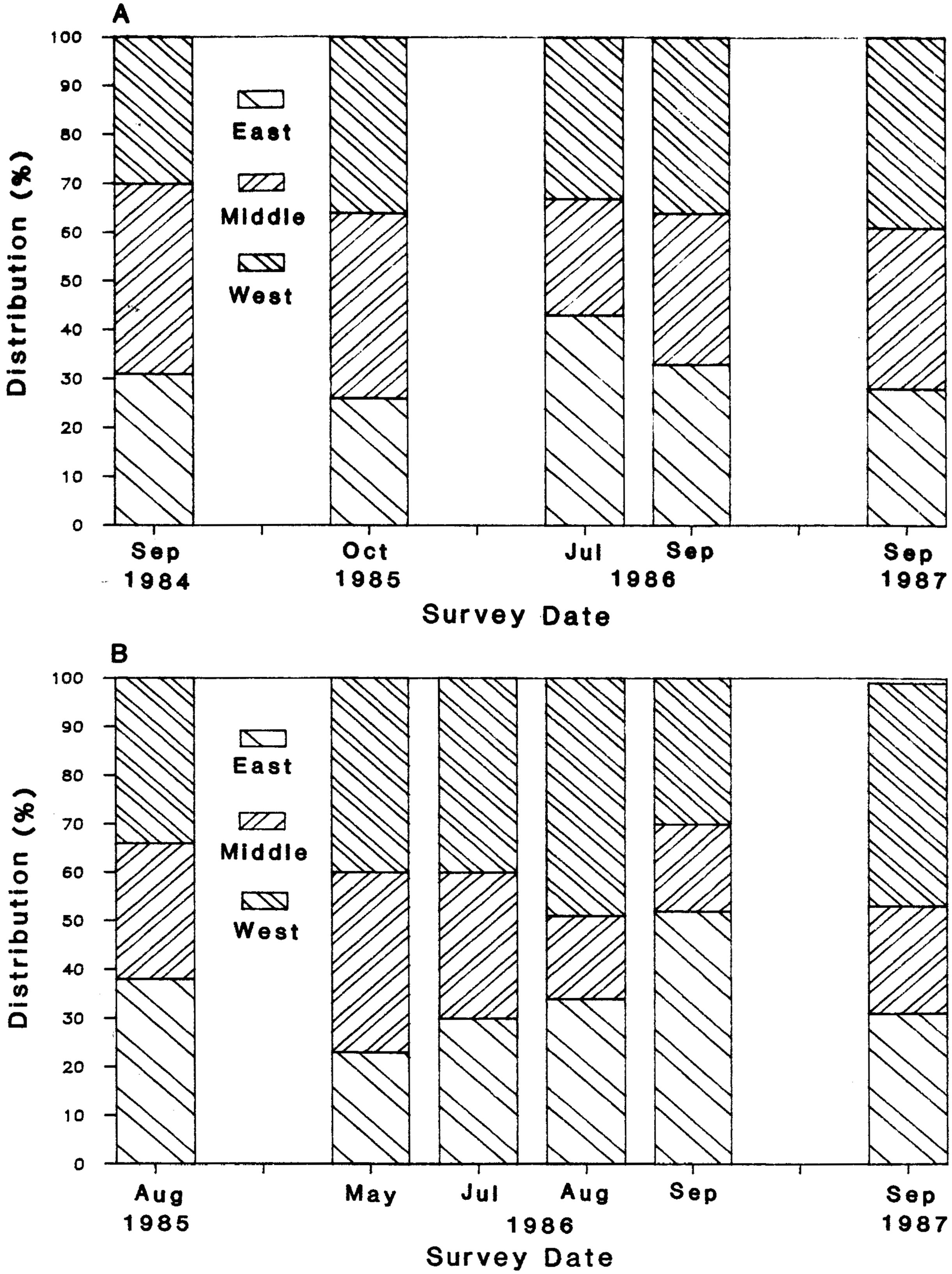


Figure 2. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for surveys conducted at Karluk Lake (A) and Frazer Lake (B).

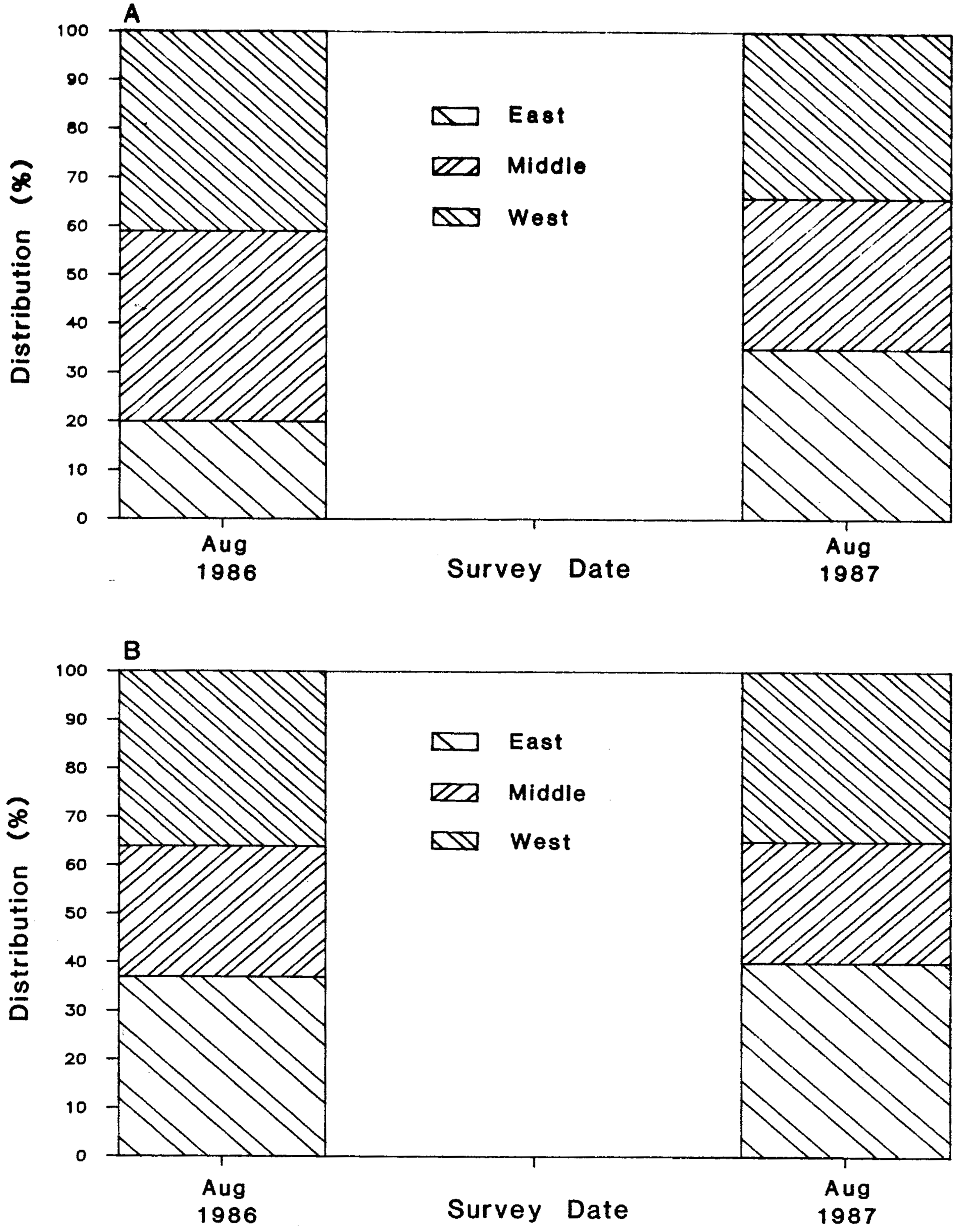


Figure 3. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for surveys conducted at Chenik Lake (A) and Delight Lake (B).

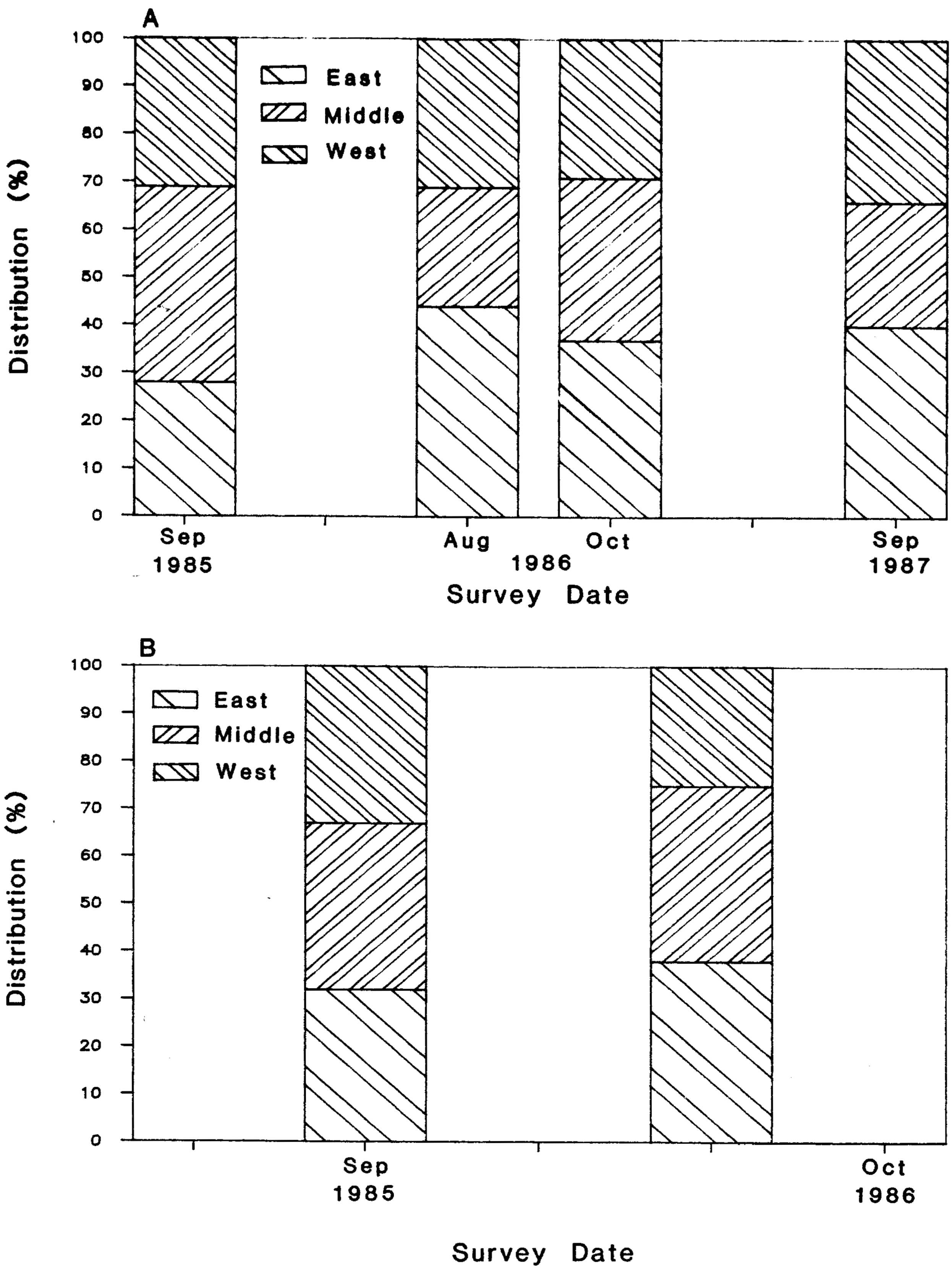


Figure 4. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for surveys conducted at Larson Lake (A) and Shell Lake (B).

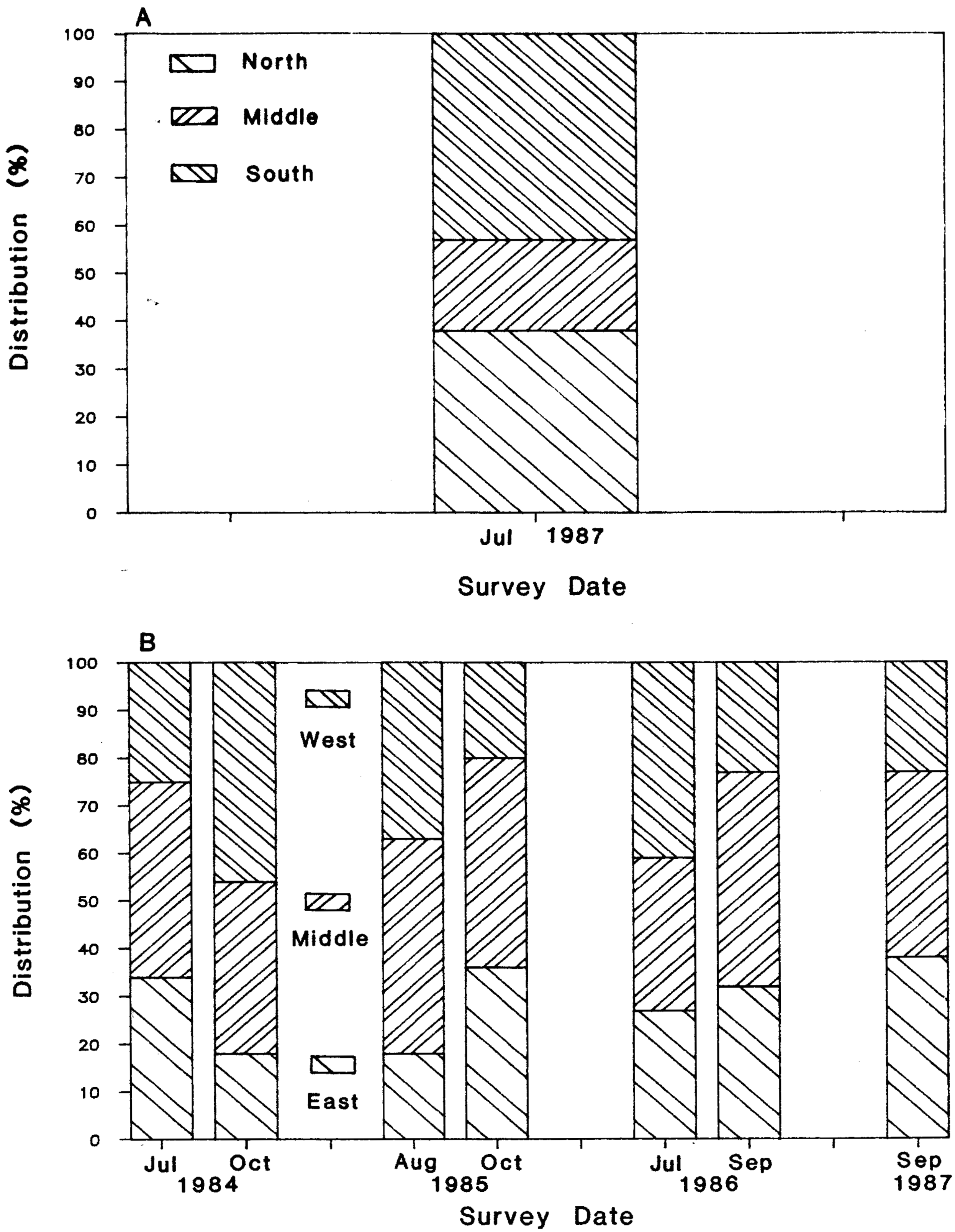


Figure 5. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for surveys conducted at Hidden Lake (A) and Packers Lake (B).

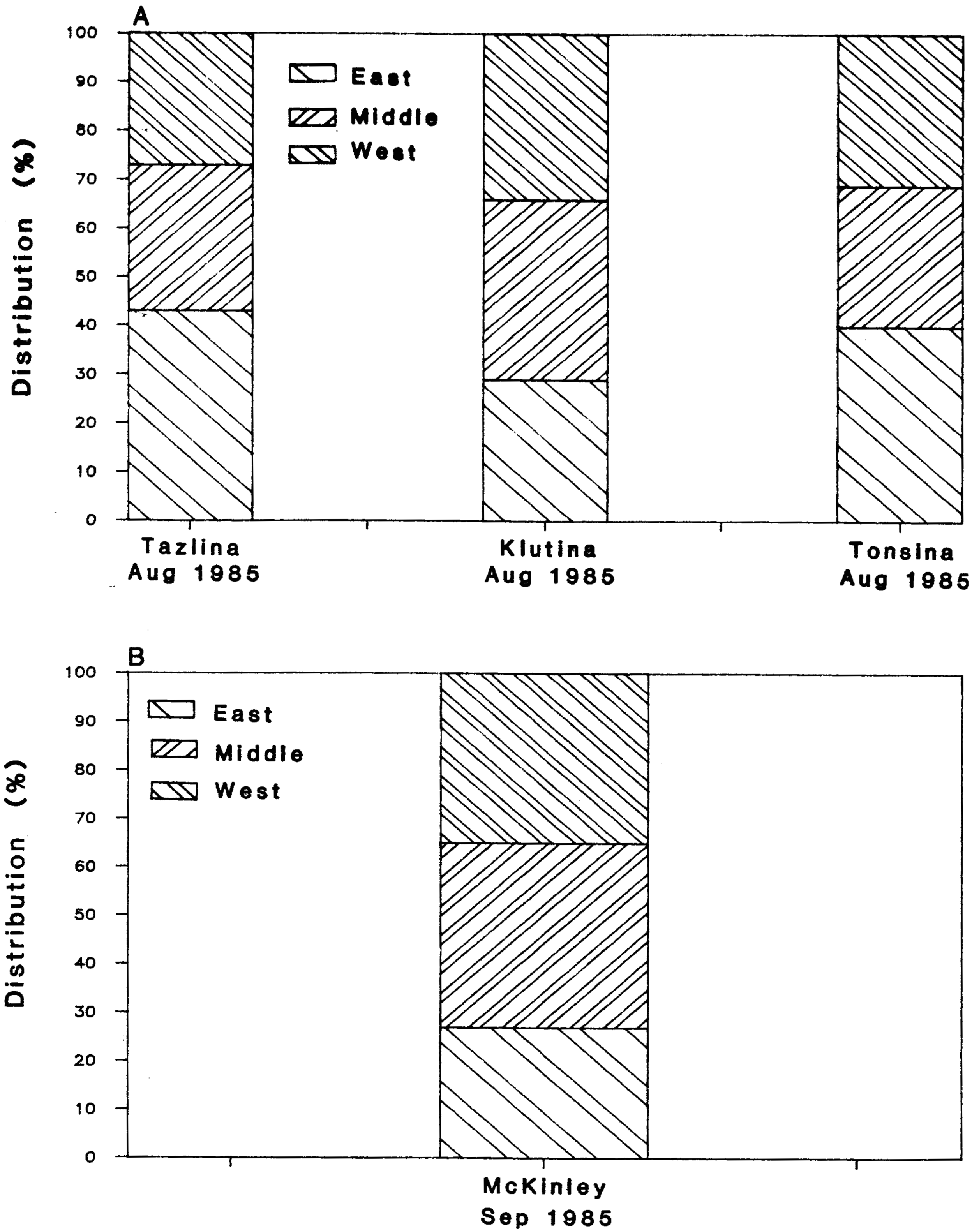


Figure 6. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for surveys conducted at Tazlina, Klutina, and Tonsina Lakes (A), and McKinley Lake (B).

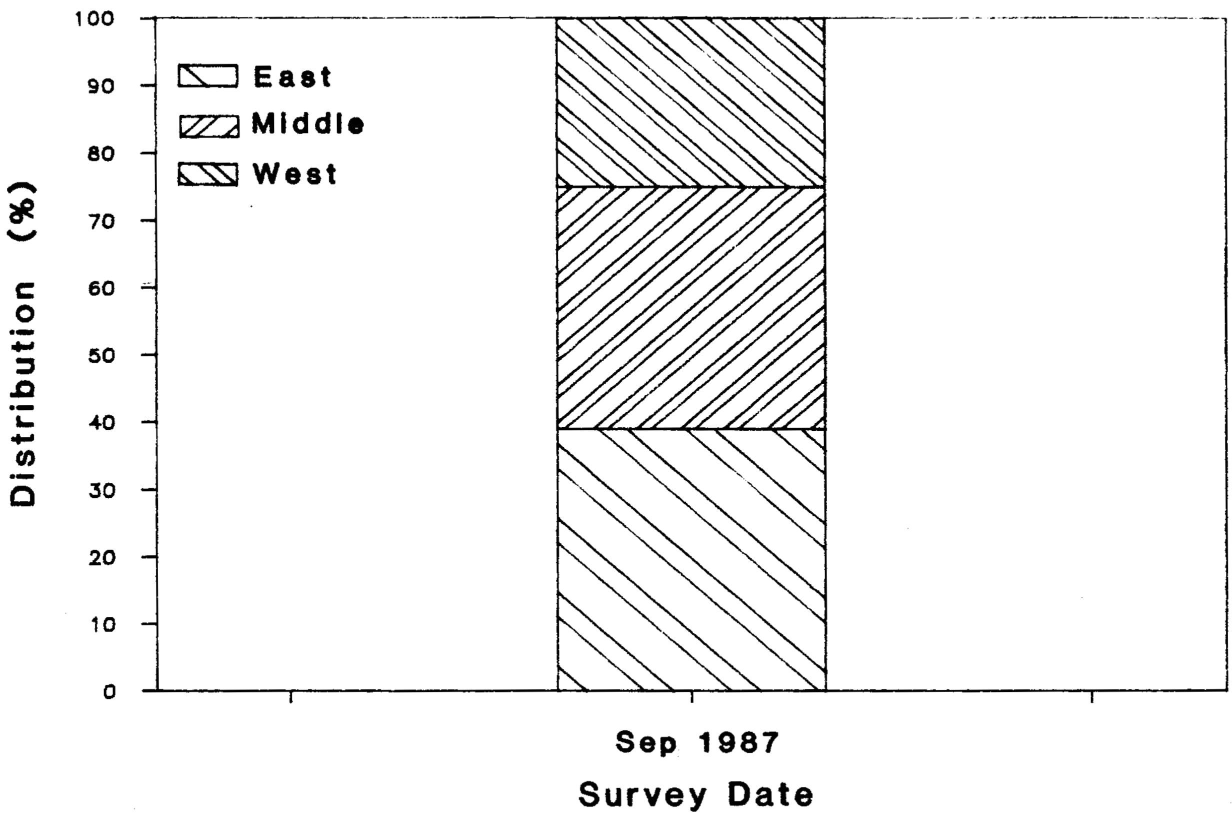


Figure 7. Horizontal distribution of fish density by transect thirds expressed as a percent of the total density for all transects combined for the survey conducted at Summit Lake.

Finally, there were some differences in horizontal distributions for both immediate transect runs (R_1 and R_2) of 1986 and whole lake series (S_1 and S_2) of 1987. For example, in the 1986 re-run of transects in six lakes, the horizontal distribution as a percentage of the total fish density changed the most for surveys conducted at Larson and Packers Lakes (Figure 8). However, comparing the three subsections of these lakes (eastern, middle, and western one-third subsection) for both transect runs, changes in distribution were not found significant ($P<0.05$; Mann-Whitney U-test). Similarly, for the 1987 surveys, in which all transects of the same six lakes were sampled once before a second series was conducted, changes in fish distribution along all transects, for most surveys, were slight (Figure 8). Only during the Chenik and Frazer Lake surveys did the fish distribution change somewhat; however, the changes were again found insignificant ($P<0.05$; Mann-Whitney U-test). The insignificant changes in fish distributions along transects, particularly those between transect series, strongly suggests that the horizontal movement of fish during the night surveys of late fall was slight. Moreover, the minimal horizontal fish movements between transects re-runs and the two series reduces the variance of the acoustic population estimates.

Vertical Distributions-- Juvenile sockeye salmon are normally found distributed in the upper to middle part of the water column during the night, and have been characterized in many lakes (Narver 1969; McDonald 1973; Eggers 1978; Robinson and Barraclough 1978; Simpson et al. 1981). The vertical distribution of fish in the southcentral Alaska surveys, as determined from combined data of the two transect runs, varied by lake and sometimes by date within and between years (Figures 9-19); however, for the most part, the fish were distributed in the typical pattern at night. In the majority of the surveys, the vertical distribution pattern generally consisted of higher densities in the first two depth intervals with reduced densities at deeper depth intervals. However, in some surveys the distribution pattern began with a lower fish density in the upper depth intervals, and increased with depth before decreasing. For example, at Karluk Lake (Figure 11), where for all surveys except one, the fish distribution for the first 10 m was less than 10% of the total, and increased to 20% or greater between 10-25 m before decreasing below depths of 25 m.

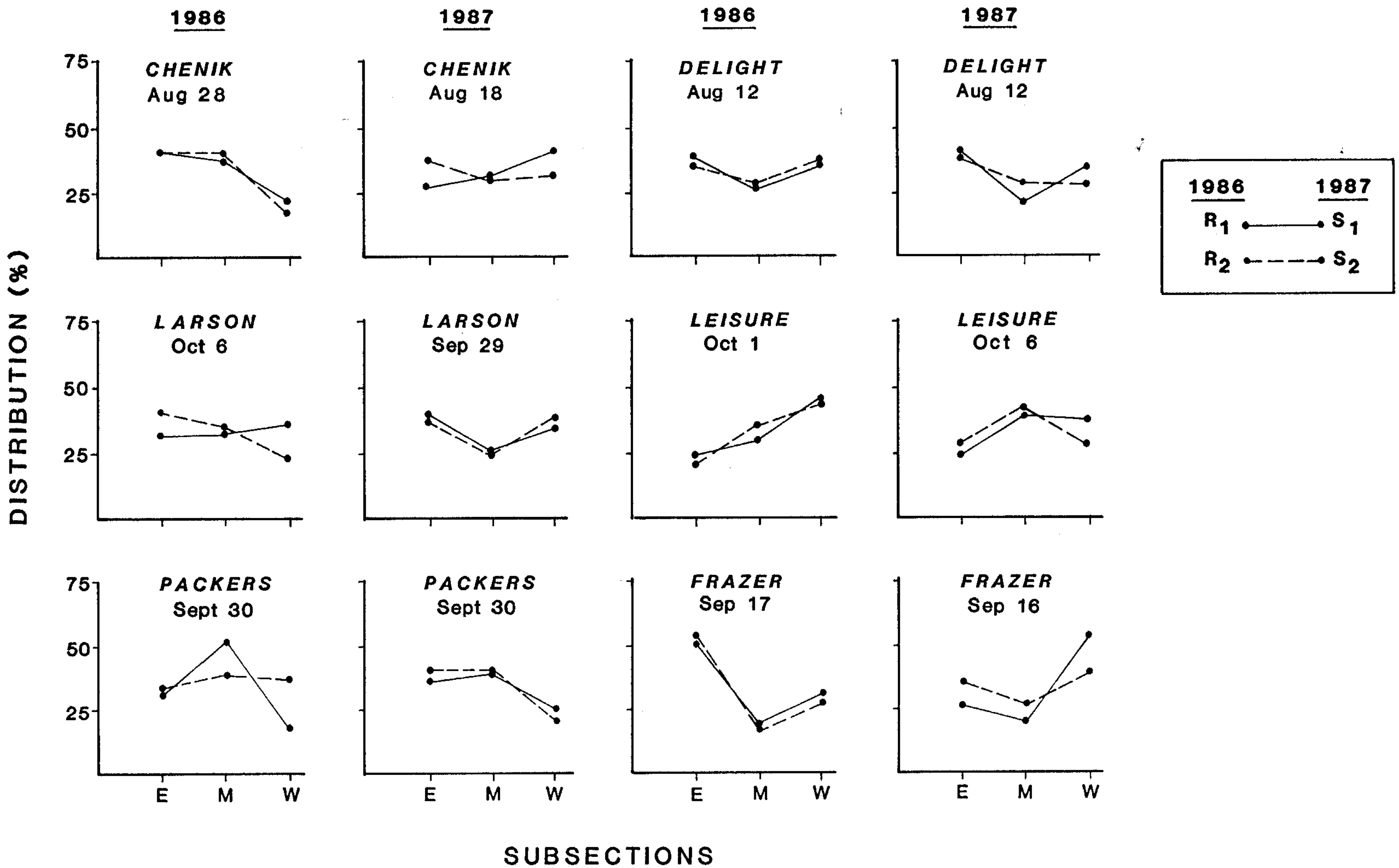
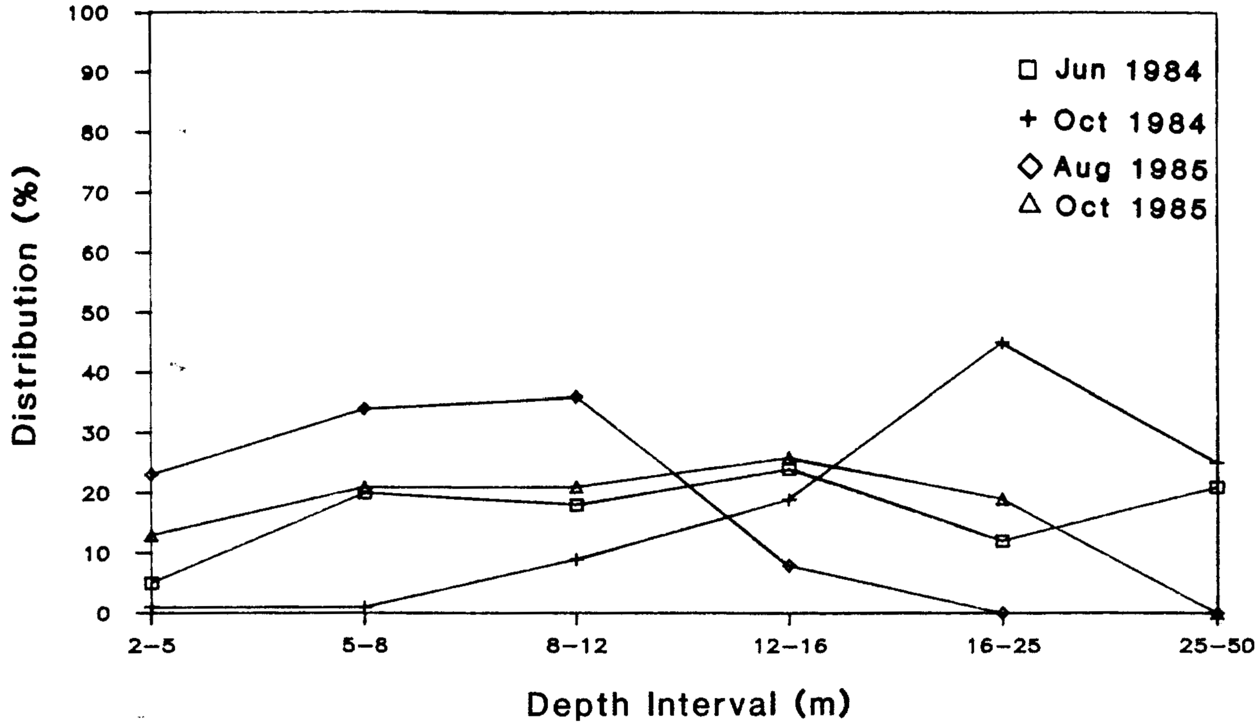


Figure 8. Comparisons of horizontal distributions (%) of fish density by transect thirds (subsections) showing the insignificant ($P<.05$) changes for both immediate transect runs (R_1 and R_2) of 1986, and whole lakes series (S_1 and S_2) of 1987.



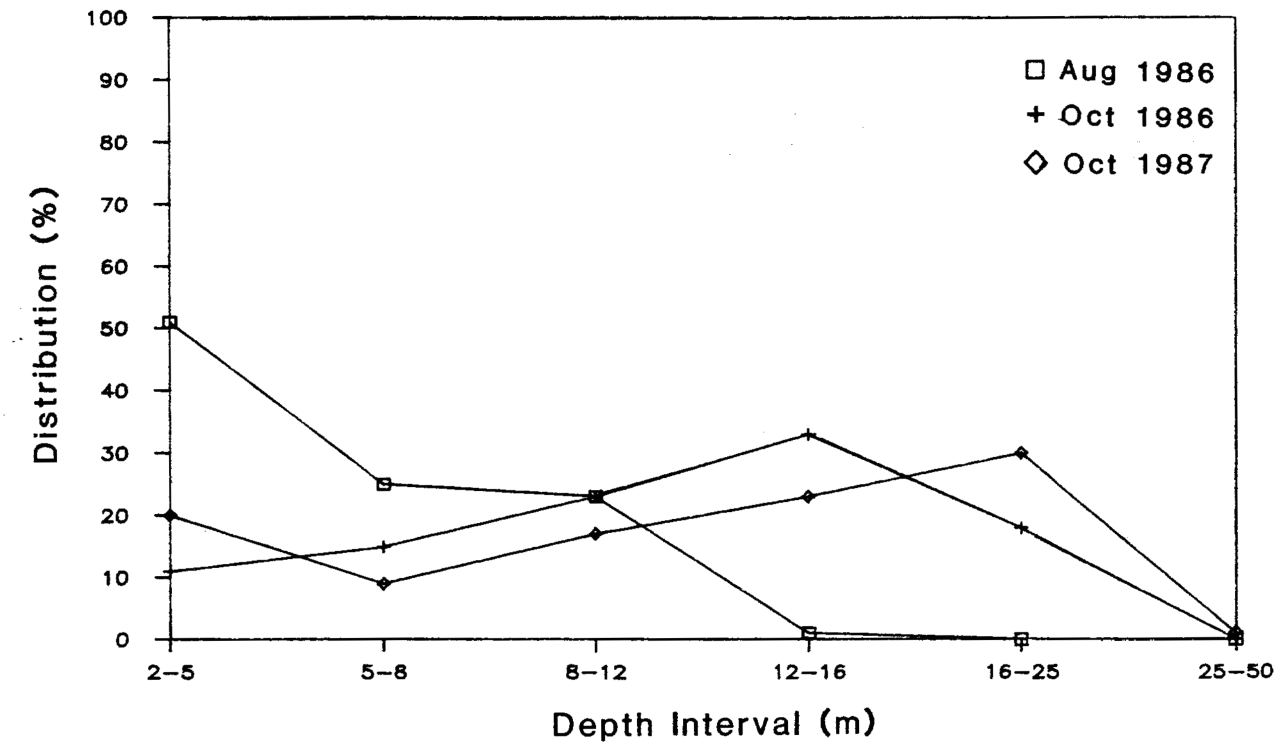
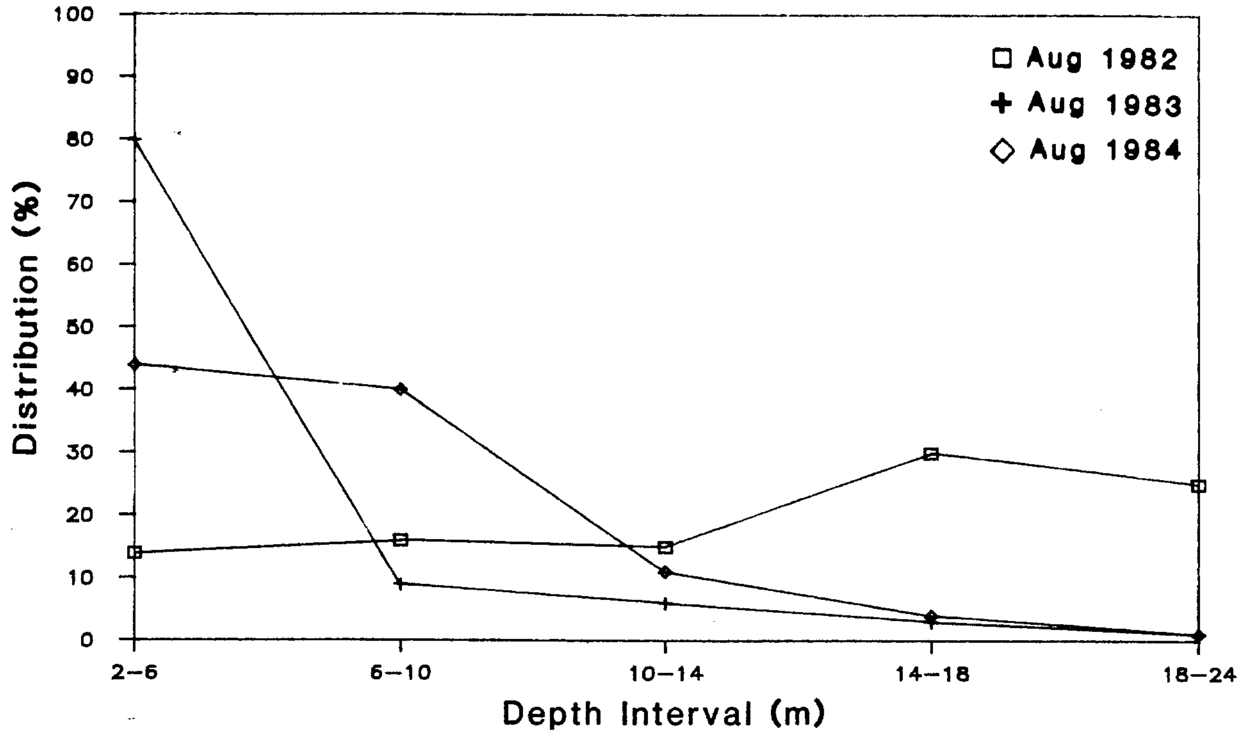


Figure 9. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Leisure Lake.



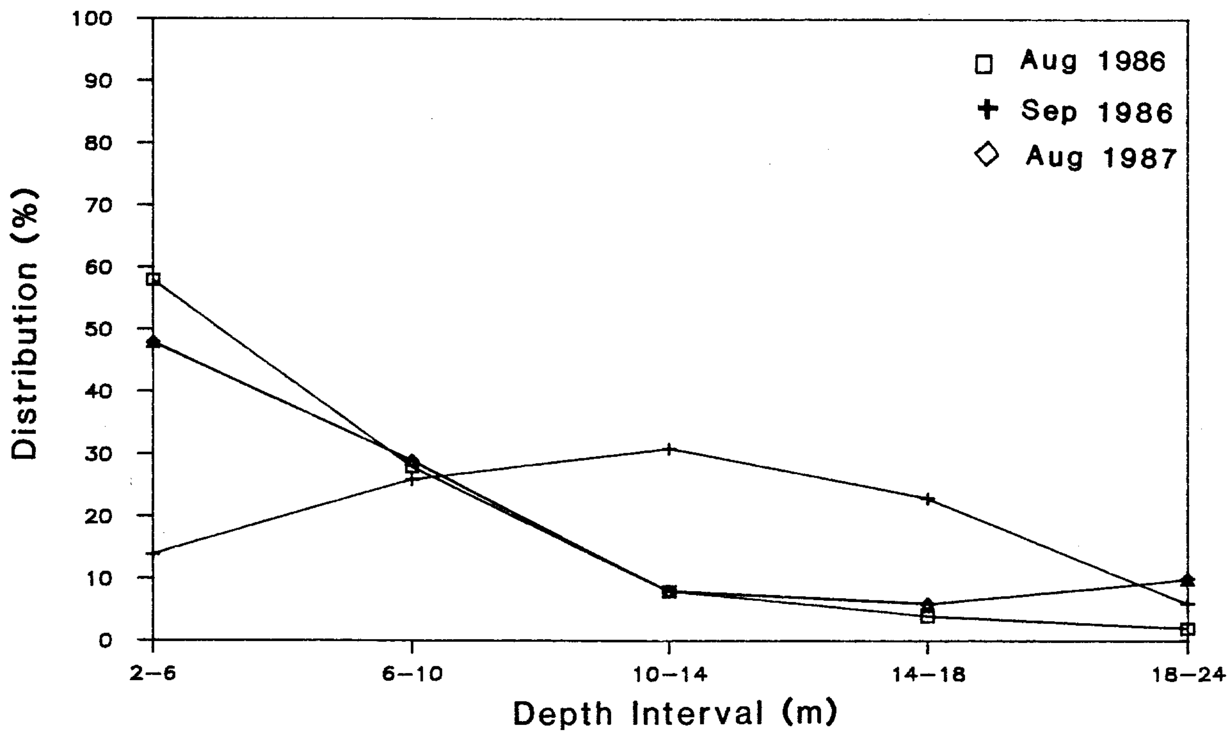
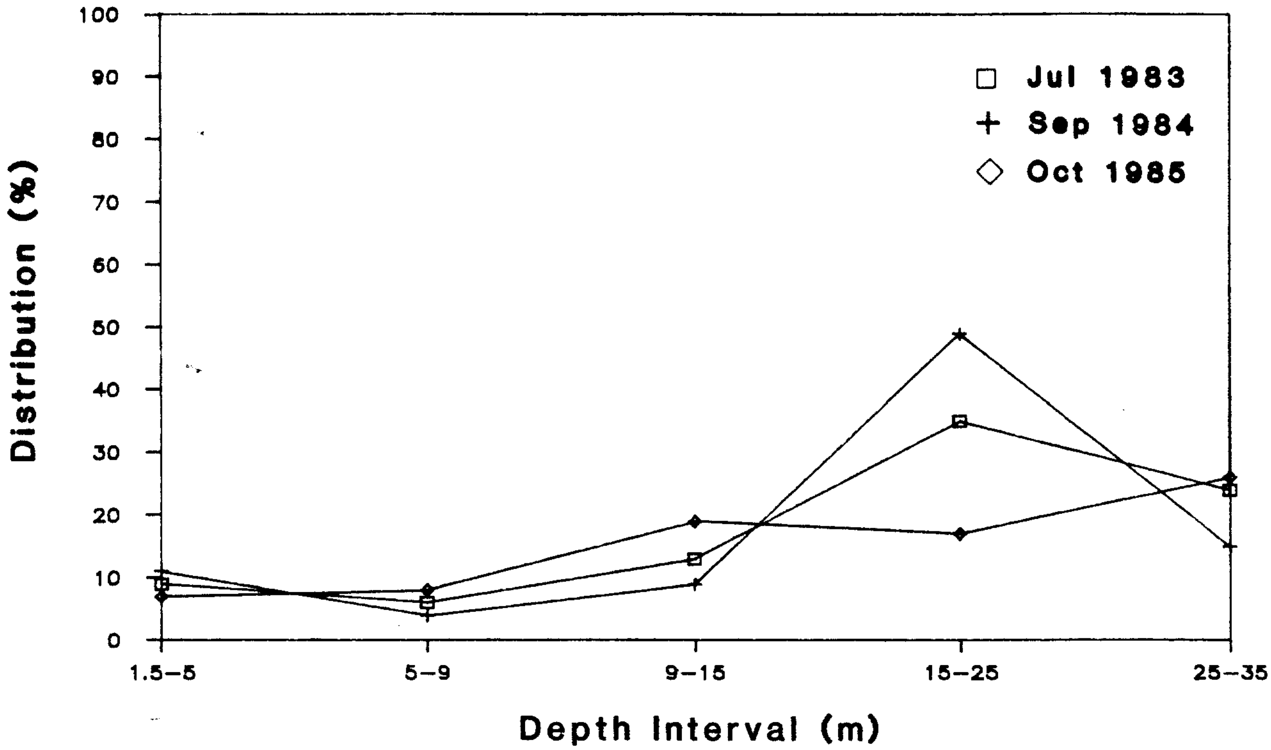


Figure 10. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Tokun Lake.



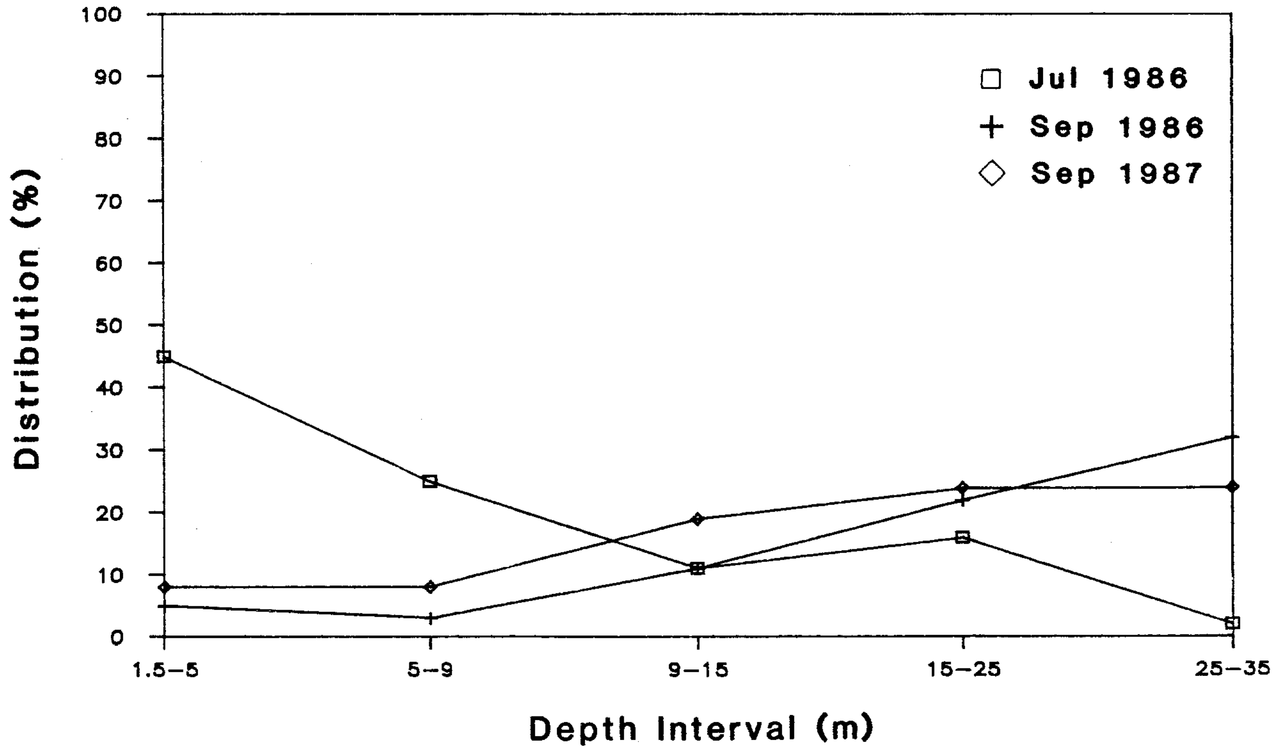


Figure 11. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Karluk Lake.

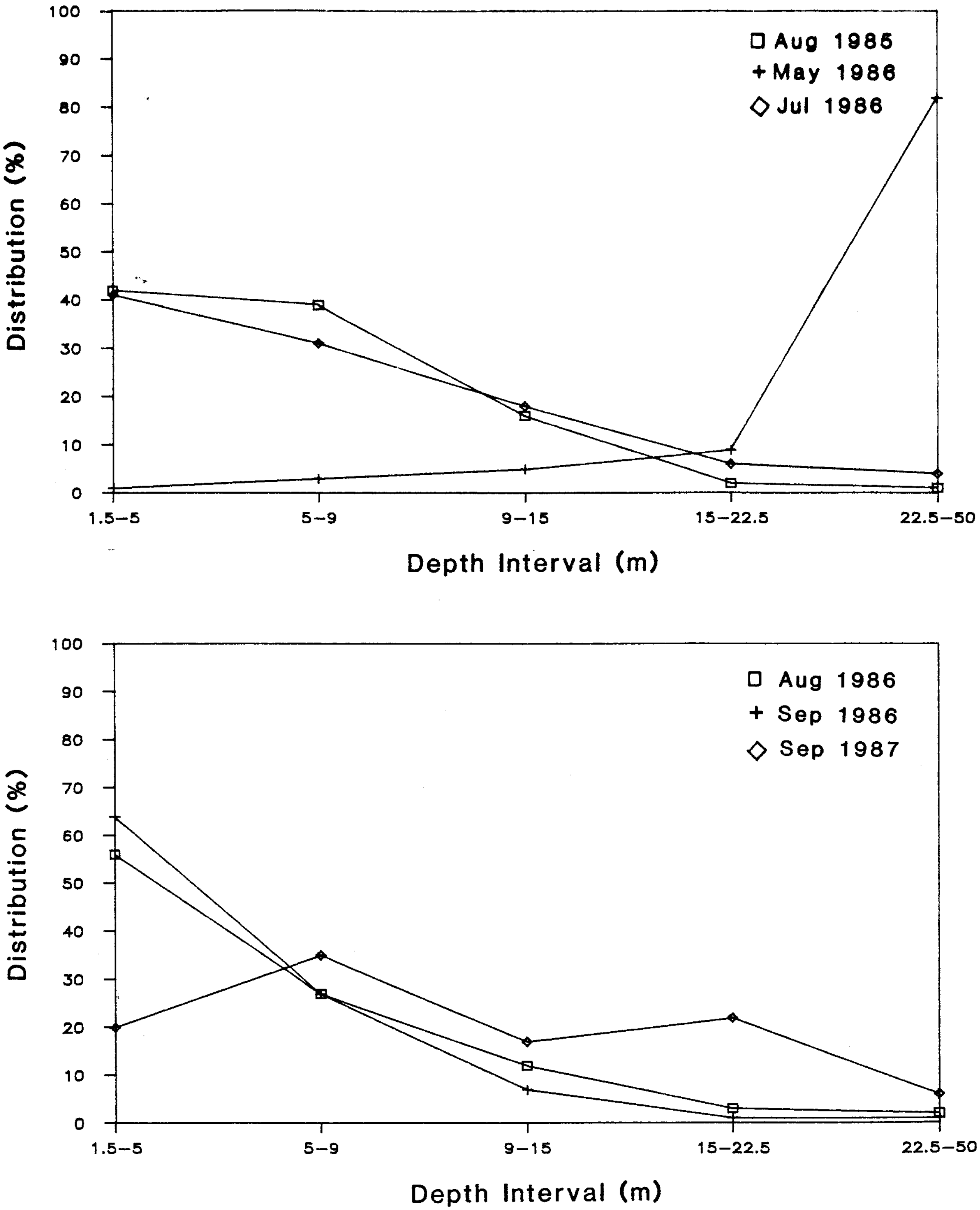


Figure 12. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Frazer Lake.

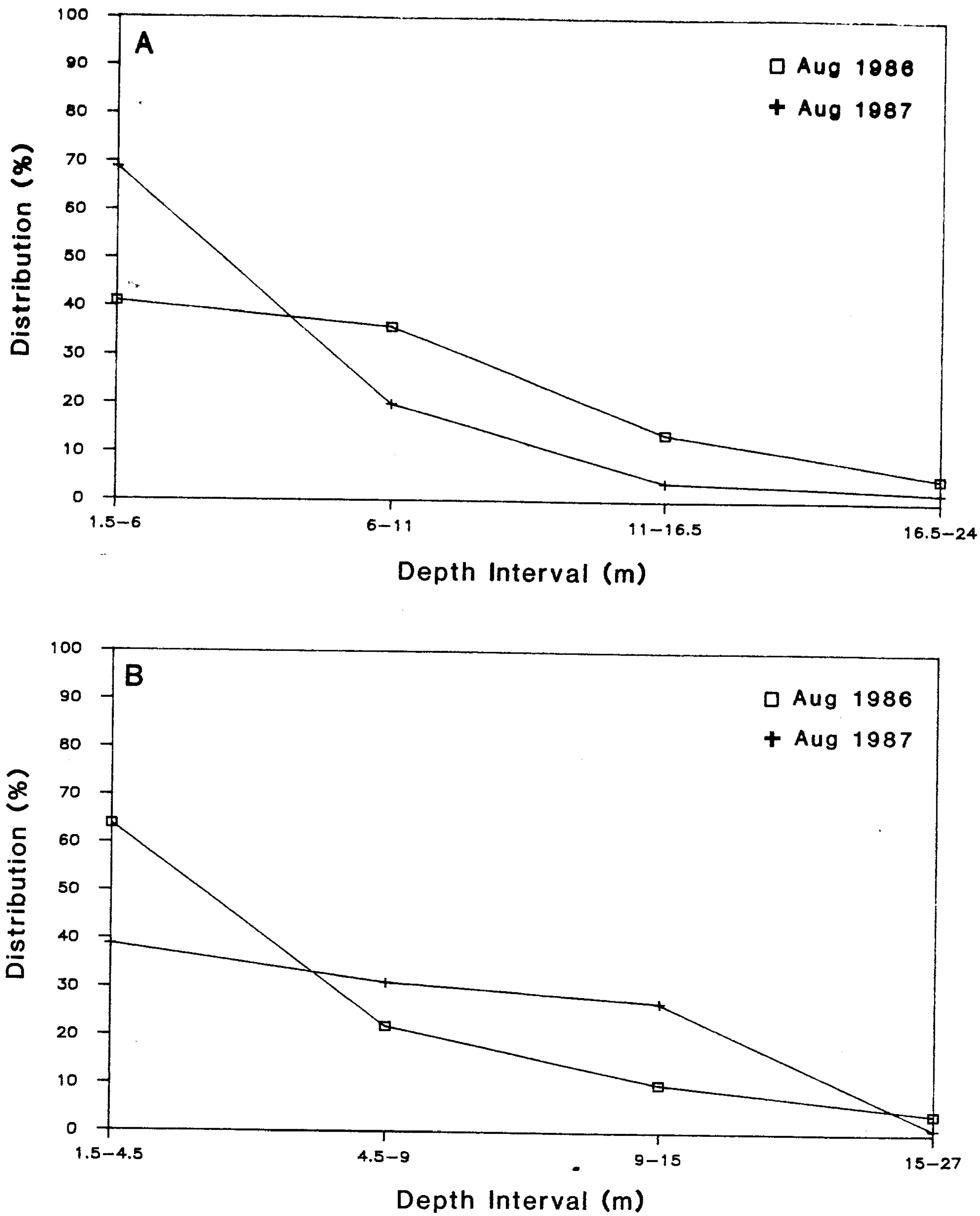
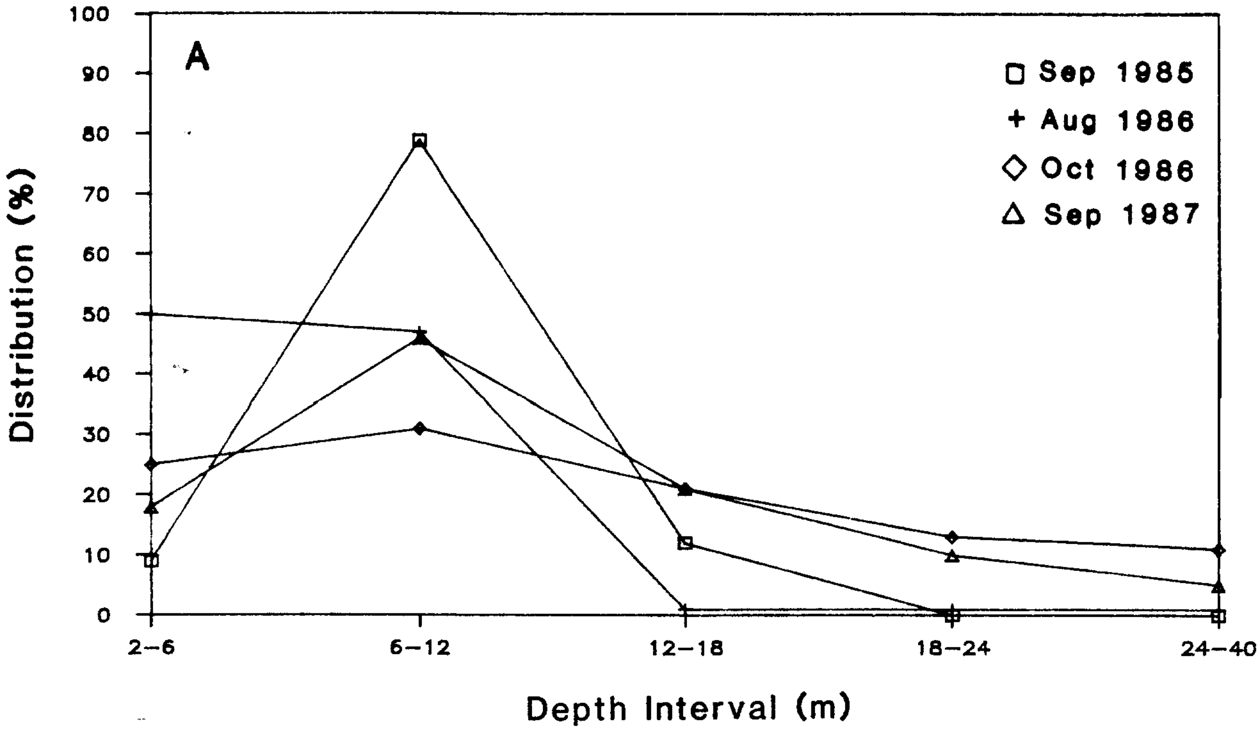


Figure 13. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Delight Lake (A) and Chenik Lake (B).



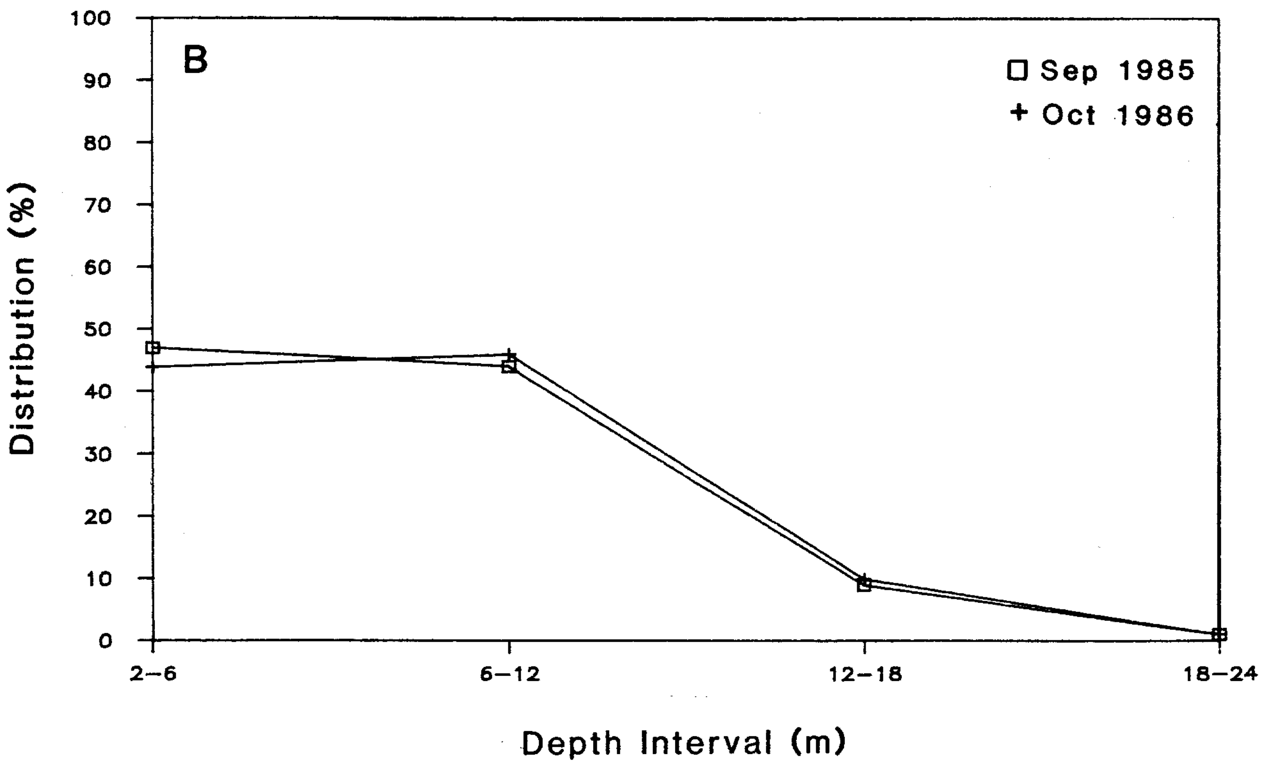
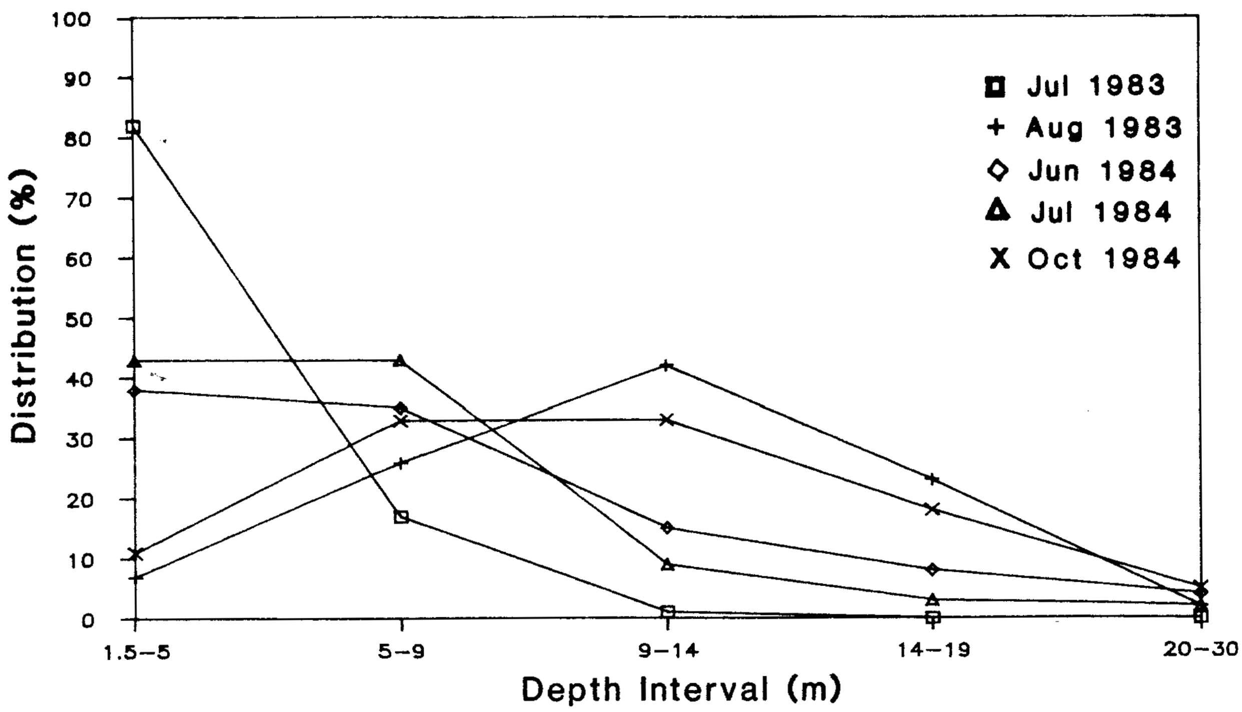


Figure 14. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Larson Lake (A) and Shell Lake (B).



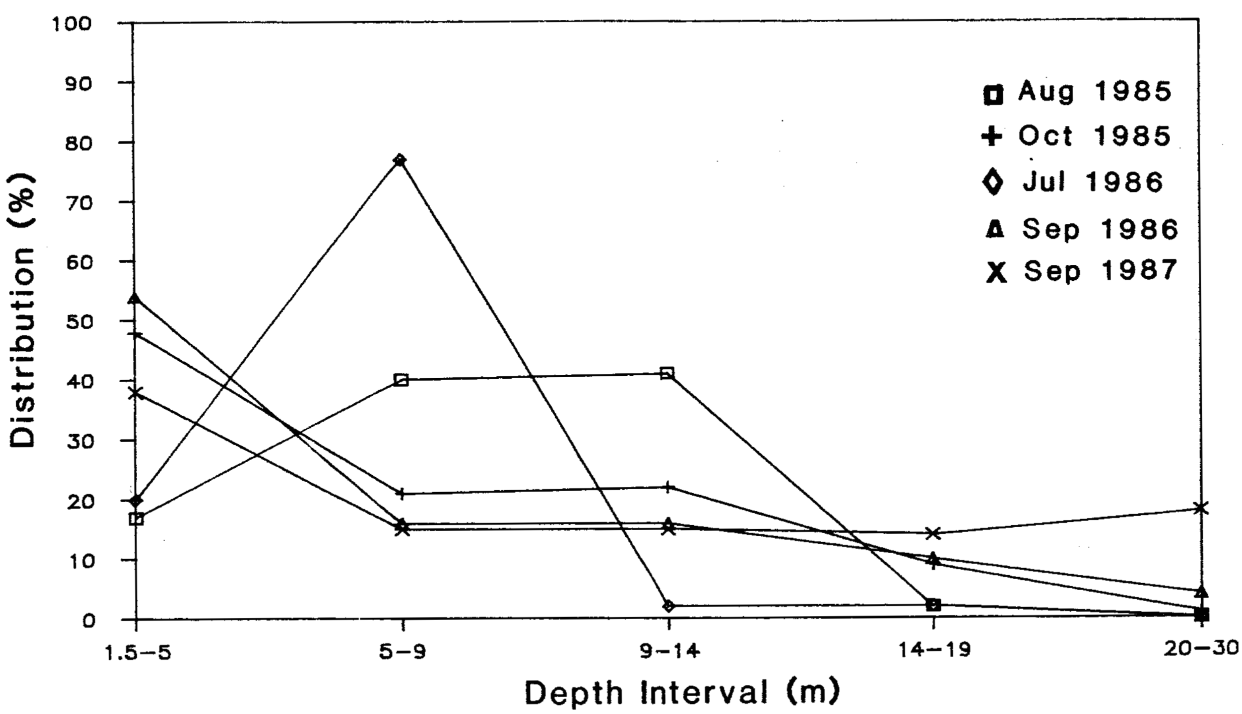


Figure 15. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Packers Lake.

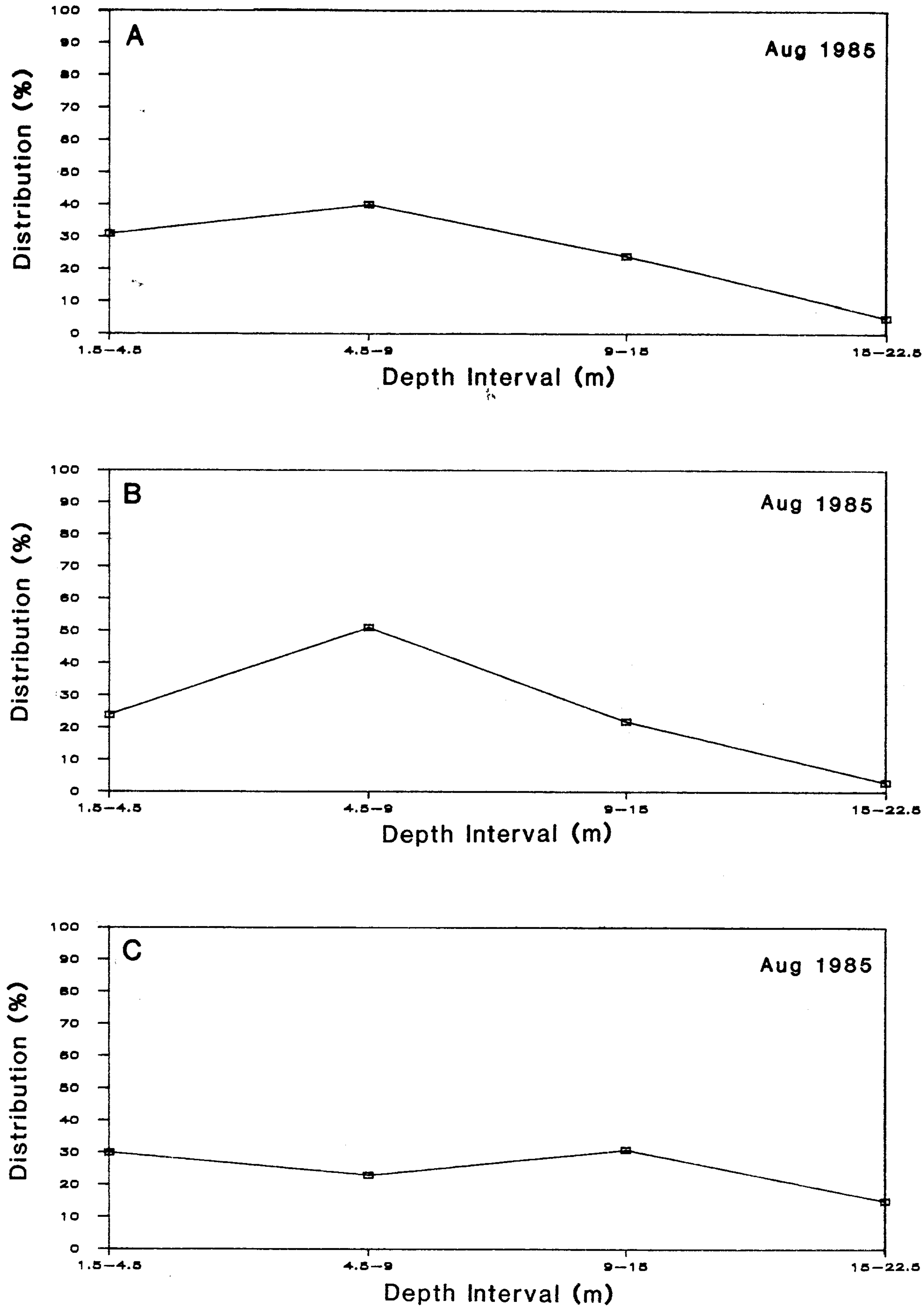


Figure 16. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Tazlina Lake (A), Klutina Lake (B), and Tonsina Lake (C).

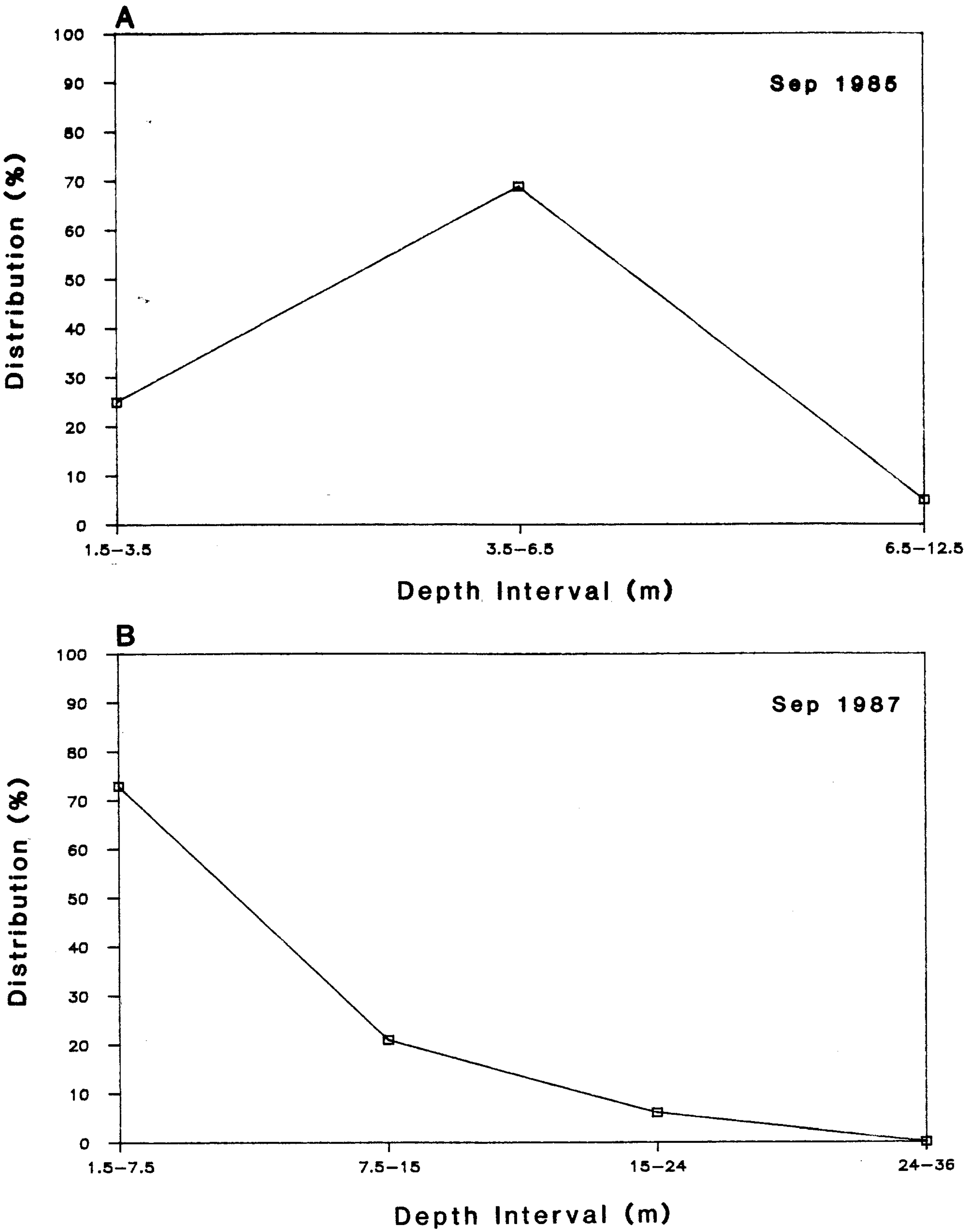


Figure 17. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at McKinley Lake (A) and Summit Lake (B).

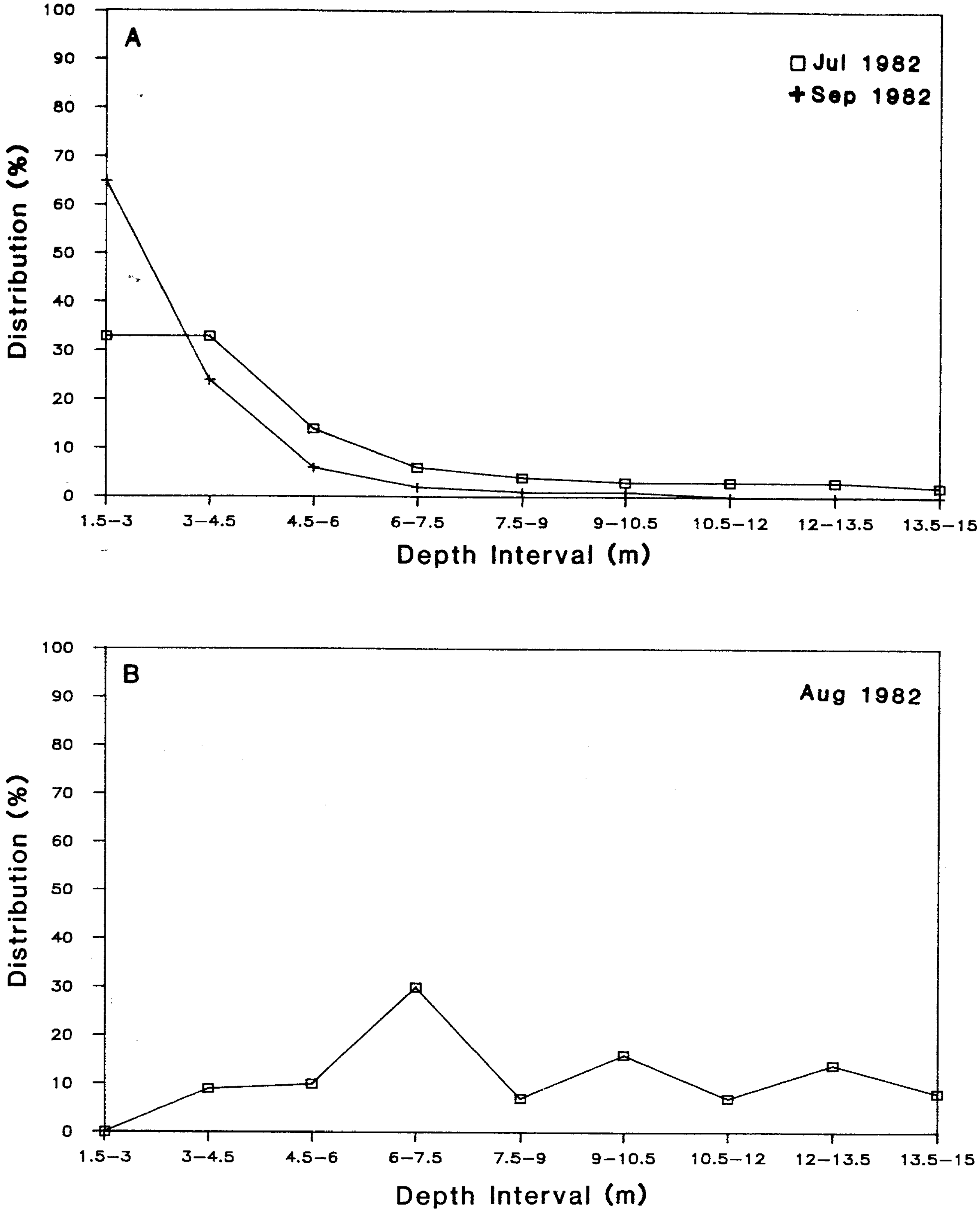


Figure 18. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for surveys conducted at Crescent Lake (A) and Eshamy Lake (B).

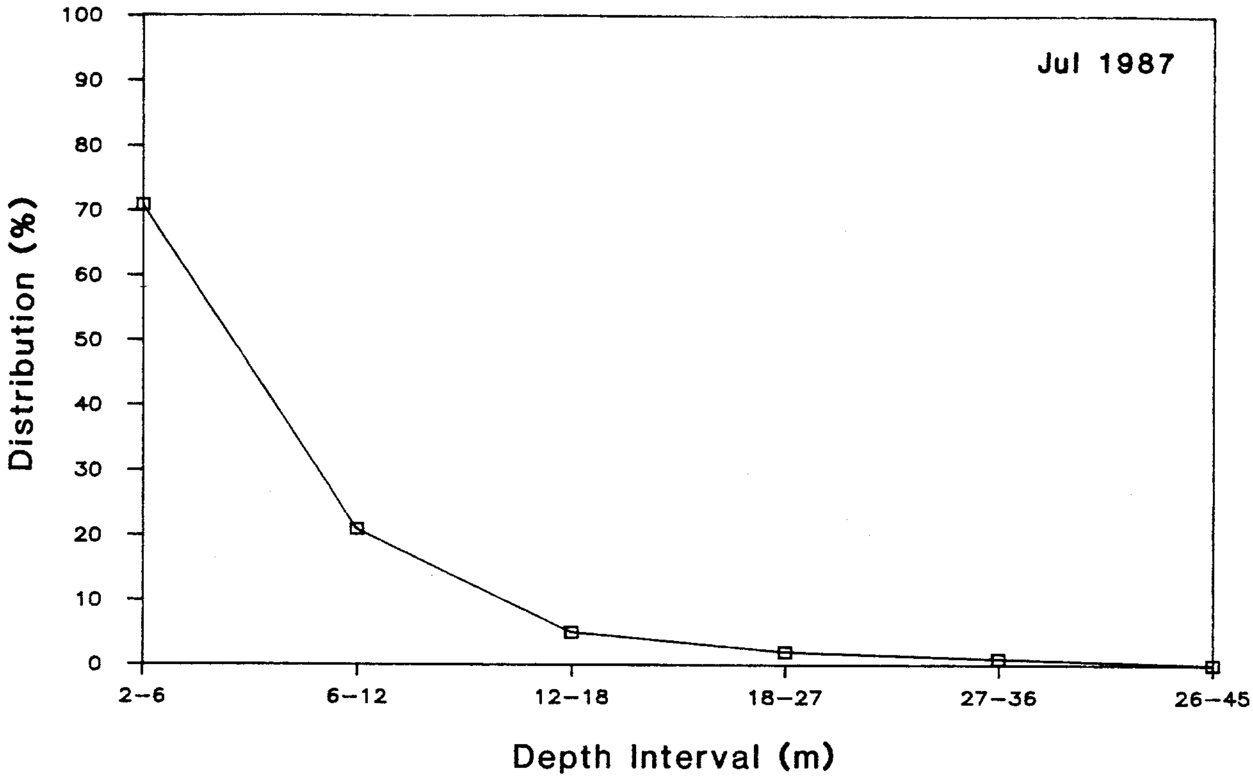


Figure 19. Vertical distribution of fish density by depth strata expressed as a percent of the total density for all transects combined for the survey conducted at Hidden Lake.

The variability in vertical fish distribution within a year is illustrated best in Packers Lake. In Packers Lake, early and late surveys were done during 1983-1986 (Figure 15). In both the early (July) surveys of 1983 and 1984, a higher percentage of fish was found in the first depth interval than in the later surveys (August 1983 and October 1984). Also, in the mid-depth interval (9-14 m), the percent distribution of fish during the 1983 and 1984 July surveys was lower than in the October surveys. In contrast, during the 1985 and 1986 early surveys, a lower percentage of fish in the first depth interval was found than in the later surveys. In addition, in the mid-depth interval (9-14 m), the percent distribution of fish was higher for the earlier survey of 1985 than the later October survey, but lower for the earlier survey of 1986 than the later September survey of 1986.

Yearly variation in vertical fish distribution is apparent from the 1982-1987 August surveys conducted on Tokun Lake, as only two fish distributions (1986 and 1987) resembled each other (Figure 10). Probable causes for between year as well as within year variations in vertical distributions of fish at night, in particular for juvenile sockeye salmon are predator avoidance, light penetration (cloud conditions), surface perturbations (wind storms), and food distribution. These factors and others have been considered to explain diel vertical movements of juvenile sockeye salmon (Brock and Riffenburgh 1960; Narver 1969; Brett 1971; Chernoff 1971; McDonald 1973; Eggers 1978; Levy 1987). In all likelihood, more than one factor at one time may be influencing the nightime vertical migration behavior of juvenile sockeye salmon.

Comparison of transecting technique relative to immediate transect runs (1986) and whole lake series (1987), indicates very minor changes in vertical fish distributions between runs (R_1 and R_2) and some discreet changes between series (S_1 and S_2) (Figure 20). Changes in the vertical migration of fish between transect series appeared to be more substantial for Chenik and Leisure Lakes than the other lakes. However, the vertical distribution of fish, as a percentage of the total fish density, was not significantly ($P<0.05$; Mann-Whitney U-test) different between the initial transect series (S_1), and the second series (S_2) at Chenik and Leisure Lakes. In particular, the fish were substantially

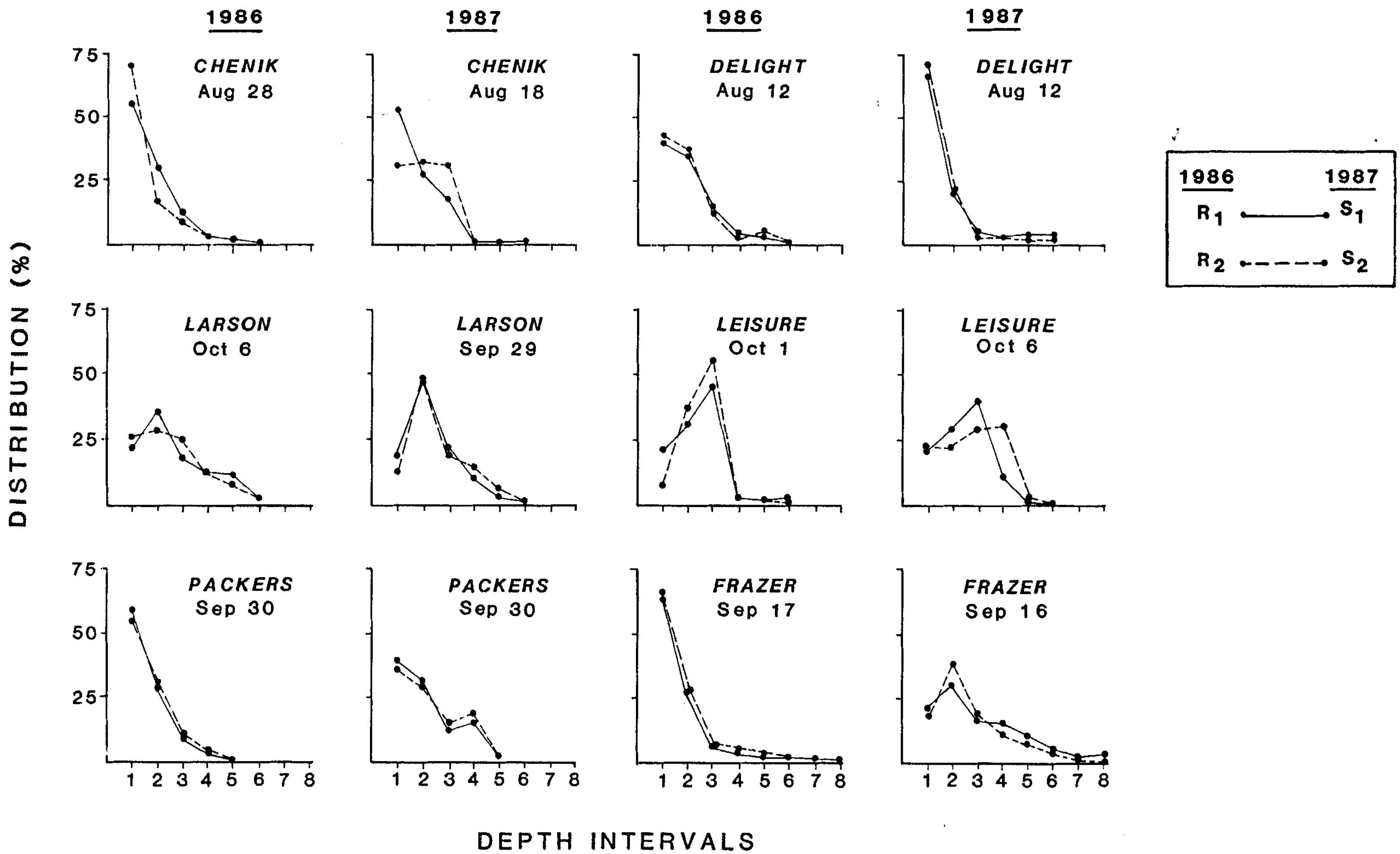


Figure 20. Comparison of vertical distributions (%) of fish density by depth intervals showing the insignificant (P<.05) changes for both immediate transect runs (R_1 and R_2) of 1986, and whole lake series (S_1 and S_2) of 1987.

less dense in the near-surface depth interval during S_2 than S_1 at Chenik Lake, and the fish shifted to a deeper depth interval during S_2 at Leisure Lake (Figure 20). These results effect the population variance of both lakes, and could underestimate the Chenik Lake fish population, as many fish could have been too near the surface for acoustical detection during S_1. Finally, the vertical fish distribution in 12 of the 54 surveys conducted during 1982-1987 was greater than 50% of the total in the first depth interval (~1.5-5.0 m). Near-surface distribution of fingerlings in these 12 surveys has the potential to underestimate the juvenile sockeye salmon population estimate. However, there are indirect and direct techniques to estimate fish densities in the depth strata (<2 m) excluded from acoustical detection (*see* next section).

Population Estimates-- Total fish population estimates for the 54 surveys conducted during 1982-1987 are summarized in Table 1. The highest total fish population was estimated in 1987 at Karluk Lake (81.2 million), and the lowest was 40,000 at Chenik Lake in 1986 (Table 1). The 95% confidence interval ranged from ±3-58% of the mean population estimate, and averaged ±17%. Towing effort, catch composition, and juvenile sockeye salmon population estimates are summarized in Table 2. In 35 of the 46 surveys that catch composition information from townetting was obtained, the sockeye salmon composition was greater than 80%. Thus, in the majority of the lakes, juvenile sockeye salmon dominated the limnetic fish population. The proportion of catch in surveys that species composition was not obtained due to either low fish density, or net avoidance (Leisure, Hidden, Tazlina, and Tonsina Lakes), was assumed to comprise mainly of juvenile sockeye salmon based on escapement and netting information, and knowledge of the resident fish population. The highest juvenile sockeye salmon population estimate was obtained in 1987 at Karluk Lake (18.2 million) and the lowest at Chenik Lake in 1986 (40,000).

Fish populations in surveys which had greater than 50% of the fish density in the first depth interval, and consequently had a high probably of underestimation due to the undetectability in the near-surface area (<2.0 m), were estimated from extrapolation of fish densities in the first depth interval to the lake volume of near-surface strata

Table 1. Summary of hydroacoustic surveys and fish population estimates (nearest 1000) in lakes surveyed throughout southcentral Alaska, 1982-1987.

Lake	Geographical area	Lake type	Number of transects	Survey date	Total fish population estimate and 95% CI
Crescent	Cook Inlet	Semi-glacial	5	04-Jul-82	874,000 +/- 370,000
				24-Sep-82	1,656,000 +/- 961,000
Packers	Cook Inlet	Stained	7	05-Jul-83	22,000 +/- 25,000
				08-Aug-83	405,000 +/- 86,000
				27-Jun-84	116,000 +/- 43,000
				26-Jul-84	241,000 +/- 68,000
				22-Oct-84	289,000 +/- 44,000
				16-Aug-85	213,000 +/- 21,000
				15-Oct-85	353,000 +/- 22,000
				21-Jul-86	461,000 +/- 23,000
				30-Sep-86	515,000 +/- 54,000
				30-Sep-87	916,000 +/- 108,000
Leisure	Cook Inlet	Clear	6	19-Jun-84	86,000 +/- 34,000
				31-Oct-84	428,000 +/- 40,000
				28-Aug-85	146,000 +/- 6,000
				10-Oct-85	515,000 +/- 49,000
				05-Aug-86	729,000 +/- 86,000
				01-Oct-86	2,083,000 +/- 139,000
				06-Oct-87	900,000 +/- 74,000
Larson	Cook Inlet	Clear	7	17-Sep-85	379,000 +/- 53,000
				20-Aug-86	197,000 +/- 19,000
				06-Oct-86	387,000 +/- 47,000
				29-Sep-87	1,024,000 +/- 128,000
Shell	Cook Inlet	Clear	6	20-Sep-85	1,038,000 +/- 78,000
				10-Oct-86	1,497,000 +/- 131,000
Delight	Cook Inlet	Clear	5	12-Aug-86	819,000 +/- 57,000
				12-Aug-87	885,000 +/- 123,000
Chenik	Cook Inlet	Clear	6	28-Aug-86	42,000 +/- 6,000
				18-Aug-87	504,000 +/- 173,000
Hidden	Cook Inlet	Clear	7	23-Jul-87	52,000 +/- 20,000

-continued-

Table 1 continued. Summary of hydroacoustic surveys and fish population estimates (nearest 1000) in lakes surveyed throughout southcentral Alaska, 1982-87.

Lake	Geographical area	Lake type	Number of transects	Survey date	Total fish population estimate and 95% CI	
Tokun	Prince William Sound	Clear	6	27-Aug-82	831,000 +/-	209,000
				18-Aug-83	341,000 +/-	88,000
				20-Aug-85	1,609,000 +/-	251,000
				05-Aug-86	177,000 +/-	18,000
				26-Sep-86	624,000 +/-	113,000
				13-Aug-87	2,463,000 +/-	250,000
McKinley	Prince William Sound	Clear	5	19-Sep-85	197,000 +/-	32,000
Eshamy	Prince William Sound	Clear	8	24-Aug-82	371,000 +/-	29,000
Karluk	Kodiak	Clear	8-12	12-Jul-83	10,204,000 +/-	943,000
				18-Sep-84	42,705,000 +/-	25,631,000
				02-Oct-85	65,020,000 +/-	15,277,000
				07-Jul-86	9,571,000 +/-	1,856,000
				15-Sep-86	48,066,000 +/-	4,684,000
				19-Sep-87	81,278,000 +/-	18,205,000
Frazer	Kodiak	Clear	6	08-Aug-85	2,000,000 +/-	156,000
				27-May-86	1,224,000 +/-	160,000
				11-Jul-86	8,000,000 +/-	876,000
				12-Aug-86	4,227,000 +/-	127,000
				17-Sep-86	4,720,000 +/-	358,000
				16-Sep-87	4,663,000 +/-	828,000
Tazlina	Glennallen	Glacial	9	26-Aug-85	543,000 +/-	120,000
Klutina	Glennallen	Glacial	8	30-Aug-85	2,515,000 +/-	881,000
Tonsina	Glennallen	Glacial	7	03-Sep-85	663,000 +/-	104,000
Summit	Glennallen	Clear	8	09-Sep-87	1,494,000 +/-	683,000

Table 2. Summary of townetting results and estimates of juvenile sockeye salmon (nearest 1000) in lakes surveyed throughout southcentral Alaska, 1982-1987.

Lake	Survey date	Number of tows	Combined towing time (minutes)	Sockeye catch number	Sockeye catch composition	Juvenile sockeye population estimate and 95% CI	
Crescent	04-Jul-82	3	90	5	100%	874,000 +/-	370,000
	24-Sep-82	3	90	26	100%	1,656,000 +/-	961,000
Packers	05-Jul-83	2	80	19	86%	187,000 +/-	22,000
	08-Aug-83	2	60	71	100%	405,000 +/-	86,000
	27-Jun-84	2	60	59	100%	116,000 +/-	43,000
	26-Jul-84	3	45	190	98%	236,000 +/-	67,000
	22-Oct-84	2	60	73	90%	260,000 +/-	40,000
	16-Aug-85	2	60	61	86%	183,000 +/-	18,000
	15-Oct-85	2	60	165	97%	342,000 +/-	21,000
	21-Jul-86	2	60	182	100%	461,000 +/-	23,000
	30-Sep-86	2	30	156	92%	474,000 +/-	50,000
	30-Sep-87	2	60	266	94%	861,000 +/-	101,000
Leisure	19-Jun-84	2	60	0	100%[a]	86,034 +/-	34,000
	31-Oct-84	2	60	30	100%	428,000 +/-	40,000
	28-Aug-85[b]	1	---	---	100%[a]	145,520 +/-	6,000
	10-Oct-85	2	40	37	82%	423,000 +/-	40,000
	05-Aug-86	1	15	266	100%	729,000 +/-	86,000
	01-Oct-86	2	30	52	98%	2,041,000 +/-	136,000
	06-Oct-87	2	45	26	96%	864,000 +/-	70,000
Larson	17-Sep-85	1	30	30	67%	254,000 +/-	36,000
	20-Aug-86	2	60	0	0%	---	---
	06-Oct-86	2	60	8	33%	128,000 +/-	16,000
	29-Sep-87	2	60	30	17%	174,000 +/-	22,000
Shell	20-Sep-85	2	60	58	20%	208,000 +/-	16,000
	10-Oct-86	1	60	46	17%	254,000 +/-	18,000
Delight	12-Aug-86	2	45	1	100%	819,000 +/-	57,000
	12-Aug-87	2	45	304	99%	876,000 +/-	121,000
Chenik	28-Aug-86	3	45	15	100%	42,000 +/-	6,000
	18-Aug-87	2	45	24	100%	504,000 +/-	173,000
Hidden	23-Jul-87[c]	0	0	---	100%[a]	52,000 +/-	20,000

-continued-

Table 2 continued. Summary of townetting results and estimates of juvenile sockeye salmon (nearest 1000) in lakes surveyed throughout southcentral Alaska, 1982-1987.

Lake	Survey date	Number of tows	Combined towing time (minutes)	Sockeye catch number	Sockeye catch composition	Juvenile sockeye population estimate and 95% CI	
Tokun	27-Aug-82	2	60	15	94%	781,000 +/-	193,000
	18-Aug-83	3	60	24	100%	341,000 +/-	88,000
	20-Aug-85	3	70	853	100%	1,609,000 +/-	251,000
	05-Aug-86	2	40	100	100%	177,000 +/-	18,000
	26-Sep-86	2	45	71	100%	624,000 +/-	113,000
	13-Aug-87	3	55	211	100%	2,463,000 +/-	250,000
McKinley	19-Sep-85	2	20	0	0%	---	---
Eshamy	24-Aug-82	3	45	18	100%	371,000 +/-	29,000
Karluk	12-Jul-83	5	140	16	14%	1,418,000 +/-	132,000
	18-Sep-84	4	100	88	5%	1,989,000 +/-	1,104,000
	02-Oct-85	4	175	28	17%	11,336,000 +/-	2,700,000
	07-Jul-86	11	330	1,332	14%	1,367,000 +/-	248,000
	15-Sep-86	23	690	930	13%	6,037,000 +/-	594,000
	19-Sep-87	14	420	120	20%	18,205,000 +/-	3,200,000
Frazer	08-Aug-85	4	80	37	100%	2,000,000 +/-	156,000
	27-May-86	2	60	4	100%	1,224,000 +/-	160,000
	11-Jul-86	2	60	31	97%	7,760,000 +/-	850,000
	12-Aug-86	2	60	96	94%	3,973,000 +/-	119,000
	17-Sep-86	1	30	13	81%	3,835,000 +/-	358,000
	16-Sep-87	2	60	150	64%	2,984,000 +/-	532,000
Tazlina	26-Aug-85[c]	0	---	---	100%[a]	543,000 +/-	120,000
Klutina	30-Aug-85	2	60	3	100%	2,515,000 +/-	881,000
Tonsina	03-Sep-85	2	60	0	100%[a]	663,000 +/-	104,000
Summit	09-Sep-87	2	60	11	100%	1,494,000 +/-	683,000

[a] Assumes 100% of the fish population estimate comprised of juvenile sockeye salmon.
[b] Townet became entangled and was rendered unuseable for further tows.
[c] Very low number of targets encountered during survey, no tows conducted.

(Table 3). Estimates of juvenile sockeye salmon populations were made to 9 of the 12 surveys, as 3 of the 12 surveys with near-surface fish distributions were excluded from population adjustment (Crescent Lake - 24 September 1982; Packers Lake - 05 July 1983; and Tokun Lake - 18 August 1983), because stationary uplooking deployment of the transducer indicated few targets in the acoustically-undetectable depth strata. Increases in the sockeye salmon juvenile population estimates for the 9 surveys ranged from 10.1-33.2%. The largest percent adjustment to the population estimate was for the 18 August 1986 survey of Chenik Lake, which with the higher percentage of fish found during the first transect series (S_1) of 1987 (Figure 20), suggests a propensity for near-surface orientation at night by juvenile sockeye salmon in this lake. Thus, a higher fish density in the near-surface depth strata (<1.5 m) than in the first depth strata (1.5-4.5 m) would cause further underestimation of the juvenile sockeye salmon population in Chenik Lake.

Finally, of the 46 surveys in which catch composition (townet) information was obtained, only the townetting conducted in organically-stained Packers Lake revealed the presence of juvenile sockeye salmon older than age-0. However, based on smolt information from most of the surveyed lakes, age-1 juveniles are present. Thus, the townet catches are biased in favor of catching smaller/younger fish, and consequently, underestimate the composition of age-1 juveniles; resulting in the inability to estimate the population of cohorts.

EVALUATION

Sources of Error in Acoustic Estimates-- The direct duration-in-beam analysis to determine the effective sample volume requires establishment of a counting threshold, and making subsequent counts of the number of insonifications per target in order to derive the beam diameter. Essentially there are two major potential sources of error in this technique. The first is boat speed; however, in our surveys this error is minimized by recording the duration of each transect to calculate boat speed, and, more importantly, boat speed is monitored several times during transecting with an accurate velocity meter. The second source of error is analyst-induced, and involves the

Table 3. Estimates of near-surface populations (<2 m) of juvenile sockeye salmon based on measured fish densities in the first recorded depth interval and the measured lake volume of the near-surface strata in nine lakes surveyed during 1982-1987 with near-surface fish distributions.

Lake	Survey date	Mean fish density in first depth interval (no./1000 m^3)	X	Lake volume of surface to first depth interval (X 1000 m^3)	=	Extrapolated near-surface total population estimate	X	Sockeye composition (%)	=	Extrapolated near-surface sockeye population estimate	Increase in percent of total sockeye population estimate
Packers	30-Sep-87	31.2		2,970		93,000		94		87,000	10.1
Leisure	05-Aug-87	89.9		2,050		184,000		100		184,000	25.3
Delight	12-Aug-87	45.6		4,040		184,000		99		182,000	20.8
Chenik	18-Aug-86	8.0		1,760		14,000		100		14,000	33.2
Hidden	23-Jul-87	1.1		13,210		15,000		100[a]		15,000	28.1
Tokun	26-Sep-86	20.1		3,590		72,000		100		72,000	11.6
Frazer	12-Aug-86	48.3		24,540		1,185,000		94		1,114,000	28.1
	17-Sep-86	43.9		24,540		1,077,000		100		1,077,000	22.8
Summit	09-Sep-87	11.6		16,260		189,000		100		189,000	12.6

[a] Assumes 100% of the fish population comprised of juvenile sockeye salmon.

establishment of a counting threshold and making insonification counts. However, in our surveys, signal-to-noise ratios are high and fish densities are generally low enough to minimize counting errors. In addition, the duration-in-beam technique has been demonstrated both theoretically (Crittenden et al. 1988) and empirically using Alaska survey data (Thorne 1988) to provide an accurate and consistent beam angle measurement for sample volume computation of fish density.

Similarly, echo counting for fish density estimates is also susceptible to an analyst-induced errors through descriminating and counting individual targets over the threshold. However, the echo-counting technique is well suited for the majority of lakes surveyed in Alaska, as in 65% of the surveys, fish density and frequency of multiple targets were relatively low.

The empirical method of scaling the echo integrator is not immune from biases and potential sources of error; however, this method has been successfully used (Nunnallee 1983), and minimizes analytical error and/or bias relative to scaling by target strengths (TS) through dual-beam processing (Dr. Richard Thorne[1], personal communication). The major potential source of error in empirical scaling of the echo integrator is obtaining a representative, survey-wide scaling factor from echo counts in low density areas/depths of the lake. However, echo-count densities are made in a variety of discreet horizontal and vertical areas, and regressed against the integration values to obtain a representative scaling factor (usually correlation coefficients exceed 0.90). Moreover, both the empirical scaling and the TS scaling (dual-beam processing) of the echo integrator have a common assumption that individual target count/strength measurements taken in lower density sections of the lake are characteristic of the mean target strength in higher densities. Although the dual-beam procedure is better at making TS measurements at high densities than the echo-counting procedure is of making counts at high densities, the dual-beam/integrator processors are also sensitive to

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[1]BioSonics, Inc., 3670 Stone Way North, Seattle, WA 98103.

errors at high densities due to mis-identification of multiple targets. In addition, relatively small changes in counting thresholds, pulse-width parameters, and other input parameters of TS-scaled integration can substantially affect the integrator output. In contrast, the echo-count/duration-in-beam technique is more tolerant to a wide variation in gain settings, noise levels, and frequency of multiple targets. For example, Thorne (1988) states that a change in an assumed target strength from -50 dB to -44 dB results in a population estimate error of 10% for the duration-in-beam analysis, but a 300% error in the TS-scaled integration analysis.

Another source of error in hydroacoustic lake surveys is near-boundary fish distributions. Nine surveys out of the 54 conducted during 1982-1987 had near-surface distributions (Table 3), and two additional surveys had near-shore distributions. Detection of fish near boundaries is limited by the pulse width of transmitted sound. For near-surface distributions of fish, the detection problem is exacerbated by potential avoidance of the boat (Olsen et al. 1982). Techniques for detection and estimating near-shore fish distributions in lakes have been developed (Johnson 1981; Marino 1987), but are very labor-intensive. The technique of up-looking stationary deployment of the transducer for detection of fish near the surface (<2 m) has the disadvantage of small sampling power, but in some circumstances may work (Thorne and Thomas 1984). The extrapolation of measured fish densities from the first depth interval to the undetected near-surface depth strata assumes equivalent densities near surface. This may or may not be the case, and can result in a potential for overestimation or underestimation of the fish population (e.g., Chenik Lake).

The most evident source of error in hydroacoustic estimations of fish in lakes is the bias associated with townetting to partition a fish population by age class (cohort) and species. From townet catches, fish population estimates are characterizd by species and ages to provide estimates of sockeye salmon cohorts and freshwater survival. However, there appears to be substantial net avoidance by older/larger sockeye salmon fingerlings. Consequently, differential net avoidance biases the age composition and prohibits estimation of sockeye salmon juveniles by age class. On the other hand, in the limnetic area of the majority of lakes surveyed, the major fish species was juvenile sockeye salmon, thereby reducing the problem of differential avoidance of the net by different fish species. However, in a few lakes (Larson, Shell, and Karluk) threespine sticklebacks (*Gasterosteus aculeatus*) dominate the fish composition. Because sticklebacks overwhelm the composition in these lakes, and are not as efficient at avoiding the townet as juvenile sockeye salmon, sticklebacks may act to provoke an early aviodance response for sockeye salmon juveniles and further biases the fish species composition. Finally, the influence of unique environmental factors can make substantial differences in townet catches. Robinson and Barraclough (1978) showed that changes in net catches of juvenile sockeye salmon were related to changes in moonlight and cloud cover. Thus, mechanisms for variability in net catches can be identified; however, determining bias factors associated with netting is at best difficult, if not impossible to obtain, due to the lack of an absolute technique to validate species and age compositions.

RECOMMEDATIONS

The use of the hydroacoustic/townet technique to assess juvenile sockeye salmon populations in Alaskan lakes has some limitations and potential sources of error. Moreover, assumptions such as the fish density along a transect being representative of the population between transects (sampling problem), and others (e.g., integrator scaling), are predisposed to validity. However, in theory, acoustic surveys, like any other population assessment technique, are capable of yielding absolute estimates. It is clear that knowledge of fish behavior and distribution patterns can facilitate sample design and data interpretation. Consequently, the following recommedations are suggested for future surveys:

1) Use past lake-specific hydroacoustic survey data to optimize sampling strategy of future surveys;

2) Modify transect sampling design to include immediate replicate (2-3) transects within each of 6-12 equal areas of a lake (dependent on lake size);

3) Develop an alternate sampling technique to reduce or eliminate bias associated with townetting in discriminating fish species composition and age groups, or develop a netting bias factor through testing against an absolute measure; and

4) Develop a simplified and direct technique to quantitatively obtain fish densities near the lake surface;

5) Compare population estimates generated through the echo-counting/duration-in-beam technique and through the new BioSonics, Inc. echo signal processor (ESP) to evaluate the possibility of automating data analysis; and

6) In lakes with available information, compile a comparison of fall fingerling acoustic estimates with non-acoustical estimates of respective smolts to validate the hydroacoustic technique for estimating populations of juvenile sockeye salmon.

ACKNOWLEDGEMENTS

I thank Richard Yanusz, Jim Edmundson, and Virginia Patanovitch of the Limnology Section of the ADF&G for assisting with data collection. In addition, I thank Dr. Richard Thorne (and associates) of BioSonics Inc. for guidance in initiating the hydroacoustic surveys, and for the analysis of all recorded hydroacoustic tapes. Finally, I thank Carol Schneiderhan of ADF&G for drafting the figures in this report.

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