FISHERY RESEARCH

DWORSHAK RESERVOIR NUTRIENT ENHANCEMENT RESEARCH, 2010

DWORSHAK DAM RESIDENT FISH MITIGATION PROJECT

ANNUAL PROGRESS REPORT
March 1, 2010 – February 28, 2011

Prepared by:

Sean M. Wilson, Fishery Research Biologist

Andrew M. Dux, Principal Fishery Research Biologist

and
Richard J. Downing, Senior Fishery Technician

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Sean M. Wilson
Andrew M. Dux
and
Richard J. Downing

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707
USA

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ABSTRACT

Nutrient supplementation is being tested to restore declining reservoir productivity and benefit fisheries in Dworshak Reservoir. In 2007, Idaho Department of Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) began a cooperative nutrient supplementation pilot project on the reservoir. Under this agreement, the USACE applied nutrients, IDFG monitored the results using a combination of limnological and fish surveys, and TG Eco-Logic provided the nutrient application schedule and analyzed limnological data. This report summarizes results from 2010, the fourth year of the project.

Water quality parameters measured in 2010 fell within the range of previously observed data and did not exceed the limits specified in the Consent Order. The snowpack and resulting runoff were below average. A thermocline developed slightly later and dissipated earlier than usual. Dissolved oxygen minima, which are typically observed during late summer and fall, were similar to previous years. None of the water quality standards set forth in the Consent Order issued by the Idaho Department of Environmental Quality (IDEQ) were violated. The median Secchi depth of 3.0 m equaled, but did not exceed, the specified limit. Measurements of total dissolved phosphorus (TDP) and chlorophyll *a* (Chl *a*) in the epilimnion were well below upper limits specified in the Consent Order.

Picoplankton biovolumes in 2010 were within the range observed in previous years. The mean biovolume of edible phytoplankton was similar to previous years while the biovolume of inedible taxa was lower than presupplementation years. The mean percentage of the overall biovolume composed of toxigenic cyanobacteria (blue-green algae) was lower than any previous year. Increases in the proportion of edible phytoplankton taxa appear to be sustaining increases in the density of zooplankton. Mean zooplankton density continued to increase, although the mean length of *Daphnia* was similar to presupplementation years. Kokanee abundance and biomass were higher than in all other treatment years. Additionally, mean fish length and total biomass were higher than 2006 (a pretreatment year with similar abundance), indicating better growth conditions in response to nutrient supplementation.

Dworshak Reservoir appears to be responding positively to nutrient supplementation during the first four years of the pilot project. Picoplankton increased dramatically during the first year of the project, followed by relative increases in edible phytoplankton and zooplankton in subsequent years. Kokanee size at a given density and total biomass increased by the fourth year, presumably as a result of increased forage. These results are consistent with those reported for nutrient supplementation in Kootenay and Arrow lakes in British Columbia.

Authors:

Sean M. Wilson
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

Richard J. Downing
Senior Fishery Technician

INTRODUCTION

Dworshak Reservoir is the most popular fishing destination in Clearwater County and the third most popular destination in the Clearwater region, based on total angler trips in 2003 (IDFG 2003). It provides a multispecies fishery for naturally reproducing kokanee *Oncorhynchus nerka*, smallmouth bass *Micropterus dolomieu,* and westslope cutthroat trout *Oncorhynchus clarkii lewisi*, as well as hatchery stocked rainbow trout *Oncorhynchus mykiss*. The reservoir also provides important habitat for Endangered Species Act (ESA) listed bull trout *Salvelinus confluentus*.

Kokanee were first stocked into Dworshak Reservoir in 1972 (Horton 1981). Although two stocks were originally introduced (early spawners from Anderson Ranch Reservoir, Idaho and late spawners from Lake Whatcom, Washington), the early spawning variety soon dominated (Horton 1981). Kokanee provide the most popular fishery on the reservoir, with annual effort levels that have exceeded 140,000 angler hours and annual harvest of over 200,000 fish (Mauser et al. 1989). The pelagic nature and planktivorous feeding habits of kokanee make them well suited for an oligotrophic reservoir with fluctuating water levels, such as Dworshak Reservoir (Maiolie and Elam 1996).

Entrainment and oligotrophication have been identified as the primary factors limiting the kokanee population in Dworshak Reservoir (Stark and Stockner 2006). With the exception of high runoff years, entrainment was reduced beginning in the early 1990s when drawdown began occurring during the summer and early autumn to provide cool water for Chinook salmon *Oncorhynchus tshawytscha* in the Snake River. During this time period, kokanee are distributed farther from the dam and less vulnerable to entrainment than during winter (Maiolie and Elam 1997). Bennett (1997) found that discharge from January through March had the highest negative correlation with survival compared to other time periods examined. While entrainment remains a limiting factor for kokanee in some years, oligotrophication is more often the primary limiting factor. Bennett (1997) identified declining productivity as a critical factor limiting the kokanee fishery and recommended it be addressed before implementing intensive fisheries management practices.

Following this recommendation, Stockner and Brandt (2005) provided a detailed assessment of the reservoir and recommendations for a nutrient supplementation program. Based on phosphorous loading and mean chlorophyll densities, they classified Dworshak Reservoir as borderline oligo-mesotrophic. However, they found that the phytoplankton communities and associated food web present during the spring were dominated by microbial communities typical of ultraoligotrophic lakes and reservoirs. Dworshak Reservoir becomes nitrogen limited by mid-summer, leading to a dominance of nitrogen fixing cyanobacteria (blue-green algae). Blue-green algae are typically abundant from mid-summer to early fall, and because they are inedible to zooplankton, represent a considerable carbon sink. Mid-summer nitrogen limitation and the subsequent impact to zooplankton results in reduced fish production.

The Idaho Department of Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) initiated a five-year nutrient supplementation pilot project in 2007. This report covers results of the fourth year of supplementation. The USACE applied ammonium nitrate to the reservoir on a weekly basis from April through July (see Scofield et al. 2011 for spread tables). IDFG conducted surveys to monitor limnological changes and the kokanee population response. TG Eco-Logic, a private consulting company, was contracted to interpret the results of the limnological data and adjust the nutrient prescriptions as necessary. The goal of the program is to restore the system productivity by improving the nitrogen (N) to phosphorus (P) ratios in the reservoir, thereby promoting the growth of desirable phytoplankton (i.e. edible by zooplankton). Increased abundance of edible phytoplankton is expected to lead to an increased abundance of zooplankton, therefore providing an improved forage base for fish. Stockner and Brandt (2005) anticipated that a moderate N nutrient supplementation would benefit fish populations without degrading water quality.

The primary task of IDFG's monitoring program was to evaluate the effectiveness of the nutrient supplementation program at improving the flow of carbon to the kokanee population in Dworshak Reservoir without adversely affecting water quality. Thus, limnological surveys were conducted to meet three major requirements. The first requirement was to ensure that water quality standards, as stipulated in the Consent Order issued by the Idaho Department of Environmental Quality (IDEQ), were maintained. Secondly, limnological data were collected to make comparisons with presupplementation conditions to determine the biological effects of the project, including changes to the plankton communities. Finally, data were provided to TG Eco-Logic to actively manage the nutrient applications. In addition to limnological monitoring, surveys were conducted to monitor the kokanee population. The objectives in the IDFG Fisheries Management Plan for the Dworshak Reservoir kokanee fishery are to maintain a catch rate of 0.7 fish per hour with an average size of 254 mm (IDFG 2007). An effective nutrient supplementation program is expected to increase the average size of kokanee at any given population density. Kokanee surveys were conducted to determine whether this occurred and if nutrient supplementation will achieve fisheries management plan objectives.

STUDY SITE

Dworshak Reservoir was impounded after the construction of Dworshak Dam in 1972 on the North Fork Clearwater River approximately 2.4 km from its confluence with the mainstem Clearwater River. The reservoir is narrow, steeply sloped, and primarily surrounded by coniferous forests. The North Fork Clearwater River and its tributaries drain nearly 632,000 ha, which is composed primarily of montane forests in steeply sloped terrain (Falter et al. 1977). The underlying geology is composed of Columbia River basalt and metamorphic sediments with granitic intrusions covered by shallow soils (Falter et al. 1977). Most of the North Fork Clearwater watershed above the reservoir lies within the Clearwater National Forest. The reservoir is immediately surrounded by land managed by the USACE, but much of the lower watershed is privately owned. Timber harvest is the primary commercial activity, although there is some agriculture in the lower watershed.

At full pool, Dworshak Reservoir is 86.3 km long with a surface area of 6,916 ha and a volume of 4.3 billion m^3 (Falter 1982). Typical annual drawdown lowers the pool elevation by 24 m and reduces the surface area by 27%. Peak pool elevation is typically reached by late June and drawdown begins after the first week of July, with winter levels reached by the second week of September. The mean hydraulic retention time is 10.2 months (Falter 1982) and the mean daily discharge from 2000-2009 was 146 m^3/s (http://www.cbr.washington.edu/dart/; accessed 3/29/11).

OBJECTIVE

1. Maintain a kokanee population that can sustain a catch rate of 0.7 fish per hour with a minimum average size of 254 mm total length.

METHODS

Environmental Conditions

Daily mean reservoir inflow, discharge, and pool elevation data provided by the USACE were acquired through the Columbia River Data Access in Real Time (DART) website (http://www.cbr.washington.edu/dart/; accessed 3/29/11).

Physical and Chemical Limnology

Sample Collection

Limnological sampling was conducted at seven stations on the reservoir and one station on the North Fork Clearwater River (NFC) below Dworshak Dam (Figure 1). Five stations on the main reservoir were designated as RK-2, RK-31, RK-56, RK-66, and RK-72, corresponding with the approximate river kilometer (RKM). Two additional stations were located in untreated areas of the reservoir, RKM six of the Elk Creek arm (EC-6) and RKM three of the Little North Fork arm (LNF-3).

Limnological sampling was conducted twice monthly from April through September and once monthly during March, October, and November. When all seven reservoir stations and the river station could not be sampled in one day, samples were collected over a two-day period.

Physical parameters measured included water depth, Secchi depth, water temperature, dissolved oxygen (DO), and photosynthetically active radiation (PAR). Chemical parameters included total phosphorus (TP), total dissolved phosphorus (TDP), nitrate plus nitrite nitrogen (N+N), total dissolved solids (TDS), and dissolved organic carbon (DOC). Biological parameters included chlorophyll *a* (Chl *a*), picoplankton, phytoplankton, and zooplankton. Sampling for DOC was only conducted at RK-31 and RK-72 during the first event each month. Only TP, TDP, N+N, TDS, DOC and Chl *a* were analyzed for NFC. In addition, TP, TDP, and N+N were collected on a monthly basis from two raceways used to rear Chinook salmon *Oncorhynchus tshawytscha*, one each at Clearwater Fish Hatchery (CFH) and Dworshak National Fish Hatchery (DNFH), one burrows pond for rearing steelhead at DNFH, and at the boat ramp on the main-stem Clearwater River approximately 1 km above the confluence with the North Fork Clearwater and above all effluent from DNFH.

Water depth was measured using a Garmin™ Model GSD22 depth sounder in conjunction with a GPS MAP 4212 chart plotter. Secchi depth was measured using a 20 cm Secchi disc, which was lowered from the shaded side of the boat until no longer visible, then raised until it reappeared. Water temperature and dissolved oxygen (DO) measurements were taken concurrently with a Yellow Springs Instruments® model 58 meter with a 60 m cable and probe assembly with a high sensitivity membrane. The probe was calibrated at each site following the manufacturer's instructions. After recording air temperature, both water temperature and DO measurements were recorded at the surface, 1 m, 2 m, and every 2 m thereafter to 60 m or the reservoir bottom. The depth of the thermocline, defined as a one-degree change in temperature over a one-meter change in depth, was recorded.

The level of PAR was measured using a Li-Cor® model LI-250A light meter and a 400-700 µm quantum sensor (model LI-192SA). The sensor was mounted on a frame and weighted with a lead weight. A 15-second average PAR reading was taken at the water surface and at one meter intervals to 15 m or a reading of zero. A second meter and dry sensor were used to take air readings concurrently with the wet readings.

Water samples were collected from the epilimnion (EPI) and hypolimnion (HYPO) at each station using a 2.2 L Kemmerer bottle. EPI samples consisted of a composite of water from 1, 3, 5, and 7 m, regardless of the presence or depth of a thermocline. One liter of water from each depth was mixed in a splitter bucket. HYPO samples were collected during the first event each month and consisted of a single ‘grab’ from 25 m. For water depths less than 28 m, HYPO samples were taken 3 m above the bottom and the depth noted on the field datasheet. Two 250 mL polyethylene sample bottles were filled from each sample depth (EPI and HYPO). One bottle (unfiltered sample) was pretreated with sulfuric acid (H_2SO_4) by the contracting lab as a preservative. The other bottle (filtered sample) was filled with water filtered through a 47 mm filtering manifold and a 0.45 µm cellulose acetate filter. A vacuum of up to 38 cm of mercury (Hg) was applied using a hand operated pump. The DOC samples were collected by filling a 40 mL glass vial, leaving no headspace, with the EPI composite water. All bottles were labeled with station, date, time, depth (EPI or HYPO), and filtered or unfiltered. Sample bottles were stored on ice while in the field and transferred to a refrigerator until shipping. Samples were shipped via overnight carrier to the contracting lab within two days of collection. Chemical analyses were performed by AM Test Labs of Kirkland, Washington. Analytical methods used for each parameter can be found in Wilson et al. 2010.

A Chl *a* sample was collected by filtering 250 mL of the EPI composite water through a 0.45 µm glass fiber filter using a similar filtering manifold and hand pump, also taking care not to exceed a vacuum of 38 cm Hg. The filter was removed from the manifold and folded in half on a 15 by 15 cm piece of aluminum foil. The foil was folded around the filter, placed in a Ziploc™ bag and kept on ice until returning to the field office. After returning to the field office, Chl *a* samples were placed in a freezer until shipping.

Picoplankton samples were collected by filling a 60 mL amber polyethylene bottle with the EPI composite water and preserved with six drops of 50% glutaraldehyde. Phytoplankton samples were collected by filling a 125 mL amber polyethylene bottle with sample water, one each for EPI and HYPO. Samples were preserved with 15 drops of Lugol’s solution. All sample bottles were labeled with station, date, time, and depth (EPI or HYPO).

Zooplankton were collected using a 50 cm diameter, 80 µm mesh Wisconsin style net fitted with an OceanTest Equipment flow meter. One vertical tow was performed at each station from 10 m to the surface. Tows were completed by lowering the net to depth and retrieving at a rate of 0.5 m/s. The number of revolutions on the flow meter was recorded on the datasheet and plankton were rinsed from the net into the collection bucket, then rinsed into a collection jar and preserved in 70% ethanol. Collection jars were labeled with station, date, and depth of tow. Prior to the field season, several tows were performed with no net and the number of revolutions recorded to serve as a reference point. All plankton and Chl *a* samples were sent to TG Eco-Logic of Spokane, Washington for analysis. Analytical methods used for each parameter can be found in Wilson et al. 2010.

Data Analysis

The compensation depth is the depth where light intensity is 1% of the light intensity at 0 m. Before calculating compensation depth, the light intensity at depth was adjusted according to the ratio of the concurrent air measurement divided by the air measurement concurrent with the surface reading. Compensation depths were then calculated from the adjusted light intensity profiles by transforming the data as follows:

$$x = Ln\left[100\left(\frac{l_D}{l_S}\right)\right]$$

Where: Ln = natural logarithm
I_D = light intensity at depth
I_S = light intensity at 0 m

A regression was then developed using the transformed data as the independent variable and the depth (m) at which the measurement was taken as the dependent variable. The resulting equation was solved for x = *Ln*(1) = 0 to determine the compensation depth.

When summarizing the results of chemical analyses, numerous measurements were below the detection limit of a given assay. In order to calculate descriptive statistics, the detection limit for a given chemical analysis was used whenever the true value was below the detection limit.

Descriptive statistics were computed using JMP 9.0 from Statistical Analysis Software (SAS). Means were reported for data that were normally distributed and medians were reported for data that were not normally distributed. In the case of normally distributed data for which a median value was stipulated in the Consent Order issued by IDEQ, both a mean and median value were reported.

Between year comparisons of limnological data were performed using a multiyear sampling frame, which consisted of months and stations that were sampled consistently for all years compared for the metric in question. This sampling frame included data from stations RK-2, RK-31, RK-56, and RK-72 from May through November, unless noted otherwise. When comparing chemical concentrations, in cases where the minimum detection limit was not consistent for all years compared, the minimum was artificially adjusted upward to match the year with the highest minimum level. That is, values in all years below the minimum level for the year with the highest minimum level were considered to be equal to that level for the purposes of calculating descriptive statistics.

Phytoplankton densities were recorded both in terms of natural counting units (NCU), which refers to colony numbers for some species and cells for others. Prior to 2008, cells/mL was not recorded for colonial species. Therefore, densities will be reported as cells/mL whenever possible, except when making comparisons among years.

Inconsistencies also existed between years in zooplankton collection. To keep comparisons as consistent as possible, only data from collections with an 80 µm mesh net were used. Presupplementation data were collected from a depth that was twice the Secchi depth to the surface. Since this depth was, on average, similar to the current depth strata, it was compared directly to the data collected from 2008 through 2010 at depths from 10 m to the surface. Since data from 2007 was collected from 30 m to the surface, it was first adjusted by calculating the proportion of zooplankton collected in 2008 from 10 to 0 m to the total amount collected in the 10 to 0 m and 30 to 10 m tows (Wilson et al. 2010). The annual mean for this proportion was then applied to the 30 to 0 m data from 2007 to estimate the density of zooplankton from 10 to 0 m. These estimates were used when comparing 2007 data to other years.

Due to inconsistencies in the data, we chose to make comparisons between years using a graphical analysis of means and confidence intervals rather than attempting more rigorous statistical tests. Means were weighted by month to account for differences in sampling intensity throughout the year. For data that was not normally distributed, we used a bootstrap technique to derive 95% confidence intervals (Chernick 1999; Efron and Tibshirani 1994). For this, the original data was resampled with replacement using SYSTAT 11.0. For each year, 1000 iterations were performed in which a bootstrap mean was calculated. Confidence intervals were derived using the percentile method, in which the lower confidence limit was equal to the 2.5 percentile of the bootstrap distribution and the upper confidence interval was equal to the 97.5 percentile (Chernick 1999).

Quality Assurance

All equipment was rinsed in ethanol, followed by a triple rinse with distilled water, prior to each sampling event. The Kemmerer and splitter bucker were rinsed in surface water at each site prior to sample collection. Vacuum manifolds were rinsed in distilled water prior to installation of a new filter. For each sampling event, a station was randomly chosen to collect field duplicates, rinsates, and blanks. Field duplicates for chemical analysis were collected by filling additional sample bottles (one each for filtered and unfiltered) with EPI water. Rinsates were collected by transferring water provided by the analytical lab from the Kemmerer to the splitter bucket and the filtering manifold (filtered sample only) before filling additional sample bottles (one each for filtered and unfiltered). Blanks were obtained by filling additional sample bottles (one each for filtered and unfiltered) with water provided by the analytical lab. Additionally, a duplicate chlorophyll sample was obtained by filtering an additional aliquot of EPI water as previously described.

For each field duplicate that was collected, the relative percent difference (RPD) between the duplicate and original sample was calculated using the following formula:

$$RPD = \frac{|S_1 - S_2|}{(S_1 + S_2)/2} \times 100$$

Where: S_1 = Original sample
S_2 = Duplicate sample

Kokanee Population Monitoring

Abundance

As part of our sampling design, the reservoir was stratified into three sections (Figure 1). Section 1 extended from the dam to Dent Bridge at river kilometer 27.0, while Section 2 extended from Dent Bridge to Grandad Bridge at river kilometer 65.2. Section 3 encompassed the reservoir above Grandad Bridge.

A single hydroacoustic survey was conducted in July concurrent with a trawl survey. The survey was conducted using a Simrad model EK-60 echo sounder and a 120 kHz split beam transducer. The unit was calibrated prior to the survey using a -40.4 decibel (dB) calibration sphere. Kokanee abundance was estimated using a stratified systematic sampling design using the previously described strata. Transects of similar length were laid out in a zigzag pattern across the reservoir, with one transect beginning where the last one ended (Simmonds and

MacLennan 2005). Boat speed during the survey averaged 1.6 m/s. The echo sounder was set to ping at 1 s intervals with a pulse width of 0.256 milliseconds.

The pelagic region of each echogram was analyzed using Echoview 4.0 software. For the analysis, a maximum beam compensation of 6.0 dB and a minimum and maximum normalized pulse length of 0.3 and 1.8 were used to distinguish fish from noise. Depths between 10 and 30 m were analyzed using an echo integration technique to calculate the nautical area scattering coefficient (NASC) and mean target strength (TS). Fish densities were calculated as:

$$\text{Density (fish/ha)} = (\text{NASC} / 4\pi 10^{TS/10})\ 0.00292$$

Frequency distributions were developed by binning the number of single targets in 1 dB intervals (adjusted target strength) for a given transect. Age breaks were then determined using length at age data from the trawl survey. For this, length at age breaks from trawl caught fish were converted into target strengths using Love's (1971) equation. The percentage of age-0 fish in a particular transect was then determined based on these age breaks and the target strength distribution from that transect. Fish above this age break (age-1 and older) were partitioned based on the proportion of each age class captured in the trawl.

The mean densities were multiplied by the area of kokanee habitat in each section to arrive at an estimate of age specific abundance for each section. This area was determined by first subtracting the mean depth for single targets in each section from the pool elevation at the time of the survey to determine the mean elevation of the kokanee layer. The reservoir elevation at this elevation was then looked up from a table provided by the USACE (Sam Martin, USACE, personal communication). This table was created using USGS topographic data from pre-impoundment.

Age and Growth

Trawl surveys were based on methods described by Rieman (1992). An 8.5 m diesel powered boat was used to tow a fixed-frame midwater trawl. The net was 10.5 m long and attached to a 3.0 m high by 2.2 m wide steel frame. The body of the net consisted of four panels with bar mesh sizes of 32, 25, 19, and 13 mm. The cod end was composed of 6 mm delta mesh held open by a 0.8 m steel hoop.

Three surveys were conducted, one each in April, July, and November. A November survey was conducted in lieu of an October survey in 2010 due to mechanical difficulties with the trawler. All surveys were conducted within five nights of the new moon to maximize capture efficiency (Bowler et al. 1979). For the July trawling, five randomly preselected transects were surveyed in each section. For the April and November trawling, 3-6 transects were conducted per section in Section 1 and 2. Trawling was not performed in Section 3 due to low reservoir levels. All fish were measured to the nearest mm total length (TL) and a subsample was weighed to the nearest gram. Scales were collected from ten fish from every 1 cm length class from each section. Scales were later examined by two independent readers to determine age (Nielsen and Johnson 1983).

The relative weight (W_r) was calculated for all fish above 119 mm TL. Standard weights (W_s) for kokanee of a given length were obtained from Hyatt and Hubert (2000). A W_r for each fish with a known TL and weight (W) was then calculated using the formula from Anderson and Neumann (1996).

In order to estimate the number of fish from each age class caught in the trawl, the proportion of each age class represented in each 1 cm bin was calculated by dividing the number of fish of each age class, as determined from scale analysis, by the total number of fish aged in that bin. These proportions were then applied to the remaining fish in the length bin, which were not aged, in order to estimate the number from each age class within each bin. To calculate the mean TL and W_r for each age class, we first calculated these for each length bin regardless of age. The means for each bin were then multiplied by the estimated number of fish from each age class in that bin, and the products were totaled for each age class to calculate an arithmetic mean. Standard deviations were calculated in a similar manner using the following formula from Zar (1999).

$$s = \sqrt{\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}}$$

Where:
s = standard deviation of the population
X_i = i^{th} individual observation
n = sample size

The timing of trawl surveys for previous years could potentially vary by up to a month, depending on the timing of the new moon in July. To account for differences in length due to annual differences in the timing of the trawl surveys, we fit length data for individual fish from each age class to the following Von Bertalanffy growth model (Isely and Grabowski 2007) for each year in which multiple trawl surveys were performed (2004 and 2008 – 2010).

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

Where:
L_t = The predicted length at time t
t = The Julian date
t_0 = The theoretical date for L = 0
L_∞ = The theoretical maximum mean length
K = Brody growth rate coefficient

Because age-2 fish typically spawn that fall, there were typically only two data points (spring and summer). Therefore, we used age-1 fish to estimate K and assumed this value when fitting the model for age-2 fish. Data from the 2007 trawl were not used because individual length data were not available for the fall survey. Models were independently fit to data for each year and age class using JMP 9.0. The L_∞ for each model represents the theoretical maximum mean length that each age class should obtain that year. In order to make adjustments for all years, including those for which we did not have enough data to model, we calculated the mean ratio of L_∞/L_t for each age class for each day in July as a correction factor for that Julian date. The mean TL for trawl caught fish was then multiplied by the correction factor for the Julian date of the trawl survey in order to estimate L_∞ for a given year. This estimate for L_∞ was used to compare age specific size between years taking the time of year that fish were sampled into account. In order to assess differences in fish size due to N supplementation, we compared mean size for years with similar abundance.

Production

Production refers to the overall gain in biomass of a fish stock over a specific period, regardless of the fates of the individual fish that make up the stock (Ricker 1975). To estimate kokanee production between July 2009 and July 2010, we adapted a summation method described by Hayes et al. (2007). For this, we first calculated the mean abundance of each cohort using acoustic estimates for each year. We then calculated the mean weight gain for an individual in each cohort based on data from trawling surveys conducted at the same time. The mean weight gain was multiplied by the mean abundance to obtain an estimate of production, assuming linear rates of growth and mortality.

Spawner Counts

Ten days prior to peak spawning, prespawn fish were collected from each of the index streams using a seine and dip nets. All fish were measured to the nearest mm TL and weighed to the nearest g. Sex was determined using secondary sexual characteristics or by expressing gametes. Females were euthanized, the ovaries removed and weighed to the nearest g, and preserved in 95% ethanol. Secondary oocytes were later enumerated for each ovary. Mean oocyte weight was calculated by dividing the number of oocytes by the total weight of the ovary (somatic tissue was considered inconsequential). The gonadal somatic index (*GSI*) was calculated for females using the following formula:

$$\mathrm{GSI} = \frac{\mathrm{GW}}{\mathrm{BW} - \mathrm{GW}} \times 100$$

Where: *GW* = gonad weight
BW = body weight

Peak spawner counts were conducted on four index streams on the lower North Fork Clearwater River above the reservoir on September 23-24. These included Isabella (RKM 92), Skull (RKM 105), Quartz (RKM 109), and Dog (tributary to Isabella at RKM 2.6) creeks. Each of the index streams were walked from the mouth to the uppermost extent of utilization by spawning kokanee. All spawning kokanee were individually counted when possible or estimated in the case of a deep pool with a large group of fish.

RESULTS

Environmental Conditions

In 2010, inflow to Dworshak Reservoir peaked at 606 m^3/s on June 3 (Figure 2). The mean inflow of 113 m^3/s was lower than the ten-year mean (2000-2009) of 146 m^3/s. The peak discharge from Dworshak Dam was 388 m^3/s on June 21 (Figure 2). The mean discharge of 103 m^3/s was the same as the ten-year mean (2000-2009). Reservoir elevation began at a low of 461 m on January 14 and reached full pool (487.7 m above mean sea level) on June 24 (Figure 2).

Physical and Chemical Limnology

Temperature

In 2010, water temperatures at 1 m were within the range observed for previous years. The mean temperature for the multiyear sampling frame in 2010 was 18.2°C, which was similar to the long-term mean (2004–2009) of 18.4°C. The minimum temperature observed within this sampling frame in 2010 was 7.1°C, which was lower than the minimum observed in all but one of the previous five years. The maximum temperature observed was 25 3°C, which fell within the range of other years (range = 24.0 to 27.2°C). Graphic representations of temperature data are presented in Appendix A.

A thermocline developed at all stations by May 17 and persisted throughout the reservoir through August 23. Stratification occurred earlier or persisted later at some stations, but not reservoir wide. Thermocline data are presented in Appendix B.

Dissolved Oxygen

In general, DO concentrations remained near saturation for much of the season. As is typical with Dworshak Reservoir, reductions in DO were observed in the metalimnion and hypolimnion late in the year. DO levels below 5 ppm were observed at all stations except RK-2. Although they occurred as early as late July, they were typically observed during August and September. Low DO levels were typically observed near the bottom and were most severe at RK-66 in September and at EC-6 from late September through November. Additional summaries of DO data can be found in Scofield et al. (2011).

Water Clarity

The median Secchi depth in 2010 was 3.0 m for treated areas of the reservoir, which was equal to the minimum value specified in the Consent Order. The median depth for the reference sites was 2.5 m. In 2010, the median Secchi depth for the multiyear sampling frame was 3.2 m, which was within the range of medians observed prior to supplementation (range = 3.0 to 4.9 m). In order to compare Secchi measurements between years, means and bootstrap confidence intervals were calculated for the multiyear sampling frame. The confidence interval for 2010 overlapped with those from 2006 and 2009, but no other years. Additional summaries of Secchi depths for 2010 can be found in Scofield et al. (2011).

The mean compensation depth in 2010 was 9.7 m for treated areas of the reservoir and 8.5 m for the reference sites. To compare annual means from 2007 to 2010, traditional confidence intervals were calculated using data from the multiyear sampling frame with the addition of RK-66. Confidence intervals overlapped for all four years. Compensation depth, as calculated from PAR data, is not available for years prior to 2007. Compensation depths for 2010 are summarized in Appendix C.

Phosphorus

The annual median value for TP in the epilimnion was 0.004 mg/L. This was well below the limit of 0.025 mg/L set forth in the Consent Order. The annual median for the multiyear sampling frame for 2010 was also 0.002 mg/L, which was the lowest value for the study period (range = 0.002 to 0.019 mg/L). Median values for applications years were all less than median values for presupplementation years (no test for significance). In order to compare TP levels across years, the data were first corrected to a minimum detection level of 0.01 mg/L for all years. Sample means were lower in supplementation years than in presupplementation years; however, bootstrap confidence intervals overlap for most years (Figure 3). The confidence interval for 2010 did not overlap with any presupplementation years.

The annual median for TP in the hypolimnion was 0.003 mg/L, which was similar to that of the epilimnion. As with the epilimnion, sample means for the multiyear sampling frame appear to be trending down. The bootstrap confidence interval for the 2010 multiyear sampling frame did not overlap with that for any presupplementation years (Figure 3).

The annual median for TP at NFC was 0.005 mg/L, which was similar to both depth strata from the reservoir. There was no apparent trend in sample means since nutrient supplementation began. Of the downstream sampling sites, TP was highest in the burrows pond at DNFH, although confidence intervals overlapped slightly with NFC (Figure 4). The mean TP concentration was similar for all other sites.

In 2010, the annual median value for TDP in the epilimnion was 0.001 mg/L for the whole reservoir and the multiyear sampling frame. Median values for TDP ranged from 0.006 to 0.012 mg/L prior to nutrient supplementation and from 0.001 to 0.003 mg/L during supplementation. In order to compare TDP levels across years, no adjustment to the minimum detection limit was necessary. Sample means were higher in presupplementation years and bootstrap confidence intervals did not overlap between presupplementation and supplementation years (Figure 3).

The annual median for TDP in the hypolimnion was 0.001 mg/L, which was equal to that of the epilimnion. Annual means for the multiyear sampling frame exhibited a similar trend to that of the epilimnion. As with TP, mean TDP values for the hypolimnion were higher presupplementation and bootstrap confidence intervals did not overlap (Figure 3). The annual median for NFC was 0.001 mg/L, which was equal to both strata in the reservoir. There was no apparent trend in sample means for NFC since 2007. Of the downstream sites, the burrows pond also had the highest mean TDP value. Confidence intervals overlapped with the raceways and Clearwater River, but not the North Fork Clearwater River or the reservoir (Figure 4). Additional summaries of phosphorus data for 2010 can be found in Scofield et al. (2011).

Nitrogen

In 2010, the annual median value for N+N in the epilimnion was 0.001 mg/L for the whole reservoir and the multiyear sampling frame. Median values for N+N ranged from 0.001 to 0.013 mg/L prior to nutrient supplementation and from 0.001 to 0.003 mg/L during supplementation. In order to compare N+N levels across years, the data were first corrected to a minimum detection level of 0.01 mg/L for all years. Mean nitrogen values were variable from year to year and there were no apparent effects due to nitrogen supplementation. Bootstrap confidence intervals for 2010 overlapped with all years except 2006 (Figure 3).

The annual median for N+N in the hypolimnion was 0.013 mg/L, which was greater than that of the epilimnion. Hypolimnetic N+N has declined since 2006, but means for supplementation years are similar to 2005 (Figure 3).

The annual median for NFC was 0.045 mg/L, which was greater than both strata in the reservoir. There was no apparent trend since 2007 and bootstrap confidence intervals overlap for all three years. Of the downstream sampling sites, NFC had the highest mean N+N concentration; however, confidence intervals overlapped with both DNFH sites (Figure 4). Additional summaries of nitrogen for 2010 can be found in Scofield et al. (2011).

Total Dissolved Solids

The annual mean for TDS was 20.0 mg/L for the whole reservoir. Annual means for 2007 through 2010 were compared using traditional confidence intervals calculated from data for all months and treated areas of the reservoir. Confidence intervals for all four years overlapped.

The annual mean for TDS at NFC was 21.0 mg/L. Annual means for 2007 through 2010 were compared using traditional confidence intervals calculated from data for all months. Confidence intervals for all four years overlapped. Additional summaries of TDS data for 2010 can be found in Scofield et al. (2011).

Dissolved Organic Carbon

The concentration of DOC was measured from the epilimnion at RK-31 and RK-72 during the first sampling event each month. The annual median was 4.5 mg/L. Levels of DOC have trended upward since nutrient applications began in 2007. Bootstrap confidence intervals show that DOC was significantly higher in 2010 than in 2007 and 2008, but not 2009.

Biological Indicators

Chlorophyll *a*

The annual median for Chl *a* in the epilimnion was 1.80 µg/L for the whole reservoir, which was below the maximum stipulated in the Consent Order. The median value for the multiyear sampling frame was 1.70 µg/L and the mean was 2.10 µg/L. The bootstrap confidence interval for the 2010 mean overlapped with those for all other years (Figure 5).

The annual median for Chl *a* at NFC was 0.25 µg/L, which was less than the epilimnetic median for the reservoir (Figure 5). The concentration of Chl *a* at NFC was always 78% or less of the concentration measured at RK-2 during the same sampling event, and in most instances was 15% or less. Additional summaries of Chl *a* data for 2010 can be found in Scofield et al. (2011).

Picoplankton

The annual mean density of picocyanobacteria was 131,000 cells/mL and the median was 113,000 cells/mL. Differences between annual means for stations were not significant (ANOVA: $F_{6, 98} = 1.48$; $p = 0.19$). Reservoir-wide densities were lowest in May (median = 13,000 cells/mL) and peaked in July (median = 220,000 cells/mL). Comparisons were made for the multiyear sampling frame between May and October. Mean densities were substantially higher for supplementation years and bootstrap confidence intervals overlapped for supplementation years, but no supplementation years overlapped with 2006 (Figure 6).

The annual mean density of heterotrophic bacteria was 947,000 cells/mL. Differences between stations were not significant (ANOVA: $F_{6, 98} = 0.63$; $p = 0.70$). Reservoir-wide densities were lowest in March (mean = 563,000 cells/mL) and highest in October (mean = 1,239,000 cells/mL). Comparisons were made for the multiyear sampling frame between May and October. As with picocyanobacteria, the mean density of heterotrophic bacteria was substantially higher for all supplementation years than in 2006 (Figure 6). Bootstrap confidence intervals for supplementation years did not overlap with 2006. Confidence intervals for 2010 overlapped with intervals for 2008 and 2009, but were lower than 2007. Additional summaries of picoplankton data can be found in Scofield et al. (2011).

Phytoplankton

In 2010, the mean epilimnetic total phytoplankton density for all stations was 11,594 NCU/mL and the median was 9,439 NCU/mL. Of the major taxa, blue-green algae exhibited the highest annual density (mean = 7,439 NCU/mL), followed by flagellates (mean = 2,914 NCU/mL) diatoms (mean = 674 NCU/mL) and coccoid greens (mean = 529 NCU/mL). Dinoflagellates (mean = 36 NCU/mL) and euglenoids (mean = 3 NCU/mL) represented a minor portion of the phytoplankton community.

Phytoplankton densities were lowest in March (mean = 5,380 NCU/mL) and November (mean = 3,763 NCU/mL). Densities peaked in July (mean = 20,199 NCU/mL), driven in large part by increases in blue-greens (mean = 15,795 NCU/mL) and diatoms (mean = 2,520 NCU/mL).

Blue-greens were the dominant species encountered at all stations, accounting for 53% of the phytoplankton counted over the entire season on average. Flagellates accounted for 35%, diatoms accounted for 6%, and coccoid greens accounted for 5%. The remaining groups accounted for less than 1%. Reservoir-wide, flagellates were the dominant species from March through May, while blue-greens were dominant in all other months.

Synechococcus sp. was the dominant taxa of blue-greens in every month except July, August, and October, accounting for 56% of the blue-greens counted throughout the entire season. *Microcystis sp.* was dominant from August through October (*Synechococcus* and *Microcystis* co-dominated in September), accounting for 19% of the blue-greens throughout the year. *Aphanothecae* sp. was dominant in July and accounted for 13% of the blue-green taxa for the year. *Chroococcus sp.* accounted for 8%, while all other taxa accounted for 2% or less. *Microcystis sp.* and *Anabaena sp.* are of concern because they are not only inedible to zooplankton, but can produce toxins under certain conditions, making them a potential public health hazard. While *Anabaena sp*. was not observed at high enough densities to cause concern in 2010, *Microcystis sp.* was observed at densities in excess of 20,000 cells/mL at RK-66 on October 4.

Phytoplankton edibility was determined from published research and is a key metric for evaluating the effectiveness of the nutrient supplementation program. The mean percentage of phytoplankton in a given sample (measured in NCU/mL) for which edibility could be established was 96% for the entire season. The annual mean density of edible phytoplankton across all stations was 6,452 NCU/mL, which represented 70% of all phytoplankton for which edibility could be established. These figure increased to 8,62 NCU/mL and 81% when including taxa that are edible during only a portion of their life history.

Densities of edible phytoplankton were highest at EC-6 (median = 8,025 NCU/mL) and lowest at RK-2 (median = 5,293 cells/mL). The percentage of edible phytoplankton was highest at EC-6 (median = 82%) and lowest at RK-56 (median = 67%). Densities of edible phytoplankton were lowest in November (median = 2,390 NCU/mL) and peaked in June (median = 8,183 NCU/mL) and September (median = 8,281 NCU/mL). The percentage of edible phytoplankton was highest in March and April (median = 97%) and lowest in July (median = 40%).

Comparisons between years were made using biovolume (mm^3/L), since density measurements are not consistent between years. Total phytoplankton in 2010 was similar to 2005 and 2008, but less than 2006, 2007, and 2009 (Figure 7). The mean biovolumes of blue-greens, flagellates, and coccoid greens were all down from the previous year, although means for blue-greens and coccoid greens were similar to other years. The mean biovolume of flagellates was the lowest in recent years, but confidence intervals overlapped with 2007. Mean biovolumes of diatoms and dinoflagellates have remained low since 2008. The mean biovolume of edible phytoplankton remained similar to previous years and the biovolume of inedible taxa has remained low since 2008 (Figure 8).

The dominant taxa of toxigenic blue-greens in Dworshak Reservoir have historically been *Anabaena* and *Microcystis*. The proportion of the total phytoplankton biovolume that was composed of toxigenic blue-greens has steadily declined since 2007, to the point that this percentage was lower in 2010 than for any year for which we have data (Figure 9). This is due to a steady decrease in the proportion of *Anabaena* in our samples. The mean proportion of *Microcystis* has remained similar in most supplementation years as compared to presupplementation years. The exception being 2009, which had the highest mean proportion of any year for which we have data. However, confidence intervals for 2009 overlap with all years except 2006 and 2010. Additional summaries of phytoplankton data can be found in Scofield et al. (2011).

Zooplankton

The mean density for total zooplankton across all stations in 2010 was 45.5 individuals/L and the median was 36.8 individuals/L. Total zooplankton densities were lowest in November (mean = 12.7 individuals/L) and highest in July (mean = 84.5 individuals/L). The zooplankton community was composed of two major groups: copepods and cladocerans. The mean density of copepods across all stations was 34.4 individuals/L and the median was 24.3 individuals/L. The mean density of cladocerans across all stations was 11.1 individuals/L and the median was 6.3 individuals/L. Copepods were the dominant group in every month, ranging from 53% of the individuals counted in August and September to 93% in June.

Cyclopoids were the dominant taxa of copepods throughout the reservoir, comprising from 54% of the mean zooplankton density at RK-72 to 65% at RK-66. *Cyclopoids* were dominant across all stations in every month, although they accounted for less than 50% of all zooplankton from August through November.

Cladoceran densities are of particular interest, as they are the preferred forage of kokanee. In terms of annual means, *Bosmina sp.* was the dominant genera of cladoceran at RK-2, RK-31, EC-6 and LNF-3, whereas *Daphnia sp.* was the dominant genera at RK-56, RK-66 and RK-72. *Diaphanosoma* was the third most prevalent genera at all stations, while the remaining cladocerans composed less than 1% of the total zooplankton on average. *Bosmina sp.* was the dominant genera of cladocerans from March through June and again in September and October. *Daphnia sp.* was the dominant cladoceran in July, August, and November.

Zooplankton densities were compared between years using data from stations (RK-2, RK-31, RK-56, and RK-72) and months (June through November) that were consistently sampled in all years. Data was only used from tows of similar depths or using data that was adjusted for depth strata (2007). The mean density of total zooplankton was highest in 2010. Confidence intervals only overlapped slightly with 2009, with an overall trend of increasing zooplankton with N supplementation (Figure 10). This pattern also holds true for copepods and cladocerans independently. Mean *Daphnia sp.* densities were also highest in 2010. Confidence intervals for the mean *Daphnia sp.* density in 2010 overlap with those of other supplementation years, but do not overlap with those for the presupplementation years.

Annual mean lengths of *Daphnia sp.* were below 1 mm for all stations except RK-72 and EC-6. *Daphnia sp.* were smallest in March (mean = 0.61 mm) and largest in August (mean = 1.10 mm). The mean length for RK-2, RK-31, RK-56, and RK-72 from June through November was below 1 mm for 2010 and confidence intervals overlapped with presupplementation years, but not with the first three years of supplementation (Figure 11).

Annual mean total lengths of *Bosmina sp.* ranged from 0.41 mm at RK-72 and RK-66 to 0.44 mm at RK-2 and EC-6. *Bosmina sp.* were smallest in July (mean = 0.37 mm) and largest in October (mean = 0.45 mm). The mean *Bosmina sp.* length for the 2010 multiyear sampling frame was longer than any previous year and confidence intervals only overlapped with those for 2008. Additional summaries of zooplankton data can be found in Scofield et al. (2011).

Kokanee Population Monitoring

Abundance and Density

From the hydroacoustic survey conducted on July 5-8, we estimated an overall abundance of 4,539,000 kokanee in Dworshak Reservoir (Table 1). Of these, 2,331,000 were age-0, 1,177,000 were age-1, 1,030,000 were age-2, and 1,500 were age-3. These estimates were based on an overall density of 835 fish/ha (Table 1). When broken out by age, the densities were 429 fish/ha for age-0, 217 fish/ha for age-1, 190 fish/ha for age-2, and 0.3 fish/ha for age-3.

Overall abundance (1,944,000) was highest in Section 1, while density (1,727 fish/ha) was highest in Section 3 (Table 1). Overall abundance (1,105,000) was lowest in section 3 and density (649 fish/ha) was lowest in Section 1. Abundance of age-0 (935,000) fish was highest in Section 2, while the abundance of age-1 (562,000) and age-2 (703,000) fish was highest in Section 1. Density of age-0 and age-1 were highest in Section 3, while density of age-2 was highest in Section 1. Age-3 fish were only found in Section 3 based on trawl surveys. Historical abundance estimates for kokanee are presented in Appendix E.

Age and Growth

Midwater trawls conducted on April 22-23, July 13-14, and November 3 sampled a total of 930 kokanee. Of these, 104 were captured during April trawling, 672 in July, and 154 in November. In April, trawl-caught kokanee ranged from 79 to 222 mm total length (Figure 12). Only age-1 and age-2 fish were sampled in April; no age-0 kokanee were encountered. A total of 47 age-1 kokanee were captured in April, ranging from 79 to 145 mm total length (TL) with a mean of 117 mm (Table 2). A total of 57 age-2 kokanee were captured, ranging in size from 172 to 222 mm TL. Age-2 kokanee had a mean TL of 198 mm and a mean W_r of 79.

In July, trawl caught kokanee ranged from 33 to 285 mm TL (Figure 12). Of these, 190 were age-0 between 23 and 69 mm total length, with a mean TL of 44 mm (Table 2). Through scale analysis and length distributions, 309 were determined to be age-1, ranging in size from 136 to 188 mm TL. The mean TL of age-1 kokanee was 172 mm and the mean W_r was 87. Another 172 were determined to be age-2, ranging in size from 191 to 265 mm TL. Age-2 kokanee had a mean TL of 219 mm and a mean W_r of 86. A single age-3 kokanee measuring 285 mm TL was captured in Section 3 during the July trawl survey.

In November, trawl-caught kokanee were between 58 and 236 mm TL (Figure 12). Of these, 132 were age-0 and ranged in size from 58 to 133 mm TL (Table 2). Age-0 kokanee had a mean TL of 92 mm. Another 16 were determined to be age-1, ranging in size from 171 to 201 mm TL. Age-1 kokanee had a mean TL of 189 mm and a mean W_r of 89. A total of six kokanee captured in November were determined to be age-2, ranging from 208 to 236 mm TL. Age-2 kokanee had a mean TL of 218 mm and a mean W_r of 86.

The mean TL of age-0 kokanee increased by 48 mm from July to November (Table 2). The mean TL of age-1 kokanee increased by 55 mm from April to July and by 17 mm from July to November, for a total of 72 mm. The mean TL of age-2 kokanee increased by 21 mm from April to July. Growth, in terms of increases in mean TL, was slower in 2010 than for any recent year for which data exists, including 2004 (presupplementation). Seasonal increases in W_r were second only to 2008 for age-1 kokanee, and only slightly less than 2004 for age-2 kokanee.

Von Bertalanffy growth models were fitted to each year class for each year that we have multiple trawl survey data (2004 and 2008 – 2010). The predicted L_∞/L_t for each model resulted in a set of parallel lines for the month of July with no more than 3% difference between years for each year class. Therefore, we used an average value for each day to create a conversion factor, which was used to estimate L_∞ for all years with July trawl data based on the observed L_t, since there is insufficient data to estimate this value by fitting the model in years with a single trawl survey. Estimates of L_∞ can be found in Table 3.

There were two pairs of years that had similar abundance of age-1 and older fish. The years 2004 (347,000) and 2008 (326,000) represent a pairing of low density years and 2006 (2.7 million) and 2010 (2.2 million) represent a pairing of high density years (Figure 13). The mean TL and estimated L_∞ for age-2 fish in 2004 and 2008 were very similar; however, age-2 fish were almost 20 g heavier in 2008. The mean TL and estimated L_∞ for age-2 fish in 2010 were both nearly 25 mm longer than in 2006, and fish were 35 g, or over 50%, heavier in 2010 as compared to 2006.

Production

Kokanee production from July of 2009 to July of 2010 was estimated as 103.7 metric tonnes (t). During this period, biomass was estimated to have increased from 69.6 t in 2009 to 151.7 t in 2010. Mortality by weight was estimated to be 1.9 t. Historical production estimates can be found in Appendix F.

Spawner Counts

On September 15, we captured 60 prespawn kokanee: 40 from Isabella Creek and 20 from Skull Creek. In addition, we collected 22 post-spawn carcasses during spawner counts on September 23 and 24, for a total of 82 adult kokanee. Of these, an equal number (41) were male and female. Prespawn kokanee exhibited a unimodal length distribution (Figure 14) that ranged from 223 mm to 294 mm (Figure 14), with male and female kokanee averaging 246 mm and 244 mm TL, respectively. Two prespawn kokanee greater than 289 mm TL, one male and one female, were captured. Based on scale analysis from trawl caught fish in July and November, these were presumed to be age-3, while all others were presumed to be age-2.

Ovaries were obtained from 20 prespawn females from Isabella Creek. The mean fecundity was 372 oocytes per female and the mean oocyte weight was 0.055 g per oocyte. We used linear regression to examine the relationship between TL and GSI, fecundity or mean egg weight. The relationships between TL and *GSI* (linear regression, $p = 0.25$, $r^2 = 0.07$) and TL and mean egg weight (linear regression, $p = 0.89$, $r^2 < 0.01$) were not significant. However, the relationship between TL and fecundity was highly significant (linear regression, $p < 0.001$, $r^2 = 0.50$).

Peak kokanee spawner counts were performed on September 23-24, during which 59,409 spawning kokanee were counted in four index streams. This included 25,529 in Isabella Creek, 24,212 in Skull Creek, 5,283 in Quartz Creek, and 3,385 in Dog Creek. Historical spawner count data are shown in Appendix G.

DISCUSSION

Water Quality

While the goal of the nutrient supplementation project is to restore lost productivity to the reservoir, it is imperative to do so without degrading overall water quality. In 2010, water quality standards, as set forth in the Consent Order issued by the IDEQ, were not exceeded. Although water clarity, as measured by Secchi depth, was the lowest measured during the study period, it was within the range observed during the three years prior to supplementation. Not only was the median Chl *a* concentration for 2010 within the limit set by IDEQ, but Chl *a* does not appear to be increasing due to nutrient additions. Since phosphorus is no longer applied, we do not expect the project to result in increased TP loading. Moreover, TP and TDP continue to trend downward since nitrogen supplementation was initiated.

Another water quality parameter of concern is DO. As with previous years, DO minima were observed in the metalimnion and hypolimnion at several stations on the upper end of the reservoir during late summer and early fall. These minima are presumed to be caused by phytoplankton that senesce, settle out of the epilimnion, and collect in the metalimnion where they begin to decay (TG Eco-Logic 2008). Although these metalimnetic DO minima occurred prior to the nutrient enhancement project, it is possible that the addition of nutrients and the increased productivity of the system could intensify this phenomenon (TG Eco-Logic 2008). The low DO levels observed in 2010 were similar to most years except 2008, which was a high flow year (Scofield et al. 2011). Comparisons of DO concentrations across years did not provide any evidence that nitrogen supplementation is intensifying the late season DO minima (Scofield et al. 2011).

Water quality downstream of the reservoir in the North Fork Clearwater River was also a concern. We continued to sample the river below the dam in addition to the reservoir to evaluate downstream effects of supplementation. Unfortunately, no samples were collected prior to nutrient supplementation, so direct comparisons to previous years are impossible. However, nutrient concentrations at NFC most closely resembled those from the hypolimnion. Comparisons of water temperatures from the epilimnion, hypolimnion, and river indicate that the river temperature closely tracks the temperature of the hypolimnion but not the epilimnion, suggesting that the hypolimnion is the primary water source for the river. Nutrient levels in the hypolimnion have decreased since nutrient applications were started, thus it is unlikely that nutrient levels in the river have increased. Furthermore, there has been no apparent trend in nutrient concentrations in the river since N supplementation began.

The effects of N supplementation on operations at the two fish hatcheries immediately downstream of Dworshak Dam have been an ongoing concern. Personnel working at both hatcheries have reported increased periphyton growth since the nutrient supplementation project began. It has been suggested that increased algae in burrows ponds has increased stress levels on juvenile steelhead reared at DNFH, leading to increased IHN mortality. However, the degree of this growth remains uncertain and there are no presupplementation measurements for comparison. In 2010, we collected additional water samples from both hatcheries to assess differences in nutrient loading. In particular, the burrows pond used for steelhead rearing at DNFH tended to have higher concentrations of P than the source water, suggesting that internal sources (i.e. fish and feed) may be a significant contributor to the nutrient loading in these ponds. Raceways at both hatcheries, which have a higher flush rate and no water re-use, had similar nutrient concentrations as the source water. Personnel at both hatcheries kept raceway and pond surfaces relatively clean for the majority of our visits and no disease outbreaks occurred in 2010 that could be linked to algae growth. In our discussions with hatchery personnel, algae growth was considered to be a manageable problem regardless of the cause.

Reservoir Productivity

Dworshak Reservoir is an ecologically complex system with a great deal of annual variation. Environmental conditions, such as snowpack and runoff, appear to be the key drivers of the limnological conditions and resultant plankton communities within the reservoir (TG Eco-Logics 2008, 2009; Scofield et al. 2010). The current intensity of the limnological sampling will be critical in separating the effects of nutrient supplementation from the effects of year-to-year variation in the environment and we should gain a better understanding of how the reservoir is responding to nutrient supplementation with each year that data is collected.

In 2010, N supplementation was suspended in late July due to a legal challenge which led to a change in permitting requirements. We believe this resulted in changes to the phytoplankton community structure and food web efficiency late in the year, but likely did not have a large effect on the annual productivity of the reservoir.

Chl *a* is often used as an indicator of productivity in lakes and reservoirs. Mean Chl *a* has not increased in response to nitrogen supplementation, suggesting that productivity has not increased. However, the relationship between chl *a* and phytoplankton biomass is dependent on many variables, including species composition. Furthermore, if the composition of the phytoplankton community has shifted to more edible species, those species may be grazed off by zooplankton at a higher rate, thus masking the increase in productivity (Scofield et al. 2010).

For the fourth consecutive year, densities of picoplankton were substantially higher than in 2006 (a presupplementation year). The picoplankton response in Dworshak Reservoir is similar in magnitude to that observed during the first years of nutrient supplementation in BC lakes and reservoirs (Pieters et al. 2003; Stockner and MacIsaac 1996; Stockner and Shortreed 1994). These taxa are capable of rapid nutrient uptake and nearly exponential growth (Stockner and Antia 1986), and it is a clear indication that nutrient supplementation is stimulating the lower trophic levels. Since picoplankton are a food source for flagellates (Jurgens and DeMott 1995), it is likely that increases in picoplankton will also result in increased densities in higher trophic levels.

In previous reports, phytoplankton densities have been compared using natural counting units (NCU). An NCU could be a single cell for many species, or a colony for others. In 2008, the counting methodology was changed to use cells instead of colonies for as many species as possible in order to improve accuracy. However, data collected as cells/mL is not comparable with data collected in colonies/mL. Furthermore, increases in cells/mL of total phytoplankton may not represent an increase in biovolume if there is a shift toward smaller species. Therefore, comparisons with previous years were made using biovolume for this report.

There is no clear trend in mean biovolume of total phytoplankton; therefore, N supplementation does not appear to have led to an increase in the standing biovolume of phytoplankton. However, N supplementation appears to have led to a shift in the community structure of phytoplankton. When examining the trend in biovolume of edible phytoplankton, there does not appear to be any appreciable increases. However, this data represents standing biovolume only, and does not indicate whether or not there has been any increase in growth rates. Increased productivity in edible species can be masked by increased grazing from zooplankton. Zooplankton densities in 2010 were the highest observed in recent years (Figure 10), suggesting that grazing may have been a significant limiting factor in phytoplankton standing biovolume. Furthermore, the biovolume of inedible species has remained lower for most supplementation years as compared to presupplementation years. Since these species are not vulnerable to grazing, we can assume that production has shifted toward the edible varieties. If this is indeed the case, it indicates that the system is becoming more efficient in transferring energy up the food chain.

In previous years, densities of toxigenic cyanobacteria (blue-green algae) have been a cause for concern. *Microcystis* and *Anabaena* are the two predominant taxa that have led to this concern. These taxa typically become prevalent in late summer and fall after available nitrogen has been exhausted. In 2010, *Anabaena* was never observed in our composite samples at densities that would be cause for concern (maximum = 2,805 cells/mL). *Microcystis* densities remained well below the threshold that World Health Organization (WHO) determined was a mild health concern (20,000 cells/mL; Falconer et al. 1999) for the period that N was applied. However, on October 5, more than two months after N application was suspended, *Microcystis* was observed at a density of 23,416 cells/mL at RK-66. Additionally, USACE personnel detected a low level of microcystin, a toxin produced by cyanobacteria, including *Microcystis* and *Anabaena*, near the Visitor's Center in late August, approximately one month after applications were suspended.

Overall, the percentage of the total phytoplankton biovolume represented by toxigenic cyanobacteria has steadily decreased since N applications began in 2007. This is due primarily to a decrease in the proportion of the phytoplankton community represented by *Anabaena*. Prior to 2009, *Anabaena* was the dominant taxa of toxigenic cyanobacteria. Beginning in 2009, *Anabaena* was replaced by *Microcystis* as the dominant taxa. The proportion of *Microcystis* in our samples has not decreased, and has been higher in some supplementation years than some presupplementation. However, the sharp decrease in *Anabaena* has more than offset any increases in *Microcystis*, resulting in a lower overall proportion of toxigenic taxa. This trend is likely a direct effect of N supplementation. Since *Anabaena* can fix atmospheric N, its competitive advantage under N exhaustion is removed by adding N in a form that other, more desirable taxa can use. *Microcystis*, on the other hand, cannot fix atmospheric N, but can continue to take up fixed N at very low concentrations, thus giving it a competitive advantage when available N is very low, but not completely exhausted. Therefore, continued addition of N at current levels is not likely to reduce the proportion of *Microcystis*, but should continue to keep the proportion of *Anabaena* at very low levels, and thus reduce the overall proportion of toxigenic taxa (Darren Brandt, Advanced Eco-solutions, personal communication).

These shifts in the phytoplankton community structure are presumed to be translating into increased forage for kokanee. Densities of *Daphnia*, the preferred forage of kokanee (Stark and Stockner 2006), were higher in all supplementation years than the two years preceding supplementation. The mean length of *Daphnia* was higher in three out of four supplementation years compared to the two years prior to supplementation. During the first two years of nutrient supplementation, it was not known if these increases were due to increased productivity or reduced grazing pressure due to a collapse in kokanee numbers following high densities in 2006. The return in mean *Daphnia* length to that of presupplementation suggests a combination of both. While the mean length of *Daphnia* has declined, densities have remained higher than before. This suggests that the productivity of the *Daphnia* population must be greater in order to maintain higher densities under heavy grazing pressure, but heavy selective grazing is reducing the mean length. The mean biomass of *Daphnia* estimated for 2010 was more than twice that estimated for 2006 (Scofield et al. 2011) and the biomass of kokanee in 2010 was more than 40% higher than that estimated for 2006. These observations suggest that *Daphnia* production must have been higher in 2010 in order to maintain a higher biomass of both *Daphnia* and kokanee.

Kokanee Population Monitoring

A major step toward achieving our project objective is to improve kokanee growth. Since kokanee typically exhibit density dependent growth (i.e. lower densities result in larger fish and vice versa), it is important to consider densities when evaluating growth. In order to account for the effects of density on fish growth, we compared mean sizes for years with similar abundance. Abundance was used instead of density because density changes with available habitat. The current regime of summer reservoir drawdowns leads to rapid changes in available habitat and therefore fish density. Thus, fish density can be affected by the timing of the survey more so than abundance. Furthermore, we only considered the abundance of age-1 and older fish, as age-0 fish represent a small proportion of the overall biomass and abundance estimates for age-0 fish are less certain.

Our comparisons indicate that kokanee were heavier, but not longer, under supplementation at the lower abundance, and both longer and heavier at the high abundance. The increase in mean weight at the high abundance resulted in the highest estimate for overall biomass in recent years. There are two explanations for the greater observed differences in the size of age-2 fish for 2010. The first possibility is that the growth advantage due to N supplementation increases with increasing abundance. In other words, forage availability does not limit growth at low fish densities. The second is that the growth advantage has increased over time. Increases in zooplankton density, particularly in 2010, would support the latter. However, it is difficult to draw conclusions based on two pairings of data. Additional years of data will be needed to determine the real effect of N supplementation on kokanee growth.

While these comparisons are useful, it is difficult to find many years for which abundance is similar. Modeling fish size as a function of abundance has been explored as method that would allow us to take all years for which we have data into account. However, there are currently very few years for which we have data on both fish size and abundance. Therefore, the predictive models we have explored do not fit well using more than a single predictor and have little statistical power. Future efforts will focus on using the technique developed by Weisberg et al. (2010) to model growth using back-calculated lengths from scale analyses. We believe this approach will yield greater statistical power. Furthermore, since mean size is a function of growth over multiple years, it is more accurate to measure actual growth for a given year, rather than the size achieved.

Regardless of whether the increases in body weight were due to N supplementation, improved weight has multiple benefits. In 2006, the year before N supplementation began, kokanee densities reached a record level. However, these fish were not only the smallest observed, but body condition was very poor as well. We surmised that poor overwinter survival from 2006 to 2007 was due to poor body condition. Fish sampled from the trawl in July of 2010 were not only heavier than predicted at that density, but were observed to have high levels of fat in the coelomic cavity. Since these fish were in better condition, they are expected to survive better as well. If this turns out to be the case, the result would be that the reservoir could support higher densities of kokanee. Since kokanee do not grow fast at these higher densities, we would not see larger fish as a result of supplementation, but would likely see higher densities on a more regular basis. Higher densities of kokanee should support higher catch rates for the recreational fishery as long as the mean size is not reduced compared to that typically observed prior to supplementation. Furthermore, higher densities of kokanee will result in an increased forage base for predatory fish, including bull trout and smallmouth bass. Additionally, by producing a higher biomass of adult kokanee in the reservoir, more nutrients will be recycled to the watershed above the reservoir. These recycled nutrients are further expected to benefit resident fish communities in the watershed above the reservoir (Grant et al. 1998; Wipfli et al. 1998; Richardson 1993; Wilzbach 1985).

Another way to assess benefits to the kokanee population is to assess production. The growth of an individual fish is related to the quantity and quality of forage as well as the number of fish competing for the available forage. Production, on the other hand, is a measure of how the biomass of the population increased over time, irrespective of the fates of individual fish. Since production should be somewhat density independent, it may be a better indicator of how the population responds to increased forage. Production during each of the first four years of N supplementation has been higher than 2004 (the only year for which we can currently calculate production presupplementation). However, production for the years we can calculate is also positively correlated ($r^2 = 0.93$) to the abundance of age-1 and older fish at the beginning of the period for which it was calculated. Therefore production is not completely density independent. Since we only have one year prior to supplementation for comparison, further caution should be used in interpreting these results. It should be noted that for this one year, the abundance for the beginning period was moderate and that the observed production was less than that observed for a supplementation year with similar abundance (2007-2008). It should also be noted that production for 2006–2007, the period of highest estimated production, spanned a portion of a presupplementation year and a supplementation year.

CONCLUSIONS

Nutrient supplementation in Dworshak Reservoir continues to show signs of success, similar to the responses observed in several BC lakes and reservoirs following nutrient addition. While water clarity appears to have decreased somewhat during the first three years of nutrient supplementation, it has not declined below the range observed prior to supplementation, or to the point where it is expected to be detrimental to recreational uses. The effects of N supplementation have now been observed at all trophic levels we are monitoring. We observed increases in picoplankton, which represent the lowest trophic level, beginning with the first year of nutrient additions. This appears to have translated into increases in the proportion of edible phytoplankton, which has in turn lead to increases in zooplankton density and biomass. The increases in available zooplankton appear to be resulting in increased kokanee body weight at a given density. The increases in both mean length and weight at a given abundance have led to a substantial increase in overall biomass by the fourth year. If sustained, these benefits to the reservoir and kokanee population are expected to provide improved recreational fishing opportunities in the reservoir. Furthermore, the increased abundance and biomass of spawning kokanee in the North Fork Clearwater subbasin are expected to have a beneficial effect on resident fish and wildlife in this ecosystem. While it will take additional years of data to determine whether the observed effects are real, nutrient supplementation appears to be having a beneficial effect on the ecology of the reservoir.

RECOMMENDATIONS

1. The five-year pilot phase of the nutrient project should be continued so that the effects of the project can be properly assessed.

2. Continue semimonthly sampling of the epilimnion during the pilot phase of the project to ensure sufficient data to evaluate the project, adequately monitor compliance with the IDEQ Consent Order, and provide data for active management of the nutrient applications.

ACKNOWLEDGMENTS

The Dworshak Reservoir Nutrient Enhancement Project is a cooperative effort involving many people and several organizations. Darren Brandt of Advanced Eco-Solutions was responsible for the fertilizer prescriptions, while Paul Pence and Ben Perkins, with the U.S. Army Corps of Engineers, made sure that fertilizer was accurately applied. John Bailey, Tim Dykstra, Steve Juul, and Ben Tice, also with the USACE, all played important roles in this project. Bill Ament and Bill Harryman assisted with trawl, acoustic, and spawner surveys for this project. We also thank the anonymous IDFG personnel from Region 2 who assisted with fieldwork. This project was funded by the Bonneville Power Administration and we thank Jan Brady and Roy Beaty for administering the BPA contract. Rob Ryan and Martin Koenig provided reviews of an earlier draft of this report.

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Table 1. Abundance (thousands of fish) and density (fish per ha) of kokanee in Dworshak Reservoir in July 2010. Estimates were derived from a hydroacoustic survey and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section.

	Abundance (thousands of fish)				
Section	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**All Ages**
Section 1	679	562	703	0	1944
Section 2	935	325	230	0	1490
Section 3	717	291	98	1	1105
Whole reservoir	2331	1177	1030	1	4539

		Density (fish per ha)				
Section	**Area (ha)**	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**All Ages**
Section 1	2993	227	188	235	0	649
Section 2	1800	520	180	128	0	828
Section 3	640	1120	454	153	2	1727
Whole reservoir	5434	429	217	190	0	835

Table 2. Descriptive statistics for total lengths of kokanee captured during midwater trawl surveys on Dworshak Reservoir on April 22-23, July 13-14, and November 3, 2010. Growth is given as the increase in mean length (mm) observed in each age class between surveys.

		Total Length (mm)					Growth
Month	**Age**	**N**	**Min**	**Mean**	**Max**	**SD**	**(mm)**
Apr	1	47	79	117	145	18.7	
	2	57	172	198	222	11.5	
Jul	0	190	33	44	69	5.9	
	1	309	136	172	188	7.0	55
	2	172	191	219	265	12.2	21
	3	1	285	285	285		
Nov	0	132	58	92	133	15.2	48
	1	16	171	189	201	7.3	17
	2	6	208	218	236	10.0	

Table 3. Length statistics for two age classes of kokanee from Dworshak Reservoir from three years prior to N supplementation (2003, 2004, and 2006) and four years during N supplementation (2007–2010). Statistics include the mean total length (TL), the L_∞ estimated from Von Bertalanffy growth models fitted independently to each age class for each year that surveys were performed at multiple times throughout the season, a correction factor (CF) developed by taking the mean proportion of L_∞/L_t for each day in July, an estimate of L_∞ obtained by multiplying the CF for the trawl date by the mean TL, and the mean TL of spawning kokanee (age-2) or age-1 kokanee captured in the fall.

Length statistics for Age-2 kokanee

Trawl date	Year	Mean TL (mm)	L_∞ from model	CF	L_∞ from CF	Mean TL (spawners)
30-Jul	2003	262.0		1.05	274	278
13-Jul	2004	300.7	317	1.06	318	308
24-Jul	2006	196.3		1.05	206	210
13-Jul	2007	241.0		1.06	255	264
31-Jul	2008	302.2	328	1.05	316	306
20-Jul	2009	271.7	284	1.05	286	285
14-Jul	2010	220.2	227	1.06	233	249

Length statistics for Age-1 kokanee

Trawl date	Year	Mean TL (mm)	L_∞ from model	CF	L_∞ from CF	Mean TL October
30-Jul	2003	203.6		1.14	233	
13-Jul	2004	202.5	317	1.19	240	231
24-Jul	2006	144.9		1.16	168	
13-Jul	2007	198.0		1.19	235	
31-Jul	2008	208.7	328	1.14	238	235
20-Jul	2009	168.8	284	1.17	197	190
14-Jul	2010	172.0	227	1.18	204	189[a]

[a] The trawl survey for the fall of 2010 was conducted in November rather than October due to mechanical difficulties with the trawler.

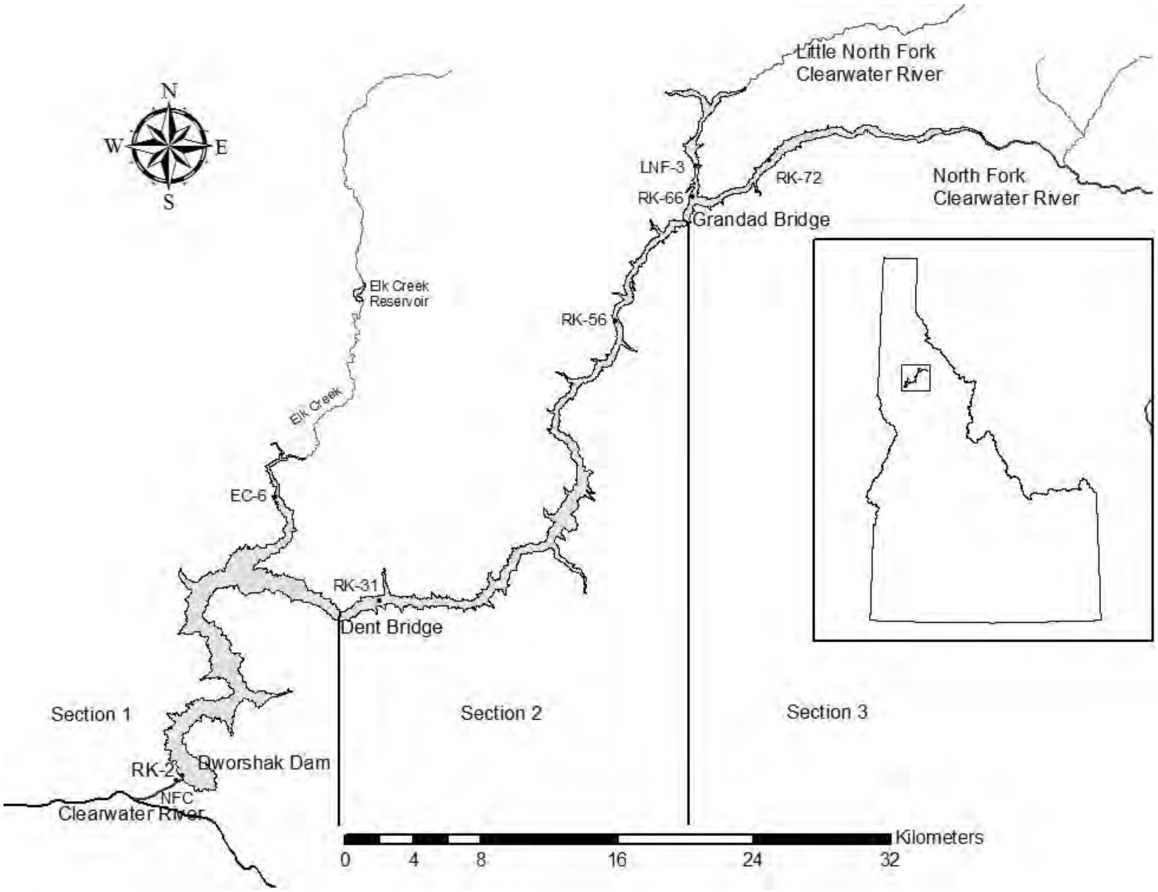


Figure 1. Map of Dworshak Reservoir depicting the locations of seven limnological sampling stations on the reservoir and one on the North Fork Clearwater below Dworshak Dam. Boundaries of reservoir sections used in statistical stratification are also shown.

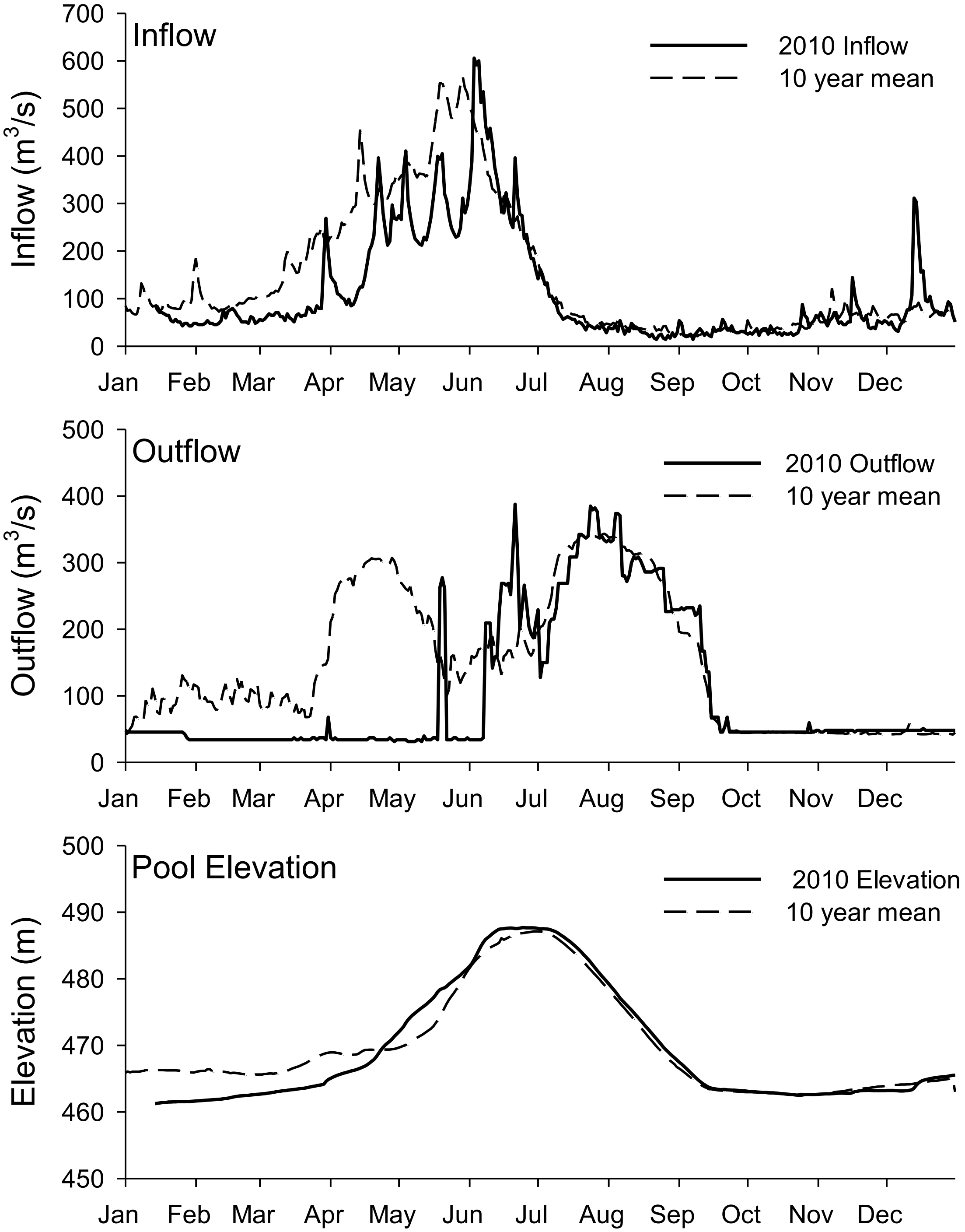


Figure 2. Mean daily inflow, outflow, and pool elevation for Dworshak Reservoir during 2010 along with the 10-year mean (2000-2009). Data provided by the U.S. Army Corps of Engineers through the Columbia River DART website (http://www.cbr.washington.edu/dart/; accessed March 2011).

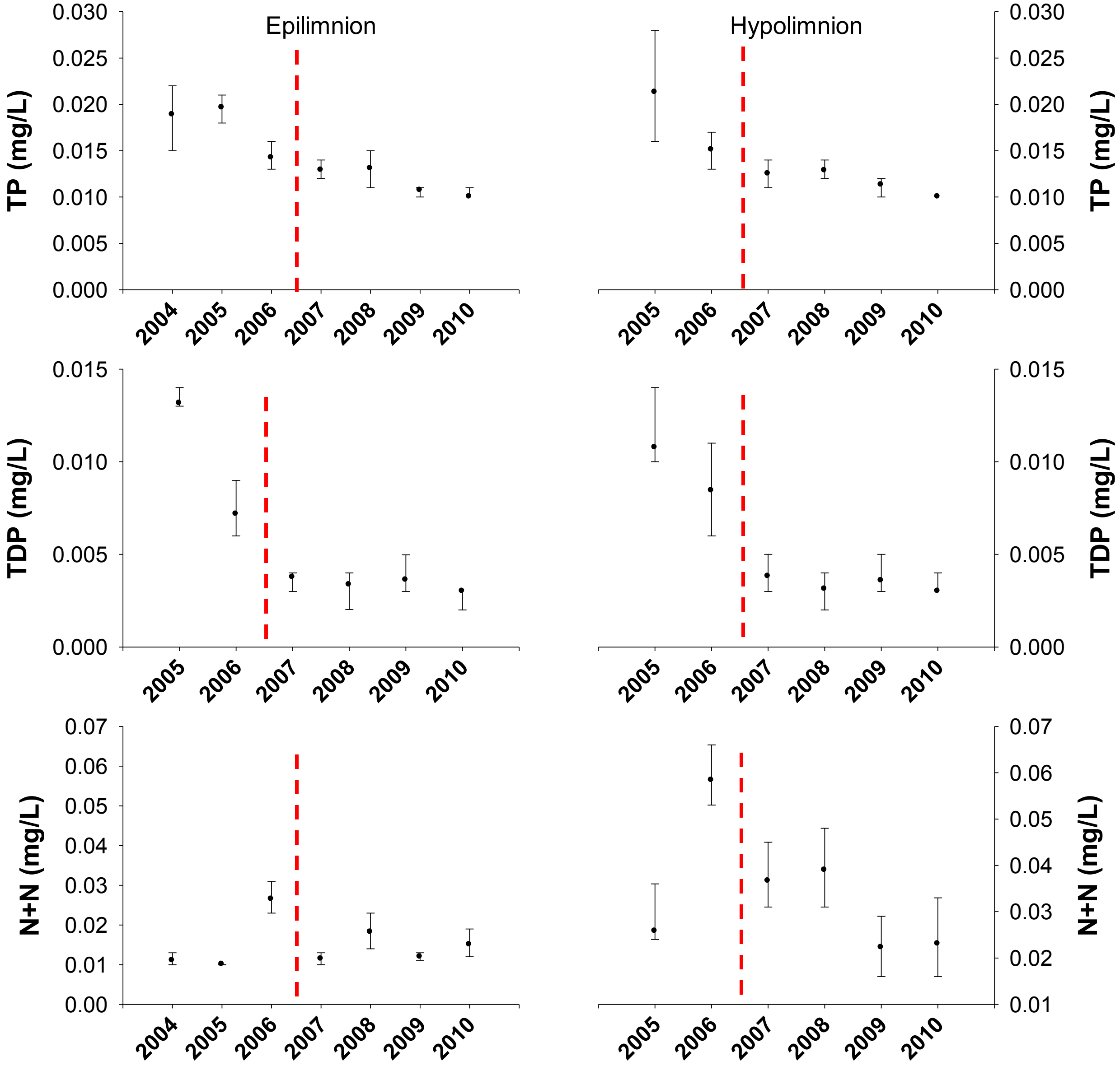


Figure 3. Mean concentration of nutrients measured from two depths at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Nutrients include total phosphate (TP), total dissolved phosphate (TDP), and nitrite plus nitrate nitrogen (N+N). Because detection limits for TP and N+N differed between years, means were calculated from values that were adjusted to reflect the highest detection limit. Error bars represent 95% confidence intervals derived by bootstrapping. Broken red lines indicate the begging of nutrient supplementation.

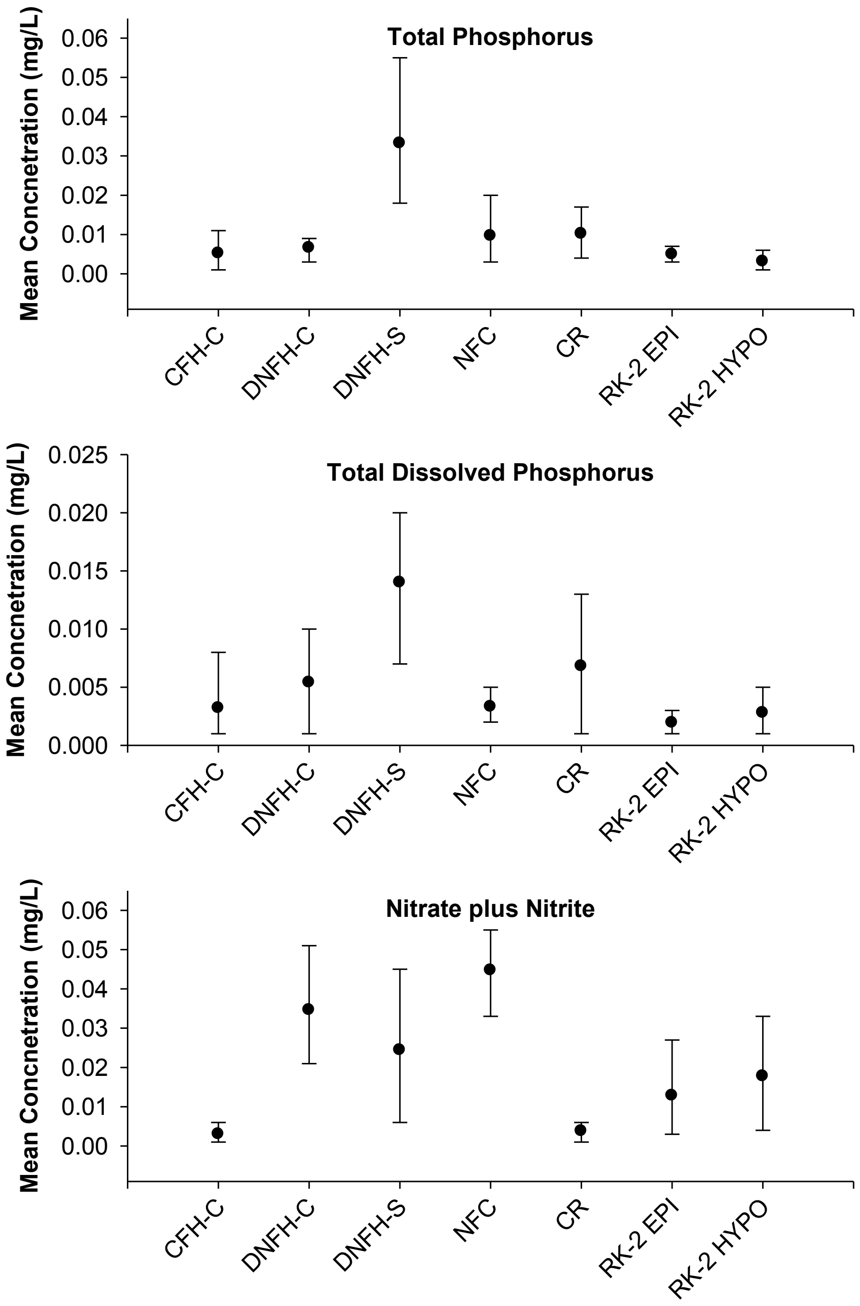


Figure 4. Mean concentration of nutrients measured from four locations below Dworshak Reservoir, one location on the Clearwater River (CR) approximately 1 km above the confluence with the North Fork Clearwater River and above hatchery influence, and two depths from the forebay (RK-2 EPI and RK-2 HYPO). Samples were taken monthly from June through November. Sites below the dam include raceways for rearing Chinook salmon *Oncorhynchus tshawytscha* at Clearwater Fish Hatchery (CFH-C) and Dworshak National Fish Hatchery (DNFH-C), one Burrow’s pond for rearing steelhead (DNFH-S), and the North Fork Clearwater River (NFC). Error bars represent 95% confidence intervals derived by bootstrapping.

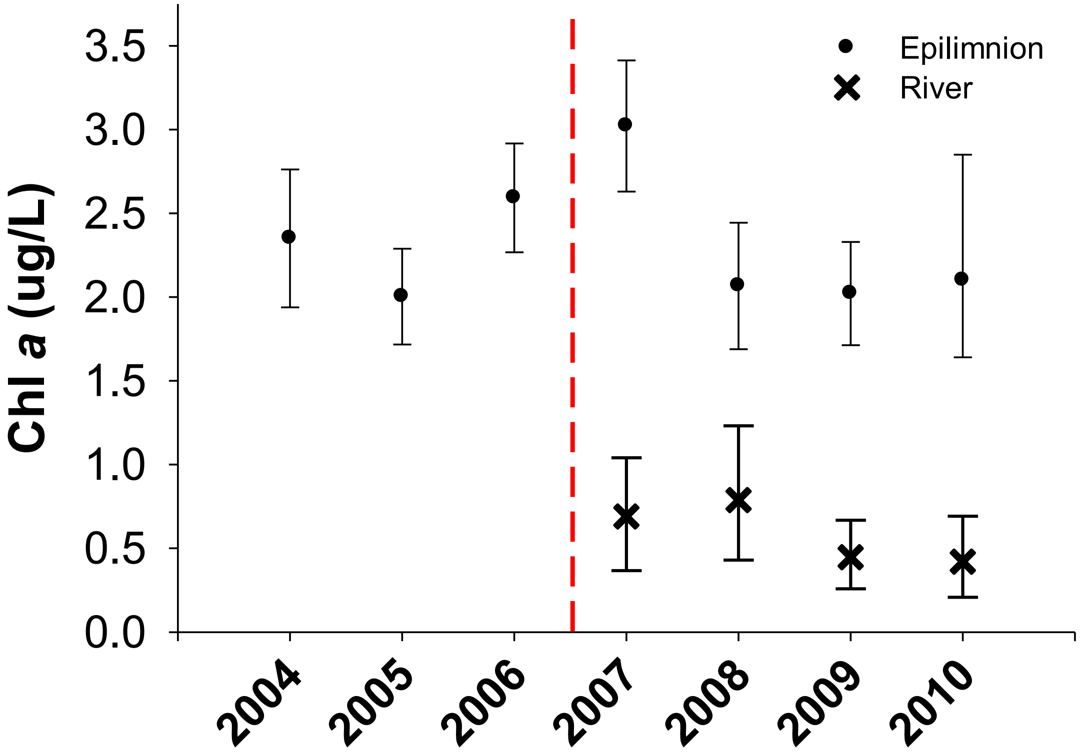


Figure 5. Mean concentration of chlorophyll *a* (Chl *a*) measured at four sampling stations (RK-2, RK-31, RK-56 and RK-72) from May through November for three years prior (2004–2006) to and the first four years (2007–2010) of nutrient supplementation. Also included are means for the NFC, the station below Dworshak Dam, for the first four years of supplementation. Error bars represent 95% confidence intervals derived by bootstrapping. The broken vertical red line indicates the beginning of nutrient supplementation.

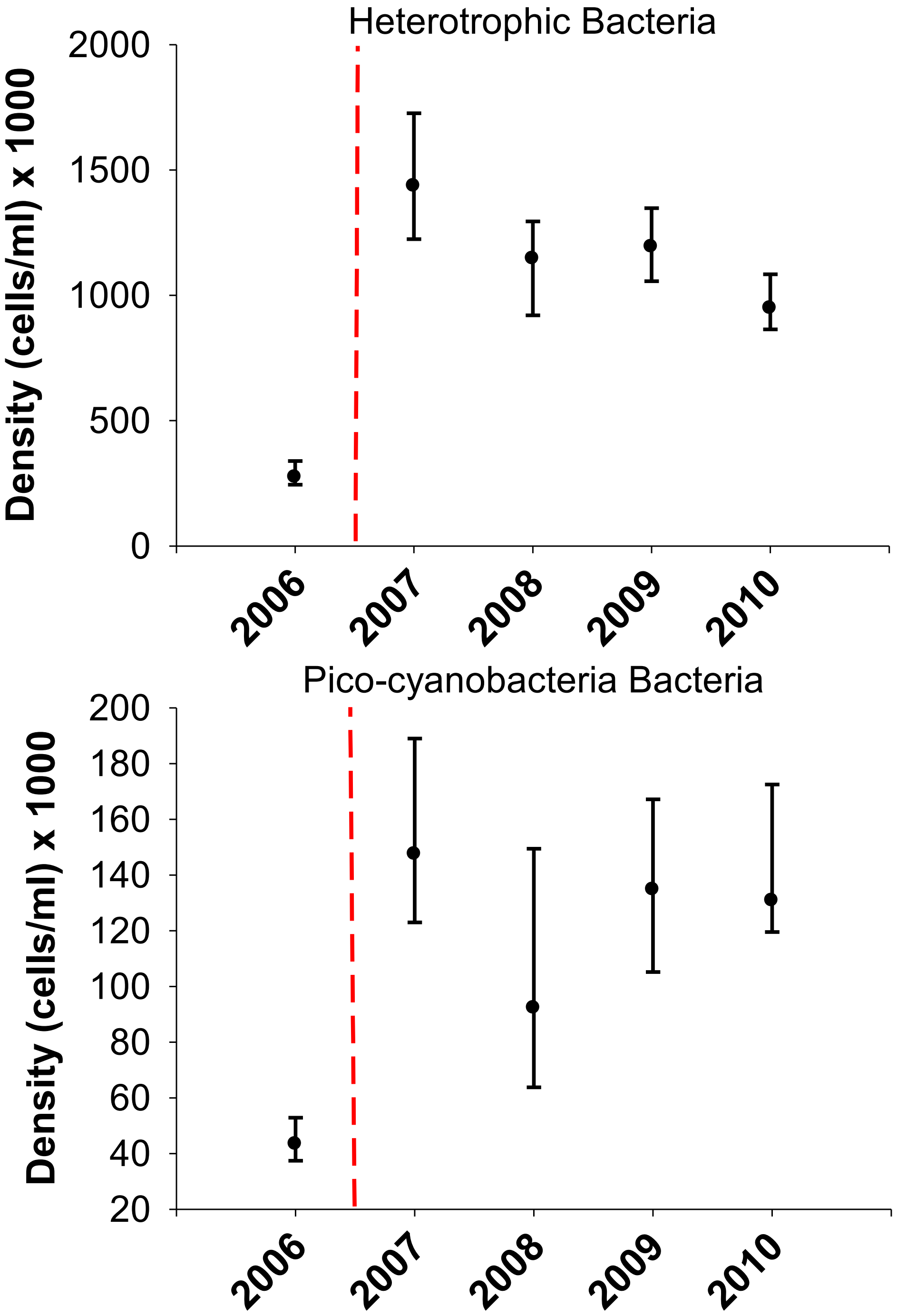


Figure 6. Mean density of picoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Error bars represent 95% confidence intervals derived by bootstrapping. The broken vertical red lines indicate the beginning of nutrient supplementation.

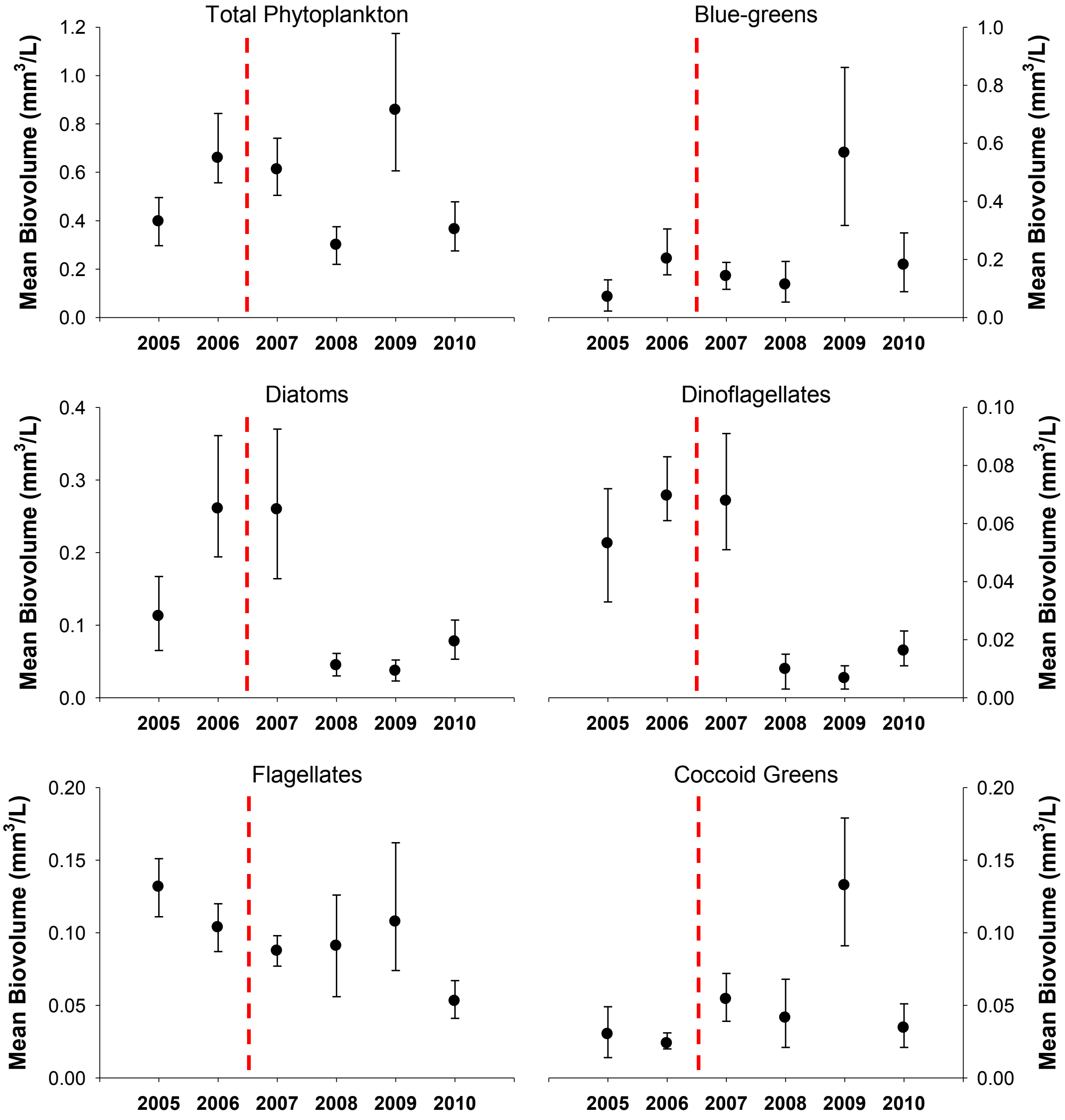


Figure 7. Mean biovolume (mm^3/L) of phytoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Biovolumes are given for total phytoplankton and broken out by the five major taxonomic groups present. Error bars represent 95% confidence intervals obtained by bootstrapping. The broken vertical red lines indicate the beginning of nutrient supplementation.

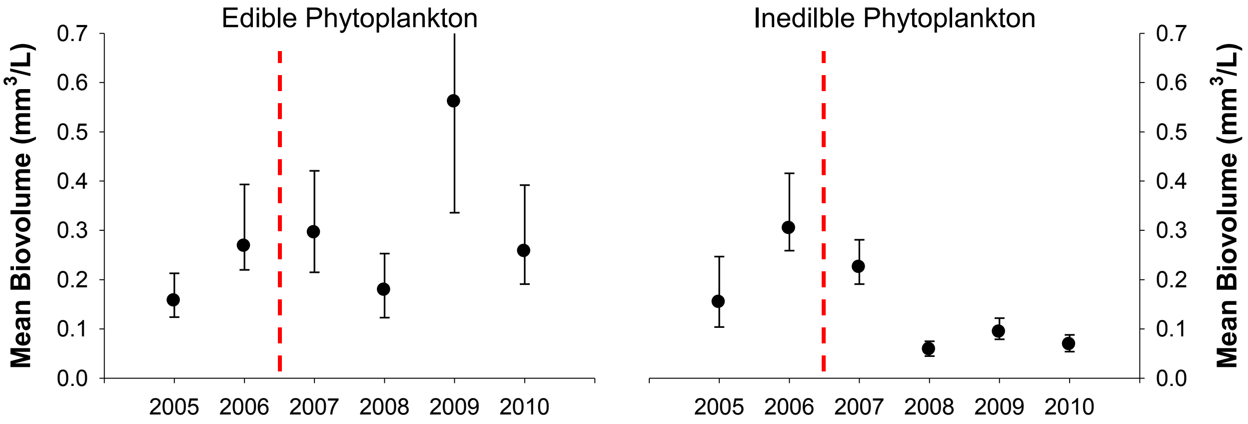


Figure 8. Mean biovolume (mm^3/L) of phytoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Biovolumes are given for species that are known to be edible to zooplankton during at least part of their life history and those that are known to be inedible. Species for which published information on edibility is not available are not included. Error bars represent 95% confidence intervals obtained by bootstrapping. The broken vertical red lines indicate the beginning of nutrient supplementation.

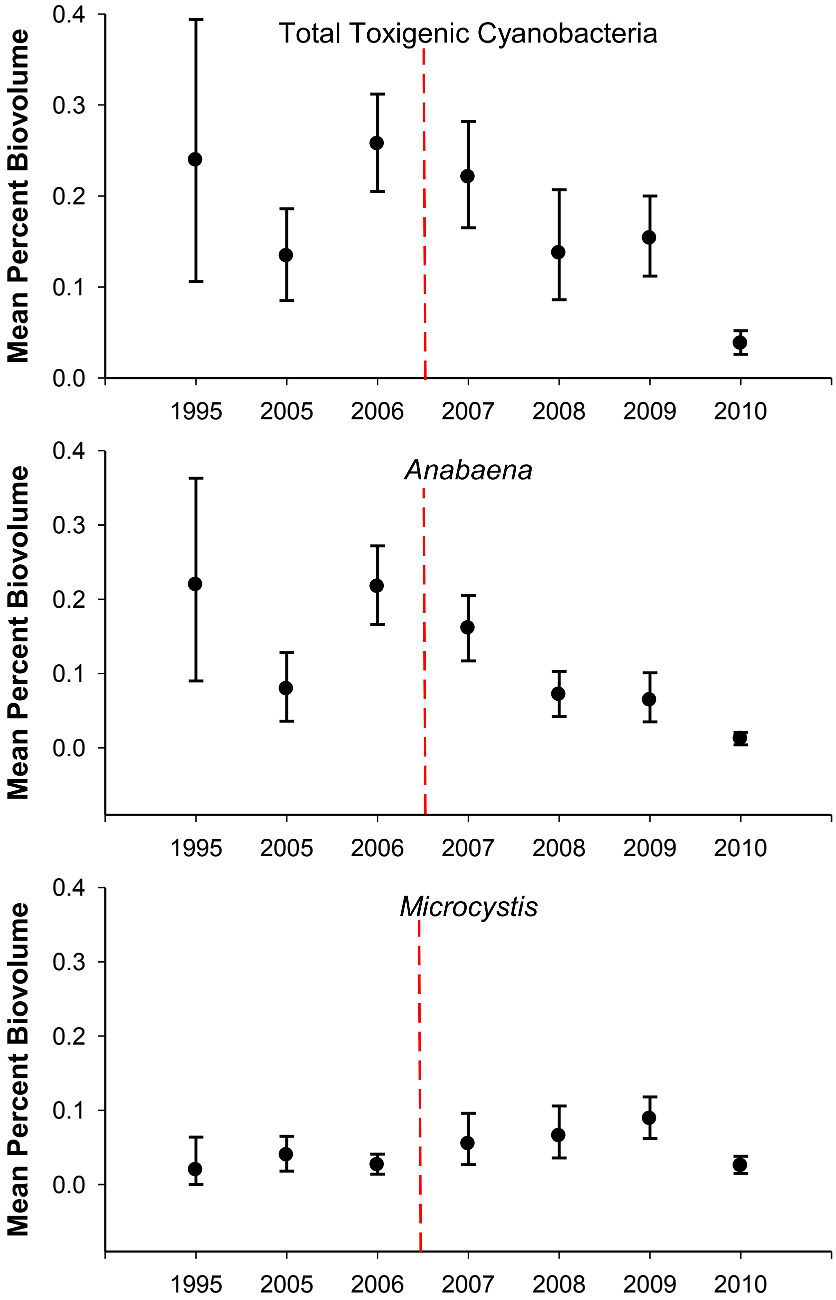


Figure 9. Mean percentages of total phytoplankton biovolume that was composed of toxigenic cyanobacteria (blue-green algae) for three years prior to N supplementation and the first four years of N supplementation. Means were taken from samples collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Error bars represent 95% confidence intervals obtained by bootstrapping. The broken vertical red line indicates the beginning of N supplementation.

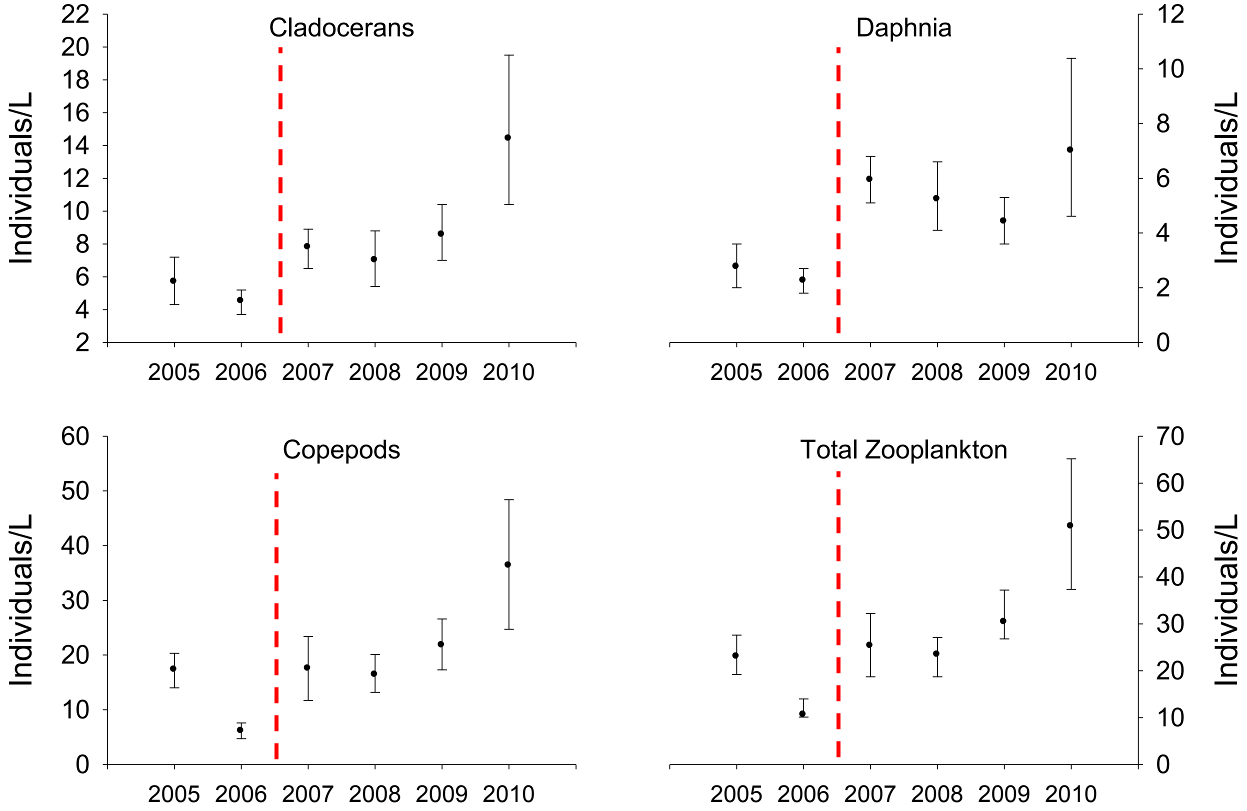


Figure 10. Mean density of zooplankton collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Densities are presented for three taxonomic groups as well as total zooplankton. Error bars represent 95% confidence intervals obtained by bootstrapping. The broken vertical red line indicates the beginning of N supplementation.

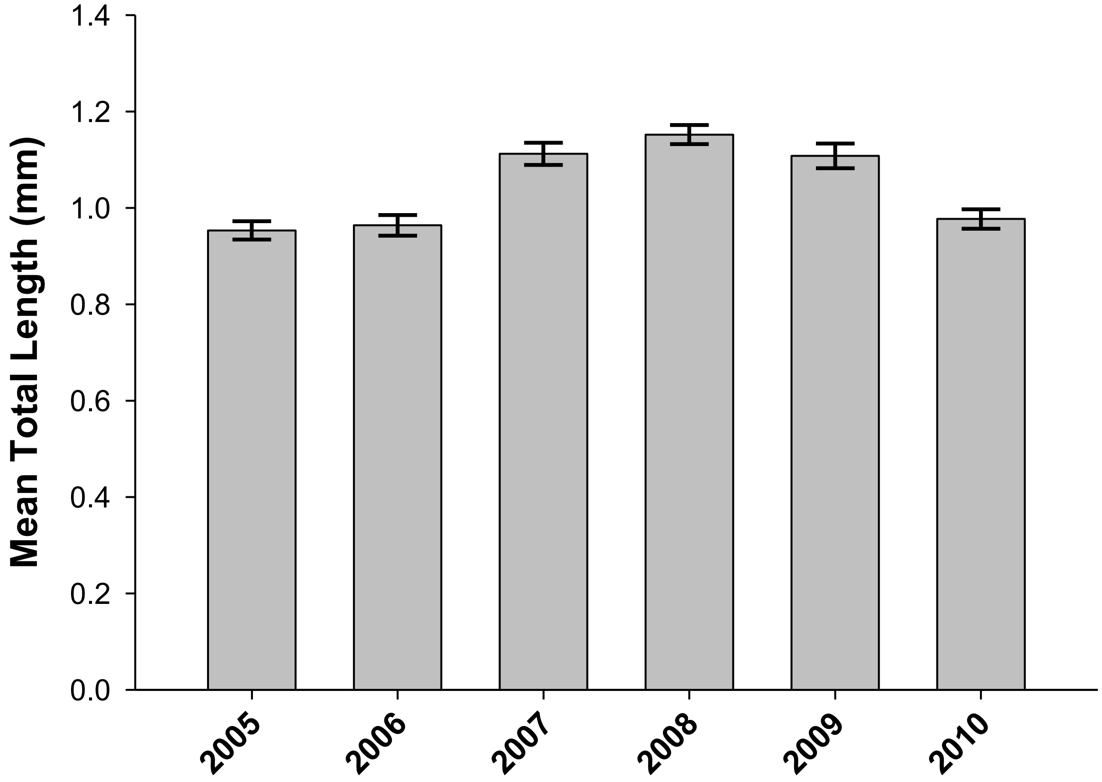


Figure 11. Mean length of Daphnia collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Error bars represent 95% confidence intervals obtained by classical methods.

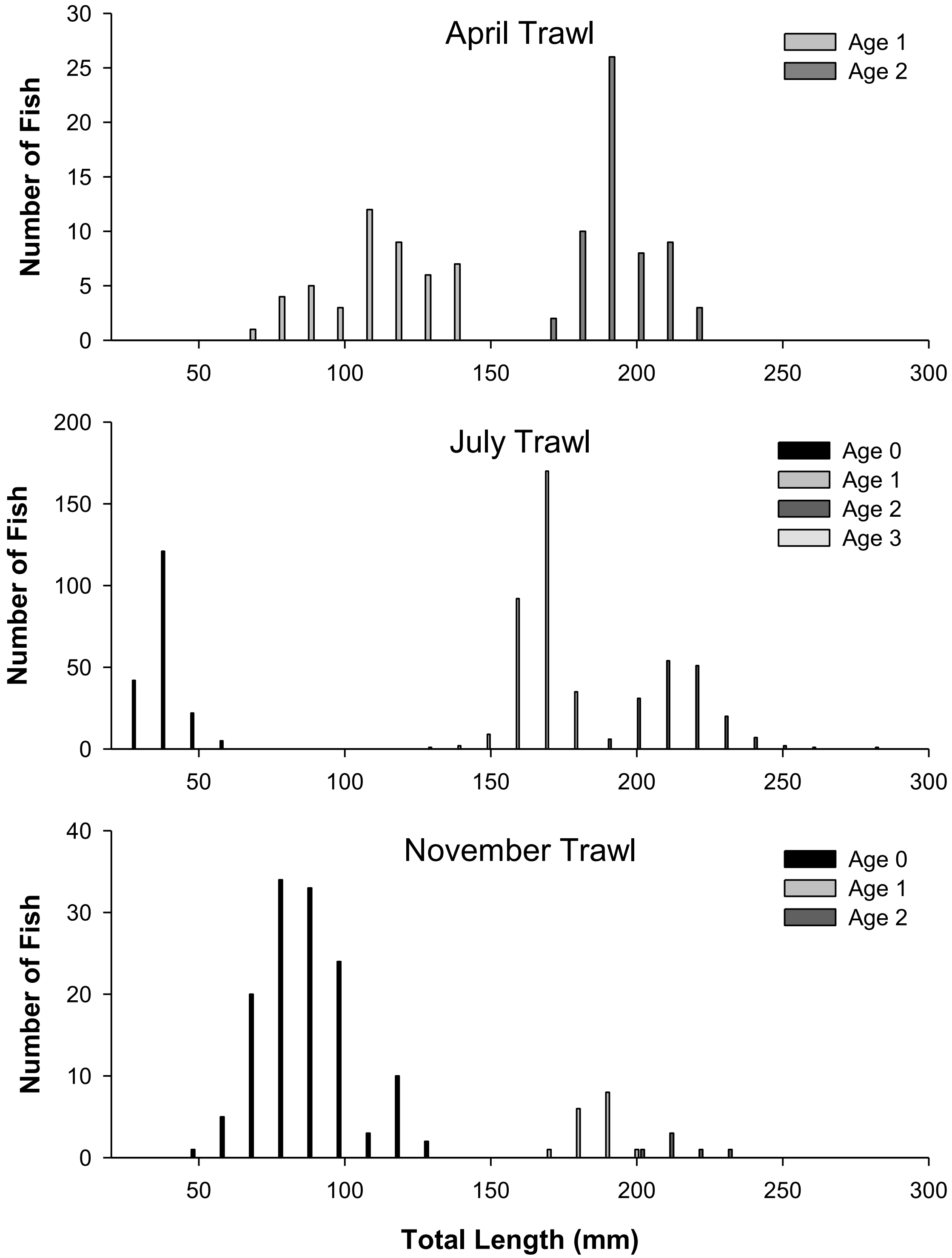


Figure 12. Length frequency of kokanee captured in mid-water trawl surveys on Dworshak Reservoir on April 22-23, July 13-14, and November 3.

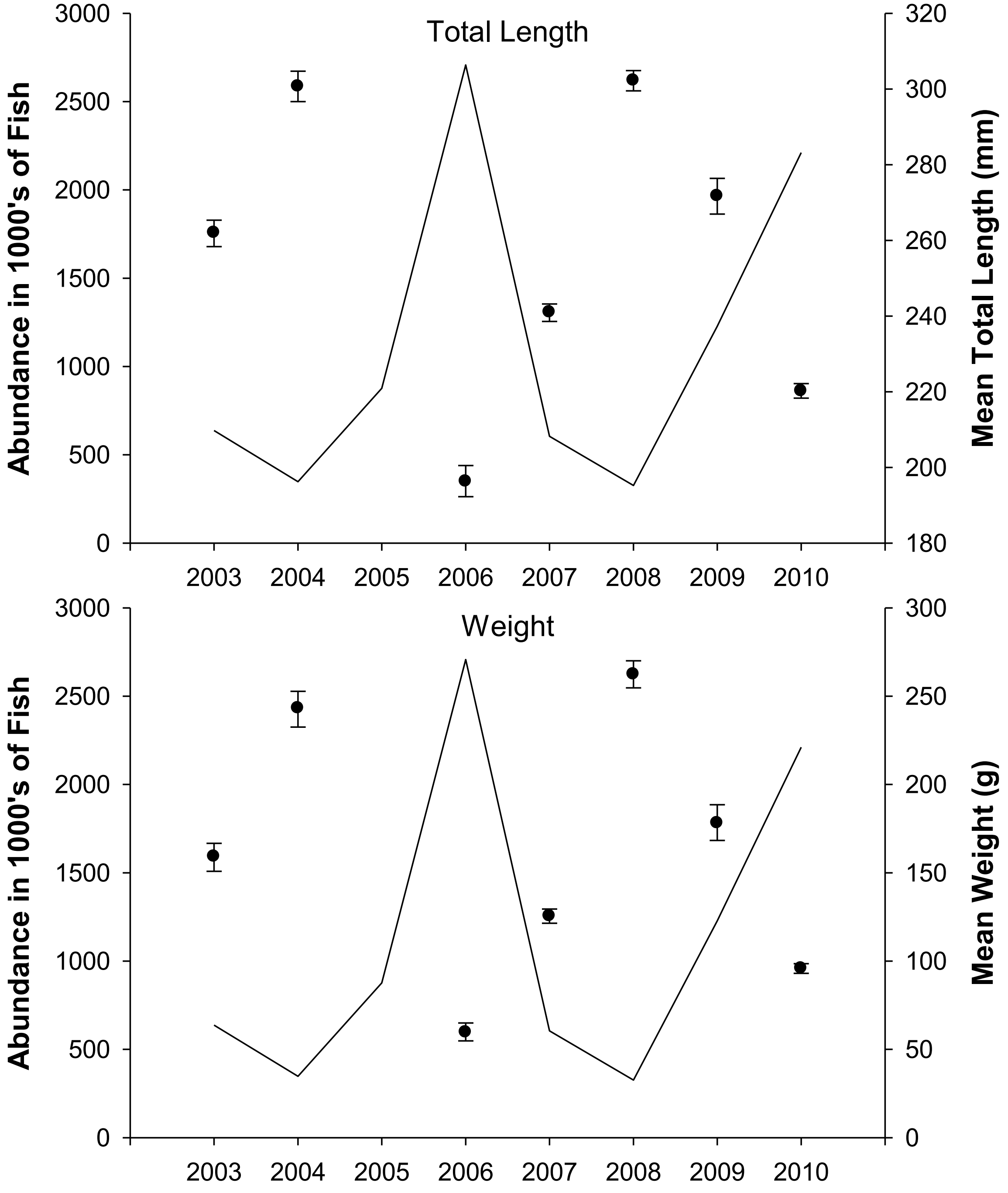


Figure 13. The mean total length (mm) and weight (g) of age-2 kokanee, denoted by the solid black circles, captured during July trawl surveys for three years presupplementation and four years post-supplementation, along with estimated abundances, denoted by the solid black lines, of age-1 and older kokanee as estimated by hydroacoustic surveys conducted within one week. No trawl survey was conducted in 2005.

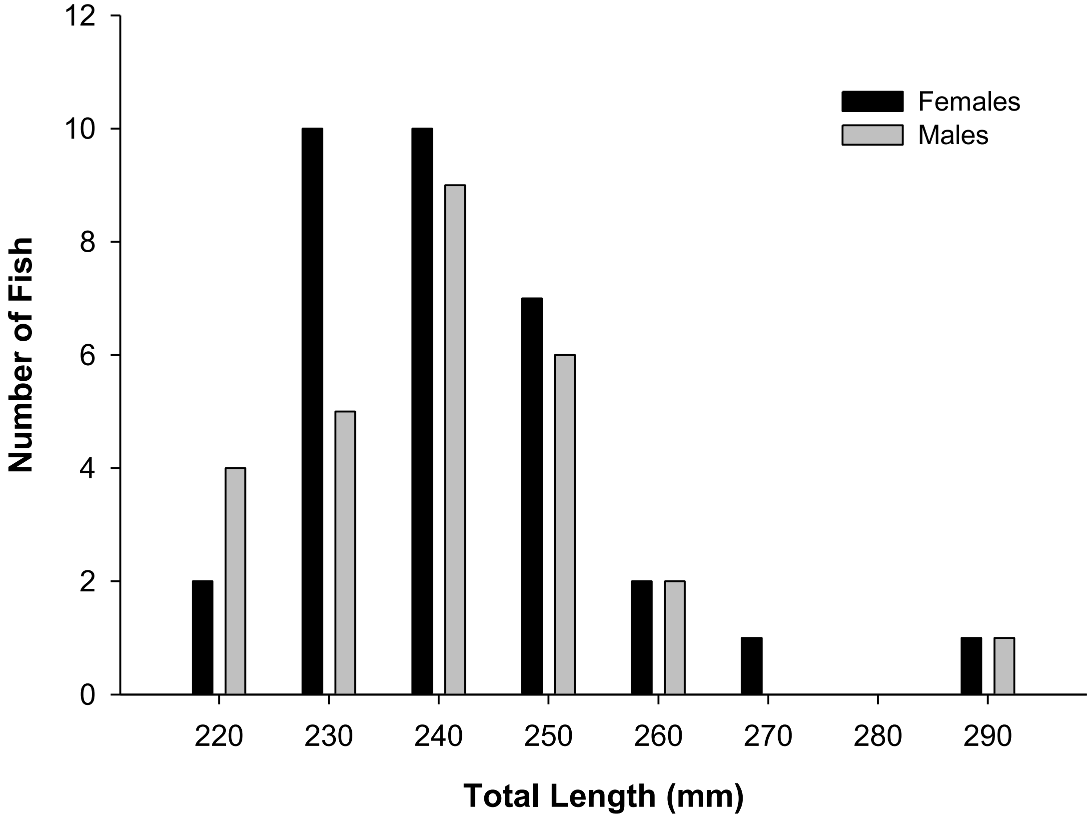
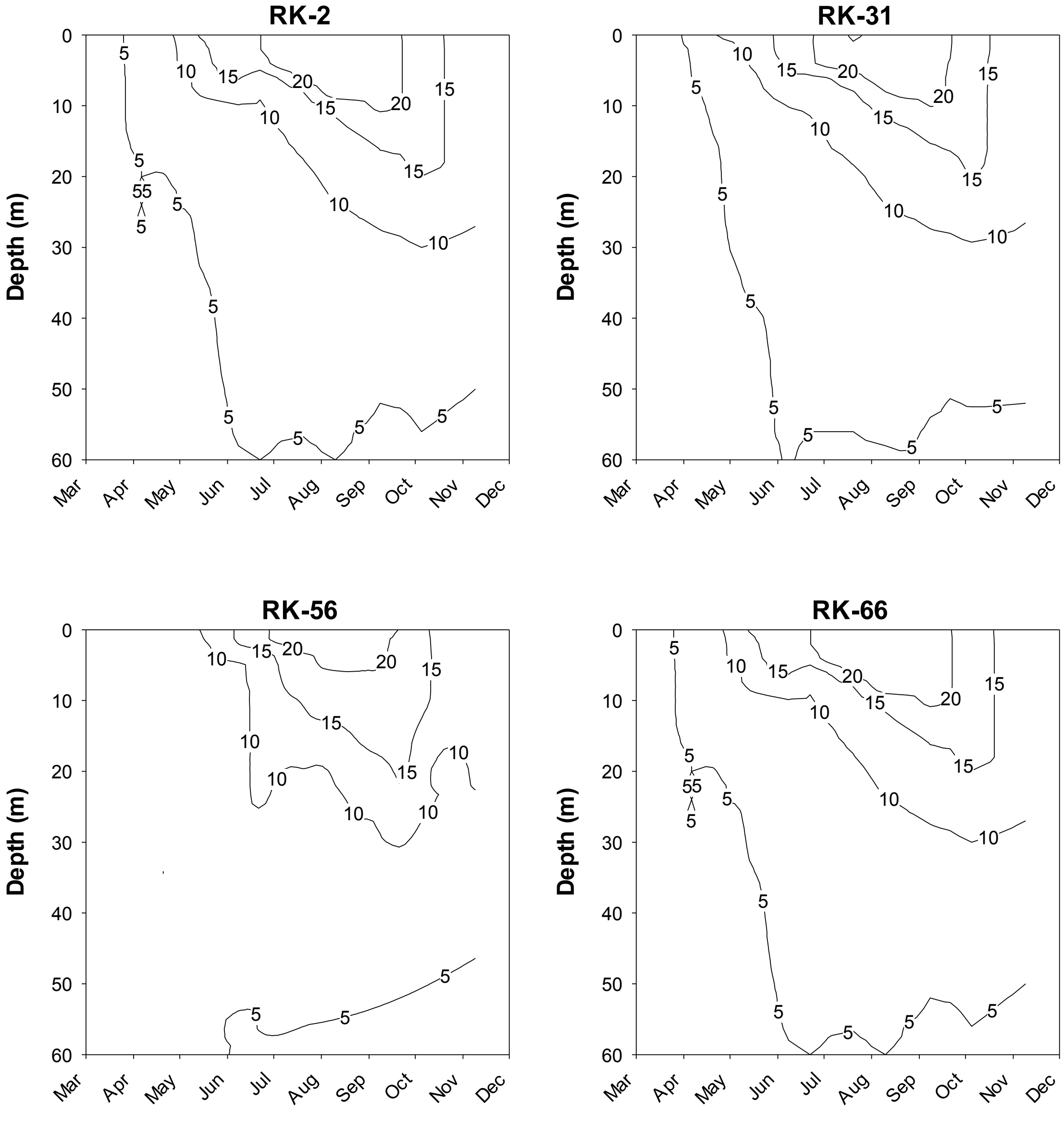


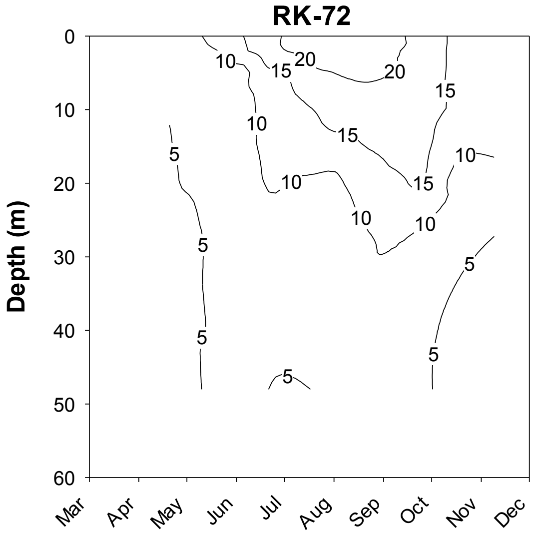
Figure 14. Length frequency of prespawn kokanee in three tributaries to the North Fork Clearwater River collected on September 15, 2010. The tributaries surveyed include Isabella, Skull, and Quartz creeks. Dog Creek was surveyed the following week for peak spawner counts but no prespawn fish were sampled.

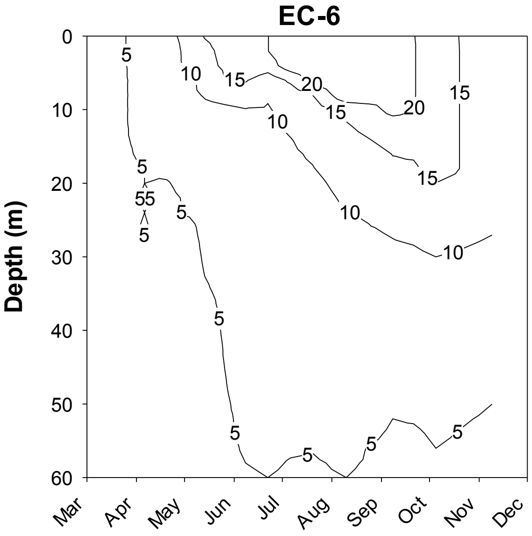
APPENDICES

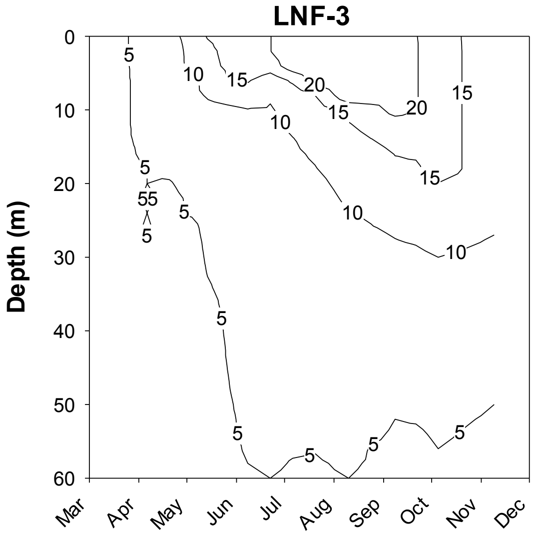
Appendix A. Depth and temperature profiles for seven sampling stations on Dworshak Reservoir from March through November 2010. Isopleths indicate water temperature in degrees Celsius at 5 degree intervals.



Appendix A. Continued.


RK-72


EC-6


LNF-3

Appendix B. Depth of the thermocline measured at each of seven sampling stations on Dworshak Reservoir from March through November 2010. The thermocline was defined as a change in temperature of one degree Celsius over a depth of one meter. NS denotes times and locations where stratification was weak or absent.

	Depth of Thermocline (m)						
Date	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**	**EC-6**	**LNF-3**
Mar 22	NS	NS	NS	NS	NS	NS	NS
Apr 5	NS	NS	NS	NS	NS	NS	NS
Apr 19	9.0	NS	4.0	2.0	2.0	3.0	2.0
May 3	NS	NS	7.0	NS	NS	NS	NS
May 17	5.0	7.0	3.0	2.0	2.0	3.0	2.0
Jun 7	5.0	5.0	3.0	2.0	2.0	3.0	2.0
Jun 21	5.0	5.0	5.0	3.0	3.0	5.0	3.0
Jul 5	5.0	5.0	5.0	3.0	5.0	5.0	3.0
Jul 19	5.0	5.0	5.0	5.0	5.0	4.0	3.0
Aug 9	7.0	7.0	4.0	4.0	4.0	7.0	4.0
Aug 23	8.0	9.0	8.0	6.0	7.0	7.0	5.0
Sep 6	14.0	13.0	NS	21.0	NS	NS	19.0
Sep 20	14.0	13.0	NS	NS	NS	14.0	NS
Oct 4	15.0	14.0	NS	NS	NS	15.0	NS
Nov 8	21.0	23.0	NS	NS	15.0	NS	NS

Appendix C. Descriptive statistics for compensation depth at seven sampling stations on Dworshak Reservoir from March through November 2010. Compensation depths were calculated as the depth at which 1% of the photosynthetically active radiation measured at the surface was still present. Statistics are presented by month (all stations combined) and by station (entire year).

	Compensation Depth (m)					
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SD**
Mar	7	8.5	10.5	10.7	11.7	1.2
Apr	14	6.1	8.4	8.0	11.9	1.7
May	14	6.1	8.1	8.0	11.4	1.6
Jun	14	6.1	9.0	9.0	11.7	1.6
Jul	14	3.9	8.4	9.1	9.9	1.7
Aug	14	5.7	8.8	9.1	10.2	1.2
Sep	14	6.1	9.1	9.3	11.6	1.4
Oct	7	8.9	10.6	11.2	12.0	1.3
Nov	7	9.5	11.2	11.3	13.2	1.4
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SD**
RK-2	15	3.9	9.6	9.8	11.9	2.1
RK-31	15	7.3	9.7	9.3	13.2	1.4
RK-56	15	7.2	9.5	9.8	12.5	1.6
RK-66	15	7.0	9.2	9.2	11.2	1.3
RK-72	15	6.3	9.1	9.1	11.5	1.4
EC-6	15	5.7	7.2	6.7	9.9	1.4
LNF- 3	15	6.8	9.1	9.0	11.9	1.5

Appendix D. Summary of the relative percent difference and difference between original and duplicate samples for six water quality parameters measured at seven sampling stations on Dworshak Reservoir from March through November 2010.

	Relative Percent Difference				**Difference**			
Parameter	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
TDP (mg/L)	26.6%	0.0%	0.0%	200.0%	0.001	0.000	0.000	0.004
TP (mg/L)	82.0%	40.0%	0.0%	200.0%	0.003	0.002	0.000	0.008
N+N (mg/L)	61.0%	4.4%	0.0%	200.0%	0.005	0.001	0.000	0.025
TDS (mg/L)	7.9%	5.4%	0.0%	31.1%	1.6	1.0	0.0	7.0
Chl *a* (µg/L)	26.0%	15.7%	8.1%	67.6%	0.79	0.33	0.03	4.00

Appendix E. Estimates of kokanee abundance and adult (age-2 and older) densities for Dworshak Reservoir. Estimates from 2003 to present have been revised using estimates of available kokanee habitat from data provided by Sam Martin of the USACE.

		Kokanee Abundance					**Adult Density (fish/ha)**
Year	**Sampling Method**	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**Total**	
2010	Hydroacoustic	2,331,120	1,177,439	1,030,226	1,483	4,538,785	190
2009	Hydroacoustic	1,022,086	1,109,492	118,753	0	2,250,331	15
2008	Hydroacoustic	1,359,430	233,123	71,024	21,986	1,685,563	18
2007	Hydroacoustic	531,703	147,300	457,245	0	1,136,248	93
2006	Hydroacoustic	1,996,987	1,550,134	1,082,431	0	4,629,552	242
2005	Hydroacoustic	2,339,695	696,738	179,734	0	3,216,167	35
2004	Hydroacoustic	448,833	272,802	74,419	0	796,054	14
2003	Hydroacoustic	372,664	281,254	356,434	0	1,010,353	69
2002	Hydroacoustic	1,246,959	1,101,232	127,933	0	2,476,124	24
2001	Hydroacoustic	1,962,000	781,000	405,000	0	3,150,000	75
2000	Hydroacoustic	1,894,857	303,680	199,155	0	2,397,691	37
1999	Hydroacoustic	1,143,634	363,250	38,464	0	1,545,347	7
1998	Hydroacoustic	537,000	73,000	39,000	0	649,000	7
1997	Trawling	65,000	0	0	0	65,000	0
1996	Hydroacoustic	231,000	43,000	29,000	0	303,000	5
1995[a]	Hydroacoustic	1,630,000	1,300,000	595,000	0	3,539,000	110
1994	Hydroacoustic	156,000	984,000	304,000	9,000	1,457,000	69
1993	Trawling	453,000	556,000	148,000	6,000	1,163,000	33
1992	Trawling	1,040,000	254,000	98,000	0	1,043,000	22
1991	Trawling	132,000	208,000	19,000	6,000	365,000	5
1990[a]	Trawling	978,000	161,000	11,000	3,000	1,153,000	3
1989[b]	Trawling	148,000	148,000	175,000	0	471,000	32
1988	Trawling	553,000	501,000	144,000	12,000	1,210,000	29

[a] June sampling likely resulted in an underestimate of age-0 kokanee.

[b] September sampling likely resulted in an underestimate of mature kokanee.

Appendix F. Production and biomass estimates for kokanee in Dworshak Reservoir, Idaho for 2004 through 2010. Production was calculated from July of the previous year to July of the year listed when weight data from trawl surveys was available in both years. Biomass was calculated for July in all years where weight data was available.

	Production (metric tonnes)			
Year	**Age 0-1**	**Age 1-2**	**Age 2-3**	**Total**
2010	48.6	54.8		103.7
2009	52.3	16.4		68.7
2008	32.2	21.3	32.7	86.2
2007	71.2	99.6		170.8
2006				
2005				
2004	23.5	30.5		54.1
2003				

	Biomass (metric tonnes)				
Year	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**Total**
2010	1.4	53.2	97.1		151.7
2009	0.7	47.7	21.1		69.6
2008	0.9	19.8	18.6	5.8	45.1
2007	0.3	9.9	57.4		67.5
2006	1.0	40.1	64.5		106.1
2005					
2004	0.3	20.1	18.1		38.5
2003	0.3	20.1	56.7		77.1

Appendix G. Number of kokanee spawners counted in index tributaries to the North Fork Clearwater River above Dworshak Reservoir, Idaho during September 1988-2010. Counts were performed on or near September 25, the historical peak of spawning activity.

Year	Isabella Creek	Skull Creek	Quartz Creek	Dog Creek	Total	Mean TL (mm)
2010	26,529	24,212	5,283	3,385	59,409	249
2009	5,366	4,343	918	626	11,253	285
2008	3,738	2,160	462	1,073	7,433	306
2007	11,342	10,913	1,268	1,771	25,294	264
2006	12,604	12,077	2,717	2,345	29,743	210
2005	6,890	3,715	2,137	617	13,359	243
2004	6,922	2,094	450	1,474	10,940	308
2003	12,091	10,225	1,296	1,083	24,695	278
2002	15,933	7,065	2,016	1,367	26,381	267
2001	3,751	1,305	722	301	6,079	305
2000	3,939	402	124	565	5,030	314
1999	10,132	361	827	2,207	13,527	
1998	627	20	13	18	678	
1997	144	0	0	0	144	
1996	2,552	4	13	82	2,651	
1995	12,850		2,780	1,160	16,790	
1994	14,613	12,310	4,501	1,878	33,302	
1993	29,171	7,574	2,476	6,780	46,001	
1992	7,085	4,299	1,808	1,120	14,312	
1991	4,053	1,249	693	590	6,585	
1990	10,535	3,219	1,702	1,875	17,331	
1989	11,830	5,185	2,970	1,720	21,705	290
1988	10,960	5,780	5,080	1,720	23,540	280

Prepared by:	**Approved by:**
	IDAHO DEPARTMENT OF FISH AND GAME
Sean M. Wilson Fishery Research Biologist	Daniel J. Schill Fisheries Research Manager
Andrew M. Dux Principal Fishery Research Biologist	Edward B. Schriever, Chief Bureau of Fisheries
Richard J. Downing Senior Fishery Technician	