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SNAKE RIVER SOCKEYE SALMON HABITAT AND LIMNOLOGICAL RESEARCH

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SNAKE RIVER SOCKEYE SALMON HABITAT AND LIMNOLOGICAL RESEARCH

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EXECUTIVE SUMMARY

Since the late 1980's, Snake River sockeye *Oncorhynchus nerka* adults have only returned to Redfish Lake, one of five lakes in the Sawtooth Basin which historically reared sockeye. In 1995 a fish passage barrier was removed at the outlet of Pettit Lake to provide access to more spawning and rearing habitat for sockeye. In 1997 the USDA Forest Service removed an irrigation diversion on the outlet stream from Alturas Lake that had made passage for adult sockeye unlikely during below average precipitation years. These two projects have corrected local upstream and downstream passage problems. Stocking of Sockeye from the captive broodstock program using a variety of release strategies has been implemented in Redfish, Pettit, and Alturas lakes. In this report we will summarize activities conducted by Shoshone Bannock Tribal Fisheries Department personnel during the calendar year of 1997.

1997 Project objectives included 1) characterization of the limnology of Sawtooth Valley lakes; 2) fertilization of Redfish, Pettit, and Alturas lakes; 3) *O. nerka* lake population surveys; 4) estimation of kokanee escapement and fry production in Alturas Lake Creek, Stanley Lake Creek, and Fishhook Creek; 5) reduce the number of spawning kokanee in Fishhook Creek; 6) evaluate hatchery rainbow trout overwinter survival and potential competition and predation interactions with *O. nerka* in Pettit Lake, 7) assess predation from bull trout *Salvelinus malma*, brook trout *S. fontinalis*, and northern squawfish *Ptychocheilus oregonsis* on lentic *O. nerka*; and 8) establish screw trap and weir sites to monitor smolt emigration.

1) Annual limnological trends between 1996 and 1997 were the same for the three fertilized lakes yet differed from Stanley Lake, a non-fertilized control lake. Whole-lake zooplankton biomass in Redfish Lake increased to 8.2 μg/l, 5% higher than 1996. Following a large decline in 1995, zooplankton biomass increased to 11.2 μg/l in 1997 in Pettit Lake. Alturas Lake had a similar zooplankton biomass with a seasonal mean of 11.0 μg/l in 1997. In all three lakes chlorophyll *a* increased, and mean secchi depth and the mean 1% light level decreased. Mean secchi and 1% light level in Stanley Lake remained the same from 1996, chlorophyll *a* showed a slight increase and zooplankton biomass decreased.

2) Nitrogen (N) and phosphorus (P) was applied to all three lakes from June through early October. A total amount of 4,289 gallons of 28-0-0 and 384.3 gallons of 10-34-0 liquid fertilizer was used. That resulted in 3,843, 672, and 1,447 kg of N, and 198, 33.6, and 71.5 kg of P to Redfish, Pettit, and Alturas lakes, respectively. The N:P ratio of 20:1 was higher than used for fertilization of Great Central Lake, B.C. (Parsons, et al. 1972) to prevent a possible stimulation of N fixing Cyanophyta. Applications were made weekly by traversing parallel transects across the lakes at two to ten mph in a boat with the fertilizer solution directed by hose into the boat wake.

3) During September 1997 we assessed fish densities using hydroacoustic sampling in

Redfish, Pettit, and Alturas lakes. Hydroacoustic estimates of *O. nerka* densities in the fall of 1997 ranged from 91.1 ± 17.4 to 390.1 ± 182.6 fish/ha, and biomass ranged from 2.34 to 23.25 kg/ha in Alturas and Pettit lakes, respectively. Fish/ha in Redfish Lake was 213.8 ± 52.3 with a corresponding biomass of 3.37 kg/ha.

4) Adult *O. nerka* escapement was 8,572 in Fishhook Creek, 629 in Stanley Lake Creek, and 8,492 in Alturas Lake Creek. Fry production was estimated at 126,000 in Fishhook Creek, 51,700 in Alturas Lake Creek, and 3,400 in Stanley Lake Creek for 1997. Using 1997 escapement numbers there are 70,200, 92,700, and 5,900 fry predicted to be produced in Fishhook, Alturas Lake, and Stanley Lake creeks respectively in 1998.

5) A picket weir was installed in Fishhook Creek to enumerate spawners and allow only 3,000 adults (1,200 females) to pass in an attempt to limit recruitment to Redfish Lake in 1997. The weir was operated from 12 August through 06 September, however the weir failed to capture all fish. Therefore in order to control recruitment 9,700 fry were culled as they emigrated in the spring.

6) Rainbow trout studies in Pettit Lake indicate that the strain of Kamloops rainbow, stocked in 1996, had a higher overwinter survival compared to the Hayspur strain which had been stocked previously. The Hayspur strain was used again for stocking in 1997. Diet overlap between *O. nerka* and rainbow was 0.30 in June and 0.12 in September. No predation on *O. nerka* by stocked rainbow trout was observed in 1997. The only fish species preyed on by hatchery rainbow in the stomach analyses was redside shiner (*Richardsonius balteatus*).

7) There were no *O. nerka* found in the guts of any fish examined. However, bull trout and northern squawfish both had unidentifi salmonids and other unidentified fish in their diets.

8) We installed three concrete anchors next to the stream of Alturas Lake Creek to attach our screw trap. The screw trap will be located ~8.75 km below the outlet of Alturas Lake and ~0.5 km above the mouth of Pettit Lake Creek. In the future, trapping operations will run concurrently with the Pettit Lake weir.

We also assisted the Idaho Department of Fish and Game in net pen operations and planting egg incubator boxes in Redfish Lake.

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INTRODUCTION

In March of 1990 the SBT petitioned the National Marine Fisheries Service (NMFS) to list Snake River sockeye salmon under the Endangered Species Act. Snake River sockeye were formally listed as endangered in November of 1991 (56 FR 58619). Nineteen ninety seven represented the sixth year that the Shoshone-Bannock Tribes (SBT) had been actively involved in Snake River sockeye salmon recovery.

All activities described in this report have been endorsed by the Stanley Basin Technical Oversight Committee (TOC), a committee formed in 1991 with members representing all agencies involved with sockeye recovery. The purpose of this committee is to make recommendations regarding new research, coordinate ongoing research, and actively participate in all elements of Snake River sockeye recovery. Member agencies include the SBT, the Idaho Department of Fish and Game (IDFG), the National Marine Fisheries Service (NMFS), the USDA Forest Service, the Bonneville Power Administration (BPA), the University of Idaho (UI), and the Idaho Department of Environmental Quality (DEQ).

Historically, thousands of Snake River Sockeye salmon returned to the Sawtooth Valley to spawn. Evermann (1896) reported that the Sawtooth Valley Lakes "were teeming with red fish." Bjornn (1968) estimated that 4,360 sockeye returned to Redfish Lake in 1955. In the 1980's, less than 50 Snake River sockeye salmon survived to spawn (Bowler 1990). Since 1990, only 15 sockeye have returned to Redfish Lake. We focused our efforts in 1997 on four lakes (Redfish, Pettit, Alturas, and Stanley) designated critical habitat (57 FR 57051) for sockeye salmon.

During 1997 a total of 153,027, 8,643 and 94,746 sockeye pre-smolts from the captive broodstock program were released into Redfish, Pettit, and Alturas lakes, respectively. We used five release strategies for Redfish Lake; direct lake release in the spring, direct lake release in the fall, summer net pen rearing where the fish were released into the lake in October, 85,000 fertilized eggs were placed in lake incubator boxes in the fall, and eighty adults were also released in October. The fish were released directly into Pettit Lake during July and Alturas Lake during the summer and fall. Much of the work we did in 1997 was addressed toward evaluating if those releases, and nutrient additions to Redfish Lake affected lake environments.

Nutrients were added to Redfish, Pettit, and Alturas lakes to stimulate forage resources and increase survival of the released fish in 1997. Nutrients were added from June through October, a period similar to our fertilization of Redfish Lake in 1995.

STUDY AREA

Four lakes in the Sawtooth Valley are currently the focus of our habitat and limnological studies. The lakes were glacially formed, range in elevation from 1985 to 2138 m, and are located in central Idaho (Figure 1). Specific features of the sockeye rearing lakes are shown in Table 1.

All of the Sawtooth Valley lakes are oligotrophic. Mean summer total phosphorous concentrations in the epilimnion range from 5.9 to 9.0 μg/L. Chlorophyll *a* concentrations range from 0.3 to 1.5 μg/L. Mean summer secchi disk transparencies range from 10.9 - 15.2 m, excluding Stanley Lake which was 7 m in 1996 and 1997.

Table 1. Morphological features of the Sawtooth Valley Lakes.

Lake	Area (km^2)	Volume ($m^3 x10^6$)	Mean Depth (m)	Drainage Area (km^2)
Redfish	6.15	269.9	44	108.1
Alturas	3.38	108.2	32	75.7
Pettit	1.62	45.0	28	27.4
Stanley	0.81	10.4	13	39.4
Yellow Belly	0.73	10.3	14	30.4

Redfish Lake is approximately 1,450 kilometers from the mouth of the Columbia River. There are 616 kilometers of free flowing river from Redfish Lake to the mouth of the Salmon River (Figure 1).

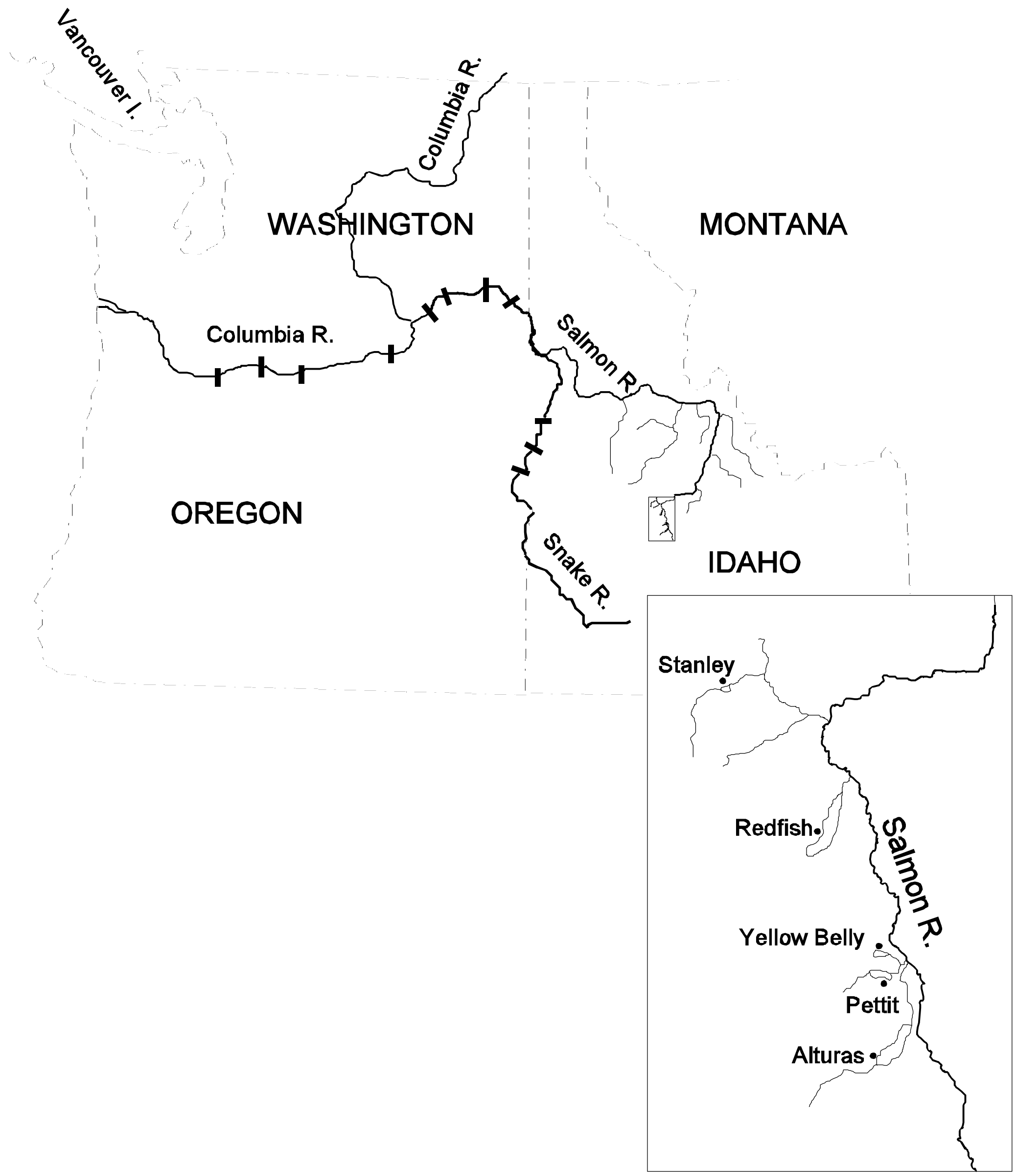


Figure 1. Sockeye rearing lakes in the Sawtooth Valley of central Idaho. Lines across the rivers indicate hydroelectric dams.

Native fish species found in the nursery lake system include sockeye/kokanee salmon (*Oncorhynchus nerka*), rainbow trout (*O. mykiss*), chinook salmon (*O. tshawytscha*), cutthroat trout (*O. clarki*), bull trout (*Salnelinus confluentus*), mountain whitefish (*Prosopium williamsoni*), sucker (*Catastomus sp*.), redside shiner (*Richardsonius balteatus*), dace (*Rhinichthys sp*.), northern squawfish (*Ptychocheilus oregonensis*), and sculpin (*Cottus sp*.). Non-native species include brook trout (*S. fontinalis*) and lake trout (*S. namaycush*). The only pelagic species besides *O. nerka* are redside shiners. The two species are not sympatric because of differing vertical distributions.

Hatchery rainbow trout are stocked throughout the summer in all lakes except for Redfish Lake. Sport fishing for salmonids is open on all lakes as well as inlet and outlet streams.

Ice forms on the lakes during December and usually persists until mid-May. Sockeye out-migration begins in April and lasts into June. Adult sockeye historically entered Redfish Lake in July and continued through October (Bjornn et al. 1968). Spawning occurs in October and early November.

CHAPTER 1

Fish Population Dynamics Sawtooth Valley Lakes, Idaho

METHODS

Fishhook Creek Fry Recruitment

Kokanee fry were collected from Fishhook Creek to estimate egg to fry survival and recruitment to Redfish Lake. Fry were collected with rectangular steel framed drift nets 30 cm wide and 60 cm in length. Each frame was fitted with a tapered nylon net that directed fry to plywood live boxes.

Live boxes contained wire mesh screen on one side with longitudinal plywood partitions used to create backwater refuge for captured fish. The frames and live boxes were adjusted according to stream flow on rebar that was embedded in the substrate. Three fry traps were set on Fishhook Creek near the bridge located 50 m above the mouth to Redfish Lake. Fry traps were operated at least five days each week from 22 April to 8 June 1997.

Daily fry recruitment was estimated by summing the number of kokanee fry captured in each trap and applying a variable correction factor (mean 22 %) garnered from trap efficiencies. Trap efficiencies were estimated using a radish release method (Teuscher and Taki 1993). To estimate the proportion of the stream sampled, neutrally buoyant radishes were released 100 m above the traps. Radish tests were performed when fry traps were installed and when flows changed markedly throughout the sampling period. Discharge was measured by a metered staff gauge. On non-count days fry recruitment was estimated by applying a modified Area Under the Curve (AUC) method where the difference between the first and last counts were divided by the days between the counts. The resulting value is added to the first count day and is additive through successive non-count days.

All other fry production estimates were calculated using spawner escapement, fecundity, and percent egg to fry survival rates.

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). A 15 degree transducer was used, and the echosounder criteria were set to a pulse width of 0.4 milliseconds, a time varied gain of 40 log(R) + $2\alpha r$, and four pings per second for Redfish lakes, and five pings per second for Alturas and Pettit Lake. A minimum of five pings per target was necessary to qualify as a fish target. Data were recorded on a Panasonic SV-3700 digital audio tape recorder.

Identical transects set with a global positioning system (GPS) during 1994 (Teuscher and Taki 1995) were followed. Waypoints were set to allow for sampling transects to run zigzag across all lakes except Pettit Lake, where we used five parallel and one diagonal transect (Teuscher and Taki 1995). We sampled twelve and fourteen transects at Alturas and Redfish lakes, respectively.

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

Vertical gill netting and trawling (by IDFG) were done concurrently with hydroacoustic sampling. Vertical gill net sampling was used to assist in partitioning targets in Pettit Lake since past trawling efforts have indicated a selectivity for *O. nerka*. Therefore, vertical gillnets were employed to determine if other fish species were found in the pelagic areas during sampling. Previous gill net sampling conducted in Alturas Lake has not yielded sufficient numbers for partitioning targets and therefore was not used. Due to permit requirements we were unable to set vertical gillnets in Redfish Lake.

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

$$TS = 19.1 \cdot Log(L) - 0.9 \cdot Log(F) - 62.0 \qquad (1)$$

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

$$X\,(ABS \cdot (M^{TS} - F^{TS})^{Y} \qquad (2)$$

was used where X = 8.6, ABS = absolute value of the target strength remainder, M^{TS} = minimum system detection (-60), F^{TS} = 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

$$\overline{D}_i = \frac{\sum_{j=1}^{T_i} L_j \overline{D}_{ij}}{\sum_{j=1}^{T_i} L_j} \qquad (3)$$

and variance was estimated by

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

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).

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

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

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

Correlation analysis was used to compare trawl versus hydroacoustic population estimates. Comparisons were made by comparing previous years results for total lake populations and cohort estimates.

O. nerka Spawning Surveys

Stream Spawning- Stream surveys were conducted to estimate kokanee spawning abundance in Redfish, Stanley, and Alturas lake tributary streams from 29 July to 9 September, 1997. Estimated length of tributaries surveyed for Redfish, Stanley and Alturas lakes were 1.7, 2.4 and 3.7 kilometers, respectively. Counts were conducted from the bank by one or two observers equipped with polarized sunglasses. Surveys were conducted at four day intervals. On days when surveys were not taken, the number of fish in the stream were estimated by dividing the difference between the actual counts by the number of days between the counts. The average value was added to the actual count day for the following successive non-count days. Total escapement estimates were made by summing daily counts of kokanee and dividing by average stream life as described by English et al. (1992).

On Fishhook Creek, a picket weir was deployed as an alternative method for estimating kokanee escapement and to cull a portion of the female kokanee spawners.

The weir was checked daily and during peak immigration checked twice daily. Upstream post-spawning mortalities impinged on the pickets were enumerated and sent downstream along with accumulated debris. Culling was implemented in 1995 to control eventual fry recruitment to Redfish Lake as part of the kokanee management program. The programs objective is a reduction in the kokanee population to lower competitive interactions with introduced juvenile sockeye salmon. Escapement goals for kokanee in Fishhook Creek were set at 1,200 spawning females. Based on previous years' weir counts, we used a three day running average to determine the number of females and males to pass on a given day. If the cumulative number had not been reached then we passed more fish to get to the total for a given day. Production estimates for egg deposition (233 eggs/female) and subsequent fry emergence (12.3% egg to fry survival) for 1,200 females is 279,600 eggs and 34,391 fry.

<u>*Beach Spawning*</u>- Redfish Lake was snorkeled on four nights from 14 October to 4 November 1997, to estimate the relative abundance of residual spawners. Sockeye Beach and a small section of the south east corner of Redfish Lake are spawning grounds for residual sockeye. At least three observers, equipped with waterproof flashlights, snorkeled parallel to shore 10 m apart, observing at depths ranging from 0.5 to 5 m. For Sockeye Beach, we estimated residual spawner abundance within the boundaries (600 m) of Sockeye Beach as delineated by U.S.D.A. Forest Service signs. Spawning ground surveys in the south end of the lake were conducted in the 200 m shoal area section near the two southeast inlet streams.

Redd counts were conducted in Redfish Lake by boat to estimate the number of spawning sockeye adults released from the captive broodstock program. The survey area was in the south end of the lake in a 200 m shoal area near the two southern inlet streams. Three observers equipped with polarized sunglasses conducted redd counts from a boat traveling 0-2 mph. A total of 80 captive brood sockeye adults were released into Redfish Lake at a 1:1 sex ratio. Additional boat surveys were conducted in Alturas and Pettit Lakes.

The entire lake shore area of both lakes were surveyed. A total of 20 captive brood sockeye adults were released into each lake at a 1:1 sex ratio.

Gillnet Sampling

Gillnets were used to estimate distribution, relative abundance, and diet of *O. nerka*, hatchery rainbow trout, brook trout, bull trout and squawfish. Horizontal gillnets were set monthly except during April and December when ice breakup and ice buildup occurred and August and October when no gillnetting was conducted. Four horizontal nets, 30 m in length and 1.8 m in depth, were used to sample the littoral region. Mesh sizes were 2.54, 3.17, 3.81, 5.08 and 6.35 cm in graduated panels 6 m in length, with the smallest mesh size closer to shore.

Gillnets were set perpendicular to the shore in the morning during ice-cover and in the evening during regular sampling periods and retrieved the following day. During periods of ice-cover a chainsaw was used to cut through the ice for gill net placement.

Four vertical gillnets, 30 m in length, were used to sample the pelagic region. Mesh sizes for each gill net were 1.9, 2.54, 3.81 and 5.08 cm. No vertical gillnets were set in Pettit Lake during the month of July to prevent lethal take of pelagically released listed sockeye. Fish captured were identified, measured for fork length to the nearest mm and weighed, otoliths removed for aging (*O. nerka*), fecundity estimates (*O. nerka*) and stomachs preserved for diet analysis. Horizontal gillnets were set on 23 July 1997 in Alturas lake to obtain predatory diet information on July 2, 1997 pre-smolt *O. nerka* direct release.

Diet Analysis

Stomach contents were analyzed from *O. nerka* , hatchery rainbow trout, brook trout, bull trout, and squawfish captured by gill nets and trawls in 1997. Fish stomachs were removed and placed in 70% ethanol. Non-zooplankton prey items were sorted by order, blotted dry and weighed to the nearest 0.01 g. Zooplankton prey were enumerated in a water bath under a compound microscope. Zooplankton lengths were converted to weight using the length weight regression equation reported in McCauley (1984).

We calculated aggregate percent by weight (Swanson et al. 1974) for all species of fish sampled. Aggregate percent by weight totals were used to determine diet overlap and electivity indices. Diet overlap indices between *O. nerka* and other species captured were calculated using equations described by Koenings et al. (1987). Electivity indices (Ivlev 1961) describing calculations for prey preferences were used for *O. nerka*.

RESULTS

Fishhook Creek Fry Recruitment

Using trap data an estimated 98,179 kokanee fry emigrated from Fishhook Creek to Redfish Lake from 22 April to 8 June 1997. Correlations between discharge and estimated daily emigration are presented in Figure 2.

Based on a daily average of 4 previous years, 85% of kokanee fry recruitment was completed before suspension of trapping activities. As part of the kokanee control

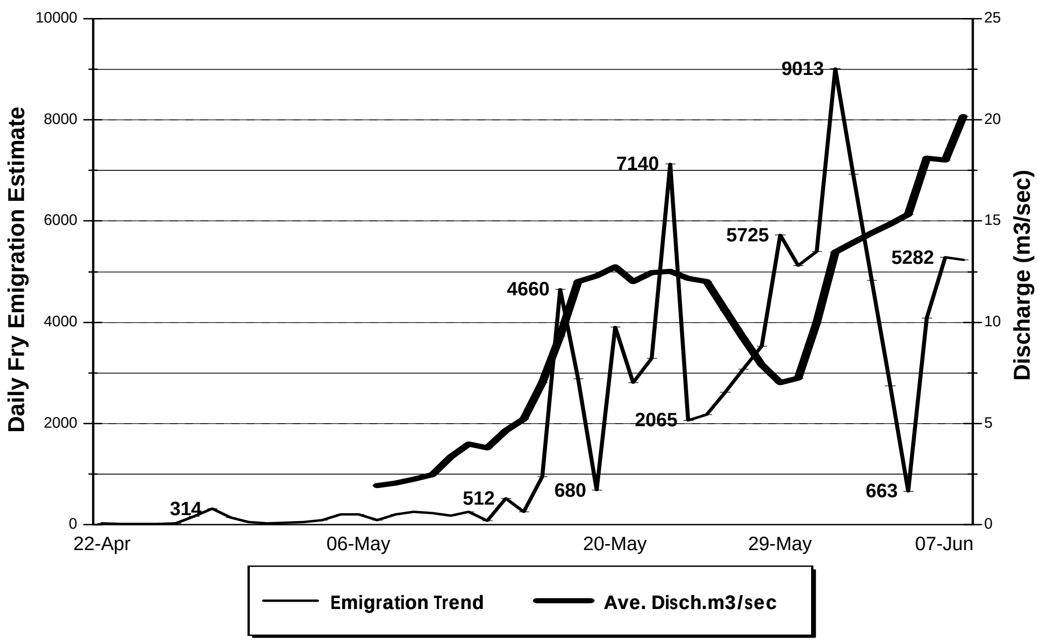


Figure 2. Fishhook Creek kokanee fry daily emigration and discharge.

management plan 9,754 kokanee fry were culled or ~8% of the total fry emigration estimate before trapping suspension due to flooding. Total fry recruitment was 126,980 fish based on a four year daily average. Previous escapements and corresponding recruitment are shown in Table 2.

Table 2. Adult escapement, fecundity, egg to fry survival, and kokanee recruitment in Fishhook, Alturas, and Stanley Lake Creeks.

Location	Brood Year	Adult Escapement	Mean Eggs/♀ (n)	♂ : ♀ Ratio	Egg-Fry Survival	Fry Recruits
Fishhook	1997	8,572	233 (24)	1.4:1	12.3%[(a)]	70,186
Fishhook	1996	10,662	286 (26)	3:1	12.5%	126,980
Fishhook	1995	7,000	230 (68)	1:1	12.3%[(a)]	99,015
Fishhook	1994	9,200	330	1:1	13.6%	143,888
Fishhook	1993	10,800	300*	1:1	11.0%	142,000
Fishhook	1992	9,600	300*	1:1	12.0%	166,000
Fishhook	1991	7,200	300*	1:1	3.0%	36,000
Alturas	1997	8,492	168 (2)	1:1	13.0%[(b)]	92,733
Alturas	1996	744	150	1:1	13.0%[(b)]	51,677
Alturas	1995	1,600	150	1:1	13.0%[(b)]	15,600
Alturas	1994	3,200	150	1:1	13.0%[(b)]	30,000
Alturas	1993	200	-	1:1	13.0%	2,000
Alturas	1992	60	-	1:1	na	na
Stanley	1997	629	270	1:1	7.0%[(c)]	5,935
Stanley	1996	825	270	1:1	7.0%[(c)]	3,431
Stanley	1995	90	270	1:1	7.0%[(c)]	850
Stanley	1994	600	270	1:1	7.0%	5,000
Stanley	1993	1,900	-	1:1	7.0%	19,000

[(a)] 1992-94 average [(b)] survival estimate 1993 [(c)] 1993-94 average

*Personal communication, Dr. Ernie Brannon, U.I, 1991.

Hydroacoustic Population Estimates

Hydroacoustic estimates of *O. nerka* densities in September of 1997 ranged from 91.1 ± 17.4 to 390.1 ± 182.6 fish/ha, and biomass ranged from 2.34 to 23.25 kg/ha in Alturas and Pettit lakes, respectively. Fish/ha in Redfish Lake was 213.8 ± 52.3 with a corresponding biomass of 3.37 kg/ha. Redfish Lake experienced the greatest increase in population, almost doubling the 1996 estimate. Alturas Lake also increased while Pettit Lake decreased (Figure 3; Table 3).

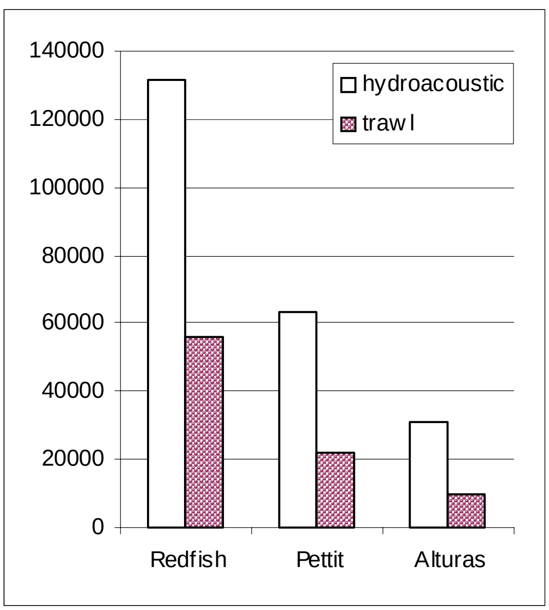


Figure 3. Hydroacoustic and trawl estimates for 1997 (trawl estimates from J. Pravecek, IDFG).

Table 3. Hydroacoustic and trawl estimates of *O. nerka* abundance in three Sawtooth Valley lakes.

Lake	Year	Acoustic	Trawl	A/T Ratio
Redfish	1997	131,513	55,762	2.4
Redfish	1996	66,325	56,213	1.2
Redfish	1995	103,570	61,646	1.7
Redfish	1994	133,360	51,529	2.6
Redfish	1993	203,500	49,628	4.1
Redfish	1992	188,000	39,480	4.8
Pettit	1997	63,195	21,730	2.9
Pettit	1996	77,680	71,655	1.1
Pettit	1995	77,765	59,004	1.3
Pettit	1994	12,265	14,743	0.8
Pettit	1993	20,400	11,597	1.8
Pettit	1992	19,000	3,009	6.3
Alturas	1997	30,795	9,761	3.1
Alturas	1996	20,620	13,012	1.6
Alturas	1995	32,260	23,052	1.4
Alturas	1994	10,980	5,785	1.9
Alturas	1993	200,700	49,038	4.1
Alturas	1992	144,000	47,238	3.1

Hydroacoustic estimates in Pettit Lake may have been confounded by the hatchery rainbow trout stocked in 1997. These fish were smaller than in previous years and overlapped with the *O. nerka* in the lake. A cursory examination of the echograms indicated several targets that were included as *O. nerka* may have been rainbow trout based on the littoral locations of the targets.

Redfish Lake- The total *O. nerka* population in Redfish Lake increased substantially from 1996. The 98% increase in total lake population was reflected in every cohort (Table 4). The YOY cohort increased 194% over 1996 which tracks the increase of fry recruitment to the lake for the corresponding years as well as contributions from egg releases and adult sockeye spawning. During the fall of 1996, 105,000 eyed eggs were put in in-lake egg boxes and 120 adult sockeye were released into the lake. The increase in the age one population may be attributed to the release of almost 22,000 sockeye from the captive broodstock program in July of 1997. Following the same cohort from 1996, the trawl estimate also showed an increase, yet not as pronounced. The decline in the two year old cohort from 1996 of 12.4% would be expected from natural mortality. However, predicting annual mortality for a given cohort in Redfish Lake has proven difficult due to the addition of sockeye from the captive broodstock program.

Pettit Lake- The total *O. nerka* population in Pettit Lake declined by 14,485 (18.65%) fish from 1996. The trawl estimate declined 70% (Table 3).

Table 4. Redfish Lake hydroacoustic fish population estimates by cohort from 1994-1995.

Cohort	1994	1995	1996	1997
0+	76,600 ± 19,560	22,360 ± 6,410	12,680 ± 5,030	37,234 ± 14,449
I+	36,000 ± 8,240	49,120 ± 12,400	34,950 ± 21,040	51,681 ± 14,533
II+	20,760 ± 7,470	31,070 ± 12,340	18,700 ± 4,570	30,623 ± 6,599
III+				11,973 ± 3,104

In the past where lengths of rainbow trout have been higher than *O. nerka*, targets were excluded if they were larger than the longest kokanee. This was also done for 1997 estimates but may have included rainbow trout which overlapped in size with the largest *O. nerka*. After the data had been analyzed a closer inspection of the echogram charts showed that many targets which fell within the size guidelines were in the littoral zone where rainbows are captured in horizontal gill nets. The only time *O. nerka* have been captured in those areas was during the winter when they are spawning. Therefore, it is very likely that we overestimated the population of kokanee. Also, in 1997 the trawl did not capture any YOY or one year old cohorts (Table 5). That would account for some of the discrepancy between overall trawl and hydroacoustic population estimates.

Alturas Lake- Whole lake *O. nerka* population estimates increased by 49% of the 1996 estimate. The biggest discrepancy, based on 1996 estimates, was a fairly large one year old cohort that was almost triple the estimate of YOY's in 1996. Surprisingly, the trawl did not capture any fish in that cohort.

There was also a high population estimate of three and four year olds that indicates there will be a large number of kokanee spawners in 1998. Since 1994 Alturas Lake has shown a three-fold increase in the *O. nerka* population.

Table 5. Pettit Lake trawl and hydroacoustic population estimates by cohort for 1996 and 1997 (trawl data provided by Jay Pravecek, IDFG).

Cohort	**1996 trawl**	**1996 acoustic**	**1997 trawl**	**1997 acoustic**
O+	0	4,740 ± 3,020	0	4,471 ± 2,705
I+	1,339 ± 670	17,890 ± 3,020	0	14,061 ± 6,010
II+	43,529 ± 2,919	31,800 ± 5,820	21,335 ± 11,235	23,635 ± 11,485
III+	26,787 ± 4,391	23,247 ± 5,100	395 ± 789	21,027 ± 11,502

Based on trawl estimates, 1994 marked a drastic decline from previous years. Trawl population estimates for Alturas Lake began in 1990, four years before we began hydroacoustic estimates. In 1990 the kokanee population was estimated to be 126,644. That resulted in a zooplankton collapse (see Chapter 2) and substantially reduced the kokanee population to levels similar to recent years.

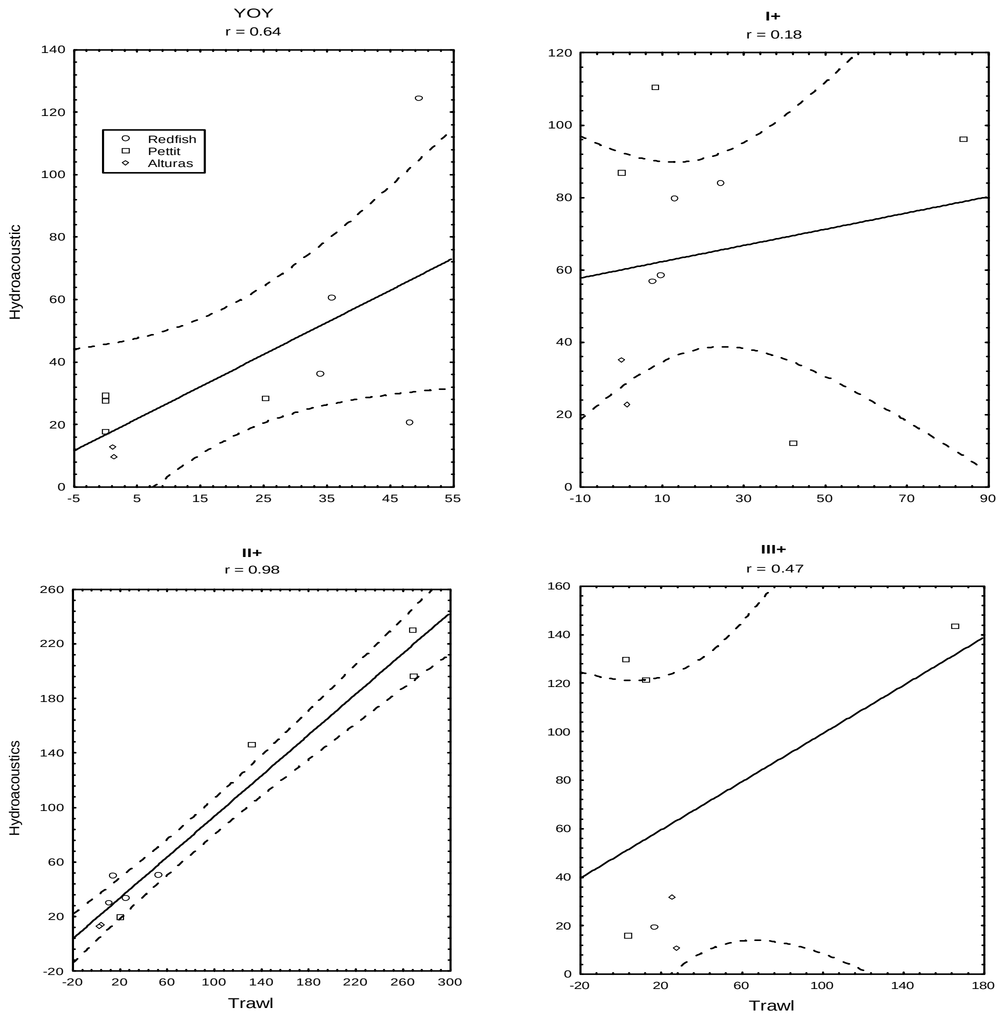


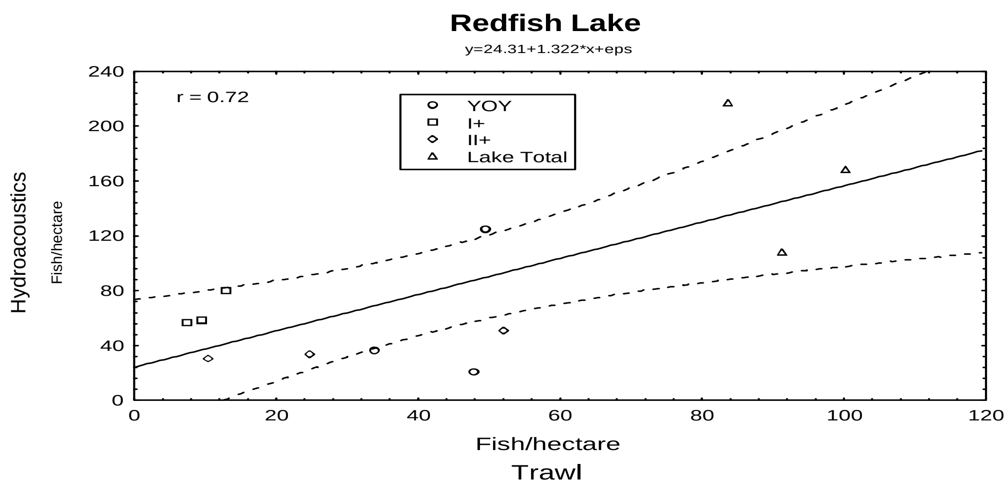
Figure 4. Correlation between hydroacoustics and trawl population estimates for four cohorts of *O. nerka* in Redfish, Pettit, and Alturas lakes for 1994 through 1998.

Hydroacoustic/trawl comparisons

Correlating hydroacoustic and trawl population estimates varied by what was compared. Combining individual cohorts from Redfish, Pettit, and Alturas lakes revealed that only the two year old cohort were strongly related (Figure 4).

Comparing all cohorts within a lake gives different results for which lake the correlation is used. Pettit Lake has a very strong relationship (r = 0.95) while Redfish Lake doesn't have as tight of a relationship(r = 0.72)(Figure 5).

Alturas Lake was not used because of the difficulty discerning age classes before



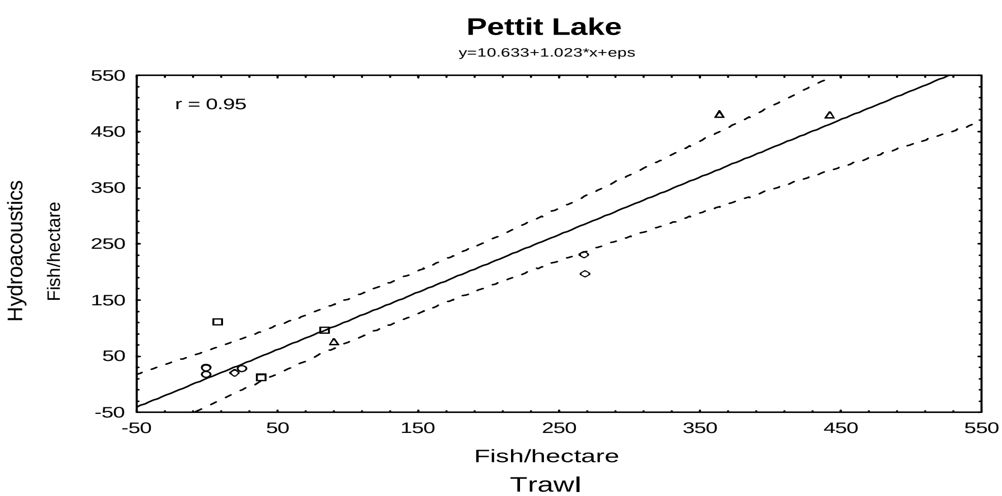


Figure 5. Correlation between hydroacoustic and trawl population estimates for Redfish and Pettit lakes from 1994-1996.

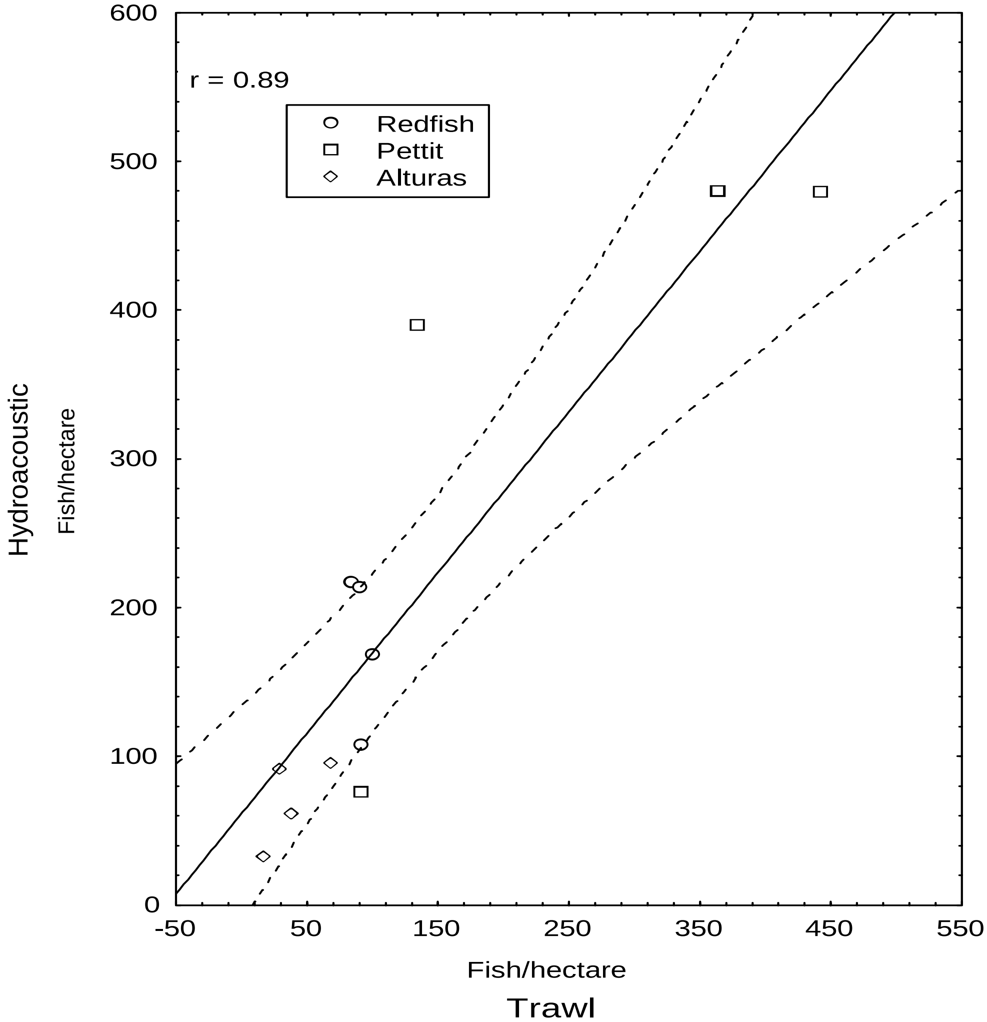


Figure 6. Comparing whole lake hydroacoustic and trawl population estimates from Redfish, Pettit, and Alturas lakes from 1994 through 1997.

1996. With only two years of data available there is not enough data to run a valid correlation of cohorts. By comparing whole lake estimates a fairly strong relationship is given (r = 0.89)(Figure 6). Parkinson et al. (1994) found the greatest discrepancy between trawl and hydroacoustic estimates in areas with the lowest density of fish. Conversely, from 1994 through 1997 Alturas Lake had the lowest density of fish in the Sawtooth

Valley yet was the only lake that fell within the 95% confidence intervals every year (Figure 6).

Adult *O. nerka* spawning surveys

Stream Spawning

Fishhook Creek kokanee escapement remains relatively constant with an estimated 8,572 fish in 1997 (Fig. 7).

Predicted fry recruitment for Fishhook Creek kokanee is 70,186 fry based on a male to female sex ratio of 1.4:1 (2,449 females), 233 eggs/female, and 12.3% egg to fry survival. In 1997, the Fishhook Creek kokanee adult run began 12 August and ended 9 September. Males dominated

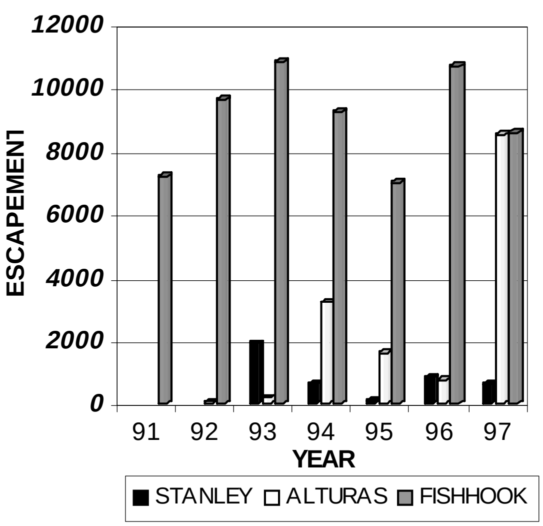


Figure 7. Escapement estimates for Fishhook, Alturas, and Stanley creeks.

the run to 30 August. Bed raking was implemented downstream from the weir on 10 September as part of the kokanee control management plan. An estimated 2,400 adults escaped through the weir but this number was inaccurate due to fish that were not counted getting through the weir. Final escapement estimates were derived from stream surveys. Fecundity estimates of 233 eggs per female (n=24), male and female mean fork lengths of 232 mm (n=74), and mean egg weight of 18.9 g (n=14) were lower than 1996 values.

Stanley Lake Creek had an estimated kokanee escapement of 629 fish in 1997. This will produce an estimated 5,935 kokanee fry recruits in Stanley Lake Creek assuming a male to female sex ratio of 1:1 (314 females), 270 eggs/female, and 7.0% egg to fry survival. Fecundity values from 1995-97 for Stanley lake were carried over from estimates made in 1994.

Alturas Lake Creek had an estimated kokanee escapement of 8,492 fish. There is a predicted 92,733 kokanee fry recruits for Alturas Lake Creek based on a male to female sex ratio of 1:1 (4,246 females), 168 eggs/female (n=2), and 13.0% egg to fry survival. Alturas Lake Creek kokanee had a mean weight of 96.1 g, mean fork length of 200.5 mm, and a mean egg weight of 15.9 g. Fecundity estimates for Alturas Lake kokanee were derived from 1994. The 1997 Alturas Lake Creek escapement population is the highest recorded for the 6 years of monitoring on that creek.

Beach Spawning- Night snorkel surveys conducted in Redfish Lake for residual sockeye spawning activity on 21, 28 October and 4 November revealed 2, 5, and 14 residual spawners, respectively. No residual sockeye were observed on 15 October. Spawning activity for sockeye adult broodstock was observed each week from 15 October to 4 November, from boat surveys conducted in the South Beach area of Redfish lake.

Gillnet Sampling

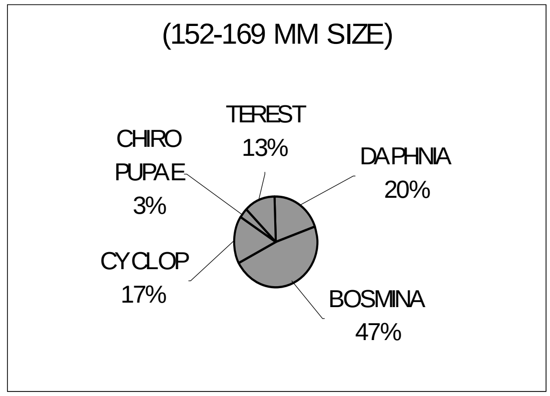
Horizontal gillnets at the four stations combined in Pettit Lake had a mean kokanee CPUE of 0.17. Mean kokanee length was 206 mm with a mean weight of 93 g. Total mean rainbow trout CPUE was 0.14 with a mean CPUE of 0.39 during Sept. and Nov. sampling. Rainbow trout had a mean length of 267 mm and a mean weight of 233 g. Monthly summaries of CPUE, mean fork length, weight, and gillnet hours for *O. nerka*, rainbow, brook, and bull trout in Pettit Lake is presented in Tables 6 thru 10. Mean fecundity for Pettit Lake kokanee sampled on 10 February was 348 eggs/female (Table 11). Fecundity estimates were actual counts and eggs may have been lost during gillnet capture due to net constriction. A monthly summary of CPUE, mean fork length, and gillnet hours for rainbow, bull trout, and squawfish in Alturas Lake is presented in Table 12.

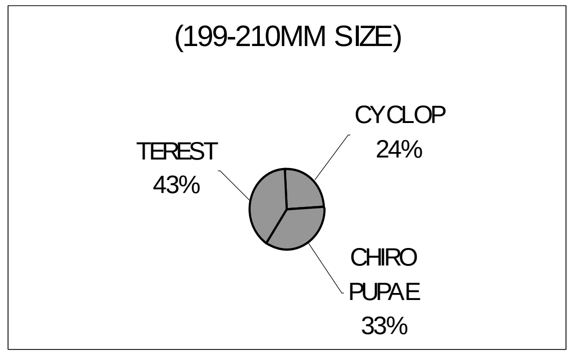
Diet Analysis

The diet of Pettit Lake small, size class kokanee was dominated by zooplankton and demonstrated a shift to insects for larger size classes (Fig. 8, appendix A1). Pettit Lake rainbow trout diet consisted of 46% mulusca, 30% insect, and 24% cyprinid during ice over. During ice free period the rainbow trout diet consisted of 79% insects, 15% plant, 3% cyprinid, and 3%Mollusca.(Appendix B). Pettit Lake squawfish diet was 97% cyprinids (Appendix E). Alturas Lake kokanee (mean length 167 mm) diet consisted of 80% zooplankton and 10% insects

(Appendix A.2). Alturas Lake Squawfish diet consisted of 74% salmonids, and 25% insects while Alturas Lake Bull trout ate 64% salmonids, with 25% unidentifiable fish, and 11% Mollusca (Appendix F).

Gut content analysis was performed on 114 kokanee captured in trawls and gill nets. Mean percent dry weight values were derived from 83 kokanee containing varying numbers of prey items. Thirty one kokanee were void of prey items or prey were highly digested and unidentifiable. I.D.F.G. trawls conducted on September 3 -4 in Pettit and Alturas lakes, garnered 3 and 2 sockeye respectively. Dominant *O. nerka* prey items during the ice-cover period for Pettit lake were cyclopoids and *Bosmina spp*. (Appendix A). Electivity indices (Ivlev, 1961) were performed for prey items found in gut content analysis (mean percent dry weight) in proportion to zooplankton density (#/l) found in Pettit Lake on concurrent sampling events (Figure 9).





O. nerka selection index was the highest for daphnia (1.0) during periods of high prey availability (March through September). The selective ability of *O. nerka* is the sum total of two factors; preference for particular prey and the degree of accessibility (Ivlev 1961). During the ice-cover period, when daphnia biomass was low, kokanee selected for nauplii. Preference modes for selection indices were exhibited for *Bosmina spp*. and cyclops in concert with daphnia during the period when there was no ice-cover.

Figure 8. Pettit Lake kokanee diet by size class.

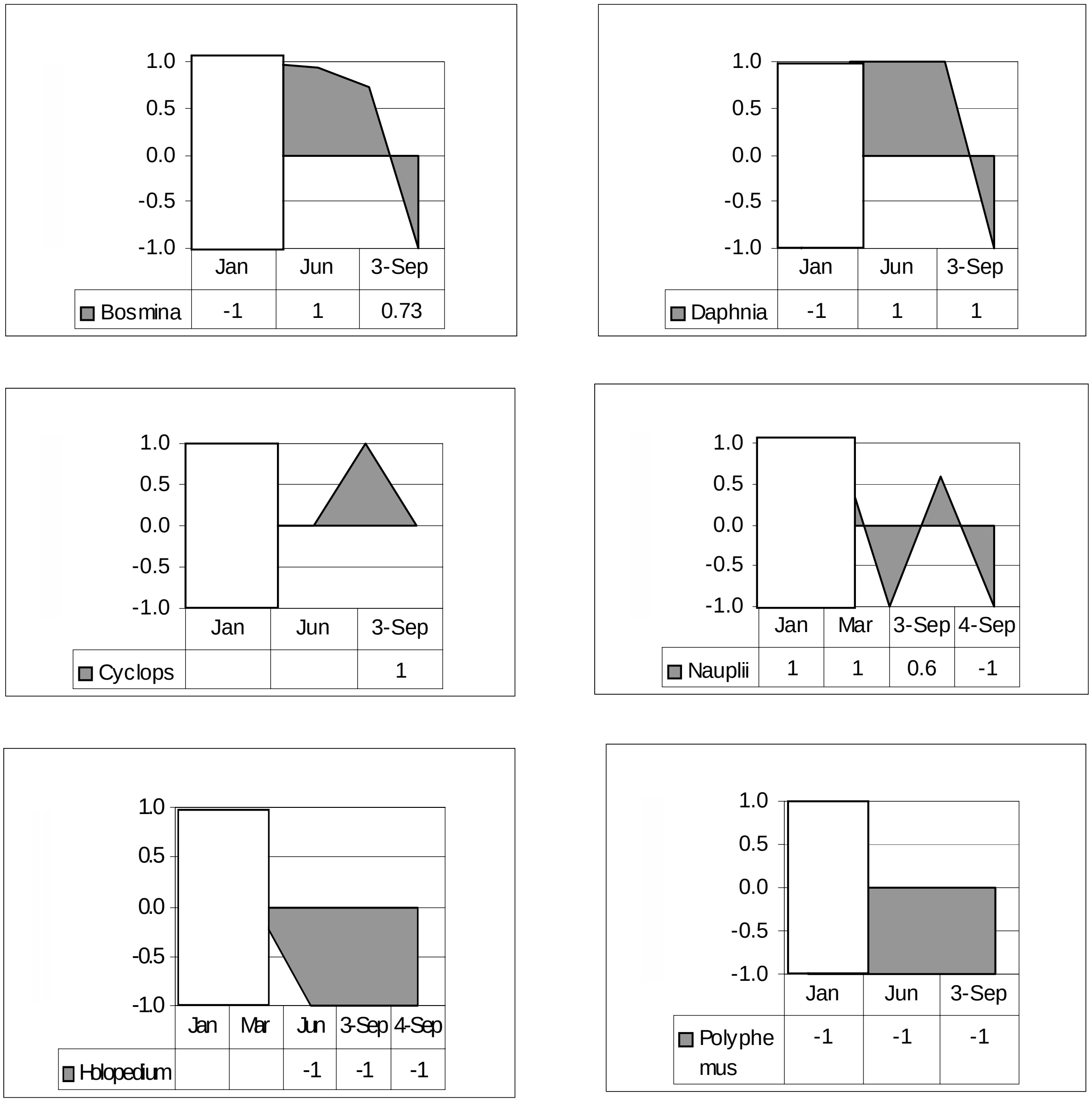


Figure 8. Ivlev electivity indices of mean number of prey items found in the environment (#/l) proportional to mean percent dry weight of gut content prey items. Positive values indicate selection, negative values indicate avoidance or inaccessibility. Semi-transparent areas denote ice-cover during sampling periods. Indices for September 4 were collected from I.D.F.G. trawl.

Table 6. 1997 Pettit Lake gillnet percent catch per unit effort by station.

Date	Station A	Station B	Station C	Station D
22 Jan[1]	14.80%	44.40%	0.00%	40.70%
10 Feb	24.00%	12.00%	8.00%	56.00%
11 Feb	0.00%	6.70%	66.70%	26.70%
26 Mar	25.00%	25.00%	25.00%	25.00%
25 Jun[2]	30.00%	40.00%	0.00%	30.00%
16 Jul	66.63%	6.67%	0.00%	26.67%
3 Sep	64.30%	0.00%	35.70%	0.00%
5 Nov	14.30%	34.30%	34.30%	17.10%
Mean	**29.89%**	**21.14%**	**21.21%**	**27.78%**

[1] *Stations B & C combined*

[2] *No station C*

Table 7. Pettit Lake rainbow trout horizontal gillnet summary, 1997.

Date	CPUE (n)	Mean Fork Lt. (mm)	Mean Weight (g)	Mean Gillnet Hours
22 Jan	0.025 (2)	279.0	na	19.9
10 Feb	0.038 (4)	276.8	267.3	21.2
11 Feb	0.017 (2)	243.5	128.6	23.7
26 Mar	0.050 (4)	266.8	252.3	20.0
25 Jun	0.077 (3)	256.0	na	13.0
16 Jul	0.100 (6)	273.3	na	15.0
3 Sep	0.367 (11)	258.2	na	15.0
5 Nov	0.430 (33)	287.5	246.6	18.5

Table 8. Pettit Lake *O. nerka* horizontal gillnet summary, 1997.

Date	CPUE (n)	Mean Fork Lt. (mm)	Mean Weight (g)	Mean Gillnet Hours
22 Jan	0.289 (23)	208.2	na	19.9
10 Feb	0.189 (20)	210.3	99.4	21.2
11 Feb	0.228 (27)	203.7	86.7	23.7
25 Jun	0.077 (3)	207.3	98.3	13.0
5 Nov	0.040 (3)	202.6	90.7	18.5

Table 9. Pettit Lake bull trout horizontal gillnet summary, 1997.

Date	CPUE (n)	Mean Fork Lt. (mm)	Mean Weight (g)	Mean Gillnet Hours
10 Feb	0.009 (1)	235.0	130.9	21.2
25 Jun	0.026 (1)	301.0	na	13.0
16 Jul	0.033 (2)	292.5	na	15.0
3 Sep	0.067 (2)	306.0	na	15.0
5 Nov	0.040 (3)	378.6	711.7	18.5

Table 10. Pettit Lake brook trout horizontal gillnet summary, 1997.

Date	CPUE (n)	Mean Fork Lt. (mm)	Mean Weight (g)	Mean Gillnet Hours
22 Jan	0.025 (2)	232.0*	na	19.9
11 Feb	0.008 (1)	400.0	1,362	23.7
25 Jun	0.128 (5)	229.8	na	13.0
16 Jul	0.083 (5)	239.6	na	15.0
5 Nov	0.010 (1)	300.0	278.5	18.5

Table 11. Pettit Lake *O. nerka* fecundity summary 10 February 1997.

Fork Lt. (mm)	Weight (g)	Eggs/Female
229	115.5	279
220	104.7	410
224	109.1	348
214	100.5	366
224	106.5	351
228	102.6	334
Mean 223.2	**Mean 106.5**	**Mean 348**

Table 12. Alturas Lake horizontal gillnet summary, 24 July 1997.

Species	CPUE (n)	Fork Lt. (mm)	Weight (g)	Gillnet Hours
Bull Trout	0.19 (6)	291.3	na	16.0
Squawfish	0.41(13)	232.2	na	16.0
Rainbow	0.13 (4)	273.8	na	16.0

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Appendix A.1. 1997 Pettit Lake kokanee stomach content analysis. Mean percent dry weight.

Date	$\bar{x}$Lt.(mm)	n	Da	Bo	Po	Ca	Cycl	Ch.P	Ch.L	T.Ins
22 Jan	199.5	2	0.0	0.0	0.0	0.0	73.2	0.0	0.0	26.9
26 Mar	169.5	1	1.1	48.9	0.0	0.0	50.0	0.0	0.0	0.0
25 Jun	207.3	6	0.0	0.0	0.0	0.0	0.0	98.9	0.0	1.1
3 Sep	152.7	6	40.0	24.6	0.5	0.0	0.0	8.8	0.0	27.0
4 Sep*	152.3	24	19.5	63.0	0.5	0.2	1.7	0.8	3.1	11.2
5 Nov	210.0	1	0.6	0.0	0.0	0.0	0.2	0.0	0.0	99.1

*IDFG Trawl

Appendix A.2. Alturas Lake I.D.F.G. trawl kokanee stomach content analysis, 4 September 1997. Mean percent dry weight.

Date	$\bar{x}$Lt.(mm)	n	Da	Bo	Po	Ca	Cycl	Ch.P	Ch.L	T.Ins
4 Sep	167.6	23	87.8	0.5	0.0	2.2	0.0	0.0	0.0	9.5

Appendix A.3. 1997 Redfish Lake I.D.F.G. trawl kokanee stomach content analysis. Mean percent dry weight.

Date	$\bar{x}$Lt.(mm)	n	Da	Bo	Po	Ca	Cycl	Ch.P	Ch.L	T.Ins
3 Sep	114.6	20	55.3	0.1	0.0	0.0	0.0	20.1	4.7	19.7

Appendix B. 1997 Pettit Lake rainbow stomach content analysis*. Mean percent dry weight.

Date	**$\bar{x}$Lt. mm**	**$\bar{x}$Wt. g**	**Cp**	**Ml**	**Od**	**Tr**	**Co**	**He**	**Ch.P**	**T.Ins**	**Di**
22 Jan	273.5	na	47.8	2.2	50.0	0.0	0.0	0.0	0.0	0.0	0.0
11 Feb	267.8	239.5	20.0	51.0	9.1	0.0	0.0	0.0	0.0	0.0	0.0
26 Mar	266.8	252.3	0.0	74.0	1.1	25.0	0.0	0.0	0.0	0.0	0.0
25 Jun	256.0	177.9	0.0	0.6	57.9	3.3	0.0	0.2	21.7	1.0	9.2
16 Jul	273.3	200.0	8.3	0.3	49.1	0.0	5.7	0.0	13.3	8.2	4.2
3 Sep	258.2	na	0.0	3.0	32.0	0.0	3.5	0.9	1.7	10.0	33
5 Nov	296.0	289.4	3.2	8.8	25.7	2.1	1.3	16.4	0.2	8.6	0.8

**Plant matter not included*

Appendix C. 1997 Pettit Lake brook trout stomach content analysis. Mean percent dry weight.

Date	**$\bar{x}$Lt.(mm)**	**n**	**Cp**	**Un**	**Od**	**Tr**	**Sa**	**Ch.P**	**Pm**
22 Jan	230.0	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11 Feb	400+	1	0.0	14.6	0.0	0.0	85.4	0.0	0.0
25 Jun	227.7	3	61.3	0.0	36.5	0.5	0.0	1.6	0.0
16 Jul	239.6	5	0.0	0.0	94.9	5.1	0.0	0.0	0.0

Appendix D. 1997 Pettit Lake bull trout stomach content analysis. Mean percent dry weight.

Date	**$\bar{x}$Lt.(mm)**	**n**	**Cp**	**Un**	**Od**	**Tr**	**Sa**	**Ch.P**	**Pm**
25 Jun	301.0	1	0.0	0.0	0.0	0.0	0.0	50.0	50.0
16 Jul	292.5	2	0.0	0.0	9.6	0.0	90.4	0.0	0.0
3 Sep	306.0	2	50.0	0.0	0.0	0.0	50.0	0.0	0.0
7 Nov	296.0	3	0.0	100.0	0.0	0.0	0.0	0.0	0.0

Appendix E. 1997 Pettit Lake squawfish stomach content analysis.

Mean percent dry weight.

Date	$\bar{x}$Lt.(mm)	n	Cp	Un	Od	Ot	Sa	Ch.P	Pm
25 Jun	154.0	1	97.3	0.0	0.0	2.7	0.0	0.0	0.0
16 Jul	202.5	2	96.7	0.0	0.0	0.0	0.0	0.0	3.3

Appendix F. Alturas Lake stomach content analysis, 23 July 1997.

Mean percent dry weight.

Species	$\bar{x}$Lt.(mm)	n	Un	Sa	Ml	Od	Co	T.Ins	Pm
Rainbow	273.5	4	47.8	2.2	50.0	0.0	0.0	0.0	0.0
Bull trout	267.8	3	20.0	51.0	9.1	0.0	0.0	0.0	0.0
Squawfish	266.8	9	0.0	74.0	1.1	25.0	0.0	0.0	0.0

KEY

Cp: Cyprinidae	Ml: Molluscs	Od: Odonata
Tr: Trichoptera	Co: Coleoptera	He: Hemiptera
Ch.P: Chironomid Pupae	Di: Diptera	T.Ins: Terrestrial Insects
Pm: Plant Matter	Sa: Salmonid	Un: Unidentified Fish
Ot: Other	Da: *Daphnia*	Ho: *Holopedium*
Bo: *Bosmina*	Po: *Polyphemus*	Ca: Calanoids
Cycl: Cyclopoids	Ch.P: Chironomid Pupae	Ch.L: Chironomid Larvae
T.Ins: Terrestrial insects		

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CHAPTER 2: LIMNOLOGY OF THE SAWTOOTH VALLEY LAKES, 1997.

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INTRODUCTION

In December 1991, the National Marine Fisheries Service listed Snake River sockeye salmon (*O. nerka*) as endangered under the Endangered Species Act (Waples et al. 1991). As a result, the Sawtooth Valley Project was initiated to conserve and rebuild sockeye salmon populations in the Sawtooth Valley lakes (Redfish, Pettit, Alturas, and Stanley lakes). The recovery strategy involved increasing the number of juveniles recruiting into the nursery lakes using hatchery broodstocks (Johnson and Pravecek 1995, Flagg and McAuley 1994), and improving growth and survival of juvenile sockeye salmon by increasing lake carrying capacities via lake fertilization (Stockner and MacIsaak 1996).

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

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

METHODS

Lakes were sampled from January to November 1997. Redfish, Pettit, and Alturas lakes were sampled once per month in January, March, May, October, and November and twice a month from June through September. In 1997, these three lakes were stocked with juvenile sockeye salmon from the Redfish Lake captive broodstock and were enriched with liquid fertilizer. Stanley Lake was not stocked with sockeye salmon and did not receive nutrient applications. Stanley Lake was sampled once in May, June, August, September, and October to help distinguish the effects of natural annual variation versus fertilization treatments. Utah State University, contracted by the Shoshone-Bannock Tribe, studied these lakes extensively from 1991 to 1995. Data collected, compiled, and reported by USU have been used throughout this project (Spaulding 1993, Teuscher et al. 1994, Teuscher et al. 1995, Teuscher and Taki 1996). Water for nutrient analysis, chlorophyll *a*, and phytoplankton was collected from the epilimnion, metalimnion and hypolimnion during stratification. Three discrete samples were collected from each stratum with a three L Van Dorn bottle and mixed in a churn splitter. When lake strata could not be delineated, surface water was collected from 0-6 m with a 25 mm diameter, 6 m long lexan® tube and discrete samples were collected from mid-depth (Redfish = 45 m, Pettit and Alturas = 25 m, and Stanley = 12 m) and 1-2 meters above the bottom.

Lake Fertilization

In 1997, the Shoshone-Bannock Tribes, operating under a consent order issued by the Idaho Division of Environmental Quality (DEQ), added supplemental nutrients to Redfish, Pettit, and Alturas lakes. The consent order requires measurement of water transparency once per week and estimates of epilimnetic and metalimnetic chlorophyll *a* and nutrient concentrations every two weeks. The consent order specifies that nutrient enhancement activities may continue so long as these parameters remain within defined limits. Limits include; water transparency greater than 8, 6 and 4 m in Redfish, Pettit and Alturas lakes until July 15 and greater than 8 m after July 15 in all three lakes. Epilimnetic chlorophyll *a* less than 3 *u*g/l, metalimnetic *chlorophyll a* less than 6 *u*g/l, and total phosphorus concentrations less than 15 *u*g/l in the epilimnion and metalimnion of all three lakes.

Liquid ammonium phosphate (20-5-0) and ammonium nitrate (28-0-0-0) fertilizer was applied weekly from June 10 to September 23. Stockner (1997) developed fertilization prescriptions for each lake. Nutrients were applied at a ratio of approximately 20:1 N:P by mass (45:1 molar) and were purposely skewed toward high nitrogen loads to avoid stimulation of nitrogen fixing Cyanophytes. The quantity of nutrients applied each week was variable, intended to simulate the natural hydrograph. Thus, initial applications were relatively small, rapidly increased to a peak in mid-July, and then gradually declined until September. The applications were made from a 5.5 m boat equipped with a portable plastic tank and electric pump. The fertilizer was loaded into the tanks off-site then pumped into the boat's wake while traveling over the surface of the lake. Twenty predetermined transect lines were followed at Redfish Lake, 12 at Alturas Lake and 8 at Pettit Lake, using GPS, compass, and local landmarks to evenly disperse the nutrients over the surface of the lake.

Profile Data

Temperature (ºC), dissolved oxygen (mg/l), and conductivity (*u*S/cm) profiles were collected at the main station of each lake using a Hydrolab® Surveyor3™ equipped with a Hydrolab H20® submersible data transmitter or a Yellow Springs Instrument Model 58 dissolved oxygen meter. The instrument was calibrated each day prior to sampling. Dissolved oxygen was calibrated using barometric pressure estimated from elevation. Standards obtained from the Myron L Company were used to calibrate conductivity. Temperature, dissolved oxygen and conductivity were recorded at one-meter intervals from the surface to 10 m, one to two meter intervals from 10 m to the thermocline, then at 2-10 m intervals to the bottom. Mean water temperatures from 0-10 m were used to calculate seasonal mean (May-October) surface water temperatures.

Water transparency and light penetration

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

Light attenuation was measured at the main station of each lake with a LiCorr® Li-1000 data logger equipped with a Li-190SA quantum sensor deck cell and a LI-193SA spherical sea cell. Photosynthetically active radiation (400-700 nm) was measured at two-meter intervals from surface to 2-4 m below the 1% light level. Deck and sea cell readings were made simultaneously to correct for changes in ambient light. Depth of the 1% light level was determined by linear regression of the natural log of percent surface light at each depth versus depth (Wetzel and Likens 1991).

Water chemistry

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

Chlorophyll *a* and phytoplankton

Water was collected for chlorophyll *a* each sample period and for phytoplankton once per month from June through October from the epilimnion, metalimnion, and the 1% light level. Water samples were stored at 4°C in the field, then filtered onto 0.45 um cellulose acetate membrane filters with 130 mm Hg vacuum pressure. Filters were placed in centrifuge tubes and frozen (-25°C). The filters were then placed in methanol for 12-24 hours to extract the chlorophyll pigments. Florescence was measured with a Turner model 10-AU fluorometer calibrated with chlorophyll standards obtained from Sigma Chemical Company. Samples were run before and after acidification to correct for phaeophytin. (Holm-Hansen and Rieman 1978). Phytoplankton samples were fixed in Lugol's solution and shipped to Eco-Logic, Inc for identification and analysis. Phytoplankton was identified to species using an inverted fluorescent microscope and abundance, biovolume, and carbon content were determined (Stockner 1998).

Primary Productivity

Primary productivity estimates were obtained on 3-6 September and 17-20 October 1997 at two stations in Redfish Lake and one station each in Pettit, Alturas and Stanley lakes. State of Washington Water Research Center personnel trained in the handling of radioisotopes estimated primary productivity. Primary productivity was evaluated within the photic zone, which was delineated by the depth of the 1% light level. Discrete primary productivity estimates were made at eight depths that were determined from light attenuation data. Field and laboratory procedures used to make discrete productivity estimates are summarized in Wierenga et al. (1998). Discrete primary productivity (mg C/m^3/hour) estimates were plotted and integrated using plainimetry to determine hourly rates of primary productivity based on surface area (mg C/m^2/hour). Hourly productivity estimates were expanded to daily productivity (mg C/m^2/hour) using solar irradiance data and the methodology described by Vollenweider (1965) and Britton and Greeson (1987). Wierenga et al. (1998) provides a complete description of methods used to determine primary productivity in 1997.

Zooplankton

Zooplankton was sampled one to two times per month. Vertical hauls were made with a 0.35 diameter, 1.58 m long, 80 um mesh conical net, with a removable bucket. The net was equipped with a release mechanism that allowed sampling at discrete depth intervals. A General Oceanics flow meter modified with an anti-reverse bearing was mounted in the mouth of the net. The flow meter was used to correct for net efficiency (clogging). The net was retrieved by hand at a rate of one meter per second from 10-0 m, 30-10 m, 60-30 m and 2 m above bottom to 60 m at the deep station in Redfish Lake. The shallow stations in Redfish and all stations in Pettit and Alturas lakes were sampled from 10-0 m, 30-10 m, bottom-30 m. Stanley Lake was sampled at 10-0 m and bottom to 10 m. Samples were preserved in 10% buffered sugar formalin. Techniques used to subsample, count, and measure zooplankton were adopted from Utah State University (Steinhart et al. 1994) using techniques and length-weight relationships developed by McCauley (1984) and Koenings et al. (1987).

RESULTS

In 1997, above average snowpack resulted in the second highest mean annual discharge observed for the Salmon River at Salmon, Idaho (USGS gage 13302500) since record keeping began in 1913 and the highest mean annual discharge since limnological investigations began in 1991. Mean annual discharge was 86.3 m^3/s, 156% above the average mean annual discharge of 55.4 m^3/s (Figure 1). Mean seasonal air temperatures at Stanley, Idaho for May through October 1997 was 10.0 ^oC, slightly higher than the 33 year average of 9.5 ^oC (Figure 2).

Lake Fertilization

In 1997, Redfish Lake was fertilized with 190 kg total phosphorus (TP) and 3695 kg total nitrogen (TN) (Figure 3). This was the third consecutive year nutrients were added to Redfish Lake. Applications in 1997 were 27% less than those in 1995 and nearly four times the 1996 additions (Table 3). Pettit and Alturas lakes were fertilized for the first time in 1997. Pettit Lake was fertilized with 31.6 kg TP and 632 kg TN and Alturas Lake was supplemented with 63.5 kg TP and 1339 kg TN. Areal loading rates were 30.9,19.5, and 18.8 mg TP m2 for Redfish, Pettit and Alturas lakes, respectively. Total nutrient additions for Pettit and Alturas lakes, based on lake surface area, were approximately 62% of applications to Redfish Lake in 1997. TN:TP ratios were 19.4, 20.0, and 21.1 in Redfish, Pettit and Alturas lakes, respectively. During 1997, we remained in full compliance with DEQ water quality limits and nutrient enhancement activities were uninterrupted.

<u>Profile Data</u>

The Sawtooth Valley lakes were inversely stratified and ice covered from December 1996 to May 1997. The study lakes opened between 7 and 14 May and were weakly stratified by the time they were sampled in late May (Figure 4).

Thermoclines were well developed from July through late October. By November, the lakes were nearly isothermic. Dissolved oxygen concentrations in the Sawtooth lakes were generally greater than 5 mg/l, the minimum level that will support good growth and survival of salmonids (Lagler 1956). Alturas Lake maintained dissolved oxygen concentrations above 5 mg/l throughout the water column the entire year. Redfish and Stanley lakes developed slight oxygen deficits (< 5 mg/l) in August or September in the bottom two meters. Dissolved oxygen levels in Pettit Lake were less than 5 mg/l at depths below 30 m throughout the year, an indication that Pettit Lake did not mix completely in 1997. Decomposition of precipitated organic matter expanded the region of low dissolved oxygen (<5 mg/l) from 35 m to bottom in 1995 and 1996 to approximately 30m to bottom in 1997 (Luecke et al. 1996, Griswold 1997). The region below 30 m represents 26% of the total lake volume. Conductivities were approximately 16-21 *u*S/cm above 30 m depth and 21-35 *u*S/cm at depths greater than 30 m in Pettit, 21-26 *u*S/cm in Redfish, 40-45 *u*S/cm in Alturas and 25-40 uS/cm in Stanley lakes. Conductivities were relatively consistent throughout the year and were similar to those reported by Luecke et al. (1996) and Griswold (1997). Seasonal mean epilimnetic water temperatures were 11.4, 11.5, 10.5, and 10.7 ºC in Redfish, Pettit, Alturas, and Stanley lakes, respectively. Seasonal mean surface water temperatures were less than the 6 year average, possibly a result of increased snowpack and the resultant increase in discharge (Table 4). However estimates may be biased since surface water temperatures were calculated from simple means during 1992-1995 which may have over-estimated mean seasonal values because sampling was more frequent during summer when water temperatures were highest.

Water transparency and light penetration

Water transparencies followed similar patterns as observed in the past (Budy et al.1996, Griswold 1997). Transparencies were lowest during January and February when lakes were ice covered and in June after spring mixing stimulated phytoplankton production (Figure 5). Transparencies in all lakes increased throughout the summer and fall until the lakes mixed in the fall. Seasonal mean water transparencies (May-October) were 11.3 and 10.9 in Redfish and Pettit, respectively, the shallowest observed since the project began in 1992. Water transparencies in Redfish and Pettit lakes were approximately 2 meters less than the six-year average (Table 4). Alturas Lake was 1.5 m less than the six year average of 11.7. Transparencies in Alturas Lake were similar to those observed in 1996 and deeper than the seasonal mean in 1995. The seasonal mean water transparency in Stanley Lake was 7.0 m, similar to the 6 year average and shallower than in 1995. The lakes showed similar ranking to past years with Redfish Lake having the deepest water transparency, followed by Pettit, Alturas, and Stanley lakes.

Depth of the 1% light level (photic zone) in 1997 was lowest during January and February when lakes were ice covered and during June. Photic zone depth increased gradually from June until September when light penetration was highest (Figure 6). Seasonal mean (May-October) photic zone depths were shallower than previously observed in the Sawtooth lakes. The mean seasonal photic zone depth (and percent of the six year average) was 20.0 m (75%) in Redfish, 19.0 m (78%) in Pettit, 15.5 m (78%) in Alturas and 12.2 m (86%) in Stanley Lake (Table 4). Redfish Lake had the deepest photic zone followed by Pettit, Alturas, and Stanley, consistent with the past six years rankings.

Water chemistry

In 1997, total phosphorus (TP) concentrations during spring turnover were highest in Alturas Lake (10 *u*g/l), followed by Stanley Lake (7.2 *u*g/l), Redfish Lake (6.0 *u*g/l) and Pettit Lake (5.5 *u*g/l). These concentrations and relative ranking are similar to those observed during previous years (Table 5).

Nitrate concentrations just after spring turnover ranged from 10-17 *u*g/l and the ranking from highest to lowest was Redfish, Pettit, Alturas, and Stanley. Nitrate concentrations during spring turnover were higher than previously observed in all four lakes, and the three lakes that received supplemental nutrients were proportionately higher than unfertilized Stanley Lake. Spring TP and nitrate values were calculated as the mean of all depths sampled during May, values were not depth weighted which may bias estimates.

Nutrient concentrations in surface waters of the Sawtooth Valley lakes remained low in 1997, even during lake fertilization. Total phosphorus concentrations ranged from 4-8 *u*g/l in Redfish, 4-9 *u*g/l in Pettit, 5-13 *u*g/l in Alturas and 4-7 *u*g/l in Stanley Lake (Figure 7). Total phosphorus concentrations were below average in all four lakes except during July and August when concentrations in Redfish, Pettit and Alturas lakes exhibited peaks of 8 *u*g/l, 9 *u*g/l, and 13 *u*g/l, respectively. Unfertilized Stanley Lake did not exhibit this mid-summer peak.

Total nitrogen concentrations in surface waters were relatively stable during 1997. TN concentrations ranged from 52-97 *u*g/l in Redfish, Pettit and Alturas lakes and from 40-70 *u*g/l in Stanley Lake. Mean seasonal TN was lower than observed in previous years except in Redfish and Pettit lakes (Table 6). The three lakes, which received supplemental nutrients in 1997, had higher TP and TN concentrations than unfertilized Stanley Lake except for Alturas Lake, which had a relatively low TN concentration.

Soluble nutrients were at or below pre-fertilization levels (Redfish 1992-1994, Pettit and Alturas 1992-1996), except for nitrate concentrations in Redfish Lake which were 5-13 *u*g/l during May through August. Nitrate levels in Redfish during this time were higher than previously observed except during 1992 and were higher than values observed in the other lakes during 1997 (Figure 8). Nitrate concentrations in Alturas and Stanley lakes were slightly elevated after mixing in May, compared to previous years, then dropped below the method detection level (MDL) of 2 *u*g/l in June. Nitrate concentrations in Alturas and Pettit lakes rose to approximately 4 *u*g/l by mid-summer then fell below the MDL for the remainder of the growing season. Nitrate concentrations in Pettit Lake did not rise above MDL after spring mixing perhaps a result of incomplete mixing.

Ammonia concentrations in the four Sawtooth lakes were low in 1997, compared to previous years (Figure 8). Ammonia was sampled once during June, August, September, and October and remained at or below the method detection level of 3 *u*g/l, except during August when ammonia concentrations rose to 6 *u*g/l in Redfish and Stanley lakes. In Pettit lake ammonia concentrations were 3.5 *u*g/l, slightly above MDL during September. Ammonia concentrations remained below MDL in Alturas Lake during all months sampled.

Orthophosphorus was only sampled late in the growing season (August -October) because concentrations reported in past years have generally been below detection levels. Orthophosphorus concentrations remained below detection levels in all four lakes during 1997.

<u>Chlorophyll *a* and phytoplankton</u>

In 1997, surface chlorophyll *a* concentrations ranged from 0.6 to 2.5 *u*g/l in the four Sawtooth Valley lakes. Chlorophyll *a* concentrations under ice peaked at 1.7 and 2.5 *u*g/l during January in Redfish and Pettit lakes, respectively (Figure 9). Alturas and Stanley lakes were not sampled in January. During the ice-free season surface chlorophyll *a* concentrations peaked during May and June in Pettit, Alturas, and Stanley lakes and during September in Redfish Lake. Peak chlorophyll *a* concentrations were 2.5 *u*g/l in Alturas Lake, 2.4 *u*g/l in Redfish Lake and 1.9 *u*g/l in Pettit and Stanley lakes. Seasonal mean chlorophyll *a* concentrations were higher than previously observed in any of the Sawtooth lakes (Table 4). Prior to lake fertilization (1992-1994), the seasonal mean chlorophyll *a* concentration in Redfish Lake surface water was 0.5 *u*g/l. During lake fertilization (1995-97) seasonal mean chlorophyll *a* was 1.0 *u*g/l, a 100% increase. During the same time period in Stanley lake, chlorophyll *a* concentrations increased from 0.9 to 1.1 *u*g/l, a 22% increase. In Pettit and Alturas lakes, chlorophyll *a* concentrations increased from a pre-fertilized (1992-96) average of 0.5 and 0.6 *u*g/l, respectively to 1.4 and 1.7 *u*g/l. in 1997. During the same time periods Stanley Lake increased from 0.9 and 1.3 *u*g/l chlorophyll *a*. The relative increases in chlorophyll *a* concentrations for Pettit, Alturas, and Stanley lakes under fertilization were 180%, 143%, and 44%, respectively.

Chlorophyll a concentrations at the 1% light level were highest in Redfish Lake, especially during late June when chlorophyll *a* peaked at 9.4 *u*g/l (Figure 10). Redfish Lake remained high relative to the other lakes until late September. Pettit and Alturas lakes peaked during early June when chlorophyll *a* at the 1% light level was 5.4 and 3.3 *u*g/l. By August, chlorophyll *a* concentrations in Pettit and Alturas lakes were approximately 2 *u*g/l where they remained through October. Chlorophyll *a* concentration at the 1% light level in Stanley Lake was similar to that observed in Pettit Lake during June then dropped below 2 *u*g/l in August.

Chryso- and Cryptophycean nano-flagellates and autotrophic picoplankton (Cyanophceae) dominated phytoplankton communities in the Sawtooth Valley lakes during 1997. Total phytoplankton densities ranged from 1,855 to 10,677 cells/ml and total phytoplankton biovolume ranged from 0.07 to 0.76 mm^3/l in the four lakes. Chryso- and Cryptophycean nano-flagellates and Dinophycean dinoflagellates generally had the highest biovolume of any phytoplankton taxa and the small (<2 *u*m) Cyanophyte Scenechococcus was numerically dominant. Phytoplankton populations were generally stable but followed a pattern of highest abundance during June or July and declined slowly until October. The phytoplankton communities were dominated by small grazable taxa (Stockner 1998).

In the epilimnion of Redfish Lake, total phytoplankton densities ranged from 2200-6000 cells/ml (Figure 11). The small Cyanophyte Scenechococcus (<2 *u*m) was numerically dominant, followed by nano-flagellates. During 1997, total biovolume in the epilimnion was 0.08 to 0.21 mm^3/l, well below the estimates obtained in 1995 when epilimnetic biovolume ranged from approximately 0.25 to 0.8 mm^3/l (Luecke et al. 1996). Species composition of epilimnetic biovolume was similar between 1997 and 1995, with biovolume fairly evenly split between taxa.

In the metalimnion, total phytoplankton densities ranged from 1583 to 5391 cells/ml (Figure 11). Chryso- and Cryptophycean nano-flagellates were the most abundant taxa in the metalimnion, particularly when nano-flagellates peaked during July. Total phytoplankton biovolume reached 0.76 mm^3/l during the July peak, the highest biovolume observed in any of the lakes during 1997 and higher than the depth stratified estimates obtained in July 1995 (approximately 0.55 mm^3/l). However, total phytoplankton biovolume reached similar levels (approximately 0.8 mm^3/l) during August 1995 (Luecke et al. 1996).

The Bacillariophytes (diatoms) Cyclotella stelligera, Melosira sp. and Rhizosolenia sp. were fairly common in the metalimnion, particularly during the early part of the growing season, less so in the epilimnion.

In Pettit Lake, total phytoplankton densities in the epilimnion were between 2634 and 5891 cells/ml (Figure 12). Phytoplankton density peaked in June and again in September, both resulting from increases of the Chryso- and Cryptophycean nano-flagellates and the Cyanophyte Scenechococcus. Phytoplankton density and biovolume in the epilimnion was similar to Redfish Lake, except the summer peak occurred earlier and nano-flagellates were more abundant during June and July. In the metalimnion, phytoplankton densities were relatively low and stable from June through August then rose to over 10,000 cells/ml during a September Scenechococcus bloom (Figure 12). Bacillariophytes were common during early summer and consisted of Cyclotella stelligera and Rhizosolenia sp. The Dinophyceans Peridinium sp. and Gymnodinium sp. were less common but because of their relatively large size made up a large proportion of total biomass.

Alturas Lake phytoplankton populations obtained maximum abundance and biovolume during July, similar to Redfish Lake. In the epilimnion total phytoplankton densities were between 1855 and 5189 cells/m (Figure 13). The Cyanophyte Scenechococcus, Chryso-Cryptophycean nano-flagellates and Bacillariophytes were numerically dominant. Epilimnetic biovolume ranged from 0.08 to 0.26 mm^3/l. During the early summer biovolume was predominately the large diatoms, Asterionella formosa and Cyclotella sp. After August, biovolume was evenly split between Chryso- and Cryptophycean nano-flagellates, the dinoflagellates Peridinium sp. and Gymnodinium sp. and the diatoms Asterionella formosa and Cyclotella sp. Species assemblages were similar in the metalimnion. Metalimnetic densities ranged from 3167 to 9200 cells/ml and biovolume was 0.11 to 0.48 mm^3/l. Bacillariophytes were more abundant in Alturas Lake relative to the other Sawtooth Valley lakes in 1997 and during July 1995 (Luecke et al. 1996).

Stanley Lake phytoplankton populations were sampled less frequently than the other Sawtooth Valley lakes during 1997. During August through October total phytoplankton density was approximately 3000-4000 cells/ml and was dominated by the Cyanophyte Scenechococcus and the Chryso-Cryptophycean nano-flagellates in both the epilimnion and metalimnion (Figure 14). Total biovolume was approximately 0.1 mm^3/l in both strata. Chryso- and Cryptophycean nano-flagellates had the highest biovolume in the epilimnion and metalimnion although biovolume was fairly evenly split between the taxonomic groups.

Primary productivity

In 1997 the State of Washington Water Research Center at Washington State University (WRC) was contracted to estimate primary productivity in the Sawtooth Valley lakes. Analytical techniques used for primary productivity determinations were similar to those used by USU but slight differences in the data analysis raised concerns about the comparability of the estimates. In 1999, the USU data sets were re-analyzed to minimized differences between the two data sets and improve our ability to interpret trends in productivity in the Sawtooth

Valley lakes (Wierenga 1999).

USU integrated discrete productivity estimates to a nominal photic zone depth (30-35 m for Redfish, Pettit, and Alturas lakes and 20-25 m for Stanley Lake). The WRC estimated primary productivity within the photic zone using actual photic zone depths obtained in the field. Carbon uptake by phytoplankton is known to occur below the 1% light level, but the standard methodology generally measures carbon uptake within the euphotic zone as defined by the 1% light level (APHA 1995). Although the two methods provided similar results, nominal depths were deeper than the actual euphotic zone depth, which included production below the 1% light level at some sites/dates (Wurtsbaugh and Budy 1997). As a result, some estimates of integrated daily productivity within the photic zone were elevated because carbon uptake below the photic zone was included (Wierenga 1999). Revised primary productivity estimates are shown in Table 7.

Depth integrated hourly and daily primary productivity was higher in all four lakes during the latter part of the 1997 growing season compared to previous years (Table 7)(Wierenga et al. 1998). Productivity was higher in September than in October in all four lakes. In 1997, hourly productivity (mg C/m^2/hour) in Pettit Lake was approximately 74% of the mean level found in Redfish Lake. Hourly productivity estimates in Alturas Lake and Stanley lakes were about 60% and 64% of Redfish Lake productivity, respectively. These relationships are similar to those found in 1996, when the productivity estimates in Pettit and Alturas lakes were 70% and 60% of the mean found in Redfish Lake (Wurtsbaugh and Budy, 1997).

Mean daily productivity in 1997 was higher in both fertilized and unfertilized lakes relative to data from 1993, 1995 and 1996 (Figure 15) (Steinhart et al. 1994, Luecke et al. 1996, Wurtsbaugh and Budy, 1997). Daily productivity in Redfish Lake increased approximately 86% relative to previous years, Pettit Lake increased nearly 73%, while Alturas and Stanley lakes were 16% and 50% above the 1993-1996 average. In 1997, sampling was conducted late in the growing season when productivity is typically high. As a result, primary productivity estimates for 1997 may overestimate productivity over the entire growing season. Furthermore, the 50% increase in productivity in Stanley Lake was based on a small data set (n=5) available from 1993-1996. In Alturas Lake the relative increase in daily productivity could have been underestimated, because of the relatively high value obtained in 1993 which was based on a single data point.

Zooplankton

Annual zooplankton biomass maximums occurred during late August in Stanley Lake and during early September in Redfish and Alturas lakes and coincided with daphnia biomass peaks. Pettit Lake biomass peaked in late July, coinciding with peak in Holopedium biomass.

Redfish Lake zooplankton species composition and biomass remained stable in 1997. Species composition was similar to that observed in 1996 with the summer/fall community dominated by Holopedium, Daphnia and Bosmina, (Figure 16). During early summer, biomass was almost exclusively Holopedium. Daphnia biomass peaked in early September 1997 at approximately 11 *u*g/l, similar to peak Daphnia biomass observed in 1994 and 1996, and well below the 20 *u*g/l peak observed in 1995. During this peak, Daphnia density was approximately 2 per liter, similar to 1994 and 1996. During January 1997, biomass was predominately Bosmina, with approximately 0.5 *u*g/l each of Daphnia and Cyclopoid copepods. During the March and May, total zooplankton biomass was extremely low, 0.7 and 0.9 *u*g/l, respectively and was dominated by Cyclopoid copepods.

Pettit Lake zooplankton biomass remained depressed compared to 1993 and 1994, when biomass reached 40-50 *u*g/l (Figure 17). More importantly, species composition was dominated by the small cladocerans Bosmina and Holopedium, a major shift from 1994 when Daphnia and Cyclopoid copepods were abundant. Pettit Lake biomass peaked in late July with approximately 25 *u*g/l total biomass, coinciding with a peak in Holopedium biomass. Daphnia reached a maximum biomass of only 0.3 *u*g/l (density 0.05/l) during late September and October 1997. During January 1997, total zooplankton biomass was 3.4 *u*g/l and was predominately Bosmina and Cyclopoid copepods, similar to winter 1994-1995. In

March and May 1997, total biomass declined to approximately 1.5 *u*g/l and was comprised of Holopedium, Bosmina, and Cyclopoid copepods. This represents the lowest winter biomass observed in Pettit Lake since winter sampling began in 1993-1994.

Alturas Lake zooplankton populations appear to be recovering after experiencing a collapse in the early 1990's. In 1997, summer zooplankton populations consisted of Daphnia and Bosmina. Total biomass reached 40 *u*g/l in early September, the highest biomass observed since monitoring began in 1992. Prior to 1996, the zooplankton community was almost exclusively Bosmina; during the summers of 1996 and 1997 Daphnia biomass reached 12 and 30 *u*g/l, respectively (Figure 18). Total zooplankton biomass during the winter was also the highest observed to date in Alturas lake and was mostly Cyclopoid copepods.

Stanley Lake zooplankton populations were stable in 1997. The peak zooplankton biomass of 50 *u*g/l was the highest observed in any of the Sawtooth Valley Lake in 1997. During summer 1997, zooplankton species composition was similar to that observed in 1995 and 1996, with most biomass represented by Daphnia, Holopedium and Calanoid copepods (Figure 19). The summer peak occurred in August, coincident with seasonal peaks of all three taxa (Daphnia 23 *u*g/l, Holopedium 17 *u*g/l, and Calanoid copepods 9 *u*g/l). Zooplankton was not sampled during winter 1996-1997 in Stanley Lake.

DISCUSSION

Supplemental nutrients were added to Redfish, Pettit, and Alturas lakes to increase primary productivity and thereby increase secondary productivity within the lakes. Nutrient supplementation was initiated in Redfish Lake in 1995 because anticipated stocking of endangered sockeye salmon combined with the existing population of kokanee salmon were expected to exceed the lakes carrying capacity. Trawl and hydroacoustic estimates of *O. nerka* populations in Alturas and Pettit lakes have shown large fluctuations in fish abundance and/or biomass (Teuscher and Taki 1996, Taki and Mikkelsen 1997). During peaks in *O.*

nerka population cycles, intense grazing pressure on macrozooplankton caused shifts in species composition and declines in zooplankton biomass, density, and size. In Alturas Lake, the zooplankton communities remained depressed for over 5 years following a collapse. Pettit Lake zooplankton communities collapsed in 1995 and remain depressed at this time (May 1999). To reduce the risk of overgrazing the zooplankton populations in Redfish Lake, a nutrient supplementation program was initiated in 1995. Modest nutrient additions were used to help support the very few sockeye salmon stocked into Redfish Lake, during 1996. In 1997, Redfish Lake was fertilized aggressively and Pettit and Alturas lakes received nutrient supplementation for the first time.

Identifying impacts from the lake fertilization program has been confounded by changes in meteorological conditions in the basin. Prior to fertilization of Redfish Lake, snowpack and subsequent discharge in the watershed was at or below normal. Since fertilization began in 1995 snowpack and discharge has been above average in the basin. Gross (1995) modeled nutrient loading into Redfish Lake during the record low water year of 1992 and during the normal water year of 1993 and found a positive correlation between discharge and nutrient loading. Assuming this relationship also applies to Stanley Lake, changes in water transparency, light penetration, chlorophyll *a* concentrations and primary productivity would be expected. The data set from Stanley Lake, which has not received nutrient supplementation and has a stable *O. nerka* population, supports this idea. Comparisons of seasonal averages from the 1992-1994 data set compared with the 1995-1997 data set show a 19 % reduction in water transparency, 28% decline in light penetration, 32% increase in surface chlorophyll *a* and a 26% increase in mean daily primary productivity.

Comparison of pre- (1991-1994) and post (1995-1997) fertilization seasonal means in Redfish Lake show smaller reductions in water transparency and light penetration and larger increases in surface chlorophyll *a* and primary productivity than occurred during the same time periods in Stanley Lake. Mean seasonal surface water transparency declined by 11%, light penetration decreased by 21%, surface chlorophyll *a* increased by 67% and mean daily primary productivity increased by 149%. Disproportionately larger shifts in Redfish Lake chlorophyll *a* and primary productivity relative to observed changes in Stanley Lake provide evidence that nutrient supplementation stimulated primary productivity in Redfish Lake. The relatively large decrease in water transparency and light penetration observed in Stanley Lake may be caused by suspended abiotic particles resulting from the interaction between discharge and the different drainage: lake surface area relationships of the lakes. In Stanley lake water transparency was inversely correlated with discharge (R^2= -0.57) but not chlorophyll *a* (R^2= -0.03). In Redfish Lake, water transparency was closely correlated with discharge (R^2= -0.92) and less so with chlorophyll *a* (R^2= -0.47).

Pettit and Alturas lakes were fertilized for the first time in 1997. Similar difficulties were encountered in assessing the impacts of nutrient additions since 1997 was the second highest water year since record keeping began in 1913. Given this level of discharge in the basin high natural nutrient loading was expected and the utility of using pre/post data sets to evaluate the treatments was reduced. Comparison with the Stanley Lake data set for the pre-fertilized years (1991-1996) with the fertilized year of 1997 provides evidence that lake fertilization was effective. Mean seasonal surface water transparency declined by 19% in Pettit Lake, 18% in Alturas Lake and 3% in Stanley Lake. Depth of the 1% light level declined by 25% in Pettit Lake, 26% in Alturas Lake and 17% in Stanley Lake. Mean seasonal surface chlorophyll *a* increased by 149% in Pettit, 69% in Alturas, and 39% in Stanley Lake. Primary productivity increased 93% in Pettit Lake, 35% in Alturas Lake, and 48% in Stanley Lake. Again, disproportionate increases in surface chlorophyll *a* and primary productivity in Pettit Lake and surface chlorophyll *a* in Alturas Lake compared to Stanley Lake supports the idea that nutrient supplementation was effective. As expected, relative increases in primary productivity in Pettit and Alturas lakes were less than those observed in Redfish Lake. Nutrient applications were approximately 63 and 61% of the applications of Redfish Lake on an areal basis (mg P/m2). In addition, primary productivity in Alturas Lake during 1993 was based on a single estimate. This estimate of 193.8 mg C/m2/day was high relative to the other lakes, which may underestimate the relative increase in primary productivity under fertilization. If the single 1993 estimate is excluded the average primary productivity becomes 101.6 mg C/m2/day during 1995-1996 in Alturas Lake and primary productivity increases by 76% under fertilization.

Numerous studies have reported effects of nutrient additions by sampling before, during and after fertilization treatments. However, these studies may be subject to misinterpretation if annual variation caused by meteorological forcing or other impacts was not accounted for (Schindler 1987). Because drought conditions existed during the early years of this study and high water years have been the norm since lake fertilization began, Stanley Lake has been loosely used as a "control". However, Stanley Lake should be considered only a gross indicator of variable conditions since the Lake is morphologically dissimilar to the Redfish, Pettit, and Alturas lakes. Stanley Lake has a drainage area 47 times the size of the lake compared to ratios of 17.6, 16.9 and 22.4 for Redfish, Pettit, and Alturas lakes, respectively. This results in a much shorter water retention time and higher nutrient loading (Gross 1995). However, the short retention time could also cause in a higher degree of "washout" of nutrients, phytoplankton, resting stages, and eggs compared to the other Sawtooth Valley lakes, especially during high water years (Goldman et al. 1989). If Stanley Lake is more susceptible to washout, then nutrient supplementation impacts may be over-estimated in the other Sawtooth Valley lakes. Prior to 1995, Stanley Lake had shallower water transparency and photic zone depths, relatively high nutrient and surface chlorophyll *a* concentrations, and high primary productivity on a volumetric basis, compared to the pre-fertilized conditions in Redfish, Pettit, and Alturas lakes. Since the end of the drought and since fertilization has begun, Redfish, Pettit, and Alturas lakes have become more similar to Stanley Lake.

Cascading trophic interactions are known to influence primary productivity of lakes (Carpenter et al. 1985, Carpenter and Kitchell 1987, Carpenter and Kitchell 1988). Although phytoplankton data for the Sawtooth Valley lakes are limited it appears phytoplankton species assemblages have remained stable under fertilization and are typically oligotrophic. Small grazable autotrophic picoplankton, nano-flagellates, and diatoms dominate phytoplankton species assemblages in the Sawtooth Valley lakes. The predominance of these phytoplankton and the absence of accumulations of non-grazable taxa (sinks) are indicators of efficient energy transfer between trophic levels, which should result in improved forage production for endangered sockeye salmon (Stockner and MacIsaac 1996, Stockner 1998). Some attempts to stimulate lake productivity with nutrient additions have been unsuccessful; energy sinks developed from inefficient trophic transfer which prevented energy flow to juvenile sockeye salmon (Stockner and Hyatt 1984, Stockner 1987, Stockner and Shortreed 1988). Phytoplankton sampling was limited in 1997, yet given the importance of identifying potential energy sinks, sampling should be increased in 1998 to help assess the efficiency of energy transfer from lower to higher trophic levels.

Potential benefits of the lake fertilization program to sockeye salmon include increased growth and survival and a reduced risk of exceeding lake carrying capacity and causing a collapse of the macrozooplankton population. The consequences of a collapsed forage base in Redfish lake were considered severe since Redfish lake represents 61% of the sockeye salmon rearing habitat in the Sawtooth Valley and recovery appears to take many years as evidenced by zooplankton data from Alturas Lake.

Several potential problems are associated with lake fertilization, including increased intra-specific competition and effects of lake eutrophication. Habitat use and foraging behavior of kokanee are similar to sockeye salmon (Rieman and Myers 1992) so potential benefits to sockeye salmon from fertilization may be offset by increases in growth, survival and fecundity of kokanee. A positive response by kokanee to lake fertilization could result in increased competition with sockeye salmon in future years. Managers should carefully weigh the short-term benefits of lake fertilization against the longer term adverse impacts of intra-specific competition.

Successful lake fertilization may increase precipitated organic matter resulting in larger oxygen deficits in deep waters. This is particularly important in Pettit Lake where *O. nerka* habitat is significantly reduced (26% by volume) by low oxygen concentrations below 30-35 m depth. Based on dissolved oxygen profiles it appears that Pettit Lake did not mix completely in 1996 or 1997. Whether Pettit Lake ever mixes completely is unknown. Macrozooplankton are capable of growth and reproduction at D.O. concentrations down to 1 mg/l (Pennack 1989). Zooplankton biomass below 30 m in Pettit Lake was relatively high (1.5-18.1 *u*g/l) during 1997, an indication that zooplankton standing crop was not significantly reduced by hypoxic conditions in the deep waters of Pettit Lake. If zooplankton vertically migrate out of this hypoxic region or if *O. nerka* make foraging excursions into the hypoxic region then effects on predator/pray balance in Pettit Lake will be minimized. Alternatively, this hypoxic region could provide a refuge for macrozooplankton and reduce foraging opportunities for *O. nerka*. An additional concern of this expanding hypoxic region concerns nutrient loading. In the future, if the lake does mix completely, regenerated nutrients, which have accumulated for years, will be released which could result in reduced water quality and shifts in phytoplankton species assemblages.

In 1997, our exhausted Hydrolab dissolved oxygen probe was replaced which shifted the calibration window slightly and precluded calibration at high altitude/ low barometric pressure. As a result dissolved oxygen profiles were not possible during every sample period. A resistor modification was performed by Hydrolab Corporation technicians during winter 1997-1998 which should prevent similar problems from occurring in future years. In 1998, dissolved oxygen will be monitored more frequently to determine if Pettit Lake mixes completely and if seasonal oxygen deficits are increasing in the other Sawtooth Valley lakes.

Increased snowpack and discharge into the Sawtooth Valley lakes during 1995-1997 was expected to increase nutrient loading into the lakes (Gross 1995). Cumulative effects of three years of nutrient supplementation directly affects lake nutrient load and should affect nutrient concentrations after spring mixing when nutrients are released from the sediments. During spring 1997, elevated nitrate concentrations were observed in all four of the Sawtooth lakes although Stanley Lake exhibited the smallest increase. This may be partly a result of nutrient supplementation, although spring nitrate concentrations began to rise in 1995 in Pettit and Alturas lakes before fertilization was initiated, concurrent with increased snowpack and discharge. Also, the relatively small increase in spring nitrate levels in Stanley Lake may be partly due to the relatively large drainage: lake surface area that would make Stanley Lake more susceptible to "washout" (Goldman et al. 1989). If spring nutrient levels continue to increase initiation of lake fertilization may need to be delayed to prevent violations in DEQ water quality criteria.

Macrozooplankton response to fertilization is variable but 1.2 to 2.0 fold increases in abundance and biomass have been observed (Stockner and MacIsaac 1996). In Pettit and Alturas Lakes, annual fluctuations of *O. nerka* standing crop estimates caused major shifts in zooplankton species assemblages. These changes have precluded evaluation of nutrient supplementation at the macrozooplankton level. However, in Redfish Lake it appears that macrozooplankton populations have been maintained at least in part by lake fertilization. Since 1995, *O. nerka* biomass estimates (2x trawl) in Redfish Lake have increased by over 300% and exceeded the Lake's unfertilized carrying capacity (Stockner 1997). During this time macrozooplankton biomass and sockeye salmon overwinter survival and size at out-migration has remained remarkably stable (Jay Pravecek, Doug Taki, personal communication).

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

Lake	Area (km2)	Volume (m3x106)	Elevation (m)	Mean Depth (m)	Maximum Depth (m)	Drainage Area (km2)	Area/lake surface area	Water residence time in years (Gross, 1993)
Redfish	6.15	269.9	1996	44	91	108.1	17.6	3.0
Pettit	1.62	45.0	2132	28	52	27.4	16.9	2.2
Alturas	3.38	108.2	2138	32	53	75.7	22.4	1.8
Stanley	0.81	10.4	1985	13	26	39.4	48.6	0.3

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

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

Table 3. Supplemental nutrient additions to Redfish, Pettit, and Alturas lakes, Idaho.

Lake	Year	P (kg)	N (kg)	mg P/m^2	mg N/m^2
Redfish	1995	261	4,623	42	752
	1996	51	934	8	152
	1997	190	3,695	31	601
Pettit	1995	0	0	0	0
	1996	0	0	0	0
	1997	32	632	20	390
Alturas	1995	0	0	0	0
	1996	0	0	0	0
	1997	64	1,339	19	396

Table 4. Seasonal mean (May - October) surface water temperature (oC), water transparency (m), depth of 1% light level (m), epilimnetic chlorophyll *a* (*u*g/l), and whole-lake total zooplankton biomass (*u*g/l).

Lake	Year	Surface temperature (°C) 0-10 m	Water transparency (m)	1% light level (m)	Epilimnetic chl *a* (*u*g/l)	Wholelake zooplankton biomass (*u*g/l)
Redfish	1992	14.4	13.6	32.5	0.5	4.7
Redfish	1993	12.2	13.6	26.3	0.7	6.9
Redfish	1994	14.0	15.0	31.0	0.4	11.3
Redfish	1995	12.9	12.3	28.4	0.4	11.7
Redfish	1996	11.0	13.7	22.6	0.8	7.8
Redfish	1997	11.4	11.3	20.0	1.5	8.2
mean		**12.7**	**13.3**	**26.8**	**0.7**	**8.4**
Pettit	1992	14.9	15.2	29.3	0.4	30.7
Pettit	1993	12.7	14.3	23.3	0.6	23.3
Pettit	1994	14.5	14.1	30.5	0.3	31.4
Pettit	1995	12.7	12.6	23.8	0.5	4.0
Pettit	1996	11.1	11.1	20.6	1.0	9.9
Pettit	1997	11.5	10.9	19.0	1.4	11.2
mean		**12.9**	**13.0**	**24.4**	**0.7**	**18.4**
Alturas	1992	14.3	13.5	26.2	0.6	4.7
Alturas	1993	11.8		20.6	1.0	0.5
Alturas	1994	13.4	14.7	23.5	0.5	3.2
Alturas	1995	12.0	9.6	17.6	0.4	2.7
Alturas	1996	10.4	10.3	16.1	1.1	5.2
Alturas	1997	10.5	10.2	15.5	1.2	11.0
mean		**12.1**	**11.7**	**19.9**	**0.8**	**4.5**
Stanley	1992	14.2	8.2	18.6	0.8	32.1
Stanley	1993	11.1	7.5	15.4	1.4	19.9
Stanley	1994	14.1	7.8	15.5	0.5	24.0
Stanley	1995	11.4	5.6	11.4	0.9	19.5
Stanley	1996	10.0	7.0	12.2	1.1	21.8
Stanley	1997	10.7	7.0	12.2	1.4	19.9
mean		**11.9**	**7.2**	**14.2**	**1.1**	**22.9**

Table 5. Nutrient concentrations (*u*g/l) and TN/TP ratio during May (after spring mixing) 1992-1997 in Redfish, Pettit, Alturas, and Stanley lakes, Idaho. Concentrations are simple means of three discrete depths.

Lake	Year	TP	TN	Nitrate	Ammonia	Orthophos	TN/TP
Redfish	1992	6.5	61.0	5.5		1.0	9.5
Redfish	1993	8.6	52.7	6.7			6.2
Redfish	1994	5.6					
Redfish	1995	5.0	74.2	3.8	2.0	1.0	14.8
Redfish	1996	4.8	77.0	12.7	2.3		16.1
Redfish	1997	6.0		17.0			
mean		**6.1**	**66.2**	**9.1**	**2.2**	**1.0**	**11.7**
Alturas	1992	10.0	74.0	2.0		2.8	7.4
Alturas	1993	9.4	72.5	3.3			8.2
Alturas	1994	13.9					
Alturas	1995	8.2	66.4	5.8	3.5	1.4	7.7
Alturas	1996	6.0	74.6	11.6	2.2		12.4
Alturas	1997	10.0		14.7			
mean		**9.6**	**71.9**	**7.5**	**2.9**	**2.1**	**8.9**
Pettit	1992	6.4	94.5	7.0		1.0	18.3
Pettit	1993	5.8	94.0	4.0			29.2
Pettit	1994	6.6					
Pettit	1995	4.8	88.8	12.0	3.5	1.0	18.4
Pettit	1996	5.3	64.3	13.0	7.1		11.6
Pettit	1997	5.5		16.5			
mean		**5.7**	**85.4**	**10.5**	**5.3**	**1.0**	**19.4**
Stanley	1992	10.5	93.5	5.0	4.0	1.0	8.9
Stanley	1993	11.4	129.8	8.5			12.7
Stanley	1994	11.3					
Stanley	1995	7.0	103.0	9.2	18.0	1.2	14.8
Stanley	1996	6.5					
Stanley	1997	7.2		9.7			
mean		**9.0**	**108.8**	**8.1**	**11.0**	**1.1**	**12.1**

Table 6. Seasonal mean (May - October) epilimnetic nutrient concentrations (*u*g/l) and TN/TP ratio in Redfish, Pettit, Alturas and Stanley lakes during 1992-1997.

Lake	Year	TP	TN	Nitrate	Ammonia	Orthophos	TN/TP
Redfish	1992	8.3	50.1	6.5		1.7	7
Redfish	1993	6.8	65.1	2.4	3.2	1.6	10
Redfish	1994	8.5				2.0	
Redfish	1995	7.1	85.5	3.7	6.4	1.7	15
Redfish	1996	4.9	48.1	1.9	1.3	0.9	11
Redfish	1997	5.6	67.0	5.8	3.5	0.0	16
mean		**7.0**	**63.5**	**4.2**	**4.0**	**1.3**	**11**
Pettit	1992	5.9	87.4	4.6		1.9	16
Pettit	1993	6.5	75.0	2.1	3.0	1.7	13
Pettit	1994	6.4				1.0	
Pettit	1995	5.5	82.4	1.0	3.3	1.4	16
Pettit	1996	5.8	40.6	0.6	1.3	0.9	8
Pettit	1997	5.4	71.6	2.0	2.6	0.0	18
mean		**6.0**	**74.6**	**2.2**	**2.7**	**1.3**	**15**
Alturas	1992	7.8	82.4	4.0		1.3	10
Alturas	1993	8.6	87.6	3.4	2.6	1.2	13
Alturas	1994	11.8				2.4	
Alturas	1995	8.4	109.8	2.2	7.0	1.8	15
Alturas	1996	7.8	61.7	2.1	1.7	1.0	9
Alturas	1997	8.2	52.0	1.7	1.8	0.3	10
mean		**8.9**	**86.2**	**2.7**	**3.6**	**1.4**	**12**
Stanley	1992	8.0	90.9	3.9	4.0	1.8	11
Stanley	1993	7.0	98.1	4.7	11.6	1.6	15
Stanley	1994	9.9				2.7	
Stanley	1995	7.9	90.6	2.3	7.3	1.8	12
Stanley	1996	7.1					
Stanley	1997	4.9	57.3	3.0	3.3	0.0	14
mean		**7.8**	**88.6**	**3.6**	**7.7**	**1.6**	**13**

Table 7. (A). Hourly (mg C/m3/hour) and (B). daily (mg C/m2/day) estimates of primary productivity in Redfish, Pettit, Alturas, and Stanley lakes for years 1993, 1995, 1996, and 1997.

A.		Hourly Primary Productivity (mgC/m^2/hr)					
Year	Lake	June	July	August	September	October	Mean
1993	Redfish	3.2	14.6	13.4	16.2	------	11.8
1993	Pettit	------	10.6	7.2	13.3	------	10.4
1993	Alturas	------	------	22.8	------	------	22.8
1993	Stanley	------	------	11.2	------	------	11.2
1995	Redfish	16.5	46.2	23.8	34.4	------	30.2
1995	Pettit	9.7	16.9	26.3	23.1	------	19.0
1995	Alturas	8.4	12.7	17.4	11.0	------	12.4
1995	Stanley	9.6	14.7	22.6	8.7	------	13.9
1996	Redfish N	11.3	14.7	16.5	19.0	22.9	16.9
1996	Redfish S	24.1	9.3	19.7	17.5	17.6	17.6
1996	Pettit	14.1	8.5	14.7	15.3	11.2	12.8
1996	Alturas	10.6	7.8	10.1	13.8	------	10.6
1997	Redfish N	------	------	------	47.9	25.6	36.8
1997	Redfish S	------	------	------	46.5	29.4	38.0
1997	Pettit	------	------	------	33.2	21.9	27.6
1997	Alturas	------	------	------	27.4	17.5	22.5
1997	Stanley	------	------	------	31.2	16.8	24.0

B.		Daily Primary Productivity (mgC/m^2/day)					
Year	Lake	June	July	August	September	October	Mean

1993	Redfish	24.8	113.9	104.5	126.4	------	92.4
1993	Pettit	------	91.2	61.7	114.4	------	89.1
1993	Alturas	------	------	193.8	------	------	193.8
1993	Stanley	------	------	110.2	------	------	110.2
1995	Redfish	128.7	360.4	185.6	268.3	------	235.8
1995	Pettit	83.4	145.3	226.2	198.7	------	163.4
1995	Alturas	71.2	108.0	147.9	93.5	------	105.2
1995	Stanley	77.8	119.1	183.1	70.3	------	112.6
1996	Redfish N	97.6	130.4	140.1	130.1	146.3	128.9
1996	Redfish S	206.3	83.6	152.5	122.7	108.4	134.7
1996	Pettit	117.9	68.7	130.2	148.7	88.0	110.7
1996	Alturas	105.4	57.0	116.4	113.2	------	98.0
1997	Redfish N	------	------	------	431.1	184.3	307.7
1997	Redfish S	------	------	------	469.7	205.8	337.8
1997	Pettit	------	------	------	318.7	148.9	233.8
1997	Alturas	------	------	------	227.4	129.5	178.5
1997	Stanley	------	------	------	218.4	110.9	164.7

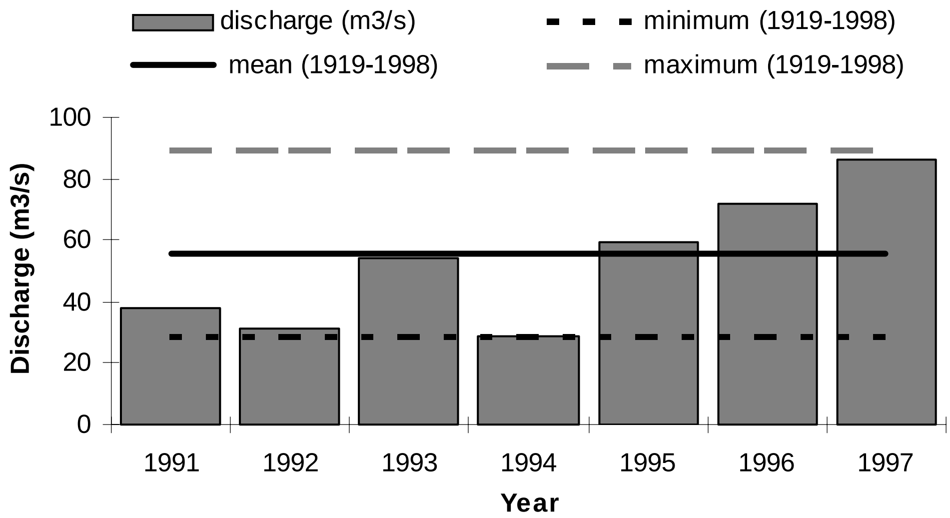


Figure 1. Mean annual discharge for the Salmon River at Salmon, Idaho for 1991 through 1997. Mean, minimum, and maximum are for period of record, 1913 to 1997.

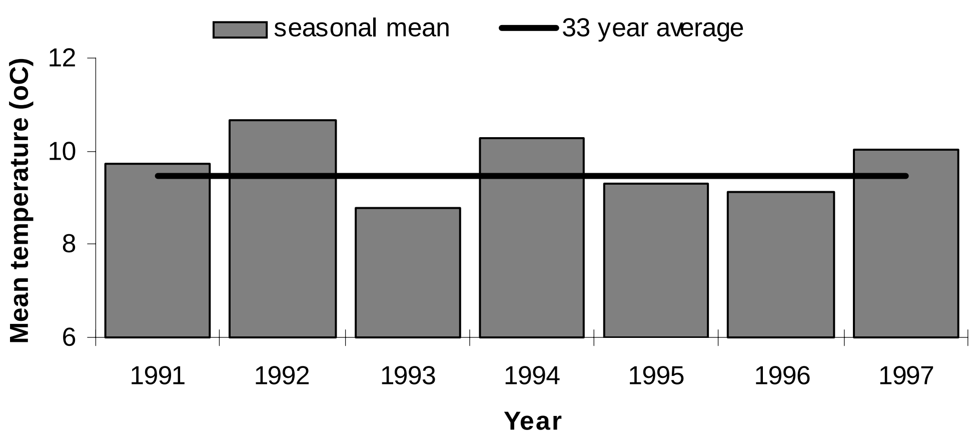


Figure 2. Seasonal mean (May-October) air temperature (^{o}C) at Stanley, Idaho, 1991 to 1997.

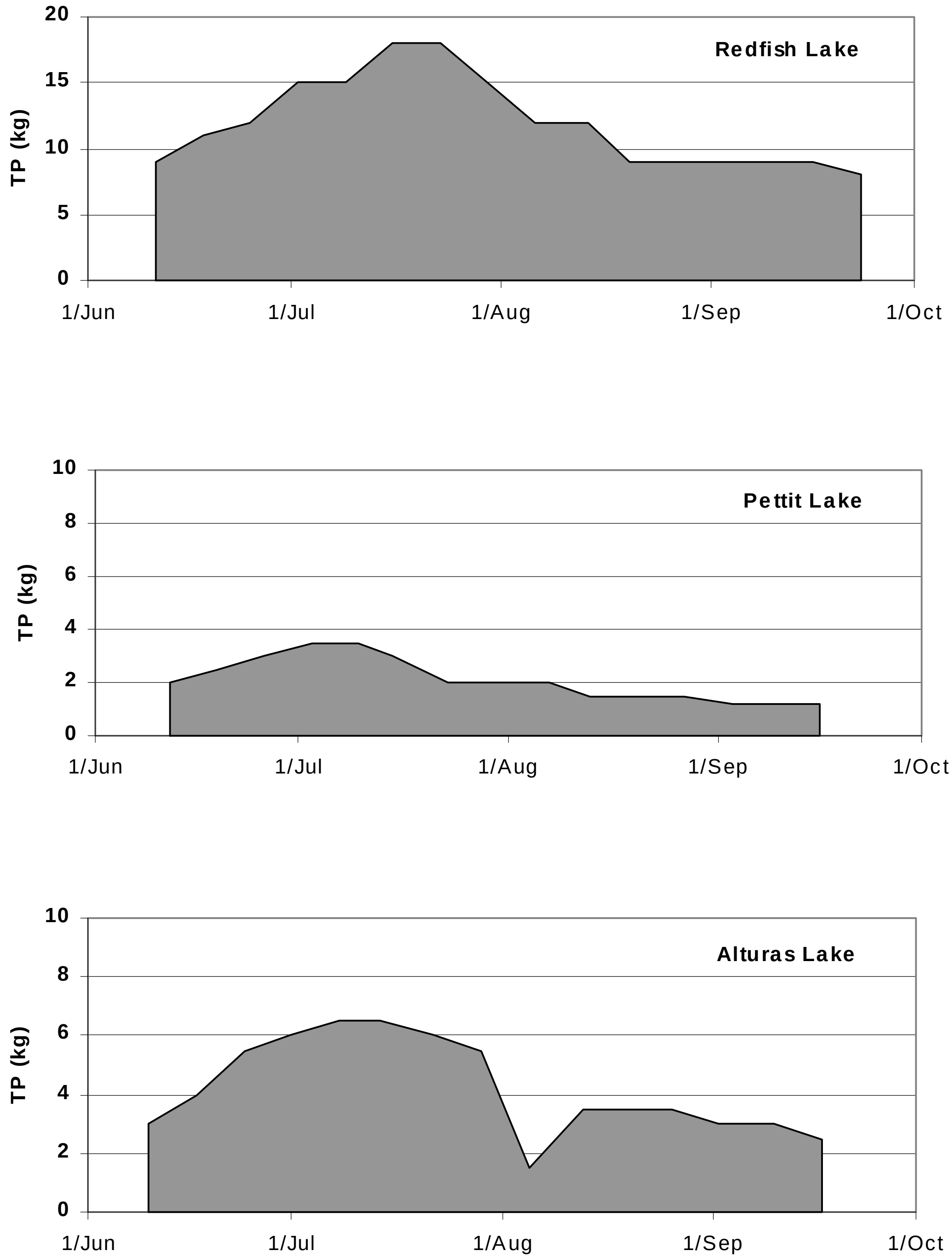


Figure 3. Supplemental nutrient additions to Redfish, Pettit, and Alturas lakes, Idaho, during June through September, 1997.

A. Redfish Lake

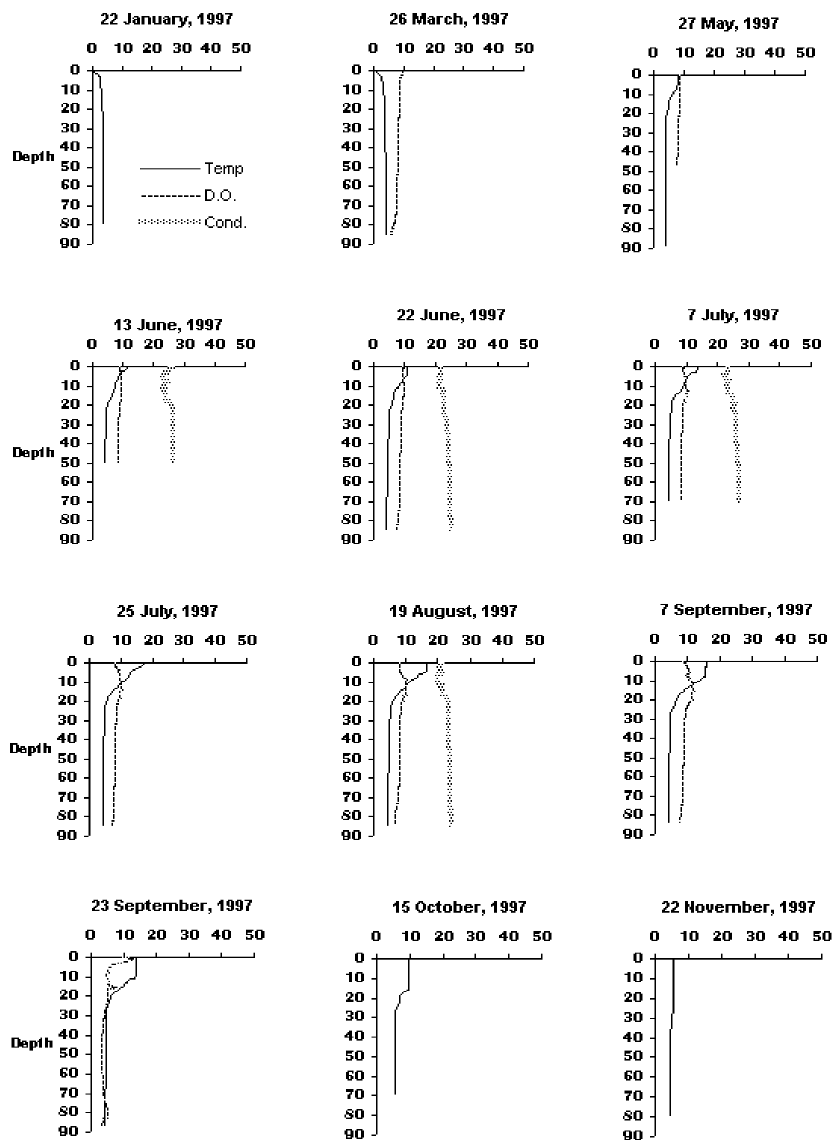
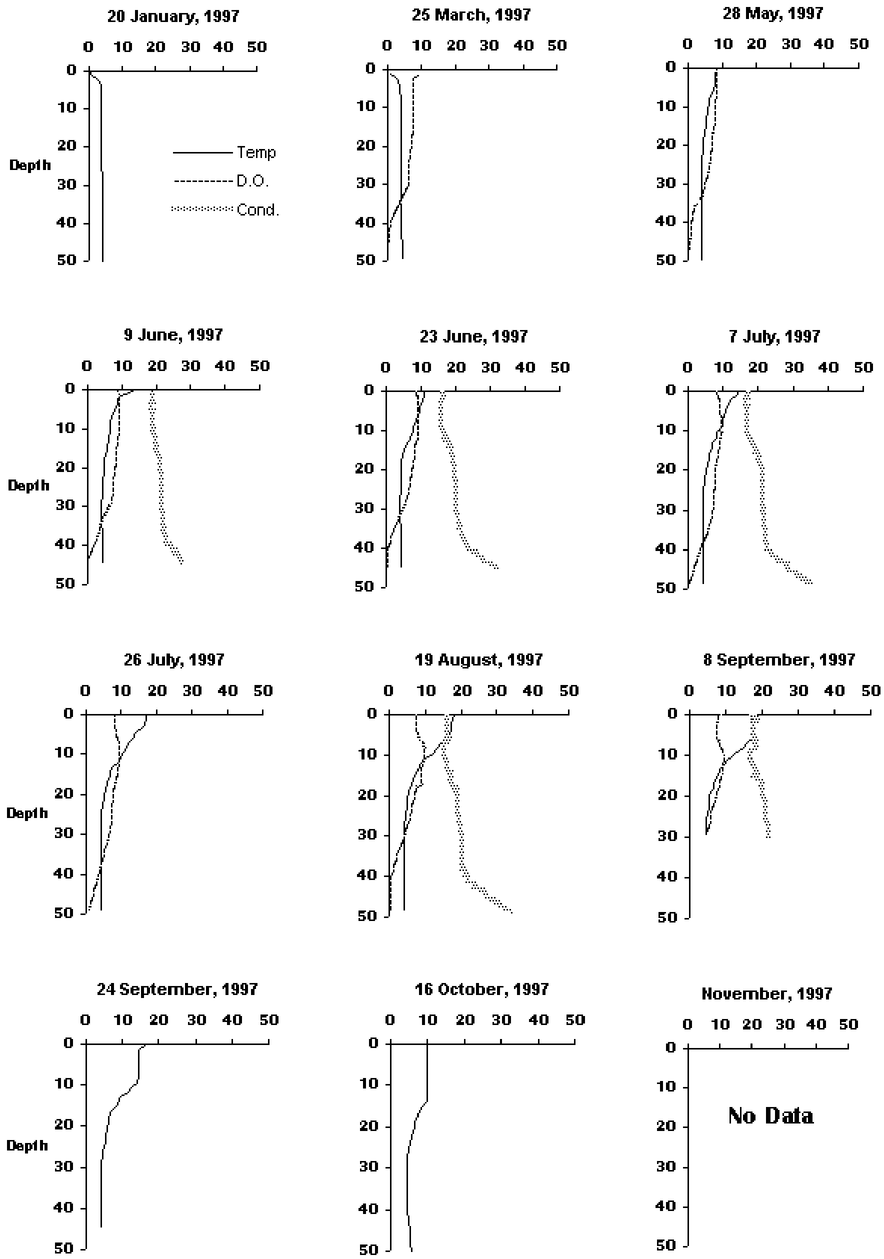
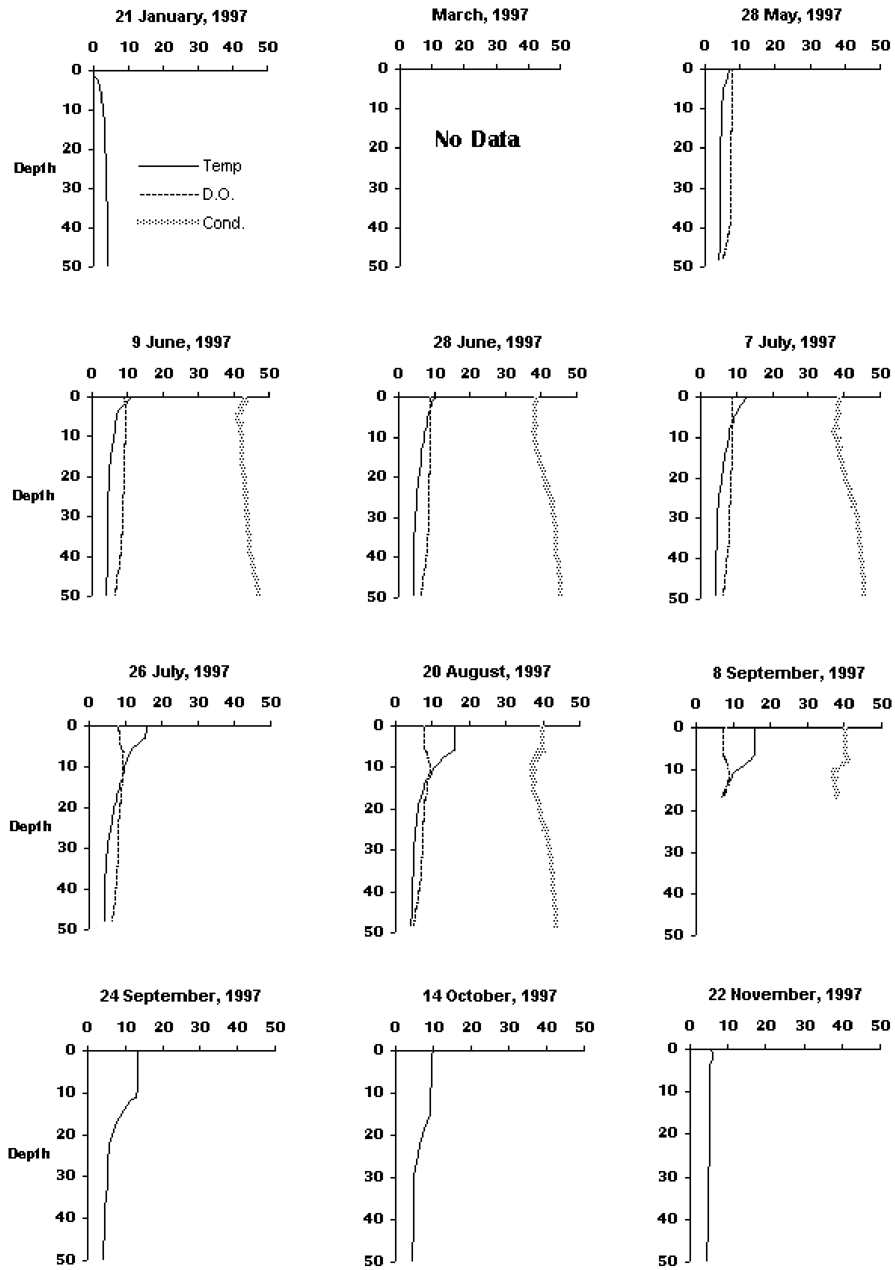


Figure 4. Temperature (^{o}C), dissolved oxygen (mg/l), and conductivity (uS/cm) profiles for January through November, 1997 in (A) Redfish Lake (B) Pettit Lake (C) Alturas Lake and (D) Stanley Lake.

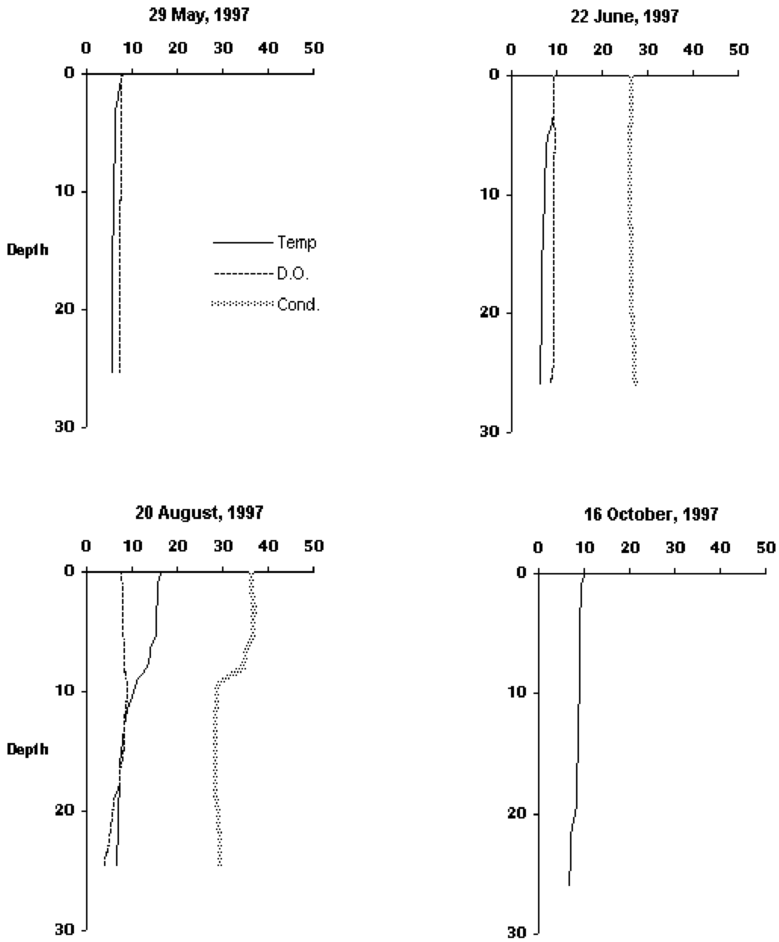
B. Pettit Lake



C. Alturas Lake



D. Stanley Lake



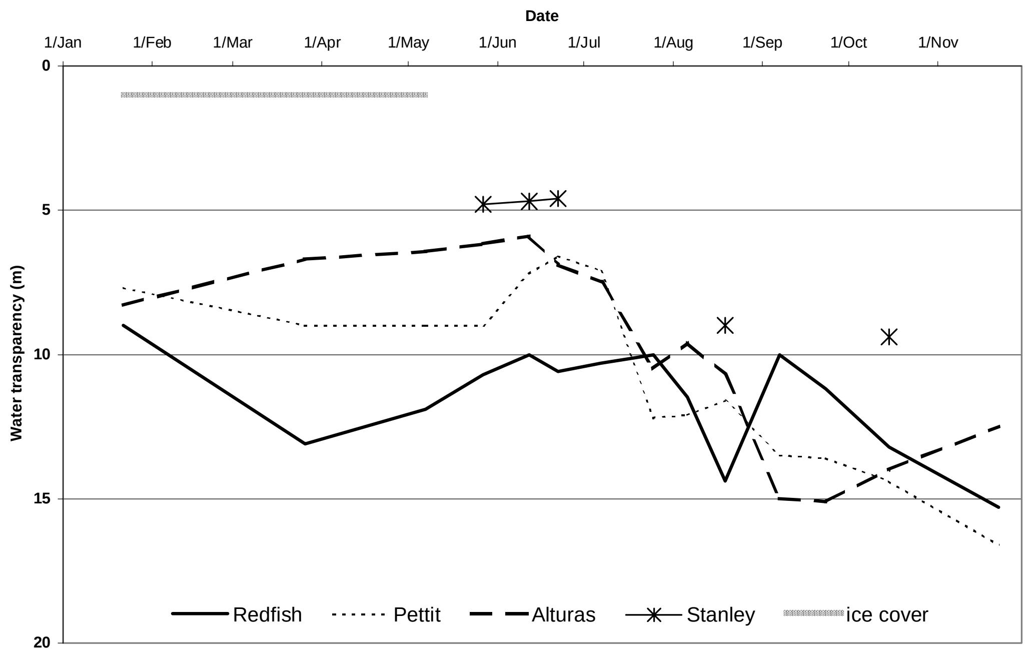


Figure 5. Water transparencies (secchi depth) in meters for Redfish, Pettit, Alturas, and Stanley lakes, January through November 1997.

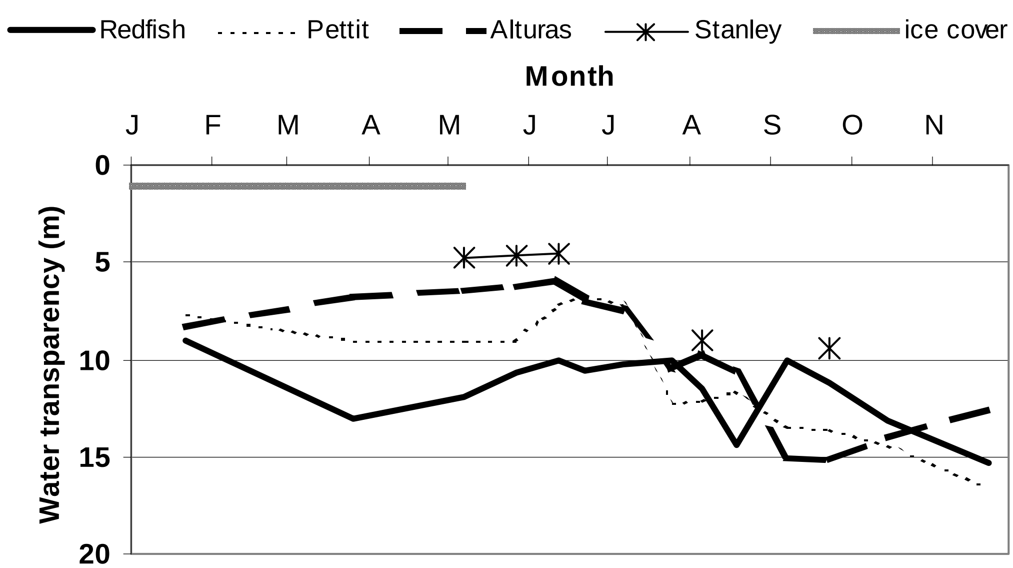


Figure 6. Photic zone depth defined by the 1% light level (in meters) for Redfish, Pettit, Alturas and Stanley lakes, January through November, 1997.

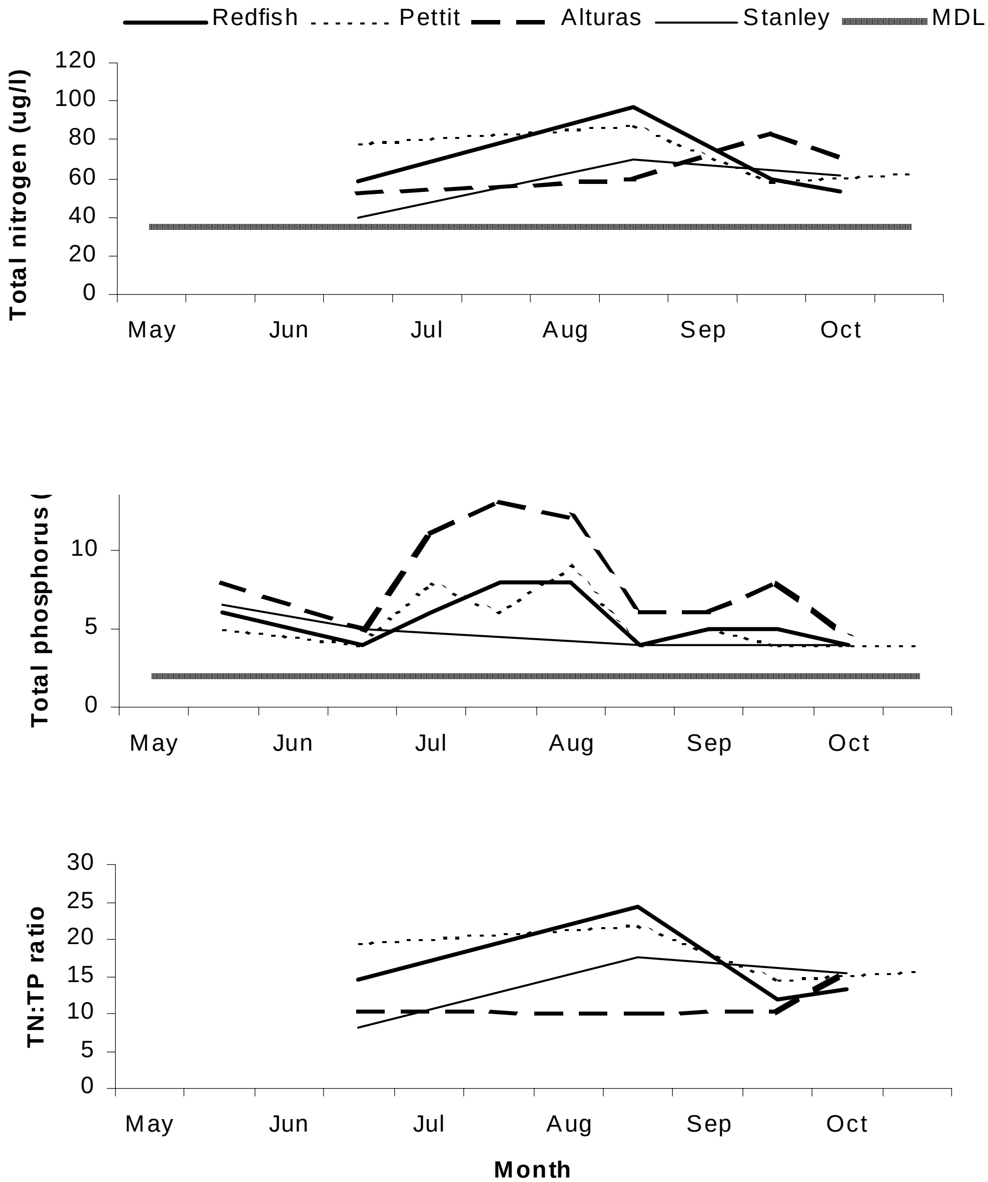


Figure 7. Epilimnetic total nitrogen (TN) and total phosphorus (TP) concentrations (*u*g/l), and the TN/TP ratio in the epilimnetic waters of Redfish, Pettit, Alturas and Stanley lakes, 1997. Grey line denotes method detection level.

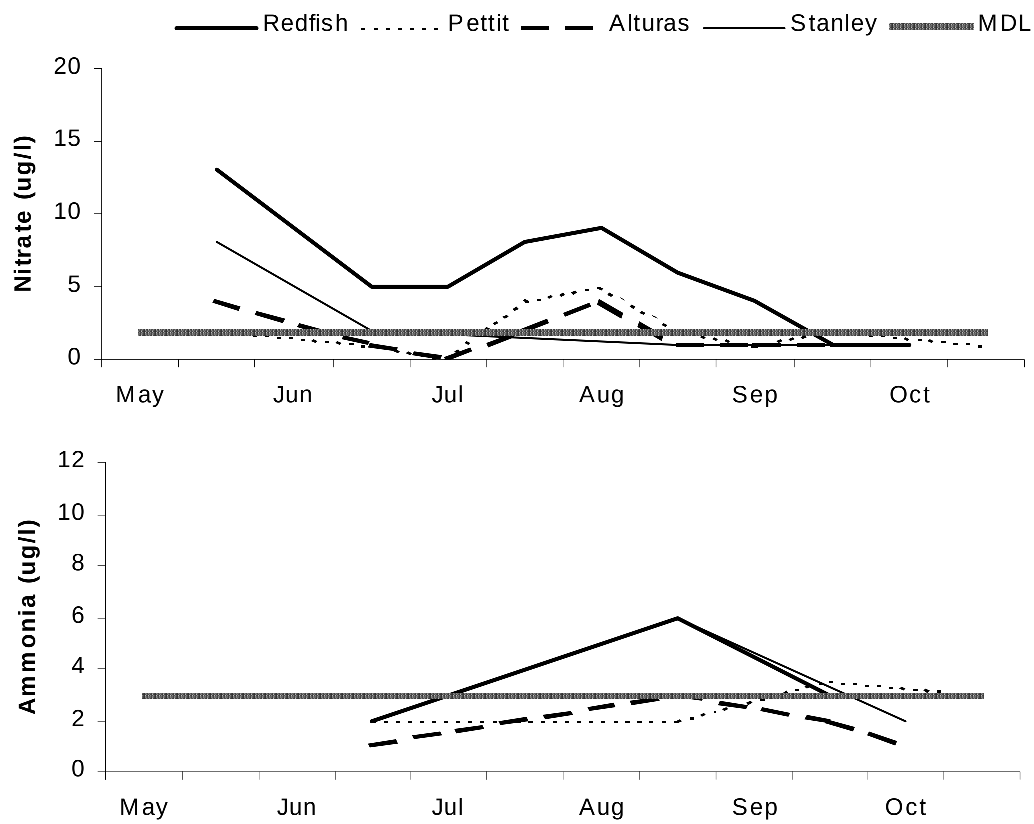


Figure 8. Epilimnetic nitrate and ammonia concentrations (*u*g/l) in Redfish, Pettit, Alturas and Stanley lakes, Idaho, during 1997. Grey line denotes method detection level.

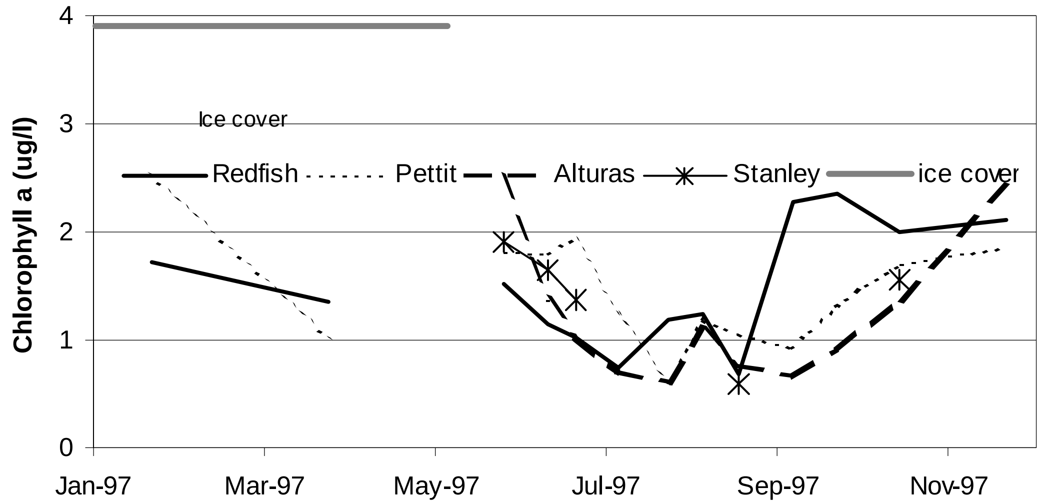


Figure 9. Surface chlorophyll *a* concentrations (*u*g/l) in Redfish, Pettit, Alturas, and Stanley lakes, Idaho during 1997. Shaded line indicates ice cover.

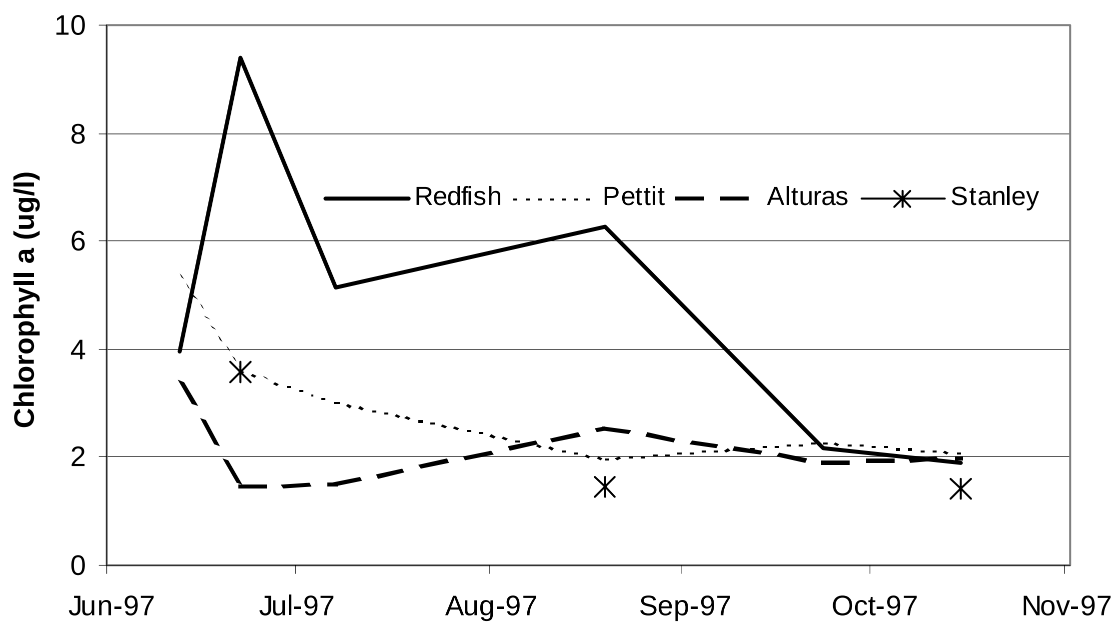


Figure 10. Chlorophyll *a* concentrations (*u*g/l) at the 1% light level in Redfish, Pettit, Alturas and Stanley lakes, Idaho during 1997.

Redfish Lake - 1997

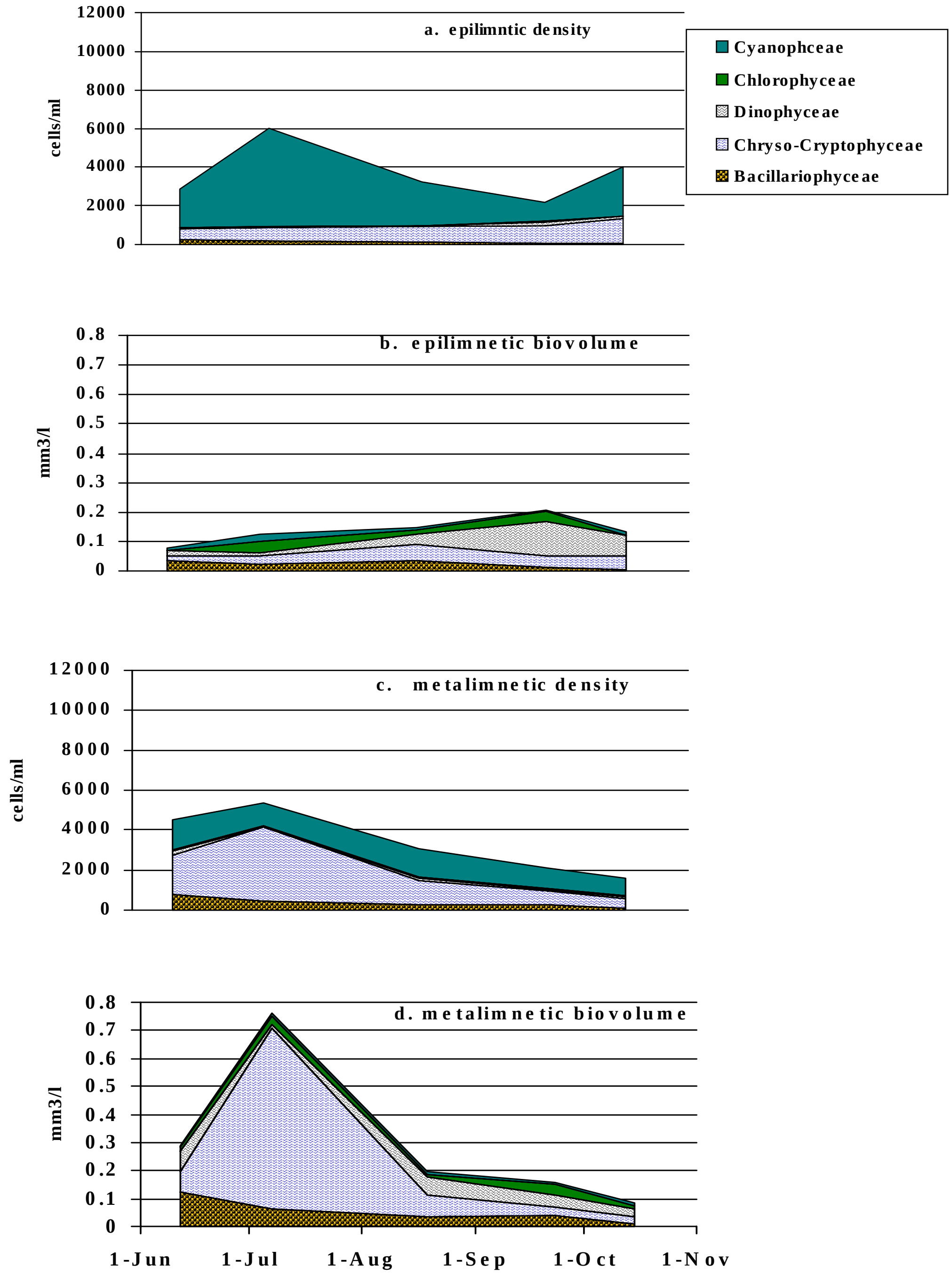


Figure 11. Epilimnetic and metalimnetic density (cells/l) and biovolume (mm^3/l) of phytoplankton in Redfish Lake, Idaho during June through October 1997.

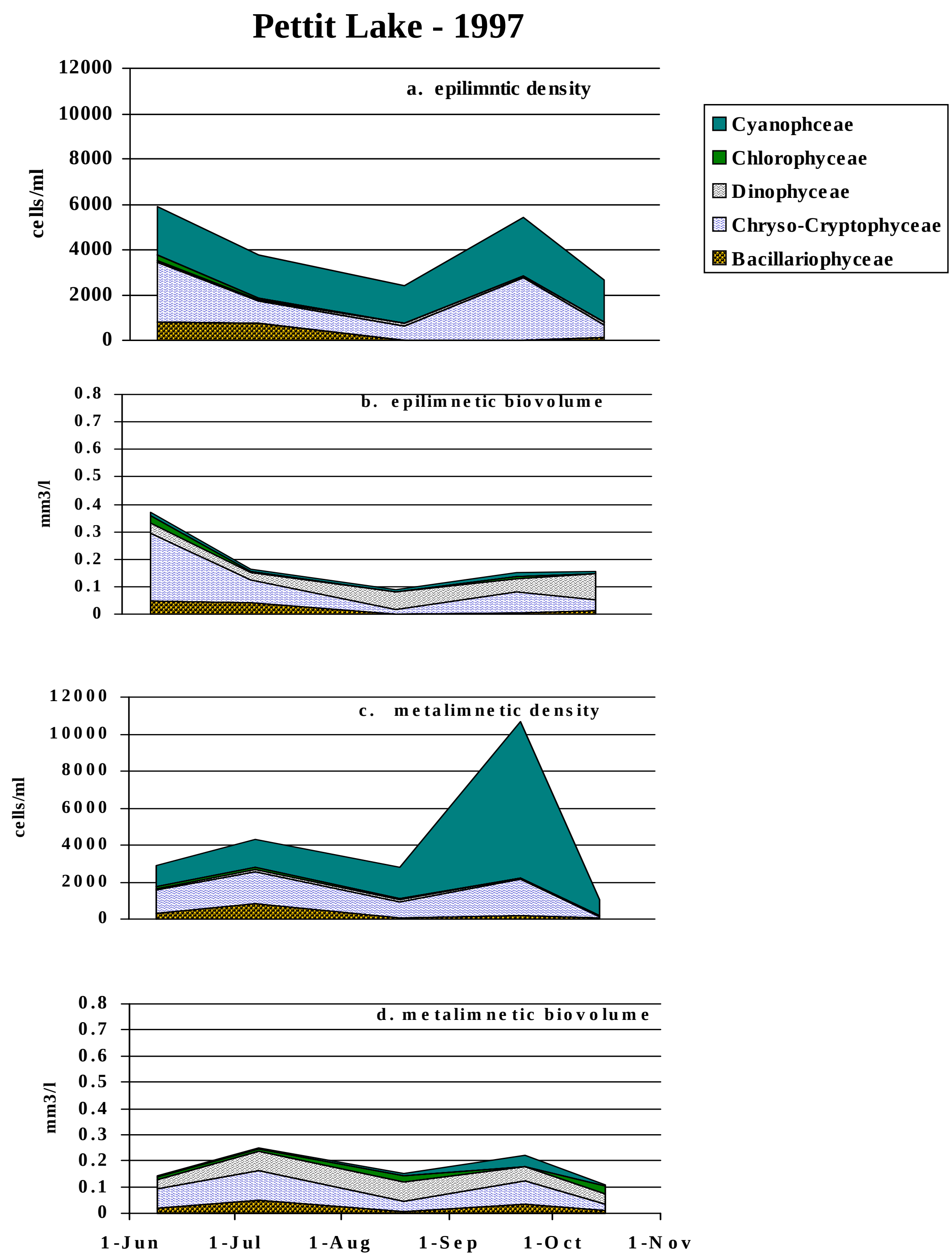


Figure 12. Epilimnetic and metalimnetic density (cells/l) and biovolume (mm^3/l) of phytoplankton in Pettit Lake, Idaho during June through October 1997.

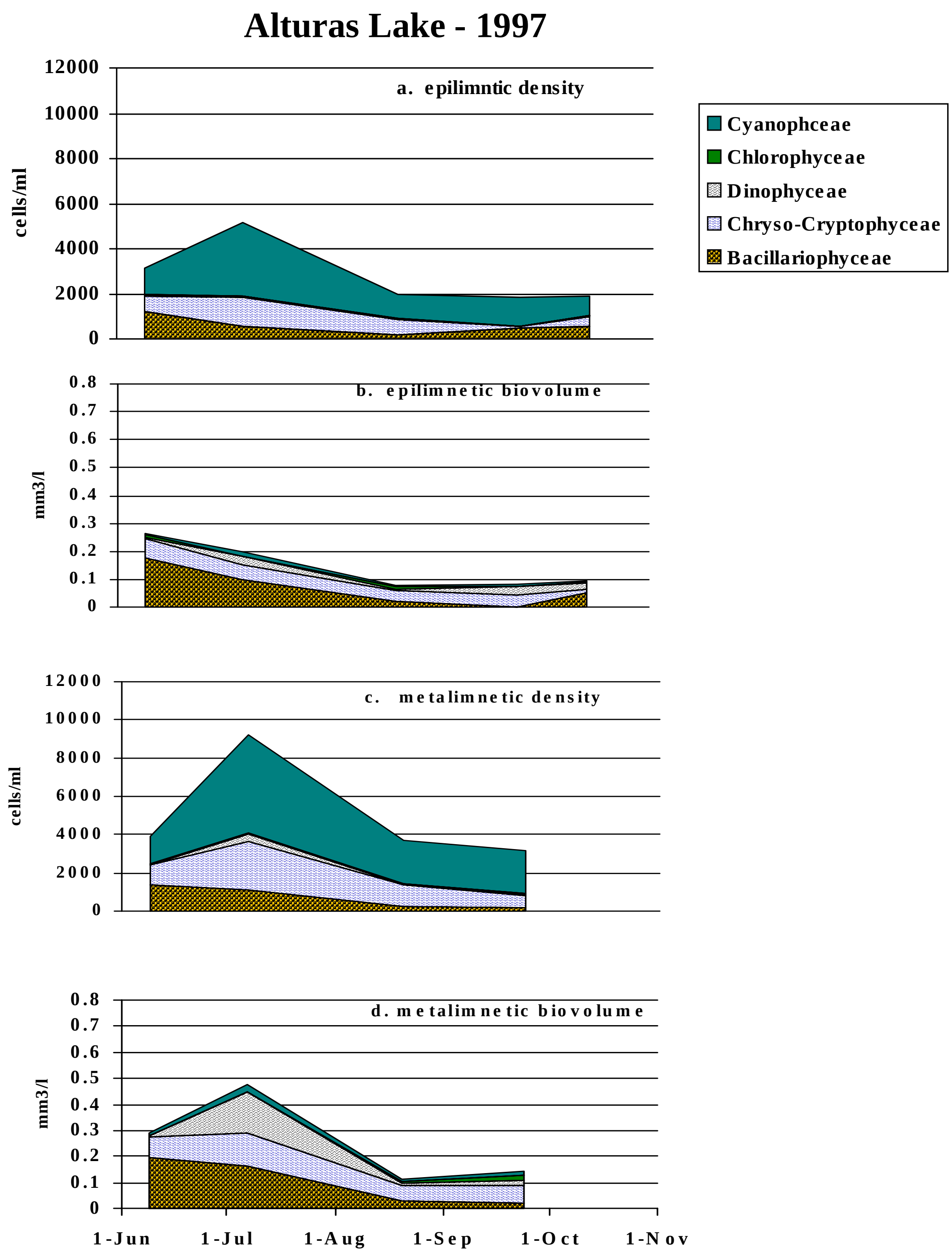


Figure 13. Epilimnetic and metalimnetic density (cells/l) and biovolume (mm^3/l) of phytoplankton in Alturas Lake, Idaho during June through October 1997.

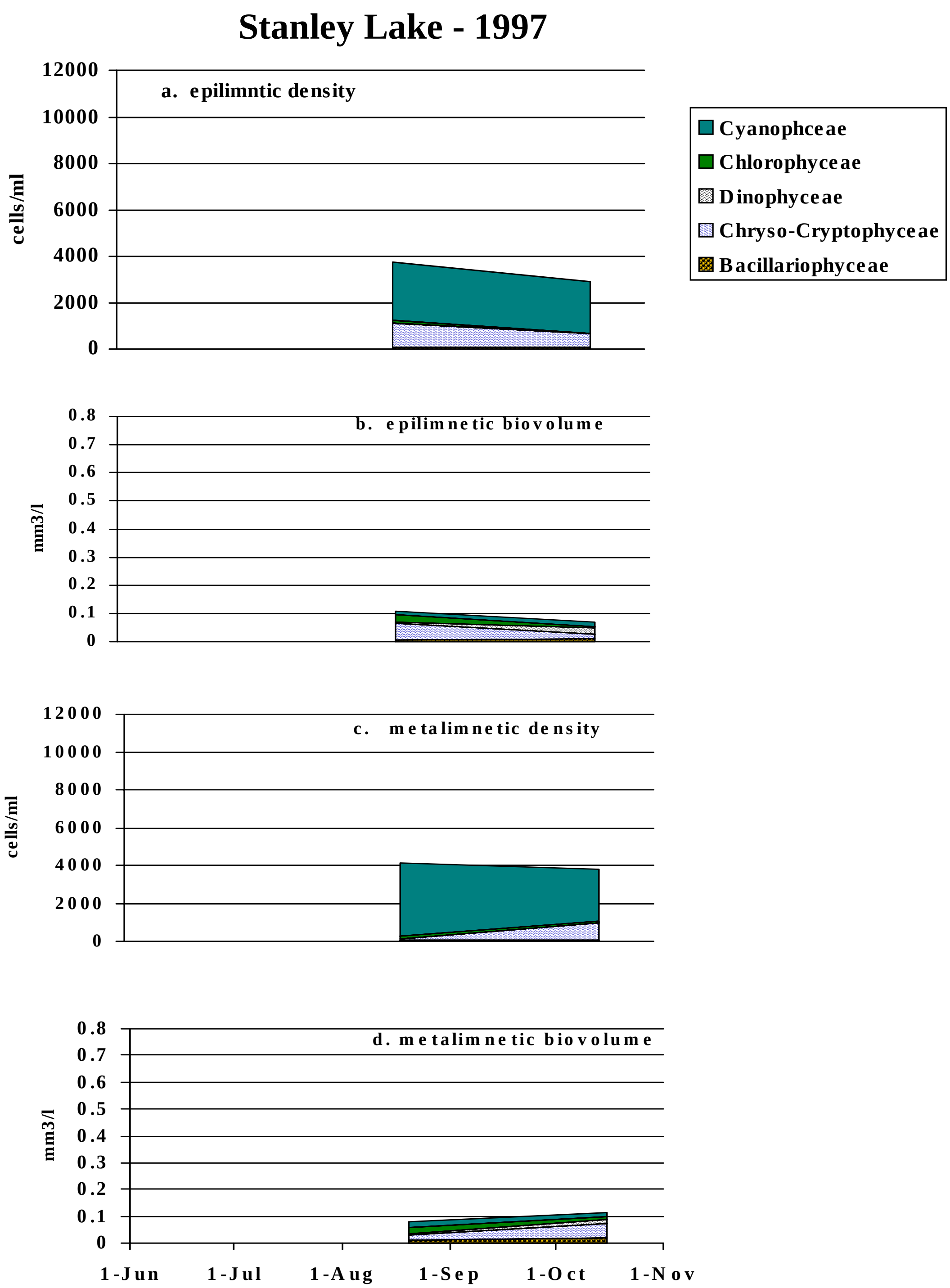
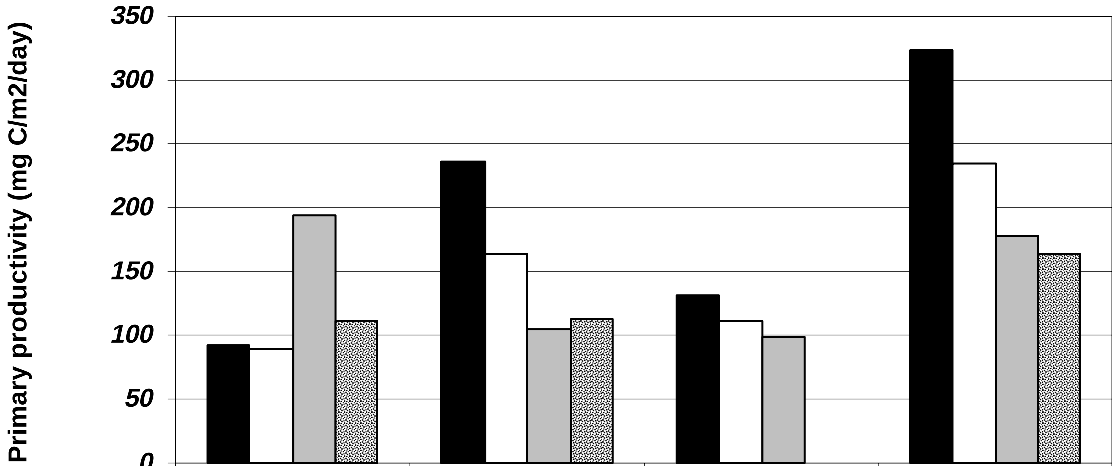


Figure 14. Epilimnetic and metalimnetic density (cells/l) and biovolume (mm^3/l) of phytoplankton in Stanley Lake, Idaho during August through October 1997.



	1993	1995	1996	1997
Redfish	92.4	235.8	131.8	322.8
Pettit	89.1	163.4	110.7	233.8
Alturas	193.8	105.2	98.0	178.5
Stanley	110.2	112.6		164.7

Figure 15. Mean seasonal primary productivity estimates (mg C/m2/day) in Redfish, Pettit, Alturas, and Stanley lakes, Idaho during 1993 through 1997.

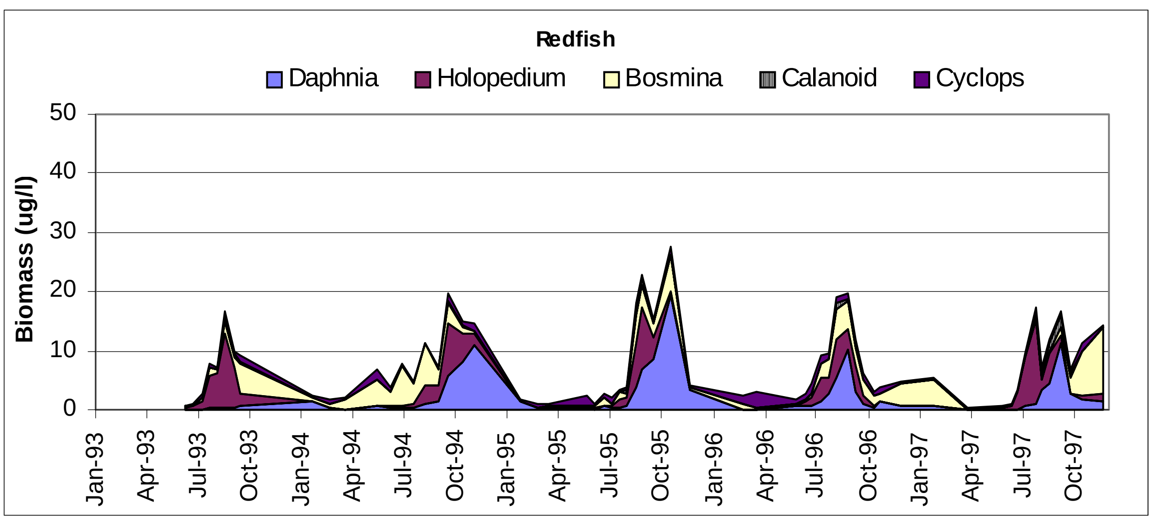


Figure 16. Redfish Lake zooplankton biomass (*u*g/l) weighed by lake volume, 1993-1997.

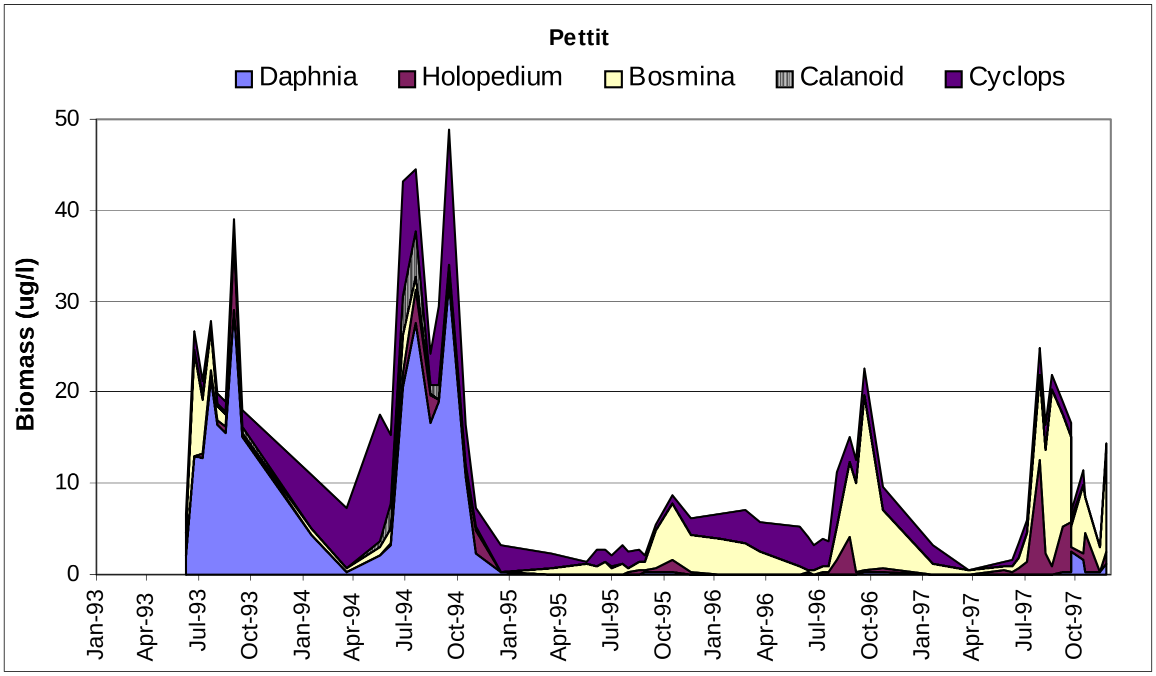


Figure 17. Pettit Lake zooplankton biomass (*u*g/l) weighed by lake volume, 1993-1997.

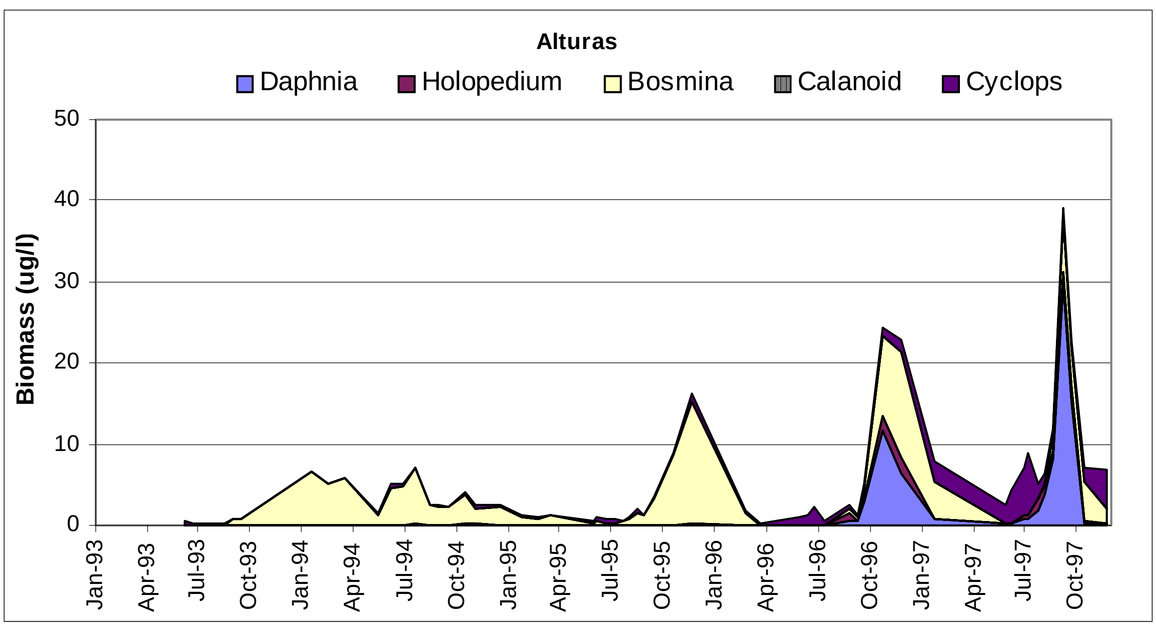


Figure 18. Alturas Lake zooplankton biomass (*u*g/l) weighed by lake volume, 1993-1997.

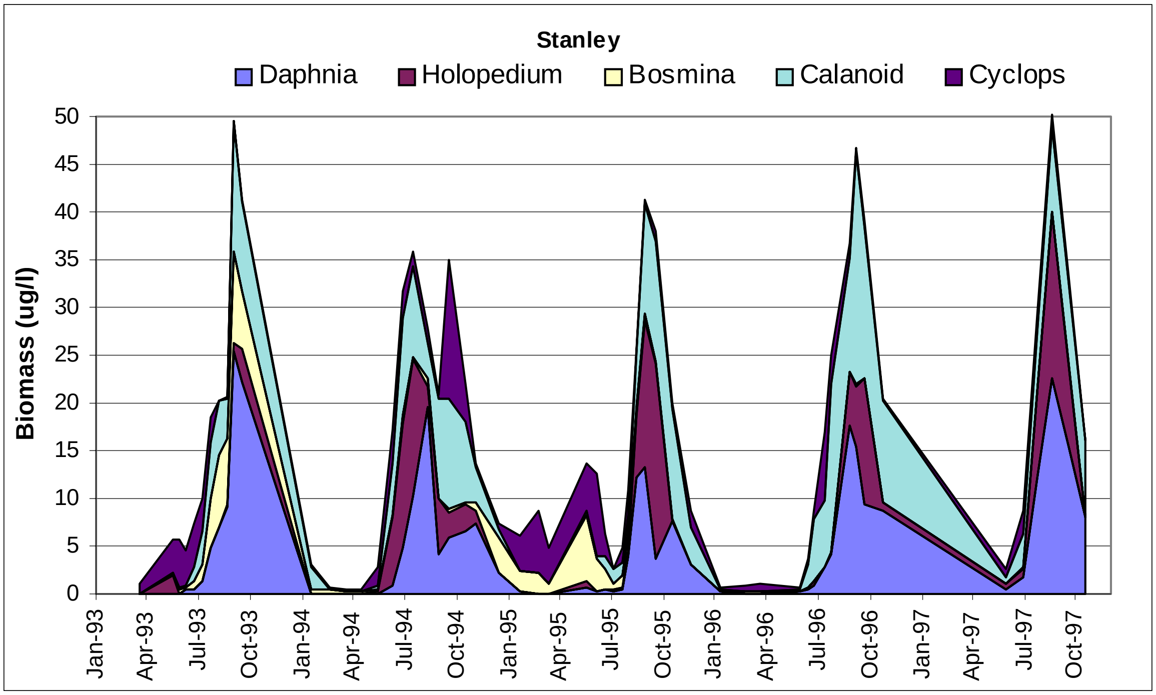


Figure 19. Stanley Lake zooplankton biomass (*u*g/l) weighed by lake volume, 1993-1997.

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