SUSITNA DRAINAGE SOCKEYE SALMON INVESTIGATIONS: 1993 ANNUAL REPORT ON FISH AND LIMNOLOGICAL SURVEYS

by

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ABSTRACT

In 1993, fish and limnological surveys were conducted on nine key lakes supporting sockeye salmon within the Susitna River drainage to assess productivity based on physical, chemical, and biological parameters. Fall fry estimates were made using hydroacoustic techniques and fall fry sizes were compared. In addition, weir feasibility analysis was done to determine sites, and construction and operational costs. The focus of this study is to evaluate the current sockeye salmon escapement goal of 200,000 fish for the Susitna River drainage relative to key fisheries and limnological parameters in major sockeye salmon nursery lakes. The first year of study revealed that the lakes varied in productivity status and two of the nine lakes do not warrant further assessment as they are very shallow and have a low zooplankton forage base. The largest lake surveyed was Chelatna Lake, which also was the most oligotrophic of the lakes surveyed. Although because of its size it offers the greatest potential (based on euphotic volume) for expanding sockeye salmon production, the zooplankton forage base has recently decreased and changed in composition. Of the seven lakes surveyed by hydroacoustics, sockeye salmon fry densities were lowest in Red Shirt Lake and highest in Judd Lake. Sockeye salmon juveniles comprised greater than 80% of the catch in Judd, Byers, and Chelatna lakes; the other lakes were dominated by stickleback. Mean length of age-0 sockeye salmon ranged from 46 mm (Judd Lake) to 63 mm (Shell Lake), and mean weight ranged from 1.2 g to 3.5 g for the same lake populations. The age-0 sockeye salmon fry rearing in 1993 were from a low 1992 escapement estimate of 66,000 adults in the Yentna River, which represent a total Susitna River drainage escapement estimate of 132,000 adults. The 1992 escapement estimate for the Susitna River was one-third less than the minimum escapement goal of 200,000. Thus, the 1993 fry reared under conditions that should have provided low intraspecific competition. The initial year of funding provided some data to plan future investigations; however, future funding appears unlikely. Our recommendation is to discontinue investigations on Whiskey and Red Shirt lakes, as these systems have a low potential (low zooplankton forage base) for supporting sockeye salmon fry. In addition, the fall hydroacoustic/townet surveys should be continued in 1994 to compare densities and sizes of fry produced from an escapement into the Susitna River drainage that was double that for the fry produced and sampled in 1993. The lakes showing the most excessive affects of escapements (1994 fry density and size information), and those offering the greatest productive potential would be sampled intensively for limnological parameters in 1995.

INTRODUCTION

In early 1993, a unified lobbying effort of the legislature by sport anglers, commercial fishermen, and special interest groups resulted in the Alaska Department of Fish and Game (ADF&G) receiving $150,000 to study sockeye salmon production in the Susitna River drainage. This funding was intended to provide money for the initial year of a five-year study to determine if the current sockeye salmon escapement goal for the Susitna River was providing maximum sustained yield.

Historical lake investigations have been done within the Susitna River drainage (Marcuson 1985-1987; Tarbox and Kyle 1989), but most of the work has been limited in scope and duration. Before 1981, sockeye salmon escapements within the Susitna River drainage were monitored at a site in the lower section of the mainstem of the Susitna River (Figure 1). However, this site eroded away and because no other suitable site was found in the mainstem, the counting site was moved to the Yentna River, the largest tributary in the Susitna River drainage. Based on data collected during the Susitna hydroelectric assessment studies and stock separation studies, the escapement (index count) for the Yentna River is believed to be approximately 50% of the total sockeye salmon escapement for the Susitna River drainage (D. Waltemyer, pers. comm., ADF&G, Soldotna AK). Thus, the Yentna River sonar counts are used as an indicator of the sockeye salmon escapement into the Susitna River drainage, and are used in part to manage the Upper Cook Inlet drift and set net fisheries.

Only one attempt has been made to estimate the sockeye salmon production potential within the Susitna River drainage. Tarbox and Kyle (1989) estimated adult sockeye salmon production for 24 lakes within this drainage based on preliminary measurements of euphotic volume (Koenings and Burkett 1987). These lakes can be separated into four geographic regions (different watershed drainages) (Figure 1). Within the Talkeetna region, most of the sockeye salmon production is believed to come from Larsen and Stephan lakes. In the Chulitna region, numerous small lakes within this drainage contribute to sockeye salmon production, and Byers Lake is believed to have the largest production potential. The Yentna region has at least 12 lakes that are known to support sockeye salmon, of which four (Chelatna, Shell, Hewitt, and Judd lakes) are believed to have the majority of the production potential. The mainstem of the Susitna River is the fourth region, and there are six primary lakes supporting sockeye salmon. In addition to the lake systems in the four geographic regions, sockeye salmon spawning and rearing have also been documented in side sloughs and the mainstem of the Susitna River (Thompson et al. 1986). It is unknown how much of these areas of the mainstem contribute to the total sockeye production within the Susitna River drainage.

The preliminary analysis done by Tarbox and Kyle (1989) indicated that lakes in the Chulitna region have the smallest cumulative lake surface area and the lowest amount of adult production potential based on euphotic volume (Table 1). Conversely, lakes in the Yentna region have the largest cumulative lake surface area and the highest amount of adult production potential based on euphotic volume. The majority of adult production potential in the Yentna region is attributable to Chelatna Lake. Also, Tarbox and Kyle (1989) found that the system-wide production (escapement) of sockeye salmon was similar to the summation of individual production estimates based on euphotic volume measurements in the 24 lakes. However, there were some systems in which survey escapements were considerably less than the escapement potential based on euphotic volume. The analysis was preliminary as the euphotic volume calculations were based on limited measurements of light penetration.

The focus of this study is to evaluate the current sockeye salmon escapement goal of 200,000 fish for the Susitna River drainage relative to key fisheries and limnological parameters in nine major sockeye salmon nursery lakes (Table 2). The first year objectives of this study were:

1. Assess relative lake productivity based on physical, chemical, and biological parameters.

2. Estimate rearing sockeye salmon fry densities and determine fry size using hydroacoustic/townet sampling techniques.

3. Determine adult weir sites, and estimate weir construction and operational costs.

4. Make recommendations regarding future investigations to assess the escapement goal within the Susitna River drainage.

Study Site Description

The Susitna River watershed comprises 49,210 km^2, and originates in the glacial mountains of the Alaska Range about 145 km south of Fairbanks. The Susitna River flows southwesterly from the Alaska Range for approximately 400 km before entering upper Cook Inlet, just west of Anchorage (Figure 1). There are three major tributaries within the Susitna River drainage. The largest tributary is the Yentna River, which receives drainage from the Skwenta River, Lake Creek, and the Kahiltna River. Chulitna River receives drainage from Byers Lake, while the Talkeetna River watershed receives drainage from several lakes including Stephan and Larson lakes. The nine study lakes range in elevation from 37-560 m, and in size from 325-2,740 acres (*see* Appendix A). The Susitna River drainage lies within the northern fishing district of Upper Cook Inlet (UCI). Total harvest information is not available; however, during 1966-1992 an average of 112,000 sockeye salmon and 348,000 salmon of all species have been harvested by set gillnets in the northern district (Ruesch and Fox 1993). In addition, during 1978-1985 an average of 216,000 sockeye salmon were estimated to enter the Susitna River to spawn (Ruesch and Fox 1993). During this period, escapements ranged from about 94,000 to 340,000 sockeye salmon. The average sockeye salmon escapement for the Yentna River during 1986-1993 was 96,000 (Davis and King 1994). In 1993, a peak escapement 141,700 sockeye salmon escaped into the Yentna River.

METHODS

Limnology Sampling

Limnology sampling consisted of measuring physical parameters (temperature, dissolved oxygen, and light penetration), water-quality parameters (alkalinity, pH, conductivity, etc.), nutrients (both phosphorus and nitrogen), and biological parameters (algal biomass, zooplankton diversity and biomass). All sampling and analytical methodologies followed those described by Koenings et al. (1987). In each lake, samples were taken from one station (*see* Appendix A) at two depths representing the epilimnion (1 m) and the hypolimnion. All nine lakes were sampled once in August of 1993. The euphotic volume (surface area x euphotic zone depth) was calculated for predicting sockeye salmon production in these lakes (Koenings and Burkett 1987). There is some historical limnological information available for the study lakes except for Judd and Whiskey lakes. This information has been included (expressed as the overall mean values) in the results; however, because the sampling schedules were inconsistent between years and lakes, we ranked the lakes according to several indices of productivity (trophic state) based on the 1993 data only.

Hydroacoustic/Townet Surveys

Hydroacoustic/townet surveys were conducted once in August/September of 1993 on seven of the nine study lakes (Red Shirt, Shell, Larson, Hewitt, Judd, Byers, and Chelatna) to estimate the abundance and distribution of rearing sockeye salmon fry. Whiskey Lake is too small and shallow to survey, and inclement weather prevented surveying Stephan Lake. Hydroacoustic surveys consisted of recording data along transects perpendicular to the longitudinal axis of each surveyed lake. Each lake except Judd and Byers was divided into equidistant transects, with the interval between transects calculated to provide at least 20 transects. Interval distances at Judd and Byers Lakes were considered short enough that only 10 transects were necessary. Data were collected on every other transect (10 minimum), and if there was sufficient time before daylight, additional data were collected on the remaining transects, as well as in the nearshore area between transects. However, only the cross transects were used to estimate fish populations.

Before starting each survey, a single transect was run repeatedly for one hour beginning thirty minutes before sunset. This was done for future assessment of fish behavior during the period of transition from daylight to dark when sockeye salmon fry in clearwater lakes typically migrate from near-shore or near-bottom areas to pelagic areas of the lake. Recording of down-looking acoustic data along the transects began 30 minutes after sunset. In addition, if there was time (and calm conditions) at the end of the survey, upward-looking data were collected to determine the extent of targets in the near-surface area not sampled by the down-looking acoustic equipment.

A BioSonics model-105 echosounder system with a 6/15° dual-beam transducer was used for the surveys. Fish signals were recorded electronically using a Sony digital audio tape (DAT) recording system and on paper using a BioSonics model-115 chart recorder. The pulse width was set at 0.4 ms and the pulse repetition rate at 5 pulses sec^{-1}. A single-beam 15° transducer was used to collect data in the upward-looking mode. The surveys were conducted using a 5-m raft and 35-hp outboard. The transducer was deployed approximately 1 m below the lake surface, and transecting speed was ~2 m sec^{-1}.

Analysis of the recorded hydroacoustic tapes was conducted by Dr. Richard Thorne of BioSonics, Inc., under a State of Alaska contract. Fish densities were low enough in all surveys to employ echo-counting techniques (Thorne 1983) for the population estimates. Sampling volumes were estimated by the duration-in-beam technique (Nunnallee and Mathisen 1972; Nunnallee 1980; Thorne 1988). Fish densities were determined for several depth intervals along thirds of each transect. For each depth interval, fish densities (no. m^{-3}) were summed to determine the total areal fish density (no. m^{-2}) for each transect. The total population estimate was obtained by multiplying the lake area representing each transect by the mean transect fish density, and summing all transect population estimates.

Townetting was conducted in conjunction with the hydroacoustic surveys to determine species of acoustically-counted fish, and to determine age and size of juvenile sockeye salmon. Townetting procedures consisted of a midwater trawl with a mouth opening of 4 m by 2 m, and a length of 10 m. Mesh size decreased from 7.6 cm at the mouth to 0.3 cm at the cod end. The gear was towed between two 5-m rafts at approximately 1-2 m sec^{-1}, and the tows ranged from near surface to 15 m deep. A minimum of 3 tows of at least 30-min duration were conducted in each lake. At the end of each tow all fish captured were identified and enumerated. All sockeye salmon fry and a representative sample of the other fish species were preserved in a 10% buffered formalin solution. The minimum sample size for each lake was 300 sockeye salmon fry. After 30 days in preservative, fork length (nearest 1.0 mm), weight (nearest 0.1 g), and scales (for age determination) were collected from a random sample of sockeye salmon fry. Lengths were also measured from a minimum of 100 fish of other species captured in each lake.

Weir Feasibility Assessment

Eight of the nine lake systems (Chelatna was not surveyed because Cook Inlet Aquaculture Association already operates a weir at that location) were surveyed to select the best weir site. Sites were selected based on access and stream morphology. Each site was measured to determine the amount of weir materials and the weir design needed to obtain a total adult enumeration. Detailed costs to build and operate each weir were estimated.

RESULTS

Lake Morphometry

A summary of morphometric parameters for the nine study lakes is presented in Table 3, and morphometric maps are included in Appendix A. Bathymetric maps have yet to be developed for Judd and Whiskey lakes; however, from the limited limnological sampling and hydroacoustic surveys the mean and maximum depths have been estimated. Chelatna Lake is the largest and deepest of the nine lakes with a surface area of 16.9 km^2 and a mean depth of 64 m. Shell Lake is the next largest system with a surface area of 6.0 km^2 and a mean depth of 11.9 m. Next in size are Red Shirt and Stephan lakes, followed by the remaining five lakes that are relatively similar in size. Both Red Shirt and Whiskey lakes are shallow compared to the other systems, and Byers, Judd, and Larson have maximum depths in the range of about 45-50 m.

Light Penetration and Lake Typology

The highest Secchi disk (SD) transparency (10.9 m), the lowest light-extinction coefficient (Kd) (0.18 m^{-1}), and the greatest euphotic zone depth (EZD; 26.7 m) occurred in Judd Lake (Table 4), which also had the least amount of turbidity and color (Table 5). The lowest SD transparency was measured in Chelatna (2.3 m) and Hewitt lakes (2.6 m), which had the highest turbidity. The turbidity in Chelatna Lake is derived from glacial input, while in Hewitt Lake phytoplankton (suspended algal cells) is the main source of turbidity, as chlorophyll *a* (chl *a*) concentrations were relatively high (Table 5). In Whiskey Lake, SD transparency (3.3 m) was somewhat obscured due to the extensive growth of macrophytes. The highest Kd occurred in Shell Lake (0.63 m^{-1}) (Table 4), which had the greatest amount of color (17 Pt units) (Table 5). Light penetration expressed as Kd x SD can be used to characterize light attenuation in lakes, and in turn, can be used to classify lake type (glacial, stain, and clear). The product of Kd x SD is lower in systems with turbidity, has a median value of 1.9 for clearwater lakes, and is higher in systems with higher values of color units (Koenings and Edmundson 1991). Also, EZD ÷ SD, another criteria of lake type, is lower in turbid waters and higher in colored waters, and has a median value of 2.4 for clearwater lakes. Using these criteria, Judd and Hewitt lakes are classified as clearwater lakes. Chelatna Lake is considered a semi-glacial system, as the seasonal mean turbidity (~3.5 NTU) is on the low range for glacial lakes (Koenings and Edmundson 1991). In Byers, Larson, Red Shirt, Shell, and Stephan lakes color ranged from 9 to 17 Pt units (Table 5), and consequently are classified as organically-stained systems. Although color was relatively consistent with depth in these lakes, turbidity increased more than four fold (4.6 NTU) within the deeper strata of Red Shirt Lake, which is presumably due to suspended bottom sediments. Light penetration was not measured in Whiskey Lake, but at the time of sampling this system appeared to be clear.

Thermal Regimes and Dissolved Oxygen

All of the lakes displayed thermal stratification during the 1993 surveys (Table 6), except for Whiskey Lake, presumably due to the shallow depth of this lake. In general, a thermocline occurred at a depth of from 5 to 10 m; however, the thermocline was deeper (10-20 m) in Judd Lake and much less pronounced in Chelatna Lake (at least in July). Surface temperatures ranged from 15-17° C, except in Chelatna and Judd lakes. In Chelatna Lake, the surface temperature was cooler (11° C) due to the influence of cold, glacier meltwater. In Judd Lake, the lower surface temperature (12° C) probably reflected the small surface area-to-volume ratio (Table 3). Generally, dissolved oxygen (D.O.) concentrations in the surface water of the study lakes during the dates sampled in 1993 ranged between 85% and 100% of saturation; however, low D.O. levels were observed in Red Shirt Lake (78% saturation) and Whiskey Lake (75% saturation). In contrast, the surface water of Chelatna Lake was slightly supersaturated at 107%. Oxygen levels were generally consistent with depth, except in Hewitt and Red Shirt lakes where D.O. concentrations fell rapidly below the thermocline to 15% (2.0 mg L^{-1}) and 3% (0.5 mg L^{-1}) of saturation, respectively.

General Water Chemistry

The pH, alkalinity, and conductivity (an indicator of total dissolved solids) showed little vertical variation in all nine lakes (Table 5). All the study lakes have a circumneutral pH and low to moderate alkalinity. Hewitt, Red Shirt, and Stephan lakes had the highest alkalinity (range 37-44 mg L^{-1}) and conductivity (range 84-109 µmhos cm^{-1}), while Chelatna and Judd lakes had the lowest (range 5-11 mg L^{-1} and 18-27 µmhos cm^{-1}, respectively). Byers, Larson, Shell, and Whiskey lakes were intermediate with alkalinity ranging between 12-23 mg L^{-1} and conductivity between 33-72 µmhos cm^{-1}. Calcium and magnesium, two important hardness-producing cations, were highest in Hewitt and Stephan lakes and lowest in Chelatna and Judd lakes. All nine lakes are considered 'medium-water' lakes (as opposed to soft- or hard-water lakes). Iron levels within the 1-m stratum were highest in Chelatna (256 µg L^{-1}) and Shell Lake (115 µg L^{-1}) compared to the other lakes (range 33-88 µg L^{-1}). Unlike clearwater lakes, which typically exhibit iron levels <20-40 µg L^{-1}, concentrations were elevated in Chelatna Lake due to the input of glacial silt and in Shell Lake due to organic stain.

Nutrients and Algal Biomass

Of all (historical and 1993) samples collected from the nine lakes, total phosphorus (TP) concentrations within the epilimnion (1 m) ranged from a low of 2.2 µg L^{-1} in Judd Lake to a high of 12.2 µg L^{-1} in Stephan Lake (Table 5). Based on epilimnetic TP concentration, Judd Lake would be classified as ultra-oligotrophic (TP <3 µg L^{-1}), Hewitt and Stephan lakes as slightly mesotrophic (TP = 10-20 µg L^{-1}), and the remaining lakes would fall within the oligotrophic category (TP = 3-10 µg L^{-1}). The TP levels were relatively consistent between the two sample depths, except in Whiskey Lake, which had a concentration of 27 µg L^{-1} at a depth of 4 m. The high TP concentration in the hypolimnion of this lake coincided with an increase in phytoplankton biomass as indicated by the relatively high chl *a* concentration (Table 5). Thus, the higher TP concentration is presumably due to an increase in the particulate organic fraction of phosphorus. Filterable reactive phosphorus (FRP), the fraction of TP considered readily available for algal assimilation, was lowest in Judd Lake (1.7 µg L^{-1}) and highest in Stephan Lake (5.2 µg L^{-1}). Like TP concentrations, FRP levels exhibited little variation by depth.

Inorganic nitrogen levels varied considerably in the study lakes (Table 5). For example, epilimnetic nitrate + nitrite concentrations were very high in Byers (440 µg L^{-1}), Shell (500 µg L^{-1}, and Larson lakes (529 µg L^{-1}). In contrast, the average nitrate + nitrite concentration was below the level of detection (<4 µg L^{-1}) in both Red Shirt and Whiskey lakes, averaged only 40 µg L^{-1} in Hewitt Lake and 16 µg L^{-1} in Stephan Lake, and was intermediate in Chelatna and Judd lakes (~200 µg L^{-1}). The nitrate + nitrite concentration increased markedly with depth in Hewitt Lake (169 µg L^{-1}) and Red Shirt Lake (117 µg L^{-1}), whereas there was little variation by depth in the other lakes. Ammonia concentrations in the epilimnion were relatively low in all lakes (range 3.7-21.3 µg L^{-1}), but concentrations increased three fold in the hypolimnion of Hewitt Lake (60.8 µg L^{-1}) and Shell Lake (34.3 µg L^{-1}) (Table 5). The total Kjeldahl nitrogen (TKN) (organic nitrogen + ammonia) concentration in the epilimnion was lowest (range 64-99 µg L^{-1}) in Judd, Chelatna, and Byers lakes, and ranged from 181-245 µg L^{-1} in the remaining lakes (Table 5).

Chelatna and Judd lakes had the lowest epilimnetic chl *a* concentration (~0.20 µg L^{-1}), and Whiskey Lake had the highest concentration (4.30 µg L^{-1}). In all the lakes except Red Shirt and Whiskey lakes, hypolimnetic chl *a* concentrations were either equal to or less than in the epilimnion. The higher hypolimnetic chl *a* concentrations in Red Shirt and Whiskey lakes indicates higher algal production, probably a result of the shallow depths in these lakes. As expected, lakes with the higher chl *a* concentrations coincided with those having lower nutrient (nitrate + nitrite) concentrations.

Ranking of Trophic Status

Because the historical limnological data were not collected consistently within a season or by year for each lake, we ranked the nine study lakes using morphometric characteristics (surface area-to-volume ratio), the morphoedaphic index (conductivity ÷ mean depth), and TP and chl *a* concentrations based on the August 1993 data. This ranking provides a cursory but relative comparison of lacustrine productivity based on certain parameters from a one-time sample trip. The results should be viewed cautiously as the data are limited and they do not directly translate to the potential for sockeye salmon production. In addition, other factors such as spawning area and success, physical factors, and the zooplankton community play an important role in the rearing capacity of nursery lakes. For example, based on the parameters used, Whiskey Lake is ranked the highest in productivity (Table 7). However, it is ranked high because of the small-size and shallow depth that provide conditions (e.g., high temperatures, extensive light penetration, large surface area-to-volume ratio) conducive to high productivity. However, given its shallow basin and the extensive growth of macrophytes (another indication of high productivity) severe oxygen depletion may occur in this lake as a result of decomposition during the winter. Chelatna Lake, a known sockeye-salmon producer ranked last (ninth) in all variables except TP. This lake is the most oligotrophic system because of its glacial influence. Judd Lake (ranked eighth) is also very nutrient poor as exemplified by the low TP and chl *a* concentrations. Stephan, Red Shirt, Hewitt, and Shell lakes (ranked 2-5, respectively) have similar morphometry and nutrient levels. Finally, Larson and Byers lakes (the two smallest stained systems) ranked sixth and seventh, respectively. This relative comparison ranking provides a limited assessment of trophic status for these lakes, and does not reflect their potential for sockeye production, as the following zooplankton information demonstrates.

Zooplankton Community

Previous to 1993, zooplankton data were collected on seven of the nine lakes; no previous data were available for Judd and Whiskey lakes (Table 8). Of the nine lakes, Larson Lake had the highest density and biomass of zooplankton (Figure 2a) in 1993. This lake's community comprised mainly (~80% by density and biomass) of two copepods *(Cyclops and Diaptomus)*, which are more elusive prey than the cladocerans (*Daphnia* and *Bosmina)* because of greater mobility. On 17 August 1993 the zooplankton density was 607,000 m^{-2} and the biomass was 1,546 mg m^{-2}. *Cyclops* represented 60% of the density and 37% of the biomass, whereas *Diaptomus* represented 22% by density and 43% of the biomass. The body size of *Cyclops* (0.67 mm) in 1993 (Figure 2b) was relatively small compared to other year in Larson Lake, which may indicate size-selective predation by planktivorous fish. However, compared to previous years of sampling, the zooplankton density and biomass in 1993 appears robust in this lake.

The zooplankton community of Stephan Lake was also dominated by copepods. On 17 August 1993 the total zooplankton density was 299,000 m^{-2} and the biomass was 864 mg m^{-2} (Table 8). *Diaptomus* and *Cyclo*ps represented 34% and 64% by density and 36% and 25% by biomass, respectively. The numerically low but large-size (2.9 mm) *Heterocope* and *Daphnia* (1.5 mm) comprised the remaining community. The presence of these two large-size zooplankton suggests a low occurrence of size-selective predation; however, the size of *Cyclops* in Stephan Lake (0.58 mm) was less than that observed in Larson Lake (Figure 2b).

The zooplankton community of Byers Lake before 1993 was dominated by *Cyclops* with some *Daphnia* and *Bosmina* (Table 8). On 17 August 1993, the community was almost equally divided between *Cyclops* and *Bosmina*. The density of *Cyclops* was 130,000 m^{-2} and for *Bosmina* was 104,000 m^{-2}; the total density for all taxa was 283,000 m^{-2}. *Cyclops* and *Bosmina* accounted for 31% and 37% of the total biomass (693 mg m^{-2}), respectively. The zooplankton community of this lake also appears robust as most of the body sizes in August (near the end of the rearing season) were above average for a lake supporting sockeye salmon fry. The exception was the size of *Cyclops,* which like that found in Larson and Stephan lakes, was smaller than the other lakes (Figure 2b).

Sampling on 20 August 1993 at Judd, Shell, and Hewitt lakes indicated very similar biomass levels of zooplankton; ranging from 582 mg m^{-2} in Judd Lake to 548 mg m^{-2} in Hewitt Lake (Table 8). However, each of these lakes have slightly different dominant taxa. For Judd Lake, no historical zooplankton information is available, but the one sample taken in August of 1993 indicated a density of 110,000 m^{-2}. The sample was dominated by the cladoceran *Holopedium* (49% by density; 68% by biomass), which is an easy prey for sockeye salmon fry but usually not one preferred if other prey are present. *Cyclops* represented the second highest density. The sizes of *Holopedium* and *Cyclops* were 0.84 mm and 1.1 mm respectively (Figure 2b), indicating the lack of size-selective predation by planktivorous fish. The large size of these taxa accounted for the similar biomass in this lake compared to Shell and Hewitt lakes that had considerably higher densities (Figure 2a). In Shell Lake, the density in August of 1993 was 209,000 m^{-2}, and the community comprised mainly of *Cyclops* (59% by density; 43% by biomass). The remainder of the community comprised of *Diaptomus* and to a lesser extent *Bosmina*. Although the density in 1993 was similar to 1987 (and most of the previous years), the lower biomass was due to slightly smaller sizes of each taxa in 1993. However, the body sizes of most of the zooplankton taxa do not indicate severe predation (Figure 2b). In Hewitt Lake during 1993, the zooplankton community was dominated by *Cyclops*, and followed by *Daphnia*. *Cyclops* represented 56% by density and 59% by biomass, while *Daphnia* represented 24% by density and 15% by biomass. In addition to these taxa, *Diaptomus* and *Epischura* were also present, and except for the small body size of the less abundant *Bosmina* (Figure 2b), the body sizes of observed taxa were not indicative of intense predation.

Previous to 1990, sampling in Chelatna Lake (1 to 4 times per season) indicated zooplankton biomass (1,438-1,882 mg m^{-2}) similar to that found in Larson Lake in 1993 (Table 8). However, since 1990 zooplankton biomass collected three times per season ranged from 224 mg m^{-2} (1991) to 485 mg m^{-2} (1993), for an average decrease of almost five fold. Although the density was higher in 1992 and 1993 compared to 1990 and 1991, the reappearance of *Diaptomus* in substantial numbers was not evident, which accounted for a large portion of the biomass in previous years. This suggests that *Diaptomus* in Chelatna Lake are currently experiencing poor reproduction and/or survival due to perhaps a change in environmental conditions, a competitive disadvantage, or as they are quite larger in individual body size than other zooplankton in this lake, may be highly selected by planktivorous fish. This dramatic decrease in zooplankton abundance and change in composition has a pronounced affect on the rearing capacity for sockeye salmon fry in this lake.

Red Shirt and Whiskey lakes had the lowest zooplankton density and biomass of the lakes sampled in 1993 (Table 8). The zooplankton community of Red Shirt Lake comprised mainly of *Cyclops* (49% by density; 54% by biomass). Although the zooplankton density was quite low, the body sizes of zooplankton taxa were not considerably different from Hewitt Lake (Figure 2b). In Whiskey Lake *Epischura* dominated, but the total density in August of 1993 was a mere 5,500 m^{-2}. The low densities (especially the cladocerans) but the occurrence of large size zooplankton in these two lakes indicates the absence of severe predation by planktivorous fish and a low potential to support sockeye salmon fry.

Fall Fry Population Estimates and Sizes

Of the seven lakes surveyed, the total number of hydroacoustic targets ranged from 108,000 in Byers Lake to 3,100,714 in Hewitt Lake (Table 9). Peak densities of fish were lowest in Chelatna (0.0080 m^{-3} in the 4 to 8 m strata) and Byers (0.0084 m^{-3} in the near surface strata) lakes. Highest density in an individual strata were measured in the 1 to 5 m zone of Hewitt Lake (0.2055 m^{-3}). When only sockeye were considered, peak densities ranged from 0.0001 m^{-3} in the 1 to 4 m zone of Red Shirt Lake to 0.0296 m^{-3} in the 1 to 5 m zone of Hewitt Lake. Highest densities in all lakes were measured at depths of less than 10 m (Figure 3). When densities were standardized to numbers of fish m^{-2} of surface area, sockeye salmon fry had the lowest density in Red Shirt Lake and the highest in Judd Lake.

The townet crew obtained a minimum of 300 sockeye salmon fry from two of the seven lakes and was within 10% of this goal on one lake (Table 10). Less than 100 sockeye salmon fry were captured in three of the lakes despite efforts in excess of 250 minutes of towing in each lake. Sockeye salmon juveniles comprised greater than 80% of the catch from Judd, Byers, and Chelatna lakes. The fish composition in the remaining lakes was dominated (>85%) by sticklebacks. The predominant age class of sockeye salmon in all lakes was age-0 (Table 11). The highest percentage of age-1 sockeye salmon fry (7.3%) was found in Judd Lake. Mean length of age-0 sockeye salmon ranged from 46 mm (Judd Lake) to 63 mm (Shell Lake), and mean weight ranged from 1.2 g to 3.5 g for the same lake populations (Table 11). The age-1 sockeye salmon fry from Judd Lake averaged 64 mm and 3.1 g.

Non-salmonid fish found in 4 of the 7 lakes belonged mainly to the family Gasterosteidae, including representatives of *Gasterosteus* sp. and *Pungitiuius* sp. Length of these fish (mainly stickleback) ranged from 17 to 58 mm in Red Shirt, Shell, Larson, and Hewitt lakes (Table 11), and comprised 85% or greater of the total catch. Although length frequency distributions for sockeye salmon juveniles and stickleback in the lakes were different (Figure 4), there was insufficient separation such that target strength analysis could be used to estimate the population of each. Although target strength data from these lakes were not deemed useful to separate fish species, there was potential for bias in undercounting stickleback (based on the townet catches) where the acoustic size of the smaller stickleback approached, or was less than, the counting threshold. As a comparison, euphausids and krill in the 11 to 40 mm size range (similar to the smaller stickleback in the study lakes) have mean target strengths smaller than -74 dB (MacLennan and Simmonds 1992). The counting threshold for the surveys on the study lakes varied depending on the noise level and size of the largest targets of interest. For example, the highest counting threshold (-67 dB) was used for the Larson Lake survey and the lowest (-79 dB) was used for the survey conducted on Hewitt Lake. Thus, there could have been bias related to the counting threshold for these surveys such that the net effect would be an underestimate of the stickleback populations.

Peak densities of sockeye salmon juveniles in the Susitna basin lakes were comparable to those measured in lakes on the Kenai Peninsula. In Skilak Lake, in which there was an estimated 8.5 million fry, the peak density was 0.0178 fish m^{-3} in September 1992 (Tarbox and Brannian 1993). Similarly, sockeye salmon fry in Kenai Lake were measured at densities of 0.0112 m^{-3} during the same period. In Upper Russian Lake, a major clearwater sockeye nursery lake on the Kenai Peninsula, peak sockeye salmon densities reached 0.0594 fish m^{-3} (G. Kyle, unpublished data).

The accuracy of the population estimates of sockeye salmon fry rearing in lakes of the Susitna River drainage was affected by several factors. The distribution of total targets in the water column was highest near the surface in 4 of the 7 lakes. However, these fish were rarely detected in the upward looking acoustic sampling because the overall densities (except for Hewitt Lake) were less than 52 fish per 1000 m^3 and the sampling volume of the upward-looking system was quite small. Thus, the net effect was an underestimate of targets since those fish in the upper 2-2.5 m of the water column were not included in the estimate (not detectable by the equipment in the downlooking mode). In the three lakes dominated by sockeye salmon fry, the estimates seemed to be reasonable indices of the sockeye salmon population, given the magnitude of escapements estimated in previous years.

In most of the lakes where stickleback were the predominant species, the expected adult return from the sockeye salmon fry estimates would be considerably less than historical escapement surveys. This could be a function of net selectivity, acoustic estimate errors, or simply be related to the low parent-year escapement into the drainage in 1992. The one exception was Hewitt Lake, which had a total fish estimate in excess of 3 million and a sockeye salmon fry estimate of 447,080. The expected adult return from such an estimate does not seem unreasonable given that historic escapement surveys have revealed 13,000 fish.

Weir Feasibility Analysis

All nine lake systems were surveyed to determine the best location for an adult salmon weir to enumerate escapements. Suitable weir sites were located in the vicinity of the lake outlets except at Byers Lake, where the best weir site was found on Byers Creek upstream from the Parks Highway Bridge. Weir locations at Red Shirt and Byers lakes are located on private property, and the other weir locations are located on public land (Table 12). The Byers Lake weir site is accessible by road from the Parks Highway, the Larson Lake weir site is accessible by an all-terrain vehicle (ATV) trail from the Talkeetna Spur Road, Red Shirt Lake can be accessed by a foot trail from the Nancy Lake State Recreation Area, and the other weir sites are accessible only by plane. The only system that imposes a problem with counting adult salmon is at Hewitt Lake. The outlet of this lake is subject to flooding and would cause difficulty in maintaining a picket weir.

The cost to purchase, fabricate, and transport materials to the sites is an estimated $73,000 (Table 12). This equates to a cost of approximately $100 per foot of weir. The Hewitt Lake weir site would be the most difficult to operate as high water in the Yentna River in the fall of 1993 backed up into the outlet of this lake. In previous years of study this has been observed (Marcuson 1986). In addition, the outlet of Hewitt Lake is deep (up to 2 m) and would be difficult to weir using conduit pickets. Weirs have previously been run at the outlets of Larson and Shell Lakes by Cook Inlet Aquaculture Association (Marcuson 1985, 1987) without major problems. The other sites appeared quite reasonable to operate an adult weir. Dates of weir operation may vary for each system. However, historic data from Larson and Shell lakes (Marcuson 1985, 1987) suggest a weir would need to be operated from about 15 July to 1 September. It is probably reasonable to assume that weir operations at any of the systems have a potential duration of approximately 2 months.

The estimated cost to outfit one weir camp is $9,000 (Table 13). This includes lodging, a 12' raft, 15-hp outboard motor, a generator, chain saw, refrigerator, stove, communication equipment (phone or radio) and other miscellaneous camp supplies. Weir operational costs, with the exception of air charter, should be similar for each location. Two technicians at each weir site for two months would total ~$16,000 per weir. Camp supplies, food, fuel, and miscellaneous gear would cost about $2,500 per weir. As mentioned earlier, Byers Lake and Larson Lake are accessible by the road system; however, for the other lake systems access would be by floatplane. The cost of air charters would depend on whether the camps are supplied out of Soldotna, Anchorage, or Willow. Air charter from Willow would be the cheapest; while from Anchorage the cost would be approximately 50% greater and from Soldotna about twice as much. The basic air charter for one weir for a whole season is estimated at $4,000 from Willow. The total estimated cost to run each weir for the first season and thereafter with air charter support from Willow is presented in Table 13.

DISCUSSION

This sockeye salmon investigation study was intended to evaluate the escapement goal in the Susitna River drainage by assessing key fisheries and limnological parameters that would indicate excessive or moderate use of the rearing area in nine nursery lakes. The age-0 sockeye salmon fry rearing in 1993 were from a 1992 escapement estimate of 66,000 adults in the Yentna River, which represent a total Susitna River drainage escapement estimate of 132,000 adults. The 1992 escapement estimate for the Susitna River was one-third less than the minimum escapement goal of 200,000. Thus, the 1993 fry reared under conditions that should have provided low intraspecific competition.

The limnological sampling in 1993, and the historical information suggests that some of the lakes are more productive than others, and the zooplankton community in some lakes have undergone changes. The ranking of trophic status based on limnological parameters revealed that the more shallow systems such as Whiskey and Red Shirt lakes had a low ranking (Table 7), indicating that these systems were more productive. However, because of their relatively shallow depth, the zooplankton forage base, which is the major food source for rearing sockeye salmon fry, was relatively small (Table 8). In contrast, Stephan Lake, which also is shallow relative to the other lakes, was second to Larson Lake in zooplankton biomass (Table 8). This lake may have a relatively long water resident time as suggested by the high nutrient and chlorophyll *a* concentrations (Table 5), which are consistent with a high standing stock (biomass) of zooplankton. The most significant change in zooplankton based on the limited historical data, was for Chelatna Lake. This glacially-influenced lake is the most oligotrophic of the nine lakes surveyed in 1993 (Table 7), and since 1990 the zooplankton biomass has been consistently less than during 1984-1989 (Table 8). Also, the zooplankton structure has changed from the dominance of *Diaptomus* to *Cyclops*. The reason(s) for these changes in the zooplankton community of Chelatna Lake is largely unknown; however, the dramatic decrease in zooplankton biomass has a pronounced affect on the ability of this lake to support sockeye salmon fry.

Considering the hydroacoustic/townet surveys conducted in the fall of 1993, it is apparent that the study lakes contained varying densities of sockeye salmon fry (Table 9), and in four of the seven lakes surveyed, stickleback were much more abundant than sockeye salmon fry (Table 10). Of the seven lakes, the size of age-0 fry were smallest in Hewitt and Judd lakes, and of equal size in Shell, Byers, and Chelatna lakes (Table 11). The sizes of age-0 fry in the fall, except for Hewitt and Judd lakes, were comparable to other lakes within the Cook Inlet watershed. The small fry sizes in Hewitt and Judd lakes could be due to high intraspecific competition; however, except for small size *Bosmina* in Hewitt Lake, the zooplankton community does not reflect this condition.

Originally, this study was intended to last five years with an annual budget of $150,000. The initial year of funding provided some data to plan future investigations; however, future funding appears unlikely. Of the original $150,000, approximately $80,000 remains for further investigations. As construction and operational costs for each weir on the study lakes approximate $40,000 (Table 13), the remaining funds would cover the cost to operate an adult weir at only two lakes.

Our recommendation is to discontinue investigations on Whiskey and Red Shirt lakes, as these systems have a low potential (low zooplankton forage base) for supporting sockeye salmon fry. In addition, the fall hydroacoustic/townet surveys should be continued in 1994 to compare densities and sizes of fry produced from an escapement into the Susitna River drainage that was double that for the fry produced and sampled in 1993. Since the Yentna River sockeye salmon escapement in 1993 was near the upper end of the goal (150,000), we assume rearing fry characteristics in 1994 will provide more meaningful data for assessing the escapement goal. Finally, limnology surveys would be initiated on some lakes in 1995 after review of the 1994 data. We feel that because of the high cost of flying into these lakes, and the need for consistent limnological sampling (monthly sampling), no lakes should be sampled in 1994 until we collect data on fish abundance and size from a high broodyear escapement. The lakes showing the most excessive affects of escapements (1994 fry density and size information), and those offering the greatest productive potential would be sampled intensively in 1995.

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

Geographical region	Lake	Surface area (acres)	Adult production (number)[a]	Adult production expressed as percent of the grand total
Chulitna	Byers	368	37,200	3.7
	Swan	385	11,000	1.1
	Spink	252	23,500	2.3
	Bunco	106	1,600	0.2
	Total	1,111	73,300	7.3
Mainstem	Caswell	159	13,700	1.4
	Trapper	1,188	16,800	1.7
	Fish	132	10,600	1.1
	Sucker	273	8,300	0.8
	Red Shirt	1,272	69,500	6.9
	Neil	115	7,600	0.8
	Total	3,139	126,500	12.5
Talkeetna	Larson	437	45,100	4.5
	Stephan	899	63,700	6.3
	Total	1,336	108,800	10.8
Yentna	Chelatna	4,181	389,200	38.6
	Trinity	308	19,300	1.9
	Whiskey	271	23,600	2.3
	Fish Creek	111	9,000	0.9
	Shell	1,487	103,800	10.3
	Puntilla	90	8,800	0.9
	Eightmile	115	5,600	0.6
	Movie	110	6,700	0.7
	Lockwood	233	11,000	1.1
	Judd	316	59,500	5.9
	Hewitt	697	60,600	6.0
	Red Salmon	113	3,400	0.3
	Total	8,032	700,500	69.4
	Grand Total	13,618	1,009,100	100.0

[a]Source: Tarbox and Kyle (1989).

Table 2. Potential sockeye salmon production and percent of regional production for the nine study lakes.

Geographical region	Lake	Surface acres	Adult production potential based on euphotic volume: Number of fish	Percent of region total[a]
Chulitna	Byers	368	37,200	50.8%
Talkeetna	Larson	437	45,100	41.5%
	Stephan	899	63,700	58.5%
Mainstem	Red Shirt	1,272	69,500	54.9%
Yentna	Chelatna	4,181	389,200	55.6%
	Shell	1,487	103,800	14.8%
	Judd	316	59,500	8.5%
	Hewitt	697	60,600	8.7%
	Whiskey	271	23,600	3.4%

[a]See table 1.

Table 3. Summary of morphometric parameters for study lakes of the Susitna River drainage.

Lake	Surface area (km^2)	Mean depth (m)	Maximum depth (m)	Volume ($m^3 \times 10^6$)
Chelatna	16.92	64.0	125.0	707.7
Shell	6.02	11.9	28.7	62.3
Red Shirt	5.15	5.3	15.2	25.6
Stephan	3.64	7.0	27.7	33.7
Hewitt	2.82	13.5	34.0	38.0
Larson	1.77	16.4	42.6	29.1
Byers	1.49	20.0	54.0	26.7
Judd	1.28	na[a]	45.0[b]	na
Whiskey	1.10	3.0[a]	6.0[b]	na

[a]Indicates not available.

[b]Estimated from 1993 field sampling.

Table 4. Comparison of Secchi disk (SD) transparency, light-extinction coefficient (Kd), euphotic zone depth (EZD), Kd x SD, and EZD/SD in study lakes of the Susitna River drainage.

Lake	SD (m)	Kd (m^{-1})	EZD (m)	Kd x SD	EZD/SD
Byers	5.7	0.46	10.6	2.6	1.9
Chelatna	2.3	0.52	12.0	1.2	5.2
Hewitt	2.6	0.51	9.9	1.3	3.8
Judd	10.9	0.18	26.7	1.9	2.5
Larson	5.1	0.50	9.7	2.6	1.9
Red Shirt	5.3	0.58	8.2	3.1	1.5
Shell	4.5	0.63	7.8	2.8	1.7
Stephan	4.3	0.53	9.0	2.3	2.1
Whiskey	3.3	na[a]	na	na	na

[a]Indicates not available

Table 5. Summary of general water-quality parameters, metals, nutrient concentrations, and algal pigments within the epilimnion (1 m) and hypolimnion for study lakes of the Susitna River drainage.

LAKE	(n)	Specific conductance (umhos cm^{-1})	pH (Units)	Alkalinity (mg L^{-1})	Turbidity (NTU)	Color (Pt units)	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Iron (ug L^{-1})	Total-P (ug L^{-1})	Total filterable-P (ug L^{-1})	Filterable reactive-P (ug L^{-1})	Total Kjeldahl nitrogen (ug L^{-1})	Ammonia (ug L^{-1})	Nitrate+ nitrite (ug L^{-1})	Reactive silicon (ug L^{-1})	Carbon (ug L^{-1})	Chlorophyll a (ug L^{-1})	Phaeophytin a (ug L^{-1})
Epilimnion																			
Byers	14	32	6.7	14.2	0.5	9	5.6	0.4	76	7.0	3.1	2.5	99.0	9.4	439.6	3330	114	0.53	0.47
Chelatna	12	26	6.9	9.5	3.6	7	3.8	0.5	256	5.5	3.7	2.9	64.2	3.8	200.0	1676	89	0.20	0.13
Hewitt	8	86	7.1	42.9	2.1	6	11.4	1.9	97	11.8	7.0	3.6	204.8	21.3	40.3	4579	240	3.29	2.03
Judd	1	18	6.5	5.5	0.3	3	2.0	0.2	36	2.2	1.1	1.7	63.5	11.0	200.8	3644	na[a]	0.20	0.12
Larson	46	67	6.8	12.2	1.0	11	6.5	0.2	36	9.2	4.1	2.4	181.4	11.2	529.0	3381	138	0.91	0.57
Red Shirt	4	83	7.2	35.5	1.1	14	9.1	1.8	37	9.1	5.2	2.9	245.3	3.7	0.1	2586	134	0.94	0.89
Shell	25	33	6.7	12.8	1.5	17	4.4	0.6	112	9.0	3.7	3.2	213.0	12.0	500.1	4073	108	0.50	0.49
Stephan	7	101	7.4	36.6	1.7	16	10.7	2.5	97	12.2	7.6	5.2	228.2	6.6	15.6	4737	117	1.67	1.12
Whiskey	1	59	7.0	22.0	1.0	9	7.7	1.6	88	9.3	4.6	4.5	241.0	8.9	1.5	4254	na	4.30	1.23
Hypolimnion																			
Byers	14	34	6.7	14.4	0.6	15	4.8	0.3	78	6.4	3.1	3.0	83.0	9.8	524.8	3556	108	0.22	0.33
Chelatna	11	27	6.8	11.2	3.8	5	3.7	0.4	335	6.5	2.0	1.8	42.4	2.6	230.4	1727	54	0.18	0.11
Hewitt	8	97	6.9	39.2	2.6	8	13.1	1.7	188	16.1	7.1	3.8	239.7	60.8	168.9	5135	248	2.73	2.45
Judd	1	18	6.0	5.0	0.4	3	2.0	0.7	34	2.7	2.3	2.3	59.1	17.6	384.9	3799	na	0.20	0.12
Larson	45	72	6.6	11.6	0.7	11	6.7	0.4	62	7.1	3.1	2.3	149.8	9.7	584.7	3754	93	0.23	0.44
Red Shirt	4	83	6.9	34.8	4.6	14	8.7	1.9	75	11.9	4.7	3.5	252.5	13.3	117.3	3458	42	1.42	1.37
Shell	25	32	6.5	13.3	0.8	17	4.4	0.5	174	8.5	3.6	3.2	211.5	34.3	535.4	4182	88	0.26	0.43
Stephan	7	107	7.2	38.5	1.5	17	10.2	2.4	131	13.8	7.8	5.8	163.6	6.0	19.6	5315	132	1.41	1.21
Whiskey	1	59	6.9	23.0	3.3	6	8.7	1.6	180	26.8	3.9	2.8	332.7	11.5	4.1	4242	na	8.95	4.43

[a]Indicates not available.

Table 6. Comparison of temperature profiles and dissolved oxygen (D.O.) concentrations during July and August 1993 for study lakes of the Susitna River drainage.

Byers (8/17/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	15.0	8.7
1	14.5	9.0
2	14.5	8.9
3	14.4	9.1
4	14.1	9.0
5	13.6	9.0
6	12.9	8.9
7	12.4	9.2
8	11.7	9.2
9	10.1	9.5
10	8.2	9.7
15	5.8	9.2
20	5.2	9.2
25	5.0	9.0
30	4.7	9.0
35	4.6	8.9
40	4.6	8.8

Chelatna (7/6/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	11.0	11.9
1	11.0	11.9
2	11.0	11.9
3	11.0	11.9
4	10.5	12.0
5	10.5	12.0
6	8.5	13.1
7	7.5	13.3
8	7.5	13.4
9	7.0	13.4
10	7.0	13.4
16	6.0	13.7
20	5.0	13.5
25	4.5	13.3
30	4.0	12.9
35	4.0	12.7
40	4.0	12.3

Hewitt (8/20/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	15.3	8.5
1	15.4	8.5
2	15.4	8.5
3	15.4	8.7
4	15.4	8.6
5	14.7	8.8
6	11.8	9.6
7	9.4	11.3
8	7.4	11.9
9	5.9	8.0
10	5.2	6.6
12	5.0	6.0
14	4.8	5.6
16	4.5	4.0
18	4.4	2.0

Judd (8/25/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	12.0	9.8
1	11.8	10.2
2	11.3	10.2
3	11.3	10.2
4	11.0	10.5
5	11.0	10.8
6	11.0	10.7
7	10.8	10.7
8	10.6	10.8
9	10.4	10.8
10	10.1	10.8
15	7.5	12.2
20	5.0	12.5
25	4.0	12.0
30	4.0	10.0
35	4.0	10.0

Larson (8/17/93)		
Depth (m)	Temp (C)	D.O. (mg/L)
0	17.3	8.7
1	17.0	8.8
2	16.8	8.8
3	16.8	8.8
4	16.8	8.8
5	16.8	8.8
6	16.5	8.7
7	12.8	10.0
8	10.9	10.2
9	8.8	11.5
10	6.6	12.2
15	4.5	11.2
20	4.2	11.3
25	4.0	11.0
30	3.9	10.8
35	3.8	9.7

Red Shirt (8/20/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	16.8	7.6
1	16.8	7.5
2	16.8	7.5
3	16.8	7.5
4	16.8	7.5
5	16.8	7.7
6	16.8	7.7
7	14.2	2.5
8	10.9	2.2
10	8.6	1.1
11	8.1	0.8
12	8.0	0.6
13	7.8	0.6
14	7.7	0.5

Shell (8/20/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	15.0	9.6
1	15.0	9.8
2	15.0	9.8
3	15.0	9.9
4	15.0	10.0
5	15.0	9.8
6	15.0	9.6
7	15.0	9.6
8	13.0	9.6
9	10.5	9.5
10	9.0	9.2
15	7.5	8.8
20	7.0	8.8
25	6.8	8.6

Stephan (8/17/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	14.7	8.7
1	14.5	8.8
2	14.4	8.8
3	14.3	8.8
4	14.3	8.6
5	14.1	8.4
6	13.0	7.9
7	11.5	7.8
8	9.5	7.4
9	8.7	7.3
10	8.1	7.3
15	6.9	6.7
20	6.3	6.0

Whiskey (8/20/93)		
Depth (m)	Temp (°C)	D.O. (mg L^{-1})
0	15.3	7.6
1	15.3	8.0
2	15.3	8.1
3	15.1	8.0
4	15.1	7.4

Table 7. Value and corresponding ranking by surface area/volume (SA/V), morphoedaphic index (MEI), total phosphorus (TP), chlorophyll a (CHL *a*), and summation (SUM) derived from the August 1993 limnological surveys on study lakes within the Susitna River drainage. Data are ranked numerically from 1 to 9 indicating an increase in the degree of oligotrophy.

	SA/V		MEI		TP		CHL *a*			
Lake	Value	Rank	Value	Rank	Value	Rank	Value	Rank	SUM	Overall Ranking
Byers	0.06	6.5	1.8	7	4.1	6	0.40	7	26.5	7
Chelatna	0.02	9	0.4	9	2.3	8	0.17	9	35	9
Hewitt	0.07	5	6.2	4	7.4	3	1.66	2	14	4
Judd	0.05	8	<1.0	8	2.2	9	0.20	8	33	8
Larson	0.06	6.5	4.1	5	3.2	7	0.72	6	24.5	6
Red Shirt	0.20	2	12.2	3	5.5	4.5	1.23	3	12.5	3
Shell	0.10	4	2.8	6	5.5	4.5	0.87	4	18.5	5
Stephan	0.11	3	14.6	2	8.6	2	0.77	5	12	2
Whiskey	0.37	1	19.7	1	9.3	1	4.30	1	4	1

Table 8. Summary of zooplankton density and biomass for study lakes of the Susitna River drainage.

Lake	Sample year	Number of sample dates	Station	Mean density (no m^{-2})	Mean biomass (mg m^{-2})	Numerically dominant taxa
Larson	1981	4	A	671,895	1,586	*Cyclops*
		4	B	170,097	445	*Cyclops*
			Mean 1981	420,996	1,016	
	1984	3	A	333,716	820	*Cyclops*
		2	B	146,165	300	*Cyclops*
			Mean 1984	239,941	560	
	1985	4	A	274,201	815	*Cyclops*
	1986	4	A	602,122	1,515	*Cyclops*
		4	B	442,364	1,722	*Cyclops* & *Bosmina*
			Mean 1986	522,243	1,619	
	1987	3	A	674,540	2,381	*Cyclops* & *Daphnia*
		3	B	786,414	3,555	*Daphnia*
			Mean 1987	730,477	2,968	
	1993	1	1	606,688	1,546	*Cyclops*
Stephan	1984	2	1	363,365	1,094	*Diaptomus* & *Cyclops*
	1985	4	1	403,795	912	*Cyclops* & *Diaptomus*
	1986	1	1	159,236	311	*Cyclops*
	1993	1	1	299,362	864	*Cyclops* & *Diaptomus*
Byers	1981	1	A	29,865	105	*Cyclops*
		1	B	358,975	1,124	*Cyclops*
			Mean 1981	194,420	615	
	1982	1	A	32,086	111	*Cyclops*
		1	B	276,009	1,090	*Cyclops*
			Mean 1982	154,048	601	
	1983	3	A	630,045	1,282	*Cyclops*
	1984	3	A	304,288	740	*Cyclops*
	1993	1	1	282,908	693	*Cyclops* & *Bosmina*
Judd	1993	1	1	110,403	582	*Holopedium* & *Cyclops*
Shell	1984	4	A	332,995	962	*Cyclops* & *Daphnia*
		1	B	61,301	157	*Cyclops* & *Bosmina*
			Mean 1984	197,148	560	
	1985	5	A	270,140	1,039	*Cyclops* & *Daphnia*
	1986	4	A	200,370	636	*Cyclops* & *Daphnia*
	1987	3	A	313,163	1,099	*Cyclops* & *Diaptomus*
		3	B	133,492	338	*Cyclops* & *Diaptomus*
			Mean 1987	223,328	719	
	1993	1	1	208,599	575	*Cyclops* & *Diaptomus*
Hewitt	1984	3	1	629,954	1,270	*Cyclops* & *Daphnia*
	1985	4	1	822,253	1,559	*Cyclops* & *Daphnia*
	1986	2	1	102,088	317	*Cyclops* & *Daphnia*
	1993	1	1	181,529	548	*Cyclops* & *Daphnia*
Chelatna	1984	3	A	450,991	1,671	*Diaptomus*
	1985	2	A	511,812	1,768	*Cyclops* & *Diaptomus*
	1988	4	A	619,559	1,882	*Diaptomus*
	1989	1	A	489,649	1,438	*Diaptomus* & *Cyclops*
	1990	3	A	69,445	309	*Cyclops*
	1991	3	A	60,102	224	*Cyclops* & *Diaptomus*
	1992	3	A	142,445	400	*Diaptomus*
	1993	3	A	143,931	485	*Cyclops*
Red Shirt	1984	3	1	173,523	419	*Cyclops*
	1985	1	1	91,165	195	*Cyclops*
	1993	1	1	27,070	82	*Cyclops*
Whiskey	1993	1	1	5,520	25	*Epischura*

Table 9. Summary of 1993 juvenile sockeye salmon population estimates and fish densities in seven lakes within the Susitna River drainage.

Lake	Total estimated targets	Estimated no. sockeye fry	Highest density strata			Mean surface density	
			No. of fish m^{-1}	No. of sockeye fry m^{-1}	Strata (m below transducer)	No. of fish m^{-1}	No. of sockeye fry m^{-1}
Redshirt	1,025,000	1,082	0.0519	0.0001	1-4	0.2320	0.0002
Shell	1,354,520	19,843	0.0230	0.0003	5-10	0.2542	0.0037
Larson	269,064	9,737	0.0207	0.0007	2-4.5	0.1591	0.0058
Hewitt	3,100,714	447,080	0.2055	0.0296	1-5	1.4140	0.2039
Judd	343,000	277,559	0.0249	0.0202	5-10	0.2861	0.2315
Byers	108,000	91,256	0.0084	0.0071	5-9	0.0749	0.0633
Chelatna	1,427,000	1,293,813	0.0080	0.0073	4-8	0.1407	0.1276

Table 10. Summary of the number of fish caught during towneting in seven lakes within the Susitna River drainage during 1993.

Lake	Tow minutes	Number of fish								Percent sockeye
		Sockeye	Coho	Stickleback	Sculpin	Rainbow trout	Lake trout	Whitefish	Total	
Byers	297	109	4	11	4	1			129	84.5
Chelatna	490	68						7	75	90.7
Hewitt	75	620		3,680					4,300	14.4
Judd	262	369	1	86					456	80.9
Larson	351	267	1	7,110					7,378	3.6
Redshirt	263	6		5,675	1				5,682	0.1
Shell	252	19		1,275	2		1		1,297	1.5

Table 11. Size and age of juvenile sockeye salmon fry and size of stickleback caught during townetting of seven lakes within the Susitna River drainage in 1993.

Lake	Age-0 sockeye							Age-1 sockeye							Stickleback			
		Length (mm)			Weight (g)				Length (mm)			Weight (g)				Length (mm)		
	N	Min	Max	Mean	Min	Max	Mean	N	Min	Max	Mean	Min	Max	Mean	N	Min	Max	Mean
Redshirt															113	22	47	32
Shell	13	55	72	63	2.1	4.7	3.3								121	24	51	34
Larson	249	37	75	55	0.6	5.2	2.1	5	65	75	68	3.4	5.2	4.0	293	17	43	28
Hewitt	596	29	69	49	0.2	4.1	1.4	17	66	82	75	3.2	6.7	4.9	154	20	58	28
Judd	329	27	65	46	0.2	2.9	1.2	29	57	72	64	2.1	4.4	3.1	67	16	51	34
Byers	97	49	86	64	1.3	8.0	3.5	0							11	28	60	52
Chelatna	65	34	82	62	0.5	8.1	3.3	1										

Table 12. Location, land status, ownership, size, and estimated costs of potential weir sites for eight lakes within the Susitna River drainage.

Lake	Location	Land status	Land owner	Weir size (feet)	Manpower for weir construction	Estimated costs: Weir materials	Estimated costs: Manpower	Estimated costs: Total
Red Shirt	T18N, R5W, sec33, 4 USS 3223	Private	Helen Kurtz HCR 02 Box 7010 Palmer, AK. 99645	50	1 man/month	$1,400	$3,500	$4,900
Byers	T30N, R5W, sec 4 USS 7418	Private	Jas Peter Seibert & Paul J Nangle RR 3 Box 1142 Crete, IL. 60417	100	2 man/months	$2,300	$7,000	$9,300
Larson	T26N, R3W, sec 8 Tract C ADL 026805 (06158)	Public	State of Alaska Department of Natural Resources	100	3 man/months	$3,600	$10,500	$14,100
Stephan	T30N, R3E, sec 19 USS5206	Public	Federal Government Bureau of Land Management	100	2 man/months	$2,300	$7,000	$9,300
Judd	T21N, R13W, sec 13 USS 3917 Lot 3	Public	State of Alaska Alaska Department of Fish and Game	130	2.5 man/months	$2,900	$8,750	$11,650
Shell	T21N, R12W, sec 8 Tract A USS 3987	Public	State of Alaska Department of Natural Resources	80	1.5 man/months	$2,000	$5,250	$7,250
Hewitt	T22N, R11W, sec 19 Lot 42 Hewitt Whiskey Lake Subdivision (6140)	Public	State of Alaska Department of Natural Resources	130	2.5 man/months	$2,900	$8,750	$11,650
Whiskey	T22N, R12W, sec 24 Lot 58 Hewitt Whiskey Lake Subdivision (6140)	Public	State of Alaska Department of Natural Resources	50	1 man/month	$1,400	$3,500	$4,900
			Totals	740	15.5 man/months	$18,800	$54,250	$73,050

Table 13. Estimated operation cost for adult salmon counting weirs at eight lakes within the Susitna River drainage.

Lake	Weir materials[a]	Camp supplies[b]	Personnel[c]	Air charter[d]	Food and misc supplies[e]	Total expenditures	
						First year	Other years
Red Shirt	$5,000	$9,000	$16,000	$4,000	$2,500	$36,500	$22,500
Byers	$10,000	$9,000	$16,000		$2,500	$37,500	$18,500
Larson	$10,000	$9,000	$16,000		$2,500	$37,500	$18,500
Stephan	$10,000	$9,000	$16,000	$4,000	$2,500	$41,500	$22,500
Judd	$13,000	$9,000	$16,000	$4,000	$2,500	$44,500	$22,500
Shell	$8,000	$9,000	$16,000	$4,000	$2,500	$39,500	$22,500
Hewitt	$13,000	$9,000	$16,000	$4,000	$2,500	$44,500	$22,500
Whiskey	$5,000	$9,000	$16,000	$4,000	$2,500	$36,500	$22,500
Totals	$74,000	$72,000	$128,000	$24,000	$20,000	$318,000	$172,000

[a]Assumes a cost for weir materials and fabrication of $100 per foot of weir.
[b]Camp supplies include weatherport, rubber raft, outboard motor, refrigerator, stove, heater, etc..
[c]Assumes 2 technicians for 2 months at $4,000 per month (includes overtime).
[d]Assumes aircharter from Willow, add $2,000 per weir from Anchorage and $4,000 from Soldotna.
[e]Covers food, fuel, batteries, and miscellaneous camp supplies.

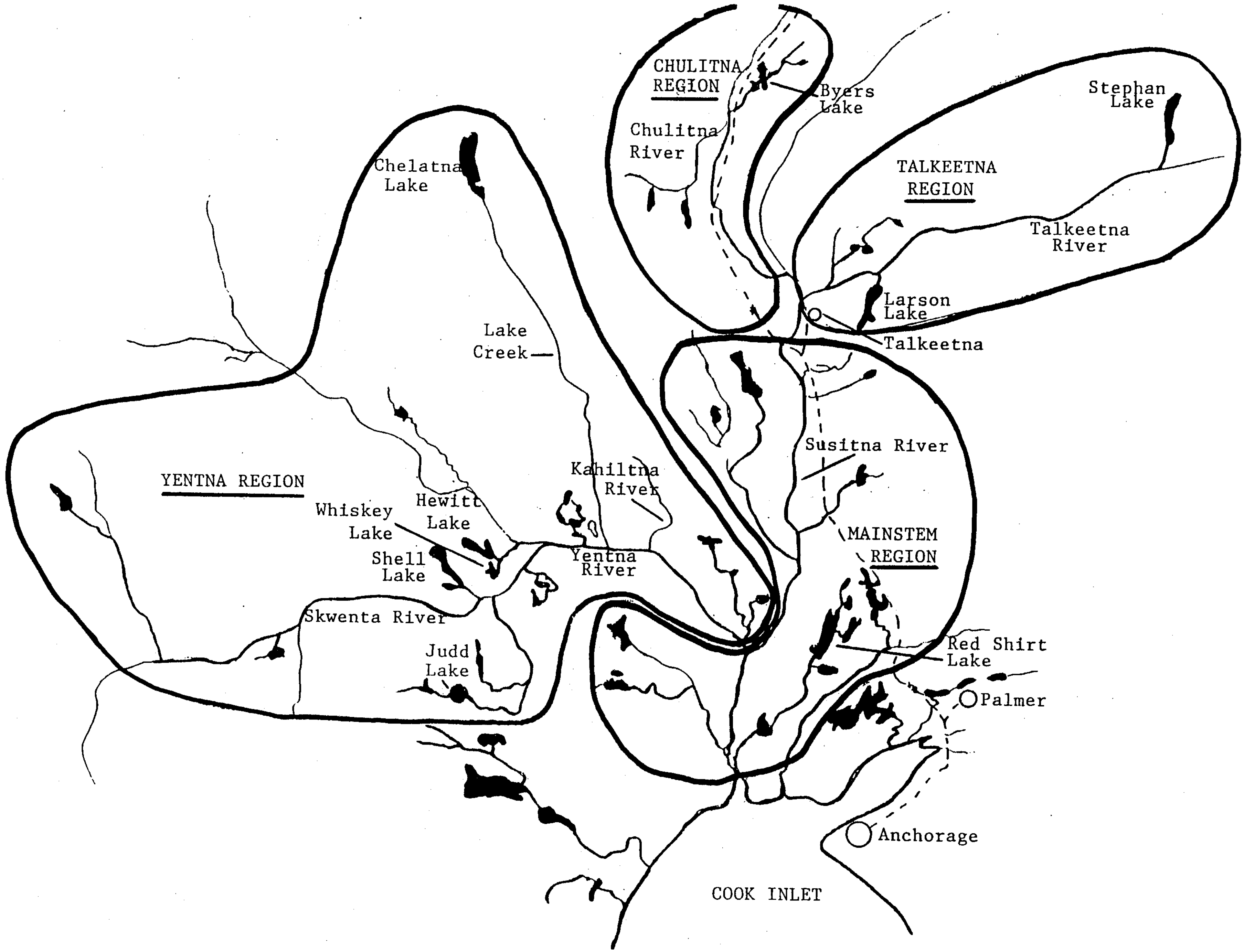


Figure 1. Location of the nine study lakes and the four regions within the Susitna River drainage.

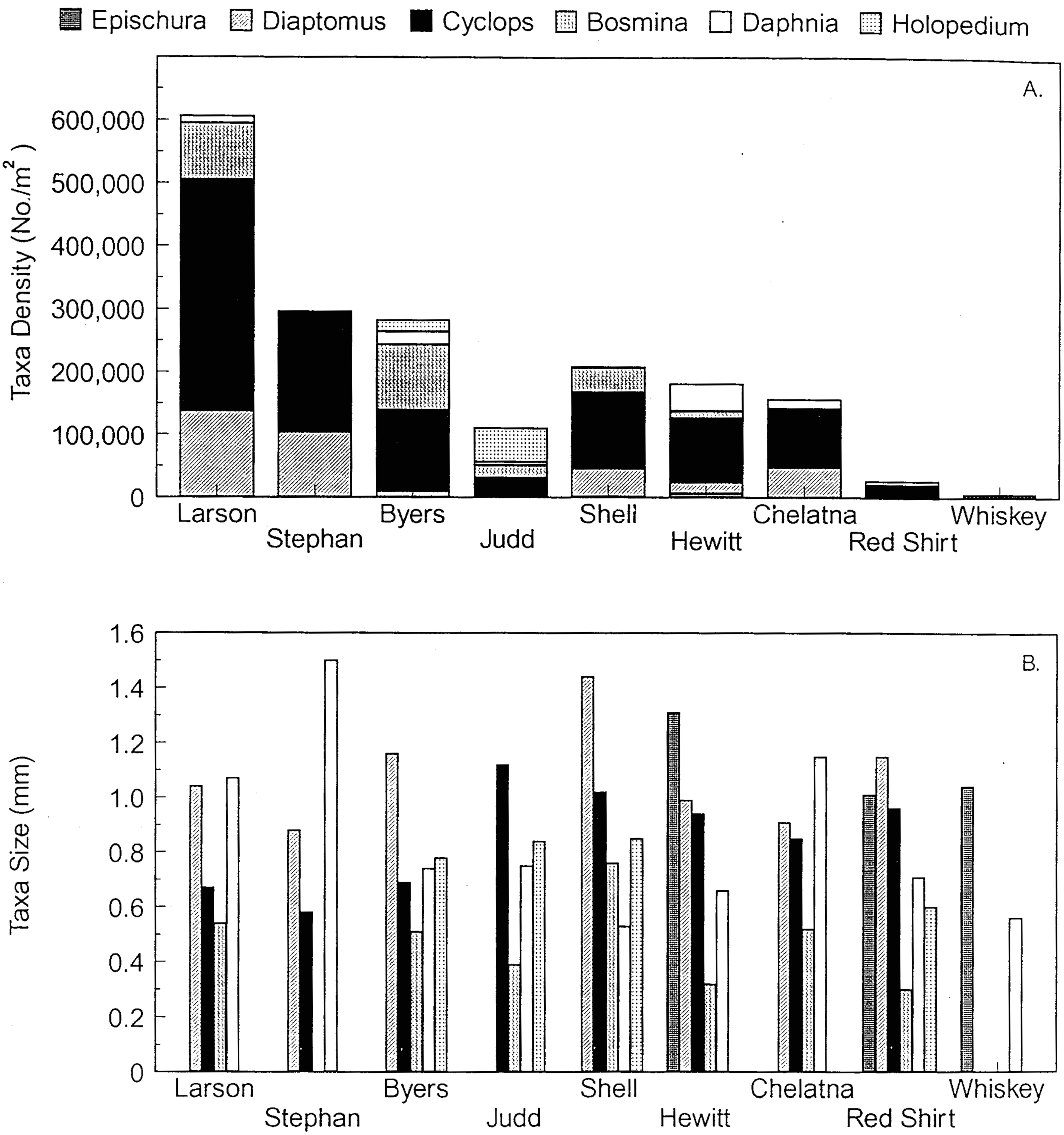


Figure 2. Zooplankton density(A) and taxa size (B) for nine lakes within the Susitna River drainage that were sampled once in 1993.

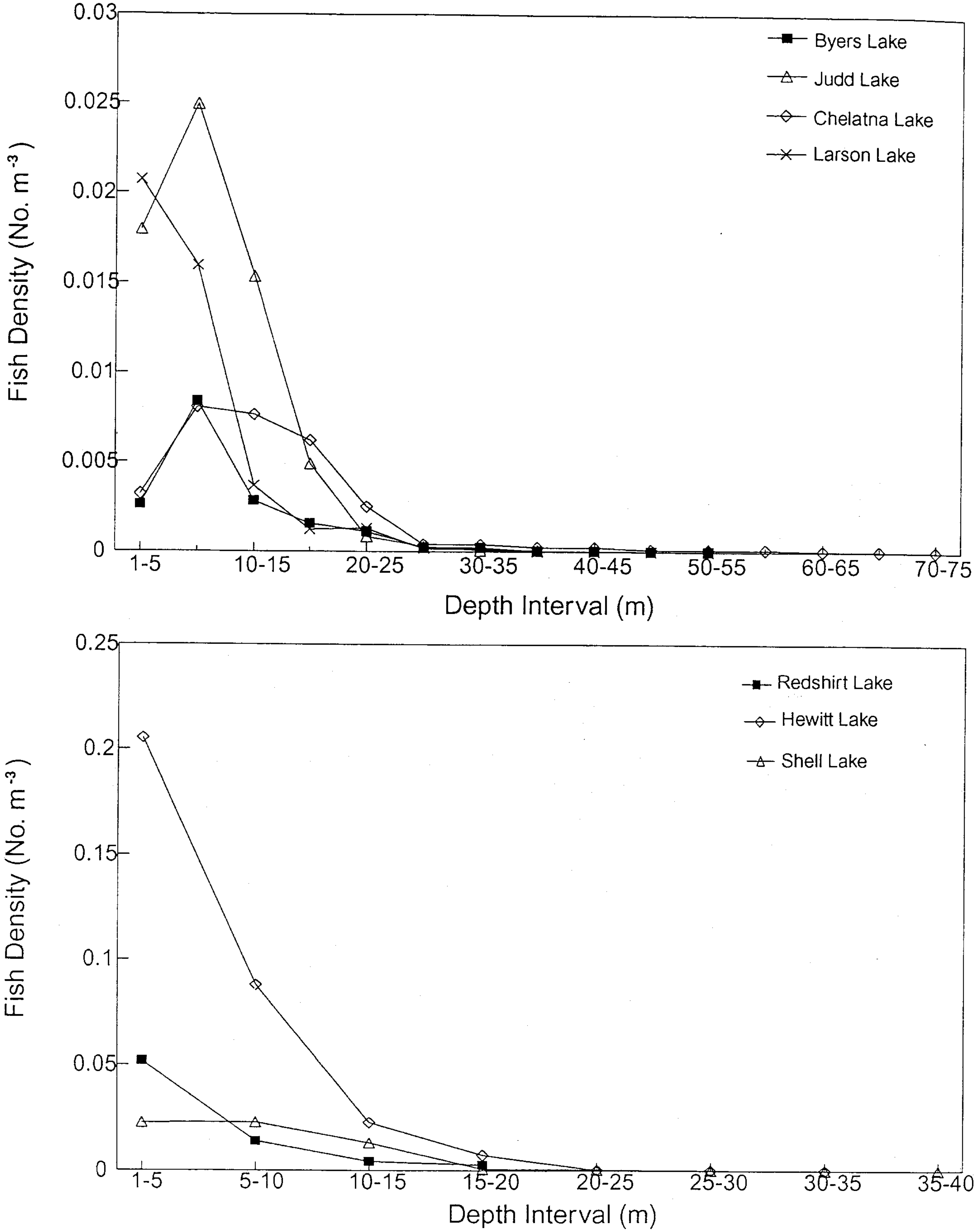


Figure 3. Fish density by depth interval for seven lakes within the Susitna River drainage that were surveyed once in 1993.

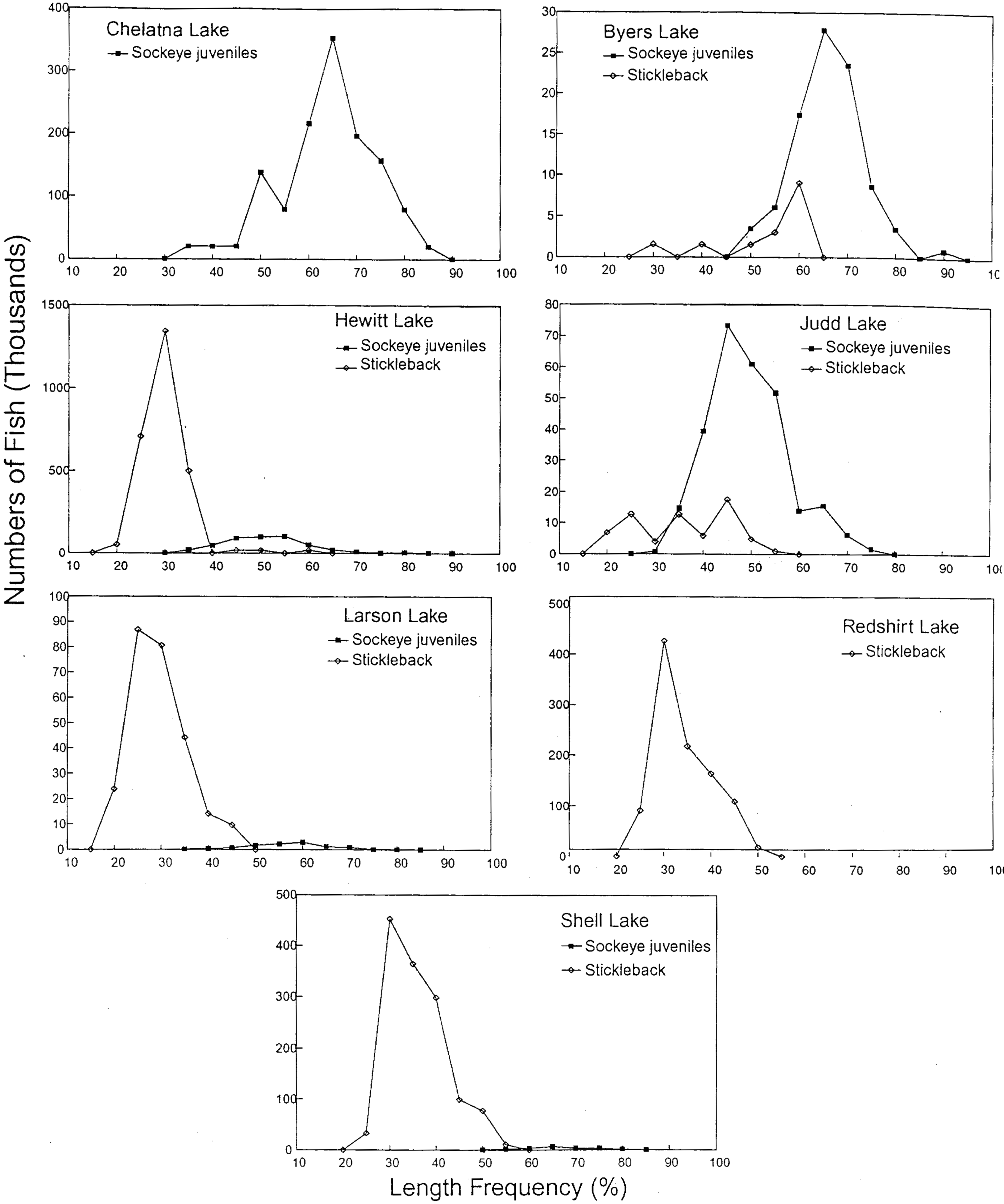
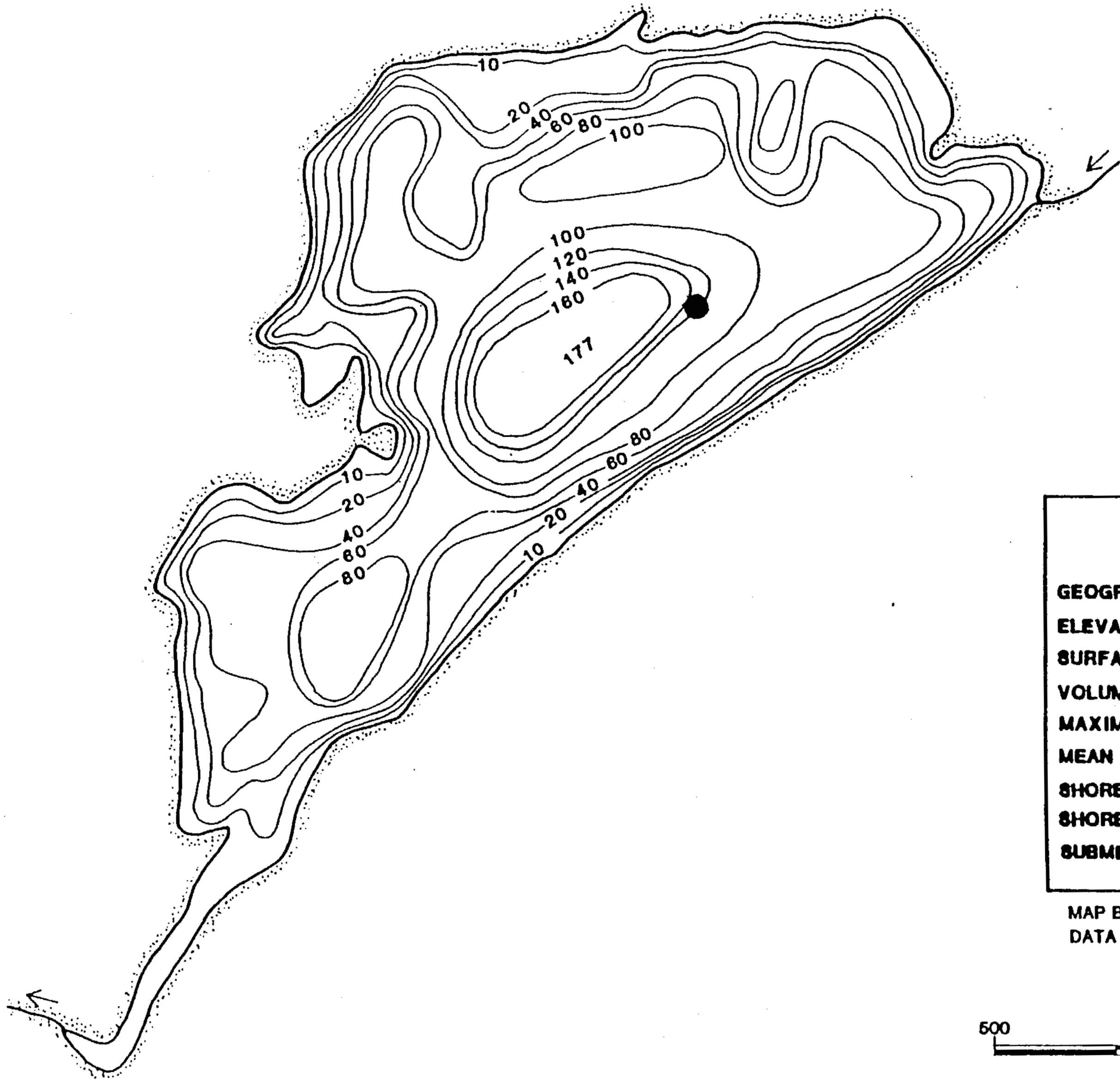


Figure 4. Length frequency distributions of fish caught during townetting in seven lakes within the Susitna River drainage in 1993.

APPENDIX A

Morphometric maps of study lakes



NORTH

BYERS LAKE

GEOGRAPHIC LOCATION:	62°44'15"N 150°06'40"W
ELEVATION:	248.8m (816ft)
SURFACE AREA:	131.5ha (325a
VOLUME:	26.7 x $10^6 m^3$ (21,635a-ft)
MAXIMUM DEPTH:	54.0m (177ft)
MEAN DEPTH:	20.0m (66ft)
SHORELINE LENGTH:	6.4km (4.0mi)
SHORELINE DEVELOPMENT:	1.58
SUBMERGED CONTOURS:	feet

MAP BY: Bradley & Wilson (ADFG) 8/75
DATA BY: Lebida & Probasco (ADFG) 8/79

500 0 1000 feet

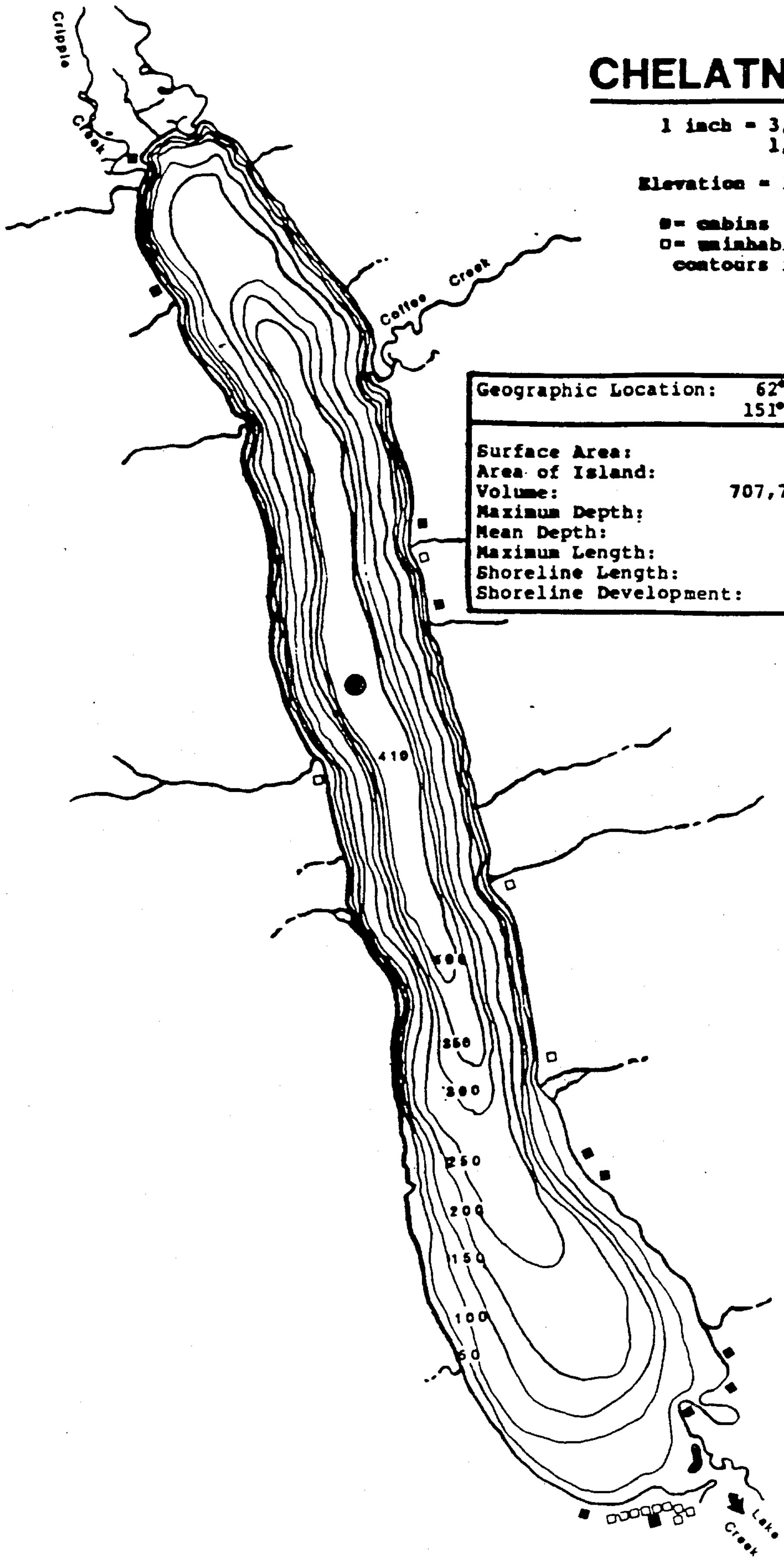
500 0 500 meters

CHELATNA LAKE

1 inch = 3,827 feet
1,167 m

Elevation = 1,384 feet
422 m

■= cabins
□= uninhabited cabins
contours in feet



Geographic Location:		
	62° 29' 30'' North Latitude	
	151° 27' 15'' West Longitude	
Surface Area:	1,108 ha	2,739 A
Area of Island:	2 ha	5 A
Volume:	707,700,000 m³	573,675 AF
Maximum Depth:	125 m	410 FT
Mean Depth:	64 m	209 FT
Maximum Length:	9.9 km	6.1 MI
Shoreline Length:	23.4 km	14.5 MI
Shoreline Development:	2.0	

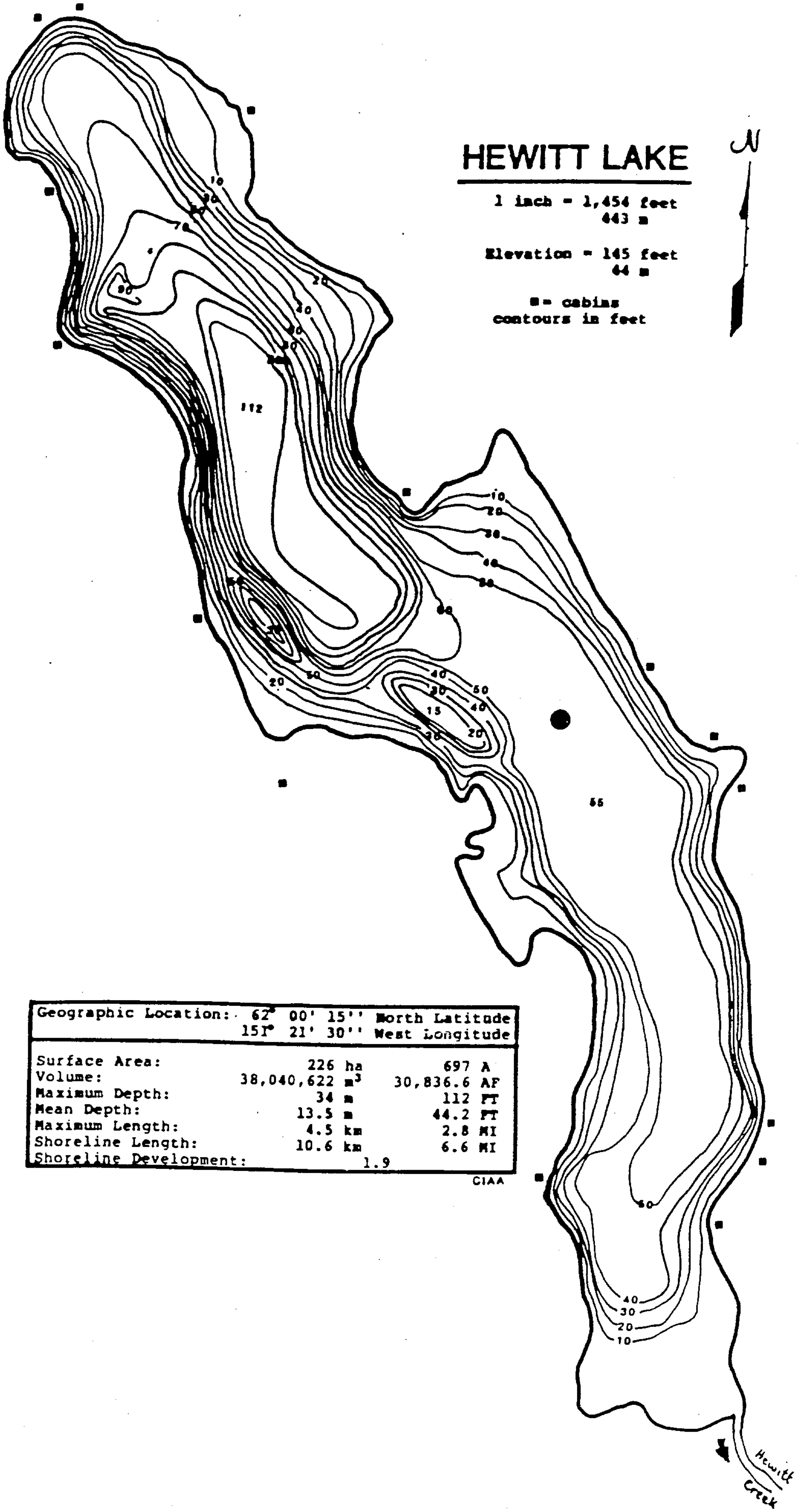
CIAA

HEWITT LAKE

1 inch = 1,454 feet
443 m

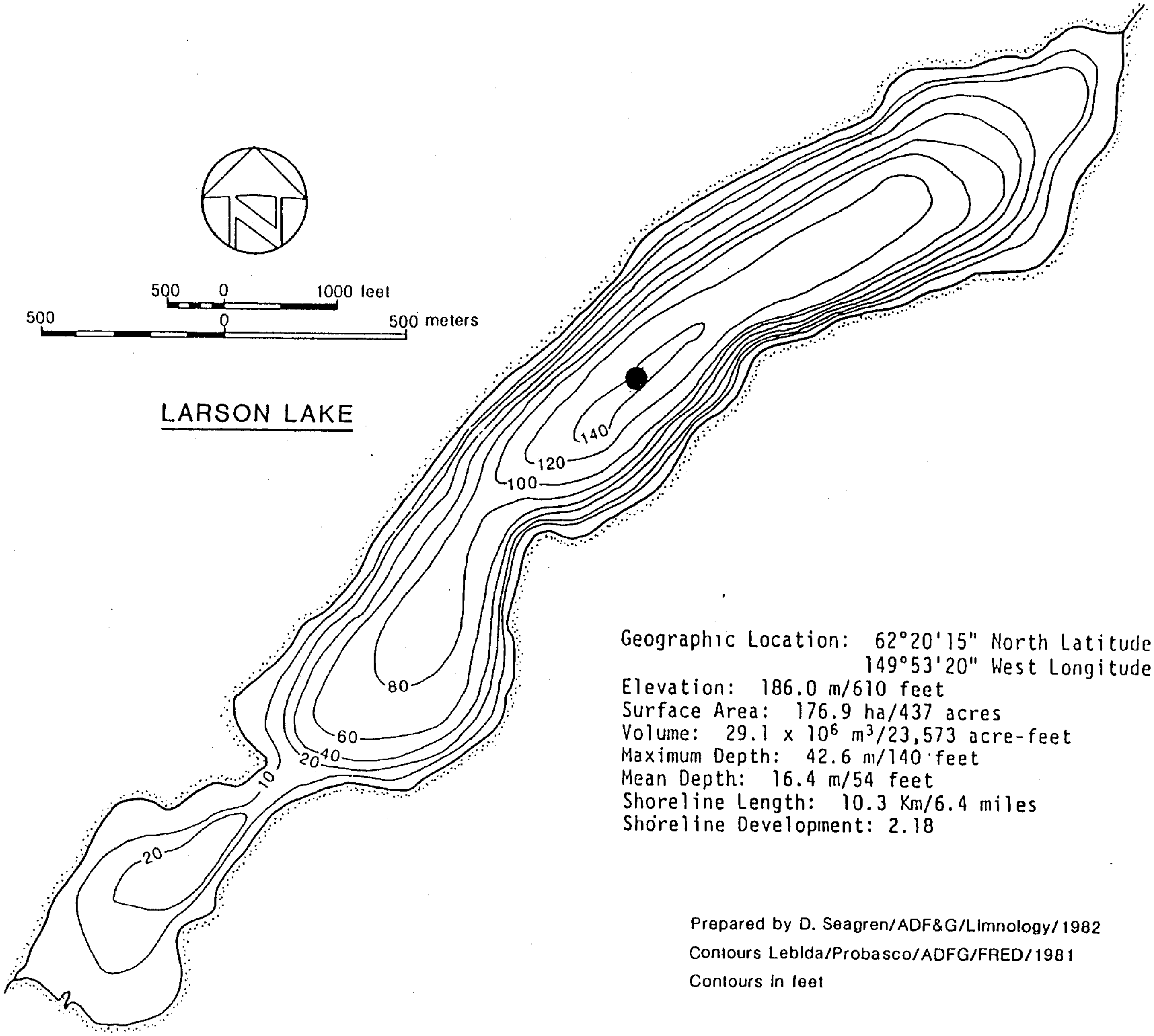
Elevation = 145 feet
44 m

■ = cabins
contours in feet



Geographic Location:	62° 00' 15'' North Latitude	
	151° 21' 30'' West Longitude	
Surface Area:	226 ha	697 A
Volume:	38,040,622 m^3	30,836.6 AF
Maximum Depth:	34 m	112 FT
Mean Depth:	13.5 m	44.2 FT
Maximum Length:	4.5 km	2.8 MI
Shoreline Length:	10.6 km	6.6 MI
Shoreline Development:	1.9	

LARSON LAKE

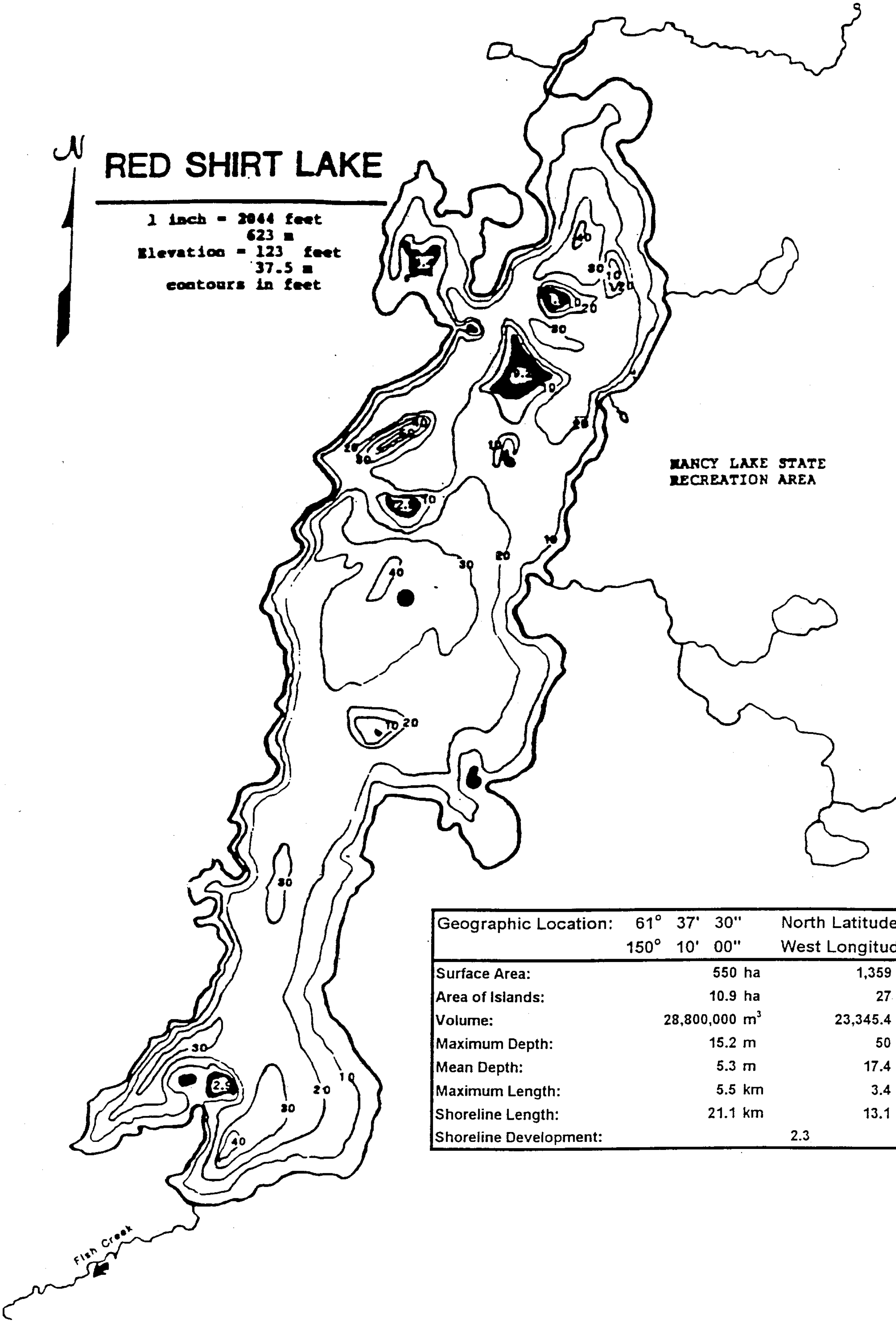


Geographic Location: 62°20'15" North Latitude
149°53'20" West Longitude
Elevation: 186.0 m/610 feet
Surface Area: 176.9 ha/437 acres
Volume: 29.1 x 10^6 m^3/23,573 acre-feet
Maximum Depth: 42.6 m/140 feet
Mean Depth: 16.4 m/54 feet
Shoreline Length: 10.3 Km/6.4 miles
Shoreline Development: 2.18

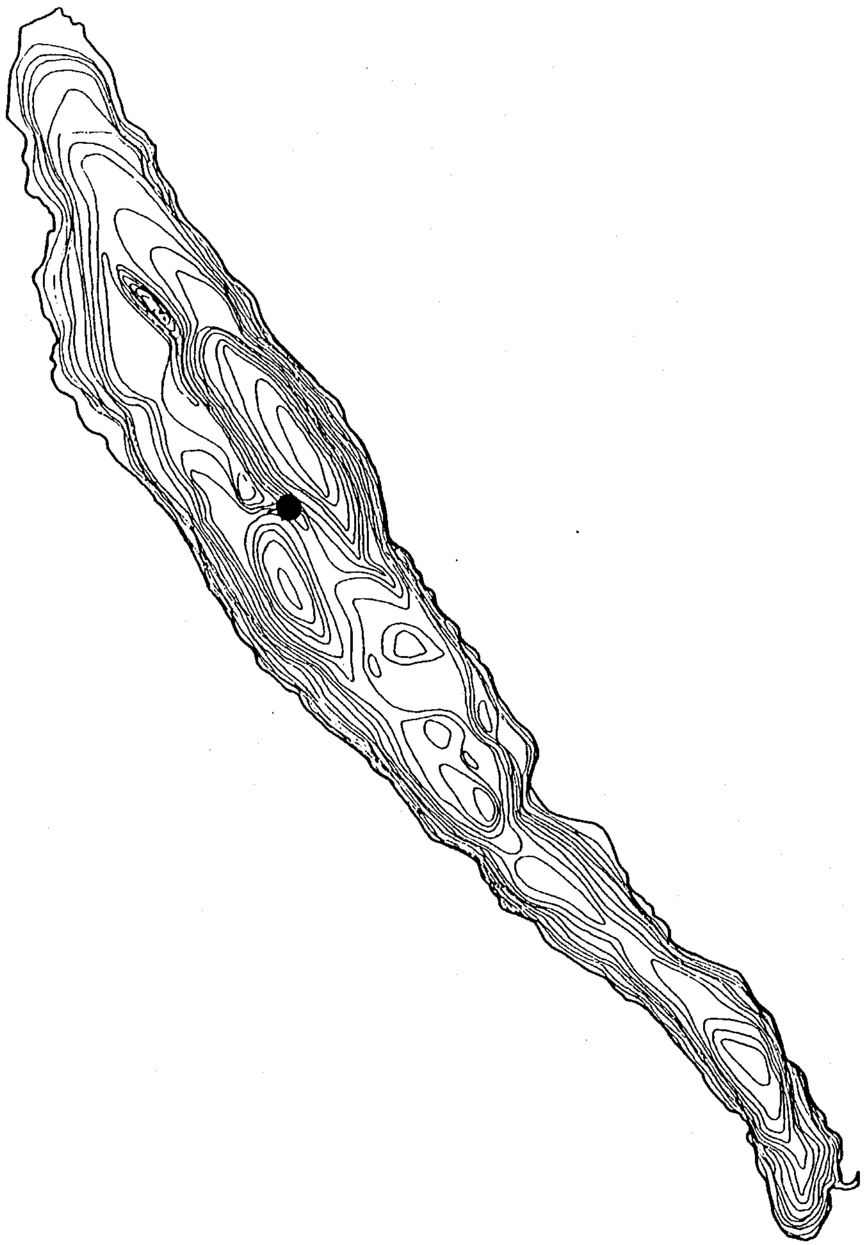
Prepared by D. Seagren/ADF&G/Limnology/1982
Contours Lebida/Probasco/ADFG/FRED/1981
Contours in feet

RED SHIRT LAKE

1 inch = 2044 feet
623 m
Elevation = 123 feet
37.5 m
contours in feet



Geographic Location:	61° 37' 30"	North Latitude
	150° 10' 00"	West Longitude
Surface Area:	550 ha	1,359 A
Area of Islands:	10.9 ha	27 A
Volume:	28,800,000 m^3	23,345.4 AF
Maximum Depth:	15.2 m	50 FT
Mean Depth:	5.3 m	17.4 FT
Maximum Length:	5.5 km	3.4 MI
Shoreline Length:	21.1 km	13.1 MI
Shoreline Development:	2.3	



NORTH

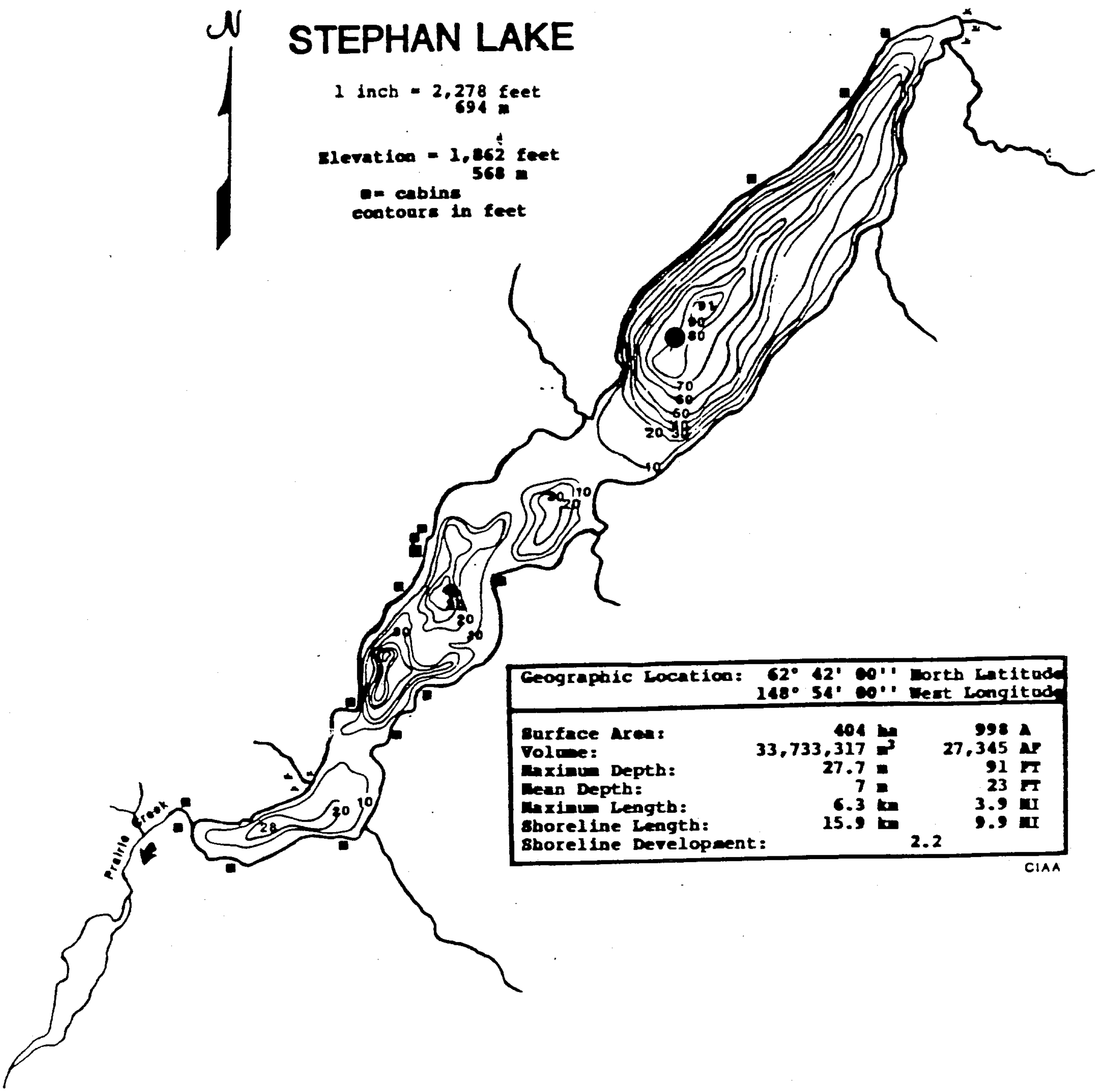
SHELL LAKE

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

MAP BY: Lebida (ADFG) 11/81
DATA BY: Seagren (ADFG) 2/82

1000 0 2000 feet

1000 0 1000 meters



Geographic Location:	62° 42' 00'' North Latitude	
	148° 54' 00'' West Longitude	
Surface Area:	404 ha	998 A
Volume:	33,733,317 m^3	27,345 AF
Maximum Depth:	27.7 m	91 FT
Mean Depth:	7 m	23 FT
Maximum Length:	6.3 km	3.9 MI
Shoreline Length:	15.9 km	9.9 MI
Shoreline Development:	2.2	