Document ID #P112786

SNAKE RIVER SOCKEYE SALMON HABITAT AND LIMNOLOGICAL RESEARCH: 2008 ANNUAL PROGRESS REPORT

Prepared by:

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

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

[1] Biolines Environmental Consulting
P.O. Box 4957
Ketchum, ID 83340

Prepared for:

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

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

In March 1990, the Shoshone-Bannock Tribes petitioned the National Marine Fisheries Service (NMFS) to list Snake River sockeye salmon (*Oncorhynchus nerka*) as endangered. Snake River sockeye salmon were 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 Project was implemented. This project is part of an interagency effort to prevent the extinction of the Redfish Lake stock of Snake River sockeye salmon. The Shoshone-Bannock Tribal goal for this project is two tiered: the immediate goal is to increase the population of Snake River sockeye salmon while preserving the unique genetic characteristics of the evolutionarily significant unit (ESU). The Tribes long term goal is to maintain a viable population that warrants delisting and provides Tribal harvest opportunities.

The Bonneville Power Administration (BPA) provides funding for this interagency Recovery effort. Collaborators in the recovery effort include the National Oceanic and Atmospheric Administration (NOAA), the Idaho Department of Fish and Game (IDFG), the University of Idaho (UI), and the Shoshone-Bannock Tribes (SBT). This report summarizes activities conducted by Shoshone-Bannock Tribal Fisheries Department personnel during the 2008 calendar year.

Project tasks include: 1) monitor limnological parameters of the Sawtooth Valley lakes to assess lake productivity; 2) conduct lake fertilization in Pettit and Alturas lakes; 3) reduce the number of mature kokanee salmon spawning in Alturas Lake Creek; 4) monitor, enumerate, and evaluate sockeye salmon smolt migration from Pettit and Alturas lakes; 5) monitor spawning kokanee salmon escapement and estimate fry recruitment in Fishhook and Alturas Lake creeks; 6) conduct sockeye and kokanee salmon population surveys; 7) evaluate potential competition and predation between stocked juvenile sockeye salmon and a variety of fish species in Redfish, Pettit, and Alturas lakes; and 8) assist IDFG with captive broodstock production activities.

Task 1. Limnological parameters including temperature, dissolved oxygen, conductivity, Secchi depth, light compensation depth, nutrient concentrations, chlorophyll *a* concentrations,

phytoplankton, and zooplankton assemblage characteristics (species composition and densities) were sampled once during January in Pettit Lake. We did not sample any lakes in February or March due to unsafe conditions. Limnological sampling was conducted at Redfish, Pettit, and Alturas lakes twice a month from June-September, and once a month in October and November.

Task 2. Supplemental nutrients were added to Pettit and Alturas lakes to enhance primary productivity and improve forage conditions for juvenile sockeye salmon. Between 15 July and 21 October 2008, 71 kg phosphorus (P) and 1,448 kg nitrogen (N) were added to Pettit Lake. Alturas Lake received supplemental nutrient applications of 89.9 kg phosphorus (P) and 1,778 kg nitrogen (N) between 15 July and 28 October 2007. Nutrients were applied at a ratio of approximately 20:1 N:P by mass to avoid stimulation of nitrogen fixing Cyanophytes. Nutrient applications were curtailed on 24 September when chlorophyll *a* concentrations exceeded the DEQ criterion of 3 *u*g/L in the epilimnion.

Task 3. Controlling spawning kokanee salmon numbers under current conditions and with existing equipment was deemed unsuccessful by the SBSTOC in Fishhook Creek and Alturas Lake Creek; no control weirs were installed in 2008. Kokanee salmon were collected for fecundity rates (n = 12) and genetic evaluations (n = 66 and 25) from Fishhook and Alturas Lake creeks, respectively.

Task 4. The number of sockeye salmon that migrated from Pettit Lake was enumerated using catches at the Pettit Lake Creek weir and PIT tag interrogations from the lower Snake River dam complex. We evaluated direct lake fall releases of Sawtooth Hatchery parr. Five thousand five hundred and eighty yearling and 382 age II+ hatchery migrants moved past the Pettit Lake Creek weir in the spring of 2008, with a corresponding 59% migration rate of the 10,113 Sawtooth Hatchery parr that were released into Pettit Lake in 2007. We also captured 100 (96 yearling and 4 age II+) natural migrants, most likely from egg box and residual spawning production.

Stocked juvenile sockeye salmon migration from Alturas Lake was estimated using catches at the Alturas Lake Creek screw trap and SURPH survival estimates. We estimated that 53% (5,210 yearling) of the 9,977 Sawtooth Hatchery sockeye parr released into Alturas Lake in 2007 migrated in 2008. We also estimated 63 two year old hatchery smolts left the lake. Migration for Redfish Lake sockeye salmon was monitored by IDFG.

Task 5. Stream spawner counts were used to monitor adult kokanee salmon escapement to inlet streams on Redfish and Alturas lakes in 2008. Fishhook Creek, the primary kokanee salmon spawning tributary on Redfish Lake, had an estimated spawning escapement of 4,908 adult spawners; Alturas Lake Creek had an estimated 10,312 adult spawners. No Stanley Lake Creek kokanee salmon spawning estimate is provided due to decreased funding. Fry recruitment, calculated from male-female ratios, fecundity, and egg to fry survival rates is estimated at 57,954 and 138,078 fry for Redfish and Alturas lakes, respectively.

Task 6. Monitoring of spawning residual and anadromous sockeye salmon populations in Redfish Lake has occurred since 1993. Trends in these populations are evaluated with monitoring data collected by weekly snorkel surveys. In 2008, 16 residual sockeye salmon and 403 sockeye salmon adults were observed during snorkel surveys at the SE Inlet and Sockeye Beach spawning areas in Redfish Lake. During final boat surveys in November 2007, SBT and IDFG personnel estimated a total of 338 captive reared and anadromous sockeye salmon volitional spawning redds were constructed within Redfish Lake. In addition, monitoring of spawning residual sockeye salmon in Pettit Lake revealed a large spawning population. We conducted boat surveys during Oct-Nov 2008 and estimated approximately 329 residual sockeye salmon redds were constructed in Pettit Lake.

Task 7. Potential competition and predation between stocked sockeye salmon and unmarked *O. nerka* (egg box production sockeye salmon, residual sockeye salmon production, or kokanee salmon) was investigated. We did not capture enough stocked sockeye salmon to evaluate intraspecific diet competition with *O. nerka*. Resident kokanee salmon, the primary competitor with lake rearing juvenile sockeye salmon, fed almost entirely on zooplankton prey species.

Task 8. SBT personnel assisted in PIT tagging juvenile sockeye at the Sawtooth Fish Hatchery during September 2008.

Through the spawning matrix design used in the captive broodstock program, we have sustained the genetic integrity of the stock (Willard et al. 2003). However, to reach our long term goal of a viable population, the adverse effects caused by out of basin activities need to be remedied. For example, adult returns to the Sawtooth Valley in 2000 of two hundred and fifty-seven adults were the largest recorded in several decades. Unfortunately, the smolt-to-adult ratio (SAR) for those fish was only 0.22%. If that ratio increased to between two and four percent, our adult return in 2000 would have been 2,886 to 5,772 returning adults; adult escapement of that magnitude would move the recovery program toward achieving our long term goal.

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 (*Oncorhynchus nerka*) ESU is the only extant Snake River sockeye salmon stock. The spawning and freshwater rearing habitat of this stock is located in the Sawtooth Valley, Idaho, a traditional SBT fishing and hunting area. In March 1990, the SBT petitioned the National Marine Fisheries Service (NMFS) to list the Snake River sockeye salmon as endangered. Snake River sockeye salmon was officially listed as endangered in November 1991 under the Endangered Species Act (56 FR 58619). The SBT have been actively involved in the sockeye salmon recovery project since its inception.

The Bonneville Power Administration (BPA) provides funding for this interagency recovery program through their Integrated Fish and Wildlife Program. Collaborators in the recovery program include the National Oceanic and Atmospheric Administration Fisheries (NOAA), Idaho Department of Fish and Game (IDFG), the University of Idaho (UI), and the SBT: the NOAA manages the permitting of activities and the captive rearing program hatchery operations in Manchester, WA; the IDFG monitors a variety of fisheries parameters in the field and is responsible for the captive rearing program with hatchery operations in Eagle and Stanley, ID and analyzes genetic samples and participates in designing breeding matrices; and the SBT monitor a variety of fisheries biology parameters and evaluate spawning and rearing habitat in nursery lakes.

In 1991, only four adult sockeye salmon returned to Redfish Lake. These four fish and emigrating juveniles captured over the next two years formed the initial captive brood stock. The captive broodstock was supplemented with returning adult sockeye salmon, residuals, and emigrating juveniles in subsequent years. Historically, thousands of sockeye salmon returned to the Sawtooth Valley lakes. Everman (1896) reported observing fish in Redfish, Pettit, and Alturas lakes during 1894 and 1895. 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, the dam was breached and upstream anadromous fish populations rebounded. Bjornn (1968) estimated that 4,360 sockeye salmon returned to Redfish Lake in 1955. There has been a steady decline in adult sockeye salmon returns since that time until, in the late 1980's, only a small number of fish were returning to the Sawtooth Valley. A total of 23 adult sockeye salmon returned to the Sawtooth Valley during the 1990's. The recovery program has focused its efforts on restoring anadromous *O. nerka* to Redfish, Pettit, and Alturas lakes, designated as critical spawning and rearing habitat under the ESA listing (56 FR 58619). The Interior Columbia Basin Technical Recovery Team (ICBTRT) places this ESU at a very high risk of extinction. Because the ESU contains only one major population group (MPG), the inherent risk of extinction is greatly amplified. Component populations of the MPG are limited to Alturas Lake and Pettit Lake. The ICBTRT recommendation for recovery is to achieve and maintain 2 highly viable and 1 viable population group in Redfish, Alturas, and Pettit lakes, with a following emphasis on recovery efforts in Stanley and Yellowbelly lakes. Redfish and Alturas lakes fall into an intermediate size category, and as such, the ICBTRT set a minimum spawning abundance threshold at 1,000 natural spawners for each lake; Pettit, Yellowbelly, and Stanley lakes were placed into the smallest historical size category, and a minimum spawning abundance of 500 natural spawners was recommended. The SBT support the ICBTRT concept of applying recovery criteria and population viability goals across the full range of available historic habitat. In the Sawtooth Valley, this includes spawning and rearing habitat in five alpine lakes: Stanley, Redfish, Yellowbelly, Pettit, and Alturas lakes.

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

The Stanley Basin Technical Oversight Committee (SBTOC) provided input regarding all activities conducted by the SBT in association with the sockeye salmon recovery project. The SBTOC is composed of representatives from all participating agencies (BPA, NOAA, IDFG, UI, and SBT). The SBTOC was formed in 1991 to guide new research, coordinate ongoing research, and actively participate in all technical elements of the Snake River sockeye salmon recovery effort. Scientists with expertise in related fields are often invited to SBTOC meetings to present their research and discuss activities conducted by SBTOC agencies. The project as a whole or in part is subject to further review by the Idaho Department of Environmental Quality (IDEQ), the Northwest Power and Conservation Council (NWPCC), and the Independent Scientific Review Panel (ISRP).

STUDY AREA

Five lakes: Stanley, Redfish, Yellowbelly, Pettit, and Alturas, in the Sawtooth Valley, Idaho 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). Specific features of the sockeye salmon rearing lakes are shown in Table 1.

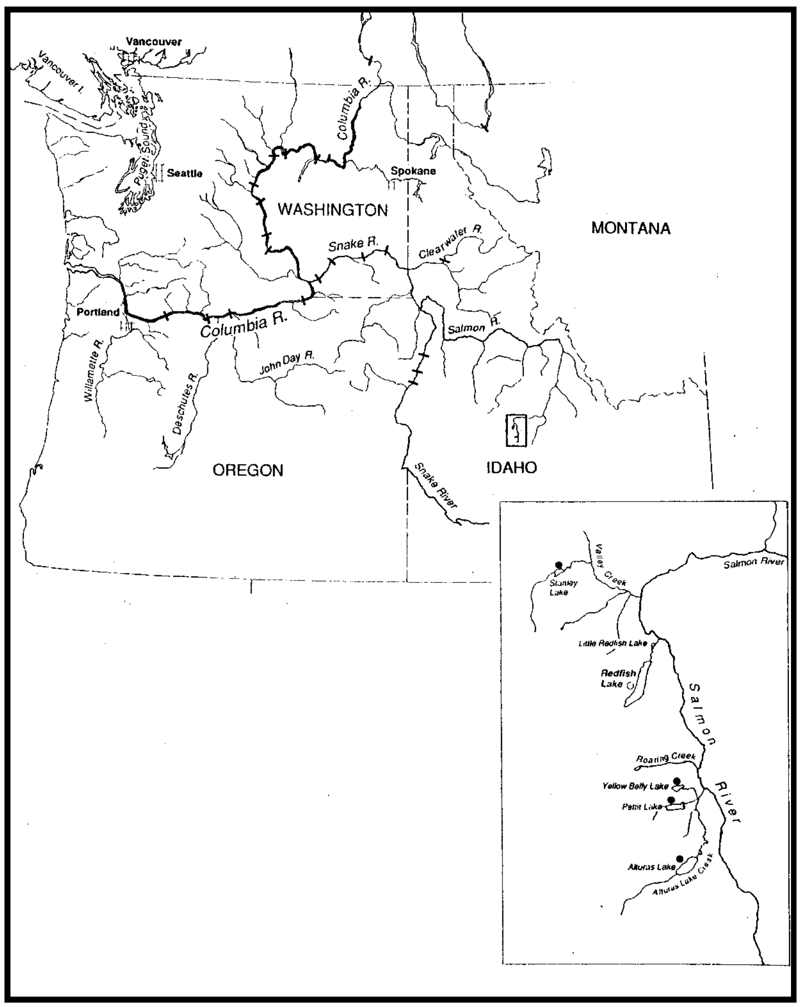


Figure 1. Map of study area.

All of the Stanley Basin lakes are oligotrophic: mean summer total phosphorus (TP) concentrations in the epilimnion range from 3.1 to 11.6 *ug*/L; surface chlorophyll *a* concentrations range from 0.3 to 2.0 *ug*/L; and mean summer secchi disk transparencies range from 9.8 to 17.8 m, excluding Stanley Lake which ranges from 5.0 to 10 m.

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

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

Lake	**Area (km^2)**	**Volume (m^3x10^6)**	**Mean Depth (m)**	**Drainage Area (km^2)**
Stanley	0.81	10.4	13	39.4
Redfish	6.15	269.9	44	108.1
Yellowbelly	0.73	10.4	14	30.4
Pettit	1.62	45.0	28	27.4
Alturas	3.38	108.2	32	75.7

Native fish species found in the nursery lake system include: sockeye/kokanee salmon *Oncorhynchus nerka*, steelhead/rainbow trout *O. mykiss*, Chinook salmon *O. tshawytscha*, cutthroat trout *O. clarki lewisi*, bull char *Salvelinus confluentus*, mountain whitefish *Prosopium Williamson*, sucker *Catastomus* spp., redside shiner *Richardsonius balteatus*, dace *Rhinichthys* spp., northern pikeminnow *Ptychocheilus oregonensis*, and sculpin *Cottus* spp.. Nonnative species include brook char *S. fontinalis* and lake trout *S. namaycush*. The only pelagic species besides *O. nerka* are redside shiners. The two species are not sympatric because of differing vertical distributions. Hatchery rainbow trout are stocked by IDFG throughout the summer in all lakes except for Redfish and Yellowbelly lakes. Sport fishing for salmonid fishes is open on all lakes as well as inlet and outlet streams.

The Sawtooth Valley lakes have several different forms of *O. nerka*, the primary pelagic zooplanktivore in the system. There are three distinct life histories in Redfish Lake: anadromous sockeye salmon, residual sockeye salmon, and kokanee salmon. Kokanee salmon, a non-anadromous form of *O. nerka*, spends its entire life cycle in fresh water lakes. Kokanee salmon generally spawn at three to five years of age in the inlet creeks of the Sawtooth Valley lakes during late summer and die afterwards. The Redfish Lake kokanee salmon population is admixed, consisting of several out-of-basin stocks, and is genetically dissimilar to the anadromous form. This kokanee salmon population is temporally and spatially separated during spawning from the listed Snake River sockeye salmon. Stanley, Yellowbelly, and Pettit lakes were treated by the IDFG with rotenone (1950's and 60's) and kokanee salmon were reintroduced from out-of-basin stocks. Genetic data indicates that these fish are not indigenous *O. nerka*. No Sawtooth Valley kokanee salmon are listed as endangered.

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

MATERIALS AND METHODS

Limnology

Limnological sampling was conducted at Redfish, Pettit, and Alturas lakes twice a month from June-September, and once a month in October and November. We sampled Pettit Lake in January but our attempts to sample at Redfish and Alturas lakes were unsuccessful because of thin ice. We tried again in February and March to no avail: Pettit Lake was flooded and Redfish and Alturas lakes had not formed sufficient ice to allow for safe travel. Redfish, Pettit, and Alturas lakes were stocked with sockeye salmon parr from the Redfish Lake captive broodstock in early October 2008. Additionally, adult sockeye salmon were stocked into Redfish Lake for volitional spawning and eyed eggs in incubators were placed in Pettit Lake. Water temperature (°C), dissolved oxygen (mg/L), conductivity (µS/cm), Secchi depth (m), compensation depth (m), nutrient concentrations (µg/L), chlorophyll a concentrations (µg/L), phytoplankton density (cells/mL) and bio-volume (mm3/L), and zooplankton density (no./L) and biomass (µg/L and mg/m2) were sampled near the middle of each lake. Additional zooplankton samples were collected from one or two other stations in each lake. Nutrients were sampled in all lakes once per month in June, August, September and October.

During stratification, water for nutrient analysis was collected from the epilimnion, metalimnion, and hypolimnion. Phytoplankton samples were collected from the epilimnion and compensation depth. Three discrete samples were collected from each stratum with a 3 L Van Dorn bottle and mixed in a churn splitter. When lake strata could not be delineated, surface water was collected from 0-6 m with a 25 mm diameter, 6 m long lexan® tube.

Temperature (^{o}C), dissolved oxygen (mg/L), and conductivity (µS/cm) profiles were collected at the main station of each lake using a Hydrolab® Surveyor4™ equipped with a Hydrolab DS5® submersible data transmitter. The instrument was calibrated each day prior to sampling using barometric pressure and conductivity standards. Temperature, dissolved oxygen, and conductivity were recorded at 1 m intervals from the surface to 10 m, 1-2 m intervals from 10 m to the thermocline, then at 2-10 m intervals to the bottom. Mean water temperatures from 0-10 m were used to calculate seasonal mean (June-October) surface water temperatures. Secchi depth was measured with a 20 cm Secchi disk and a viewing tube, and light attenuation was measured with a Li-Cor® Li-1000 data logger equipped with a Li-190SA quantum sensor deck cell and a LI-193SA spherical sea cell. Photosynthetically active radiation (400-700 nm) was measured at 2-4 m intervals from surface to 2-4 m below the compensation depth (1% light level). Compensation depth was identified using the technique of Wetzel and Likens 1991.

Water collected for nutrient analysis was transferred to Nalgene bottles rinsed in hydrochloric acid (0.1 N) and then rinsed in sample water and stored on ice while in the field. Water was filtered through 0.45 µm acetate filters at 130 mm Hg for ammonium (NH_4), nitrate-nitrite (NO_3-NO_2-N), and total dissolved phosphorus (TDP) assays. Water samples were then frozen and shipped to the High Sierra Water Lab for analysis. NH_4 was assayed with the indophenol method, NO_3-NO_2-N with the hydrazine method, organic nitrogen (TKN) using kjeldahl nitrogen, and total phosphorus (TP) and total dissolved phosphorus (TDP) samples were assayed by persulfate digestion (APHA 1995). Total nitrogen (TN) concentrations were estimated by adding TKN and NO_3-NO_2-N.

Water for chlorophyll *a* analysis was stored on ice in the field and then filtered onto 0.45 µm cellulose acetate membrane filters with 130 mm Hg vacuum pressure. Filters were frozen and then placed in methanol for 12-24 hrs to extract the chlorophyll pigments. Chlorophyll *a* concentrations were measured with a Turner model 10-AU fluorometer calibrated during the spring with commercial chlorophyll standards. Samples were run before and after acidification to correct for phaeophytin (Holm-Hansen and Riemann 1978).

Phytoplankton samples were fixed in Lugol's solution and total cell abundance and biovolume determined at 1560x magnification using a Zeiss Inverted Plankton microscope following the protocol of Utermohl (1958).

Zooplankton was sampled with a 1.58 m long, 0.35 m diameter, 80 µm mesh conical net equipped with a removable bucket. Vertical hauls were made using a release mechanism that allowed sampling at discrete depth intervals. A General Oceanics flow meter was mounted in the mouth of the net to quantify the volume of water filtered. The net was retrieved using an electric winch and davit at a rate of 1 m/sec. Retrievals were made from 10-0 m, 30-10 m, and bottom (~ 60 m) to 30 m; at the main station in Redfish Lake an additional haul was made from approximately 85 m to 60 m. 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).

Fertilization

In 2008, the SBT, operating under a consent order issued by the IDEQ, added supplemental nutrients (liquid ammonium phosphate (20-5-0) and ammonium nitrate (28-0-0-0)) to Pettit and Alturas lakes. Nutrients were applied at a ratio of approximately 20:1 N:P by mass. As required by the consent order, we measured water transparency once per week, epilimnetic and metalimnetic chlorophyll *a* concentrations every two weeks, and nutrient concentrations once per month. Under the consent order, nutrient enhancement activities are allowed as long as water transparencies exceed 6 m, chlorophyll *a* concentrations remain below 3 µg/L in the epilimnion and 6 µg/L in the metalimnion, and total phosphorus concentrations remain below 15 µg/L in both the epi- and metalimnions. Nutrient applications were made from a 6.7 m boat equipped with a portable plastic tank and electric pump. Fertilizer was loaded into tanks off-site and sprayed into the boat's wake while traveling over the surface of the lake. Predetermined transect lines were followed using GPS, compass, and local landmarks to evenly disperse the nutrients over the surface of the lake.

Smolt Monitoring

Pettit Lake

A weir was operated at the outlet of Pettit Lake, Idaho (Section 31, Township 8 North, Range 14 East) from 17 April through 10 June 2008. The weir was used to evaluate migration of Snake River sockeye salmon smolts. We checked the trap for fish and cleaned the weir at sunrise and sunset. The weir was visited more frequently when high levels of debris were present. The weir ran continuously at 100% capture efficiency until 16 May when discharge overwhelmed weir operations. Discharge ranged from 0.10 m^3/s to 4.20 m^3/s.

Immediately after removal from the trap, all sockeye salmon were scanned for passive integrated transponder (PIT) tags. Approximately 1,000 fish planted in October 2007 were PIT tagged prior to release. All of the fish containing PIT tags were placed in a live box and eight to ten at a time 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 anesthetized fish were weighed to the nearest 0.1 grams and fork length was measured to the nearest millimeter. Fish were held in a live well for 1 to 10 hours after handling and then released. Approximately 50 fish were PIT tagged each day to evaluate downstream survival and SAR's. A condition factor (Fulton's K value (weight x 10^5/length^3)) for each fish was calculated; mean, minimum, and maximum K values 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 downstream from Alturas Lake, Idaho (Section 32, Township 8 North, Range 14 East) from 15 April through 10 June 2008. *Oncorynchus nerka* smolts were captured to determine the number of migrants and to allow tagging of Snake River sockeye salmon smolts using PIT tags. Shoshone-Bannock Tribal fisheries personnel checked for fish and cleaned the screw trap at sunrise and sunset. During high flows we checked and cleaned the trap at approximately 6 hour intervals during the night to prevent debris accumulation.

All fish captured were handled similar to methods used at the Pettit Lake Creek weir. Discharge ranged from 0.12 m^3/s to 50.73 m^3/s. Daily numbers of captured, marked, and recaptured fish were used to estimate trap efficiency, with the assumption that marked fish are released far enough upstream to permit random mixing with unmarked juveniles. Trap efficiency estimates were made separately for hatchery and wild fish.

Growth Rates

Specific growth rates are used to express growth relative to an interval of time and are commonly expressed as a percentage. We calculated instantaneous growth rates using the following formula:

$$\textit{Growth rate (G)} = (\log_e Y_2 - \log_e Y_1)/(t_2 - t_1)$$

Y_1= fish size *(length and weight)* at the beginning of a time interval
Y_2= fish size at the end of a time interval
t_1= time at the beginning of an interval
t_2= time at the end of an interval

We then multiplied the resulting values by 100 to report a specific growth rate (percent weight/length gain per day). Data used in growth rate analyses came from individual pit tagged fish released into Redfish, Pettit, and Alturas lakes as presmolts and recaptured the following spring as smolts; therefore, lake specific growth rates represent a mean from samples of individual fish with length and weight data (Y_1 and Y_2) at t_1 and t_2. When the sample size of individually pit tagged fish at t_1 and t_2 was considered too small, group means were used to calculate growth rates.

Stream Spawning

Stream surveys were conducted to estimate kokanee salmon escapement in tributaries to Redfish and Alturas lakes. Budget reductions precluded surveys in Stanley Lake Creek and Pettit Lake has no stream spawning kokanee salmon population. Fish were counted from the bank by one or two observers equipped with polarized sunglasses. On days when counts were missed, the number of fish in the stream was interpolated by dividing the difference between the actual counts by the number of days between the counts. Spawning surveys began 08 August, with the final count occurring on 20 October. Total escapement estimates were calculated by summing daily counts of kokanee salmon 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 sockeye salmon and adult sockeye salmon. Night snorkel surveys were conducted at both locations to estimate numbers of spawning residual sockeye salmon, anadromous sockeye salmon, and hatchery sockeye salmon. Snorkel surveys in Redfish Lake were conducted weekly from 14 October to 3 November 2008. 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 sockeye salmon 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 near the two small southeast inlet streams.

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 was 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 Pettit and Alturas lakes. A minimum of six pings per target was necessary to qualify as a fish target.

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 (Teuscher and Taki 1996). Eleven, five, and eight transects were sampled at Redfish, Pettit, and Alturas lakes, respectively. Surveys were conducted on two moonless nights during 30

September and 01 October. We began at approximately 1½ hours after sunset and maintained a boat speed of approximately 1.5 m/s during data collection.

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

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

developed by Love (1977) where TS = target strength in decibels, L = fork length in centimeters, and F = frequency of transmitted sound (kHz). Using Echoscape (v 2.11) software developed by Hydroacoustic Technology, Inc., an MS Access file was created for each transect surveyed. This software allows inspection of every target and false echoes can be removed. After completing all transects for a given lake, we then made a master spreadsheet to compile all transects. Then we created a new MS Access database using data from the Excel file. In this database, transect length and size bins (fork length) were entered to represent each cohort. We used a histogram created by IDFG from trawl samples to create size bins for length classes. Four different size classes were used for all three lakes. After entering all the parameters, we queried for fish density by size class and transect. Total *O. nerka* abundance was 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

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

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

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

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

and variance was estimated by

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

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

Gillnet Sampling

Horizontal and vertical gillnet sampling was conducted to quantify fish population characteristics including: species composition, habitat utilization (pelagic versus littoral), and diet analysis. Horizontal gillnets (30 m long, 1.8 m high) with lead sinking lines composed of five panels 6 m long of graduated mesh size (2.54, 3.17, 5.08, and 6.35 cm) were set at selected points along the bank, perpendicular to the shore in Pettit Lake. Nets were set with the smallest mesh size panel closest to shore (approximately 10 m from shore) and the largest mesh size panel deeper and further from shore. Vertical gillnets, 3 m wide and 30 m deep, each composed of a different mesh size (1.27, 1.90, 2.54, and 3.81 cm), were set in the pelagic zones of Pettit and Alturas lakes. Due to NMFS section 10 permit limitations, no gillnets were set in Redfish Lake.

Diet Analysis

Fish stomachs collected from gillnet and trawl samples were examined to determine diet composition. Stomach samples from rainbow trout, bull char, brook char, northern pike minnow, kokanee salmon, and sockeye salmon were collected. Starting in 1997, Pettit and Alturas lakes have received eyed-egg plants from captive broodstock sockeye salmon; therefore, unmarked juveniles collected for diet analysis are referred to as *O. nerka,* as distinctions between resident kokanee salmon and sockeye salmon cannot be made in the field. Fish were measured (fork length to the nearest millimeter) and weighed (to the nearest 0.1 gram), after which stomachs were removed and placed in 70% ethanol. Prey were identified, enumerated, blotted dry, and weighed to the nearest 0.01 g. Zooplankton were enumerated from zooplankton tows collected during the same months. Aggregate percent of diet by dry weight for all species of fish sampled was calculated (Swanson et al. 1974). Aggregate percent by dry weight (total diet composition) was used to determine diet overlap and aggregate percent of abundance (zooplankton diet composition) was used to develop 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 prey preferences were used for *O. nerka*.

RESULTS

Limnology

In 2008, mean annual discharge of the Salmon River at Salmon, Idaho (USGS gage 13302500) was 51.5 m^3/s, slightly lower than the 1913-2007 average of 54.3 m^3/s (Figure 2). The upper Salmon River region experienced drought conditions from 1987 to 1994 and 2000 to 2005. Since 1990, the upper Salmon River has experienced the three lowest water years since measurements began in 1913.

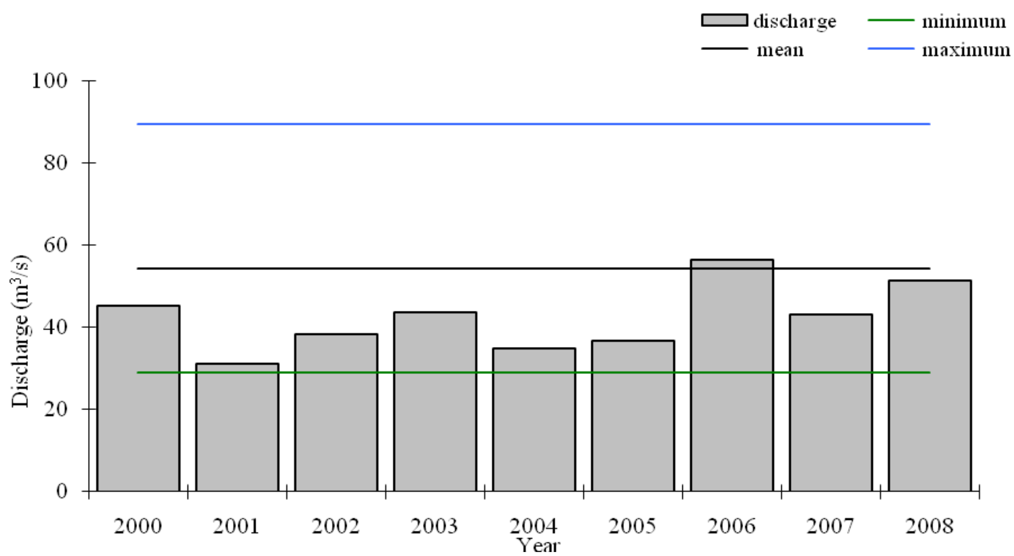


Figure 2. Mean annual discharge for the Salmon River at Salmon, Idaho, 2000-2008. Minimum, mean, and maximum are for period of record, 1913 to 2008.

Profile Data

The Sawtooth Valley lakes were inversely stratified and ice covered from January to April 2008. All three lakes were free of ice by mid-May 2008. In 2008, our Hydrolab H2O sonde malfunctioned: parts and service were no longer available, so sampling was precluded until a replacement was obtained. Thermoclines were present in all lakes from July through September. Maximum surface temperatures were approximately 16 ^oC in Redfish Lake and 18-19 ^oC in Pettit and Alturas lakes (Appendix A).

Redfish Lake mixed completely in spring 2008. Hypolimnetic oxygen deficits were minimal; oxygen concentrations were less than 5 mg/L in the bottom 1 m during October. Pettit Lake, being meromictic, did not mix completely. During late summer and fall, dissolved oxygen concentrations were less than 5 mg/L below approximately 27 m depth. In Alturas Lake, oxygen concentrations were less than 5 mg/L in the bottom 7 m during November. During November, the three lakes were nearly isothermic but had not mixed completely.

Table 2. Seasonal mean (June-October) surface water temperature (^oC), Secchi depth (m), compensation depth (m), epilimnetic chlorophyll *a* (µg/L), and whole-lake total zooplankton biomass (mg/m^2) for the Sawtooth Valley lakes, 2000-2008

Lake	**Year**	**Surface temperature (^oC) 0-10 m**	**Secchi depth (m)**	**Compensation depth (m)**	**Epilimnetic chlorophyll *a* (µg/L)**	**Zooplankton biomass (mg/m^2)**
Redfish	**2008**	-	17.4	26.5	0.7	1201.1
	2007	13.9	16.3	27.0	0.9	1280.6
	2006	13.3	12.4	22.8	1.5	989.1
	2005	14.1	16.3	27.1	0.9	1519.3
	2004	13.5	16.5	27.0	0.9	1105.4
	2003	13.9	15.8	25.6	0.7	2005.6
	2002	13.6	13.9	24.5	1.5	1023.4
	2001	14.3	14.5	27.4	1.4	1266.3
	2000	14.2	17.8	26.1	0.8	1166.7
	mean	**14.0**	**15.7**	**26.0**	**1.0**	**1284.2**
Pettit	**2008**	-	10.4	20.8	2.0	2287.5
	2007	13.6	11.6	23.0	1.8	1202.1
	2006	12.1	12.1	19.8	1.2	1175
	2005	13.7	14.1	23.4	1.5	2525.5
	2004	14.0	10.4	22.3	2.6	3121.4
	2003	13.7	13.2	21.3	1.2	2760.7
	2002	13.8	15.5	24.2	0.7	2869.6
	2001	14.8	15.7	26.2	0.6	1441.7
	2000	14.4	15.0	24.5	1.0	466.7
	mean	**14.0**	**13.1**	**22.8**	**1.4**	**1983.4**
Alturas	**2008**	-	10.2	17.5	2.3	284.1
	2007	13.6	11.9	20.2	1.8	564.3
	2006	12.7	11.3	16.9	1.4	669.3
	2005	13.1	13.6	20.3	1.8	1070.8
	2004	13.3	15.6	22.3	0.7	883.3
	2003	12.9	11.8	17.1	0.7	484.3
	2002	12.3	12.5	20.0	0.7	405.8
	2001	14.0	13.9	22.8	0.8	140.6
	2000	13.8	14.5	19.8	0.9	272.5
	mean	**13.4**	**12.8**	**19.7**	**1.2**	**530.6**

Secchi depth and compensation depth

Secchi depths in the Sawtooth Valley lakes are typically shallow during the spring, then gradually increase in depth during the summer and fall with minor declines in the late fall (October-November). In 2008, Secchi depths in Redfish Lake followed this pattern; however, in Pettit and Alturas lakes, Secchi depths deviated from this trend after nutrient supplementation began in mid-July. In Pettit Lake, Secchi depths declined steadily after nutrient supplementation began, reaching a minimum water transparency of 7.2 m in early November. Alturas Lake Secchi depths continued to increase through early September, then reached a plateau which lasted through November (Figure 3). Seasonal mean Secchi depths were below average in the lakes receiving supplemental nutrients (Pettit and Alturas) and above average in unfertilized Redfish Lake (Table 2). Compensation depths followed similar patterns, consistent with nutrient applications. In Redfish Lake, light penetration generally increased as the season progressed, while light penetration declined in Pettit Lake and remained relatively stable in Alturas Lake during lake fertilization. Maximum light penetration occurred during September in Redfish Lake (29.3 m), during July in Pettit Lake (22.3 m), and during August in Alturas Lake (19.2 m) (Figure 4). Mean compensation depths, June through October, were similar to the 1992-2007 averages in Redfish Lake and approximately 2.5 m less than average in Pettit and Alturas lakes (Table 2).

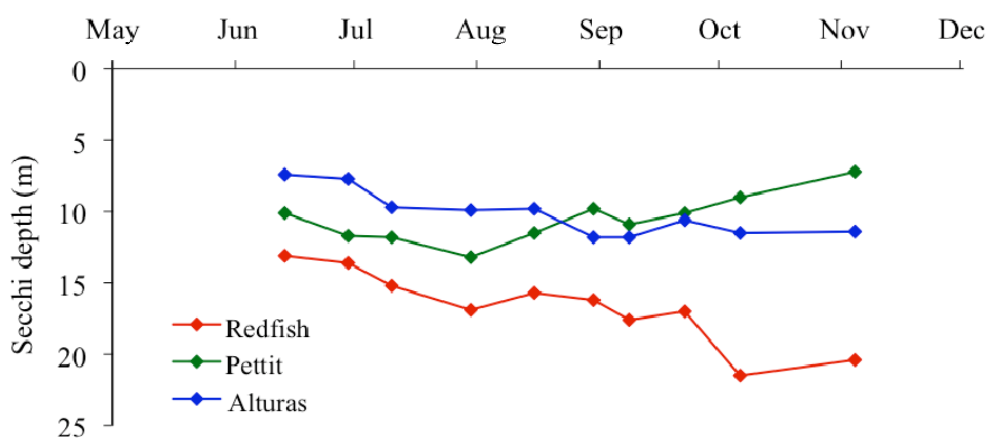


Figure 3. Secchi depths (m) for Redfish, Pettit, and Alturas lakes, June through November 2008.

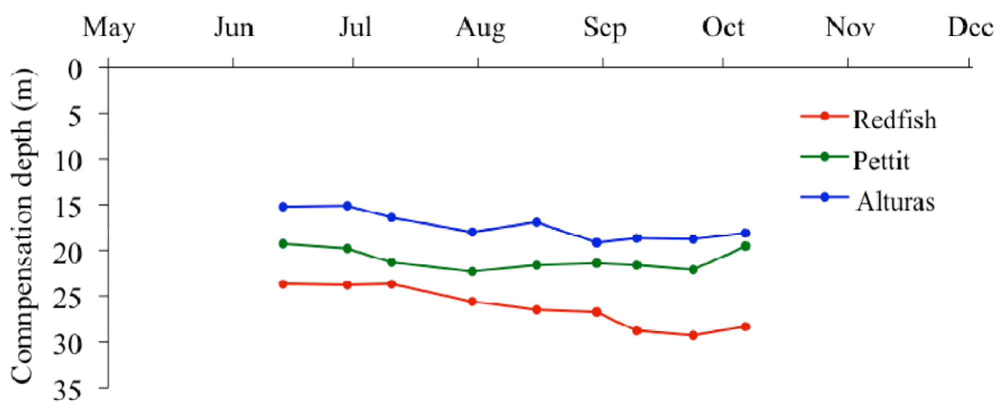


Figure 4. Compensation depths (m) for Redfish, Pettit, and Alturas lakes, June through November 2008.

Water Chemistry

During spring turnover (June 2008) depth integrated nutrient concentrations remained extremely low, typical for the oligotrophic conditions of the Sawtooth Valley lakes. TP concentrations were between 5 and 6 µg/L and TN concentrations ranged from 76 to 97 µg/L resulting in TN:TP ratios between 13:1 and 19:1. NO_3-NO_2-N concentrations were less than 1 µg/L and TDP was 3-5 µg/L in the three Sawtooth Valley lakes.

Nutrient concentrations were relatively low and stable in the Sawtooth Valley lakes during 2008 (Figure 5). Seasonal mean epilimnetic TP concentrations were between 6-9 µg/L and TDP ranged from 2-6 µg/L in Redfish, Pettit, and Alturas lakes. Mean TN concentrations were 111 µg/L in Redfish Lake, 131 µg/L in Pettit Lake, and 102 µg/L in Alturas Lake resulting in TN:TP ratios of 14.2, 21.4 and 16.1, respectively. Mean NO_3-NO_2-N concentrations were < 3 µg/L in the three lakes (Table 3).

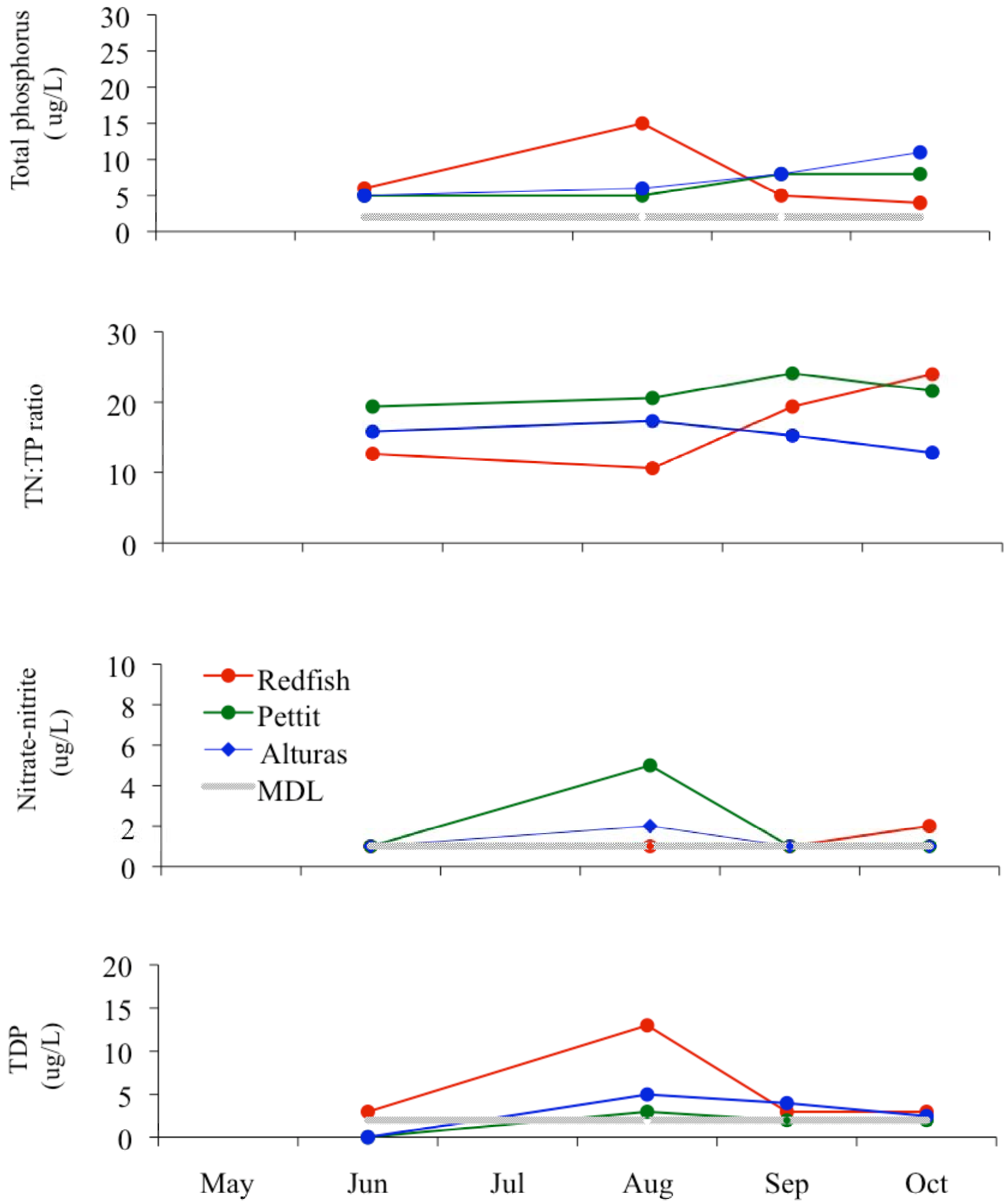


Figure 5. Concentrations of total nitrogen, total phosphorus, TN:TP ratio, nitrate-nitrite (NO3-NO2-N), and total dissolved phosphorus (TDP) in the epilimnetic waters of Redfish, Pettit, and Alturas lakes, June through October 2008. Grey line denotes method detection level.

Table 3. Seasonal mean (June-October) epilimnetic nutrient concentrations (µg/L) and TN:TP ratio in Redfish, Pettit, and Alturas lakes during 2000-2008.

Lake	Year	TP	TDP	TN	$N0^3 + NO^2$	TN:TP
Redfish	2008	8.7	6.3	110.7	1.0	14.2
	2007	4.0	3.0	85.3	1.0	31.2
	2006	5.0	3.3	75.2	1.5	17.0
	2005	6.2	4.3	59.3	1.0	10.7
	2004	6.2	3.6	60.8	1.4	10.2
	2003	4.2	2.9	100.1	1.4	26.0
	2002	5.0	3.0	65.8	4.1	14.3
	2001	3.2	2.1	108.0	4.6	27.2
	2000	4.9	3.0	69.5	1.8	13.2
	mean	5.3	3.5	81.6	2.0	18.2
Pettit	2008	6.0	2.5	131.0	2.3	21.4
	2007	4.1	2.7	91.3	1.0	27.6
	2006	5.3	3.3	81.2	1.0	16.5
	2005	5.6	3.8	106.6	1.8	19.2
	2004	5.4	3.6	125.4	9.8	23.2
	2003	4.3	2.7	101.0	1.4	27.1
	2002	4.8	3.2	100.8	1.8	24.5
	2001	3.1	2.0	117.6	1.2	38.3
	2000	5.3	2.7	57.5	1.0	11.2
	mean	4.9	3.0	101.4	2.4	23.2
Alturas	2008	6.3	4.5	101.7	1.3	16.1
	2007	5.0	2.8	87.0	1.3	19.5
	2006	7.3	4.0	79.8	1.0	13.4
	2005	7.6	5.2	77.2	1.4	10.2
	2004	-	-	-	-	-
	2003	-	-	-	-	-
	2002	-	-	-	-	-
	2001	-	-	-	-	-
	2000	7.1	5.2	65.0	1.9	11.0
	mean	6.7	4.3	82.1	1.4	14.1

Chlorophyll a

In 2008, epilimnetic chlorophyll *a* concentrations ranged from 0.6 to 4.7 µg/L in the three Sawtooth Valley lakes (Figure 6). Concentrations were typically low (~1µg/L) from June through July. In late summer and fall, during nutrient supplementation, chlorophyll *a* levels increased in Pettit and Alturas lakes before peaking in November. Redfish Lake remained relatively stable, increasing slightly between September and November. June-October mean epilimnetic chlorophyll *a* concentrations were comparatively low in Redfish Lake (0.7 µg/L), and higher than average in Pettit (2.0 µg/L) and Alturas (2.3 µg/L) lakes (Table 2).

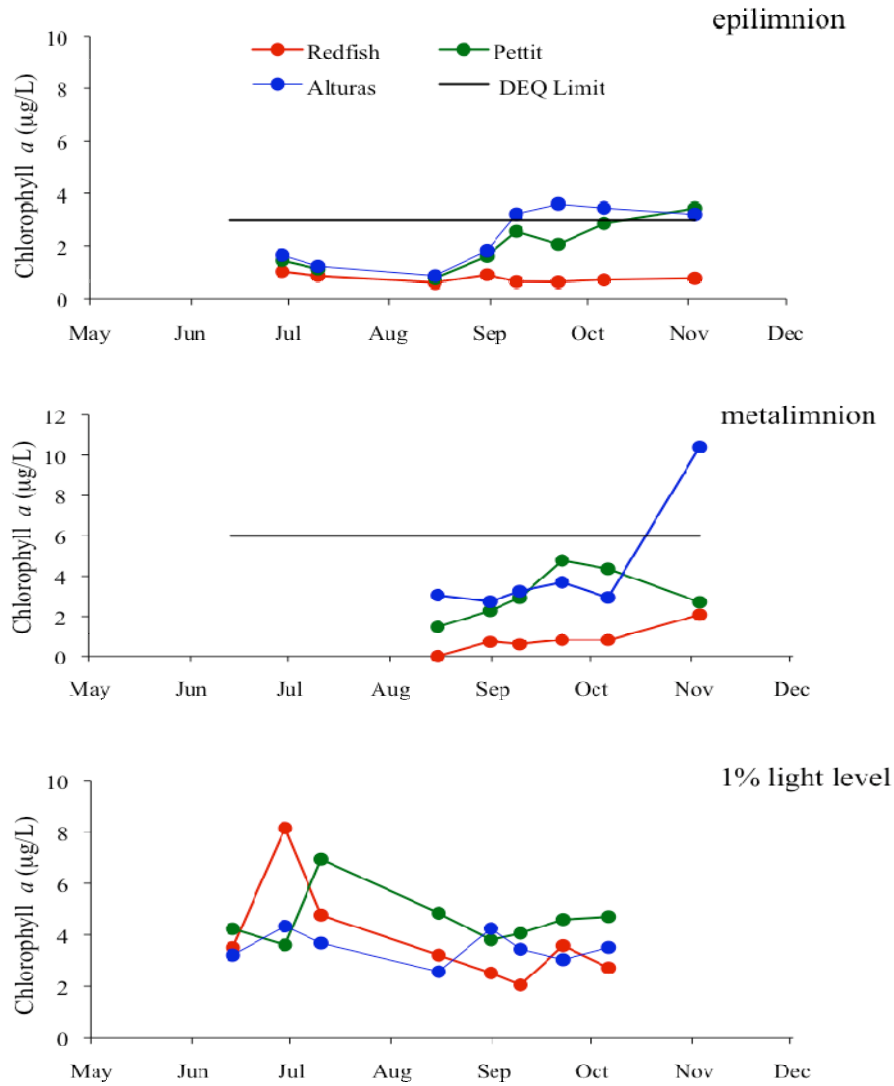


Figure 6. Chlorophyll *a* concentrations (µg/L) in the epilimnion, metalimnion, and compensation depths in Redfish, Pettit, and Alturas lakes, June-November 2008.

Phytoplankton

Phytoplankton communities in the Sawtooth Valley lakes were dominated by small grazable taxa during 2008. Total phytoplankton densities ranged from 912-3,923 cells/mL and total phytoplankton bio-volume ranged from 0.11-0.61 mm^3/L in the epilimnions of the three Sawtooth Valley lakes (Table 4). Epilimnetic phytoplankton densities and bio-volumes were lowest in unfertilized Redfish Lake, highest in Pettit Lake, and intermediate in Alturas Lake.

In Redfish Lake, epilimnetic phytoplankton densities and bio-volumes were low and stable with an August peak of 1,683 cells/mL and 0.203 mm^3/L. Cyanophaceae (mostly *Oocystis* and *Cosmarium*; 0.11 mm^3/L) and Chryso- and Cryptophacean nano-flagellates (small microflagellates and *Chrysochromulina* sp.) were numerically dominant (Appendix B1). Bio-volume at the compensation depth displayed three strong peaks occurring in late June, July, and September. *Dinophyceae* dominated these peaks (mostly *Gymnodinium*) averaging 0.535mm^3/L. Bacillariophytes (mostly *Fragilaria* and *Cyclotella*) were common at the compensation depth.

In Pettit Lake, Bacillariophyceae (mostly *Asterionella*; 5,119 cells/mL and 0.513 mm^3/L) and Chlorophytes (*Scenedesmus*; 1,166 cells/mL) caused epilimnetic phytoplankton levels to peak strongly in early November (Appendix B2). Pettit lake reached peak compensation depth densities in late July (3,132 cells/mL), primarily comprised of Chlorophytes (*Stichococcus miutissmus* and *Scenedesmus*; 3,132 cells/mL). Compensation depth bio-volume was elevated during late August and September and was dominated by Chlorophytes, primarily *Cosmarium* (0.104 mm^3/L) and Dinophytes (*Gymnodinium*; 0.138 mm^3/L). Relative to the other lakes, Pettit Lake had high densities and bio-volumes of Chlorophytes.

Alturas lake reached peak epilimnetic densities of phytoplankton in late July (2,767 cells/mL), but densities remained relatively consistent throughout the season. Chryso- and Cryptophyceae (small microflagellates) dominated (Appendix B3) the phytoplankton community. Epilimnetic bio-volume peaked in late July (0.391mm^3/L) and early October (0.409 mm^3/L). In late July this peak was predominantly Chryso- and Cryptophyceae (*Chrysochromulina*); while in late October Dinophyceae and Bacillariophytes dominated. Compensation depth density and bio-volume also peaked in late July (2,798 cells/mL and 0.383 mm^3/L). Cyanophyceae (*Synechococcus*) and Chryso- and Cryptophyceae (small microflagellates) were the most abundant taxa and bio-volume was dominated by Bacillariophytes (mostly *Fragilaria* and *Asterionella)* and Dinophytes.

Table 4. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnions and compensation depths in three Sawtooth Valley lakes during June-October 2008.

		Density			Bio-volume		
Lake	**Strata**	**min**	**mean**	**max**	**min**	**mean**	**max**
Redfish	epilimnion	912	1,247	1,855	0.11	0.15	0.20
	compensation depth	1,744	2,140	2,585	0.25	0.60	0.87
	mean		**1,694**			**0.38**	
Pettit	epilimnion	963	2,207	3,923	0.14	0.28	0.61
	compensation depth	983	1,962	3,132	0.14	0.26	0.44
	mean		**2,085**			**0.27**	
Alturas	epilimnion	1,389	1,960	2,767	0.14	0.24	0.41
	compensation depth	1,166	1,801	2,798	0.15	0.26	0.40
	mean		**1,881**			**0.25**	

Zooplankton

In 2008, Pettit Lake had the highest seasonal mean zooplankton biomass followed by Redfish and Alturas lakes (Figure 7). Zooplankton biomass has been relatively stable for the past 5 years in Redfish Lake. In Pettit Lake, zooplankton biomass increased dramatically in 2008, while in Alturas lake zooplankton biomass continued to decline for the third consecutive year. Seasonal mean biomass (June-October) was 1,201 mg/m^2 in Redfish Lake, 2,288 mg/m^2 in Pettit Lake, and 284 mg/m^2 in Alturas Lake (Table 2).

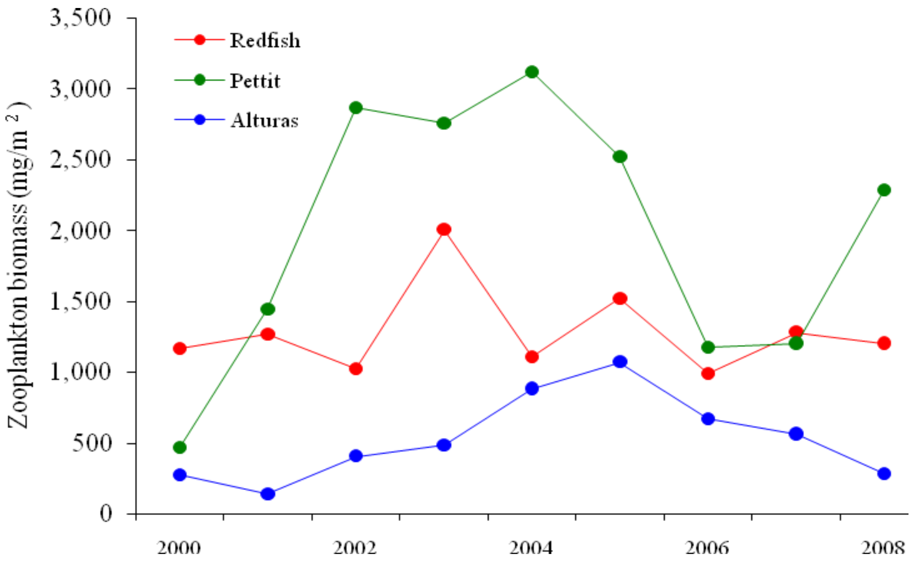


Figure 7. Seasonal mean zooplankton biomass (June-October) for the Sawtooth Valley lakes, 2000-2008.

Redfish Lake zooplankton biomass decreased slightly in 2008, but has been relatively stable during the past eight years with the exception of 2003. *Daphnia* (261 mg/m^2), *Holopedium* (592 mg/m^2), and cyclopoid copepods (204 mg/m^2) dominated mean summer biomass (Figure 8). Due to unsafe ice conditions, zooplankton samples were not collected during the winter of 2008.

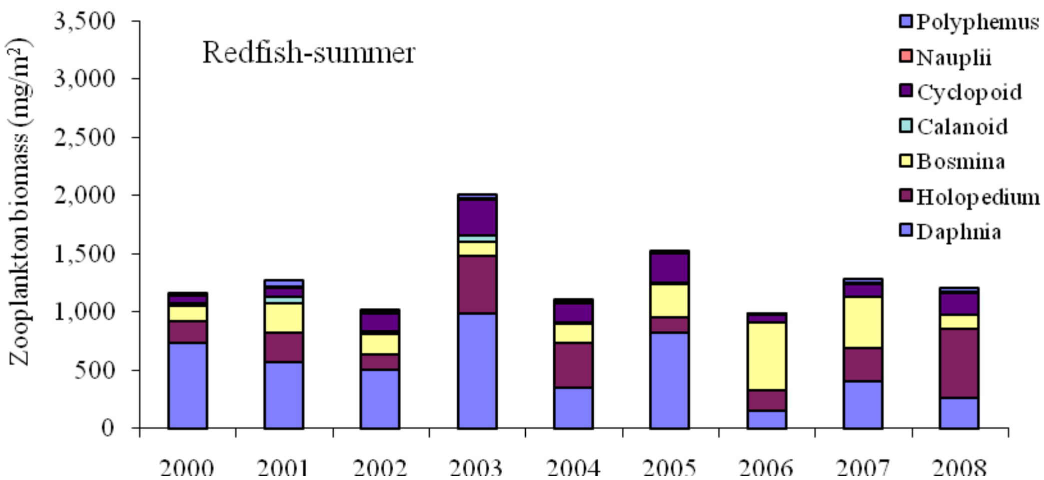


Figure 8. Mean areal zooplankton biomass (June-October) in Redfish Lake, 2000-2008.

Pettit Lake total summer zooplankton biomass increased significantly from 2007 (Figures 7 and 9). Summer zooplankton biomass was predominately *Daphnia* (1,255 mg/m^2) and cyclopoid copepods (882 mg/m^2). In January 2008, total zooplankton biomass decreased to 967 mg/m^2 and was dominated by cyclopoid copepods (844 mg/m^2) and *Nauplii* (63 mg/m^2).

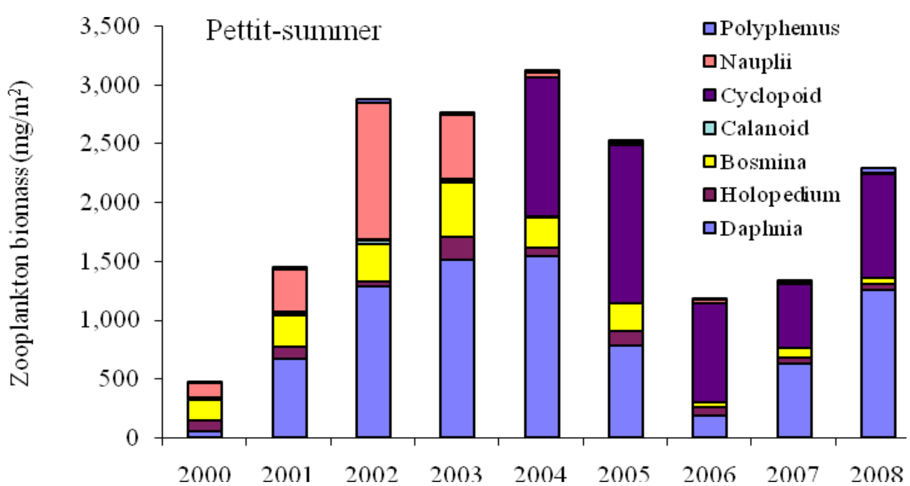


Figure 9. Mean areal zooplankton biomass (June-October) in Pettit Lake, 2000-2008.

In Alturas Lake, total zooplankton biomass declined, continuing a downward trend since 2005. Alturas Lake continues to have the lowest zooplankton biomass of the three Sawtooth Valley lakes, with a seasonal mean of 284 mg/m^2 in 2008 (Figure 7 and Figure 10). During the summer of 2008, zooplankton populations consisted predominantly of *Bosmina* (86 mg/m^2) and cyclopoid copepods (129 mg/m^2). Because of unsafe ice conditions, samples were not taken during winter of 2008.

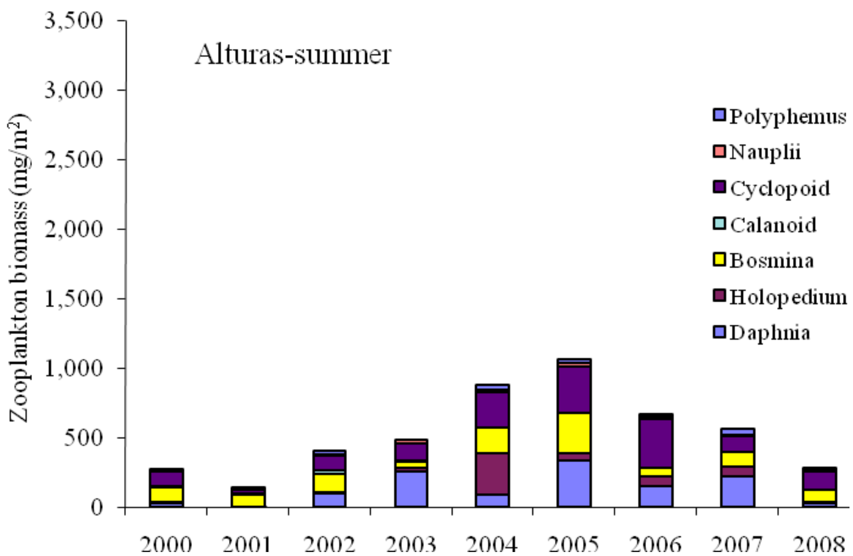


Figure 10. Mean areal zooplankton biomass (June-October) in Alturas Lake, 2000-2008.

Fertilization

Between 15 July and 21 October 2008, 71 kg phosphorus (P) and 1,448 kg nitrogen (N) were added to Pettit Lake to enhance its productivity (Figure 11). Applications were made once per week during a 15-week period with the exception of 11 August, 30 September, and 14 October. Chlorophyll *a* concentration in the epilimnion exceeded DEQ standards defined in the consent order during October and November. Areal loading rates were 43.9 mg P/m^2 per year or the equivalent of an adult escapement of approximately 8,817 sockeye salmon to Pettit Lake.

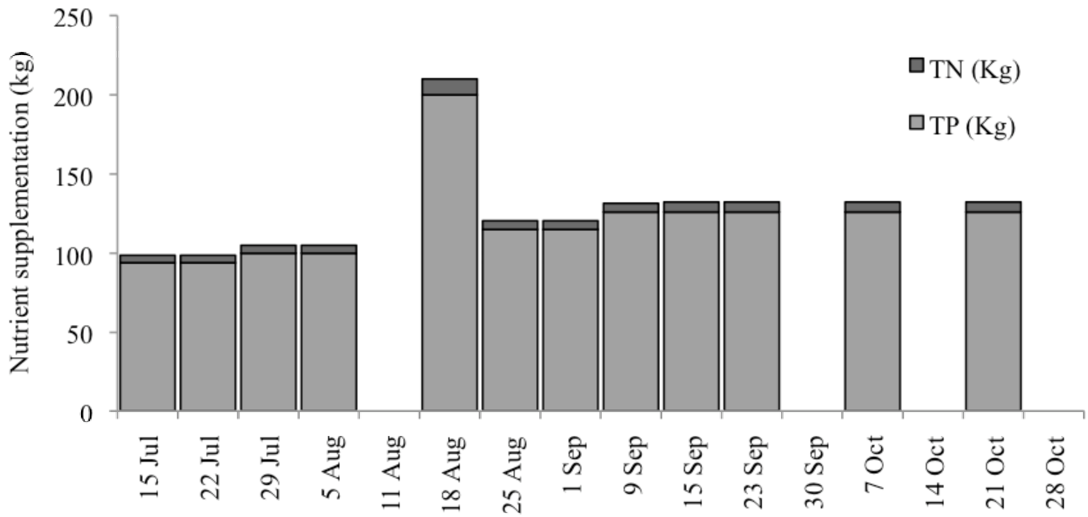


Figure 11. Supplemental nutrient applications for Pettit Lake, 15 July to 21 October 2008.

Alturas Lake received supplemental nutrient applications of 89.9 kg P and 1,778 kg N between 15 July and 28 October 2008 (Figure 12). Applications were made once per week except for 11 August; 9, 23 and 30 September; and 7 and 14 October. At the end of August, chlorophyll *a* criteria was exceeded resulting in reduced applications in September, October, and November. However, chlorophyll *a* levels remained above 3.0 µg/L through November. The areal loading rate for Alturas was 26.6 mgP/m^2 per year, which is the equivalent to the escapement of 11,148 sockeye salmon.

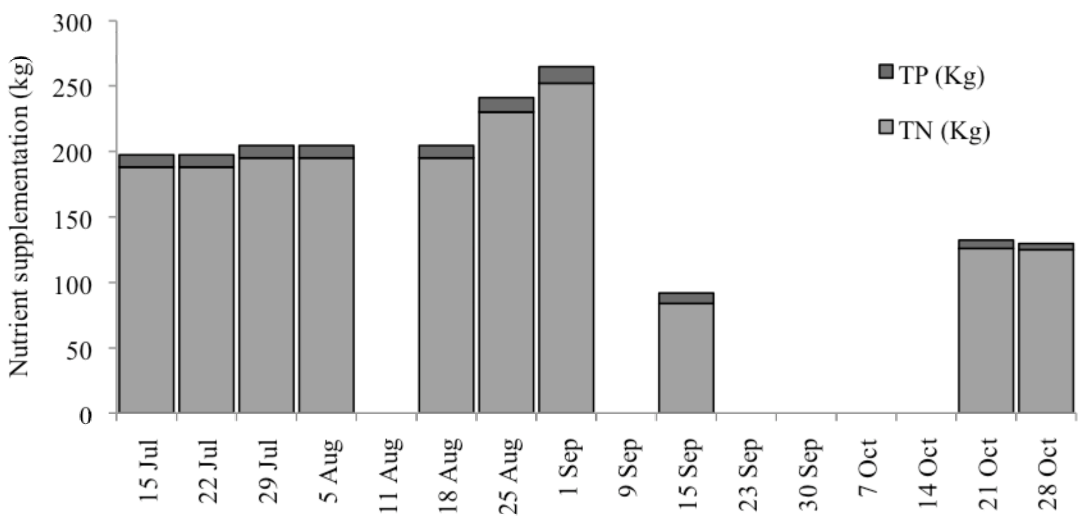


Figure 12. Supplemental nutrient applications for Alturas Lake, 15 July to 28 October 2008.

Smolt Monitoring

Pettit Lake

The Pettit Lake Creek weir, installed on 17 April, fished at 100% efficiency until 16 May when flow conditions overwhelmed the weir. Weir operations continued when flows decreased on 28 May and ended on 10 June. We estimated 6,062 Snake River sockeye salmon migrated from Pettit Lake in 2008. Pettit Lake migrants were comprised of 5,962 (5,580 age I+ and 382 age II+) fall release hatchery fish from the Sawtooth Fish Hatchery and 100 (96 age I+ and 4 age II+) *O. nerka* with adipose fins (presumably from eyed egg or residual spawning production). We recaptured 139 smolts that had been PIT tagged prior to release the previous year. We PIT tagged 23 natural and 217 hatchery smolts.

An estimated 59 percent of the parr released in the fall of 2007 passed the Pettit Lake Creek weir in 2008. Migrant numbers and timing, discharge, length frequency histograms, release numbers, numbers of migrants, percent migration, mean fork length, weight, and condition factors of smolt migrants are located in Figures 13 and 14 and Table 5 and 6.

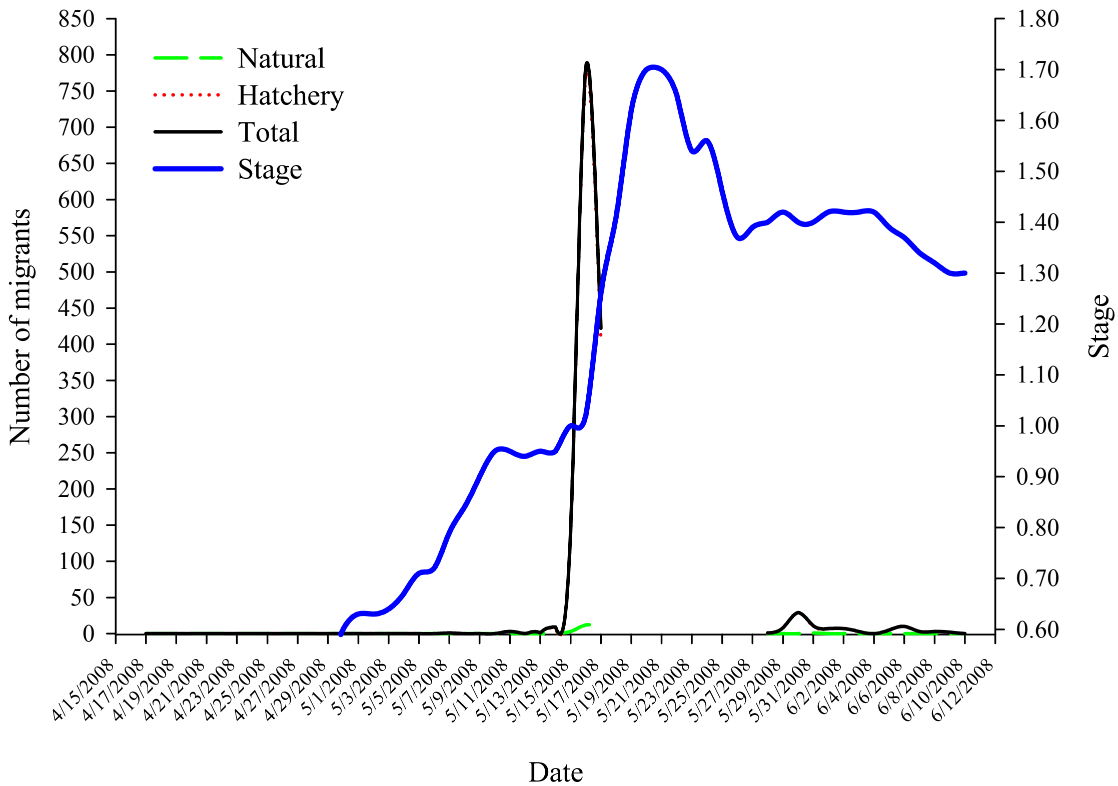


Figure 13. Pettit Lake Creek migrant trapping data and hydrograph, 2008.

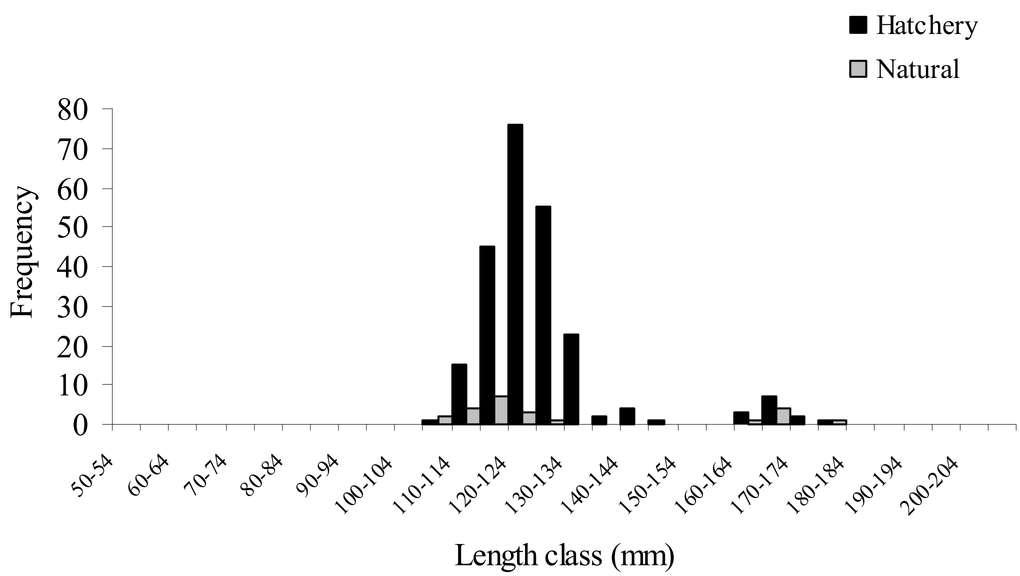


Figure 14. Pettit Lake migrant length frequency histogram, 2008.

Alturas Lake

The Alturas Lake Creek screw trap was installed on 16 April 2008. We PIT tagged 218 hatchery sockeye salmon smolts and 427 natural *O. nerka*. We recaptured 34 sockeye salmon smolts that had been PIT tagged prior to release in October 2007.

Hatchery smolts migrating from Alturas Lake had an estimated migration rate of 53 percent, representing 5,273 (3,947-6,265) fish (5,210 age I+ and 63 age II+). We estimated 15,903 (12,255-23,429) natural *O. nerka* smolts (13,977 age I+ and 1,926 age II+) migrated past the Alturas Lake Creek screw trap in 2008. Migrant timing and discharge, length frequency histograms, release numbers, number of migrants, percent migration, mean length, weight, and condition factors of smolt migrants are located in Figures 15 and 16 and Tables 5 and 6.

Table 5. Pettit and Alturas lake sockeye salmon release and percent migration data by brood year, 2000-2008.

Lake	Release year	Release season	Hatchery origin	Mark	Number released	migration year	Number of migrants	Percent migration
Pettit	2007	Fall	Sawtooth	AD	10,113	2008	5,580*	55.18*
	2006	Fall	Sawtooth	AD	18,494	2007	5,058	27.35
	2005	Fall	Sawtooth	AD	15,289	2006	9,235	60.40
	2004	Fall	Sawtooth	AD	30,700	2005	17,441	56.81
	2003	Fall	Sawtooth	AD	14,961	2004	5,365	35.86
	2002	Fall	Sawtooth	AD	19,981	2003	11,795	59.03
	2002	Summer	Bonneville	ADRV	7,805	2003	1,579	20.23
	2001	Fall	Sawtooth	AD	4,993	2002	1,287	25.78
	2001	Summer	Sawtooth	ADRV	2,998	2002	200	6.67
	2001	Summer	Eagle	ADLV	3,059	2002	152	4.97
	2000	Fall	Sawtooth	AD	6,067	2001	1,907	31.43
	2000	Summer	Eagle	ADRV	2,915	2001	57	1.96
	2000	Summer	Sawtooth	ADLV	3,092	2001	156	5.05
Alturas	2007	Fall	Sawtooth	AD	9,977	2008	5,210*	52.22*
	2006	Fall	Sawtooth	AD	26,994	2007	6,922	25.64
	2005	Fall	Sawtooth	AD	16,949	2006	6,256	36.91
	2004	Fall	Sawtooth	AD	20,129	2005	16,560	82.27
	2003	Fall	Sawtooth	AD	2,017	2004	1,091	54.09
	2002	Summer	Bonneville	ADRV	6,123	2003	553	9.03
	2001	Fall	Sawtooth	AD	5,990	2002	3,505	58.51
	2001	Summer	Sawtooth	ADRV	3,059	2002	72	2.35
	2001	Summer	Eagle	ADLV	3,064	2002	51	1.66
	2000	Fall	Sawtooth	AD	6,003	2001	4,520	75.30
	2000	Summer	Eagle	ADRV	2,917	2001	14	0.48
	2000	Summer	Sawtooth	ADLV	3,069	2001	476	15.51

*Incomplete brood year

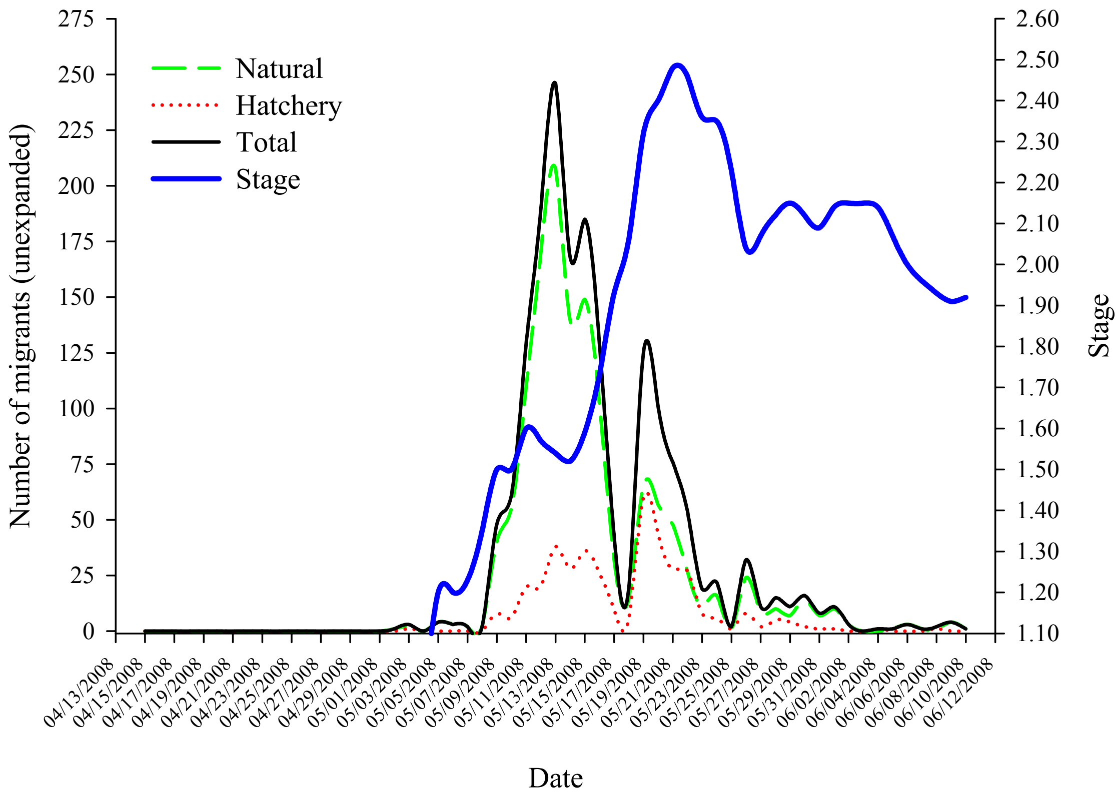


Figure 15. Alturas Lake migrant trapping data and hydrograph, 2008.

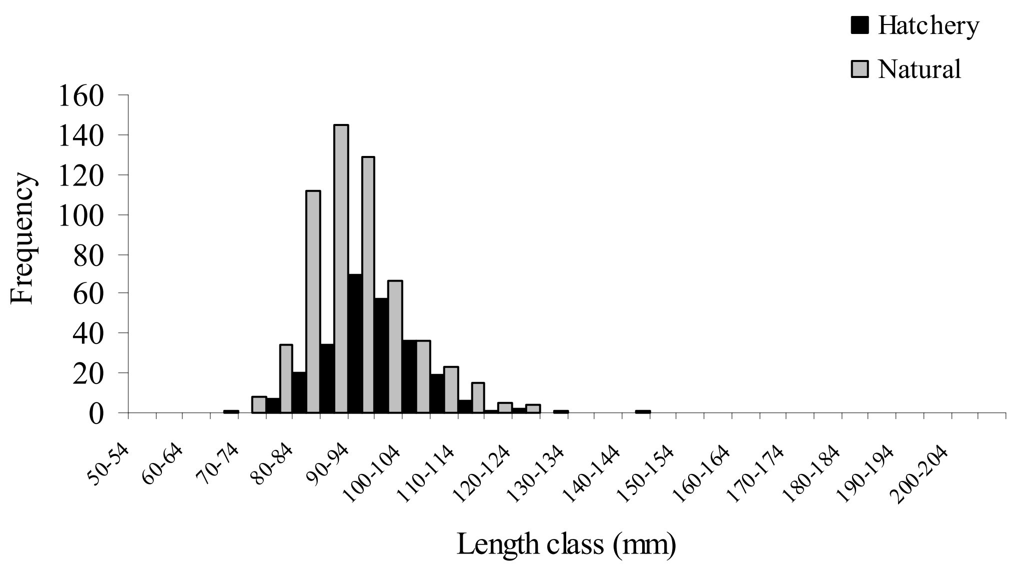


Figure 16. Alturas Lake migrant length frequency histogram, 2008.

Growth Rates

Juvenile sockeye salmon from the captive broodstock program were measured and weighed during two periods in Redfish, Pettit, and Alturas lakes: at release into the lakes in 2007 and at capture as smolts in 2008. Their growth (fork length and weight) increased in Redfish, Pettit, and Alturas lakes from the time of release to the time of capture as smolts. Redfish, Pettit, and Alturas lake hatchery sockeye salmon decreased in condition factor during the same period (Figures 17a; 17b; 17c; Tables 6 and 7). Fall release fish in Pettit Lake exhibited the greatest increase in length and weight between release as parr and capture as smolt relative to Redfish and Alturas lakes.

Table 6. Hatchery sockeye salmon release and migration length, weight, and condition factor data, 2000-2008

	Hatchery sockeye salmon parr release information							Hatchery sockeye salmon smolt migrant information				
Lake	Release date	Mark	Hatchery origin	Mean fork length (mm)	Mean weight (g)	Mean condition factor (k)	Sample size	Migration year	Mean fork length (mm)	Mean weight (G)	Mean condition factor (K)	Sample size
RED	10/03/07	AD	Sawtooth	89.11	7.54	1.05	61	2008	103.15	8.28	0.75	61
	10/03/06	AD	Sawtooth	86.41	6.63	1.02	54	2007	100.48	7.83	0.71	460
	10/06/05	AD	Sawtooth	87.61	6.38	0.94	101	2006	98.32	7.36	0.76	316
	10/05/04	AD	Sawtooth	91.59	8.12	1.02	211	2005	108.30	9.87	0.77	1,058
	10/7/03	AD	Sawtooth	105.67	10.99	0.92	302	2004	108.82	10.55	0.81	61
	10/8/02	AD	Sawtooth	111.87	15.31	1.09	995	2003	124.16	16.84	0.88	741
	8/29/02	ADRV	Bonneville	104.00	9.51	0.85	900	2003	126.50	17.27	0.85	670
	10/8/01	AD	Sawtooth	110.70	13.78	0.99	20	2002	125.42	15.73	0.96	1,204
	10/13/00	AD	Sawtooth	104.70	11.11	0.93	20	2001	115.69	13.49	0.86	1,391
PET	10/02/07	AD	Sawtooth	97.68	10.72	1.14	132	2008	123.11	15.95	0.85	132
	10/02/06	AD	Sawtooth	87.50	6.97	1.02	219	2007	106.12	10.66	0.92	251
	10/05/05	AD	Sawtooth	86.81	5.99	0.89	101	2006	101.51	9.54	0.91	111
	10/04/04	AD	Sawtooth	105.01	11.49	0.98	202	2005	115.53	13.84	0.89	524
	10/7/03	AD	Sawtooth	103.14	10.72	0.97	300	2004	123.19	17.78	0.95	696
	10/8/02	AD	Sawtooth	111.90	14.81	1.03	999	2003	126.53	18.16	0.89	617
	8/27/02	ADRV	Bonneville	102.23	8.89	0.83	574	2003	138.30	23.47	0.87	174
	10/8/01	AD	Sawtooth	110.70	13.78	0.99	20	2002	146.88	29.66	0.92	520
	7/30/01	ADRV	Sawtooth	72.75	3.63	0.93	20	2002	161.19	38.73	0.92	114
	7/26/01	ADLV	Eagle	110.35	14.19	1.05	20	2002	168.45	43.71	0.91	87
	10/12/00	AD	Sawtooth	104.70	11.11	0.93	20	2001	128.12	18.61	0.88	137
	7/28/00	ADRV	Eagle	97.42	8.45	0.91	50	2001	121.29	16.99	0.94	7
	7/27/00	ADLV	Sawtooth	66.50	2.95	0.99	50	2001	125.40	17.45	0.87	15
ALT	10/02/07	AD	Sawtooth	90.45	7.34	0.98	33	2008	94.48	7.28	0.86	33
	10/02/06	AD	Sawtooth	85.27	6.22	0.99	11	2007	89.53	6.26	0.88	180
	10/05/05	AD	Sawtooth	85.81	6.08	0.95	101	2006	97.03	7.35	0.80	79
	10/04/04	AD	Sawtooth	105.67	11.68	0.97	211	2005	106.04	10.80	0.90	211
	10/7/03	AD	Sawtooth	93.99	7.95	0.95	99	2004	101.21	8.08	0.77	52
	8/27/02	ADRV	Bonneville	101.48	8.71	0.83	694	2003	111.81	12.99	0.83	16
	10/8/01	AD	Sawtooth	110.70	13.78	0.99	20	2002	112.21	10.56	0.73	380
	7/30/01	ADRV	Sawtooth	72.75	3.63	0.93	20	2002	94.83	6.12	0.71	12
	7/26/01	ADLV	Eagle	110.35	14.19	1.05	20	2002	97.60	7.40	0.69	5
	10/11/00	AD	Sawtooth	104.70	11.11	0.93	20	2001	104.41	9.21	0.78	129
	7/28/00	ADRV	Eagle	97.42	8.45	0.91	50	2001	----	----	----	----
	7/27/00	ADLV	Sawtooth	66.50	2.95	0.99	50	2001	90.84	6.27	0.82	19

RFL= Redfish Lake, PET= Pettit Lake, ALT=Alturas Lake

Table 7. Specific growth rate data, 2000-2008.

Lake	Hatchery	Release type	Migration year	Specific growth (L)	Specific growth (W)
RED	Sawtooth	fall	2008	0.0633	0.0458
	Sawtooth	fall	2007	0.0607	0.0110
	Sawtooth	fall	2006	**0.0517**	**0.0629**
	Sawtooth	fall	2005	0.0517	0.0532
	Sawtooth	fall	2004	0.0242	0.0018
	Bonneville	summer	2003	0.0752	0.2312
	Sawtooth	fall	2003	0.0475	0.0482
	Sawtooth	fall	2002	**0.0564**	**0.1240**
	Sawtooth	fall	2001	**0.0482**	**0.1101**
	Sawtooth	fall	2000	**0.0580**	**0.0315**
PET	Sawtooth	fall	2008	0.1028	0.1799
	Sawtooth	fall	2007	0.0775	0.1864
	Sawtooth	fall	2006	0.0679	0.2056
	Sawtooth	fall	2005	0.0482	0.1132
	Sawtooth	fall	2004	0.0782	0.2272
	Bonneville	summer	2003	0.1219	0.3836
	Sawtooth	fall	2003	0.0430	0.0573
	Sawtooth	fall	2002	**0.1190**	**0.3222**
	Sawtooth	summer	2002	**0.2718**	**0.8131**
	Eagle	summer	2002	**0.1390**	**0.3686**
	Sawtooth	fall	2001	**0.1028**	**0.2849**
	Sawtooth	summer	2001	**0.2183**	**0.6103**
ALT	Sawtooth	fall	2008	0.0206	0.0066
	Sawtooth	fall	2007	**0.0299**	**0.0381**
	Sawtooth	fall	2006	**0.0536**	**0.0885**
	Sawtooth	fall	2005	**0.0019**	**-0.0403**
	Sawtooth	fall	2004	**0.0324**	**-0.0050**
	Bonneville	summer	2003	**0.0342**	**0.1097**
	Sawtooth	fall	2002	**0.0059**	**-0.1263**
	Sawtooth	summer	2002	**0.0945**	**0.1893**
	Sawtooth	fall	2001	**0.0002**	**-0.0846**
	Sawtooth	summer	2001	**0.1096**	**0.2645**
	Sawtooth	fall	2000	**0.0313**	**0.0315**

Bold = group means used to calculate growth instead of individual pit tag data

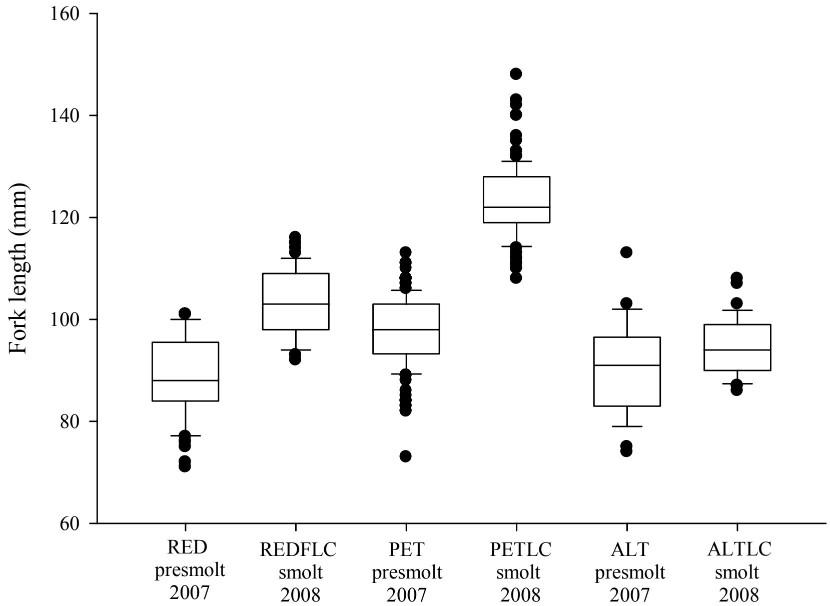


Figure 17a. Redfish, Pettit, and Alturas lakes growth rate evaluation using length data.

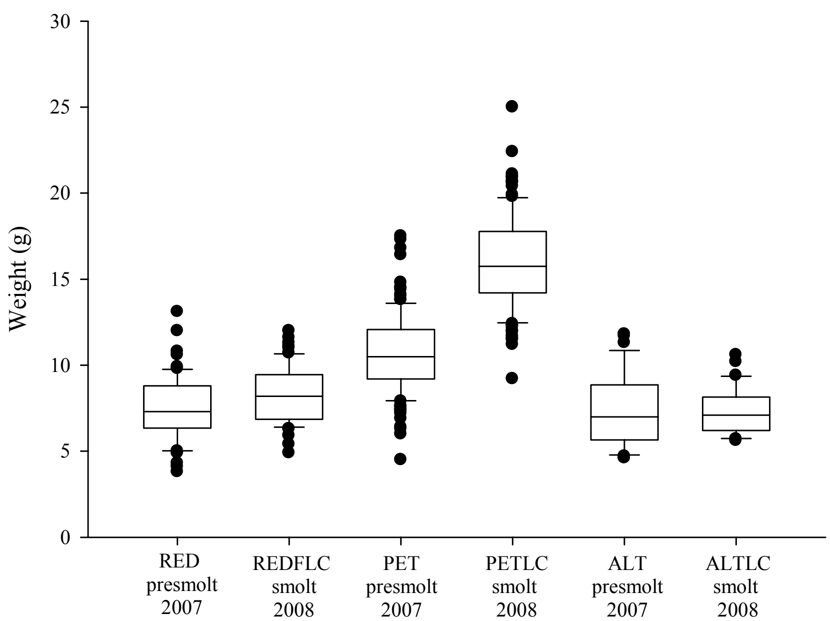


Figure 17b. Redfish, Pettit, and Alturas lakes growth rate evaluation using weight data.

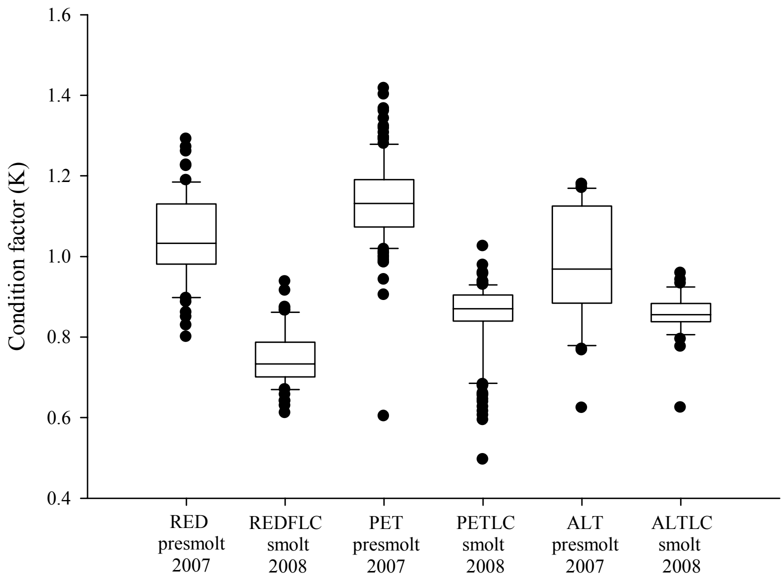


Figure 17c. Redfish, Pettit, and Alturas lakes growth rate evaluation using condition factor data.

Stream Spawning

Starting in 2000, escapement of adult kokanee salmon to Fishhook Creek increased each year until effective kokanee salmon control efforts were achieved in 2004. Kokanee salmon adult escapement in Fishhook Creek decreased 84 percent from 9,679 adult spawners in 2003 to 1,508 adult spawners in 2004. Then, in 2005, kokanee escapement increased 190 percent to 4,375 spawners. In 2006, no control efforts were taken, and an estimated 14,021 adult kokanee salmon spawners entered Fishhook Creek. In 2007, another year without control efforts, an estimated 11,235 kokanee salmon spawned in Fishhook Creek. In 2008, an estimated 4,908 kokanee salmon spawned in Fishhook Creek with no control efforts. Escapement in Alturas Lake Creek reached an all time low of forty-eight spawners in 2003; however, 2004 adult escapement increased dramatically to 7,101 adults. In 2005, esapement increased again to 11,652, a 64 percent increase from 2004 numbers. In 2006, a control weir was installed in Alturas Lake Creek and a total of 2,276 kokanee salmon spawners, consisting of 556 females and 1,720 males were passed above the control weir for natural spawning. In 2007, an estimated 519 kokanee salmon spawned in Alturas Lake Creek. In 2008, a dramatic escapement increase of 1,887 percent occurred when 10,312 kokanee salmon spawners were estimated in Alturas Lake Creek.

No kokanee salmon escapement estimate is available for Stanley Lake Creek. Escapement numbers, length data, and fry recruitment estimates are found in Figures 18-19 and Table 8.

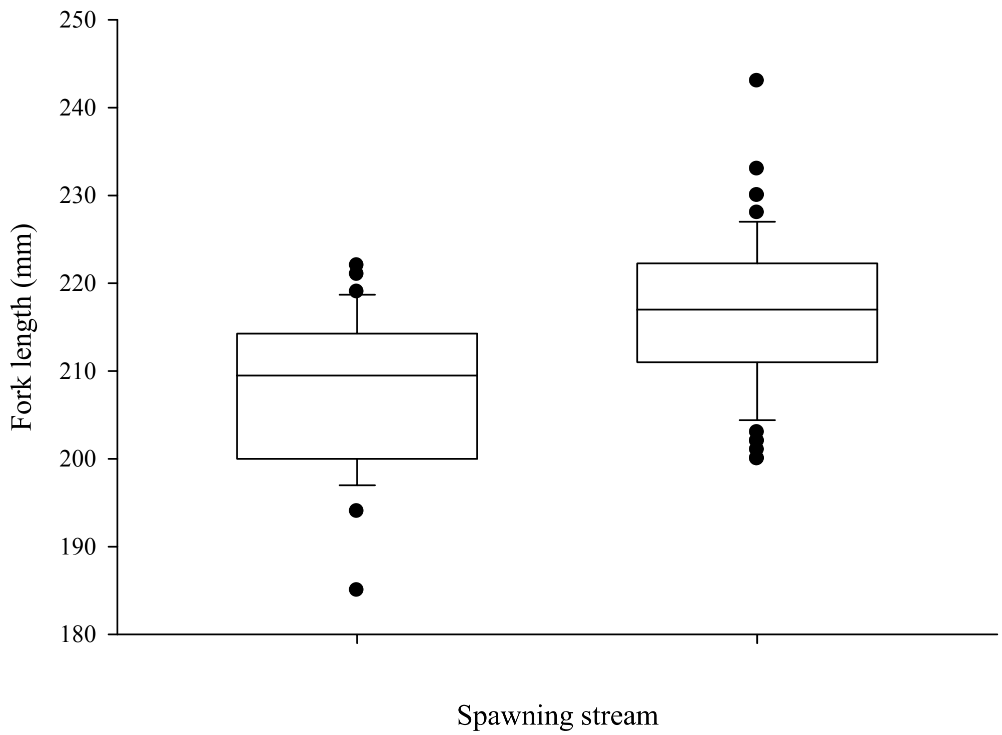


Figure 18. Alturas Lake Creek and Fishhook Creek kokanee salmon length data, 2008. Box plots represent median, quartiles, 95 percent confidence intervals, and outliers.

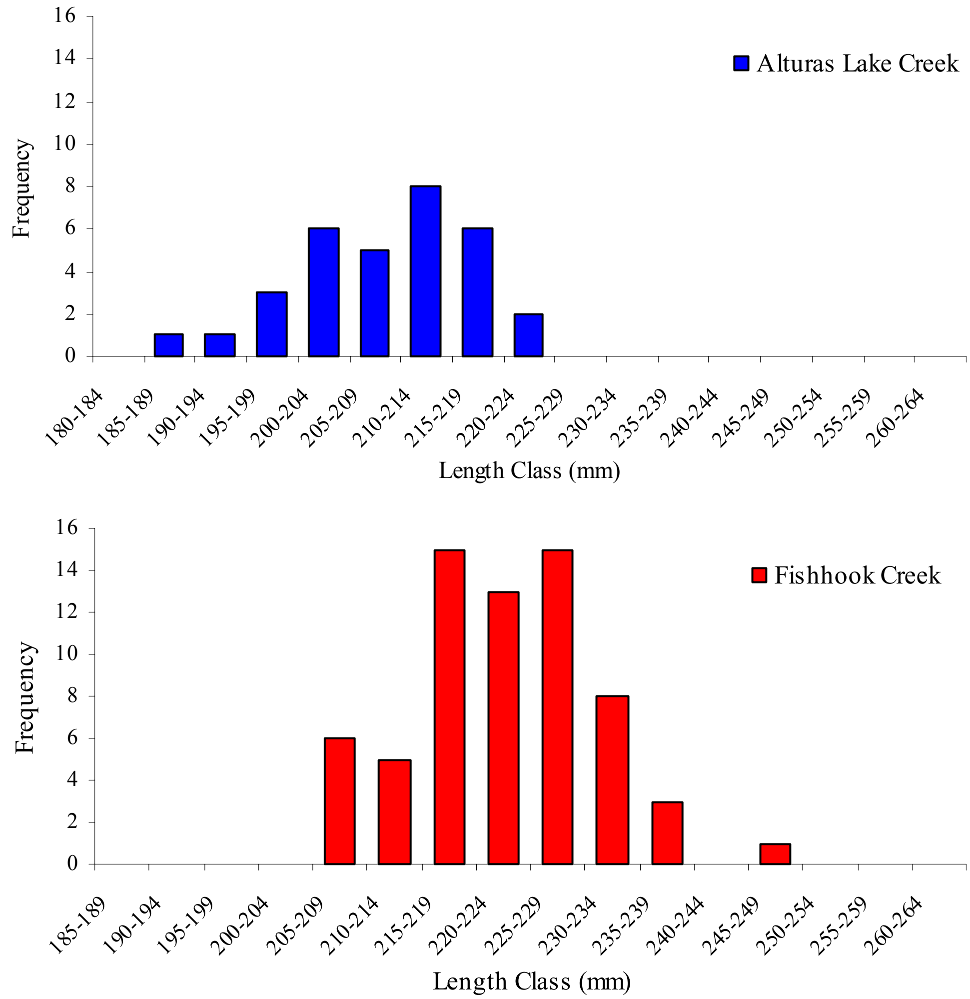


Figure 19. Alturas Lake Creek and Fishhook Creek kokanee salmon length frequency histograms, 2008.

Table 8. Fry recruitment, egg-to-fry survival, and adult escapement in Fishhook Creek and Alturas Lake Creek, 2000-2008.

Location	Brood year	Adult escapement	Mean # eggs	Male:female ratio	Egg-Fry survival	Fry recruits
Fishhook Creek	2008	4,908	192	1:1	12.3%	57,954
	2007	11,235	212	1:1	12.3%	146,482
	2006	14,021	230	1:1	12.3%	198,327
	2005	4,375	244	1:1	12.3%	65,651
	2004	1,508	429	1:1	12.3%	39,786
	2003	9,679	453	1:1	12.3%	269,652
	2002	8,626	281	1:1	12.3%	149,070
	2001	5,853	272	1:1	12.3%	97,909
	2000	60	148	1:1	12.3%	546
Alturas Lake Creek	2008	10,312	206	1:1	13.0%	138,078
	2007	519	220	1:1	13.0%	7,422
	2006	2,276	339	1:1	13.0%	50,152
	2005	11,652	305	1:1	13.0%	231,758
	2004	7,101	269	1:1	13.0%	62,080
	2003	48	150	1:1	13.0%	468
	2002	99	150	1:1	13.0%	965
	2001	145	150	1:1	13.0%	1,414
	2000	827	339	1:1	13.0%	18,223

Beach Spawning and redd counts

We snorkeled in Redfish Lake to enumerate beach spawning residual sockeye salmon and captive reared adult sockeye salmon. Two areas were snorkeled in Redfish Lake: Sockeye Beach and the Southeast inlet area. In 2008, we observed 16 residual and 403 adult sockeye salmon at the SE Inlet and Sockeye Beach spawning areas. Peak counts of residual sockeye salmon were 3 and 3 at Sockeye Beach and the Southeast inlet area, respectively. This represents a dramatic decrease in residual spawner numbers relative to those observed in 2004, when peak counts were 345 and 21 at Sockeye Beach and the Southeast inlet area, respectively. Peak counts in 2004 were the highest since 1994 at the Southeast inlet area and the highest observed to date at Sockeye Beach (Figure 20). Mountain whitefish and redside shiners represented the largest composition of all the fish species observed during snorkeling at Sockeye

Beach and the Southeast inlet respectively (Figure 21). During final boat surveys in November 2008, SBT and IDFG personnel estimated a total of 338 captive reared and anadromous sockeye salmon redds were constructed within Redfish Lake.

Similar to observations in 2007, monitoring of residual sockeye salmon in Pettit Lake revealed a large spawning population in 2008. We conducted boat surveys and estimated approximately 329 residual sockeye salmon redds were constructed in Pettit Lake during Oct-Nov 2008.

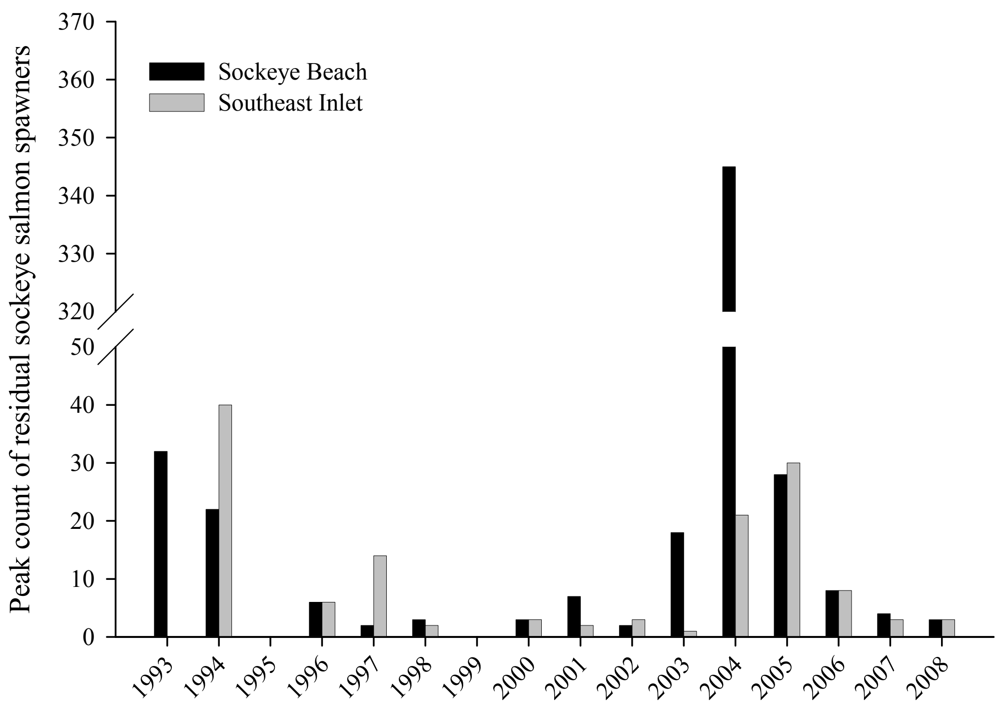
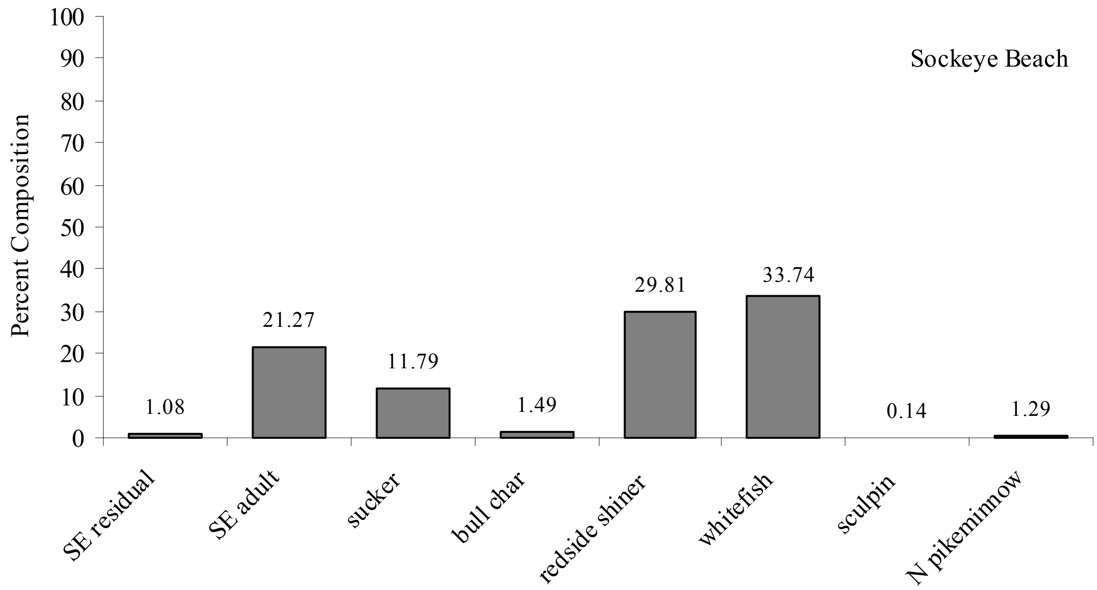


Figure 20. Redfish Lake residual sockeye salmon counts from snorkel surveys at Sockeye Beach and the Southeast Inlet (1995 data not available).



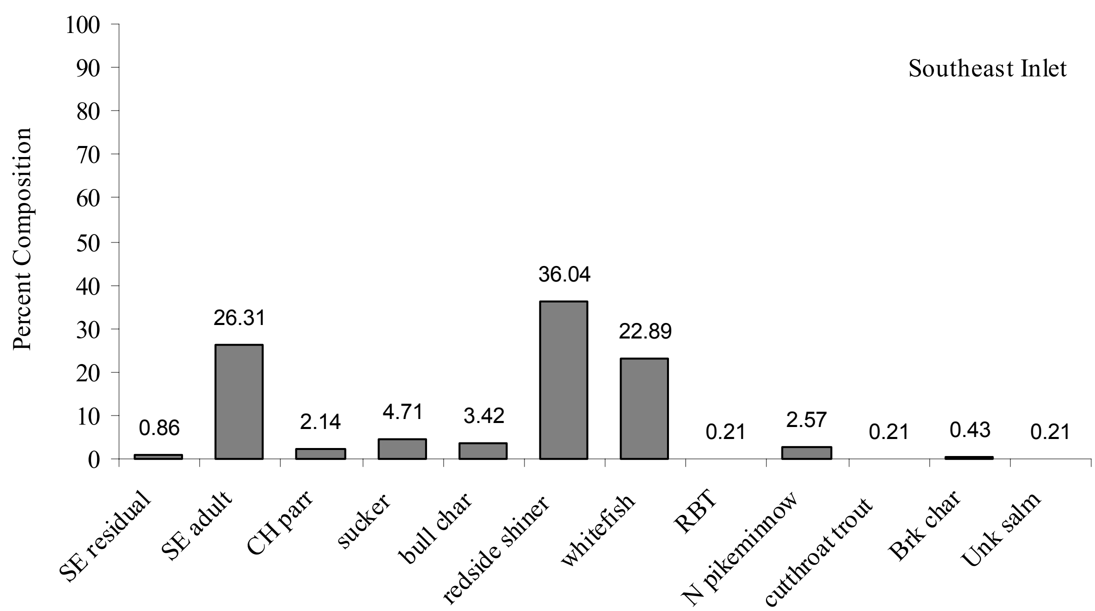


Figure 21. Redfish Lake residual sockeye salmon snorkel survey species composition data at Sockeye Beach and Southeast Inlet, 2008.

Hydroacoustic Population Estimates

Hydroacoustic estimates of *O. nerka* in the Sawtooth Valley lakes during October 2008 revealed densities ranging from 292 fish/ha (98,861 total abundance) to 103 fish/ha (63,439 total abundance) in Alturas and Redfish lakes, respectively (Table 9). Pettit Lake was intermediate with an estimated *O. nerka* population of 112 fish/ha (18,162 total abundance). Nerkoid populations in all three lakes were lower than previous years.

Unlike the relatively stable populations experienced during the three previous years, the *O. nerka* population in Pettit Lake experienced a sharp decline. Redfish Lake has been moderately cyclic and 2008 may be the start of a few years of lower densities. Alturas Lake, the lake that displays the highest fluctuations, had an intermediate population estimate that was lower than the last two years.

Redfish Lake

In 2008, the total nerkoid population in Redfish Lake declined for the second straight year. This marked the first time in the last several years the estimate has been below 100,000 fish (Table 9).

Pettit Lake

The total *O. nerka* population estimate in Pettit Lake declined to the lowest level in over ten years. This lake had densities of 303 to 353 fish/ha during the three previous years. Genetic analysis indicates sockeye salmon represent a large component of this population.

Alturas Lake

Whole lake *O. nerka* population estimates in Alturas Lake decreased for the second straight year. These declines follow the 2006 estimate of 448 fish/ha, the largest we have ever recorded.

Table 9. Hydroacoustic and trawl nerkoid population estimates for three Sawtooth Valley lakes, 2000-2007.

	Population Estimate	(± 95% C.I)	density(fish/ha)		Biomass (kg/ha)	
LAKE	**Acoustic**	**Trawl**	**Acoustic**	**Trawl**	**Acoustic**	**Trawl**
REDFISH 2008	63,439 ± 28,359	26,284 ± 13,226	103	43	1.05	0.29
2007	114,912 ± 20,121	73,702 ± 24,195	187	120	3.30	0.84
2006	130,455 ± 20,499	82,796 ± 47,407	212	134	4.13	2.37
2005	117,327 ± 43,015	56,219 ± 4,192	191	91	2.94	0.3
2004		82,258 ± 35,922		134		0.3
2003	130,087 ± 29,979	81,727 ± 25,995	212	133	4.13	1.60
2002	61,535 ± 11,597	50,204 ± 28,485	100	82	2.82	1.00
2001	43,849 ± 16,747	12,980 ± 11,982	71	21	0.71	0.10
2000	24,481 ± 10,520	10,268 ± 5,675	40	17	0.41	0.07
PETTIT 2008	18,162 ± 10,229	6,933 ± 3,793	112	0.38	5.93	2.67
2007	57,167 ± 20,952	14,746 ± 7,099	353	92	20.90	3.84
2006	53,402 ± 28,444	33,246 ± 12,416	330	208	12.63	7.45
2005	49,138 ± 16,410	23,970 ± 2,136	303	148	8.44	2.2
2004		46,065 ± 22,258		287		9.8
2003	19,805 ± 13,234	11,961 ± 3,255	122	74	6.19	5.5
2002	25,642 ± 10,949	18,328 ± 2,351	158	115	8.91	12.00
2001	37,410 ± 24,864	16,931 ± 7,556	231	105	9.08	6.10
2000	40,435 ± 20,977	40,559 ± 11,717	250	250	9.04	10.20
ALTURAS 2008	98,861 ± 46,525	71,088	292	210	4.66	2.67
2007	126,665 ± 18,997	124,073 ± 23,327	375	367	5.96	3.43
2006	151,373 ± 35,782	105,779 ± 50,779	448	313	4.13	3.3
2005	34,258 ± 59,226	20,995 ± 2,136	101	62	2.24	0.3
2004		36,206 ±14,170		107		1.9
2003	48,671 ± 14,564	46,234 ± 26,442	144	137	6.37	5.5
2002	53,339 ± 15,625	24,374 ± 16,968	158	72	4.01	2.20
2001	130,359 ± 29,446	70,159 ± 18,642	386	208	3.16	2.40
2000	134,867 ± 33,244	125,462 ± 27,037	399	371	6.12	2.08

Table 20. Redfish, Pettit, and Alturas lakes total and cohort population estimates from hydroacoustic sampling, October 2008.

Size class (mm)		mean weight (g)	fish/ha	kg/ha
Redfish Lake				
Lake Total =	63,439 ± 28,359			
40-75	24,974 ± 17,369	2	41	0.10
76-115	23,335 ± 13,002	9	38	0.03
116-160	9,844 ± 2,768	26	16	0.42
161 +	5,285 ± 2,093	59	9	0.50
Pettit Lake				
Lake Total =	18,162 ± 10,229			
30-70	1,612 ± 1,171	3	10.0	0.03
71-110	3,917 ± 1,283	8	24.2	0.20
111-160	6,410 ± 4,995	33	39.6	1.30
161- 205	6,222 ± 4,993	115	38.4	4.40
Alturas Lake				
Lake Total =	98,861 ± 46,525			
40-75	26,658 ± 18,387	3	79	0.22
76-110	41,392 ± 22,173	8	122	0.97
111-160	24,117 ± 14,303	30	71	2.12
161-200	6,693 ± 3,742	68	20	1.35

Gillnet Sampling

We conducted vertical and horizontal gillnet sampling in Pettit Lake in 2008; ice conditions precluded sampling in Alturas Lake. Fish species captured during 2008 sampling events included: rainbow trout, bull char, brook char, northern pikeminnow, and *O. nerka*. Results including location sampled, set type, sample size, catch per unit effort, species sampled, mean fork length, mean weight, and total hours fished are summarized in Table 11.

Table 11. Results of Pettit Lake gillnet samples, 2008.

Date	Station	Set type	(n) CPUE	Mean L (mm)	Mean W (g)	Hrs Fished
Pettit Lake						
Kokanee salmon spawner						
January 19, 2008	A	horizontal	(11) 0.52	225.5	----	21.0
Rainbow Trout						
January 19, 2008	A	horizontal	(7) 0.33	252.0	167.6	21.0
Bull Char						
January 19, 2008	A	horizontal	(4) 0.19	403.0	925.0	21.0
Brook Char						
January 19, 2008	A	horizontal	(1) 0.13	275.0	239.6	21.0
February 8, 2008	E	vertical	(2) 0.11	----	----	19.0
Northern Pikeminnow						
January 19, 2008	A	horizontal	(7) 0.33	267.0	239.4	21.0
O. nerka						
January 19, 2008	E	vertical	(6) 0.26	165.0	58.7	22.8
February 8, 2008	E	vertical	(11) 0.58	170.6	59.0	19.0
Sockeye salmon						
January 19, 2008	E	vertical	(2) 0.09	111.0	16.6	21.0
February 8, 2008	E	vertical	(3) 0.11	129.0	28.3	19.0

Diet Analysis

We analyzed stomach contents for diet composition in Redfish, Pettit, and Alturas lakes from samples collected in 2008. Samples were drawn from gillnet and trawling efforts conducted by the SBT and IDFG, respectively. Summarized data including *O. nerka* vertical gillnet and trawl diet composition, fork length, weight, and condition factor are presented in Table 12. *Oncorhynchus nerka* electivity indices are presented in Table 13.

Table 12. *O. nerka* vertical gillnet and trawl mean length, weight, condition factor, and zooplankton diet percent composition in Redfish, Pettit, and Alturas lakes, 2008.

Date	Lake	Set type	Species	Sample size	L (mm)	W (g)	Condition factor (K)	Daph	Hol	Bos	Cal	Cyc	Naup	Poly
09/30/08	RED	trawl	*O. nerka*	20	74.30	6.46	0.93	57.82	0.00	0.01	0.00	42.01	0.00	0.17
01/20/08	PET	vertical	*O. nerka*	8	151.50	48.16	1.28	13.56	0.00	0.00	0.00	86.33	0.00	0.10
02/08/08	PET	vertical	*O. nerka*	14	161.64	55.06	1.24	7.33	0.00	0.00	0.00	92.67	0.00	0.00
09/29/08	PET	trawl	*O. nerka*	17	99.76	15.57	0.95	82.53	0.00	0.44	0.00	6.31	0.00	10.72
10/01/08	ALT	trawl	*O. nerka*	56	112.16	16.85	0.91	60.02	0.00	0.18	2.91	32.68	0.00	4.22

Daph=Daphnia, Hol=Holopedium, Bos=Bosmina, Cal=Calanoid, Cyc=Cyclopoid, Naup=Nauplii, Poly=Polyphemus

Table 13. *O. nerka* gillnet and diet composition data including electivity indices (**E**), 2008.

Date	Lake	Set type	Species	n		Daph	Holo	Bosm	Cala	Cycl	Naup	Poly
09/30/2008	Redfish	trawl	*O. nerka*	20	R_i	57.82	0.00	0.01	0.00	42.01	0.00	0.17
					P_i	47.60	4.27	16.65	0.00	19.37	9.32	2.80
					E	**0.10**	**-1.00**	**-1.00**	**----**	**0.37**	**-1.00**	**-0.89**
01/20/2008	Pettit	vertical	*O. nerka*	8	R_i	13.56	0.00	0.00	0.00	86.33	0.00	0.10
					P_i	1.63	0.00	3.45	0.00	39.57	55.35	0.00
					E	**0.79**	**----**	**-1.00**	**----**	**0.37**	**-1.00**	**1.00**
02/09/2008	Pettit	vertical	*O. nerka*	14	R_i	7.33	0.00	0.00	0.00	92.67	0.00	0.00
					P_i	1.63	0.00	3.45	0.00	39.57	55.35	0.00
					E	**0.64**	**----**	**-1.00**	**----**	**-0.40**	**-1.00**	**----**
09/29/2008	Pettit	trawl	*O. nerka*	17	R_i	82.53	0.00	0.44	0.00	6.31	0.00	10.72
					P_i	57.53	0.10	2.10	0.00	32.18	7.31	0.78
					E	**0.18**	**-1.00**	**-0.66**	**----**	**-0.67**	**-1.00**	**0.86**
10/01/2008	Alturas	trawl	*O. nerka*	56	R_i	60.02	0.00	0.18	2.91	32.68	0.00	4.22
					P_i	16.67	0.09	3.23	0.00	21.43	58.00	0.58
					E	**0.57**	**-1.00**	**-0.90**	**1.00**	**0.21**	**-1.00**	**0.76**

n=sample size, R_i=percent composition of stomach contents, P_i=percent composition of prey items in the environment, E=electivity index
Daph=Daphnia, Holo=Holopedium, Bosm=Bosmina, Cala=Calanoid, Cycl=Cyclopoid, Naup=Nauplii, Poly=Polyphemus

DISCUSSION

Limnology and Fertilization

Direct benefits to sockeye salmon from nutrient supplementation programs can be difficult to quantify; however, the theory is well understood and numerous examples exist that document improved growth and survival of juvenile sockeye salmon (Stockner 1987, Hyatt et al. 2004). Annual fluctuations in zooplanktivorous fish populations, changes in plankton assemblages, and meteorological variation can obfuscate fertilization impacts. However, we have ample indirect evidence that nutrient supplementation is an effective strategy that should be utilized to improve rearing conditions of endangered Snake River sockeye salmon.

In 2008, we added supplemental nutrients to Pettit and Alturas lakes. As a result, we observed diverging parameter values during the season. In unfertilized Redfish Lake, Secchi depth and light penetration was slightly deeper than average, while Pettit and Alturas lakes showed reductions in Secchi depth and light penetration, as expected with supplemental nutrient applications. Total nitrogen and total phosphorus concentrations were slightly elevated during September and October in the lakes receiving supplemental nutrients, relative to Redfish lake, but TN:TP ratios were similar between the fertilized and unfertilized lakes. Nitrate-nitrite and total dissolved phosphorus concentrations were low in all three lakes, near detection levels, except in August and did not follow any apparent trend with regard to nutrient supplementation activities. Chlorophyll *a* concentrations were lower than normal in untreated Redfish Lake and elevated in Pettit and Alturas lakes during nutrient supplementation. During the fall, chlorophyll *a* levels exceeded the criteria determined by the Department of Environmental Quality in the lakes receiving supplemental nutrients. Epilimnetic phytoplankton densities and bio-volumes were lowest in unfertilized Redfish Lake, highest in Pettit Lake, and intermediate in Alturas Lake. Phytoplankton assemblages were dominated by small grazable taxa, an indication nutrient supplementation enhanced primary productivity and that sockeye salmon should have benefited from this additional production via trophic transfer. We saw no evidence of trophic bottlenecks or sinks that would have interrupted energy transfer to juvenile sockeye salmon.

Zooplankton biomass rebounded in Pettit lake in 2008 and was dominated by *Daphnia*, this, coupled with abundant Chlorophaceans, should have allowed efficient energy transfer (short food chain) to sockeye salmon. In Alturas Lake, zooplankton biomass continued to decline and *Daphnia* were rare, thus we expect that enhanced phytoplankton production may have been underutilized by macrozooplankton and energy transfer to juvenile sockeye salmon would have been less efficient. However, *O. nerka* biomass (particularly kokanee salmon) is currently declining in Alturas Lake and we believe that continued supplementation will ultimately benefit sockeye salmon as zooplankton populations rebuild.

Growth Rates and Survival

Growth rates of stocked sockeye salmon presmolts from the captive rearing program provide insight into performance differences associated with lake rearing conditions. We evaluated fall release groups consisting of fish reared at the Sawtooth Fish Hatchery and released into Redfish (n=62,015), Pettit (n=10,113), and Alturas (n=9,977) lakes on 2 and 3 October 2007. Growth rates were highest in Pettit Lake followed by Redfish and Alturas lake migrants. Corresponding percent migration estimates of smolt migrants was 28 percent in Redfish Lake, 59 percent in Pettit Lake, and 53 percent in Alturas Lake. Smolt migration estimates assume that stocked sockeye salmon presmolts (fall release) migrate the following spring as 1 year olds; however, a variable portion of sockeye salmon stocked into Sawtooth Valley lakes migrate as 2 year olds. Therefore, we view migration estimates as a conservative measure of overwinter survival.

Sockeye salmon pre-smolts released in Redfish Lake experienced low zooplankton biomass dominated by *Daphnia* and *Holopedium* during fall 2007 (Figure 22). Pre-smolts grew in length and weight during the winter, but condition factor declined from 1.05 at release to 0.75 at migration. Approximately 28% of the stocked fish left Redfish Lake during spring 2008.

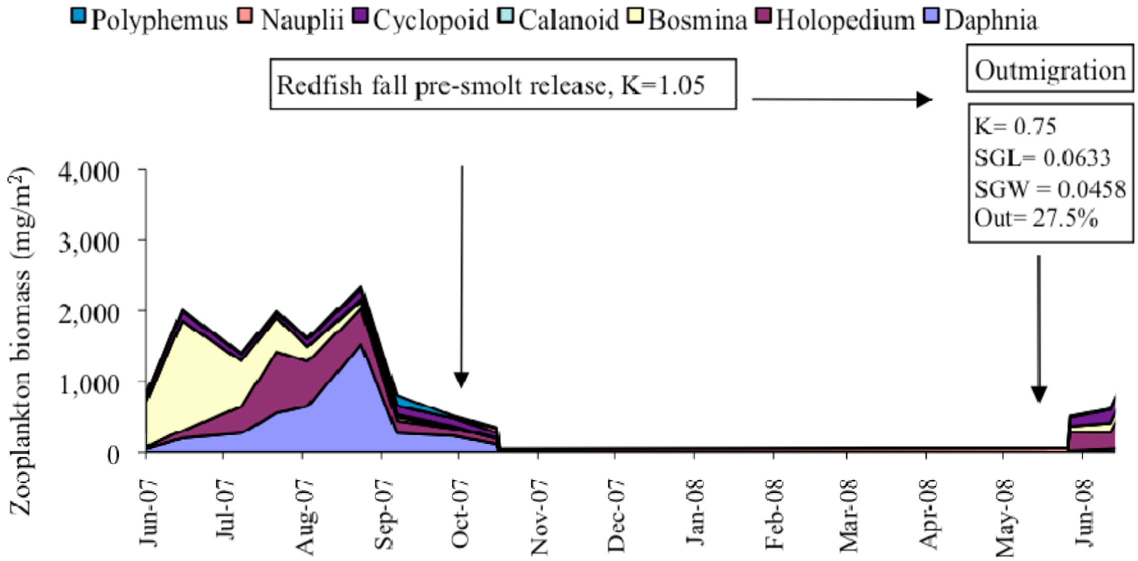


Figure 22. Redfish Lake zooplankton biomass (mg/m^2) June 1, 2007 to June 30, 2008 with overwinter sockeye salmon pre-smolt specific growth rates in length (SGL), weight (SGW), condition factor (K) and percent out-migration (Out).

Consistent with previous trends, sockeye stocked into Pettit Lake exhibited better growth when compared to the same release groups in Redfish and Alturas lakes. Sockeye salmon pre-smolts released into Pettit Lake during the fall of 2007 experienced moderate total zooplankton biomass composed primarily of cyclopoid copepods and *Daphnia* for the first month after release. During the winter moderate zooplankton biomass was present in the form of cyclopoid copepods (Figure 23). This group had the highest growth rate of any of the release groups in both length and weight. Condition factors declined slightly more than previous years from release as pre-smolt to outmigration from 1.14 to 0.85. Approximately 59% of the pre-smolts released during October 2007 out-migrated during spring 2008, this was a 34% increase in outmigration from the previous year.

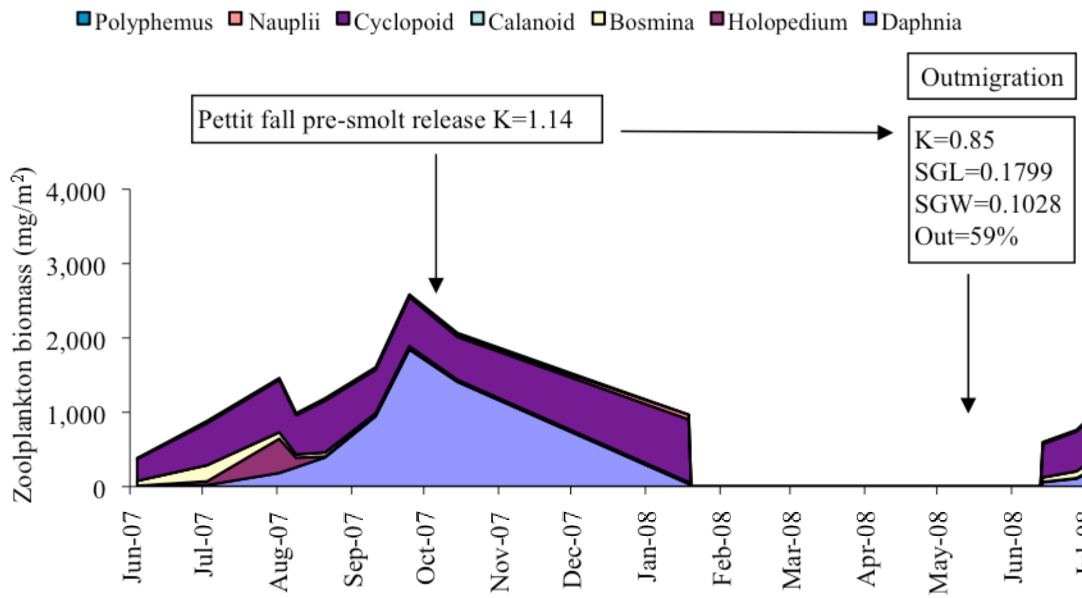


Figure 23. Pettit Lake zooplankton biomass (mg/m^2) June 1, 2007 to July 1, 2008 with overwinter sockeye salmon pre-smolt specific growth rates in length (SGL), weight (SGW), condition factor (K) and percent out-migration (Out).

In Alturas Lake, fall release parr experienced low zooplankton biomass during the fall. Specific growth length and weight in the Alturas Lake release group was lower than those observed in Pettit and Redfish lakes (Figure 24). The mean condition factor of sockeye salmon smolts migrating from the lake was slightly higher than that observed for sockeye salmon migrating from both Pettit and Redfish lakes. Approximately 53% of fish released in October 2007 migrated during the spring of 2008, this was an 33% increase in migration from the previous year, despite the trend in decline of zooplankton.

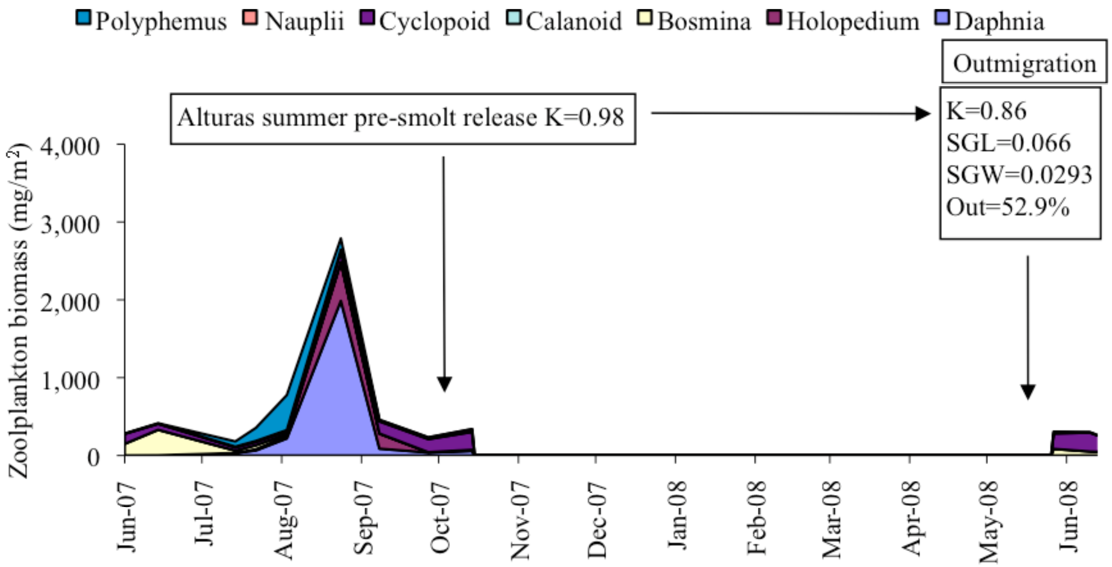


Figure 24. Alturas Lake zooplankton biomass (mg/m^2) June 1, 2006 to June 1, 2007 with overwinter sockeye salmon pre-smolt specific growth rates in length (SGL), weight (SGW), condition factor (K) and percent out-migration (Out).

Differences in sockeye salmon performance (growth, condition factor, percent migration), kokanee salmon population abundance, and zooplankton abundance, biomass, and species composition are considered each year to determine appropriate numbers of sockeye salmon pre-smolts to stock into each lake. Hydroacoustic data collected during fall 2008 indicated between 103-292 *O. nerka*/ha in the three lakes. *O. nerka* biomass was 1.4 kg/ha in Redfish, 5.9 kg/ha in Pettit, and 4.7 kg/ha in Alturas Lake. During summer 2008 mean zooplankton biomass was 2,288 mg/m^2 in Pettit Lake, 1,201 mg/m^2 in Redfish Lake, and 284 mg/m^2 in Alturas Lake (Table 2). In 2008, 84,005 sockeye salmon pre-smolts were available for stocking. Equal allocation into each lake based on surface area would have resulted in 46,335 fish into Redfish Lake, 12,205 fish into Pettit Lake, and 25,465 fish into Alturas Lake, resulting in a loading rate of 75 fish/ha in each lake. After discussing allocations at the SBTOC level, stocking rates were adjusted to 57,093 fish (93/ha) into Redfish Lake, 10,048 fish (62/ha) into Pettit Lake, and 16,864 fish (50/ha) into Alturas Lake. In addition, 494 pre-spawn adult sockeye salmon were stocked into Redfish Lake and 51,008 eyed eggs were placed in incubators in Pettit Lake during the fall of 2007. Continued monitoring and evaluation of growth, condition factor, and percent outmigration of sockeye salmon will continue in 2010.

Diet Analysis

Intraspecific competition has been identified as one of the potential limiting factors in the sockeye salmon rearing habitat of the Sawtooth Valley lakes. In sockeye salmon 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 salmon has been detected in populations in both Redfish and Alturas lakes. This ontogenetic diet shift may be an evolutionary adaptation to reduce intraspecific competition between age classes and between anadromous sockeye salmon and kokanee salmon.

The vertical distribution of kokanee salmon and zooplankton prey may influence interactions and prey availability. *Onchorynchus 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 salmon in other systems (Levy 1987, Levy 1990). 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 and *Polyphemus* sp. and *Daphnia* sp. were found at low densities throughout the water column. Kokanee salmon diet data and zooplankton dispersal patterns seem to indicate that age 0+ kokanee salmon are feeding primarily in deeper waters. Levy (1990) hypothesized that during the day juvenile sockeye salmon in lakes with piscivorous fish populations were concentrated in deeper areas with lower light levels to aid in predator avoidance.

We found stocked juvenile sockeye salmon from the captive rearing program in the stomachs of stocked rainbow trout (*O. mykiss*) in Pettit Lake during 1995, the first year we stocked sockeye salmon into that lake (Teuscher and Taki 1996). The sockeye salmon were released at the boat ramp in the littoral zone. After detection of *O. nerka* in *O. mykiss* stomachs, we modified the stocking strategy to a pelagic release using a barge. Since the pelagic release was implemented, annual (1996-03) *O. mykiss* diet analysis is used to monitor potential predation on stocked sockeye salmon. No subsequent predation of *O. nerka* by *O. mykiss* has been conclusively documented in Pettit Lake.

Northern pikeminnow are known to prey on juvenile salmon and are the subject of control efforts in the main stem of the Columbia and Snake rivers. Northern pikeminnow are one of the more abundant species found in the sockeye salmon rearing/nursery lakes of the Sawtooth Valley. Concern has been expressed about their potential predation on stocked juvenile sockeye salmon. Diet analysis has found that while piscivorous, *O. nerka* have only been positively identified in the stomach of one northern pikeminnow; significant predation on *O. nerka* has not been documented. During gillnet sampling, the majority of northern pikeminnow are caught in the littoral zone of the lakes. *O. nerka* are primarily a pelagic species. The low degree of habitat utilization overlap may limit the opportunity for northern pikeminnow to prey on *O. nerka*. Predation by northern pikeminnow is not currently considered a problem. Ongoing monitoring of the northern pikeminnow populations and diet is warranted in order to detect any potential changes.

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

Stream Spawning Kokanee Salmon

Kokanee salmon escapement in 2008 showed variation in population abundance, timing, and fecundity. The Fishhook Creek kokanee salmon spawning population had been declining since 1996, when escapement was estimated to be 10,662, to a low of 60 individual spawners in 2000. In 2008, no kokanee salmon control efforts were undertaken and 4,908 (34 percent below the

1991-2007 mean) spawners were counted in Fishhook Creek. Female kokanee salmon fecundity was estimated to be 192, 29 percent below the 1991-2007 mean of 270. The Alturas Lake Creek kokanee salmon escapement estimate was up (173 percent above the 1992-2007 mean) from 519 in 2007 to 10,312 in 2008. Alturas Lake Creek kokanee salmon fecundity was estimated to be 206 eggs per female, 13 percent lower than the 1994-2007 average of 236. The Stanley Lake Creek kokanee salmon spawning population was not monitored in 2008 due to insufficient funding. Based on variation in Fishhook Creek, Stanley Lake Creek, and Alturas Lake Creek kokanee salmon fecundity, all three populations should be sampled annually. Length, weight, and condition factor should also be measured in order to quantify changes that may be associated with lake fertilization, meteorological forcing, and variable fish population dynamics.

Beach Spawning Residual Sockeye Salmon

In Redfish Lake, unmarked sockeye salmon smolts have been captured every year since 1991. Residual spawners were identified in 1993 (Teuscher and Taki 1994) and have been documented every year since then. In 2004, a peak snorkel survey count identified 345 residual sockeye salmon spawners in Redfish Lake. Unmarked smolts migrating from Redfish Lake are the product of two possible production origins: volitional spawning captive reared and anadromous sockeye salmon, residual sockeye salmon production, or kokanee salmon production. In Pettit Lake, residual spawning was first documented in 2004 (Kohler et al. 2004). During that year the first post spawn carcass from a hatchery released parr was recovered (Doug Taki, SBT personal observation) and 115 residual spawner redds were observed. This number includes an earlier estimate of 49 redds and 66 circular depressions that were not recorded as redds in 2004; we now feel confident that the observed circular depressions were indeed residual spawner redds and have included them in the stated estimate. Residual sockeye salmon spawning has been documented every year since 2004 in Pettit Lake. Monitoring of spawning residual sockeye salmon in Pettit Lake revealed a large spawning population in 2007. We observed 159 residual sockeye salmon spawners during two survey events in October and November. We captured 89 residuals on November 06, 2007 and collected length, weight, fecundity, age, and genetic data (n=48); remaining fish were live released (n=41). Genetic evaluation has revealed that all 48 tissue samples collected from residual spawners in Pettit Lake were Snake River sockeye salmon. Boat surveys revealed approximately 226 residual sockeye salmon redds in Pettit Lake during Oct-Nov 2007. In 2008, another large spawning population of residual sockeye salmon was observed. We conducted boat surveys and estimated approximately 329 residual sockeye salmon redds were constructed in Pettit Lake during Oct-Nov 2008. Unmarked smolts migrating from Pettit Lake are the product of three possible production origins: eyed-egg incubation production, residual sockeye salmon production, and kokanee salmon production.

ACKNOWLEDGEMENTS

We would like to thank Kenneth Ariwite, Robert Trahant, and Duane Dupree for their dedication and work accomplished. Mark Palmer (High Sierra Water Lab) assayed nutrient samples, Dr. John Stockner and Ms. Ellie Stockner processed phytonplankton samples and Odette Brandt identified and counted zooplankton samples. We would also like to thank the personnel from the Sawtooth Fish Hatchery and Dan Baker, Jeff Heindel, Mike Peterson and the rest of the IDFG crew from the Eagle Fish Hatchery.

REFERENCES

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

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

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

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

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

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

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

Everman, B.W. 1896. A report upon salmon investigations in the headwaters of the Columbia River in the State of Idaho, in 1895. Bulletin U.S. Fish Commission 16:151-202.

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

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

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

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

Kohler, A.E., D. Taki and R. Griswold. 2005. Snake River sockeye salmon habitat and limnological research: 2004 annual progress report. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71.

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

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

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

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

Pilati, A. and W. A. Wurtsbaugh. 2003. Importance of zooplankton for the persistence of a deep chlorophyll layer: A limnocorral experiment. Limnology and Oceanography, 48(1), 249-260.

Steinhart, G., H.P. Gross, P. Budy, C. Luecke, and W.A. Wurtsbaugh. 1994. Limnological investigations and hydroacoustic surveys of Sawtooth Valley Lakes *in* S. Spaulding, editor. Snake River Sockeye Salmon Habitat and Limnological Research. Annual Report 1993. U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon. Project number 91-71.

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

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

Taki, D., A. Kohler, and R. Griswold. 2005. Snake River sockeye salmon habitat and limnological research: 2004 annual progress report. U.S. Department of Energy, Bonneville Power Administration, Portland, OR. Project number 91-71.

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

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

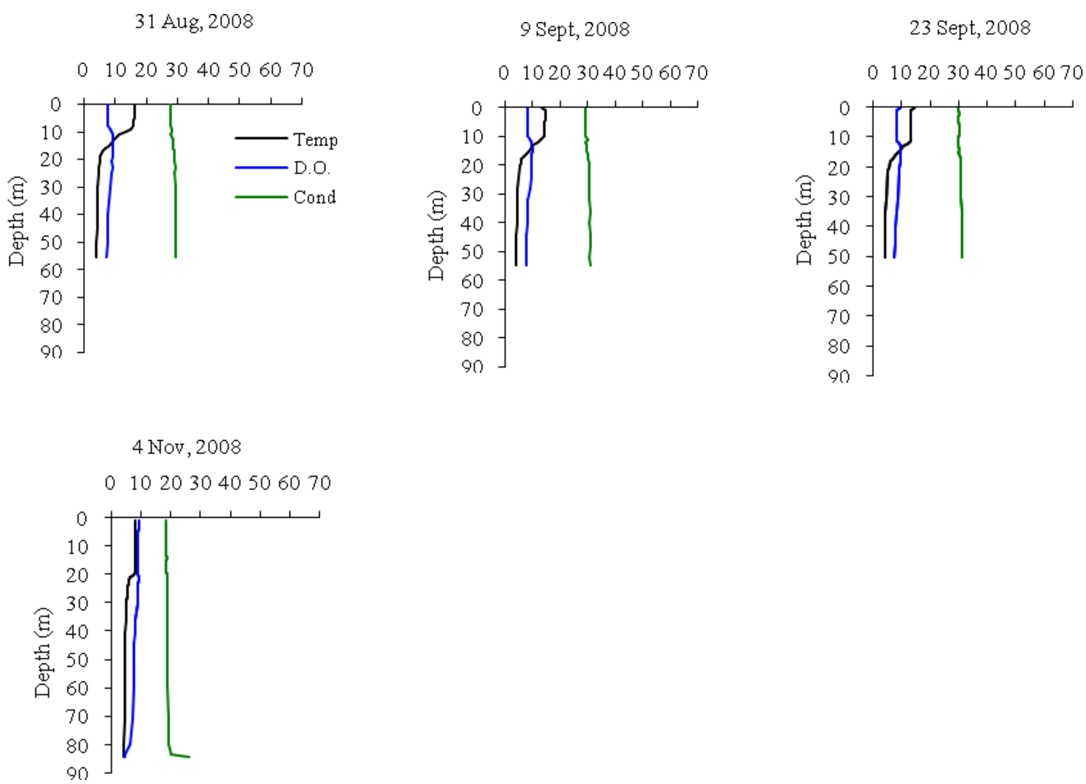
Utermohl, H. 1958. Zur Vervollkommnung der quantitativen phytoplankton methodik. International Vereinigung fuer Theoretische und Angewandte Limnologie und Verhandlugen. Mitteilungen No. 9.

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

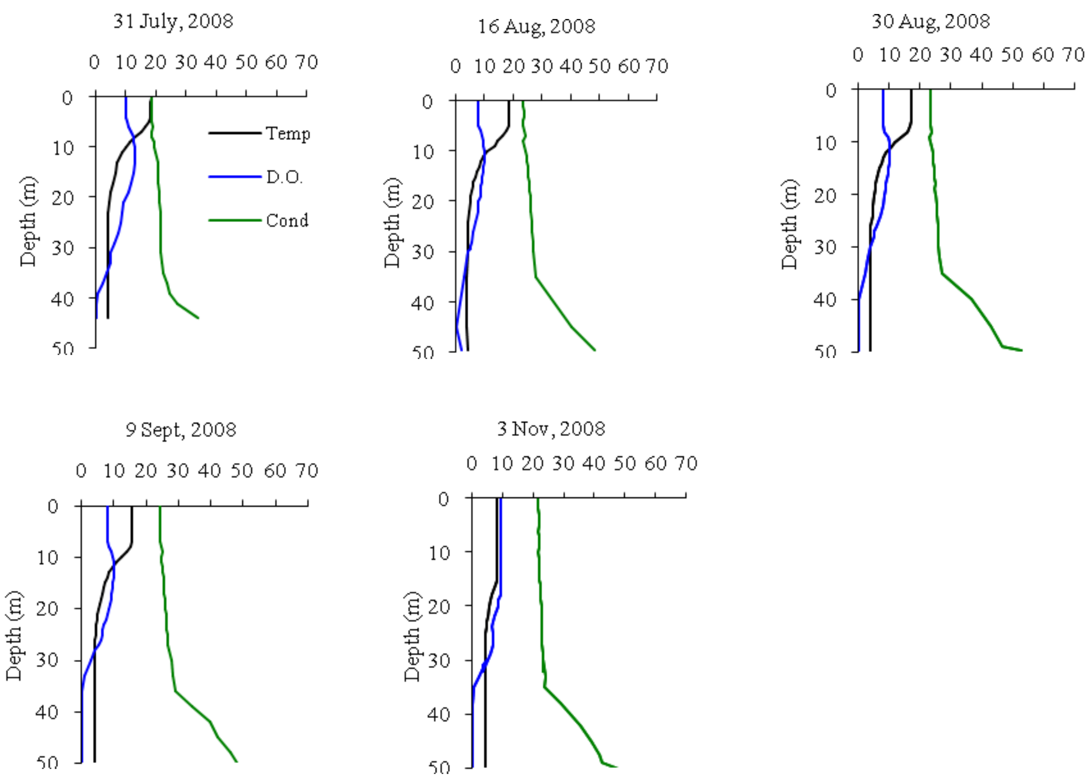
Willard, C. 2003. Personal Communication. Idaho Department of Fish and Game. Nampa, Idaho.

Wurtsbaugh, W.A., H. P. Gross, P. Budy, and C. Luecke. 2001. Effects of epilimnetic versus metalimnetic fertilization on the phytoplankton and periphyton of a mountain lake with a deep chlorophyll maxima. Canadian Journal of Fisheries and Aquatic Sciences 58: 2156-2166.

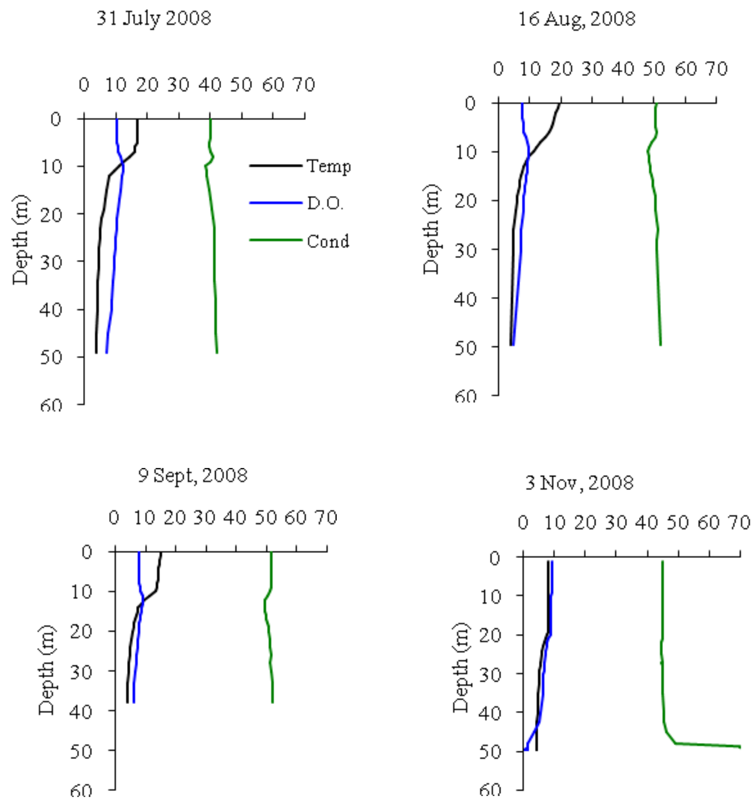
Appendix A. **Profile Data**



Appendix A1. Temperature (ºC), dissolved oxygen (mg/L), and conductivity (μS/cm) profiles for Redfish Lake, August through November 2008.

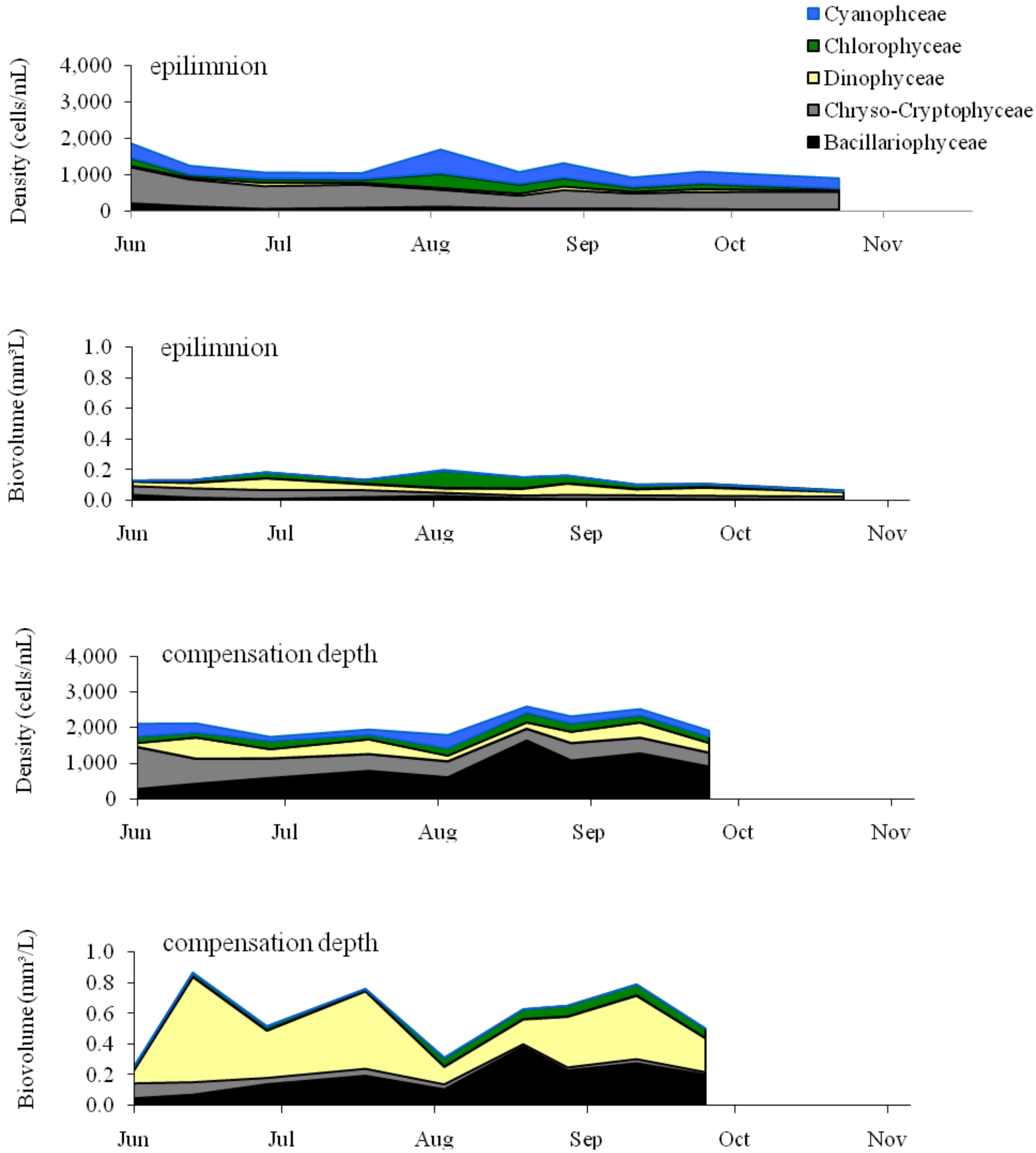


Appendix A2. Temperature (ºC), dissolved oxygen (mg/L), and conductivity (μS/cm) profiles for Pettit Lake, July through November 2008.

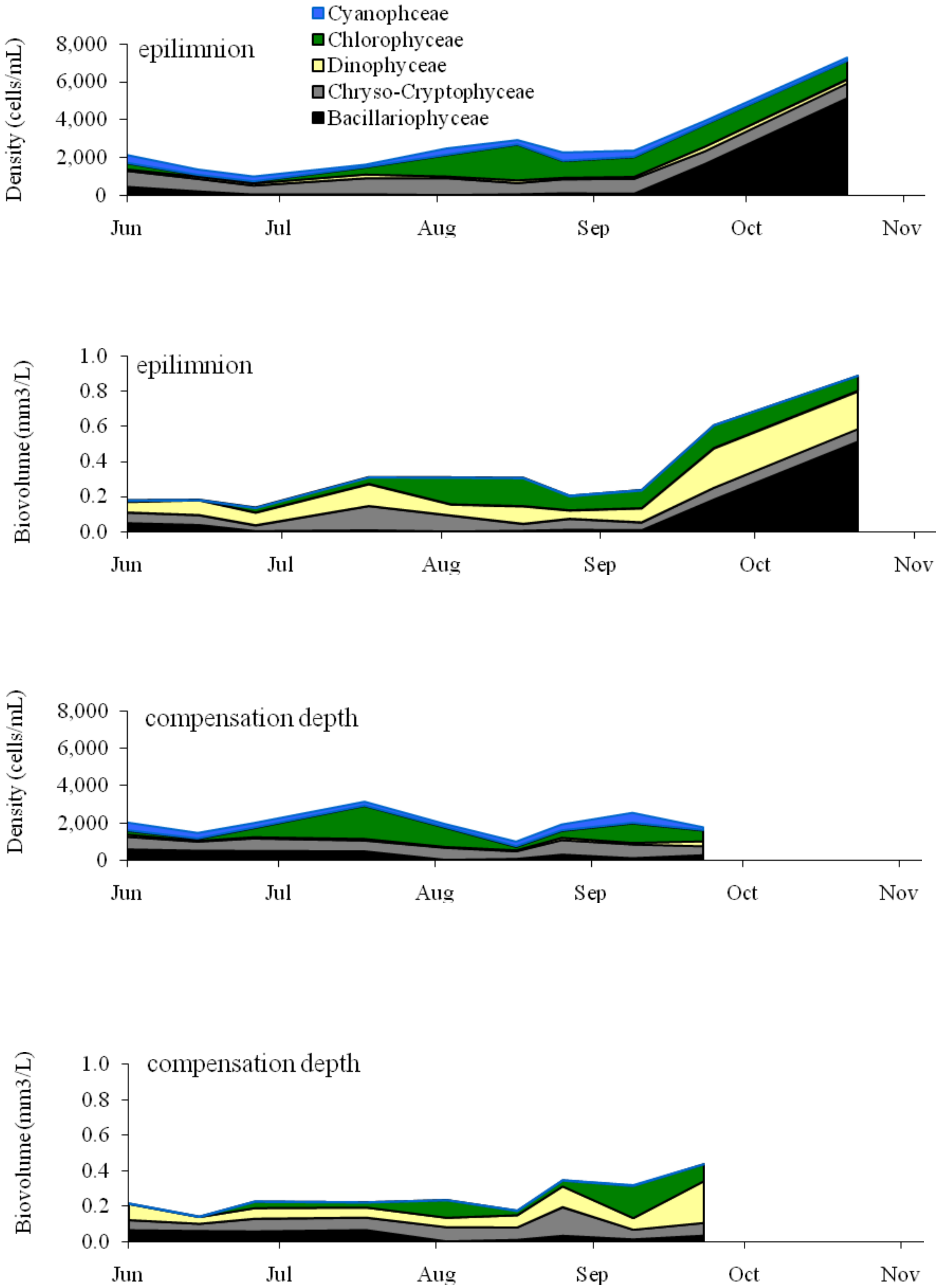


Appendix A3. Temperature (ºC), dissolved oxygen (mg/L), and conductivity (μS/cm) profiles for Alturas Lake, July through November 2008.

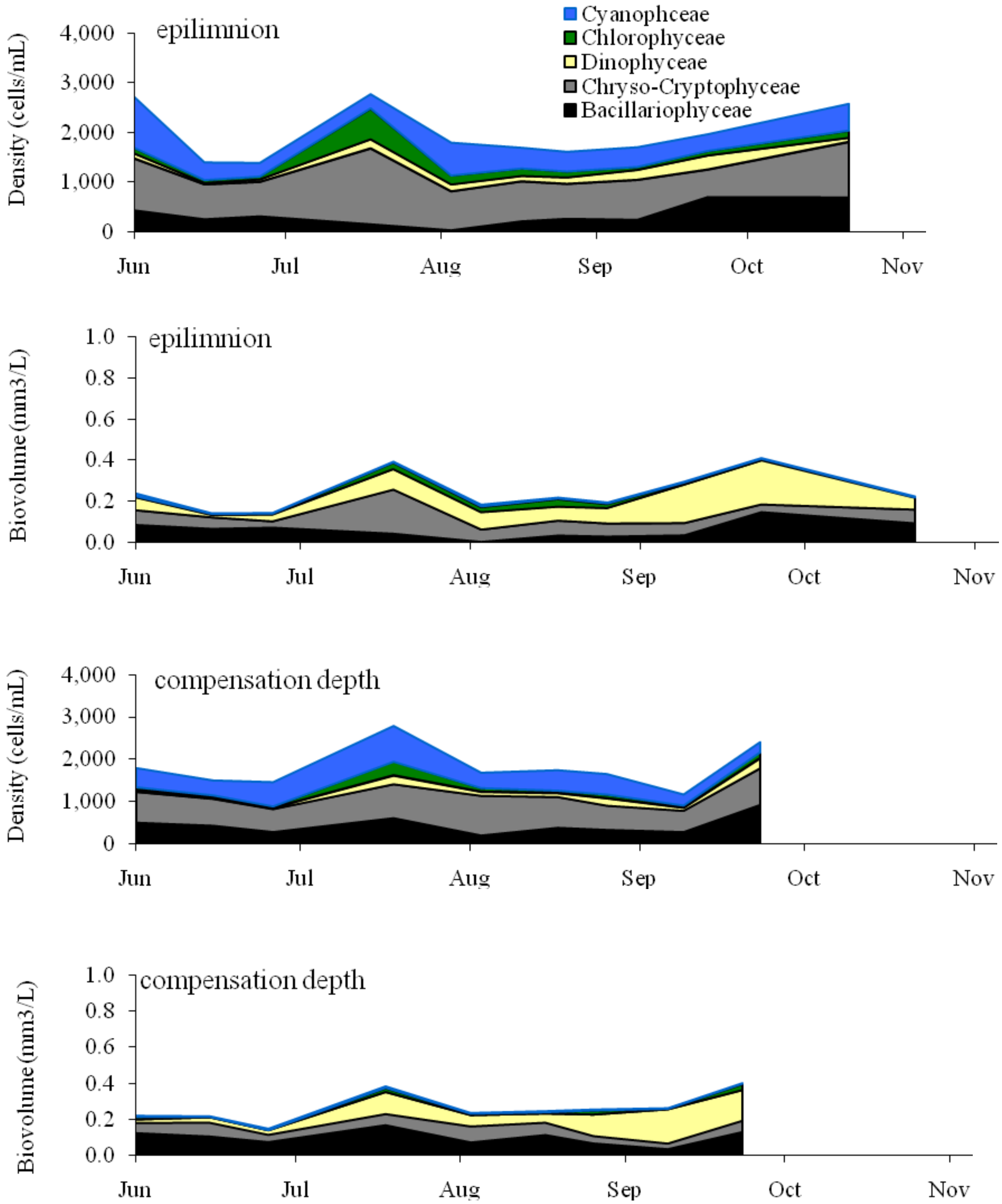
Appendix B. Phytoplankton densities and bio-volume



Appendix B1. Phytoplankton density (cells/mL) and bio-volume (mm³/L) in the epilimnion and compensation depth in Redfish Lake, June through November 2008.



Appendix B2. Phytoplankton density (cells/mL) and bio-volume (mm³/L) in the epilimnion and compensation depth in Pettit Lake, June through November 2008.



Appendix B3. Phytoplankton density (cells/mL) and bio-volume (mm^3/L) in the epilimnion and compensation depth in Alturas Lake, June through November 2008.