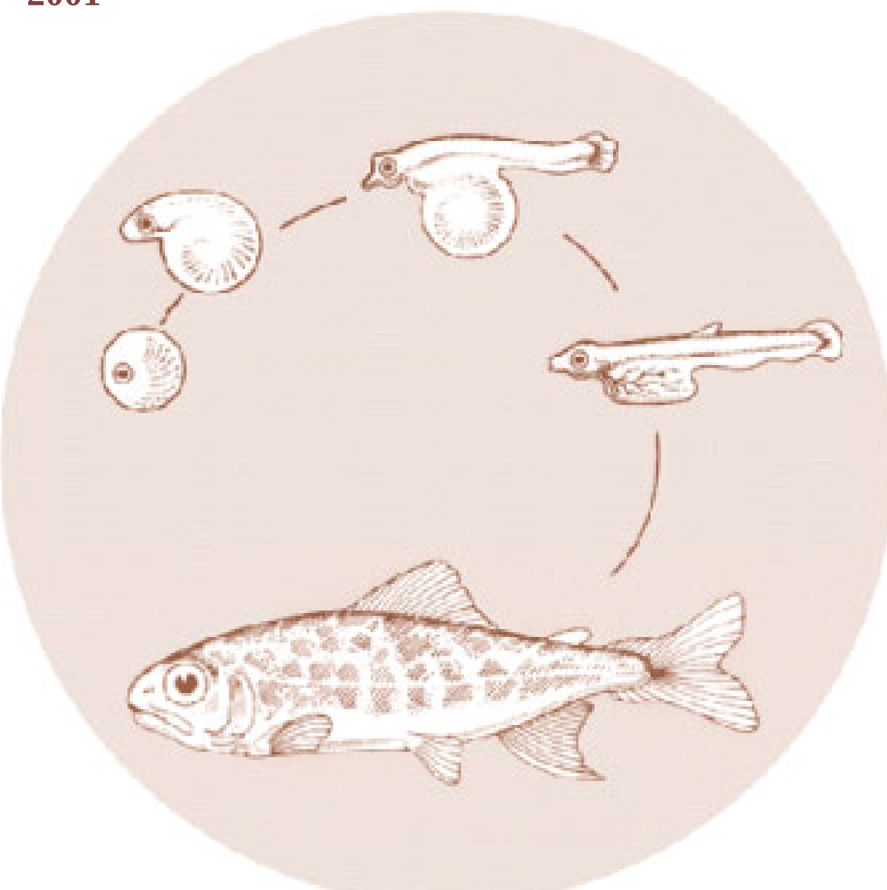
Snake River Sockeye Salmon Habitat and Limnological Research

Annual Report
2001



DOE/BP-00004343-4

August 2004

This Document should be cited as follows:

Kohler, Andre, Doug Taki, Robert Griswold, "Snake River Sockeye Salmon Habitat and Limnological Research", 2001 Annual Report, Project No. 199107100, 108 electronic pages, (BPA Report DOE/BP-00004343-4)

Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

SNAKE RIVER SOCKEYE SALMON HABITAT

AND LIMNOLOGICAL RESEARCH: 2001 ANNUAL PROGRESS REPORT

Prepared by:

Andre E. Kohler
Doug Taki
Robert G. Griswold[1]

Shoshone-Bannock Tribes
P.O. Box 306
Fort Hall, Idaho 83203

[1] Biolines
HC-64 Box 9965
Stanley, Idaho 83278

Prepared for:

U.S. Department of Energy
Bonneville Power Administration
Environment, Fish and Wildlife
P.O. Box 3621
Portland, Oregon 97208-3621

Project Number 91-71

April 2003

EXECUTIVE SUMMARY

In March 1990, the Shoshone-Bannock Tribes petitioned the National Marine Fisheries Service (NMFS) to list the Snake River sockeye salmon *Oncorhynchus nerka* as endangered. As a result of that petition the Snake River sockeye salmon was officially listed as endangered in November 1991 under the Endangered Species Act (56 FR 58619). In 1991, the Snake River Sockeye Salmon Habitat and Limnological Research Program was implemented (Project Number 91-71, Intergovernmental Contract Number DE-BI79-91bp22548). This project is part of an interagency effort to prevent the extinction of the Redfish Lake stock of *O. nerka*.

The Bonneville Power Administration (BPA) provides funding for this interagency recovery program through the Northwest Power Planning Council Fish and Wildlife Program (Council). Collaborators in the recovery effort include the National Marine Fisheries Service (NMFS), the Idaho Department of Fish and Game (IDFG), the University of Idaho (UI), U.S. Forest Service (USFS), and the Shoshone-Bannock Tribe (SBT). This report summarizes activities conducted by Shoshone-Bannock Tribal Fisheries Department personnel during the 2001 calendar year. Project objectives include: 1) monitor over-winter survival and emigration of juvenile anadromous *O. nerka* stocked from the captive rearing program; 2) fertilize Redfish Lake, fertilization of Pettit and Alturas lakes was suspended for this year; 3) conduct kokanee (non-anadromous *O. nerka*) population surveys; 4) monitor spawning kokanee escapement and estimate fry recruitment on Fishhook, Alturas Lake, and Stanley Lake creeks; 5) evaluate potential competition and predation interactions between stocked juvenile *O. nerka* and a variety of fish species in Redfish, Pettit, and Alturas lakes; 6) monitor limnological parameters of Sawtooth Valley lakes to assess lake productivity.

Objective 1. Stocked juvenile sockeye over-winter survival in Pettit Lake was estimated using catches at the Pettit Lake Creek weir. Three release strategies were evaluated: 1) a direct lake summer release of Eagle Hatchery parr, 2) a direct lake summer release of Sawtooth Hatchery parr, and 3) a direct lake fall release of Sawtooth Hatchery parr. Two

thousand nine hundred and fifteen parr sockeye from the Eagle Fish Hatchery (adipose and right ventral fin clip (ADRV)) captive rearing program were stocked into Pettit Lake in the summer of 2000. Fifty-seven ADRV smolts out-migrated from Pettit Lake during the spring of 2001, resulting in an estimated 2.0% over-winter survival rate. Additionally, 3,092 parr sockeye from the Sawtooth Fish Hatchery (adipose and left ventral fin clip (ADLV)) were stocked into Pettit Lake in the summer of 2000. One hundred fifty-six ADLV smolts emigrated from Pettit Lake during the spring of 2001, resulting in an estimated 5.1% over-winter survival rate. In the fall of 2000, 6,067 parr sockeye from the Sawtooth Fish Hatchery (adipose clip only (AD)) were stocked into Pettit Lake. 1,756 AD smolts emigrated from Pettit Lake during the spring of 2001, resulting in an estimated 29.0% over-winter survival rate. Stocked juvenile sockeye over-winter survival in Alturas Lake was estimated using catches at the Alturas Lake Creek screw trap. Three release strategies were evaluated: 1) a direct lake summer release of Eagle Hatchery parr, 2) a direct lake summer release of Sawtooth Hatchery parr and 3) a direct lake fall release of Sawtooth Hatchery parr. Alturas Lake was stocked with 2,917 parr (ADRV) sockeye from the Eagle Fish Hatchery captive rearing program in the summer of 2000. An estimated 14 ADRV smolts emigrated from the lake in the spring of 2001, resulting in an estimated 0.5% over-winter survival rate. Additionally, 3,069 parr (ADLV) sockeye from the Sawtooth Fish Hatchery were stocked into Alturas Lake in the summer of 2000. An estimated 476 ADLV smolts emigrated from the lake in the spring of 2001, resulting in an estimated 15.5% over-winter survival rate. In the fall of 2000, 6,003 parr (AD) sockeye from the Sawtooth Fish Hatchery captive rearing program were stocked into Alturas Lake. An estimated 4,520 AD smolts emigrated from Alturas Lake during the spring of 2001, resulting in an estimated 75.3% over-winter survival rate. Over-winter survival and out-migration for Redfish Lake was monitored by IDFG.

Objective 2. In 2001, only Redfish Lake received supplemental fertilization. Fertilizer was applied on a weekly basis by Shoshone-Bannock Tribal fisheries personnel during the summer growing season. Limnological parameters were concurrently monitored by

Tribal personnel and Biolines Consulting. For a detailed review of supplemental fertilization please see the limnological chapter of this report.

Objective 3. The hydroacoustic estimate of *O. nerka* population in the fall of 2001 for Redfish Lake was 43,849 ± 16,747 with a density of 71 fish/ha. Pettit Lake had an estimated population of 37,410 ± 24,864 and a density of 231 fish/ha. Alturas Lake had an estimated population of 130,359 ± 29,446 and a density of 386 fish/ha. Concurrent trawl sampling and density estimates were conducted by IDGF.

Objective 4. Stream spawner counts were used to monitor adult kokanee escapement to inlet streams on Redfish, Alturas, and Stanley lakes in 2001. Fishhook Creek, the primary kokanee spawning tributary on Redfish Lake, had an estimated escapement of 5,853 adult spawners, Stanley Lake Creek had an estimated 6,180 kokanee spawners, and Alturas Lake Creek had an estimated 145 adult spawners. Fry recruitment, calculated from male-female ratios, fecundity, and egg to fry survival rates is estimated at (78,327), (65,178), and (1,414) fry for Fishhook, Stanley Lake, and Alturas Lake creeks, respectively.

Objective 5. Potential competition and predation between stocked sockeye salmon (anadromous *O. nerka*), rainbow trout *O. mykiss*, and other fish species was investigated. In an analysis of rainbow trout diets there were no *O. nerka* found in the guts of any of the fish sampled. Diet overlap in Alturas Lake and Pettit Lake was 4% and 1% respectively for rainbow trout and *O. nerka* consisting of chironomid pupae. Age 0 sockeye salmon, the life stage of primary interest, fed primarily on zooplankton while rainbow trout diets were dominated by aquatic insects. Several potential kokanee/sockeye predators were identified in the lakes including bull char *Salvelinus confluentus*, northern pikeminnow *Ptychocheilus oregonensis*, and brook char *S. fontinalis*. Piscivory was evident with cyprinids found in the diet of northern pikeminnow and cyprinids and salmonids found in the diet of brook char. Bull char diet was composed primarily of salmonids and cyprinids. Due to the progressed state of digestion found in many stomach samples we cannot conclusively rule out predation on *O. nerka* by potential predators.

Objective 6. Limnological parameters including nutrient levels, chlorophyll *a*, secchi depth, primary productivity, heterotrophic bacteria, autotrophic picoplankton, phytoplankton, and zooplankton assemblage characteristics (species composition and densities) were monitored concomitant with fertilization activities.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1: Fisheries of the Sawtooth Valley Lakes

By

Andre Kohler and Doug Taki

Shoshone-Bannock Tribes
P.O. Box 306
Fort Hall, Idaho 83203

INTRODUCTION

Snake River salmon are a valuable cultural resource to the Shoshone-Bannock Tribes. The Shoshone-Bannock Tribes (SBT) traditionally utilized salmon of the Snake River Basin as a subsistence food resource. The Redfish Lake sockeye salmon evolutionarily significant unit (ESU) is the only extant Snake River stock of *O. nerka*. The spawning and freshwater rearing habitat of this stock is located in the Sawtooth Valley, Idaho, a traditional SBT fishing and hunting area. In March 1990, the SBT petitioned the National Marine Fisheries Service (NMFS) to list the Snake River sockeye salmon as endangered. As a result of that petition the Snake River sockeye salmon was officially listed as endangered in November 1991 under the Endangered Species Act (56 FR 58619). The Upper Snake River Endangered Sockeye Salmon Recovery Program was implemented that same year. The SBT have been actively involved in the sockeye salmon recovery project (BPA Project Number 91-71) since its inception.

The Bonneville Power Administration (BPA) provides funding for this interagency recovery program through the Northwest Power Planning Council's Fish and Wildlife Program. Collaborators in the recovery program include the National Marine Fisheries Service (NMFS), Idaho Department of Fish and Game (IDFG), the University of Idaho (UI), the U.S. Forest Service (USFS), and the SBT. The NMFS manages the permitting of activities and the captive rearing program hatchery operations in Manchester, WA. The IDFG monitors a variety of fisheries parameters in the field and is responsible for the captive rearing program hatchery operations in Eagle and Stanley, ID. The UI analyzes genetic samples and participates in designing breeding matrices. The USFS participates in permitting activities and habitat improvements. The SBT monitors a variety of fisheries biology parameters and spawning and rearing habitat evaluation in nursery lakes.

In 1991, only four adult sockeye returned to Redfish Lake. These four fish and emigrating juveniles captured over the next two years formed the initial captive brood stock. The captive brood stock was supplemented with returning adult sockeye, residuals, and emigrating juveniles in subsequent years. Historically, thousands of sockeye returned to the Sawtooth Valley lakes. Everman (1896) reported that the lakes were 'teeming with redfish'. In 1910, anadromous fish migration was blocked when the Sunbeam Dam was built on the mainstem of the Salmon River approximately 20 miles downstream from the Sawtooth Valley. In 1934 that dam was breached and upstream anadromous fish populations rebounded. Bjornn (1968) estimated that 4,360 sockeye returned to Redfish Lake in 1955. There has been a steady decline in adult sockeye returns since that time until, in the late 1980's, only a small number of fish were returning to Redfish Lake. A total of 23 adult sockeye returned to the Sawtooth Valley in the 1990's. The recovery program has focused its efforts on restoring anadromous *O. nerka* to Redfish, Alturas, and Pettit lakes, which were designated as critical spawning and rearing habitat under the ESA listing (56 FR 58619).

A variety of activities has been conducted in the effort to conserve and rebuild the Redfish Lake *O. nerka* stock. The captive brood stock has served to preserve the unique genome. Fish barriers on Alturas and Pettit lake creeks have been removed to facilitate fish passage. Fish from the captive brood stock have been reintroduced into the wild. A variety of stocking strategies have been implemented and evaluated, including adult release for volitional spawning, in-lake egg incubators, net pen rearing with parr release, parr releases (spring, summer, fall), and smolt releases. Lake fertilization has also been implemented in order to increase lake-carrying capacities. Kokanee (non-anadromous form of *O. nerka*) control measures have been implemented in Redfish Lake to reduce intraspecific competition. A variety of fishery and limnological parameters have been monitored in association with these strategies.

The Technical Oversight Committee (TOC) has guided all activities conducted by the SBT in association with the sockeye recovery project. The TOC is composed of representatives of all participating agencies (BPA, NMFS, IDFG, UI, and SBT). The TOC was formed in 1991 to guide new research, coordinate ongoing research, and actively participate in all elements of the Snake River sockeye recovery effort. Scientists with expertise in related fields are often invited to TOC meetings to present their research and discuss activities conducted by TOC agencies. The project as a whole or in part is subject to further review by the Idaho Department of Environmental Quality (DEQ), the USFS, and the NWPPC Independent Scientific Review Panel (ISRP).

STUDY AREA

Four lakes, Redfish, Alturas, Pettit, and Stanley, in the Sawtooth Valley are currently the focus of on going SBT habitat and limnological studies. The lakes were glacially formed, range in elevation from 1,985 m to 2,157 m, and are located in central Idaho (Figure 1-1). Specific features of the sockeye rearing lakes are shown in Table 1-1.

All of the Stanley Basin lakes are oligotrophic. Mean summer total phosphorous (TP) concentrations in the epilimnion range from 4.9 to 11.8 *u*g/L. Surface chlorophyll *a* concentrations range from 0.3 to 2.3 *u*g/L. Mean summer secchi disk transparencies range from 9.6 to 15.2 m, excluding Stanley Lake which ranges from 5.0 to 8.2 m.

Table 1-1. Morphological features of the Sawtooth Valley lakes.

Lake	Area (km^2)	Volume ($m^3 x 10^6$)	Mean Depth (m)	Drainage Area (km^2)
Redfish	6.15	269.9	44	108.1
Alturas	3.38	108.2	32	75.7
Pettit	1.62	45.0	28	27.4
Stanley	0.81	10.4	13	39.4

Redfish Lake is approximately 1,451 kilometers from the mouth of the Columbia River. There are 616 kilometers of free flowing river from Redfish Lake to the mouth of the Salmon River (Figure 1-1) and an additional 835 km with eight dams on the Snake and Columbia rivers.

Native fish species found in the nursery lake system include sockeye/kokanee salmon *Oncorhynchus nerka*, steelhead/rainbow trout *O. mykiss*, chinook salmon *O. tshawytscha*, cutthroat trout *O. clarki lewisi*, bull char *Salvelinus confluentus*, mountain whitefish *Prosopium williamsoni,* sucker *Catastomus sp*., redside shiner *Richardsonius balteatus*, dace *Rhinichthys sp*., northern pikeminnow *Ptychocheilus oregonensis*, and sculpin

Cottus sp.. Non-native species include brook char *S. fontinalis* and lake trout *S. namaycush*. The only pelagic species besides *O. nerka* are redside shiners. The two species are not sympatric because of differing vertical distributions. Hatchery rainbow trout are stocked by IDFG throughout the summer in all lakes except for Redfish and Yellow Belly lakes. Sport fishing for salmonids is open on all lakes as well as inlet and outlet streams.

The Sawtooth Valley lakes have several different forms of *O. nerka*, the primary pelagic zooplanktivore in the system. There are three distinct life histories in Redfish Lake; anadromous, residuals, and kokanee. Kokanee, a non-anadromous form of *O. nerka*, spends its entire life cycle in the fresh water lakes. Kokanee generally spawn at three to four years of age in the inlet creeks of the lakes during late summer and die afterwards. The Redfish Lake kokanee population is admixed, consisting of several out-of-basin stocks and is genetically dissimilar to the anadromous form. This kokanee population is temporally and spatially separated during spawning from the listed Snake River *O. nerka*. Alturas Lake kokanee are closely related, sharing haplotypes with listed Snake River *O. nerka* (Matt Powell, U of I, personal communication). Pettit and Stanley lakes were treated with rotenone (1950's and 60's) and kokanee were reintroduced from out-of-basin stocks. Data indicate that these fish are genetically different from remaining indigenous *O. nerka*. No Sawtooth Valley kokanee are listed as endangered.

Residuals are another form of *O. nerka* found only in Redfish Lake and are listed as part of the ESU. The residual population remains in freshwater for their entire life cycle, yet are genetically similar to the anadromous *O. nerka* form. The residual population spawns at the same time as the anadromous form and, similar to the anadromous form, creates redds on the lake shore instead of the inlet creeks.

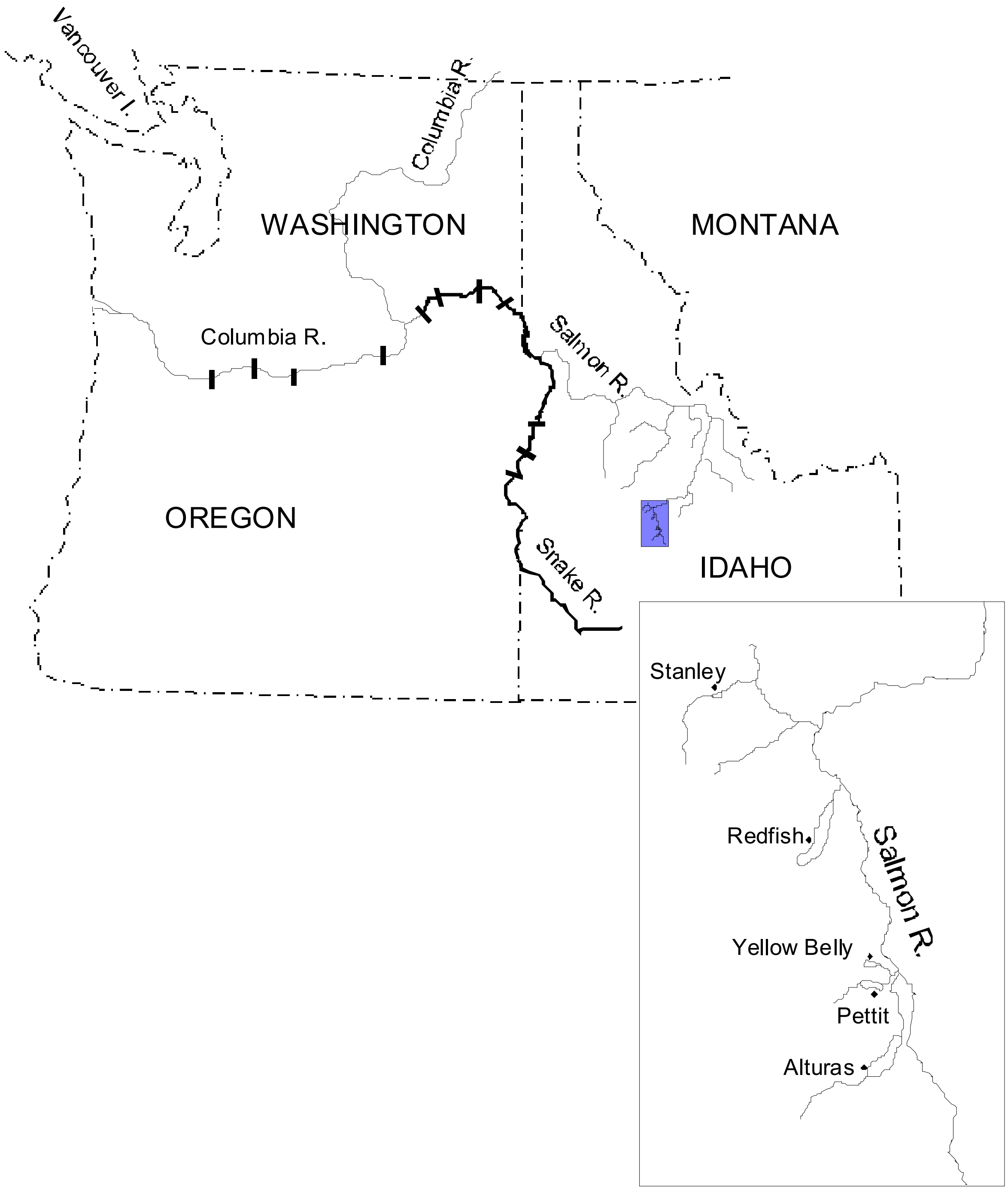


Figure 1-1. Map of study area.

The anadromous form of *O. nerka* spends one or two years in fresh water, emigrating during spring high flows as one or two year old smolts. Anadromous forms then spend the majority of their life in the Pacific Ocean, generally returning at four years of age to the Sawtooth Valley lakes. Similar to many species of salmon, some anadromous *O. nerka* return as three year olds, which are referred to as jacks or jills depending on sex. The anadromous and residual forms have been designated as an ESU.

MATERIALS AND METHODS

Hydroacoustic Population Estimates

Data Acquisition

Echo sounding data were collected with a Hydroacoustic Technology, Inc. Model 240 split-beam system. Split-beam echosounders have been shown to have less variability for target strength estimates than dual-beam systems (Traynor and Ehrenberg, 1990) and the target tracking capabilities of the split-beam system further reduce variability of individual targets (Ehrenberg and Torkelson, 1996). We used a 15 degree transducer, and the echo-sounder criteria were set to a pulse width of 0.4 milliseconds, a time varied gain of 40 log(R) + 2 r, and five pings per second for Redfish Lake, and six pings per second for Alturas and Pettit Lake. A minimum of six pings per target was necessary to qualify as a fish target. Data were recorded on a Panasonic SV-3700 digital audio tape recorder.

Established transects were followed using a global positioning system (GPS). Waypoints were established in 1994 and set to allow for sampling transects to run zigzag across all lakes except Pettit Lake, where five parallel and one diagonal transects were used (Teuscher and Taki 1995). Twelve and fourteen transects were sampled at Alturas and Redfish lakes, respectively.

Surveys were conducted during two moonless nights in September. We began at approximately 1½ hours after sunset. Boat speed during data collection ranged from 1-1.5 m/s.

Trawling (by IDFG) and vertical gill netting were done concurrent to hydroacoustic sampling. Vertical gill net sampling was used to assist in partitioning targets in Pettit Lake. Vertical gillnets were used to determine if other fish species were found in the pelagic areas during sampling. Previous gill net sampling conducted in Alturas Lake has not yielded sufficient numbers for partitioning targets and therefore was not used. Due to NMFS Section 10 permit limitations vertical gillnet sampling in Redfish Lake was not conducted.

Data Analysis

Target strengths and fish densities were processed using a Model 340 Digital Echo Processor and plotted with a Model 402 Digital Chart Recorder. Target strengths were used to estimate fish length by the equation

$$TS = 19.1 \operatorname{Log}(L) - 0.9 \operatorname{Log}(F) - 62.0 \qquad (1\text{-}1)$$

developed by Love (1977) where TS = target strength in decibels, L = fork length in centimeters, and F = frequency of transmitted sound (kHz). Fish density estimates were calculated for different size classes for each lake to approximate cohort densities based on 1999 length frequency distributions and age analyses performed by the IDFG from fish captured in the trawl. Four different size classes were used for all three lakes. Due to overlap in Alturas Lake, we combined the III+ and IV+ kokanee cohorts. Total abundance and vertical distribution were also estimated.

Individual fish detections were weighted by the ratio of the designated area width to the diameter of the acoustic beam at the range of the detected targets. An effective beam width was calculated for each tracked target for the fish-weighting algorithm.
The effective beam width equation

$$X[\mathrm{ABS}\ (M^{rs} - F^{rs})]^{Y} \qquad (1\text{-}2)$$

was used where X = 8.6, ABS = absolute value of the target strength remainder, M^{RS} = minimum system detection (-60), F^{RS} = mean target strength, and Y = 0.47 (P. Nealson, HTI, personal communication).

Fish densities were computed by using adjacent transects as replicates within a stratum (lake). Population estimates for individual size classes were obtained with the equation

$$\overline{D}_i = \frac{\sum_{j=1}^{Ti} L_j \overline{D}_{ij}}{\sum_{j=1}^{Ti} L_j} \tag{1-3}$$

and variance was estimated by

$$Var\overline{D}_i = \frac{T_i}{T_i - 1} \sum_{j=1}^{Ti} L_j^2 (\overline{D}_{ij} - \overline{D}_i)^2 \bigg/ \left(\sum_{j=1}^{Ti} L_i \right)^2 \tag{1-4}$$

where D_i = mean density (number/m^2) in stratum i, D_{ij} = mean density for the jth transect in stratum i, L_i = length of transect j, and T_i = number of transects surveyed in stratum i (Gunderson, 1993).

FISHPROC software was used to compile acoustic target information for each lake. This allowed us to select targets based on acoustic size, depth or other parameters. We could process single or multiple transects and fish were sorted into one or two decibel bins. Vertical distribution was estimated by

$$\overline{D}_i = \sum_{i=1}^{h} D_{vi} (R_{iu} - R_{il}) \tag{1-5}$$

where D_{vi} = number of fish/m^3 in depth stratum i, R_{iu} = upper range limit for depth stratum i, R_{il} = lower range limit for depth stratum i, and h = number of depth strata.

These values were then multiplied by the percentage of each depth stratum surveyed within the conical beam.

Correlation analysis was used to compare trawl versus hydroacoustic population estimates. Comparisons were made by combining current and previous year's results for total lake populations and cohort estimates.

Smolt Monitoring

Pettit Lake

A weir was operated at the outlet of Pettit Lake, Idaho (Section 31, Township 8 North, Range 14 East) from 02 May through 22 May 2001. The weir was used to monitor over-winter survival and emigration of Snake River sockeye salmon smolts. The weir ran continuously during operation at 100% capture efficiency. Shoshone-Bannock Tribal fisheries personnel checked for fish and cleaned the weir at sunrise and sunset. The trap was checked more frequently when high levels of debris were present. Sampling was discontinued when peak flows associated with spring run-off created logistical problems.

Immediately after removal from the trap, the fish were anesthetized for measuring and weighing using a stock solution of 15 grams of MS222 and 30 grams of sodium bicarbonate per liter of water. All fish that were anesthetized were weighed to the nearest 0.1 grams and measured (fork length) to the nearest millimeter and were held in a live well for 5 to 10 hours after handling and then released. A condition factor (K value, $(\text{weight}x10^5)/(\text{length})^3$) for each fish was estimated; mean, minimum, and maximum K value are presented in results. All other fish were counted and immediately released below the weir.

Alturas Lake

A screw trap was operated in Alturas Lake Creek 8 miles down stream from Alturas Lake, Idaho (Section 32, Township 8 North, Range 14 East) from 29 April through 25 May 2001. *O. nerka* smolts were captured to estimate over-winter survival and smolt emigration and to allow tagging of Snake River sockeye salmon smolts using passive integrated transponders (PIT). Shoshone-Bannock Tribal fisheries personnel checked for fish and cleaned the screw trap at sunrise and sunset. For one week during peak run-off we checked and cleaned the trap at approximately 6 hour intervals during the night to prevent debris accumulation.

A condition factor (K value, [weight x 10^5]/[length]^3) for each fish was estimated; mean, minimum, and maximum K value are presented in results.

Anesthetized fish were weighed to the nearest 0.1 grams, measured (fork length) to the nearest millimeter, and PIT tagged. Fish were held in a live well for 1/2 to 10 hours after handling and released at dusk. All other fish were counted and immediately released below the screw trap. PIT tags and needles were sterilized in 70% ethanol. PIT-tagged fish used in the mark recapture capture efficiency estimation were held in a live well and released at dusk approximately 300 meters upstream.

Growth Rates

Growth rates of stocked juvenile *O. nerka* were compared in an effort to evaluate fitness associated with differences between lakes, hatchery origin, and stocking strategy. Length (mm) and weight (g) data of stocked *O. nerka* were collected at the time of tagging and smolt emigration. Lengths and weights at the time of tagging were compared to length and weight data of *O. nerka* collected during smolt emigration monitoring. Growth rates are graphically presented with bar charts for the summer release groups in Alturas and Pettit lakes and for the fall release groups in Alturas, Pettit, and Redfish lakes. A second descriptive comparison was generated using a linear regression between the lengths and weights of parr and smolts for the fall release group. The slopes of the regression lines were used to compare growth rates of fish between lakes.

Gillnet Sampling

Horizontal and vertical gillnet sampling was conducted to quantify fish population characteristics, including species composition, habitat utilization (pelagic versus littoral), and diet analysis. Horizontal gillnets (30 m long, 1.8 m high) with lead sinking lines composed of five panels 6 m long of graduated mesh size (5, 6.5, 7.5, 10.0, and 12.0 cm) were set at selected points along the bank perpendicular to the shore in Pettit Lake. Nets were set with the smallest mesh size panel closest to shore (approximately 10 m from shore) and the largest mesh size panel deeper and further from shore. Vertical gillnets 3 m wide and 30 m deep were composed of graduated mesh sizes (2.54, 3.17, 5.08, and 6.35 cm). Horizontal gillnet sampling was conducted on 22 January, 7 May, 21 May, 19 September, and 10 October in Pettit Lake. Vertical gillnet sampling on Pettit Lake was conducted on 22 January, 12 February, 19 September. Vertical gillnet sampling was conducted on 23 January and 13 February on Alturas Lake. Due to NMFS section 10 permit limitations, there were no gillnets set in Redfish Lake.

Diet Analysis

Fish stomachs collected from gillnet and trawl samples were examined to determine diet composition. Stomach samples from rainbow trout, bull char, brook char, northern pike minnow, and kokanee were collected. Fish were measured (fork length to the nearest millimeter) and weighed (to the nearest 0.1 gram) after which stomachs were removed and placed in 70% ethanol. Prey were identified, enumerated, blotted dry, and weighed to the nearest 0.01 g. Zooplankton were enumerated and lengths were derived from zooplankton tows collected during the same months. Zooplankton lengths were converted to dry weight using the length-weight relationship reported in McCauley (1984). Aggregate percent of diet by dry weight for all species of fish sampled was calculated (Swanson et al. 1974). Aggregate percent by dry weight (total diet composition) was used to determine diet overlap and aggregate percent by dry weight (zooplankton diet composition) was used to determine electivity indices. Diet overlap indices for *O. nerka* and other species captured were calculated using equations described by Koenings et al. (1987). Electivity indices (Ivlev 1961) describing calculations for prey preferences were used for *O. nerka*.

Stream Spawning

Stream surveys were conducted to estimate kokanee escapement in tributaries to Redfish, Stanley, and Alturas lakes. Pettit Lake has no identified stream spawning kokanee population. Fish were counted from the bank by one or two observers equipped with polarized sunglasses. The number of fish in the stream, on days when counts were missed, was interpolated by dividing the difference between the actual counts by the number of days between the counts. Total escapement estimates were calculated by summing daily counts of kokanee and dividing by average stream life as described by English et al. (1992).

Beach Spawning

Sockeye Beach, located near the Redfish Lake boat ramp, and a small section of the southeast corner of Redfish Lake are spawning grounds for residual and adult sockeye. Night snorkel surveys were conducted to estimate the relative abundance of residual spawners, anadromous returns, and adult sockeye stocked from the captive-rearing program in both locations. Snorkel surveys in Redfish Lake were conducted weekly on five nights from 2 to 30 October 2001. At least three observers, equipped with waterproof flashlights, snorkeled parallel to shore 10 m apart, at depths ranging from 0.5 to 5 m. At Sockeye Beach, estimates of residual spawner abundance were conducted within the boundary (600 m) of Sockeye Beach as delineated by USFS signs. Spawning ground surveys in the south end of the lake were conducted in the 200 m shoal area section near the two small southeast inlet streams.

RESULTS

Hydroacoustic Population Estimates

Hydroacoustic population estimates of *O. nerka* in the Sawtooth Valley lakes during September of 2001 ranged from 130,359 to 37,410 fish in Alturas and Pettit lakes, respectively (Table 2). Redfish Lake was intermediate with an estimated *O. nerka* population of 43,849.

Table 1-2. Hydroacoustic and trawl *O. nerka* population estimates for three Sawtooth Valley lakes, 1994-2001.

LAKE	Population Estimate (± 95% C.I.) Acoustic	Trawl	Density (fish/ha) Acoustic	Trawl	Biomass Estimate kg/ha Acoustic	Trawl	A/T
REDFISH 1994	133,360	51,529 ± 33,179	217	84	2.39	1.41	2.58
REDFISH 1995	103,570 ± 24,500	61,646 ± 27,639	168	100	3.41	4.36	1.68
REDFISH 1996	66,325 ± 24,000	56,213 ± 27,306	108	91	2.23	2.83	1.19
REDFISH 1997	131,513 ± 32,319	55,762 ± 13,961	214	91	3.37	2.48	2.35
REDFISH 1998	107,613 ± 33,615	31,485 ± 10,839	175	51	2.50	1.79	3.43
REDFISH 1999	69,472 ± 29,887	42,916 ± 13,097	113	70	1.66	0.93	1.61
REDFISH 2000	24,481 ± 10,520	10,268 ± 5,675	40	17	0.41	0.07	2.35
REDFISH 2001	43,849 ± 16,747	12,980 ± 11,982	71	21	0.71	0.10	3.38
PETTIT 1994	12,265 ± 8,360	14,743 ± 3,683	76	91	4.67	3.12	
PETTIT 1995	77,765 ± 46,900	59,002 ± 15,735	480	364	34.16	14.73	1.32
PETTIT 1996	77,680 ± 15,850	71,655 ± 10,631	480	442	36.23	15.19	1.09
PETTIT 1997	63,195 ± 29,581	21,730 ± 11,262	390	134	23.25	5.10	2.91
PETTIT 1998	67,206 ± 30,950	27,654 ± 8,764	415	171	13.47	9.74	2.43
PETTIT 1999	51,496 ± 12,171	31,422 ± 21,280	318	194	9.76	6.33	1.64
PETTIT 2000	40,435 ± 20,977	40,559 ± 11,717	250	250	9.04	10.20	1.00
PETTIT 2001	37,410 ± 24,864	16,931 ± 7,556	231	105	9.08	6.10	2.20
ALTURAS 1990		126,644 ± 31,611				3.26	
ALTURAS 1991		125,045 ± 30,708				3.97	
ALTURAS 1992		47,237 ± 61,868				2.42	
ALTURAS 1993		49,037 ± 13,175				2.58	
ALTURAS 1994	10,980 ± 1,090	5,785 ± 6,919	33	17	1.07	0.43	1.90
ALTURAS 1995	32,260 ± 5,090	23,061 ± 9,182	95	68	3.31	1.66	1.40
ALTURAS 1996	20,620 ± 4,140	13,012 ± 4,668	61	39	0.97	1.34	1.59
ALTURAS 1997	30,795 ± 5,869	9,761 ± 4,664	91	29	2.34	2.10	3.15
ALTURAS 1998	101,519 ± 32,605	65,468 ± 33,479	300	194	2.09	1.42	1.55
ALTURAS 1999	130,133 ± 25,936	56,675 ± 43,536	385	168	4.20	0.40	2.30
ALTURAS 2000	134,867 ± 33,244	125,462 ± 27,037	399	371	6.12	2.08	1.08
ALTURAS 2001	130,359 ± 29,446	70,159 ± 18,642	386	208	3.16	2.40	1.86

Redfish Lake *O. nerka* abundance in 2001 was 79% higher than in 2000, the year with the lowest population estimate since we began sampling in 1994. Pettit Lake has experienced a slow decline in *O. nerka* since 1998. Since 1999 Alturas Lake has had the largest *O. nerka* population of the three lakes. During 1999 and 2000 an estimated 372,276 kokanee fry recruited to Alturas Lake (Kohler, et al. 2002). That number declined to 18,223 fry in 2001. However, the hydroacoustic estimate for that cohort of

28,689 ± 11,911 could indicate a higher egg to fry survival, or a reduced growth of the I+ cohort.

Redfish Lake- The total *O. nerka* population in Redfish Lake increased for the first time following a three year decline from the 1997 high of 131,513 ± 32,319. The increase was seen in every cohort. We are not allowed to set vertical gill nets in Redfish Lake so we have to assume every fish tracked in the pelagia is an *O. nerka,* and that no *O. nerka* are in the littoral zone when we sample.

Pettit Lake- The total *O. nerka* population in Pettit Lake declined by 3,025 (7.48%) fish from 2000, the fourth consecutive annual decline. The trawl estimate decreased 58.26% (Table 2), but they only captured two age classes. No cohorts from the YOY or II+ were captured.

Alturas Lake- Whole lake *O. nerka* population estimates in Alturas Lake experienced a slight decline from the record high of 134,867 in 2000. We observed in Pettit Lake that as fish densities exceeded 400 fish/ha the zooplankton population suffered a serious decline. In 2000 the *O. nerka* density in Alturas Lake was 399 fish/ha. Consequently, the whole lake zooplankton biomass seasonal mean dropped from 12.3 µg/L in 1999 to 5.9 µg/L in 2000 (Kohler, et al. 2002). Even though *O. nerka* density declined slightly, zooplankton biomass continued to decrease to a seasonal mean of 3.7 µg/L.

The 1990 trawl estimate in Alturas Lake was 126,644, the highest of the decade. Hydroacoustic sampling did not begin until 1994 when the lowest estimate for both techniques (hydroacoustic and trawl) was recorded, 10,908 for hydroacoustics and 5,785 for trawl (Teuscher and Taki 1996). *O. nerka* abundance is typically cyclic in rearing lakes (Kyle et al. 1988; Hume et al. 1996). *O. nerka* abundance appears to have peaked in Alturas Lake during 1990 and again in 2000, similar to what was observed in Pettit Lake during 1995 and 1996.

Hydroacoustic/trawl comparisons

Hydroacoustic/trawl ratios in 2001 were 3.38, 2.20, and 1.86 for Redfish, Pettit, and Alturas lakes, respectively. Parkinson et al. (1994) found ratios ranging from 3.3 to 1.8

in a comparison of these two methods. The eight year mean hydroacoustic/trawl ratios are 2.32, 1.85, and 1.80 for Redfish, Alturas, and Pettit lakes, respectively.

Correlating hydroacoustic and trawl population estimates varied by what was compared. Correlating eight years of total lake *O. nerka* estimates reveals a relationship of r=0.85 (Figure 1-2). Combining individual cohorts from Redfish, Pettit, and Alturas lakes revealed that the YOY and the two year old cohorts had a similar relationship, (r=0.89; Figure 1-3) and (r=0.88; Figure 1-4), respectively. It should be noted that the trawl rarely catches any fish from the YOY cohort in Pettit Lake and only one years data was used in that comparison.

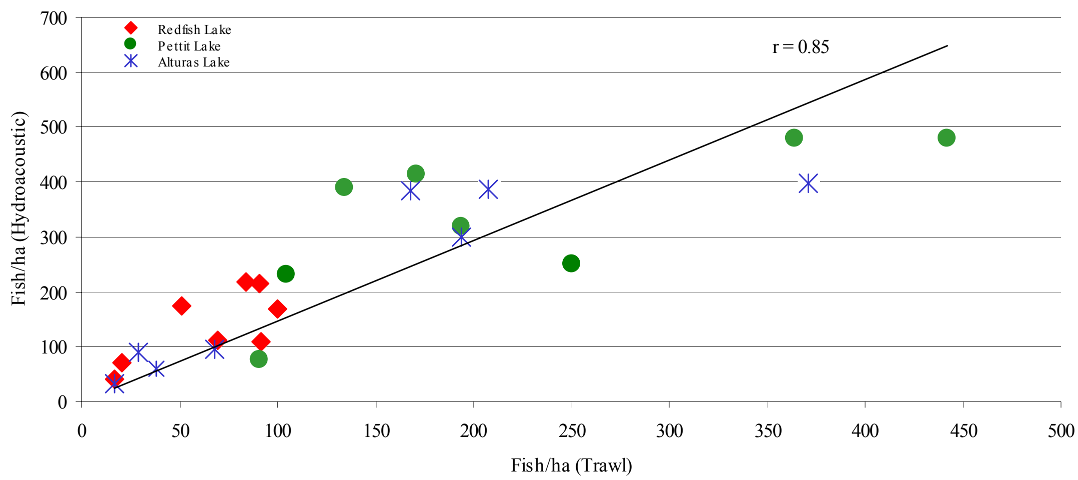


Figure 1-2. Comparison of total *O. nerka* population estimates between hydroacousitcs and trawl samples in three Sawtooth Valley lakes, 1994-2001.

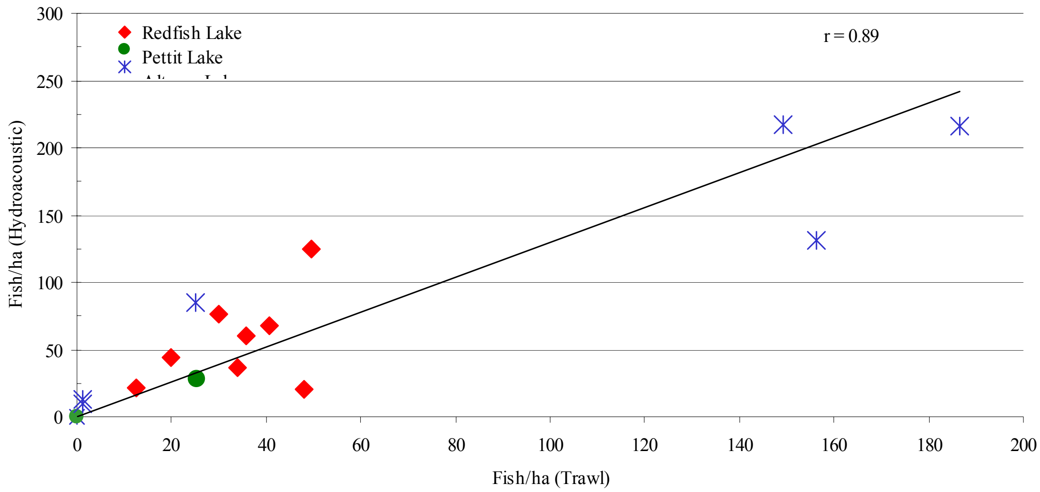


Figure 1-3. Comparison of yoy *O. nerka* population estimates between hydroacoustics and trawl samples in three Sawtooth Valley lakes, 1994-2001.

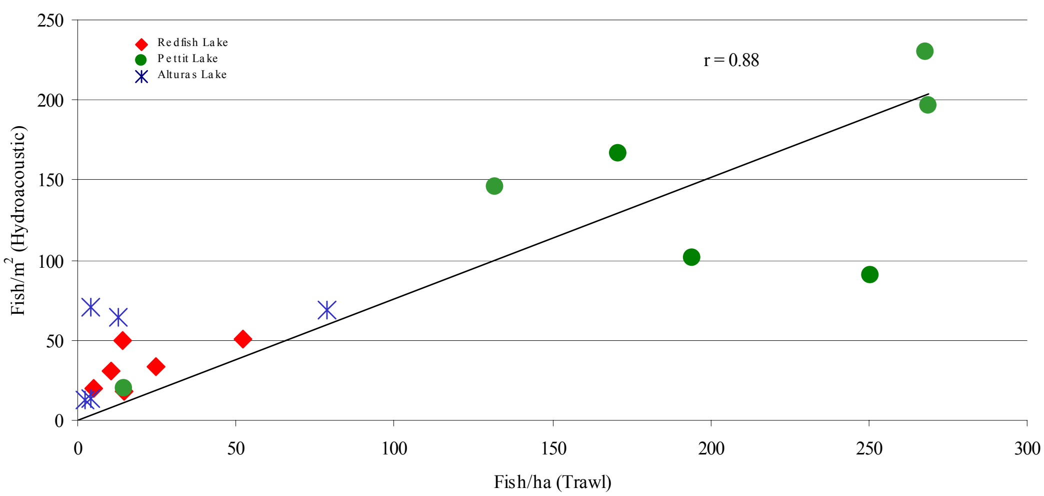


Figure 1-4. Comparison of II+ *O. nerka* population estimates between hydroacousitcs and trawl samples in three Sawtooth Valley lakes, 1994-2001.

Smolt Monitoring

Pettit Lake Creek

In the summer of 2000 there were 2,915 ADRV (Eagle Fish Hatchery) and 3,092 ADLV (Sawtooth Fish Hatchery) Snake River sockeye parr stocked into Pettit Lake. Additionally, in the fall of 2000, 6,067 AD (Sawtooth Fish Hatchery) Snake River sockeye parr were stocked into Pettit Lake. Weir monitoring of smolt emigration began on 2 May 2001. The first sockeye was captured on 5 May 2001. Trapping was discontinued on 22 May 2001 (Figure 1-5). Over the course of smolt trapping 57 ADRV, 156 ADLV, 1,756 AD, and 13 wild fish were captured at the Pettit Lake Creek weir. Over-winter survival estimates were calculated from catches at the Pettit Lake Creek weir. Survival estimates were 2.0, 5.1, and 28.9% for ADRV, ADLV, and AD fish respectively.

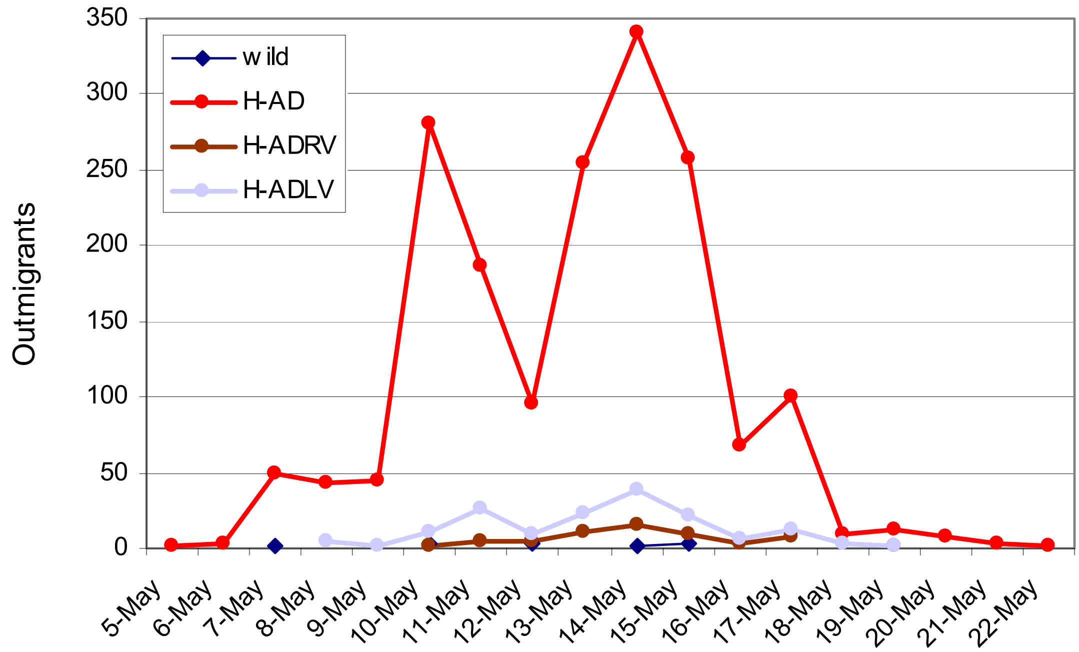


Figure 1-5. Pettit Lake *O. nerka* emigration.

The mean fork length of fall release (AD) captive brood stock *O. nerka* captured at the weir was 130 mm (range 98-174 mm) (Figure 1-8), mean weight was 19.9 g (range 8.5-46.8 g), and mean K value (condition factor) was 0.88 (range 0.59-1.23). Also captured at the trap were summer release Sawtooth Hatchery (ADLV) captive brood stock *O. nerka.* Mean length was 125 mm (range 113-138 mm), mean weight was 17.2 g (range 10.1-22.6 g), and mean K value was 0.87 (range 0.70-0.96). Summer release Eagle Hatchery (ADRV) captive brood stock *O. nerka* captured at the weir had a mean fork length of 121 mm (range 111-130 mm), mean weight of 16.6 g (range 13-22.1 g), and mean K value of 0.93 (range 0.88-1.01). Wild *O. nerka* captured at the weir were so rare that insufficient length, weight, and condition factor data exist to present means.

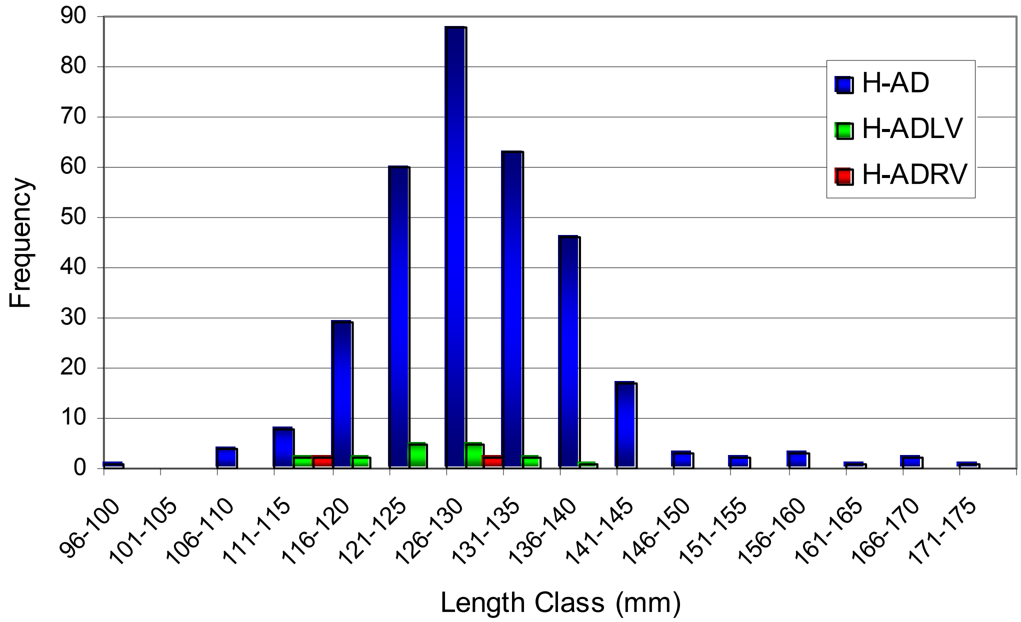


Figure 1-6. Length frequency distribution of captive brood stock sockeye captured at the Pettit Lake Creek weir in 2001.

Alturas Lake Creek

In the summer of 2000 there were 2,917 ADRV (Eagle Fish Hatchery) and 3,069 ADLV (Sawtooth Fish Hatchery) Snake River sockeye parr stocked into Alturas Lake. Additionally, in the fall of 2000, 6,003 AD (Sawtooth Fish Hatchery) Snake River sockeye parr were stocked into Alturas Lake. Screw trap monitoring of smolt emigration began on 20 April 2001. The first sockeye was captured on 29 April 2001. Trapping was discontinued on 25 May 2001. Sixty seven ADLV, 2 ADRV, 636 AD, and 290 wild smolts were captured during trapping efforts. Trap efficiencies ranged from 6% to 40% for wild and hatchery fish. There were 759 sockeye smolts PIT tagged at the screw trap and released downstream. No clear relationship between discharge and numbers of emigrating fish was found (Figure 1-7).

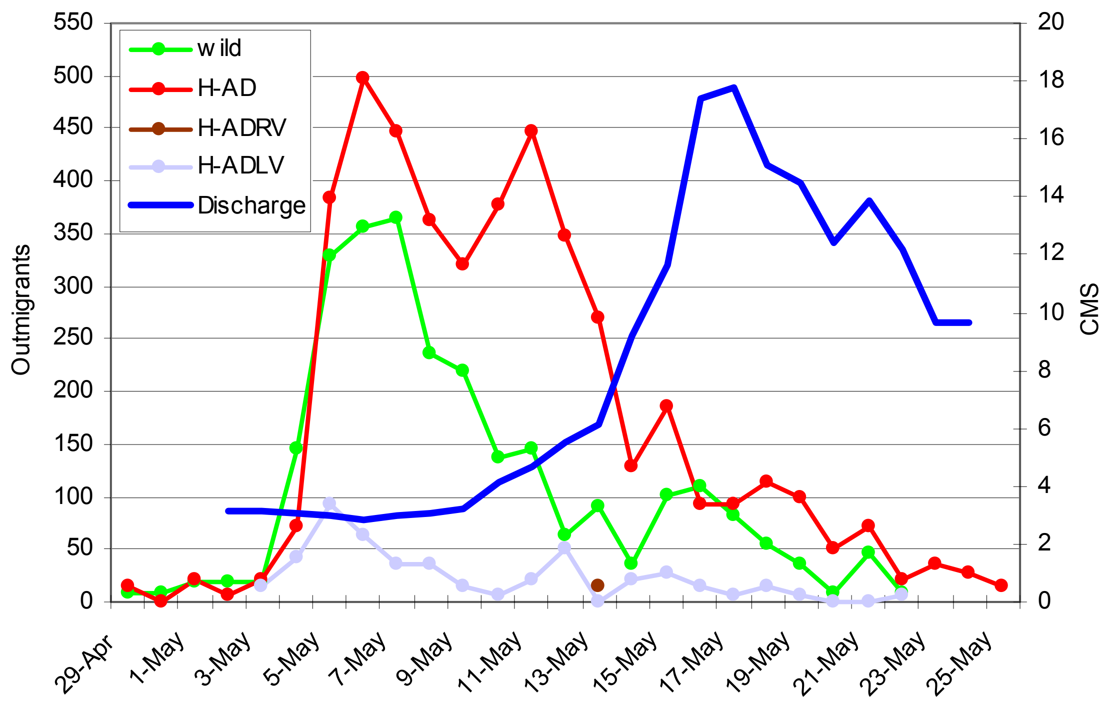


Figure 1-7. Alturas Lake *O. nerka* emigration and spring hydrograph timing.

Using the number of captured hatchery sockeye smolts and a seasonal mean trap efficiency of 14%, it was estimated that 5,011 hatchery sockeye smolts emigrated from Alturas Lake. Over-winter survival estimates were calculated from catches at the Alturas Lake Creek screw trap. Survival estimates were 0.5, 15.5, and 75.3% for ADRV, ADLV, and AD fish respectively. Over the course of smolt trapping 14 ADRV, 476 ADLV, and 4,520 AD were estimated to have emigrated past the trap. Using the number of captured wild smolts and a seasonal mean trap efficiency of 11%, it was estimated that 2,641 wild smolts emigrated from Alturas Lake. The actual number is potentially higher because additional emigration could have occurred after the trap was pulled. Maximum likelihood population estimates with confidence intervals (alpha-0.05) were also calculated for Alturas Lake Creek outmigrants using a Gauss outmigration program developed by Kirk Steinhorst at the University of Idaho (Steinhorst, 2000). Using the Gauss outmigration program, it was estimated that 1,868 (1,144-3,483) wild and 5,485 (3,600-9,138) hatchery smolts emigrated past the screw trap during the spring of 2001.

Mean fork length of fall release (AD) captive brood stock *O. nerka* captured at the trap was 105 mm (range 71-137 mm) (Figure 1-8), mean weight was 9.0 g (range 2.5-18.0 g), and mean K value (condition factor) was 0.78 (range 0.49-0.97). Also captured at the trap were summer release Sawtooth Hatchery (ADLV) captive brood stock *O. nerka.* Mean length was 94 mm (range 76-129 mm), mean weight was 6.3 g (range 3.3-8.9 g), and mean K value (condition factor) was 0.82 (range 0.68-0.95). Summer release Eagle Hatchery (ADRV) captive brood stock *O. nerka* were so rare that no length, weight, or condition factor means are available. Wild *O. nerka* captured at the trap had a mean fork length of 85 mm (range 65-123), a mean weight of 4.9 g (range 1.7-15.0), and a mean K value of 0.80 (range 0.40-1.14).

Water temperatures at the screw trap ranged from 3.0 to 14.5 ^{o}C. All listed fish captured were handled according to the protocol described in the permit request, and no mortalities were attributed to handling or PIT tagging.

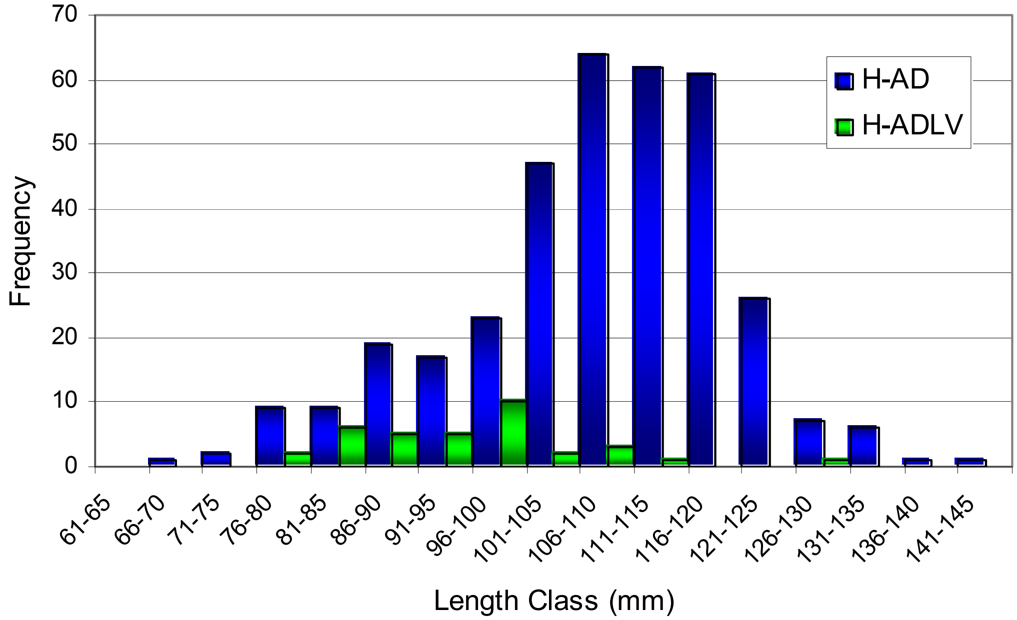


Figure 1-8. The length frequency distribution of *O. nerka* from the captive brood stock captured at the Alturas Lake Creek screw trap in 2001.

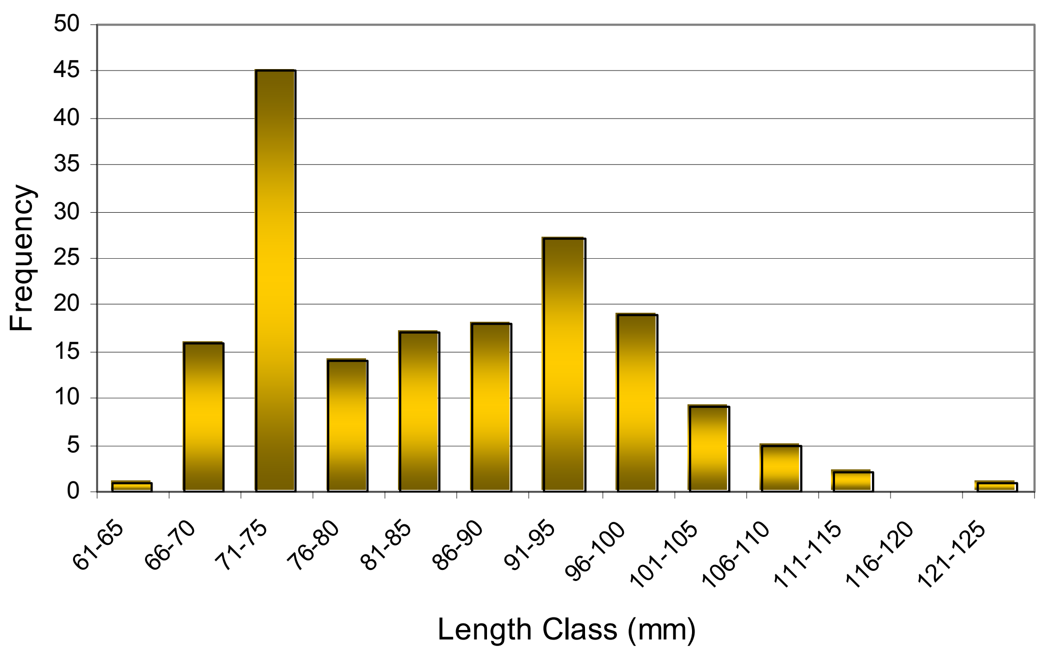


Figure 1-9. The length frequency distribution of wild *O. nerka* captured at the Alturas Lake Creek screw trap in 2001.

Growth Rates

To facilitate growth and survival comparisons between lakes and between hatcheries, approximately equal numbers of differentially marked summer release parr hatchery groups were introduced into Pettit and Alturas lakes on July 31, 2000. Growth rate comparisons for summer release groups in Alturas and Pettit lakes are presented in Figures 1-10 and 1-11. Similar comparisons are presented in figures 1-12 through 1-15 for Sawtooth fall release parr that reared in Alturas, Pettit, and Redfish lakes.

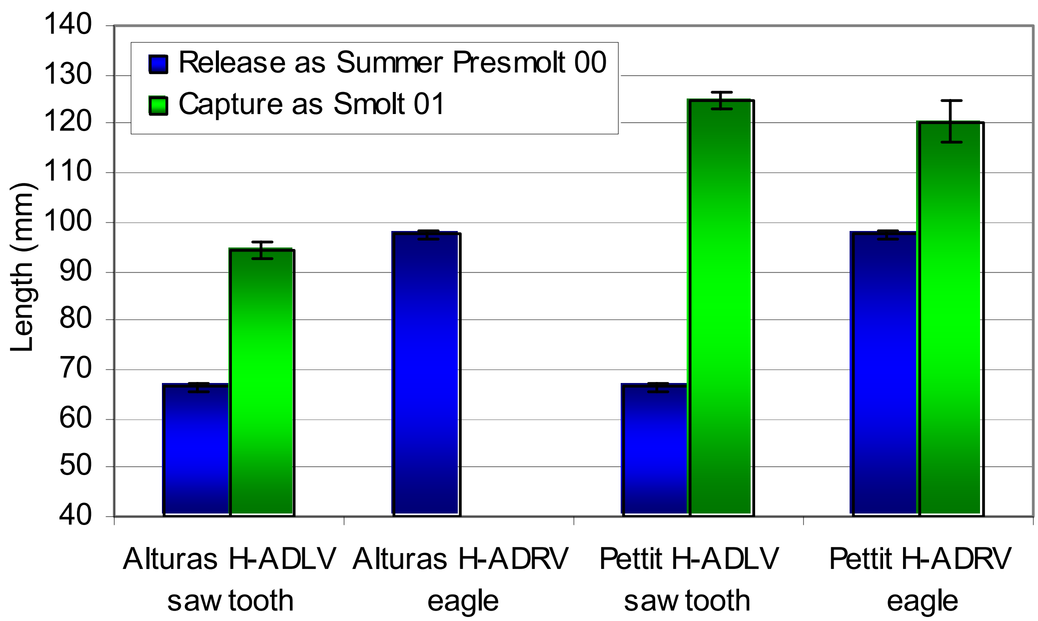


Figure 1-10. *O. nerka* (length) summer release comparison between Alturas and Pettit lakes at time of release and emigration. Error bars represent (±) one standard error.

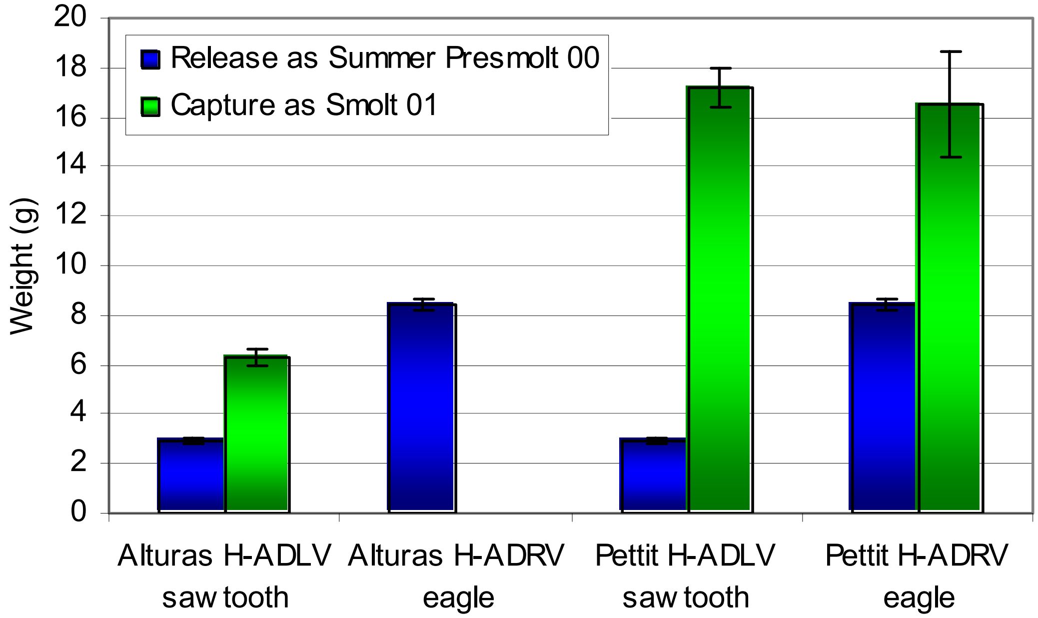


Figure 1-11. *O. nerka* (weight) summer release comparison between Alturas and Pettit lakes at time of release and emigration. Error bars represent (±) one standard error.

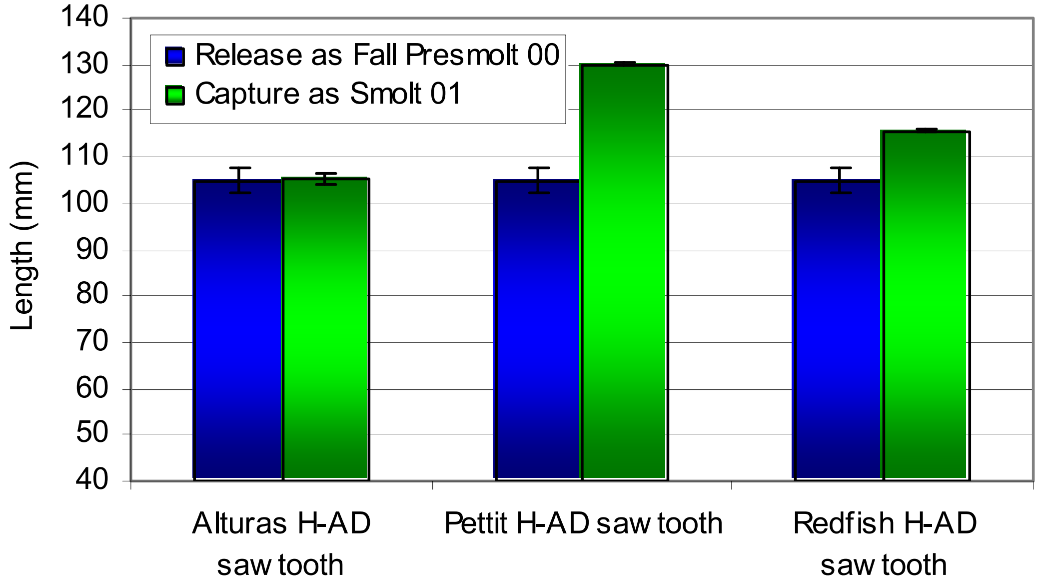


Figure 1-12. *O. nerka* (length) fall release comparison between lakes at time of release and emigration. Error bars represent (±) one standard error.

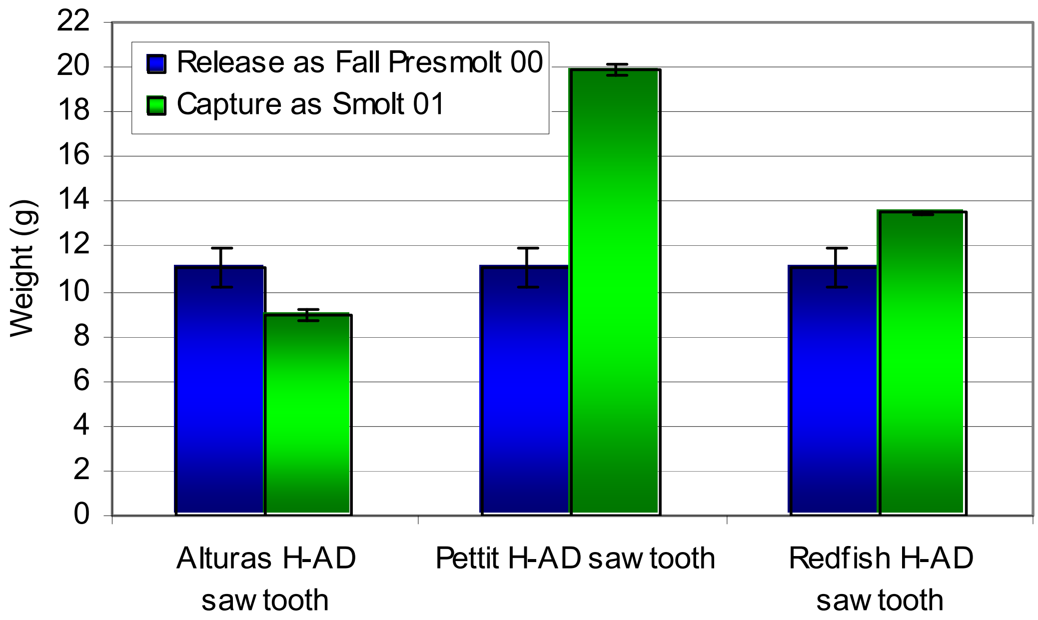


Figure 1-13. *O. nerka* (weight) fall release comparison between lakes at time of release and emigration. Error bars represent (±) one standard error.

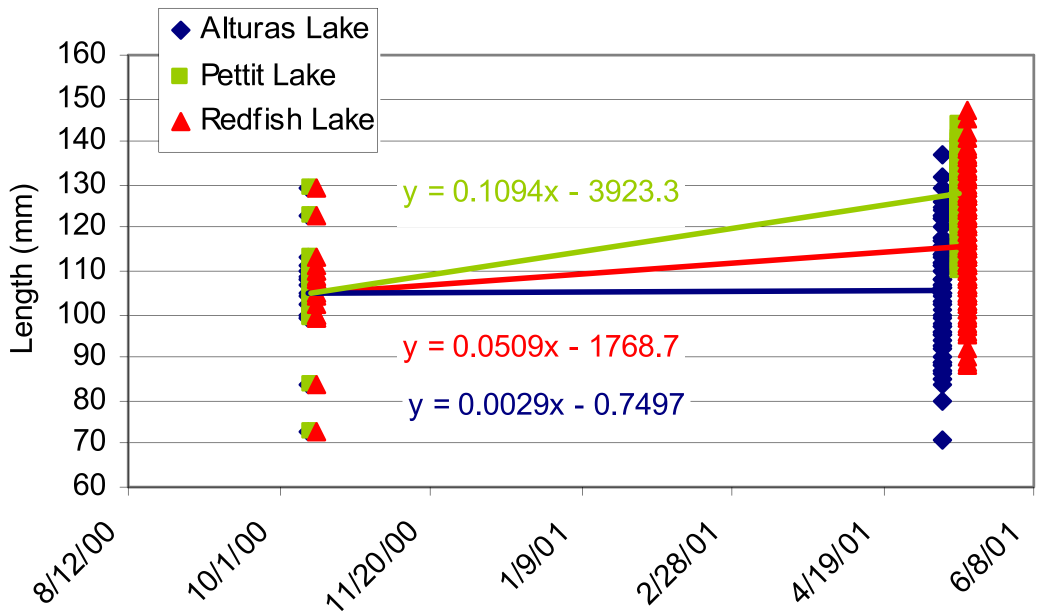


Figure 1-14. Regression of *O. nerka* (length) data to generate growth rates for Alturas, Pettit, and Redfish lakes.

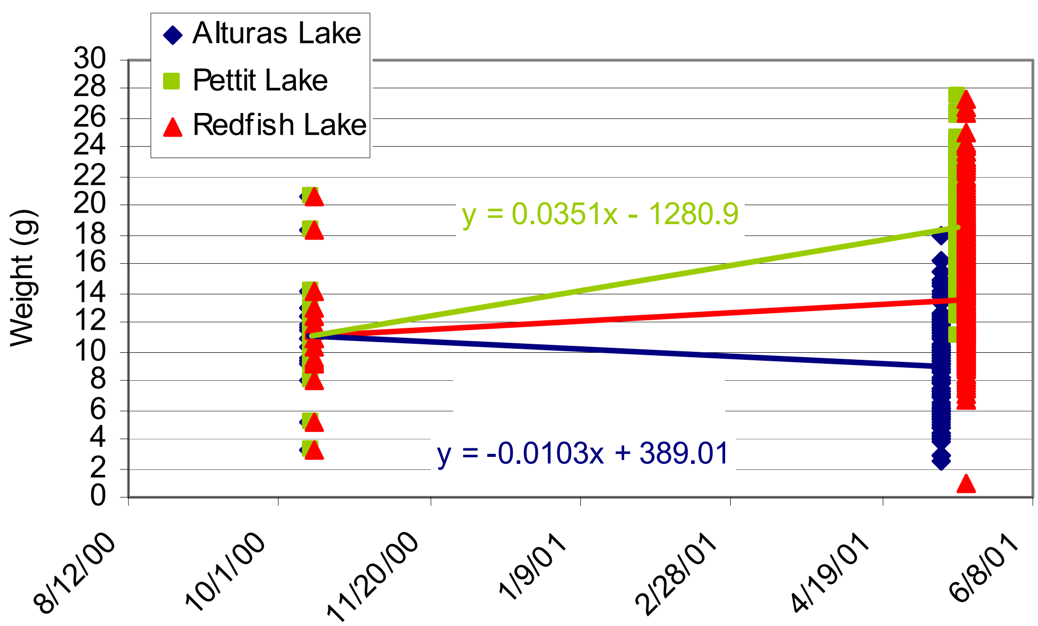


Figure 1-15. Regression of *O. nerka* (weight) data to generate growth rates for Alturas, Pettit, and Redfish lakes.

Gillnet Sampling

In Pettit Lake horizontal gillnet mean (Jan.-Oct.) catch per unit effort (CPUE) was highest for northern pikeminnows (0.85) followed by rainbow trout (0.31), bull char (0.15), whitefish (0.09), kokanee (0.04), and brook trout (0.04), (Table 1-3).

Table 1-3. Results of Pettit Lake horizontal gillnet samples 2001.

Date	(n)CPUE	Mean Length (mm)	Mean Weight (g)	Gillnet Hours
Rainbow Trout				
January 22, 2001	(1) 0.05	NA	NA	21.75
May 07, 2001	(6) 0.30	271	-	20.25
May 21, 2001	(1) 0.07	NA	NA	13.75
Sept. 19, 2001	(11) 0.72	261	-	15.20
October 09, 2001	(7) 0.42	259	182	16.80
Bull Char				
January 22, 2001	(2) 0.09	395	-	21.75
May 07, 2001	(3) 0.15	358	-	20.25
May 21, 2001	(6) 0.44	462	-	13.75
Sept. 19, 2001	(0) 0.00	NA	NA	15.20
October 09, 2001	(1) 0.06	-	-	16.80
Brook Char				
January 22, 2001	(1) 0.05	NA	NA	21.75
May 07, 2001	(0) 0.00	NA	NA	20.25
May 21, 2001	(2) 0.15	385	-	13.75
Sept. 19, 2001	(0) 0.00	NA	NA	15.20
October 09, 2001	(0) 0.00	NA	NA	16.80
Whitefish				
January 22, 2001	(0) 0.00	NA	NA	21.75
May 07, 2001	(3) 0.15	288	-	20.25
May 21, 2001	(0) 0.00	NA	NA	13.75
Sept. 19, 2001	(0) 0.00	NA	NA	15.20
October 09, 2001	(5) 0.30	268	247	16.80
Northern Pikeminnow				
January 22, 2001	(2) 0.09	238	163	21.75
May 07, 2001	(0) 0.00	NA	NA	20.25
May 21, 2001	(30) 2.18	248	-	13.75
Sept. 19, 2001	(20) 1.32	244	-	15.20
October 09, 2001	(11) 0.65	268	243	16.80
Kokanee				
January 22, 2001	(3) 0.14	183	73	21.75
May 07, 2001	(0) 0.00	NA	NA	20.25
May 21, 2001	(0) 0.00	NA	NA	13.75
Sept. 19, 2001	(1) 0.07	NA	NA	15.20
October 09, 2001	(0) 0.00	NA	NA	16.80

Vertical gillnet sampling was conducted in Pettit and Alturas lakes during January and February 2001 and again in Pettit Lake in September 2001. Winter Gillnet effort mean CPUE for Pettit Lake was 0.22 and 0.24 for sockeye and kokanee respectively. Alturas Lake winter gillnet mean CPUE was 0.07 for sockeye, 0.44 for kokanee, and 0.19 for bull char. Results from Pettit Lake gillnet sampling in September 2001 are presented below in Table 1-4.

Table 1-4. Results of Pettit and Alturas Lake vertical gillnet samples 2001.

Date	Lake	Station	(n) CPUE	Mean Length (mm)	Mean Weight (g)	Hours Fished
Rainbow Trout						
September 19, 2001	Pettit	D	(5) 0.33	260	-	15.3
Bull Char						
January 24, 2001	Alturas	Boat Ramp	(3) 0.14	418	817	22.0
February 13, 2001	Alturas	Boat Ramp	(5) 0.23	396	-	21.5
Northern Pikeminnow						
September 19, 2001	Pettit	D	(6) 0.39	261	-	15.3
Sockeye						
January 22, 2001	Pettit	E	(2) 0.10	125	19	21.8
February 13, 2001	Pettit	E	(7) 0.33	125	17	21.0
January 23, 2001	Alturas	Boat Ramp	(1) 0.05	NA	NA	21.5
February 13, 2001	Alturas	Boat Ramp	(2) 0.09	116	13	22.0
Kokanee						
January 23, 2001	Alturas	Boat Ramp	(13) 0.60	145	35	21.5
February 13, 2001	Alturas	Boat Ramp	(6) 0.27	134	21	22.0
January 22, 2001	Pettit	E	(3) 0.14	184	57	21.8
February 13, 2001	Pettit	E	(1) 0.33	NA	NA	21.0
September 19, 2001	Pettit	D	(20) 1.31	137	-	15.3

Diet Analysis

The stomachs of 58 rainbow trout (RBT) caught during Pettit Lake gillnet and trawl efforts (January through October 2001) were analyzed for diet comparison. No *O. nerka* were found in the stomachs of any RBT. The diet composition of the 58 RBT analyzed was composed of 43% plant matter, 7% mollusks, 5% terrestrial insects, 2% coleopterans, 22% odonates, <1% hemipterans, 19% chironomid pupae, <1% cyprinids, and <1% unidentified fish (Figure 1-16).

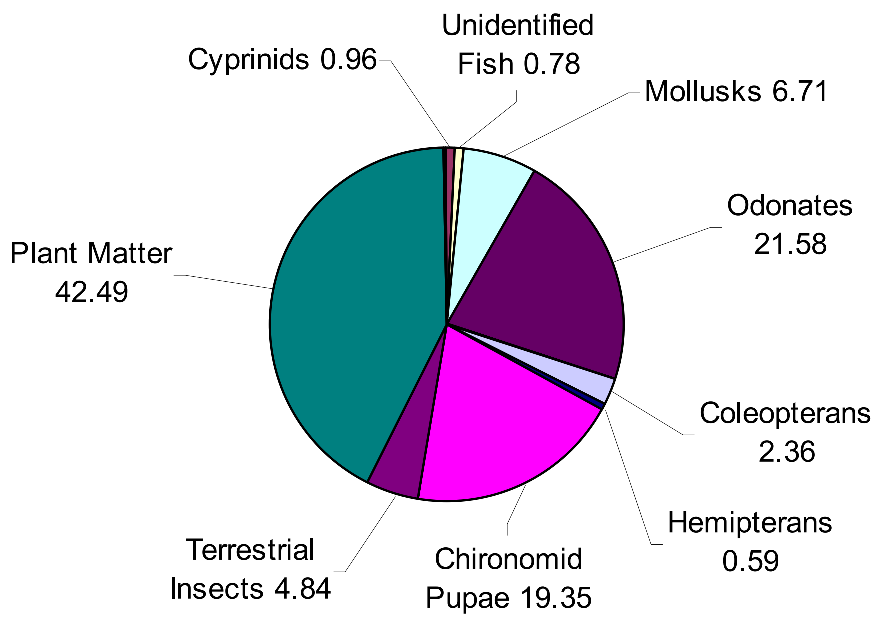


Figure 1-16. Combined diet of RBT captured during gillnet and trawl sampling 2001 (n=58). Diet is presented as percent composition by dry weight.

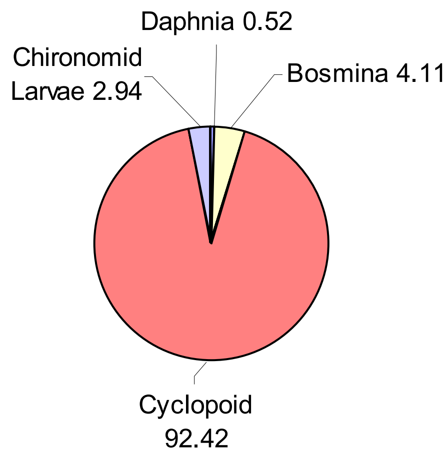
Diet analysis was also conducted on kokanee that were collected during winter gillnet efforts (January and February) and September 2001 gillnet and trawl efforts. Kokanee mean size for each lake and season was as follows: Pettit Lake (winter gillnet) fork length of 136 mm (range 115-175 mm) and mean weight of 23.4 g (range 13.1-46.1 g); Alturas Lake (winter gillnet) mean fork length of 143 (range 98-242 mm) and mean weight of 32.7 g (range 8.1-129.6 g) (Figure 1-17). Alturas Lake kokanee were divided into age classes according to size (age 0 <85 mm and age 1+ >85 mm) in order to quantify potential ontogenetic diet shifts (Figure 1-18). Pettit Lake was eliminated from this comparison because only one size class of kokanee was caught in the trawl (Figure 1-

19). The diet (percent zooplankton prey item by dry weight) of age 1+ Alturas Lake kokanee during January and February of 2001 was dominated by 95% cyclopoids, representing 36% of the in-lake zooplankton biomass (electivity index 0.45) (Tables 1-5 and 1-6, Figures 1-17). No age 0 kokanee were caught during winter gillnet efforts in Alturas Lake.

The diet (percent zooplankton prey item by dry weight) of age 1+ Pettit Lake kokanee during January and February of 2001 was dominated by 80% cyclopoids, representing 20% of the in-lake zooplankton biomass (electivity index 0.60) (Tables 1-5 and 1-6, Figures 1-17). No age 0 kokanee were caught during winter gillnet efforts in Pettit Lake. The diet of age 1+ Pettit Lake kokanee during September of 2001 was dominated by 90% *Daphnia* sp., representing 64% of the in-lake zooplankton biomass (electivity index 0.16) (Tables 1-5 and 1-6, Figures 1-19).

Differences were found in age 0 and age 1+ kokanee diets (percent zooplankton prey item by dry weight) from samples collected in September 2001 in Alturas Lake. The diet of age 0 kokanee was dominated by 55% cyclopoid copepod, representing 54% of the in-lake zooplankton biomass (electivity index of 0.02) (Tables 1-5 and 1-6, Figures 1-18). The diet of age 1+ kokanee in Alturas Lake in September 2001 was dominated by 69% *Daphnia* sp., representing 31% of the in-lake zooplankton biomass (electivity index of 0.38) (Tables 1-5 and 1-6, Figures 1-17). Diet overlap between age 1+ and age 0 Alturas Lake kokanee in September was 47%.

Age 1+ (>85mm) Alturas Lake *O. nerka*



Age 1+ (>85mm) Pettit Lake *O. nerka*

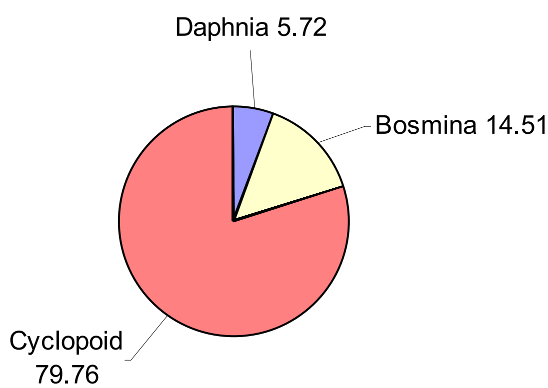
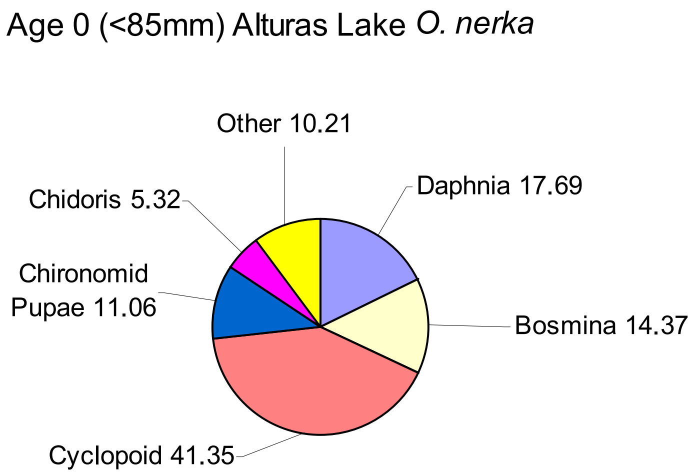


Figure 1-17. Diet of age 1+ (>85mm) *O. nerka* caught in Alturas and Pettit lakes during winter (January and February) 2001 gillnet efforts. Diet is presented as percent composition by dry weight.



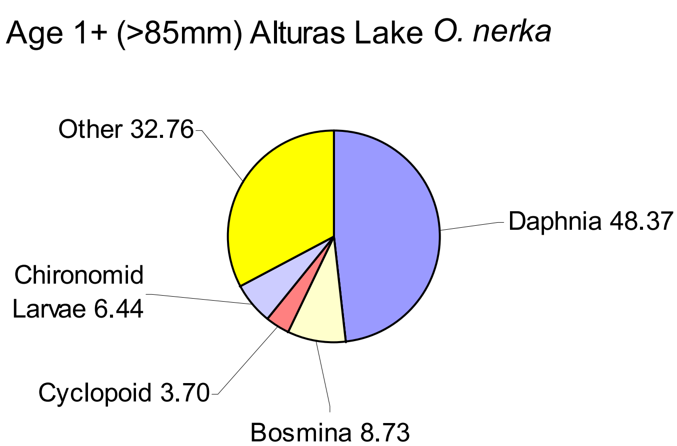


Figure 1-18. Diet of age 0 (<85mm) and age 1+ (>85mm) *O. nerka* caught in Alturas Lake, September 2001 Diet is presented as percent composition by dry weight.

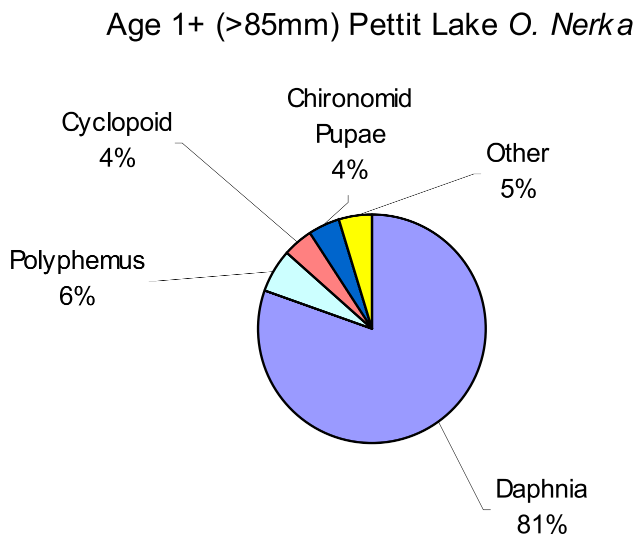


Figure 1-19. Diet of age 1+ (>85mm) O. nerka caught in Pettit Lake, September 2001. Diet is presented as percent composition by dry weight.

Table 1-5. Comparison of Alturas Lake kokanee diet by age class (Age 0 and 1+) and Pettit Lake (age 1+) diet from September 2001. Diet is presented as percent composition by dry weight.

	DAPH	HOLO	BOSM	POLY	CYCLOP	CHIRO	CALAN	CHIDORIS	OTHER
Alturas Lake									
Age 0 (n=11)	17.69	0.00	14.37	0.00	41.35	11.06 (pupae)	0.00	5.32	10.21
Age 1+ (n=7)	48.37	0.00	8.73	0.00	3.70	6.44 (larvae)	0.00	0.00	32.76
Pettit Lake									
Age 1+ (n=19)	80.36	0.00	0.04	6.33	4.05	4.43 (pupae)	0.00	0.00	4.78

Table 1-6. Zooplankton electivity indices from Alturas and Pettit lakes, 2001.

	Season	DAPH	HOLO	BOSM	POLY	CALAN	CYCLO	NAUPLII
Alturas Lake								
Age 1+	Jan/Feb	0.17	*	-0.67	*	*	0.45	-1.00
Age 0	September	-0.13	-1.00	0.75	-1.00	*	0.02	-1.00
Age 1+	September	0.38	-1.00	0.79	-1.00	*	-0.83	-1.00
Pettit Lake								
Age 1+	Jan/Feb	0.50	-1.00	-0.67	*	*	0.60	-1.00
Age 1+	September	0.16	-1.00	-0.99	0.65	*	-0.72	-1.00

*Prey item not found in fish stomach or lake environment.

Diet overlap between kokanee and rainbow trout was examined in Alturas and Pettit lakes in 2001. There was an average diet overlap of 4% for kokanee and rainbow trout in Alturas Lake and 1% in Pettit Lake. This overlap was solely attributed to chironomid pupae. Past diet surveys (Teuscher and Taki 1995) found that chironomid pupae dominated kokanee diets in early summer and shifted to zooplankton in late summer.

Additional diet analysis was conducted on fish from Pettit Lake that were identified as potential *O. nerka* predators (Table 1-6). An analysis of bull char diet (n=6) revealed that a large proportion of their diet consists of salmonid prey items. Due to the advanced state of digestion these salmonid prey items were not identified to species and may have been *O. nerka*. Bull char diet composition consisted of 82% salmonid prey items, 0.5% cyprinid, and 16.7% unidentified fish. The average diet of rainbow trout captured in 2001 (n=30) consisted of 1% cyprinids, 0.8% unidentified fish, 6.7% mollusks, 21.6% odonates, 2.4% coleopterans, 4.8% terrestrial insects, 42.5% plant matter, and 0.3% unidentified prey items. Northern pikeminnow diet (n=12) was composed of 25% cyprinids, 10.6% unidentified fish, 55.6% odonates, and 8.8% unidentified prey items. Brook char diet (n=3) consisted of 11.7% salmonid prey items, 5.4% unidentified fish, and 82.9% odonates. Again, the salmonid prey items found in brook char stomachs may have been *O. nerka* but were not identified to species.

Table 1-7. Diet by mean percent dry weight of piscivorous fish caught in Pettit Lake during 2001 gillnet sampling.

	SAL	CYP	U. F.	MOL	ODO	TRI	COL	HEM	DIP	CHI	TER	PLANT	OTHER
BULL	82.7	0.5	16.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RBT	0.0	1.0	0.8	6.7	21.6	0.0	2.4	0.0	0.0	0.0	4.8	42.5	0.3
PIKE	0.0	25.0	10.6	0.0	55.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8
BRK	11.7	0.0	5.4	0.0	82.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

(BRK= brook char, BULL=bull char, RBT=rainbow trout, PIKE=northern pikeminnow, SAL=salmonid, CYP=cyprinid, U. F.=unidentified fish, MOL=mollusca, ODO=odonate, TRI=tricoptera, COL=coleoptera, HEM=hemiptera, DIP=diptera, CHI=chironomid pupae, TER=terestrial insect, PLANT=plant material)

Diet analysis was also conducted on fish from Alturas Lake that were identified as potential *O. nerka* predators (Table 1-8). An analysis of bull char diet (n=4) revealed that a large proportion of their diet consists of salmonid prey items. Due to the advanced state of digestion these salmonid prey items were not identified to species and may have been

O. nerka. Bull char diet composition was 93.9% salmonid prey items, 5.3% cyprinids, and 0.8% unidentified fish. The diet composition of rainbow trout captured in 2001 (n=28) consisted of 5.8% molluscs, 0.1% odonates, 2.1 % trichopterans, 3.6% coleopterans, 4.0% hemipterans, 0.1% dipterans, 26.9% chironomid pupae, 3.4% terrestrial insects, 44.2% plant matter, and 9.8% unidentified prey items.

Table 1-8. Diet by mean percent dry weight of piscivorous fish caught in Alturas Lake during 2001 gillnet sampling.

	SAL	CYP	U. F.	MOL	ODO	TRI	COL	HEM	DIP	CHI	TER	PLANT	OTHER
BULL	93.9	5.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RBT	0.0	0.0	0.0	5.8	0.1	2.1	3.6	4.0	0.1	26.9	3.4	44.2	9.8

(BRK= brook char, BULL=bull char, RBT=rainbow trout, PIKE=northern pike minnow, SAL=salmonid, CYP=cyprinid, U. F.=unidentified fish, MOL=mollusca, ODO=odonate, TRI=tricoptera, COL=coleoptera, HEM=hemiptera, DIP=diptera, CHI=chironomid pupae, TER=terestrial insect, PLANT=plant material)

Stream Spawning

Using a modified area under the curve (AUC) method, kokanee escapement for 2001 was estimated for Fishhook Creek (5,853), Alturas Lake Creek (145), and Stanley Lake Creek (6,180) (Table 1-10, Figure 1-20).

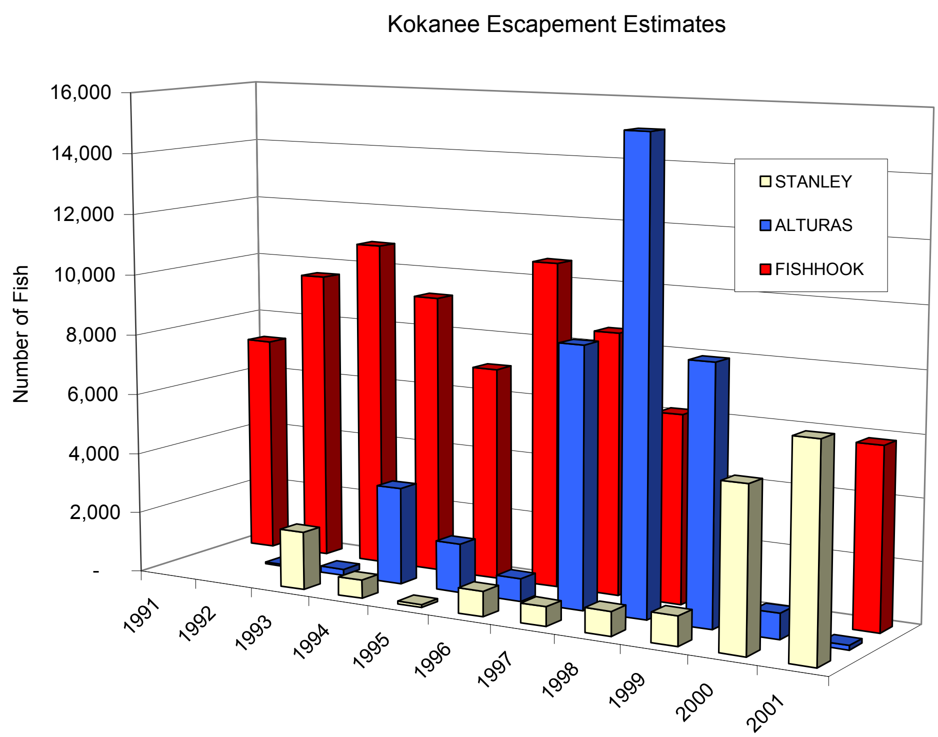


Figure 1-20. Kokanee escapement estimates for Stanley, Alturas, and Fishhook creeks.

Alturas Lake Creek

The 2001 Alturas Lake Creek kokanee escapement (145 fish) was down significantly from escapement numbers seen in the past. Spawning populations have been variable in Alturas Lake Creek, ranging from a low of 60 in 1992 to a high of 15,237 in 1998. In 2001 the escapement timing for 20, 50, and 80% of kokanee entering the creek (Table 1-9) was slightly later than the 1996-2000 mean. Escapement estimates for Alturas Lake Creek were calculated from field counts between 13 August and 19 September 2001. Assuming equal sex ratios, there was an estimated female escapement of approximately 73 fish in 2001. At 150 eggs per female, there were an estimated 10,950 eggs deposited in Alturas Lake Creek. Using a 13% egg-to-fry survival rate (Teuscher and Taki 1995) an estimated 1,414 emigrating fry will be produced from 2001 spawning activities (Table 1-10).

Stanley Lake Creek

The 2001 Stanley Lake Creek kokanee escapement (6,180) was up 9% from the 2000 escapement estimate (Figure 1-20). Escapement timing for 20, 50, and 80% of kokanee entering the creek (Table 1-9) was later (approximately 4, 11, and 14 days, respectively) than the 1996-2000 mean. Escapement estimates for Stanley Lake Creek were calculated from field counts made between 13 August and 27 September. Assuming equal sex ratios, the escapement estimate for kokanee females in 2001 was 3,090 fish. Using a mean fecundity of 257 eggs per female approximately 794,130 eggs were deposited in Stanley Lake Creek. An estimated 55,589 emigrating fry will be produced (7% egg to fry survival rate) from the 2001 spawning event (Teuscher and Taki 1995) (Table 1-10).

Fishhook Creek

The Fishhook Creek kokanee escapement estimate for 2001 (5,853 fish) was substantially higher than 2000 kokanee escapement numbers (60 fish), the lowest recorded on that creek since monitoring started (Figure 1-20). In 2001 the escapement timing for 20, 50, and 80% of kokanee entering the creek (Table 1-9) was similar to the 1996-2000 mean. Fishhook Creek escapement estimates were calculated from counts conducted from 13 August to 19 September 2001. Using a 1.5:1 sex ratio and estimated escapement there were approximately 2,341 females spawning in the creek with 636,806 eggs (272 eggs per female) deposited. A 12.3% egg-to-fry survival rate (Teuscher and Taki 1995) will produce an estimated 78,327 emigrating fry in the spring of 2002 (Table 1-10).

Table 1-9. Escapement timing for Fishhook, Alturas, and Stanley Lake creeks. Mean number of days past 1 August that 20, 50, and 80% of the total spawning population had entered each creek. Presented are 1992-1995 mean (except for Stanley, which starts in 1993), 1996-2000 mean, and 2001.

Creek	Mean 1992-1995			Mean 1996-2000			2001		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Fishhook	21	29	38	25	32	38	24	31	39
Alturas	18	26	33	25	30	36	22	32	39
Stanley	12	18	27	12	18	25	16	29	39

Table 1-10. Fry recruitment, egg-to-fry survival, and adult escapement in Fishhook, Alturas, and Stanley Lake creeks.

Location	Brood Year	Adult Escapement	Mean # Eggs	Male:female Ratio	Egg-Fry Survival	Fry Recruits
Fishhook	2001	5,853	272	1.5:1	12.3%	78,327
Fishhook	2000	60	148	2.4:1	12.3%	321
Fishhook	1999	2,336	233	1:1	12.3%	33,474
Fishhook	1998	6,149	233	4.6:1	12.3%	35,549
Fishhook	1997	8,572	233	1.4:1	12.3%	102,360
Fishhook	1996	10,662	286	3:1	13.1%	99,866
Fishhook	1995	7,000	230	1:1	12.3%	99,015
Fishhook	1994	9,200	230	1:1	13.6%	143,888
Fishhook	1993	10,800	230	1:1	11.5%	142,830
Fishhook	1992	9,600	300	1:1	11.5%	165,600
Fishhook	1991	7,200	300	1:1	3.3%	35,640
Alturas	2001	145	150	1:1	13.0%	1,414
Alturas	2000	827	339	1:1	13.0%	18,223
Alturas	1999	8,334	285	1:1	13.0%	154,387
Alturas	1998	15,273	220	1:1	13.0%	217,889
Alturas	1997	8,492	168	1:1	13.0%	92,733
Alturas	1996	744	150	1:1	13.0%	7,254
Alturas	1995	1,600	150	1:1	13.0%	15,600
Alturas	1994	3,200	150	1:1	13.0%	31,200
Alturas	1993	200	-	1:1	13.0%	2,000
Stanley	2001	6,180	257	1:1	7.0%	55,589
Stanley	2000	5,665	243	1:1	7.0%	48,181
Stanley	1999	948	270	1:1	7.0%	16,637
Stanley	1998	783	270	1:1	7.0%	7,399
Stanley	1997	629	270	1:1	7.0%	5,935
Stanley	1996	825	270	1:1	7.0%	7,796
Stanley	1995	90	270	1:1	7.0%	850
Stanley	1994	600	270	1:1	7.0%	5,670
Stanley	1993	1,900	-	1:1	7.0%	19,000

Beach Spawning

On 02 October 2001, snorkel surveys were conducted by three divers at the southeast shore of Redfish Lake starting at 20:40. Divers recorded 4 CH juveniles, 10 suckers, and 6 whitefish. On the same night divers surveyed sockeye beach on Redfish Lake and observed 1 CH juvenile, 69 suckers, 4 bull char, and 162 whitefish. A second snorkel survey at the southeast shore by two divers was conducted on the night of 9 October 2001 starting at 21:00. Fourteen CH juveniles, 5 bull char, 42 redside shiners, and 12 whitefish were observed. On the same night, 3 divers surveyed sockeye beach starting at 22:40. Fish observed included 48 sockeye juveniles, 30 suckers, 1 bull char, 52 redside shiners, 172 whitefish, 3 sculpins, and 2 northern pikeminnows. A third survey was conducted by two divers on 16 October 2001 starting at 20:30 at the southeast shore. Fish observed included 3 sockeye residuals, 1 sockeye adult, 10 CH juveniles, 5 suckers, 5 bull char, 12 redside shiners, 8 whitefish, and 1 rainbow trout. On the same night, three divers snorkeled sockeye beach starting at 21:20. Fourteen sockeye residuals, 53 suckers, 1 bull char, 17 redside shiners, 110 whitefish, 8 sculpin, and 1 northern pikeminnow were observed at sockeye beach. A fourth survey was conducted on 23 October 2001 by 2 divers at the southeast shore starting at 20:15. Fish observed included 2 sockeye juveniles, 4 adult sockeye, 9 CH juveniles, 1 sucker, 2 bull char, 13 redside shiners, 40 whitefish, 7 rainbow trout, and 1 sculpin. On the same evening, 3 divers surveyed sockeye beach starting at 21:00. Twenty five suckers, 3 bull char, 23 redside shiners, 124 whitefish, and 10 sculpin were observed. A final snorkel survey was conducted on 30 October 2001. Snorkeling began at 19:00 at the southeast shore with two divers. Two sockeye juveniles, 25 CH juveniles, 14 suckers, 3 bull char, 28 redside shiners, 34 whitefish, 2 rainbow trout and 1 northern pikeminnow were observed. At sockeye beach snorkeling started at 19:45 with 2 sockeye juveniles, 26 suckers, 1 bull char, 36 redside shiners, 67 whitefish, and 2 sculpin observed (Figure 1-21).

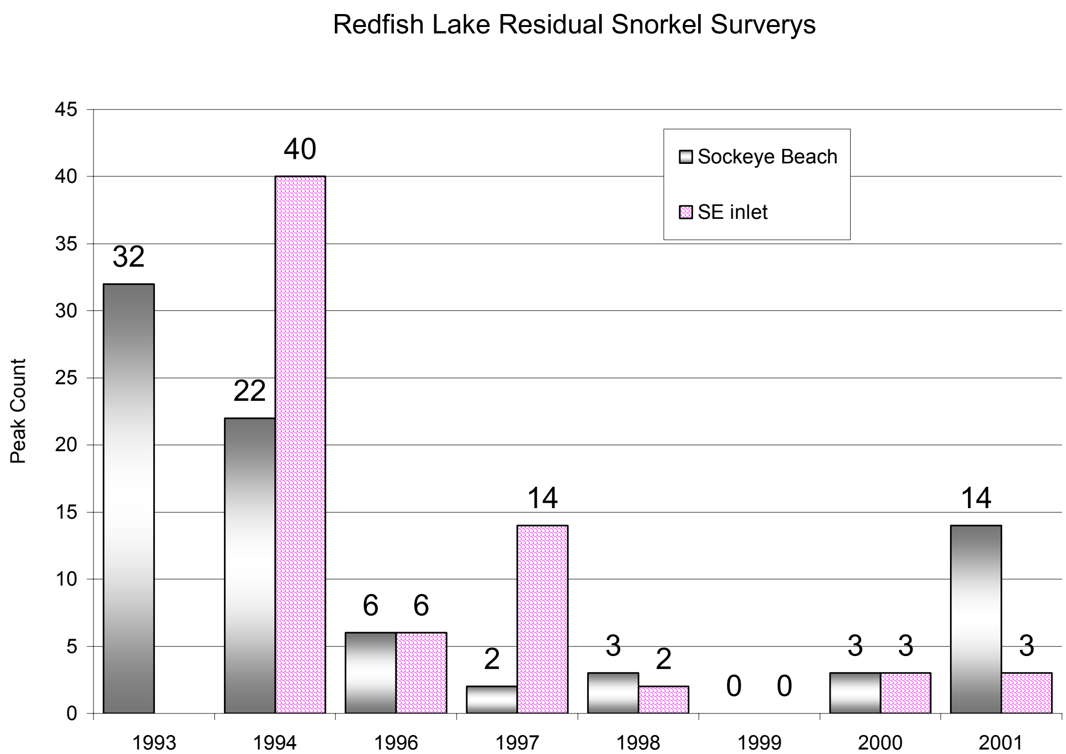


Figure 1-21. Redfish Lake residual O. nerka counts from snorkel surveys (1995 data not available).

DISCUSSION

Growth Rates and Survival

Growth rates of stocked *O. nerka* from the captive rearing program may provide insight into potential performance differences associated with hatchery origin, lake rearing conditions, and stocking strategies. Two groups were evaluated with respect to stocking strategies: 1) a summer release group consisting of fish reared at Eagle Fish Hatchery and Sawtooth Fish Hatchery and 2) a fall release group reared at the Sawtooth Fish Hatchery. Summer release fish were stocked into Pettit and Alturas lakes while fall release fish were released into Redfish, Pettit, and Alturas lakes. Growth rates were examined and compared in order to investigate differences between lakes, hatchery origin, and stocking strategy. Although growth rates of summer release fish in Pettit and Alturas lakes appeared to be higher than fall release fish, over-winter survival rates were very low (6% over-winter survival for combined Alturas and Pettit lake summer release fish compared to a 52% over-winter survival for combined Alturas and Pettit lake fall release fish). Explanations for these findings are complex and may include factors such as differential foraging efficiencies, release timing, seasonal zooplankton community dynamics, and fish community dynamics associated with each lake. Fall release fish reared at the Sawtooth Fish Hatchery and released into Pettit and Alturas lakes in 2000 had variable over-winter growth rates and survival. Pettit Lake fish appeared to grow well from the time of release to smolt emigration while Alturas Lake fish appeared to lose weight in their lake environment. This is not surprising. Pettit Lake zooplankton biomass was 12.8 and 39.1 *u*g/L in 2000 and 2001 respectively, compared to a whole-lake zooplankton biomass of 5.9 and 3.7 *u*g/L for the same time period in Alturas Lake. However, over-winter survival rates are considerably higher in Alturas Lake (75%) when compared to the fall release group that over-wintered in Pettit Lake (29%). Seemingly counterintuitive, differences in over-winter survival estimates between Pettit and Alturas lakes may be associated with unique lake rearing conditions that lead to differential outmigration patterns. Our over-winter survival estimates assume that stocked *O. nerka* parr outmigrate the following spring as 1 year olds. Data suggests that a variable portion of sockeye stocked into Sawtooth Valley lakes outmigrate as 2 year olds, thus confounding our over-winter survival estimates. Continued monitoring and evaluation of over-winter survival rates, outmigration patterns, and release strategies will continue in 2002.

Diet Analysis

Intraspecific competition has been identified as one of the potential limiting factors in the sockeye rearing habitat of the Sawtooth Valley lakes. In sockeye systems, intraspecific competition has been demonstrated to be much stronger than the interspecific component (Burgner 1987). An ontogenetic diet shift between age 0 and age 1+ kokanee has been detected in populations in both Redfish and Alturas lakes. This ontogenetic diet shift may be an evolutionary adaptation to reduce intraspecific competition between age classes and between the anadromous form and kokanee form of *O. nerka*.

The vertical distribution of kokanee and zooplankton prey may influence interactions and prey availability. *O. nerka* in the Sawtooth Valley lakes exhibit a diel vertical migration pattern (found higher in the water column at night and deeper during daylight) (Beauchamp et al. 1992) similar to that of sockeye in other systems (Levy 1987, Levy 1990). In a Sawtooth Valley sockeye rearing habitat evaluation, Budy et al. (1995) documented *Bosmina* sp. movement from a depth of 46 m during the day to 15 m at night. Cyclopoid copepods were concentrated in the hypolimnion. *Polyphemus* sp. and *Daphnia* sp. were found at low densities throughout the water column. Kokanee diet data and zooplankton dispersal patterns seem to indicate that the age 0 kokanee are feeding primarily in deeper waters. Levy (1990) hypothesized that during the day juvenile sockeye in lakes with piscivorous fish populations were concentrated in deeper areas with lower light levels to aid in predator avoidance

Stocked juvenile sockeye from the captive rearing program were found in the stomachs of stocked rainbow trout (*O. mykiss*) in Pettit Lake during 1995, the first year that sockeye were stocked into that lake (Teuscher and Taki 1996). The sockeye were released at the boat ramp in the littoral zone. After detection of *O. nerka* in *O. mykiss* stomachs, the stocking strategy was modified to a pelagic release using a barge. Since the pelagic release was implemented, annual (1996-99) *O. mykiss* diet analysis has been used to monitor potential predation on stocked *O. nerka*. During that monitoring no subsequent predation of *O. nerka* by *O. mykiss* has been conclusively documented in Pettit Lake.

Northern pikeminnow are known to prey on juvenile salmon and are the subject of control efforts in the main stem of the Columbia River. Northern pikeminnow are one of the more abundant species found in the sockeye rearing/nursery lakes of the Sawtooth Valley. There has been concern expressed about their potential predation on stocked juvenile sockeye. Diet analysis has found that while piscivorous, cyprinids and unidentified fish composed 36% of prey items in 2001 (Table 1-10), there has been no conclusive evidence of predation on *O. nerka* by northern pikeminnow. During gillnet sampling, the majority of northern pikeminnow are caught in the littoral zone of the lakes. *O. nerka* are primarily a pelagic species. The low degree of habitat utilization overlap may limit the opportunity for northern pikeminnow to predate on *O. nerka*. Predation by northern pikeminnow is not currently considered a problem. Ongoing monitoring of the northern pikeminnow populations and diets is warranted in order to detect any potential changes.

Bull char are the top piscivorous predator of the fish community in the Sawtooth Valley lakes. Monitoring associated with this program has found that bull char diet is composed primarily of fish prey (Taki et al. 1999). However, no *O. nerka* have been detected in any of the samples. Salmonids, too digested to be identified, were found in some of the samples and some may have been *O. nerka*. Bull char were listed as a threatened species in 1998 under the Endangered Species Act and, as the top predator, are an important component of fish community dynamics in the Sawtooth Valley lakes and upper Salmon River. Any predation by this species on *O. nerka* is considered a natural process and no control measures will be implemented. Continued incidental takes during gillnet sampling are anticipated and will allow for monitoring of bull char population dynamics.

Stream Spawning

Kokanee escapement in 2001 showed variation in population densities, timing, and fecundity. The Fishhook Creek kokanee spawning population had been declining since 1996 when escapement was estimated to be 10,662. This years spawning population was estimated at 5,853 individuals, substantially higher than the 2000 estimate of 60 adult spawners. No direct control of kokanee escapement occurred in Fish Hook Creek in 2001. The Alturas Lake Creek kokanee escapement estimate was down from 827 in 2000 to 145 in 2001 and is well below the 1993-2000 mean of 4,834. The Stanley Lake Creek kokanee spawning population increased from 5,665 in 2000 to 7,246 in 2001, well above the 1991-1999 mean of 825. Kokanee escapement timing in Fishhook and Alturas lake creeks was similar to 1992-1995 and 1996-2000 mean escapement timing. However, the time at which 20, 50, and 80% of the kokanee spawning adults had entered Stanley Lake Creek was 4, 11, and 13 days later than the 1992-2000 mean. Alturas Lake Creek female kokanee had lower fecundity compared to previous measurements. The mean number of eggs per female in 2001 was 150, 28% below the 1991-2000 mean of 209. Female kokanee in Fishhook Creek exhibited higher fecundity compared to previous measurements. The mean number of eggs per female in 2001 was 272, 12% above the 1991-2000 mean of 242. Stanley Lake Creek female kokanee fecundity was estimated to be 257 eggs per female in 2001, up slightly from the 2000 estimate of 243 and similar to the 1994-2000 mean estimate of 266. Based on variation in Alturas Lake and Fishhook creek kokanee fecundity all three populations should be measured annually. Length, weight, and condition factor should also be measured in order to quantify changes that could be associated with lake fertilization, meteorological forcing, and changes in population dynamics.

Beach Spawning

Night snorkel surveys along Sockeye Beach and at the south end of Redfish Lake were implemented in 1993 to monitor the densities and spawning activities of residual *O. nerka*. There has been a downward trend in the number of residual *O. nerka* observed since the surveys began. However, in 2001, 17 residual spawners were observed; up from 6 in 2000 and 0 in 1999. Yearly monitoring will continue to track residual spawner populations at these locations.

REFERENCES

Beauchamp, D. A., P. E. Budy, W. A. Wurtsbaugh, H. Gross, C. Luecke, and S. Spaulding. 1992. Fisheries assessment of the abundance and temporal distribution of sockeye and kokanee salmon in lakes of the Sawtooth Valley. In Spaulding, S. (Ed) Snake River sockeye salmon habitat and limnological research. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71.

Bjornn, T. C., D. R. Craddock, and R. Corley. 1968. Migration and survival of Redfish Lake, Idaho, sockeye salmon, Oncorhynchus nerka. Trans. Am. Fish. Soc. 97:360-373.

Budy, P., C. Luecke, W. A. Wurtsbaugh, H. P. Gross and C. Gubala. 1995. Limnology of Sawtooth Valley Lakes with respect to the potential growth of juvenile Snake River sockeye salmon. Northwest Science. 69:133-150.

Burgner, R. L. 1987. Factors influencing age and growth of juvenile sockeye salmon (*Oncorhynchus nerka*) in lakes. p. 129-142. *In* G. D. Smith, L. Margolis, and C. C. Wood (ed.) Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Ehrenberg, J. C. and T. C. Torkelson. 1996. Application of dual-beam and split-beam target tracking in fisheries acoustics. ICES Journal of Marine Science. 53:329-334.

English, K. K., T. C. Bocking and J. R. Irving. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Can. J. Fish. Aquat. Sci. 49:1982-1989.

Griswold, R., A. Kohler and D. Taki. 2000. Salmon River sockeye salmon habitat and limnological research: 1997 annual progress report. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71.

Gunderson, D. R. 1993. Surveys of fisheries resources. John Wiley and Sons, Inc. New York, New York. 248 pp.

Hume, J. M. B., K. S. Shortreed, and K. F. Morton. 1996. Juvenile sockeye rearing capacity of three lakes in the Fraser River system. Can. J. Fish. Aquat. Sci. 53:719-733.

Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. Yale University Press, New Haven, CT.

Koenings, J.P., J.A. Edmundson, G.B. Kyle, and J.M. Edmundson. 1987 Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation, Enhancement and Development. Juneau, Alaska.

Kyle, G.B., J. P. Koenings, and B. M. Barrett. 1988. Density-dependent, trophic level responses to an introduced run of sockeye salmon (*Oncorhynchus nerka*) at Frazer Lake, Kodiak Island Alaska. Can. J. Fish. Aquat. Sci. 45:856-867.

Levy, D. A. 1987. Review of the ecological significance of diel vertical migrations by juvenile sockeye salmon (*Oncorhynchus nerka*). p. 44-52. *In* G. D. Smith, L. Margolis, and C. C. Wood (ed.) Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96.

Levy, D. A. 1990. Sensory mechanism and selective advantage for diel vertical migration behavior in juvenile sockeye salmon. Can. J. Fish and Aquat. Sci. 47: 1796-1802.

Lewis, B., D. Taki and B. Griswold. 2000. Snake River sockeye salmon habitat and limnological research: 1998 annual progress report. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71. Pp.1-50.

Love, R. H. 1977 Measurements of fish target strength: a review. Fisheries Bulletin 69:703-715.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. In Eds. J. A. Downing and F. Ringler. Secondary production in freshwater, Second edition. Blackwell Scientific Publishing, Oxford, UK.

Parkinson, E. A., B. E. Rieman, and L. G. Rudstam. 1994. Comparison of acoustic and trawl methods for estimating density and age composition of kokanee. Trans. Of American Fisheries Society. 123:841-854.

Swanson, G. A., G. L. Krapu, J. C. Bartonek, J. R. Serie, and D. H. Johnson. 1974. Advantages of mathematically weighted waterfowl food habitat data. Journal of wildlife management. 38:302-307.

Taki, D., B. Lewis, and R. Griswold. 1999. Salmon River sockeye salmon habitat and limnological research: 1997 annual progress report. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71.

Teuscher, D. and D. Taki. 1996. Salmon River sockeye salmon habitat and limnological research, In Teuscher, D. and D. Taki (ed). Snake River sockeye salmon habitat and limnological research: 1995 annual progress report. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71. Pp.1-50.

Traynor, T. C. and J. C. Ehrenberg. 1990. Fish and standard-sphere target-strength measurements obtained with a dual-beam and split-beam echosounding system. Rapp. P.-v. Reun Cons. Int. Explor. Mer. 189:325-335.

Chapter 2: Limnology of the Sawtooth Valley Lakes, 2001

By

Robert G. Griswold

Biolines
HC-64 Box 9965
Stanley, Idaho 83278

INTRODUCTION

In December 1991, the National Marine Fisheries Service listed Snake River sockeye salmon O*ncorhynchus nerka* as endangered under the Endangered Species Act (Waples et al. 1991). As a result, the Sawtooth Valley Project was initiated to conserve and rebuild sockeye salmon populations in the Sawtooth Valley lakes (Redfish, Pettit, Alturas, and Stanley lakes). The recovery strategy was to increase the number of juvenile sockeye salmon rearing in the nursery lakes using hatchery broodstocks (Flagg et al. 1998, Kline and Willard 2001), improve growth and survival of juvenile sockeye salmon, and increase lake carrying capacities via lake fertilization (Griswold et al. 2001, Stockner and MacIsaac 1996). During 1993 and 1994, Utah State University conducted mesocosm studies to determine the efficacy of supplemental nutrient additions to the Sawtooth lakes (Budy and Wurtsbaugh 1998). Based on the results of these studies, supplemental nutrients were added to Redfish Lake during 1995-1998 and to Pettit and Alturas lakes during 1997-1999. In 2001, only Redfish Lake received supplemental nutrients.

In 2001, limnological monitoring was conducted to assess productivity and identify changes in physical and chemical characteristics of the Sawtooth Valley lakes. The information was used to identify inter-annual variation of physical and chemical characteristics, evaluate the effects of past and present nutrient supplementation efforts, evaluate sockeye rearing conditions, and determine *O. nerka* carrying capacities of the Sawtooth Valley lakes. These data are used to make decisions about sockeye salmon stocking rates and their allocation between the different Sawtooth Valley lakes.

STUDY AREA

The Sawtooth Valley lakes are located in south-central Idaho near the town of Stanley. The watersheds are located in the Sawtooth Mountains, mostly within the Sawtooth Wilderness Area and administered by the United States Department of Agriculture, Forest Service, Sawtooth National Recreation Area. The Sawtooth Mountains are part of the Idaho batholith, comprised of granite like rock, consisting of granodiorite, quartz diorite and quartz monzonite (Emmett 1975). The lakes are at a relatively high elevation (1985-2157 m), generally ice covered from January to May, and classified as oligotrophic. The ratio of drainage area to lake surface area is 48.6 for Stanley Lake, 22.4 for Alturas, 17.6 for Redfish, and 16.9 for Pettit Lake (Table 2-1)(Gross et al. 1993). Morphometric maps and descriptions of the lakes and their watersheds are reported in Spaulding (1993) and Budy et al. (1993), a map of the study area is in Chapter 1 (Figure 1-1) of this report.

Table 2-1. Physical and morphological features of Redfish, Pettit, Alturas, and Stanley lakes, Idaho.

Lake	Area (km^2)	Volume (m^3x106)	Mean Depth (m)	Maximum Depth (m)	Drainage Area (km^2)	Drainage area/ lake surface area	Water residence time in years (Gross, 1993)
Redfish	6.15	269.9	44	91	108.1	17.6	3.0
Pettit	1.62	45.0	28	52	27.4	16.9	2.2
Alturas	3.38	108.2	32	53	75.7	22.4	1.8
Stanley	0.81	10.4	13	26	39.4	48.6	0.3

METHODS

In 2001, the Shoshone-Bannock Tribes (SBT), operating under a consent order issued by the Idaho Division of Environmental Quality (DEQ), added supplemental nutrients (liquid ammonium phosphate (20-5-0) and ammonium nitrate (28-0-0-0)) to Redfish Lake. The DEQ consent order required measurement of water transparency once per week and estimates of epilimnetic and metalimnetic chlorophyll *a* concentrations every two weeks and measurement of nutrient concentrations once per month. The consent order specified that nutrient enhancement activities might continue as long as water transparencies exceed 8 m, chlorophyll *a* concentrations remain below 3 µg/L in the epilimnion and 6 µg/L in the metalimnion, and total phosphorus concentrations remain below 15 µg/L in both the epilimnion and metalimnion. Nutrient applications were made from a 6.7 m boat equipped with a portable plastic tank and electric pump. Fertilizer was loaded into tanks off-site and sprayed into the boat's wake while traveling over the surface of the lake. Twenty predetermined transect lines were followed using GPS, compass, and local landmarks to evenly disperse the nutrients over the surface of the lake.

Limnological monitoring was conducted once per month in January- March, May, October, and November and twice per month from June through September at Redfish and Pettit lakes. Alturas and Stanley lakes were sampled once per month in January, March and May-October. Redfish, Pettit, and Alturas lakes were stocked with juvenile sockeye salmon from the Redfish Lake captive broodstock in 2001. Stanley Lake was not stocked with sockeye salmon. Water temperature (^{o}C), dissolved oxygen (mg/L), conductivity (µS/cm), Secchi depth (m), compensation depth (m), nutrient concentrations (µg/L), chlorophyll *a* concentrations (µg/L), heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL), phytoplankton density (cells/mL) and biovolume (mm^3/L), and zooplankton density (No./L) and biomass (µg/L) were sampled near the middle of each lake. Additional zooplankton samples were collected from two other stations in each lake. Nutrients were only sampled during May 2001 in Alturas and Pettit Lakes, whereas nutrients were sampled once per month from May-October in Redfish and Pettit lakes.

During stratification, water for nutrient analysis was collected from the epilimnion, metalimnion, and hypolimnion. Chlorophyll *a*, bacteria, APP and phytoplankton samples were collected from the epilimnion, metalimnion, and compensation depth. Three discrete samples were collected from each stratum with a three L Van Dorn bottle and mixed in a churn splitter. When lake strata could not be delineated, surface water was collected from 0-6 m with a 25 mm diameter, 6 m long lexan® tube and discrete samples were collected from mid-depth (Redfish = 45 m, Pettit and Alturas = 25 m, and Stanley = 12 m) and 1-2 m above the bottom.

Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles were collected at the main station of each lake using a Hydrolab® Surveyor3™ equipped with a Hydrolab H20® submersible data transmitter. The instrument was calibrated each day prior to sampling using barometric pressure and conductivity standards. Temperature, dissolved oxygen, and conductivity were recorded at 1 m intervals from the surface to 10 m, 1-2 m intervals from 10 m to the thermocline, then at 2-10 m intervals to the bottom. Mean water temperatures from 0-10 m were used to calculate seasonal mean (June-

October) surface water temperatures. Secchi depth was measured with a 20 cm Secchi disk and a viewing tube, and light attenuation was measured with a Li-Cor® Li-1000 data logger equipped with a Li-190SA quantum sensor deck cell and a LI-193SA spherical sea cell. Photosynthetically active radiation (400-700 nm) was measured at two-meter intervals from surface to 2-4 m below the compensation depth (1% light level). Compensation depth was identified using the technique of Wetzel and Likens 1991.

Water collected for nutrient analysis was transferred to nalgene bottles that had been rinsed in hydrochloric acid (0.1 *N*) and sample water. Samples were stored at 4^o C while in the field. Water was filtered through 0.45 μm acetate filters at 130 mm Hg for ammonium (NH_4), nitrate-nitrite (NO_3+NO_2), and total dissolved phosphorus (TDP) assays. Water samples were then frozen and shipped to the University of California at Davis Limnology Laboratory for analysis. NH_4 was assayed with the indophenol method, NO_3+NO_2 with the hydrazine method, organic nitrogen (TKN) using kjeldahl nitrogen, and total phosphorus (TP) and total dissolved phosphorus (TDP) samples were assayed by persulfate digestion (APHA 1995). Total nitrogen (TN) concentrations were estimated by adding TKN and NO_3+NO_2.

Chlorophyll *a* samples were stored at 4^o C in the field and then filtered onto 0.45 μm cellulose acetate membrane filters with 130 mm Hg vacuum pressure. Filters were placed in centrifuge tubes and frozen (-25^o C). The filters were then placed in methanol for 12-24 hrs to extract the chlorophyll pigments. Chlorophyll *a* concentrations were measured with a Turner model 10-AU fluorometer calibrated during the spring with commercial chlorophyll standards. Samples were run before and after acidification to correct for phaeophytin (Holm-Hansen and Rieman 1978). Heterotrophic bacteria and APP were first sampled in September and October of 2000. In 2001, we sampled these populations throughout the summer and fall. Bacteria and APP samples were fixed in gluteraldehyde and shipped to Eco-Logic Inc. for enumeration. Picoplankton were stained with DAPI fluorochrome stain and were enumerated using a Carl Zeiss Standard Epi-florescence© microscope with mercury lamp following the protocol of MacIsaac and Stockner (1993). Phytoplankton samples were fixed in Lugol's solution and total cell abundance and bio-volume determined at 1560x magnification using a Zeiss Inverted Plankton microscope following the protocol of Utermohl (1958).

Zooplankton was sampled with a 0.35 m diameter, 1.58 m long, 80 µm mesh, conical net with a removable bucket. Vertical hauls were made using a release mechanism that allowed sampling at discrete depth intervals. A General Oceanics flow meter was mounted in the mouth of the net to quantify volume of water filtered. The net was retrieved by hand at a rate of approximately 1 m/sec. In Redfish, Pettit, and Alturas lakes hauls were made from 10-0 m, 30-10 m, and bottom (~ 60 m) to 30 m: at the main station in Redfish Lake an additional haul was made from approximately 85 m to 60 m. Stanley Lake was sampled at 10-0 m and bottom (~26 m) to 10 m. Samples were preserved in 10% buffered sugar formalin. Techniques used to subsample, count, and measure zooplankton were adopted from Utah State University (Steinhart et al. 1994) using techniques and length-weight relationships developed by McCauley (1984) and Koenings et al. (1987). Seasonal means were calculated from monthly means for June-October.

RESULTS

In 2001, mean annual discharge of the Salmon River at Salmon, Idaho (USGS gage 13302500) was 31.2 m^3/s, 43% less than the 1913-2001 average of 55.2 m^3/s (Figure 2-1). Mean annual discharge for the Salmon River at Salmon was below average from 1990 to 1994 and above average each year from 1995 to 1999. During the past decade the Upper Salmon River has experienced the three lowest water years since measurements began in 1913.

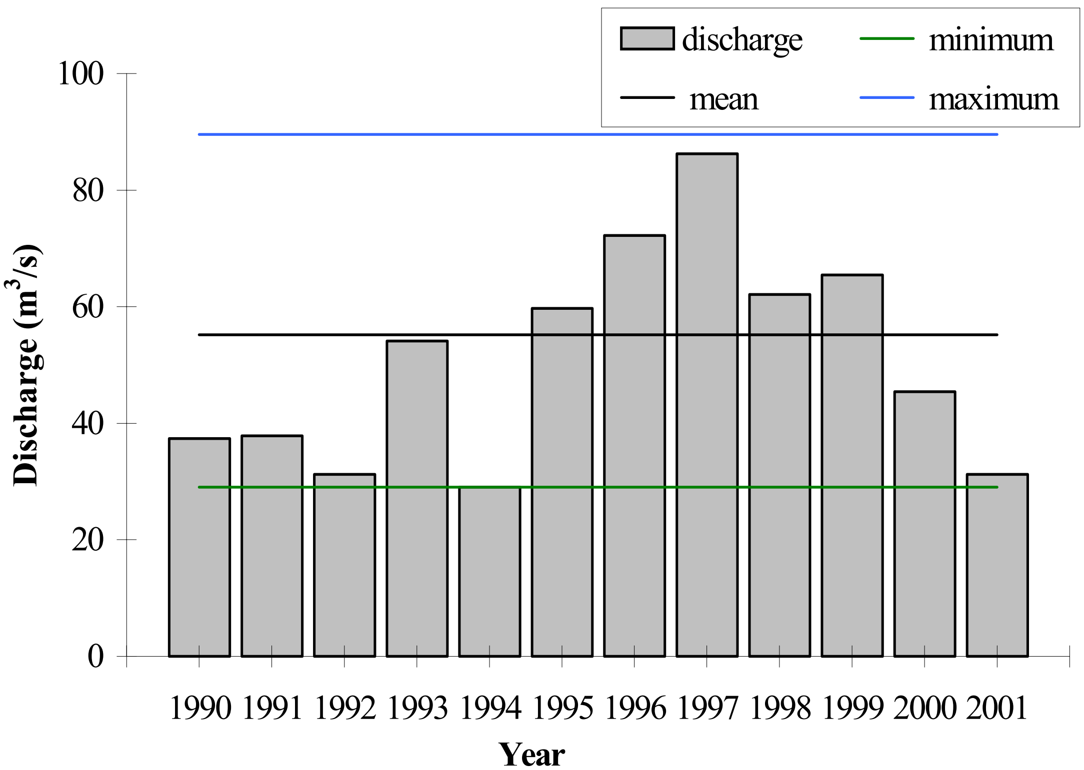


Figure 2-1. Mean annual discharge for the Salmon River at Salmon, Idaho, 1990 through 2001. Minimum, mean and maximum are for period of record, 1913 to 2001.

Lake Fertilization

Between 28 June and 27 September 2001, 199 kg phosphorus (P) and 5,652 kg nitrogen (N) were added to Redfish Lake to enhance the lakes productivity. Applications were made for 14 consecutive weeks with a large initial dose, followed by a smaller application on the second week. Weekly supplementation then gradually increased to a peak on week twelve, followed by two smaller additions (Figure 2-2). Additions during weeks 3 and 7 were less than planned because of mechanical failures. Areal loading rates were 32.4 mg P/m^2, or the equivalent of an adult escapement of approximately 26,000 sockeye salmon to Redfish Lake. Nutrients were applied at a ratio of approximately 28:1 N:P by mass and were purposely skewed toward high nitrogen loads to avoid possible stimulation of nitrogen fixing Cyanophytes. We remained in compliance with DEQ limits and nutrient supplementation proceeded uninterrupted.

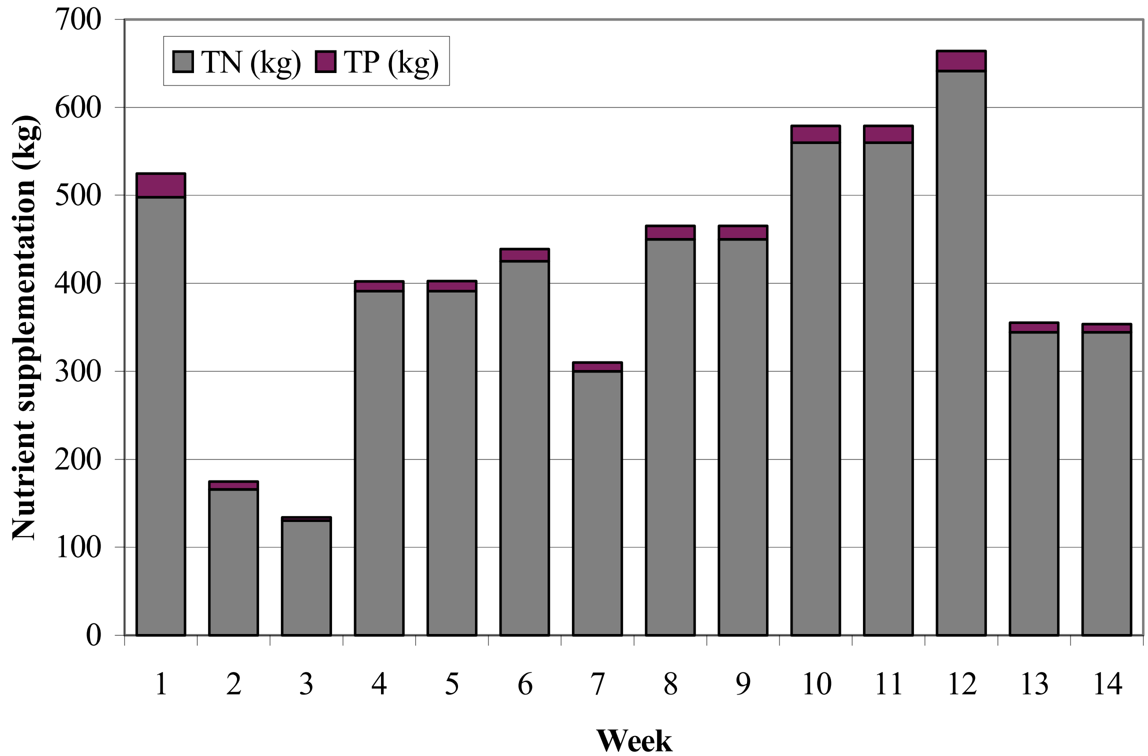


Figure 2-2. Supplemental nutrient applications for Redfish Lake 28 June-27 September 2001.

Profile Data

The Sawtooth Valley lakes were inversely stratified and ice covered from early January to late April 2001. Thermoclines were well developed from July through October (Figures 2-3a, 2-3b, 2-3c, and 2-3d). The lakes remained weakly stratified in November.

Dissolved oxygen concentrations in the Sawtooth Valley lakes were generally greater than 5 mg/L, the minimum level that will support growth and survival of salmonids (Lagler 1956). Dissolved oxygen concentrations in Redfish Lake remained above 5 mg/L throughout the entire water column between January and September, then oxygen concentrations fell below 5 mg/L in the bottom 2-3 m during November 2001. Pettit Lake, which is meromictic, had dissolved oxygen concentrations less than 5 mg/L below approximately 30 m depth throughout the year. Alturas Lake had low oxygen concentrations in the bottom 5 m by August and the lower 10 m by November. In Stanley Lake, DO concentrations were 5 mg/L throughout the entire water column during May. During the summer, dissolved oxygen concentrations gradually declined in the deep waters and by October the bottom 7-8 m were hypoxic (< 5mg/L).

Conductivities ranged from approximately 22-26 µS/cm above 30 m depth and 23-50 µS/cm at depths greater than 30 m in Pettit, 25-32 µS/cm in Redfish, 46-56µS/cm in Alturas, and 44-72 µS/cm in Stanley lakes.

Seasonal mean surface (0-10 m) water temperatures were 14.3, 14.8, 14.0 and 13.0 ^{o}C in Redfish, Pettit, Alturas, and Stanley lakes, respectively (Table 2-2). Seasonal mean surface water temperatures were similar or slightly warmer than 2000, and warmer than during the high discharge years of 1995-1999, but cooler than the extremely low water years of 1992 and 1994. Seasonal mean surface water temperatures were negatively correlated with discharge in the Sawtooth Valley lakes during 1992-2001 ($r = -0.84$, $n=36$).

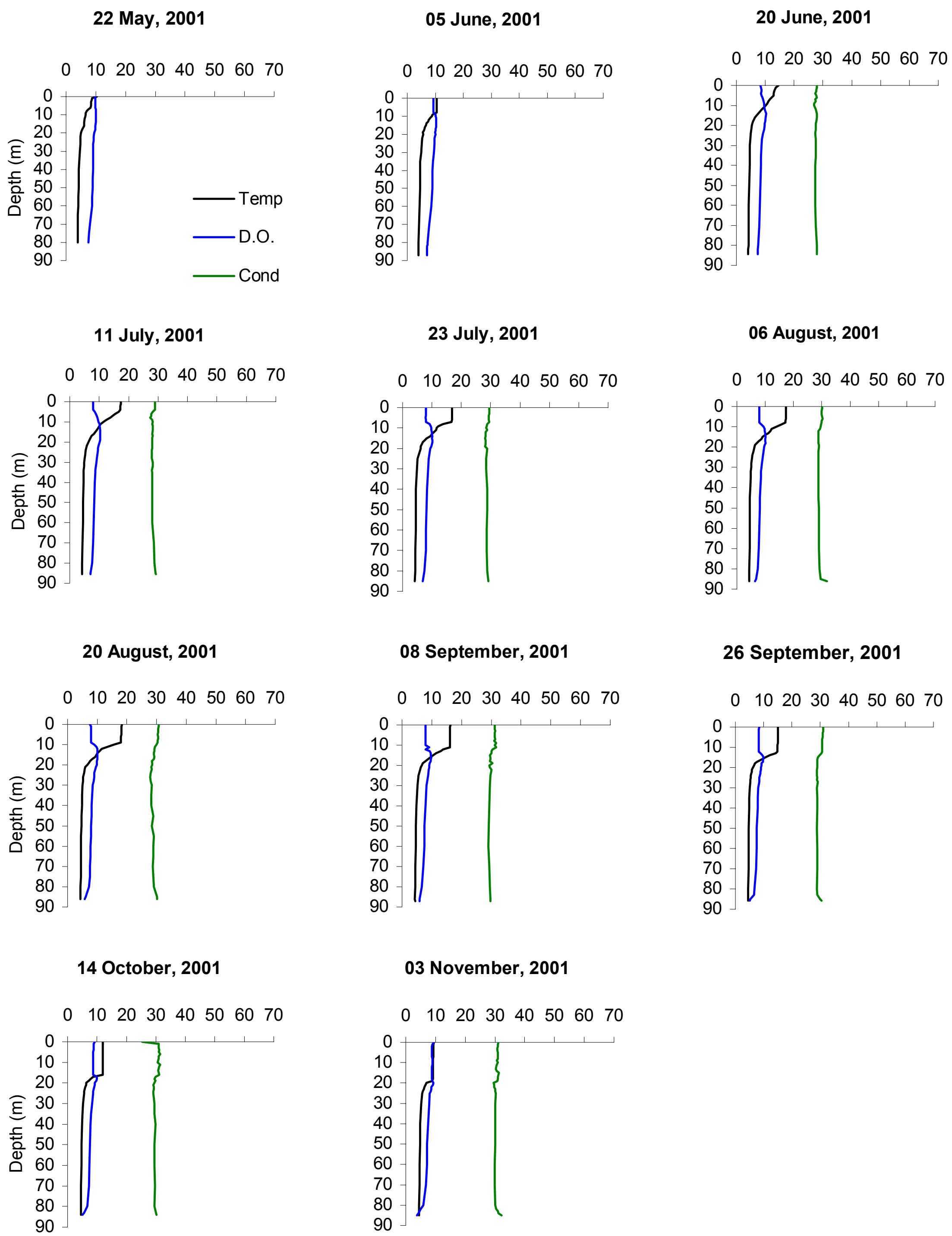


Figure 2-3a. Temperature (°C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles for Redfish Lake, May through November 2001.

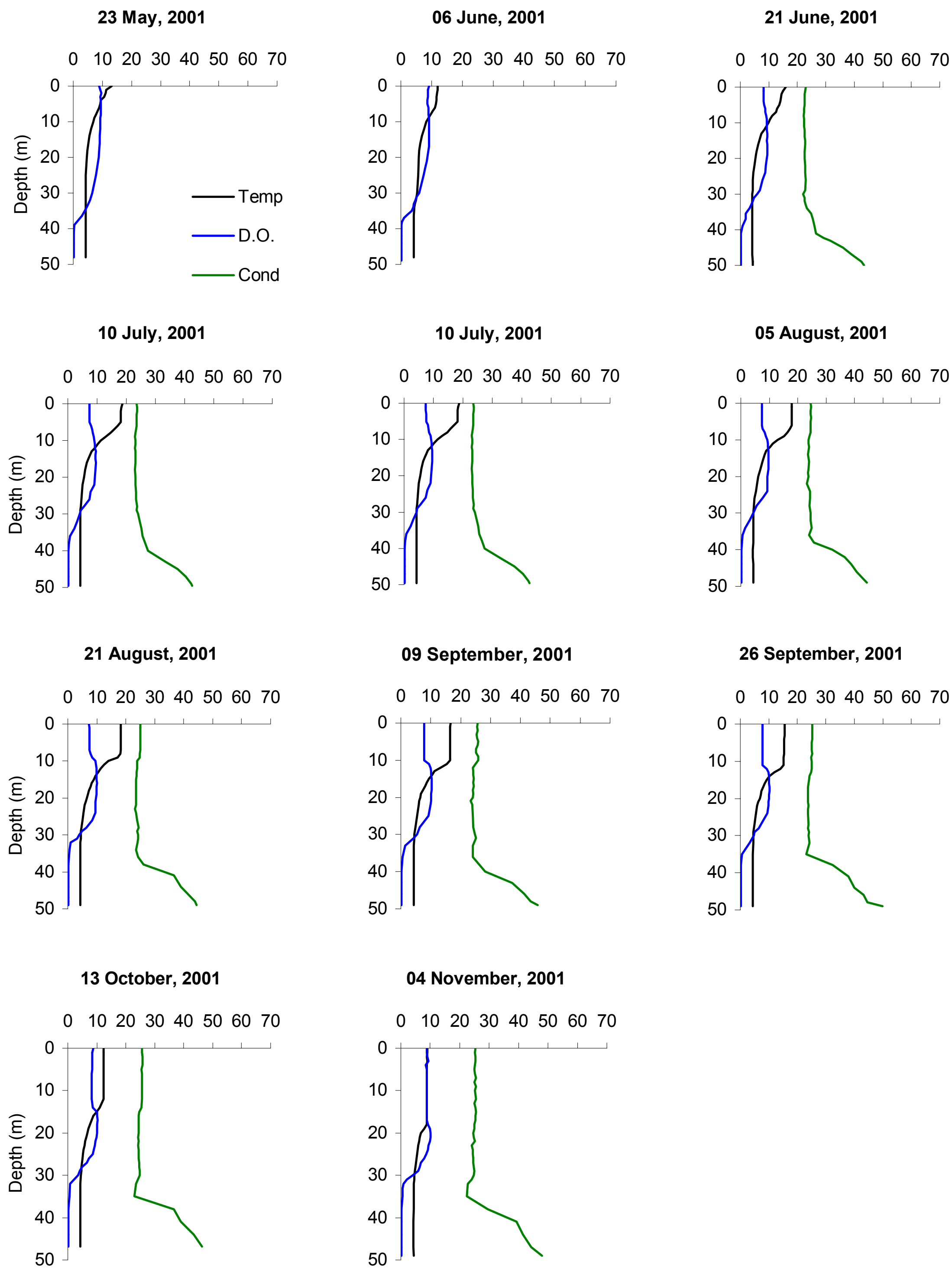


Figure 2-3b. Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles for Pettit Lake, May through November 2001.

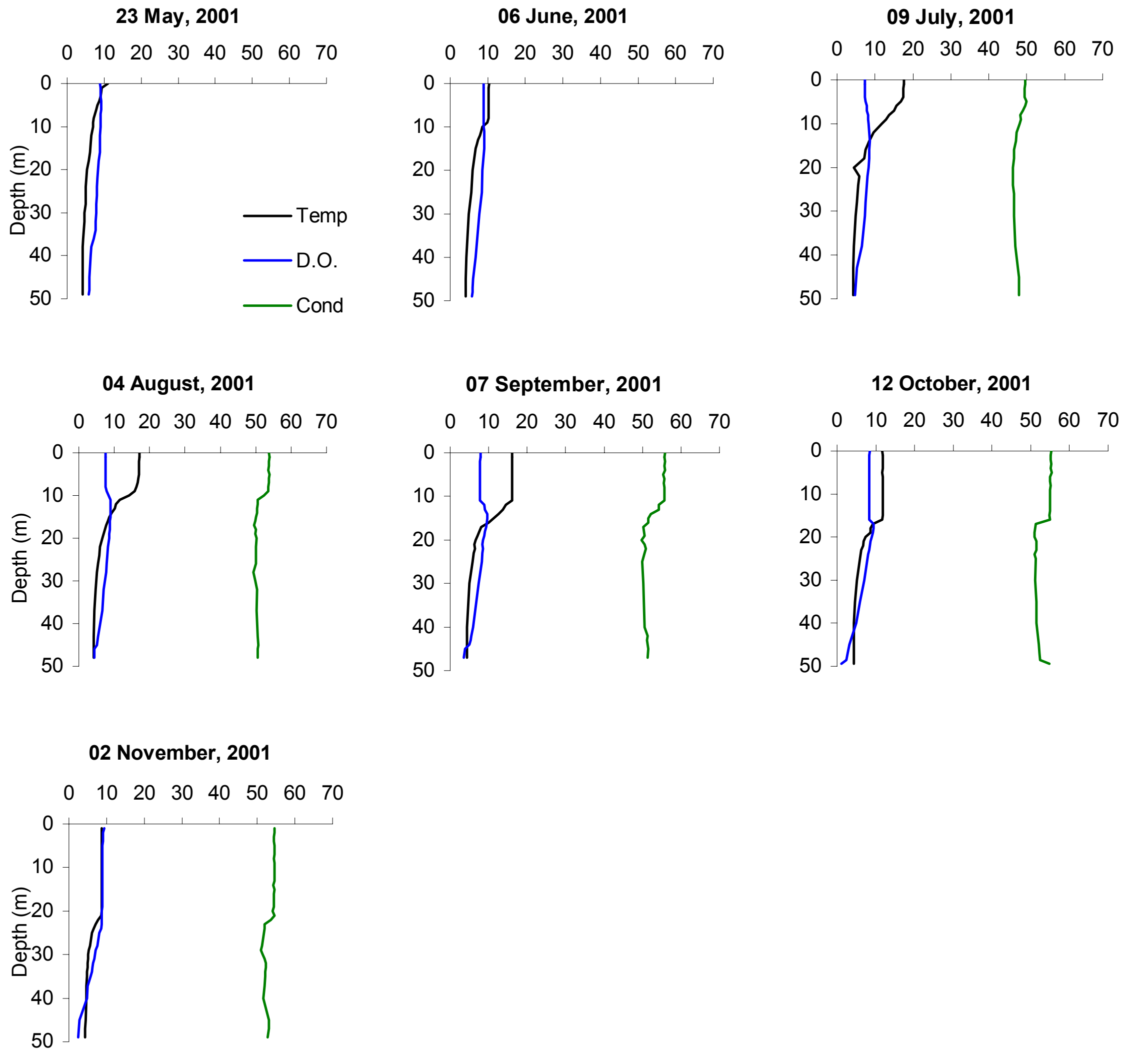


Figure 2-3c. Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles for Alturas Lake, May through November 2001.

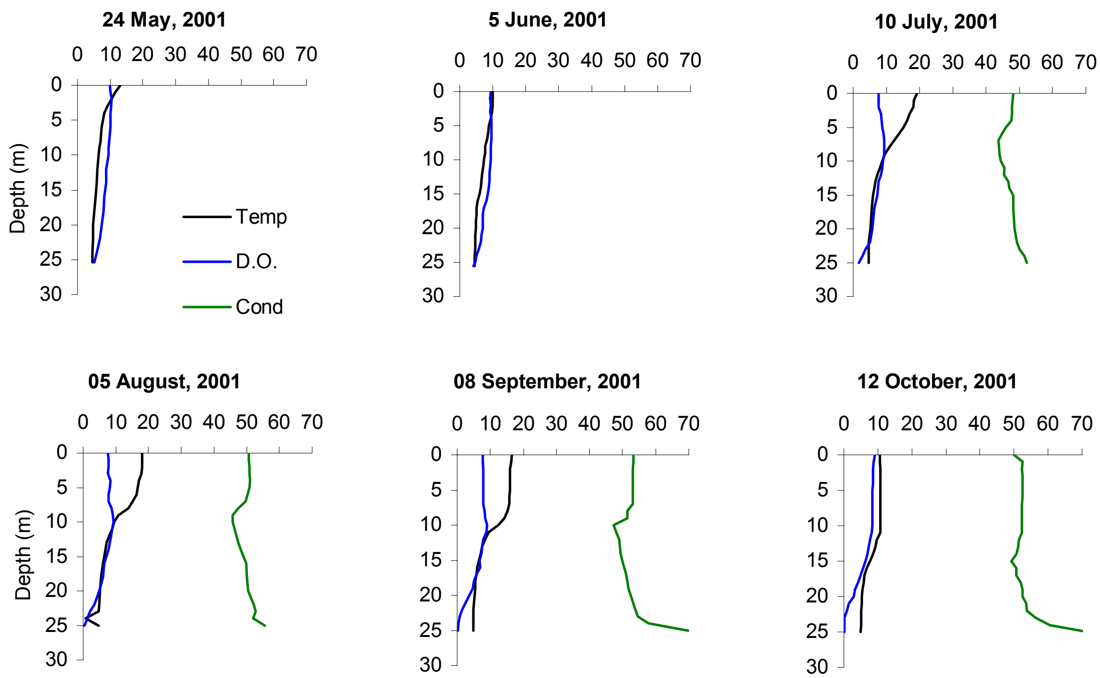


Figure 2-3d. Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles for Stanley Lake, May through October 2001.

Table 2-2. Seasonal mean (June-October) surface water temperature (^{o}C), Secchi depth (m), compensation depth (m), epilimnetic chlorophyll a (µg/L), and whole-lake total zooplankton biomass (µg/L) for the Sawtooth Valley lakes 1992-2001.

Lake	Year	Surface temperature (^{o}C) 0-10 m	Secchi depth (m)	Compensation depth (m)	Epilimnetic chl *a* (µg/L)	Whole-lake zooplankton biomass (µg/L)
Redfish	**1992**	14.9	13.8	33.3	0.5	-
	1993	13.4	14.0	26.3	0.6	6.9
	1994	14.7	15.8	31.8	0.3	9.9
	1995	13.4	12.1	26.2	0.5	11.3
	1996	12.0	14.1	18.5	0.7	7.5
	1997	12.2	11.4	19.7	1.5	8.1
	1998	13.3	12.1	22.1	1.6	9.9
	1999	12.7	14.6	22.5	0.9	6.8
	2000	14.2	17.8	26.1	0.8	19.1
	2001	14.3	14.5	27.4	1.4	17.1
	mean	**13.5**	**14.0**	**25.4**	**0.9**	**10.7**
Pettit	**1992**	15.1	15.7	29.1	0.4	-
	1993	13.6	14.8	23.3	0.6	23.3
	1994	15.6	15.2	30.8	0.3	28.3
	1995	13.2	12.4	22.2	0.5	3.7
	1996	12.2	11.8	17.4	0.8	9.0
	1997	12.4	11.3	19.1	1.3	11.0
	1998	13.6	10.6	22.6	1.5	9.1
	1999	12.7	11.2	21.7	1.4	13.0
	2000	14.4	15.0	24.5	1.0	12.8
	2001	14.8	15.7	26.2	0.6	39.1
	mean	**13.8**	**13.4**	**23.7**	**0.8**	**16.6**
Alturas	**1992**	14.7	14.4	27.6	0.6	-
	1993	13.1	-	20.6	0.9	0.5
	1994	14.3	14.7	24.1	0.4	3.6
	1995	12.2	9.8	16.5	0.4	3.1
	1996	11.5	10.6	13.6	1.0	6.5
	1997	11.4	10.9	15.7	1.0	12.6
	1998	12.6	10.8	17.3	2.0	12.4
	1999	11.8	10.5	16.9	1.2	12.3
	2000	13.8	14.5	19.8	0.9	5.9
	2001	14.0	13.9	22.8	0.8	3.7
	mean	**13.0**	**12.2**	**19.5**	**0.9**	**6.7**
Stanley	**1992**	14.7	8.6	20.0	0.7	-
	1993	11.9	8.3	15.4	1.1	23.2
	1994	14.6	8.3	16.6	0.5	28.1
	1995	12.0	5.8	11.9	0.8	19.7
	1996	10.7	7.5	10.9	1.0	25.9
	1997	11.5	7.5	13.7	1.2	19.9
	1998	11.8	5.0	11.8	1.0	26.2
	1999	11.1	6.6	11.4	1.6	20.6
	2000	12.4	7.6	13.8	0.8	30.4
	2001	13.0	8.1	14.8	1.3	28.7
	mean	**12.4**	**7.3**	**14.0**	**1.0**	**24.8**

Secchi Depth and Compensation depth

Secchi depths were lowest in May and June then increased as summer progressed with slight reductions during the fall (Figure 2-4). Redfish Lake differed from the other lakes with fairly dramatic reductions in Secchi depth during August and September, likely a result of nutrient supplementation. Seasonal mean Secchi depths were deeper than average in all four lakes, however Redfish showed the least deviation from the mean. (Table 2-2).

Compensation depths were the shallowest in June after spring turnover and gradually increased throughout the summer and fall, except in Redfish Lake where reductions in compensation depth were observed during the fall. These reductions corresponded with reduced Secchi depth measurements but were less pronounced (Figure 2-5). In 2001, mean compensation depths were deeper than the 10 year average in all four lakes. In general, light penetration was less than observed during the dryer, pre-fertilized years (1992 and 1994) and deeper than observed in recent years (Table 2-2). Secchi and compensation depth measurements for the ice-free seasons 1992-2002 were positively correlated (r = 0.78, n=345).

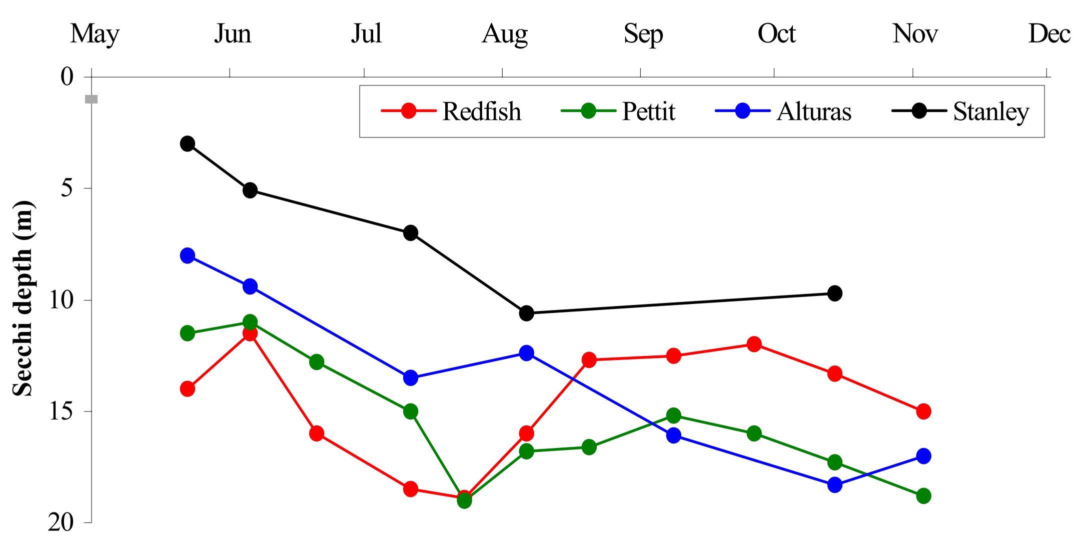


Figure 2-4. Secchi depth (m) for Redfish, Pettit, Alturas, and Stanley lakes, May through November 2001.

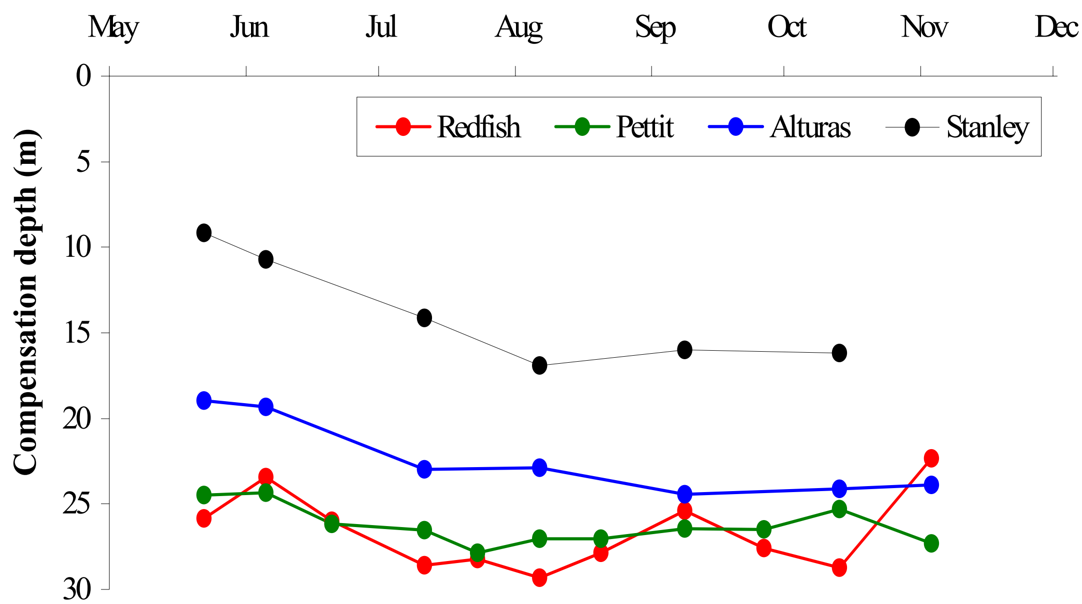


Figure 2-5. Compensation depth (m) defined by the 1% light level for Redfish, Pettit, Alturas, and Stanley lakes, May through November 2001.

Water Chemistry

During spring turnover (May 2001) depth integrated nutrient concentrations remained extremely low, consistent with the oligotrophic condition of the Sawtooth Valley lakes. TP concentrations were between 4.4 and 7.2 µg/L, TDP was less than 3.6 µg/L, and TN concentrations were less than 85 µg/L. Nitrate-nitrite concentrations were approximately 4 µg/L and TN/TP ratios were near 12 (Table 2-3). During the summer TN concentrations steadily increased in both lakes while TP remained fairly low and consistent (Figure 2-6). As a result, TN/TP ratios increased from approximately ten in May 2001 to approximately 50 by mid-October. Although Redfish Lake received supplemental nutrients, the only difference we observed between the lakes was with nitrate-nitrite concentrations. In Pettit Lake, nitrate-nitrite concentrations remained near method detection levels (1µg/L) throughout the summer while in Redfish Lake nitrate-nitrite concentrations rose to 5-6µg/L after supplementation began on 28 June 2001. TDP remained near detection levels during the growing season in both lakes (Figure 2-7).

Table 2-3. Nutrient concentrations (µg/L) and TN/TP ratio during late May-early June (after spring mixing) 1992-2001 in Redfish, Pettit, Alturas, and Stanley lakes, Idaho. Concentrations are averages of three discrete depths.

Lake	Year	TP	TDP	SRP	TN	$N0_3 + NO_2$	NH_4	TN/TP
Redfish	**1992**	6.5	-	1.0	61.0	5.5	-	9.5
	1993	8.6	-	-	52.7	6.7	-	6.2
	1994	5.6	-	-	-	-	-	
	1995	5.0	-	1.0	74.2	3.8	2.0	14.8
	1996	4.8	-	-	77.0	12.7	2.3	16.1
	1997	6.0	-	-	-	17.0	-	
	1998	11.0	-	1.0	82.6	37.0	5.2	7.7
	1999	6.8	-	-	78.4	20.4	2.7	11.6
	2000	4.9	-	-	84.0	19.0	4.1	17.1
	2001	4.4	2.5	-	52.1	3.4	-	12.3
	mean	**6.2**	**2.5**	**1.0**	**71.0**	**13.0**	**3.1**	**12.3**
Pettit	**1992**	6.4	-	1.0	94.5	7.0	-	18.3
	1993	5.8	-	-	94.0	4.0	-	29.2
	1994	6.6	-	-	-	-	-	-
	1995	4.8	-	1.0	88.8	12.0	3.5	18.4
	1996	5.3	-	-	64.3	13.0	7.1	11.6
	1997	5.5	-	-	-	16.5	-	-
	1998	10.2	-	0.9	48.0	3.1	0.7	4.8
	1999	5.9	-	-	79.5	6.6	1.9	13.5
	2000	5.2	-	-	37.7	2.0	0.3	7.3
	2001	5.3	1.8	-	66.7	3.9	-	12.4
	mean	**5.9**	**1.8**	**1.0**	**71.5**	**7.7**	**2.9**	**14.2**
Alturas	**1992**	10.0	-	2.8	74.0	2.0	-	7.4
	1993	9.4	-	-	72.5	3.3	-	8.2
	1994	13.9	-	-	-	-	-	-
	1995	8.2	-	1.4	66.4	5.8	3.5	7.7
	1996	6.0	-	-	74.6	11.6	2.2	12.4
	1997	10.0	-	-	-	14.7	-	-
	1998	18.1	-	1.9	69.6	17.8	3.1	3.8
	1999	10.3	-	-	77.4	6.6	1.7	7.4
	2000	7.5	-	-	56.7	5.4	1.8	7.6
	2001	7.2	3.5	-	58.6	4.5	-	8.2
	mean	**9.9**	**3.5**	**1.7**	**68.3**	**8.1**	**2.6**	**7.9**
Stanley	**1992**	10.5	-	1.0	93.5	5.0	4.0	8.9
	1993	11.4	-	-	129.8	8.5	-	12.7
	1994	11.3	-	-	-	-	-	-
	1995	7.0	-	1.2	103.0	9.2	18.0	14.8
	1996	6.5	-	-	-	-	-	-
	1997	7.2	-	-	-	9.7	-	-
	1998	15.1	-	1.2	78.5	19.0	11.6	5.1
	1999	14.0	-	-	86.4	14.5	2.5	6.2
	2000	5.7	-	-	82.3	15.0	4.7	15.4
	2001	7.0	2.6	-	84.9	3.8	-	11.9
	mean	**9.3**	**2.6**	**1.1**	**96.9**	**10.5**	**10.6**	**11.4**

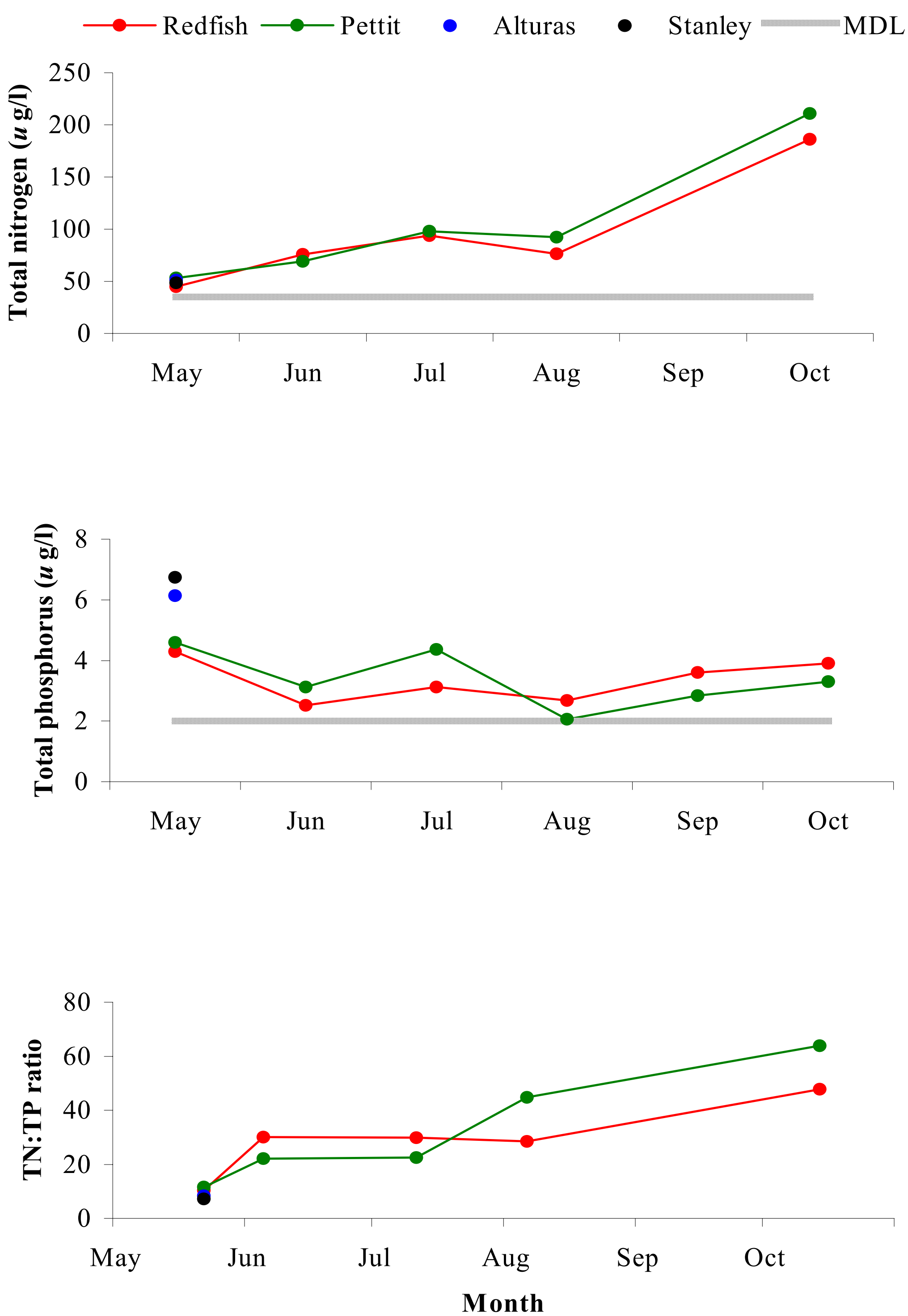


Figure 2-6. Concentrations of total nitrogen, total phosphorus and the TN/TP ratio in the epilimnetic waters of Redfish, Pettit, Alturas, and Stanley lakes during May through October 2001. Grey line denotes method detection levels.

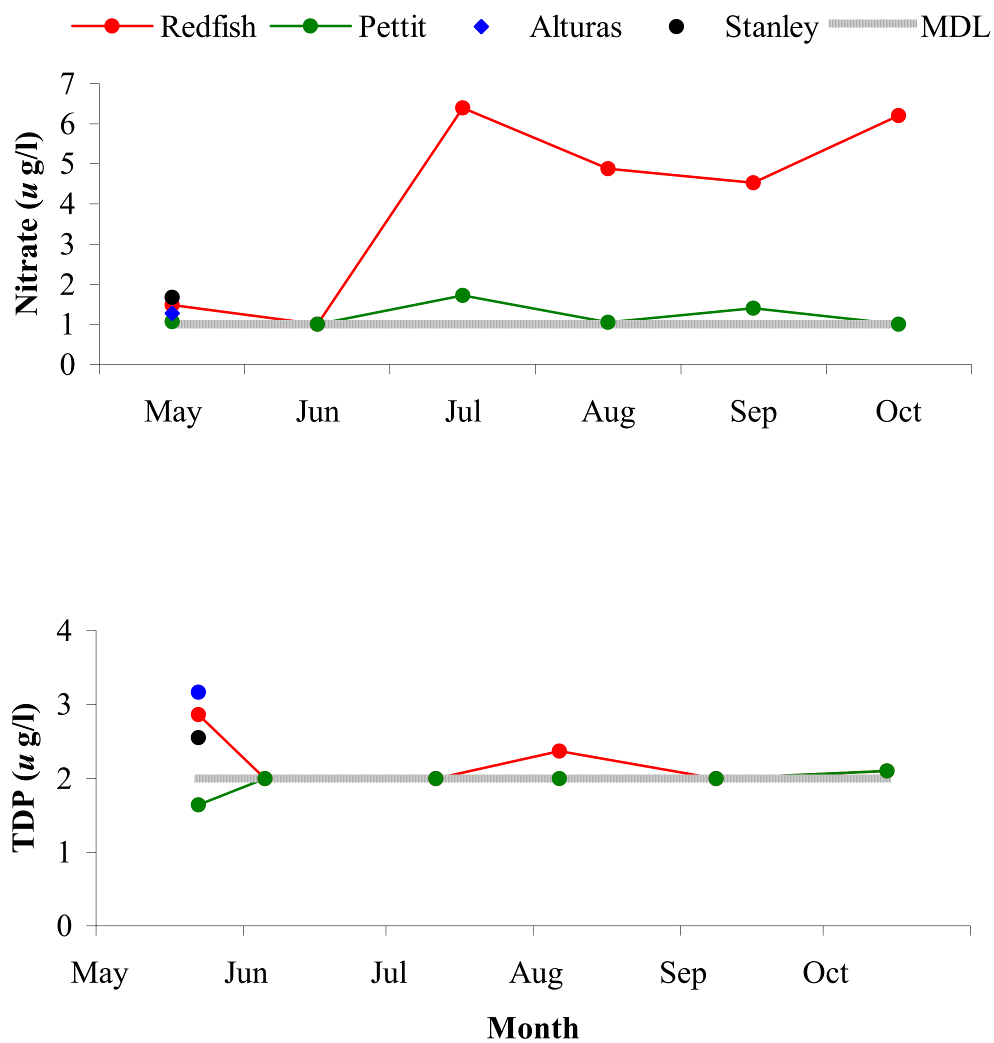


Figure 2-7. Nitrate-nitrite and total dissolved phosphorus concentrations in the epilimnetic waters of Redfish, Pettit, Alturas, and Stanley lakes during May through October 2001. Grey line denotes method detection levels.

Seasonal mean epilimnetic nutrient concentrations in Redfish and Pettit lakes differed from the long-term averages. TP was approximately half of the ten year mean and TN concentrations were about 50-60% higher than average. This resulted in high seasonal mean TN/TP ratios (27 and 38 in Redfish and Pettit lakes, respectively) (Table 2-4).

Table 2-4. Seasonal mean (June-October) epilimnetic nutrient concentrations (µg/L) and TN/TP ratio in Redfish, Pettit, Alturas, and Stanley lakes during 1992-2001.

Lake	Year	TP	TDP	SRP	TN	$N0_3 + NO_2$	NH_4	TN/TP
Redfish	**1992**	8.6	-	1.8	47.7	6.7	-	6.1
	1993	6.4	-	1.6	65.4	1.6	3.2	10.7
	1994	8.5	-	2.0	-	-	-	-
	1995	7.3	-	1.8	87.1	3.8	6.5	14.8
	1996	5.0	-	0.9	45.7	0.9	1.2	10.3
	1997	5.5	-	0.0	67.0	4.9	3.5	16.0
	1998	6.2	-	-	61.9	7.2	3.4	10.0
	1999	5.2	-	-	54.7	3.0	5.1	9.2
	2000	4.9	-	-	69.5	1.8	3.3	13.2
	2001	3.2	2.1	-	108.0	4.6	-	27.2
	mean	**6.5**	**2.2**	**1.5**	**66.9**	**3.9**	**4.0**	**12.8**
Pettit	**1992**	5.8	-	2.2	84.6	3.6	-	15.7
	1993	6.2	-	1.7	70.1	1.7	3.0	13.6
	1994	6.6	-	1.0	-	-	-	-
	1995	5.8	-	1.5	86.9	1.0	3.0	16.9
	1996	6.0	-	0.9	42.5	0.5	0.9	8.0
	1997	5.5	-	0.0	71.6	2.0	2.6	17.9
	1998	5.4	-	-	86.4	1.3	2.3	15.2
	1999	6.3	-	-	101.5	2.4	5.0	14.0
	2000	5.3	-	-	57.5	1.0	2.7	11.2
	2001	3.1	2.0	-	117.6	1.2	-	38.3
	mean	**5.7**	**2.1**	**1.3**	**80.4**	**1.7**	**2.8**	**17.0**
Alturas	**1992**	7.5	-	1.0	84.5	4.3	-	10.6
	1993	8.0	-	1.2	88.8	3.2	2.6	14.3
	1994	11.6	-	2.4	-	-	-	-
	1995	8.5	-	1.7	120.5	2.6	6.6	16.4
	1996	8.2	-	1.0	61.1	0.5	1.7	7.9
	1997	8.2	-	0.3	66.6	1.4	1.8	11.6
	1998	8.2	-	-	76.6	1.1	2.8	9.3
	1999	7.9	-	-	93.9	1.7	6.6	9.9
	2000	6.3	-	-	65.0	2.1	3.9	11.0
	2001	-	-	-	-	-	-	-
	mean	**8.5**	**5.2**	**1.3**	**84.7**	**2.2**	**3.8**	**11.9**
Stanley	**1992**	7.2	-	2.2	89.8	3.4	-	12.4
	1993	5.3	-	1.6	76.0	3.0	11.6	16.1
	1994	9.6	-	2.7	-	-	-	-
	1995	7.9	-	1.8	88.1	2.6	5.4	11.5
	1996	7.3	-	-	-	-	-	-
	1997	4.3	-	0.0	57.3	1.3	3.3	13.7
	1998	7.6	-	-	66.5	1.1	1.8	9.2
	1999	9.9	-	-	64.5	5.4	2.6	7.0
	2000	6.8	-	-	66.5	1.3	2.0	10.3
	2001	-	-	-	-	-	-	-
	mean	**7.4**	**3.3**	**1.8**	**75.3**	**2.6**	**5.4**	**11.7**

Chlorophyll a

In 2001, surface chlorophyll *a* concentrations ranged from 0.3 to 4.5 µg/L in the four Sawtooth Valley lakes. While the lakes were ice covered, chlorophyll *a* concentrations exceeded 1.2 µg/L in Stanley Lake and ranged from 2.2 to 3.3 µg/L in Redfish, Pettit and Alturas lakes. During the ice-free season surface chlorophyll *a* concentrations were elevated in May and June, fell to approximately 0.3 to 0.5 µg/L during July and early August, and peaked again in October or November (Figure 2-8). Surface chlorophyll *a* concentrations were much higher in Redfish Lake during late August through November, likely a result of nutrient supplementation. Peak chlorophyll *a* concentrations during the ice-free period were less than 1.5 µg/L except in Redfish Lake, which attained a maximum concentration of 2.5 µg/L during October.

Seasonal mean surface chlorophyll *a* concentrations ranged from 0.6 to 1.4 µg/L in the four lakes. Redfish Lake had the highest seasonal mean chlorophyll *a* concentration (1.4 µg/L), and the largest deviation from the long-term mean. Stanley Lake was also relatively high compared to the long-term average. Seasonal mean chlorophyll *a* concentrations in Pettit and Alturas lakes were relatively low and similar to the long-term averages for those lakes (Table 2-2).

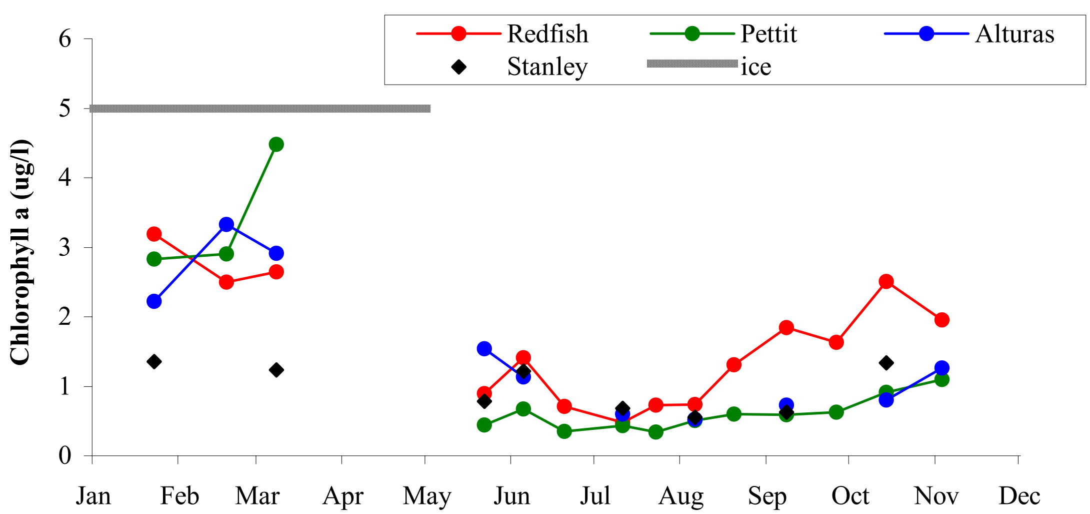


Figure 2-8. Surface chlorophyll *a* concentrations (µg/L) in Redfish, Pettit, Alturas, and Stanley lakes, January-November 2001. Shaded line indicates ice cover.

Heterotrophic bacteria and autotrophic picoplankton

Heterotrophic bacteria densities ranged from 200,000 to 3,000,000 cells/mL in the four Sawtooth Valley lakes with the mean for all four lakes and depths approximately 1,800,000 cells/mL (Table 2-5).

In Redfish Lake, bacteria densities were lowest in spring (prior to the addition of supplemental nutrient), highest during summer, and then declined to moderate levels during the fall (Appendix A-1). Summer epilimnetic bacterial populations averaged approximately 1,500,000 cells/mL, higher than in treated and untreated coastal sockeye systems in British Columbia (MacIsaac et al. 1981) and higher than the 300,000-500,000 cells/mL observed in Redfish Lake during September and October 2000. Autotrophic picoplankton (APP) densities were extremely low during the spring and early summer (<4,000 cells/mL), increased to 180,000 cells/mL in the epilimnion during late August, then gradually declined to 9-10,000 cells/mL in the fall (Appendix A-1). During September and October 2000 (prior to nutrient supplementation) APP densities were <4,000 cells/mL.

Pettit Lake bacterial populations were higher than in Redfish but showed the same general trend of low spring abundance that increased during the summer. The fall decline was less pronounced primarily because bacterial populations at the compensation depth remained high (Appendix A-2). Epilimnetic bacterial densities during the summer were slightly lower than in Redfish during the same time period. APP populations were relatively low and stable (mean approximately 10,000-12,000 cells/mL).

Heterotrophic bacteria were more abundant in Alturas Lake than in Redfish and Pettit lakes during 2001 (Table 2-5). During May, populations were approximately 500,000 cells/mL. Subsequently, population abundance dramatically increased to approximately 2,500,000 cells/mL in the epilimnion in September and remained relatively high (1,500,000 cells/mL) during October and November (Appendix A-3). APP were relatively low except during September when APP exceeded 50,000 cells/mL in the epilimnion and > 100,000 cells/mL in the metalimnion and at the compensation depth

(Appendix A-3). Heterotrophic bacteria and APP were abundant in Stanley Lake. Both bacteria and APP peaked during September with epilimnetic densities of 4,000,000 and 250,000 cells/mL, respectively (Appendix A-4).

Table 2-5. Range of values for Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in four Sawtooth Valley lakes during June-October 2001.

		Heterotrophic bacteria			Phototrophic pico-cyanobacteria		
Lake	**Strata**	**min**	**mean**	**max**	**min**	**mean**	**max**
Redfish	epilimnion	203,874	1,115,725	2,415,940	1,140	33,780	182,443
	metalimnion	575,122	1,062,100	2,155,104	570	18,862	78,251
	compensation depth	601,313	1,087,106	1,395,809	143	17,551	68,594
	mean		**1,088,310**			**23,398**	
Pettit	epilimnion	769,680	1,185,192	1,898,544	3,136	12,495	29,504
	metalimnion	679,884	1,422,403	2,227,796	713	11,609	28,649
	compensation depth	332,673	1,809,087	3,003,890	428	9,518	31,500
	mean		**1,472,227**			**11,207**	
Alturas	epilimnion	1,255,006	1,714,914	2,514,288	855	23,756	53,878
	metalimnion	523,810	1,982,282	3,875,125	1,425	47,545	134,083
	compensation depth	750,082	1,390,294	1,915,648	855	36,862	106,595
	mean		**1,695,830**			**36,054**	
Stanley	epilimnion	1,329,836	2,623,861	3,917,885	0	133,625	267,250
	metalimnion	739,392	1,333,934	1,928,476	570	33,959	67,347
	compensation depth	820,992	1,483,772	2,146,552	0	28,774	57,548
	mean		**1,813,855**			**65,452**	

Phytoplankton

Phytoplankton communities in the Sawtooth Valley lakes continued to be dominated by small grazable taxa during 2001. Total phytoplankton densities ranged from 1,166-7,238 cells/mL and total phytoplankton bio-volume ranged from 0.12 to 0.68 mm^3/L in the four lakes (Table 2-6)(Appendix B). Generally, Chryso- and Cryptophycean nano-flagellates (*Chrysochromulina* sp., *Chromulina* sp. and *Rhodomonas* sp.) and Cyanophytes (*Synechococcus* sp. and *Oscillatoria* sp.) were numerically dominant. Chryso- and Cryptophycean nano-flagellates (*Chryptomonas* sp., *Chrysochromulina* sp., *Rhodomonas* sp., and *Dinobryon* sp.), Dinophycean dinoflagellates (*Gymnodinium* sp. *and Peridinium* sp.), and Bacillariophytes (*Asterionella* sp. and *Cyclotella* sp.) had the highest bio-volume of any phytoplankton taxa. Chlorophyceans were present in low densities/bio-volume and were split between (*Cosmarium* sp., *Oocystis* sp., *Elakatothrix* sp., *Staurastrum* sp.). Bio-volume of Cyanophytes was low because of their relatively small size and was comprised of *Synechococcus* sp. and *Oscillatoria* sp.)

Table 2-6. Range of values for phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in four Sawtooth Valley lakes during June-October 2001.

		Density			Biovolume		
Lake	**Strata**	**min**	**mean**	**max**	**min**	**mean**	**max**
Redfish	epilimnion	1,267	2,359	4,237	0.15	0.38	0.68
	metalimnion	1,500	2,567	4,227	0.22	0.32	0.58
	compensation depth	2,463	3,117	3,943	0.28	0.45	0.62
	mean		**2,664**			**0.38**	
Pettit	epilimnion	1,166	1,933	2,484	0.14	0.20	0.32
	metalimnion	1,784	2,594	3,244	0.18	0.30	0.41
	compensation depth	2,321	4,150	5,281	0.34	0.43	0.49
	mean		**2,854**			**0.31**	
Alturas	epilimnion	1,196	3,570	6,376	0.13	0.25	0.40
	metalimnion	1,216	2,765	3,528	0.12	0.23	0.34
	compensation depth	1,703	3,396	7,187	0.14	0.23	0.38
	mean		**3,244**			**0.24**	
Stanley	epilimnion	3,163	4,863	5,667	0.20	0.27	0.31
	metalimnion	4,562	5,447	6,670	0.20	0.30	0.42
	compensation depth	3,041	5,210	7,238	0.24	0.38	0.62
	mean		**5,149**			**0.32**	

Zooplankton

In 2001, Pettit Lake had the highest peak and seasonal mean zooplankton biomass followed by Stanley, Redfish, and Alturas lakes (Figure 2-9). Seasonal mean biomass (June-October) was 39.1 µg/L in Pettit Lake, 28.7 µg/L in Stanley Lake, 17.1µg/L in Redfish Lake and 3.7 µg/L in Alturas Lake (Table 2-2). Peak zooplankton biomass occurred during July and August in Redfish, Alturas, and Stanley lakes and during October in Pettit Lake.

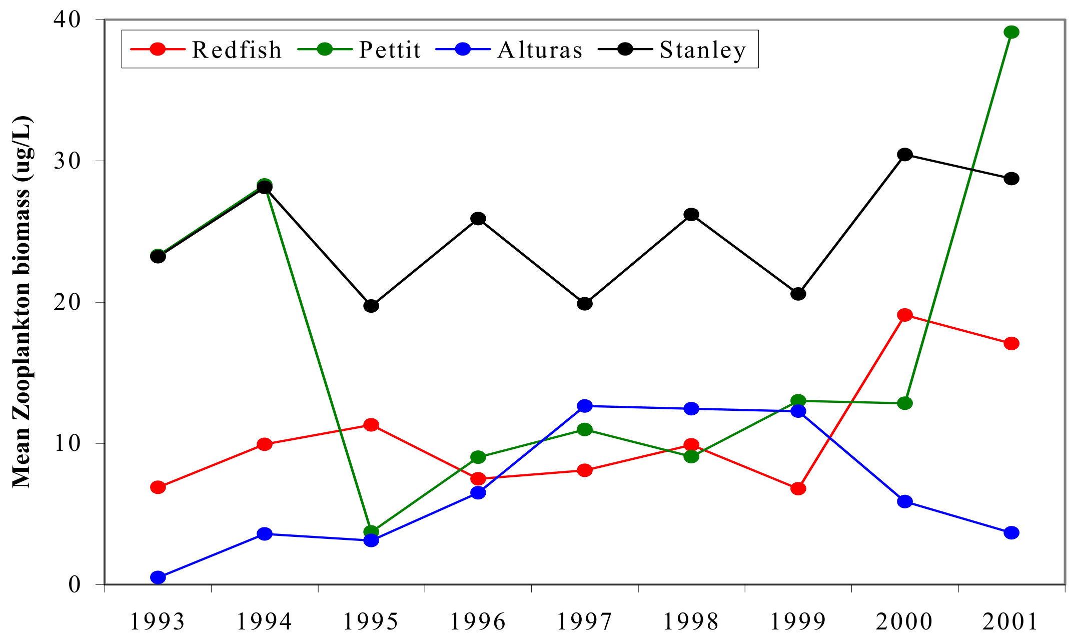


Figure 2-9. Seasonal mean zooplankton biomass (June-October) for the Sawtooth Valley lakes, 1993-2001.

Redfish Lake zooplankton biomass was relatively high in 2001 but slightly lower than 2000, when the highest peak and seasonal mean biomass was observed since sampling began in 1992. *Daphnia* (9.0 µg/L) and *Holopedium* (4.0 µg/L) dominated summer biomass (Figure 2-10a). Mean length of *Daphnia* was high relative to previous years (1.0 mm). During January-March 2001, whole-lake zooplankton biomass averaged 4.4 µg/L and was evenly split between cyclopoid copepods, *Daphnia*, nauplii, and *Bosmina.*

Pettit Lake total zooplankton biomass was dramatically higher than previously observed in any of the Sawtooth lakes, representing a complete recovery of zooplankton populations after the collapse observed in 1995 (Figure 2-9). Zooplankton biomass peaked in mid October at 79.0µg/L, coinciding with peaks in *Daphnia* (65.1 µg/L) and cyclopoid copepod (10.0 µg/L) biomass (Figure 2-10b). Mean length of *Daphnia* was high relative to previous years (1.0 mm). During January-March 2001, total zooplankton biomass was 11.5µg/L and was predominately *Bosmina* and cyclopoid copepods.

In Alturas Lake, mean seasonal total zooplankton biomass continued to decline (Figure 2-9). Zooplankton populations in Alturas Lake experienced a collapse in the early 1990's, recovered during 1996-1999 and began to decline in 2000. During Summer 2001, zooplankton populations consisted predominantly of *Bosmina* and cyclopoid copepods (Figure 2-10c). Total biomass peaked at 8.8 µg/L in July. *Daphnia* were present at low biomass (peak = 2.0 µg/L during November) and small size (mean length=0.7 mm). Mean zooplankton biomass during January and March was 1.6 µg/L and was mostly composed of *Bosmina* and cyclopoid copepods.

Stanley Lake continues to have relatively stable zooplankton assemblages. Seasonal mean and peak zooplankton biomass were slightly lower than observed in 2000 (Figure 2-9 and Figure 2-10d)). During summer 2001, zooplankton species composition was similar to that observed in 2000, with most biomass represented by *Daphnia* and calanoid copepods. Seasonal mean *Daphnia* biomass was 14.0 µg/L, higher than previous years studied. Seasonal mean length of Daphnia was 0.9 mm, typical for Stanley Lake and slightly smaller than mean lengths observed in Redfish and Pettit lakes. Total zooplankton biomass peaked in early August, a result of the seasonal biomass peaks of *Daphnia* and calanoid copepods. In January-March 2001, total biomass was 12.8 µg/L and was predominately *Bosmina* (9.4 µg/L), cyclopoid copepods (0.8 µg/L), and *Daphnia* (0.7µg/L).

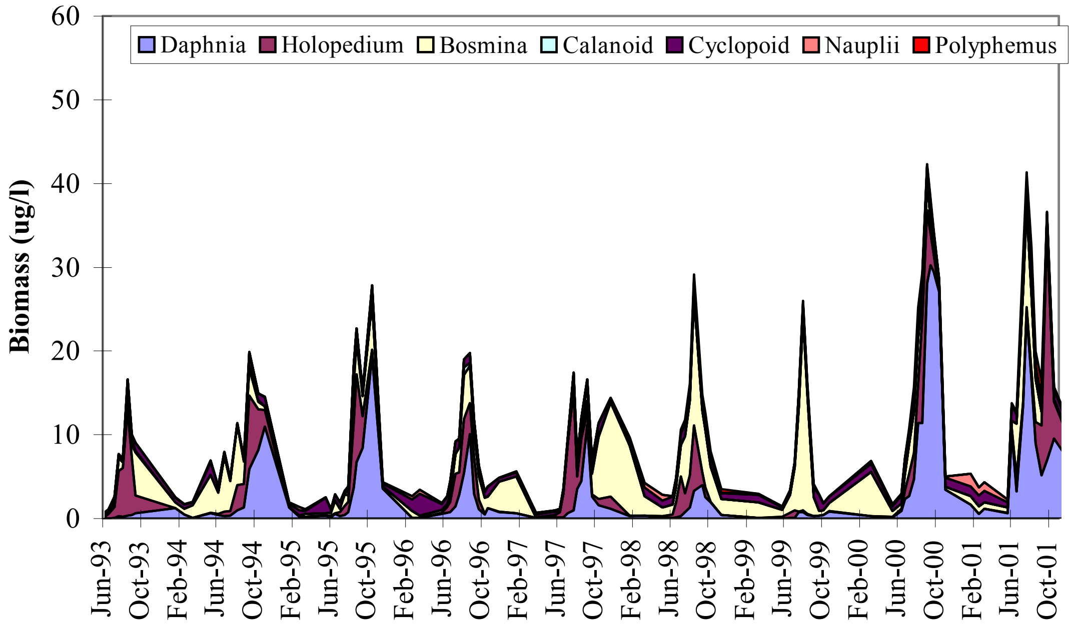


Figure 2-10a. Redfish Lake zooplankton biomass (µg/L) weighted by lake volume, 1993-2001.

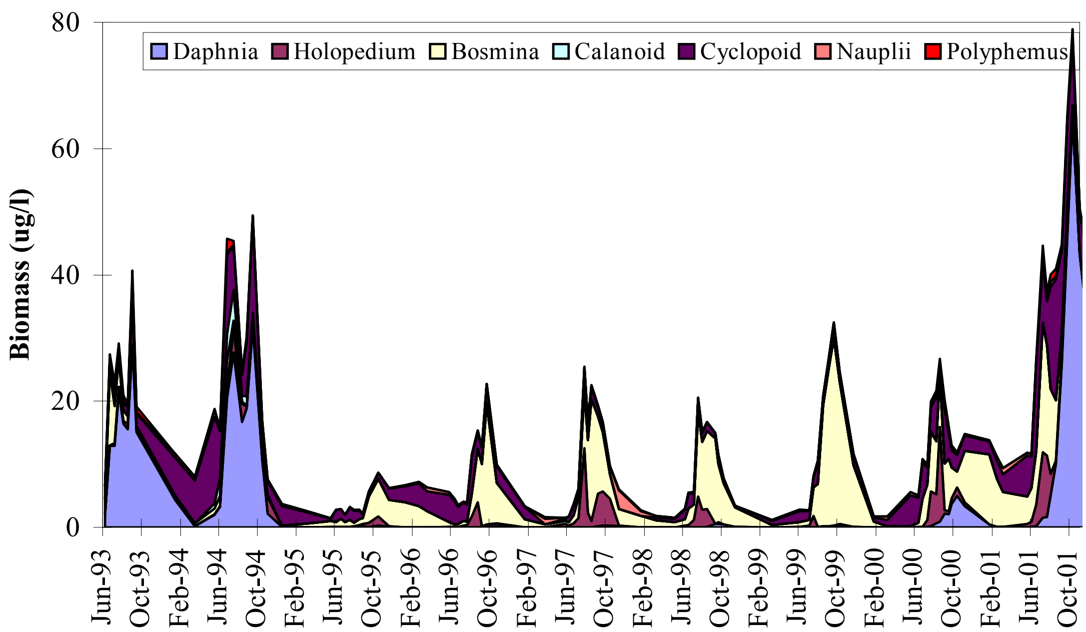


Figure 2-10b. Pettit Lake zooplankton biomass (µg/L) weighted by lake volume, 1993-2001.

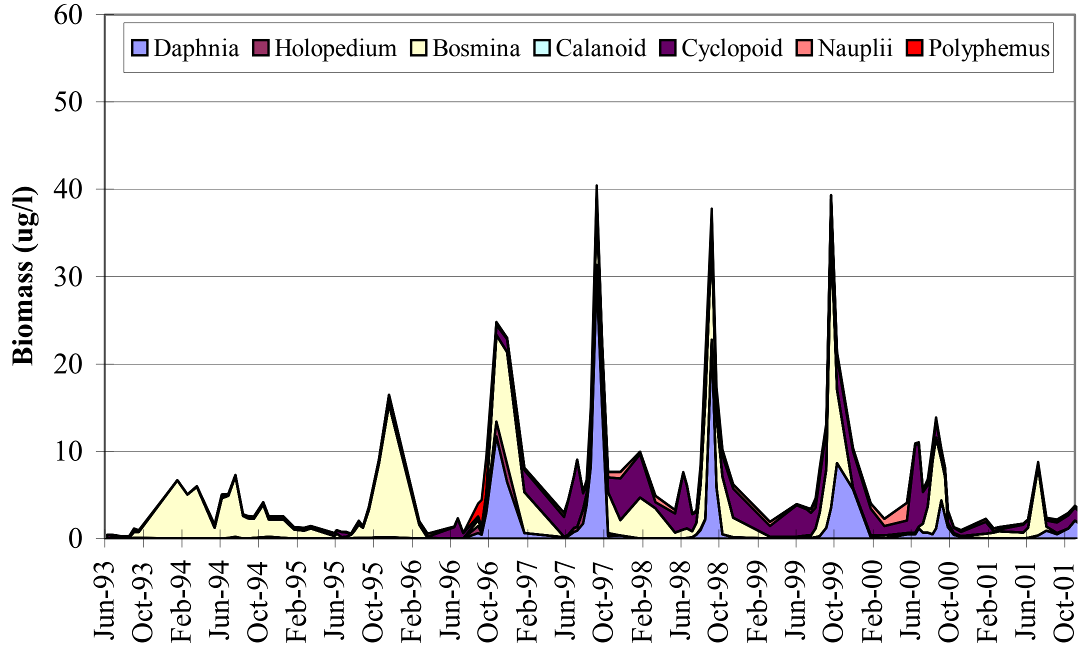


Figure 2-10c. Alturas Lake zooplankton biomass (μg/L) weighted by lake volume, 1993-2001.

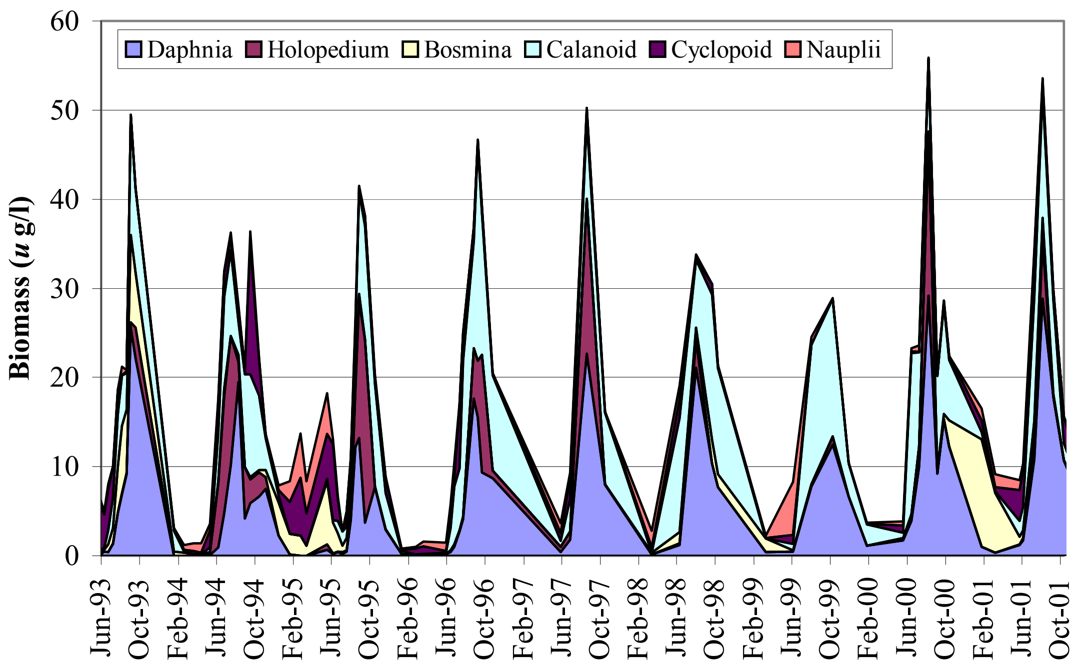


Figure 2-10d. Stanley Lake zooplankton biomass (μg/L) weighted by lake volume, 1993-2001.

DISCUSSION

During 2001, the Sawtooth Valley experienced a drought, resulting in reduced inflows to the Sawtooth lakes, warmer than normal surface water temperatures, and slightly deeper Secchi and compensation depths. Redfish Lake, which received supplemental nutrients in 2001, deviated from the other lakes with moderate reductions in Secchi depth and compensation depth during the later part of the summer. Primary productivity estimates were not obtained in 2001 but based on past relationships we expected lower primary productivity during a low water year. Nutrient concentrations were low in the Sawtooth Valley lakes during 2001, relative to previous years, with the exception of Redfish Lake, which experienced elevated nitrate-nitrite concentrations after nutrient supplementation began. Seasonal mean chlorophyll *a* concentrations were 30% above average in Stanley Lake and 56% above average in Redfish Lake. Pettit and Alturas lakes were slightly below average. Heterotrophic bacteria, APP and phytoplankton populations were highest in Stanley Lake followed by Alturas, Pettit and Redfish lakes and inversely related to water residence time. Prior to the application of fertilizer, APP, and phytoplankton populations in Redfish, Pettit, and Alturas lakes closely resembled those of fast-flushing, ultra-oligotrophic, B.C. coastal lakes. APP and bacteria populations dominate these phytoplankton communities and form the primary carbon template for linked microbial food webs. These small-celled 'microbial' dominated communities are capable of rapid growth and high turnover rates, even in extreme low-nutrient habitats and possess a relatively high mean abundance, but low biomass owing to their small size (Stockner 1981,1987; Stockner and Shortreed 1988; Stockner and MacIsaac 1996). Passage of both heterotrophic bacterial and APP carbon production to higher trophic levels is chiefly by μ-flagellate and small ciliate grazers which are plentiful in the Sawtooth lakes. In turn, these are consumed by large ciliates, rotifers, nauplii and other small micro-zooplankton grazers, also abundant in these lakes. Microbial communities of ultra-oligotrophic lakes are noted for their low standing stock and production. However, when supplemental nutrients are added, these populations have the potential for explosive growth as was observed during August in Redfish Lake (Stockner and Porter 1988, Stockner 1991, Stockner and Shortreed 1994, Stockner and MacIsaac 1996). High densities of heterotrophic bacteria in Alturas and Stanley lakes during September were more characteristic of meso- and eutrophic conditions (Bird and Kalff 1986) and indicate high concentrations of dissolved organic matter (DOM). Given the absence of measurable precipitation during this time period, high DOM may be a by-product of intense zooplankton grazing (Weisse 1990).

Hydroacoustic estimates of *O. nerka* populations in the Sawtooth Valley lakes have shown large fluctuations in kokanee salmon abundance and/or biomass (Chapter 1, Table 1-2). During peaks in kokanee salmon population cycles, intense grazing pressure on macrozooplankton caused abrupt declines in zooplankton biomass (Figure 2-11) and striking shifts in species composition (Figures 2-10a, 2-10b, 2-10c, and 2-10d). In 2001, *O. nerka* densities were low to moderate in Redfish and Pettit lakes (71 and 231 fish/ha, respectively), and relatively high in Alturas Lake (386 fish/ha). Zooplankton populations reflected these differences with seasonal mean zooplankton biomass estimates in Redfish, Pettit and Stanley lakes near or above the highest levels observed in 10 years of sampling. Alturas Lake zooplankton biomass was much lower, apparently a result of intense grazing by this expanding kokanee population. Overwinter survival of sockeye pre-smolts, which were stocked during fall 2000 and out-migrated during spring 2001, was 20% in Redfish Lake (Hebdon et al., in preparation), 29% in Pettit Lake and 75% in Alturas Lake. Growth rates showed a different pattern, with the largest gains in length and weight observed in Pettit Lake. Growth rates in Redfish Lake were intermediate, while smolts emigrating from Alturas Lake were essentially the same length as they were at stocking and had lost weight while over-wintering (Figures 1-10, 1-11,1-12 and 1-13).

While density dependent relationships are clear between zooplankton and *O. nerka*, benefits to rearing sockeye salmon from differing zooplankton assemblages are not (see chapter 1 discussion). Until these questions are answered we will continue a risk adverse management strategy and attempt to maintain a forage base dominated by large bodied cladocerans in the Sawtooth lakes. Large cladocerans are relatively easily captured by sockeye salmon and since they are capable of grazing a wide size range of particles they represent a relatively short food chain and lower energy losses through trophic transfer.

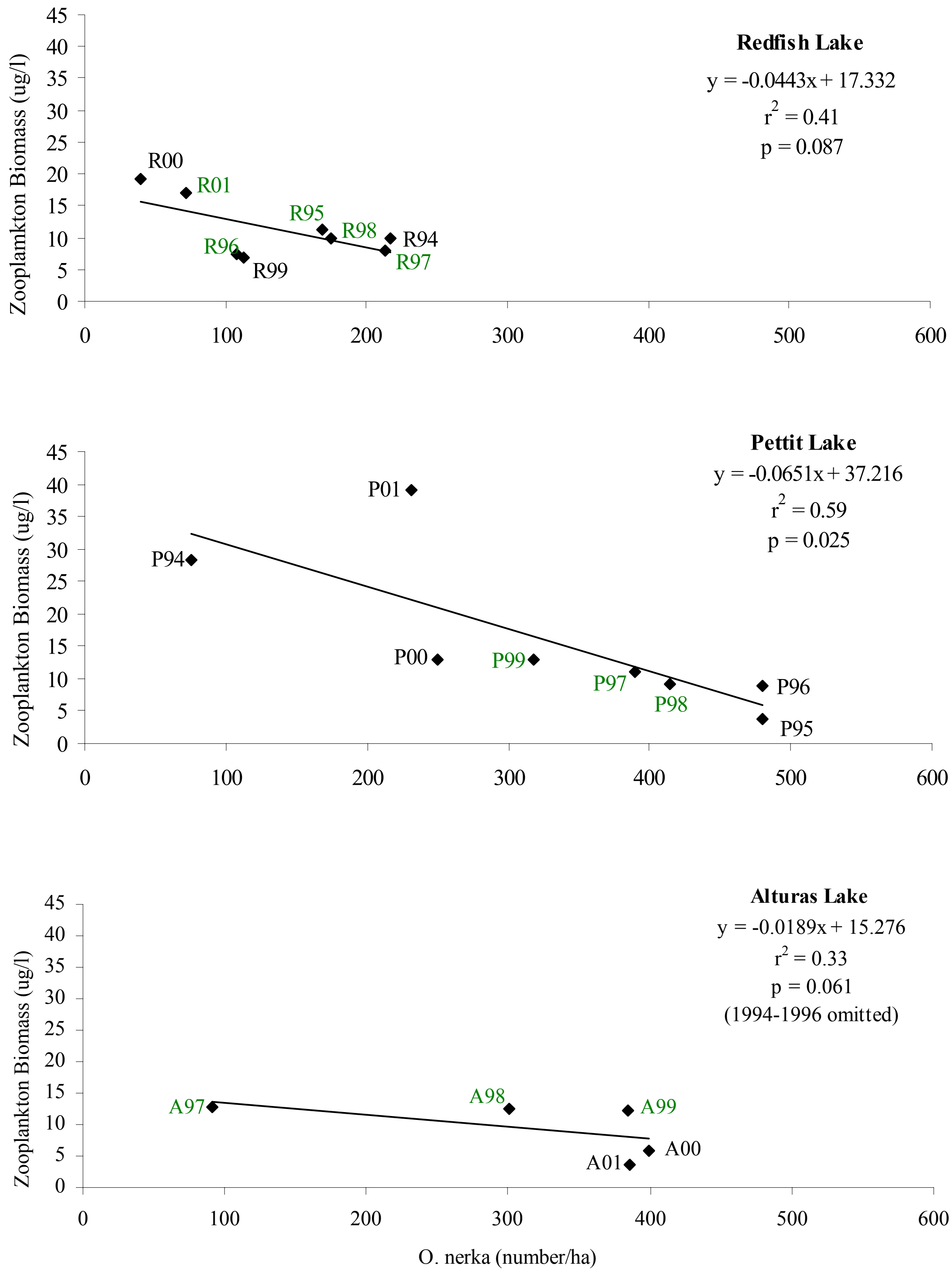


Figure 2-11. Relationships between *O. nerka* density (num/ha) based on September hydroacoustic estimates and seasonal mean zooplankton biomass (µg/L) for Redfish, Pettit, and Alturas lakes, 1994-2001. Data labels indicate lake and year

ACKNOWLEDGEMENTS

Limnological monitoring of the Sawtooth Valley lakes has been conducted since 1991, during which time many individuals have contributed to the development of the sampling design, methodologies, and data collection. The Shoshone-Bannock Tribes initiated recovery efforts for Snake River Sockeye Salmon and funded this project with money obtained from the Bonneville Power Administration. Dr. Jeff Gislason, Contracting Officer for the Bonneville Power Administration, facilitated funding and coordinated project meetings. Kenneth Ariwite, Kim Gilliland, Kurt Gindling, Mattie Griswold, Judy Hall-Griswold, JeNelle McEwan, and Rob Trahant collected limnology data. Patricia Bucknell and Mark Palmer, (University of California at Davis) assayed nutrient samples. Dr. John Stockner and Ms. Ellie Stockner of Eco-Logic, Inc. processed phytoplankton, bacteria, and picoplankton samples and provided interpretations of various data sets. Odette Brandt processed zooplankton samples. Brent Snider, Kurtis Schilling, and Rodger Elmore at the Idaho Department of Fish and Game, Sawtooth Hatchery, provided assistance and support for our research activities in the Sawtooth Valley.

REFERENCES

APHA (American Public Health Association), American Water Works Association, and Water Environment Federation. 1995. Standard Method for the examination of water and wastewater, 19th edition. APHA, Washington D.C.

Bird, D.F., and J. Kalff. 1986 Bacterial grazing by planktonic algae. Science, 231: 493-495.

Budy, P., C. Luecke, W. A. Wurtsbaugh, and H. Gross. 1993. Limnological conditions of Sawtooth Valley Lakes with respect to potential growth of juvenile Snake River Sockeye Salmon. *In* Snake River Sockeye Salmon (*Oncorhynchus nerka*) habitat/ limnological research. Annual report 1992. U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon.

Budy, P., C. Luecke, and W. A. Wurtsbaugh. 1998. Adding nutrients to enhance the growth of endangered sockeye salmon: Trophic transfer in an oligotrophic lake. Transactions of the American Fisheries Society. 127: 19-34.

Emmett, W.W. 1975. The channels and waters of the upper Salmon River, Idaho: Hydrologic evaluation of the upper Salmon River area, Idaho. U. S. Geological Survey professional paper, Paper 870A. Washington, D.C.

Flagg, T. A., and five coauthors. 1998. Redfish Lake sockeye salmon captive broodstock program, NMFS. Pages 1-9 *in* Proceedings of the 48th Northwest Fish Culture Conference. Glenden Beach, Oregon.

Griswold, R.G., D. Taki, and J. G. Stockner. 2001. Redfish Lake sockeye salmon: nutrient supplementation as a means of restoration *in* Nutrients in Salmonid Ecosystems: sustaining production and biodiversity. (In Press).

Gross, H.P., W.A Wurtsbaugh, C. Luecke, and P. Budy. 1993. Nutrient limitation of phytoplankton in oligotrophic lakes of the Sawtooth Valley, Idaho. Pages 29-52 in Snake River Sockeye Salmon (*Oncorhynchus nerka*) habitat/limnological research. Annual report 1992. U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon.

Hebdon, J.L., Castillo, J. and P.A. Kline. *In preparation* Snake River Sockeye Salmon Captive Broodstock Program Monitoring and Evaluation Element. Idaho Department of Fish and Game Annual Progress Report January 1, 2001 - December 31, 2001, Report to Bonneville Power Administration, Contract No. 00000167, Project No. 199107200, (BPA Report DOE/BP-00000167-2).

Holm-Hanson, O., and B. Rieman, 1978. Chlorophyll *a* determination: improvements in methodology. Oikos 30:438-447.

Kline, Paul A., and Catherine Willard. 2001. Snake River Sockeye Salmon Captive Broodstock Program Hatchery Element. Idaho Department of Fish and Game Annual Progress Report January 1, 2000 - December 31, 2000, Report to Bonneville Power Administration, Contract No. 00000167, Project No. 199107200, 42 electronic pages (BPA Report DOE/BP-00000167-2).

Koenings, J.P., J.A. Edmundson, G.B. Kyle, and J.M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation, Enhancement and Development. Juneau, Alaska.

Lagler, K. F. 1956. Freshwater Fishery Ecology, 2nd edition. WM. C. Brown Company Publishers, Dubuque, Iowa.

MacIsaac, E.R., K.S. Shortreed, and J.G. Stockner. 1981. Seasonal distribution of bacterioplankton numbers and activities in eight fertilized or untreated oligotrophic British Columbia Lakes. Canadian Technical Report of Fisheries and Aquatic Sciences 4, 43 pp.

MacIsaac, E.R., and J.G. Stockner. 1993. Enumeration of phototrophic picoplankton by auto-fluorescence microscopy, p. 187-197. B. Sherr and E. Sherr [Eds.], The handbook of methods in aquatic microbial ecology, CRC Press, Boca Raton, Fl.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. Chapter 7 in J. A. Downing and F. Rigler, editors. A manual on methods of secondary productivity in freshwaters, 2nd edition. Blackwell Scientific, Oxford, UK.

Spaulding, S. 1993. Snake River Sockeye Salmon (*Oncorhynchus nerka*) habitat/limnological research. Annual Report 1992. U.S. Department of Energy, Bonneville Power Administration, Portland, OR.

Steinhart, G., H.P. Gross, P. Budy, C. Luecke, and W.A. Wurtsbaugh. 1994. Limnological investigations and hydroacoustic surveys of Sawtooth Valley Lakes. Annual Report 1993. In Snake River Sockeye Salmon Habitat and Limnological Research. U.S. Department of Energy, Bonneville Administration, Division of Fish and Wildlife.

Stockner, J.G. 1981. Whole-lake fertilization for the enhancement of sockeye salmon *Oncorhynchus nerka* in British Columbia, Canada. Verh. Int. Verein. Limnol. 21: 293-299.

Stockner, J.G. 1987. Lake Fertilization: The enrichment cycle and lake sockeye salmon *Oncorhynchus nerka* production. pp. 198-215. In: HD Smith, L Margolis and CC Woods [Eds.] Sockeye salmon *Oncorhynchus nerka* population biology and future management. Can. Spec. Publ. Fish. Aquat. Sci. 96, 486p.

Stockner, J.G. 1991. Autotrophic picoplankton in freshwater ecosystems: The view from the summit. Int. Rev. gesamten Hydrobiol. 76: 483-492.

Stockner, J.G., and E.A. MacIsaac. 1996. British Columbia Lake enrichment programme: Two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management. 12:547-561.

Stockner, J.G., and K.G. Porter. 1988. Microbial food webs in fresh water planktonic ecosystems, Carpenter SR (Ed), Complex interactions in lake communities, pp 71-84, Springer Verlag, New York, NY

Stockner, J.G., and K.S. Shortreed. 1988. Algal picoplankton production and contribution to food-webs in oligotrophic British Columbia lakes. Verh. Internat. Verein. Limnol. 23: 214-215.

Stockner, J.G., and K.S. Shortreed. 1994. Autotrophic picoplankton community dynamics in a pre-alpine lake in British Columbia, Canada. Hydrobiologia 274: 133 142.

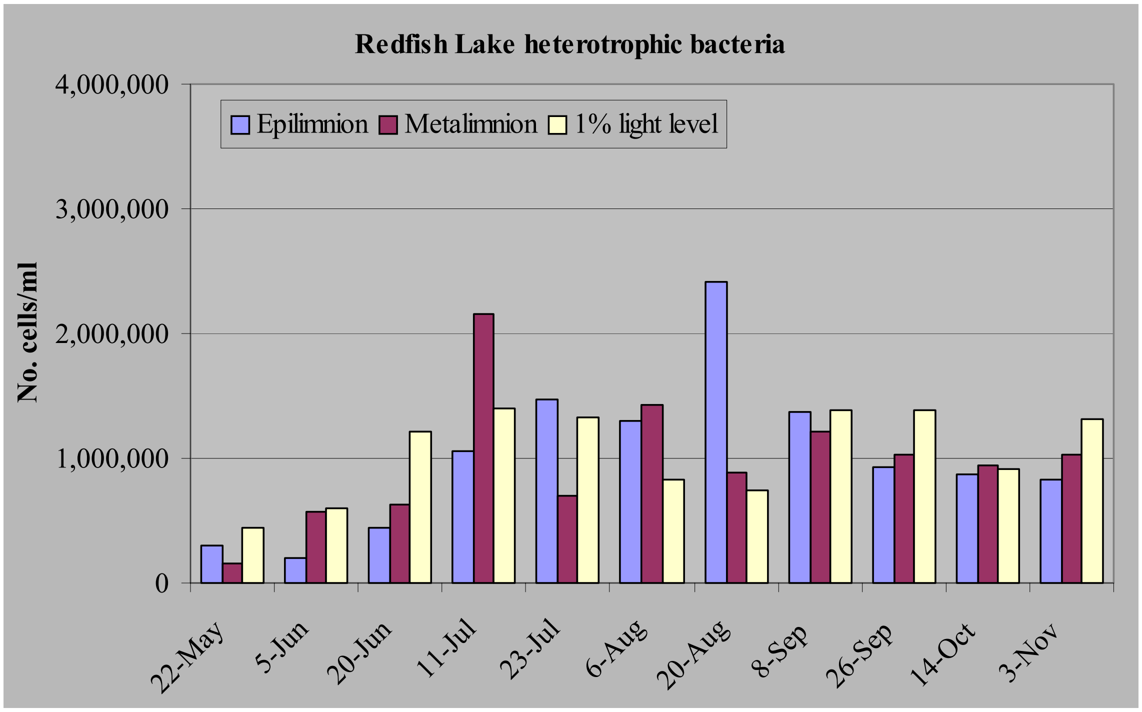
Utermohl, H. 1958. Zur Vervollkommnung der quantitativen phytoplankton methodik. International Vereinigung fuer Theoretische und Angewandte Limnologie und Verhandlugen. Mitteilungen No. 9

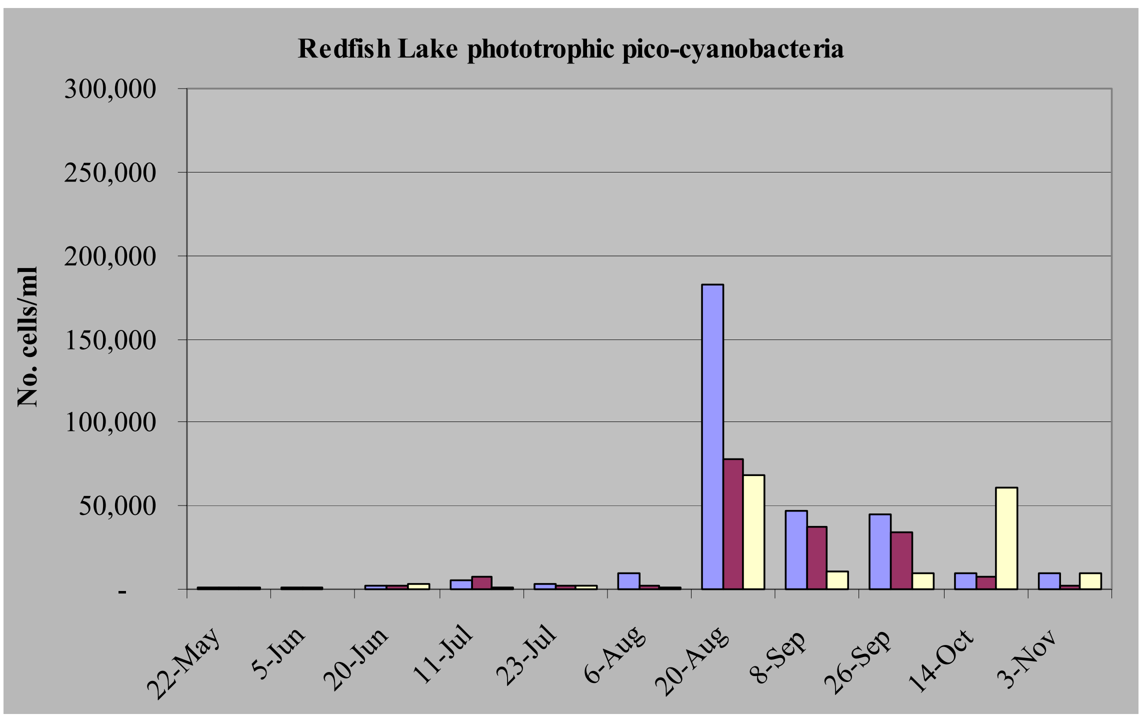
Waples, R. S., O. W. Johnson, and R. P. Jones, Jr. 1991. Status review for Snake River sockeye salmon. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Technical Memo. NMFS F/NWC-195.

Weisse, T. 1990. Trophic interactions among heterotrophic microplankton, nanoplankton and bacteria in lake Constance (FRG). Hydrobiologia 191: 111-122.

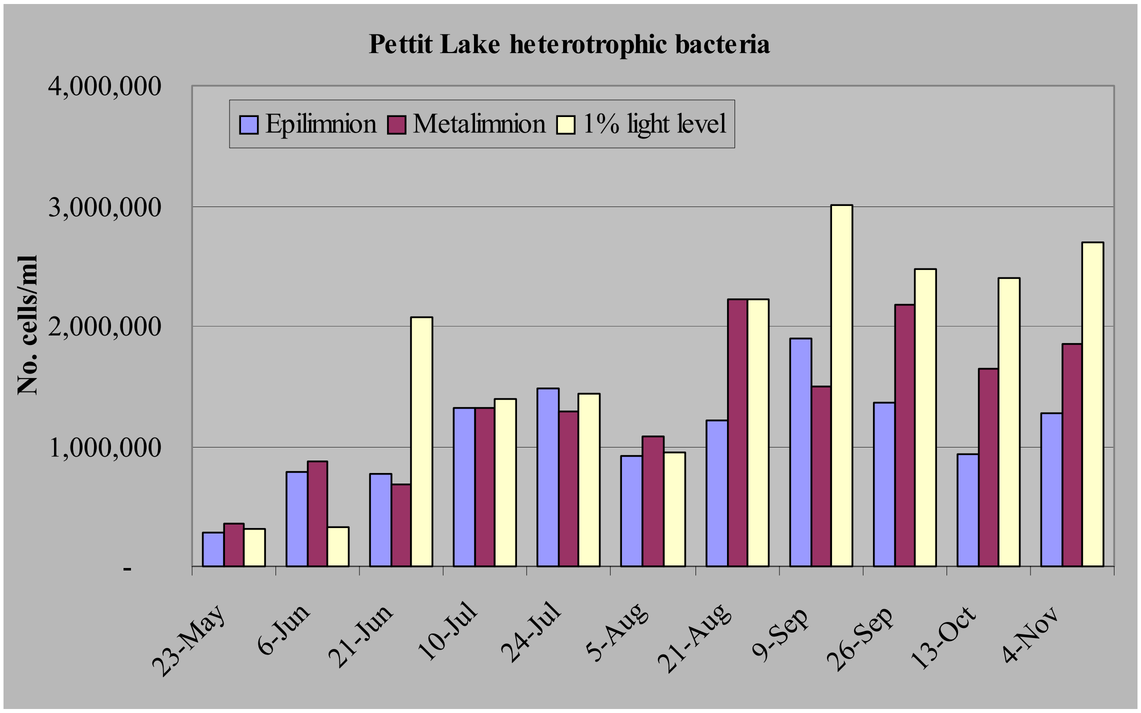
Wetzel, R.G., and G.E. Likens. 1991. Limnological Analyses, 2nd edition. Springer-Verlag. New York.

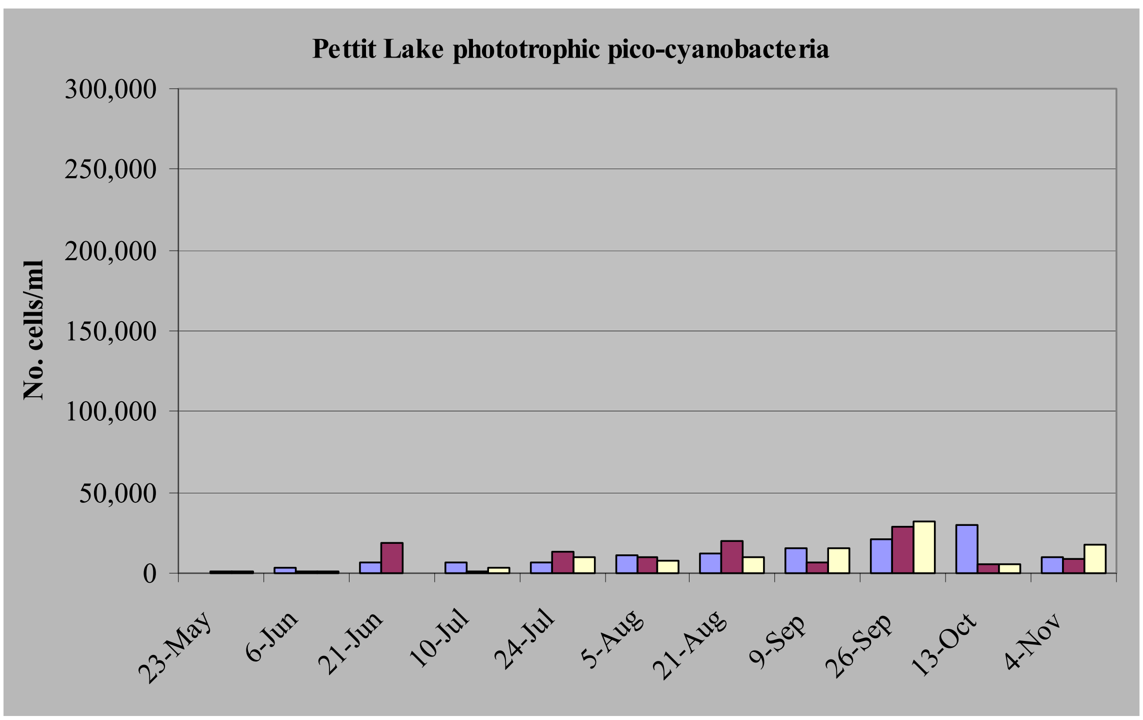
APPENDIX A. Heterotrophic bacteria and autotrophic picoplankton densities



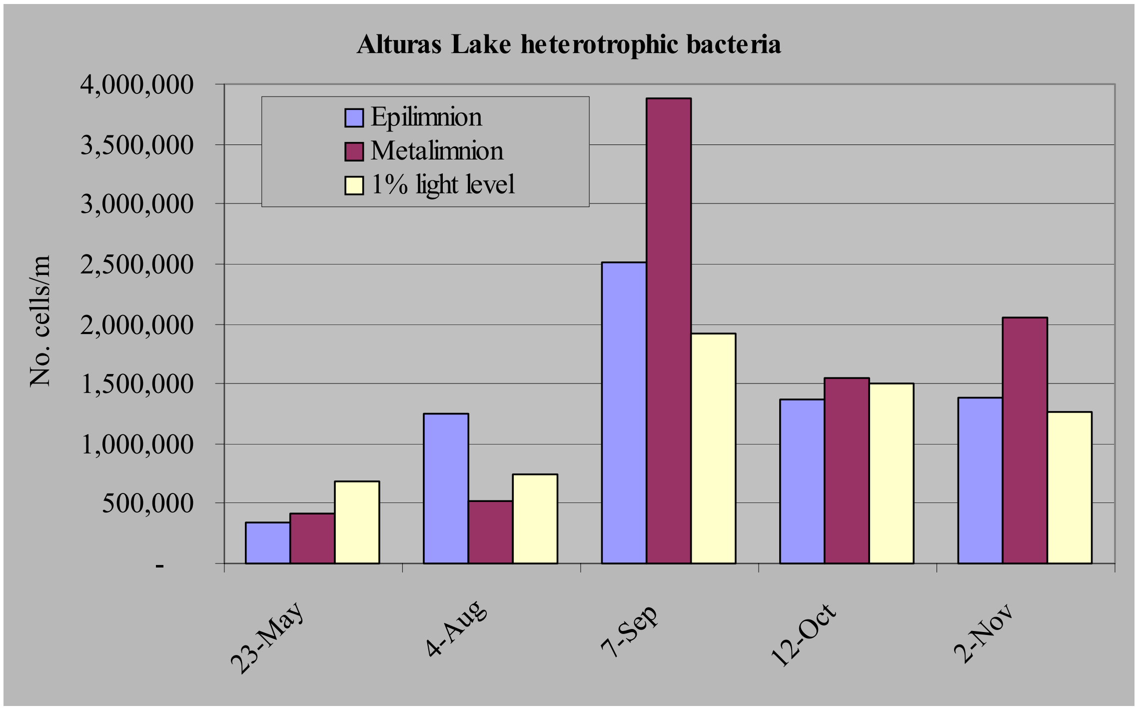


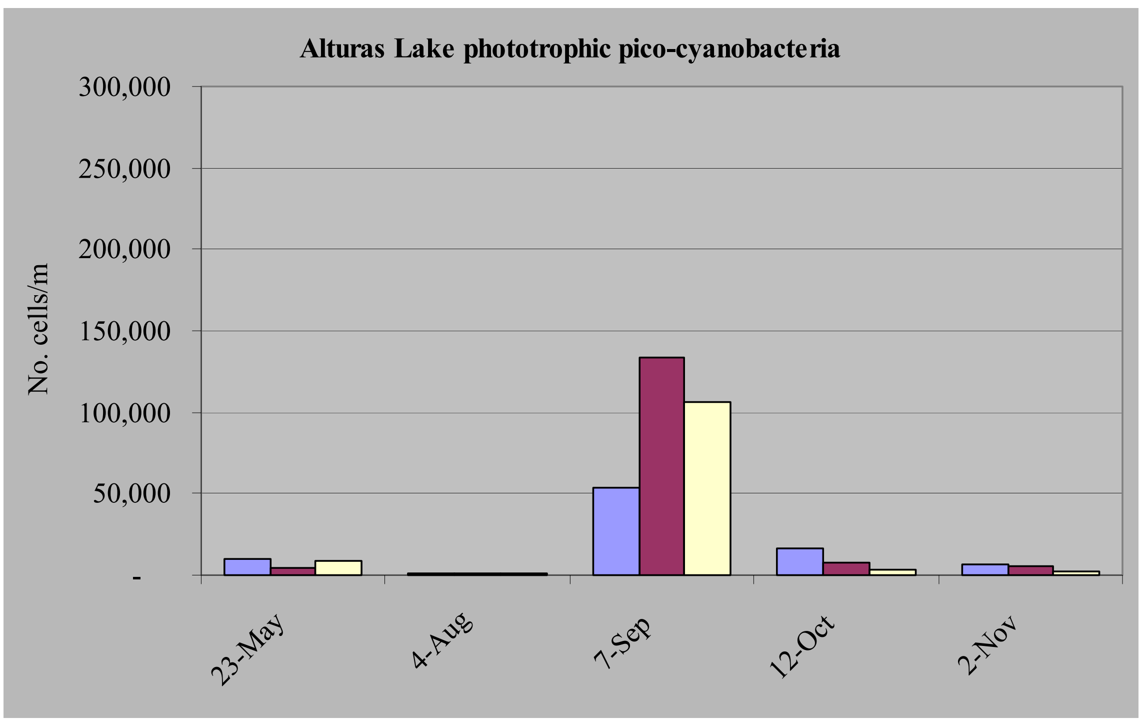
Appendix A-1. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Redfish Lake, March through November 2001.



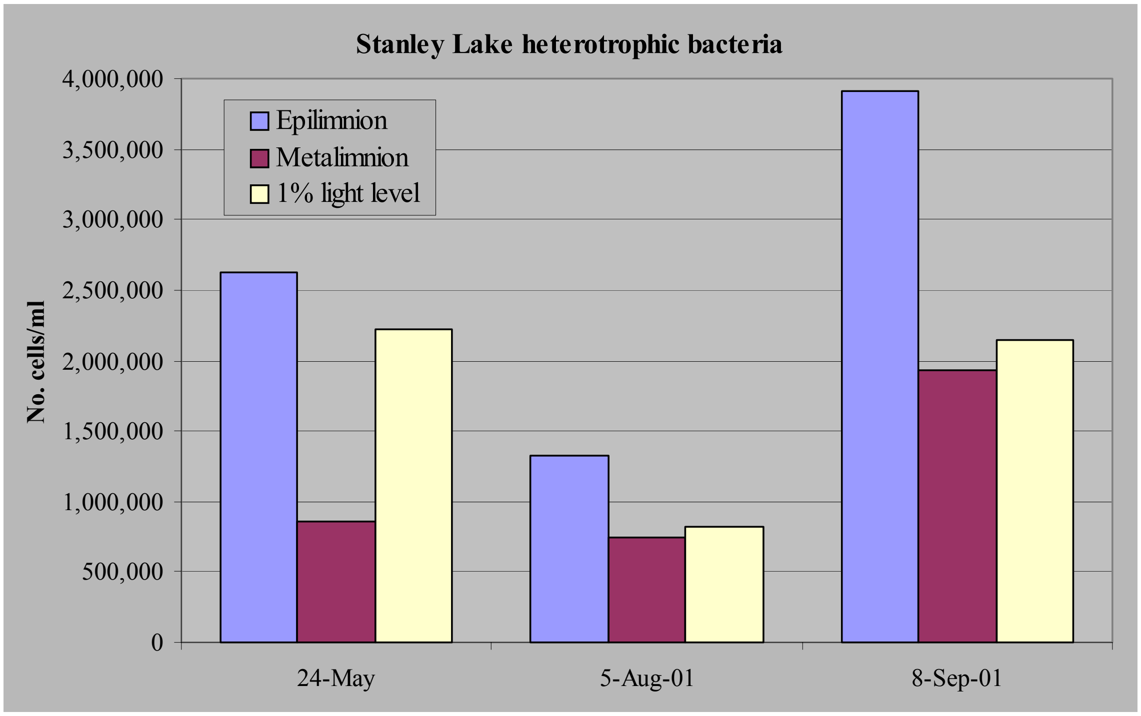


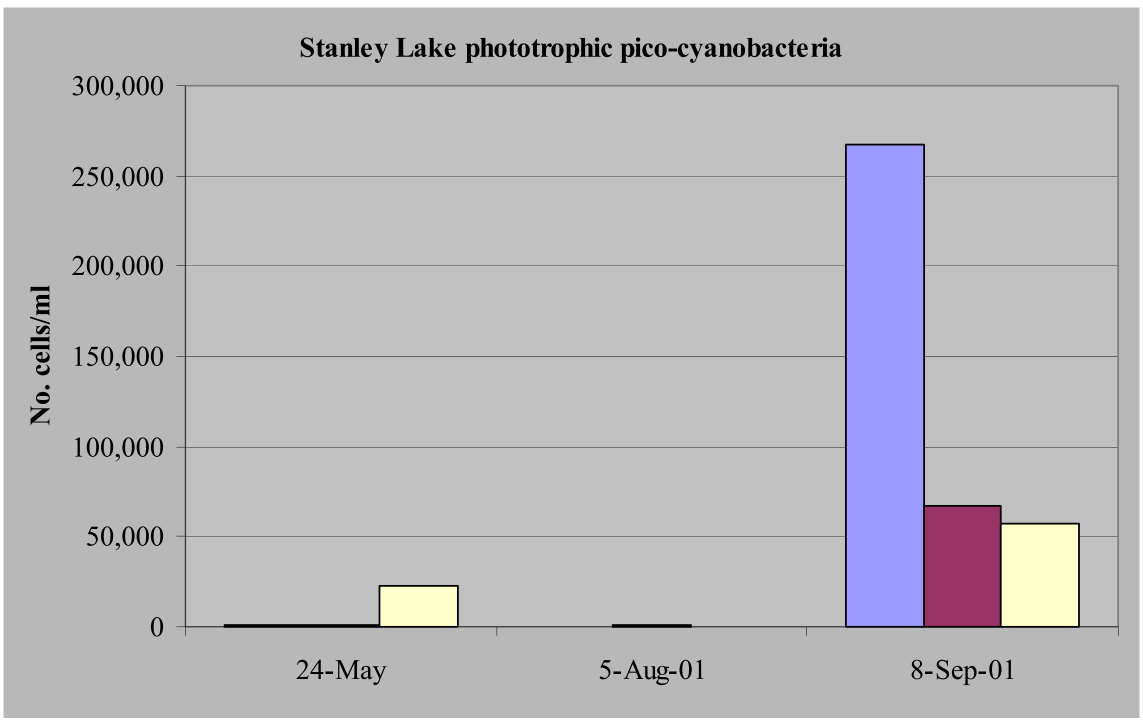
Appendix A-2. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Pettit Lake, March through November 2001.





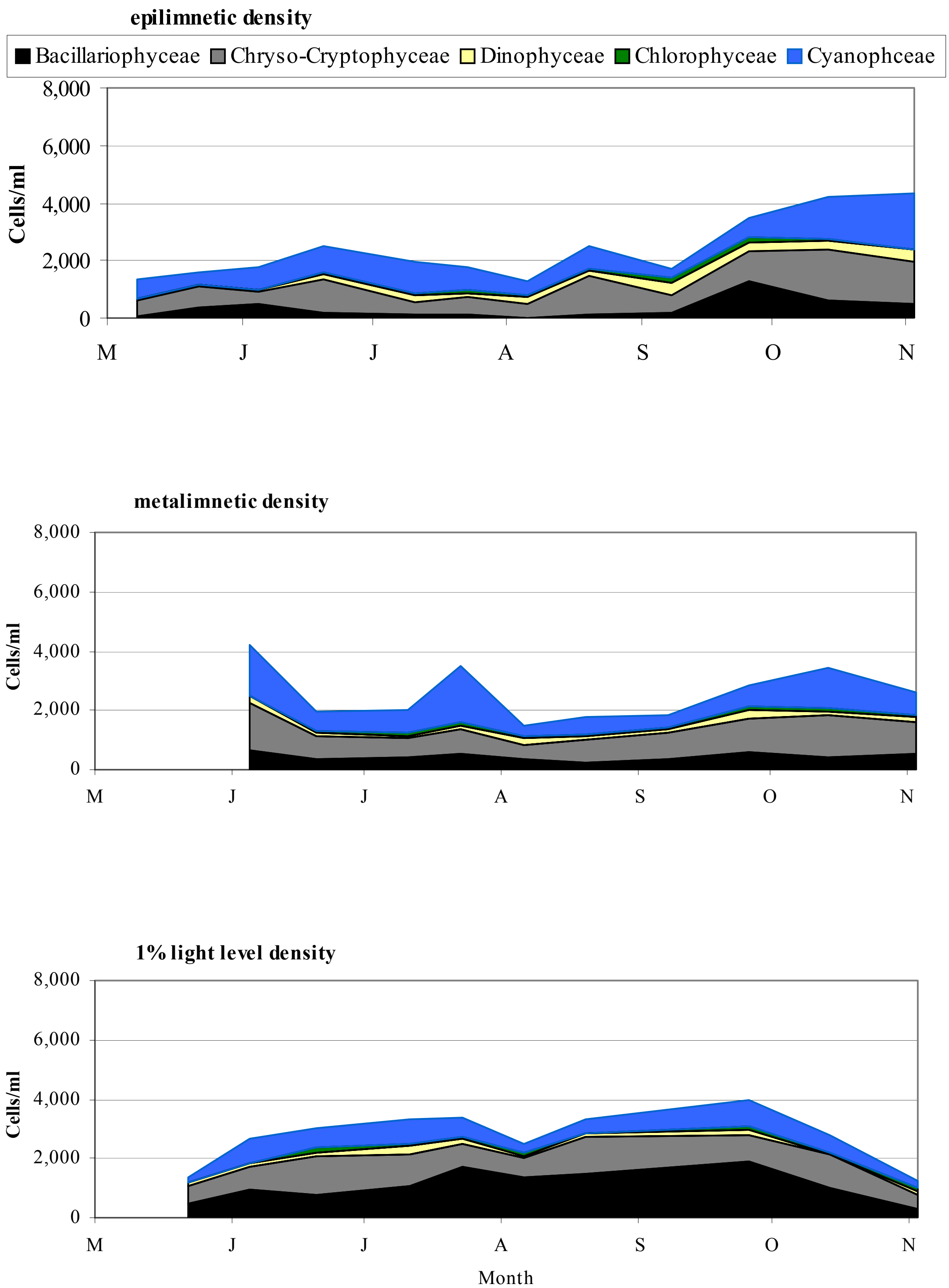
Appendix A-3. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Alturas Lake, March through November 2001.



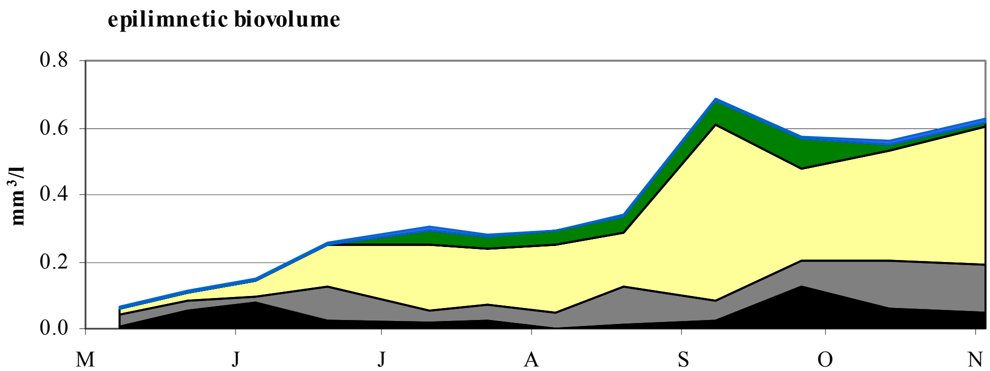


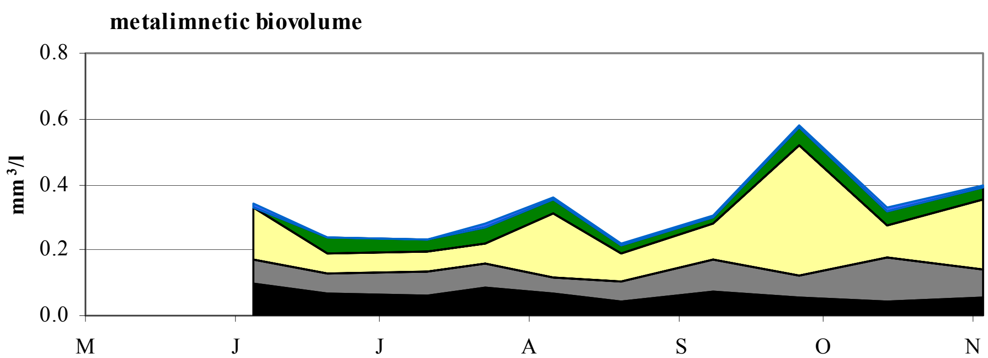
Appendix A-4. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Stanley Lake, March through November 2001.

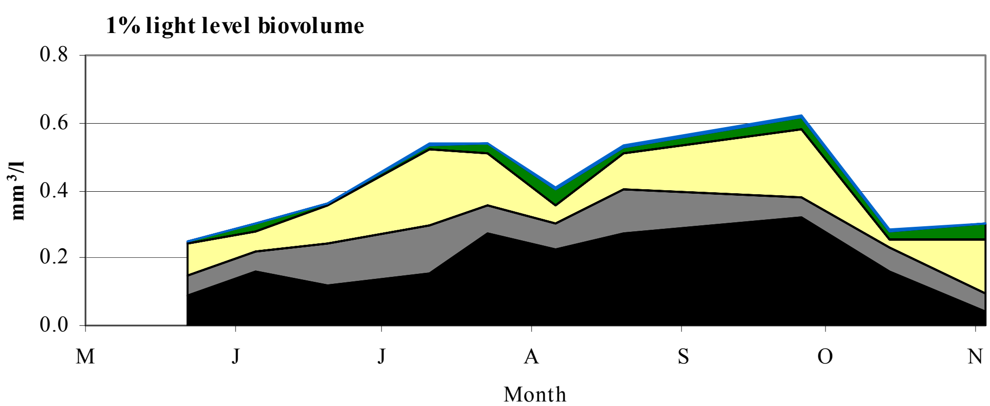
APPENDIX B. Phytoplankton densities and biovolumes



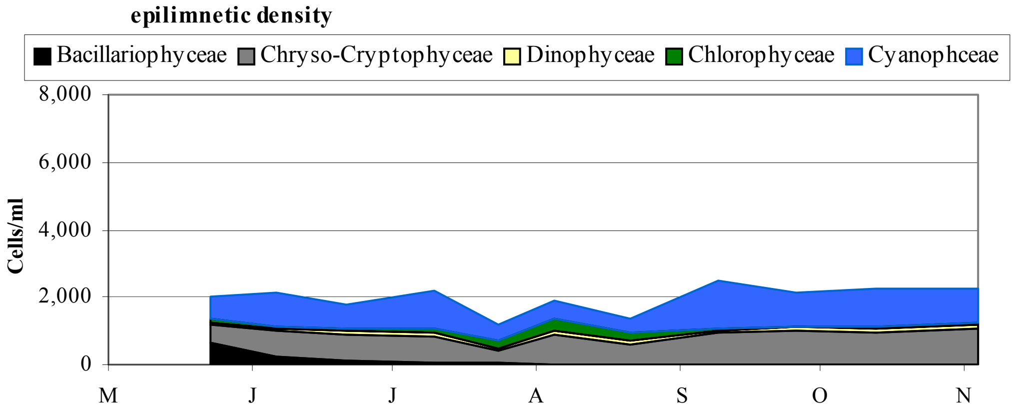
Appendix B-1. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Redfish Lake, March through November 2001.

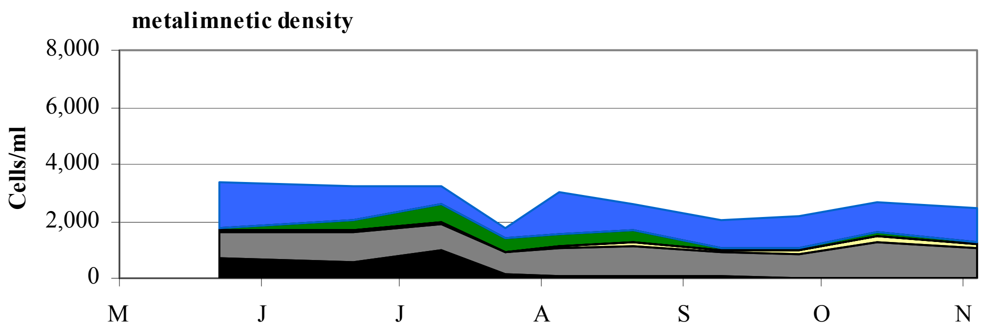


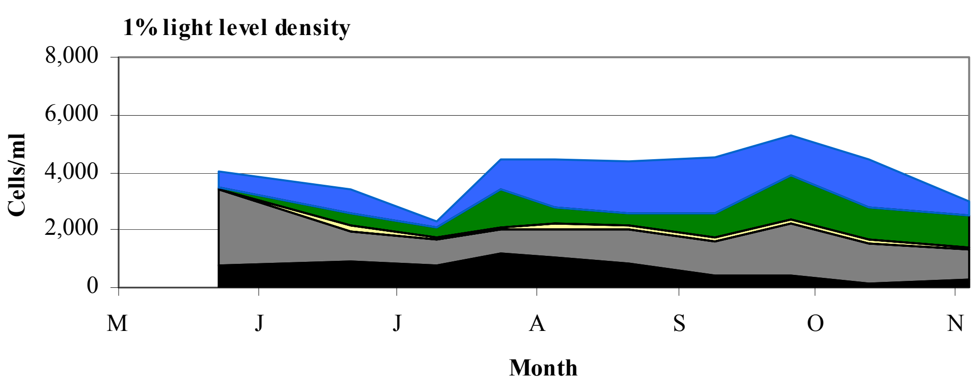




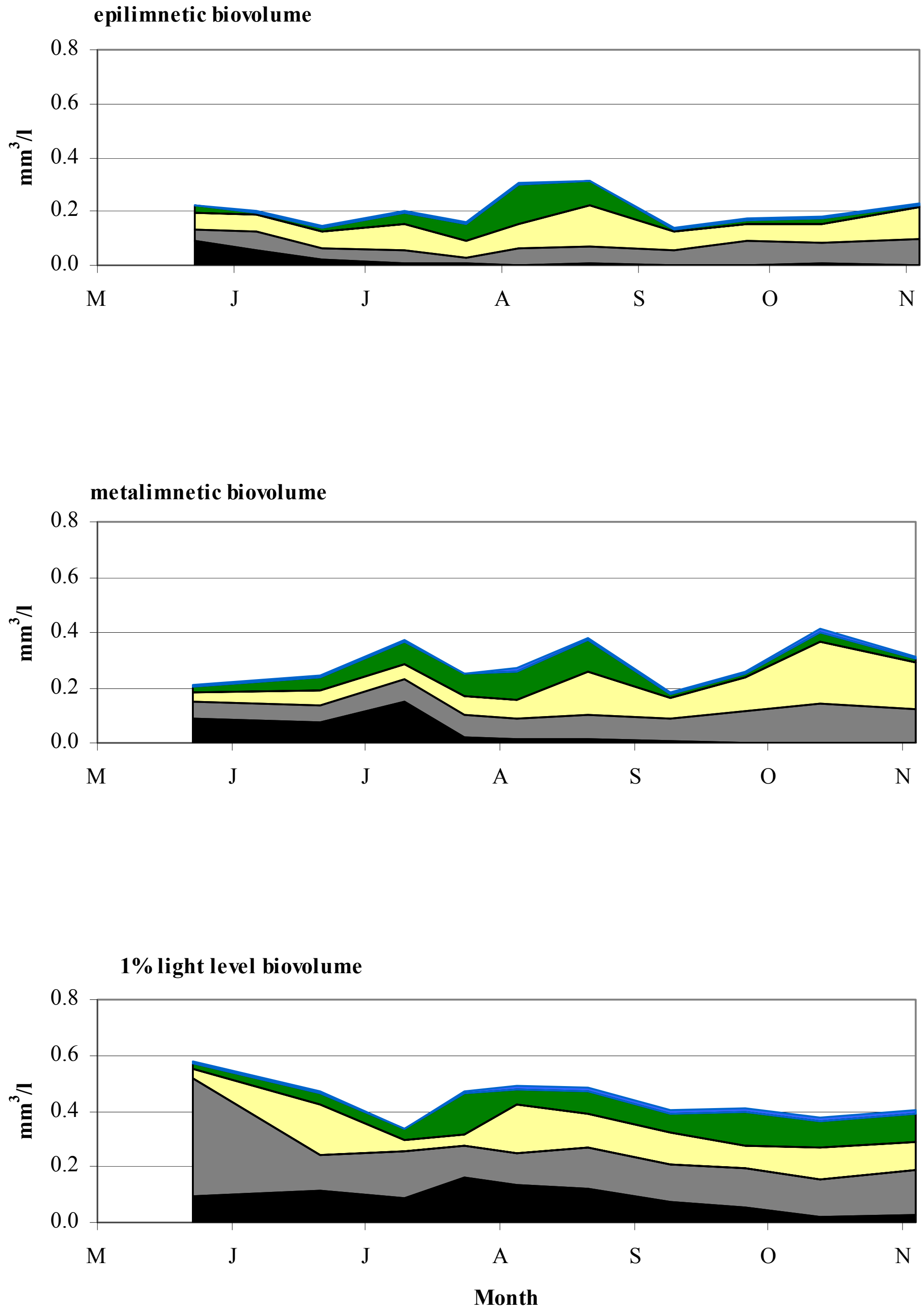
Appendix B-1. Continued.



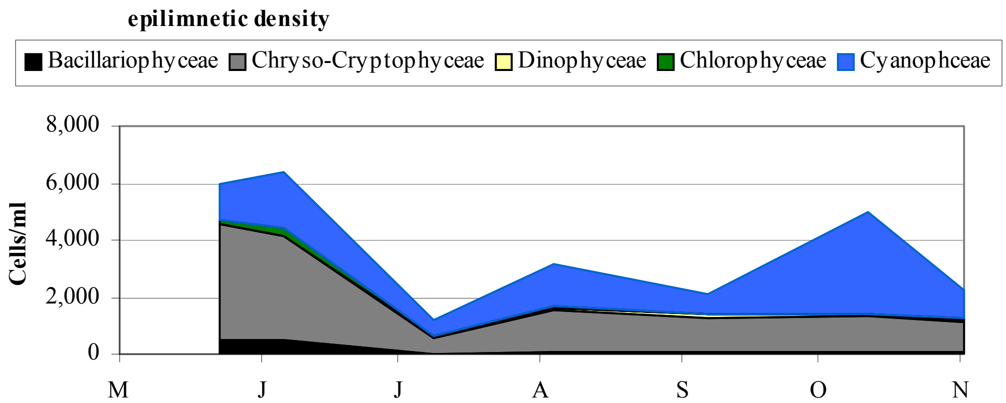


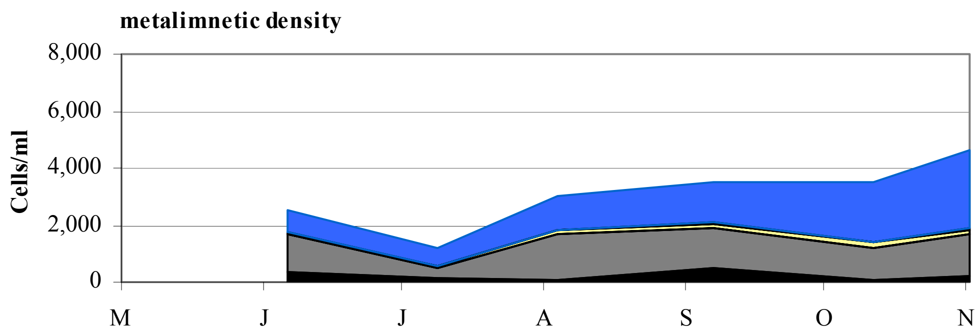


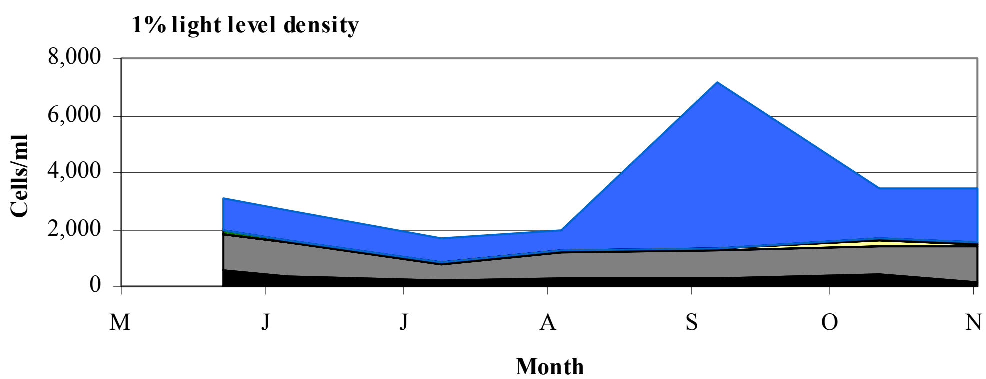
Appendix B-2. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Pettit Lake, March through November 2001.



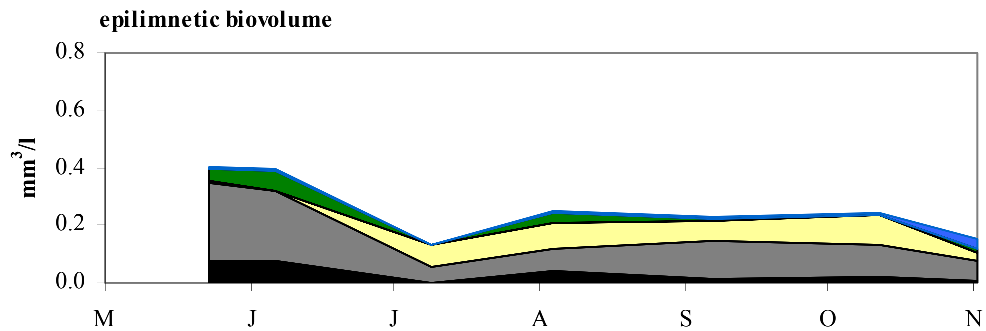
Appendix B-2. Continued.

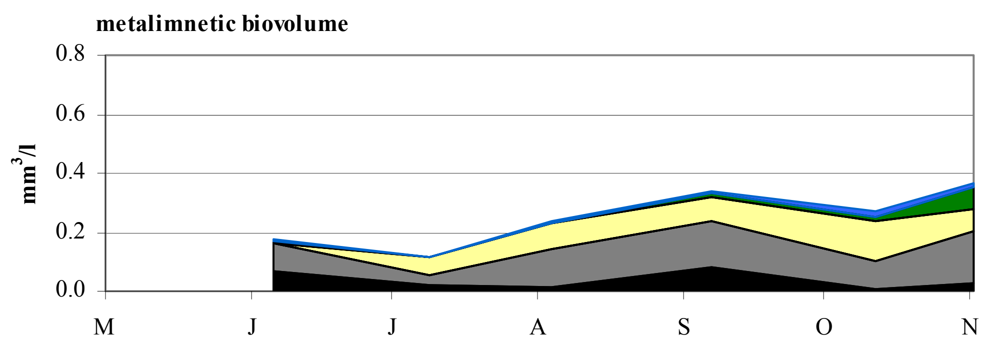


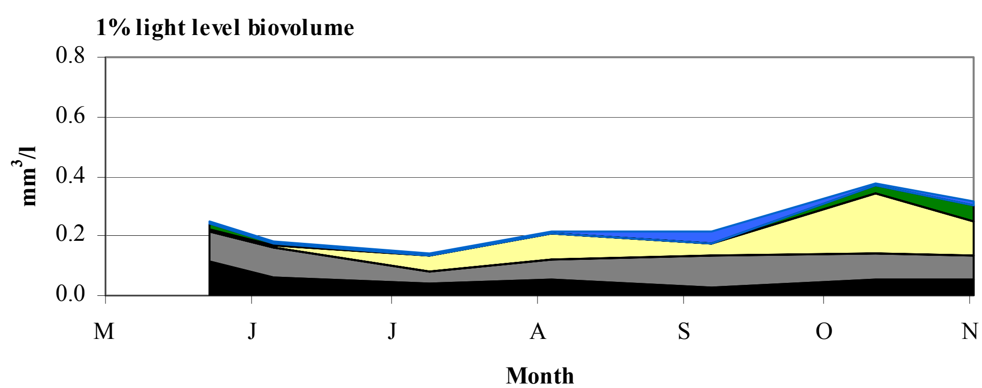




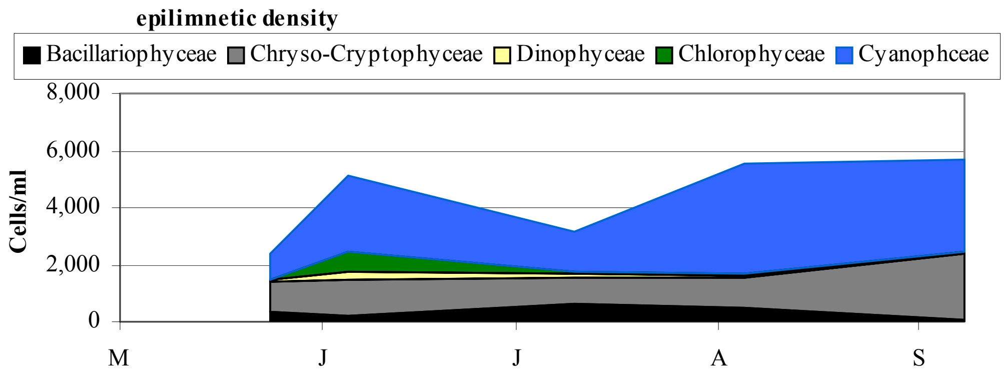
Appendix B-3. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Alturas Lake, March through November 2001.

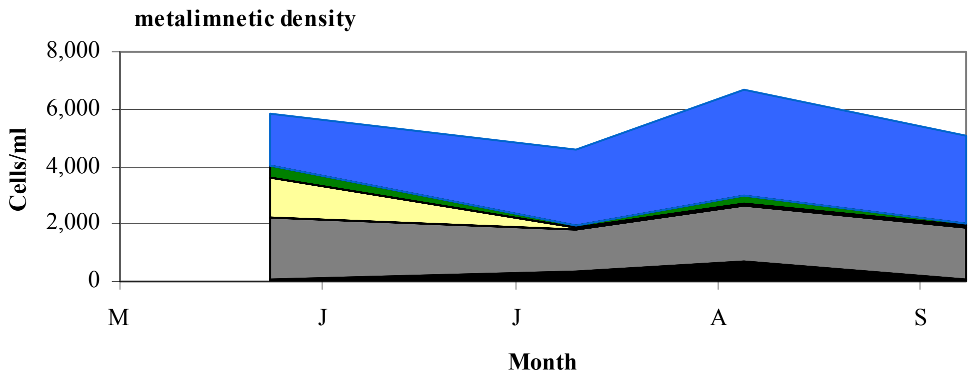


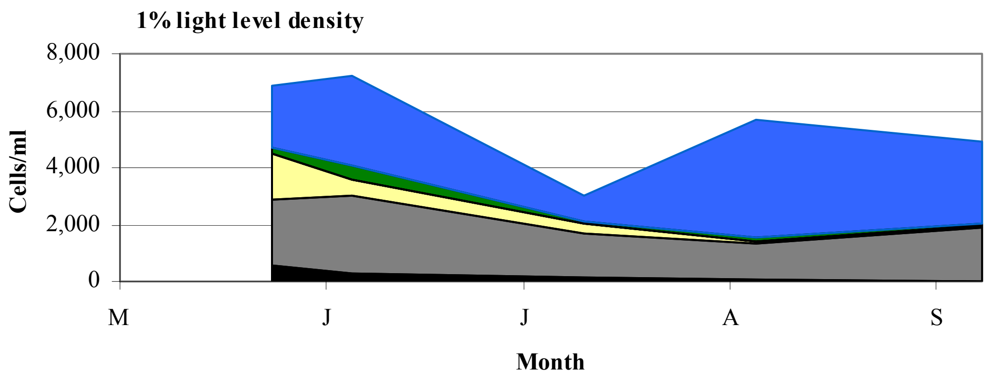




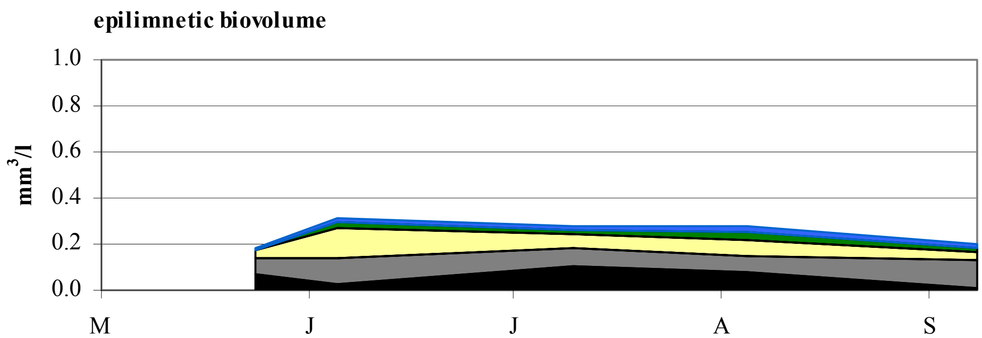
Appendix B-3. Continued.

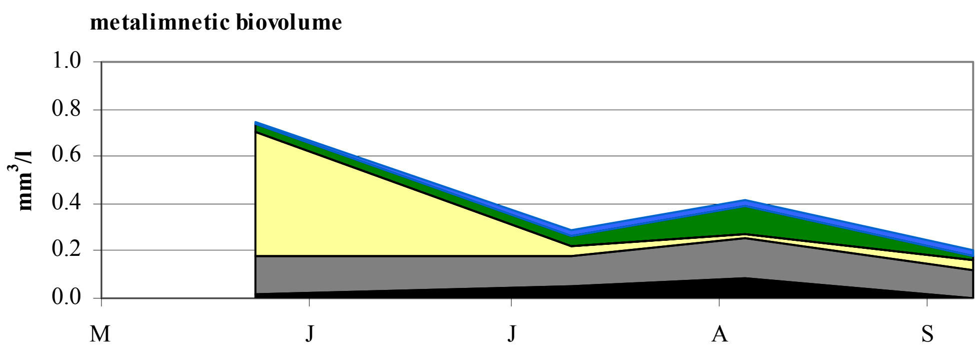


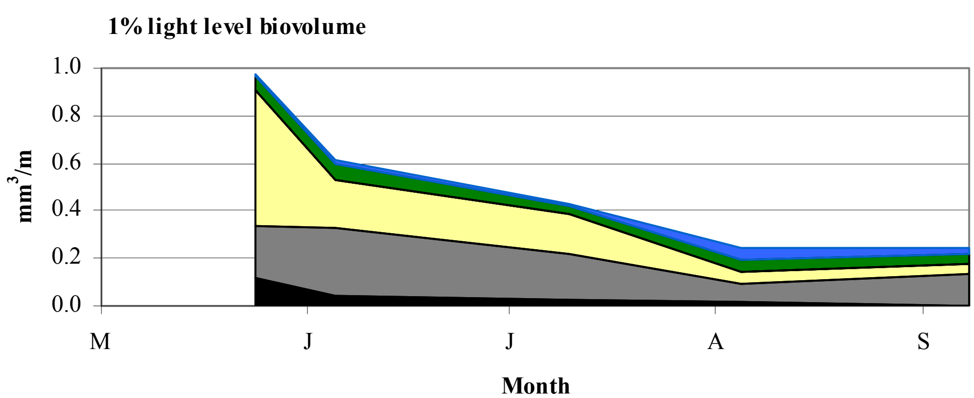




Appendix B-4. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Stanley Lake, March through October 2001.







Appendix B-4. Continued.