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The Carrying Capacity of Pitt Lake for Juvenile Sockeye Salmon (*Oncorhynchus nerka*)

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THE CARRYING CAPACITY OF PITT LAKE FOR JUVENILE SOCKEYE SALMON (*Oncorhynchus nerka*)

by

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ABSTRACT

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The Pitt Lake ecosystem was examined to determine factors that limit the production of juvenile sockeye salmon (*Oncorhynchus nerka)* in the lake and to estimate the carrying capacity of the lake for juveniles when expressed in terms of annual fry inputs. Pitt Lake is an oligotrophic system but more productive than most other sockeye salmon nursery lakes near the coast of British Columbia. The species composition, density, and size distribution of the zooplankton in Pitt Lake is similar to other coastal sockeye salmon nursery lakes except for the presence of the large zooplankter, *Leptodora kindtii*. There appears to be minimal overlap in the distribution between juvenile sockeye salmon and the two other dominant planktivores, threespine stickleback (*Gasterosteus aculeatus*) and longfin smelt (*Spirinchus thaleichthys*). Further, there is little overlap in the diet between juvenile sockeye salmon and longfin smelt (adequate diet information for threespine stickleback is not yet available). Juvenile sockeye salmon in Pitt Lake grow rapidly during the spring and summer and most migrate to the ocean after one year of freshwater residence at a size that is larger than that of outmigrants from other Fraser River sockeye salmon stocks. Although the foregoing suggests a recruitment limited system, there is also strong evidence for density dependent fry-to-adult survival and freshwater growth for Pitt Lake sockeye salmon. Current evidence suggests that food limitation and/or predation during the early period of lake residence for the sockeye salmon fry may limit the production of sockeye smolts in Pitt Lake, and therefore, adult returns.

RÉSUMÉ

Henderson, M. A., R. E. Diewert, J. Hume, K. Shorteed, D. Levy, and K. Morton. 1991. The carrying capacity of Pitt Lake for juvenile sockeye salmon (*Oncorhynchus nerka*). Can. Tech. Rep. Fish. Aquat. Sci. 1797: 161 p.

L'écosystème du lac Pitt a fait l'objet d'une étude visant à déterminer quels facteurs limitent la production de saumons rouges (*Oncorhynchus nerka*) juvéniles et à estimer la capacité d'accueil des juvéniles, exprimée du point de vue de l'apport annuel en alevins. Bien qu'il soit oligotrophe, le lac Pitt est plus productif que la plupart des autres nourriceries de saumon rouge du littoral de la Colombie-Britannique. La composition en espèces, la densité et la distribution selon la taille du zooplancton de ce lac sont similaires à celles observées dans d'autres nourriceries de saumon rouge de la côte, mais on y trouve aussi le grand zooplanctonte *Leptodora kindtii*. Il semble exister un chevauchement minimal entre la distribution des saumons rouges juvéniles et celle des deux autres planctonophages dominants: l'épinoche à trois épines (*Gasterosteus aculeatus*) et l'éperlan d'hiver (*Spirinchus thaleichthys*). De même, le chevauchement est faible entre les régimes alimentaires, du moins ceux du saumon et de l'éperlan (on ne dispose pas encore de renseignements suffisants sur le régime alimentaire de l'épinoche à trois épines). Les saumons rouges juvéniles du lac Pitt connaissent une croissance rapide au printemps et en été et la plupart émigrent vers l'océan après avoir vécu un an en eau douce; les migrateurs ont une plus grande taille que ceux provenant d'autres stocks de saumons rouges du Fraser. D'après ce qui précède, il semble que le système soit limité par le recrutement; toutefois, il est probable que les taux de survie jusqu'au stade adulte et de croissance en eau douce du saumon rouge du lac Pitt soient fonctions de la densité. Les données actuelles portent à croire que le caractère limité des ressources alimentaires et/ou la prédation au début de la période de résidence des alevins de saumon rouge pourraient nuire à la production de saumoneaux, donc au retour des adultes, dans le lac Pitt.

1.0 INTRODUCTION

The overall objectives of this study are to determine factors that limit the production of juvenile sockeye salmon (*Oncorhynchus nerka*) in Pitt Lake and to determine the carrying capacity of Pitt Lake for juvenile sockeye salmon. Meeting these objectives in a conclusive manner will require several years of study. However, based on analyses of historical data as well as data from field programs implemented in 1989 and 1990, it is possible to make some tentative inferences regarding the objectives. The purpose of this report is to provide these inferences and to identify important information gaps based on sampling programs conducted through March 31, 1990.

The specific objectives of the study are to i) determine the growth and age structure of juvenile sockeye salmon in Pitt Lake, ii) determine the spatial and temporal distribution and seasonal diet patterns of juvenile sockeye and potential competitors with juvenile sockeye salmon in Pitt Lake, and iii) determine the limnological characteristics of Pitt Lake as they relate to juvenile sockeye production. Information gathered for each of the objectives was used to address the overall objectives described above.

2.0 DESCRIPTION OF STUDY SITE

Pitt Lake (49° 26′ N, 122° 32′ W) is located in southwestern British Columbia in the lower portion of the Fraser River basin, at an elevation of < 10 m (Fig. 1). The climate at Pitt Lake is warm mediterranean, with warm summers and cool, wet winters. The lake has a surface area of 51 km^2 and is situated in the coastal western hemlock biogeoclimatic zone (Farley 1979). It receives 250-350 $cm \cdot yr^{-1}$ of precipitation at the southern portion of its drainage basin, and >350 $cm \cdot yr^{-1}$ over much of the remainder. The low elevation of Pitt Lake and its proximity to the mouth of the Fraser River result in the lake being affected by tidal forces, with daily tidal fluctuations in the lake averaging 0.6 m at low river discharges.

The topography of the Pitt Lake basin is quite mountainous, becoming increasingly so in a south to north direction. Portions of the basin have been extensively glaciated. The outlet of the lake extends to the edge of the low-relief farmland of the lower Fraser valley. The lake is steep-sided with limited littoral areas except for a large (12 km^2) shoal area (generally < 5 m in depth) located at the outlet of the lake. This highly unusual "negative" estuary is caused by tidal currents which carry sediments into the lake. Flood streams which enter the lake are stronger (but of shorter duration) than the combined effects of river discharge and ebb streams, resulting in a net transport of sediments into the lake (Thomson 1981). Ashley (1977) estimated that the delta at the outlet of Pitt Lake is advancing into the lake at an average rate of 1.28 $m \cdot yr^{-1}$. Mean depth of the lake is 52 m, which is increased to 68 m if the delta is excluded. Water residence time of this warm monomictic lake is estimated to be 0.8 yr.

Pitt Lake has a diverse fish community containing many potential predators of and competitors with juvenile sockeye salmon (Table 1). Longfin smelt (*Spirinchus thaleichthys*) and threespine stickleback (*Gasterosteus aculeatus*) are the most common limnetic species and are much more abundant than juvenile sockeye salmon. Prickly sculpins (*Cottus asper*) and mountain whitefish (*Prosopium williamsoni*) are also occasionally found in the limnetic zone. Potential predators of juvenile sockeye which occur in Pitt Lake include Dolly Varden char (*Salvelinus malma*), rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarki clarki*) and northern squawfish (*Ptychocheilus oregonensis*).

The major spawning grounds for Pitt Lake sockeye salmon are located in tributaries to, and the mainstem of, the Upper Pitt River. Fry production derives from both natural spawning and a sockeye salmon hatchery located on Corbold Creek. A smaller sockeye stock spawns in Widgeon Creek and Widgeon Slough, both tributary to the lower Pitt River.

Upper Pitt River maturing adult sockeye salmon are present in significant numbers in coastal fishing areas adjacent to the Fraser River throughout July (Vernon 1982). During this period, several major sockeye salmon stocks are also present in the fishery including those from the Quesnel, Chilko and Stellako systems (Woodey 1987). Upper Pitt River sockeye salmon begin to arrive on the spawning grounds in mid August with peak spawning activity occurring between early and mid September. Widgeon Creek-Widgeon Slough sockeye salmon arrive later and have a period of peak spawning activity between late October and mid November. The timing of the movement of juvenile sockeye salmon out of Pitt Lake is uncertain and is one focus of the current sampling program.

3.0 DATA SOURCES AND METHODS

3.1 GENERAL BIOLOGY, GROWTH AND AGE STRUCTURE OF PITT LAKE SOCKEYE SALMON

Estimates of the annual total adult return of Pitt Lake sockeye salmon from the 1948 to the 1984 brood year were from analyses performed by personnel of the International Pacific Salmon Fisheries Commission (IPSFC). Over the same period of time the IPSFC also collected age structure data for adult populations, prepared counts of the number of circuli in the freshwater growth zone from adult scales (Clutter and Whitesel 1956) and generated estimates of hatchery and wild fry production that were used in our study. Annual estimates of hatchery fry production were determined using a 5% sampler located on the hatchery outlet channel. Estimates of wild fry production were determined by applying an egg to fry survival rate that was calculated using a regression relationship between winter discharge levels and egg survival, to an estimate of total egg deposition (Rosberg et al 1986). More recently (1985-1990) the same data for adults and fry has been collected by the Fraser River Division of the Canadian Department of Fisheries and Oceans.

3.2 LIMNOLOGY

Limnological data reported here were collected in July and October of 1989 and March of 1990. Physical, chemical and biological data were collected from six locations (L1 to L6) in the lake (Fig. 1). At three of these locations (L2, L4 and L5) more detailed chemical and biological sampling was carried out. Photosynthetic rates were estimated at one of the locations (L4) (Fig. 1). Analysis of data from the three sampling dates in the study will enable us to make a first approximation of the lake's trophic status, to identify major components of the lake's plankton communities, and to identify some major factors limiting lake productivity. Lake area and mean depth were obtained by digitizing depth contours on Canadian Hydrographic Service chart 3062 (Pitt Lake). Zooplankton data from 1978 and 1980 in this report were collected under the auspices of the International Pacific Salmon Fisheries Commission (IPSFC).

Temperature and conductivity data were collected from the lake surface to the bottom using an Applied Microsystems Ltd. Model STD-12 conductivity, temperature and depth meter. Surface temperatures were taken with a NBS-calibrated mercury thermometer. Buoyancy frequencies (Turner 1973) were calculated and used to determine thermocline depths. Photosynthetically active radiation (PAR: 400-700 nm) was determined using a Li-Cor Model 185A light meter equipped with a Model 192S underwater quantum sensor. These data were used to calculate vertical light extinction coefficients and euphotic zone depths. Water clarity was measured with a standard 22-cm white Secchi disk. *In-vivo* fluorescence (IVF) profiles were obtained at each station with an Elektro-Optik (Juan F. Suarez) *in-situ* fluorometer.

An opaque 6-L Van Dorn sampler was sterilized with alcohol and used for collection of all water. We partitioned the euphotic zone into three depth intervals and then integrated water samples collected within each interval. A sample was also collected from 50 m. Replicate samples for chemical and biological analyses were taken from water from each depth interval, as well as from the deep sample. All chemical analyses were done according to methods described by Stephens and Brandstaetter (1983) and Stockner and Shortreed (1985).

Samples for chlorophyll determination were collected on Millipore AA filters, on 2.0-μm Nuclepore filters, and on 20-μm Nitex. Samples were frozen and later analyzed fluorometrically after maceration in 90% acetone. *In-situ* photosynthetic rates were determined by filling five 125-mL glass bottles (three clear and two light-proof) with water from each of the three depth intervals, inoculating with a sodium bicarbonate solution containing ^{14}C, and incubating for 1.5-2 h at the mid-point of each depth interval. Incubations commenced between 0900 and 1000 h. After the incubations, aliquots of each sample were filtered onto 0.2-μm Nuclepore filters, 2.0-μm Nuclepore filters, and 20-μm Nitex screens. Filters and screens were placed in scintillation vials containing a tissue solubilizer, scintillation cocktail was later added to the vials, and samples were then counted in a Packard Model 4530 liquid scintillation counter. Dissolved inorganic carbon (DIC) concentrations were determined using the potentiometric method of APHA (1980). Photosynthetic rates were calculated using Strickland's (1960) equation. Phytoplankton larger than the picoplankton size fraction (>2 μm maximum linear dimension) were identified and enumerated using a Wild inverted microscope equipped with phase optics. Cells were classified as either nanoplankton (>2 to 20 μm) or microplankton (>20 μm) based on maximum linear dimensions. Picoplankton (0-2 μm) were collected on a 0.2-μm pore size Nuclepore filter at a vacuum pressure <15 cm Hg, and later enumerated with a Zeiss epifluorescent microscope using methods and apparatus described in MacIsaac and Stockner (1985).

Bacterioplankton densities were determined from water samples fixed with formalin and later counted with DAPI on an epifluorescent microscope using a method modified from Porter and Feig (1980). Bacteria sizes were not measured in this study.

Zooplankton samples were collected using a 160-μm mesh size Wisconsin net having a mouth area of 0.05 m^2. Hauls were made from 30 m to the surface at a speed of approximately 0.5 $m \cdot s^{-1}$ at all stations. In 1978 and 1980, samples were collected once monthly (May-October) at two locations, preserved in 4% formalin, and later subsampled with a Folsom plankton splitter to provide 300-600 organisms for enumeration and identification to genus (excluding rotifers). After enumeration, the entire sample was dried at 90°C for 24 h and then weighed. Counts and dry weight measurements from the two sampling locations were averaged. In 1989 and 1990, in addition to the vertical Wisconsin net hauls which were collected at six stations, vertically stratified zooplankton samples were collected at three stations using a 12-volt diaphragm pump and a flexible hose system. The 2.5-cm diameter hose was lowered from the surface to 30 m with the aid of a weighted cable and water pumped from depth was filtered through a 20-μm Nitex screen. Integrated samples were collected from three depth intervals (0-10, 10-20, and 20-30 m) which were chosen to approximate the epilimnion, metalimnion and hypolimnion. Sampling depths were measured with an analog cable metre block and sample volume was recorded by an in-line digital flow meter. All samples were preserved in a sucrose-buffered 4% formalin solution (Haney and Hall 1973). Samples were subsampled in the laboratory by withdrawing known volumes to provide 100 organisms <0.6 mm and 300 organisms >0.6 mm for analysis. Zooplankton within a subsample were identified to genus or species and total body length, excluding spines and antennae, was measured using an electronic measuring system. Rotifers were identified and enumerated only from samples collected with a pump and a 20-μm mesh net. Subsequent biomass estimates were calculated using length-weight regressions adapted from Bird and Prairie (1985), Culver et al. (1985), Stemberger and Gilbert (1987), and Yan and Mackie (1987).

3.3 DISTRIBUTION OF PELAGIC FISH

3.3.1 HISTORICAL SAMPLING

The International Pacific Salmon Fisheries Commission undertook studies on the pelagic fish population of Pitt Lake between 1977 and 1982. The objective of this research effort was to monitor the migration behaviour of juvenile sockeye salmon within the pelagic zone and to estimate juvenile sockeye (presmolt) population sizes (Johnson MS 1981). Hydroacoustic sampling was undertaken in conjunction with trawl sampling to determine the vertical and horizontal distribution of Pitt Lake sockeye juveniles. Because of the co-occurrence of longfin smelt and threespine stickleback within the pelagic zone, a substantial sampling effort was expended, particularly in 1979 (Table 2).

Fish were captured in a mid-water trawl net similar to the device described by Enzenhofer and Hume (1989). The trawl was 18 m long with mouth dimensions 3 m wide by 7 m deep, and mesh sizes ranging from 10.2 cm at the mouth to 3 mm at the cod end. The net was deployed from a 7 m towing vessel at night, and towed at desired depths (as determined by the location of fish targets on echograms) by establishing a relationship between towing depth and warp length. Fish specimens were preserved in formalin and later identified and enumerated. All data collected by the IPSFC from this and other Fraser River lakes is reported in Mueller and Enzenhofer (1991 in press).

Unlike the closing trawl described by Enzenhofer and Hume (1989), the net device operated by IPSFC did not have closing capability. Thus catches from deeper depth strata were likely contaminated by fish captured in shallow depths during net deployment and retrieval. Enzenhofer and Hume's (1989) study in Harrison Lake showed that the proportion of juvenile sockeye from deep strata could be underestimated by as much as a factor of 4 due to contamination of trawl catches by smelt and sticklebacks occurring in shallower depths.

The pelagic zone of Pitt Lake was divided into 3 trawl sampling areas (Fig. 1) each containing 2 acoustic transects. Sampling dates were distributed throughout the year, with most intensive sampling between April and October (Table 2). The most intensive sampling was undertaken in 1979, followed by 1978 and 1980. Sampling was relatively infrequent in 1977, 1981 and 1982 when only 1 or 2 sampling trips were undertaken.

Hydroacoustic sampling was undertaken with a 70 kHz Simrad EY-M echo sounder coupled to an analogue AM tape recorder and Tektronix 214 oscilloscope. A calibration tone was recorded at the beginning of each transect to allow for adjustments due to system drift prior to signal processing. Short tape segments were processed by both echo counting (with an oscilloscope) and echo integration, to derive scaling co-efficients between echo integrator values and absolute counts. The remainder of the tapes were then echo integrated and scaled by the estimated co-efficient as described by Nunnallee (1980). Effective sample volumes were estimated with an oscilloscope using the duration-in-beam technique (Nunnallee 1973; Thorne 1988).

3.3.2 1989 SAMPLING

Research was undertaken in 1989 to up-date the earlier sampling effort by IPSFC and describe current fish distribution patterns within the pelagic zone of Pitt Lake. Over the past decade there have been advances in both trawling capability and hydroacoustic technology which permit more effective sampling and a refined ability to describe pelagic fish populations.

Two surveys were conducted in 1989; the first on July 25-26, and the second on November 15-16. Trawling was undertaken with a closing midwater trawl device as described by Enzenhofer and Hume (1989). Because of the net's closing capability, it can be deployed and retrieved from depth in a closed position and effectively avoid contamination by surface or shallow-oriented fish populations. Except for the closed operation, the net and trawling technique were the same as those previously employed by IPSFC.

Hydroacoustic sampling during 1989 was undertaken with a dual beam, 420 kHz BioSonics Model 105 echosounder. Echo signals were monitored in the field on an oscilloscope and taped in digital format on a Sony DAT tape recorder for processing at a later date. A dual beam transducer (6°/15°) was housed within a fibreglass towed body to isolate the movements of the transducer from the survey vessel. Acoustic transects adopted during 1989 were the same as those used by IPSFC (transect locations shown on Fig. 1) and transecting was conducted at night when fish targets were dispersed as individuals.

Signal processing included both dual beam processing (for target strength estimation) and echo integration with a BioSonics Model 221/281 echo signal processor. Ehrenberg (1983) provides a summary of dual beam echo sounding theory, and Burczynski and Johnson (1986) provide an example of an application of this technology to estimate pelagic juvenile sockeye abundance within Cultus Lake. Voltage thresholds during analysis were set at 100 mV above ambient noise levels as determined by an oscilloscope.

3.4 SEASONAL FEEDING PATTERNS AND DIET ANALYSIS

Samples of juvenile sockeye salmon and longfin smelt were taken from Pitt Lake in 1978 and 1979 by staff of the International Pacific Salmon Fisheries Commission as described above. Contents of the esophagus and cardiac portion of the stomach from preserved specimens were removed and enumerated using a dissecting microscope. All food items were counted and identified. Zooplankton prey were identified to genus except for juvenile copepods and nauplii. Insects, if present, were identified to order. Stomach volume occupied by each food type was estimated.

Stomach content data were summarized for each sampling trip. If more than one sampling trip occurred in one month then data were pooled for that month. Only age 0^+ sockeye were used in the diet analysis as this age group made up 93.5% and 95.6% respectively of the catch of sockeye during the 1978 and 1979 surveys (Table 3). Smelt of all size classes were pooled.

Numbers of stickleback sampled were too low to be included in this analysis.

Seasonal patterns of feeding activity of sockeye and smelt were determined based on the average percent fullness of stomachs over the season. The degree of overlap in the sockeye and smelt diets was ascertained by determining types of prey items consumed by each species.

4.0 RESULTS

4.1 GENERAL BIOLOGY, GROWTH AND AGE STRUCTURE

4.1.1 STOCK SIZE

The total run size (catch plus spawning escapement) of adult Pitt Lake sockeye salmon originating from the brood years 1948 to 1984 has ranged from approximately 16,000 to over 217,000 and averaged 77,000 (Fig. 2). The size of the Pitt Lake sockeye salmon run increased discontinuously from the 1948 to the 1971 brood years and then declined precipitously and remained at low levels through the 1984 brood year. The brood years from 1977 to 1982 were particularly weak with an average total run size of approximately 25,000 fish.

4.1.2 FRY PRODUCTION

The Pitt lake sockeye salmon stock is sustained by both wild and enhanced production. The enhanced production, in the form of fry, is from a hatchery that began operation in 1960 on a tributary of the Upper Pitt River. The average annual total sockeye salmon fry production (i.e. wild and enhanced) from the Upper Pitt River increased discontinuously from two to seven million from the brood years in the early 1960's to over 18 million in 1976 and 1978 (Fig. 2). Production declined in more recent years and averaged approximately five million fry between the 1980 and 1983 brood years. The contribution of enhanced fry production has ranged from less than 20% to more than 80% of total production over the period of brood years from 1960 to 1983 (Fig. 3) and has averaged approximately 47%.

4.1.3 AGE STRUCTURE

Estimates of the age structure of the juvenile sockeye salmon in Pitt Lake were based on a total of 525 trawl samples taken in 1978, 1979 and 1980 (Table 3). Most of these fish, ranging from 93.5 to 100% were in their first year of freshwater residence (age 0^+). The remainder were in their second year or 1+ fish. The very small proportion of 1+ fish indicates that nearly all juvenile sockeye salmon in Pitt Lake migrate to the ocean after one year of freshwater residence.

Almost all returning adults are four or five years old with one year of freshwater residence (i.e. age 4_2 or 5_2). Unlike most other Fraser River sockeye salmon stocks, five year old fish often form the greatest part of a return from a brood year (Fig. 4). Two features of the age structure of the returning adults in recent years require special mention. First, over the last 10 brood years there appears to have been increasing interannual variation in the percent of the run that returns at age five. Second, it has become increasingly common for the percent of the total run to return as five year old fish to be very large. Five out of the ten brood years from 1974 to 1983 exhibited returns that were composed of more than 80% five year old fish. The number of years when the percent of the total run consisting of five year old fish was greater than 80% for the 1954 to 1963 and 1964 to 1973 periods was two and one respectively.

4.1.4 FRY-TO-ADULT SURVIVAL

Survival from the fry to adult stage was generally between 1-2% from the 1960 to 1983 brood years (Fig. 5). However, there were two periods when survival showed large departures from this range. Fry-to-adult survival approached 5% for both the 1963 and 1964 brood years. These high levels of survival have not been repeated since that time. In contrast, there was a prolonged period of low survival in brood years from 1974 to 1982. Over this period, fry-to-adult survival was always less than 1% and averaged 0.52%.

There is evidence for density dependent fry-to-adult survival for Pitt Lake sockeye salmon. The largest estimates of survival (Fig. 5) occurred during the early to mid 1960's when fry inputs were the lowest (Fig. 2). Survival decreased over the period between the mid 1960's and early 1970's when fry inputs were increasing. Fry inputs increased dramatically from the 1973 to the 1979 brood years. Over this same time period estimates of fry-to-adult survival were the lowest on record. Fry production has declined in more recent brood years to levels similar to those of the early 1960's while fry-to-adult survival has increased. An exponential model was fit to the survival data using a least squares procedure to estimate the parameters (Draper and Smith 1966) for the period of brood years from the 1960-1983 (Fig. 6). The model is of the form:

$$S = Ae^{nx}$$

where S is the percent smolt-to-adult survival at different levels of fry production, x, and A (1.12) and n (-.13) are constants. The slope of the relationship, -.13, is significantly different from zero ($P < .05$) and the correlation coefficient (r^2) is .22. Overall, an increase in fry production from 4 to 18 million resulted in an 80% decrease in fry to adult survival.

Freshwater growth as exhibited by the number of circuli in the freshwater zone of the scale (Clutter and Whitesel 1956), also showed evidence of density dependence (Fig. 7). The number of circuli declined from an approximate range of 14 to 22 when fry production was less than 10 million to 13 to 16 when fry production was greater than 10 million. The relationship between circuli count and fry production was fit to the exponential function described above where S is the freshwater circuli count at different levels of fry production, x, and A (7.19) and n (-.02) are constants. The slope of the relationship, -.02, is significantly different from zero ($P < .05$) and the correlation coefficient is .32.

4.1.5 JUVENILE GROWTH

The form of growth of juvenile sockeye salmon from Pitt Lake, as reflected in a length-weight relationship, was very similar to the form of growth of four other sockeye stocks in the Fraser River basin; Harrison, Cultus, Quesnel and Fraser Lake (Fig. 8).

The seasonal freshwater growth pattern of Pitt Lake sockeye juveniles from January to December was based on a composite of measurements made in 1978, 1979, and 1980 (Fig. 9). Fork-length of juvenile sockeye salmon remained constant at approximately 30 mm between January and early May. This was followed by a period of rapid growth through early October when average fork-length was between 80 and 90 mm. A comparison with juvenile sockeye salmon samples from four other systems in the Fraser River basin, Harrison, Cultus, Quesnel and Shuswap, indicated that Pitt Lake sockeye have a higher growth rate during the spring and summer period and achieve a larger size by the end of the growing season (Fig. 10). In comparison to the size of Pitt Lake juvenile sockeye salmon in early October, 80 to 90 mm fork-length, Cultus and Shuswap sockeye were between 60 an 70 mm fork-length and Quesnel and Harrison sockeye ranged from 70 to 80 mm fork-length.

The instantaneous daily growth rate, calculated on the basis of weight, of the 1978 brood of sockeye salmon in Pitt Lake began to increase in early May and peaked at approximately 4.0% in early August (Fig. 11). It then declined through the end of the growing season. The pattern of the instantaneous daily growth rate was qualitatively similar for the 1979 brood year although the peak, approximately 6%, occurred earlier in the season. The peak in instantaneous daily growth rate for the 1980 brood year, approximately 2%, was less than for the two previous brood years.

The average instantaneous daily growth rate was greater for the Pitt Lake stock than for any other stock in the Fraser River system for which these estimates were available (Table 4). Pitt Lake sockeye had an average instantaneous daily growth rate for the 1978 and 1979 brood years combined of 2.14%. Comparable estimates for Cultus (1976, 1982, 1986), Quesnel (1977, 1981) and Shuswap (1974-75, 1977-79, 1982-83, 1986) sockeye were 1.25%, 1.91% and 1.56% respectively.

4.2 LIMNOLOGY

4.2.1 PHYSICS

Surface temperatures in Pitt Lake were warmer at the southern, or outlet end of the lake than they were near the north end in both July and October. Thermoclines strengthened considerably in a north to south direction and averaged depths of 13.9 m in July and 24.3 m in October, with considerably weaker stratification present on the October sampling date (Table 5; Figs. 12,13). The lake was isothermal in March, with surface temperatures ranging from 5.1 to 5.5°C. Variation in thermal structure along the lake is due primarily to morphometric factors which cause prevailing north winds and to the cool temperatures of the Upper Pitt River. The result of this morphometry and thermal structure (which occurs in other British Columbia lakes such as Chilko, Morice, and Quesnel) is considerable spatial heterogeneity in production and biomass, with higher biological production usually occurring near lake outlets, which are physically more stable areas of the lake.

Euphotic zone depths ranged from 6.4 to 12.8 m, and averaged 8.8 m in July, 7.8 m in October, and 9.6 m in March (Table 5). The glacial origins of some lake tributaries contributed to the relatively turbid conditions. July epilimnion depths averaged 13.9 m, or almost 40 % greater than euphotic zone depths. Under these conditions no hypolimnetic photosynthesis can occur, and photosynthesis of a portion of the epilimnetic phytoplankton community will be light-limited (dependent on the extent of surface mixing), resulting in possibly lower production and biomass than would be predicted strictly on the basis of available nutrients.

4.2.2 CHEMISTRY

Conductivity (normalized to 25°C) ranged from 29-33 $\mu S \cdot cm^{-1}$ and exhibited little spatial variability, but tended to be slightly higher in the deep water of the lake (Figs. 14,15). Profiles extended to the lake bottom and no evidence of a deep saline layer was found. The range in conductivities found in Pitt Lake was up to 5 times lower than those which occur in Fraser river system lakes which are located in the interior of British Columbia, but was similar to that found in many other coastal British Columbia lakes (K. Shortreed, unpubl. data). Epilimnetic pH values were slightly acidic (range: 6.4-6.9), and considerably lower than interior Fraser River system lakes (Stockner and Shortreed 1983), but similar to a number of other coastal British Columbia lakes (Nidle and Shortreed 1985). The low pH and low conductivity indicate that Pitt Lake has little capacity to prevent a drop in current pH levels if the acidity of local precipitation increases. While it does not appear to be a problem at present, the proximity of Pitt Lake to the heavily industrialized areas of Greater Vancouver is a cause for concern, and pH of the lake should be closely monitored.

Hypolimnetic silicate concentrations averaged 1.78 $mg \cdot L^{-1}$ on both sampling dates, while average epilimnetic concentrations increased from 1.36 to 1.60 $mg \cdot L^{-1}$ between July and October. Concentrations averaged 1.80 $mg \cdot L^{-1}$ in March (Tables 6-14). The data indicate that while biological production during the summer period had a measurable effect on silicate concentrations, silicate limitation was not a factor in determining phytoplankton production or community structure, since only concentrations <0.5 $mg \cdot L^{-1}$ are considered limiting (Lund 1950).

Epilimnetic nitrate concentrations in July averaged 63 $\mu g\ N \cdot L^{-1}$, slightly lower than the hypolimnetic average of 73 $\mu g\ N \cdot L^{-1}$ (Tables 6-14). On the late October survey, hypolimnetic concentrations were similar to those in July (72 $\mu g \cdot L^{-1}$), while epilimnetic levels had decreased to an average of 44 $\mu g\ N \cdot L^{-1}$. The lower autumn concentrations are still well above levels that could be considered limiting to phytoplankton production, but they do indicate that substantial biological production occurred between July and October. Because of the rapidly weakening thermal structure on the late October sampling date, it is highly probable that at this time nitrate concentrations were increasing from an unknown seasonal minimum. By March 1990, average nitrate concentrations had increased to 118 $\mu g \cdot L^{-1}$. Nitrate levels in Pitt Lake were much greater than those found in many other lakes near the British Columbia coast (Costella et al. 1983; Nidle and Shortreed 1985), and were similar to those found in a number of Fraser River system lakes in the interior of British Columbia (Stockner and Shortreed 1983). Epilimnetic ammonia concentrations ranged from 1-14 $\mu g\ N \cdot L^{-1}$ and also tended to be lower in October than in July.

Total phosphorus (TP) concentrations ranged from 2.4-8.0 $\mu g\ P \cdot L^{-1}$ and averaged 3.5 $\mu g\ P \cdot L^{-1}$, while the observed range in particulate phosphorus (PP) concentration was 1.1-3.3, with an average of 1.8 $\mu g\ P \cdot L^{-1}$. An average of 51% of the TP occurred as PP, which was considerably lower than the 75% Stockner and Shortreed (1985) observed in a wide range of coastal British Columbia lakes. It is possibly that there is a surplus of both N and P in Pitt Lake and that some other factor is limiting phytoplankton production, but more probably the apparent large proportion of filtrable phosphorus was in a form (perhaps refractive organics) that was not biologically available.

Growing season (July and October) concentrations of particulate carbon (PC) and particulate nitrogen (PN) averaged 313 $\mu g \cdot L^{-1}$ and 22 $\mu g \cdot L^{-1}$, respectively, resulting in a C:N:P molar ratio of 409:25:1. This is somewhat similar to the ratio of 390:44:1 that Stockner and Shortreed (1985) found for a wide range of coastal British Columbia lakes, and lower than the ratio of 756:62:1 that Shortreed and Stockner (1990) reported in an unfertilized lake on Vancouver Island. According to criteria developed for freshwater phytoplankton by Healey and Hendzel (1980), ratios of PN:PP, Chl:PC, PP:PC, and PN:PC all indicate that the lake is moderately to severely nutrient limited. Further work is needed to confirm that phosphorus availability is a major factor limiting phytoplankton production in Pitt Lake.

4.2.3 PHYTOPLANKTON

On the July and October sampling dates epilimnetic chlorophyll concentrations averaged 2.07 $\mu g \cdot L^{-1}$ (range: 1.14-2.82 $\mu g \cdot L^{-1}$) and generally had a uniform vertical distribution in the epilimnion. In March 1990 average chlorophyll concentrations were only 0.15 $\mu g \cdot L^{-1}$, indicating the lack of a late winter-early spring production peak. Concentrations in the southern half of the lake tended to be higher than those in the northern portion (Table 5; Figs. 16,17). The relationship between growing season averages of epilimnetic chlorophyll and TP concentration has been widely used to categorize the trophic status of various lakes (Vollenweider 1976; Stockner and Shortreed 1985) and in order to rank Pitt Lake we plotted average Pitt values on a regression developed for coastal British Columbia lakes (Stockner and Shortreed 1985) (Fig. 18). Average chlorophyll and TP data from Pitt Lake are averages of only 2 sampling dates and would likely change if detailed seasonal information were available, but they do enable us to make preliminary comparisons of the lake's trophic status with these other coastal lakes. Our Pitt data fits the regression line quite well and has similar chlorophyll and TP values to a number of lakes undergoing nutrient additions, but it has substantially higher chlorophyll and TP values than other unfertilized sockeye nursery lakes near the British Columbia coast. However, the lake is still well within the oligotrophic category. Epilimnetic bacterioplankton densities, which are useful indicators of trophic status in lakes (Bird and Kalff 1984; Shortreed and Stockner 1986), ranged from $5.1 \times 10^5 \cdot mL^{-1}$ to $1.08 \times 10^6 \cdot mL^{-1}$, also placing the lake well within the oligotrophic category (the upper limit for bacteria density in oligotrophic lakes is $1.7 \times 10^6 \cdot mL^{-1}$).

Photosynthetic rate measurements carried out in July indicated that picoplankton (≤2 μm) accounted for only 34% of the total, yet comprised 78% of total phytoplankton biomass (as chlorophyll). Nanoplankton (>2 to 20 μm) photosynthesis comprised 64% of the total, and microplankton (>20 μm) accounted for the remaining 2%. It is well documented that the relative contribution of picoplankton to photosynthesis generally decreases as trophic status increases. Picoplankton photosynthesis averaged 50% of the total in a highly oligotrophic coastal British Columbia lake (Shortreed and Stockner 1990) and in oligotrophic Lake Superior (Fahnenstiel et al. 1986), decreased to 40% in a more productive (but still oligotrophic) interior British Columbia lake (Stockner and Shortreed 1989), and was 15% in a meso-eutrophic European lake (Weisse 1988), which provides further evidence that Pitt Lake is in the more productive end of the oligotrophic category. Throughout the study, chlorophyll content of the microplankton was below our analytical detection limit of $0.01\ \mu g \cdot L^{-1}$, with the result that nanoplankton made up the remaining 32% of the chlorophyll. Production/biomass (P/B) ratios were accordingly far higher in the nanoplankton ($0.98\ \mu g\ C \cdot \mu g\ Chl^{-1} \cdot hr^{-1}$) than in the picoplankton (0.15). These data suggest that nanoplankton (normally the preferred zooplankton food resource) are being heavily grazed but are maintaining high turnover rates. Since the high planktivore densities in the lake maintain low cladoceran and copepod numbers, it is probable that rotifers account for much of the grazing pressure.

Phytoplankton community structure in Pitt Lake was similar to that found in a number of other British Columbia lakes (unpublished data). The coccoid cyanobacteria *Synechococcus* spp. (both single celled and colonial forms) was the dominant member of the autotrophic picoplankton community and the most abundant phytoplankter in Pitt Lake, with very low numbers of coccoid eucaryotic picoplankters present. Dominant diatoms were the ubiquitous *Rhizosolenia* sp., which averaged epilimnetic densities of ca. $400 \cdot mL^{-1}$, and the centric diatom *Cyclotella* spp. (primarily *C. glomerata*) which was present in slightly greater densities than the much larger *Rhizosolenia*. Other common phytoplankton were the flagellates *Chromulina* spp. and *Chroomonas* sp., the dinoflagellate *Gymnodinium* sp., and the chlorophyte *Crucigenia* sp., all species which are desirable food sources for herbivorous zooplankton.

4.2.4 ZOOPLANKTON

In both years (1978 and 1980) for which seasonal zooplankton data are available , the maximum zooplankton biomass of 425-450 mg dry wt·m^{-2} occurred in July, with a smaller peak of 400-410 mg·m^{-2} occurring in September (Fig. 19). These standing crops are similar to those found in unfertilized coastal British Columbia lakes (Stockner and Hyatt 1984), but lower than those in sockeye nursery lakes in the interior of British Columbia (Goodlad et al. 1974). Average zooplankton dry weights (measured) in 1989 were similar to those in 1978 and 1980, with estimates of 390 and 299 mg·m^{-2} in July and October, respectively. Average standing crop declined to 24 mg dry wt·m^{-2} in March 1990. In 1989, zooplankton dry weights tended to be higher in the central and northern areas of the lake and were lowest at the south end (Fig. 20). Calculated zooplankton dry weights (derived from length-weight regressions) from 1989 Wisconsin samples ranged from 112-395 mg·m^{-2} and calculated dry weights from integrated pump samples ranged from 176-439 mg·m^{-2}. Calculated dry weights from Wisconsin samples were highly correlated ($r=0.96$, $n=12$, $p<0.01$) with measured dry weights (also from Wisconsin samples) and the regression equation had a slope of one (Fig. 23). The intercept was 28 mg measured dry wt·m^{-2} but was not significantly different than 0, indicating that in Pitt Lake estimates of zooplankton biomass from measured dry weights are directly comparable with zooplankton biomass derived from length measurements.

Bosmina longirostris was the most abundant macrozooplankton species during the growing season, reaching seasonal maxima of 95,000·m^{-2} in July both in 1978 and in 1980 (Fig. 24). Greatest numbers (75,000·m^{-2}) of *Diacyclops* sp. also occurred in July (Fig. 25). The large cladoceran *Leptodora kindtii* was very rare in May but increased to an August peak of 300·m^{-2} in 1978 and 160·m^{-2} in 1980 (Fig. 24). Densities of *Epischura lacustris* ranged from 5,000-20,000·m^{-2}, with seasonal maxima occurring in June (Fig. 25). In March 1990, *Diacyclops* was the most abundant zooplankton species. Macrozooplankton such as *Daphnia*, *Leptodiaptomus*, and *Eubosmina*, although common in other Fraser River system sockeye nursery lakes, were either not present or extremely rare in Pitt Lake.

Vertically stratified sampling (using plankton pumps and 20-μm mesh nets) revealed considerable heterogeneity in zooplankton distribution. On the July 1989 sampling date zooplankton were concentrated in the epilimnion (0-10 m), with metalimnetic (10-20 m) and hypolimnetic (20-30 m) populations considerably less abundant (Tables 6-14; Fig. 21). The sole exception to this distribution pattern was *Diacyclops* in the central and southern portions of the lake, where it was much more abundant in the hypolimnion than at the shallower depths. Vertical distribution of zooplankton was generally uniform in October and in March (Fig. 22, 22a). Distribution of some zooplankton species exhibited considerable horizontal heterogeneity (Tables 6-14). In July, *B. longirostris* was less abundant at the southern end of the lake than elsewhere, whereas in October and March its distribution was variable but did not exhibit distinct trends. In July and October highest densities of the copepod *Diacyclops* were found in the northern half of the lake and lowest densities at the southern end. In March, its spacial distribution was considerably more uniform. Both *L. kindtii* and *H. gibberum* had highest densities at the north end of the lake in July; in October and March their numbers were extremely low throughout the lake. The most abundant rotifers in Pitt Lake in 1989 were *Kellicottia*, *Polyarthra*, *Ploesoma*, and *Conochilus* (Tables 6-14). Total rotifer densities were highest in the epilimnion on all sampling dates, although at the northern end of the lake *Conochilus* densities were greater in the 10-20 m sample than in the epilimnion. *Ploesoma* was much more abundant in October than in July, and its October epilimnetic density of $18.7 \cdot L^{-1}$ at the southern end of the lake was the highest recorded for any zooplankton genus in the Pitt Lake study. *Kellicottia* was the dominant rotifer on the March sample date although total rotifer numbers were extremely low. The importance of rotifer populations in sockeye nursery lakes is very poorly understood, and with the available data we are not able to explain variations in rotifer species composition or density, or to estimate the importance of rotifers to macrozooplankton and to planktivores in Pitt Lake. However, since rotifers can be an important food source for *L. kindtii* (Cummins et al. 1969), and since *L. kindtii* is an important item of sockeye diet in Pitt Lake (see 4.4) it is possible that rotifers play an important role in the food chain leading to juvenile sockeye.

Sizes of Pitt Lake zooplankton tended to be similar to zooplankton found in other sockeye lakes near the coast of British Columbia (Rankin and Radziul 1986). *B. longirostris* ranged from 0.20 mm to 0.40 mm with mean lengths of 0.29 mm in July and March and 0.28 mm in October (Fig. 26, 27, 27a). *Diacyclops* body length ranged from 0.3-1.0 mm with means of 0.67 mm in July, 0.76 mm in October, and 0.51 mm in March. *E. lacustris* were 0.4-1.4 mm in size and averaged 0.96 mm and 0.82 mm in July and October, respectively. *L. kindtii* ranged from 1.0 mm to 6.0 mm in July with a mean body length of 3.1 mm.

Summer planktivore densities in Pitt Lake exhibit considerable within-year variation, primarily because of immigration and emigration of stickleback, smelt, and sockeye in and out of the limnetic zone (see 4.3). However, in all years for which data are available, summer planktivore densities were very high, at times exceeding $10{,}000 \cdot ha^{-1}$ in late summer, and juvenile sockeye generally comprised <5% of total planktivores. These densities suggest that grazing pressure on the zooplankton community is high in most or all years, and since zooplankton community structure and biomass was similar in the three years, it appears that grazing pressure was also similar in those years. The low numbers of *Daphnia* and the small average size (0.29 mm) of *B. longirostris* provide strong evidence that zooplankton in Pitt Lake are subject to very heavy grazing pressure (Kyle et al. 1988). The Pitt Lake zooplankton community, with one prominent exception (*L. kindtii*), is typical of coastal British Columbia lakes which contain substantial planktivore populations, with low numbers of larger cladocerans such as *Daphnia* and relatively large numbers of rotifers. The presence of the very large cladoceran *L. kindtii* is quite unusual in sockeye nursery lakes, and in Pitt Lake past data indicates that *L. kindtii* is an important diet item for juvenile sockeye (see 4.4). Its continuing presence is anomalous, but perhaps may be explained by the low densities of sockeye in Pitt Lake, and the possible failure of other Pitt Lake planktivores to utilize this large cladoceran.

4.3 PELAGIC FISH DISTRIBUTION

Assessing the distribution of fish in Pitt Lake presents a challenging problem due to the presence of three species of planktivores which are numerous within the pelagic zone; juvenile sockeye salmon, longfin smelt, and threespine stickleback. In order to evaluate possible competitive relationships between these species, it is necessary to first determine their degree of spatial, temporal, and food resource overlap.

4.3.1 HISTORICAL SAMPLING

Three fish species predominated in the trawl catches: age-0 sockeye, threespine stickleback, and longfin smelt (Table 15). Seasonally, sockeye juveniles comprised a declining proportion of trawl catches (Fig. 28) over the period from April/May (54%), through to July (19%) and into October/November (2%). Smelt comprised at least 20% of the trawl catches, peaking in June at 65% of the catch and declining in relative abundance thereafter (Fig. 28). Stickleback were present in low numbers during April/May, but virtually disappeared from the pelagic zone during June (Fig. 28), presumably due to an onshore spawning migration. Stickleback re-appeared in the pelagic zone in July and eventually predominated within the pelagic zone, accounting for 53% of the October/November trawl catch (Fig. 28).

Juvenile sockeye trawl catch-per-unit-effort (CPUE) peaked within Pitt Lake in May to early June and declined thereafter (Fig. 29). There was a seasonal progression in peak CPUE values between areas which was consistent with a directed migration by juvenile sockeye towards the outlet end of Pitt Lake (Area 3). Trawl catches obtained from the lower Pitt River (Fig. 30) peaked in July of 1979. These historical IPSFC trawl catch data (Figs. 29,30), taken together, suggest a rapid and directed migration of large numbers of juvenile sockeye towards the outlet of Pitt Lake during the early summer period and also suggest an emigration of age-0 sockeye from the system.

Although a component of the juvenile sockeye population may have emigrated out of the lake during the early summer, another component of the population was present in relatively low numbers during fall and winter periods (Fig. 29; Table 15). These fish were vulnerable to trawl capture in late summer, fall, and winter (Table 15) albeit in low numbers relative to stickleback and smelt catches.

Smelt occurred in trawl catches in all 3 areas of the lake, with no clearly discernable seasonal or area trends (Fig. 31). Smelt were extremely abundant within Pitt Lake, with trawl CPUE values exceeding 140/min in one sample from Area 1 (Fig. 31). Stickleback were largely absent from the pelagic zone during May and June (Fig. 32), presumably because of littoral (onshore) spawning activity. Stickleback were particularly numerous during fall months and frequently produced trawl CPUE values in excess of 50/min (Fig. 32).

Seasonal changes in the nocturnal vertical distribution of juvenile sockeye were assessed by combining the IPSFC trawl data for the period 1977-1982. The results (Fig. 33) show a seasonally increasing nocturnal depth distribution such that juvenile sockeye were deepest during fall periods. However, the large amount of variation within this data set reflects little consistency from survey-to-survey, and no confinement (nocturnally) of juvenile sockeye to particular depth strata.

During 1979 when IPSFC sampled Pitt Lake extensively, fish densities increased over the period of observation between late-April and November (Fig. 34A). These estimates reflect combined density values for the 3 predominant limnetic species (juvenile sockeye, smelt and stickleback). When the results were scaled by the trawl catches to provide specific abundance estimates for juvenile sockeye within the lake, a sharply peaked curve was obtained (Fig. 34B). The curve indicated a rapid juvenile sockeye population build-up in early May, followed by a severe population decline at the end of May. It is difficult to determine the relative contribution of emigration out of the lake, mortality processes within the lake and trawl avoidance by fry as they continue to grow, to the observed population decline.

The acoustic results (apportioned by the trawl catches) also suggested a rapid early-summer horizontal shift in the location of juvenile sockeye within Pitt Lake (Fig. 35). Following the detection of juvenile sockeye at the head of Pitt Lake in late April (Area 1), there was a rapid shift by juvenile sockeye down-lake such that by May, the weighted mean position was in Area 2 (Fig. 35). Later in June and early July, the fish shifted further down-lake (mean position between Areas 2 and 3). Thereafter the mean horizontal position was in Area 2 for most of the year (Fig. 35) reflecting an even juvenile sockeye distribution within Pitt Lake. The observed horizontal shifts in mean position of juvenile sockeye are consistent with an early summer emigration of some of the fry from the Pitt Lake system, and a continual occupation of the pelagic zone by a resident component.

The historical hydroacoustic and trawl catch data suggest the possibility of 2 distinct sockeye life history types within the Pitt Lake system. In another study to evaluate the relative survival of different chinook life history types, Reimers (1973) successfully used adult scale characteristics to examine the relative contribution of 5 distinct life history types to adult production. A similar approach was adopted to determine (qualitatively), the relative importance of the 2 life history types to adult sockeye production within Pitt Lake. The first scale annulus from emigrant juvenile sockeye will occur within the zone of "ocean-growth". Conversely, the first scale annulus from resident juvenile sockeye will occur within the zone of "freshwater-growth". With this analytical technique in mind scales from the 1987 adult spawning population were examined. No evidence was found of a fry emigrant life history type based on the growth pattern seen in these scales. This conclusion was confirmed by B. Tasaka, head scale reader for the ISPFC scale lab between 1954 and 1989. Scales from the Upper Pitt River spawning population have been routinely collected and read by ISPFC staff since the early 1940's and no evidence has ever been found in the scale patterns to suggest that a fry emigrant life history type contributes in any significant way to the returning spawning population of Upper Pitt River sockeye salmon (B. Tasaka, 4255 Gilpin Crescent, Burnaby, B.C., pers. comm.).

Diel acoustic observations were also undertaken by IPSFC on April 13, 1978, to determine shifts in fish vertical position over the diel cycle. The results (Fig. 36) suggested a well-established diel vertical migration by the fish population such that mean vertical position alternated between 50 m and 15 m during day and night periods respectively.

4.3.2 1989 SAMPLING

During the July survey, age-0 sockeye, smelt and stickleback comprised 26%, 50% and 24% of the trawl catches respectively. No yearling sockeye were encountered, and only 1 other species (prickly sculpin), was captured. While the 3 species over-lapped within the pelagic zone in July, there were differences detected in species distribution patterns (Fig. 37). Juvenile sockeye CPUE was highest in Areas 1 and 3 in July (5/min and 4/min respectively) and lowest in Area 2 where no sockeye were captured (Fig. 37). Smelt CPUE was highest in Areas 1 and 2 (8/min) and lowest in Area 3 (2/min). Stickleback CPUE values during July were high in Area 2 (12/min) and low in both Areas 1 and 3 (<1/min).

Marked differences in relative trawl species composition were observed in November when age-0 sockeye, smelt and stickleback comprised 3%, 13% and 84% of the trawl catch respectively. As in July, there were differences detected in species distribution patterns within the pelagic zone (Fig. 37). Juvenile sockeye were largely absent from Areas 1 and 2 and occurred in Area 3 in relatively low numbers (CPUE < 1/min). Smelt CPUE values were also lower in November than July with values of 2, 0, and 1/min in Areas 1, 2 and 3 respectively. Stickleback was the most numerous species in the pelagic zone with CPUE values of 10, 8 and 3/min in Areas 1, 2, and 3 respectively.

Fish depth distribution was compared between transects to determine whether differences in vertical depth profiles (as determined by echo integration) correlated with fish species composition (as determined by trawl sampling). The pelagic water column was divided into 100 (0.5 m) depth bins extending between the surface and 50 m. In July, virtually all of the fish targets were distributed (nocturnally) within the upper 20 m of the water column (Fig. 38). In November, fish targets occurred as deep as 50 m, however, the majority of the fish biomass was distributed within the upper 10 m of the water column (Fig. 39). Fish depth profiles were similar between transects in July (Fig. 38). During November (Fig. 39), deeper fish targets (below 25 m) occurred primarily in the southern transects (transects 4, 5 and 6). These trends were also reflected in the calculated mean depths of local fish populations for the different transects (Fig. 40). In contrast to July when there was no consistent trend in the mean depth results, fish in November showed an increasing mean depth with transect location (Fig. 40) such that the mean depth increased progressively from north (T1) to south (T6).

The observed differences in fish depth distribution probably reflected variations in fish species composition in the different areas of Pitt Lake. July trawl samples from 11 m (spanning a depth between 7.5 to 14.5 m) produced a mixture of sockeye, smelt and stickleback from most areas of the lake (Fig. 38). In November, shallow trawls at 11 m and 18 m captured few sockeye, while the deep trawl (39 m) from Area 3 contained relatively high numbers of juvenile sockeye (39% of the trawl catch) (Fig. 39). Thus where juvenile sockeye were numerous (Area 3 in November), depth profiles and mean depth values were correspondingly lower in the water column.

Fish vertical movements were monitored on July 26 in the vicinity of transect 3 from 18:40 hours (PDST) to after dark at 22:20 hours. During the first (daylight) transect at 18:40, fish targets occurred from the surface down to 47 m, with a mean depth below 10 m (Fig. 41). The fish migrated progressively higher in the water column as darkness approached, as indicated both by the sequential depth profiles, and also the computed mean depths over time (Fig. 41). By nightfall (T=22:20) most of the deeper fish targets disappeared, and the mean depth decreased to about 5 m. These results suggested active diel vertical migrations by fish within Pitt Lake, which was especially pronounced for the deepest (by day) fish targets.

Acoustic target strength estimates can be used to draw inferences about fish size (Love 1977) provided these are not confounded by attitude (Buerkle 1987) or other variables. Measured target strength distributions were similar between transects, both during the July and November surveys (Fig. 42). In July, bimodal distributions in target strengths were observed on 3 transects, while in November, target strengths were normally distributed but skewed towards the higher values (higher target strength values are usually associated with larger fish sizes). There was also a shift observed between target strength values between surveys such that target strengths were somewhat lower, on average, during the November survey (Fig. 42).

The observed target strength differences showed a close correspondence with the measured fish size distributions. A polymodal distribution in fish size (all species were combined for this analysis) was observed during July with peaks in the neighbourhood of 50, 70, and 125 mm fork length (Fig. 43). Measured fish sizes were unimodal during November (excluding the few individuals between 75-100 mm), and somewhat smaller than those measured during July (Fig. 43). The similarity in the shapes of the target strength (Fig. 42) and fish size (Fig. 43) curves, as well as the difference in relative magnitude between surveys, supports the conclusion that fish target strength estimates can be used to draw inferences about fish size distribution within Pitt Lake.

In order to compare depth-related differences in fish size and acoustic target strength, corresponding data for individual transects were combined and stratified according to depth category (different depth categories were required for the 2 surveys because of seasonal changes in fish depth distribution). Results suggested higher target strength values for fish in the deeper depth categories, both in July as well as in November (Fig. 44). Fish size data were similarly stratified by depth (Fig. 45), and showed a corresponding increase in fish size with depth during November for samples obtained in 3 discrete trawl depths. The observed correspondence between target strength and fish size distribution also suggests that target strength estimates may provide useful fish size information for the species assemblage within Pitt Lake.

The horizontal distribution of fish within Pitt Lake was assessed by comparing total acoustical estimates between transects. Results (Fig. 46) showed changing fish distribution throughout the year. During July highest densities (>6,000/ha) were measured along transects 1 to 5 with lowest densities (<3,000/ha) along transect 6 at the outlet end of the lake. In November highest densities (>9,900/ha) were measured along transects 3 to 6 and lowest densities (<7,000/ha) along the inlet transects 1 and 2. Thus there were seasonal differences observed in overall fish distribution patterns within Pitt Lake.

Total fish abundance was estimated at 27,600,000 fish in July and 34,800,000 in November (mean densities of 7,800 and 9,900 /ha respectively). Sockeye abundance estimates, obtained by apportioning the acoustic estimates with the trawl catches, are very uncertain due to several problems associated with trawling. Time restraints limited the amount of trawling that could be accomplished and thus there were few or no replicate samples taken. This precludes any estimate of error being made on the species composition of the catches. Secondly, trawlnets are known to be size selective. Similar but smaller nets to the one we used here have shown to be highly size selective at sizes over 2 g (K. Hyatt, Department of Fisheries and Oceans, Pacific Biological Station, Nanaimo, pers. comm.). If this is the case we would have underestimated the abundance of smelt in July when the older year classes were present and underestimated the abundance of sockeye in November when the fry were larger. The result would be an overestimate of the sockeye proportion of the catch and consequently the abundance estimate in July and an underestimate in November. With these uncertainties in mind, we did make estimates of total sockeye abundance of 8,200,000 (2,400/ha) in July and 780,000 (220/ha) in November.

4.4 SEASONAL FEEDING PATTERN AND DIET ANALYSIS

Overlap in distribution of the three major planktivorous fish species in Pitt Lake would allow for the possibility of interspecific competition for food resources. Stomach content data collected in 1978 and 1979 were analyzed for juvenile sockeye salmon and longfin smelt to investigate this possibility. Stomach content data for stickleback were insufficient for the analysis.

4.4.1 SEASONAL FEEDING PATTERN

The seasonal feeding pattern of Pitt Lake sockeye was similar in 1978 and 1979 and was similar to the pattern observed for sockeye in many other nursery lakes (Ricker 1937; Barraclough and Robinson 1972; McDonald 1973; Goodlad et al. 1974; Doble and Eggers 1978; Eggers 1978). Stomach content analysis indicated that Pitt Lake sockeye fry did not begin feeding until late May or early June (Figs. 47,48; Tables 16,17). At this point, there was a dramatic increase in feeding activity which lasted through early fall. Feeding activity declined in late fall (Figs. 47,48; Tables 16,17).

The observed lack of feeding activity in juvenile sockeye in the spring is similar to the observations of Johnson (1981). He found that growth of freshly emergent sockeye fry entering Pitt Lake from the Upper Pitt River was stagnant as they migrated to the outlet end of the lake during April and May. Our study indicated that this phase is followed by an increase in feeding activity lasting from June to September. Sockeye fry stomach samples taken during this period of active feeding showed an average percent fullness that ranged from 30% to 52% in 1978 and from 37% to 65% in 1979 (Fig. 47; Tables 16,17). During this same time period the percentage of empty sockeye stomachs remained at zero in both years (Fig. 48; Tables 16,17). This low percentage of empty stomachs indicates that all juvenile sockeye are actively feeding on a daily basis (Doble and Eggers 1978).

By November the average percent fullness of sockeye stomachs declined to 5% in 1978 and to 8% in 1979. In 1979 we see a corresponding increase in the percent of empty sockeye stomachs from 0% in September to 89% in November indicating that a large proportion of the population is not feeding. We did not see a similar increase in the percent of empty sockeye stomachs in 1978. However, the low average percent fullness of the stomachs indicated that although the fish were feeding they were doing so at a reduced rate. Other studies indicate that feeding remains at a low level throughout the winter increasing again in the spring before out migration begins (Barraclough and Robinson 1972).

The seasonal feeding pattern of longfin smelt in Pitt Lake was characterized by a sharp increase in feeding activity in May as indicated by a decrease in the percentage of empty stomachs and a corresponding increase in the average percent fullness of stomachs (Figs. 47,48; Tables 16,17). This heightened level of feeding appeared to last only until sockeye began to actively forage. At this point smelt feeding activity declined sharply. By late summer when the average percent fullness of sockeye stomachs peaked, smelt feeding as measured by percent fullness, dropped to its lowest levels measuring 2% in August of 1978 and 1% in September of 1979 (Fig. 47; Tables 16,17).

The seasonal feeding pattern exhibited by Pitt Lake smelt differed significantly from that described by Dryfoos (1965) for the Lake Washington population. That study revealed that longfin smelt in Lake Washington feed almost continuously throughout summer and fall reaching a maximum feeding intensity in September. Further, the percentage of empty stomachs never exceeded 40% during years of sampling and was generally around 10% during the seasons of active feeding. The Pitt Lake smelt population contained a higher percentage of empty stomachs than the Lake Washington population in all seasons. Also, the period of active feeding was much shorter in the Pitt Lake population and was confined to an interval of a few weeks in late spring or early summer (Fig. 49).

4.4.2 DIET ANALYSIS

Zooplankton were the predominant forage of both juvenile sockeye and all size classes of longfin smelt in Pitt Lake. Consumption of zooplankton appeared to be highly selective since zooplankton sampling revealed that both fish species consumed prey items in greater proportion than their abundance in the environment. Sockeye diet was similar throughout sampled areas of the lake but did vary seasonally. This was also true for smelt. Detailed analysis of the stomach contents of the 2 species indicated that sockeye and smelt diets did not overlap. Cladocerans were the principal prey of juvenile sockeye over both years of the study, while copepods were the dominant forage of longfin smelt (Figs. 50,51).

Active feeding of juvenile sockeye in the pelagic zone began in June and peaked in August or September. Dominant prey were cladocerans which comprised 95% of the sockeye diet in August 1978 and over 80% in August and September 1979. *Bosmina* were numerically the most abundant dietary component, however, because of their large size, *Leptodora* were more important volumetrically. Assuming a mean body length of 3.1 mm for *Leptodora* and 0.29 mm for *Bosmina* (Fig. 26), calculated dry weight of *Leptodora* per fish stomach during peak feeding was 2.6 mg while *Bosmina* was only 0.9 mg. After September, feeding slowed and sockeye consumed small numbers of *Bosmina*, *Diayclops*, and *Epischura* in equal proportions (Figs. 50,51). Numerous studies have documented the importance of cladocerans, especially *Daphnia*, in the food of several sockeye stocks (Narver 1970; Woodey 1972). The absence of *Daphnia* from the diet of Pitt Lake sockeye is most certainly due to the low abundance of *Daphnia* in the lake. However, it appears that the large cladoceran *Leptodora* has adequately replaced *Daphnia* as the most important food item in the diet of juvenile sockeye salmon in Pitt Lake.

Smelt feeding activity in the pelagic zone of Pitt Lake peaked during the spring while juvenile sockeye were shore oriented. During this time, copepods were the most frequently consumed prey, with *Diacyclops* comprising over 90% of the diet between April and May and *Diacyclops* and *Epischura* comprising over 70% of the diet in June. Feeding intensity declined after June and smelt became less selective in their forage, although copepods remained the dominant prey for the balance of the season. The importance of copepods in the diet of Pitt Lake smelt is contrary to Lake Washington smelt which have been found to have 70% of their diets comprised of cladocerans, specifically *Daphnia* (Chigbu and Sibley 1989). The paucity of cladocerans in the diet of Pitt Lake smelt during both years of the study may be indicative of some interaction with juvenile sockeye or, it may reflect differences in the ability of the 2 fish species to capture this type of prey.

Although stomach content data for Pitt Lake stickleback were insufficient for the quantitative analysis, qualitative observations of the diet of this planktivore were made. Gut samples examined indicate that copepods were the primary forage of stickleback in Pitt Lake (S. McLellan, Cultus Lake Laboratory, DFO, pers. comm.). If this is the case, then the diet of juvenile sockeye salmon in Pitt Lake does not overlap with either of the other major planktivorous fish species. However, the stickleback samples were limited in number, represented only one sample date (February, 1990) and in many cases, digestion of stomach contents made positive identification of food items difficult. Further investigation of the diet of stickleback is one focus of the current field sampling program.

5.0 DISCUSSION

5.1 GROWTH AND AGE STRUCTURE

Information on the growth and age structure of juvenile Pitt Lake sockeye salmon, taken in isolation from other components of this study, suggests that the system is recruitment limited. Pitt Lake sockeye salmon that survived through the end of their first freshwater growing season were rapidly growing, large and apparently healthy fish. They were larger than sockeye sampled in other Fraser River systems at a comparable time. In addition, their instantaneous daily growth rate over the growing season exceeded that for other Fraser River stocks and on occasion approached the theoretical maximum for sockeye (Shelbourne et al. 1973) and kokanee (Perrin and Levy 1989). Further, almost all Pitt Lake sockeye migrate to the ocean as 1^+ smolts. These characteristics, rapid freshwater growth, large size at the end of the first growing season and downriver migration as 1^+ rather than older smolts, are consistent with juvenile sockeye salmon originating from recruitment limited systems (Koenings and Burkett 1987).

Although the age structure and growth information for juvenile Pitt Lake sockeye salmon suggests they originate in a recruitment limited system, this conclusion must be tempered by the evidence for density dependent fry-to-adult survival and freshwater growth. Of particular interest is the low fry-to-adult survival for Pitt Lake sockeye salmon in the mid to late 1970's. Over this same period, the number of adults produced per spawner increased in other Fraser River and non-Fraser River sockeye stocks. The differences suggests that the low fry-to-adult survival observed for Pitt Lake sockeye in the 1970's was likely related to events in the freshwater environment rather than a general deterioration of conditions in the marine environment. The apparent paradox between the age structure and growth information on one hand and the evidence for density dependent survival and growth on the other may be explained if the density dependent process operates during the period when the fry migrate downriver into the lake and/or early in the period of lake residence. It may be that fry that survive these initial periods of relatively intense mortality, and possibly reach critical size, are able to take full advantage of the available food resources and attain the characteristic large size of Pitt Lake juvenile sockeye salmon. It was suggested in an earlier study (IPSFC 1982) that the carrying capacity of Pitt Lake might be on the order of 10-12 million fry. The relationship between fry-to-adult survival and fry production in our study (Fig. 6) although showing a negative relationship, does not exhibit any clear "break-point" in the vicinity of 10-12 million fry. However, the relationship between freshwater growth as measured by circuli count and fry production (Fig. 7) does suggest a rather abrupt decrease in growth when fry production exceeds 12 million fry.

5.2 TROPHIC STATUS

On the basis of phosphorus and chlorophyll concentrations, bacterioplankton densities, and the relative contribution of picoplankton to total photosynthesis, Pitt Lake can be categorized as oligotrophic. But, it appears to be more productive than most other sockeye nursery lakes near the British Columbia coast. The data suggest that production in the lake is limited by phosphorus supply (and perhaps would respond positively to nutrient additions), but further work (much more detailed sampling and possibly nutrient bioassays) is required before this can be confirmed. Further work is also needed to document spatial and temporal variation in density and distribution of *L. kindtii* (entailing higher sampling frequency and different collection methods) and its importance as a food resource to the dominant planktivores in Pitt Lake. It is quite probable that *L. kindtii* would respond favourably to fertilization, but it must be determined that these benefits would accrue to sockeye, and not to the far more numerous smelt and stickleback.

5.3 DISTRIBUTION

The three predominant fish species within Pitt Lake showed different seasonal patterns of abundance within the pelagic zone. Longfin smelt were present in large numbers throughout the year. Stickleback were seasonally absent from the pelagic zone during late spring-early summer, but were extremely numerous during fall-winter periods.

Juvenile sockeye showed an early spring peak in abundance followed shortly thereafter by a rapid decline in numbers. This decline is much larger than measured in other Fraser River lakes (Fig. 52). For the 1978 and 1979 brood years the IPSFC data indicates that only 12 - 14% of the initial fry population is remaining in the lake after early September. Data in other lakes indicates that on average 36% (ranging from 20 - 61%) remain after late fall. From an enhancement perspective, it is critical to determine the reason for the observed decline in juvenile sockeye numbers within the pelagic zone. Scale pattern analysis of the Upper Pitt River spawning population gives no indication that a fry emigrant life history type contributes in any significant way to the returning adult spawning population. This suggests that either this life history type does not survive to spawn or that the observed decrease in fry population is due to some as yet undetermined source of mortality.

One promising research result from the 1989 acoustic sampling was the apparent correlation between measured target strength and fish size distributions. Additional observations are required to determine whether this correlation is real or fortuitous. If it can be established that target strength distributions provide meaningful fish size information, this will provide a powerful tool permitting remote estimates of fish size distribution. There are numerous stock assessment applications where such information would be extremely valuable.

Acoustic results also suggested a large amount of spatial (horizontal and vertically) and temporal (diel and seasonal) overlap in the distribution patterns of the 3 predominant species within Pitt Lake. Such overlap makes acoustic quantification difficult, necessitating trawl sampling (and an assumption of equal catchability) to partition the relative contribution of different species to total acoustic returns. Recently Rose and Leggett (1988) used measurements from acoustic returns of cod, capelin, and mackerel schools to classify echo signals by species. Such an approach may be applicable within Pitt Lake and permit refinements to quantitative acoustic results.

5.4 DIET

Competition for a limited food resource has generally been regarded as an important process influencing the production of sockeye salmon in lakes (O'Neill and Hyatt 1987, Burgner 1987). Due to the large numbers of other planktivorous fish species in Pitt Lake, it has been suggested that competition is a major factor limiting the production of sockeye salmon from the Pitt Lake system. An examination of the early season feeding pattern of sockeye and smelt in Pitt Lake indicates that there is some interaction between these species. The increase in sockeye feeding activity that occurs in May or June is associated with a corresponding decrease in smelt feeding. This suggests that there is no negative impact on the sockeye population due to the presence of actively feeding smelt. In fact, it points to a situation in which sockeye may be outcompeting smelt for the rich cladoceran food resource that is available during this time period. Further support for this interaction is indicated by the fact that throughout the summer and fall there is an adequate food supply in Pitt Lake for the sockeye population as we find 0% empty stomachs in the samples taken during this period. During the same period we find a variable but always higher percentage of empty smelt stomachs. Also, in 1978 when the percentage of empty sockeye stomachs did not increase in November (remaining at zero) the percentage of empty smelt stomachs remained high. In 1979 the percentage of empty sockeye stomachs increased to 89% in November. At the same time there was a dramatic decrease in the percentage of empty smelt stomachs from 53% in September to 17% in November. Also, when the Pitt Lake smelt population is compared with the population of longfin smelt residing in Lake Washington we find that the percentage of empty stomachs in the Pitt Lake population is higher in all seasons and that the period of active feeding is much shorter in comparison (Fig. 49).

Stomach content analysis of Pitt Lake sockeye and smelt indicates an almost complete lack of overlap in diet. The consumption of zooplankton by sockeye is highly selective and is made up almost exclusively by cladocerans. Smelt are also selective in their feeding targeting on copepods as their dominant forage. Size, abundance and mobility of these prey items may have an effect on detection and capture by the two planktivorous predators. It is also likely that Pitt Lake smelt are outcompeted in the pelagic environment for the valuable cladoceran food resource by juvenile sockeye salmon. This may indeed be the case as we find that longfin smelt in Lake Washington feed primarily on the large cladoceran *Daphnia* in direct competition with juvenile sockeye. In Pitt Lake, it appears that *Daphnia* is largely absent and that as a result, the large cladoceran *Leptodora* has taken its place as the most important food source in the diet of juvenile sockeye salmon. The fact that smelt do not feed on *Leptodora* may indicate that they cannot compete with juvenile sockeye for this valuable resource.

When all of these points are considered it suggests that longfin smelt have little effect on the feeding activity of juvenile sockeye in the pelagic zone. However, it is important to note that we have no data at this time on sockeye use of the flats at the outlet end of the lake. In other sockeye nursery lakes this type of littoral habitat plays an important role as an early season rearing area (Jaenicke et. al. 1987). There is evidence to indicate that Pitt Lake sockeye fry spend some time between May and June rearing on these shoals (Johnson 1981) and it may be that there is intense competition for a valuable food resource while sockeye share this portion of the lake with other species. This is an area which requires further investigation and it is one focus of the current sampling program.

One more area requiring further study is that of the feeding pattern and diet of the other major planktivorous fish species in Pitt Lake: threespine stickleback. This species makes up a large portion of the total fish biomass in the lake and may have a significant impact on the survival of juvenile sockeye. Once again, the current sampling program is aimed at addressing this question.

5.5 CARRYING CAPACITY

The carrying capacity of Pitt Lake for juvenile sockeye (or its potential for increased adult sockeye production) is difficult to assess for a number of reasons: the paucity of detailed limnological data, the current high densities of other planktivores (longfin smelt and three-spine stickleback), and the lack of data on the food preferences of the three major planktivores in the lake. Models developed and used in Alaskan lakes for predicting potential production of sockeye have to date been based on seasonal averages of euphotic volume (Koenings and Burkett 1987) and on macrozooplankton biomass (J. Koenings, Fisheries Resource Enhancement Division, Soldatna, Alaska, pers. comm.). The euphotic volume model assumes that planktivores other than juvenile sockeye form an insignificant portion of the total fish community within the lake. Obviously, this assumption is not valid in Pitt Lake and any model predictions will considerably overestimate the current capacity of Pitt Lake to produce sockeye. Nevertheless, the model is perhaps of some use in predicting potential upper limits to sockeye production in Pitt Lake, if it is feasible to improve fry recruitment.

Koenings and Burkett's (1987) euphotic volume (EV) model predicted a production of 25,000 threshold-sized (2.2 g) smolts for each EV unit. If we assume that our two sampling dates produce a realistic estimate of average euphotic zone depths on Pitt Lake, then the lake has 423 EV units, or a potential production of 10 million smolts. With a fry-to-smolt survival of 10%, this would correspond to a fry input of 100 million. Assuming a typical smolt-to-adult survival of 10% (Henderson and Cass 1991), no spawning ground limitation, and an escapement of 300,000-400,000, Pitt Lake could produce approximately 1 million adult sockeye, in contrast to recent total run sizes of <50,000. It must be emphasized that this production figure assumes adequate fry recruitment to the lake and the virtual elimination of fish which compete with and feed on juvenile sockeye. As such, this scenario likely represents a theoretical maximum in terms of both optimum fry input and adult production. It could only be achieved through large scale manipulation of the Pitt Lake ecosystem (eg. whole lake fertilization, predator/competitor removal). The lower end to mid-point of a range for fry production can be set based on the density dependent fry-to-adult survival exhibited in Fig. 6. Based on this model, which does not assume any changes to the Pitt Lake ecosystem, optimum fry production would be 8 million. Adult returns would be approximately 85,000. Analyses for the subsequent report on the Pitt Lake Project will focus on narrowing the range of fry production which now extends from 8 to 100 million fry.

In the Alaskan zooplankton model, macrozooplankton were defined as plankters > 0.25 mm in length. Average macrozooplankton biomass in Pitt Lake in 1989 was 242 $mg \cdot m^{-2}$, although this figure is most likely an underestimate because sampling techniques we employed possibly did not quantitatively sample the larger zooplankters (primarily *L. kindtii*). Further, the random error in the estimate of macrozooplankton biomass is likely to be large as the lake was sampled on only two occasions. According to the model, a macrozooplankton biomass of 242 $mg \cdot m^{-2}$ should produce 4.5 $kg \cdot ha^{-1}$ of sockeye smolt biomass, which is equivalent to 900 $fish \cdot ha^{-1}$ at an optimum weight of 5 g, $2045 \cdot ha^{-1}$ of threshold-sized (2.2 g) smolts, or $562 \cdot ha^{-1}$ of 8 g smolts, which are approximately the size the lake currently produces. Theoretically, adult sockeye production in Pitt Lake could be maximized under current conditions (ie. current trophic status and planktivore densities) by producing 5 g smolts at a density of 900·ha^{-1}. It is interesting to note that despite enhancement initiatives on Pitt Lake (sockeye hatchery), sockeye densities have remained in this low range (see section 4.3.2), suggesting that the lake may currently be at or near its carrying capacity for juvenile sockeye, given the high densities of other planktivores which occur in the lake. It is probable that fertilization would increase primary and secondary production in Pitt Lake, but benefits reaching juvenile sockeye would perhaps be reduced because of the 'bottleneck' of intense competition during the early lacustrine stages.

6.0 SYNTHESIS

The overall objectives of the Pitt Lake Sockeye Salmon Project are to determine the factors that limit the production of juvenile sockeye salmon in Pitt Lake and to estimate the carrying capacity of Pitt Lake for juveniles when expressed in terms of annual fry inputs. It is implicitly assumed that increases in smolt production will result in increases in adult returns. Preliminary inferences regarding the objectives are made below. A more complete synthesis, based in part on data from 1989 and 1990 and not included in this report, will be provided in a subsequent document.

Juvenile Pitt Lake sockeye salmon sampled through the mid to latter portion of their freshwater residence appear to be healthy fish. They grow more rapidly and achieve a larger size than juvenile sockeye in other systems in the Fraser River. Their freshwater period is spent in a lake that is more productive than most other unfertilized coastal lakes. The density and size distribution of the zooplankton in Pitt Lake is similar to other coastal sockeye nursery lakes with the exception of the presence of *L. kindtii*. Further, evidence to date suggests there is minimal overlap in the distribution of juvenile sockeye, longfin smelt and stickleback and in the diet of juvenile sockeye salmon and longfin smelt. Consequently, this information does not suggest any particular feature of the Pitt Lake environment that would account for the apparent low fry-to-adult survival witnessed in recent years.

Although the foregoing suggests a recruitment limited system, this may not be the case. There is evidence for density dependent fry-to-adult survival and freshwater growth in Pitt Lake sockeye salmon. In particular, the large fry production of recent brood years has resulted in adult returns that are, in both proportional and absolute terms, less than adult returns from brood years with lower fry production. Also, the survival of sockeye fry during the first few weeks after they move into Pitt Lake appears to be very low compared to survival over a similar period in other nursery lakes in the Fraser River system. The effect of food availability for and predation on juvenile sockeye salmon during the period of early lake residence will be the focus of the second report from the Pitt Lake Project.

We think there is a real possibility that food limitation and/or predation during the early period of lake residence may limit the production of sockeye smolts in Pitt Lake, and therefore, adult returns. If so, then it may be possible to increase the number of smolts derived from the hatchery component of fry production through the use of inlake net pens. More specifically, holding and rearing sockeye fry in net pens for a period of several weeks after their normal time of migration into the lake may lead to an increase in survival. In this regard, we recommend a rigorous experimental design be developed and implemented to evaluate the effect of time and size at release from net pens on fry-to-adult survival. Such an experiment could be implemented as early as the spring of 1991 and would build on the experience gained over the last two years with regard to the use of net pens in Pitt Lake.

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Table 1. Fish species present in Pitt Lake (modified from Elson 1985).

Common Name	Scientific Name
White sturgeon	*Acipenser transmontanus*
Longnose sucker	*Catostomus catostomus*
Largescale sucker	*Catostomus macrocheilus*
Prickly sculpin	*Cottus asper*
Common carp	*Cyprinus carpio*
Threespine stickleback	*Gasterosteus aculeatus*
Brassy minnow	*Hybognathus hankinsoni*
Surf smelt	*Hypomesus pretiosus pretiosus*
Brown bullhead	*Ictalurus nebulosus*
Lamprey	*Lampetra spp.*
Peamouth chub	*Mylocheilus caurinus*
Cutthroat trout	*Oncorhynchus clarki clarki*
Pink salmon	*Oncorhynchus gorbuscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Rainbow trout and steelhead	*Oncorhynchus mykiss*
Sockeye salmon and kokanee	*Oncorhynchus nerka*
Chinook salmon	*Oncorhynchus tshawytscha*
Starry flounder	*Platichthys stellatus*
Black crappie	*Pomoxis nigromaculatus*
Mountain whitefish	*Prosopium williamsoni*
Northern squawfish	*Ptychocheilus oregonensis*
Longnose dace	*Rhinichthys cataractae*
Redside shiner	*Richardsonius balteatus*
Dolly Varden char	*Salvelinus malma*
Longfin smelt	*Spirinchus thaleichthys*
Eulachon	*Thaleichthys pacificus*

Table 2. Monthly hydroacoustic and trawl samples in Pitt Lake conducted by the IPSFC.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1977										1		
1978				1	1	2		1			1	
1979				1	4	4	4	1	2		1	
1980		1	1				1		1	1		
1981						1			1			
1982							1					
Total	0	1	1	2	5	7	6	2	4	2	2	0

Table 3. Percent of age 0^+ juvenile sockeye salmon in trawl samples taken from Pitt Lake for the years 1978 to 1980 (number in parentheseis is the total sample size).

1978	1979	1980
93.5 (31)	95.6 (435)	100.0 (59)

Table 4. Average instantaneous daily growth rate (%) for juvenile sockeye salmon in Pitt, Cultus, Quesnel and Shuswap lakes.

Lake	Brood Year	Average Daily Instantaneous Growth Rate
Pitt	1978	1.73
	1979	2.55
Cultus	1976	1.04
	1982	1.06
	1986	1.65
Quesnel	1977	2.02
	1981	1.81
Shuswap	1974	1.46
	1975	1.66
	1977	1.74
	1978	1.44
	1979	1.66
	1982	1.42
	1983	1.64
	1986	1.47

Table 5. Variation in salient physical and biological variables at six stations located along the longitudinal axis of the lake. Sampling dates are July 19/89, October 25/89, and March 21/90. Chlorophyll data are mean epilimnetic values.

	Thermocline depth (m)			Euphotic zone (m)			Surface temp. (°C)			Secchi depth (m)			Chlorophyll $\mu g \cdot L^{-1}$		
Station	Jul	Oct	Mar	Jul	Oct	Mar	Jul	Oct	Mar	Jul	Oct	Mar	Jul	Oct	Mar
1	15.7	35	iso	8.3	7.6	-	15.5	10.9	-	2.2	3.5	-	1.52	1.15	-
2	18.3	11.2	iso	9.1	12.8	9.4	15.8	11.0	5.5	2.3	3.2	7.0	1.70	1.12	-
3	16.6	22.7	iso	8.9	6.8	-	16.0	11.1	-	2.8	2.2	-	2.08	-	-
4	10.6	12.2	iso	9.4	8.9	9.8	16.8	11.5	5.2	3.2	4.3	6.3	2.62	1.38	-
5	12.2	21.0	iso	8.9	6.4	8.7	16.5	11.5	5.1	3.0	4.9	4.2	2.04	1.41	-
6	10.0	27.0	iso	8.2	6.5	-	16.8	11.6	-	3.0	4.8	-	2.45	1.48	-
Mean	13.9	24.3	iso	8.8	7.8	9.6	16.2	11.3	5.3	2.8	3.8	-	2.07	1.48	-

Table 6. Concentrations of limnological variables at station 2 on July 19, 1989.

Depths sampled	Ammonia ($\mu g\ N \cdot L_{-1}$)	Nitrate ($\mu g\ N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate ($mg\ Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^6 \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-3	8.1	59.7	3.7	2.5	1.36	13	0.71	299	23
3-6	3.8	64.1	3.9	2.8	-	-	0.82	286	22
6-10	12.7	64.6	5.9	2.9	-	-	0.93	243	21
40	48.0	73.0	3.1	2.7	1.79	19	0.49	189	12

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis ($\mu g\ C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-3	2.14	1.74	-	-	-	-	-	-	11015	5320	1690
3-6	1.74	1.16	-	-	-	-	-	-	9287	6889	1754
6-10	1.23	1.02	-	-	-	-	-	-	9534	6400	1869
40	0.07	-	-	-	-	-	-	-	3260	3508	290

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	17.2	15110	0.46	44	2.98	876	0.27	279	2.75	1788	0.05	9968
10-20	4.43	3681	0.01	11	0.04	29	0.06	41	0.00	0	0.01	2685
20-30	5.25	3929	0.00	0	0.03	45	0.04	45	0.12	16	0.00	891

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.00	0	18.02	6554	0.00	0	0.10	3277	24.66	137
10-20	1.28	577	5.40	2079	0.00	0	0.09	29	0.00	0
20-30	0.24	102	1.96	738	0.00	0	0.11	51	0.00	0

Table 7. Concentrations of limnological variables at station 2 on October 26, 1989. Only zooplankton were sampled at this station on this date.

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	7.07	7537	0.00	0	0.00	0	0.08	39	0.24	95	0.08	8210
10-20	9.00	7919	0.00	0	0.00	0	0.14	40	0.07	34	0.01	5491
20-30	4.72	4150	0.00	0	0.00	0	1.15	364	0.28	26	0.00	2185

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.14	85	7.31	2650	11.47	3932	3.90	1453	0.00	0
10-20	2.79	1342	8.60	3295	1.21	427	1.18	427	0.00	0
20-30	0.68	287	4.64	1766	0.00	0	0.34	132	0.00	0

Table 8. Concentrations of limnological variables at station 2 on March 21, 1990.

Depths sampled	Ammonia ($\mu g\ N \cdot L^{-1}$)	Nitrate ($\mu g\ N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate ($mg\ Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^6 \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-4	14.6	112.0	3.3	1.4	2.14	33	0.68	144	8
4-8	5.9	119.0	3.4	1.6	-	-	0.81	136	10
8-12	9.5	118.1	2.9	1.5	-	-	0.83	145	11
40	20.6	117.0	3.0	1.6	1.98	17	0.83	163	8

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis ($\mu g\ C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-4	0.08	<0.07	<0.07	<0.07	-	-	-	-	11015	5320	1690
4-8	0.11	<0.07	<0.07	<0.07	-	-	-	-	9287	6889	1754
8-12	0.09	<0.07	<0.07	<0.07	-	-	-	-	9534	6400	1869
40	0.09	<0.07	<0.07	<0.07	-	-	-	-	3260	3508	290

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.02	7	0.00	0	0.00	0	0.41	479	0.00	0	0.00	55
10-20	0.00	0	0.00	0	0.00	0	1.23	1455	0.02	7	0.00	62
20-30	0.00	0	0.00	0	0.00	0	1.26	1428	0.00	0	0.00	124

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.00	0	0.15	55	0.00	0	0.00	0	0.00	0
10-20	0.00	0	0.17	62	0.00	0	0.00	0	0.00	0
20-30	0.02	7	0.34	117	0.00	0	0.00	0	0.00	0

Table 9. Concentrations of limnological variables at station 4 on July 20, 1989.

Depths sampled	Ammonia ($\mu g\ N \cdot L^{-1}$)	Nitrate ($\mu g\ N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate ($mg\ Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^6 \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-3	7.0	58.0	8.0	1.6	1.38	8	0.93	403	28
3-6	7.3	60.1	4.6	1.5	-	-	0.62	341	28
6-10	14.1	63.1	3.6	1.3	-	-	0.64	367	27
40	35.8	71.6	3.9	1.2	1.74	16	0.43	-	25

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis ($\mu g\ C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-3	2.40	1.75	0.54	<0.07	1.08	0.33	0.71	0.05	10621	8394	1704
3-6	2.52	2.15	0.27	<0.07	1.23	0.42	0.81	0.00	11510	9189	1816
6-10	2.82	2.13	0.58	<0.07	0.33	0.14	0.17	0.02	11016	9556	2037
40	0.17	-	-	-	-	-	-	-	3952	1982	278

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	23.45	20264	0.22	33	0.16	33	0.07	110	3.36	1619	0.03	11748
10-20	6.30	5230	0.00	0	0.00	0	0.07	43	0.16	119	0.02	3794
20-30	4.96	3404	0.00	0	0.00	0	4.37	2393	0.71	211	0.00	1801

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.36	184	20.57	7526	0.00	0	10.26	4038	0.00	0
10-20	0.32	163	5.96	2168	3.39	1030	0.86	379	4.23	54
20-30	0.00	0	4.56	1801	0.00	0	0.00	0	0.00	0

Table 10. Concentrations of limnological variables at station 4 on October 26, 1989.

Depths sampled	Ammonia ($\mu g\ N \cdot L^{-1}$)	Nitrate ($\mu g\ N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate ($mg\ Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^{6} \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-3	3.0	44.9	2.4	2.3	1.72	15	0.90	265	19
3-6	2.4	43.0	3.1	2.2	-	-	0.76	281	22
6-10	1.3	44.1	3.2	2.1	-	-	0.85	239	19
40	4.7	73.6	2.7	3.3	1.77	16	0.62	285	21

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis ($\mu g\ C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-3	1.51	0.84	0.67	<0.01	0.45	0.17	0.26	0.02	15066	7163	583
3-6	1.34	0.83	0.50	<0.01	0.07	0.01	0.05	0.00	14917	7383	846
6-10	1.14	0.50	0.56	<0.01	0.00	0.00	0.00	0.00	15608	6643	455
40	-	-	-	-	-	-	-	-	4248	2933	381

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	8.25	7901	0.00	0	0.00	0	0.19	61	0.23	80	0.05	16025
10-20	3.75	3232	0.00	0	0.00	0	0.08	28	0.00	0	0.01	2186
20-30	1.97	1630	0.00	0	0.00	0	1.33	417	1.27	139	0.00	231

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	1.42	641	11.88	4327	23.43	7692	8.86	3365	0.00	0
10-20	0.91	306	3.70	1363	0.58	206	0.60	231	0.00	0
20-30	0.02	9	0.51	194	0.06	19	0.02	9	0.00	0

Table 11. Concentrations of limnological variables at station 4 on March 21, 1990.

Depths sampled	Ammonia ($\mu g\ N \cdot L^{-1}$)	Nitrate ($\mu g\ N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate ($mg\ Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^6 \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-3	17.9	114.3	2.9	1.4	1.77	23	0.78	137	7
3-6	7.2	115.0	2.9	1.4	-	-	0.87	109	7
6-9	4.2	119.5	2.7	1.5	-	-	0.80	128	9
40	6.4	118.6	2.6	1.7	1.66	21	0.58	128	5

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis ($\mu g\ C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-3	0.15	0.07	<0.07	<0.07	0.18	0.05	0.13	0.00	15066	7163	583
3-6	0.15	0.07	<0.07	<0.07	0.22	0.10	0.10	0.02	14917	7383	846
6-9	0.17	0.10	<0.07	<0.07	0.07	0.01	0.04	0.02	15608	6643	455
40	0.22	0.15	<0.07	<0.07	-	-	-	-	4248	2933	381

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.03	7	0.00	0	0.00	0	0.71	760	0.00	0	0.00	14
10-20	0.00	0	0.00	0	0.00	0	1.35	1277	0.00	0	0.00	34
20-30	0.00	0	0.00	0	0.00	0	1.16	1034	0.00	0	0.00	82

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.00	0	0.04	14	0.00	0	0.00	0	0.00	0
10-20	0.00	0	0.07	27	0.02	7	0.00	0	0.00	0
20-30	0.00	0	0.23	82	0.00	0	0.00	0	0.00	0

Table 12. Concentrations of limnological variables at station 5 on July 20, 1989.

Depths sampled	Ammonia (μg N·L^{-1})	Nitrate (μg N·L^{-1})	Total P (μg·L^{-1})	Part. P (μg·L^{-1})	Silicate (mg Si·L^{-1})	Tot. diss. solids (mg·L^{-1})	Bacteria (#×10^{6}·mL^{-1})	Part. C (μg·L^{-1})	Part. N (μg·L^{-1})
0-3	9.9	60.2	3.6	1.1	1.35	21	0.67	341	21
3-6	4.7	61.5	3.1	1.2	-	-	0.66	360	24
6-10	16.2	71.6	5.0	1.3	-	-	0.65	402	19
40	3.3	73.7	3.1	1.1	1.81	12	0.45	407	19

Depths sampled	Chlorophyll (μg·L^{-1})				Photosynthesis (μg C·L^{-1}·hr^{-1})				Phytoplankton (No.·mL^{-1})		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-3	1.88	1.53	0.24	<0.07	-	-	-	-	11855	8810	1392
3-6	2.45	1.94	0.40	<0.07	-	-	-	-	13732	11630	1650
6-10	1.77	1.42	0.24	<0.07	-	-	-	-	9880	8846	1963
40	0.13	-	-	<0.07	-	-	-	-	3063	2713	265

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	mg·m^{-3}	#·m^{-3}	mg·m^{-3}	#·m^{-3}	mg·m^{-3}	#·m^{-3}	mg·m^{-3}	#·m^{-3}	mg·m^{-3}	#·m^{-3}	mg·m^{-3}	#·m^{-3}
0-10	7.38	5926	0.02	5	0.09	27	0.17	167	5.48	2230	0.05	7205
10-20	4.36	3229	0.00	0	0.00	0	0.22	149	0.03	17	0.01	2254
20-30	1.42	716	0.00	0	0.00	0	3.21	1727	0.05	6	0.00	823

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	μg·m^{-3}	#·m^{-3}	μg·m^{-3}	#·m^{-3}	μg·m^{-3}	#·m^{-3}	μg·m^{-3}	#·m^{-3}	μg·m^{-3}	#·m^{-3}
0-10	0.75	328	11.04	4148	0.98	328	5.15	2183	35.72	218
10-20	0.00	0	4.97	1849	0.40	135	0.67	225	6.97	45
20-30	0.00	0	2.28	786	0.00	0	0.09	37	0.00	0

Table 13. Concentrations of limnological variables at station 5 on October, 26,1989.

Depths sampled	Ammonia ($\mu g\ N \cdot L^{-1}$)	Nitrate ($\mu g\ N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate ($mg\ Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^6 \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-4	4.2	41.7	2.7	2.1	1.48	-	1.08	333	21
4-8	4.0	40.2	2.3	2.2	-	-	1.00	244	19
8-12	8.5	39.4	2.9	2.1	-	15	0.92	259	21
40	4.3	70.9	3.7	2.9	1.78	16	0.57	-	-

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis ($\mu g\ C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-4	1.44	0.81	0.53	<0.07	-	-	-	-	16202	7578	668
4-8	1.38	0.82	0.45	<0.07	-	-	-	-	16103	6520	813
8-12	1.40	0.87	0.43	<0.07	-	-	-	-	14967	4869	327
40	-	-	-	-	-	-	-	-	4051	2440	195

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	8.97	8235	0.00	0	0.00	0	0.10	91	0.16	34	0.08	27703
10-20	10.20	9617	0.00	0	0.00	0	0.10	26	0.06	47	0.01	4902
20-30	5.29	4707	0.00	0	0.00	0	0.16	126	0.07	14	0.00	1823

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	1.81	901	11.34	4054	54.67	18694	11.59	4054	0.00	0
10-20	2.43	1198	5.66	2179	3.42	1198	0.86	327	0.00	0
20-30	0.84	450	2.49	968	0.77	270	0.29	135	0.00	0

Table 14. Concentrations of limnological variables at station 5 on March 21,1990.

Depths sampled	Ammonia (μg $N \cdot L^{-1}$)	Nitrate (μg $N \cdot L^{-1}$)	Total P ($\mu g \cdot L^{-1}$)	Part. P ($\mu g \cdot L^{-1}$)	Silicate (mg $Si \cdot L^{-1}$)	Tot. diss. solids ($mg \cdot L^{-1}$)	Bacteria ($\# \times 10^6 \cdot mL^{-1}$)	Part. C ($\mu g \cdot L^{-1}$)	Part. N ($\mu g \cdot L^{-1}$)
0-3	4.8	119.1	4.2	1.6	1.86	17	0.51	171	10
3-6	7.6	119.1	2.5	1.4	-	-	0.73	151	10
6-9	9.0	120.6	4.6	1.5	-	-	0.96	134	10
40	4.3	122.8	3.8	1.7	1.79	17	0.65	133	8

Depths sampled	Chlorophyll ($\mu g \cdot L^{-1}$)				Photosynthesis (μg $C \cdot L^{-1} \cdot hr^{-1}$)				Phytoplankton ($No. \cdot mL^{-1}$)		
	Total	Pico	Nano	Micro	Total	Pico	Nano	Micro	Pico	Nano	Micro
0-3	0.19	0.12	<0.07	<0.07	-	-	-	-	16202	7578	668
3-6	0.18	0.11	<0.07	<0.07	-	-	-	-	16103	6520	813
6-9	0.16	0.08	<0.07	<0.07	-	-	-	-	14967	4869	327
40	0.26	0.19	<0.07	<0.07	-	-	-	-	4051	2440	195

Depths sampled	*Bosmina longirostris*		*Leptodora kindtii*		*Holopedium gibberum*		*Diacylops* sp.		*Epischura lacustris*		Total Rotifers	
	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot ^{-3}$	$\# \cdot m^{-3}$	$mg \cdot m^{-3}$	$\# \cdot m^{-3}$	$mg \cdot ^{-3}$	$\# \cdot m^{-3}$
0-10	0.00	0	0.00	0	0.00	0	0.51	651	0.00	0	0.00	103
10-20	0.01	7	0.00	0	0.00	0	1.37	1431	0.00	0	0.00	36
20-30	0.00	0	0.00	0	0.00	0	1.03	956	0.00	0	0.00	11

Depths sampled	*Conochilus*		*Kellicottia*		*Ploesoma*		*Polyarthra*		*Gastropus*	
	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$	$\mu g \cdot m^{-3}$	$\# \cdot m^{-3}$
0-10	0.00	0	0.29	103	0.00	0	0.00	0	0.00	0
10-20	0.00	0	0.10	36	0.00	0	0.00	0	0.00	0
20-30	0.00	0	0.03	11	0.00	0	0.00	0	0.00	0

Table 15. IPSFC trawl catch results from Pitt Lake.

	Proportion Of Catch (%)						
	Sockeye				Stickle-		White-
Date	Age-0	Age-1	Sculpin	Smelt	Back	Other	Fish
Early Spring							
02-May-78	74.1	1.9	0.1	23.8	0.1		
30-Apr-79	19.1	0.4	0.4	22.2	57.8	0.1	
08-May-79	39.7	0.4	0.4	42.0	17.1	0.4	
15-May-79	56.3	0.5		43.1			0.2
24-May-79	70.7	0.3		29.0			
29-May-79	61.4		0.6	31.4	6.7		
Mean	53.6	0.6	0.2	31.9	13.6	0.1	0.0
SE	(20.8)	(0.7)	(0.2)	(8.9)	(22.6)	(0.2)	(0.1)
Late Spring							
09-Jun-78	2.1	0.8		97.1			
28-Jun-78	1.6			95.7	2.6		
08-Jun-79	43.8			56.3			
14-Jun-79	26.5		0.7	69.9	2.9		
18-Jun-79	7.7			91.5		0.8	
29-Jun-79	71.1		0.6	25.3	3.0		
12-Jun-81				89.2	10.8		
Mean	19.1	0.1	0.2	65.6	2.4	0.1	
SE	(27.1)	(0.3)	(0.3)	(26.6)	(3.8)	(0.3)	
Summer							
04-Aug-78	1.5	0.1	0.2	57.6	40.7		
06-Jul-79	42.4			49.6	7.9		
12-Jul-79	39.8		1.0	48.0	11.2		
18-Jul-79	18.1			62.4	19.5		
24-Jul-79	27.9			33.4	38.7		
31-Jul-79	17.2	1.0		45.3	36.5		
17-Jul-80	14.6			78.8	6.6		
06-Jul-82	4.5			93.2	2.3		
Mean	18.4	0.1	0.1	52.0	18.1		
SE	(5.0)	(0.1)	(0.1)	(6.5)	(5.3)		
Early Fall							
24-Aug-79	9.7		0.3	65.7	24.3		
05-Sep-79	4.2			46.0	49.8		
19-Sep-79	8.9			28.3	62.5	0.4	
10-Sep-80	2.5			10.0	87.5		
16-Sep-81		0.1		24.3	75.6		
Mean	4.2	0.0	0.1	29.1	49.9	0.1	
SE	(4.2)	(0.0)	(0.1)	(21.5)	(24.4)	(0.2)	
Early Winter							
05-Oct-77	2.3			31.3	66.5		
22-Nov-78	1.2	0.2	0.3	32.2	66.2		
19-Nov-79	2.9			47.5	49.6		
06-Oct-80	2.1		0.2	14.3	83.5		
Mean	1.7	0.0	0.1	25.0	53.2		
SE	(0.3)	(0.0)	(0.1)	(6.1)	(6.2)		

Table 16. Average percent fullness and percentage of empty stomachs for Pitt Lake sockeye and smelt in 1978.

MONTH	SAMPLE SIZE		% EMPTY GUTS		AVE % FULLNESS	
	sockeye	smelt	sockeye	smelt	sockeye	smelt
APR	30	115	93	70	3	5
MAY	60	91	100	57	0	5
JUN	3	70	0	17	30	36
JUL		128		9		12
AUG	3	70	0	47	52	2
SEP						
NOV	6	82	0	51	5	2

Table 17. Average percent fullness and percentage of empty stomachs for Pitt Lake sockeye and smelt in 1979.

MONTH	SAMPLE SIZE		% EMPTY GUTS		AVE % FULLNESS	
	sockeye	smelt	sockeye	smelt	sockeye	smelt
APR	20	25	100	54	0	1
MAY	20	18	90	4	1	38
JUN	22	25	50	28	37	38
JUL	12		0		46	
AUG	10	27	0	20	44	16
SEP	20	40	0	53	65	1
NOV	9	6	89	17	8	3

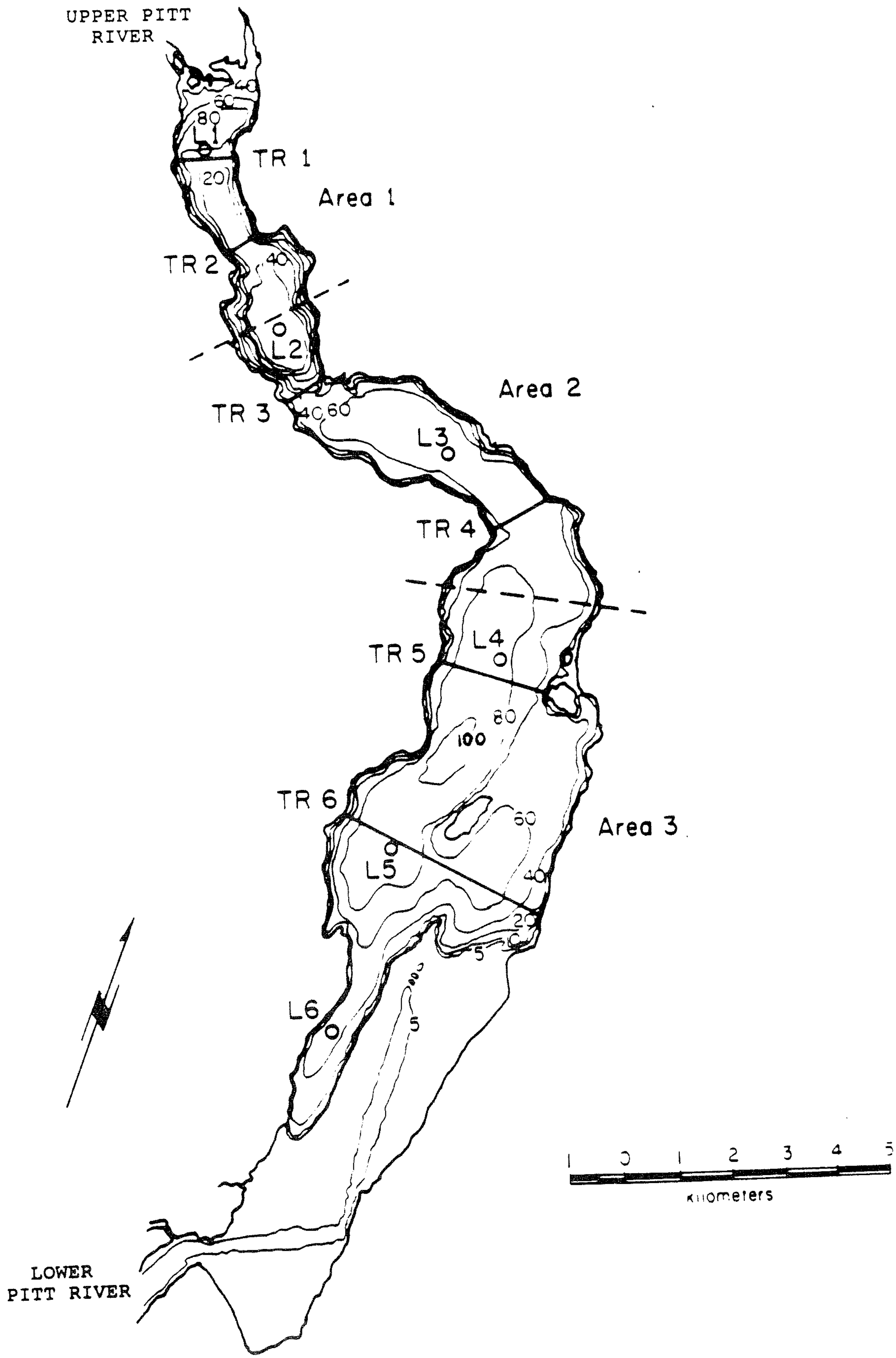


Fig. 1. Map of Pitt Lake showing location of limnology stations, hydroacoustic transects, and trawling areas.

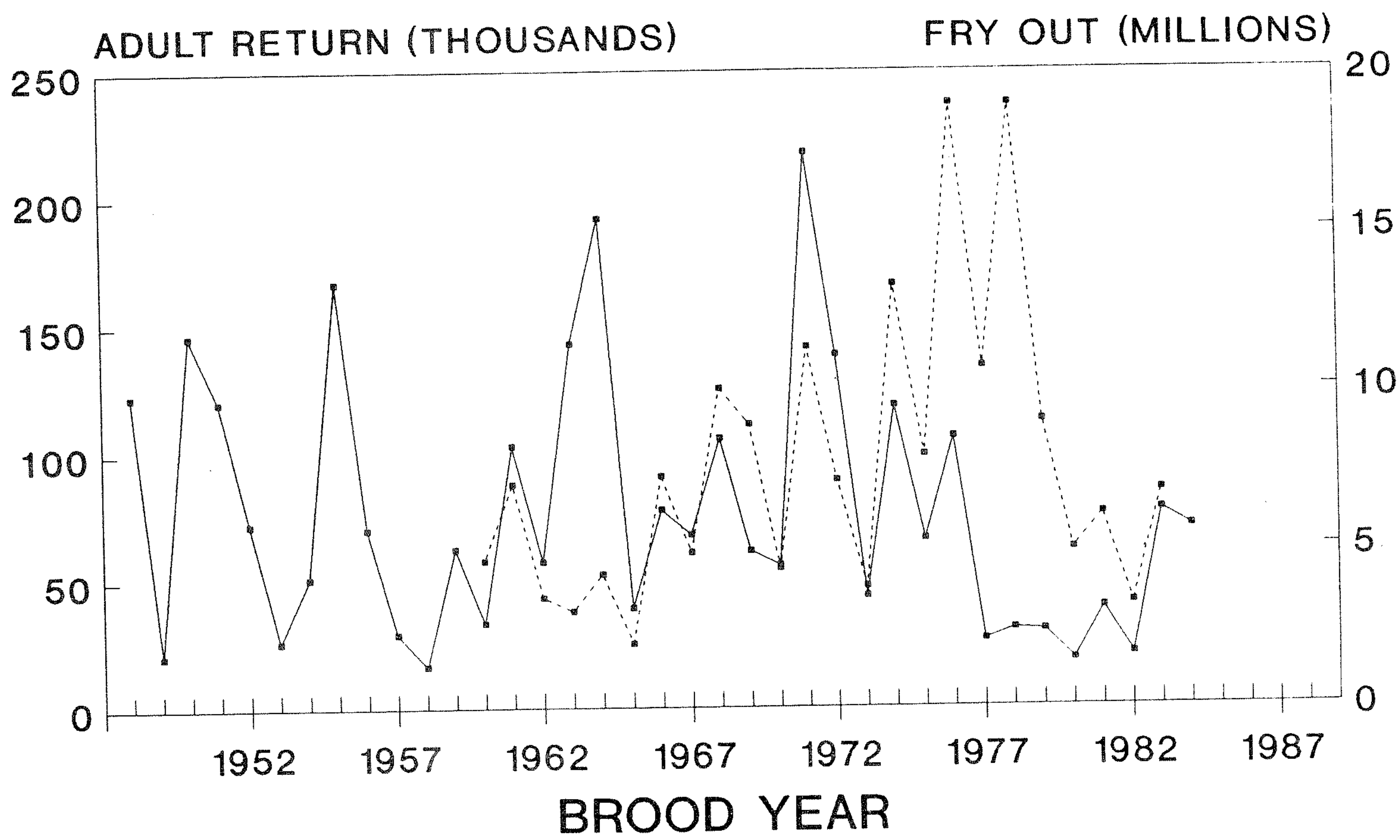


Fig. 2. Estimates by brood year of the total return (catch plus spawning escapement) (1948-1984) and fry abundance (1960-1983) for Pitt Lake sockeye salmon.

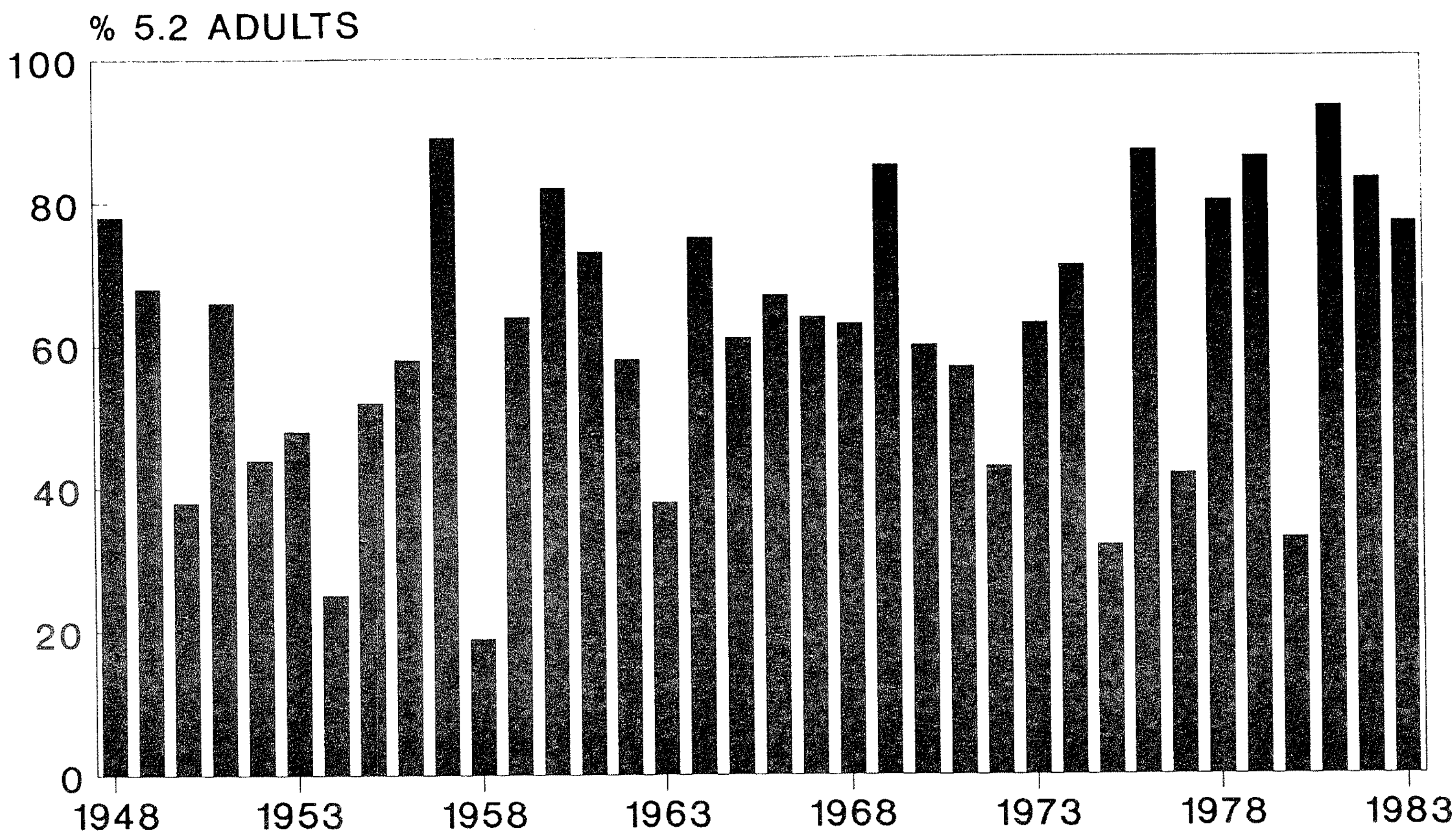


Fig. 3. Percent aged 5_2 adult sockeye salmon in Pitt Lake spawning ground samples for brood years 1948-1983.

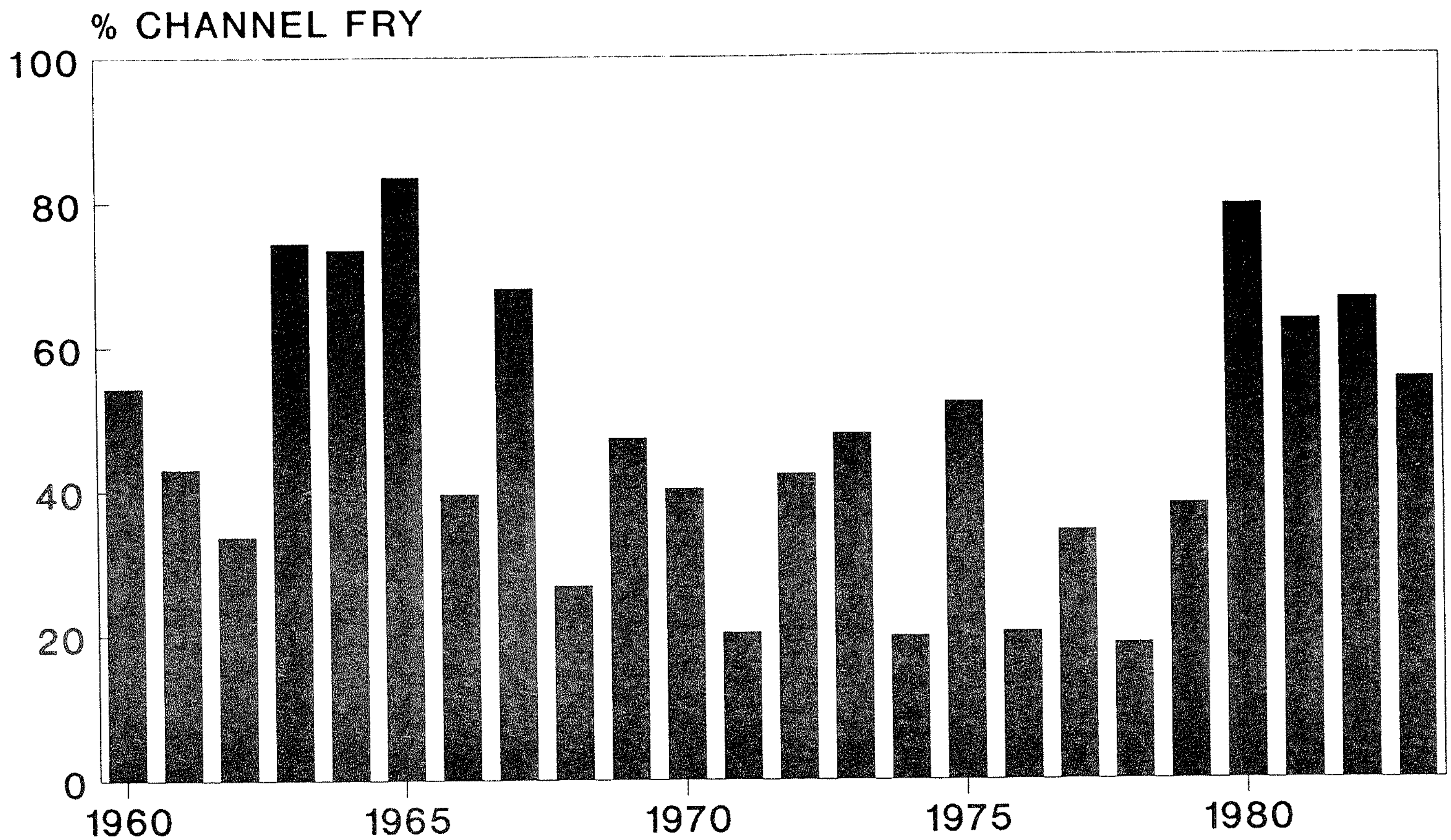


Fig. 4. Percent of total Pitt Lake sockeye salmon fry production originating from the Corbold Creek hatchery.

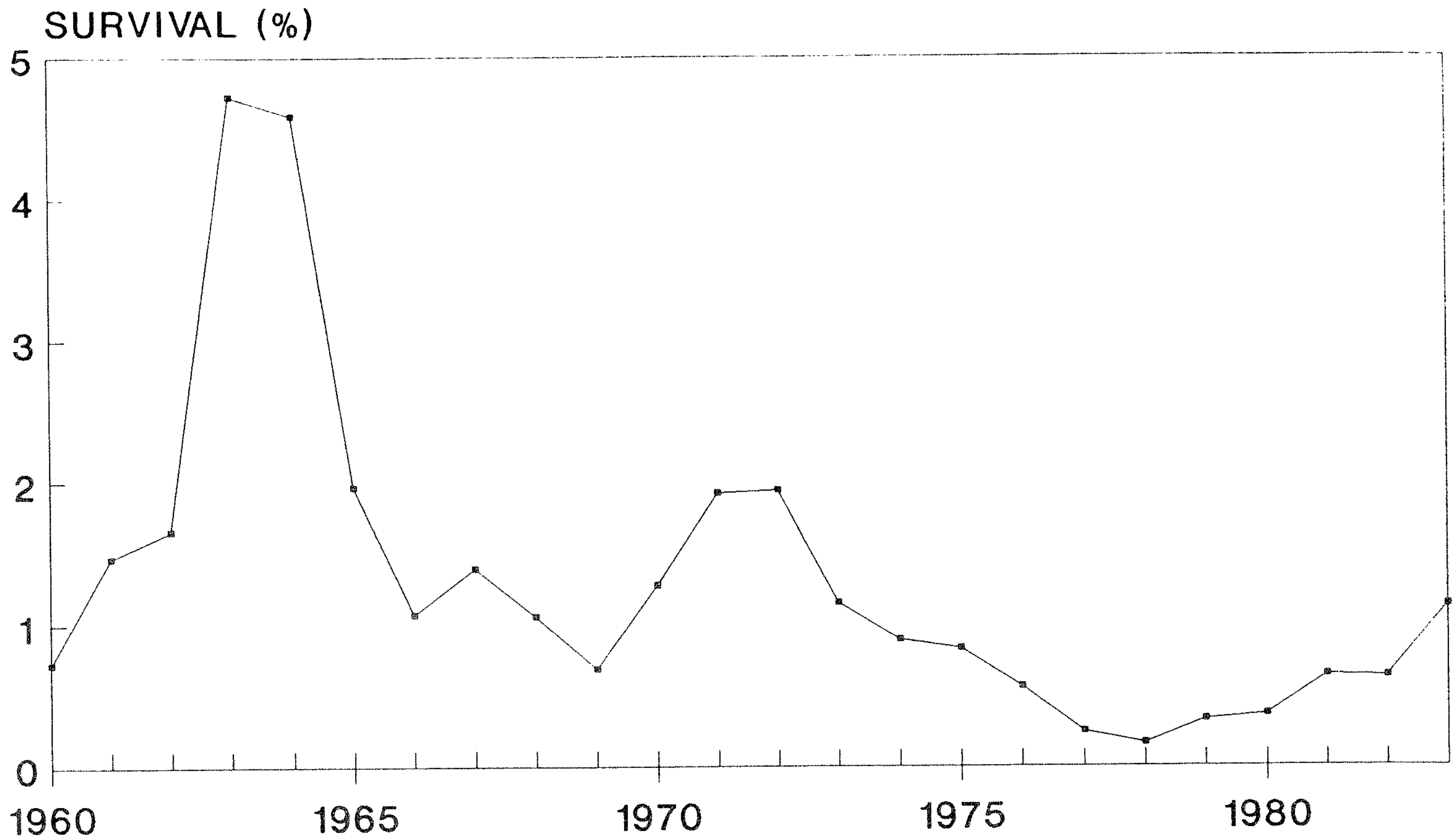


Fig. 5. Percent fry-to-adult survival for Pitt Lake sockeye salmon for the brood years from 1960-1983.

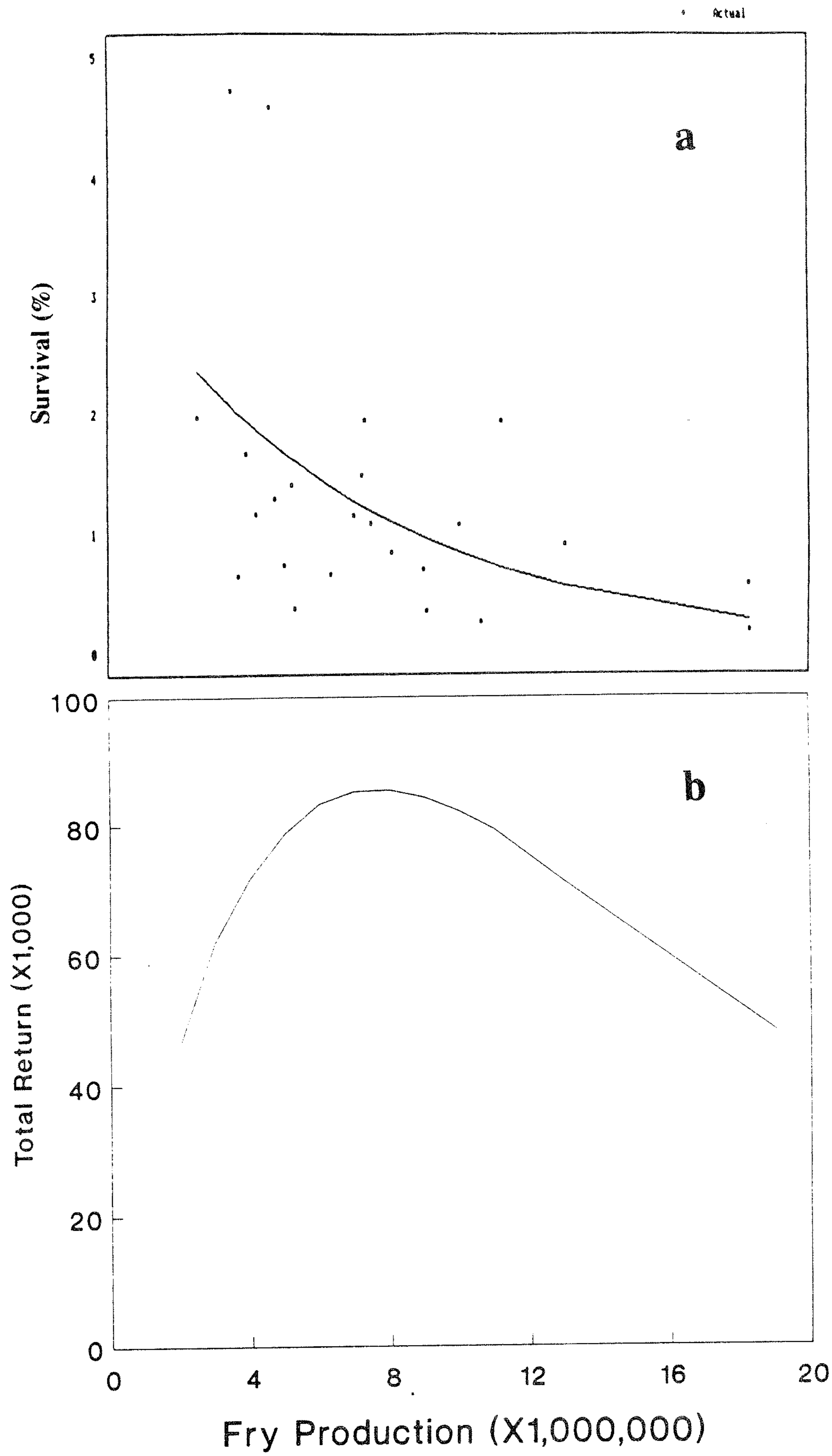


Fig. 6. Relationship between a) fry-to-adult survival and fry production for the brood years 1960-1983 and b) estimated total return based on model (a) and fry production for Pitt Lake sockeye salmon.

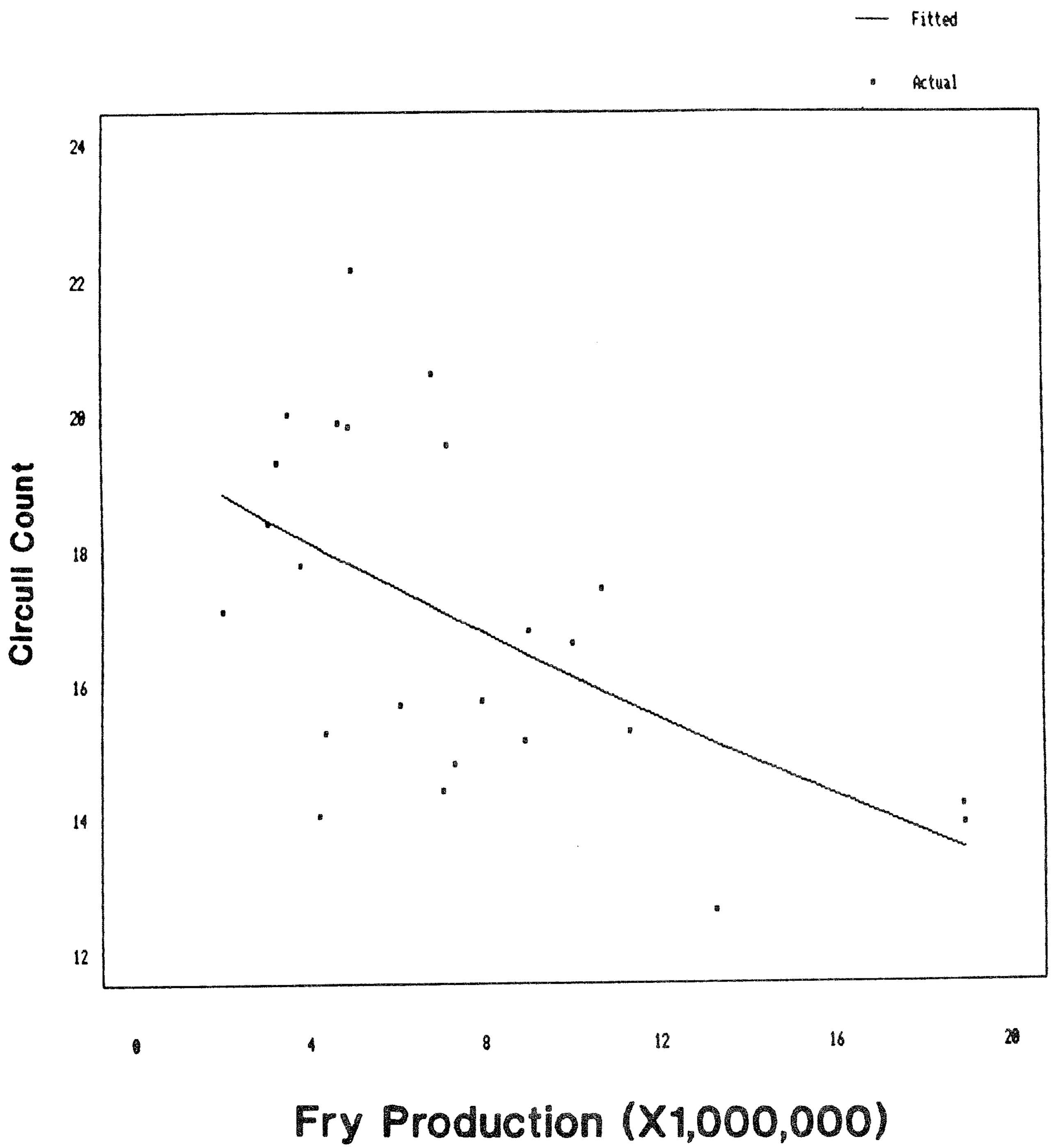


Fig. 7. Relationship between total freshwater circuli count and fry production for brood years 1960-1983 for Pitt Lake sockeye salmon.

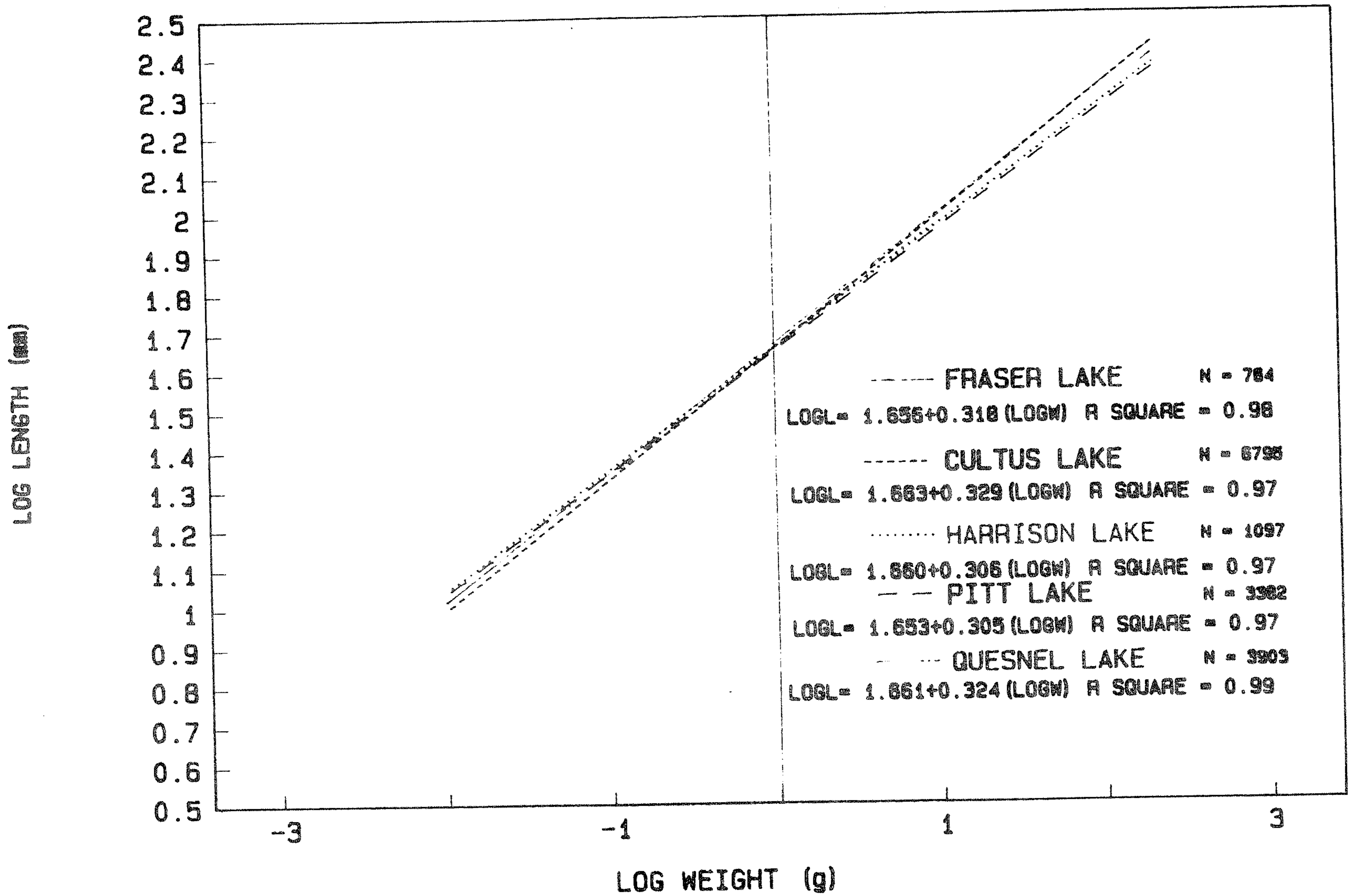


Fig. 8. Log length (mm) - log weight (g) relationship for juvenile sockeye salmon from Fraser, Cultus, Harrison, Pitt, and Quesnel lakes.

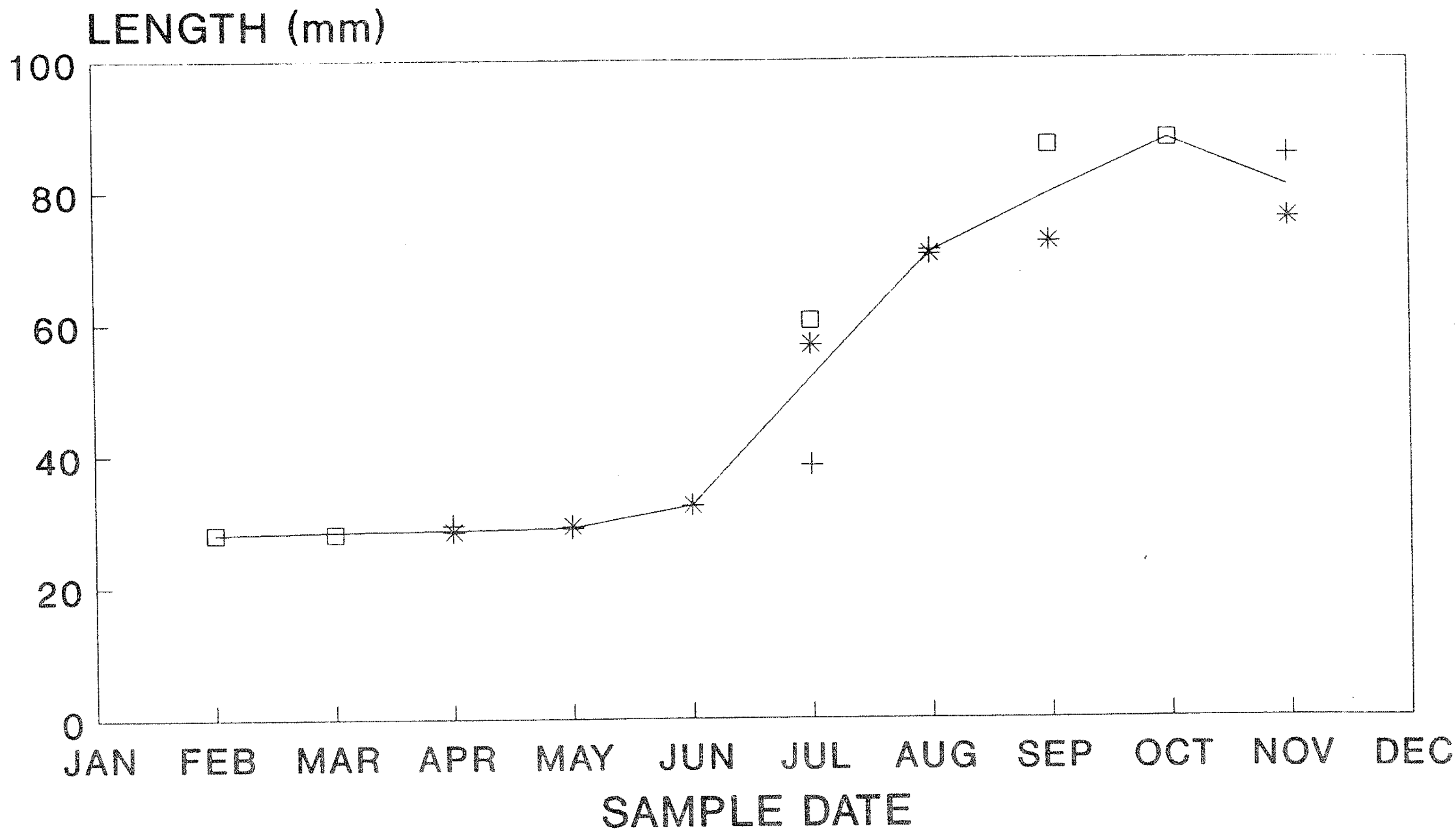


Fig. 9. Seasonal changes in fork-length (mm) of Pitt Lake sockeye salmon based on measurements made in 1978, 1979, and 1980. Solid line is the average fork-length by month from pooled measurements for the three years.

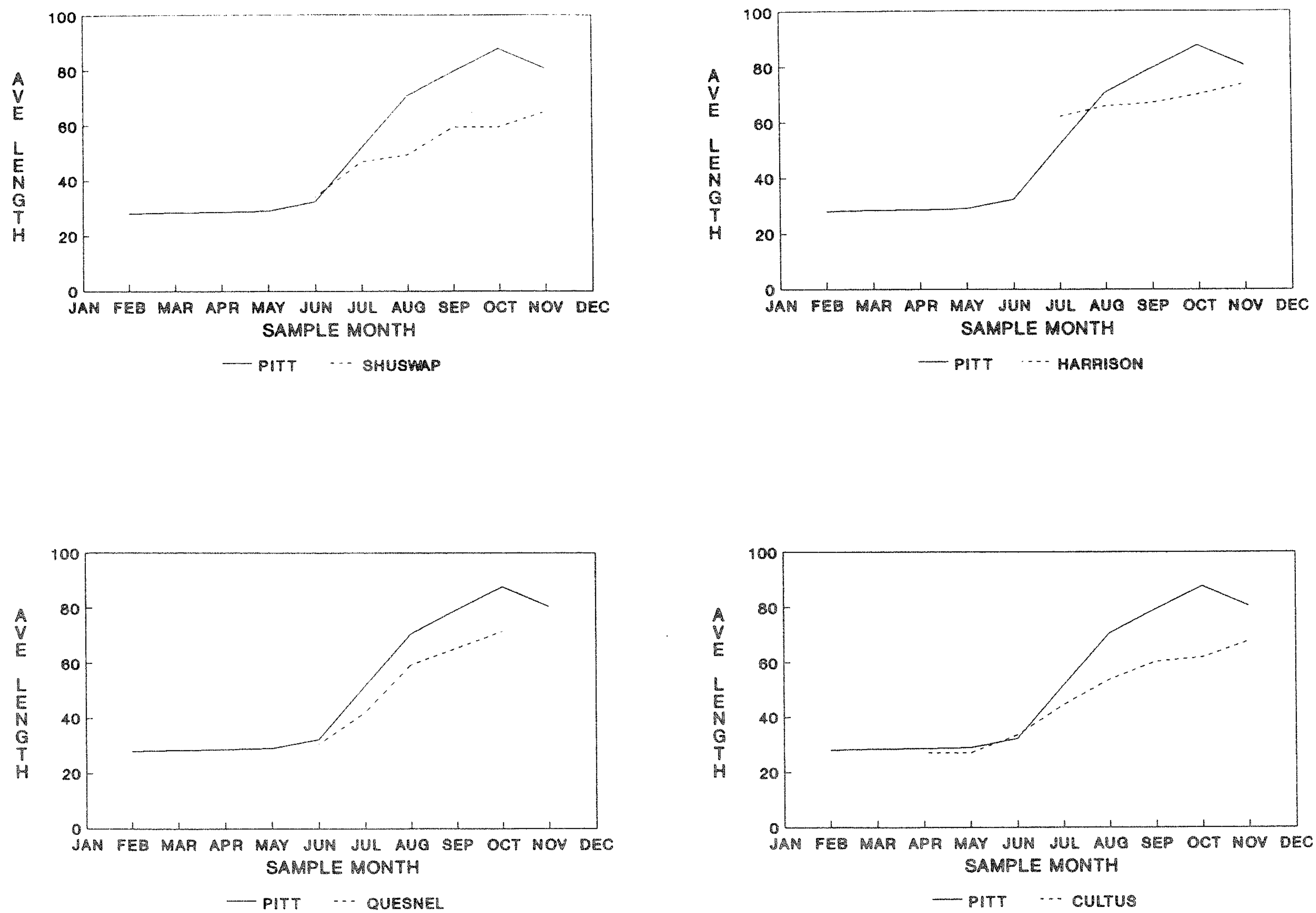


Fig. 10. A comparison of mean fork-length (mm) by month between Pitt Lake and four other sockeye salmon stocks in the Fraser River basin.

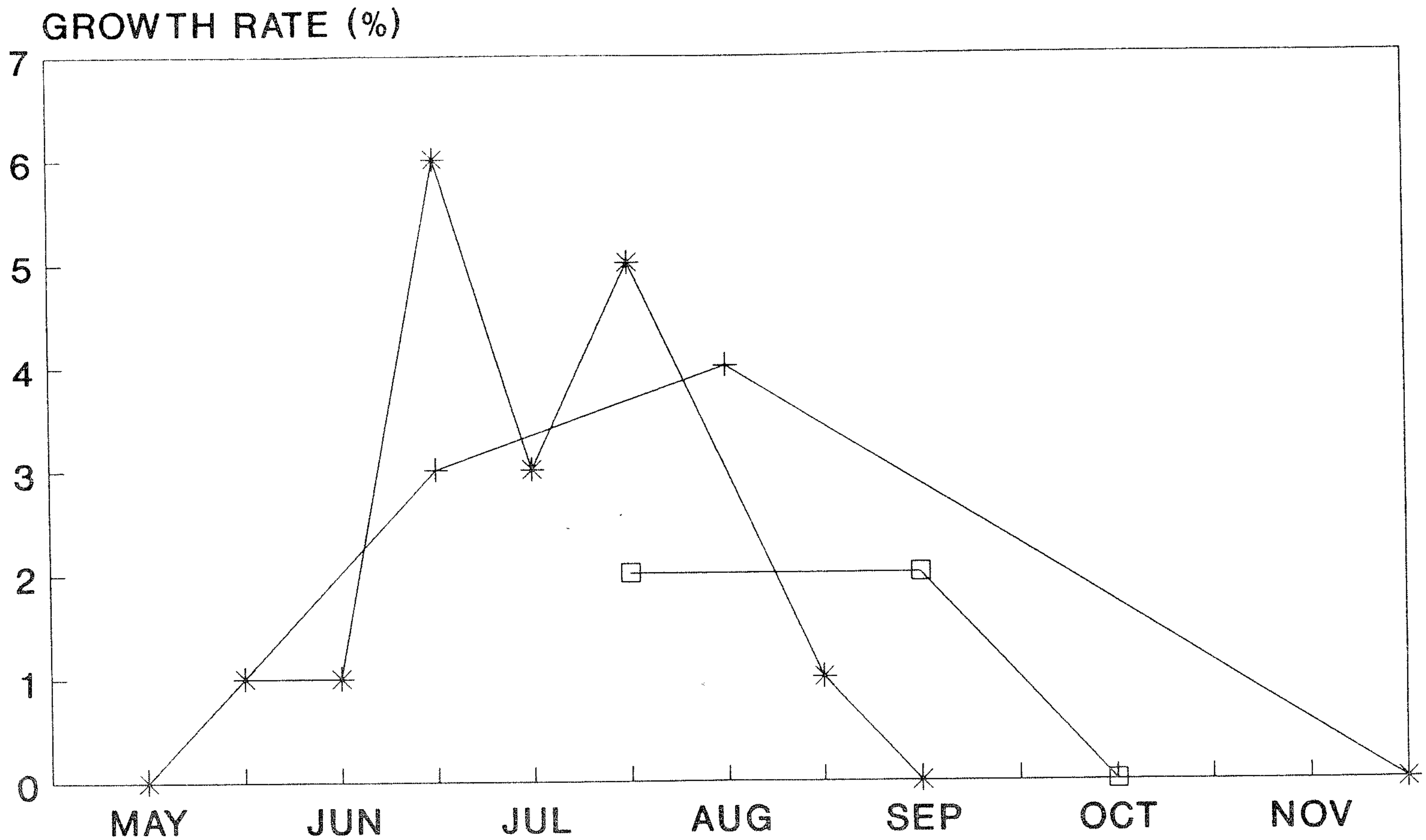


Fig. 11. Seasonal changes in the daily instantaneous growth rate (%) of juvenile sockeye salmon in Pitt Lake from 1978-1980.

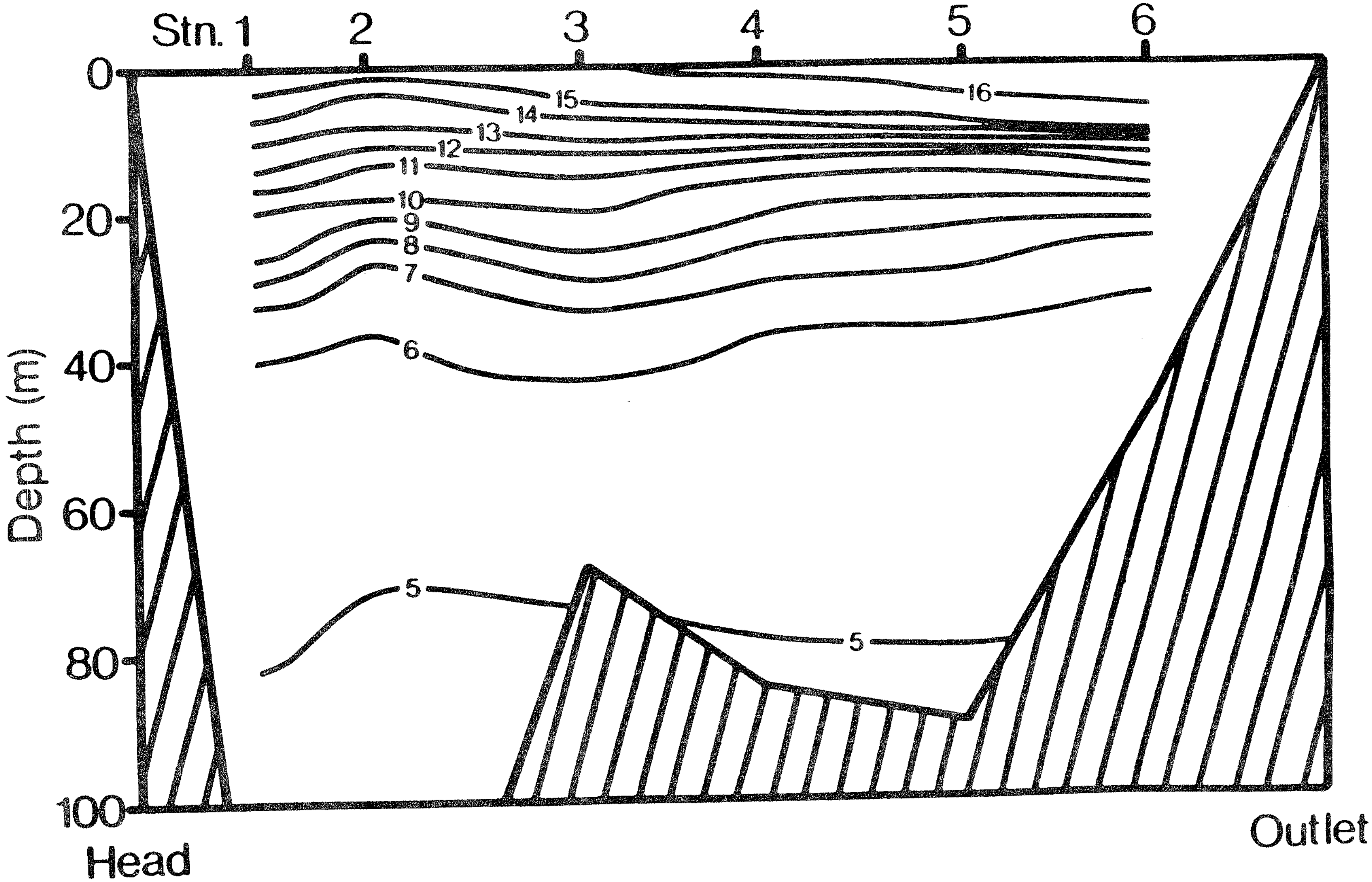


Fig. 12. Variation in temperature structure from the head to the outlet of Pitt Lake on July 19, 1989. Isolines are in 1^0C intervals.

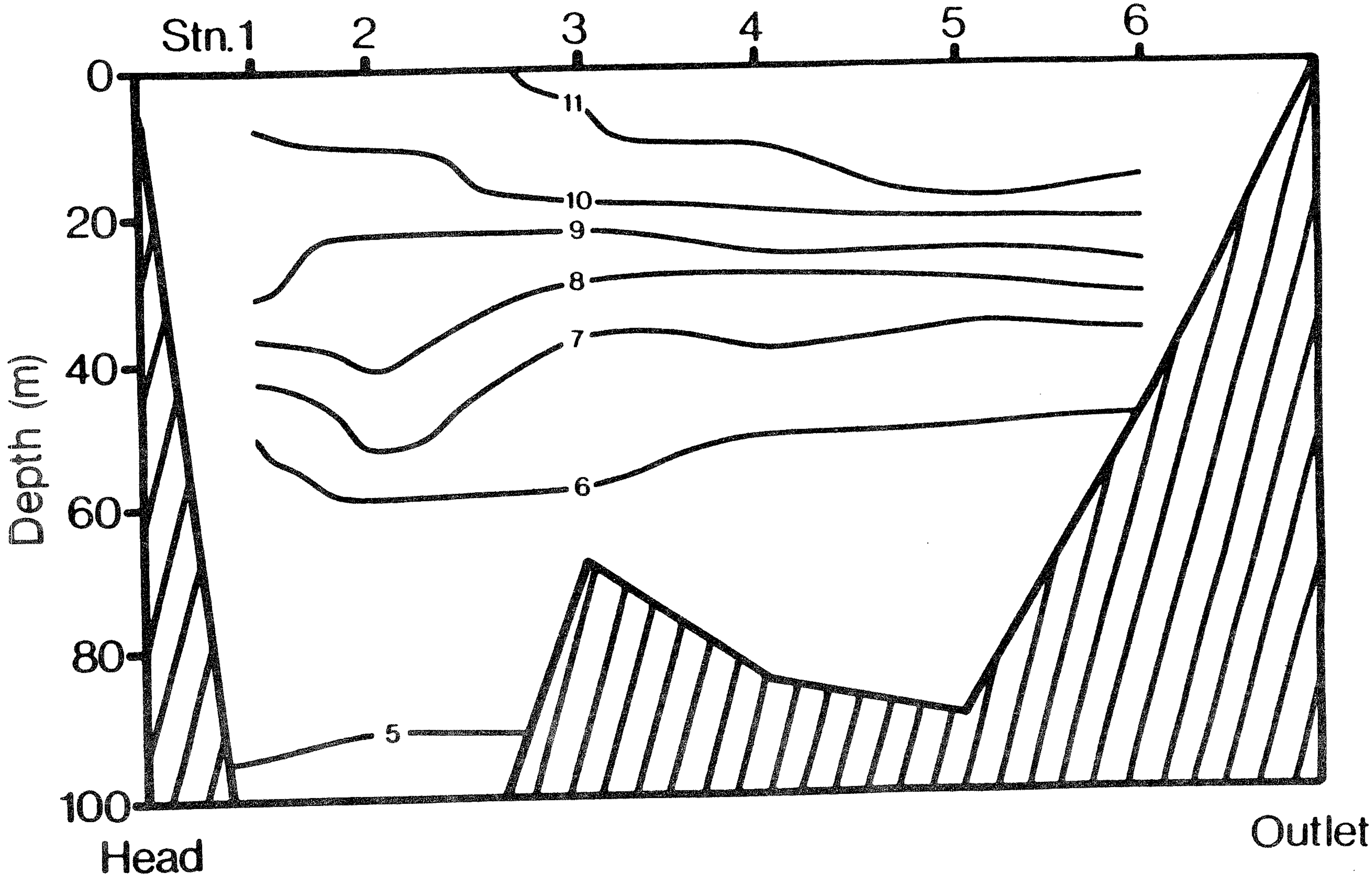


Fig. 13. Variation in temperature structure from the head to the outlet of Pitt Lake on October 25, 1989. Isolines are in 1°C intervals.

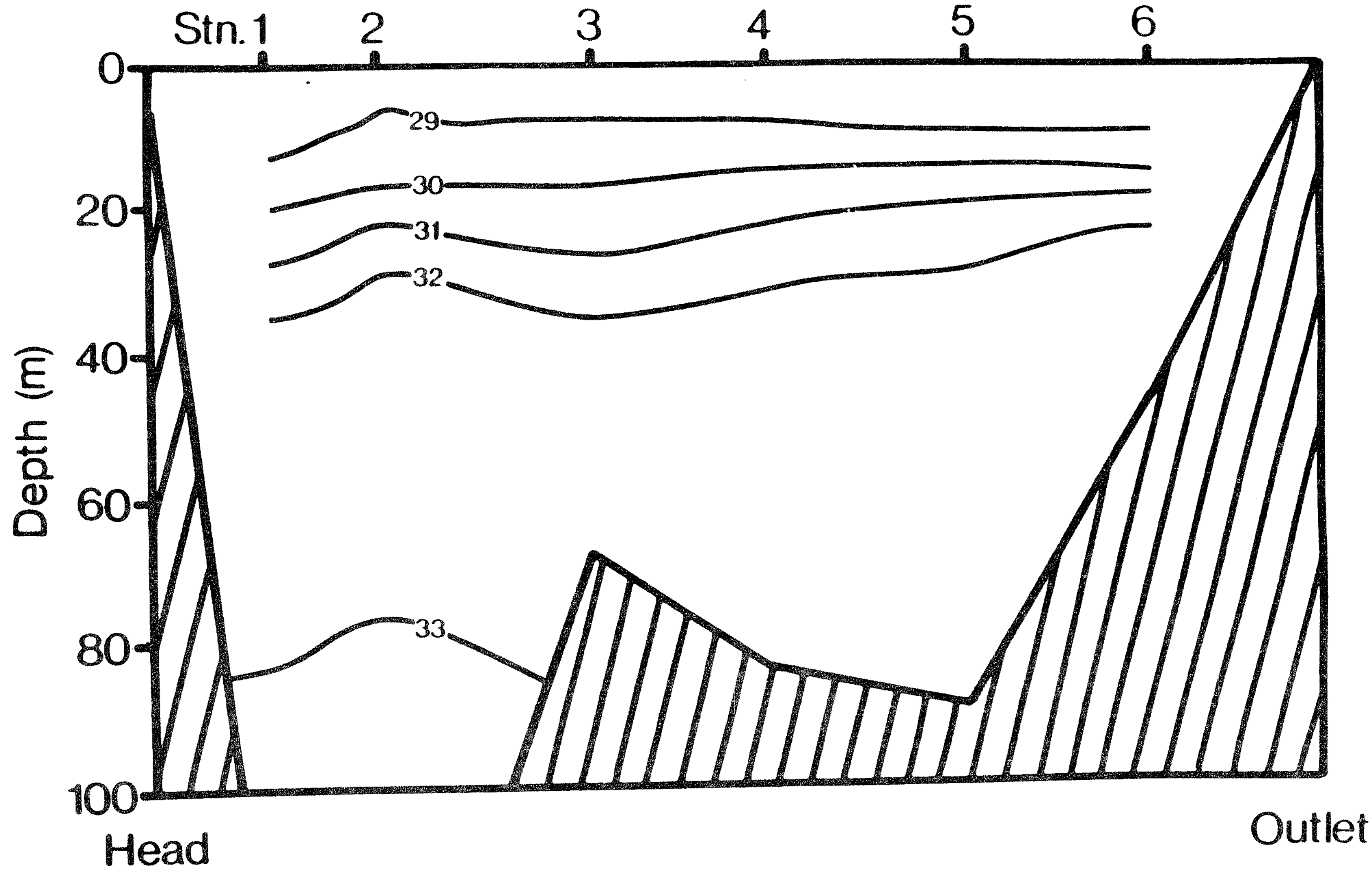


Fig. 14. Changes in conductivity in Pitt Lake on July 19, 1989. Isolines are spaced at 1 $\mu S \cdot cm^{-1}$ intervals.

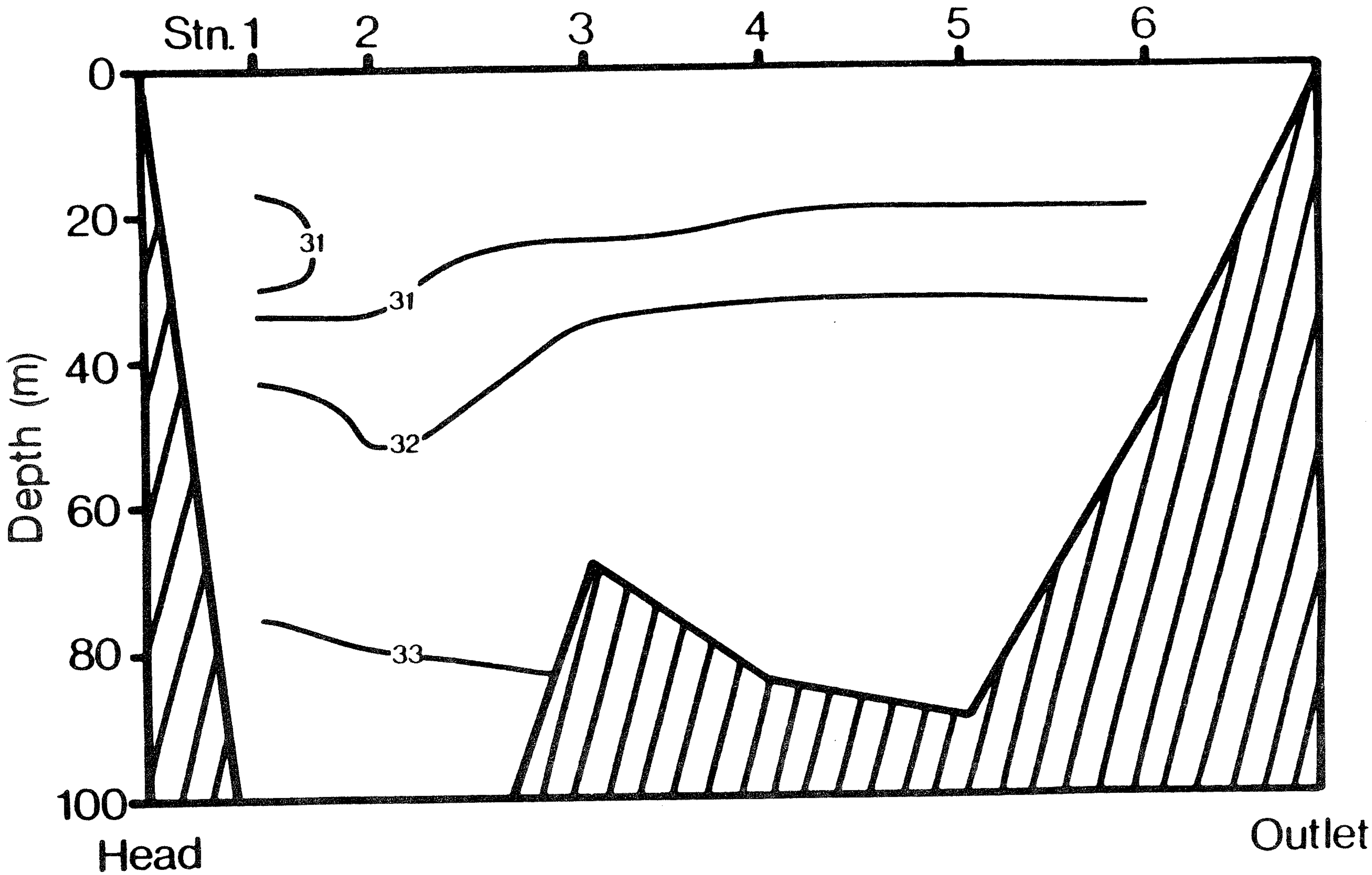


Fig. 15. Changes in conductivity in Pitt Lake on October 25, 1989. Isolines are spaced at 1 $\mu S \cdot cm^{-1}$ intervals.

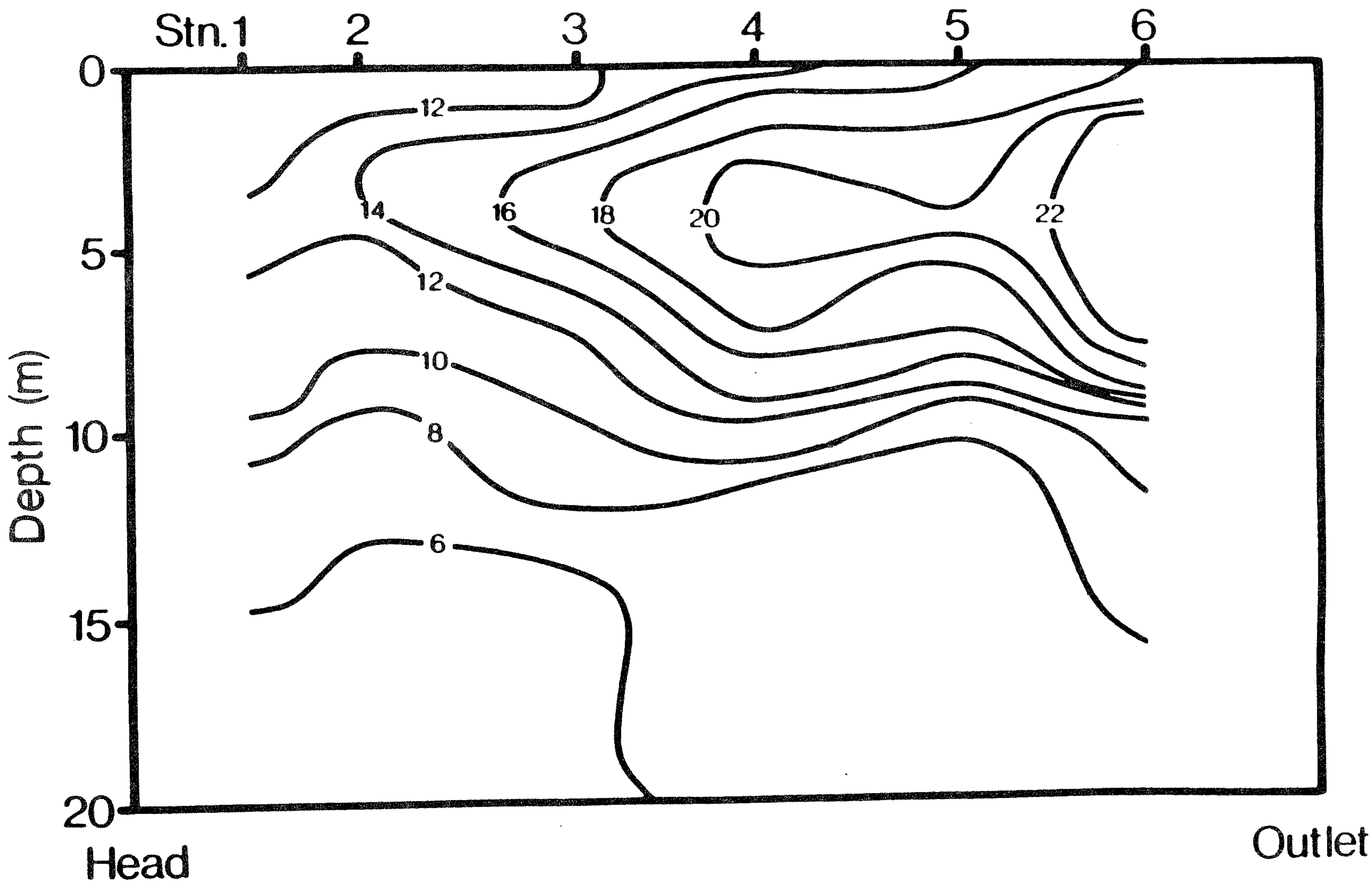


Fig. 16. *In vivo* fluorescence (IVF) on July 19, 1989. Data are in relative fluorescence units, which is a generally reliable indicator of chlorophyll concentration.

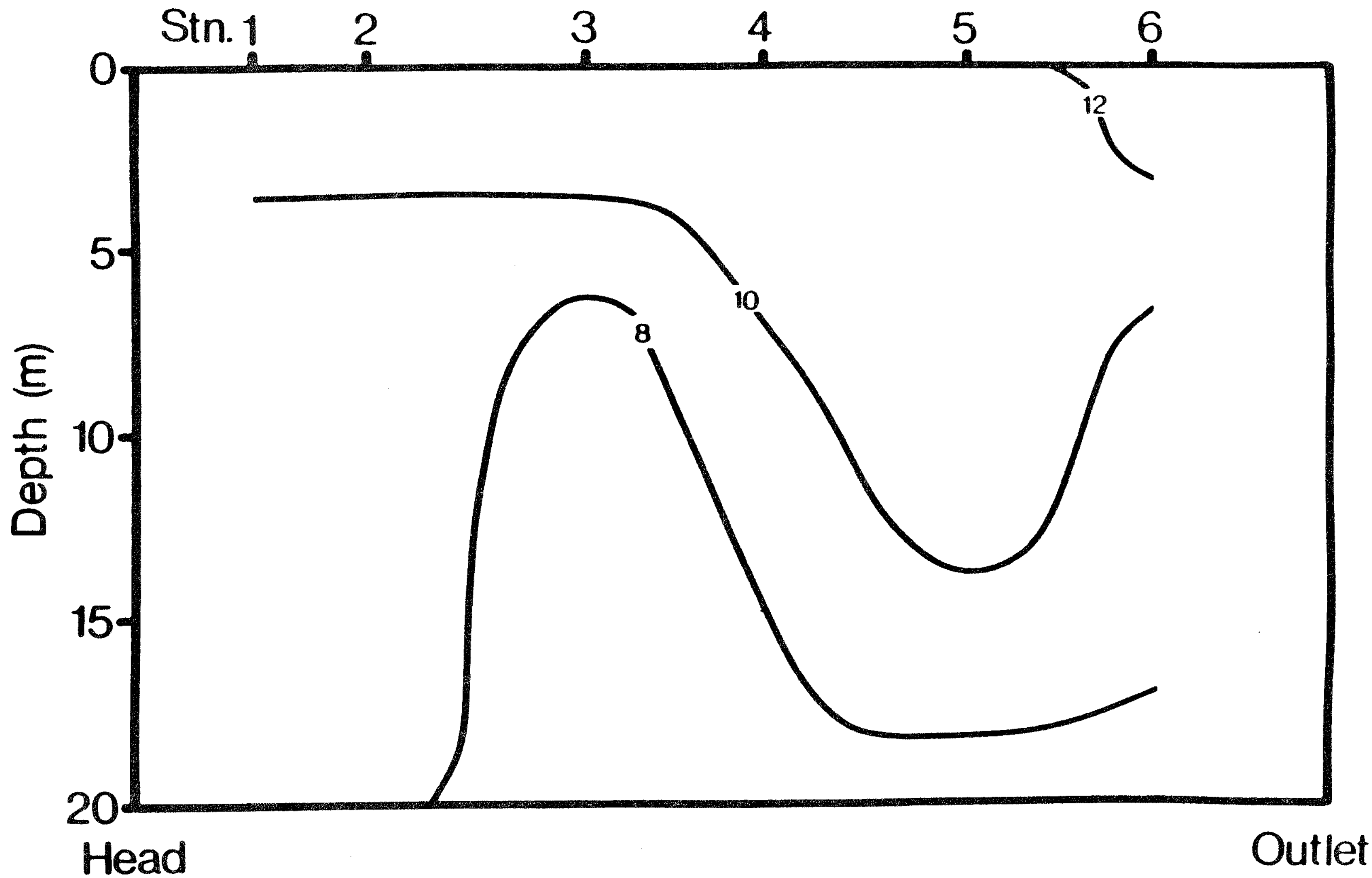


Fig. 17. Variation in IVF in Pitt Lake on October 25, 1989. Data are in relative fluorescence units.

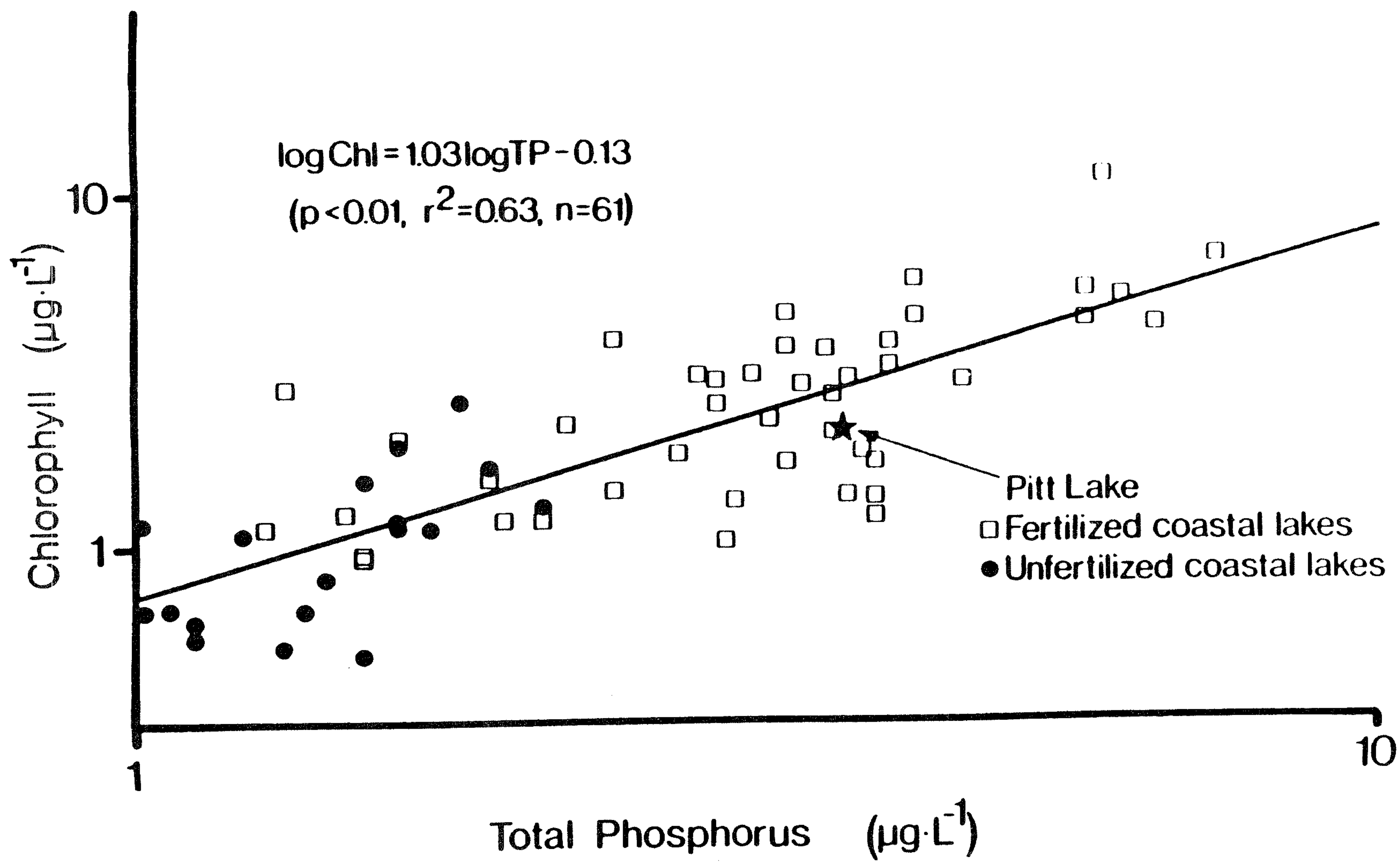


Fig. 18. Chlorophyll-total phosphorus relationship in Pitt Lake and in a number of British Columbia coastal lakes. Pitt Lake data are from this study and coastal lake data are from Stockner and Shortreed (1985).

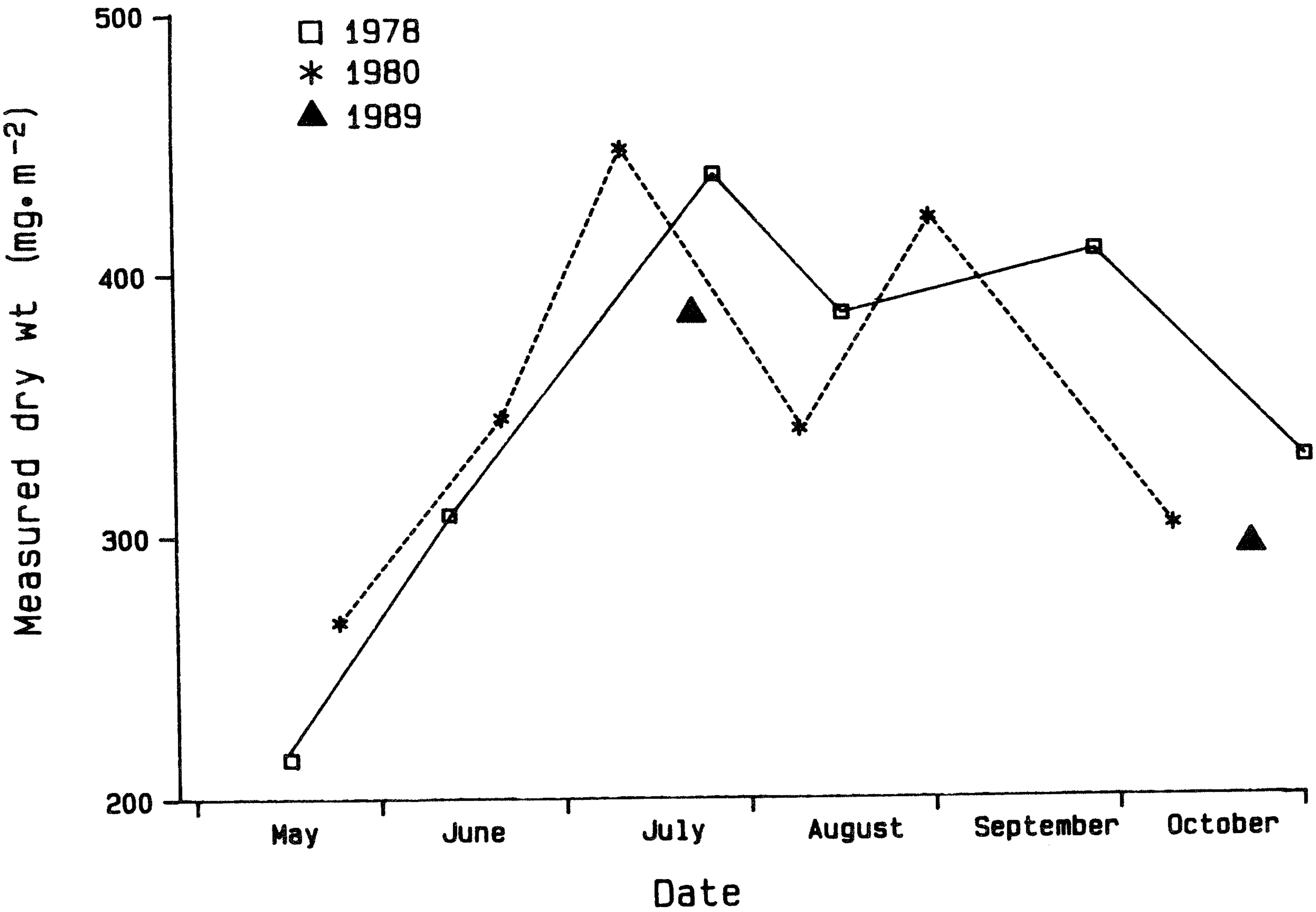


Fig. 19. Seasonal changes in zooplankton dry weights in Pitt Lake in 1978 and in 1980. Data are averages of Wisconsin net hauls collected from two locations in the lake. 1989 data are also shown.

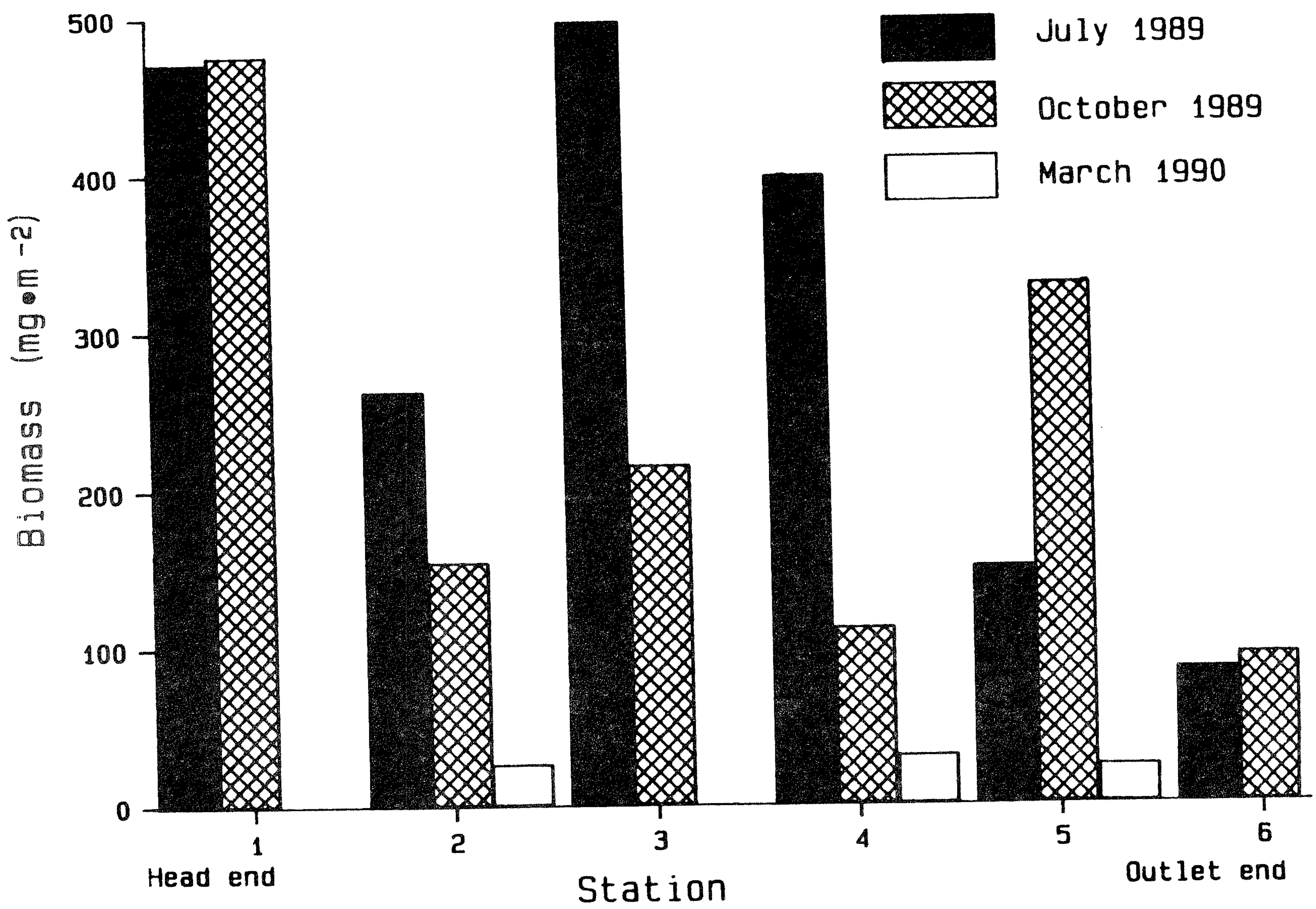


Fig. 20. Differences in July and October 1989 and March 1990 zooplankton dry weights collected at six locations along the longitudinal axis of the lake.

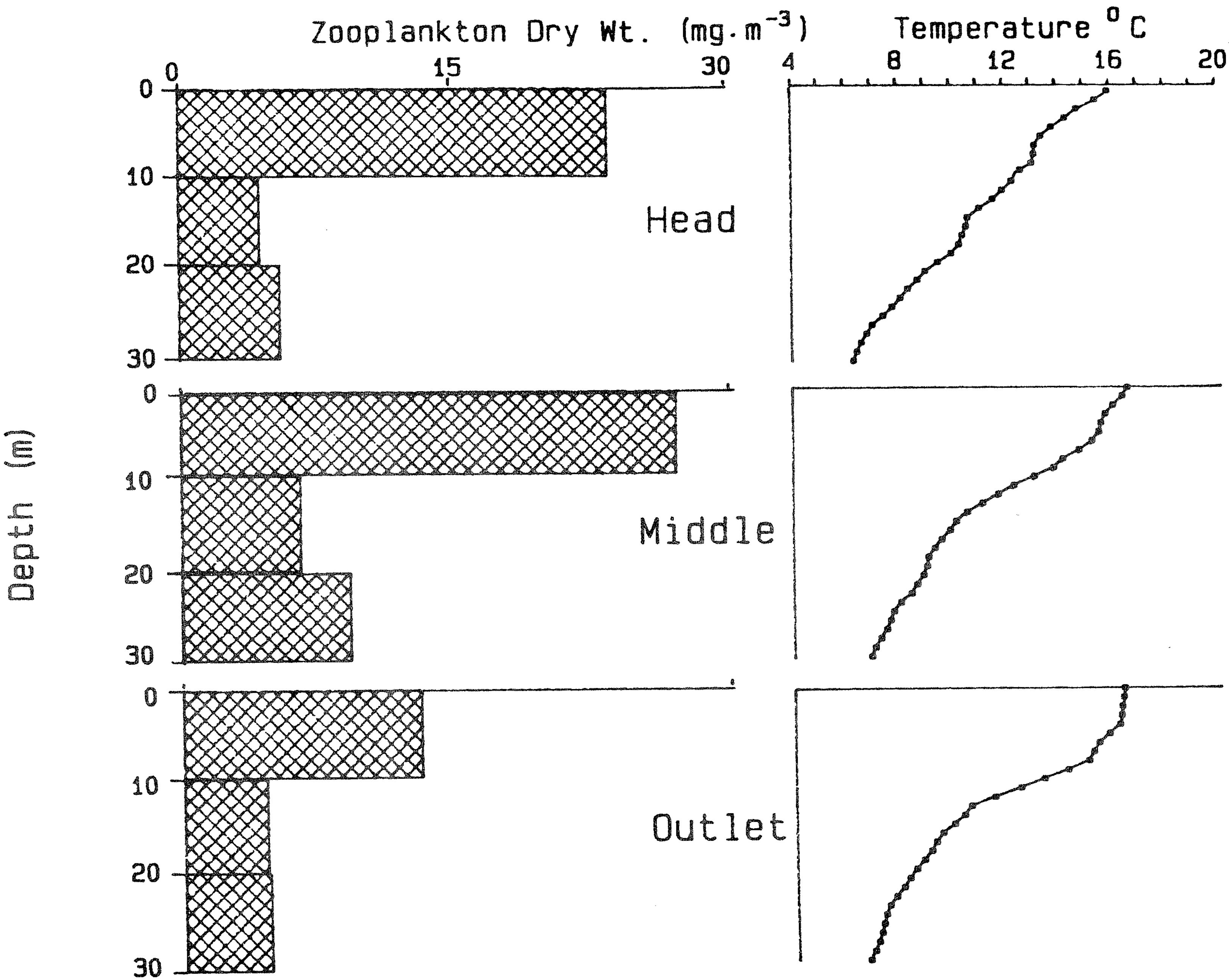


Fig. 21. Vertical variation of zooplankton dry weight (calculated from length measurements) in July 1989 at three stations located near the head, middle, and outlet of Pitt Lake.

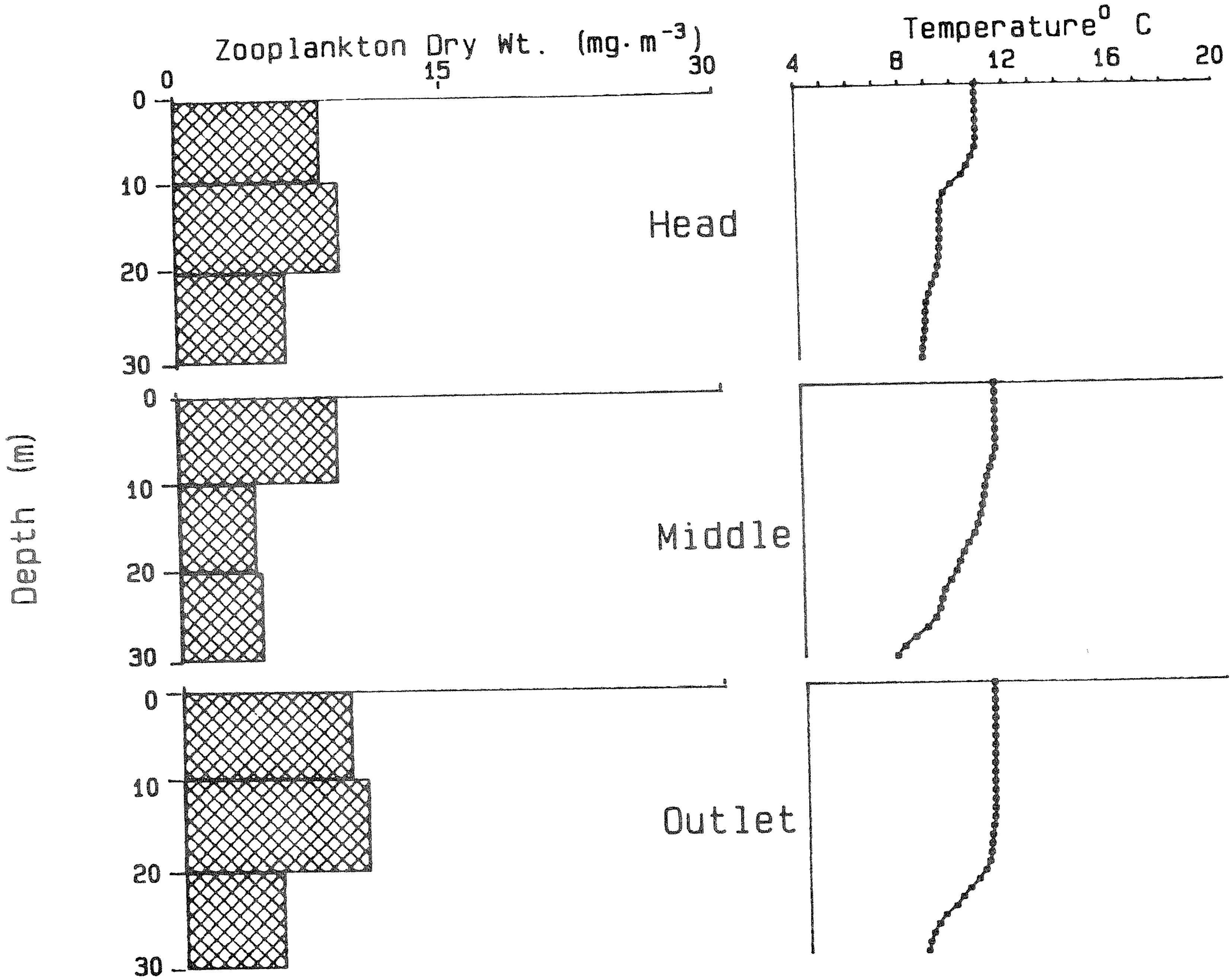


Fig. 22. Vertical variation of zooplankton dry weight (calculated from length measurements) in October 1989 at three stations located near the head, middle, and outlet of Pitt Lake.

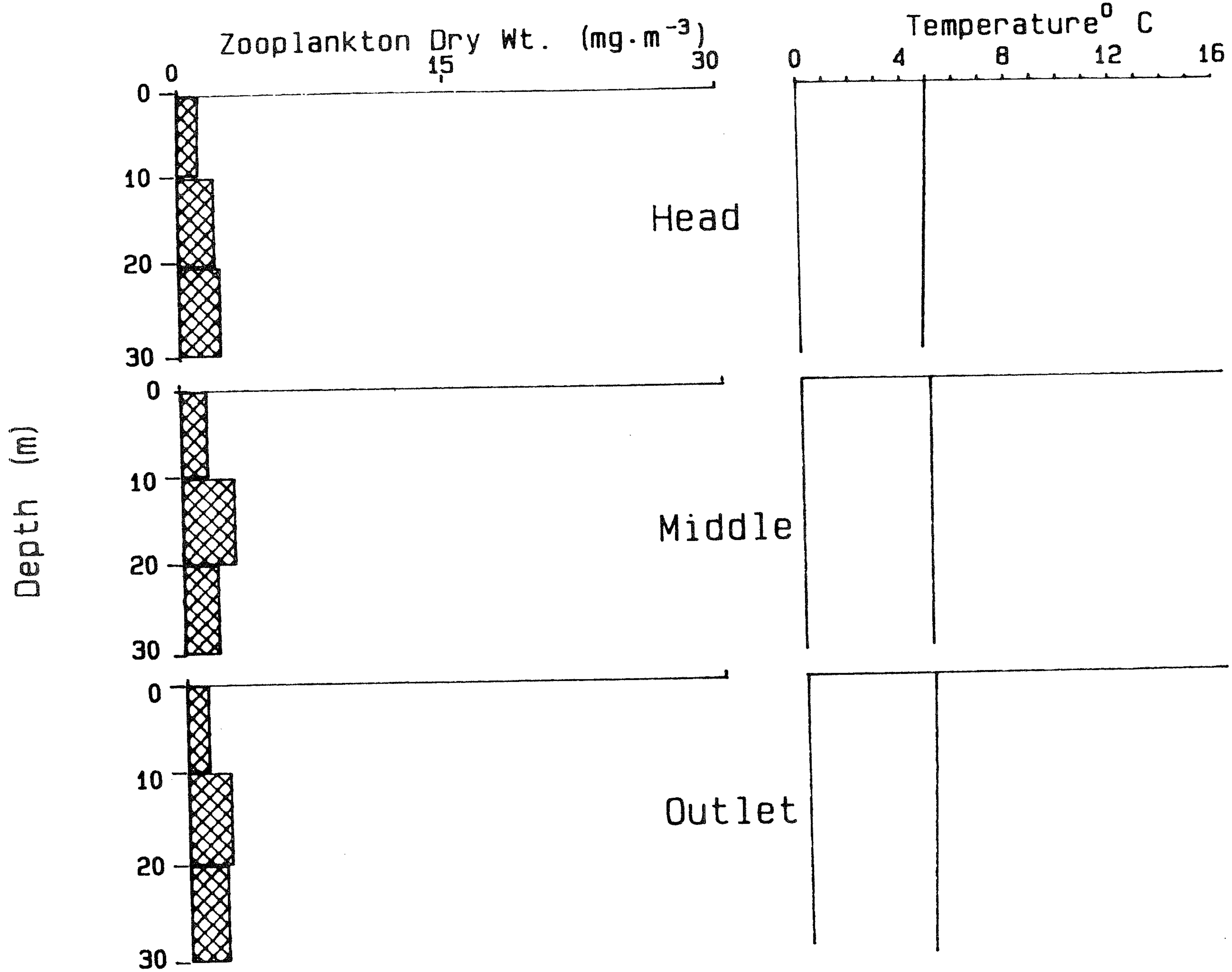


Fig. 22a. Vertical variation of zooplankton dry weight (calculated from length measurements) in March 1990 at three stations located near the head, middle, and outlet of Pitt Lake.

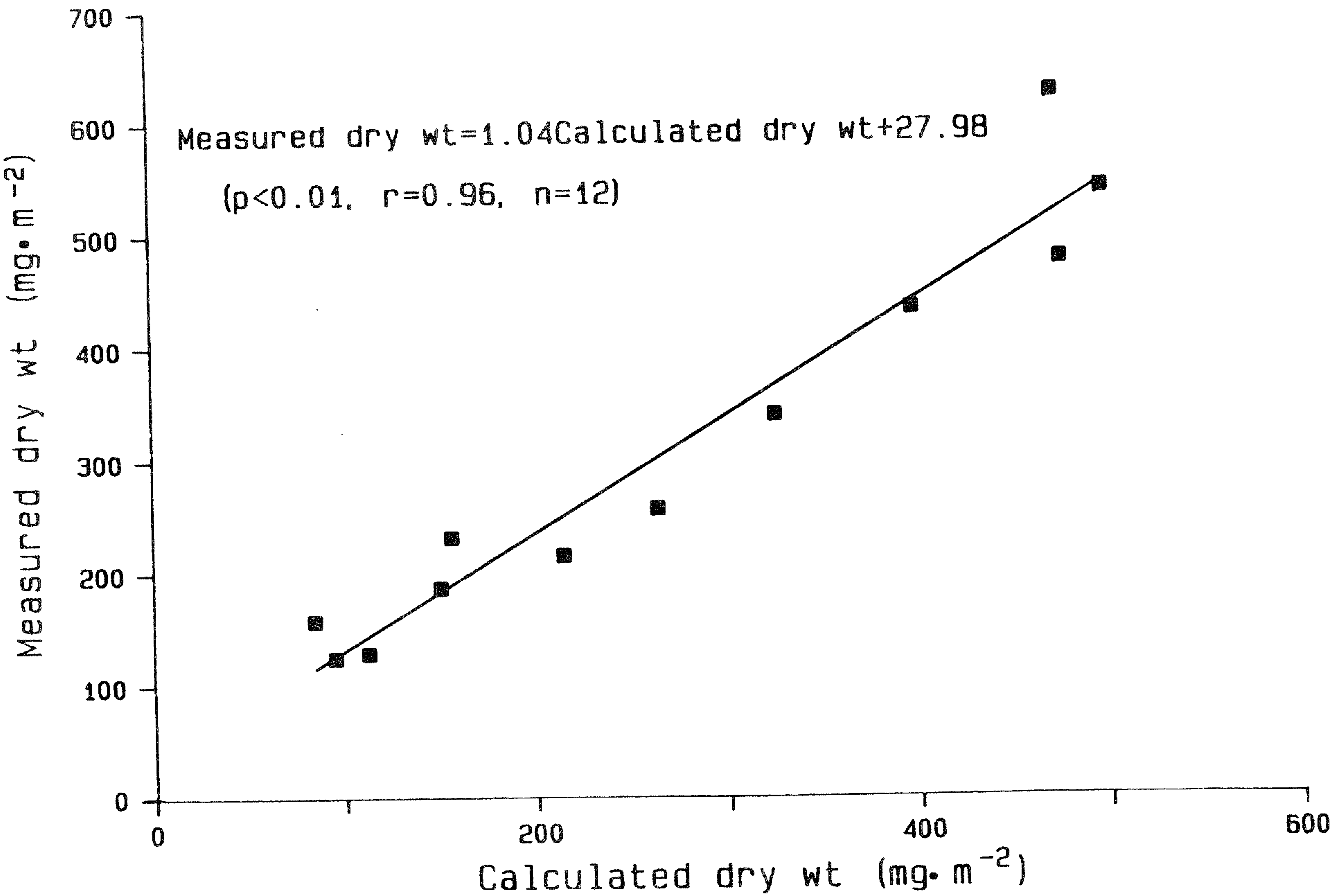


Fig. 23. Correlation of measured zooplankton dry weights versus dry weights calculated using zooplankton counts and lengths. Data are from samples collected with a Wisconsin net in 1989.

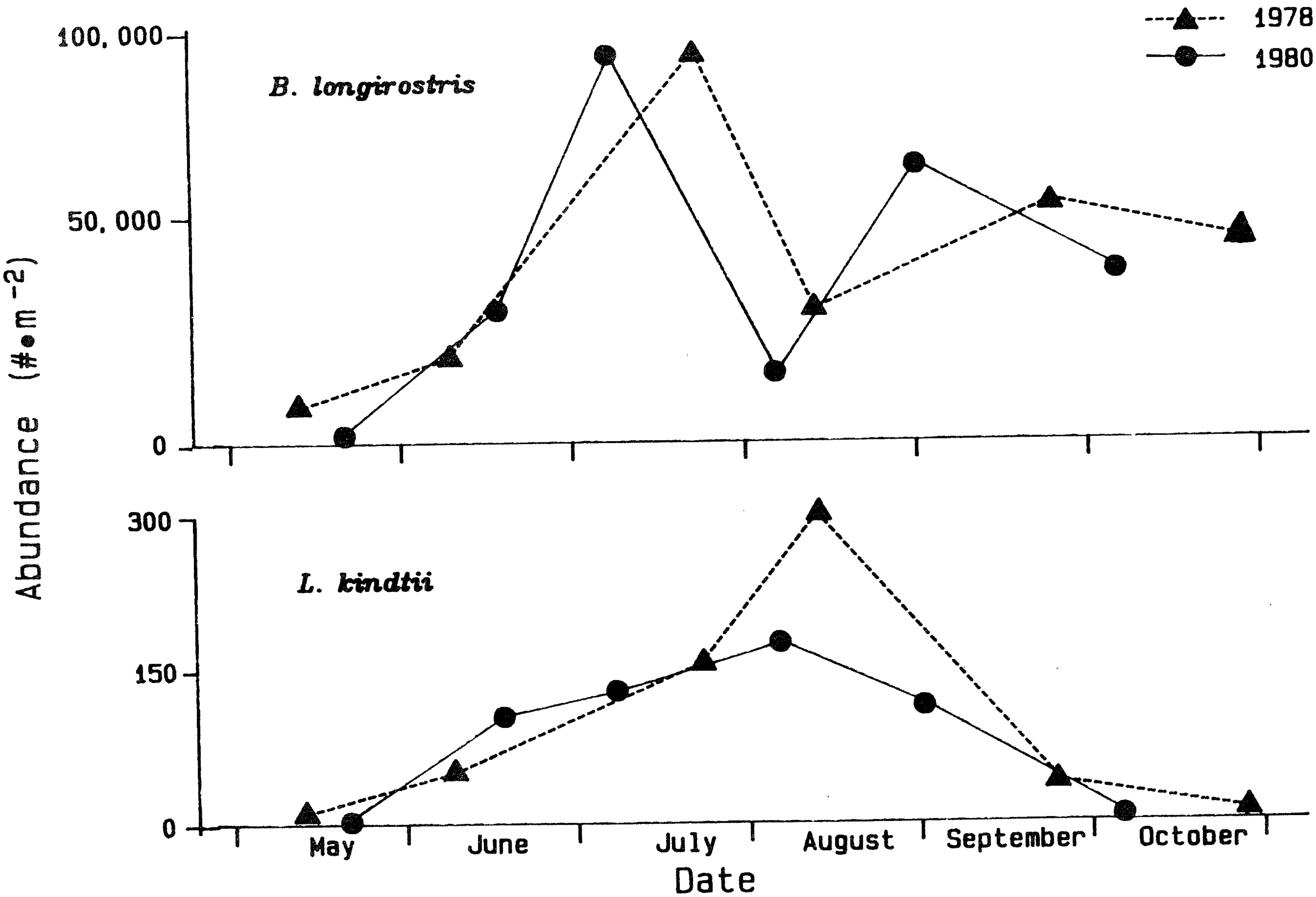


Fig. 24. Seasonal changes in the density of the cladocerans *B. longirostris* and *L. kindtii* in 1978 and 1980. Data are averages of counts from Wisconsin net hauls at two locations in the lake.

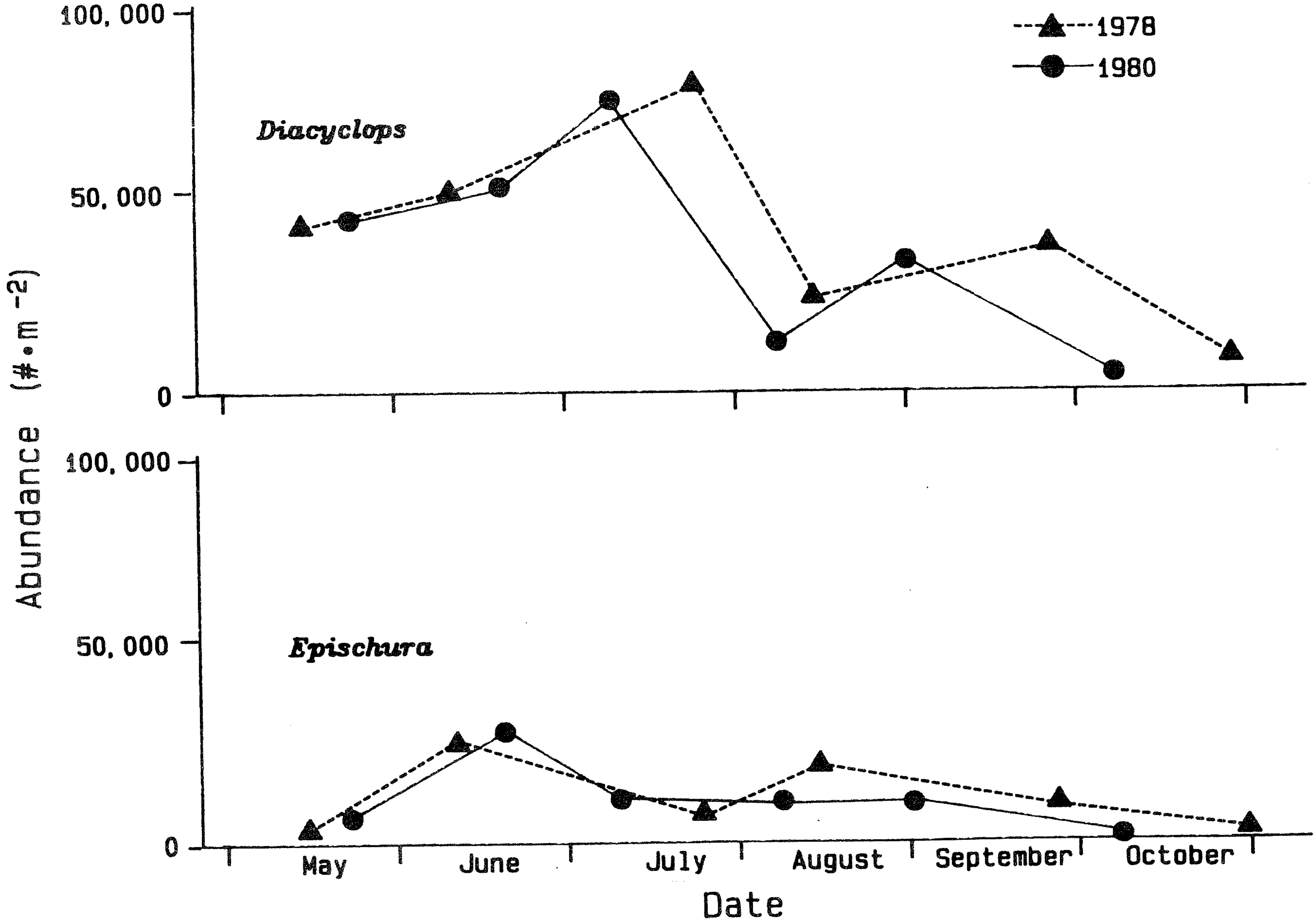


Fig. 25. Seasonal changes in the density of the copepods *Diacyclops* and *Epischura* in 1978 and 1980. Data are averages of counts from Wisconsin net hauls at two locations in the lake.

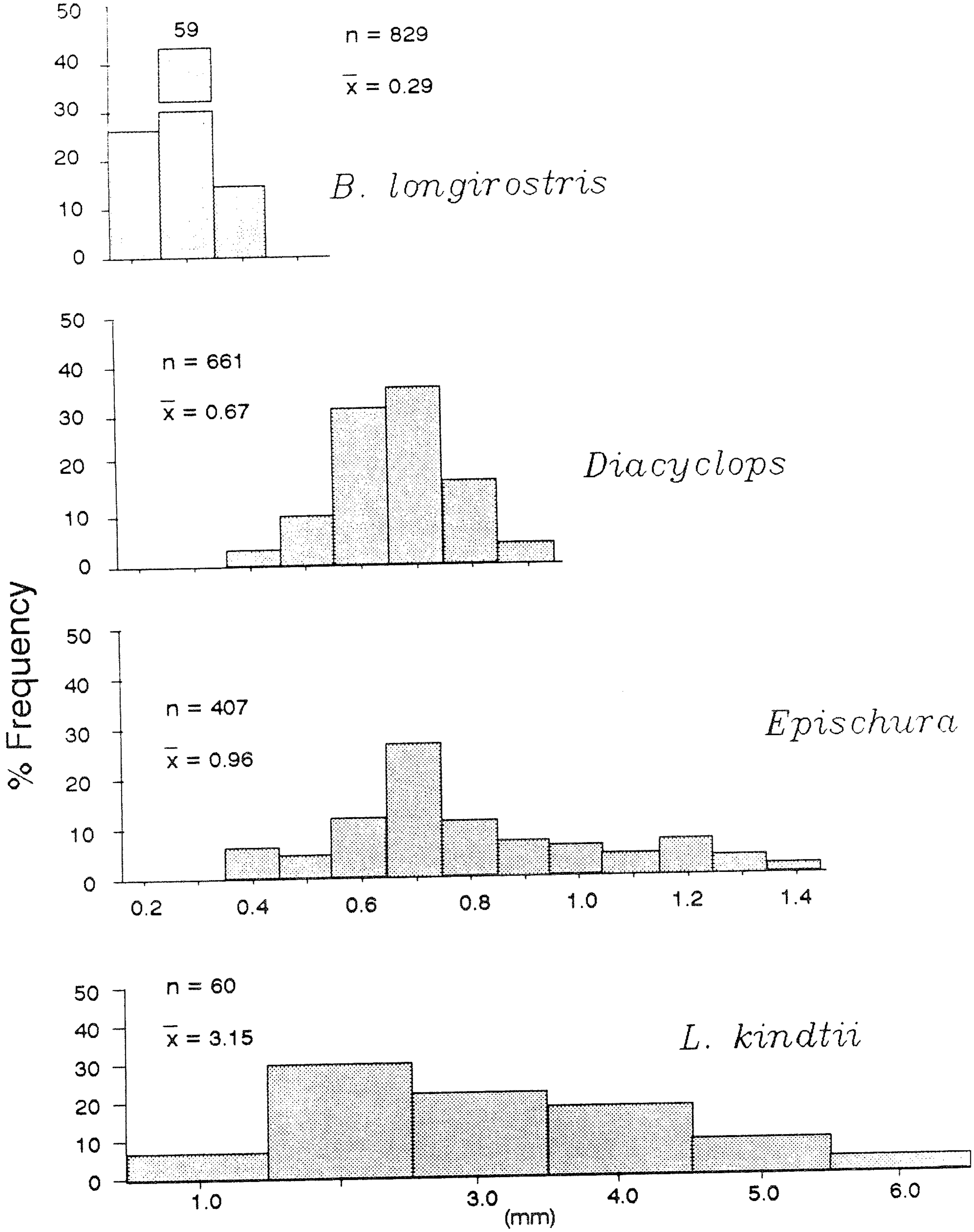


Fig. 26. Length-frequency distribution of major copepods and cladocerans in Pitt Lake in July 1989. Zooplankton were collected with a 160-μm mesh Wisconsin net.

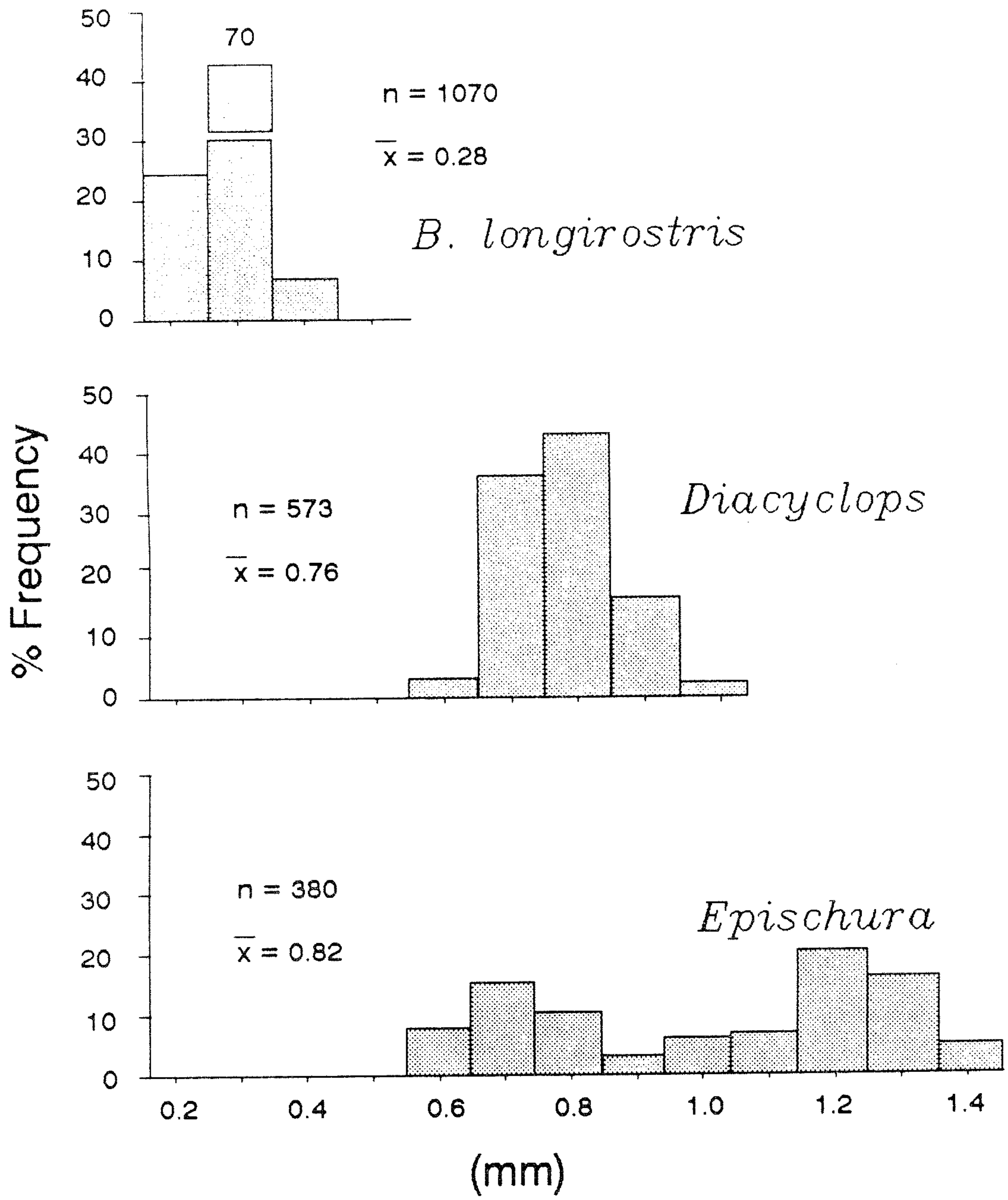


Fig. 27. Length-frequency distribution of major copepods and cladocerans in Pitt Lake in October 1989. Zooplankton were collected with a 160-μm mesh Wisconsin net.

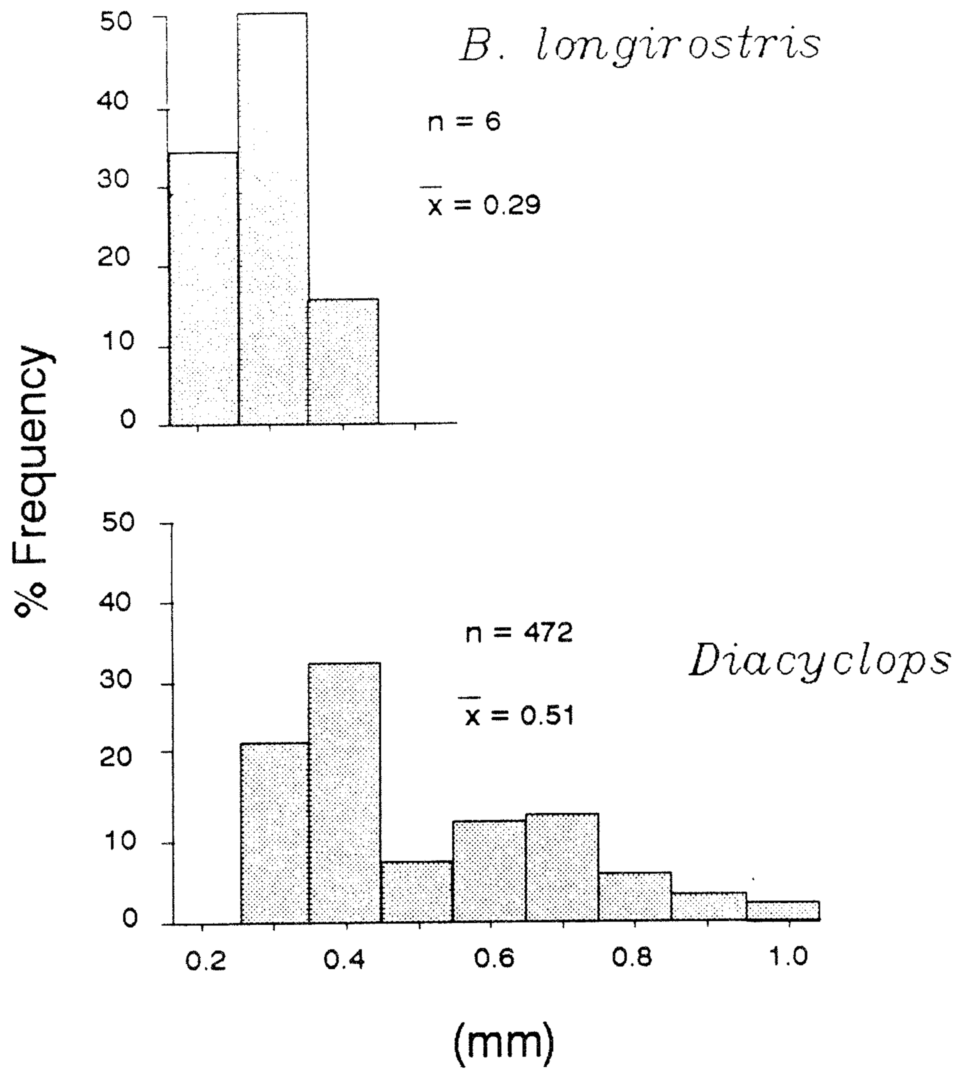


Fig. 27a. Length-frequency distribution of major copepods and cladocerns in Pitt Lake in March 1990. Zooplankton were collected with a 160-μm mesh Wisconsin net.

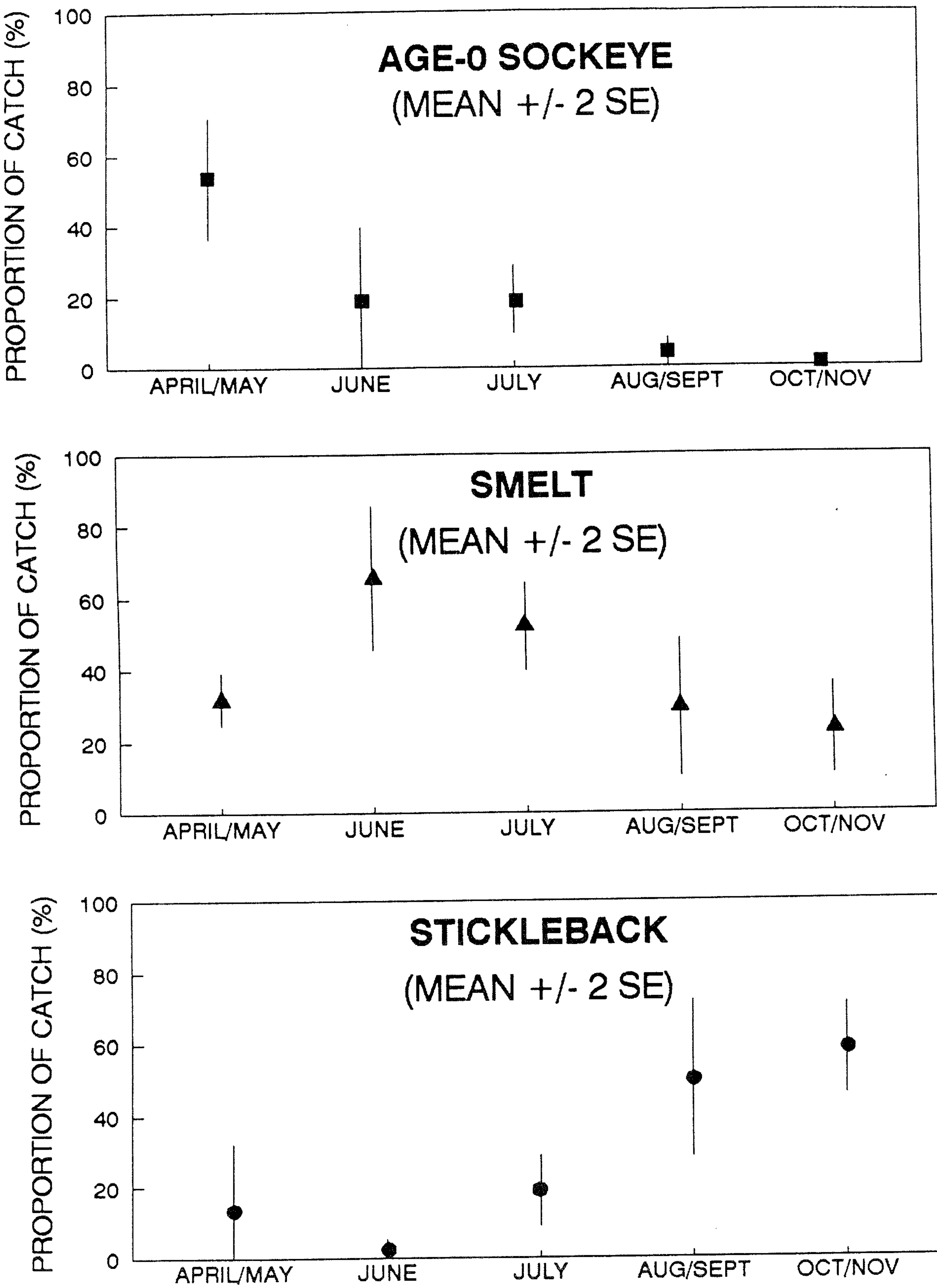


Fig. 28. Pitt Lake trawl catch composition (% of catch) between 1977 and 1982.

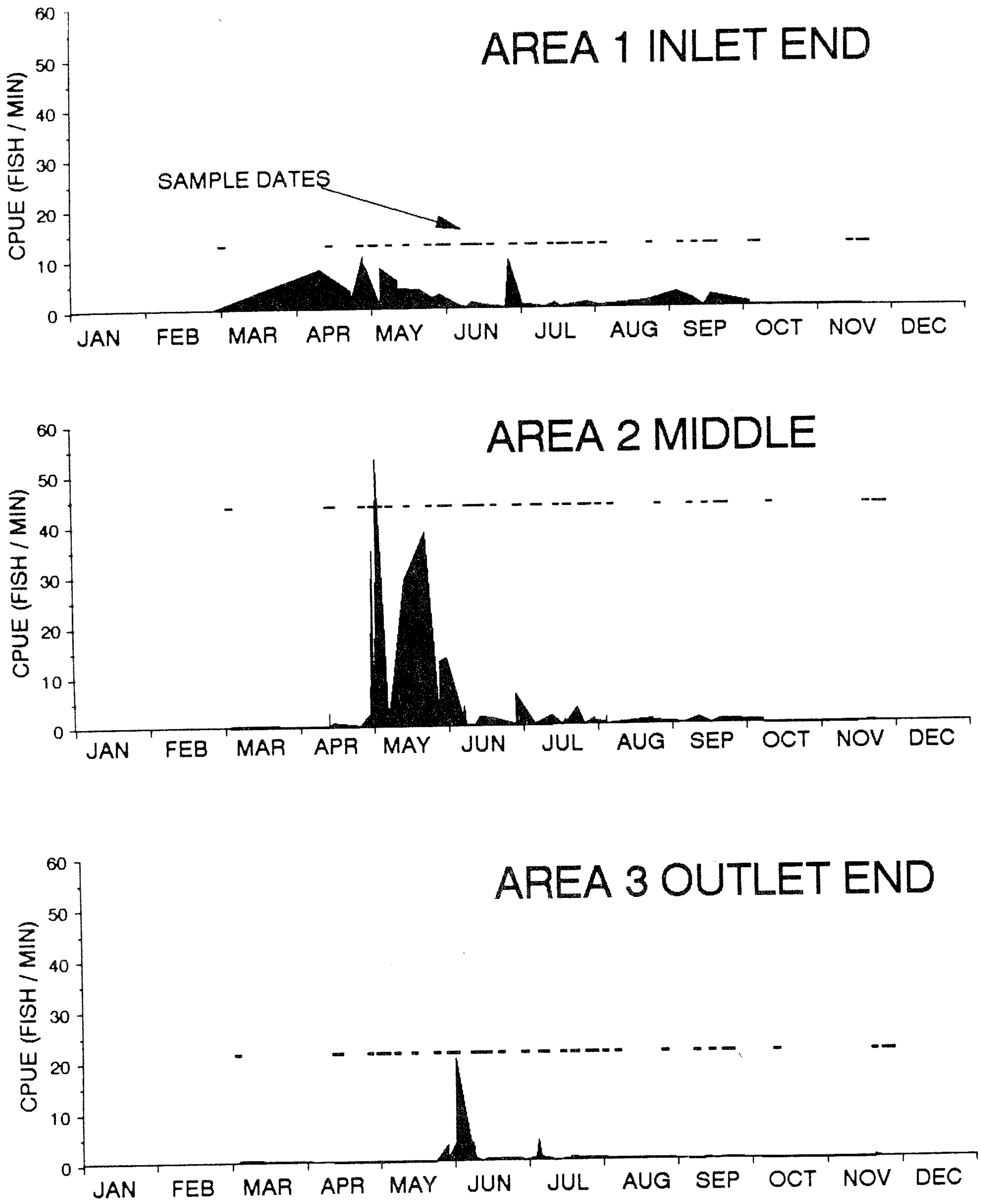


Fig. 29. Seasonal catch-per-unit-effort of age-0 sockeye in trawl samples within Pitt Lake between 1977 and 1982. Horizontal lines indicate sample dates.

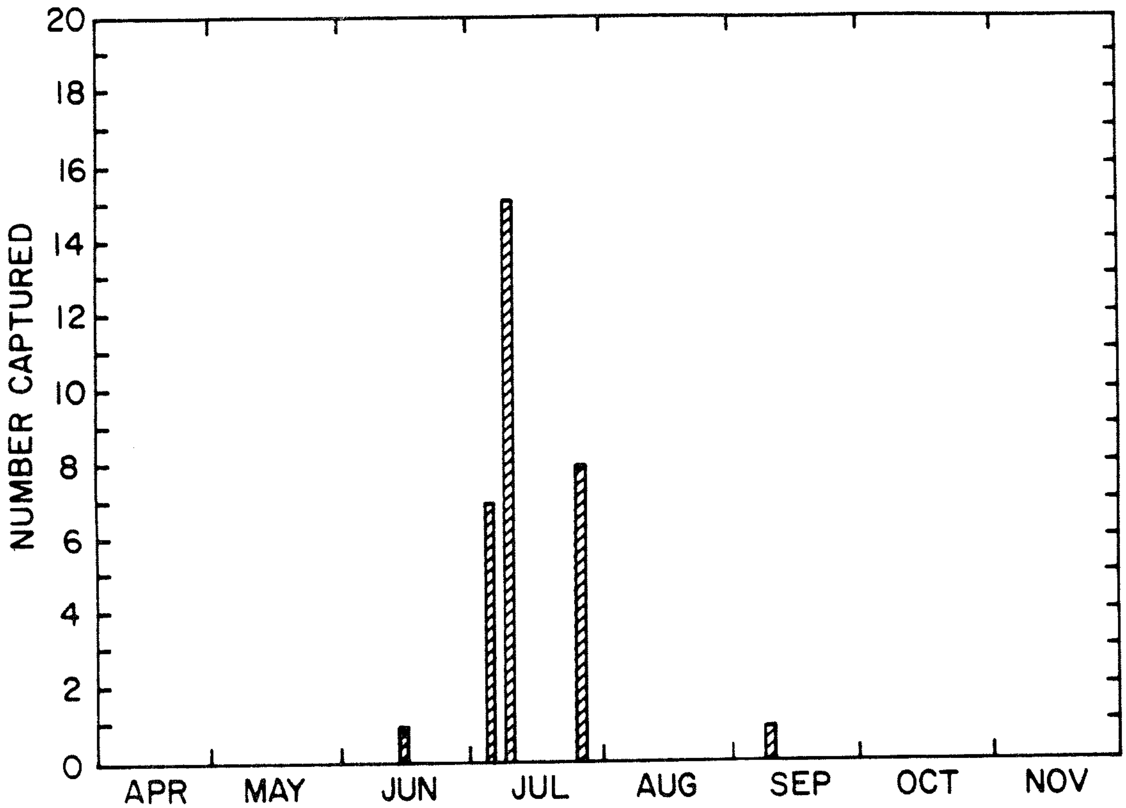
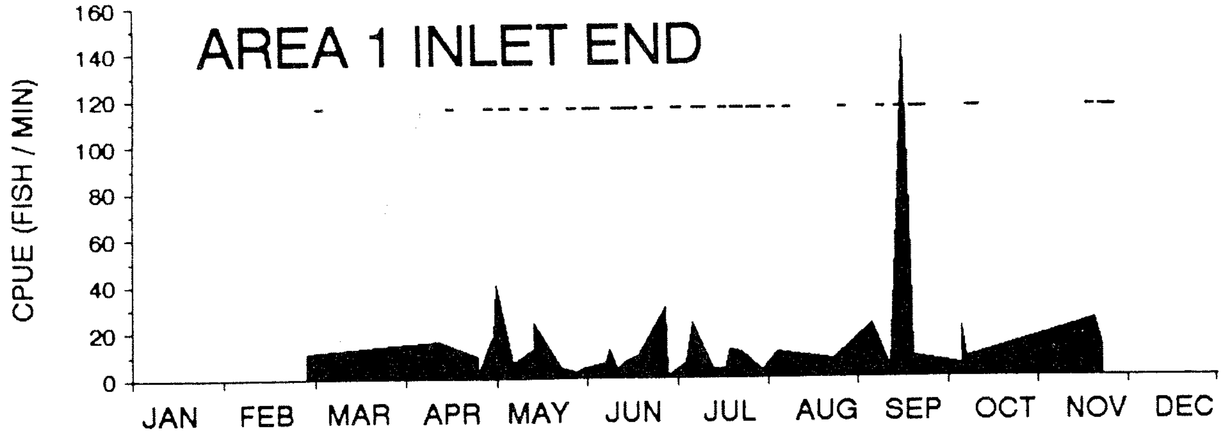
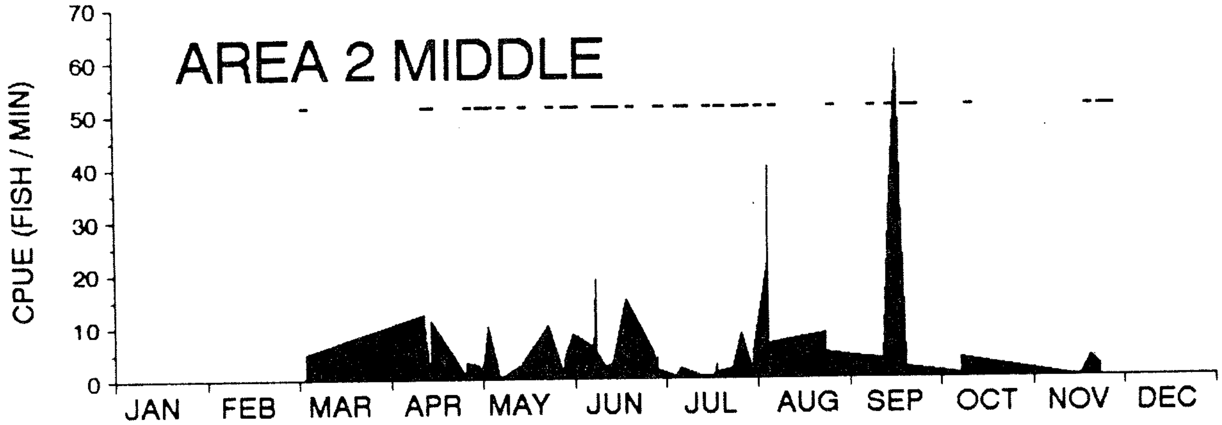


Fig. 30. Trawl catches of age-0 sockeye in the Lower Pitt River during 1979. Redrawn from Johnson (1981).





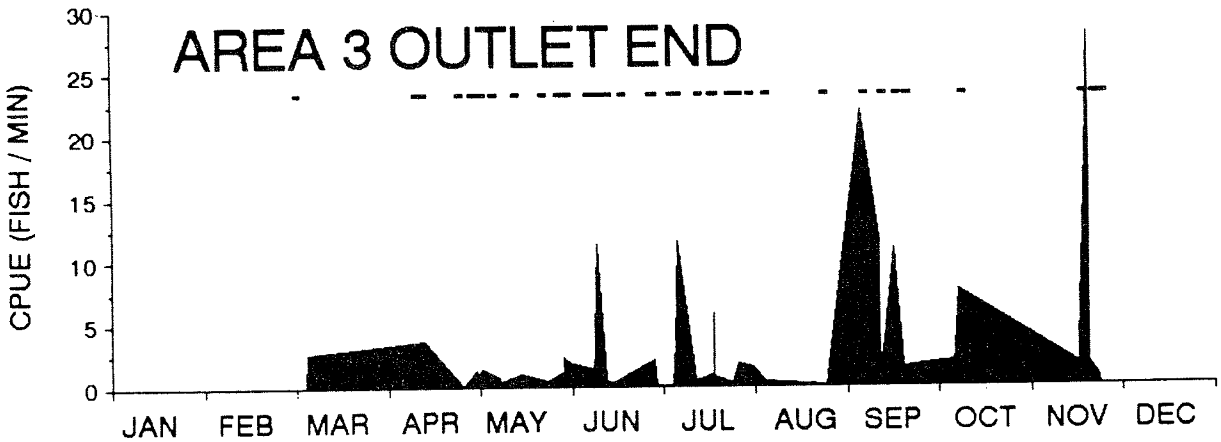


Fig. 31. Seasonal catch-per-unit-effort of longfin smelt in trawl samples within Pitt Lake between 1977 and 1982. Horizontal lines indicate sample dates.

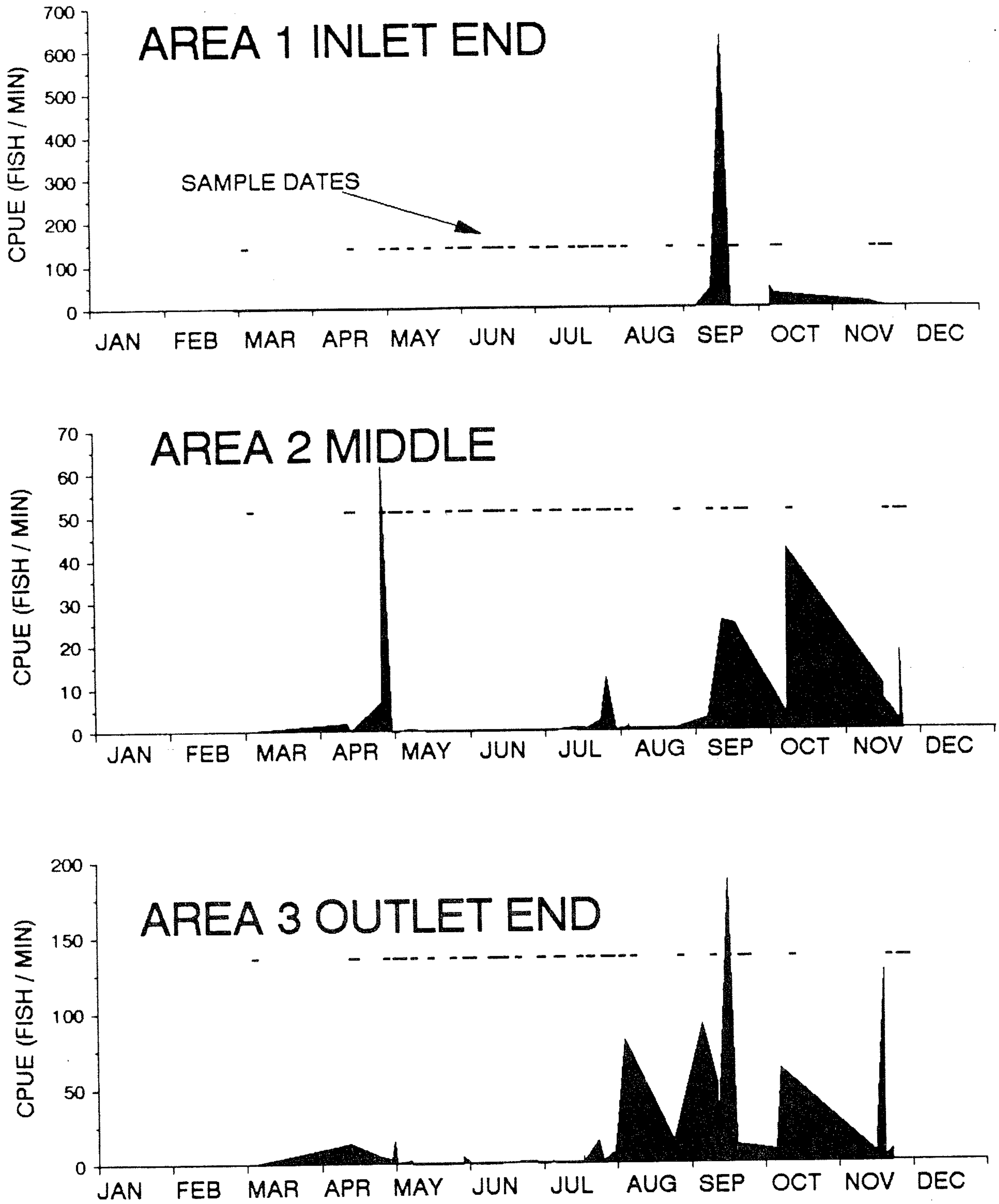


Fig. 32. Seasonal catch-per-unit-effort of threespine stickleback in trawl samples within Pitt Lake between 1977 and 1982. Horizontal lines indicate sample dates.

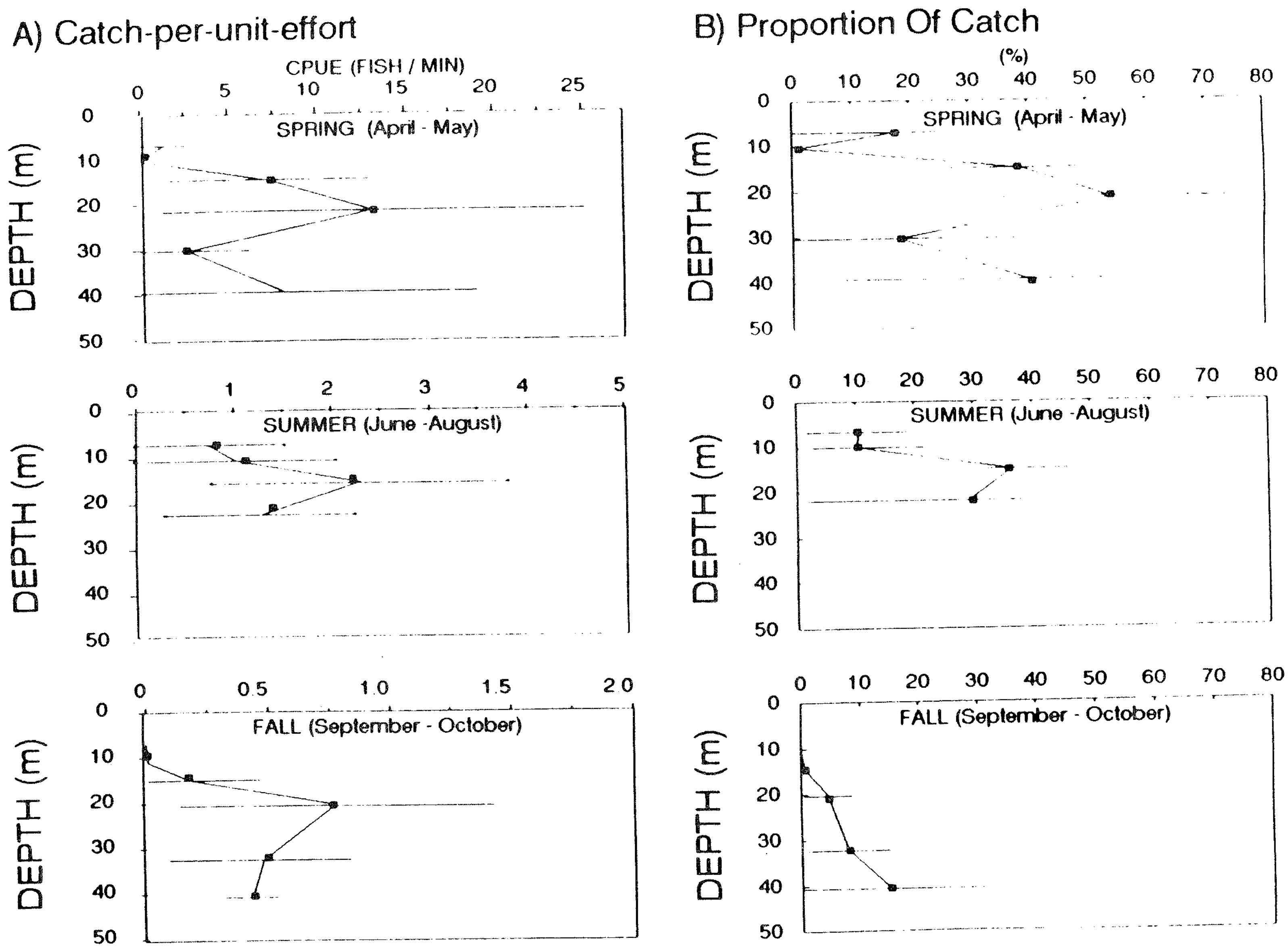


Fig. 33. Vertical distribution of age-0 sockeye expressed as (a) catch-per-unit-effort and (b) as a proportion of the catch at each depth. Data are combined for the period 1977 - 1982. Horizontal bars are +/- 2 SE.

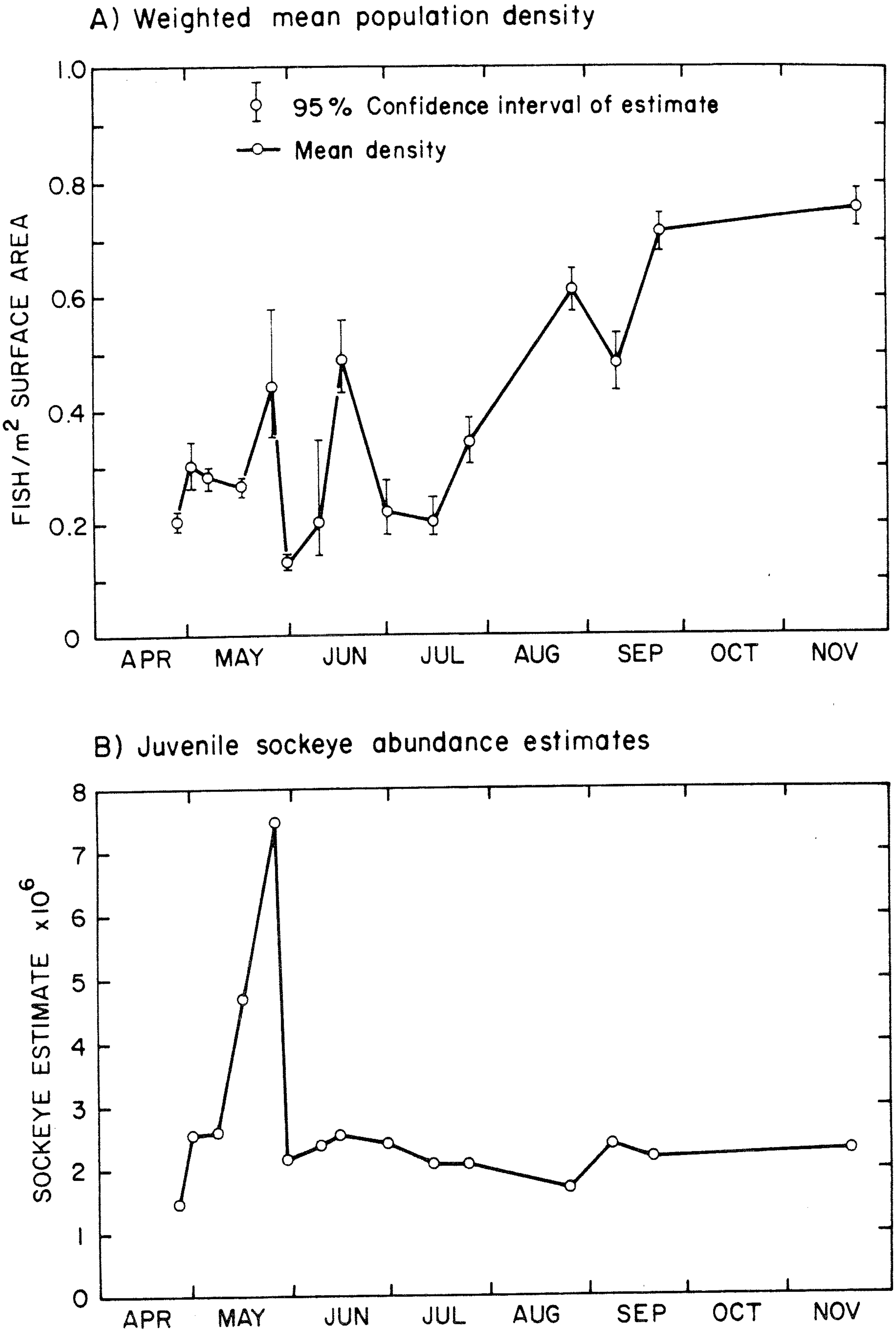


Fig. 34. Estimates of a) fish density (all species), and b) juvenile sockeye abundance within Pitt Lake during 1979. Redrawn from Johnson (1981).

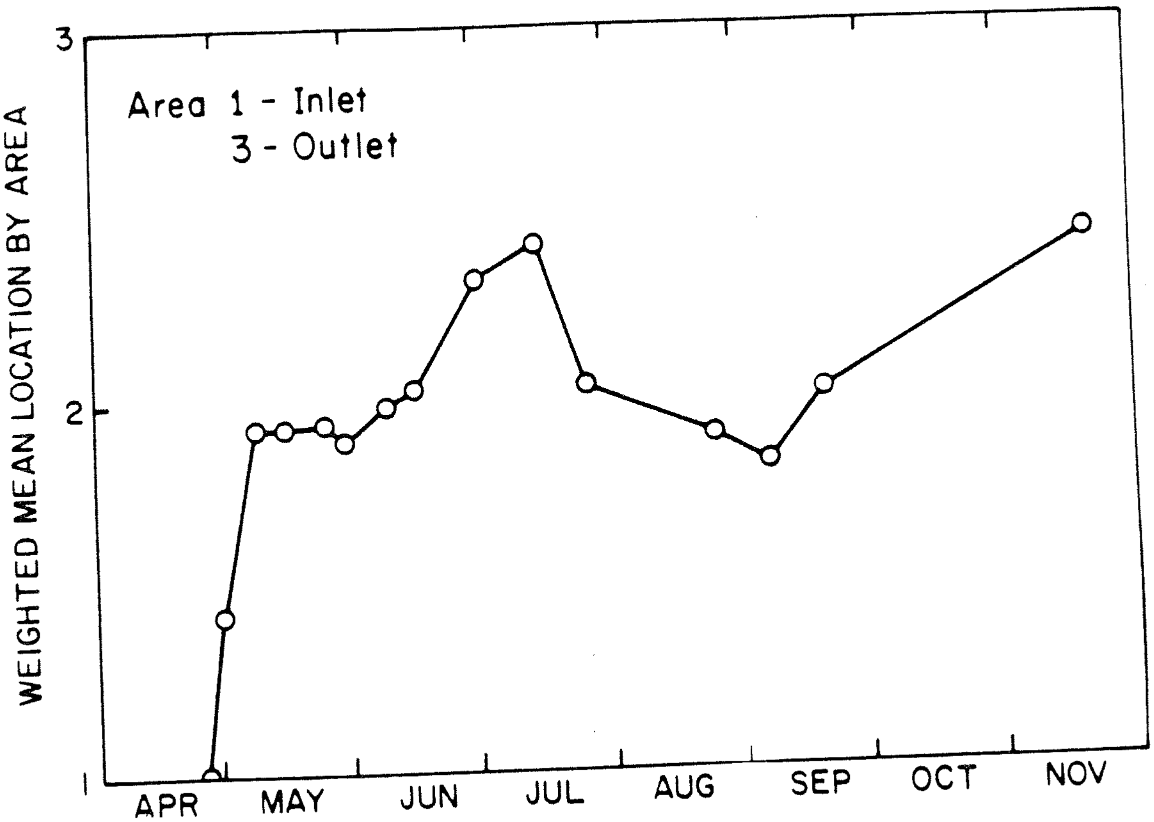


Fig. 35. Weighted mean location of juvenile sockeye within Pitt Lake as determined by hydroacoustics and trawling within Pitt Lake during 1979. Redrawn from Johnson (1981).

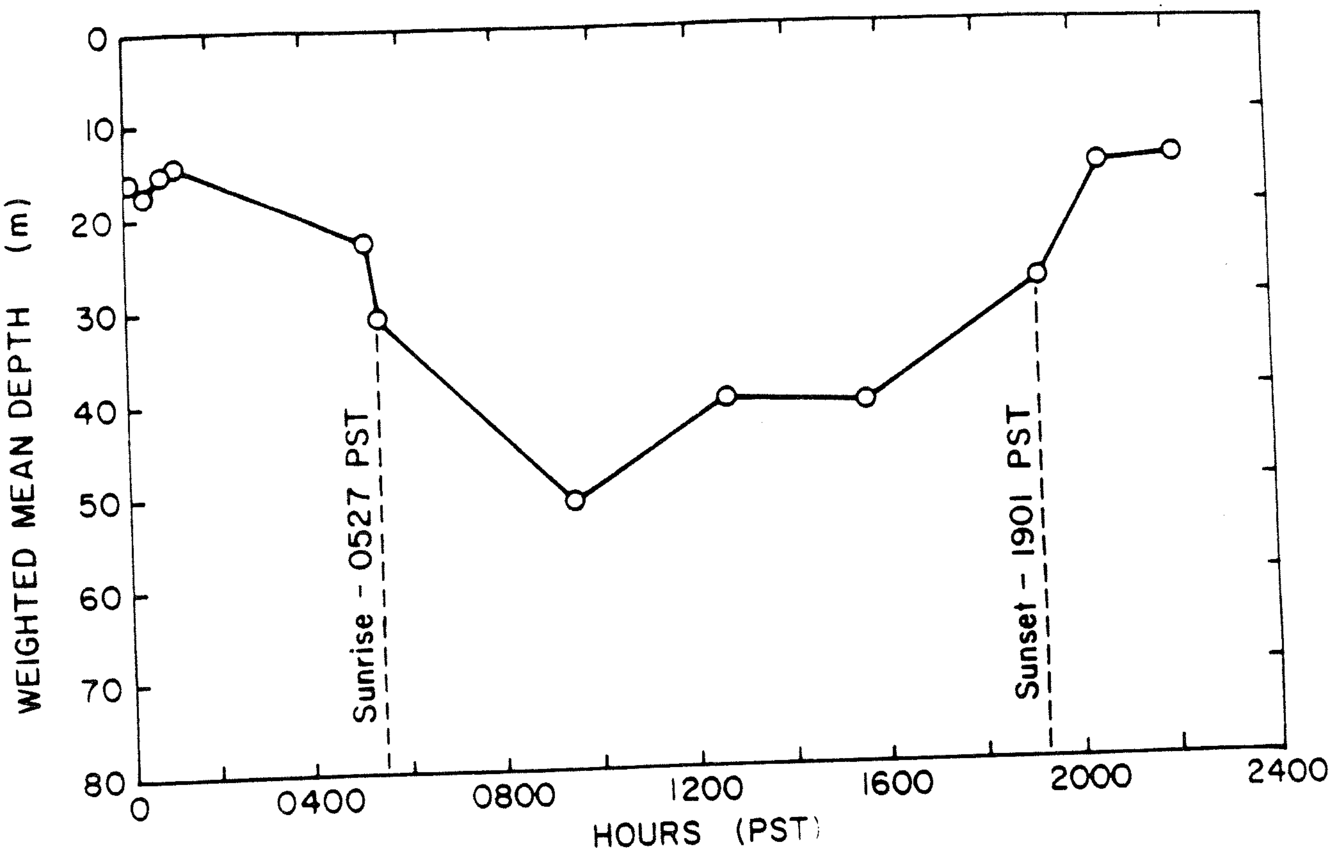


Fig. 36. Diel variation in fish depth distribution in the vicinity of transect 3 on Apr.13-14, 1978. Redrawn from Johnson (1981).

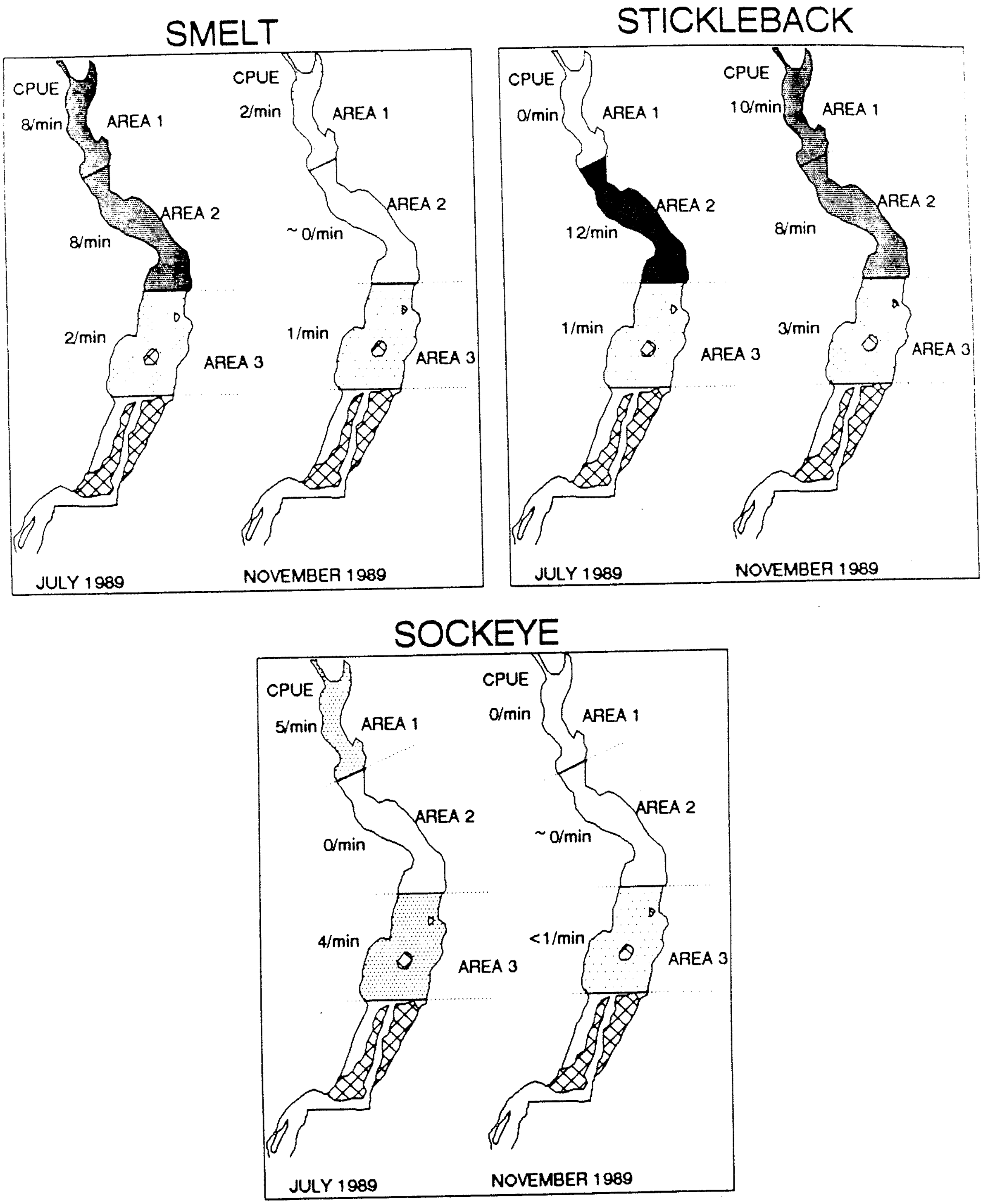


Fig. 37. Relative distribution of fish in Pitt Lake during July and November 1989 as measured by trawl CPUE in each area of the lake.

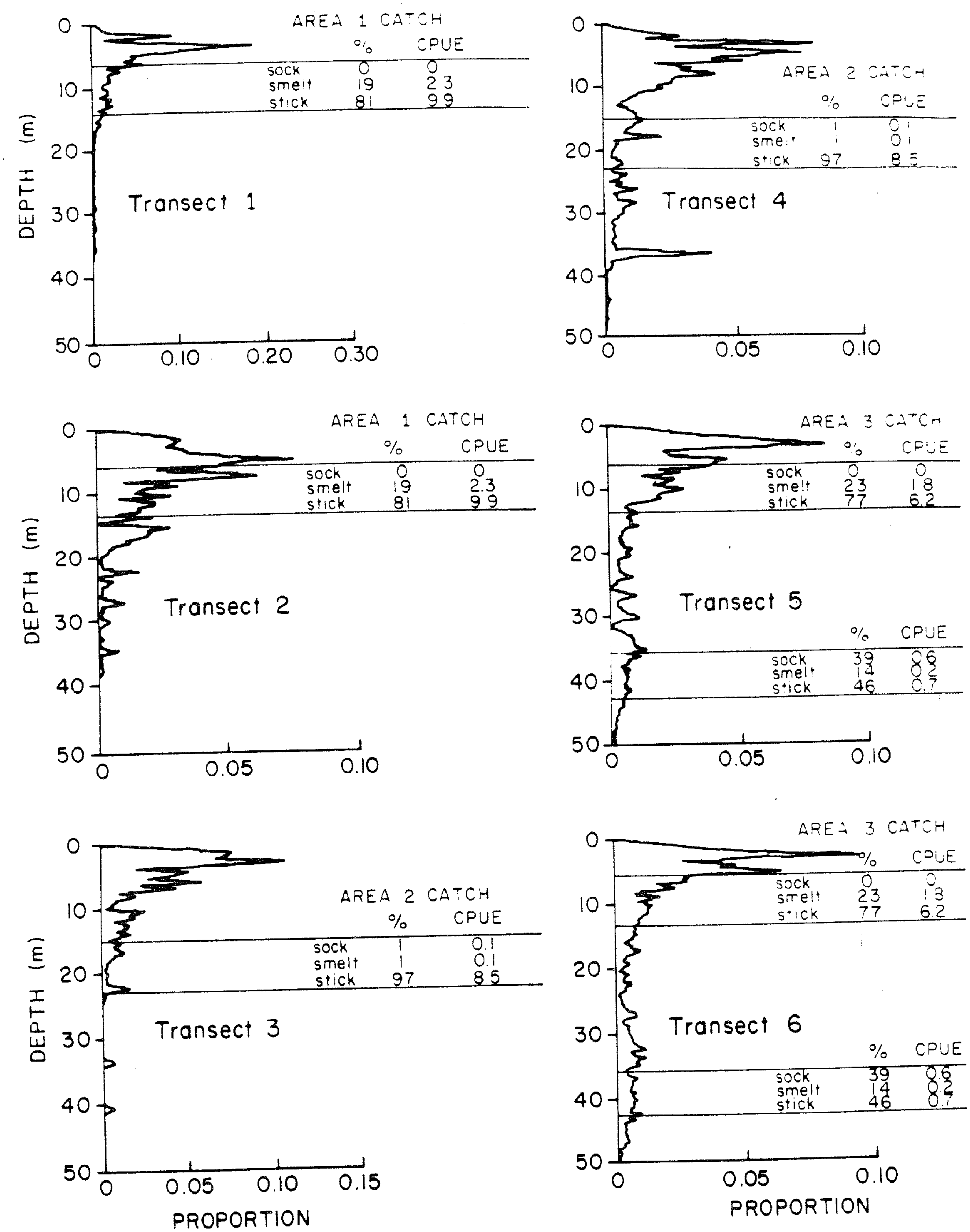


Fig. 39. Vertical distribution of fish targets in Pitt Lake on Nov. 21-22, 1989 as indicated by the proportion of the total integrated voltage within 0.5 m depth intervals. Numbers adjacent to the depth profiles show catch results (% and CPUE) within adjacent trawl samples.

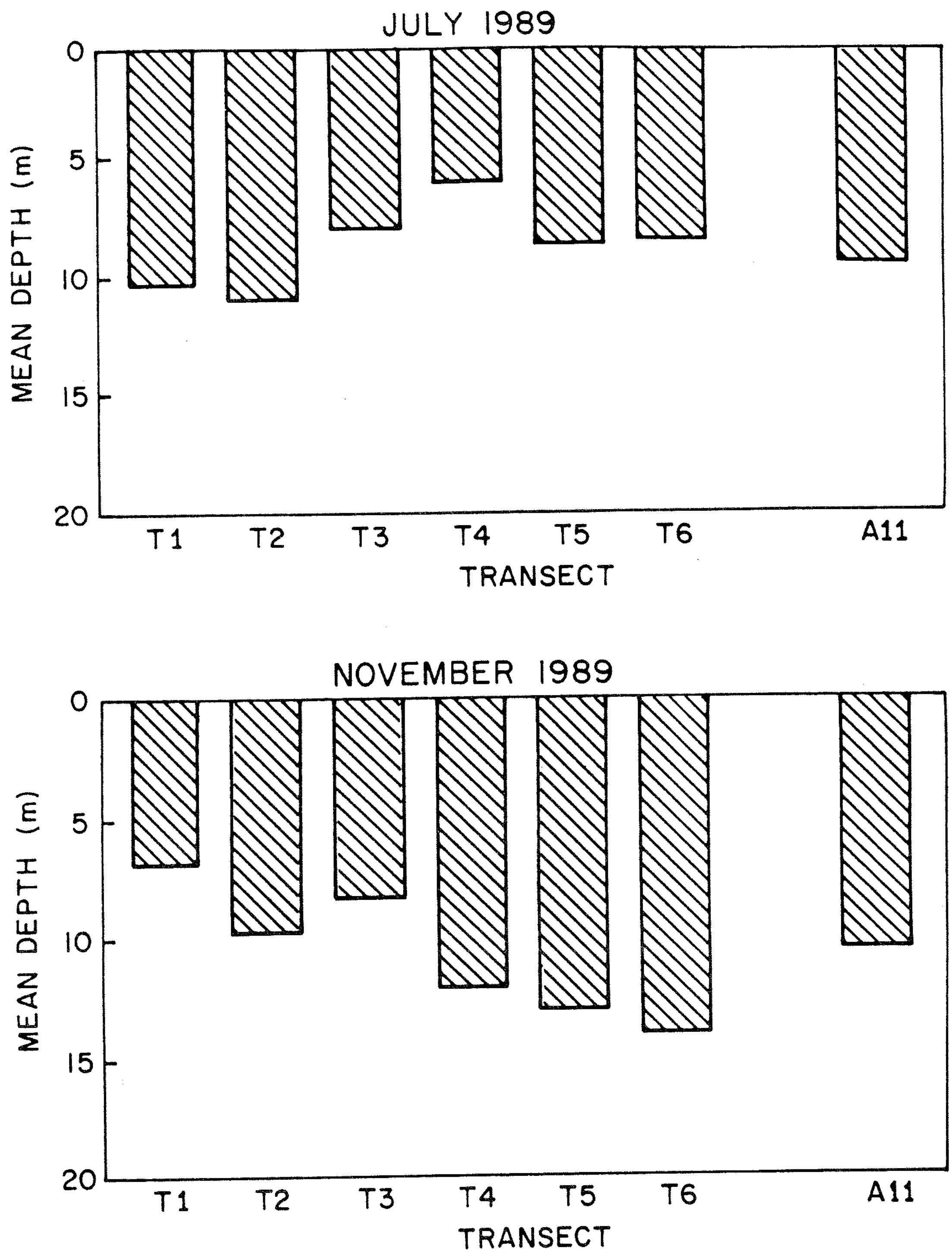


Fig. 40. Mean depth of fish targets for different transects within Pitt Lake as computed by echo integration.

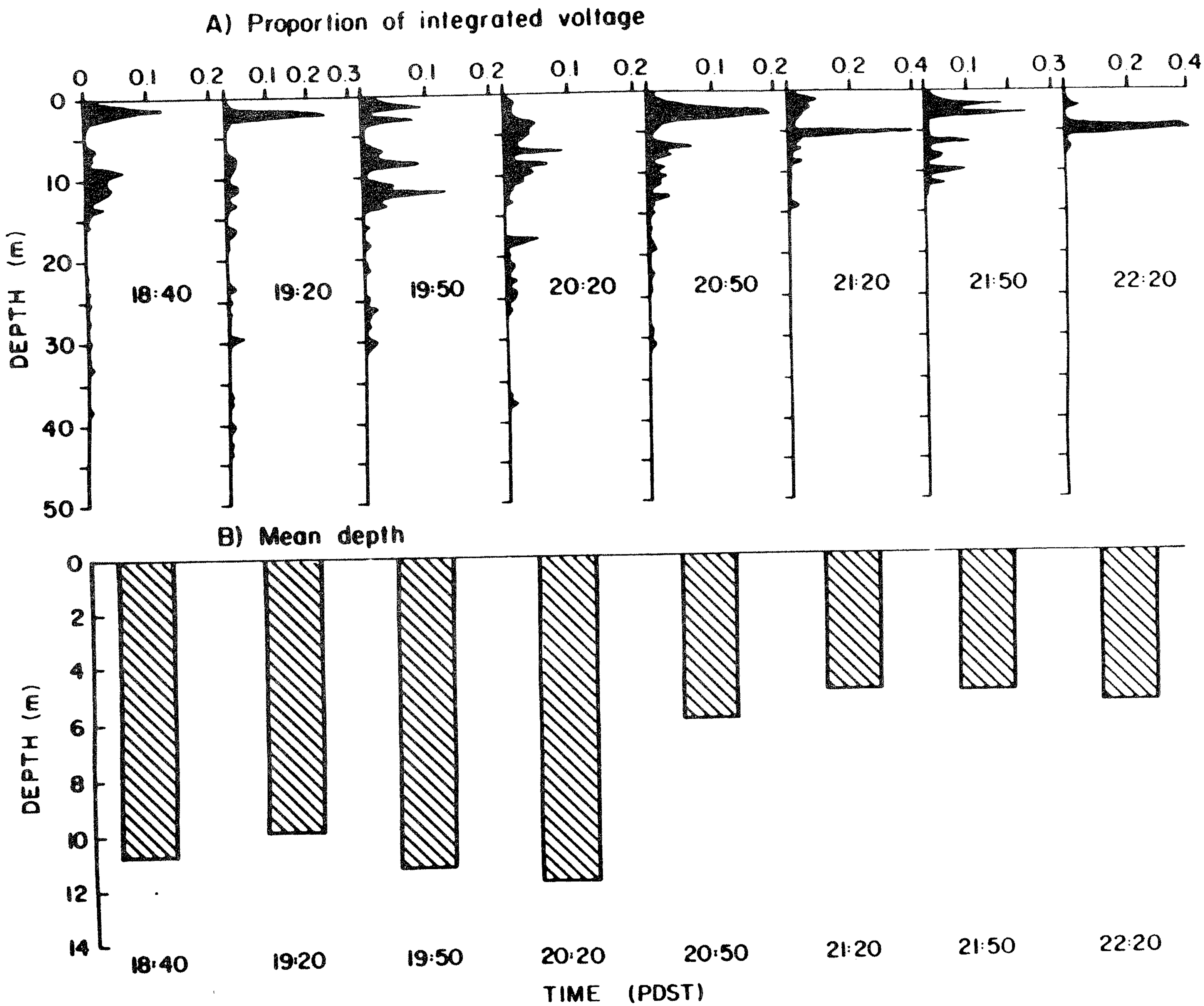


Fig. 41. (a) Changes in fish depth distribution between T=18:40 and T=22:20 on July 26, 1989, and (b) estimated changes in mean depth.

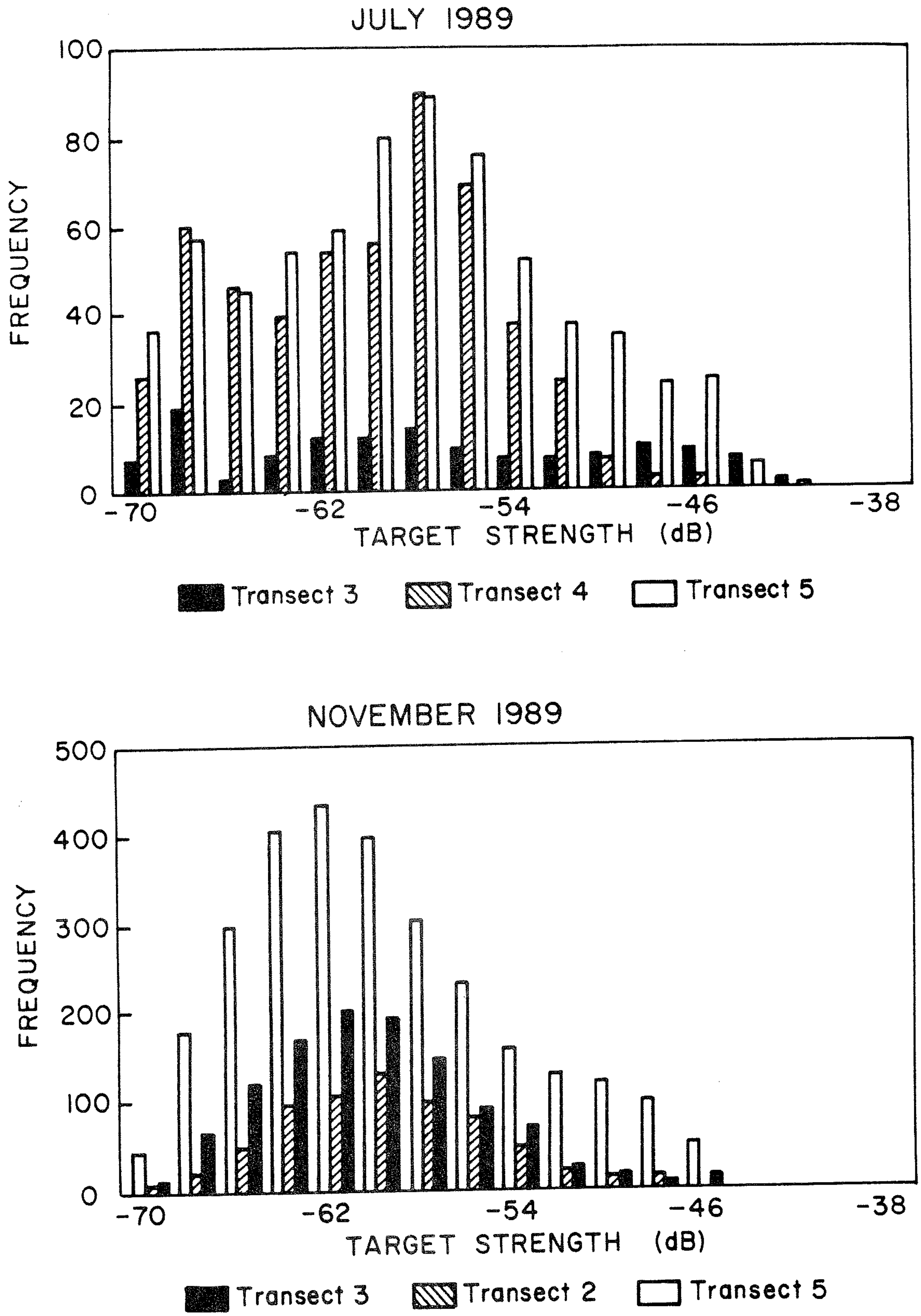
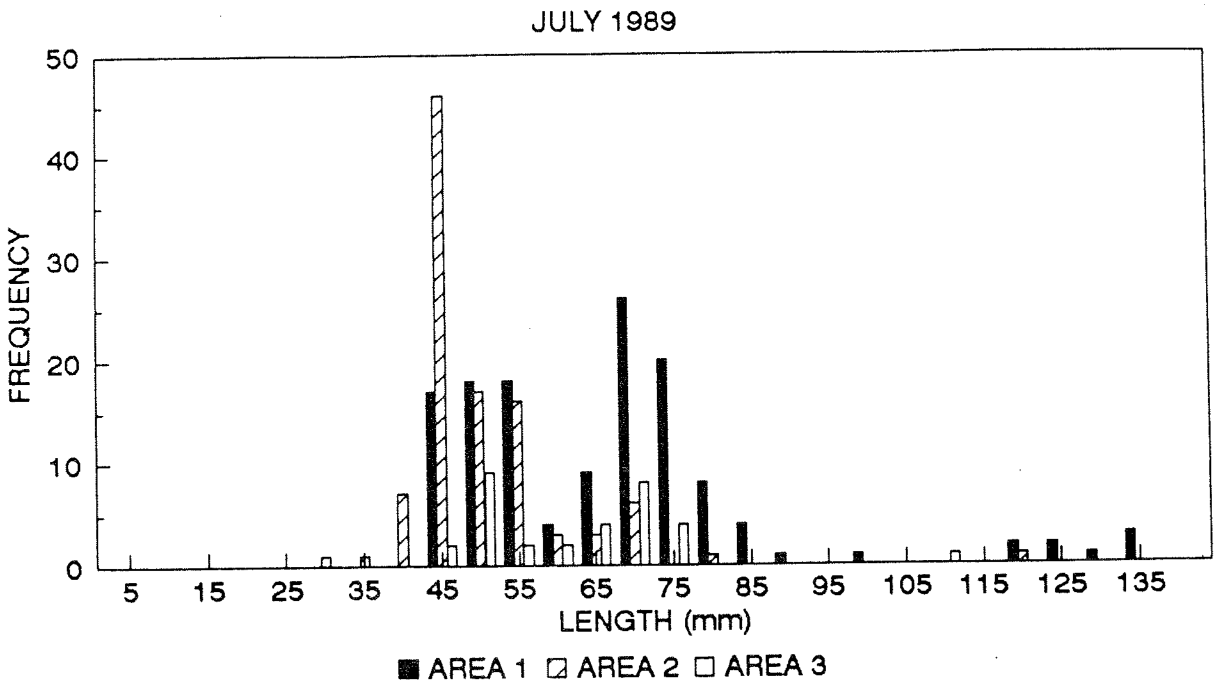


Fig. 42. Frequency distribution of target strengths for different transects in July and November, 1989.



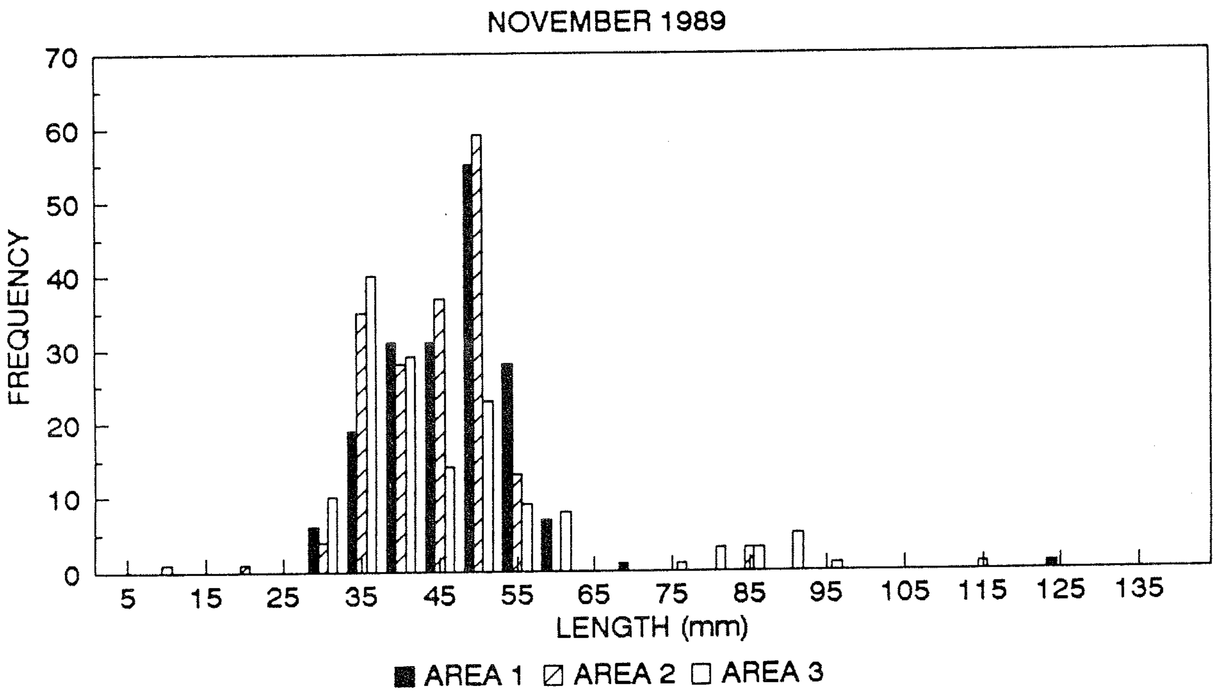


Fig. 43. Frequency distribution of fish fork lengths (all species) for different trawling areas in July and November, 1989.

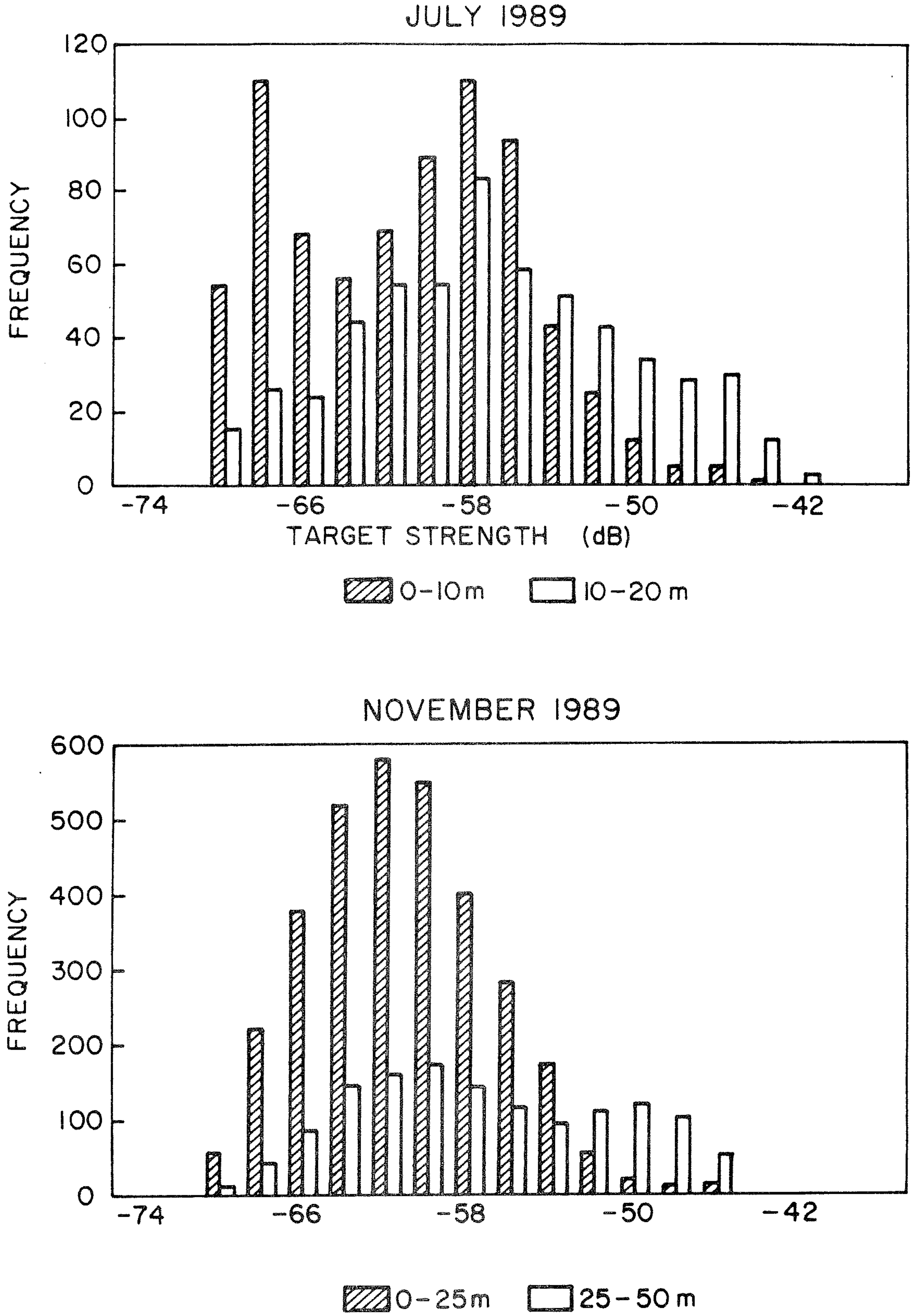
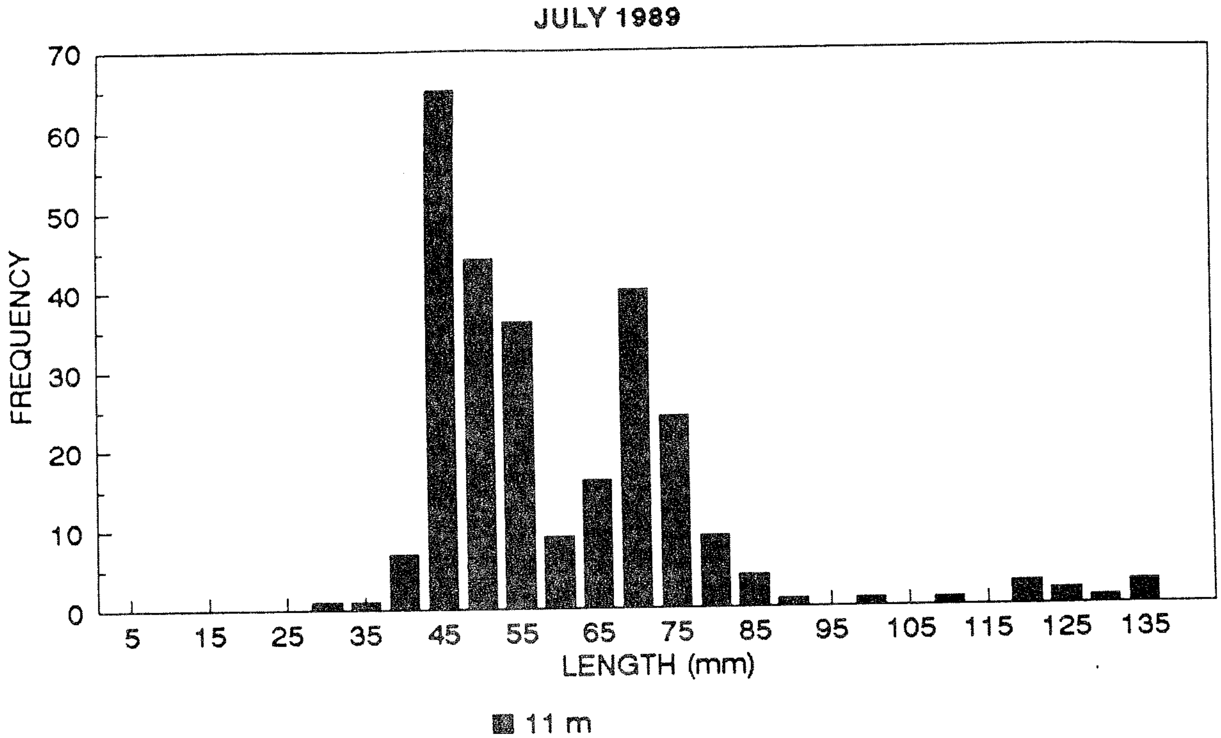


Fig. 44. Frequency distribution of target strengths for shallow and deep fish targets during July and November, 1989. Note the different depth intervals for the 2 survey periods.



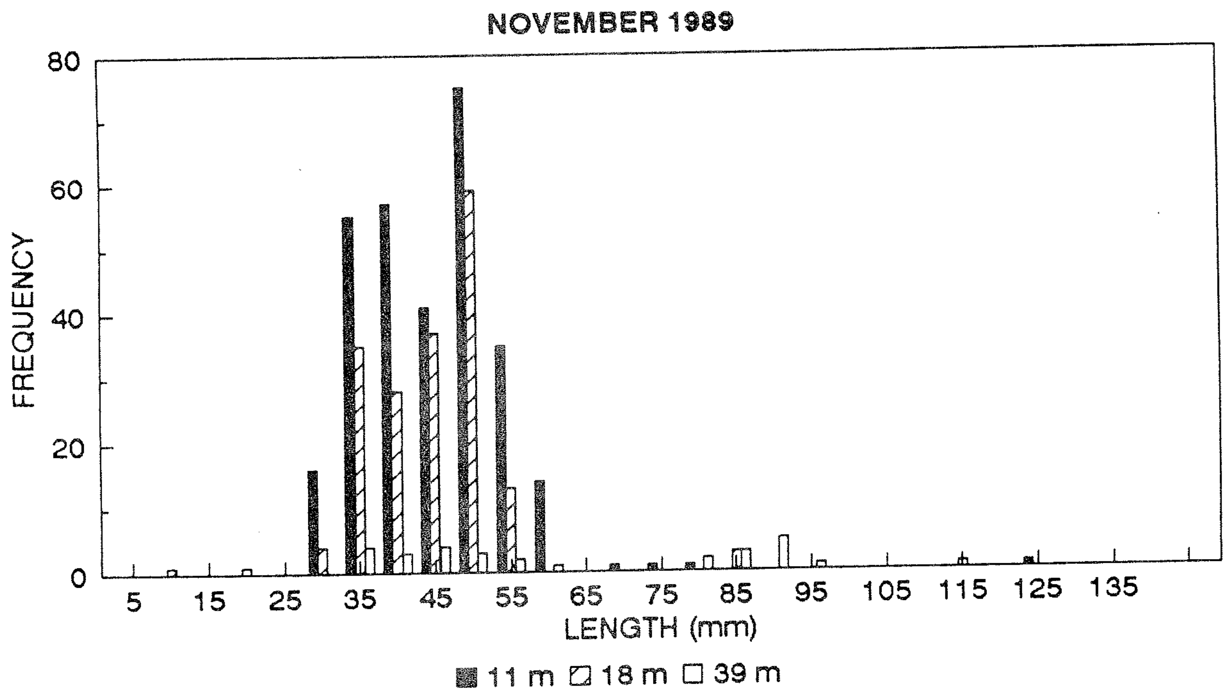


Fig. 45. Frequency distribution of fish fork lengths (all species) stratified by trawl depth during July and November, 1989.

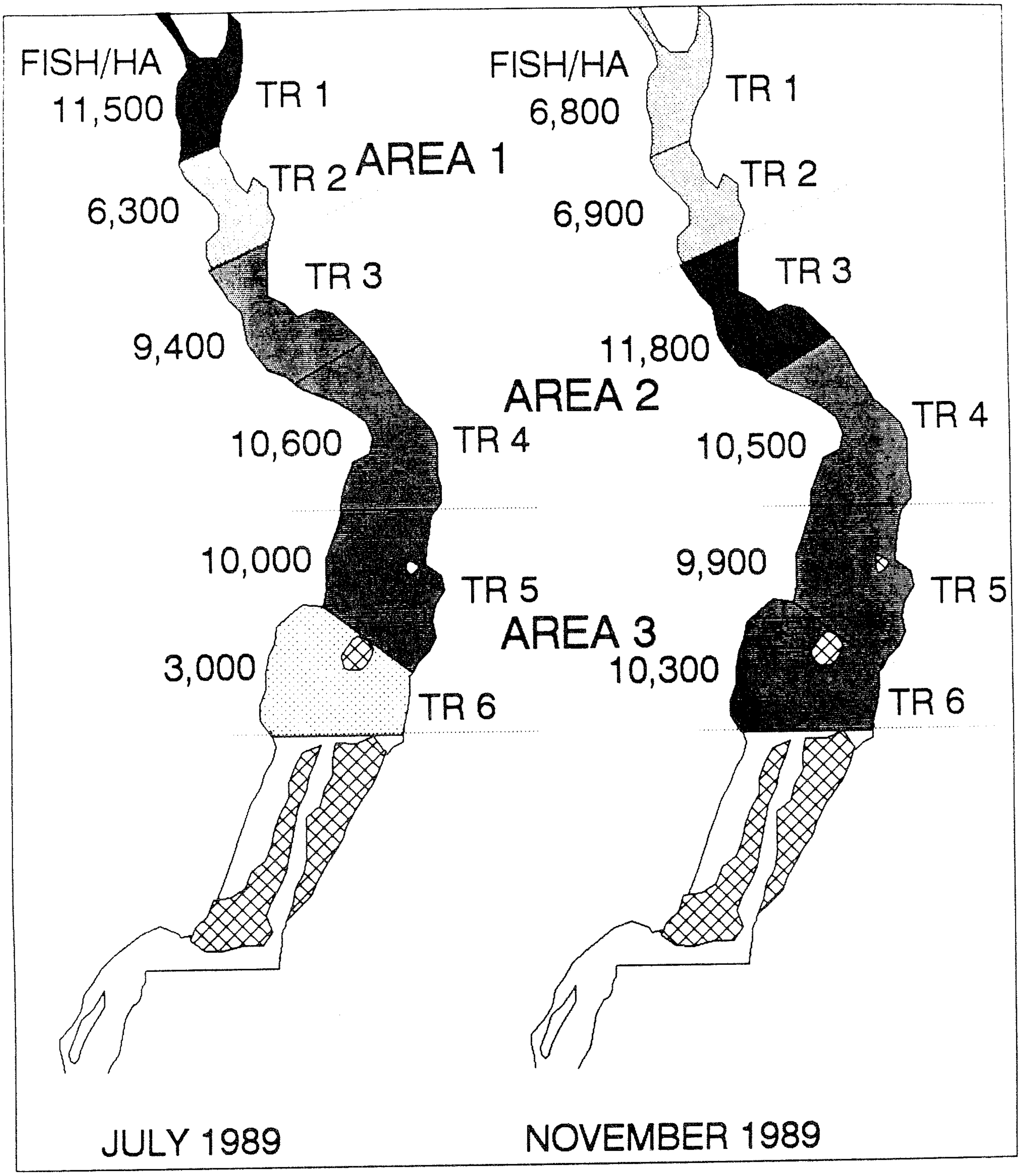


Fig. 46. Horizontal distribution of all fish in Pitt Lake during July and November, 1989, as acoustic surveys.

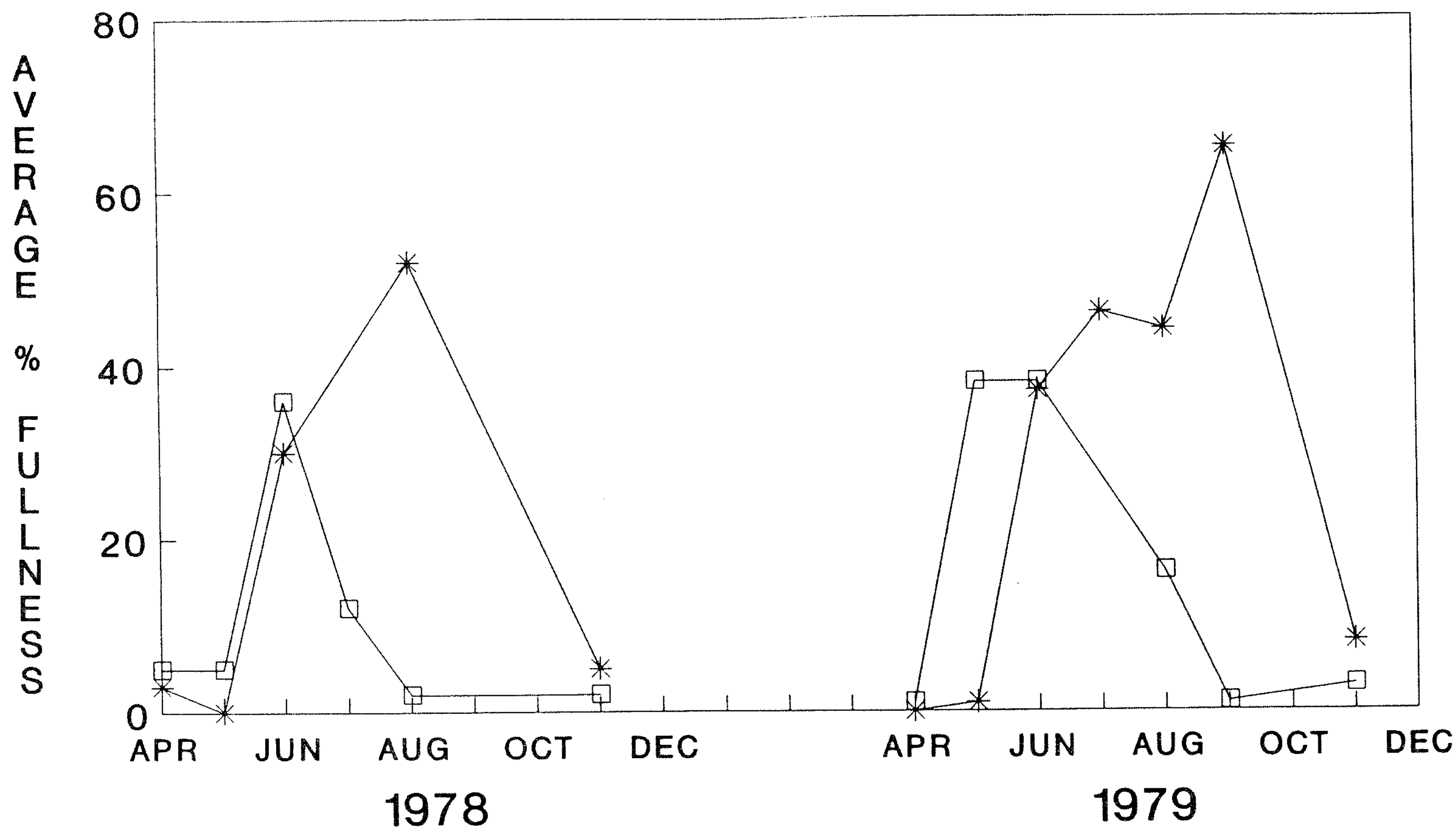


Fig. 47. Average percent fullness of Pitt Lake sockeye and smelt stomachs by month from April to November for the years 1978 and 1979.

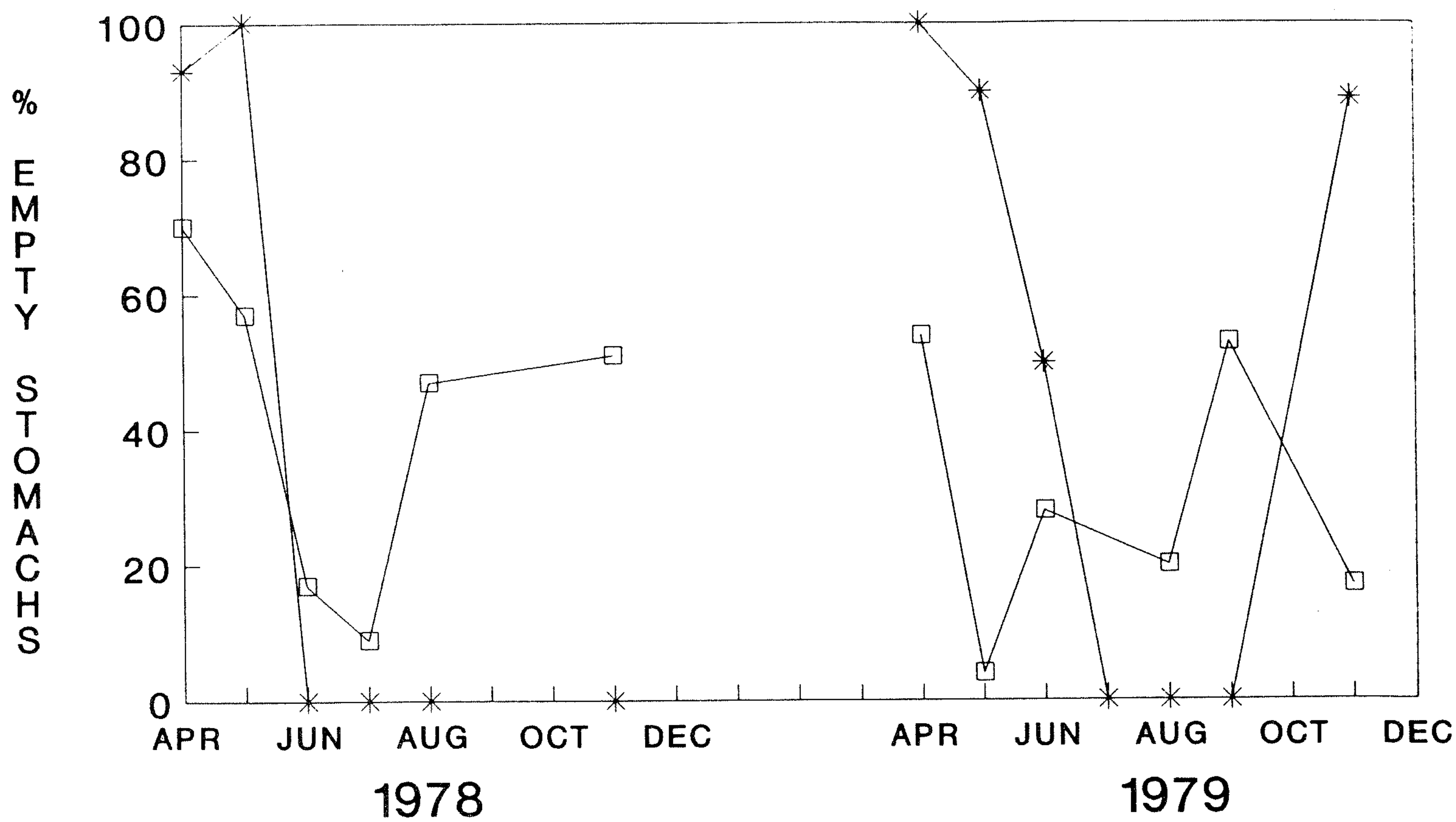


Fig. 48. Percentage of empty sockeye and smelt stomachs in samples taken from Pitt Lake by month from April to November for the years 1978 and 1979.

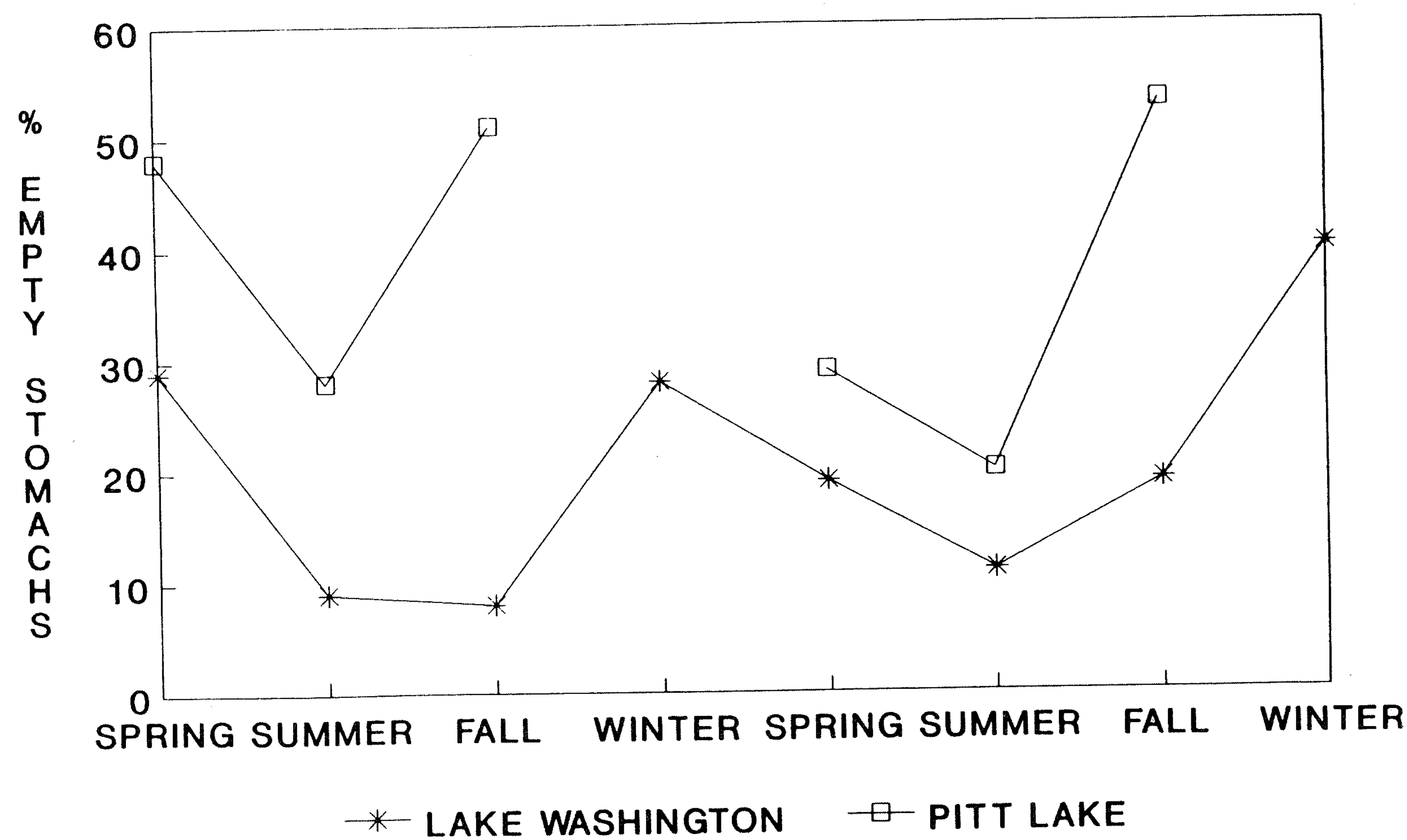


Fig. 49. Percentage of empty stomachs by season for Pitt Lake (1978-1979) and Lake Washington (1963-1964) longfin smelt populations.

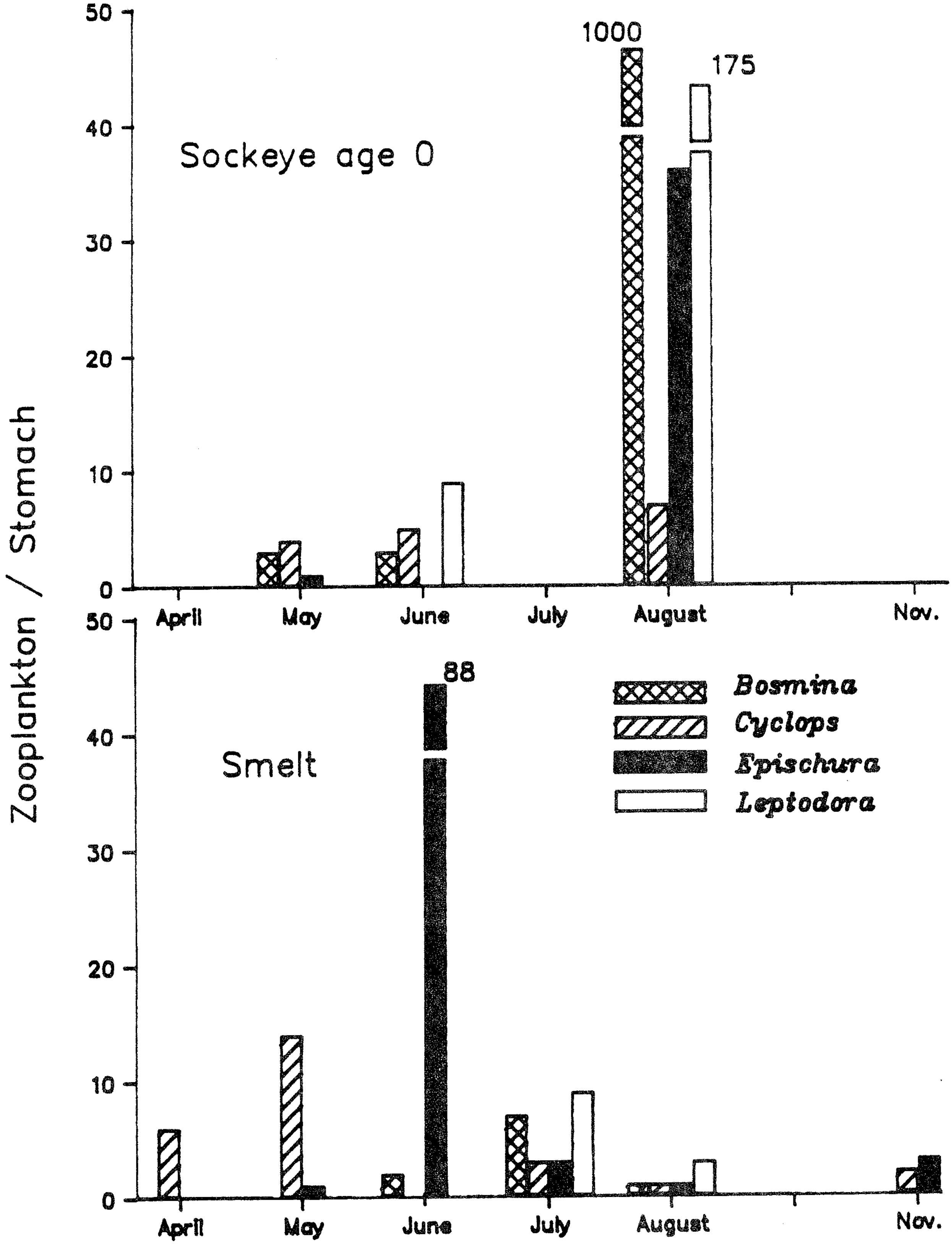


Fig. 50. Average number of each zooplankton type per stomach by month for Pitt Lake sockeye and smelt in 1978.

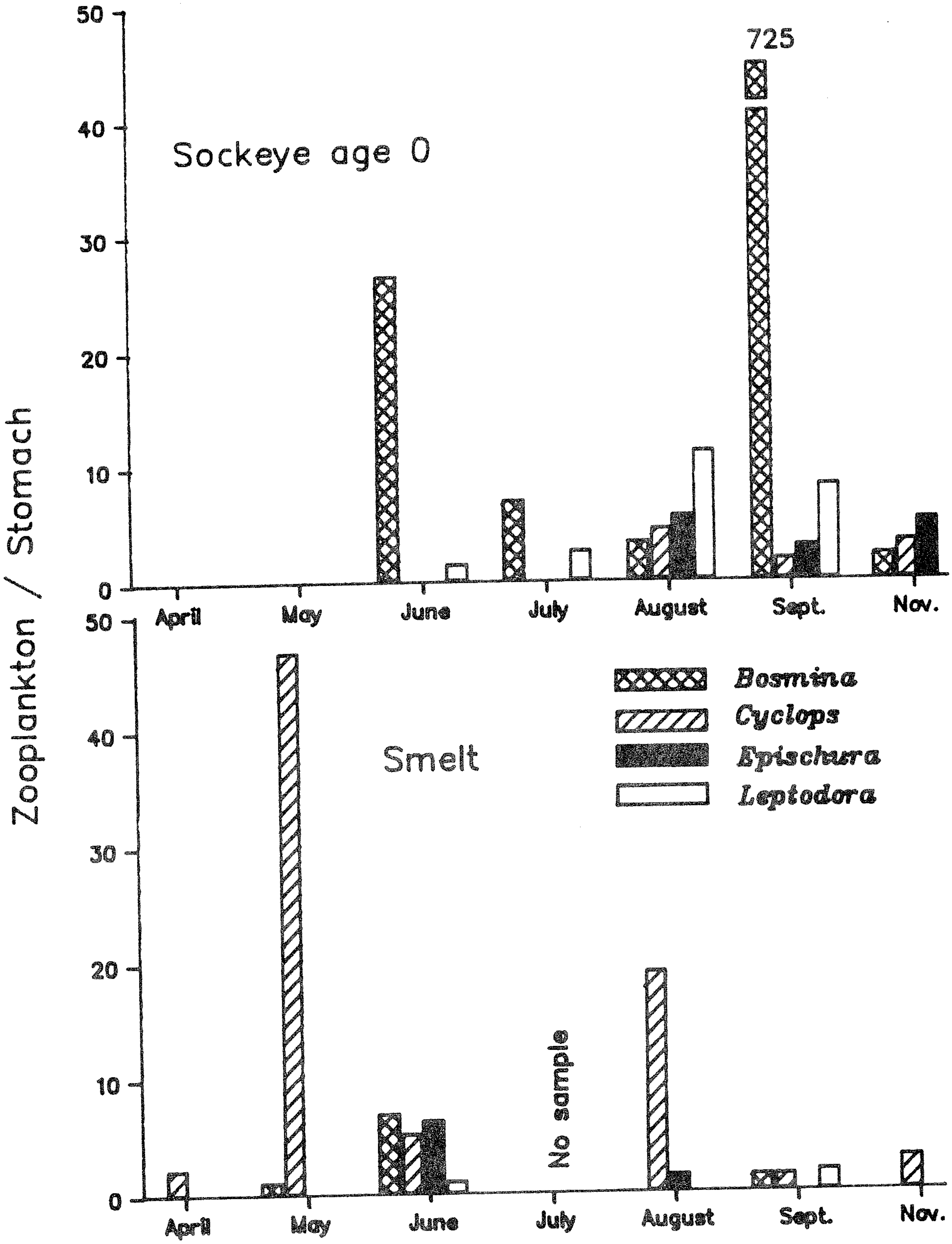


Fig. 51. Average number of each zooplankton type per stomach by month for Pitt Lake sockeye and smelt in 1979.

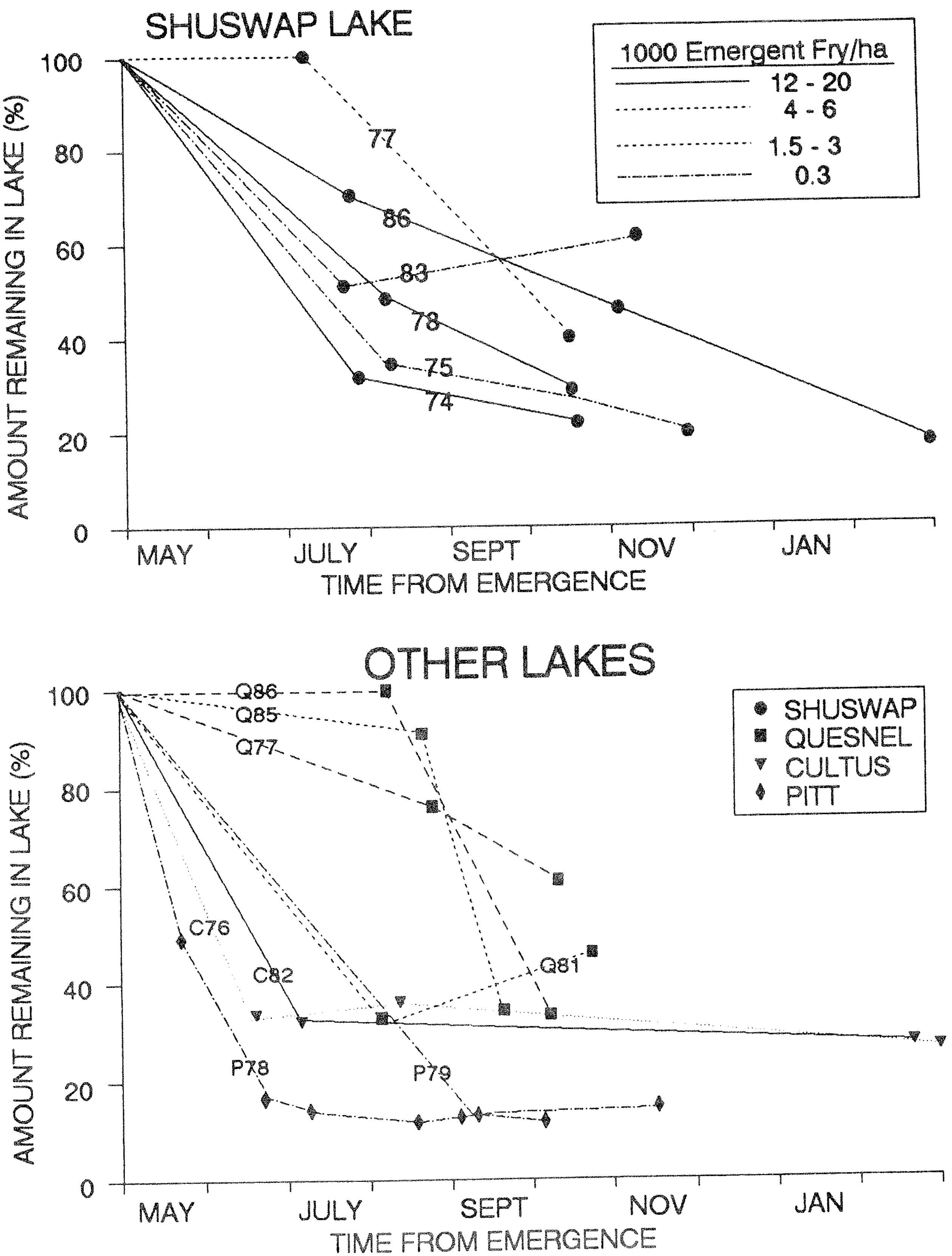


Fig. 52. Estimated population decline of juvenile sockeye in Fraser River lakes surveyed by the IPSFC.