Snake River Sockeye Salmon Habitat and Limnological Research

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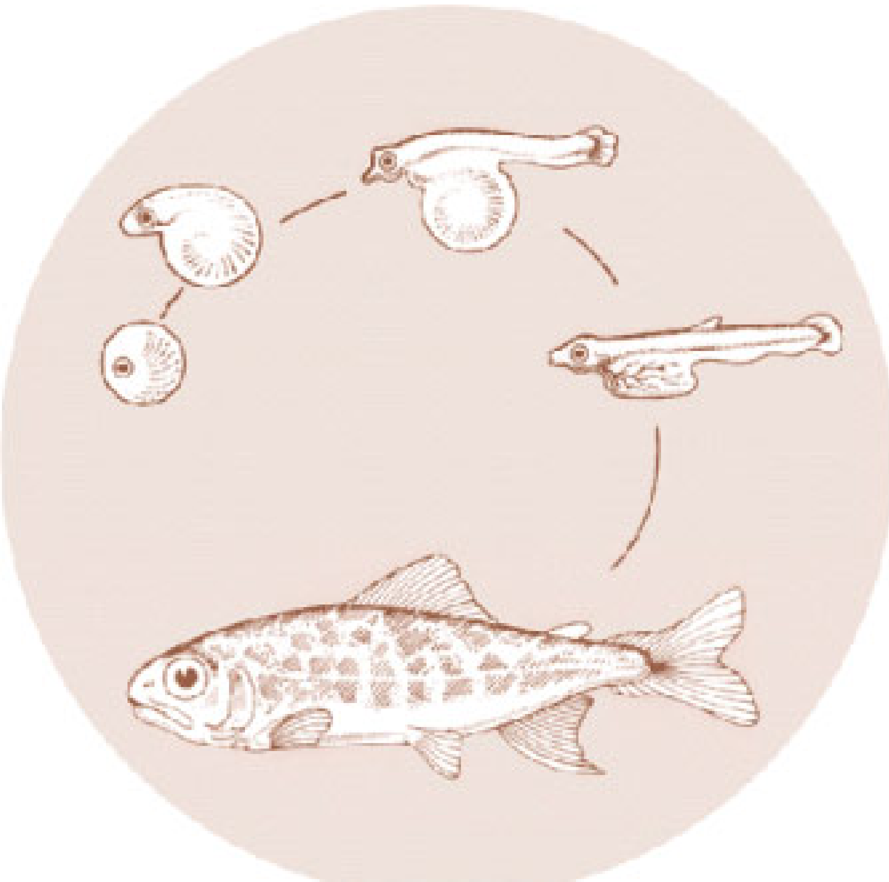

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SNAKE RIVER SOCKEYE SALMON HABITAT

AND LIMNOLOGICAL RESEARCH: 2002 ANNUAL PROGRESS REPORT

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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 Shoshone-Bannock Tribal goal for this project is two tiered: The immediate goal is to increase the population of Snake River sockeye salmon while preserving the unique genetic characteristics of the Evolutionarily Significant Unit (ESU). The Tribes long term goal is to maintain a viable population that warrants delisting and provides Tribal harvest opportunities.

The Bonneville Power Administration (BPA) provides funding for this interagency recovery program through the Northwest Power Planning Council Fish and Wildlife Program (NPPCFWP). 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 2002 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 3) conduct kokanee salmon (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 between stocked juvenile *O. nerka* and a variety of fish species in Redfish, Pettit, and Alturas lakes; and 6) monitor limnological parameters of Sawtooth Valley lakes to assess lake productivity.

Objective 1. Stocked juvenile *O. nerka* 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 (adipose and left ventral fin clip (ADLV)), 2) a direct lake summer release of Sawtooth Hatchery parr (adipose and right ventral fin clip (ADRV)) and 3) a direct lake fall release of Sawtooth Hatchery parr (adipose fin clip (AD)). Over-winter survival estimates in Pettit Lake were 5.0% for ADLV hatchery smolts, 6.7% for ADRV hatchery smolts, and 29.1% for AD hatchery smolts. Stocked juvenile *O. nerka* 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 (adipose and left ventral fin clip (ADLV)), 2) a direct lake summer release of Sawtooth Hatchery parr (adipose and right ventral fin clip (ADRV)), and 3) a direct lake fall release of Sawtooth Hatchery parr (adipose fin clip (AD)). Over-winter survival estimates in Alturas lake were 1.3% for ADLV hatchery smolts, 1.9% for ADRV hatchery smolts, and 58.5% for AD hatchery smolts. Over-winter survival and out-migration for Redfish Lake was monitored by IDFG. Survival estimates presented above for Alturas Lake Creek were based on maximum likelihood out-migration population estimates.

Objective 2. In 2002, only Redfish Lake received supplemental nutrients. Nutrients were applied weekly between 2 July and 1 October by Shoshone-Bannock Tribal fisheries personnel. One hundred and eighty three kg of phosphorus and 5,341 kg of nitrogen were added to enhance lake productivity. Areal loading rates were 29.8 mg P m^2 , or the equivalent of an adult escapement of approximately 22,700 sockeye salmon to Redfish Lake.

Objective 3. Hydroacoustic sampling of *O. nerka* populations was conducted in Redfish, Pettit, and Alturas lakes in the fall of 2002. Concurrent trawl sampling and density estimates were conducted by IDGF. Hydroacoustic data will not be presented until software acquisition and compatibility issues are resolved.

Objective 4. Stream spawner counts were used to monitor adult kokanee escapement to inlet streams on Redfish, Alturas, and Stanley lakes in 2002. Fishhook Creek, the primary kokanee spawning tributary on Redfish Lake, had an estimated spawning escapement of 8,626 adult spawners, Alturas Lake Creek had an estimated 99 adult spawners, and Stanley Lake Creek had an estimated 946 kokanee spawners. Fry recruitment, calculated from male-female ratios, fecundity, and egg to fry survival rates is estimated at 110,422, 965, and 8,940 fry for Fishhook, Alturas Lake, and Stanley 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 Pettit Lake was 0.1% for rainbow trout and *O. nerka* consisting of chironomid pupae. Age 0 sockeye salmon, the life stage of primary interest, fed mainly 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, brook char, rainbow trout, and bull char. Bull char diet was composed primarily of 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. Resident kokanee, primary competitors with lake rearing juvenile sockeye, fed almost entirely on zooplankton prey species. Diet overlap between resident kokanee and rearing sockeye parr was estimated to be 0.87 in Redfish Lake and 0.81 in Pettit Lake.

Objective 6. Three forms of *O.nerka* inhabit Redfish Lake; 1) a resident, stream spawning kokanee population, 2) listed anadromous sockeye, and 3) listed residual sockeye. The residual component spawns in October in littoral areas similar to the anadromous form. Monitoring of spawning residual and anadromous sockeye populations in Redfish Lake has occurred since 1993. Trends in these populations are evaluated with monitoring data collected by weekly snorkel surveys. In 2002, 5 residual sockeye and 5 sockeye adults were observed during snorkel surveys at the SE Inlet and Sockeye Beach spawning areas in Redfish Lake.

Objective 7. Limnological variables including lake fertilization, profile data, secchi depth, light compensation depth, water chemistry, chlorophyll *a*, primary productivity, heterotrophic bacteria, autotrophic picoplankton, phytoplankton, and zooplankton assemblage characteristics (species composition and densities) were sampled once per month during January-March and May-October in all four Sawtooth Valley lakes. Redfish and Pettit were sampled an additional time each month during June-September.

Through the spawning matrix design used in the captive broodstock program, we have been able to sustain the genetic integrity of the stock (Willard et al. 2003). However, to reach our long term goal of restoring a viable population, the adverse effects caused by out of basin activities need to be remedied. For example, adult returns to the Sawtooth Valley in 2000 of two hundred and fifty-seven adults were the largest recorded in several decades. Unfortunately, the smolt-to-adult ratio (SAR) for those fish was only 0.19%. If that ratio increased to two to four percent, our adult return in 2000 would have been between 2,886 and 5,772. Adult escapement of that magnitude would move the recovery program toward achieving our long term goal.

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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 with 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 evaluation of spawning and rearing habitat 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 have 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 Stanley Basin Technical Oversight Committee (SBTOC) has guided all activities conducted by the SBT in association with the sockeye recovery project. The SBTOC is composed of representatives of all participating agencies (BPA, NMFS, IDFG, UI, and SBT). The SBTOC 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 SBTOC meetings to present their research and discuss activities conducted by SBTOC 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 Northwest Power and Planning Council (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^3x10^6)**	**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* spp., redside shiner *Richardsonius balteatus*, dace *Rhinichthys* spp., northern pikeminnow *Ptychocheilus oregonensis*, and sculpin *Cottus* spp.. 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 Lake. Sport fishing for salmonid fishes 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 indicates 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 1996). 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

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

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

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

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

$$\overline{D}_i = \frac{\sum_{j=1}^{Ti} L_j \overline{D}_{ij}}{\sum_{j=1}^{Ti} L_j} \quad (1\text{-}3)$$

and variance was estimated by

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

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

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

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.

Smolt Monitoring

Pettit Lake

A weir was operated at the outlet of Pettit Lake, Idaho (Section 31, Township 8 North, Range 14 East) from 24 Apr through 31 May 2002. The weir was used to determine over-winter survival and emigration of Snake River sockeye salmon smolts. The weir ran continuously at 100% capture efficiency until high water at the end of May. 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 overwhelmed weir operations

Immediately after removal from the trap, 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 anesthetized were weighed to the nearest 0.1 grams, measured (fork length) to the nearest millimeter, held in a live well for 5 to 10 hours after handling, and subsequently released. A condition factor (K value, (weight x 10^5/length^3)) for each fish was estimated with mean, minimum, and maximum K values 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 downstream from Alturas Lake, Idaho (Section 32, Township 8 North, Range 14 East) from 23 April through 31 May 2002. *Oncorynchus 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.

Anesthetized fish were weighed to the nearest 0.1 grams, measured (fork length) to the nearest millimeter, and PIT tagged. A condition factor (K value, (weight x 10^5/length^3)) for each fish was estimated with mean, minimum, and maximum K values presented in results. Anesthetized 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 a 70% ethanol solution. 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, prior to release, and at smolt out-migration. Lengths and weights at the time of tagging were compared to length and weight data of *O. nerka* collected during smolt emigration monitoring. Specific growth rates comparing release groups in Alturas, Pettit, and Redfish lakes are graphically presented using instantaneous growth rates expressed as a percentage (specific growth rate). Additionally, comparisons of lengths and weights are graphically presented with bar charts for the summer release groups in Alturas and Pettit lakes and for the fall release groups in Redfish, Pettit, and Alturas lakes. A second descriptive comparison was generated using a linear regression between the lengths and weights of released parr and outmigrating 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, composed of graduated mesh sizes (2.54, 3.17, 5.08, and 6.35 cm), were set in the pelagic zones of Pettit and Alturas lakes. 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, kokanee, and sockeye were collected. Starting in 1997, Alturas and Pettit lakes have received eyed-egg plants from captive broodstock sockeye. Therefore, unmarked juveniles collected for diet analysis are referred to as *O. nerka* as distinctions between resident kokanee and sockeye cannot be made in the field. Sawtooth Valley lakes 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 from zooplankton tows collected during the same months. 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 of abundance (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, Alturas, and Stanley 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. Spawning surveys began 03 August, with the final count occurring on 20 September. 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 2002. 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 2002 are not available at this time due to software acquisition and compatability issues.

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

	Population Estimate (± 95% C.I.)		**Density** (fish/ha)		**Biomass Estimate** kg/ha		
LAKE	**Acoustic**	**Trawl**	**Acoustic**	**Trawl**	**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
REDFISH 2002	NA	NA	NA	NA	NA	NA	NA
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
PETTIT 2002	NA	NA	NA	NA	NA	NA	NA
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
ALTURAS 2002	NA	NA	NA	NA	NA	NA	NA

NA- Not Available

Smolt Monitoring

Pettit Lake Creek

In the summer of 2001 there were 3,059 ADLV (Eagle Fish Hatchery) and 2,998 ADRV (Sawtooth Fish Hatchery) Snake River sockeye parr stocked into Pettit Lake. Additionally, in the fall of 2001, 4,993 AD (Sawtooth Fish Hatchery) Snake River sockeye parr were stocked into Pettit Lake. Weir monitoring of smolt emigration began on 24 April 2002. The first sockeye was captured on 2 May 2002. Trapping was discontinued on 31 May 2002 (Figure 1-5). Over the course of smolt trapping 152 ADLV, 200 ADRV, 1,451 AD, and 1,067 unmarked 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 5.0, 6.7, and 29.1% for ADLV, ADRV, and AD fish, respectively.

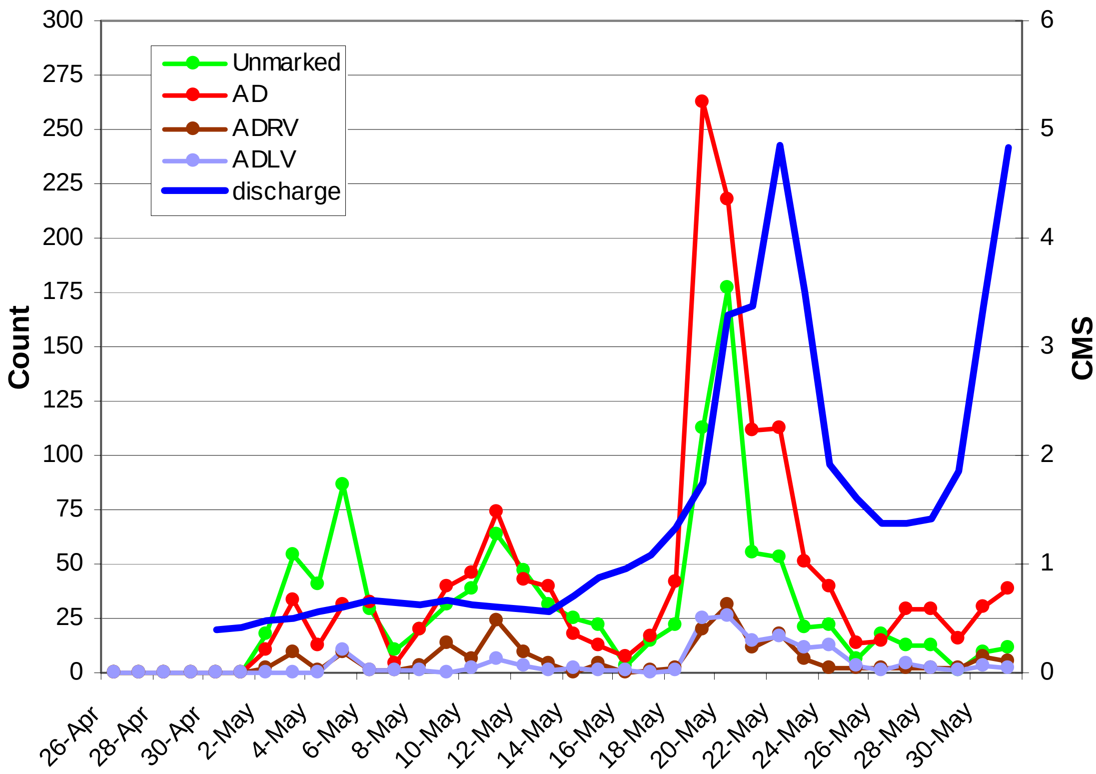

Figure 1-5. Pettit Lake hatchery sockeye emigration timing and discharge, 2002.

The mean fork length of summer release Eagle Hatchery (ADLV) sockeye was 169 mm (range 145-200 mm), mean weight was 44.1 g (range 23.3-79.5 g), and mean K value was 0.91 (range 0.76-1.00). Summer release Sawtooth Hatchery (ADRV) sockeye captured at the weir had a mean fork length of 161 mm (range 135-182 mm), a mean weight of 38.7 g (range 23.0-60.2 g), and a mean K value of 0.92 (range 0.65-1.06). Fall release Sawtooth Hatchery (AD) sockeye captured at the weir had a mean length of 147 mm (range 116-200 mm) (Figure 1-8), a mean weight of 29.7 g (range 9.2-64.3 g), and a mean K value (condition factor) of 0.92 (range 0.59-1.50). Also captured at the trap were unmarked sockeye with a mean fork length of 148 mm (range 120-166 mm), a mean weight of 29.9 g (range 17.5-38.4 g), and a mean K value of 0.91 (range 0.75-1.23).

Water temperatures at the weir ranged from 4.0 to 13.0 ^{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.

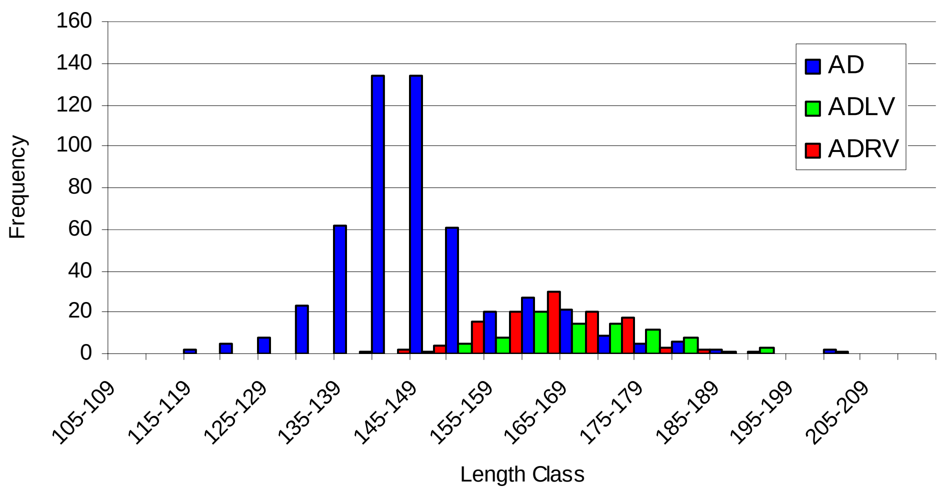

Figure 1-6. Length frequency distribution of hatchery sockeye captured at the Pettit Lake Creek weir in 2002.

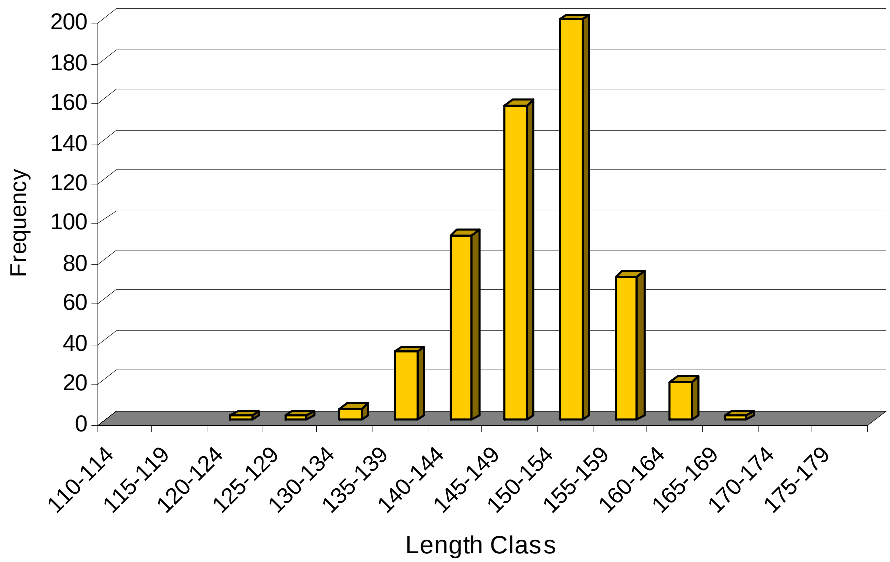

Figure 1-7. Length frequency distribution of unmarked sockeye captured at the Pettit Lake Creek weir in 2002.

Alturas Lake Creek

In the summer of 2001 there were 3,064 ADLV (Eagle Fish Hatchery) and 3,059 AD RV (Sawtooth Fish Hatchery) Snake River sockeye parr stocked into Alturas Lake. Additionally, in the fall of 2001, 5,990 AD (Sawtooth Fish Hatchery) Snake River sockeye parr were stocked into Alturas Lake. Screw trap monitoring of smolt emigration began on 23 April 2002. The first sockeye was captured on 01 May 2002. Trapping was discontinued on 31 May 2002. Eight ADLV, 12 ADRV, 482 AD, and 692 wild smolts were captured during trapping efforts. Trap efficiencies ranged from 4% to 35% for wild and hatchery fish. No clear relationship between discharge and numbers of emigrating fish was found (Figure 1-8).

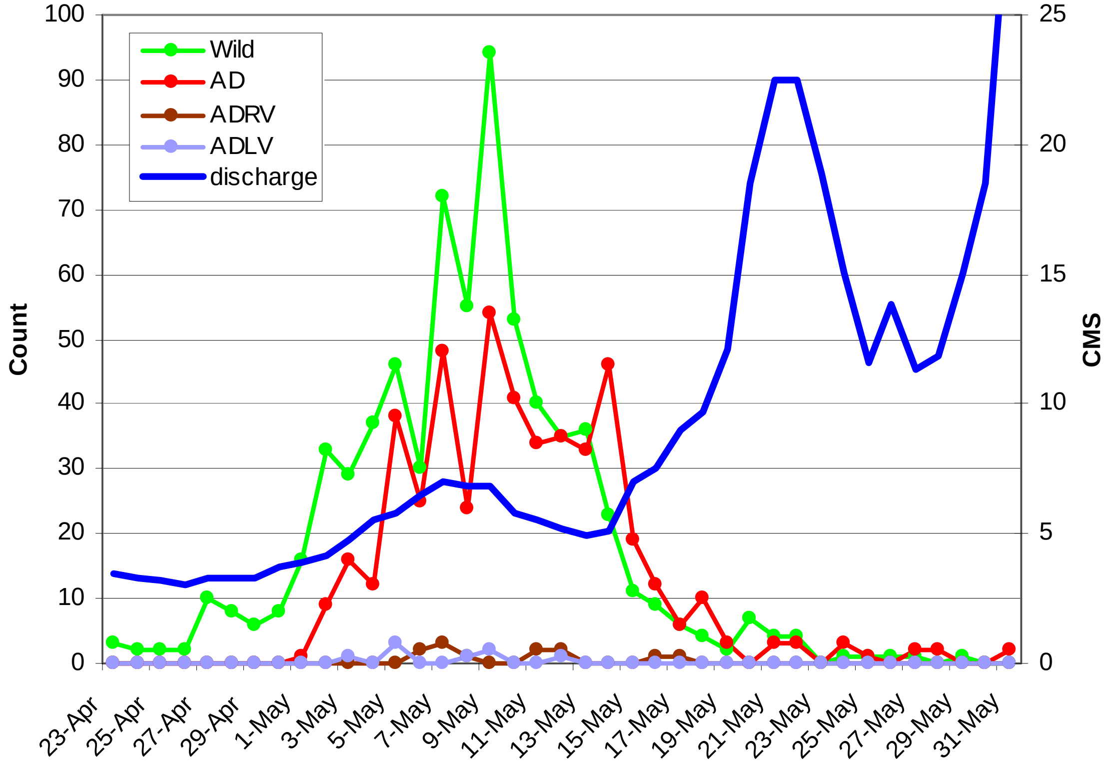

Figure 1-8. Alturas Lake *O. nerka* emigration timing and discharge, 2002.

Maximum likelihood population estimates with confidence intervals (alpha-0.05) were 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 39 (8-27,660) ADLV, 58 (14-19,853) ADRV, 3,505 (2,449-12,940) AD, 3,674 (2,580-13,308) total hatchery, and 6,176 (4,115-22,229) wild smolts emigrated past the screw trap during the spring of 2002. The actual number is potentially higher because additional emigration could have occurred after the trap was pulled. Over-winter survival estimates were calculated from catches at the Alturas Lake Creek screw trap. Survival estimates using Gauss outmigration population estimates were 1.3, 1.9, 58.5, and 30.3% for ADLV, ADRV, AD, and total hatchery fish, respectively. Previous methods for estimating numbers of emigrating fish and over-winter survival employed a stratified trap efficiency population estimate and are presented below. Using the number of captured hatchery sockeye smolts and stratified mean trap efficiencies, it was estimated that 51 ADLV, 72 ADRV, 3,130 AD, and 3,252 total hatchery sockeye smolts emigrated from Alturas Lake. Survival estimates were 1.7, 2.4, 52.3, and 26.8% for ADLV, ADRV, AD, and total hatchery fish, respectively. Using the number of captured wild smolts and stratified mean trap efficiencies it was estimated that 5,467 wild smolts emigrated from Alturas Lake. The actual number is potentially higher because additional emigration could have occurred after the trap was pulled.

Mean fork length of summer release Eagle Hatchery (ADLV) sockeye was 107 mm (range 84-152 mm), mean weight was 10.9 g (range 3.1-28.1 g), and mean K value (condition factor) was 0.71 (range 0.52-0.95). Summer release Sawtooth Hatchery (ADRV) sockeye had a mean fork length of 95 mm (range 89-103), a mean weight of 6.1 g (range 4.1-8.2), and a mean K value of 0.71 (range 0.58-0.79). Fall release Sawtooth Hatchery (AD) sockeye captured at the trap were 112 mm long (range 80-152 mm) (Figure 1-8), had a mean weight of 10.6 g (range 3.8-28.1 g), and a mean K value (condition factor) of 0.73 (range 0.45-1.03). Also captured at the trap were wild *O. nerka* with a mean fork length of 90 mm (range 70-155), a mean weight of 5.2 g (range 2.5-19.9), and a mean K value of 0.70 (range 0.42-1.28).

Water temperatures at the screw trap ranged from 2.0 to 14.0 ^{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.

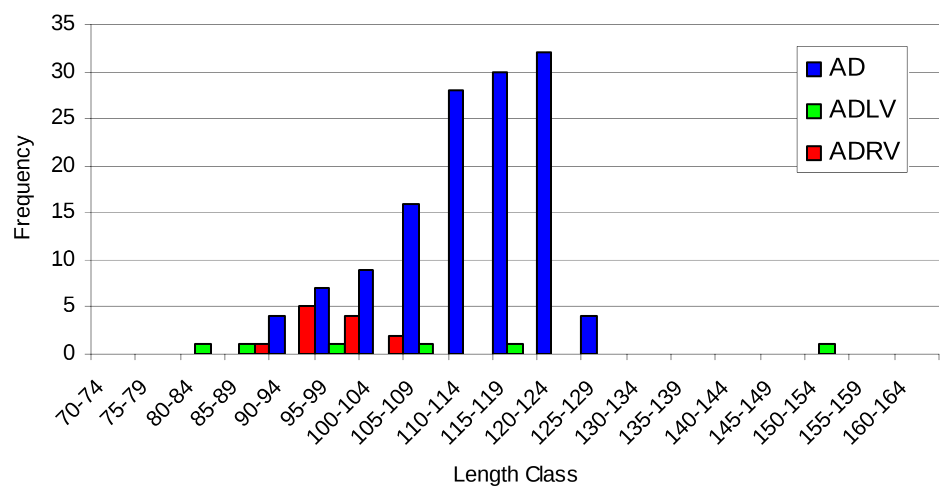

Figure 1-9. The length frequency distribution of *hatchery sockeye* captured at the Alturas Lake Creek screw trap in 2002.

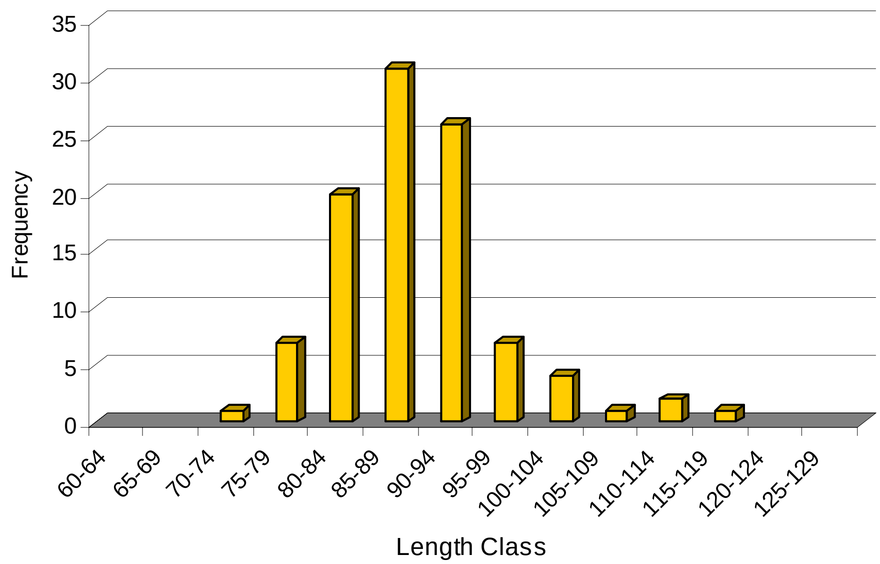

Figure 1-10. The length frequency distribution of wild *O. nerka* captured at the Alturas Lake Creek screw trap in 2002.

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 27 and 31, 2001. Growth rate comparisons for summer and fall release groups in Alturas and Pettit lakes are presented in Figures 1-11, 1-12, and 1-13. Similar comparisons are presented in figures 1-14 through 1-17 for Sawtooth fall release parr that reared in Redfish, Pettit, and Alturas lakes.

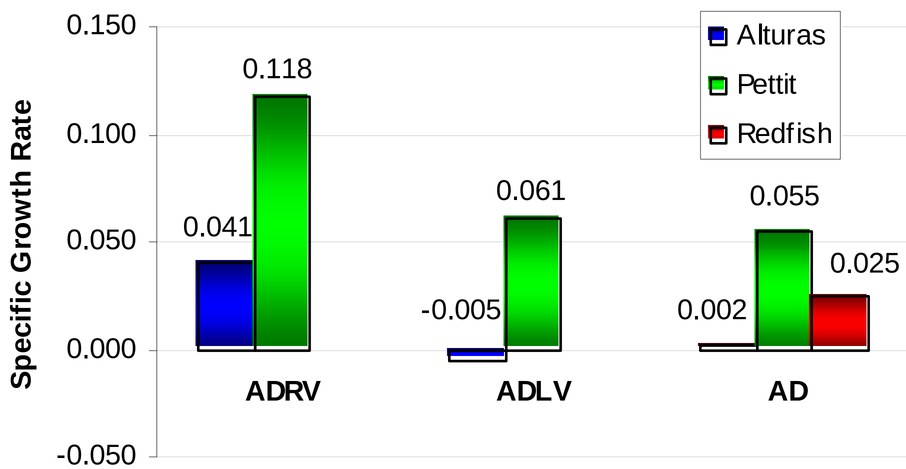

Figure 1-11. Specific growth rate comparison between release groups in Redfish, Pettit, and Alturas lakes 2002.

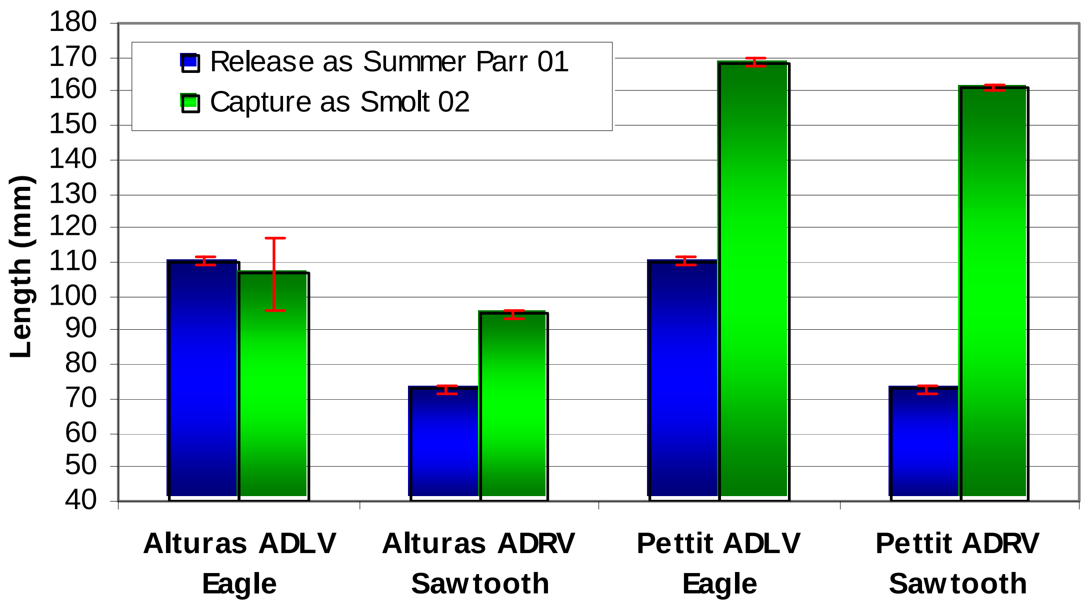

Figure 1-12. Hatchery sockeye (length) summer release comparison between Alturas and Pettit lakes at time of release and emigration. Error bars represent (±) one standard error.

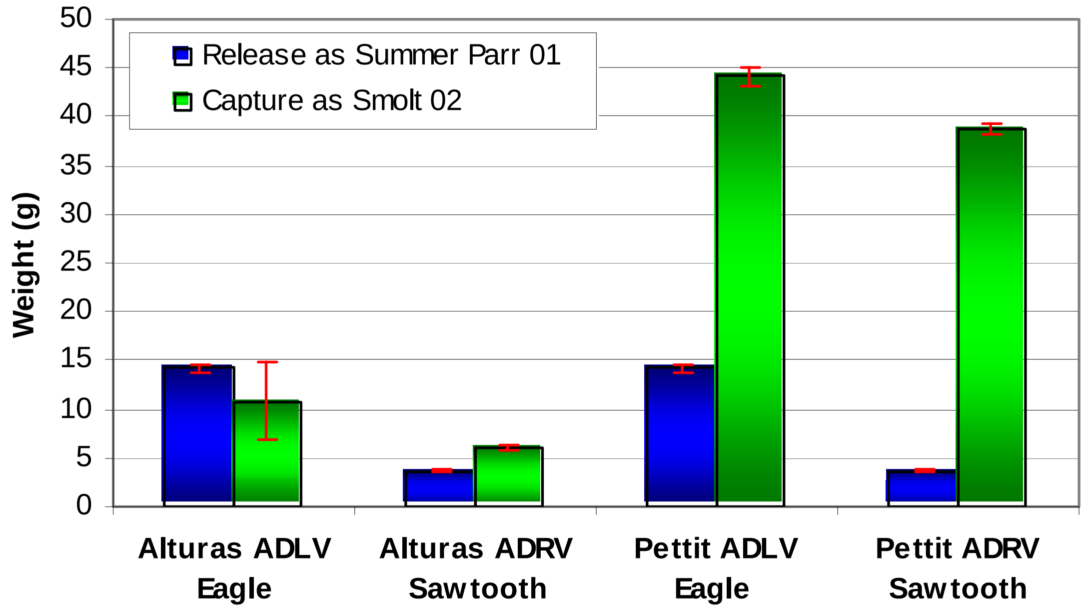

Figure 1-13. Hatchery sockeye (weight) summer release comparison between Alturas and Pettit lakes at time of release and emigration. Error bars represent (±) one standard error.

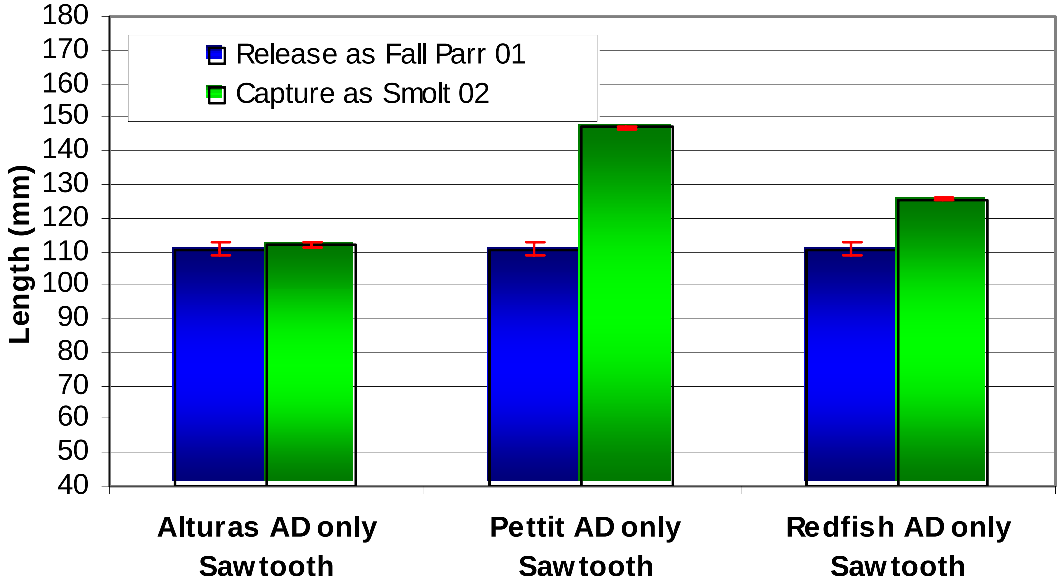

Figure 1-14. Hatchery sockeye (length) fall release comparison between lakes at time of release and emigration. Error bars represent (±) one standard error.

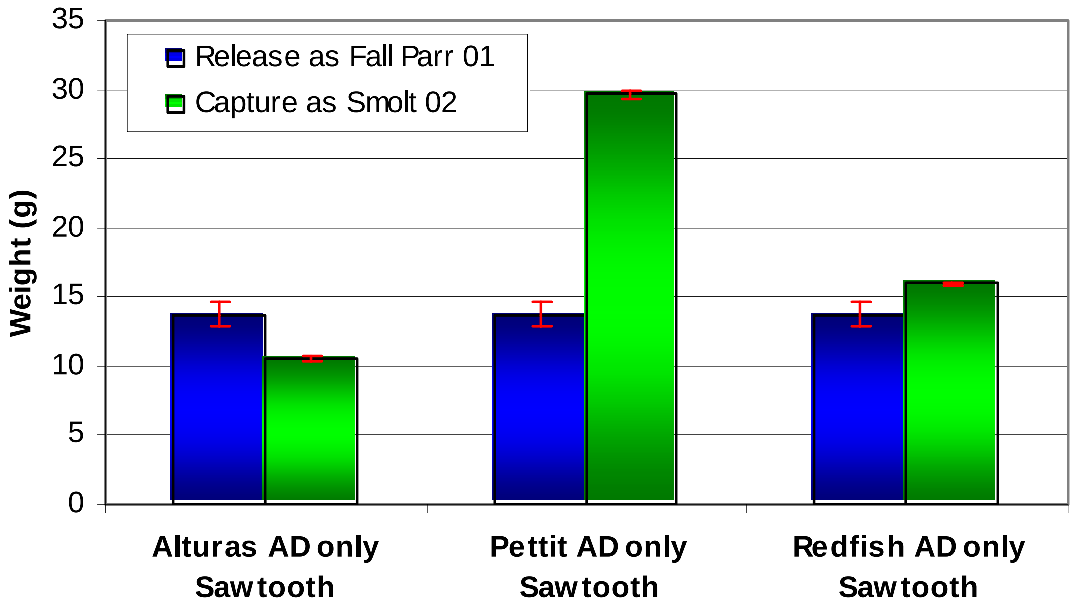

Figure 1-15. Hatchery sockeye (weight) fall release comparison between lakes at time of release and emigration. Error bars represent (±) one standard error.

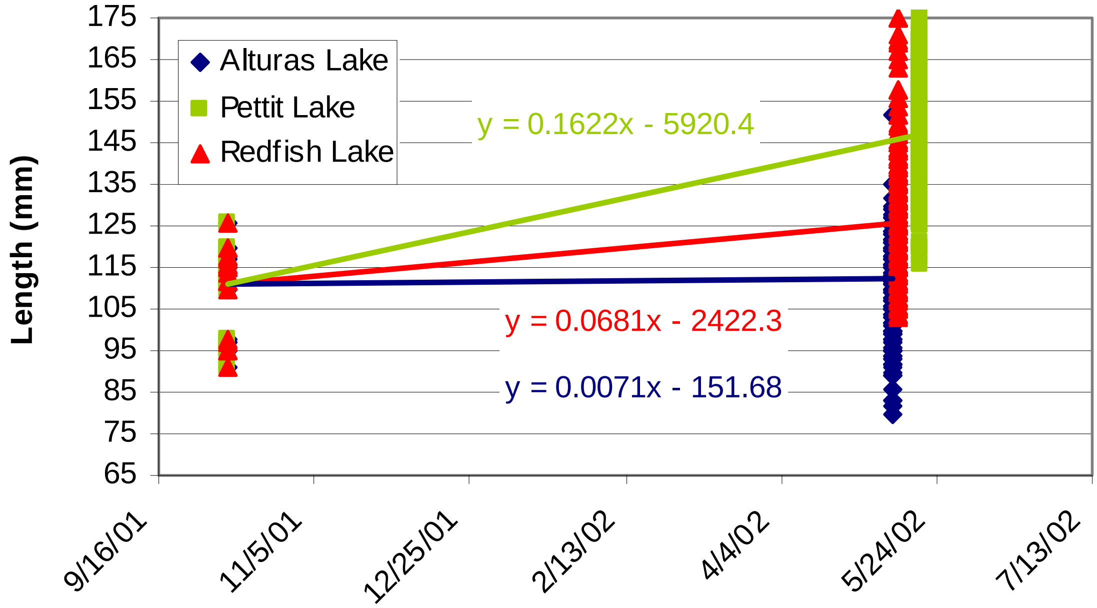

Figure 1-16. Hatchery sockeye (length) fall release data for Redfish, Pettit, and Alturas lakes.

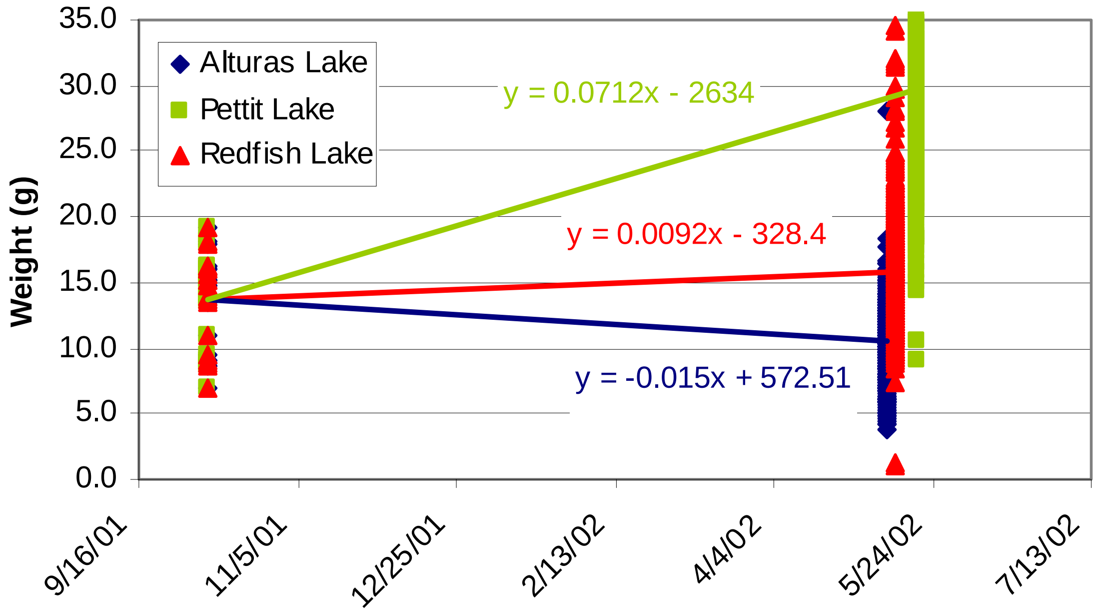

Figure 1-17. Hatchery sockeye (weight) fall release data for Redfish, Pettit, and Alturas lakes.

Gillnet Sampling

Vertical and horizontal gillnet sampling was conducted in Pettit Lake during January, February, June, and July 2002 and vertical gillnet sampling was conducted in Alturas Lake during January, 2002. Results from Pettit and Alturas lake gillnet sampling are presented below in Table 1-3.

Table 1-3. Results of Pettit and Alturas lake gillnet samples 2002.

Date	Station	Set Type	(n) CPUE	Mean LT (mm)	Mean WT (g)	Hrs Fished
			Pettit Lake			
Rainbow Trout						
February 25, 2002	A	Horizontal	(3) 0.13	258	209	22.5
June 19, 2002	A	Horizontal	(2) 0.15	305	ND	13.5
Bull Char						
February 25, 2002	A	Horizontal	(1) 0.04	NA	NA	22.5
Brook Char						
February 25, 2002	A	Horizontal	(1) 0.04	NA	NA	22.5
June 19, 2002	A	Horizontal	(7) 0.52	271	ND	13.5
Whitefish						
June 19, 2002	A	Horizontal	(1) 0.07	NA	NA	13.5
Northern Pikeminnow						
January 22, 2002	A	Horizontal	(4) 0.22	267	ND	18.5
February 25, 2002	A	Horizontal	(6) 0.27	230	159	22.5
June 19, 2002	A	Horizontal	(35) 2.59	248	ND	13.5
O. nerka						
January 22, 2002	A	Horizontal	(25) 1.35	209	ND	18.5
January 22, 2002	E	Vertical	(13) 0.63	175	35	20.8
January 23, 2002	E	Vertical	(15) 0.68	191	18	22.0
February 25, 2002	E	Vertical	(11) 0.48	ND	ND	22.8
February 25, 2002	A	Horizontal	(4) 0.18	185	81	22.5
February 26, 2002	E	Vertical	(5) 0.23	ND	ND	22.0
June 19, 2002	E	Vertical	(1) 0.07	NA	NA	14.0
July 25, 2002	E	Vertical	(2) 0.14	ND	ND	14.0
			Alturas Lake			
Bull Char						
January 24, 2002	Boat Ramp	Vertical	(5) 0.24	ND	ND	21.0
O. nerka						
January 24, 2002	Boat Ramp	Vertical	(10) 0.48	126	18	21.0

ND- No Data
NA- Not Applicable

Diet Analysis

The stomachs of 11 rainbow trout (RBT) caught during Pettit Lake gillnet and trawl efforts (February through August 2002) were analyzed for diet comparison. No *O. nerka* were found in the stomachs of any RBT. The diet composition of the 11 RBT analyzed was composed of 2% plant matter, 12% molluscs, 5% terrestrial insects, 26% odonates, 22% chironomid pupae, 1% cyprinids, and 32% other (miscellaneous material) (Figure 1-18).

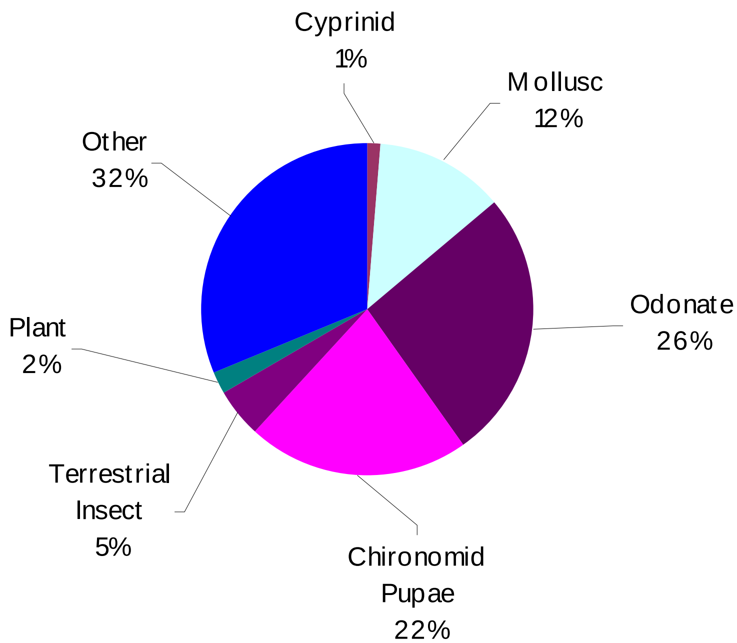

Figure 1-18. Combined diet of RBT (n=11) captured during gillnet and trawl sampling, February to August, 2002. Diet is presented as percent composition of prey items.

Diet analysis was also conducted on *O.nerka* that were collected during winter gillnet (January), summer gillnet (July), and fall (September) gillnet and trawl efforts

The diet (percent zooplankton prey item) of Alturas Lake age 1+ *O. nerka* captured during January of 2002 was composed of 77% cyclopoids, representing 12% of the in-lake zooplankton composition (electivity index 0.73) (Table 1-5 and Figure 1-19). The diet of Alturas Lake age 1+ *O. nerka* captured during September of 2002 was 95%

Daphnia spp., representing 23% of the in-lake zooplankton composition (electivity index 0.62) (Table 1-5 and Figure 1-20). The diet of Pettit Lake hatchery sockeye parr captured during January of 2002 was 65% cyclopoids, representing 19% of the in-lake zooplankton composition (electivity index 0.54) (Table 1-5 and Figure 1-21). No age 0+ *O. nerka* were caught during winter gillnet efforts in Pettit Lake. The diet of age 1+ Pettit Lake *O. nerka* during July of 2002 was dominated by 95% *Daphnia* spp., representing 18% of the in-lake zooplankton composition (electivity index 0.68) (Table 1-5). The diet of age 1+ Pettit Lake *O. nerka* captured in trawl samples during September of 2002 was dominated by 99% *Daphnia* spp., representing 52% of the in-lake zooplankton composition (electivity index 0.31) (Table 1-5 and Figure 1-22).

Differences were found in age 0+ *O. nerka* and hatchery sockeye parr diets (percent zooplankton prey item) from samples collected in September 2002 in Redfish Lake. The diet of age 0+ *O. nerka* was 59% *Daphnia* spp., representing 69% of the in-lake zooplankton composition (electivity index of -0.07) (Table 1-4). The diet of hatchery sockeye parr in Redfish Lake in September 2002 was composed of 65% cyclopoids, representing 07% of the in-lake zooplankton composition (electivity index of 0.81) (Tables 1-4). Diet overlap between age 0+ *O. nerka* and hatchery sockeye parr in Redfish Lake and Pettit Lake (September trawl) was 87 and 81%.

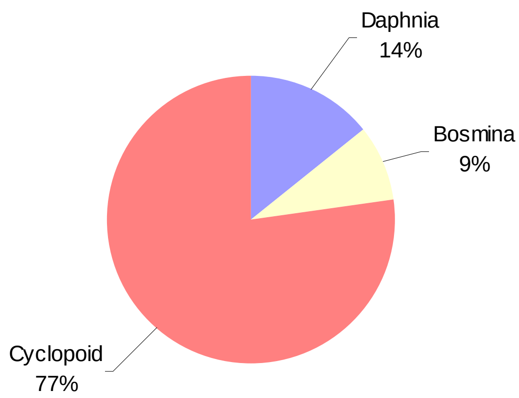

Figure 1-19. Diet of age 1+ (>85mm) *O. nerka* (n=8) caught in Alturas Lake during winter (January) 2002 gillnet efforts. Diet is presented as percent composition of prey items.

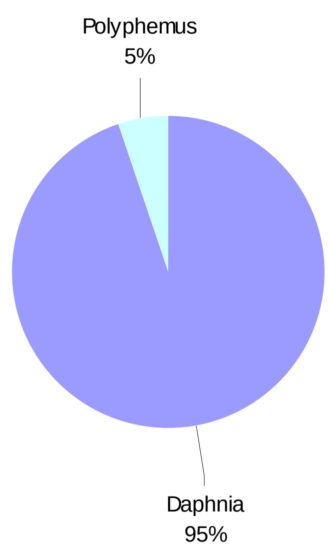

Figure 1-20. Diet of age 1+ (>85mm) *O. nerka* (n=13) caught in Alturas Lake during fall (September) 2002 trawl efforts. Diet is presented as percent composition of prey items.

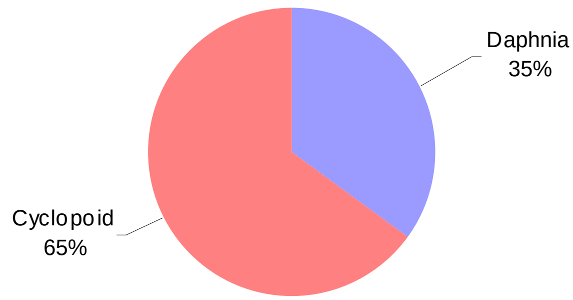

Figure 1-21. Diet of hatchery sockeye parr from the captive brood stock (n=18) caught in Pettit Lake during winter (January) gillnet efforts 2002. Diet is presented as percent composition of prey items.

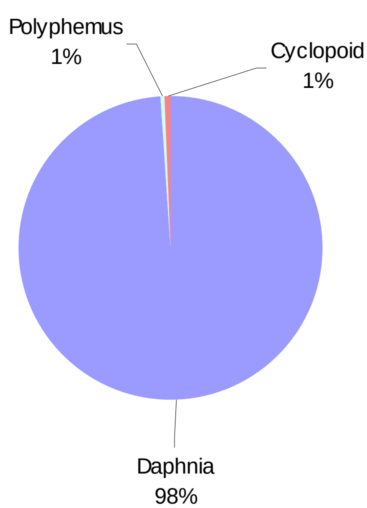

Figure 1-22. Diet of age 1+ (>85mm) *O. nerka* (n=5) caught in Pettit Lake during fall (September) 2002 trawl efforts. Diet is presented as percent composition of prey items.

Table 1-4. Comparison of Age 0+ Redfish Lake *O. nerka* and hatchery sockeye parr diets from September 2002 trawl data. Diet is presented as percent composition of prey items.

	DAPH	HOLO	BOSM	POLY	CYCLOP	CHIRO	CALAN	CHIDORIS	OTHER
Redfish Lake									
Age 0+ *O. nerka*	59.69	0.00	0.00	1.35	38.96	0.00	0.00	0.00	0.00
Age 0+ Parr SE	33.97	0.00	0.00	0.63	65.40	0.00	0.00	0.00	0.00

Table 1-5. Zooplankton electivity indices from Redfish, Pettit, and Alturas lakes, 2002.

	Season	DAPH	HOLO	BOSM	POLY	CALAN	CYCLO	NAUPLII
Redfish Lake								
Age 0+ *O. nerka*	September	-0.07	-1.00	-1.00	-0.54	*	0.69	-1.00
Age 0+ Parr SE	September	-0.34	-1.00	-1.00	-0.75	*	0.81	-1.00
Pettit Lake								
Age 0+ Parr SE	January	0.66	*	-1.00	1.00	*	0.54	-1.00
Age 1+ *O. nerka*	July	0.68	-1.00	-0.94	0.47	*	-0.95	-1.00
Age 1+ *O. nerka*	September	0.62	-1.00	-1.00	0.40	*	-1.00	-1.00
Alturas Lake								
Age 1+ *O. nerka*	January	0.85	*	0.004	*	*	0.73	-1.00
Age 1+ *O. nerka*	September	0.62	-1.00	-1.00	0.40	*	-1.00	-1.00

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

Diet overlap between *O. nerka* and rainbow trout was 0.12% in Pettit Lake. This overlap was solely attributed to chironomid pupae. Past diet surveys (Teuscher and Taki 1996) found that chironomid pupae dominated *O. nerka* 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). Diet analysis of rainbow trout captured in 2002 (n=11) consisted of 1.29% cyprinids, 12.49% molluscs, 26.38% odonates, 0.07% trichopterans, 0.08% hemipterans, 21.64% chironomid pupae, 4.83% terrestrial insects, 2.20% plant matter, and 31.01% miscellaneous prey items. Northern pikeminnow diet (n=9) was composed of 22.01% cyprinids, 11.17% unidentified fish, 0.95% mollusks, 63.16% odonates, and 2.70% miscellaneous prey items. Brook char diet (n=4) consisted of 25.00% cyprinids, 0.90% molluscs, and 36.62 % odonates, and 37.48% chironomid pupae. No salmonid prey items were found in any stomach samples, however, due to the advanced state of digestion some unidentified fish could have been *O. nerka*.

Table 1-6. Diet by mean percent dry weight of piscivorous fish caught in Pettit Lake during 2002 gillnet sampling.

	SAL	CYP	U. F.	MOL	ODO	TRI	COL	HEM	DIP	CHI	TER	PLANT	OTHER
RBT	0.00	1.29	0.00	12.49	26.38	0.07	0.00	0.08	0.00	21.64	4.83	2.20	31.01
PIKE	0.00	22.01	11.17	0.95	63.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70
BRK	0.00	25.00	0.00	0.90	36.62	0.00	0.00	0.00	0.00	37.48	0.00	0.00	0.00

(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)

Stream Spawning

Using a modified area under the curve (AUC) method, kokanee escapement for 2002 was estimated for Alturas Lake Creek (99), Stanley Lake Creek (946), and Fishhook Creek (8,626) (Table 1-7, Figure 1-23). Larger than expected returns in Fishhook Creek exceeded management goals aimed at reducing intra-specific competition for forage resources between resident kokanee and sockeye populations. Control efforts achieve this goal by maintaining female spawner populations at approximately 2000 adults.

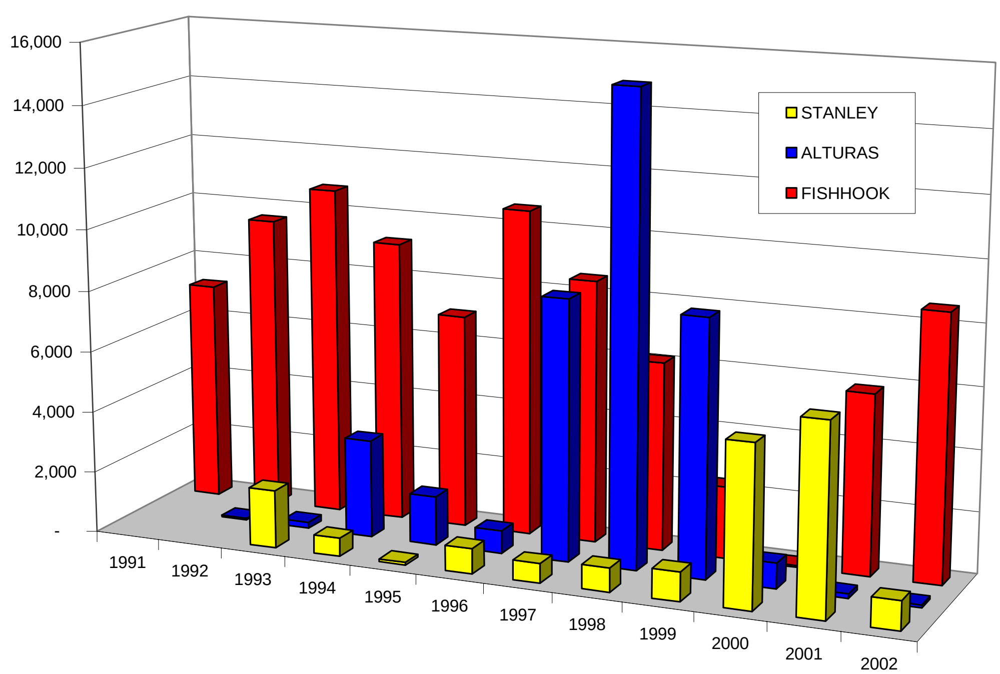

Figure 1-23. Kokanee escapement estimates for Stanley, Alturas, and Fishhook creeks, 1991 to 2002.

Alturas Lake Creek

The 2002 Alturas Lake Creek kokanee escapement (99 fish) was similar to 2001 and down significantly from escapement numbers seen in the past (93-2000) (Figure 1-23). 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 2002, the escapement timing for 20, 50, and 80% of kokanee entering the creek (Table 1-8) was later (approximately 14, 10, and 9 days, respectively) than the 1996-2001 mean. Escapement estimates for Alturas Lake Creek were calculated from field counts between 19 August and 20 September 2002. Assuming equal sex ratios, there was an estimated female escapement of approximately 50 fish in 2002. At 150 eggs per female, there were an estimated 7,500 eggs deposited in Alturas Lake Creek. Using a 13% egg-to-fry survival rate (Teuscher and Taki 1996) an estimated 965 emigrating fry will be produced from 2002 spawning activities (Table 1-7).

Stanley Lake Creek

The 2002 Stanley Lake Creek kokanee escapement (946) was down substantially from the 2001 escapement estimate (Figure 1-23). Escapement timing for 20, 50, and 80% of kokanee entering the creek (Table 1-8) was earlier (approximately 4, 5, and 5 days, respectively) than the 1996-2001 mean. Escapement estimates for Stanley Lake Creek were calculated from field counts made between 3 August and 19 September. Assuming equal sex ratios, the escapement estimate for kokanee females in 2002 was 473 fish. Using a mean fecundity of 270 eggs per female approximately 127,710 eggs were deposited in Stanley Lake Creek. An estimated 8,940 emigrating fry will be produced (7% egg to fry survival rate) from the 2002 spawning event (Teuscher and Taki 1996) (Table 1-7).

Fishhook Creek

The Fishhook Creek kokanee escapement estimate for 2002 (8,626 fish) was higher than 2001 (5,853) and substantially higher than 2000 escapement numbers (60 fish), the lowest recorded escapement on that creek since monitoring started (Figure 1-23). Escapement timing for 20, 50, and 80% of kokanee entering the creek (Table 1-8) was earlier (approximately 7, 3, and 4 days, respectively) than the 1996-2001 mean. Spawner population estimates were calculated from counts conducted from 6 August to 18 September 2002. Using a 1.7:1 sex ratio and estimated escapement there were approximately 3,195 females spawning in the creek with 897,795 eggs (281 eggs per female) deposited. A 12.3% egg-to-fry survival rate (Teuscher and Taki 1996) will produce an estimated 110,422 emigrating fry in the spring of 2002 (Table 1-7).

Table 1-7. 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	2002	8,626	281	1.7:1	12.3%	110,422
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	2002	99	150	1:1	13.0%	965
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	2002	946	270	1:1	7.0%	8,940
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

Table 1-8. 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), 1996-2001 mean, and 2002.

Creek	**Mean 1992-1995**			**Mean 1996-2001**			**2002**		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Fishhook	21	29	38	25	29	38	18	26	34
Alturas	18	26	33	18	26	33	32	36	42
Stanley	12	18	27	14	20	28	10	15	23

Beach Spawning

Five weekly snorkel surveys were conducted in the littoral zone at sockeye beach and the southeast shore of Redfish Lake beginning in early October. Over the course of observations, 2 residual *O. nerka* were observed at sockeye beach and 3 residual *O. nerka* were seen at the southeast shore (Figure 1-24).

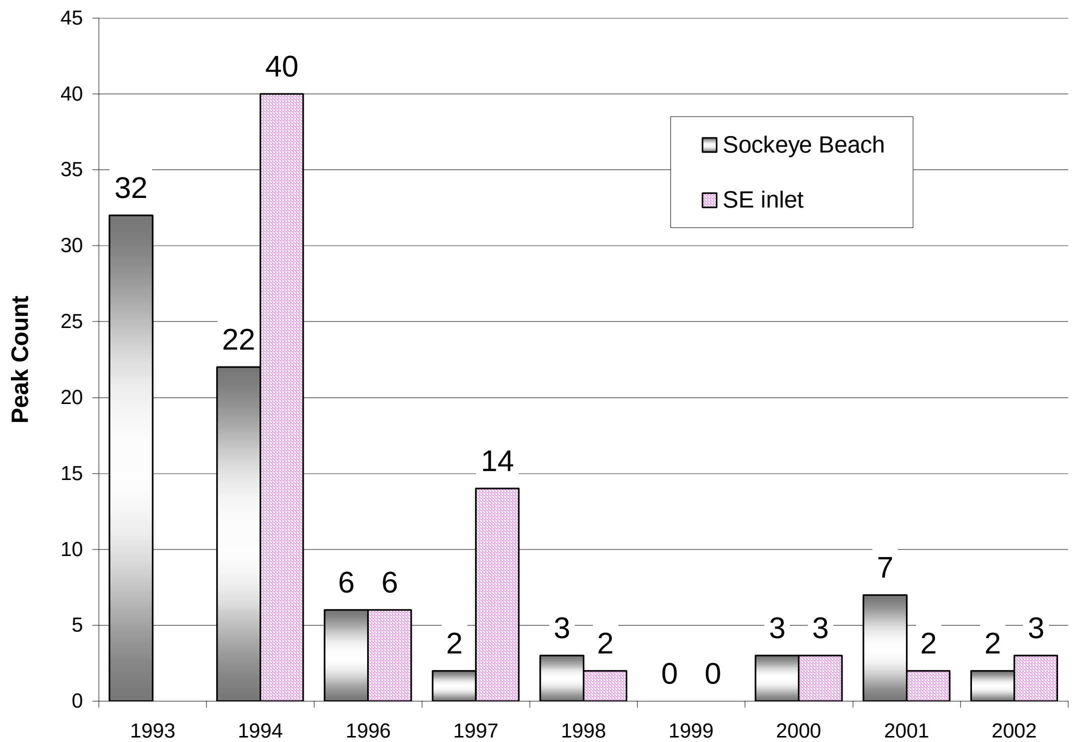

Figure 1-24. Redfish Lake residual *O. nerka* counts from snorkel surveys (1995 data not available).

Target and non-target species observed during snorkeling efforts are presented below in Figure 1-25 and Figure 1-26.

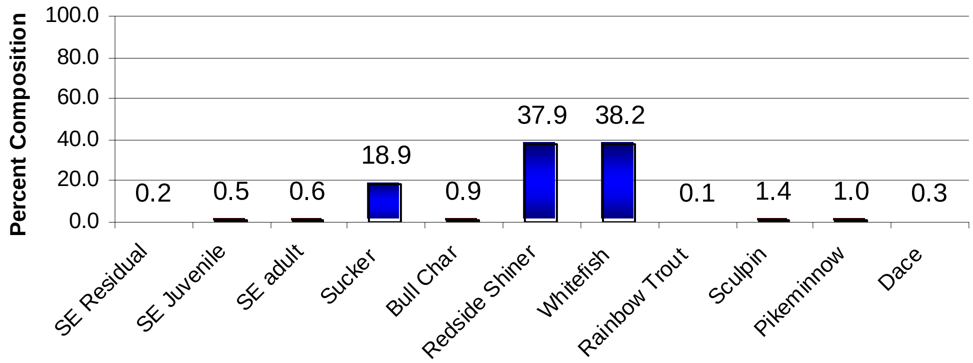

Figure 1-25. Redfish Lake residual snorkel survey species composition data at sockeye beach, 2002.

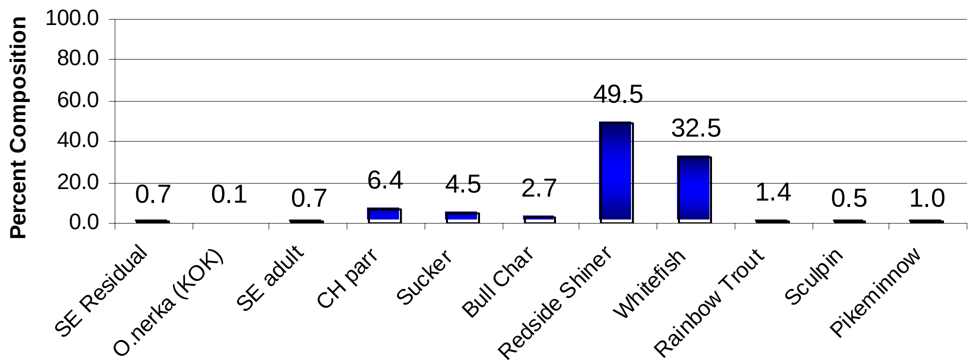

Figure 1-25. Redfish Lake residual snorkel survey species composition data at the SE Inlet, 2002.

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 from both hatcheries 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 (4% over-winter survival for combined Alturas and Pettit lake summer release fish compared to a 45% 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 behavior, release timing, seasonal zooplankton community dynamics, residualization, 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 2001 had variable over-winter growth rates and survival. Consistent with previous findings, Pettit Lake fish released during the fall of 2001 appeared to grow well from the time of release to smolt emigration while Alturas Lake fish appeared to lose weight in the lake environment. This was not surprising. Pettit Lake mean winter (Jan-March) zooplankton biomass was 24.9 *u*g/L, compared to a mean winter zooplankton biomass of 1.4 *u*g/L for the same time period in Alturas Lake. However, over-winter survival rates were considerably higher in Alturas Lake (59%) 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 2003.

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 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 33% of prey items in 2002 (Table 1-6), 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 prey on *O. nerka*. Predation by northern pikeminnow is not currently considered a problem. Ongoing monitoring of 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. Brook char have also been documented in gillnet samples from Pettit Lake. In 2002, no salmonids were found in the stomach contents of brook char.

Stream Spawning

Kokanee escapement in 2002 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. The 2001 spawning population rebounded and was estimated at 5,853 individuals, substantially higher than the 2000 estimate of 60 adult spawners. In 2002, the population was even higher with 8,626 adult spawners estimated in Fishhook Creek. No direct control of kokanee escapement occurred in Fish Hook Creek in 2002. The Alturas Lake Creek kokanee escapement estimate was down from 827 adults in 2000, 145 in 2001, to 99 in 2002, and is well below the 1992-2001 mean of 3,884. The Stanley Lake Creek kokanee spawning population decreased from 5,665 in 2000, 6,180 in 2001, to 946 in 2002, well below the 1993-2001 mean of 1,958. Female kokanee in Fishhook Creek exhibited higher fecundity compared to previous measurements. The mean number of eggs per female in 2002 was 281, 10% higher than the 1991-2001 mean of 252. Stanley Lake Creek kokanee fecundity was estimated to be 270 eggs per female in 2002, up slightly from the 2001 estimate of 257 and similar to the 1994-2001 mean estimate of 265. 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. In 2002, 5 residual spawners were observed. Yearly monitoring will continue to track residual spawner populations at these locations.

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Chapter 2: Limnology of the Sawtooth Valley Lakes, 2002

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METHODS

In 2002, 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, estimates of epilimnetic and metalimnetic chlorophyll *a* 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 the epi- and metalimnions. 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 February, March, May, and October and twice per month from June through September at Redfish and Pettit lakes. Pettit Lake was also sampled in January, but Redfish Lake was not because of unsafe ice conditions. Alturas Lake was sampled once per month in January-March and May-October. Stanley Lake was also sampled once per month from May-October, but was only sampled once during the winter in February. None of the lakes were sampled during November because of early snow accumulation that prevented access to the boat ramps.

Redfish, Pettit, and Alturas lakes were stocked with juvenile sockeye salmon from the Redfish Lake captive broodstock in 2002. Stanley Lake was not stocked with sockeye salmon. Water temperature (^oC), 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 sampled during May 2002 in Alturas and Pettit Lakes and 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.

Temperature (^oC), 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 frozen and 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 Riemann 1978). State of Washington Water Research Center personnel estimated primary productivity four times in each of the four study lakes during 2002. The lakes were sampled on 31 July-3 August, 13-16 August, 10-13 September, and 5-8 October. Primary productivity was evaluated within the photic zone, which was delineated by the depth of the 1% light level. Discrete primary productivity estimates were made at eight depths in Redfish, Pettit, and Alturas lakes and from six depths in Stanley Lake. Discrete primary productivity ($mg\ C \cdot m^{-3} \cdot hr^{-1}$) estimates were plotted and integrated using plainimetry to determine hourly rates of primary productivity based on surface area ($mg\ C \cdot m^{-2} \cdot hr^{-1}$). Hourly productivity estimates were expanded to daily productivity ($mg\ C \cdot m^{-2} \cdot day^{-1}$) using solar irradiance data and the methodology described by Vollenweider (1965) and Britton and Greeson (1987). Hauser and Barber (2002) provide a complete description of methods used to determine primary productivity in 2002. Heterotrophic bacteria and APP were first sampled in September and October of 2000. In 2001 and 2002 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 2002, mean annual discharge of the Salmon River at Salmon, Idaho (USGS gage 13302500) was 38.3 m^3/s, 30% less than the 1913-2002 average of 55.0 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.

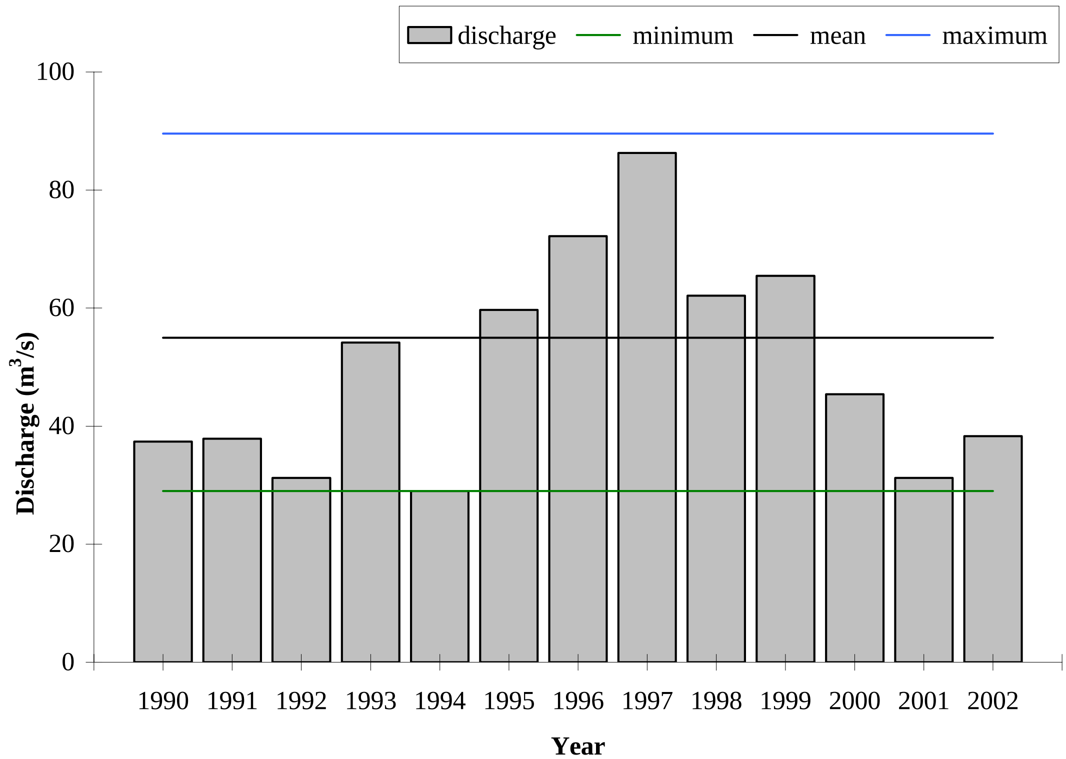


Figure 2-1. Mean annual discharge for the Salmon River at Salmon, Idaho, 1990 through 2002. Minimum, mean, and maximum are for period of record, 1913 to 2002.

Lake Fertilization

Between 2 July and 1 October 2002, 183 kg phosphorus (P) and 5,341 kg nitrogen (N) were added to Redfish Lake to enhance its productivity. Applications were made during a 14 week period. Initial applications were relatively small and during week 5 mechanical problems prevented any additions from being made. Applications gradually increased to a peak during weeks 10 and 11 (September), followed by two smaller additions (Figure 2-2). Areal loading rates were 29.8 mg P/m^2, or the equivalent of an adult escapement of approximately 22,700 sockeye salmon to Redfish Lake. Nutrients were applied at a ratio of approximately 29:1 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.

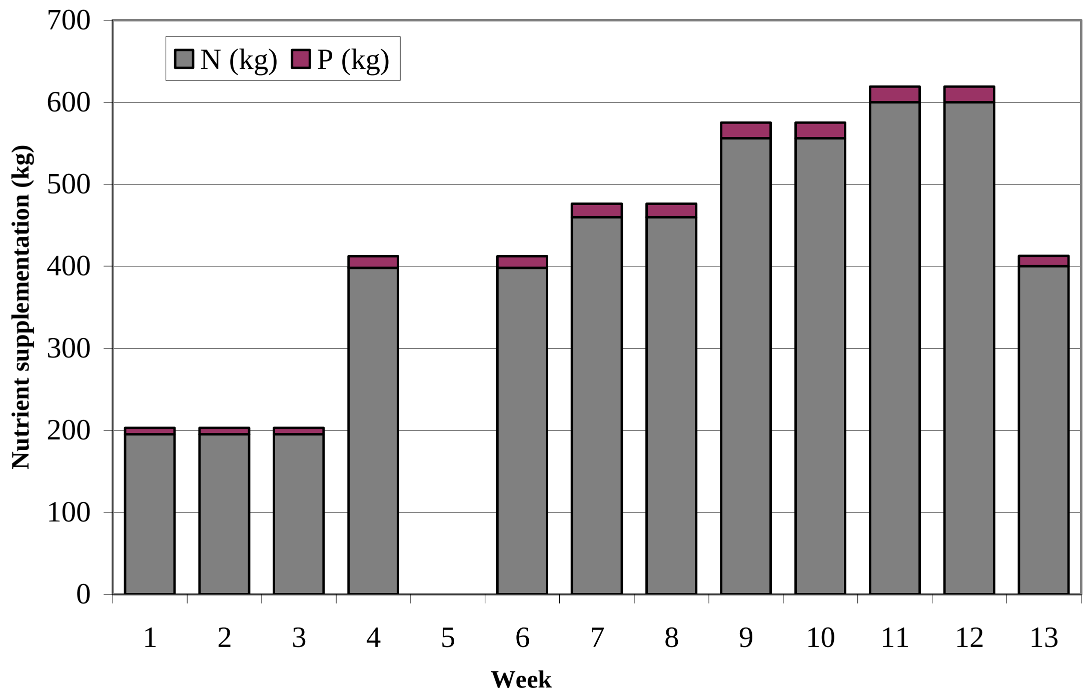


Figure 2-2. Supplemental nutrient applications for Redfish Lake, 2 July-1 October 2002.

Profile Data

The Sawtooth Valley lakes were inversely stratified and ice covered from early January to late April 2002. Thermoclines were well developed from July through October

(Figures 2-3a, 2-3b, 2-3c, and 2-3d). The lakes were not sampled during November because of early snow accumulation in the Sawtooth Valley.

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 May and early September, then in late September oxygen concentrations fell below 5 mg/L in the bottom 2-3 m. Pettit Lake, which is meromictic, had dissolved oxygen concentrations less than 5 mg/L below approximately 30 m (range 26-35 m) depth throughout the summer and early fall. Oxygen concentrations were less than 5 mg/L in the bottom 3 m of Alturas Lake during August and the lower 20 m by October. In Stanley Lake, DO concentrations were >5 mg/L throughout the entire water column during May and June. During the summer, dissolved oxygen concentrations gradually declined in the deep waters and by September the bottom 5 m were hypoxic (< 5mg/L).

Conductivities ranged from approximately 23-27 µS/cm above 30 m depth and 25-48 µS/cm at depths greater than 30 m in Pettit, 26-34 µS/cm in Redfish, 51-59 µS/cm in Alturas, and 40-64 µS/cm in Stanley lakes.

Seasonal mean surface (0-10 m) water temperatures were 14.0, 14.2, 12.3, and 11.6 ^{o}C in Redfish, Pettit, Alturas, and Stanley lakes, respectively (Table 2-2). Seasonal mean surface water temperatures in Redfish and Pettit lakes were similar to those observed during 2000 and 2001, warmer than during the high discharge years of 1995-1999, and cooler than the extremely low water years of 1992 and 1994. Alturas and Stanley lakes exhibited a different pattern. In 2002, seasonal mean surface temperatures were cooler than we predicted based on discharge. Mean temperatures were similar to the high water years of 1995-1999 and cooler than during the low discharge years (1992, 1994, 2000, and 2001). Seasonal mean surface water temperatures in the Sawtooth Valley lakes were negatively correlated with mean annual discharge in the Salmon River at Salmon, Idaho during 1992-2002 ($r = -0.77$, $n=43$).

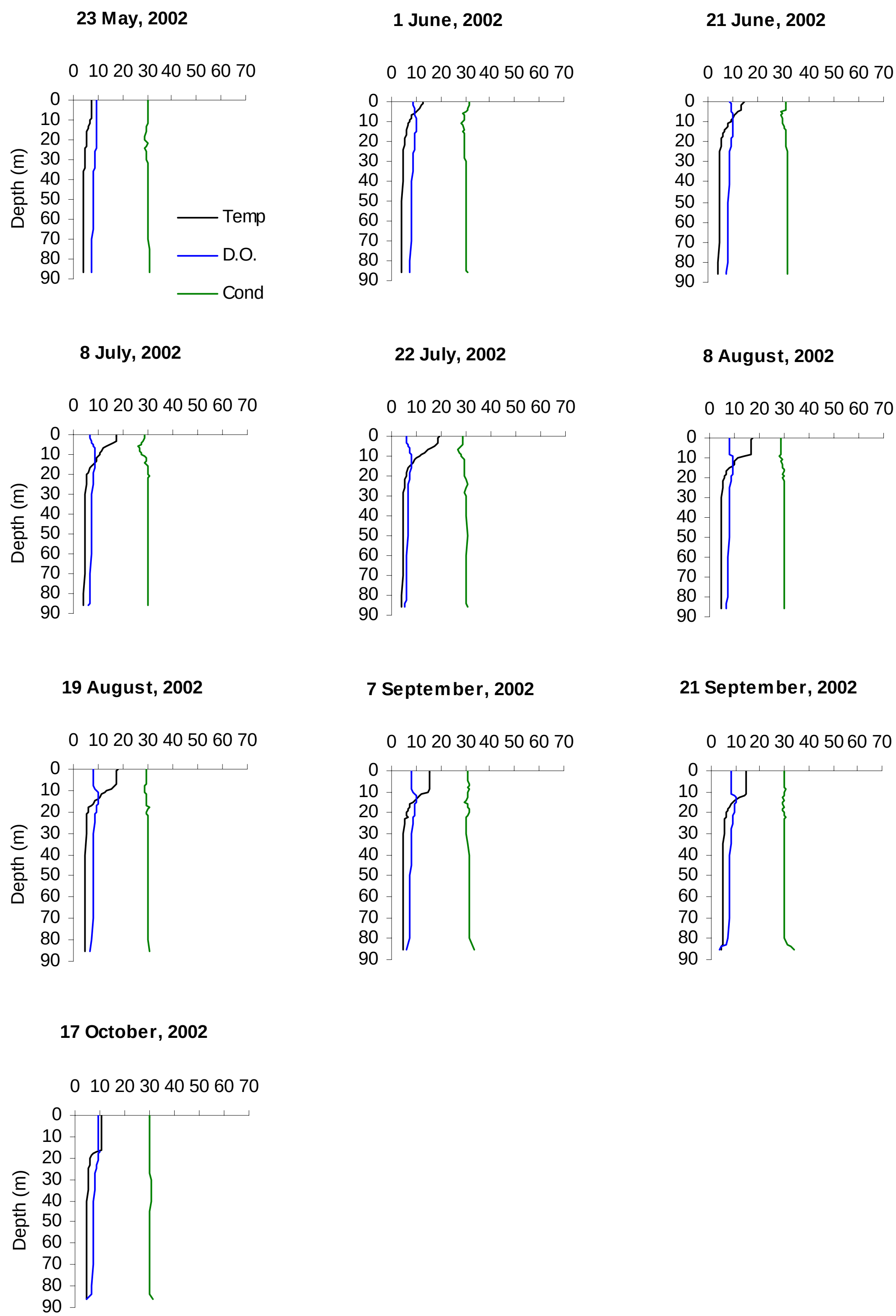


Figure 2-3a. Temperature (^oC), dissolved oxygen (mg/L), and conductivity (μS/cm) profiles for Redfish Lake, May through October 2002.

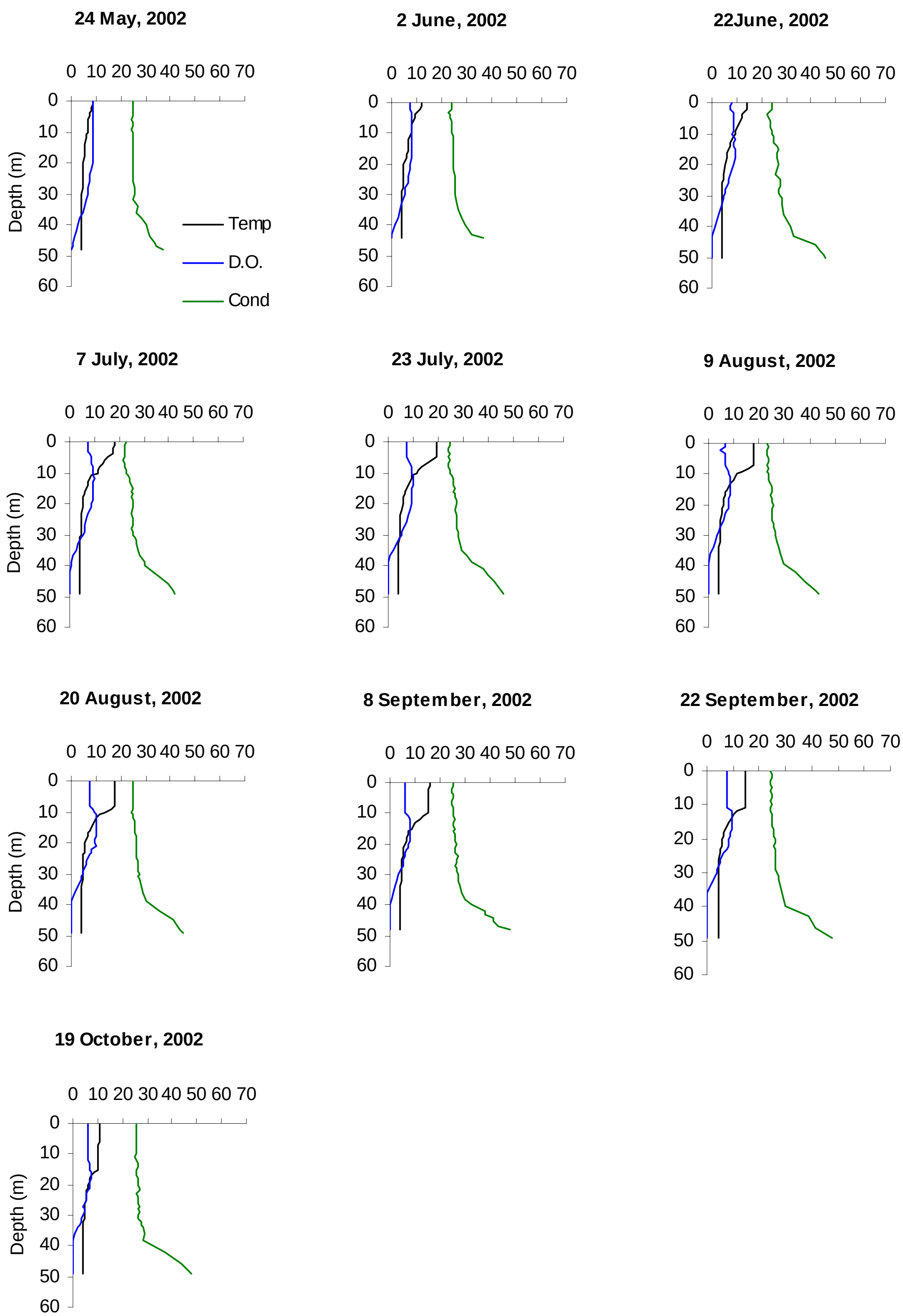


Figure 2-3b. Temperature (°C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles for Pettit Lake, May through October 2002.

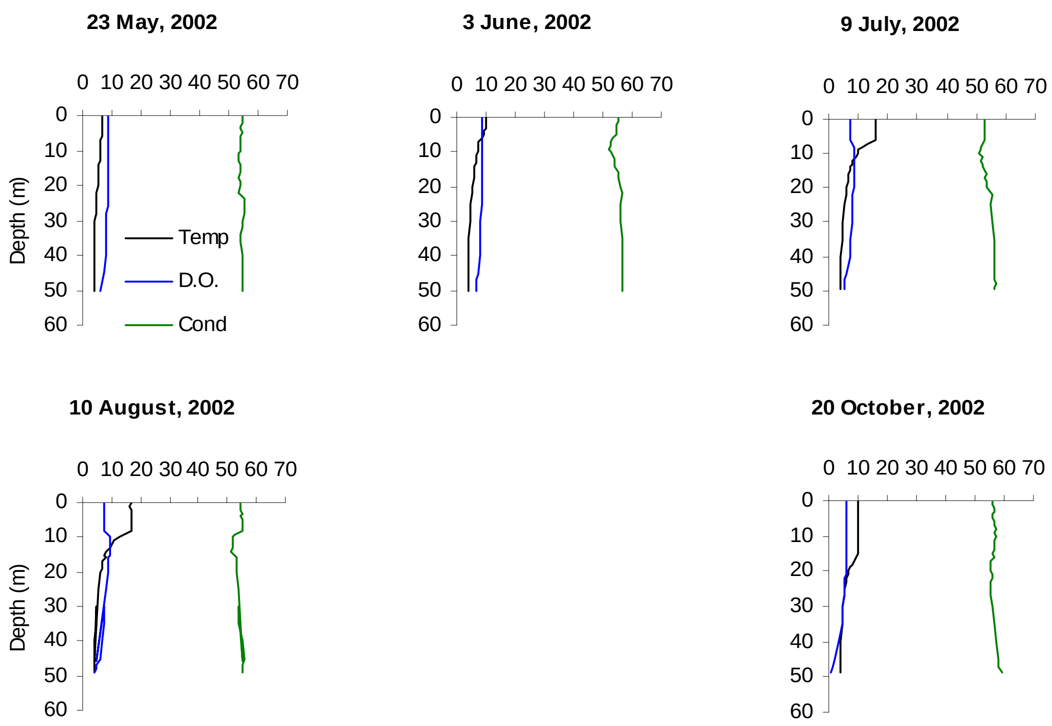


Figure 2-3c. Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (μS/cm) profiles for Alturas Lake, May through October 2002.

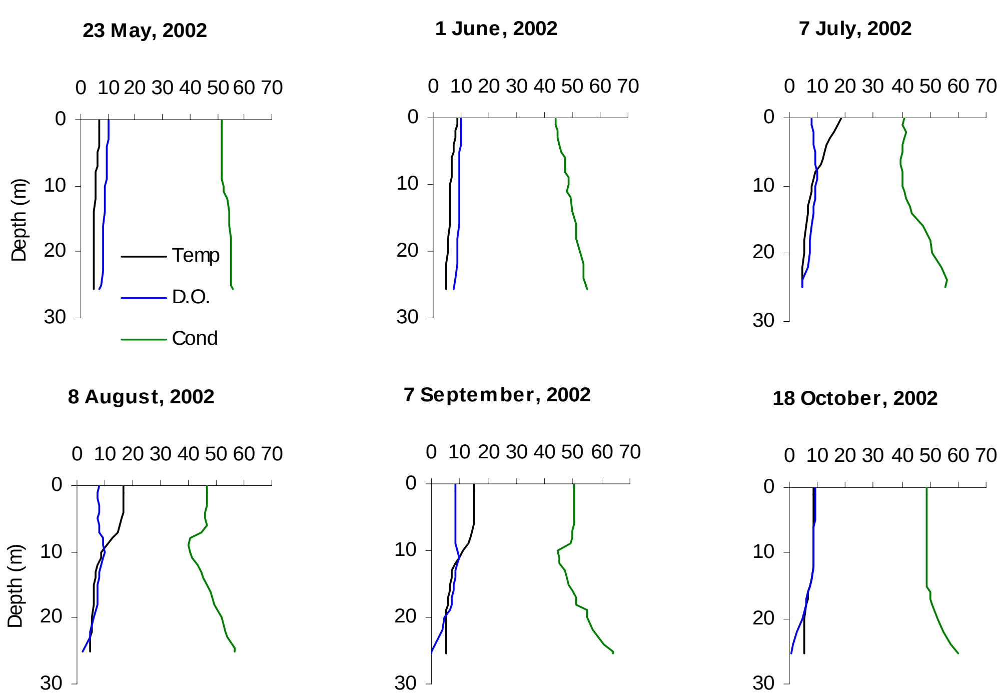


Figure 2-3d. Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (μS/cm) profiles for Stanley Lake, May through October 2002.

Table 2-2. Seasonal mean (June-October) surface water temperature (°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 1992-2002.

Lake	Year	Surface temperature (˚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	12.4
	1995	13.4	12.1	26.2	0.5	13.6
	1996	12.0	14.1	18.5	0.7	9.0
	1997	12.2	11.4	19.7	1.5	9.7
	1998	13.3	12.1	22.1	1.6	11.9
	1999	12.7	14.6	22.5	0.9	8.2
	2000	14.2	17.8	26.1	0.8	22.9
	2001	14.3	14.5	27.4	1.4	23.6
	2002	14.0	13.9	24.5	1.4	21.3
	mean	**13.6**	**14.0**	**25.3**	**0.9**	**13.9**
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	33.9
	1995	13.2	12.4	22.2	0.5	4.5
	1996	12.2	11.8	17.4	0.8	10.8
	1997	12.4	11.3	19.1	1.3	13.2
	1998	13.6	10.6	22.6	1.5	10.9
	1999	12.7	11.2	21.7	1.4	15.6
	2000	14.4	15.0	24.5	1.0	15.4
	2001	14.8	15.7	26.2	0.6	46.9
	2002	14.2	15.5	24.2	0.7	95.8
	mean	**13.8**	**13.6**	**23.7**	**0.8**	**27.0**
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
	2002	12.3	12.5	20.0	0.7	11.0
	mean	**12.9**	**12.3**	**19.5**	**0.9**	**7.2**
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	25.3
	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	29.1
	2001	13.0	8.1	14.8	1.3	28.7
	2002	11.6	7.4	12.6	1.1	28.9
	mean	**12.3**	**7.3**	**13.9**	**1.0**	**25.6**

Secchi depth and compensation depth

Secchi depths were shallow in June then gradually deepened as summer progressed, except in Redfish Lake where we observed dramatic reductions during September, a response to lake fertilization (Figure 2-4). Seasonal mean Secchi depths were near average in Redfish, Alturas, and Stanley lakes and deeper than average in Pettit Lake (Table 2-2).

Compensation depths followed similar seasonal trends as Secchi depths. Compensation depths were shallow 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 late August and September. These reductions corresponded with supplemental nutrient additions and reduced Secchi depth measurements (Figure 2-5). In 2002, mean compensation depths were less than average in Redfish and Stanley lakes and 0.5 m deeper than average in Pettit and Alturas lakes. Light penetration was less than observed during the low discharge years (1992, 1994, and 2001) (Table 2-2). Secchi and compensation depth measurements for the ice-free seasons 1992-2002 were positively correlated ($r = 0.78$, $n=345$).

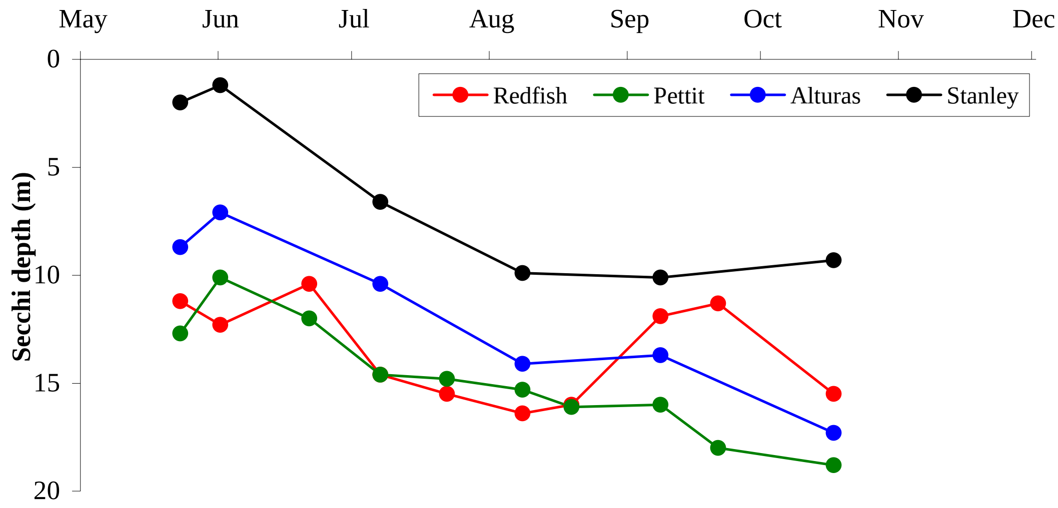


Figure 2-4. Secchi depth (m) for Redfish, Pettit, Alturas, and Stanley lakes, May through October 2002.

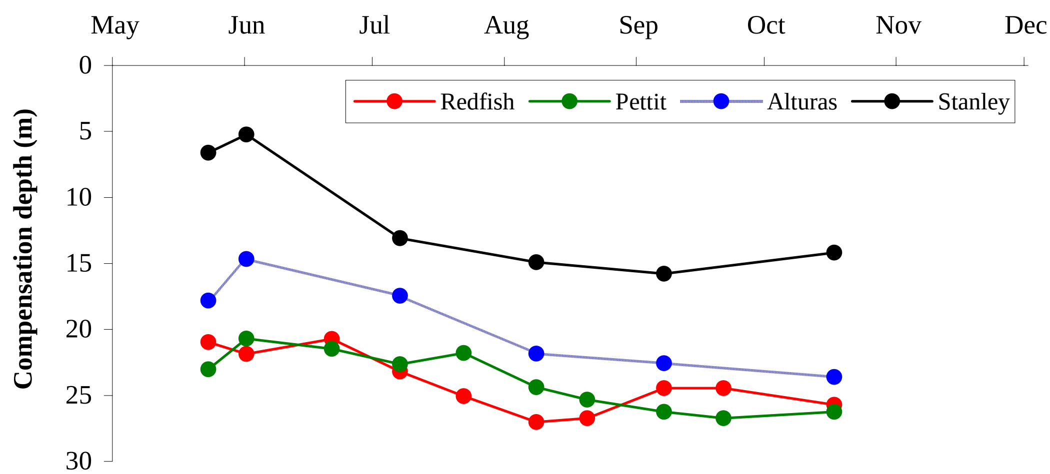


Figure 2-5. Compensation depth (m) defined by the 1% light level for Redfish, Pettit, Alturas, and Stanley lakes, May through October 2002.

Water Chemistry

During spring turnover (May 2002) depth integrated nutrient concentrations remained extremely low, consistent with the oligotrophic condition of the Sawtooth Valley lakes.

TP concentrations were between 4.1 and 8.1 µg/L, TDP was ≤ 5.1 µg/L, and TN concentrations ranged from 115 to 152 µg/L. Nitrate-nitrite concentrations ranged between 1.8 to 11.5 µg/L and TN:TP ratios were approximately 20 in Redfish and Stanley lakes, 25 in Alturas Lake and 35 in Pettit Lake (Table 2-3).

Total nitrogen concentrations in the epilimnions of Redfish and Pettit lakes declined to lows of 47µg/L in Redfish Lake and 60 µg/L in Pettit Lake during July (Figure 2-6). Total nitrogen concentrations then gradually increased during the late summer-early fall, however, the lakes diverged in October when TN increased to 161 µg/L in Pettit Lake and dropped below method detection level (35µg/L) in Redfish Lake. The low October value in Redfish is unusual, particularly since supplemental nutrients were being added at a TN:TP ratio of 30:1 which should result in increased TN concentrations. It is possible that this low value is the result of sampling error. TP concentrations remained fairly low and consistent (Figure 2-6). As a result, TN:TP ratios primarily reflected changes in TN concentrations. TN:TP ratios ranged from 5-27 in Redfish and 8-42 in Pettit Lake. Nitrate-nitrite concentrations were consistently higher in Redfish Lake than in Pettit Lake. This was particularly evident during September, a result consistent with nutrient supplementation efforts. Based on water chemistry it appears that the lakes were nitrogen limited in July ($TN < 60$, $TN:TP \cong 8$, and $TDP > 5$) and P limited during September ($TN > 90$, $TN:TP > 27$, and $TDP < 2$)(Figure 2-7).

Seasonal mean epilimnetic TP concentrations were approximately 5 µg/L and TDP was approximately 3 µg/L in Redfish and Pettit lakes. Mean TN concentrations were 66 µg/L in Redfish Lake and 101µg/L in Pettit Lake, resulting in TN:TP ratios of 14 and 24, respectively. Mean nitrate-nitrite concentrations were similar to long term averages (Table 2-4).

Table 2-3. Nutrient concentrations (µg/L) and TN:TP ratio during late May (after spring mixing) 1992-2002 in Redfish, Pettit, Alturas, and Stanley lakes, Idaho.

Lake	Year	TP	TDP	SRP	TN	NO_2 - NO_3	NH4	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
	2002	5.9	3.1		123.7	11.5		21.9
mean		6.2	2.9	1.0	80.9	12.8	3.1	14.1
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
	2002	4.1	2.3		123.1	3.2		35.0
mean		5.7	2.1	1.0	79.4	7.1	2.9	17.4
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
	2002	4.7	3.9		115.1	1.8		24.8
mean		9.5	3.7	1.7	73.3	7.4	2.6	9.7
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
	2002	8.1	5.1		151.9	5.2		19.8
mean		9.2	3.8	1.1	103.5	9.9	10.6	12.5

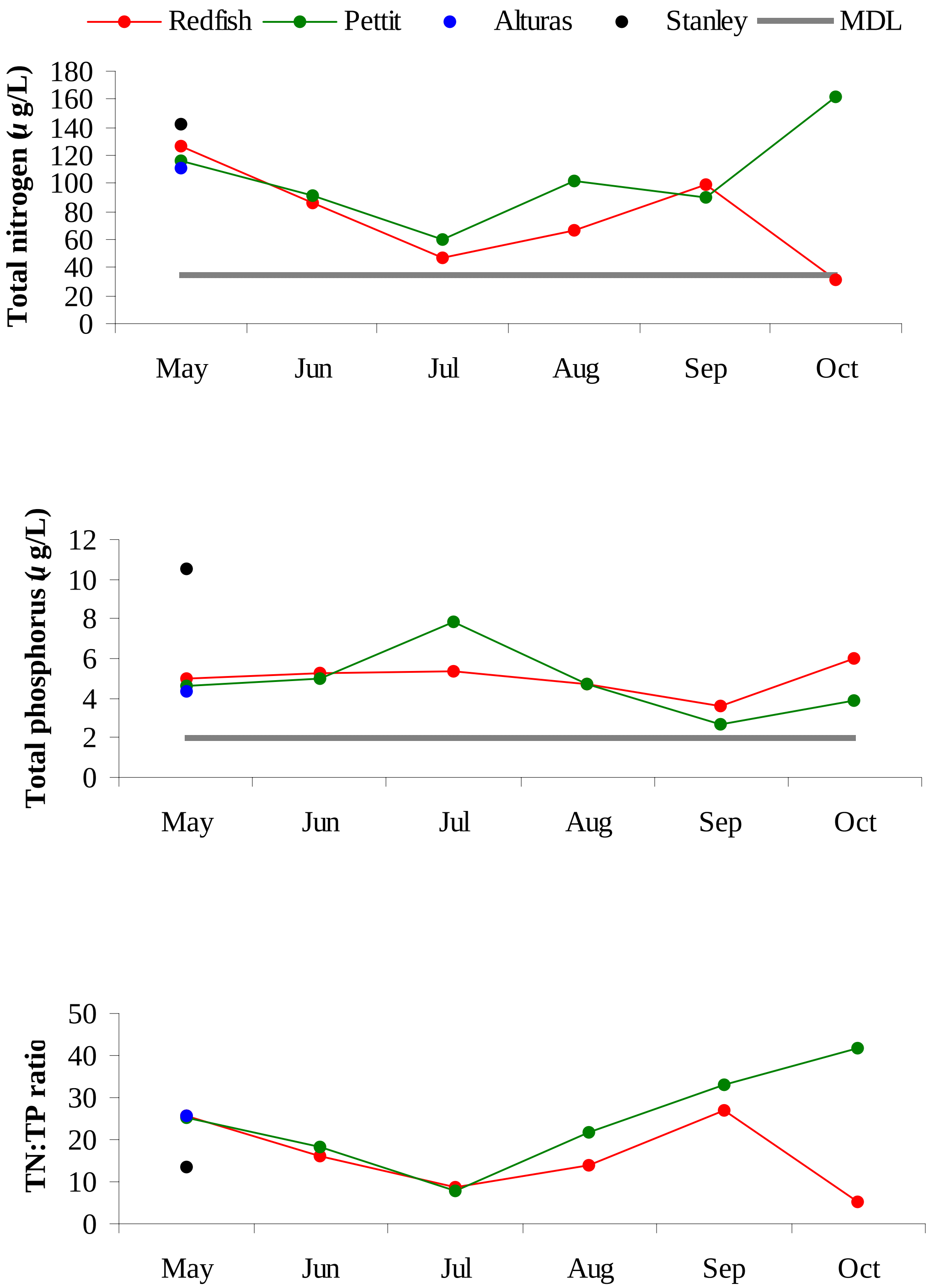


Figure 2-6. Concentrations of total nitrogen, total phosphorus and the TN:TP ratio in the epilimnetic waters of Redfish, Pettit, Alturas, and Stanley lakes during May through October 2002. Grey line denotes method detection levels.

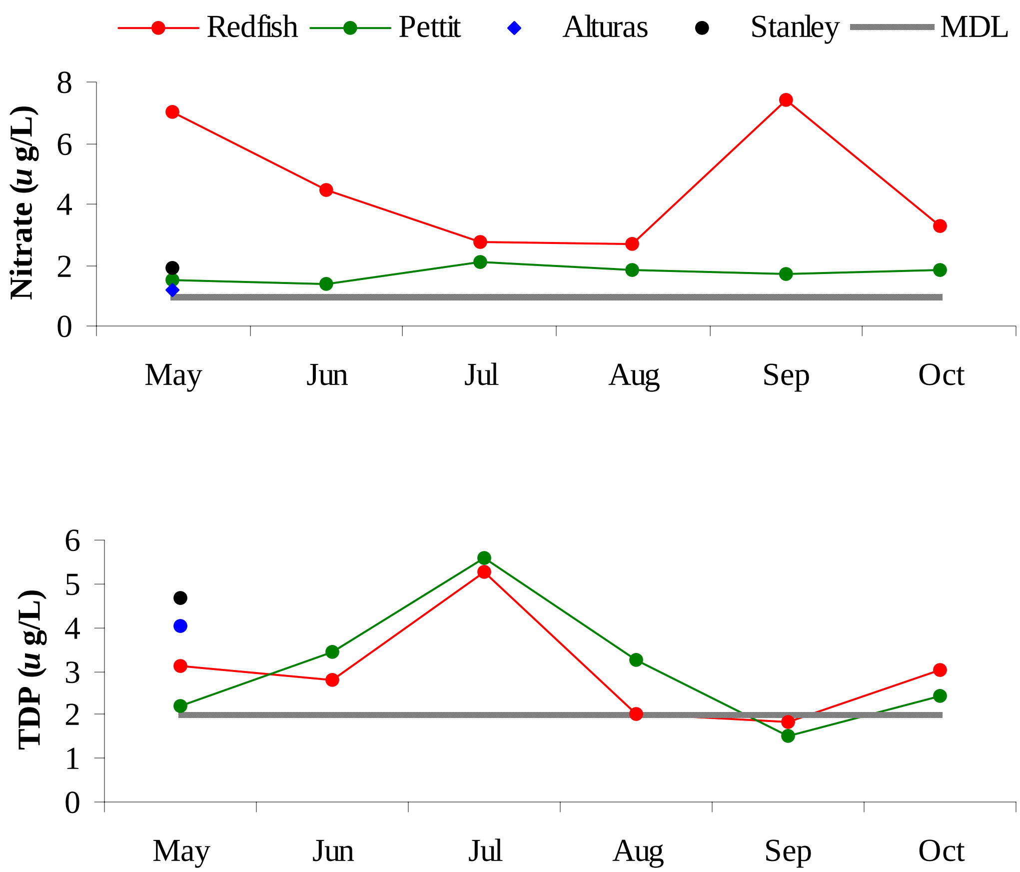


Figure 2-7. Nitrate-nitrite and total dissolved phosphorus concentrations in the epilimnetic waters of Redfish, Pettit, Alturas, and Stanley lakes during May through October 2002. Grey line denotes method detection levels.

Table 2-4. Seasonal mean (June-October) epilimnetic nutrient concentrations (µg/L) and TN:TP ratio in Redfish, Pettit, Alturas, and Stanley lakes during 1992-2002.

Lake	Year	TP	TDP	SRP	TN	$NO_3 + NO_2$	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	-	-0.3	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	3.0	-	69.5	1.8	3.3	13.2
	2001	3.2	2.1	-	108.0	4.6	-	27.2
	2002	5.0	3.0	-	65.8	4.1	-	14.3
	mean	6.4	2.6	1.5	66.8	4.0	4.0	12.9
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	2.7	-	57.5	1.0	2.7	11.2
	2001	3.1	2.0	-	117.6	1.2	-	38.3
	2002	4.8	3.2	-	100.8	1.8	-	24.5
	mean	5.6	2.6	1.3	82.8	1.7	2.8	17.9
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	5.2	-	65.0	2.1	3.9	11.0
	2001	-	-	-	-	-	-	-
	2002	-	-	-	-	-	-	-
	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	-	-0.5	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	3.3	-	66.5	1.3	2.0	10.3
	2001	-	-	-	-	-	-	-
	2002	-	-	-	-	-	-	-
	mean	**7.4**	**3.3**	**1.8**	**75.3**	**2.6**	**5.4**	**11.7**

Chlorophyll *a*

In 2002, surface chlorophyll *a* concentrations ranged from 0.4 to 10.4 μg/L in the four Sawtooth Valley lakes. The maximum concentration of 10.4 μg/L occurred during May in Stanley Lake. This was higher than usually observed in any of the lakes and at the time the lake was noticeably green in color. If we omit this value the next highest surface chlorophyll *a* concentration observed during 2002 was 2.8 μg/L. During March, when the lakes were ice covered, chlorophyll *a* ranged from 1.3 to 2.1 μg/L in Redfish, Pettit, and Alturas lakes. During the ice-free season surface chlorophyll *a* concentrations in the three unfertilized lakes were slightly elevated in May and June, fell to approximately 0.4 to 0.8 μg/L during July and early August, and increased to 0.9 – 1.1 μg/L in October (Figure 2-8). Surface chlorophyll *a* concentrations were consistently higher in Redfish Lake than in the unfertilized lakes, particularly during September and October. In late September, epilimnetic chlorophyll *a* concentration was 2.8 μg/L in Redfish Lake, close to the maximum concentration of 3 μg/L allowed by DEQ during nutrient supplementation.

Seasonal mean surface chlorophyll *a* concentrations ranged from 0.7 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 slightly higher than the long-term average. Seasonal mean chlorophyll *a* concentrations in Pettit and Alturas lakes were relatively low and less than the long-term averages for those lakes (Table 2-2).

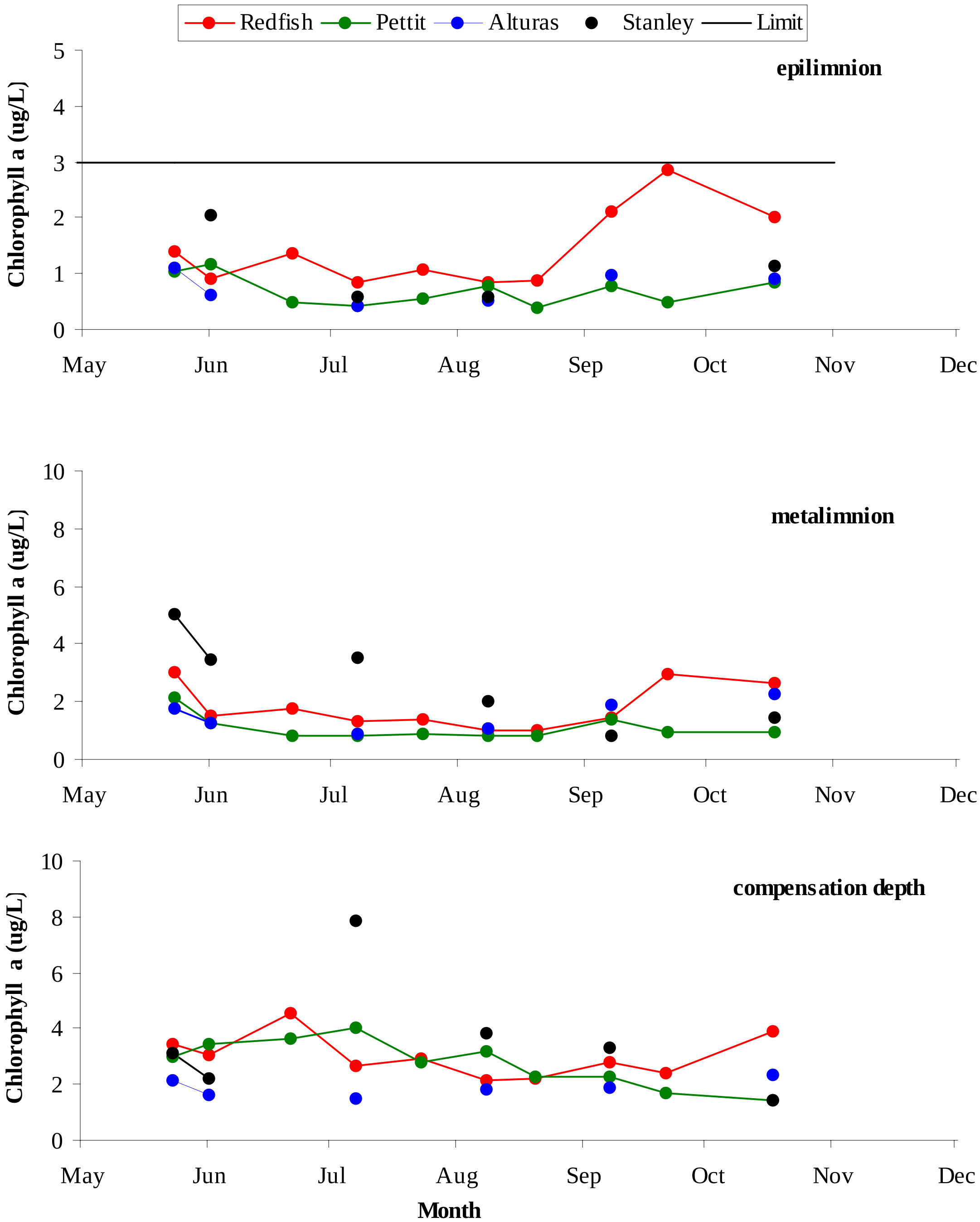


Figure 2-8. Chlorophyll *a* concentrations (µg/L) in the epilimnion, metalimnion and compensation depths in Redfish, Pettit, Alturas, and Stanley lakes, May-October 2002.

Primary Productivity

Primary productivity was exceptionally low in the Sawtooth Valley lakes during July-October 2002. Depth integrated primary productivity ranged from 46 to 146 mg C · m^{-2} ·day^{-1} in the four lakes. Mean daily productivity estimates were approximately 95 mg C · m^{-2} ·day^{-1} in Redfish and Alturas lakes, 82 mg C · m^{-2} ·day^{-1} in Stanley Lake, and 75 mg C · m^{-2} ·day^{-1} in Pettit Lake. Productivity was very low during late July - early August and increased throughout the season in Redfish, Pettit, and Alturas lakes, while Stanley Lake deviated from this trend with low estimates in late August and October (Figure 2-9). Mean annual discharge for the Salmon River at Salmon, Idaho and supplemental P (mg P/m^2) were excellent predictors of mean primary productivity in Redfish Lake ($p<0.05$, $R^2 = 0.89$, n=7) (Figure 2-10). Low primary productivity was a result of low discharge in the upper Salmon River drainage during 2002. Primary productivity was highest in Redfish Lake compared to the other Sawtooth Valley lakes, probably a result of nutrient supplementation.

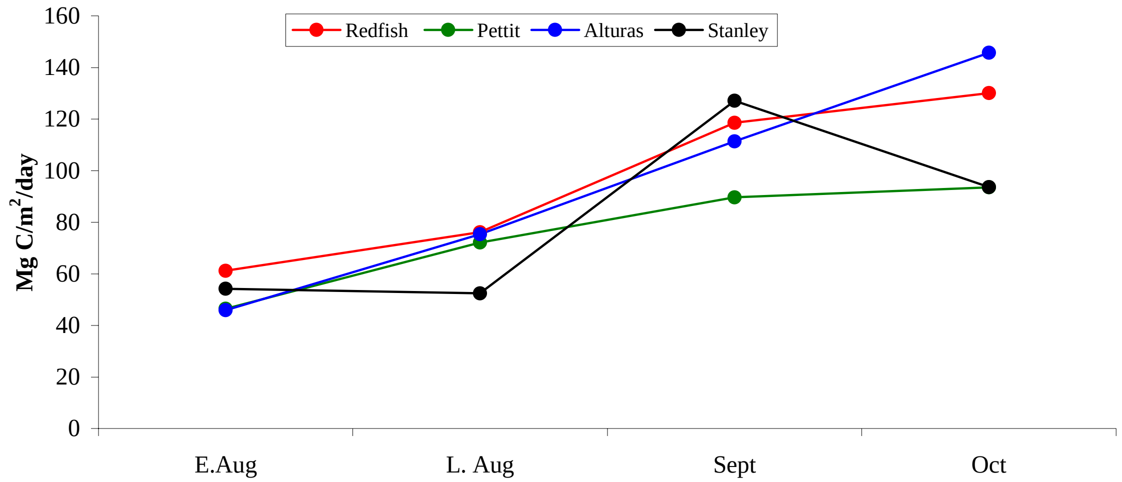


Figure 2-9. Depth integrated daily primary productivity estimates (mg C · m^{-2} ·day^{-1}) in Redfish, Pettit, Alturas, and Stanley lakes, Idaho during 2002.

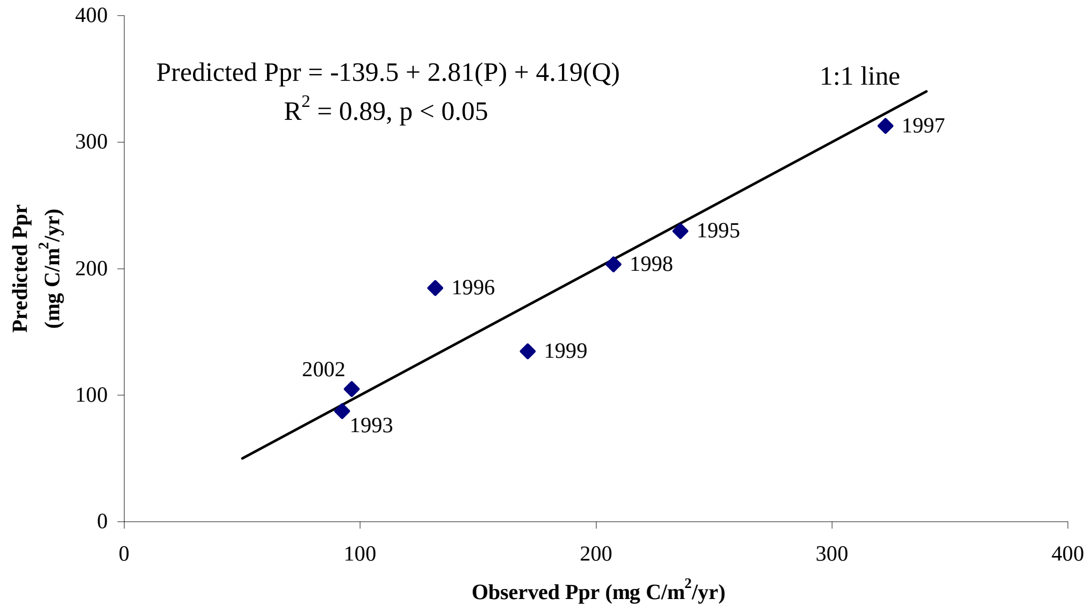


Figure 2-10. Observed and predicted mean depth integrated daily primary production (mg C · m^{-2} ·day^{-1}) in Redfish Lake, Idaho 1993-2002. P equals supplemental phosphorus in mg/m^2, Q equals mean annual discharge for the Salmon River at Salmon Idaho.

Heterotrophic bacteria and autotrophic picoplankton

Heterotrophic bacteria densities in the four Sawtooth Valley lakes ranged from 334,000 to 2,352,000 cells/mL with mean densities between 880,000 and 1,560,000 cells/mL (Table 2-5).

In Redfish Lake, bacteria densities were lowest in spring (prior to the addition of supplemental nutrients) and highest during summer with minor reductions in late September and October, except at the compensation depth where bacteria densities continued to increase (Appendix A-1). During August and September epilimnetic bacterial populations averaged approximately 1,300,000 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 relatively low and stable in 2002. In the epilimnion, APP densities were extremely low during June (<6,000 cells/mL), and then increased to approximately 15,00-20,000 cells/mL for the remainder of the year. APP densities in the metalimnion and at the compensation depth followed the same trend but attained densities of 15,000 – 45,000 cells/mL and 73,000 cells/mL during late September at the compensation depth. This peak corresponds with the relatively high densities of heterotrophic bacteria observed during this time at the compensation depth (Appendix A-1). During September and October 2000 (prior to nutrient supplementation) APP densities were <4,000 cells/mL.

Pettit Lake heterotrophic bacterial populations were higher than in Redfish Lake but showed the same general trend of low spring abundance that increased during the summer (similar to 2001)(Appendix A-2). APP populations were relatively low and stable particularly in the epilimnion where densities were often below 2,000 cells/mL. APP densities at the compensation depth were approximately 30,000 cells/mL during July-September and increased to 69,000 cells/mL in October. In the metalimnion, a similar increase was observed during September and October albeit at a lower level (~30,000 cells/mL).

Heterotrophic bacteria were more abundant in Alturas Lake than in Redfish and Pettit lakes during 2002 (Table 2-5). During June, populations were approximately 800,000 cells/mL. Subsequently, population abundance increased to approximately 1,800,000 cells/mL in the epilimnion in August and remained relatively high (>1,100,000 cells/mL) during September and October (Appendix A-3). APP were relatively low except during August when APP exceeded 30,000 cells/mL in the epilimnion and during August and September when densities were approximately 100,000 cells/mL in the metalimnion and at the compensation depth (Appendix A-3).

Heterotrophic bacteria and APP were relatively abundant in Stanley Lake. Heterotrophic bacteria increased during the summer and peaked during October at densities exceeding 1,500,000 cells/mL. APP peaked during September with densities of 30,000 - 40,000 cells/mL (Appendix A-4).

Table 2-5. 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 2002.

		Heterotrophic bacteria			Autotrophic picoplankton		
Lake	**Strata**	**min**	**mean**	**max**	**min**	**mean**	**max**
Redfish	epilimnion	334,444	932,872	1,306,853	4,276	12,210	19,385
	metalimnion	451,118	890,625	1,240,040	4,704	21,903	41,620
	compensation depth	343,790	907,047	1,539,360	5,131	29,536	72,692
	mean		**910,182**			**21,216**	
Pettit	epilimnion	541,181	1,248,018	2,239,555	570	4,672	23,803
	metalimnion	461,006	1,177,197	2,079,205	998	13,224	37,201
	compensation depth	838,096	1,424,988	2,250,245	4,704	25,263	68,580
	mean		**1,283,401**			**14,386**	
Alturas	epilimnion	796,405	1,299,583	1,834,404	3,706	13,626	32,498
	metalimnion	824,466	1,497,784	2,125,172	6,699	44,934	99,417
	compensation depth	1,245,385	1,876,095	2,351,800	10,405	63,188	121,225
	mean		**1,557,821**			**40,582**	
Stanley	epilimnion	350,632	927,709	1,616,328	4,133	20,439	40,765
	metalimnion	440,428	859,155	1,757,436	1,710	23,318	44,613
	compensation depth	343,862	854,274	1,654,812	1,568	22,036	59,151
	mean		**880,379**			**21,931**	

Phytoplankton

Phytoplankton communities in the Sawtooth Valley lakes continued to be dominated by small grazable taxa during 2002. Total phytoplankton densities ranged from 872-8,779 cells/mL and total phytoplankton bio-volume ranged from 0.11 to 0.89 mm^3/L in the four lakes (Table 2-6) (Appendix B). Generally, Chryso- and Cryptophycean nano-flagellates (*Chrysochromulina* sp. and *Rhodomonas* sp.) and Cyanophytes (*Synechococcus* sp. and *Oscillatoria* sp.) were numerically dominant. Dinophycean dinoflagellates (*Gymnodinium* sp. *and Peridinium* sp.), Chryso- and Cryptophycean nano-flagellates (*Chryptomonas* sp., *Chrysochromulina* sp., *Dinobryon* sp., and *Rhodomonas* sp.), and

Bacillariophytes (*Cyclotella* sp., *Fragilaria* sp., *and Asterionella* sp.) had the highest bio-volume of any phytoplankton taxa. Chlorophyceans were present in low densities/bio-volume and were split between (*Planctonema* sp., *Oocystis* sp., *Staurodesmus* sp., and *Elakatothrix* sp.,). Bio-volume of Cyanophytes was low because of their relatively small size and was comprised of *Synechococcus* sp. and *Oscillatoria* sp.).

Redfish Lake had higher phytoplankton biovolume in the epi- and metalimnions than observed in Pettit Lake during the summer and fall, consistent with chlorophyll *a* data. The difference was primarily a result of higher diatom, nano-flagellate, and *Asterionella* sp. biovolume. Pettit Lake had relatively sparse phytoplankton populations except at the compensation depth during July and August when species diversity was dominated by *Cyclotella* sp., *Fragilaria* sp., *Spondylosium* sp., and *Planctonema* sp. Rotifers and ciliates were common in these samples.

Table 2-6. 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 2002.

		Density			Biovolume		
Lake	**Strata**	**min**	**mean**	**max**	**min**	**mean**	**max**
Redfish	epilimnion	1,531	2,737	4,633	0.250	0.442	0.725
	metalimnion	1,531	3,043	4,764	0.219	0.401	0.685
	compensation depth	2,179	2,895	4,105	0.221	0.333	0.645
	mean		**2,892**			**0.392**	
Pettit	epilimnion	872	1,844	3,700	0.106	0.172	0.309
	metalimnion	1,156	2,205	3,680	0.176	0.238	0.296
	compensation depth	1,480	3,287	5,281	0.296	0.412	0.591
	mean		**2,445**			**0.274**	
Alturas	epilimnion	1,500	2,287	3,325	0.141	0.179	0.208
	metalimnion	1,632	2,516	3,832	0.166	0.193	0.244
	compensation depth	1,683	3,047	4,551	0.249	0.281	0.382
	mean		**2,617**			**0.218**	
Stanley	epilimnion	1,815	3,337	6,407	0.105	0.176	0.250
	metalimnion	1,460	4,158	8,779	0.163	0.387	0.888
	compensation depth	1,237	3,982	7,126	0.153	0.392	0.879
	mean		**3,826**			**0.318**	

Zooplankton

In 2002, Pettit Lake had the highest peak and seasonal mean zooplankton biomass followed by Stanley, Redfish, and Alturas lakes (Figure 2-11). Seasonal mean biomass (June-October) was 95.8 µg/L in Pettit Lake, 28.9 µg/L in Stanley Lake, 21.3 µg/L in Redfish Lake and 11.0 µg/L in Alturas Lake (Table 2-2). Zooplankton biomass peaked during August in Redfish, Alturas, and Pettit lakes and during September in Stanley Lake.

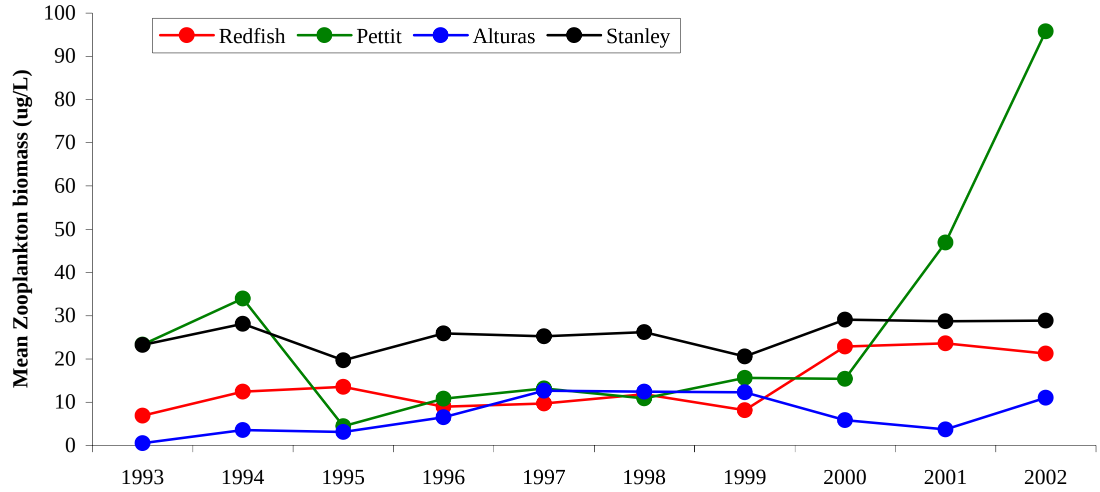


Figure 2-11. Seasonal mean zooplankton biomass (June-October) for the Sawtooth Valley lakes, 1993-2002.

Redfish Lake zooplankton biomass was relatively high in 2002 but slightly lower than 2000 and 2001. *Daphnia* (11.6 µg/L), *Bosmina* (3.3 µg/L), and Cyclopoids (3.1µg/L) dominated summer biomass (Figure 2-12a). Mean length of *Daphnia* was lower than the previous two years (0.89 mm). During February-March 2002, whole-lake zooplankton biomass averaged 4.0 µg/L and was dominated by *Daphnia* and cyclopoids.

Pettit Lake total zooplankton biomass was dramatically higher than previously observed in any of the Sawtooth Valley lakes, representing a complete recovery of zooplankton populations after the collapse observed in 1995 (Figure 2-11). Zooplankton biomass peaked in late August at 174.0 µg/L, coinciding with peaks in *Daphnia* (110.6 µg/L) and cyclopoid copepods (54.8 µg/L) biomass (Figure 2-12b). Mean length of *Daphnia* was high relative to previous years (1.15 mm). During January-March 2002, total zooplankton biomass was 24.9 µg/L and was predominately cyclopoid copepods and nauplii.

In Alturas Lake, mean seasonal total zooplankton biomass was higher than observed during the two previous years (Figure 2-11). Zooplankton populations in Alturas Lake experienced a collapse in the early 1990's, recovered during 1996-1999 and began to decline again in 2000. During the summer of 2002, zooplankton populations consisted predominantly of *Daphnia* and *Bosmina* (Figure 2-12c). Total biomass peaked at 18.0 µg/L in July, primarily because of a peak in *Daphnia* (12.0 µg/L). *Daphnia* were also larger than observed in recent years with a mean length (June-October) of 0.82 mm. Mean zooplankton biomass during January - March was extremely low with a total biomass of 1.4 µg/L representing a mix of nauplii, cyclopoid copepods, and *Bosmina*.

Stanley Lake continues to have relatively stable zooplankton assemblages. Seasonal mean and peak zooplankton biomass were similar to those observed during 2000 and 2001 (Figure 2-11 and Figure 2-12d)). During summer 2002, zooplankton species composition was similar to that observed in 2000 and 2001, with most biomass represented by *Daphnia* and calanoid copepods. Seasonal mean *Daphnia* biomass was 9.7 µg/L and seasonal mean length of *Daphnia* was 0.9 mm. Total zooplankton biomass peaked in early September, a result of the seasonal biomass peaks of *Daphnia*, *Bosmina*, and calanoid copepods.   In February 2002, total biomass was 2.9 µg/L and was predominately nauplii (1.5 µg/L), cyclopoid copepods (0.9 µg/L) and *Daphnia* (0.4µg/L).

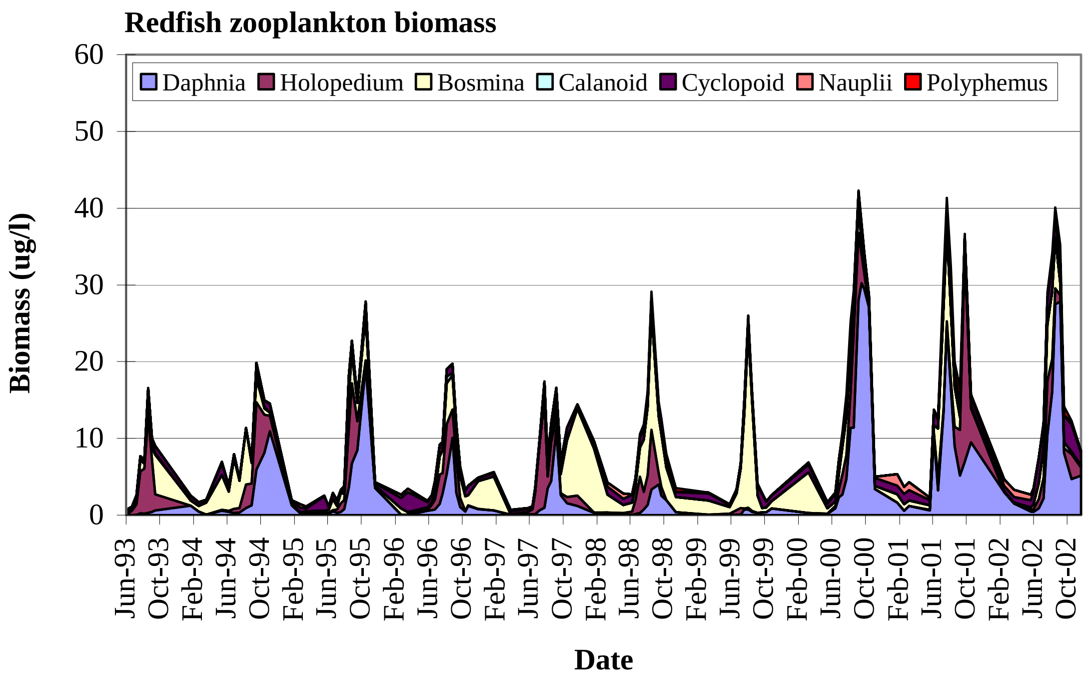


Figure 2-12a. Redfish Lake zooplankton biomass (µg/L) weighted by lake volume, 1993-2002.

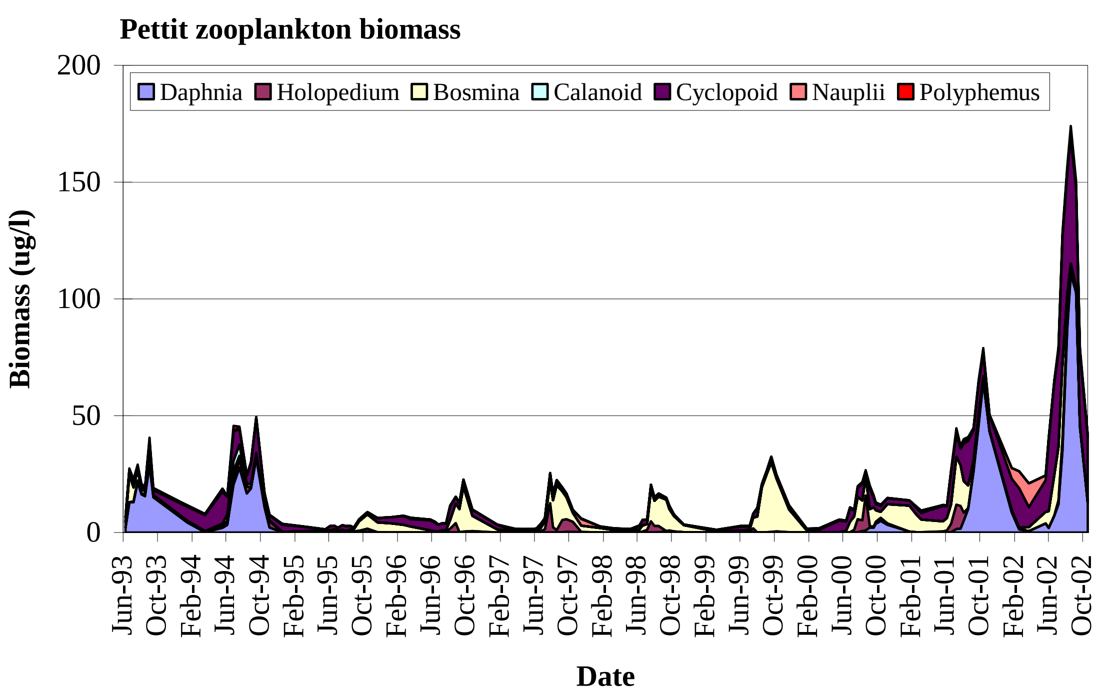


Figure 2-12b. Pettit Lake zooplankton biomass (µg/L) weighted by lake volume, 1993-2002. Note different scale on y-axis.

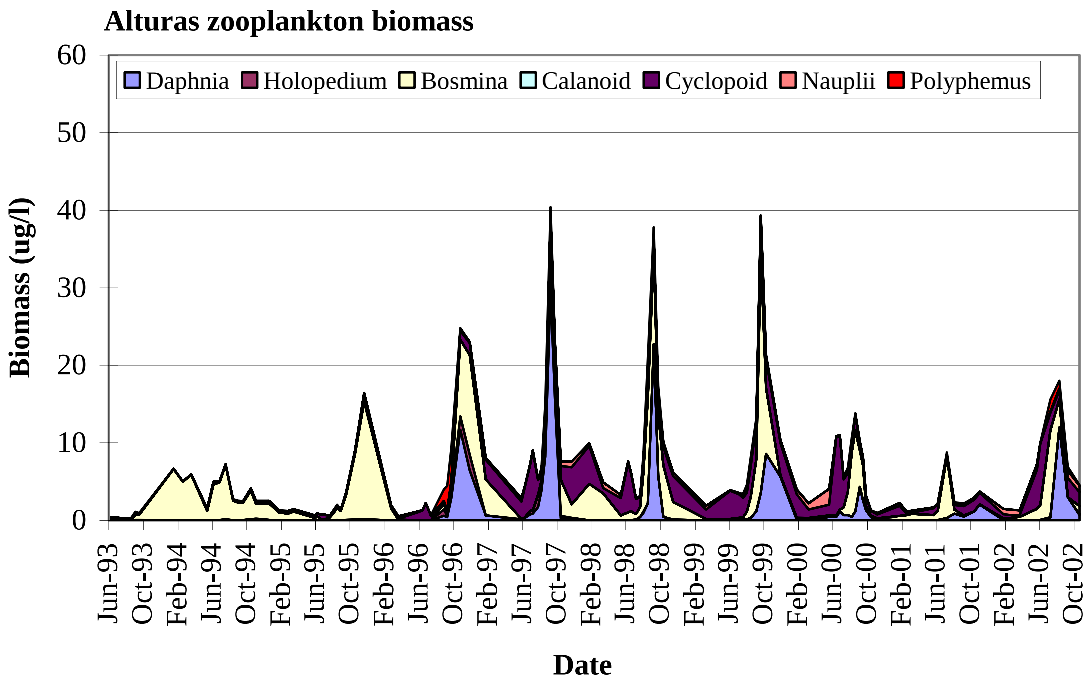


Figure 2-12c. Alturas Lake zooplankton biomass (µg/L) weighted by lake volume, 1993-2002.

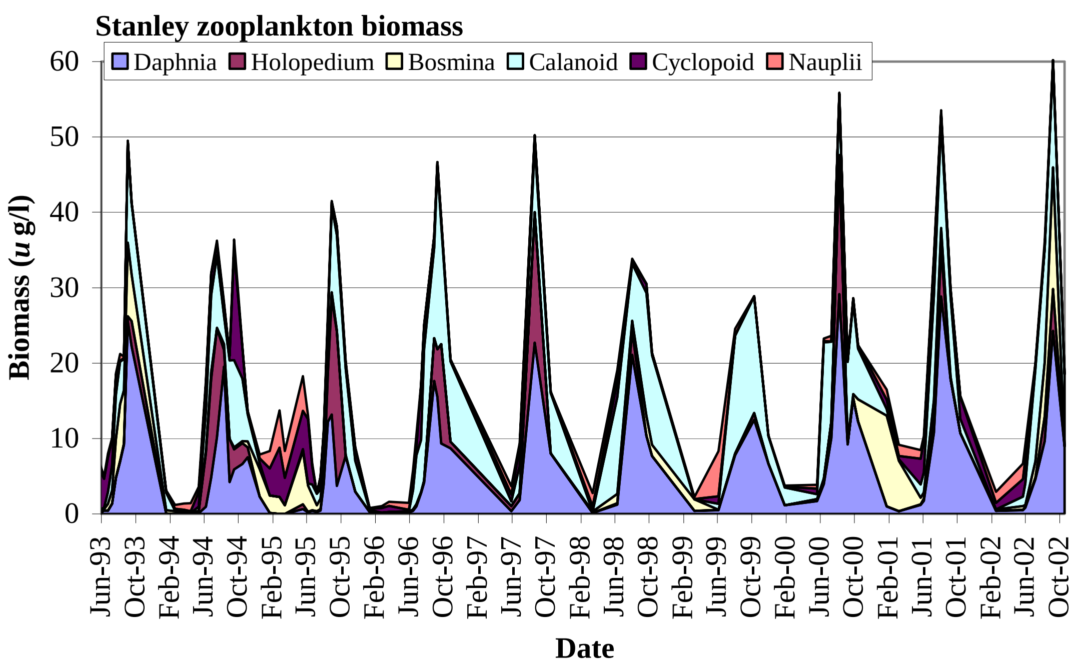


Figure 2-12d. Stanley Lake zooplankton biomass (µg/L) weighted by lake volume, 1993-2002.

DISCUSSION

During 2002, the Sawtooth Valley experienced a third year of drought, resulting in reduced inflows to the Sawtooth Valley lakes. During fertilization, Redfish Lake deviated from the other lakes with moderate reductions in Secchi depth and compensation depth during the later part of the summer. Nutrient concentrations were low in the Sawtooth Valley lakes during 2002, 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 10% above average in Stanley Lake and 56% above average in Redfish Lake, while Pettit and Alturas lakes were slightly below average. Elevated chlorophyll *a* concentrations have been observed during late summer in Redfish during the past two years when nutrients were added to the lake. Chlorophyll *a* concentrations in the metalimnions and at the compensation depths in Redfish and Pettit lakes were similar except for slightly elevated concentrations in Redfish Lake during late September and October, an indication that surface applications of supplemental nutrients increase chlorophyll *a* in the photic zone rather than altering its depth distribution. In other words, there is no evidence that increases in chlorophyll in the epilimnion are offset by reductions of chlorophyll deeper in the photic zone. As expected during a low water year, primary productivity estimates for all the Sawtooth Valley lakes were extremely low. However, primary productivity was highest in Redfish Lake, likely a result of nutrient supplementation.

Heterotrophic bacteria and APP populations were relatively low and stable in Redfish Lake during 2002. Autotrophic picoplankton and heterotrophic bacteria populations dominated phytoplankton communities in the Sawtooth Valley lakes, forming the primary carbon template for linked microbial food webs. 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 that are plentiful in the Sawtooth Valley 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 2001 in Redfish Lake (Stockner and Porter 1988, Stockner 1991, Stockner and Shortreed 1994, Stockner and MacIsaac 1996). During 2002, we did not observe a similar production pulse, however, primary production was high relative to the other study lakes and small grazable phytoplankton, bacteria, and picoplankton continued to dominate the pelagic ecosystem. Explaining the relatively high densities of heterotrophic bacteria in unfertilized Pettit and Alturas lakes during August and September is problematic but may indicate high concentrations of dissolved organic matter (DOM) that may be a by-product of intense zooplankton grazing (Weisse 1990).

Hydroacoustic and trawl based population estimates of *O. nerka* populations in the Sawtooth Valley lakes were not available for 2002, however, previous data have shown large fluctuations in *O. nerka* abundance and biomass that caused abrupt changes in zooplankton biomass and species composition (Figure 2-13)(Kohler et al. 2003). Based on limnology data collected during 2002 (particularly zooplankton population data) it appears that rearing conditions for introduced sockeye salmon were similar to conditions found during 2001 (excellent in Pettit Lake, moderate in Redfish Lake, and poor in Alturas Lake). Over-winter survival estimates of Sawtooth Hatchery sockeye pre-smolts which were stocked during fall 2001 and out-migrated during spring 2002, were 29% in Pettit Lake, 40% in Redfish Lake (IDFG handout – SBTOC meeting summary, 31 July 2002, Pocatello, Idaho), and 59% in Alturas Lake. Over-winter survival estimates of fall released hatchery sockeye salmon were inversely related to zooplankton biomass (Figure 2-14). 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 (Chapter 1, Figures 1-16 and 1-17). Sockeye growth rates were positively related to winter zooplankton biomass (Figure 2-15)

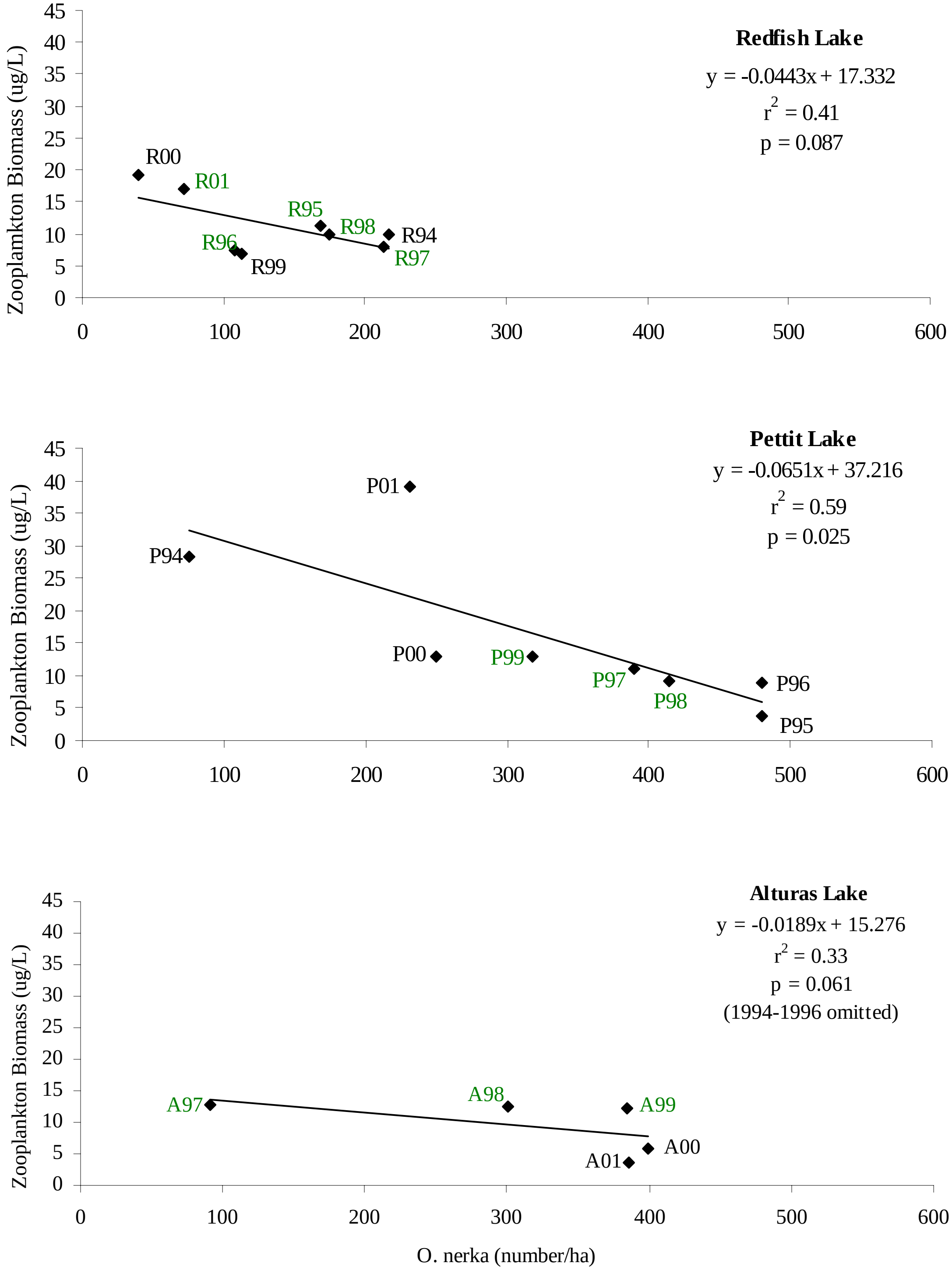


Figure 2-13. Relationships between *O. nerka* density (num/ha) based on September hydroacoustic estimates and seasonal mean zooplankton biomass (µg/L) for Redfish, Pettit, and Alturas lakes, 1994-2001. Data labels indicate lake and year.

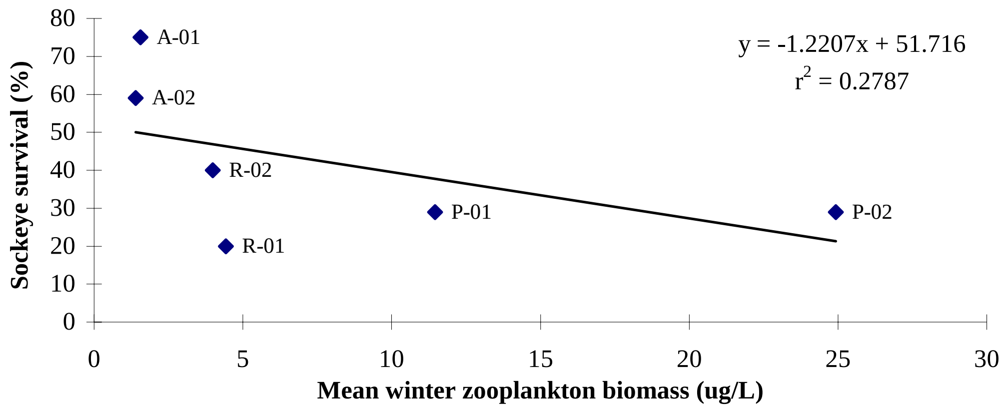
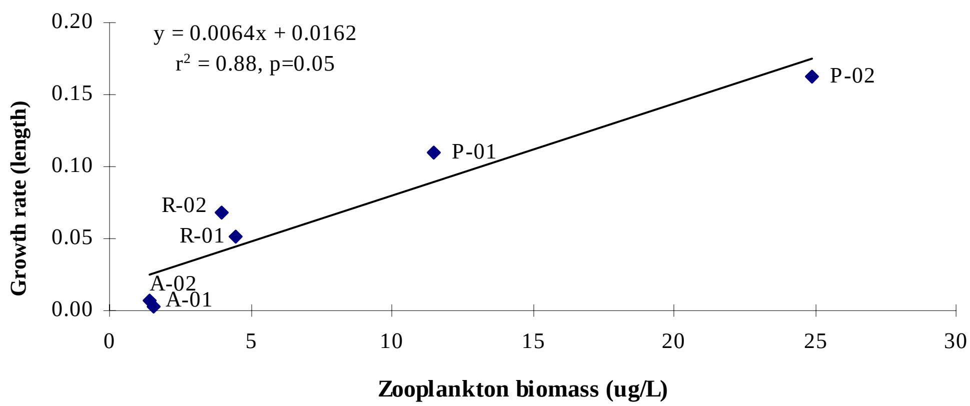


Figure 2-14. Relationship between mean winter zooplankton biomass (µg/L) and over-winter survival of Sawtooth Hatchery reared fall released sockeye salmon pre-smolts. In Redfish, Pettit, and Alturas lakes during winter 2000-2001 and 2001-2002. Data labels indicate lake and year of out-migration.



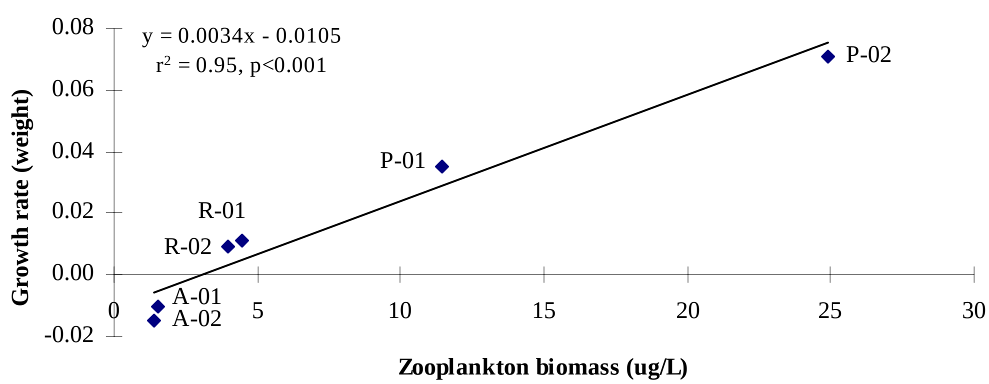


Figure 2-15. Relationship between mean winter zooplankton biomass (µg/L) and growth rates (length and weight) of Sawtooth Hatchery reared fall released sockeye salmon pre-smolts in Redfish, Pettit, and Alturas lakes during winter 2000-2001 and 2001-2002. Data labels indicate lake and year of out-migration.

Habitat surveys conducted by the SBT indicate that spawning and rearing habitat are not currently limiting sockeye recovery. The primary limitation in the freshwater rearing environment is believed to be forage availability. For Snake River sockeye salmon this is predominantly macro-zooplankton. Density dependent effects on zooplankton populations, the primary forage of juvenile sockeye salmon have been documented in many sockeye systems in Alaska and British Columbia (Goodlad et al. 1974, Kyle et al. 1998) and in the Sawtooth Valley lakes. Typically, to ensure adequate growth and survival of juvenile sockeye salmon in freshwater rearing lakes, managers strive to maintain zooplankton population structure with significant components of large bodied cladocerans (Mazumder and Edmundson 2002). In the Sawtooth lakes these are predominantly *Daphnia* spp.

Establishment of non-native landlocked sockeye salmon (kokanee) and reductions of marine-derived nutrients have reduced the sockeye salmon production potential of the Sawtooth Valley lakes. Kokanee are the primary competitor with endangered sockeye salmon in the Sawtooth Valley lakes and these relatively large, dynamic populations have effectively utilized the available forage production. Various techniques have been utilized to increase forage for endangered sockeye salmon in the Sawtooth Valley lakes. The first strategy was to limit kokanee recruitment to Redfish Lake thus making additional "space" for sockeye salmon. During 1992 to 1997, kokanee fry traps were operated near the mouth of Fishhook Creek, the primary kokanee spawning area for Redfish Lake. The traps were used to enumerate migrating fry, determine egg to fry survival and in 1997 to intercept and remove a portion of the migrating fry population.

This technique proved to be extremely labor intensive, the difficulty compounded by limited access because of snow-pack, and high spring flows which required 24 hour/day trap tending. In 1995, an alternative strategy was initiated. A picket weir was installed near the mouth of Fishhook Creek to trap and enumerate the adult kokanee spawning population. During years with relatively high escapement some adults were trapped and removed to limit kokanee recruitment, however, the weir did not always operate as designed and often kokanee were able to pass the weir.

Another strategy was to create additional forage by stimulating primary and thus secondary production through nutrient supplementation. Nutrient loading to the lakes was reduced when sockeye salmon escapements and smolt-to-adult returns declined. Large mesocosm experiments were conducted during 1993 and 1994 in Redfish and Pettit Lakes (Gross 1995, Budy et al. 1998) which lead to a recommendation to add supplemental nutrients to the lakes during years when forage resources were inadequate to support existing kokanee populations and the re-introduced sockeye salmon. Initially, the fertilization prescriptions were determined by water quality issues (primarily water clarity) and restrictions imposed by DEQ. Preliminary results of a nutrient coring study estimated that on average, approximately 30,000 sockeye salmon returned to Redfish Lake each year, prior to European influence (Bruce Finney, University of Alaska Fairbanks, personal communication). Phosphorus contributions from a return of this magnitude would have resulted in phosphorus inputs remarkably close to those applied during nutrient supplementation. Thus, fertilization prescriptions currently are aimed at replacing historic levels of salmon derived nutrients, which coincidentally is near the maximum allowable under the current DEQ consent order. These applications are very light compared to many lake fertilization programs in Alaska and British Columbia (Kyle et al. 1997, Ashley 1999). Effects of these light nutrient applications are difficult to detect. Mid-season reductions in Secchi and compensation depths, elevated nitrate-nitrite concentrations, and corresponding increases in chlorophyll *a* are unambiguous. However, direct benefits to juvenile sockeye salmon are difficult to measure because of meteorological variability, limited opportunity to sample endangered sockeye, and dramatic fluctuations in kokanee salmon population abundance.

A photosynthetic model (Shortreed et al. 1999) is currently used to estimate lake carrying capacities for *O. nerka* with a modification based on empirical data from the Sawtooth Valley lakes aimed at maintaining *Daphnia* biomass. Inputs of seasonal carbon production estimates to the model generate optimal adult escapement goals and juvenile sockeye salmon rearing capacities in number/ha and Kg/ha. During 1993-2002 the Pr model estimated carrying capacities for the combined lakes was 1026 fish/ha (10.3 kg/ha) without fertilization and 1800 fish/ha (18.0 kg/ha) during fertilization. Annual estimates of *O. nerka* population abundance and lake carrying capacities were used to determined percent of carrying capacity, which we regressed against seasonal mean *Daphnia* biomass (Figure 2-16). Based on this relationship it appears that the Sawtooth Lakes can only support approximately 25 percent of the *O. nerka* density/biomass predicted by the Pr model, if *Daphnia* are to persist. If we apply this correction, *O. nerka* carrying capacity estimates for the Sawtooth lakes average 256 fish/ha (2.6 kg/ha) during unfertilized years and 450 fish/ha (4.5 kg/ha) during fertilization. Further work needs to be conducted that will allow modification of the model based on sockeye salmon performance measures such as size at out-migration, survival to lower Snake/Columbia River dams, and smolt to adult survival.

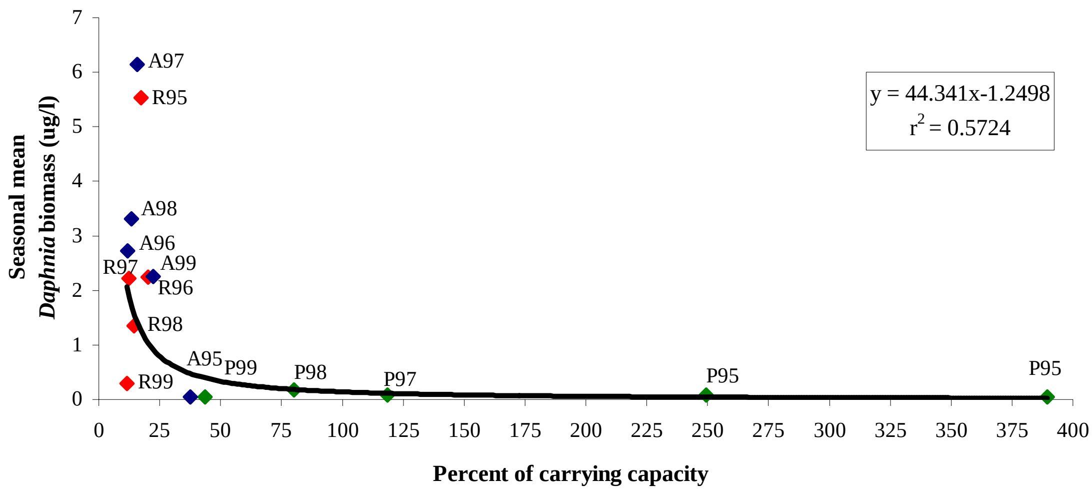


Figure 2-16. Relationship between percent carrying capacity (percent carrying capacity = *O. nerka* biomass/*O. nerka* carrying capacity) and seasonal mean *Daphnia* biomass during 1995-1999. Data labels designate lake and year (R=Redfish Lake, P=Pettit Lake and A=Alturas Lake).

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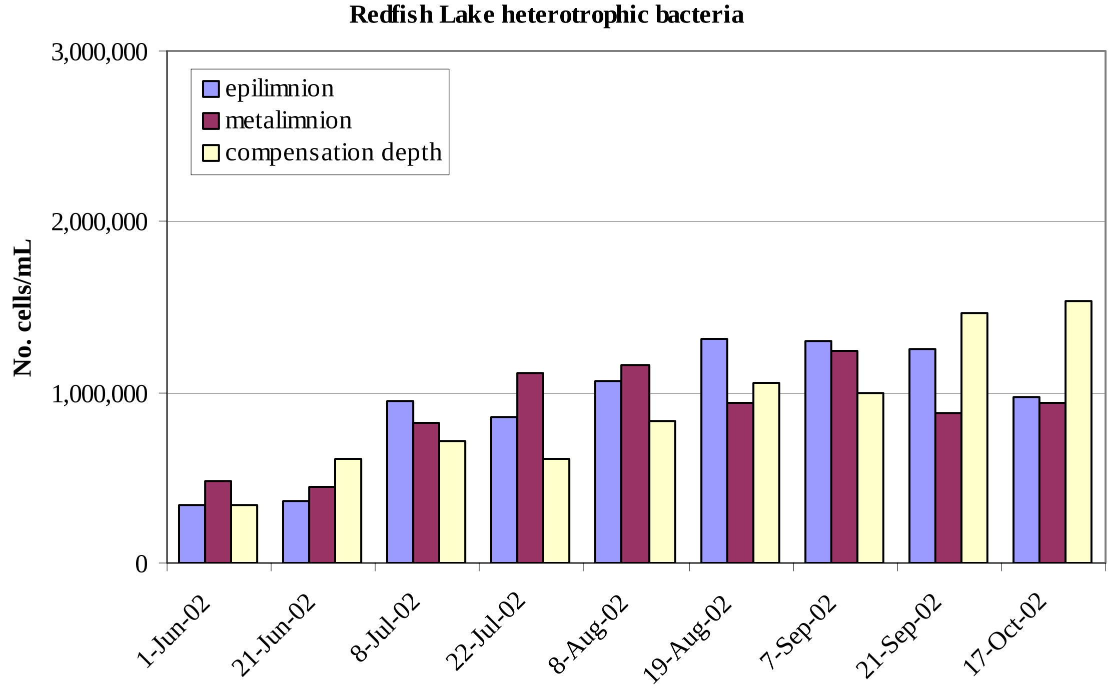
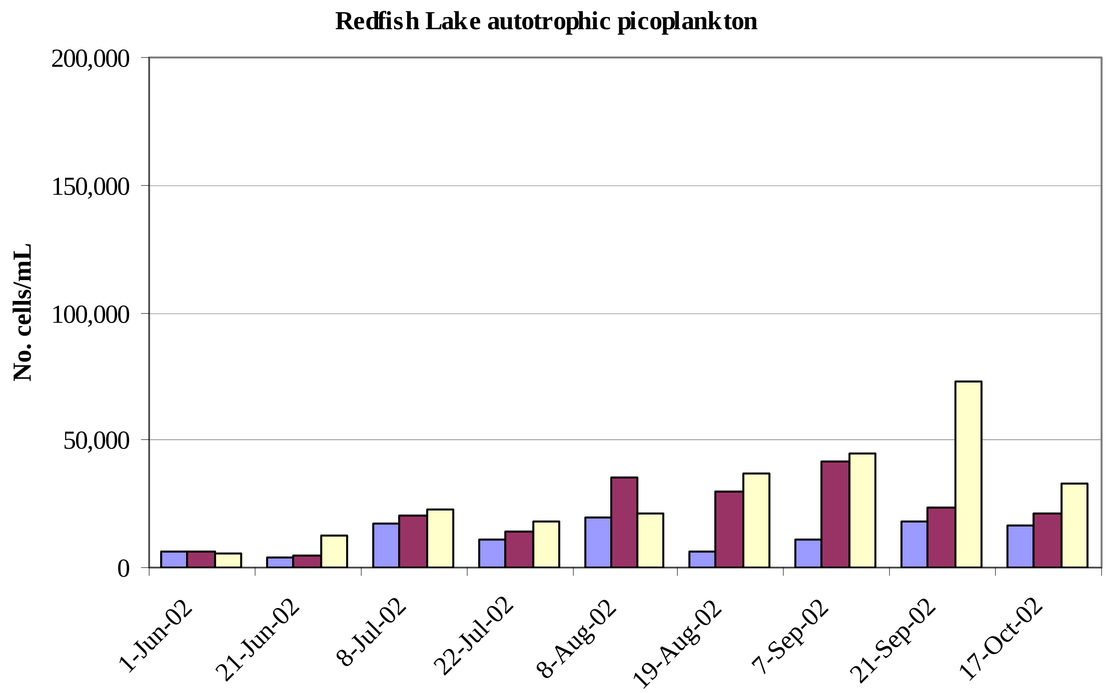
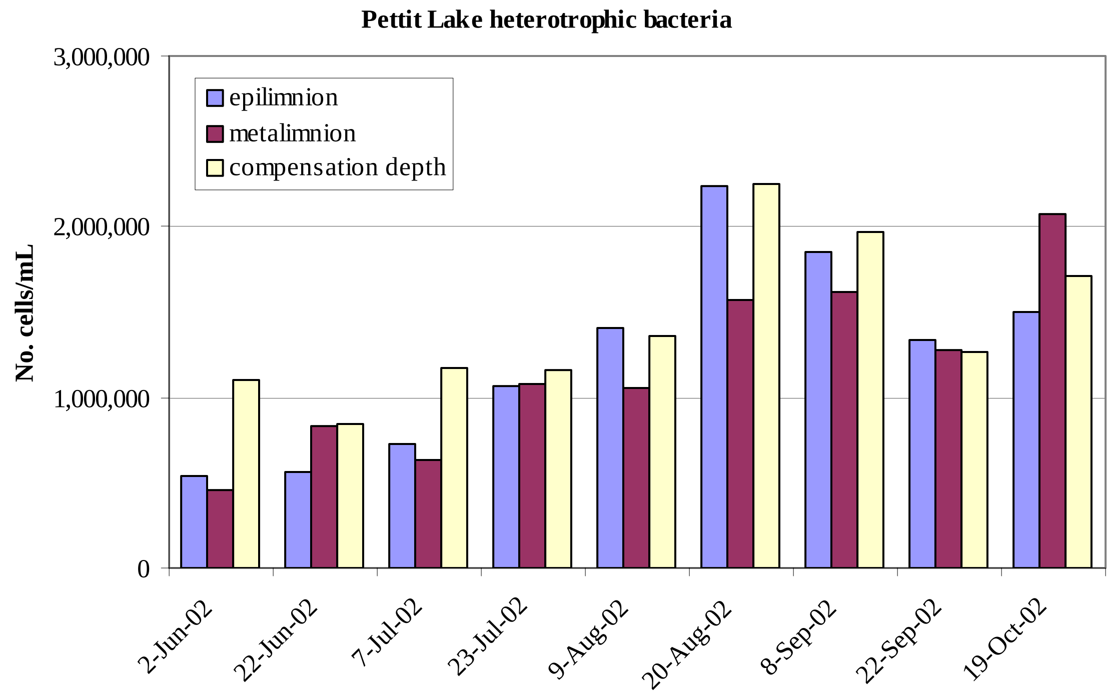
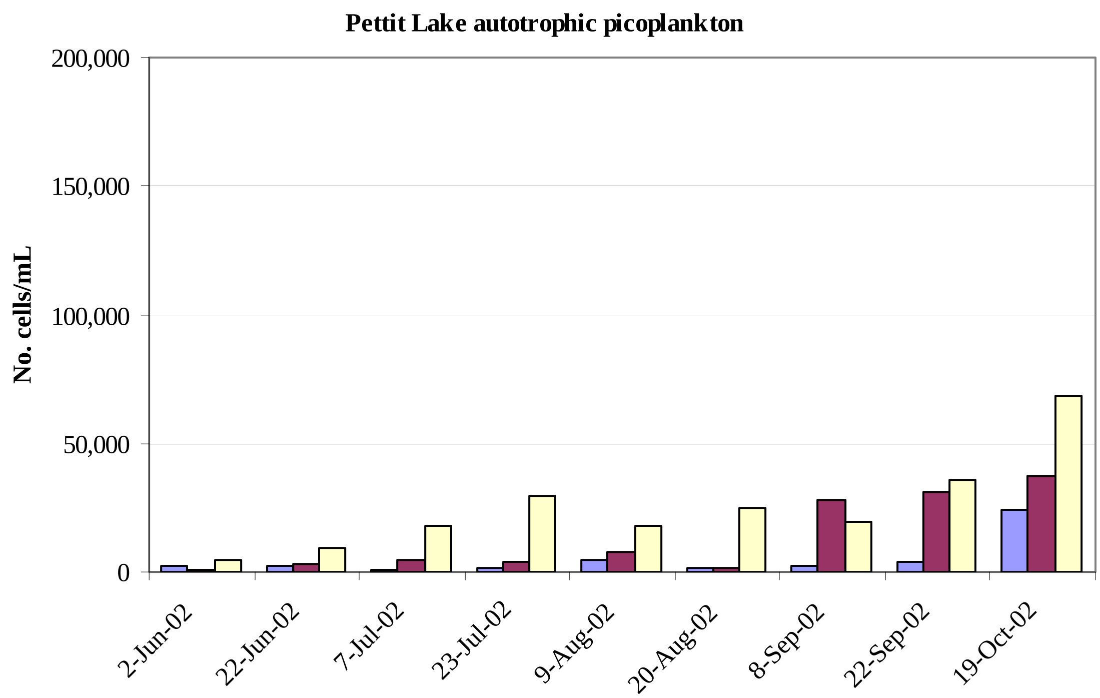
APPENDIX A. Heterotrophic bacteria and autotrophic picoplankton densities



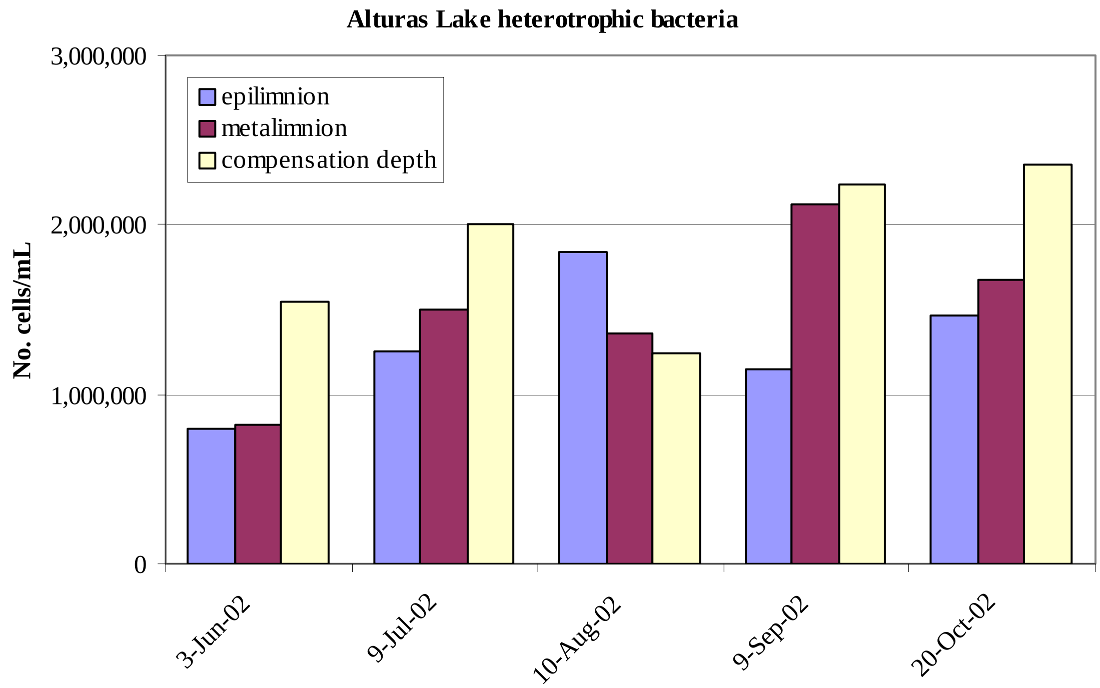


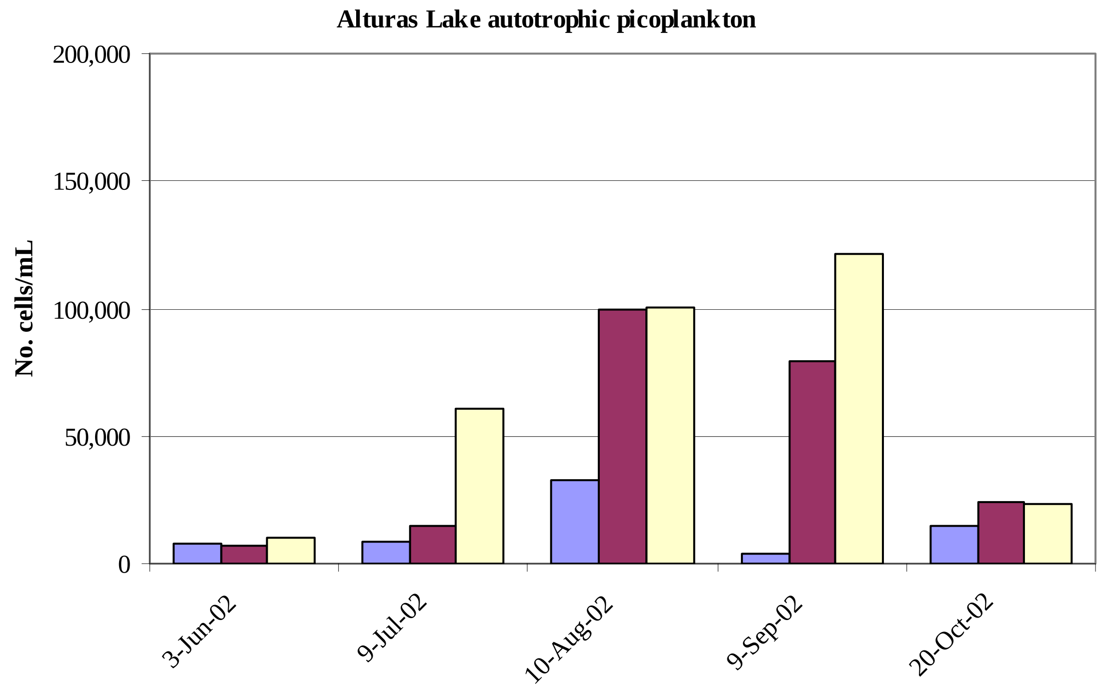
Appendix A-1. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Redfish Lake, June through October 2002.



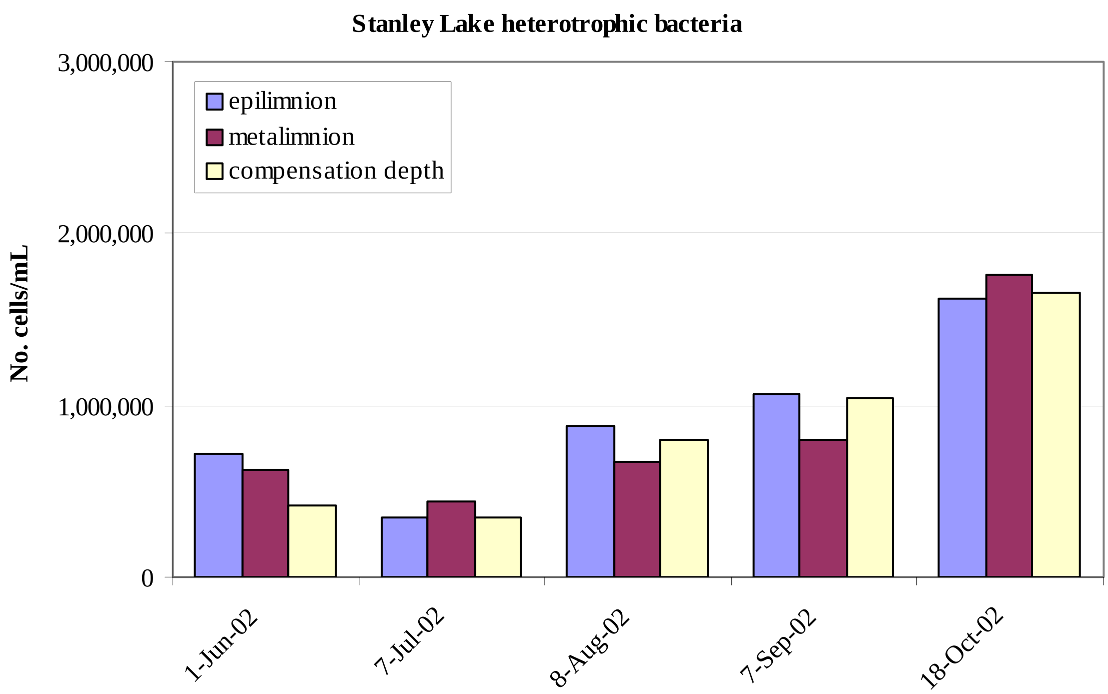


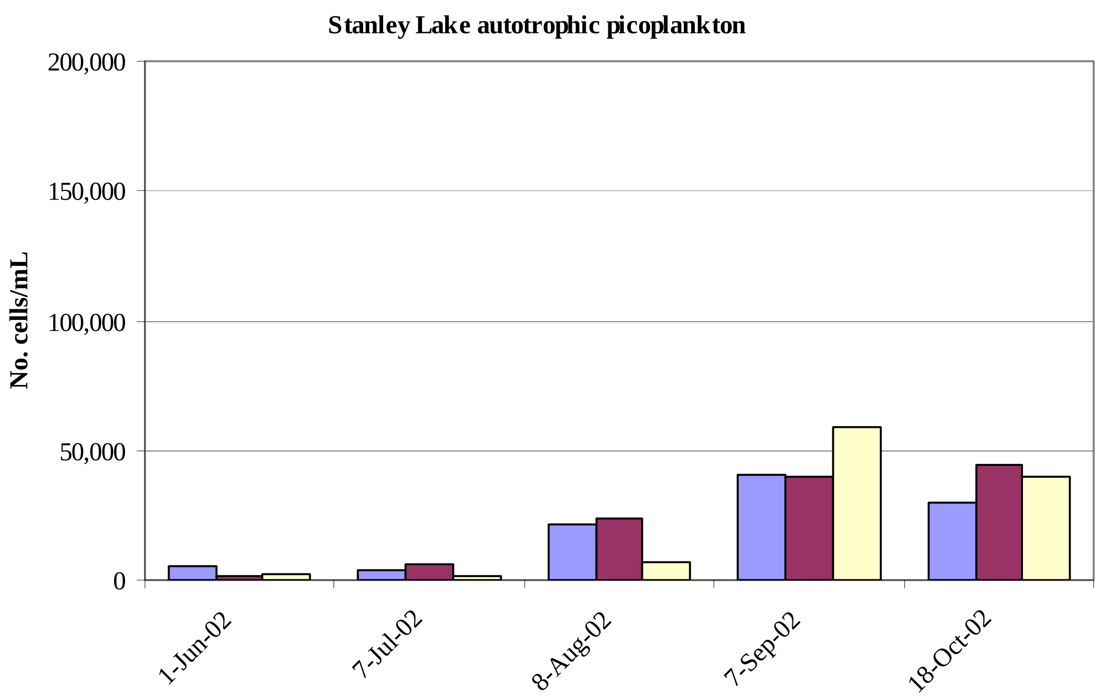
Appendix A-2. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Pettit Lake, June through October 2002.





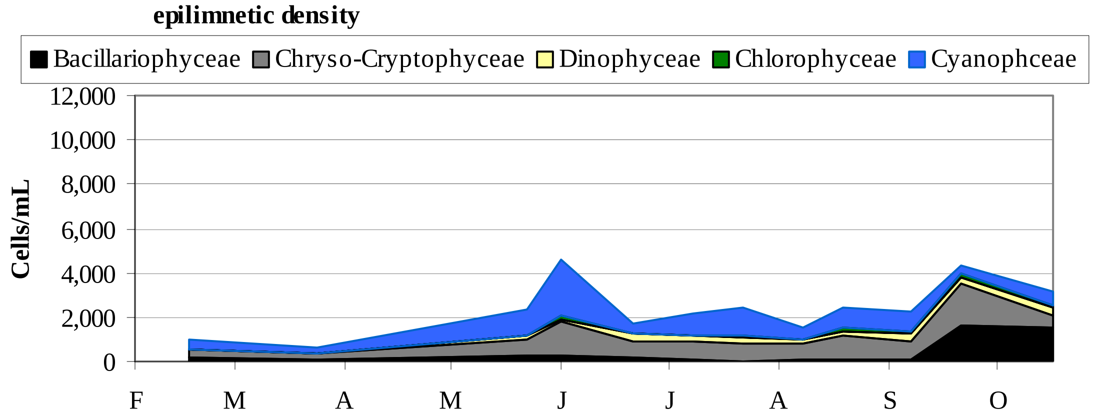
Appendix A-3. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Alturas Lake, June through October 2002.

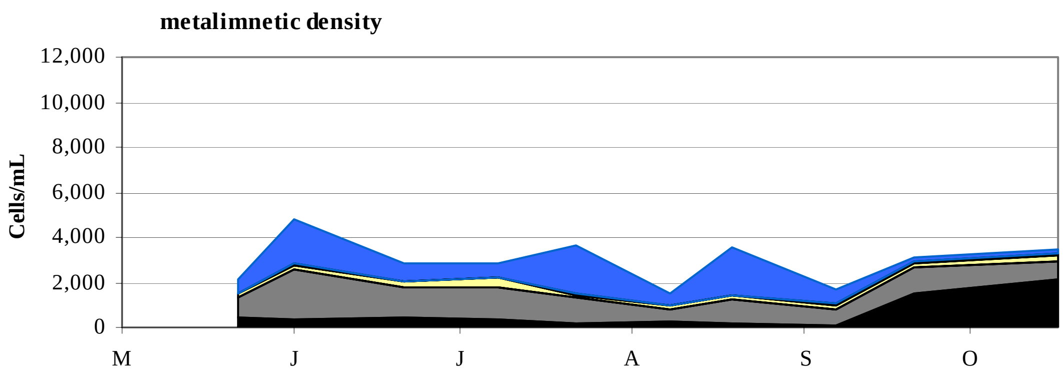


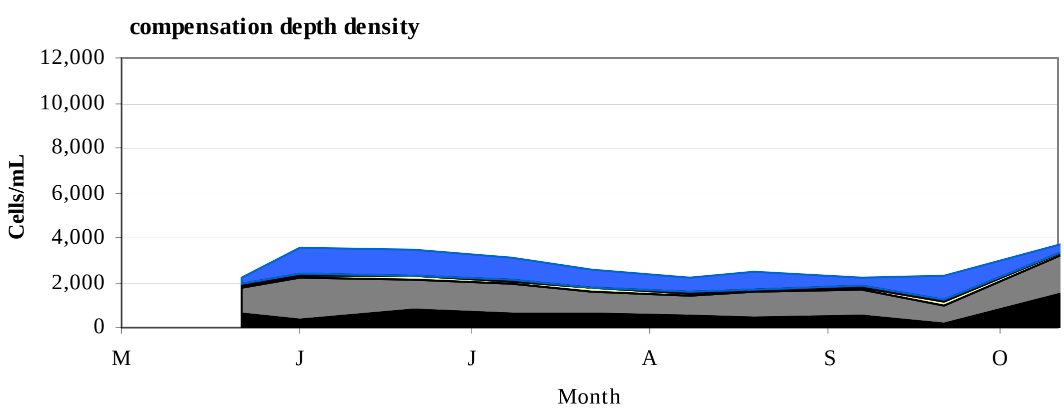


Appendix A-4. Heterotrophic bacteria and autotrophic picoplankton (APP) densities (cells/mL) in the epilimnion, metalimnion and at the compensation depth in Stanley Lake, June through October 2002.

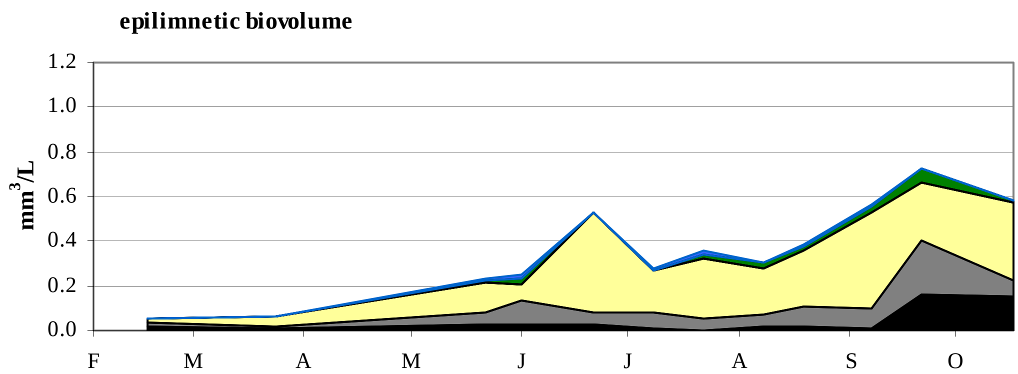
APPENDIX B. Phytoplankton densities and biovolumes

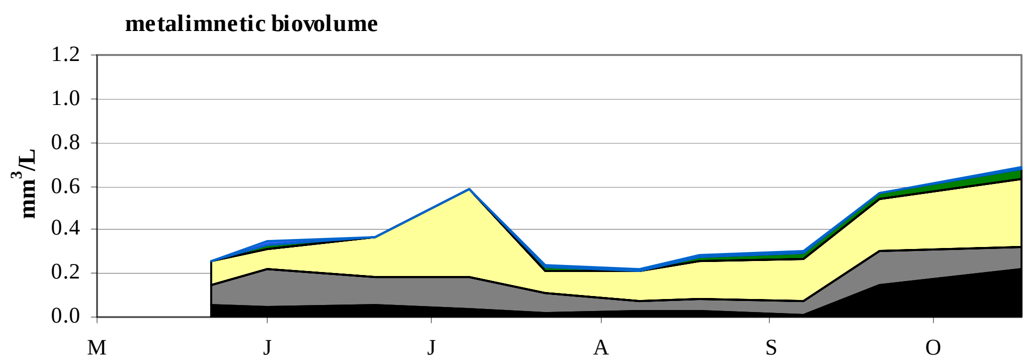


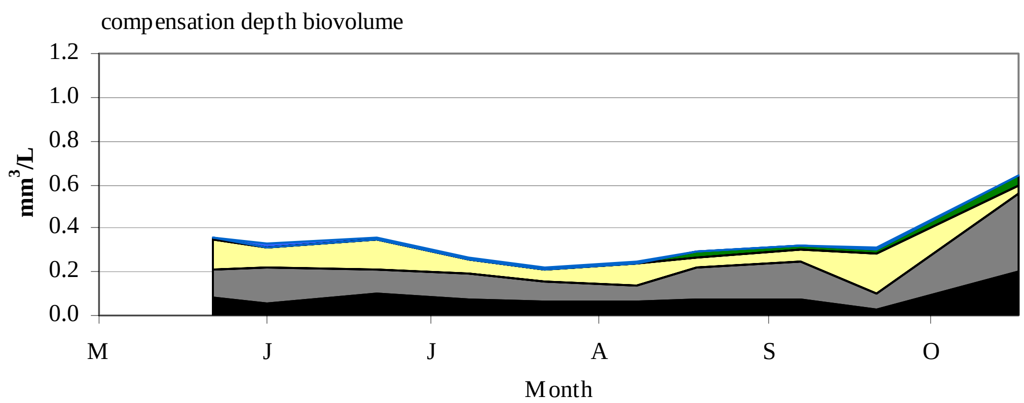




Appendix B-1. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Redfish Lake, February through October 2002.







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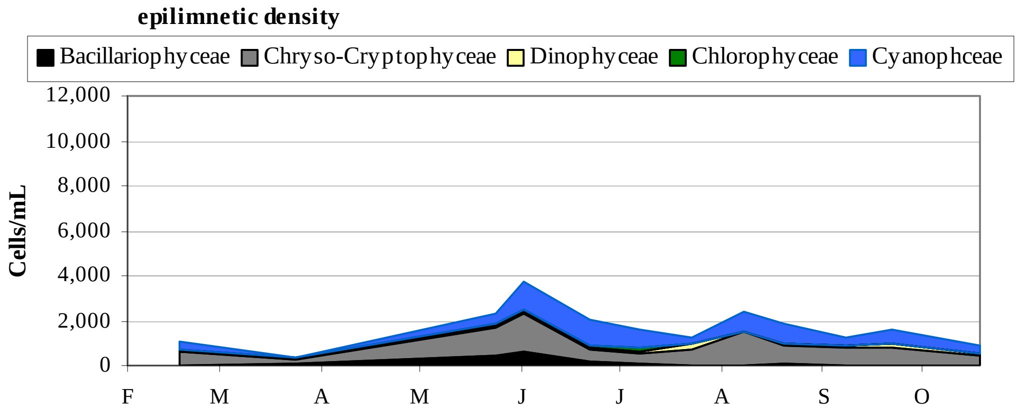
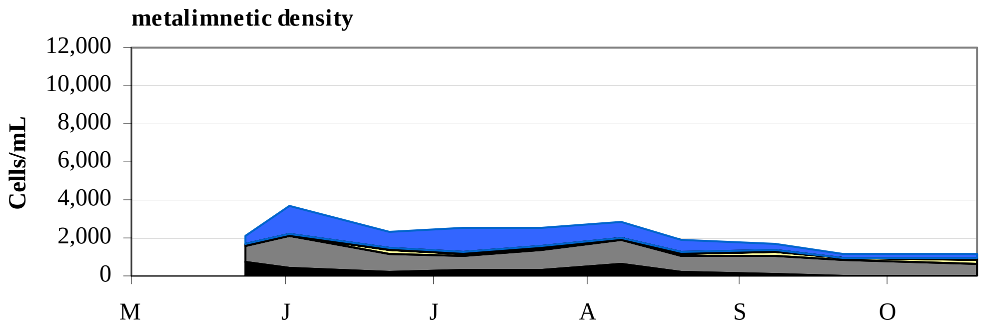
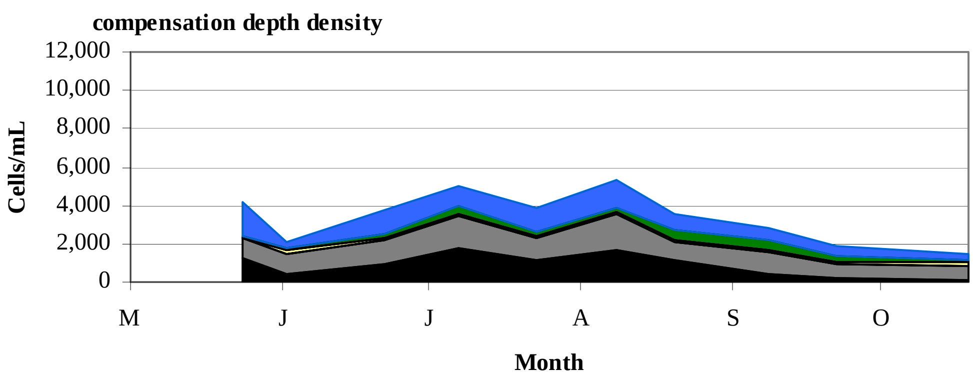
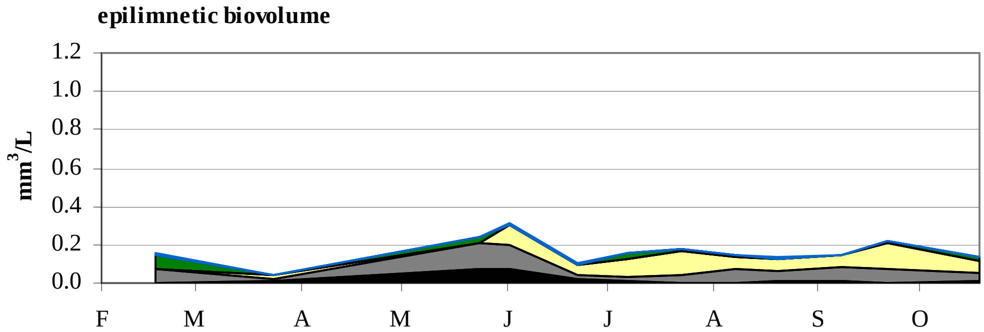
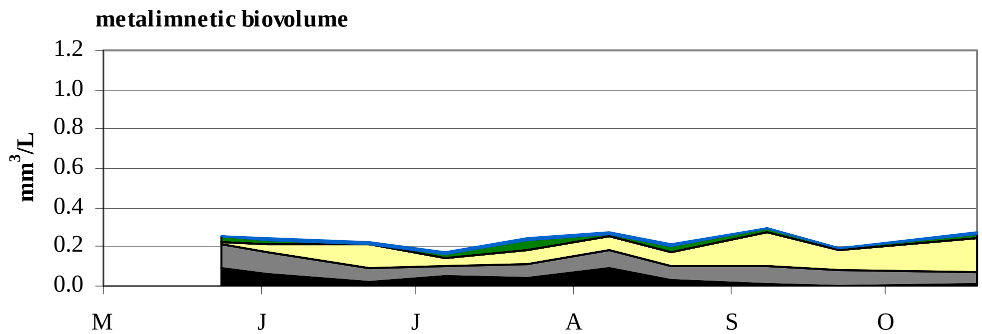


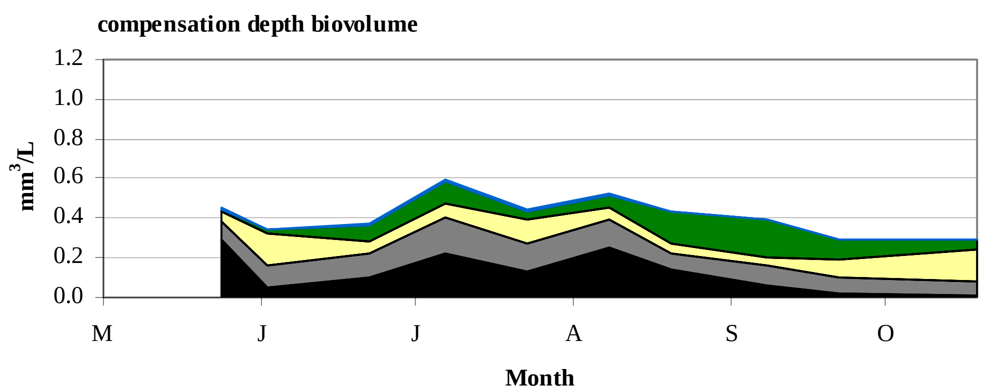




Appendix B-2. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Pettit Lake, February through October 2002.







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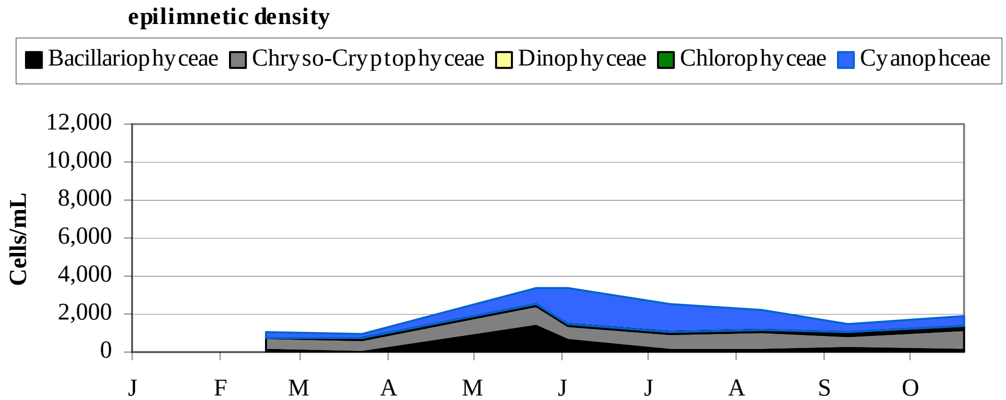
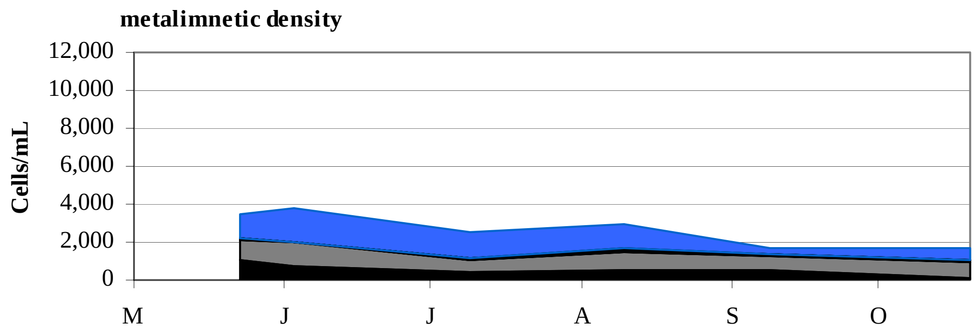
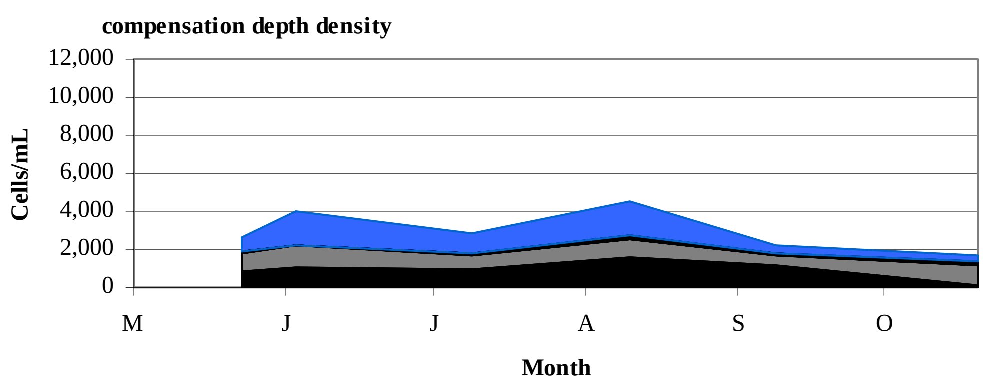
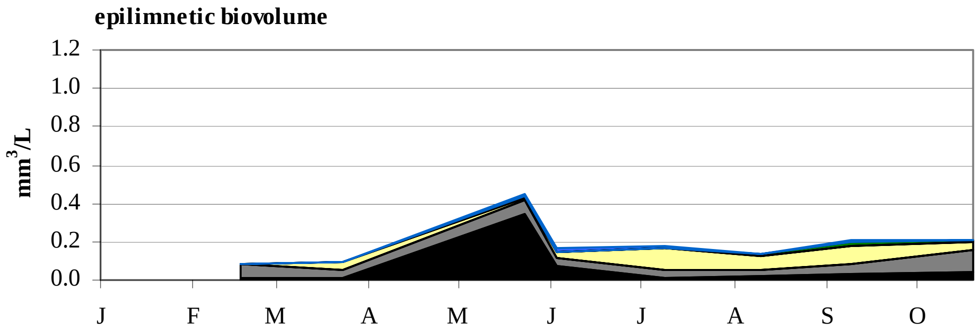
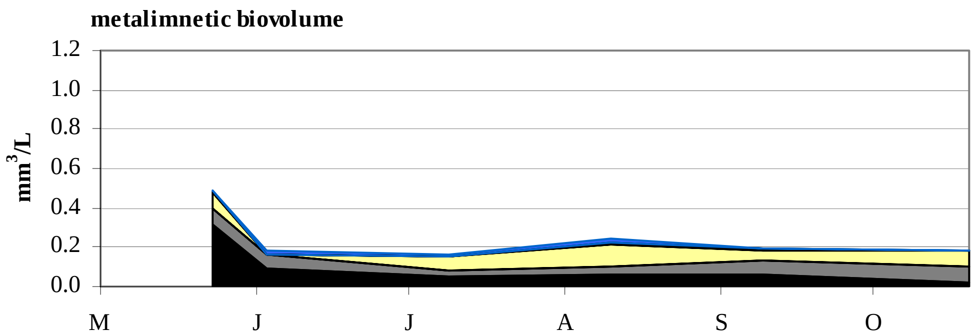


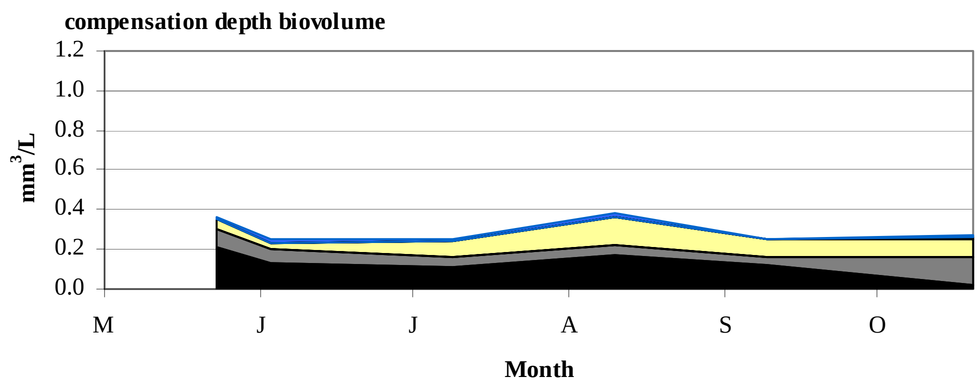




Appendix B-3. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Alturas Lake, February through November 2002.







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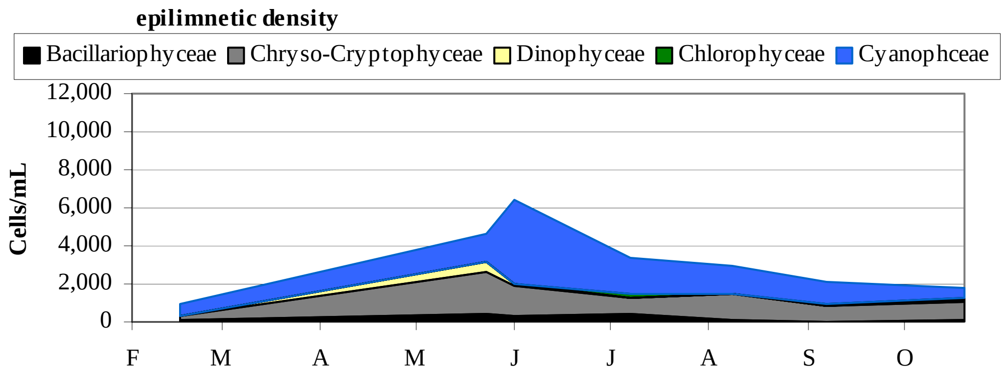
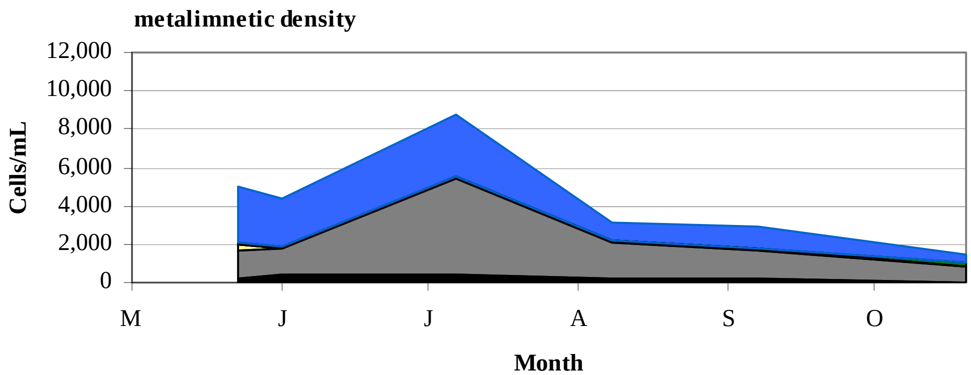
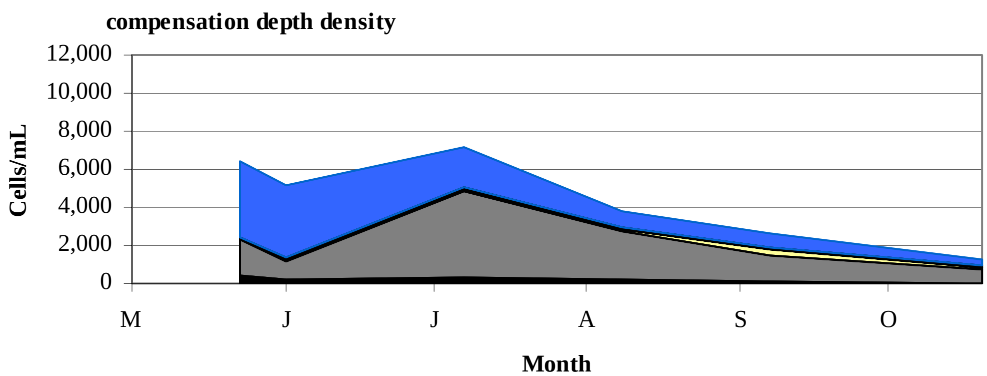
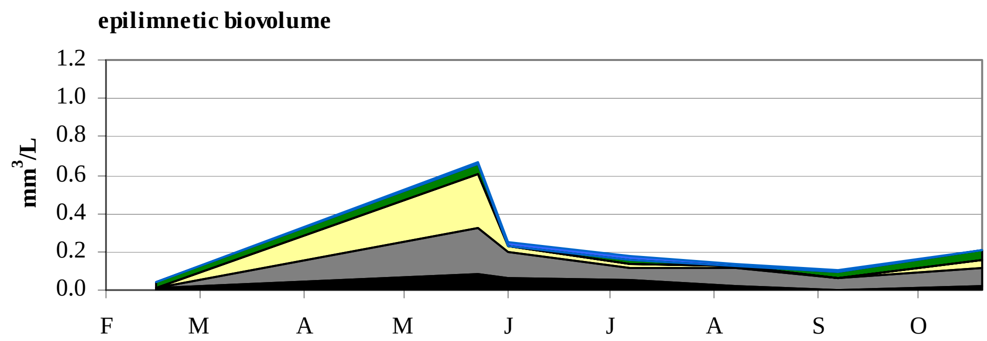
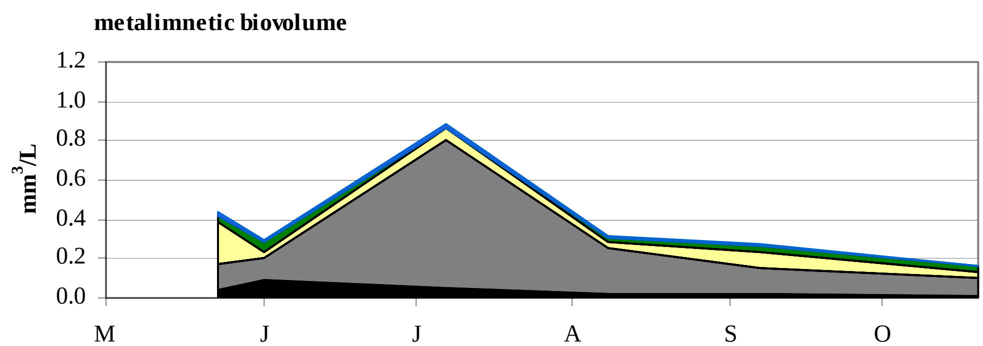


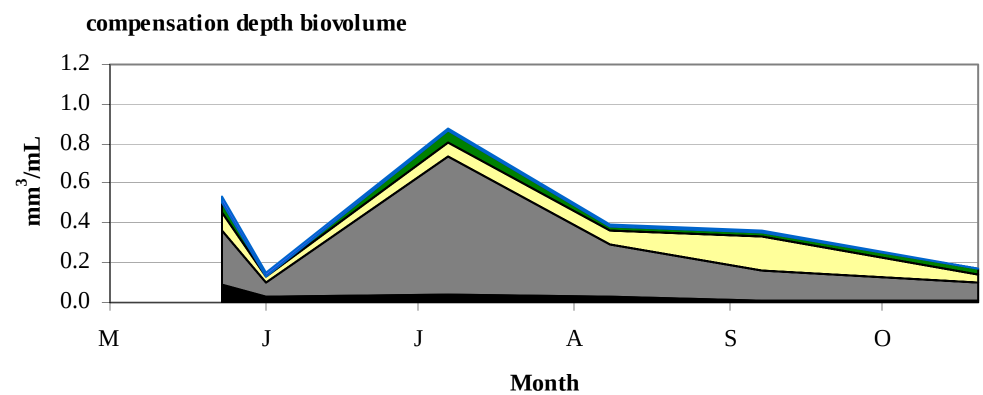




Appendix B-4. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion, metalimnion and at the compensation depth in Stanley Lake, February through October 2002.







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