Snake River Sockeye Salmon Habitat and Limnological Research

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SNAKE RIVER SOCKEYE SALMON HABITAT

AND LIMNOLOGICAL RESEARCH: 1999 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 Bonneville Power Administration (BPA) provides funding for this inter-agency 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 1999 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 Pettit, and Alturas lakes, fertilization of Redfish Lake was suspended for this year; 3) conduct kokanee (non-anadromous *O. nerka*) population surveys; 4) monitor spawning kokanee escapement and estimate fry recruitment on Fishhook, Alturas Lake, and Stanley Lake creeks; 5) evaluate potential competition and predation interactions between stocked juvenile *O. nerka* and a variety of fish species in Redfish, Pettit, and Alturas lakes; 6) examine diet of emigrating *O. nerka* smolts; 7) monitor limnological parameters of Sawtooth Valley lakes to assess lake productivity.

Objective 1. Stocked juvenile *O. nerka* over-winter survival on Pettit Lake was estimated using tag detections at Lower Granite Dam. 7,246 pre-smolts from the captive rearing program were stocked into Pettit Lake in the summer of 1998. An estimated 4,478

smolts out-migrated from the lake during monitoring in the spring of 1999. This results in an estimated 62% over-winter survival rate. Alturas Lake was stocked with 39,377 pre-smolt *O. nerka* from the captive rearing program in the fall of 1998. An estimated 11,847 smolts out-migrated from the lake in the spring of 1999, resulting in an estimated 30% over-winter survival rate. Over-winter survival and out-migration for Redfish Lake was monitored by IDFG.

Objective 2. Lake fertilization activities (addition of liquid nitrogen and phosphorous fertilizer) were continued in Pettit and Alturas lakes during 1999 in order to elevate lake carrying capacities. Fertilization of Redfish Lake was suspended this year. This is the third year of fertilization for Pettit and Alturas lakes. Pettit Lake received 30.6 kg of total phosphorous (TP) and 623.8 kg of total nitrogen (TN) and Alturas Lake received 47.9 kg of TP and 968.9 kg of TN.

Objective 3. The hydroacoustic estimate of *O. nerka* population in the fall of 1999 for Redfish Lake was 69,472 ± 29,887 with a density of 113 ± 48.6 fish/hectare. Pettit Lake had an estimated population of 51,496 ± 12,171and a density of 317.9 ± 75.1 fish/hectare. Alturas Lake had an estimated population of 130,133 ± 25,936 and density of 385.0 ± 76.7 fish/hectare. Concurrent trawl sampling and density estimates were conducted by IDGF.

Objective 4. Stream spawner counts were used to monitor adult kokanee escapement to inlet streams on Redfish, Alturas, and Stanley lakes in 1999. Fishhook Creek, the primary kokanee spawning tributary on Redfish Lake, had an estimated spawning escapement of 2,336. This number is down sharply compared to previous years. Stanley Lake Creek had an estimated 948 kokanee a similar number to earlier years. Alturas Lake Creek had an estimated 8,334 fish. Fry recruitment, calculated from male, female ratios, fecundity, and egg to fry survival rates is estimated at 33,474, 16,637, and 154,387 fry for Fishhook, Stanley Lake, and Alturas Lake creeks respectively.

Objective 5. Potential competition and predation between stocked sockeye salmon (anadromous *O. nerka*), rainbow trout (*O. mykiss*), and other fish species were 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 was 19% for rainbow trout and *O. nerka* consisting of chironomid pupae. Age 0 sockeye salmon, the life stage of primary interest, fed primarily on zooplankton while rainbow trout had a diet dominated by insects. Several potential kokanee/sockeye predators were identified in the lakes including bull trout *Salvelinus confluentus*, northern pikeminnow *Ptychocheilus oregonensis*, and brook trout *S. fontinalis*. No *O. nerka* or other salmonids were identified in the stomachs of any of the northern pikeminnow or brook trout. Piscivory was evident, however, with cyprinids found in the diets of both species. Bull trout diet was completely composed of salmonids, none of which was identified as *O. nerka*. However, many were unidentifiable due to the progressed state of digestion.

Objective 6. The diet of emigrating *O. nerka* smolts from the captive brood stock was composed primarily of emergent Hemiptera. Out of 61 smolts sampled only two had zooplankton in their stomachs.

Objective 7. Limnological parameters including nutrient levels, chlorophyll *a*, secchi depth, primary productivity, phytoplankton, and zooplankton assemblage characteristics (species composition and densities) were monitored concomitant with fertilization activities. There was a general trend of elevated productivity parameters in Pettit and Alturas lakes, demonstrating potential increased lake carrying capacity due to fertilization.

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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 evolutionary significant unit (ESU) is the only extant Upper Snake River stock of *O. nerka*. The spawning and freshwater rearing habitat of this stock is located in the Sawtooth Valley, 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, Intergovernmental Contract Number 00000503-00001) since its inception.

The Bonneville Power Administration (BPA) provides funding for this interagency recovery program through the NWPPCFW. 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 Shoshone-Bannock Tribes (SBT). The NMFS manages the permitting of activities and the captive rearing program hatchery operations in Manchester, WA. The IDFG monitors a variety of fisheries parameters in the field and is responsible for the captive rearing program hatchery operations in Eagle and Stanley, ID. The UI analyzes genetic samples and participates in designing breeding matrices. The USFS participates in permitting activities and habitat improvements. The SBT monitors a variety of fisheries biology parameters and spawning and rearing habitat 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 appear to have 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 24 adult sockeye have returned to the Sawtooth Valley in the 1990's. The recovery program has focused its efforts on restoring anadromous *O. nerka* to Redfish, Alturas, and Pettit lakes, which were designated as critical spawning and rearing habitat under the ESA listing (56 FR 58619).

A variety of activities has been conducted in the effort to conserve and rebuild the Redfish Lake *O. nerka* stock. The captive brood stock has served to preserve the unique genome. Fish barriers on Alturas and Pettit lake creeks have been removed to facilitate fish passage. Fish from the captive brood stock have been reintroduced into the wild. A variety of stocking strategies have been implemented and evaluated, including adult release for volitional spawning, in-lake egg incubators, net pen rearing with pre-smolt release, and pre-smolt release during spring, summer, and 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 to reduce intraspecific competition. A variety of fishery and limnological parameters have been monitored in association with these strategies.

The Technical Oversight Committee (TOC) has guided all activities conducted by the SBT in association with the sockeye recovery project. The TOC is composed of representatives of all participating agencies (BPA, NMFS, IDFG, UI, and SBT). The TOC was formed in 1991 to guide new research, coordinate ongoing research, and actively participate in all elements of the Snake River sockeye recovery effort. The project as a whole or in part is subject to further review by the Idaho Department of

Environmental Quality (DEQ), the USFS, and the NWPPC Independent Scientific Review Panel (ISRP).

STUDY AREA

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

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

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

Lake	Area (km^2)	Volume (m^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
Yellow Belly	0.73	10.3	14	30.4

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 trout *Salvelinus confluentus*, mountain whitefish *Prosopium williamsoni,* sucker *Catastomus sp*., redside shiner *Richardsonius balteatus*, dace *Rhinichthys sp*., northern pikeminnow *Ptychocheilus oregonensis*, and sculpin *Cottus sp*.. Non-native species include brook trout *S. fontinalis* and lake trout *S. namaycush*. The only pelagic species besides *O. nerka* are redside shiners. The two species are not sympatric because of differing vertical distributions. Hatchery rainbow trout are stocked by IDFG throughout the summer in all lakes except for Redfish and Yellow Belly lakes. Sport fishing for salmonids is open on all lakes as well as inlet and outlet streams.

The Sawtooth Valley lakes have several different forms of *O. nerka*, the primary pelagic zooplanktivore in the system. Genetics indicate that there are three distinct populations 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 four years of age in the inlet creeks of the lakes during late summer and die afterwards. Stanley and Pettit lakes were treated with rotenone (1950's or 60's) and kokanee were reintroduced from out-of-basin stocks. Data indicate that these fish are genetically different from remaining indigenous *O. nerka*. The Redfish Lake kokanee population is admixed, consisting of several out-of-basin stocks and remaining indigenous genetics. 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). No Sawtooth Valley kokanee are listed as endangered.

Residuals are another form of *O. nerka* found only in Redfish Lake and 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 its redds on the lake shore instead of the inlet creeks.

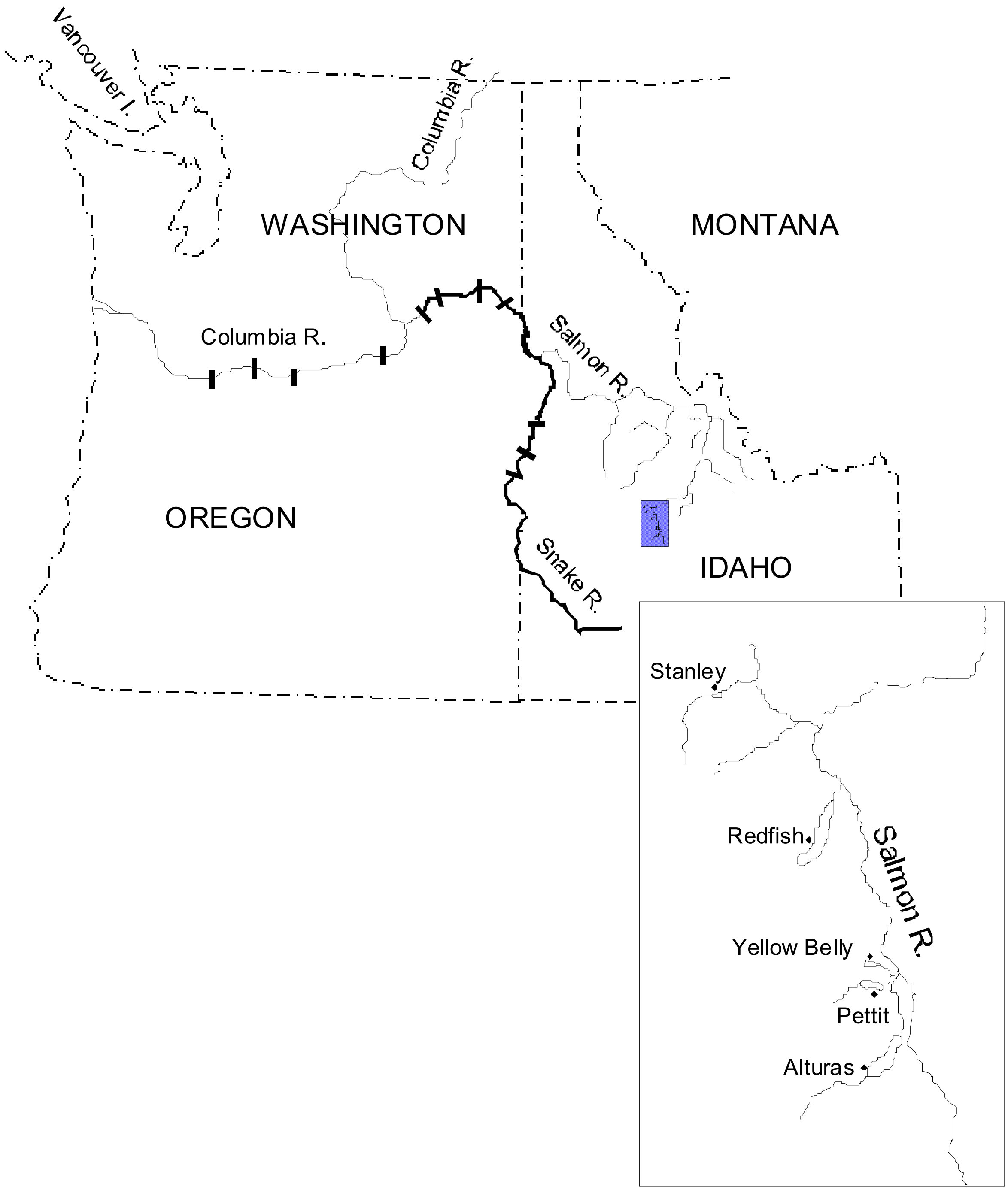

Figure 1-1. Map of study area.

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. The anadromous form spends the majority of its 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 five pings per target was necessary to qualify as a fish target. Data were recorded on a Panasonic SV-3700 digital audio tape recorder.

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

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

Vertical gill netting and trawling (by IDFG) were done concurrently with hydroacoustic sampling. Vertical gill net sampling was used to assist in partitioning targets in Pettit Lake since past trawling efforts have indicated a positive selection for kokanee. Vertical gillnets were used to determine if other fish species were found in the pelagic areas during sampling. Previous gill net sampling conducted in Alturas Lake has not yielded sufficient numbers for partitioning targets and therefore was not used. Due to NMFS Section 10 permit limitations vertical gillnet sampling in Redfish Lake was not conducted.

Data Analysis

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

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

developed by Love (1977) where TS = target strength in decibels, L = fork length in centimeters, and F = frequency of transmitted sound (kHz). Fish density estimates were calculated for different size classes for each lake to approximate cohort densities based on 1998 length frequency distributions and age analyses performed by the IDFG from fish captured in the trawl. Four different size classes were used for all three lakes. Due to overlap in Alturas Lake, we combined the III+ and IV+ kokanee cohorts. Total abundance and vertical distribution were also estimated.

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

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

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

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

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

and variance was estimated by

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

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

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

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

(1-5)

where D_{vi} = number of fish/m^3 in depth stratum i, R_{iu} = upper range limit for depth stratum i, R_{il} = lower range limit for depth stratum i, and h = number of depth strata. These values were then multiplied by the percentage of each depth stratum surveyed within the conical beam.

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

Smolt Monitoring

Pettit Lake

A weir was operated at the outlet of Pettit Lake, Idaho (Section 31, Township 8 North, Range 14 East) from 15 April through 3 May 1999. The weir was used to monitor over-winter survival and emigration of Snake River sockeye salmon smolts. In 1998, 7,246 fish were introduced as pre-smolts from the captive broodstock program into Pettit Lake. The weir ran continuously during operation at 100% capture efficiency. Shoshone-Bannock Tribal fisheries personnel checked for fish and cleaned the weir at sunrise and sunset. The trap was checked more frequently when high levels of debris were present. Sampling was discontinued when peak flows associated with spring run-off created logistical problems.

Immediately after removal from the trap, the fish were anesthetized for measuring and weighing using a stock solution of 15 grams of MS222 and 30 grams of sodium bicarbonate per liter of water. All fish that were anesthetized were weighed to the nearest 0.1 grams and measured (fork length) to the nearest millimeter and were held in a live well for 5 to 10 hours after handling and then released. A condition factor (K value, (weightx10^5)/(length)^3) for each fish was estimated; mean, minimum, and maximum K value are presented in results. All other fish were counted and immediately released below the weir.

Alturas Lake

A screw trap was operated in Alturas Lake Creek 8 miles down stream from Alturas Lake, Idaho (Section 32, Township 8 North, Range 14 East) from 18 April through 31 May 1999. *O. nerka* smolts were captured to estimate over-winter survival and smolts emigration and to allow tagging of Snake River sockeye salmon smolts using passive integrated transponders (PIT). There were 39,377 fish introduced as pre-smolts from the captive broodstock program into Alturas Lake in 1998. 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. Trap efficiency was calculated for four periods using a mark recapture method. Trap efficiency was calculated using equation 1-6.

Efficiency = number marked fish recaptured / number marked fish released (1-6)

Three different periods were sampled for efficiency based on discharge; two more periods were sampled when the trap was relocated to reduce capture of fish. Discharge was measured at a staff gauge approximately 300 meters upstream. The stage-discharge relationship had a R^2 value of 0.98. A condition factor (K value, [weight x 10^5]/[length]^3) for each fish was estimated; mean, minimum, and maximum K value are presented in results.

Anesthetized fish were weighed to the nearest 0.1 grams, measured (fork length) to the nearest millimeter, and PIT tagged. Fish were held in a live well for 5 to 10 hours after handling and released at dusk. All other fish were counted and immediately released below the screw trap. PIT tags and needles were sterilized in 70% ethanol. PIT-tagged fish used in the mark recapture capture efficiency estimation were held in a live well and released at dusk approximately 300 meters upstream.

Growth Rates

Growth rates of stocked juvenile *O. nerka* were compared in an effort to evaluate differences in fitness associated with differences between lakes and the various stocking strategies. Length data (mm) of stocked *O. nerka* were collected at the time of tagging and smolt emigration. Length data were Log_{10} transformed to normalize and create a linear relationship from an exponential growth curve to facilitate growth rate comparisons. Log_{10} transformed lengths at the time of tagging were compared to Log_{10} transformed length data of *O. nerka* collected during smolt emigration monitoring. An initial pair-wise comparison (t-test) was conducted comparing size at release and size at emigration between lakes and release strategy. A second descriptive comparison was generated using a linear regression between the Log_{10} transformed lengths of pre-smolts and smolts for each release group. The slope of the regression line represents the growth rate of each group and was used to compare the growth rates of fish between lakes and release strategies.

The summer-release group of fish spends a longer amount of time in the lakes than the fall-release group. In order to eliminate potential differences in comparisons associated with this time-in-lake factor, a millimeters of growth per cumulative temperature unit (mm/CTU) was generated for each group. The mm/CTU for each group of fish was calculated using

$$(L_1) - (L_0) / CTU \qquad (1\text{-}7)$$

where (L_0) = mean length at the time of tagging, (L_1) = mean length at time of smolt emigration, and CTU = degrees (C^o) estimated for each day summed over the appropriate time period. Temperature data were used to calculate the mean monthly temperature for the 0-10 meter depth in each lake. The mean monthly temperature was then used as the daily temperature for each month in calculating CTUs. Temperatures for periods during ice-over (January through mid-May) ranged from 4-5 ^{o}C. A temperature of 4.5 ^{o}C was used in the generation of CTUs for periods of ice-over. Temperature data were not collected between late October and January. Temperatures for November and December were estimated by taking the difference between October temperatures and January temperatures divided by three, and this number was subtracted from the prior mean monthly temperature.

Gillnet

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 shore in Pettit Lake. Nets were set with the smallest mesh size panel closest to shore (approximately 10 m from shore) and the largest mesh size panel deeper and further from shore. Vertical gillnets 3 m wide and 30 m deep were composed of graduated mesh sizes (2.54, 3.17, 5.08, and 6.35 cm). The four vertical gillnets were set in a line at a single station in the pelagic zone in the middle of Pettit Lake. Horizontal gillnet sampling was conducted on 27 January, 2 June, and 13 October 1999 in Pettit Lake. Vertical gillnet sampling on Pettit Lake was conducted on 10 March, 2 June, 18 August, and 13 October 1999. Vertical gillnet sampling was also used to assist in partitioning targets in Pettit Lake, since past trawling efforts have indicated a selectivity for larger, older age class *O. nerka*. Therefore, we employed vertical gillnets to determine if other age classes of *O. nerka* and/or other fish species were found in the pelagic areas during sampling. Due to NMFS section 10 permit limitations, there were no gillnets set in Redfish Lake.

Diet Analysis

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

Stream Spawning

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

Beach Spawning

Sockeye Beach, located near the Redfish Lake boat ramp, and a small section of the southeast corner of Redfish Lake are spawning grounds for residual and adult sockeye. Night snorkel surveys were conducted to estimate the relative abundance of residual spawners and adult sockeye stocked from the captive rearing program in both locations. Snorkel surveys in Redfish Lake were conducted weekly on four nights from 5 to 26 October 1999. 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 southeast inlet streams.

RESULTS

Hydroacoustic Population Estimates

Hydroacoustic population estimates of *O. nerka* during September 1999 ranged from 51,496 to 130,133 fish in Alturas and Pettit lakes, respectively (Table 1-2). Redfish Lake was intermediate with an estimated *O. nerka* population of 69,472. This was the first year since we began hydroacoustic sampling in 1994 that Alturas Lake had a higher abundance than Redfish Lake. Alturas Lake was the only lake that did not decline in abundance since 1998. This occurred after the two largest recorded kokanee escapements observed in Alturas Lake Creek. In 1997 an estimated 8,492 kokanee spawned in Alturas Lake Creek that resulted in 92,733 kokanee fry recruiting to the lake in the spring of 1998 (Taki et al. 1999). In 1998 an estimated 15,237 kokanee spawned in Alturas Lake Creek. Assuming a 1:1 sex ratio this may have contributed over 200,000 fry to the lake. An estimate of 73,262 ± 19,572 (Table 1-3) young of the year (YOY) fish in Alturas Lake indicates a sex ratio similar to what has been observed in Fishhook Creek on Redfish Lake (Table 1-11). There may also be a lower egg to fry survival rate than has been estimated. Redfish Lake *O. nerka* abundance declined the most from 1998 (-35%) and had the lowest density of the three lakes at 113 ± 49 fish/hectare. Pettit Lake *O. nerka* abundance declined to the lowest level since 1994 yet density remained almost three times as high as Redfish Lake (318 ± 75 fish/hectare) (Table 1-2).

Redfish Lake- The total *O. nerka* population in Redfish Lake was 65% of the 1998 estimate. The decrease was seen in every cohort except for yearlings (Table 1-4). This may be a result of the eighty adult sockeye that were released into the lake and the 85,378 fertilized eggs that were put into in lake incubation boxes in 1997.

Table 1-2. *O. nerka* abundance and density estimates for three Sawtooth Valley lakes from 1992 through 1999. 1992 and 1993 estimates were taken by a subcontractor with different sampling equipment.

Lake	Year	***O. nerka* abundance population estimate**	***O. nerka* density (fish/hectare)**
Redfish	1999	69,472 ± 29,887	113.0 ± 48.6
Redfish	1998	107,613 ± 33,615	175.0 ± 54.6
Redfish	1997	131,513 ± 32,319	213.8 ± 52.5
Redfish	1996	66,325 ± 24,000	107.8 ± 39.0
Redfish	1995	103,570 ± 24,500	168.4 ± 39.8
Redfish	1994	133,360	216.80
Pettit	1999	51,496 ± 12,171	317.9 ± 75.1
Pettit	1998	67,206 ± 30,950	414.9 ± 191.1
Pettit	1997	63,195 ± 29,581	390.1 ± 182.6
Pettit	1996	77,680 ± 15,850	479.5 ± 97.8
Pettit	1995	77,765 ± 46,900	480.0 ± 289.5
Pettit	1994	12,265 ± 8.360	75.7 ± 51.6
Alturas	1999	130,133 ± 25,936	385.0 ± 76.7
Alturas	1998	101,519 ± 32,605	300.4 ± 96.4
Alturas	1997	30,795 ± 5,869	91.1 ± 17.4
Alturas	1996	20,620 ± 4,140	61.0 ± 12.3
Alturas	1995	32,260 ± 5,090	95.4 ± 15.1
Alturas	1994	10,980 ± 1,090	32.5 ± 3.2

Table 1-3. Hydroacoustic population estimates by age class for Alturas Lake, 1996–1999.

Cohort	1995	1996	1997	1998	1999
0+	na	3,255 ± 1,490	4,330 ± 979	73,176 ± 27,411	73,262 ± 19,572
I+	na	7,670 ± 3,175	11,859 ± 3,071	20,106 ± 5,372	25,752 ± 5,834
II+	na	4,665 ± 635	4,304 ± 1,149	6,399 ± 1,734	21,583 ± 5,951
III+	na	3,702 ± 1,300	10,775 ± 2,920	1,838 ± 1,297	10,533 ± 3,303
IV+	na	1,260 ± 785	0	Na	na

Table 1-4. Hydroacoustic population estimates by age class for Redfish Lake, 1994 – 1999.

Cohort	1995	1996	1997	1998	1999
0+	22,360 ± 6,410	12,680 ± 5,030	37,234 ± 14,449	46,747 ± 19,155	41,466 ± 23,578
I+	49,120 ± 12,400	34,950 ± 21,040	51,681 ± 14,533	27,767 ± 10,955	28,199 ± 30,829
II+	31,070 ± 12,340	18,700 ± 4,570	30,623 ± 6,599	12,450 ± 5,215	11,359 ± 7,389
III+			11,973 ± 3,104	9,926 ± 5,629	2,213 ± 1,639

Table 1-5. Hydroacoustic population estimates by age class for Pettit Lake, 1995– 1999.

Cohort	1995	1996	1997	1998	1999
0+	2,880 ± 1,270	4,740 ± 3,020	4,471 ± 2,705	16,593 ± 6,548	9,508 ± 6,576
I+	15,600 ± 9,330	17,890 ± 3,020	14,061 ± 6,010	17,027 ± 9,963	13,028 ± 4,942
II+	37,270 ± 23,570	31,800 ± 5,820	23,635 ± 11,485	29,974 ± 15,704	16,453 ± 4,493
III+	19,667 ± 13,930	23,247 ± 5,100	21,027 ± 11,502	7,895 ± 4,567	8,886 ± 4,402

We are not allowed to set vertical gillnets in Redfish Lake, so we assume every fish tracked in the pelagia is an *O. nerka,* and that no *O. nerka* are in the littoral zone when we sample. Under that assumption, annual survival rates of two year old kokanee to their third year was similar to the previous year (Table 1-4). Because of the unknown contribution of stocked sockeye to the YOY and yearling population, no inference may be made for survival from YOY to yearling or yearling to two year old.

Pettit Lake- The hydroacoustic estimate of *O. nerka* population in Pettit Lake declined by 15,710 (23.4%) fish since 1998. The trawl estimate actually increased, but it had a very high confidence interval (31,422 ± 21,280).

The lowest annual survival occurred from the II+ to III+ cohort. The 30% survival from 1998 to 1999 was similar to the previous year's 33% estimate (Table 1-5). Pettit Lake has experienced a gradual decline in whole lake *O. nerka* abundance during this study, since 1995 and 1996 when it had the highest densities of the three lakes. Zooplankton abundance has increased since a collapse in 1995 but still remains below 1995-1996 abundance (see Chapter 2).

Alturas Lake- Whole lake *O. nerka* population estimates increased by 28% from 1998 (Table 1-2). The 1998 estimate was over three times that of the previous year. As was predicted in the 1998 Annual Report (Lewis et al. 2000), the estimate of YOY in 1999 was very large yet there appeared to be high mortality in the 1998 YOY cohort (Table 1-3). Based on 1998 estimates, the II+ and III+ cohorts actually increased in abundance in 1999. As with all survival comparisons, caution should be used based on the low confidence intervals around the estimated abundance. Surprisingly, the trawl did not capture any fish from the III+ cohort (IDFG, personal communication).

The 1990 trawl estimate in Alturas Lake was 126,644, the highest of the decade. Hydroacoustic sampling did not begin until 1994 when the lowest estimate for both techniques (hydroacoustic and trawl) was recorded: 10,908 for hydroacoustics and 5,785 for trawl (Teuscher and Taki 1996). *O. nerka* abundance in rearing lakes are typically cyclic (Kyle et al. 1988; Hume et al. 1996). Alturas Lake appears to be peaking in *O. nerka* abundance similar to 1990 (based on trawl estimates) and what was observed in Pettit Lake during 1995-96.

Hydroacoustic/trawl Comparisons

Hydroacoustic/trawl ratios were similar to what was found by Parkinson et al. (1994). Hydroacoustic estimates for Redfish and Pettit lakes were 1.6 times the trawl and Alturas 2.3 times the trawl estimate (Figure 1-2). The 6 year mean hydroacoustic/trawl ratios for the lakes are 2.1 for Redfish Lake, 1.7 for Pettit Lake, and 2.0 for Alturas Lake.

Correlation of hydroacoustic and trawl population estimates were variable. Correlating 6 years of total lake *O. nerka* estimates reveals a relationship of R=0.85 (Figure 1-3). Combining individual cohorts from Redfish, Pettit, and Alturas lakes revealed that the YOY was moderately related (R=0.88; Figure 1-4), and that the two year old cohort was strongly related (R=0.96; Figure 1-5).

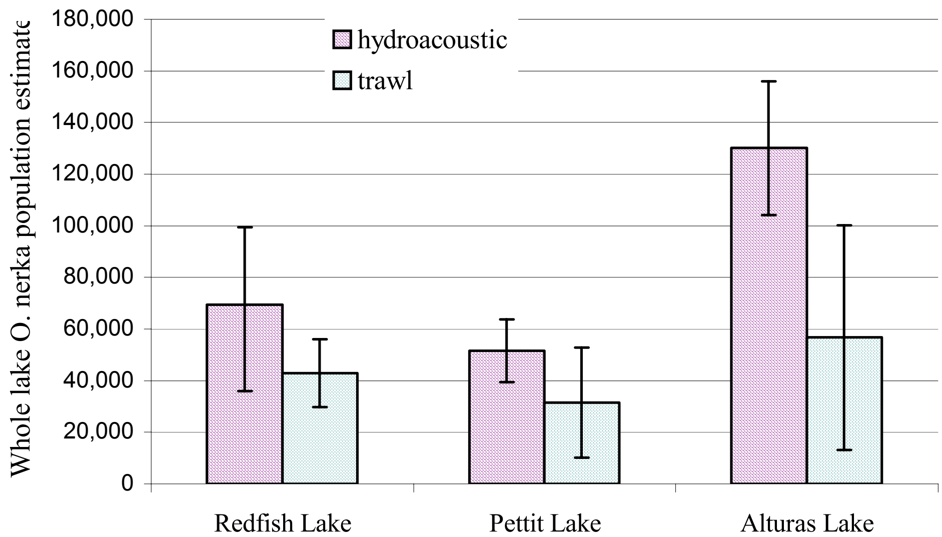

Figure 1-2. Comparison of hydroacoustic versus trawl estimates.

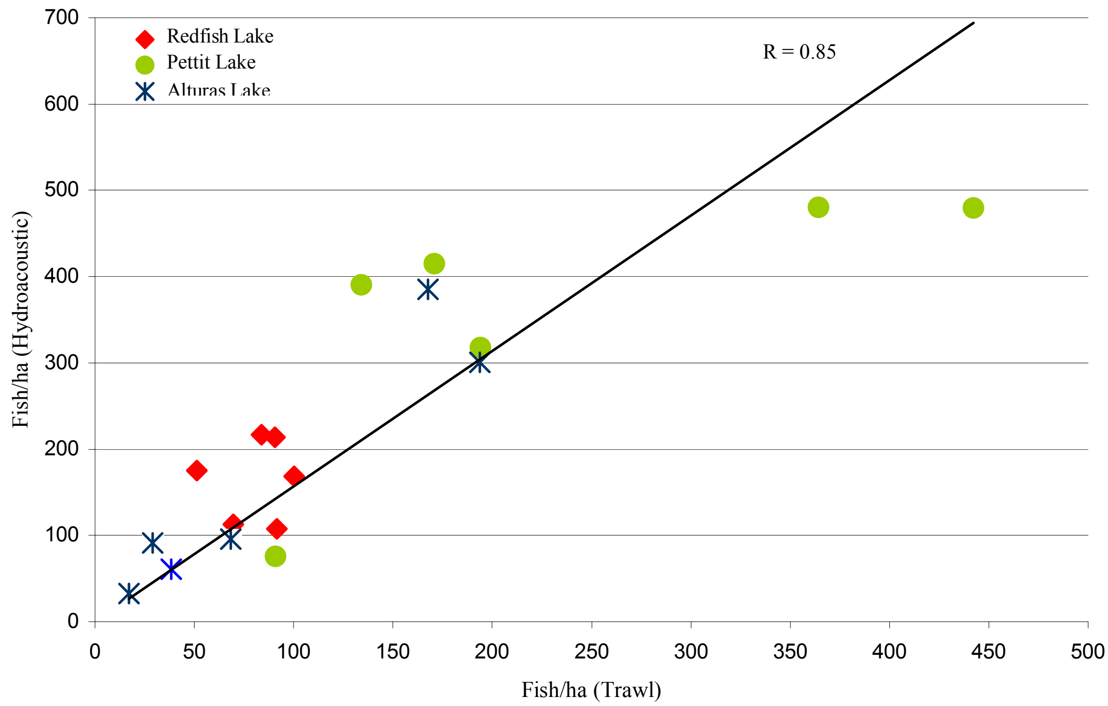

Figure 1-3. Correlation of six years of total lake *O. nerka* hydroacoustic and trawl estimates.

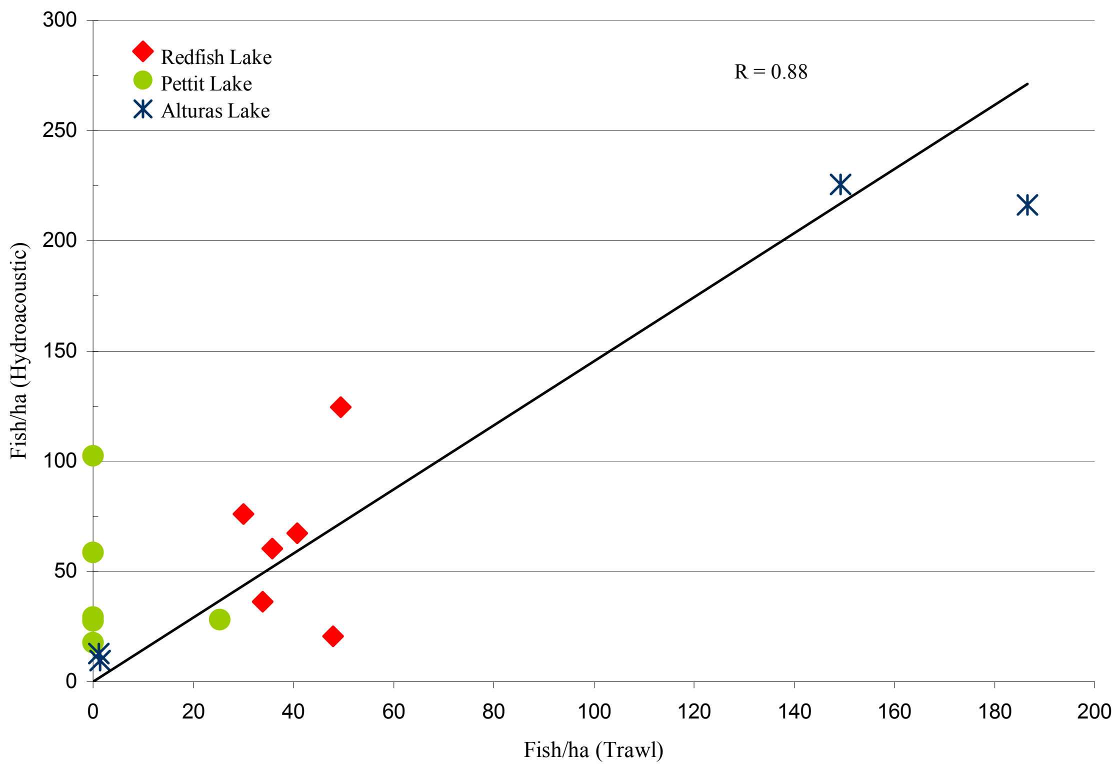

Figure 1-4. Correlation of YOY cohort from Redfish, Pettit, and Alturas lakes.

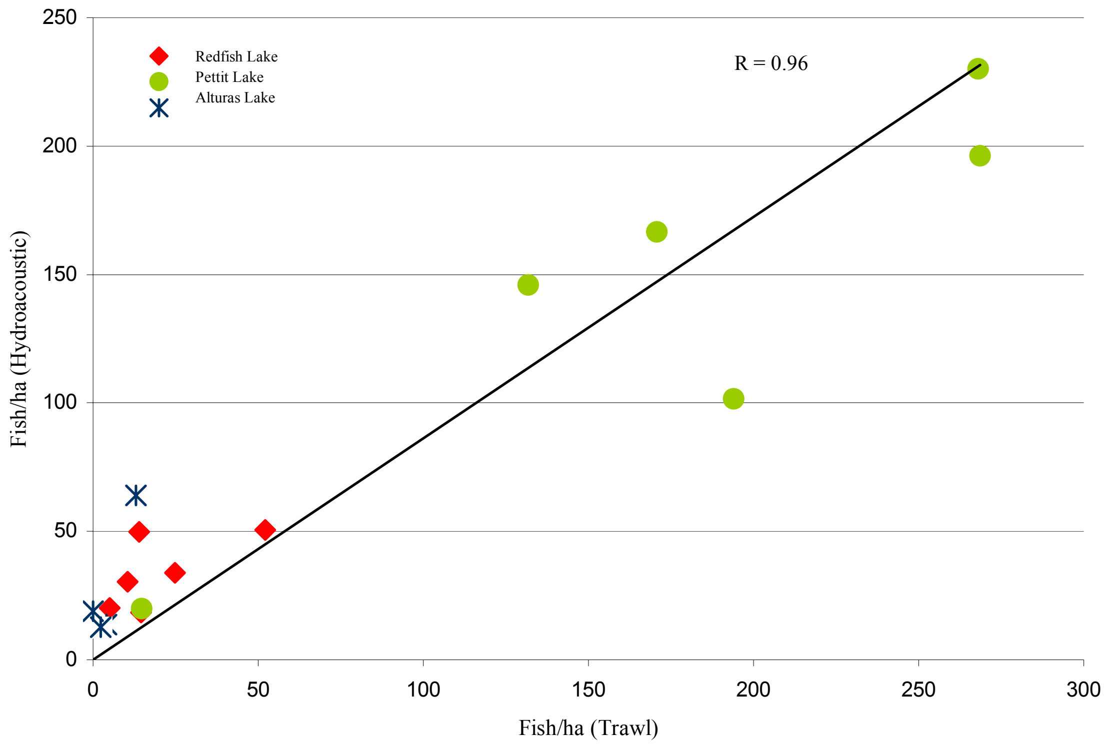

Figure 1-5. Correlation of two year old cohort from Redfish, Pettit, and Alturas lakes.

Smolt Monitoring

Pettit Lake Creek

In 1998 there were 7,269 Snake River sockeye pre-smolts from the Eagle Hatchery stocked into Pettit Lake. This release group included 1,504 PIT tagged fish. Calculations from tag detections at Lower Granite dam show an estimated over-winter survival of these fish at 4,478 (61%) (L. Hebdon, IDFG, personal communication).

The mean fork length of *O. nerka* captured at the weir (Figure 1-6) was 121 mm (range 102-169 mm), mean weight was 15.2 g (range 8.7-39.8 g), and a mean K value (condition parameter) was 0.85 (range 0.69-1.01). During weir operation, there were nine mortalities of stocked juvenile sockeye. Unlike previous years, no chinook salmon captured were at the weir during trapping operations. Other fish species captured included redside shiners, mountain whitefish, brook trout, and bull trout.

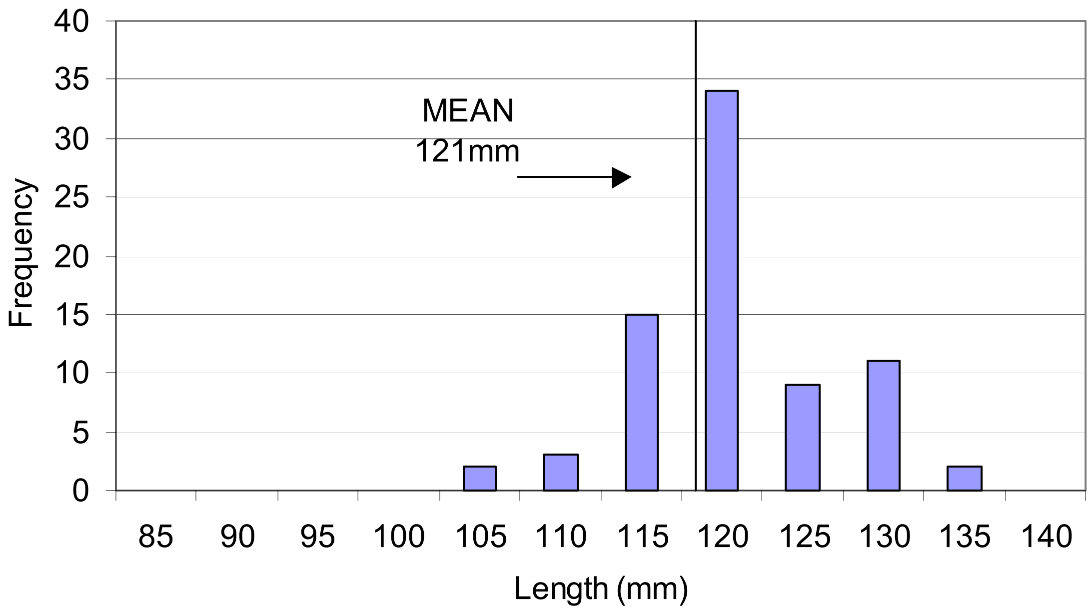

Figure 1-6. The length frequency distribution of *O. nerka* captured at the Pettit Lake Creek weir.

All sockeye salmon smolts were captured from 15 April through 3 May 1999. Down river PIT tag interrogations showed that the majority of smolts emigrated from Pettit Lake after the weir had been removed on 3 May 1998. The weir removal was necessary due to high flows, which threatened to over-top the weir. Water temperatures at the weir ranged from 0.5 to 13 °C and discharge from 0.62 to 5.01 m^3/sec.

Alturas Lake Creek

There were 39,377 pre-smolts from the Sawtooth Hatchery released into Alturas Lake on 14 October 1998. Screw trap monitoring of smolt emigration began on 18 April 1999. The first sockeye was captured on 2 May 1999. Trapping was discontinued on 31 May 1999. Screw trap efficiencies ranged from 18% to 34%, with a season mean of 24.5%. Using the number of captured sockeye smolts integrated over four calculated efficiency periods, it was estimated that a total of 11,847 sockeye smolts emigrated from Alturas Lake. This results in an estimated 30% over-winter survival/migration rate for the Snake River sockeye pre-smolts introduced from the captive broodstock to Alturas Lake in 1998. The actual number is potentially higher because additional emigration could have occurred after the trap was pulled. There were 272 sockeye smolts PIT tagged at the screw trap and released downstream. Emigration peaked with the peak of the spring hydrograph (Figure 1-7).

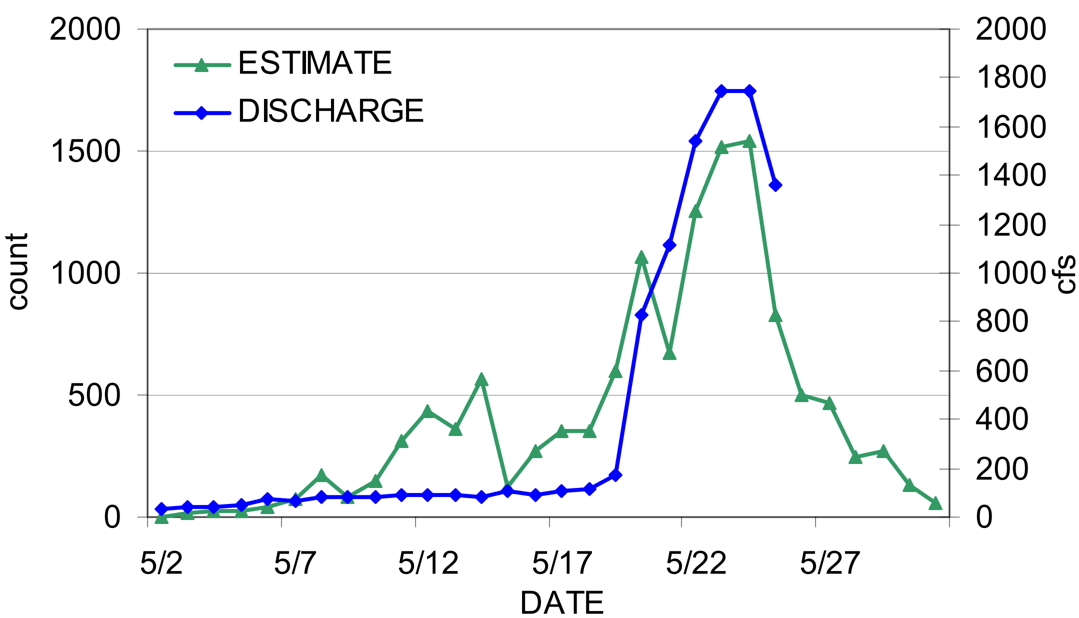

Figure 1-7. Alturas Lake *O. nerka* emigration and spring hydrograph timing.

The mean fork length of captive brood stock *O. nerka* captured at the trap (Figure 1-8) was 107 mm (range 88-151 mm), mean weight was 10.1 g (range 6.0-31.2 g), and a mean K value (condition factor) was 0.80 (range 0.51-1.01). Also captured at the trap were wild *O. nerka* with a mean fork length of 97.8 mm (range 82-125), mean weight of 7.46 g (range 3.9-15.4) (Figure 1-9), and a mean K value of 0.79 (range 0.68-0.96). Additionally 393 chinook salmon smolts emigrated during the 1999 season. There was an indirect mortality of seven sockeye and zero chinook. All of the species listed above for the Pettit Lake Creek weir operation were caught as well as eight *O. mykiss* with no fin clips. Water temperatures at the screw trap ranged from 1.0 to 11.2 ^{o}C.

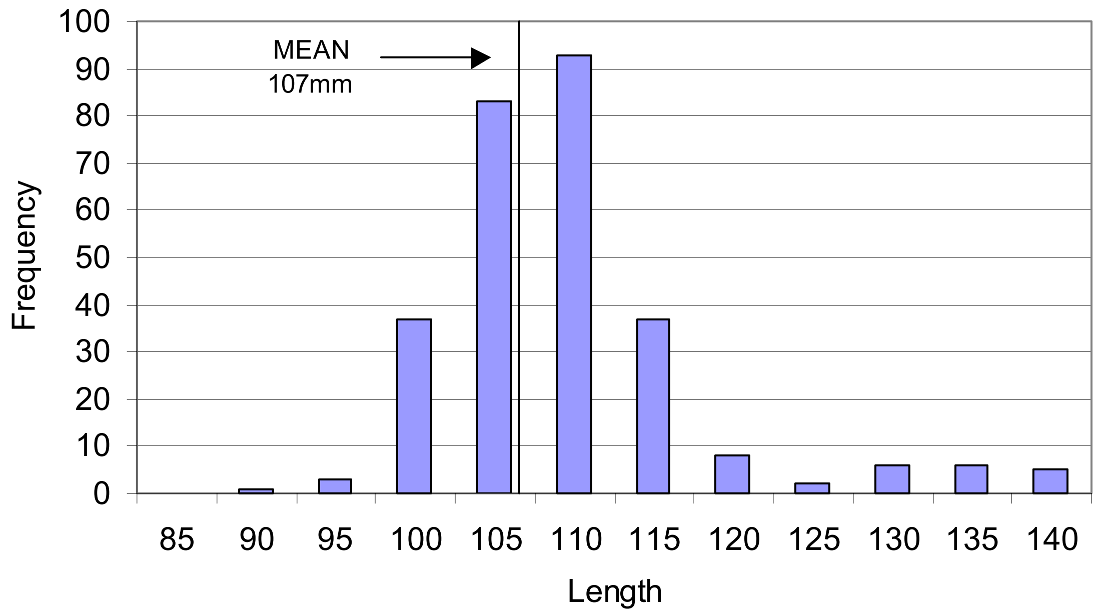

Figure 1-8. The length frequency distribution of *O. nerka* from the captive brood stock captured at the Alturas Lake Creek screw trap.

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. Sockeye captured at the weir during the morning were held until dusk of that same day for release. Although some sockeye were slightly descaled, they all appeared to be in good condition. All chinook salmon captured were released immediately and were in good condition with no evidence of descaling.

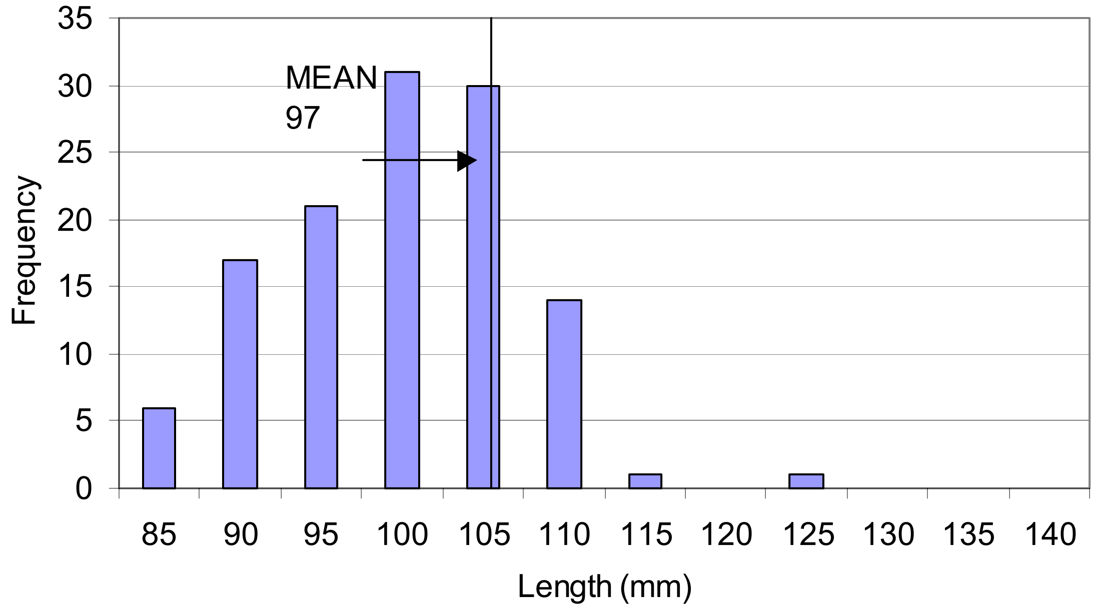

Figure 1-9. The length frequency distribution of wild *O. nerka* captured at the Alturas Lake Creek screw trap.

Growth Rates

Comparison of growth rates between lakes for 1999 yielded results similar to those found in 1998. At the time of tagging, Pettit Lake pre-smolts were significantly smaller ($P<0.0001$) than either group of pre-smolts released into Redfish and Alturas lakes (Figure 1-10). At the time of smolt emigration, Pettit Lake fish were significantly larger ($P<0.0001$) than either group of fish emigrating from Redfish and Alturas lakes (Figure 1-10). At the time of tagging Redfish Lake pre-smolts were significantly larger ($P<0.0001$) than the Alturas Lake group of fish but the same Redfish Lake fish were significantly smaller fish at the time of smolt emigration ($P<0.0001$) than the Alturas Lake group of fish (Figure 1-10).

A linear regression of the Log_{10} transformed length data at the time of tagging and smolt emigration for each group of fish by lake produced a slope of 0.0004 for Pettit Lake, 0.0001 for Alturas Lake, and 0.00005 for Redfish Lake (Figure 1-11).

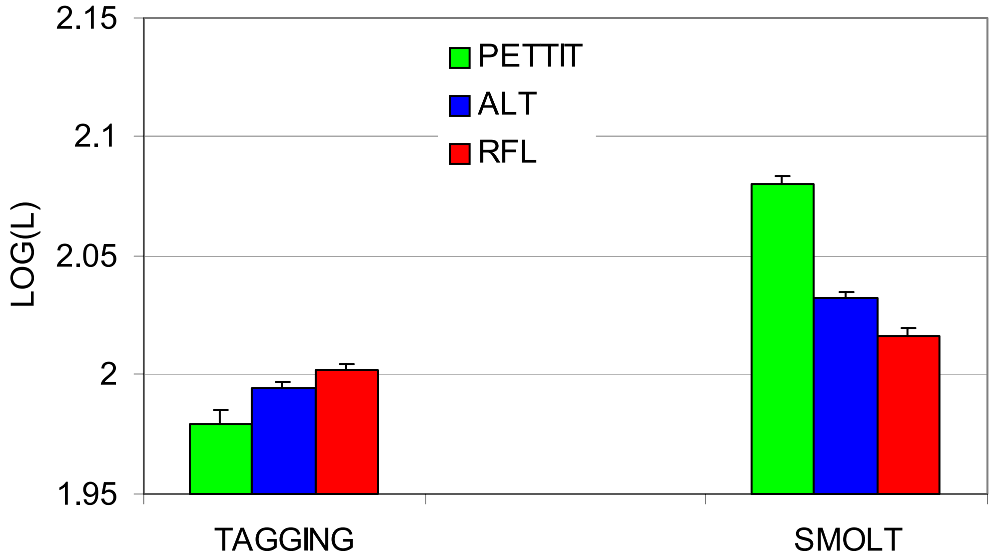

Figure 1-10. *O. nerka* Log (length) comparison between lakes at time of release and emigration.

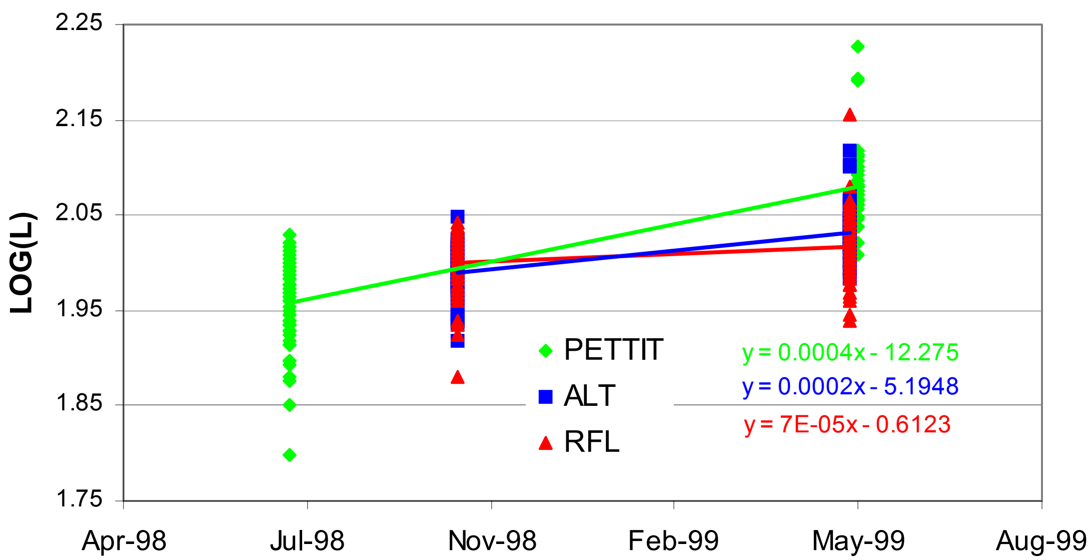

Figure 1-11. Regression of *O. nerka* Log (length) data to generate growth rates for each lake.

The millimeter growth per cumulative temperature unit (mm/CTU) calculations (Table 1-6) generated a growth rate of 0.0113 mm/CTU for Pettit Lake, 0.0073 mm/CTU for Alturas Lake, and 0.0051 mm/CTU for Redfish Lake.

Table 1-6. The millimeter growth per cumulative temperature unit for each lake for 1998 and 1999.

YEAR	PETTIT	ALTURAS	REDFISH
1998	0.0143	0.0051	0.0029
1999	0.0113	0.0073	0.0051

Gillnet

Vertical gillnet efforts yielded very few fish, total catch for all dates consisted of 7 kokanee, 3 rainbow trout, and 1 northern pikeminnow. Horizontal gillnet mean seasonal catch per unit effort (CPUE) was highest for northern pikeminnows (0.69) followed by stocked rainbow trout (0.30), brook (0.09), and bull trout (0.07) (Table 1-7).

Table 1-7. Results of Pettit Lake horizontal gillnet samples 1999.

Date	**(n)CPUE**	**Mean Length**	**Mean Weight**	**Gillnet Hours**
Rainbow Trout				
January 27, 1999	(0)	Na	Na	Na
June 2, 1999	(4) 0.17	242	Na	22
October 13, 1999	(39) 0.75	237 mm	151 g	51
Bull Trout				
January 27, 1999	(3) .05	353	616	65
June 2, 1999	(2) 0.09	372	Na	22
October 13, 1999	(4) 0.08	381	Na	51
Brook Trout				
January 27, 1999	(1) .02	224	134	65
June 2, 1999	(4) 0.17	249	Na	22
October 13, 1999	(4) 0.08	381	142	51
Northern Pikeminnow				
January 27, 1999	(4) 0.08	207	125	65
June 2, 1999	(34) 1.48	208	Na	22
October 13, 1999	(31) 0.59	211	138	51

Diet Analysis

The stomachs of 19 rainbow trout (RBT) caught during Pettit Lake gillnet efforts (4 in June, 1 in August, and 14 in October) were analyzed for diet comparison. No *O. nerka* were found in the stomachs of any of the 19 RBT. However, the diet of the 4 RBT captured in June was composed of 24% dry weight unidentified salmonids. The diet of the 15 RBT from October efforts was composed of 5% unidentified salmonids. Additional piscivory was evident with approximately 13% by dry weight of the average June RBT diet represented by cyprinids. A total of 37% by dry weight of the diet of RBT captured on 2 June 1999 (n=4) was composed of fish prey items, the remainder was composed of invertebrates (Figure 1-12).

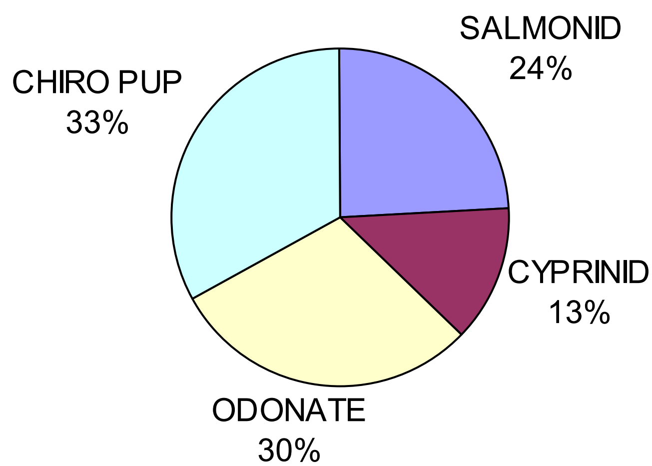

Figure 1-12. Diet of RBT captured on 2 June 1999 (n=4).

Diet analysis was conducted on kokanee that were collected by IDFG trawling in September 1999 (Pettit Lake n=19, Redfish Lake n=40, and Alturas Lake n=21). Kokanee mean size for each lake was as follows: Pettit Lake fork length of 158 mm (range 145-188 mm) and mean weight of 33.5 g (range 27-46 g); Alturas Lake mean fork length of 77.6 (range 47-119 mm); and mean weight of 5.8 g (range 0.9-16 g); and Redfish Lake mean fork length 86 mm (range 43-191) and mean weight 14.3 g (range 0.6-76). Kokanee from Redfish and Alturas lakes were divided into age classes according to size (age 0 <85 mm, age 1+ >85 mm) in order to quantify potential ontogenetic diet shifts. Pettit Lake was eliminated from this comparison because no small size class kokanee were caught in the trawl. Zooplankton biomass by species for each lake is presented here to aid interpretation. A detailed zooplankton analysis is presented in Chapter 2 of this report.

The diet (percent by dry weight) of age 0 kokanee in Redfish Lake was dominated by 62% cyclopoid copepod, which represented 45% of the in-lake zooplankton biomass (electivity index of 0.17) (Tables 1-8 and 1-9, Figures 1-13 and 1-14). The diet of age 1+ Redfish Lake kokanee was 50% *Polyphemus* sp., which represented 6% of the in-lake zooplankton biomass (electivity index of 0.78) (Tables 1-8 and 1-9, Figures 1-13 and 1-14). The diet of age 1+ kokanee was composed of only 1.5% (dry weight) cyclopoid copepod, the dominant species found in the lake by biomass (electivity index of –0.94) (Tables 1-8 and 1-9, Figures 1-14). Diet overlap between age 1+ and age 0 kokanee was 17%.

Similar differences were found in the age 0 and age 1+ kokanee diet (percent by dry weight) in Alturas Lake. The diet of age 0 kokanee in Alturas was 45% *Bosmina* sp. which represented 73% of the in-lake zooplankton biomass (electivity index of -0.23) (Tables 1-8 and 1-9, Figures 1-13 and 1-14). The diet of age 1+ kokanee in Alturas Lake was dominated by 5% P*olyphemus* sp. which represented 1% of the in-lake zooplankton biomass (electivity index of 0.98) (Tables 1-8 and 1-9, Figures 1-13 and 1-14). The diet of age 1 kokanee was composed of 1.7% *Bosmina* sp., the dominant species found in the lake by biomass (electivity index of –0.95) (Tables 1-8 and 1-9, Figures 1-13 and 1-14). Diet overlap between age 1+ and age 0 Alturas Lake kokanee was 40%.

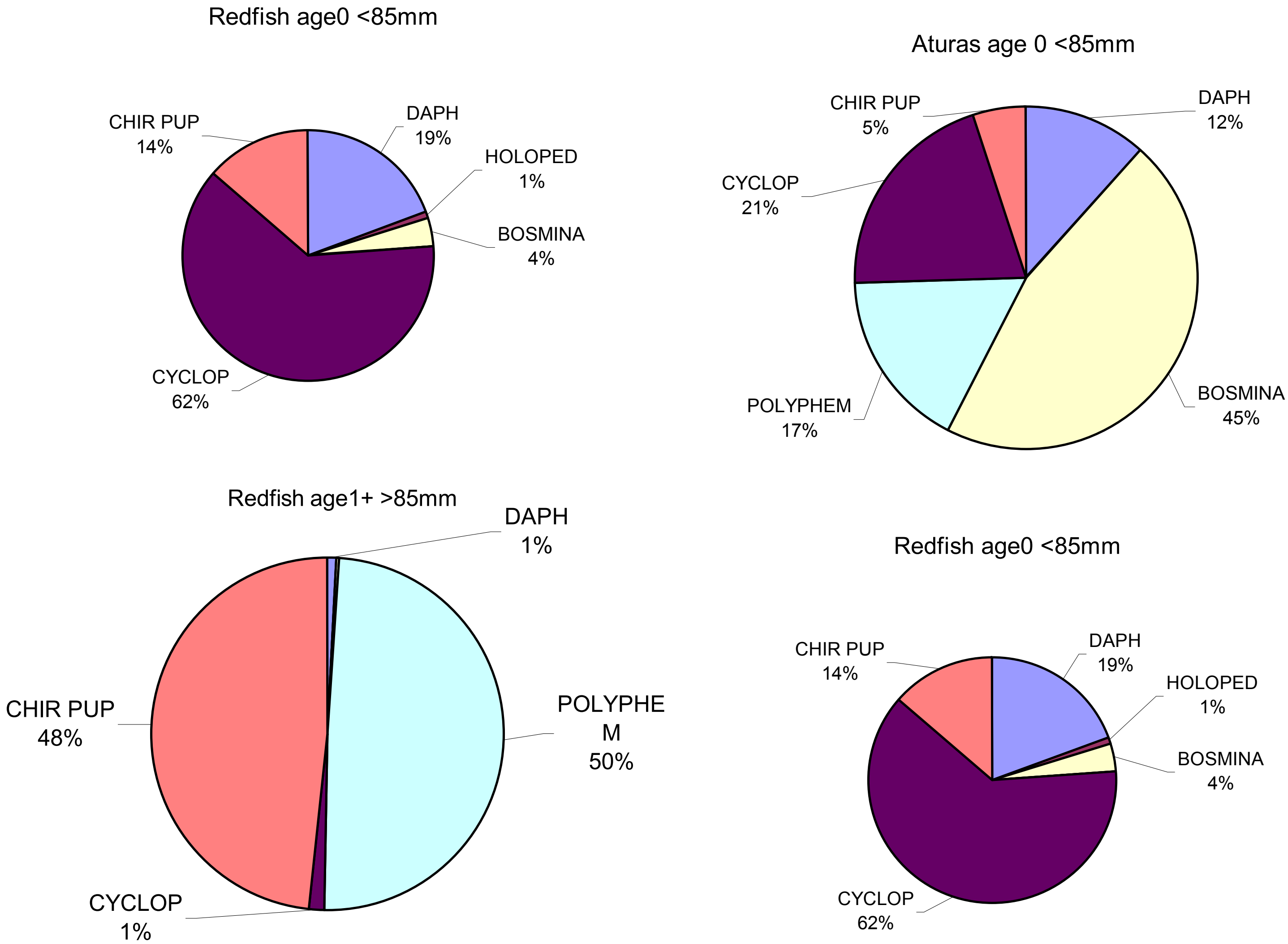

Figure 1-13. Diet of *O. nerka* by age class in September 1999 for Redfish and Alturas lakes.

Table 1-8. Comparison of Redfish and Alturas lakes kokanee diet by age class. Diet is presented as percent dry weight of prey species. There were no age 0 kokanee captured in Pettit Lake. (age 0 <85mm, age 1+ >85mm).

	DAPH	HOLOPED	BOSMINA	POLYPHEM	CYCLOP	CHIRO PUP
Redfish Lake						
Age 0	19.3	0.8	3.7	0.1	62.5	13.5
Age 1+	0.93	0.0	0.1	49.1	1.5	48.4
Alturas Lake						
Age 0	11.7	*	45.7	16.9	20.6	5.0
Age 1+	38.9	*	1.7	57.6	1.8	0
Pettit Lake						
Age 1+	4.2	0	68.0	10.7	5.9	11.2

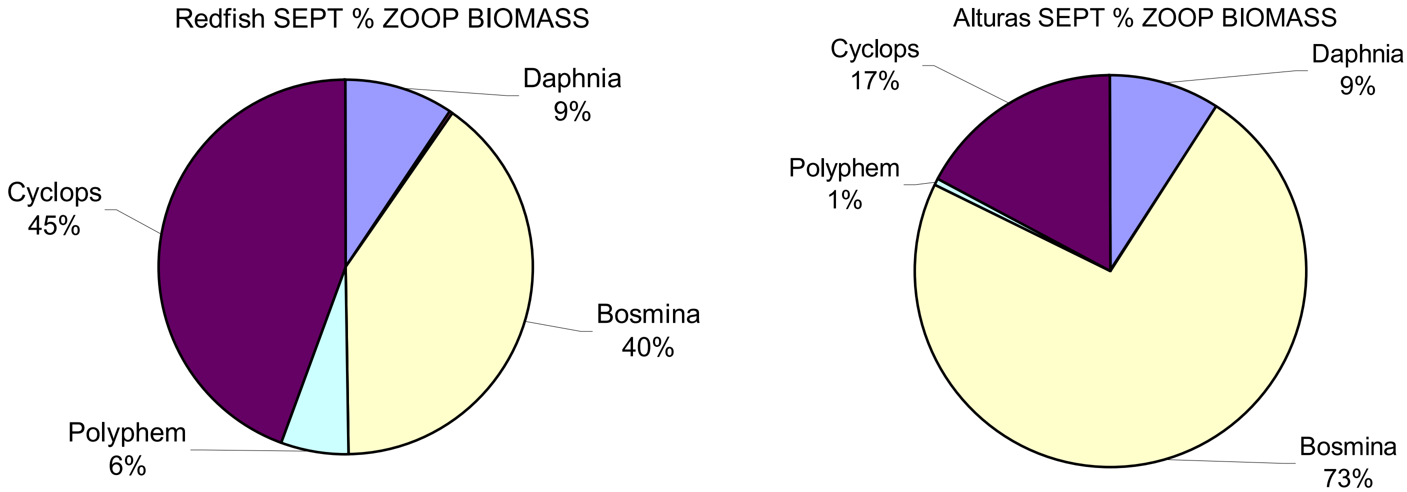

Figure 1-14. Zooplankton species composition by biomass in September 1999 for Redfish and Alturas lakes.

Table 1-9. Electivity indices comparing age 0 and 1 kokanee from Redfish and Alturas lakes.

	DAPH	HOLOPED	BOSMINA	POLYPHEM	CYCLOP
Redfish Lake					
Age 0 <85	0.35	0.53	-0.83	-0.98	0.17
Age 1+ >85	-0.82	*	-0.99	0.78	-0.94
Alturas Lake					
Age 0 <85	0.12	*	-0.23	0.93	0.09
Age 1+ >85	0.62	*	-0.95	0.98	-0.81

There was an average diet overlap of 13% for kokanee and rainbow trout in Pettit Lake. This overlap is solely attributed to chironomid pupae. Past diet surveys (Teuscher and Taki 1995) found that chironomid pupae dominated kokanee diets in early summer and shifted to zooplankton domination in late summer. This may be related to age class of the representative samples. In 1999, there was no early summer kokanee diet data available to compare and contrast changes in prey selection.

Additional diet analysis was conducted on fish from Pettit and Alturas lakes that were identified as potential *O. nerka* predators (Table 1-10). An analysis of bull trout diet (n=3 January, n=2 June, n=4 October) found no *O. nerka*. However, their diet did contain some unidentified salmonids. Due to the advanced state of digestion these salmonid prey have not been identified and may have been *O. nerka*. The average diet of northern pikeminnow captured in June (n=34) was composed of 28% cyprinids and 61% Odonates. The diet of brook trout (n=9) was dominated by 66.2% odonates followed by 13.7% cyprinids.

Table 1-10. Diet by mean percent dry weight of fish caught in Pettit Lake during all of 1999 gillnet sampling.

	SAL	CYPRIN	MOLUS	ODON	TRICOPT	COLEO	HEMIPT	CHIRO	TEREST	PLANT
BRK	0.0	13.7	7.00	66.2	1.1	11.1	0.0	0.1	0.0	0.6
BULL	59.1	25.0	0.00	13.5	0.0	0.0	0.0	0.0	0.0	0.0
RBT	4.8	2.5	13.24	8.5	0.0	1.3	6.1	12.3	5.6	35.6
PIKE	0.0	28.0	8.21	60.7	3.0	0.0	0.0	0.0	0.0	0.0

(BRK= brook trout, BULL=bull trout, RBT=rainbow trout, PIKE=northern pike minnow, SAL=salmonid, CYPRIN=cyprinid, MOLUS=mollosca, ODON=odonate, TRICOPT=tricoptera, COLEO=coleoptera, HEMIPT=hemiptera, CHIRO=chironomid pupae, TEREST=terestrial insect, PLANT=plant material)

Smolt diet

The diet of emigrating *O. nerka* smolts from all three lakes was dominated by emergent *Hemiptera* (Redfish n=24 [6 wild, 10 hatchery small size class, 8 hatchery large size class]; Alturas n=24 [12 wild, 12 hatchery]; Pettit n=13 [all hatchery]). Hemiptera larvae were also found in the guts of *O. nerka* smolts from Redfish Lake and one individual from Alturas. Chironomid pupae, Coleoptera, and terrestrial insects were also represented to a lesser degree in the diet of emigrating *O. nerka* smolts from all three lakes. Thirteen of 24 smolts from Alturas Lake had empty stomachs, 2 of 13 from Pettit Lake had empty stomachs, and 3 of 24 from Redfish Lake had empty stomachs. There were no differences in the diet composition between hatchery and wild fish, or between the different size classes. One unidentified larval fish was found in the gut of an emigrating *O. nerka* smolts from Redfish Lake. Zooplankton were found in only two emigrating *O. nerka* smolts guts, one from Alturas Lake and one from Redfish Lake.

Stream Spawning

Using a modified area under the curve (AUC) method, kokanee escapement for 1999 was estimated for Fishhook Creek (2,336), Alturas Lake Creek (8,334), and Stanley Lake Creek (948) (Table 1-11, Figure 1-15).

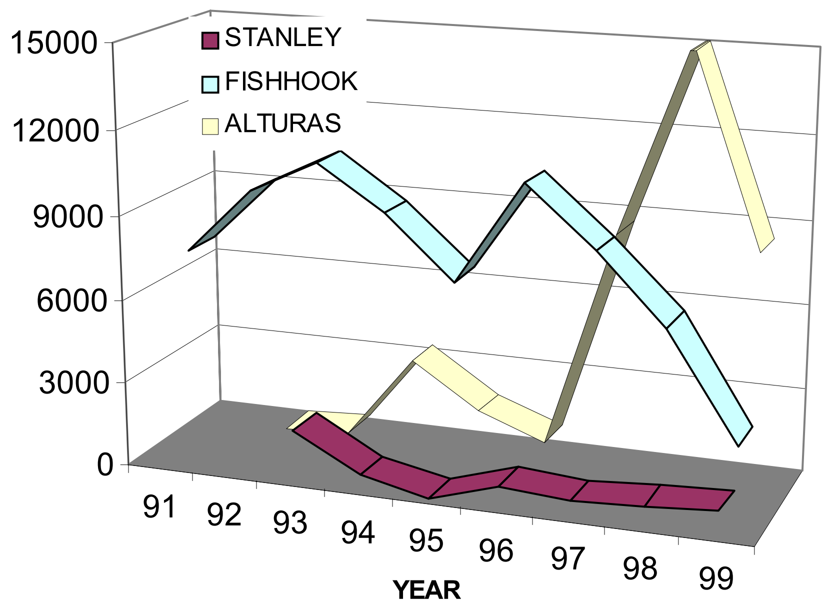

Figure 1-15. Kokanee escapement estimates for Stanley, Alturas, and Fishhook creeks.

Alturas Lake Creek

The 1999 Alturas Lake Creek spawning kokanee population (8,334 fish) was down approximately 55% from the escapement high of 1998. 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 1999 the escapement timing for 20, 50, and 80% of kokanee to enter the creek (Table 1-12) was later (7, 8, and 9 days, respectively) than the mean for all years combined. Escapement estimates for Alturas Lake Creek were calculated from field counts between 18 August and 21 September 1999. Assuming equal sex ratios, there was an estimated female escapement of 4,167 fish in 1999. Mean fecundity was estimated in 1999 at 285 eggs per female (n=12). Female kokanee had a mean fork length of 247 mm (range 230-258 mm) and a mean weight of 163.2 g (range 147-173 g). Male kokanee (n=18) had a mean fork length of 249 mm (range 231-265 mm) and a mean weight of 171 g (range 142-196 g). At 285 eggs per female, there were an estimated 1,187,595 eggs deposited in Alturas Lake Creek. Using a 13% egg-to-fry survival rate (Teuscher and Taki 1995) there were an estimated 154,387 fry were produced from the 1999 spawning activities (Table 1-11).

Stanley Lake Creek

The Stanley Lake Creek escapement remained relatively constant (948 fish) (Figure 1-15). In 1999 the escapement timing for 20, 50, and 80% of kokanee to enter the creek (Table 1-12) was earlier (approximately 3, 5, and 7 days, respectively) than the 1992-99 mean. Escapement estimates for Stanley Lake Creek were calculated from field counts made every three days from 3 August to 4 September. Assuming equal sex ratios, the escapement estimate for kokanee females in 1999 was 474 fish. Using a mean fecundity of 270 eggs per female (Teuscher and Taki 1995) approximately 71,100 eggs were deposited in Stanley Lake Creek. There would be an estimated 16,637 fry produced for 1999 at a 13% egg-to-fry survival rate (Teuscher and Taki 1995) (Table 1-11).

Fishhook Creek

The Fishhook Creek kokanee escapement estimate for 1999 (2336 fish) is the lowest recorded on that creek since monitoring started (Figure 1-15). In 1999 the escapement timing for 20, 50, and 80% of kokanee to enter the creek (Table 1-12) was later than the 1992-95 and 1996-99 means. Fishhook Creek escapement estimates were calculated from counts conducted from 16 August to 20 September 1999. Using a 1:1 sex ratio and estimated escapement there were 1,168 females spawning in the creek with 273,144 eggs (233 eggs per female) (Teuscher and Taki 1995) deposited. A 12.3% egg-to-fry survival rate (Teuscher and Taki 1995) will produce an estimated 33,454 fry in the spring of 2000 (Table 1-11).

Table 1-11. 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	1999	2,336	233	1:1	12.3%	33,474
Fishhook	1998	6,149	233	4.6:1	12.3%	31,468
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	1999	8,334	285	1:1	13.0%	154,387
Alturas	1998	15,273	220	1:1	13.0%	218,390
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	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 1-12. 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 populations had entered each creek. Presented are 1992-1995 mean (except for Stanley, which starts in 1993), 1996-1999 mean, and 1999.

Creek	Mean 1992-1995			Mean 1996-1999			1999		
	20%	50%	80%	20%	50%	80%	20%	50%	80%
Fishhook	21	29	38	22	30	37	34	30	44
Alturas	18	26	33	23	29	35	30	36	44
Stanley	12	18	27	11	17	23	8	12	16

Beach Spawning

On 5 October 1999 snorkel surveys were conducted by two divers at the southeast shore of Redfish Lake starting at 8:05 pm and finishing at 8:26 pm. Divers recorded 4 rainbow trout, 1 bull trout, 1 northern pikeminnow, 16 white fish, and 1 sucker. On the same night three divers surveyed sockeye beach on Redfish Lake and recorded a total of 1 sockeye (adipose clipped), 44 suckers, 1 bull trout, and 36 white fish. A second snorkel survey was conducted on the night of 12 October 1999 starting at 8:00 pm and finishing at 9:21 pm. No sockeye were seen at either location during this survey. Ten white fish, 12 suckers, and 1 rainbow trout were observed. A third survey of the same sights was conducted on 19 October 1999 starting at 7:50 pm and finishing at 9:30 pm. Two sockeye with adipose clips were seen at the southeast beach and no sockeye were seen at sockeye beach. Fish recorded included 8 bull tout, and 14 white fish, numerous suckers were seen but not counted. A fourth survey was conducted on 26 October 1999 starting at 7:50 pm and finishing at 9:15 pm. Fish observed included 1 adult sockeye, 1 bull trout, and 4 suckers. No residual *O. nerka* were seen during any of the 1999 snorkel survey activities (Figure 1-16).

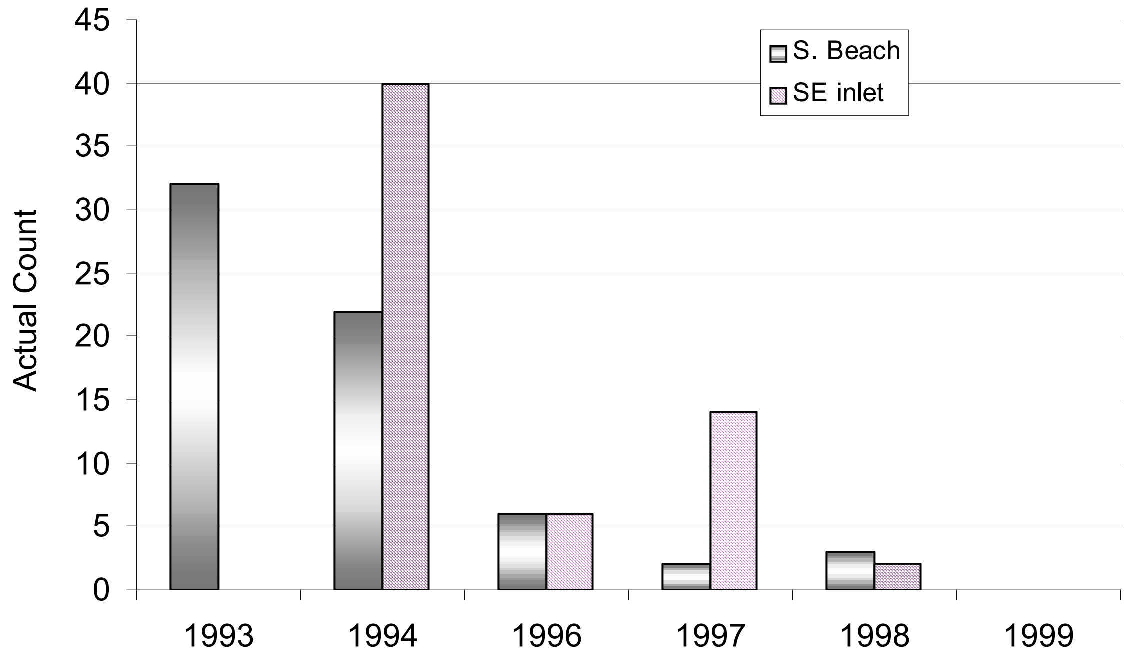

Figure 1-16. Redfish Lake residual *O. nerka* counts from snorkel surveys (1995 data not available).

DISCUSSION

Growth Rates

Growth rates of stocked *O. nerka* from the captive rearing program may provide further insight into potential performance differences associated with hatchery origin and lake rearing conditions. However, these results should be viewed with caution owing to the historic organization of the stocking strategy. Fish grew significantly faster in Pettit Lake compared to fish released into Redfish and Alturas lakes during 1998-99 replicating results found during 1997-98. Total zooplankton biomass in Pettit Lake is lower than that of Alturas and Redfish lakes from July 1998 to June 1999 (10.6, 11.3, and 12.4 *u*g/l respectively). Yet stocked *O. nerka* have significantly higher growth rates in Pettit Lake compared to the other two lakes. It is unclear if this is due to stocking timing, hatchery origin, or lake differences. In 1997 Pettit Lake received one stocking of fish on 1 July. Redfish and Alturas lakes received two fish stockings with the majority of the fish stocked in October. A similar stocking timing pattern was followed in 1998 which resulted in similar growth rates for fish in each of the lakes. The differences in growth may be associated with release timing or hatchery origin, but this cannot be determined from the current data set. Further possible explanations include factors such as foraging efficiency, zooplankton community dynamics, and fish community dynamics, which could be affecting growth rates of these fish. There are between-lake differences in zooplankton species composition. Alturas Lake kokanee population was three times greater in 1998 than in 1997, which has implications for the growth and survival of stocked juvenile *O. nerka*.

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 was 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 would indicate that the age 0 kokanee are feeding primarily in deeper waters. Levy (1990) hypothesized that during the day juvenile sockeye in lakes with piscivorous fish populations were concentrated in deeper areas with lower light levels to aid in predator avoidance. The diel vertical migration pattern of age

0 kokanee combined with the concentration of cyclopoid copepods in deeper waters explains the domination of their diet by that species.

The selection by age 1+ kokanee in Redfish and Alturas lakes for *Polyphemus* sp., a poorly represented species, may be the result of several factors. Larger age 1+ kokanee may be less susceptible to predation and have more opportunity to seek *Polyphemus* sp. throughout the water column. *Polyphemus* sp. is a larger bodied organism than cyclopoid copepod or *Bosmina* sp. and may represent a prey item of greater food value. The trade-off of higher food value could make the increased search time metabolically advantageous. Furthermore, age 1+ kokanee are found relatively higher in the water column and may have less access to cyclopoid copepods.

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 detected 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 composed 28% in 1999 and 77% of diet in 1998, Table 1-10) there has been no evidence of predation on *O. nerka* by northern pikeminnow. During gillnet sampling, the majority of northern pikeminnow are caught in the littoral zone of the lakes. *O. nerka* are primarily a pelagic species. The low degree of habitat utilization overlap may limit the opportunity for northern pikeminnow to predate on *O. nerka*. Predation by northern pikeminnow is not currently considered a problem. Ongoing monitoring of the northern pikeminnow populations and diets is warranted in order to detect any potential changes.

Bull trout are the top piscivorous predator of the fish community in the Sawtooth Lakes. Monitoring associated with this program has found that bull trout 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 trout 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 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. This will allow for monitoring of bull trout population dynamics. Otoliths and scale samples are collected from all bull trout and will be used to develop population age structure and age-at-length relationships.

Stream Spawning

Kokanee escapement in 1999 showed variation in population densities, timing, and fecundity. There has been concern that the kokanee population of Redfish Lake was too high. The TOC concluded that the stocking of anadromous juvenile *O. nerka* in addition to this large population of kokanee has potential to exceed the carrying capacity of the lake. Therefore, for the past several years kokanee escapement control efforts have been initiated on Fishhook Creek, the primary kokanee spawning habitat for Redfish Lake. The control effort had a target number of 2,000 spawning kokanee. This year there were an estimated 2,336 spawning kokanee without control efforts. This escapement was well below the 1991-98 mean of 8,647.

The Alturas Lake Creek kokanee escapement estimate was down from 15,273 in 1998 to 8,334 in 1999. The kokanee escapement for the past three years is well above the 1993-

96 mean of 1,436. The expanding kokanee population may exceed the carrying capacity of Alturas Lake in the near future, limiting the lake's usefulness to the recovery effort.

The kokanee escapement timing was later in both Fishhook and Alturas Lake creeks than the mean observed escapement time. The time at which 20% of the kokanee had entered Fishhook Creek was 13 and 12 days later than the 1992-95 and 1996-99 means respectively. The time at which 80% of the kokanee had entered Fishhook Creek was 6 and 7 days later than the 1992-95 and 1996-99 means respectively. The time at which 20% of the kokanee had entered Alturas Lake Creek was 12 and 7 days later than the 1992-95 and 1996-99 means respectively. The time at which 80% of the kokanee had entered Alturas Lake Creek was 11 and 9 days later than the 1992-95 and 1996-99 means respectively.

Alturas Lake Creek kokanee had higher fecundity compared to previous measurements. The mean number of eggs per female in 1999 was 285. The mean number of eggs per female was 220 in 1998, 168 in 1997, and 150 in 1994. The mean number of eggs per female kokanee has not been measured for several years on Fishhook and Stanley Lake creeks. Based on variation in Alturas Lake 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 steady decline in the number of residual *O. nerka* since the surveys began. Only five residuals were observed in 1998 (two during one survey and three on another), and no residuals were observed in 1999.

Smolt Diet

Analysis of smolt diet shows that *O. nerka* smolts were actively foraging at the time of emigration. Diet was composed of primarily emergent insects (*Hemiptera* sp.) demonstrating that smolts were feeding on the surface of the water. Zooplankton, a primary prey item of juvenile *O. nerka*, were found in only two of the 61 guts sampled. Zooplankton are generally at low densities in early spring. While ice cover on the lakes is common during emigration, the outlet areas of all three lakes have areas of open water. The density of early emergent insects in these areas may make them readily available compared to zooplankton. Emergent insects are significantly larger than zooplankton and may represent a higher food value resource.

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Chapter 2: Nutrient Supplementation and Limnology of the Sawtooth Valley Lakes, 1999

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INTRODUCTION

In December 1991, the National Marine Fisheries Service listed Snake River sockeye salmon (O*ncorhynchus nerka*) as endangered under the Endangered Species Act (Waples et al. 1991). Consequently, the Sawtooth Valley Project was initiated to conserve and rebuild sockeye salmon populations in the Sawtooth Valley lakes (Redfish, Pettit, Alturas, and Stanley lakes). The recovery strategy was to increase the number of juvenile sockeye salmon rearing in the nursery lakes using hatchery broodstocks (Flagg and McAuley 1994, Johnson and Pravecek 1995), improve growth and survival of juvenile sockeye salmon, and increase lake carrying capacities via lake fertilization (Stockner and MacIsaac 1996). In Redfish Lake, kokanee *O. nerka* escapement was controlled to limit kokanee recruitment to the lake and reduce intra-specific competition between kokanee and sockeye salmon (Taki and Mikkelsen 1997).

Lake fertilization has been successfully used to stimulated primary production in oligotrophic lakes and, through trophic transfer, increase macrozooplankton production thus improving rearing habitat for young planktivorous sockeye salmon (LeBrasseur et al. 1978, Hyatt and Stockner 1985, Stockner and Shortreed 1985, Stockner 1987, Kyle 1994). Lake fertilization programs replace nutrients formerly derived from decaying salmon carcasses with liquid fertilizer in nutrient limited systems with depressed adult escapement (LeBrasseur et al. 1979, Stockner and MacIsaac 1996). In Alaska and British Columbia, lake fertilization has been associated with increased survival and growth of young sockeye salmon (LeBrasseur et al. 1978, Robinson and Baraclough 1978, Hyatt and Stockner 1985, Kyle 1994) and elevated adult escapement (LeBrasseur et al. 1979, Stockner and MacIsaac 1996). The relationship between *O. nerka* population abundance and available forage in a nursery lake (carrying capacity) can be manipulated with nutrient applications resulting in higher lake carrying capacities (Stockner and MacIsaac 1996). While success of fertilization programs are often determined by increases in zooplankton abundance and biomass (Kyle 1994), a successful program could also result in stable zooplankton populations under increased grazing pressure from expanding *O. nerka* populations.

In 1999, limnological monitoring was conducted to assess productivity and identify changes in physical and chemical characteristics of the Sawtooth Valley lakes. The information was used to identify inter-annual variation of physical and chemical characteristics, evaluate nutrient supplementation efforts, and determine *O. nerka* carrying capacities of the Sawtooth Valley lakes. Methodologies and sampling designs were developed by Utah State University (USU) during the initial phase of this project (Budy et al. 1993, Steinhart et al. 1994, Budy et al. 1995, Luecke et al. 1996) and modified by Griswold (1997). The variables measured in 1999 include, water temperature, dissolved oxygen, conductivity, water transparency, light penetration, nutrient concentrations, phytoplankton species composition, abundance and bio-volume, chlorophyll *a* concentrations, primary productivity, and zooplankton density and biomass.

STUDY AREA

The Sawtooth Valley lakes are located in South Central Idaho near the town of Stanley. The watersheds are located in the Sawtooth Mountains, mostly within the Sawtooth Wilderness Area and administered by the US Forest Service, Sawtooth National Recreation Area. The Sawtooth Mountains are part of the Idaho batholith, comprised of granitelike rock, consisting of granodiorite, quartz diorite and quartz monzonite (Emmett 1975). The lakes are at a relatively high elevation (1985-2157 m), generally ice covered from January to May and classified as oligotrophic. The ratio of drainage area to lake surface area is 48.6 for Stanley Lake, 22.4 for Alturas, 17.6 for Redfish and 16.9 for Pettit Lake (Table 2-1)(Gross et al. 1993). Morphometric maps of the lakes and descriptions of the lakes and their watersheds are reported in Budy et al. (1993), a map of the study area is in Chapter 1 (Figure 1-1) of this report. Limnological sampling was conducted at three stations in each lake. The stations were positioned along the longitudinal axes of the lakes, with the main station near mid-lake, the south station near the south or west end (inlet), and the north station nearest the north or east end (outlet).

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

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

METHODS

Lakes were sampled from January to November 1999. Redfish, Pettit, and Alturas lakes were sampled once per month in March, October, and November and twice per month from June through September. In 1999, these three lakes were stocked with juvenile sockeye salmon from the Redfish Lake captive broodstock and Pettit and Alturas lakes were enriched with liquid fertilizer. Redfish Lake, which has received supplemental nutrients for the past four years, was not fertilized in 1999. Stanley Lake was not stocked with sockeye salmon and did not receive nutrient applications. Stanley Lake was sampled once per month in March, June, August, October, and November to help distinguish the effects of natural annual variation versus fertilization treatments. Utah State University, contracted by the Shoshone-Bannock Tribe, studied these lakes extensively from 1991 to 1995. Data collected, compiled, and reported by USU have been used throughout this project (Spaulding 1993, Teuscher et al. 1994, Teuscher et al. 1995, Teuscher and Taki 1996). When lakes were stratified, water for nutrient analysis was collected from the epilimnion, metalimnion, and hypolimnion. Chlorophyll *a* and phytoplankton samples were collected from the epilimnion, metalimnion, and 1% light level. Three discrete samples were collected from each stratum with a three L Van Dorn bottle and mixed in a churn splitter. When lake strata could not be delineated, surface water was collected from 0-6 m with a 25 mm diameter, 6 m long lexan® tube and discrete samples were collected from mid-depth (Redfish = 45 m, Pettit and Alturas = 25 m, and Stanley = 12 m) and 1-2 m above the bottom.

Lake Fertilization

In 1999, operating under a consent order issued by the Idaho Division of Environmental Quality (DEQ), the Shoshone-Bannock Tribes (SBT) added supplemental nutrients to Pettit and Alturas lakes. The consent order requires measurement of water transparency once per week and estimates of epilimnetic and metalimnetic chlorophyll *a* and nutrient concentrations every two weeks. The consent order specifies that nutrient enhancement activities may continue as long as 1) water transparencies are greater than 6 and 4 m in Pettit and Alturas lakes, respectively, prior to 15 July and greater than 8 m in both lakes after 15 July, 2) epilimnetic chlorophyll *a* is less than 3 *u*g/l, 3) metalimnetic chlorophyll *a* remains less than 6 *u*g/l, and 4) total phosphorus concentrations remain below 15 *u*g/l in the epilimnion and metalimnion of the two lakes.

Liquid ammonium phosphate (20-5-0) and ammonium nitrate (28-0-0-0) fertilizer was applied weekly from 20 July to 19 October in Pettit Lake and from 25 August to 19 October 1999 in Alturas Lake. Stockner (1997) developed fertilization prescriptions for each lake. Nutrients were applied at a ratio of approximately 20:1 N:P by mass (45:1 molar) and were purposely skewed toward high nitrogen loads to avoid stimulation of nitrogen fixing Cyanophytes. The applications were made from a 6.7 m boat equipped with a portable plastic tank and electric pump. The fertilizer was loaded into the tanks off-site then pumped into the boat's wake while traveling over the surface of the lake. Twelve predetermined transect lines were followed at Alturas Lake and eight at Pettit Lake, using GPS, compass, and local landmarks to evenly disperse the nutrients over the surface of the lake.

Profile Data

Temperature (^{o}C), dissolved oxygen (mg/l), and conductivity (*u*S/cm) profiles were collected at the main station of each lake using a Hydrolab® Surveyor3™ equipped with a Hydrolab H20® submersible data transmitter or a Yellow Springs Instrument Model 58 dissolved oxygen meter. The instrument was calibrated each day prior to sampling.

Dissolved oxygen was calibrated using barometric pressure estimated from elevation. Standards obtained from the Myron L Company were used to calibrate conductivity. Temperature, dissolved oxygen, and conductivity were recorded at 1m 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 (May-October) surface water temperatures.

Water Transparency and Light Penetration

Water transparency (secchi depth) was measured at the main station of each lake with a 20 cm secchi disk. The disk was lowered into the water until it disappeared from sight and the depth was noted. The depth at which the disk reappeared when raised was also noted and an average of the two values was recorded as water transparency depth (Koenings et al. 1987).

Light attenuation was measured at the main station of each lake with a LiCorr® 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 1% light level. Deck and sea cell readings were made simultaneously to correct for changes in ambient light. Photic zone depth was determined by linear regression of the natural log of percent surface light at each depth versus depth (Wetzel and Likens 1991).

Water Chemistry

Water was collected for nutrient analysis once per month in March, May or June, and July-October. Water was transferred to nalgene bottles that had been rinsed in 0.1 N HCL and sample water. Samples were stored at 4 ^{o}C while in the field. Water for ammonia, nitrate, and orthophosphorus assays was filtered through 0.45 *u*m acetate filters at 130 mm Hg vacuum in the laboratory. Water samples were frozen and shipped to the UC Davis Limnology Laboratory for analysis. Ammonia was assayed with the indophenol method, nitrate with the hydrazine method, organic nitrogen using kjeldahl nitrogen, the calorimetric method was used to determine orthophosphorus, and total phosphorus was assayed by persulfate digestion (Hunter et al. unpublished). Method detection levels (MDL) for each assay are shown in Table 2-2.

Table 2-2. Nutrient assay methods with minimum detection levels (MDL) and 99% confidence intervals (C.I.)(Hunter et al. Unpublished).

Assay	**Method**	**MDL (*u*g/l)**	**99% C.I.**
Ammonia	indophenol	3	± 0.3
Nitrate	hydrazine	2	± 0.3
Organic nitrogen	kjeldahl	35	± 16.0
Orthophosphorus	calorimetric	1	± 6.6
Total phosphorous	persulfate digestion	2	± 0.5

Chlorophyll a and Phytoplankton

Water was collected for chlorophyll *a* each sample period and for phytoplankton once per month in March and November and twice per month from June-October. Water samples were stored at 4 ^{o}C in the field and then filtered onto 0.45 *u*m cellulose acetate membrane filters with 130 mm Hg vacuum pressure. Filters were placed in centrifuge tubes and frozen (-25 ^{o}C). The filters were then placed in methanol for 12-24 hours to extract the chlorophyll pigments. Florescence was measured with a Turner model 10-AU fluorometer calibrated with chlorophyll standards obtained from Sigma Chemical Company. Samples were run before and after acidification to correct for phaeophytin. (Holm-Hansen and Rieman 1978). Phytoplankton samples were fixed in Lugol's solution and shipped to Eco-Logic, Inc for analysis. Phytoplankton were identified and counted using an inverted fluorescent microscope and abundance and bio-volume were determined (Stockner 1998).

Primary Productivity

State of Washington Water Research Center personnel estimated primary productivity in the Sawtooth Lakes. Primary productivity estimates were obtained between 27-30 July, 27-30 August, 17-20 September and 22-25 October during 1999 at one station in each lake. 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/m^3/hour) estimates were plotted and integrated using plainimetry to determine hourly rates of primary productivity based on surface area (mg C/m^2/hour). Hourly productivity estimates were expanded to daily productivity (mg C/ m^2/day) using solar irradiance data and the methodology described by Vollenweider (1965) and Britton and Greeson (1987). Juul (2000) provides a complete description of methods used to determine primary productivity in 1999.

Zooplankton

Zooplankton was sampled one to two times per month. Vertical hauls were made with a 0.35 m diameter, 1.58 m long, 80 *u*m mesh conical net, with a removable bucket. The net was equipped with a release mechanism that allowed sampling at discrete depth intervals. A General Oceanics flow meter modified with an anti-reverse bearing was mounted in the mouth of the net. The flow meter was used to correct for net efficiency (clogging). The net was retrieved by hand at a rate of one meter per second from 10-0 m, 30-10 m, 60-30 m and 2 m above bottom to 60 m at the deep station in Redfish Lake. The shallow stations in Redfish and all stations in Pettit and Alturas lakes were sampled from 10-0 m, 30-10 m, and bottom-30 m. Stanley Lake was sampled at 10-0 m and bottom 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).

RESULTS

In 1999, mean annual discharge of the Salmon River at Salmon, Idaho (USGS gage 13302500) was 65.4 m^3/s, 18% above the 1913-1999 average of 55.6 m^3/s (Figure 2-1). This represents a continuation of the pattern of below average annual discharge prior to 1995 and above average discharge since 1995. In 1999, mean annual discharge for the Salmon River was slightly higher than the 61.1 m^3/s reported in 1998 and lower than the 87.1 m^3/s recorded in 1997.

Lake Fertilization

In 1999, Redfish and Stanley lakes were not treated with supplemental nutrients. Pettit and Alturas lakes were fertilized for the third consecutive year in 1999. Pettit Lake was fertilized with 30.6 kg P and 623.8 kg N between 20 July and 19 October and Alturas Lake received 47.9 kg P and 968.9 kg N between 25 August and 19 October (Table 2-3). Total P applications in Pettit Lake were similar to applications made in 1997 and 22% higher than the 1998 treatments. Nutrient applications in Alturas Lake were 25% less than applications made in 1997 and 17% below 1998 additions. Total nutrient additions for Pettit and Alturas lakes, based on lake surface area, were approximately 61% and 46% of the 1997-98 Redfish applications. Areal loading rates were 18.9 and 14.2 mg P/m^2 for Pettit and Alturas lakes, respectively. TN:TP ratios of fertilizer additions were approximately 20:1 in both lakes during 1999. Nutrient supplementation was initiated

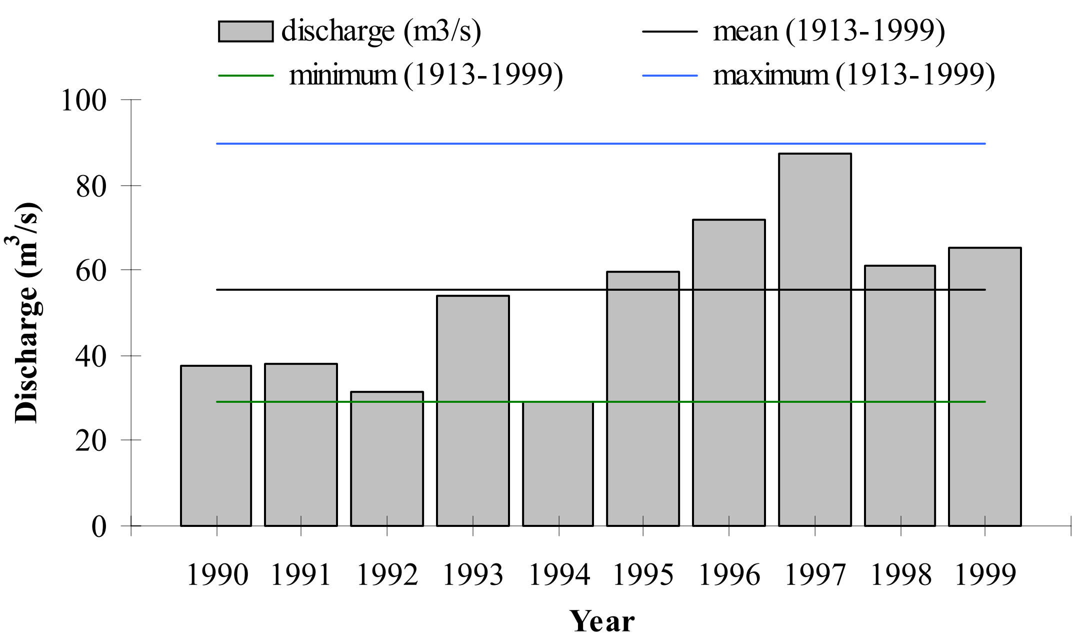


Figure 2-1. Mean annual discharge for the Salmon River at Salmon, Idaho, 1990 through 1999. Mean, minimum, and maximum are for period of record, 1913 to 1999.

Table 2-3. Supplemental nutrient additions to Redfish, Pettit, and Alturas lakes, Idaho during 1995 to 1999.

Lake	Year	P (kg)	N (kg)	mg P/m^2	mg N/m^2	TN:TP
Redfish	1995	260.6	4622.8	42.4	751.7	17.7
	1996	51.1	933.5	8.3	151.8	18.3
	1997	190.0	3695.0	30.9	600.8	19.4
	1998	189.8	3701.7	30.9	601.9	19.5
	1999	0.0	0.0	0.0	0.0	-
Pettit	1995	0.0	0.0	0.0	0.0	-
	1996	0.0	0.0	0.0	0.0	-
	1997	31.6	632.0	19.5	390.1	20.0
	1998	25.0	465.1	15.4	287.1	18.6
	1999	30.6	623.8	18.9	385.1	20.4
Alturas	1995	0.0	0.0	0.0	0.0	-
	1996	0.0	0.0	0.0	0.0	-
	1997	63.5	1339.0	18.8	396.2	21.1
	1998	58.0	1172.3	17.2	346.8	20.2
	1999	47.9	968.9	14.2	286.7	20.2

later than during previous years to avoid the violations in DEQ water quality criteria that occurred during spring 1998 (Figure 2-2). The applications were designed to increase phytoplankton productivity during late summer and early fall (clear water phase) and to improve foraging conditions for zooplankton during the fall and winter. During 1999 we remained in compliance with DEQ water quality criteria in both lakes, however nutrient applications were interrupted in Pettit and Alturas lakes during September because of manpower constraints.

Profile Data

The Sawtooth Valley lakes were inversely stratified and ice covered from late December 1998 to mid May 1999. Thermoclines were well developed from July through October (Figures 2-3a, 2-3b, 2-3c, and 2-3d). The lakes were nearly isothermic by November.

Dissolved oxygen concentrations in the Sawtooth Valley lakes were generally greater than 5 mg/l, the minimum level that will support growth and survival of salmonids

(Lagler 1956). Dissolved oxygen concentrations in Redfish Lake remained above 5 mg/l throughout the entire water column between March and November 1999. Pettit Lake,

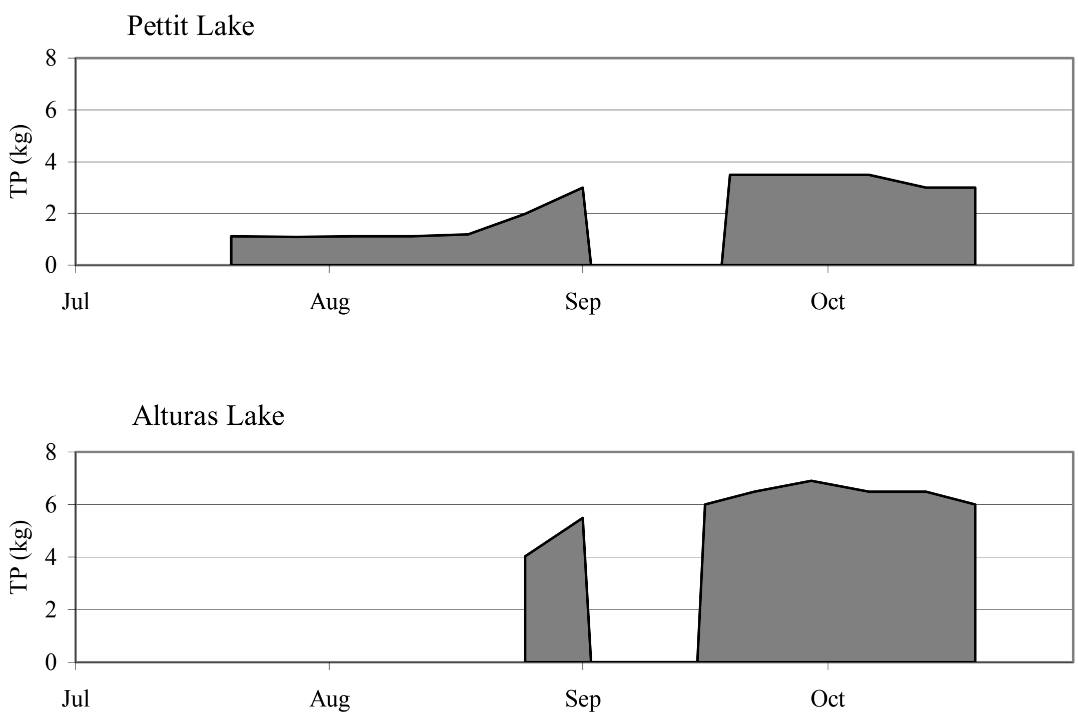


Figure 2-2. Supplemental total phosphorus additions (kg) to Pettit and Alturas lakes, July through October 1999.

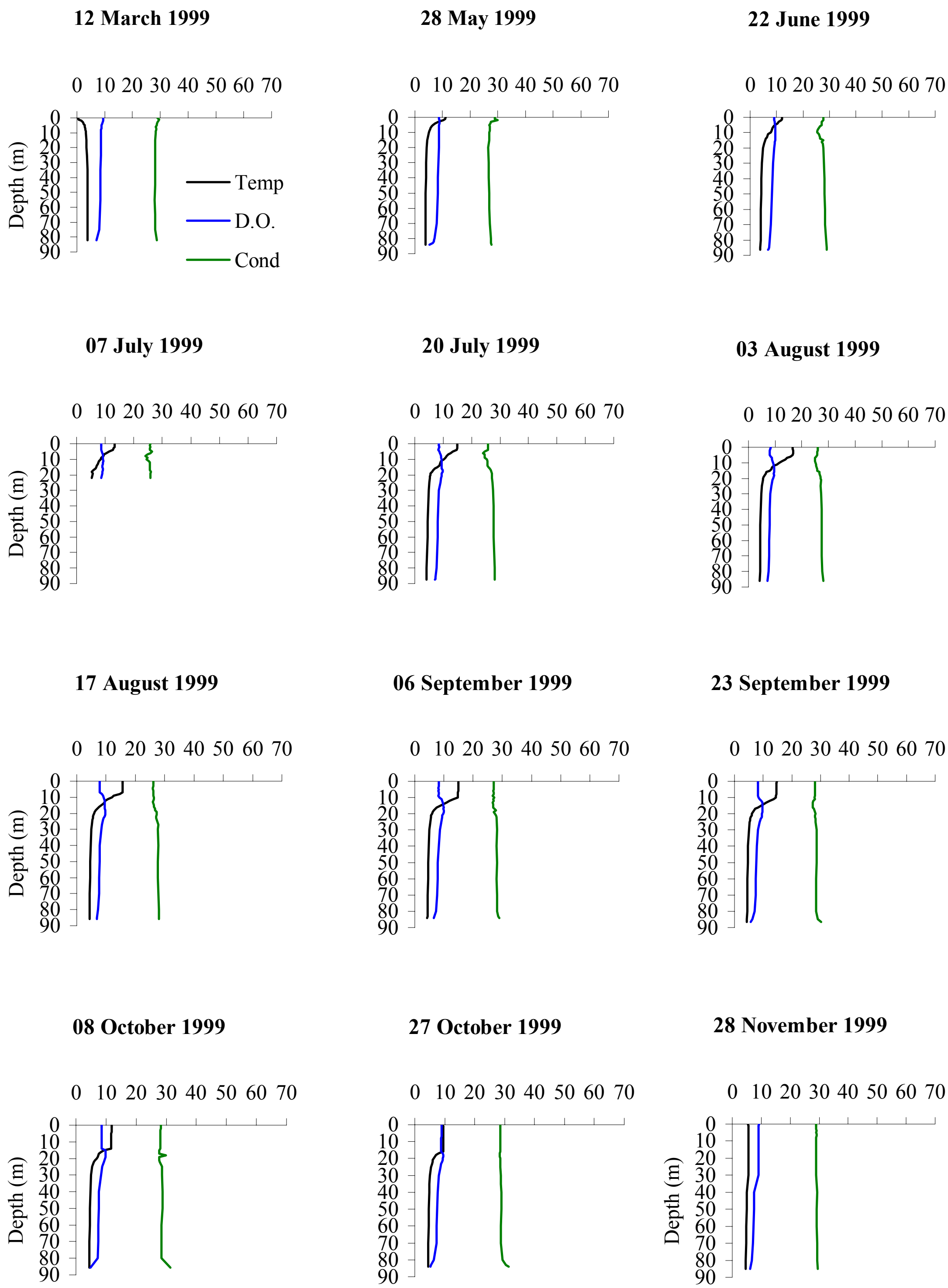


Figure 2-3a. Temperature (^oC), dissolved oxygen (mg/l), and conductivity (*u*S/cm) profiles for Redfish Lake, March through November 1999.

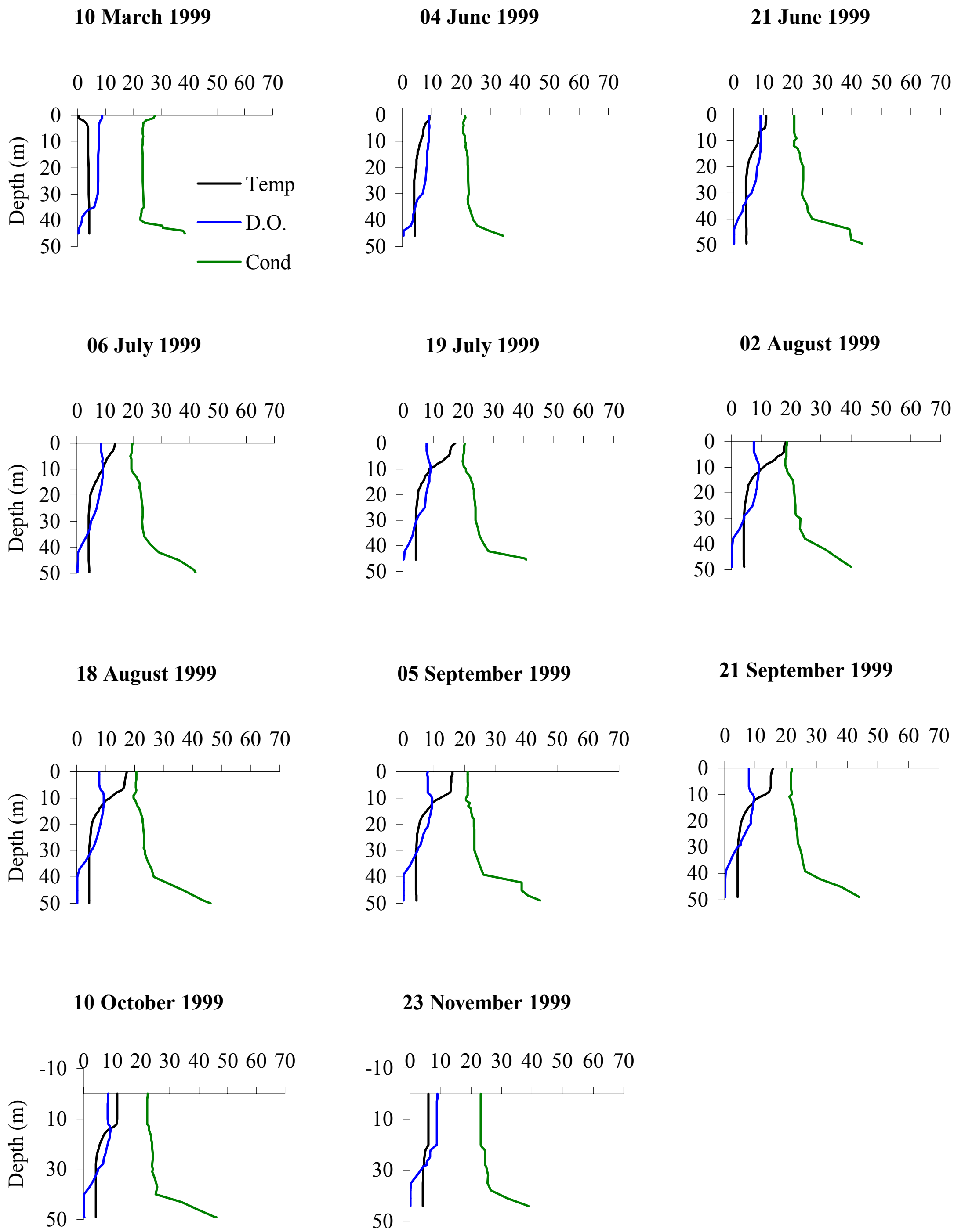


Figure 2-3b. Temperature (^{o}C), dissolved oxygen (mg/l), and conductivity (*u*S/cm) profiles for Pettit Lake, March through November 1999.

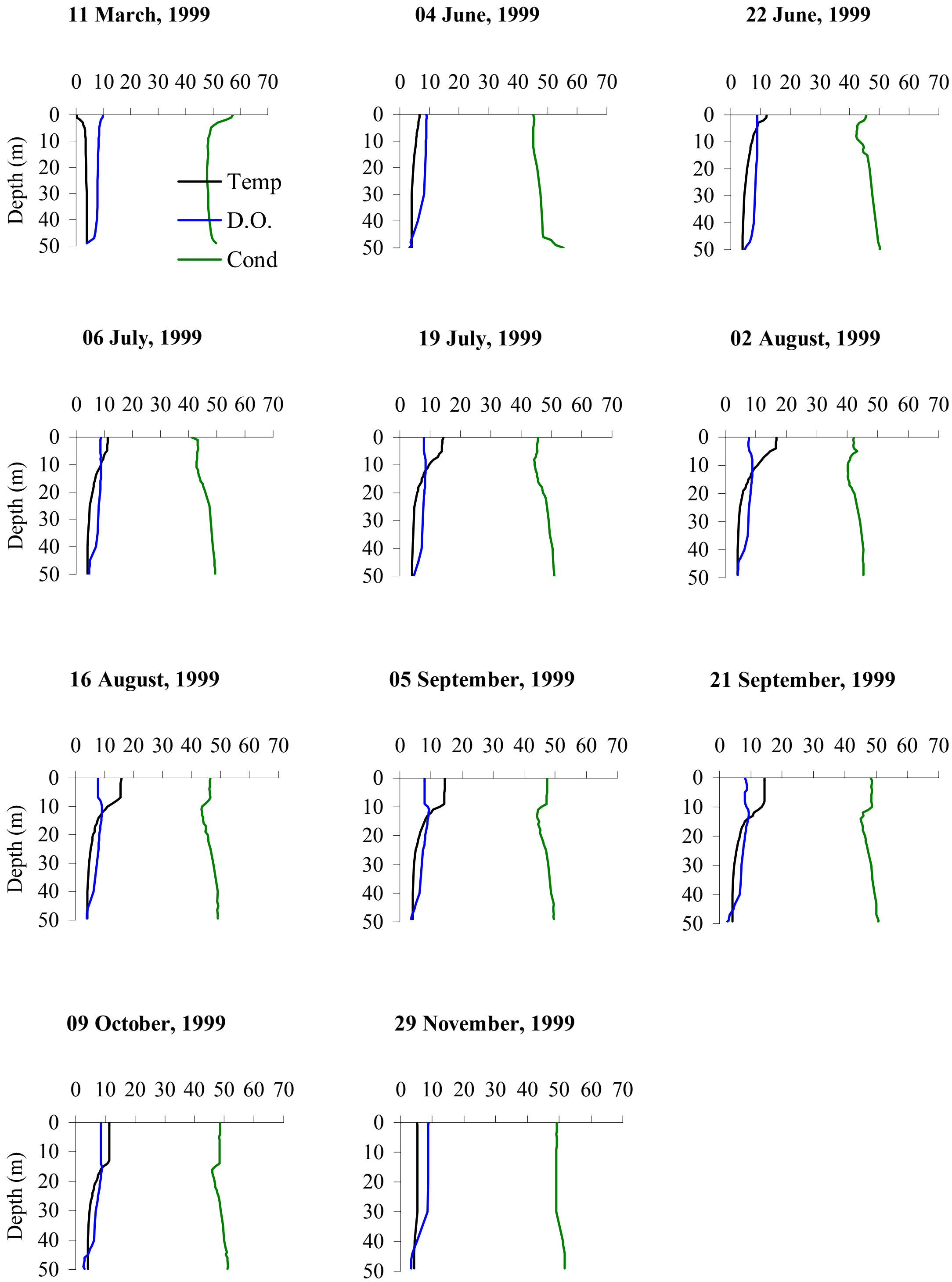


Figure 2-3c. Temperature (^{o}C), dissolved oxygen (mg/l), and conductivity (*u*S/cm) profiles for Alturas Lake, March through November 1999.

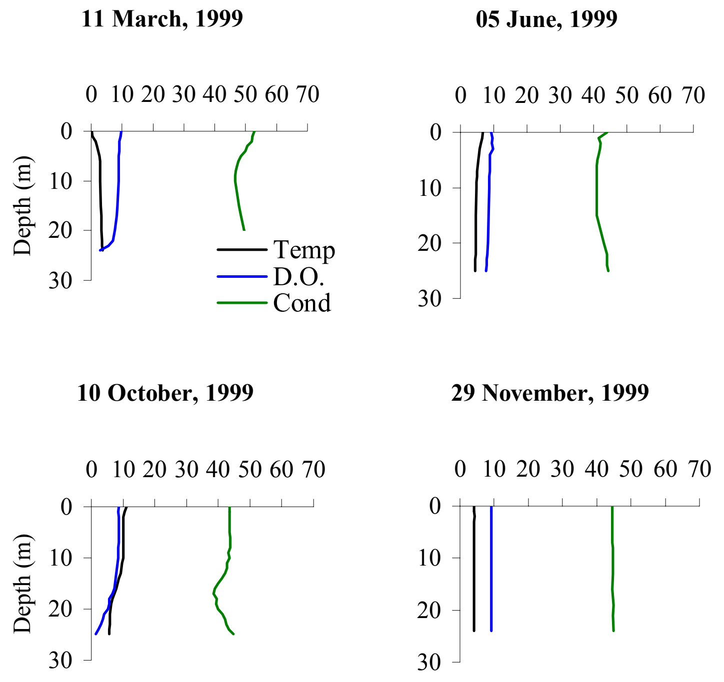


Figure 2-3d. Temperature (°C), dissolved oxygen (mg/l), and conductivity (*u*S/cm) profiles for Stanley Lake, March through November 1999.

which is meromictic, had dissolved oxygen concentrations less than 5 mg/l below 28-31 m depth. Alturas Lakes had low oxygen concentrations in the bottom 2 meters during March, this hypoxic region increased to include the bottom five meters of the lake by early June. In late June, dissolved oxygen concentrations were above 5 mg/l in all but the bottom 1-2 m. This hypoxic region increased to include the deepest 5 meters by November. In Stanley Lake, DO concentrations were less than 5 mg/l in the bottom meter during March, remained above 5 mg/l throughout the entire water column during June and August and expanded to include the bottom five meters by October. The lake mixed and the entire water column was above 5 mg/l dissolved oxygen in November. Seasonal declines in dissolved oxygen near the substrates of Redfish, Alturas, and Stanley lakes were less pronounced in 1999 than in 1998.

Conductivities were relatively consistent throughout the year and were similar to those reported by Luecke et al. (1996), Griswold (1997) and Taki et al. (1999). Conductivities ranged from approximately 18-24 *u*S/cm above 30 m depth and 22-46 *u*S/cm at depths greater than 30 m in Pettit, 24-31 *u*S/cm in Redfish, 40-51 *u*S/cm in Alturas, and 38-45 *u*S/cm in Stanley lakes.

Seasonal mean surface (0-10 m) water temperatures were 11.8, 12.7, 11.8, and 11.1 ^{o}C in Redfish, Pettit, Alturas, and Stanley lakes, respectively (Table 2-4). Seasonal mean

Table 2-4. Seasonal mean (May-October) surface water temperature (^{o}C), water transparency (m), photic zone depth (m), epilimnetic chlorophyll *a* (*u*g/l), and whole-lake total zooplankton biomass (*u*g/l).

Lake	Year	Surface Temperature (^{o}C) 0-10 m	Water transparency (m)	Photic zone depth (m)	Epilimnetic chl a (*u*g/l)	Whole-lake zooplankton biomass (*u*g/l)
Redfish	**1992**	14.4	13.6	32.5	0.5	4.7
	1993	12.2	13.6	26.3	0.7	6.9
	1994	14.0	15.0	31.0	0.4	10.3
	1995	12.9	12.3	28.4	0.4	11.8
	1996	11.0	13.7	22.6	0.8	7.8
	1997	11.4	11.3	20.0	1.5	8.2
	1998	11.9	12.7	23.5	1.4	10.4
	1999	11.8	14.1	23.0	0.9	7.0
	mean	**12.5**	**13.3**	**25.9**	**0.8**	**8.4**
Pettit	**1992**	14.9	15.2	29.3	0.4	30.7
	1993	12.7	14.3	23.3	0.6	23.3
	1994	14.5	14.1	30.5	0.3	33.9
	1995	12.7	12.6	23.8	0.5	3.9
	1996	11.1	11.1	20.6	1.0	9.1
	1997	11.5	10.9	19.0	1.4	11.2
	1998	12.3	10.6	23.1	1.4	9.3
	1999	12.7	11.2	21.7	1.4	15.6
	mean	**12.8**	**12.5**	**23.9**	**0.9**	**17.1**
Alturas	**1992**	14.3	13.5	26.2	0.6	4.7
	1993	11.8	-	20.6	1.0	0.5
	1994	13.4	14.7	23.5	0.5	3.9
	1995	12.0	9.6	17.6	0.4	2.7
	1996	10.4	10.3	16.1	1.1	5.7
	1997	10.5	10.2	15.5	1.2	11.0
	1998	11.3	10.3	17.2	2.3	10.9
	1999	11.8	10.5	16.9	1.2	12.3
	mean	**11.9**	**11.3**	**19.2**	**1.1**	**6.5**
Stanley	**1992**	14.2	8.2	18.6	0.8	32.1
	1993	11.1	7.5	15.4	1.4	18.8
	1994	14.1	7.8	15.5	0.5	24.6
	1995	11.4	5.6	11.4	0.9	20.8
	1996	10.0	7.0	12.2	1.3	21.8
	1997	10.7	7.0	12.7	1.4	19.9
	1998	10.8	5.0	11.5	1.3	26.2
	1999	11.1	6.7	11.4	1.6	20.6
	mean	**11.7**	**6.8**	**13.6**	**1.1**	**23.1**

surface water temperatures were slightly higher than in 1996-1998 in Pettit, Alturas, and Stanley lakes. Seasonal mean surface water temperature in Redfish Lake was similar to 1998 and slightly higher than in 1996 and 1997. In 1999, seasonal mean surface water temperatures were similar to the 1992-1999 average in Pettit and Stanley lakes and slightly below the eight year average in Redfish and Stanley lakes.

Water Transparency and Light Penetration

Water transparencies in Redfish, Pettit, and Alturas lakes were lowest during March when lakes were ice covered and in June after spring mixing stimulated phytoplankton production, similar to past years (Budy et al.1996, Griswold 1997, Taki et al. 1999) (Figure 2-4). Transparencies increased throughout the summer and fall until the lakes mixed in the fall.

Seasonal mean water transparencies (May-October) were 14.1, 11.2, and 10.5 m in Redfish, Pettit, and Alturas lakes, respectively (Table 2-4). Mean water transparency in Redfish Lake was higher than observed since 1994 and higher than the 1992-1999 mean of 13.3 m. Water transparencies in Pettit and Alturas lakes were slightly higher in 1999 than during 1996-1998 but still below the eight year average. In Stanley Lake the seasonal mean water transparency was 6.7 m, similar to 1996 and 1997 and the eight-year average but higher than in 1997 when a freshet introduced suspended sediment into the lake.

Photic zone depths in the four Sawtooth Valley lakes were the shallowest in June after spring turnover and in October just before fall turnover. Maximum light penetration was 25.8 m in Redfish Lake, 24.3 m in Pettit Lake, 19.9 m in Alturas Lake, and 13.9 m in Stanley Lake (Figure 2-5). Seasonal mean light penetration in 1999 was less than mean light penetration observed during the dryer, pre-fertilized years (1992-1994) and similar to mean light penetration in recent years (1995-1999) with higher discharge and nutrient supplementation (Table 2-4). Water transparencies and photic zone depths were positively correlated, $R^2 = 0.75$) (Figure 2-6)

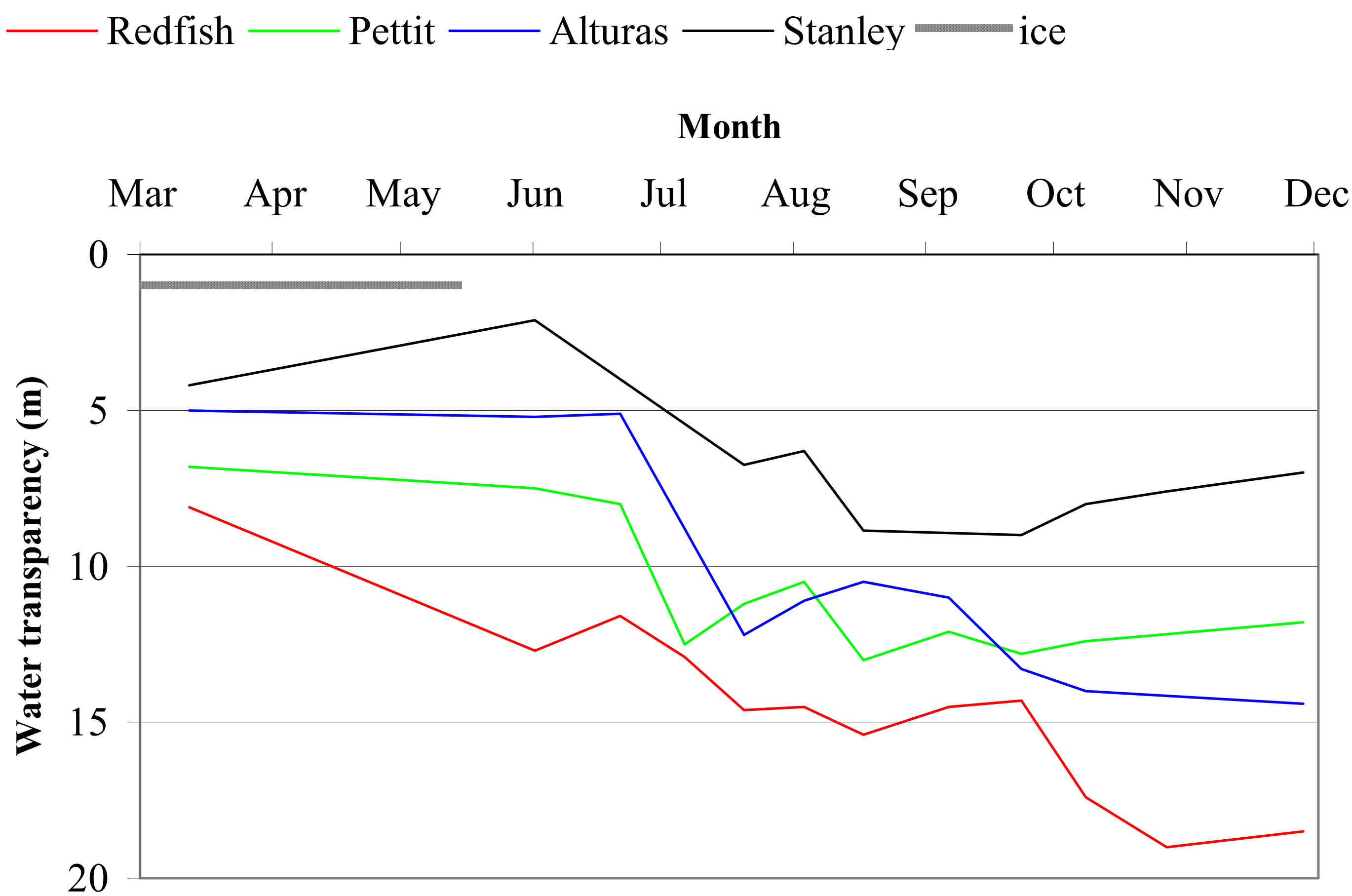


Figure 2-4. Water transparencies (secchi depth) in meters for Redfish, Pettit, Alturas and Stanley lakes, March through November 1999. Shaded line indicates ice cover.

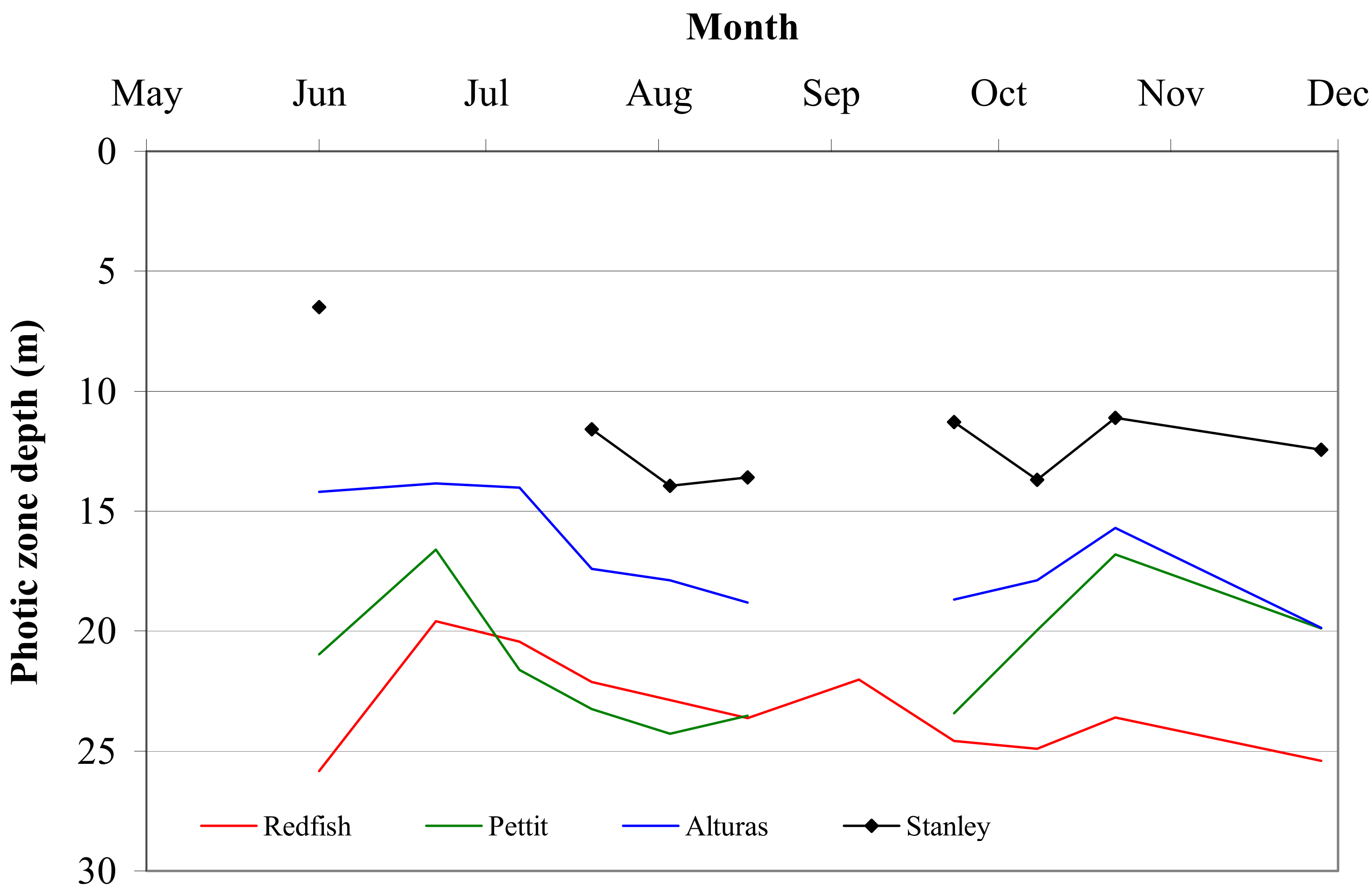


Figure 2-5. Depth of the photic zone defined by the 1% light level (in meters) for Redfish, Pettit, Alturas, and Stanley lakes, May through November 1999.

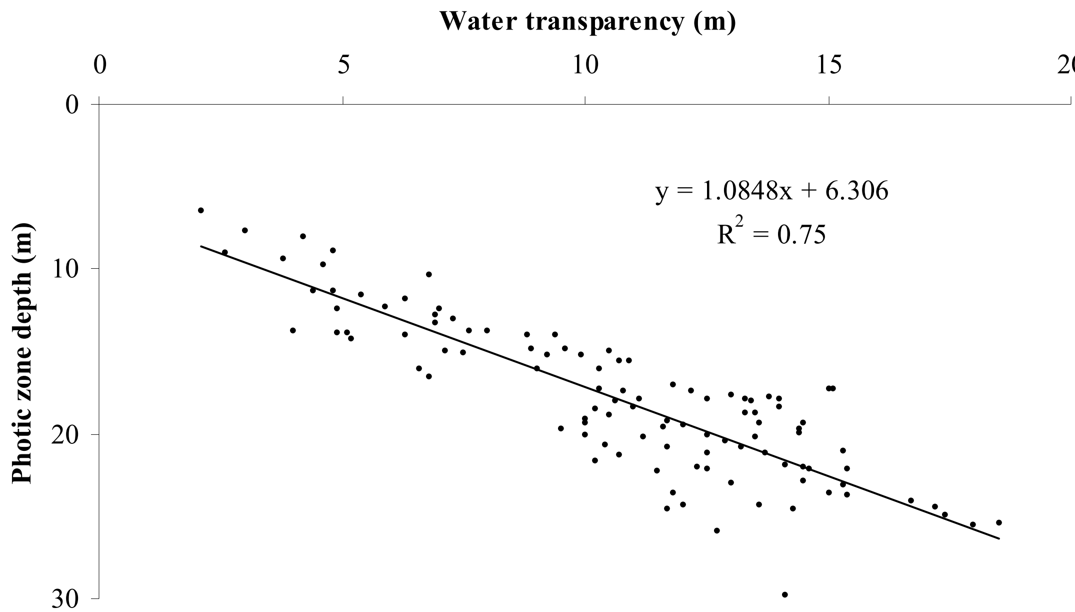


Figure 2-6. Relationship between water transparency (m) and photic zone depth (m) in Redfish, Pettit, Alturas, and Stanley lakes, October 1995-November 1999 (n=108).

Water Chemistry

During spring turnover (May 1999) depth integrated total phosphorus (TP) concentrations were similar to the 1992-1999 mean and lower than concentrations observed during 1998 in Redfish, Pettit, and Alturas lakes. Spring TP concentration in Stanley Lake was above the 8 year average and similar to 1998 values. TP concentrations were the highest in Stanley Lake (14.0 *u*g/l), followed by Alturas Lake (10.3 *u*g/l), Redfish Lake (6.8 *u*g/l), and Pettit Lake (5.9 *u*g/l) (Table 5). Depth integrated total nitrogen (TN) concentrations at spring turnover were similar to the 1992-1999 average. TN:TP ratios were 11.6 in Redfish Lake, 12.3 in Pettit Lake, 7.4 in Alturas Lake, and 6.2 in Stanley Lake. Lower TP concentrations in Redfish, Pettit, and Alturas lakes resulted in higher TN:TP ratios, relative to 1998.

Depth integrated nitrate concentrations during spring turnover were lower than in 1998 in Redfish, Alturas, and Stanley lakes (Table 2-5). In Redfish and Stanley Lakes nitrate concentrations were above the 1992-1999 mean, while Pettit and Alturas lakes had nitrate concentrations less than the 8 year average. Nutrient concentrations in surface waters of the Sawtooth Valley lakes were variable during March-October 1999 (Table 2-6). TP concentrations ranged from 4.0-7.7 *u*g/l in Redfish, 4.0-8.0 *u*g/l in Pettit, 5.0-10.0 *u*g/l in

Alturas, and 4.4-14.1 *u*g/l in Stanley lakes (Figure 2-7). TP concentrations did not exhibit clear patterns of seasonal changes. TP concentrations were relatively high in late May, August, and October. Redfish Lake was similar to the fertilized lakes until September when TP concentrations were less than those in Pettit and Alturas lakes. TP concentrations were highest in Stanley Lake during May. Seasonal mean TP concentrations were similar to the 1992-1999 average.

TN concentrations in surface waters were relatively consistent during the first half of 1999. Late in the growing season TN concentrations in Pettit and Alturas rose to approximately twice the TN concentrations in the unfertilized lakes (Figure 2-7). TN concentrations ranged from 45-160 *u*g/l in the four lakes during May-October. Seasonal mean TN in Redfish was similar to the 8 year average and to values observed during 1997 and 1998 (Table 2-6). Pettit and Alturas lakes had seasonal mean TN concentrations higher than the 1992-1999 mean and higher than seen during recent years. Stanley Lake seasonal mean TN concentration was approximately 17% lower than the 8 year average.

TN:TP ratios ranged from 5.0 to 16.0 in the four Sawtooth Valley Lakes during March through October 1999 (Figure 2-7). Seasonal mean TN:TP concentrations were 10.2 in Redfish Lake, 14.0 in Pettit Lake, 9.9 in Alturas Lake, and 7.0 in Stanley Lake (Table 2-6). Seasonal mean TN:TP ratios were similar to or slightly lower than the 1992-1999 average in Redfish, Pettit, and Alturas lakes. The mean seasonal TN:TP ratio in Stanley Lake was lower than the 8 year average and the lowest observed to date in that lake.

Table 2-5. Nutrient concentrations (*u*g/l) and TN/TP ratio during late May-early June (after spring mixing) 1992-1999 in Redfish, Pettit, Alturas, and Stanley lakes, Idaho. Concentrations are averages of three discrete depths.

Lake	Year	TP	TN	Nitrate	Ammonia	Orthphosphorus	TN/TP
Redfish	**1992**	6.5	61.0	5.5	-	1.0	9.5
	1993	8.6	52.7	6.7	-	-	6.2
	1994	5.6	-	-	-	-	-
	1995	5.0	74.2	3.8	2.0	1.0	14.8
	1996	4.8	77.0	12.7	2.3	-	16.1
	1997	6.0	-	17.0	-	-	-
	1998	11.0	82.6	37.0	5.2	1.0	7.7
	1999	6.8	78.4	20.4	2.7	-	11.6
	mean	**6.8**	**71.0**	**14.7**	**3.0**	**1.0**	**11.0**
Pettit	**1992**	6.4	94.5	7.0	-	1.0	18.3
	1993	5.8	94.0	4.0	-	-	-
	1994	6.6	-	-	-	-	-
	1995	4.8	88.8	12.0	3.5	1.0	18.4
	1996	5.3	64.3	13.0	7.1	-	11.6
	1997	5.5		16.5	-	-	-
	1998	10.2	48.0	-	0.7	0.9	4.8
	1999	5.9	72.1	6.6	1.9	-	12.3
	mean	**6.3**	**77.0**	**9.8**	**3.3**	**1.0**	**13.1**
Alturas	**1992**	10.0	74.0	2.0	-	2.8	7.4
	1993	9.4	72.5	3.3	-	-	8.2
	1994	13.9	-	-	-	-	-
	1995	8.2	66.4	5.8	3.5	1.4	7.7
	1996	6.0	74.6	11.6	2.2	-	12.4
	1997	10.0	-	14.7	-	-	-
	1998	18.1	69.6	17.8	3.1	1.9	3.8
	1999	10.3	77.4	6.6	1.7	-	7.4
	mean	**10.7**	**72.4**	**8.8**	**2.6**	**2.0**	**7.8**
Stanley	**1992**	10.5	93.5	5.0	4.0	1.0	8.9
	1993	11.4	129.8	8.5	-	-	12.7
	1994	11.3	-	-	-	-	-
	1995	7.0	103.0	9.2	18.0	1.2	14.8
	1996	6.5	-	-	-	-	-
	1997	7.2	-	9.7	-	-	-
	1998	15.1	78.5	19.0	11.6	1.2	5.1
	1999	14.0	86.4	14.5	2.5	-	6.2
	mean	**10.4**	**98.2**	**11.0**	**9.0**	**1.1**	**9.5**

Table 2-6. Seasonal mean (May-October) epilimnetic nutrient concentrations (*u*g/l) and TN/TP ratio in Redfish, Pettit, Alturas, and Stanley lakes during 1992-1999.

Lake	Year	TP	TN	Nitrate	Ammonia	Orthphosphorus	TN/TP
Redfish	**1992**	8.3	50.1	6.5	-	1.7	6.7
	1993	6.8	65.1	2.4	3.2	1.6	10.0
	1994	8.5	-	-	-	2.0	-
	1995	7.1	85.5	3.7	6.4	1.7	14.7
	1996	4.9	48.1	1.9	1.3	0.9	10.9
	1997	5.6	67.0	5.8	3.5	0.0	16.0
	1998	7.2	63.9	9.2	2.9	-	8.9
	1999	5.5	65.2	6.2	4.8	-	10.2
	mean	**6.7**	**63.6**	**5.1**	**3.7**	**1.3**	**11.1**
Pettit	**1992**	5.9	87.4	4.6	-	1.9	16.4
	1993	6.5	75.0	2.1	3.0	1.7	13.4
	1994	6.4	-	-	-	1.0	-
	1995	5.5	82.4	1.0	3.3	1.4	16.5
	1996	5.8	40.6	0.6	1.3	0.9	7.7
	1997	5.4	71.6	2.0	2.6	0.0	17.9
	1998	5.9	76.3	1.4	1.8	-	12.7
	1999	6.3	93.9	2.4	5.0	-	14.0
	mean	**6.0**	**75.3**	**2.0**	**2.8**	**1.1**	**14.1**
Alturas	**1992**	7.8	82.4	4.0	-	1.3	9.9
	1993	8.6	87.6	3.4	2.6	1.2	12.7
	1994	11.8	-	-	-	2.4	-
	1995	8.4	109.8	2.2	7.0	1.8	14.9
	1996	7.8	61.7	2.1	1.7	1.0	8.6
	1997	8.2	66.6	1.7	1.8	0.3	11.6
	1998	9.4	69.9	1.0	1.9	-	7.8
	1999	7.9	101.5	1.7	6.6	-	9.9
	mean	**8.7**	**82.8**	**2.3**	**3.6**	**1.3**	**10.8**
Stanley	**1992**	8.0	90.9	3.9	4.0	1.8	11.4
	1993	7.0	98.1	4.7	11.6	1.6	14.8
	1994	9.9	-	-	-	2.7	-
	1995	7.9	90.6	2.3	7.3	1.8	11.7
	1996	7.1	-	-	-	-	-
	1997	4.9	57.3	3.0	3.3	0.0	13.7
	1998	9.3	63.6	1.2	1.9	-	7.9
	1999	9.9	64.5	5.4	2.6	-	7.0
	mean	**8.0**	**77.5**	**3.4**	**5.1**	**1.6**	**11.1**

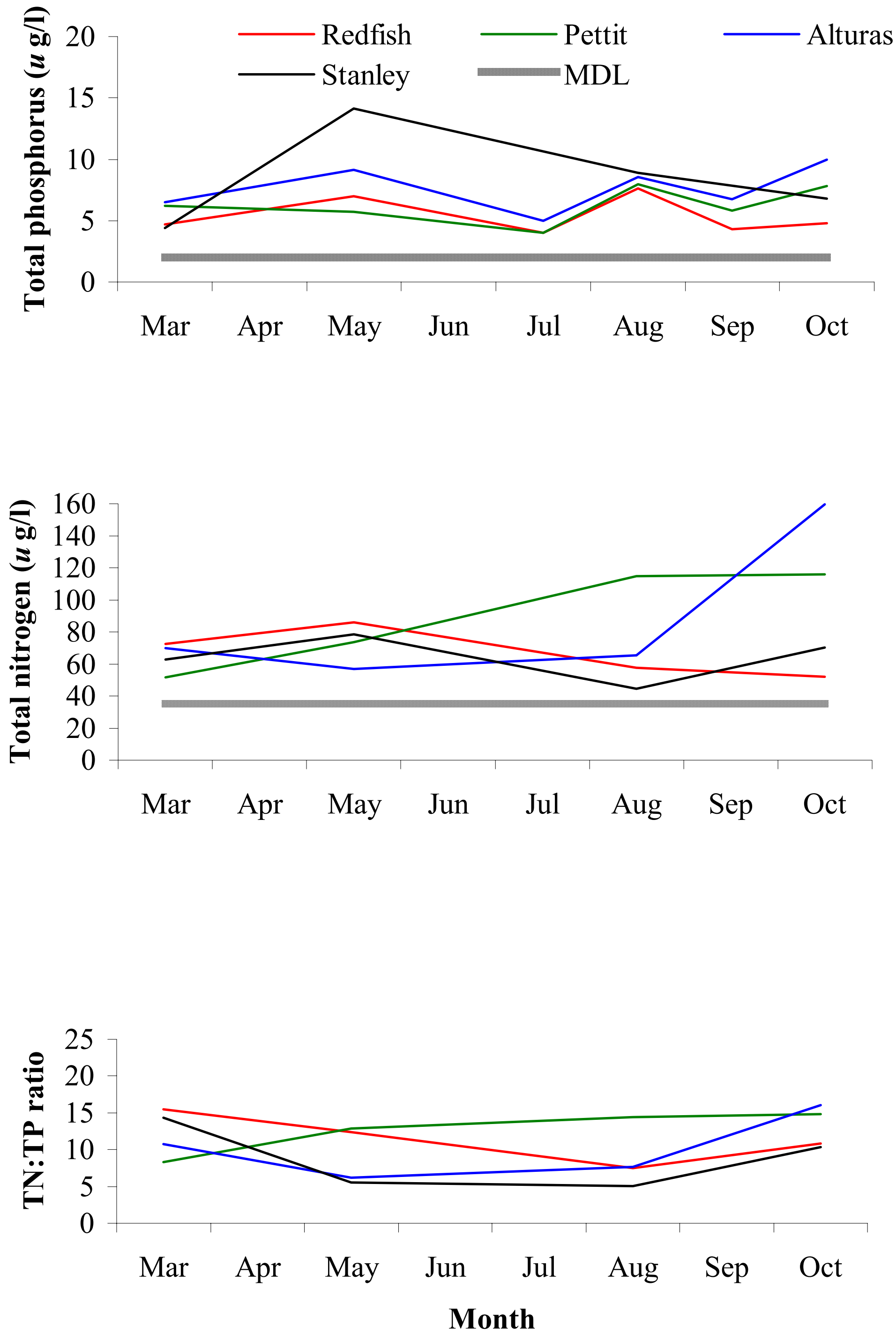
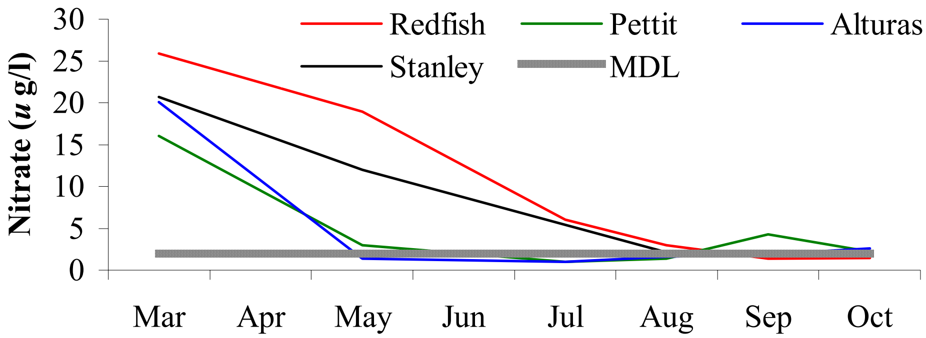


Figure 2-7. Total phosphorus and total nitrogen concentrations (*u*g/l), and the TN/TP ratio in the epilimnetic waters of Redfish, Pettit, Alturas, and Stanley lakes, March through October 1999. Grey line denotes method detection level.

Nitrate concentrations were between 16.0 and 25.9 during March 1999. Nitrate concentrations dropped rapidly in Pettit and Alturas lakes and by May were near method detection levels where they remained through October. Redfish and Stanley lakes declined at a lower rate, but were near detection levels by August (Figure 2-8). Ammonia concentrations were elevated in March and October and near detection levels during May through August.



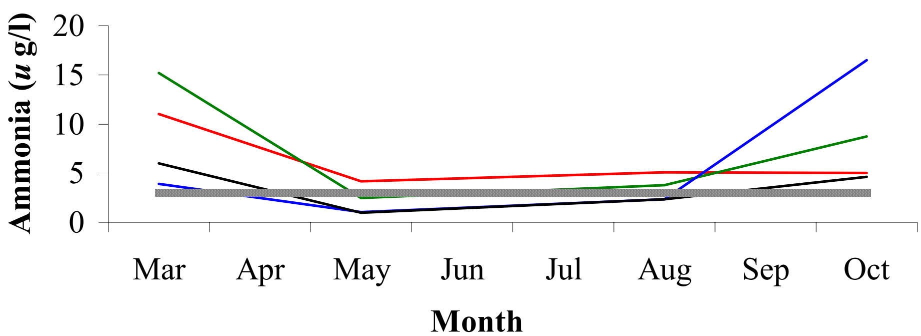


Figure 2-8. Nitrate and ammonia concentrations (*u*g/l) in the epilimnetic waters of Redfish, Pettit, Alturas, and Stanley lakes, March through October 1999. Grey line denotes method detection level.

Chlorophyll a and Phytoplankton

In 1999, surface chlorophyll *a* concentrations ranged from 0.3 to 4.1 *u*g/l in the four Sawtooth Valley lakes. Chlorophyll *a* concentrations during March were 1.1 *u*g/l in Alturas, 1.5 *u*g/l in Pettit, 0.7 *u*g/l in Stanley, and 0.3 *u*g/l in Redfish lakes. During the ice-free season surface chlorophyll *a* concentrations peaked during June in Stanley Lake, September in Pettit Lake and during December in Redfish and Alturas lakes (Figure 2-9). Peak chlorophyll *a* concentrations were 4.1 *u*g/l in Alturas Lake, 2.7 *u*g/l in Stanley Lake, 2.6 *u*g/l in Pettit Lake and 1.4 *u*g/l in Redfish Lake.

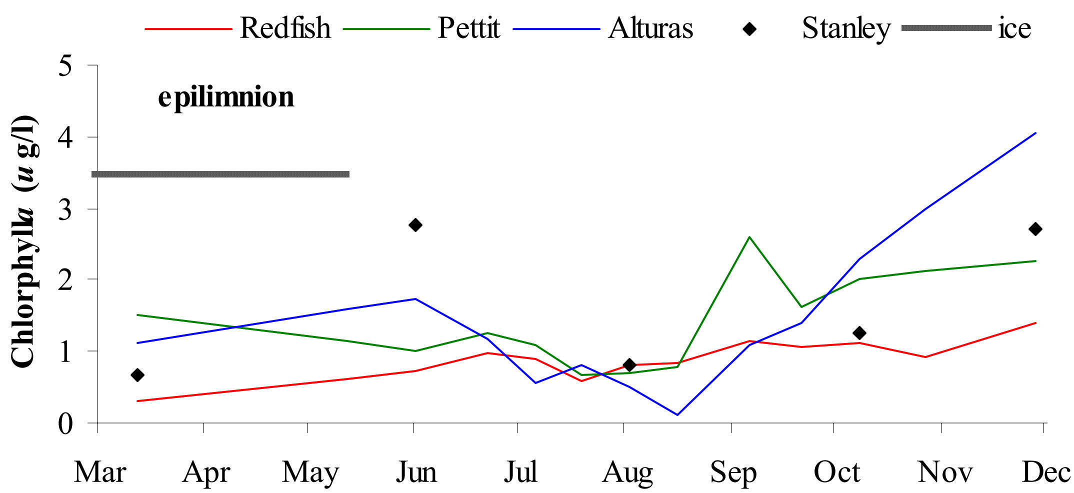


Figure 2-9. Surface chlorophyll *a* concentrations (*u*g/l) in Redfish, Pettit, Alturas, and Stanley lakes, March-November 1999. Shaded line indicates ice cover.

Seasonal mean surface chlorophyll *a* concentration in Redfish was 0.9 *u*g/l, which was lower than seasonal mean values in 1997 and 1998 and similar to the 1992-1999 average (Table 2-4). Pettit Lake had a seasonal mean surface chlorophyll *a* concentration of 1.4 *u*g/l, the same as during 1997 and 1998 and 56% higher than the 1992-1999 average. Alturas Lake had a seasonal mean surface chlorophyll *a* concentration of 1.2 *u*g/l, almost half of the 1998 mean and similar to the long-term average. Seasonal mean surface chlorophyll *a* concentration was 1.6 *u*g/l in Stanley Lake, higher than any previous years and 45% above the 1992-1999 mean.

Chlorophyll *a* concentrations at the 1% light level were highest in Redfish Lake during early August when chlorophyll *a* concentration reached 10.4 *u*g/l (Figure 2-10). Redfish Lake remained high relative to the other lakes through October. Pettit Lake peaked at 3.9 *u*g/l during July then declined to approximately 2.1-2.5 *u*g/l during August through November. Alturas and Stanley lakes had lower and less variable chlorophyll *a* concentrations at the 1% light level.

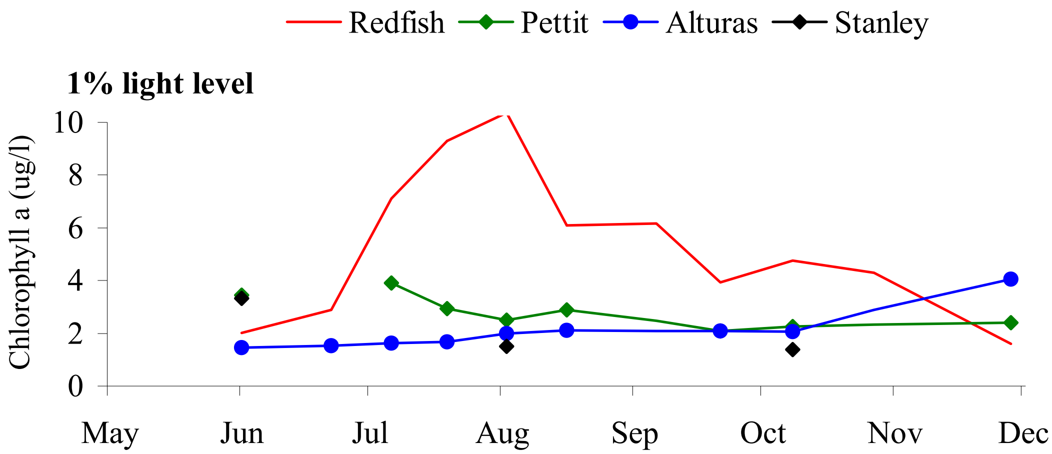


Figure 2-10. Chlorophyll *a* concentrations (*u*g/l) at the 1% light level in Redfish, Pettit, Alturas, and Stanley lakes, May-November 1999.

Phytoplankton communities in the Sawtooth Valley lakes continued to be dominated by small grazable taxa during 1999. Total phytoplankton densities ranged from 741-8906 cells/ml and total phytoplankton bio-volume ranged from 0.011 to 0.992 mm^3/l in the four lakes (Figures 2-11a- 2-11d). Generally, Chryso- and Cryptophycean nano-flagellates (*Chromulina* sp., *Chrysochromulina* sp., *Rhodomonas* sp., *Kephyrion* sp. and *Chryptomonas* sp.) and Cyanophytes (*Synechococcus* sp.) were numerically dominant. Chryso- and Cryptophycean nano-flagellates (*Chryptomonas* sp., *Dinobryon* sp., and *Chrysochromulina* sp.), Dinophycean dinoflagellates (*Peridinium* sp. and *Gymnodinium* sp.), and Bacillariophytes (*Cyclotella* sp., *Stephanodiscus* 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 (*Elakatothrix* sp.,

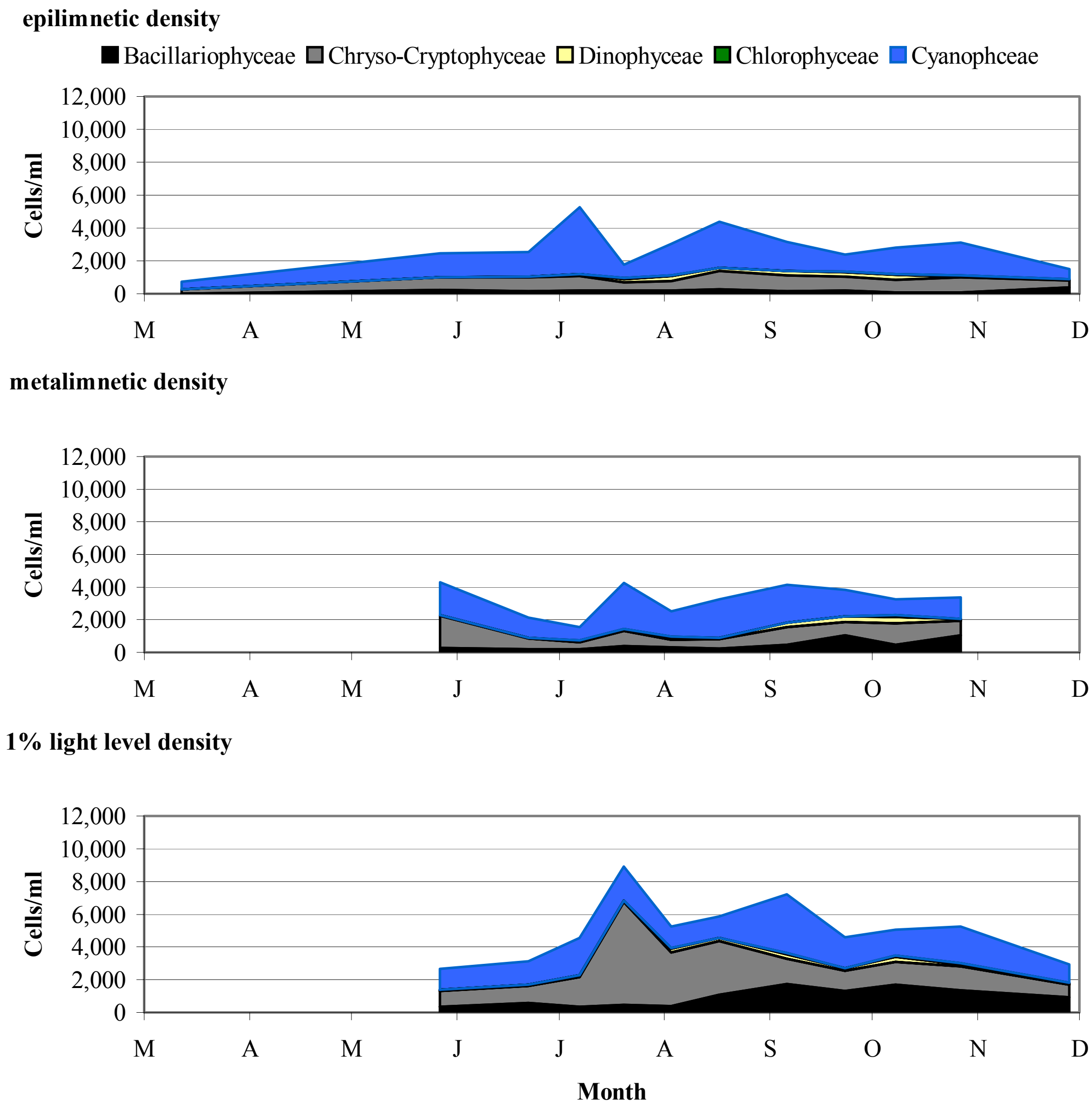


Figure 2-11a. Phytoplankton density (cells/ml) and bio-volume (mm^3/l) in the epilimnion, metalimnion and the 1% light level of Redfish Lake, March through November 1999.

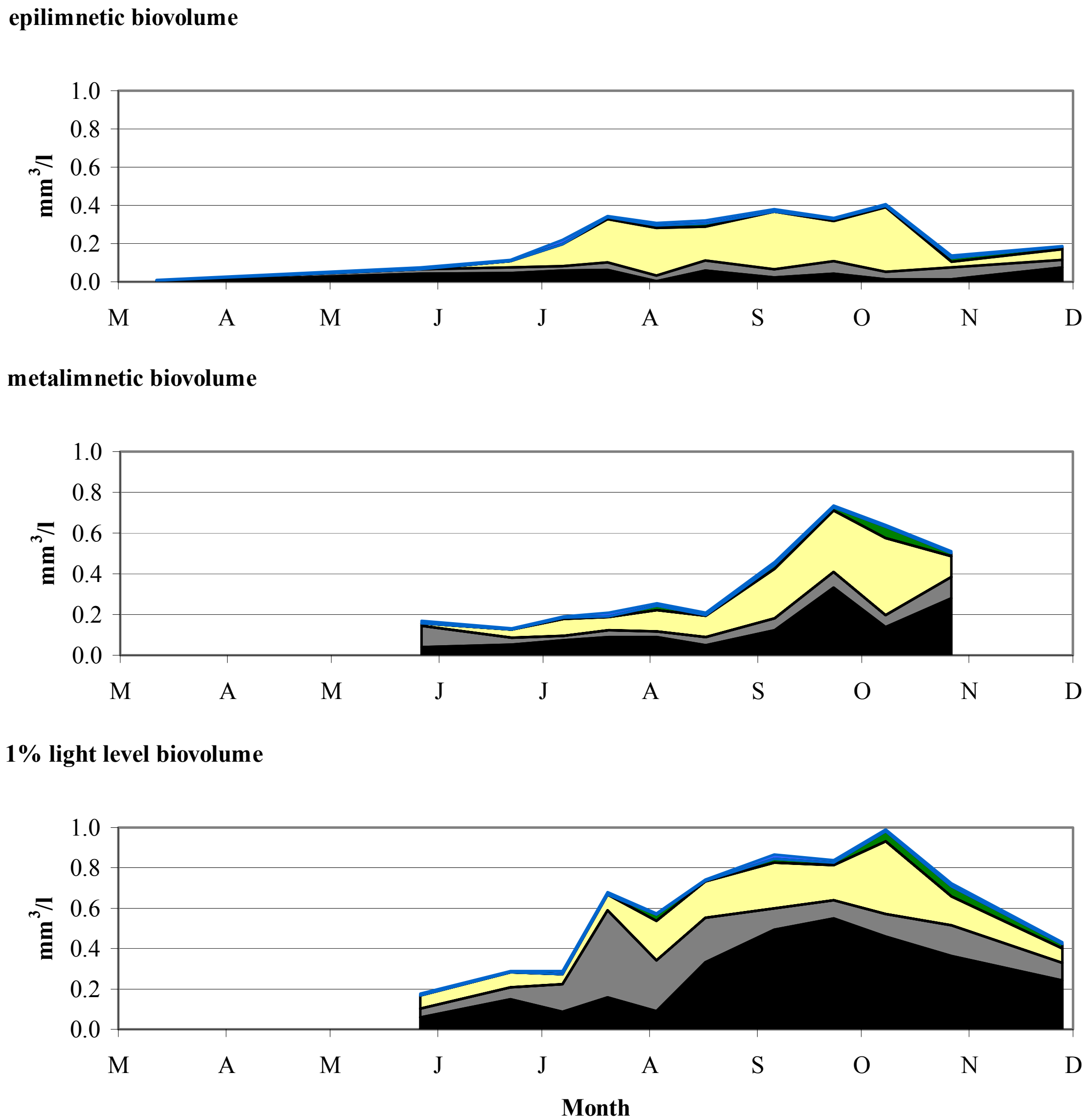


Figure 2-11a. Continued.

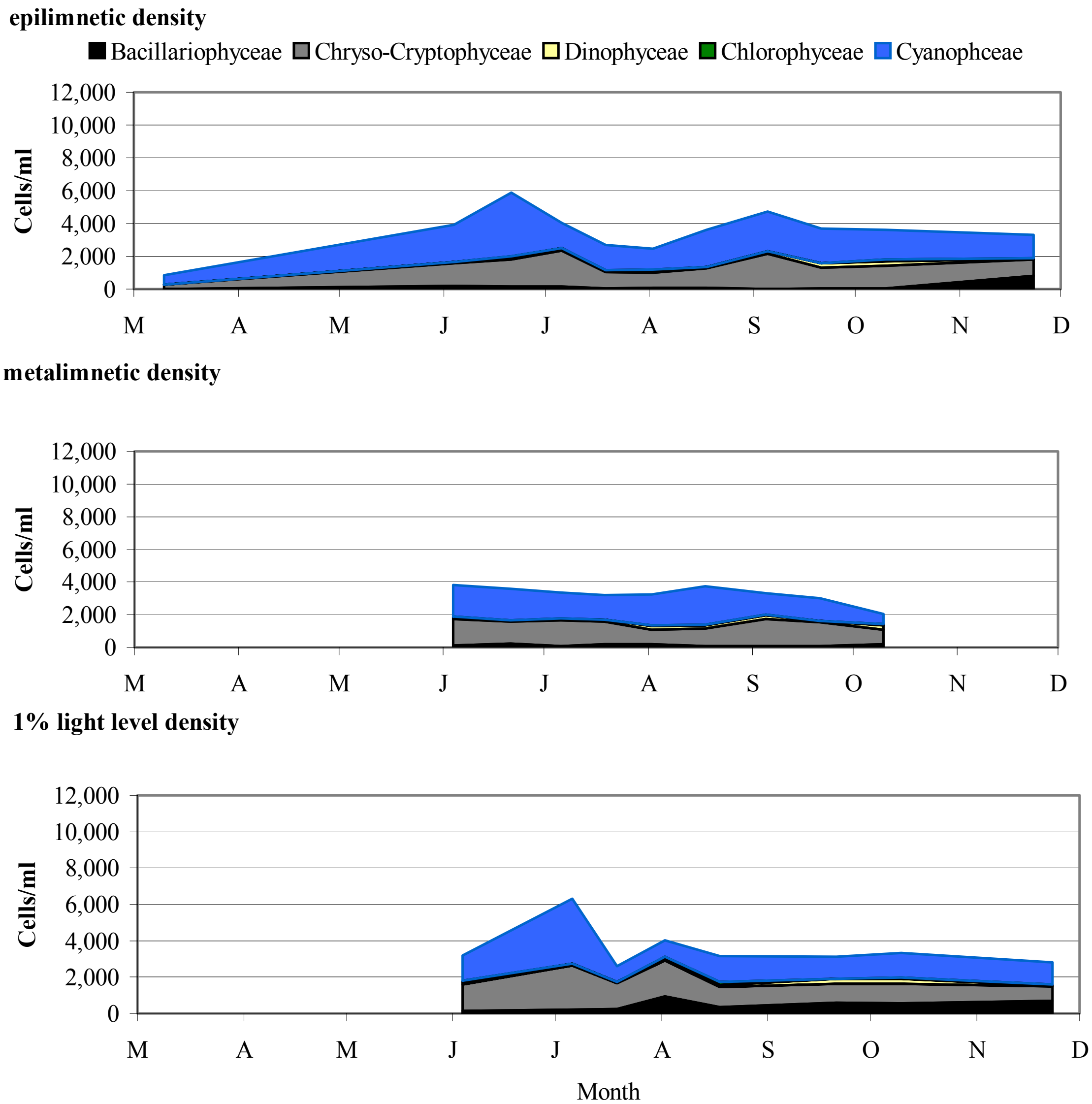


Figure 2-11b. Phytoplankton density (cells/ml) and bio-volume (mm^3/l) in the epilimnion, metalimnion and the 1% light level of Pettit Lake, March through November 1999.

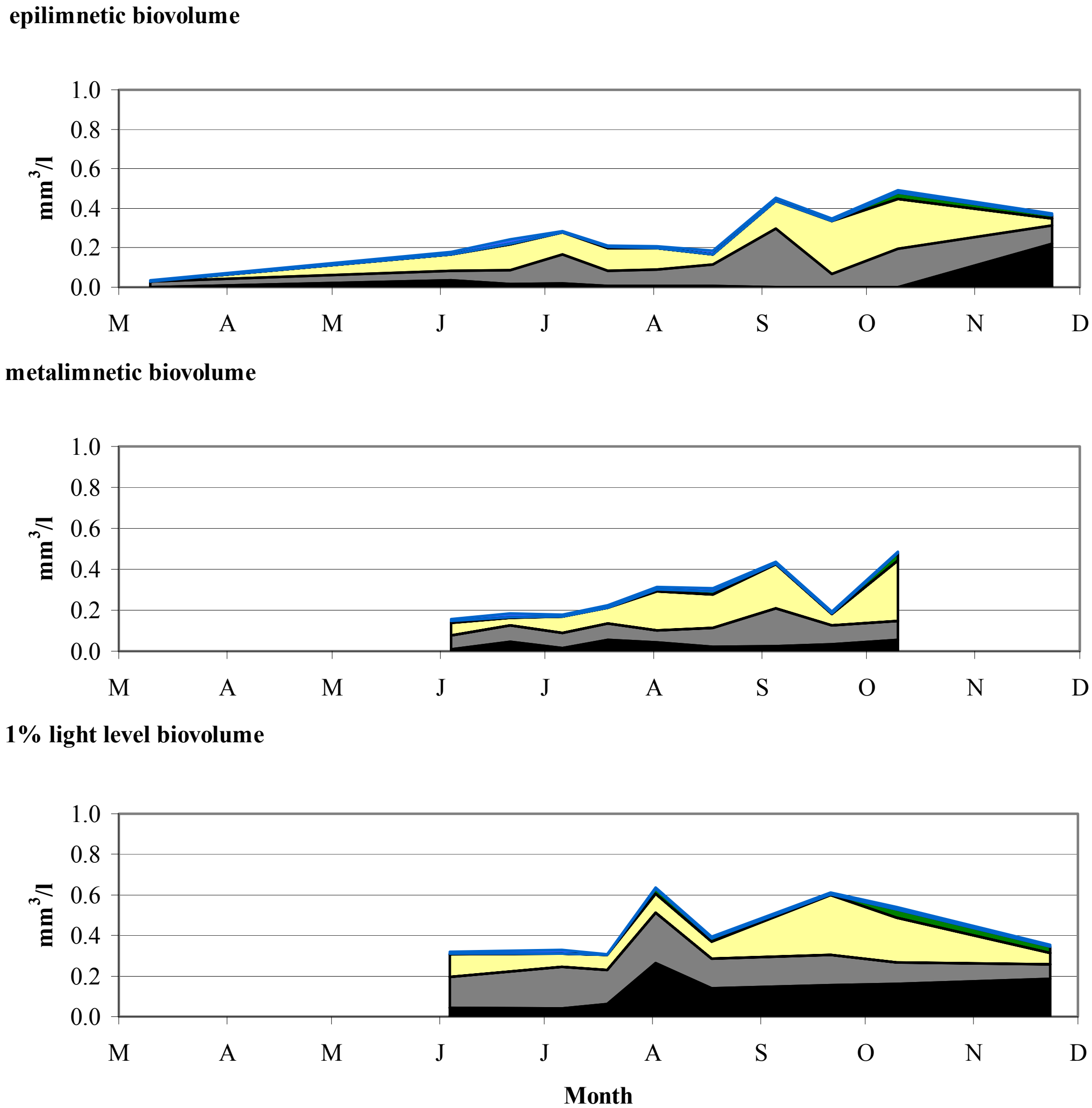


Figure 2-11b. Continued.

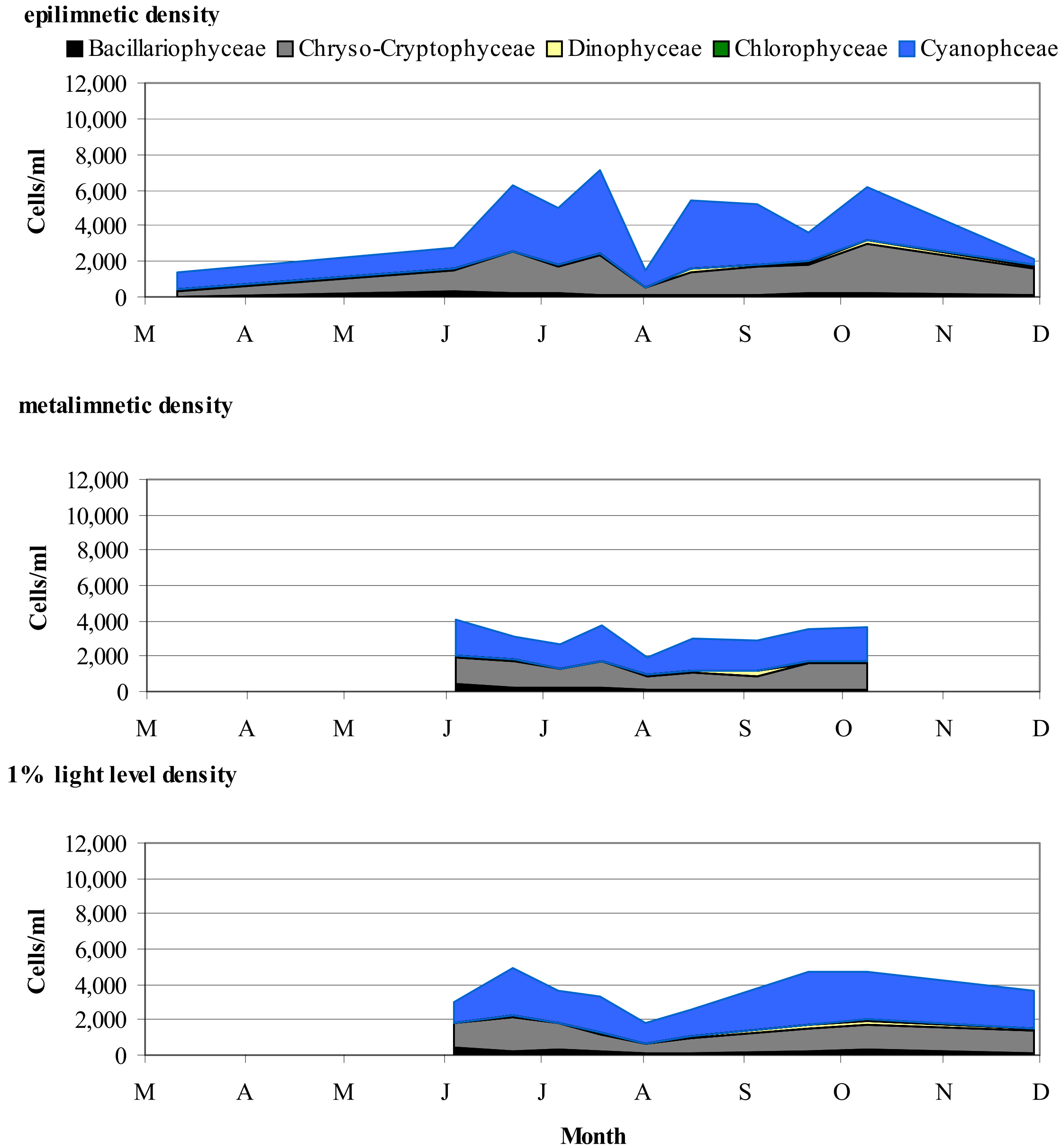
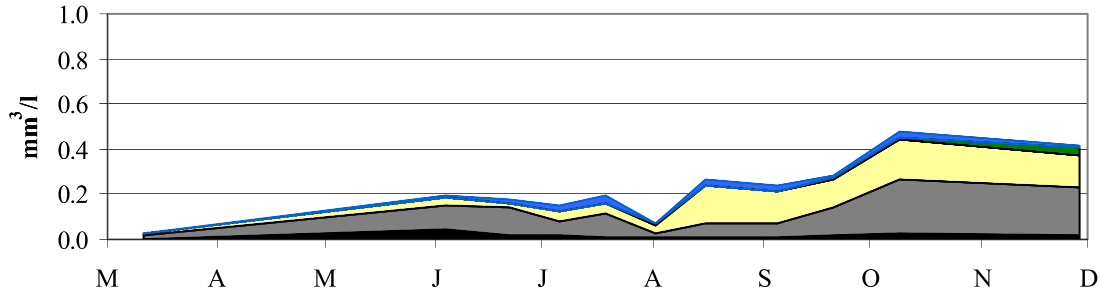
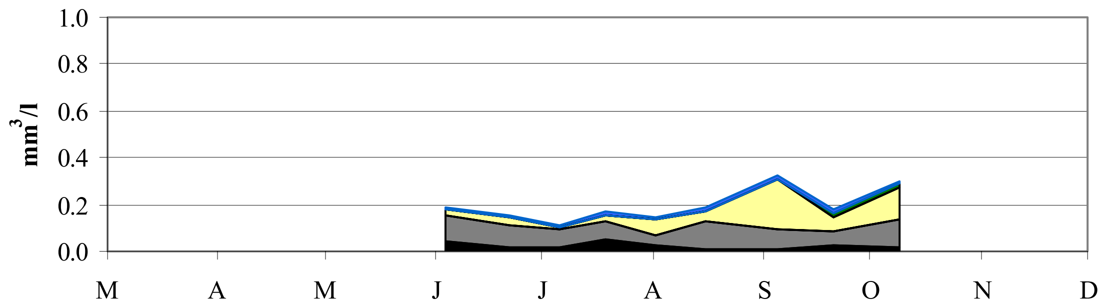


Figure 2-11c. Phytoplankton density (cells/ml) and bio-volume (mm^3/l) in the epilimnion, metalimnion and the 1% light level of Alturas Lake, March through November 1999.

epilimnetic biovolume



metalimnetic biovolume



1% light level biovolume

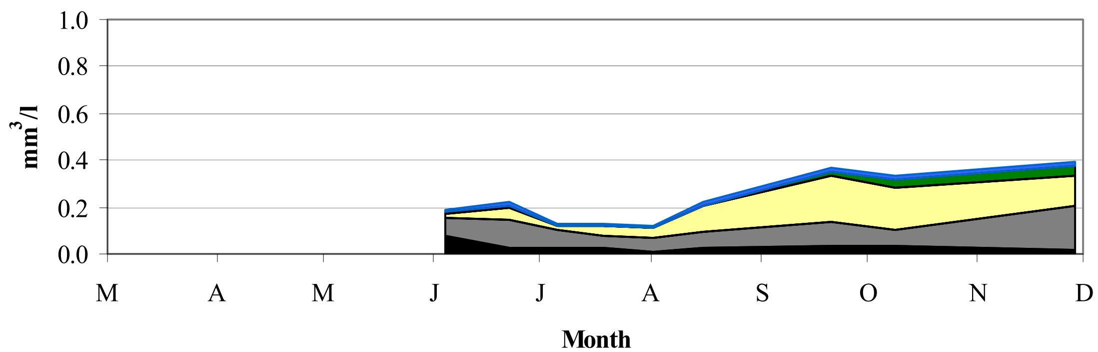


Figure 2-11c. Continued.

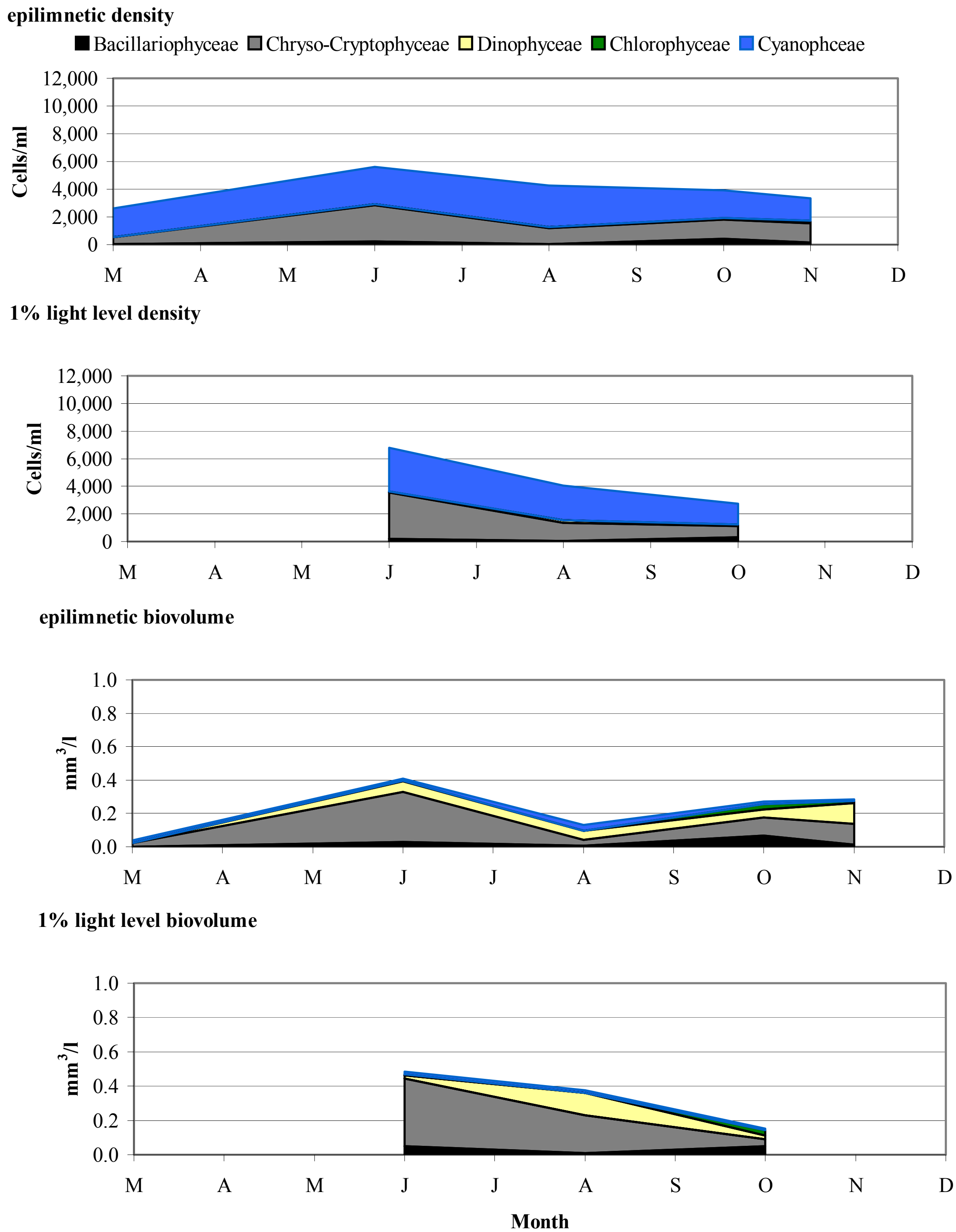


Figure 2-11d. Phytoplankton density (cells/ml) and bio-volume (mm^3/l) in the epilimnion, metalimnion and the 1% light level of Stanley Lake, March through October 1999.

Cosmarium sp., *Oocystis* sp., *Staurastrum* sp., and *Coelastrum* sp.). Bio-volume of *Synechococcus* sp. was low because of their small size (<2 *u*m).

Phytoplankton densities peaked during June or July in all four lakes. Bio-volume reached seasonal maximums during the fall, typically in September or October except in Stanley Lake, which peaked during June. The different timing in Stanley Lake likely resulted from the limited sampling that occurred in Stanley Lake during 1999.

Primary Productivity

The State of Washington Water Research Center at Washington State University (WRC) was contracted for the third consecutive year to estimate primary productivity in the Sawtooth Valley lakes in 1999. Depth integrated hourly and daily primary productivity was variable in the Sawtooth Valley lakes during July-October 1999. In 1999, average daily productivity of Redfish Lake was lower than during 1995, 1997, and 1998, years with full-scale fertilization and higher than 1993 and 1996 when the lake was either not fertilized (1993) or fertilized less intensively (1996) (Figure 2-12). Pettit and Alturas lakes had the highest average hourly and daily productivity observed since sampling began in 1993. Daily productivity in Stanley Lake was similar to 1997 and higher than previous years.

Mean productivity estimates for the unfertilized lakes (Redfish and Stanley) were approximately 20 mg C/m^2/hr (170 mg C/m^2/day) (Table 2-7) (Wierenga et al. 1999). Mean productivity in the fertilized lakes was 31.6 mg C/m^2/hr or 267.5 mg C/m^2/day (Pettit Lake) and 26.7 mg C/m^2/hr or 223.5 mg C/m^2/day (Alturas Lake). Redfish Lake had the highest hourly productivity during September and the highest daily productivity in July. Pettit, Alturas and Stanley lakes had the highest hourly and daily productivity estimates during August. Least squares regression of supplemental TP additions (mg P/m^2) and daily primary productivity (mg C/m^2/day) was positive and significant ($p<0.0001$, $R^2=0.63$) (Figure 2-13).

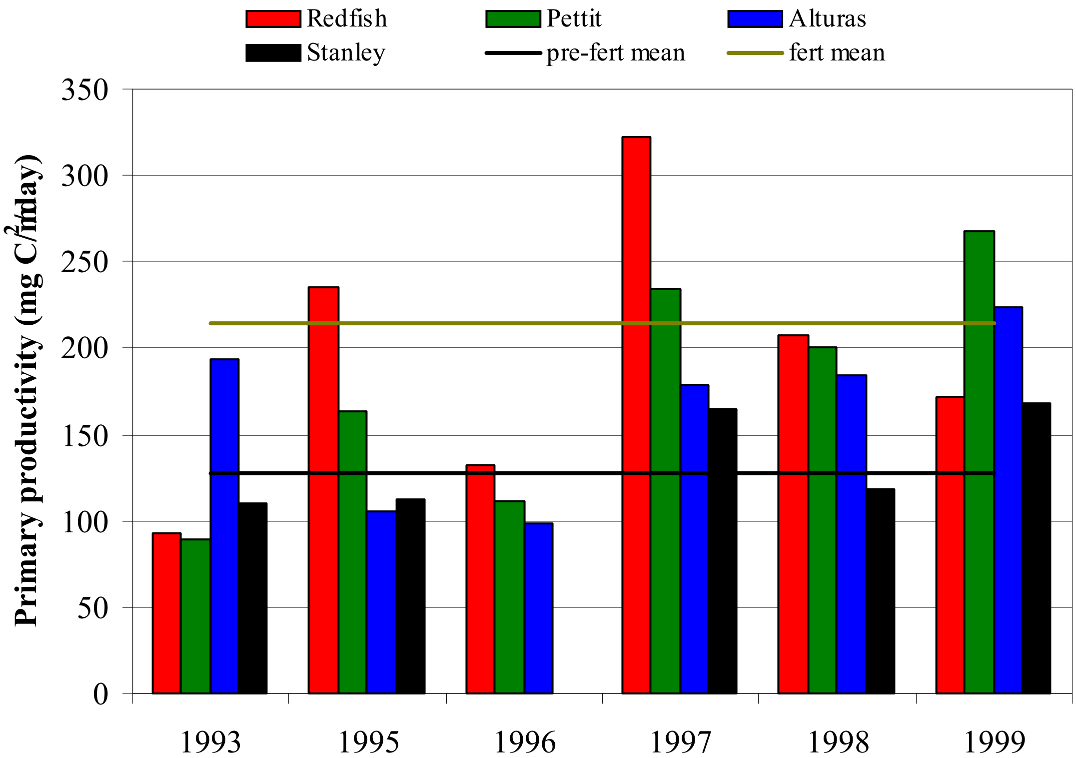


Figure 2-12. Mean seasonal primary productivity estimates (mg C/m^2/day) in Redfish, Pettit, Alturas, and Stanley lakes, 1993 and 1995-1999.

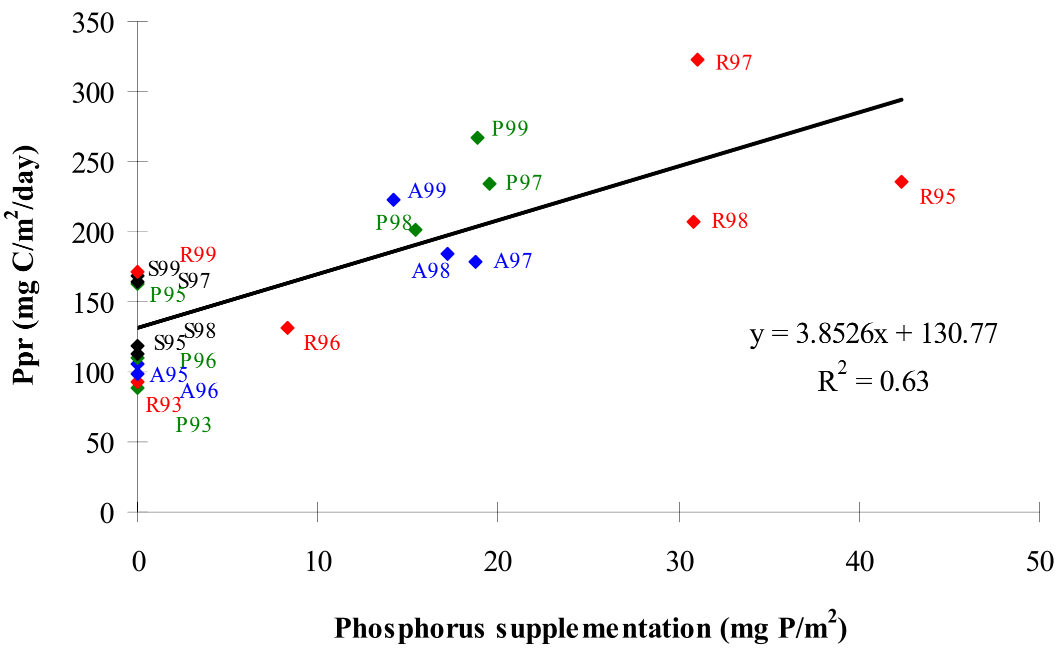


Figure 2-13. Least squares regression of TP supplementation (mg P/m^2) and primary productivity (mg C/m^2/day) for Redfish, Pettit, and Alturas lakes, 1995-1999.

Table 2-7. Hourly (mg C/m^3/hour) and daily (mg C/m^2/day) primary productivity estimates in Redfish, Pettit, Alturas, and Stanley lakes for years 1993, 1995-1999.

		Hourly Primary Productivity (mgC/m^2/hr)					
Year	**Lake**	**June**	**July**	**August**	**September**	**October**	**Mean**
1993	**Redfish**	3.2	14.6	13.4	16.2	--	11.8
	Pettit	--	10.6	7.2	13.3	--	10.4
	Alturas	--	--	22.8	--	--	22.8
	Stanley	--	--	11.2	--	--	11.2
1995	**Redfish**	16.5	46.2	23.8	34.4	--	30.2
	Pettit	9.7	16.9	26.3	23.1	--	19.0
	Alturas	8.4	12.7	17.4	11.0	--	12.4
	Stanley	9.6	14.7	22.6	8.7	--	13.9
1996	**Redfish N**	11.3	14.7	16.5	19.0	22.9	16.9
	Redfish S	24.1	9.3	19.7	17.5	17.6	17.6
	Pettit	14.1	8.5	14.7	15.3	11.2	12.8
	Alturas	10.6	7.8	10.1	13.8	--	10.6
1997	**Redfish N**	--	--	--	47.9	25.6	36.8
	Redfish S	--	--	--	46.5	29.4	38.0
	Pettit	--	--	--	33.2	21.9	27.6
	Alturas	--	--	--	27.4	17.5	22.5
	Stanley	--	--	--	31.2	16.8	24.0
1998	**Redfish N**	24.7	14.6	20.4	25.1	--	21.2
	Redfish S	22.9	20.7	17.5	22.1	--	20.8
	Pettit	22.8	20.0	21.3	16.8	--	20.2
	Alturas	17.7	8.4	23.4	30.3	--	20.0
	Stanley	10.7	14.1	14.7	10.9	--	12.6
1999	**Redfish**	--	22.1	17.4	26.0	15.1	20.2
	Pettit	--	27.0	47.7	25.3	26.3	31.6
	Alturas	--	25.5	29.9	23.0	28.4	26.7
	Stanley	--	21.4	26.6	13.9	16.1	19.5

Table 2-7. Continued.

		Daily Primary Productivity (mgC/m^2/day)					
Year	**Lake**	**June**	**July**	**August**	**September**	**October**	**Mean**
1993	**Redfish**	24.8	113.9	104.5	126.4	--	92.4
	Pettit	--	91.2	61.7	114.4	--	89.1
	Alturas	--	--	193.8	--	--	193.8
	Stanley	--	--	110.2	--	--	110.2
1995	**Redfish**	128.7	360.4	185.6	268.3	--	235.8
	Pettit	83.4	145.3	226.2	198.7	--	163.4
	Alturas	71.2	108.0	147.9	93.5	--	105.2
	Stanley	77.8	119.1	183.1	70.3	--	112.6
1996	**Redfish N**	97.6	130.4	140.1	130.1	146.3	128.9
	Redfish S	206.3	83.6	152.5	122.7	108.4	134.7
	Pettit	117.9	68.7	130.2	148.7	88.0	110.7
	Alturas	105.4	57.0	116.4	113.2	--	98.0
1997	**Redfish N**	--	--	--	431.1	184.3	307.7
	Redfish S	--	--	--	469.7	205.8	337.8
	Pettit	--	--	--	318.7	148.9	233.8
	Alturas	--	--	--	227.4	129.5	178.5
	Stanley	--	--	--	218.4	110.9	164.7
1998	**Redfish N**	276.5	151.0	192.8	232.8	--	213.3
	Redfish S	244.4	205.2	160.0	196.4	--	201.5
	Pettit	240.3	200.0	212.0	150.7	--	200.8
	Alturas	181.8	80.6	208.2	268.3	--	184.7
	Stanley	116.3	131.8	130.8	94.2	--	118.3
1999	**Redfish**	--	213.0	153.0	208.0	110	171.0
	Pettit	--	274.0	410.0	199.0	187	267.5
	Alturas	--	248.0	258.0	187.0	201	223.5
	Stanley	--	205.0	237.0	111.0	121	168.5

Zooplankton

Annual zooplankton biomass peaks occurred during early August in Redfish Lake, late September in Pettit and Alturas lakes and during October in Stanley Lake. Increases in *Bosmina* sp. and cyclopoid copepod biomass were responsible for seasonal peaks in Redfish, Pettit and Alturas lakes. Peak biomass in Stanley Lake resulted from increases in calanoid copepods and *Daphnia* sp. Peak biomass was highest in Alturas Lake (39.3 *u*g/l), followed by Pettit Lake (32.5 *u*g/l), Stanley Lake (28.9 *u*g/l) and Redfish Lake (26.0 *u*g/l). Mean seasonal (May-October) zooplankton biomass was 20.6 *u*g/l in Stanley Lake, 15.6 *u*g/l in Pettit Lake, 12.3 *u*g/l in Alturas Lake, and 7.0 *u*g/l in Redfish Lake (Table 2-4).

In 1999, Redfish Lake seasonal mean zooplankton biomass was the lowest observed since 1993. Seasonal mean *Daphnia* sp. biomass was also lower than any year since 1993. *Bosmina* sp. mean seasonal biomass was similar to 1998 and higher than 1993-1997 (Figure 2-14a). During March whole-lake zooplankton biomass was 2.9 *u*g/l and was dominated by *Bosmina* sp. and cyclopoid copepods. During summer, biomass was primarily comprised of *Bosmina* sp. *Daphnia* sp. biomass peaked in early late July-early August at <1.0 *u*g/l, well below the 10-11 *u*g/l peaks observed in 1994, 1996 and 1997 and the 20-*u*g/l peak observed in 1995.

Pettit Lake total zooplankton biomass was the highest observed since the population collapsed in 1995 but still depressed compared to 1992, 1993 and 1994 (Table 2-4). Species composition continued to be dominated by the small-bodied *Bosmina* sp., a major shift from 1994 when *Daphnia* sp. and cyclopoid copepods were abundant (Figure 2-14b). Pettit Lake biomass peaked in late September at 32.5 *u*g/l., coinciding with a peak in *Bosmina* sp. biomass. *Daphnia* sp. remained at or below 0.1 *u*g/l for the entire year. During March 1999, total zooplankton biomass was 1.1 *u*g/l and was predominately cyclopoid copepods and *Bosmina* sp. Winter zooplankton biomass was lower than observed during previous years.

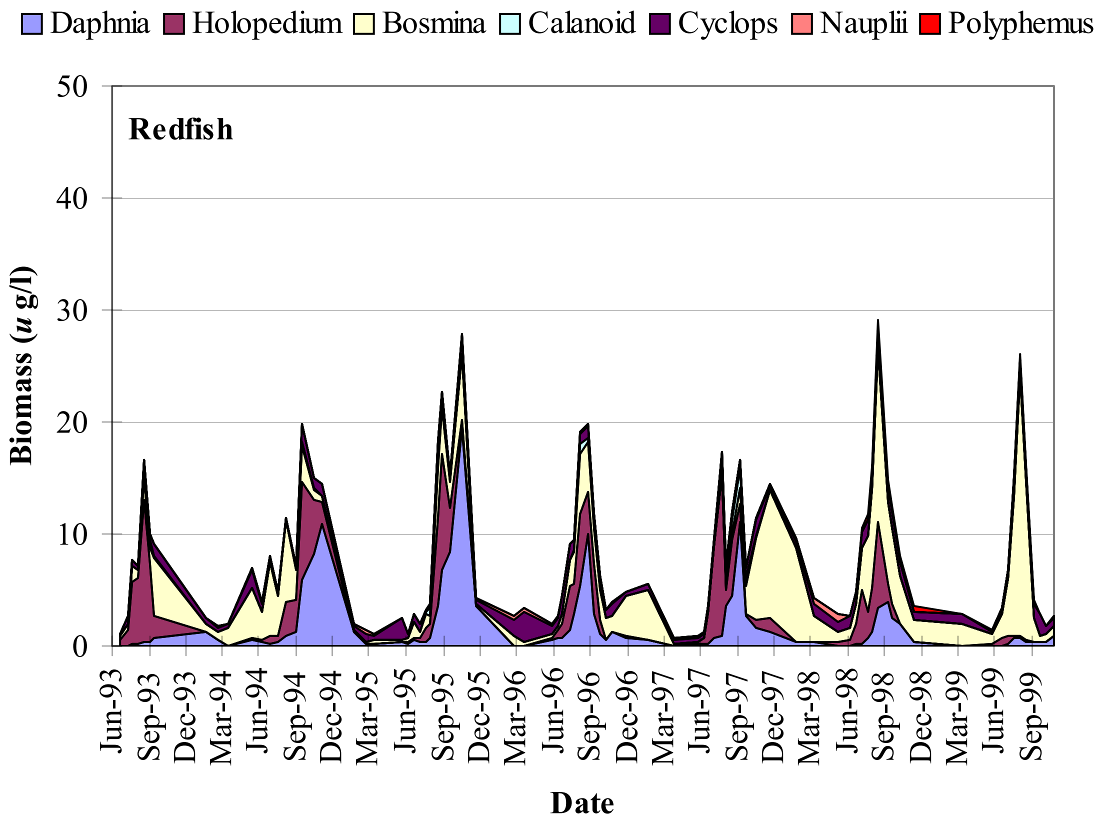


Figure 2-14a. Redfish Lake zooplankton biomass (*u*g/l) weighted by lake volume, 1993-1999.

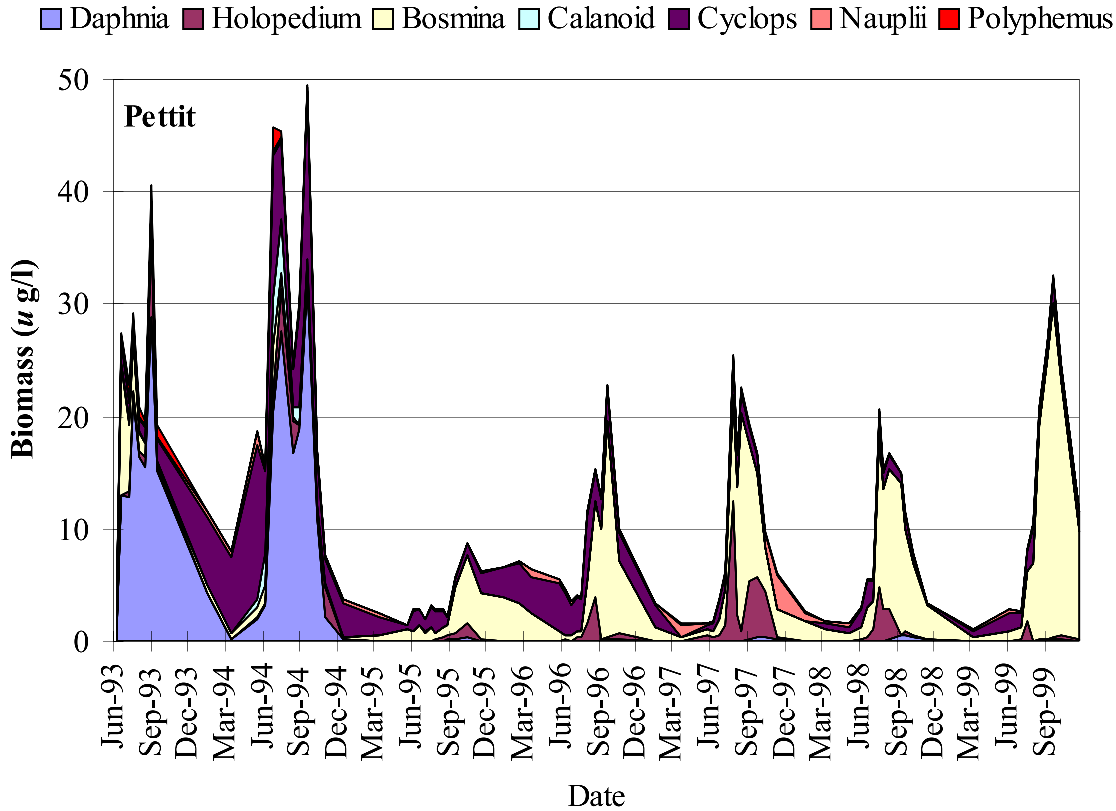


Figure 2-14b. Pettit Lake zooplankton biomass (*u*g/l) weighted by lake volume, 1993-1999.

In Alturas Lake mean seasonal total zooplankton biomass was the highest observed since sampling began in 1992 (Table 2-4). Alturas Lake zooplankton populations experienced a collapse in the early 1990's and began to recover in 1996 (Figure 2-14c). During August-October 1999, zooplankton populations consisted predominantly of *Bosmina* sp., cyclopoid copepods and *Daphnia* sp. Total biomass peaked at 39.3 *u*g/l in late September, similar to peaks observed during 1997 and 1998 and much higher than peaks observed between 1992 and 1996. Prior to 1996, the zooplankton community was almost exclusively *Bosmina* sp. *Daphnia* sp. biomass peaked at 8.6 *u*g/l during October 1999, which was less than the 22.7 *u*g/l peak in 1998. During the summers of 1996 and 1997, *Daphnia* sp. biomass reached 12 and 30 *u*g/l, respectively. Total zooplankton biomass during March was 1.9 *u*g/l and was mostly composed of cyclopoid copepods and nauplii.

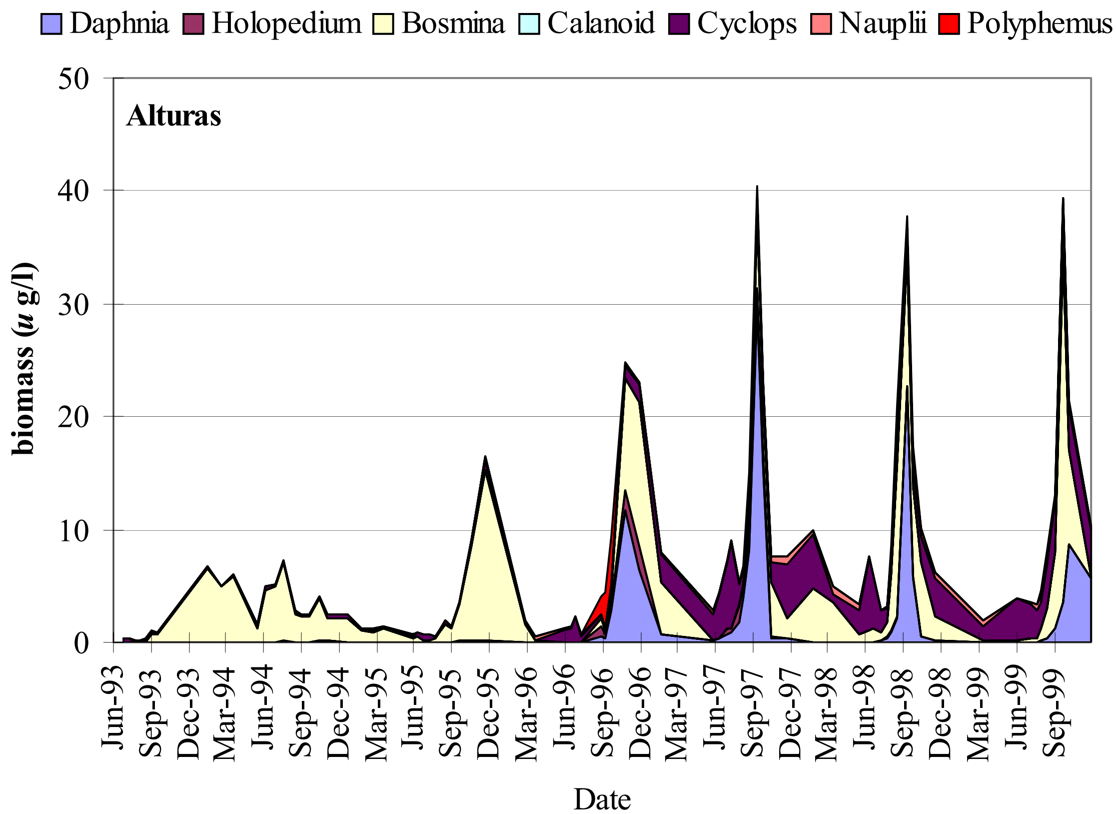


Figure 2-14c. Alturas Lake zooplankton biomass (*u*g/l) weighted by lake volume, 1993-1999.

Stanley Lake zooplankton populations were relatively stable in 1999. Peak zooplankton biomass was the lowest observed to date but the seasonal mean was similar to previous years (Table 2-4). During summer 1999, zooplankton species composition was similar to that observed in 1996-1998, with most biomass represented by calanoid copepods and *Daphnia* sp. (Figure 2-14d). *Holopedium* sp. biomass was similar to 1998 and less than observed during previous years. *Daphnia* sp. and calanoid copepod seasonal mean biomass was lower in 1999 than during 1998 and similar to previous years. Total zooplankton biomass peaked in October, a result of the seasonal biomass peaks of calanoid copepods and *Daphnia* sp. In March 1999, total biomass was 2.3 *u*g/l and was predominately *Bosmina* sp. and *Daphnia* sp.

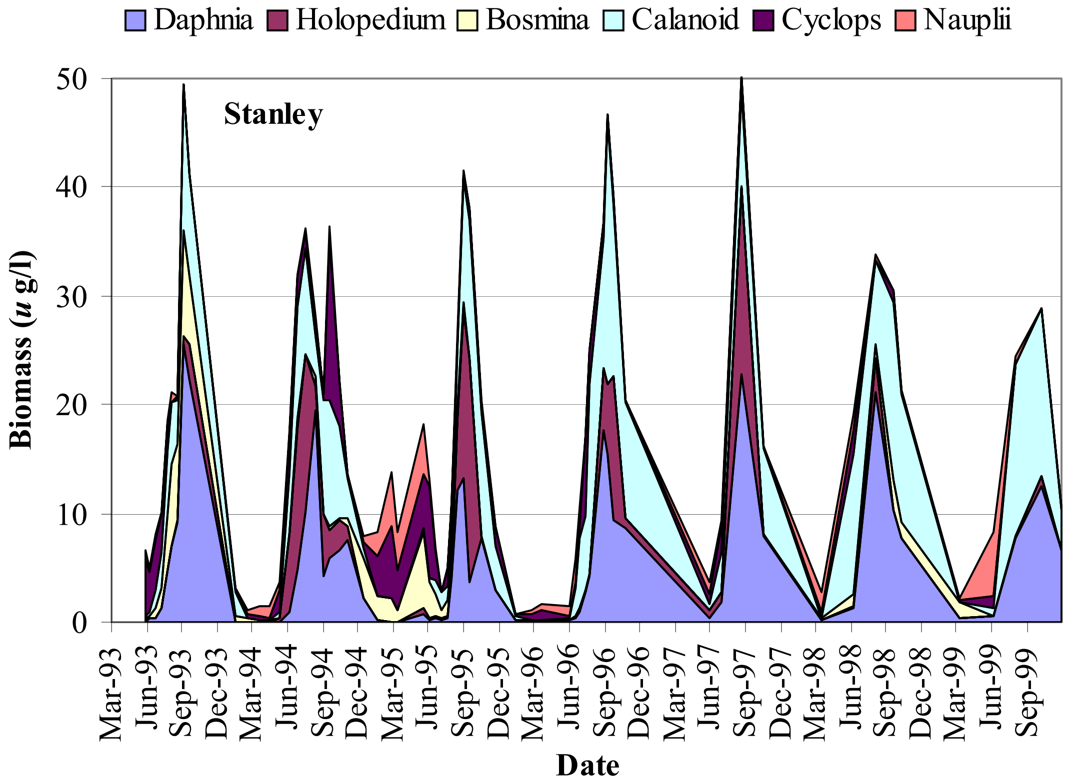


Figure 2-14d. Stanley Lake zooplankton biomass (*u*g/l) weighted by lake volume, 1993-1999.

DISCUSSION

Trawl and hydroacoustic estimates of *O. nerka* populations in Alturas and Pettit lakes have shown large fluctuations in fish abundance and/or biomass (Teuscher and Taki 1996, Taki and Mikkelsen 1997, Kline and Lamansky 1997, Taki et al. 1999). During peaks in *O. nerka* population cycles, increased grazing pressure on macrozooplankton caused shifts in species composition and declines in zooplankton biomass, density, and size. In Alturas Lake, zooplankton communities remained depressed for over 5 years following a collapse. Pettit Lake zooplankton communities collapsed in 1995 and remain depressed at this time. Nutrient supplementation was initiated in Redfish Lake in 1995 because anticipated stocking of endangered sockeye salmon combined with the existing kokanee population was expected to exceed the lake's carrying capacity. Nutrient supplementation continued in Redfish Lake during 1996-1998, although relatively small additions were made in 1996 since very few sockeye salmon were stocked that year. In 1999 we did not add supplemental nutrients to Redfish Lake, because of the natural carrying capacity of the lake was anticipated to adequately support the sockeye releases. Supplemental nutrients were added to Pettit and Alturas lakes in 1999 to increase primary productivity and through trophic transfer increase secondary productivity within the lakes. Pettit and Alturas lakes also received nutrient supplementation during 1997 and 1998.

Numerous studies have reported effects of nutrient additions by sampling before, during, and after fertilization treatments. However, these studies may be subject to misinterpretation if annual variation caused by meteorological forcing or other impacts was not accounted for (Schindler 1987). Identifying impacts from the lake fertilization program in the Sawtooth Valley has been confounded by changes in meteorological conditions. Prior to fertilization of Redfish Lake, snowpack and subsequent discharge in the watershed was at or below normal. Since fertilization began in 1995, mean annual discharge in the upper Salmon River has been above average. In 1997, seasonal discharge was the second highest for the period of record (1913-1999) and in 1999 discharge in the upper Salmon River was 18% above average. Gross (1995) modeled nutrient loading into Redfish Lake during the record low water year of 1992 and during the near normal water year of 1993 and found a positive correlation between discharge and nutrient loading. Thus, we anticipated that natural nutrient loading would be higher during the fertilization years than during the pre-fertilization years and the utility of using pre/post data sets to evaluate the fertilization treatments would be reduced. Therefore, Stanley Lake was used as a reference lake to discern nutrient supplementation impacts from meteorological effects.

If Stanley Lake responds similarly to increases in discharge we would expect declines in water transparency and light penetration and increases in chlorophyll *a* concentrations and primary productivity after 1995. Data from Stanley Lake, which has not received nutrient supplementation and has a relatively stable *O. nerka* population, supports this idea. However, Stanley Lake should only be considered a gross indicator of variable conditions since the lake is morphologically dissimilar to Redfish, Pettit, and Alturas lakes. Stanley Lake has a drainage area 48.6 times the size of the lake compared to ratios of 17.6, 16.9 and 22.4 for Redfish, Pettit, and Alturas lakes, respectively. This results in a much shorter water retention time and should result in disproportionately higher nutrient loading (Gross 1995). Alternatively, the shorter retention time could also cause a higher degree of "washout" of nutrients, phytoplankton, resting stages, and eggs compared to the other Sawtooth Valley lakes, especially during high water years (Goldman et al. 1989). If Stanley Lake is more susceptible to washout, then nutrient supplementation impacts may be over-estimated in the other Sawtooth Valley lakes.

Comparisons of seasonal averages from the 1995-1998 data set which corresponds to the years that Redfish Lake received nutrient supplementation with the 1992-1994 data set (pre-fertilization in Redfish Lake) show larger reductions in water transparency and light penetration in Stanley Lake than in Redfish Lake while increases in surface chlorophyll *a* concentrations and primary productivity were larger in Redfish Lake than in Stanley Lake (Lewis et al. 2000)(Figure 2-15). In 1999, the first year after nutrient supplementation ceased in Redfish Lake, surface chlorophyll *a* and primary productivity declined in Redfish Lake while increasing in Stanley Lake, relative to the fertilized years. However, chlorophyll *a* and primary productivity remained high compared to pre-fertilized values in both lakes, most likely a result of increased annual precipitation since the end of the drought in 1995.

Shifts in meteorological conditions obfuscated impacts of nutrient additions in Pettit and Alturas lakes. Comparison with the Stanley Lake data set for the pre-fertilized years (1992-1996) with the fertilized years (1997-1999) provides evidence that lake fertilization was effective. Mean seasonal surface water transparencies declined by 14% to 19%, while light penetration declined by 17% to 21% in the three lakes. Mean seasonal surface chlorophyll *a* increased by 145% in Pettit, 114% in Alturas and 46% in Stanley Lake. Primary productivity increased 93% in Pettit Lake, 48% in Alturas Lake and 35% in Stanley Lake (Figure 2-16). The 48% increase in primary productivity in Alturas Lake may be underestimated. In 1993, primary productivity in Alturas Lake was

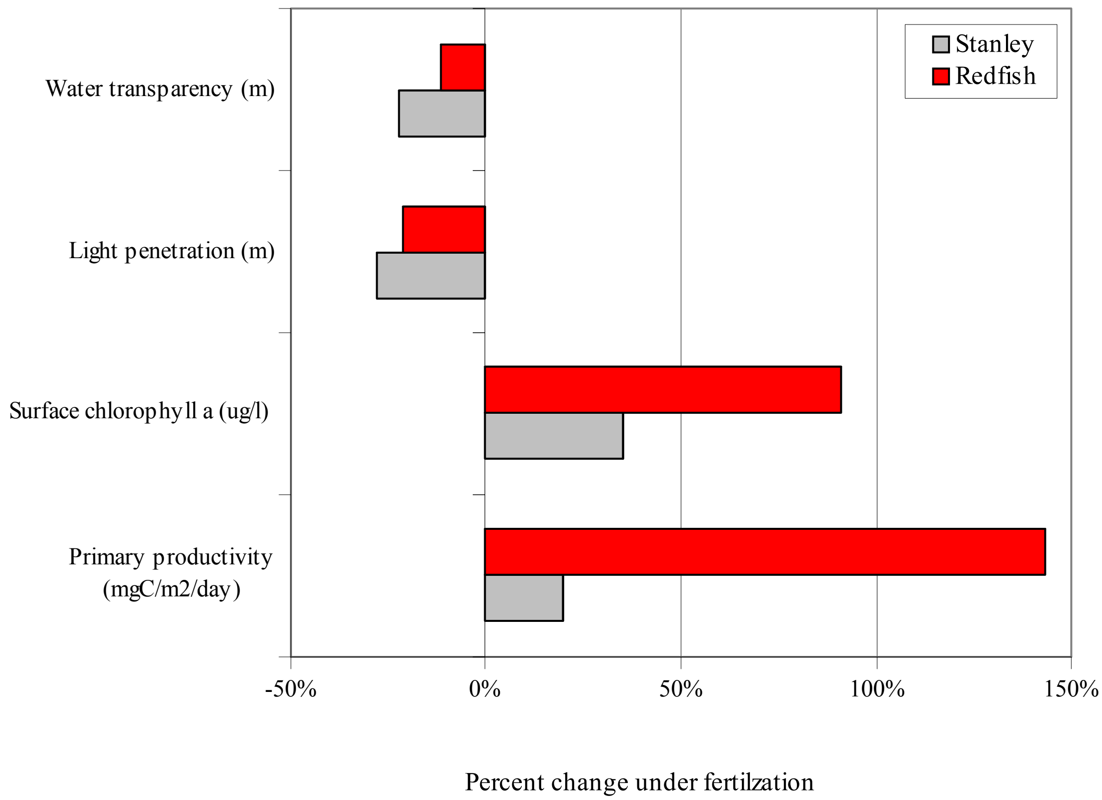


Figure 2-15. Percent change during nutrient supplementation (relative to pre-fertilized values) for mean water transparency (m), light penetration (m), surface chlorophyll *a* (*u*g/l), and primary productivity (mg C/m^2/day) in Redfish and Stanley lakes.

based on a single estimate. This single estimate of 193.8 mg C/m^2/day was high relative to the other lakes in 1993 (range 89.1-110.2 mg C/m^2/day) and to Alturas Lake in 1995 (105.2 mg C/m^2/day) and 1996 (98.0 mg/m^2/day) (Table 2-7). If the single 1993 primary productivity estimate is excluded the average primary productivity becomes 101.6 mg C/m^2/day during 1995-1996 in Alturas Lake and primary productivity increases by 92% under fertilization. Disproportionate increases in surface chlorophyll *a* and primary productivity in Pettit and Alturas lakes compared to Stanley Lake provides evidence that the lakes responded positively to nutrient supplementation without significant degradation of water quality as measured by water transparency and light penetration.

Cascading trophic interactions are known to influence primary productivity of lakes (Carpenter et al. 1985, Carpenter and Kitchell 1987, Carpenter and Kitchell 1988). Although phytoplankton data for the Sawtooth Valley lakes prior to nutrient supplementation are limited, it appears phytoplankton species assemblages have remained stable under fertilization and are typically oligotrophic. Small grazable

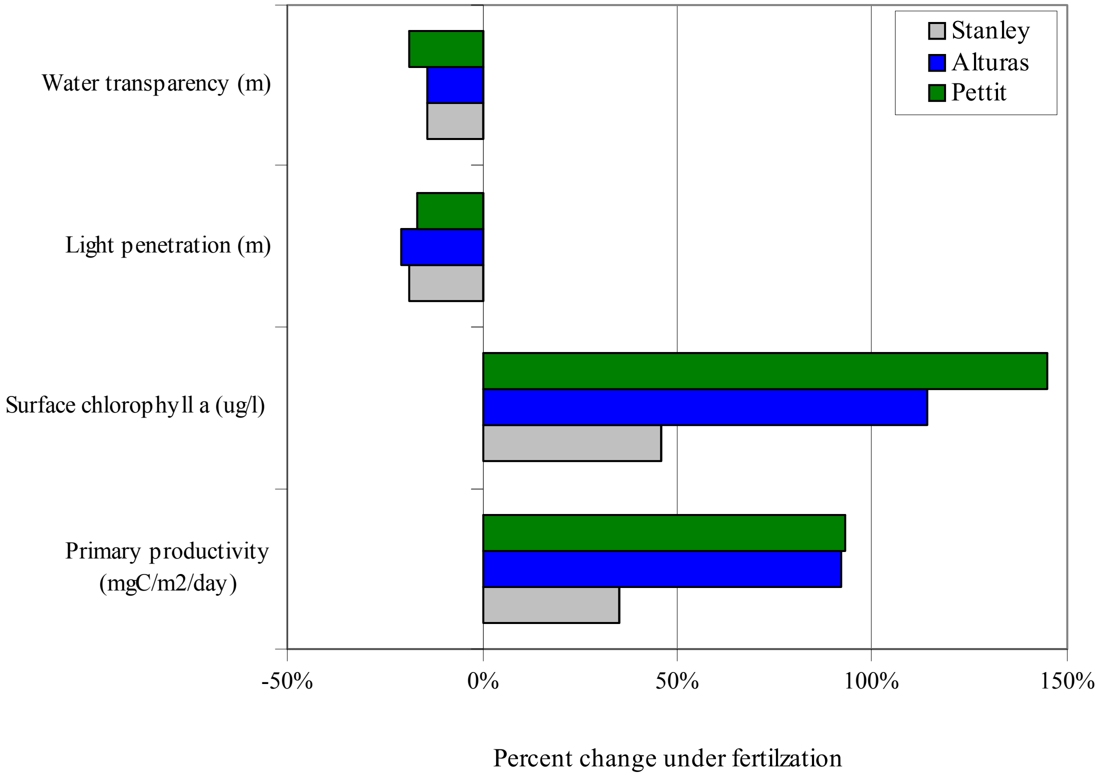


Figure 2-16. Percent change during nutrient supplementation (relative to pre-fertilized values) for mean water transparency (m), light penetration (m), surface chlorophyll *a* (*u*g/l), and primary productivity (mg C/m^2/day) in Pettit, Alturas, and Stanley lakes. Data omitted for the 1993 Alturas Lake primary production estimate.

autotrophic picoplankton, nano-flagellates, and diatoms dominate phytoplankton species assemblages in the Sawtooth Valley lakes. The predominance of these phytoplankton and the absence of accumulations of non-grazable taxa (sinks) are indicators of efficient energy transfer between trophic levels, which should result in improved forage production for endangered sockeye salmon (Stockner and MacIsaac 1996, Stockner 1998). Some attempts to stimulate lake productivity with nutrient additions have been unsuccessful; energy sinks developed from inefficient trophic transfer, which prevented energy flow to juvenile sockeye salmon (Stockner and Hyatt 1984, Stockner 1987, Stockner and Shortreed 1988).

Potential benefits of the lake fertilization program to sockeye salmon include increased growth and survival and a reduced risk of exceeding lake carrying capacity and causing a collapse of the macrozooplankton population. The consequences of a collapsed forage base were considered severe since recovery appears to take many years as evidenced by zooplankton data from Alturas and Pettit lakes. Several potential problems are associated with lake fertilization, including increased intra-specific competition and effects of lake eutrophication. Habitat use and foraging behavior of kokanee are similar to sockeye salmon (Rieman and Myers 1992) so potential benefits to sockeye salmon from fertilization may be offset by increases in growth, survival, and fecundity of kokanee. A positive response by kokanee to lake fertilization could result in increased competition with sockeye salmon in future years. This was the primary reason that Redfish Lake did not receive supplemental nutrients in 1999. The authors of this report and the Sockeye Technical Oversight Committee believed that non-native kokanee populations would disproportionately benefit from the nutrient additions, which would ultimately increase competition with endangered sockeye salmon. Managers should continue to carefully weigh the short-term benefits of lake fertilization against the longer-term adverse impacts of intra-specific competition.

Successful lake fertilization may increase precipitated organic matter resulting in larger oxygen deficits in deep waters. This is particularly important in Pettit Lake where O. nerka habitat is significantly reduced (26% by volume) by low oxygen concentrations below 30-35 m depth. Based on dissolved oxygen profiles it appears that Pettit Lake did not mix completely in 1996, 1997, 1998 or 1999. Whether Pettit Lake ever mixes completely is unknown. Cladocerans withstand D.O. concentrations less than 1 mg/l and cyclopoid copepods are even more tolerant of low oxygen concentrations (Pennack 1989). Zooplankton biomass below 30 m in Pettit Lake was relatively high (2.7-12.3 *u*g/l) during 1999, an indication that zooplankton standing crop was not significantly reduced by hypoxic conditions in the deep waters of Pettit Lake. The effects on predator/pray balance in Pettit Lake will be minimized if zooplankton vertically migrate out of this hypoxic region or if *O. nerka* make foraging excursions into the hypoxic region. Alternatively, this hypoxic region could provide a refuge for macrozooplankton and reduce foraging opportunities for *O. nerka*.

Macrozooplankton response to fertilization is variable but 1.2 to 2.0 fold increases in abundance and biomass have been observed (Stockner and MacIsaac 1996). In Pettit and Alturas lakes, *O. nerka* populations have experienced major shifts in abundance and biomass with associated changes in zooplankton biomass and species composition. These changes have precluded evaluation of nutrient supplementation at the macrozooplankton level. However, in Redfish Lake it appears that macrozooplankton populations have been maintained at least in part by lake fertilization. During 1995-1998, *O. nerka* biomass estimates (2x trawl) in Redfish Lake increased by more than 3 times and exceeded the lake's unfertilized carrying capacity each year (Stockner 1997). During this time macrozooplankton biomass and sockeye salmon overwinter survival and size at emigration remained remarkably stable (Jay Pravecek IDFG, Doug Taki, SBT, personal communication).

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