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BRIDGE COASTAL RESTORATION PROGRAM

TROPHIC STATE OF ELSIE LAKE RESERVOIR, 2005

Final Report

March 10, 2006

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TROPHIC STATE OF ELSIE LAKE RESERVOIR, 2005

Final Report

Submitted to

Bridge Coastal Restoration Program
Burnaby, B.C.

Prepared by

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Cover photo: Kiyo Masuda (Limnotek) filtering water samples on Elsie Lake Reservoir, June 2005.

EXECUTIVE SUMMARY

An assessment of the trophic state of Elsie Lake Reservoir was completed in 2005 as a first step to determine if the reservoir is a candidate for nutrient addition as a measure to restore fish populations. A suite of physical, chemical and biological parameters were examined on a monthly basis from June through October.

All measurements indicated that Elsie Lake Reservoir was ultraoligotrophic. Thermal stratification developed in the spring; it was well established in the summer, and it collapsed in the fall. The maximum epilimnetic temperature of 23°C occurred in August. The water detention time in Elsie Lake Reservoir was 35 days, indicating it is a fast flushing system that may limit pelagic community development. The reservoir had high water transparency (Secchi depth was 8-12 m) and the water column was well oxygenated. In 2005 there was minimal influence of respiration in the bottom sediments on oxygen concentrations in the water column. Concentrations of all forms of nitrogen and phosphorus were low, particularly in the spring and summer when biological demand for nutrients is high. The average TP concentration was 2.4 μg/L and the average TN concentration was 93 μg/L. The average Chl *a* concentration was 0.7 μg/L and the phytoplankton community was largely composed of microflagellated picoplankton and nanoplankton. Phytoplankton biovolume averaged just 0.1 mm^3/L. Primary productivity was extremely low, averaging 13.8 mg $C/m^2/d$, which is the lowest rate that has been measured among lakes and reservoirs in British Columbia. The mean zooplankton density was 5.4 individuals/L. Cladocerans comprised 73% of the zooplankton community, followed by copepods at 21% and finally rotifers at 6%. *Eubosmina longispina*, *Daphnia rosea* and *Holopedium gibberum* were the dominant cladocerans.

Between the summer and fall, a 39% increase in TP concentration coincided with a 67% increase in algal biomass and a 121% increase in primary production. The higher TP concentration was accompanied by a rise in the inorganic N concentrations, likely due to mobilization of nutrients from forest soils caused by increased rainfall in the fall. The increase in primary production was accompanied by a shift to larger sized phytoplankton. This change in production and community structure between seasons was driven by change in nutrient concentration, indicating the importance of nutrient availability on biological production in Elsie Lake Reservoir.

Although productivity in Elsie Lake Reservoir is limited by the availability of nutrients, data gaps remain to determine the potential response by fish to restoration that may involve nutrient addition. Application of standing crop and fish production models showed the reservoir likely supports rates of fish production that are among the lowest of coastal ultraoligotrophic lakes. The possible absence of planktivorous fish populations in the reservoir suggests that the primary food web is based on benthic productivity, possibly supplemented with invertebrate fallout from the forest canopy.

Uncertainty about the structure of the fish populations, fish population size, and habitat use in littoral and pelagic zones of the reservoir must be resolved before decisions on the potential merits of fertilization can be explored.

It is recommended that a hydroacoustic survey accompanied by gill netting and trawling be completed in 2006. The resulting data will provide information on fish community structure and habitat use by each fish species. Additionally, the stomach contents of sampled fish must be examined to provide information on the composition and source of food that each fish species is ingesting. This information is essential to determine if one or more food webs are targets for future restoration activities.

It is also recommended that a second year of limnological data be collected, including measurement of nutrient concentrations in the inflow Ash River. These data will provide information on the importance of nutrient loading from upstream and it will provide duplicate pre-treatment years of baseline data that can be used in later statistical and ecological analysis to determine the extent of a response to future treatment.

ACKNOWLEDGEMENTS

This project was completed by Limnotek Research and Development Inc. and the Hupacasath First Nation under contract to the Bridge Coastal Restoration Program, Burnaby BC. The authors (both from Limnotek) reported to Mr. Adam Lewis (Ecofish Ltd.) who was project manager for the Hupacasath First Nation and to Mr. Trevor Jones, Executive Director of the Hupacasath First Nation. The authors were assisted in the field by Kiyo Masuda (Limnotek), Tom Tatoosh (Hupacasath First Nation), and Allan Ross (Hupacasath First Nation). Flow data were provided by Cathy Bowie of BC Hydro, Power Records. Danusia Dolecki completed the zooplankton enumerations. John Stockner (Ecologic Ltd.) completed the phytoplankton enumerations and biovolume measurements. We appreciate numerous discussions with Adam Lewis (Ecofish Ltd.) regarding the scope and content of the project.

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1 INTRODUCTION

In the years immediately following the filling or expansion of a reservoir, nutrient loading can increase, leading to increased phytoplankton biomass (Ostrofsky and Duthie 1980), increased zooplankton biomass (Paterson et al. 1997), a shift from small to large cladocerans (Paterson et al. 1997), increased abundance of fish (Grimard and Jones 1982, Hecky and Guildford 1984, Baxter 1977) and successful fisheries (Stables et al. 1990, Perrin et al. 2006). This increase in biological production, often called “trophic upsurge”, is caused by the leaching and mineralization of nutrients that are released to the water column from newly flooded vegetation and soils (Kennedy and Walker 1990). Increased fish production is linked to abundant food supplies including zooplankton and additional cover provided by newly submerged vegetation (Thornton et al. 1990).

After a period of up to 20 years following impoundment or rising water surface elevation, a decline in productivity or “trophic depression” may occur. This process is thought to be a result of burial of submerged organic substrata due to advanced erosion of shorezones, a lowering of oxygen demand and declining nutrient release as labile vegetation is mineralised, leading to lower abundance of invertebrates (Popp and Hoagland 1995). In some reservoirs, the depression is caused by adsorption of phosphorus and trace electroactive elements (e.g iron) onto substrates of dissolved organic carbon (DOC) that can be abundant as leachates from previously flooded vegetation and forest floors (Schallenberg 1993, Jackson and Hecky 1980, Guildford et al. 1987). In reservoirs used to store water for hydroelectric power production, flushing rates are high and they can contribute to rapid export of soluble and particulate nutrients, which increases an oligotrophication process (Schallenberg 1993). Eventually, lower trophic production may lead to declining availability of food for fish, resulting in a decline in fish abundance (Thornton et al. 1990). This depression sequence can proceed after 20 years from the time of impoundment.

As a result of this oligotrophication process, water storage reservoirs in British Columbia that were constructed for hydroelectric power production in the 1950’s and 1960’s are in many ways similar to coastal ultraoligotrophic lakes (Stockner and Ashley 2003, Stockner and Shortreed 1985). They have low total phosphorus concentrations (≤5 µg/L), low phytoplankton biomass (<5 µg/L of chlorophyll *a* (Chl *a*)), and low densities of zooplankton (mainly <5 individuals/L) comprised mainly of small cladocerans, cyclopoid copepods, and rotifers. When exhibiting these attributes, reservoirs usually do not sustain the production of such plantivorous fish such as kokanee (*Oncorhynchus nerka*), which is commonly sought after as a sport species. The kokanee fisheries often collapse as reservoirs mature through trophic depression (Ney 1996). A possible reason for this change is that the zooplankton taxon called *Daphnia* sp. becomes absent or is present in extremely low densities, yet its availability as forage may be a requirement for sustained production of planktivorous fish like kokanee (Mazumder and Edmundson 2002).

Since production of *Daphnia* sp. and other forage species increases markedly with increased nutrient loading (Mazumder and Edmundson 2002, Perrin et al. 2006), a common restoration approach used in the oligotrophic lakes along the Pacific coast of Canada and Alaska is to increase planktivorous fish production by adding phosphorus and nitrogen (Stockner and Shortreed 1985). This bottom-up approach to increasing fish yield has been successful (Hyatt and Stockner 1985, Hyatt et al. 2004, Perrin et al. 2006), but trophic responses can be strongly attenuated through some food webs (Brett and Goldman 1997), leading to varying outcomes (Hilborn and Winton 1993). Muzumder and Edmudson (2002) showed that the pre-treatment population density and size of *Daphnia* sp. is an important determinant of fertilization success, indicating that density-dependent response, predator-prey interaction, and the potential for trophic cascades must be considered in any fertilization strategy (Carpenter et al. 1985, McQueen et al. 1989, Vanni and Findlay 1990, Power 1992). Johnston et al. (1999) showed that fertilization targeting rainbow trout (*Oncorhynchus mykiss*), provided the greatest benefit through the benthic food web in a small lake, indicating that feeding habits and food sources of a fish species are important to consider when assessing a fish population response to fertilization.

In compiling a strategic plan for the Bridge Coastal Restoration Program, Regional Consulting Ltd. (2000) showed that lake, land, and river habitat was lost as a result of construction of the Elsie Lake Dam on the Ash River in 1957 (Table 1). The combination of these habitat losses and the annual reservoir drawdown that supplies water for power production in summer was thought to have contributed to:

- reduced planktonic and benthic productivity in Elsie Lake,
- reduced nutrient availability to downstream river habitats due to nutrient retention within the reservoir compared to conditions before impoundment,
- modified thermal regime in Elsie Lake,
- shoreline erosion and unstable banks in the drawdown zone,
- stranded fish in adjacent wetlands and swales during drawdown,
- reduced fish access to and from tributaries during drawdown, and
- dewatered or inundated spawning habitat within the drawdown zone.

Table 1. Areas of habitat that were estimated to have been lost as a result of construction of the Elsie Lake Dam that started operating in 1959. Data are reprinted from Regional Consulting Ltd. (2000).

Habitat Description	Area or length of lost original habitat
Land area flooded	401 ha
Stable lake shoreline	19 km
Mainstem Ash River	5 km
River channel area	30 ha
Riparian area	30 ha*
Tributary length	5 km
Wetland area	72 ha

*calculated using a 30m width from the top of each river bank.

It is reasonable to hypothesize that the trophic status of Elsie Lake Reservoir changed after the reservoir began operating in 1959, corresponding to cycles of trophic upsurge and depression. At a present post-impoundment age of almost 50 years, trophic depression would be expected to be well advanced. Biological production within the reservoir would be expected to be low and the size of fish and fish populations may have declined over the past two or three decades. Measurements and sampling by Triton (1995) show very low nutrient concentrations, which is consistent with the hypothesis that the reservoir is oligotrophic. If this is true, another hypothesis is that addition of nutrients could improve biological production and increase the suitability of the reservoir to support fish populations. This strategy follows from the success of restoring fish populations in Wahleach Reservoir (in the Cascade Mountains near Hope, British Columbia) following nutrient addition and manipulation of fish populations over several years (Perrin et al. 2006).

In 2005, a proposal from the Hupacasath First Nations was accepted and funded by the Bridge Coastal Restoration Program (BCRP) to determine if Elsie Lake Reservoir is a suitable candidate for nutrient addition to sustain or restore fish populations. An important step in this process is to expand on the early work by Triton (1995) to determine the trophic status of the reservoir. This report provides the results from that limnological investigation to measure trophic status. The study was completed in the spring through fall months of 2005.

2 DESIGN ISSUES AND APPROACH FOR ANALYSIS

It is important to identify the necessary parameters needed to assess trophic state. Wetzel (2001) showed that measurements of total phosphorus (TP) concentration, total nitrogen (TN) concentration, average and peak phytoplankton biomass measured as Chl *a*, and Secchi depth collected in spring through fall months are the minimum data required to determine trophic state. It is clear, however, that developing a greater understanding of reservoir function than is possible with these rather simple measurements was required in the analysis of Elsie Lake. There was also intent to acquire data describing various metrics that may be used to predict fish production under present conditions (e.g. models reported by Downing et al. (1990), or the morphoedaphic index (Jenkins 1982)). These data may be used to determine the status of Elsie Lake fish populations with respect to more or less productive systems. Particularly important was measurement of primary production, which can be compared to that of lakes and reservoirs of wide ranging trophic state. Some measure of fish use of littoral and pelagic habitat, including the composition of ingested food, is also useful to interpret trophic state, as was done by Perrin et al. (2006).

Because there was intent in this project to examine more than just basic attributes of trophic state, there were two detailed objectives:

1. Measure basic parameters needed to assess trophic state including TP and TN concentration, Chl *a* concentration, and Secchi depths measured in spring through fall.
2. Measure variables that contribute detail to assessing trophic state, contribute to interpreting reservoir function, and may be used in indices of fish production. These variables included other forms of nitrogen and phosphorus (ammonium (NH_4-N), nitrate (NO_3-N), total dissolved P (TDP), soluble reactive P (SRP), water column profiles of electrochemical parameters (pH, total dissolved solids (TDS), dissolved oxygen (DO), temperature), alkalinity, primary production, and composition and abundance of zooplankton.

To meet these objectives, sampling and measurements of limnological processes were completed on a monthly frequency in the growing season of spring through fall (June – October) in 2005. The resulting data contributed background information to support decisions on whether Elsie Lake Reservoir is a candidate for restoration, potentially involving nutrient addition. Most data were descriptive, which allowed comparison to other lakes and reservoirs for purposes of assessing the extent of trophic depression that may be present. Preliminary insight into a possible response to nutrient augmentation was possible with this descriptive approach. These pre-treatment data can also be used in future years as baseline data with which to examine change in trophic attributes between years in the absence of treatment and years during and after possible treatment.

3 METHODS

3.1 Study Site

Elsie Lake Reservoir (Figure 1) is located on Vancouver Island, approximately 40 km northwest of Port Alberni, B.C. The Elsie Lake Dam was constructed in 1957 and became operational in 1959. The main dam impounded the Ash River and it increased the water surface elevation by approximately 18.2 m (312.5 m to 330.7 m). The dam is an earthfill structure that is 30 m high and 189 m long. The impoundment is also supported by four saddle dams located around the northwest end of the reservoir. At full pool elevation, Elsie Lake Reservoir has a surface area of 658 ha, a mean depth of 8 m and a maximum depth of 30 m. The reservoir is approximately 7 km long and 1 km wide. The reservoir stores up to 84 million cubic meters of water and has a normal drawdown range of 15 m between elevation 331 m and 315.5 m. The reservoir is typically drawn down from July through September and it refills in October through November. The water surface elevation is relatively stable in April through June. The inflows are from 23 streams, but only four have significant year-round flows (Burt and Robert 2003). The catchment area is 218 km^2 and the mean annual rate of inflow is 21 m^3/sec. Average annual flow of 10.7 m^3/s is diverted year-round through a 7.8 km long tunnel and steel penstock to a powerhouse on Great Central Lake that is located south of Elsie Lake Reservoir. The drop in elevation between Elsie Lake Reservoir and the powerhouse is 248 m. The water diversion occurs year round except during a one to two week shutdown for maintenance that is usually scheduled in August of each year (Ash River WUP 2003; Burt and Robert 2003). A minimum flow of 3.5 m^3/s is released through a hollow cone valve to support fish habitat in the Ash River downstream of Elsie Lake Reservoir and the average annual water release to the Ash River is 9 m^3/s. The Ash River flows south into the Stamp and Somass Rivers, and eventually drains into the Alberni Inlet.

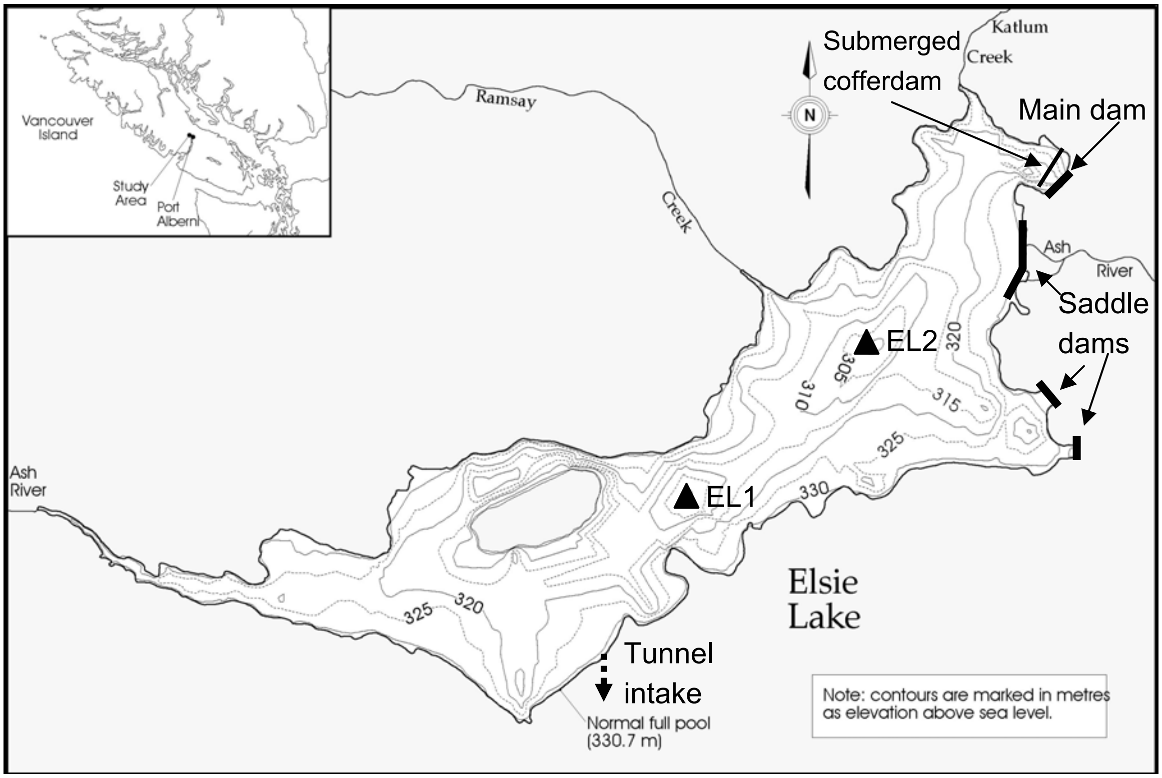


Figure 1. Map of Elsie Lake Reservoir showing the location of the two sampling stations (EL1 and EL2) established on June 27, 2005. The boat launch was located immediately north of the main dam. The map is modified from a file originally compiled by Triton Environmental Consultants.

Fish species identified in Elsie Lake and tributaries include rainbow (*Oncorhynchus mykiss*) and cutthroat trout (*Oncorhynchus clarki*), with incidental past reports of kokanee (*Oncorhynchus nerka*) and perhaps Dolly Varden char (*Salvelinus malma)* (Regional Consulting Ltd. 2000). A recent fish survey that included habitat in the reservoir and influent tributaries found only rainbow and cutthroat, with some individuals exhibiting hybrid characteristics of these two species (Burt and Robert 2003). There are no documented records of non-salmonid species upstream of the dam.

3.2 Location, logistics, and frequency of sampling

Port Alberni was used as a base for all field activities. All sampling in June through August and again in October was conducted during the daytime from an eighteen foot welded aluminium boat that was launched at a ramp located at the north end of the reservoir. In September, drawdown resulted in the exposure of a cofferdam

(Figure 1) that prevented access to the reservoir from the boat ramp. For that sampling episode, a fourteen foot boat was launched from the top of the cofferdam.

Two sampling stations were established on Elsie Lake Reservoir at the time of first sampling in June 2005 (Figure 1). A station called EL1 was fixed at 49° 27.029 N 125° 8.069 W and a second station called EL2 was fixed at 49° 25.528 N 125° 7.235 W using a Lowrance GlobalMap100 Navigation System (GPS). Selection criterion included positioning over the original inundated river channel to achieve maximum depth and distancing away from turbidity sources.

With the exception of measurements of primary productivity, all sampling occurred monthly from June to October at EL1 and EL2. A list of the physical and chemical parameters is shown in Table 1. Primary productivity measurements were completed in June, August and October at EL2.

Table 2. Sampling frequency and list of variables measured in samples collected from Elsie Lake in 2005.

	Variable Description	**Instrument or equipment used**	**Sampling Location**	**Depths**	**Sampling frequency**
1	Electrochemical parameters (pH, TDS, DO, temperature)	YSI 6920 Sonde	EL1, EL2	1-5 m intervals	Monthly*
2	Photosynthetically active radiation (PAR)	Licor LI-185A	EL1, EL2	1 m interval to 1% of surface light	Monthly*
3	Secchi depth	Secchi disc	EL1, EL2		Monthly*
4	Zooplankton density	Wisconsin Net	EL1, EL2	0-20 m	Monthly*
5	TN and TP	Van Dorn	EL1, EL2	0 and 25 m	Monthly*
6	Dissolved Nitrogen (NH_4-N, NO_3+NO_2-N)	Van Dorn	EL1 EL2	0-2 and 20-25 m 2,5,10,16,25m	Monthly* June,Aug,Oct
7	Dissolved Phosphorus (TDP, SRP)	Van Dorn	EL1 EL2	0-2 and 20-25 m 2,5,10,16,25m	Monthly* June,Aug,Oct
8	Alkalinity	Van Dorn	EL1, EL2	0-2 and 20-25 m	Monthly*
9	Chl *a* (0.45 μm and 0.2 μm)	Van Dorn	EL1, EL2	Composite of euphotic zone	Monthly*
10	Size fractionated Chl *a***	Van Dorn	EL2	2,5,10,16m	June,Aug,Oct
11	Size fractionated Primary Productivity**	Van Dorn	EL2	2,5,10,16m	June,Aug,Oct
12	Phytoplankton community composition	Van Dorn	EL1, EL2	Composite of euphotic zone	Monthly*

*all months of June through October
**size fractions were 20, 2, and 0.2 μm

3.3 Field and laboratory measurements

3.3.1 Physical and chemical

Water depth was measured with an Eagle Mark 320 depth sounder and recorded to the nearest 0.1 meter. Depth profiles of electrochemical parameters including temperature, dissolved oxygen, total dissolved solids and pH were collected using an YSI 6920 Sonde that was calibrated on the day of measurement. Irradiance profiles were measured with Licor LI-185A quantum sensor and meter at 1 m intervals from the surface down to a depth corresponding to 1% of surface irradiance. The Secchi depth was measured at approximately noon on the shady side of the boat using a standard 20-cm disk without using a viewing box. Discrete water samples were collected using a Van Dorn water sampler from the depths listed in Table 2. After dispensing water for primary productivity measurement, aliquots were immediately taken for measurement of total and dissolved nutrients, size fractionated Chl *a* and alkalinity. In addition to the discrete water samples, a depth integrated sample for analysis of Chl *a* concentration and for phytoplankton enumeration was prepared by mixing equal aliquots of water sample from at least three depths in the euphotic zone. The euphotic zone is the top part of the water column where the net growth of phytoplankton is positive. It extends from the surface down to a depth corresponding to approximately 1% of surface irradiance. This sample represented mean water condition of the euphotic zone.

The discrete water samples were collected for analysis of TP (total phosphorus), TDP (total dissolved phosphorus), TN (total nitrogen), nitrate + nitrite-nitrogen (NO_3 + NO_2-N), and ammonium (NH_4-N) determination. All samples were stored in the dark and on ice in a cooler until further processing in the field. The dissolved fractions were field filtered through a 0.75 µm combusted GF/F filter and the filtrate was collected in an acid cleaned bottle. Samples collected for TP, TDP, SRP, NO_3 + NO_2-N, and NH_4-N analyses were submitted within 24 hours to the Department of Fisheries and Oceans Laboratory at Cultus Lake. The dissolved P fractions (all in TDP) included orthophosphate, polyphosphates and organic phosphates and the particulate fractions (difference between TP and TDP) would be expected to include phosphate minerals, adsorbed phosphate, and organic particulate phosphate (Stumm and Morgan 1981). SRP always includes the orthophosphate ion which is considered biologically available, but it can also include acid-labile P compounds (Harwood et al. 1969) and overestimate biologically available P (Rigler 1968, Bothwell 1989). Samples for TP and TDP analysis were digested and analysed by Menzel and Corwin's (1965) potassium persulfate method. SRP was analysed using the molybdenum blue method (Murphy and Riley, 1962). NH_4^+ and NO_3 + NO_2-N were analysed using a Technicon autoanalyzer equipped with a long flow cell to attain a detection limit of 0.5 mg/L (Stainton et al. 1977). Samples collected for analysis of TN were submitted to the Pacific Environment Science Centre (PESC) in North Vancouver for analysis by methods outlined in APHA (1995).

Water for alkalinity determination was collected in 0.125 L polycarbonate bottles. A Beckman 44 pH meter and electrode were used to determine total alkalinity according to the standard potentiometric method of APHA (1995). Each sample was titrated with 0.02 N H_2SO_4 to pH 4.5. Titrations were performed in duplicate or triplicate to check the analytical precision of the results. Alkalinity was measured in samples collected in June through September but not in October.

3.3.2 Phytoplankton

Chl *a,* corrected for phaeopigments, was determined by *in vitro* fluorometry (Yentsch and Menzel, 1963). The depth integrated water samples that were collected from both stations over the euphotic zone (Table 2) were filtered through 47-mm diameter 0.2 µm and 0.45 µm nitrocellulose filters using a vacuum pressure differential of <100 mm of Hg. Care was taken to limit light exposure of the Chl *a* samples during field handling of water samples and laboratory analysis. Aliquots (0.25-1 L) of water samples that were collected from the discrete depths at EL2 (Table 2) were filtered using parallel filtration onto 0.2, 2.0 and 20.0 µm polycarbonate Nucleopore™ filters for analysis of size fractionated Chl *a* concentration. The water filtration was completed on the day of sample collection at a field lab that was set up in offices of the Hapacasath First Nation. Samples were stored in the dark at –20°C prior to analysis at the University of British Columbia. All Chl *a* samples were analyzed within two days of collection. Chl *a* was extracted in 5 ml of 90% acetone and stored in the dark for 20-24 h at –20°C. Fluorescence of the acetone extract was measured before and after the addition of three drops of 10% HCl in a Turner Designs™ Model 10-AU fluorometer that was calibrated with a solution of commercially available Chl *a*. Calculations to determine Chl *a* concentration were made using equations reported by Parsons et al. (1984). Phytoplankton biomass across dates was expressed as Chl *a* retained on the 0.2 µm filters.

Primary productivity was measured *in situ* as the amount of ^{14}C incorporated into particulate organic carbon (Steemann Nielsen, 1952). Water samples that were collected from discrete depths (Table 2) were transferred directly into two light and one dark 300 ml acid-cleaned BOD glass bottles. Each BOD bottle was rinsed three times with sample before filling. The samples were maintained under low light conditions during all manipulations until the start of the incubation that was started within 1 h of the water collections. Water in the BOD bottles was inoculated with 0.185 MBq (5 µCi) of $NaH^{14}CO_3$ New England Nuclear (NEC-086H). The BOD bottles were attached to an acrylic plate and were suspended at depths from which the water samples were taken. The samples were incubated *in situ* for 4-5 h between the hours of 1000 and 1500 to allow the carbon uptake to proceed. Following retrieval of the incubation array, the BOD bottles were transported to lab facilities in the Hupacasath First Nations offices in a cool dark box. The incubations were terminated by parallel filtration of 100 ml of sample through each of a 0.2, 2.0 and 20.0 µm 47-mm polycarbonate filter using <100 mm Hg vacuum differential (Joint and Pomroy, 1983). Each folded wet filter and retained biomass was placed in a 7 ml scintillation vial and stored in the dark until processing at the University of British Columbia. In the fumehood, 100 µL of 0.5 N HCl was added to each vial to eliminate the unincorporated inorganic $NaH^{14}CO_{3.}$ The scintillation vials were left uncapped in the fumehood for approximately 48 h until dry, 5 ml of Scintisafe® scintillation fluor was added to each vial, and they were stored in the dark for >24 hours before the samples were counted using a Beckman® Model #LS 6500 liquid scintillation counter. Each vial was counted for 10 minutes in an external standard mode to correct for quenching. The specific activity of the stock was determined by adding 100 µL ^{14}C-bicarbonate solution to scintillation vials containing 100 µL of ethanoalamine and 5 ml Scintisafe® scintillation cocktail. Calculation of rates of carbon incorporation followed methods reported by Parsons et al. (1984). Primary productivity values were vertically integrated according to procedures of Ichimura et al. (1980). Daily rates of primary production were calculated by multiplying the hourly primary productivity by the incubation time and by the ratio of the solar irradiance during the incubation to the solar irradiance of the incubation day. The difference between the ^{14}C incorporation in the light bottles (included photosynthetic and non-phtosynthetic uptake) and the ^{14}C incorporation in the dark bottle (included only non-photosynthetic ^{14}C uptake) indicated carbon uptake by photosynthesis.

Aliquots of the depth integrated water samples from each station were dispensed to glass amber jars, preserved with acid-Lugol's solution, and stored in a cool and dark location until the algal cells could be counted. Prior to the enumeration, the samples were gently shaken for 60 seconds and allowed to settle in 25 mL chambers for a minimum of 8 hrs (Utermohl 1958). Counts of algal cells, by taxa, were done using a Carl Zeiss© inverted phase-contrast plankton microscope. Counting followed a 2-step process. Initially, several random fields (5-10) were examined at low power (250x magnification) for large microplankton (20-200 µm) including colonial diatoms, dinoflagellates, and filamentous blue-greens. A second step involved counting all cells at high power (1,560x magnification) within a single random transect that was 10 to 15 mm long. This high magnification permitted quantitative enumeration of minute (<2 µm) autotrophic picoplankton sized cells (Cyanophyceae), and the small nanoflagellates (2.0-20.0 µm) of the Chrysophyceae and Cryptophyceae. Between 250-300 cells were consistently enumerated in each sample to assure statistical accuracy of counting results. The taxonomic reference was Canter-Lund and Lund (1995).

3.3.3 Zooplankton

Duplicate vertical hauls of a 153 µm mesh Wisconsin net having a 30 cm intake opening were made monthly from each station for collection of macrozooplankton (Table

2). The depth of each haul was 20 m. The net was raised at a speed of approx. 0.5 m/sec. The zooplankton were washed into the cod-end of the net and anaesthetized in a wash of Club Soda before being added to a 10% sugared formalin solution. The anesthetisation was conducted to prevent egg shedding while the sample was being mixed with the sugar-formalin preservative. In the laboratory, the samples were split using a Folsom splitter to a volume that contained >100 post-naupliar stages of the most abundant taxa of crustaceans. For each sub-sample, the species were enumerated at 5-100x magnification under a GSZ-Zeiss stereo microscope. The number of attached eggs was counted.

4 RESULTS

4.1 Hydrology

The reservoir water surface elevation gradually declined over the period of June through to the end of September and then it increased rapidly in October (Figure 2). The first sampling episode occurred at a water surface elevation of 328 m. Water withdrawls over the summer were greater than the inflows (Figure 3), which resulted in a 10 m drawdown of the reservoir to 318 m. For all of 2005, the top water elevation was 331 m, (occurring in May) and the bottom elevation occurring at the end of September was 318 m for a total drawdown of 13 m. The onset of storms in October produced high inflows that exceeded the rate of water withdrawal and release, causing the reservoir to rapidly fill. The reservoir water detention time for 2005 that is calculated as reservoir volume (m^3) divided by the annual water outflow (m^3/yr) was 35 days. If water detention time is calculated only for the study period, it was 113 days. The difference between these two values means that water entering the reservoir at the start of the growing season in May was likely to be flushed out by the end of August. In the winter time when river flow rates and power demands are relatively high, the water detention time is likely to be close to one or two weeks. These water detention times are very low and they will contribute to continual removal of nutrients and plankton communities. In this respect, Elsie Lake Reservoir has riverine attributes of that may limit the development of a pelagic community.

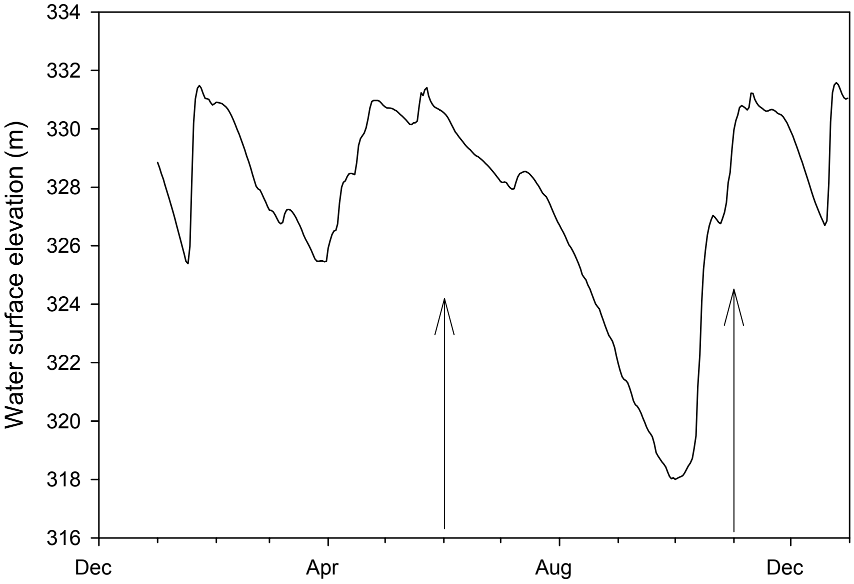


Figure 2. Water surface elevation in Elsie Lake Reservoir in 2005. Arrows indicate the start and finish of the sampling period.

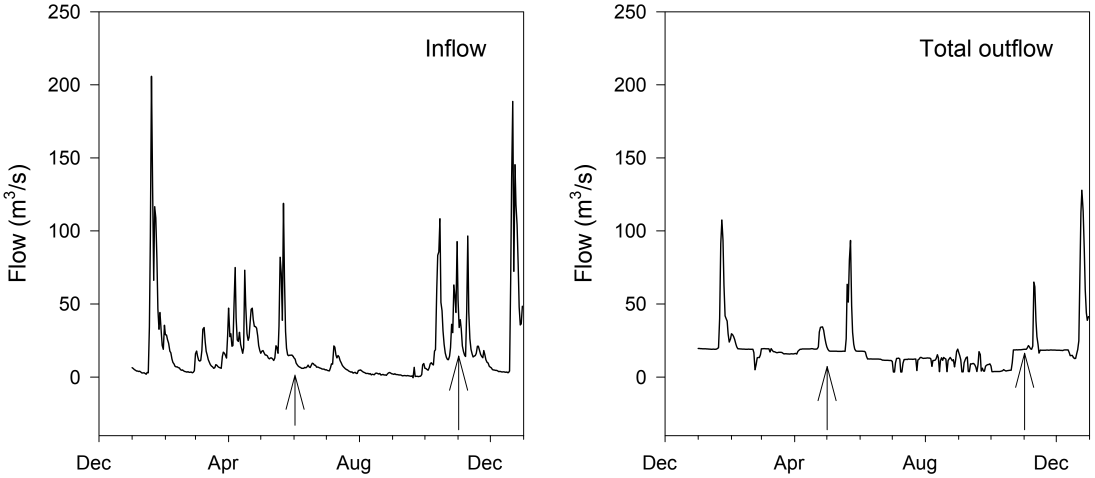


Figure 3. Elsie Lake Reservoir inflow (all sources) and outflow (turbine flow plus water release at the dam) in 2005. Arrows indicate the start and finish of the sampling period in 2005.

4.2 Temperature and dissolved oxygen profiles

Stratification in a lake is the separation of warm, low density surface water (epilimnion) from a bottom higher density cool layer (hypolimnion) by a transition zone having a wide temperature gradient (metalimnion). Interactions between solar radiation, cooling, river inflows, and wind determine internal mixing and the timing and magnitude of thermal stratification. Stratification can influence vertical diffusion gradients and thus determine the availability of various forms of nutrients for production of algae, aquatic vascular plants, and the availability of habitat for fish and the food that fish use.

Temperature profiles indicated that density stratification in Elsie Lake developed in late spring and early summer, it was well established in August and September and then collapsed with almost complete mixing of the water column in October (Figure 2). In June and July, a surface mixed layer having temperatures of 18 – 24ºC was weakly present and a thermocline extended to a depth of approximately 13 m. Temperature of the hypolimnion was 6 – 8ºC at that time. In August, temperature of the surface mixed layer was approximately 23ºC and the thermocline was between 5 m and 10 m. In September, the temperature of the surface mixed layer declined to 16ºC, the thermocline was again between 5 m and 10 m and the bottom mixed layer temperature was 7 – 8ºC. In October the surface mixed layer having a temperature of 10ºC deepened to 15 m and a very weak thermocline having a small temperature range of 8 – 10ºC was apparent at 15 – 20 m. This October profile indicated resistance to mixing was very weak and that isothermal conditions that are typical in coastal lakes in the fall was near.

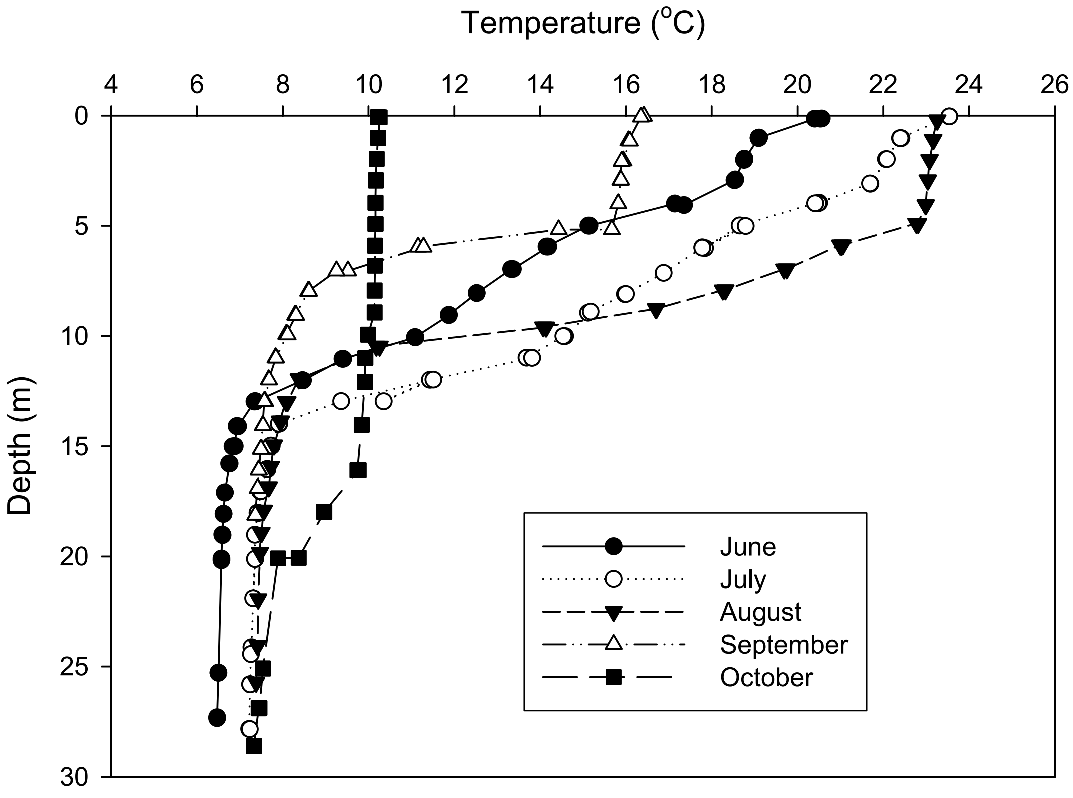


Figure 4. Monthly temperature profiles at Station EL1 on Elsie Lake in 2005.

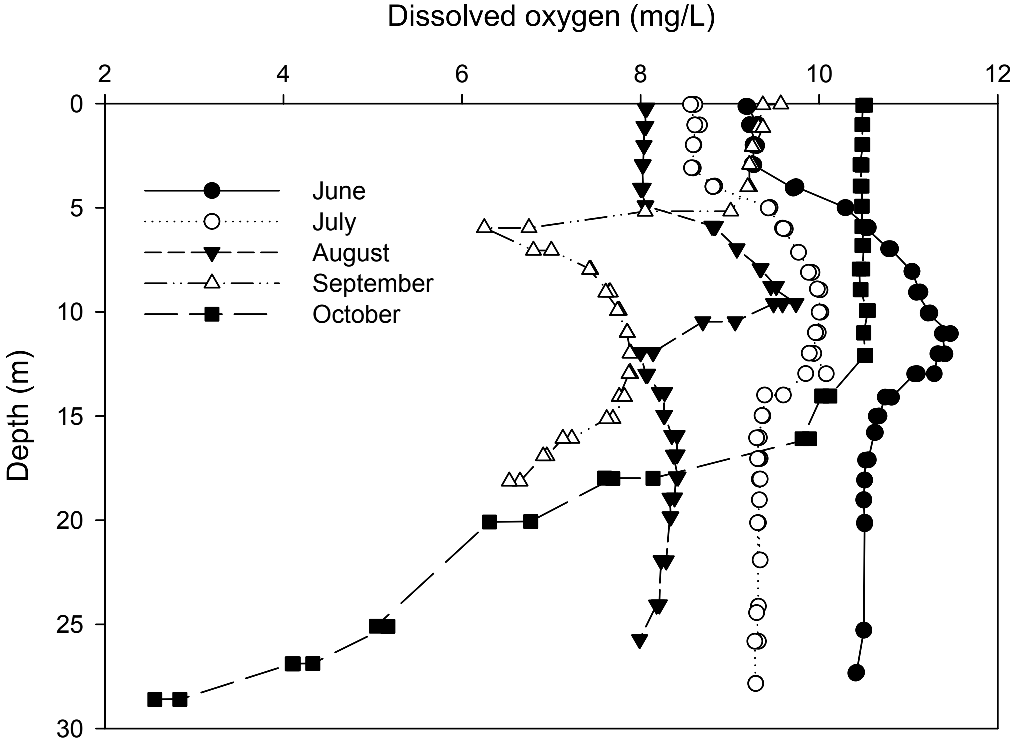
Elsie Lake was well oxygenated from surface to bottom in 2005, but the dissolved oxygen (DO) concentrations were variable between the monthly profiles (Figure 3). Variation can be introduced by wind mixing of surface water, production of oxygen from photosynthesis, oxygen demand from decomposition processes in bottom sediments, and the inflow of oxygen rich river water. River inflows will typically seek and travel along a depth within a receiving lake or reservoir where water density is the same as that of the river (e.g. plug flow). This process will not affect temperature profiles in the lake but it may introduce anomalies in oxygen concentration within a depth zone if plug flow persists.

In June, the DO concentrations were >9 mg/L (>91% saturation). A general increase in DO concentration was found over the depth profile of the surface mixed layer that extended to 12 m, potentially in association with production of oxygen from photosynthesis in the epilimnion or plug flow of oxygen rich water from the upper Ash River.

A similar pattern was found in July and August with DO concentrations of 8-9 mg/L in the surface mixed layer and rising concentrations that reached a peak near the bottom of the thermocline. At a depth of 12-13 m, the DO concentrations declined by 1-2 mg/L. The average hypolimnetic DO concentration was 9.3 mg/L (77-79% saturation) in July and 8.3 mg/L (66-70% saturation) in August.

In September, the DO concentration in the surface mixed layer was 9.4 mg/L and it dropped sharply to 6.2 mg/L within the steep thermocline that was established at that time. At the bottom of the thermocline (6 – 12 m depth) the DO concentrations increased to 8 mg/L. They then declined back to 6 mg/L within the top of the hypolimnion.

In October, DO concentration over the profile of the mixed layer was consistently 10.5 mg/L (93% saturation). It declined over greater depths to reach a minimum concentration of 2.6 mg/L (21% saturation) near the bottom of the reservoir. This gradient of declining DO concentration over the bottom half of the water column in October indicated oxygen demand. Some of the demand was likely associated with precipitation of decomposing organic matter that was produced in the epilimnion in the summer months and was sedimenting without restriction by density barriers associated with temperature stratification. Oxygen demand from bottom sediments would have contributed to the oxygen concentration gradient near the sediment – water interface.



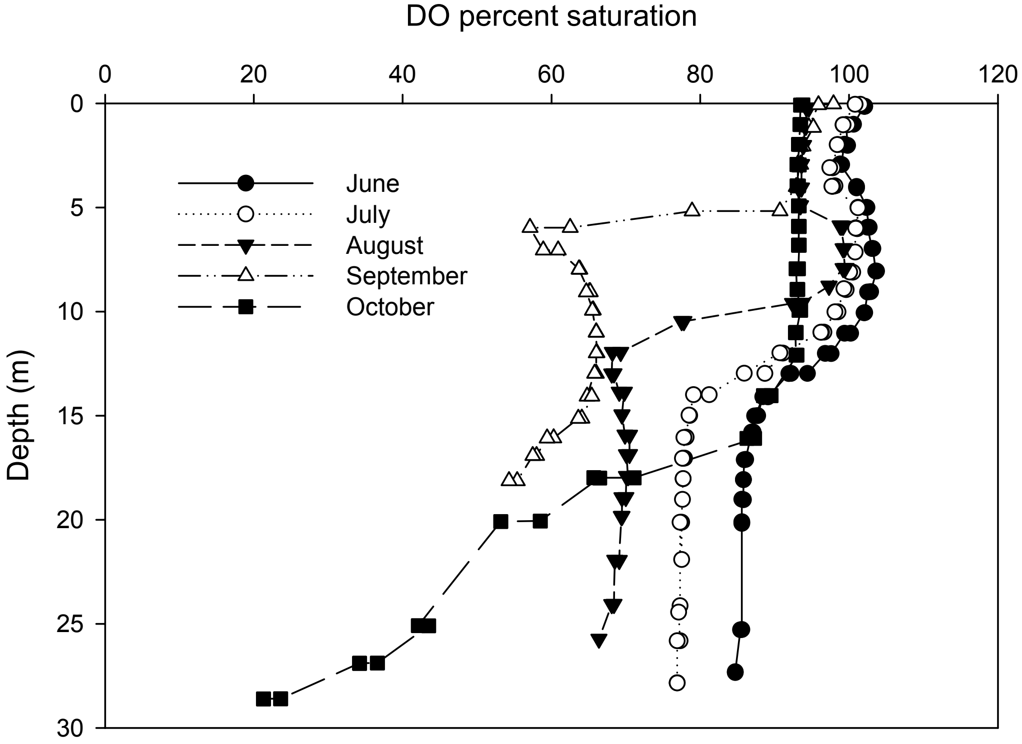


Figure 5. Monthly dissolved oxygen concentration (top) and percent saturation of dissolved oxygen (bottom) at Station EL1 on Elsie Lake in 2005.

4.3 Water Chemistry

Water in Elsie Lake Reservoir had pH values over a narrow range between 6.4 and 7.1 (Table 3). These values were in the range that indicates buffering from the CO_2-HCO_3-CO_3 system with the dominant anion being HCO_3. A very small downwards shift in pH was found with depth among all seasons, indicating some effect of respiration (the release of CO_2) in sediments on the bottom of the water column.

Table 3. Mean concentration or measurement of chemical parameters and Secchi depth in Elsie Lake Reservoir, 2005.

Parameter and units	**Mean (±SE) concentration or measurement by season and depth**					
	Spring**		**Summer****		**Fall****	
	Surface*	**Bottom**	**Surface**	**Bottom**	**Surface**	**Bottom**
Secchi depth (m)	12		11.4		8.1	
Conductivity (uS/cm)	29	28	33	30	31	32
TDS (mg/L)	19	18	21	19	20	21
pH	6.97	6.79	7.1	6.5	6.6	6.4
alkalinity (mg/L)	11	12	14	13		
TP (μg/L)	2.7	2.7	2.3	2.3	3.2	1.7
PP (μg/L)	1.1	0.9	0.5	0.7	1.5	0.7
TDP (μg/L)	1.6	1.8	1.8	1.6	1.6	1.0
SRP (μg/L)	0.4	0.3	0.4	0.2	0.8	0.6
NH_4-N (μg/L)	3.4	9.7	2.9	31.1	4.7	49.1
NO_3-N (μg/L)	0.8	21.1	0.7	27.0	30.1	28.0
TN (μg/L)	60	70	67	130	120	150
Molar TN:TP	50	57	65	128	84	195

*surface data are from the top 2 m of the water column and the bottom data are from the bottom 5 m of the water column.

**spring is June, summer is July through September and fall is October

Alkalinity is an approximate measure of acid neutralizing capacity (ANC) and it is measured as the amount of acid required to neutralize bases (mainly OH^-, CO_3^{2-} and HCO_3^-, but also including borate, silicate and phosphate). Very low alkalinity was present in Elsie Lake Reservoir and there was little variation between seasons and over depth within seasons, indicating no net demand for bases over time and depth. Specific conductivity (28 – 33 uS/cm) and dissolved solids (18 – 21 mg/L) concentrations were very low at all times. There was little change in these concentrations over depth, indicating no effect of release of dissolved compounds from lake sediments on the overlying water column. This finding was not surprising given the well oxygenated conditions that would favour complexation of cations and nutrients in sediments. The low conductivity and dissolved solids concentrations would have originated from low concentrations of major inorganic cations including Ca and Mg, and their respective anions including HCO_3, CO_3, Cl, and SO_4, which likely formed the major dissolved salts in Elsie Lake Reservoir. Concentrations of the cations would be expected to be mainly derived from weathering processes upstream of the lake and introduced from the Ash River.

Mean TP concentrations of 1.7 – 3.2 ug/L (Table 3) found in Elsie Lake Reservoir were extremely low and among the lowest of any lake in British Columbia. The soluble reactive P (SRP) that is the most biologically available form of P that can be directly analyzed using wet chemistry techniques was always <1 μg/L. There was little change in TP or soluble P concentration (TDP) with season or with depth within a season, indicating little or no release of P from sediments that is typical of nutrient – rich lakes (e.g. Perrin 2005). Little or no release of P from sediments was caused by relatively high oxygen concentrations in the hypolimnion that prevented solubilization of phosphorus. The oxygen demand that was detected in October in Elsie Lake Reservoir in October (Figure 5) was not enough to affect phosphorus solubility near the bottom of the water column. The particulate phosphorus (PP) concentrations (<2 μg/L) were very low and they were always less than the TDP concentrations, indicating little plankton biomass within the reservoir. The PP at the reservoir surface was lower in summer (0.5 μg/L) than in the other seasons (>1 μg/L), but these differences were very small and of little ecological significance.

Concentrations of all forms of nitrogen were equally low (Table 3). In spring and summer, the average epilimnetic NO_3-N concentration (<1 μg/L) was much less than it was in the hypolimnion (21 – 27 μg/L). Lower NH_4-N concentrations in the epilimnion than in the hypolimnion were also found. Possible cause of these vertical differences included demand for inorganic N by biological uptake within the epilimnion and release of N from sediments in the hypolimnion. The more reduced forms of N (e.g. NH_4-N) would be primarily released from sediments due to respiration. Given that the depth effect on N concentration was most noticeable for NO_3-N, nitrification rates in the hypolimnion may have been high, causing oxidation of the released NH_4-N to form NO_3-N. The high oxygen concentrations throughout the water column in spring and summer (Figure 5) would have supported high rates of nitrification in the presence of nitrifying bacteria. In the fall, the vertical difference in NH_4-N concentration remained intact, which suggested that the effect of surface and bottom processes that were active in the summer in determining differences in NH_4-N concentration with water depth were ongoing. The average NO_3-N concentration in the fall, however, was similar between the epilimnion (30 μg/L) and the hypolimnion (28 μg/L) (Table 3)). While vertical mixing was occurring in October (Figure 4), that process may not fully explain this similarity, particularly because of the vertical differences in NH_4-N concentration that remained in fall sampling episode. Mixing did not appear to affect the stratification of NH_4-N concentration. An alternative explanation is related to processes upstream of the reservoir. Unlike NH_4-N, NO_3-N is highly mobile in forest soils. Heavy rainfall that occurred in October would have been sufficient to mobilize the NO_3-N that had accumulated in the forest floor following the summer growing season. That mobilization of NO_3-N would have increased NO_3-N concentrations within the Ash River and in surface waters of the reservoir compared to the NO_3-N concentrations found during the drier summer months. Relatively high concentrations of TN, which has a large dissolved organic N component, in the fall compared to the summer and spring supports this hypothesis. The dissolved organic N can also be highly mobile in forest soils during fall storm events.

Measurement of nutrient concentrations in the Ash River at the same time as it is done in the reservoir would help to determine the importance of these nitrogen transport processes on the Elsie Lake Reservoir chemistry.

The very low concentrations of inorganic N and P in Elsie Lake Reservoir suggests that the reservoir may not support high plankton densities. High Secchi depth transparency of 8 – 12 m (Table 3) supported this hypothesis. This range is typical of oligotrophic lakes and it suggests that Elsie Lake Reservoir supported low rates of biological production. Secchi depths were lower in the fall (8 m) than they were earlier (11-12 m). This difference was at least in part related to light attenuation caused by higher algal biomass that was found in the reservoir in the fall compared to the other seasons (Section 4.4, Figure 6). It may also have been associated with the transport of particles and colour (related to dissolved organic matter) that can be mobilized from forest soils during heavy rainfall in the fall in coastal ecosystems.

The molar ratio of bioavailable N:P in water can indicate whether N or P potentially limits primary production (algal growth) in a reservoir. This supply N:P can sometimes be difficult to measure accurately, because of uncertainty about actual bioavailability of P in a particular form of P that might be selected. If SRP is selected, there can be difficulty in detecting it, particularly in oligotrophic waters. The same can be true for NH_4-N or NO_3-N in some waters. Organically bound nutrients can be important where organic N and P occurring in the water column at the beginning of the growing season may be mineralized and made available over the growing season (e.g. Berman 2001). For this reason, potential limitation of N and P in lakes is best determined using the ratio of total N: total P. In rivers, the organic N and P is not important in determining relative nutrient limitation because plants only use available N and P in water that passes by in water flow. The available N and P in this case includes only the inorganic fractions which are best approximated by NH_4-N plus NO_3-N for bioavailable N and SRP for bioavailalable P. Organic N and P are not directly available to periphyton in water flow.

Rhee (1978) has shown that for a given species of algae there is a sharp transition between P-limited and N-limited growth. The particular N:P ratio (using bioavailable forms of N and P) at which the transition between N and P-limitation occurs is species dependent, varying from as low as 7:1 for some diatoms (Rhee and Gotham 1980) to as high as 45:1 for some blue-greens (Healey 1985). In river and lake communities that support many algal species, the growth of most species will be N-limited at low supply ratios and P-limited at high supply ratios. Guildford and Hecky (2000) found that among lakes from wide ranging regions, N-deficient growth of phytoplankton occurs at molar TN:TP <20 while P-deficient growth consistently occurs at TN:TP > 50. At intermediate ratios, either N or P can be deficient. N deficient growth can favour blue green algae (Cyanophyta), some of which can fix nitrogen. They can be abundant in rivers and lakes where there is ample P supply and they may dominate when there is abundant P but N is in short supply for other taxa (Smith 1983), although this is not always the case (Levine and Schindler (1999).

The molar ratio of TN:TP was used to determine potential nutrient limitation in Elsie Lake Reservoir (Table 3). The focus here is on the TN:TP in the epilimnion where most algal production occurs. Spring sampling revealed a molar TN:TP of 50 in surface waters, suggesting that the phytoplankton community was mainly P-limited but that N-limitation of some taxa could not be ruled out. In summer, the TN:TP was higher, indicating sustained P-deficiency. In the fall, the TN:TP was again higher and clearly indicated potential P deficiency in the algal community. These ratios would not favour blue green algae, but would favour diatoms and microflaggelates that are well known to be common in coastal lakes of British Columbia (Stockner and MacIsaac 1996).

4.4 Phytoplankton

Average phytoplankton biomass in the euphotic zone, measured as Chl *a* concentration retained on the 0.2 µm filters, was consistently <1 µg/L on all sampling dates (Figure 6). A small increase of phytoplankton biomass was found late in the growing season when Chl *a* concentration increased by up to 2 fold from earlier dates to reach 1 µg/L. This increase in biomass coincided with the decrease in the Secchi depth from 12 m in the summer to 6 m in October (Section 4.3). It also coincided with an increase in mixed layer SRP and inorganic N (NO_3-N and NH_4-N) concentration in October compared to the earlier months. These higher nutrient concentrations would be expected to increase the growth rate and biomass of algae compared to that from earlier in the summer. Despite this small increase in algal biomass, there was no evidence of a fall “bloom” that is typically characterized by a 10-20 fold increase in algal biomass. A spring bloom was also not observed, but it may have occurred prior to the first sampling trip in June. The very low concentrations of inorganic N and soluble P in June (Table 3) suggests that phytoplankton growth earlier in the spring may have severely depleted availability of nutrients by June.

The overall average Chl a concentration in 2005 based on filtering through a 0.2 µm filter was 0.7 µg Chl *a*/L or when expressed on an areal basis and integrated over the sampling depth, it was 8.1 mg Chl *a*/m^2.

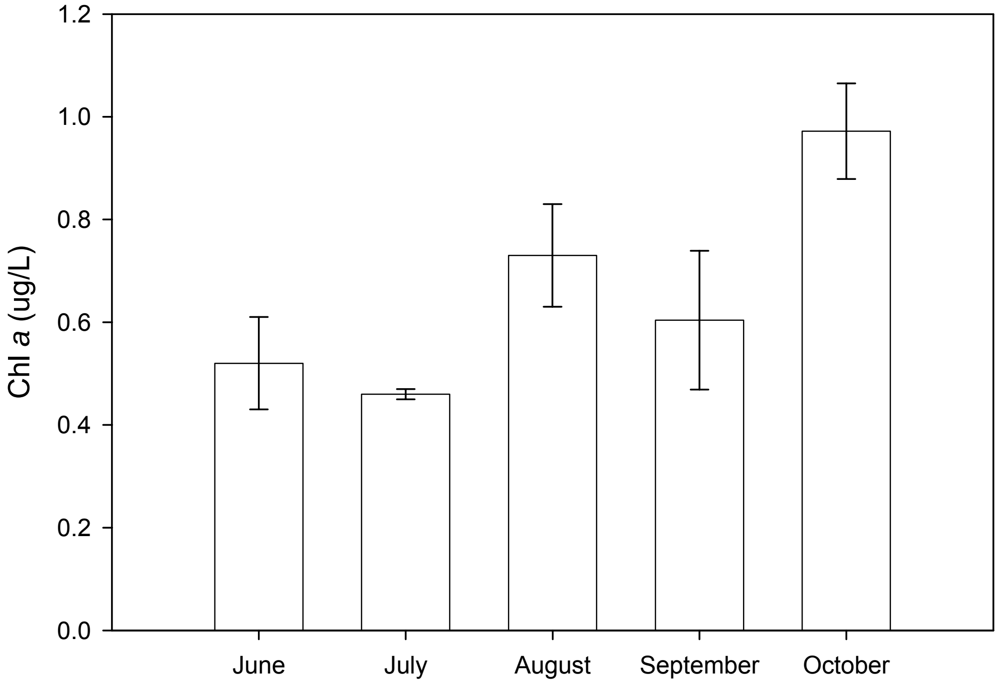


Figure 6. Mean Chl *a* concentration (±SE) in the euphotic zone of Elsie Lake Reservoir in 2005.

Picoplankton sized cells (0.2-2.0 µm) accounted for 60% of the total phytoplankton biomass, followed by nanoplankton (2.0-20.0 µm) at 30% and microplankton (>20.0 µm) accounted for 10% (Figure 7). A shift in the size distribution of phytoplankton biomass was observed in the fall sampling session, coinciding with the higher nutrient concentrations and overall greater algal biomass at that time. The predominance of picoplankton declined and the relative importance of nanoplankton (the size fraction that is mainly consumed by herbivorous zooplankton) increased from ~27% of total biomass in the summer to 39% in October (Figure 7). The contribution by microplankton increased 5-fold to account for 22% of the phytoplankton biomass. Larger size fractions such as the microplankton gain a competitive advantage over smaller cells when dissolved nutrient supply is relatively high (Suttle and Harrison 1988). Alternatively, the size distribution of phytoplankton biomass could be shaped by grazing pressure by herbivorous zooplankton.

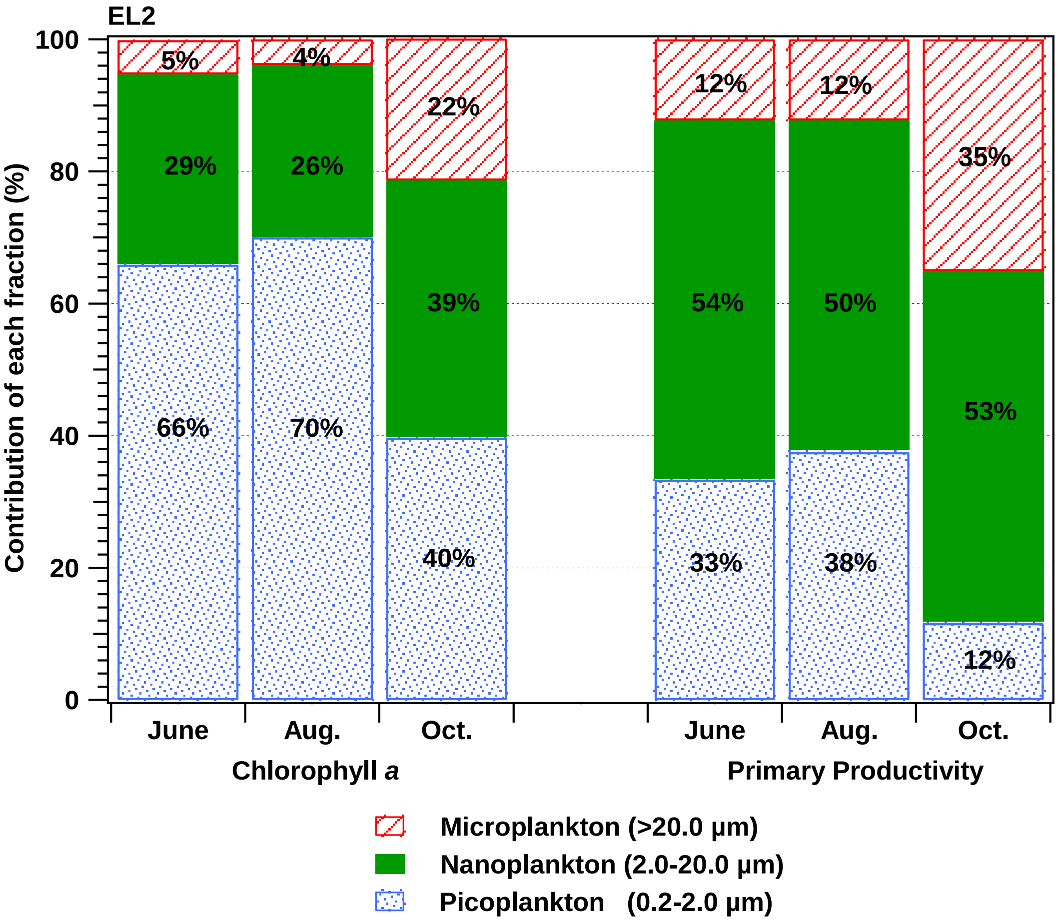


Figure 7. Percent contribution of the three phytoplankton size fractions to total biomass and to primary production at EL2.

Total primary productivity of all algal size fractions combined was 11.2 mg C m^{-2} d^{-1} in June, 9.5 mg C m^{-2} d^{-1} in August and 21.0 mg C m^{-2} d^{-1} in October, which resulted in a mean rate of 13.9 mg C m^{-2} d^{-1} for the duration of sampling in 2005.

Nanoplankton was the most productive size fraction of phytoplankton, accounting for an average of 53% of the total primary production across all dates (Figure 7). In June and August, picoplankton accounted for an average of 36% of the total productivity while in October the contribution by picoplankton dropped to 12%. A seasonal shift was also observed in microplankton production. The relative contribution of microplankton to total primary production increased by nearly 3-fold between August (12% of total primary production) and October (35% of production). The higher contribution by larger cells in the fall suggest that severe nutrient limitation declined, which allowed larger cells to out compete the smaller picoplankton cells. High microplankton production is a clear indicator of higher concentrations of bio-available nutrients, which indeed was found in the water chemistry of Elsie Lake Reservoir (Table 3).

Phytoplankton cell densities never exceeded 2,700 cells/ml across all sampling sessions (Figure 8). The highest cell density of 2,656 cells/ml was found in August and the lowest of 1,662 cells/ml occurred in July. Phytoplankton biovolume ranged from 0.08 mm^3/L in July to a high of 0.13 mm^3/L in October.

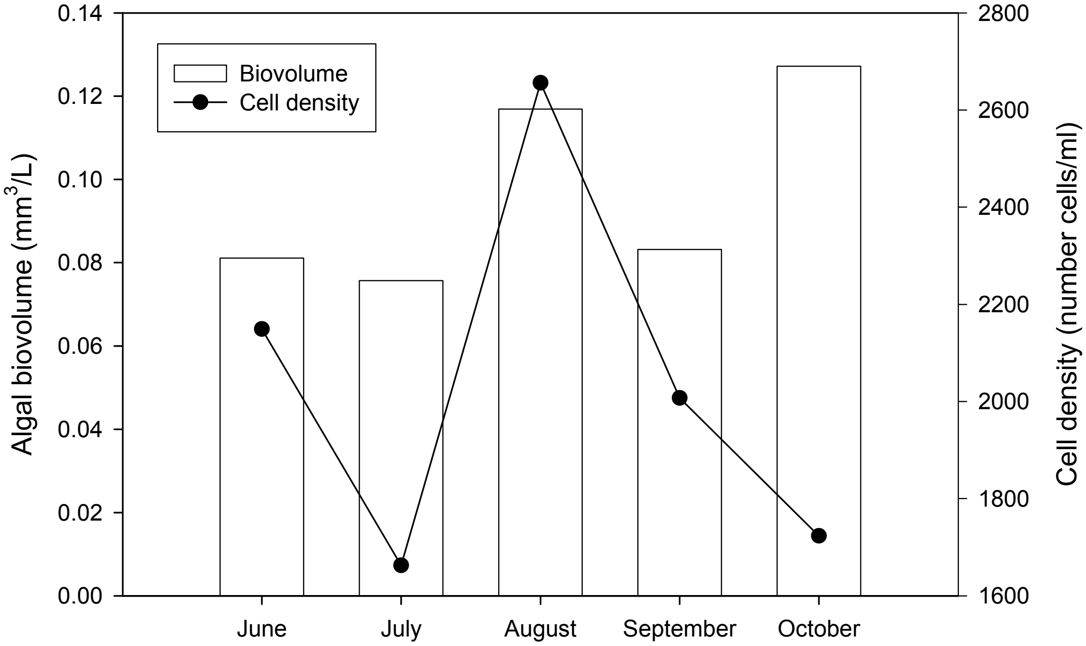


Figure 8. Epilimnetic phytoplankton cell density and biovolume at EL2 in Elsie Lake Reservoir, 2005.

A total of 29 species of phytoplankton were found in Elsie Lake Reservoir across all months in 2005 (Appendix D). Chrysophytes and Cryptophytes, which are both nanoflagellates, were the dominant classes in all months followed by small cyanobacteria (Cyanophytes), dinoflagellates (Dinophytes) and green algae (Chlorophytes), and finally diatoms (Bacillariophytes) (Figure 8).

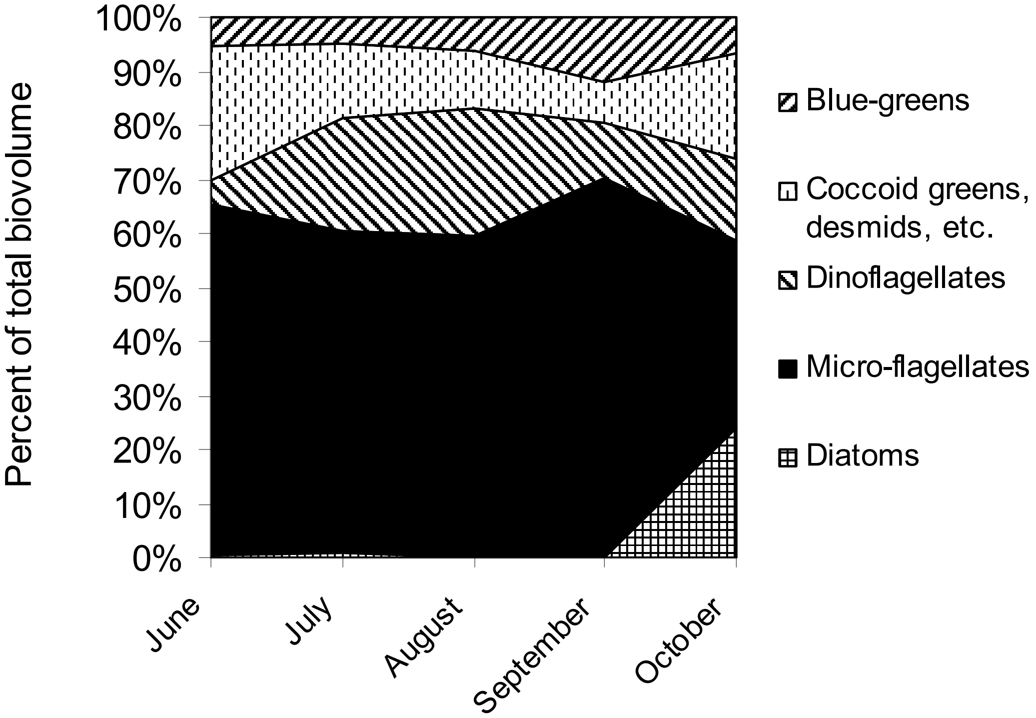


Figure 9. Time course change in the relative biovolume of algal divisions in Elsie Lake Reservoir, 2005.

The Chrysophytes and Chryptophytes accounted for 60-70% of the monthly algal biovolume in June through September but they accounted for 35% of total biovolume in October (Figure 9). The microflagellates occurring in greatest biovolume were *Chromulina* sp.*, Cryptomonas sp., Chrysochromulina* sp.*, Dinobryon* sp., *Rhodomonas* sp., and a mixed assemblage of unidentified small microflagellates. The blue-greens accounted for 5-12% of monthly biovolume with greatest biovolume occurring in September. The biovolume of *Synechococcus* sp. and *Oscillatoria* sp. was greatest among the blue green taxa. Biovolume of the dinoflagellates (Dinophyceae) was only 4% of total biovolume in June but it increased to 10-23% in the following months. Greatest biovolume occurred in August. The dinoflagellate taxa included *Peridinium* sp. and *Gymnodinium* sp. Biovolume of the green algae was 25% of total biovolume in June, it declined to 8-14% in July through September and then increased to 19% in October. The green algae were largely composed of *Elakatothrix* sp. and *Chlorella* sp. The diatoms (Bacillariophyceae) were generally absent from the reservoir in June through September but they increased to 24% of total biovolume in October. Five diatom species were found in the reservoir including *Achnanthes sp., Aulicoseira distans*, *Cyclotella glomerata*, Cyclotella stelligera and *Navicula* sp. The increase in biovolume of larger sized taxa in October (diatoms, dinoflagellates, and greens) was accompanied by a decline in the biovolume of the smaller sized microflagellates. This shift from a community of mainly small sized taxa in the summer to one of larger sized taxa in the fall coincided with the increase in epilimnetic concentrations of phosphorus and inorganic nitrogen that occurred over the same time (Table 3). The change was consistent with known evidence that small sized taxa are more effective competitors for nutrients at very low N and P concentrations while the larger sized taxa are better able to compete at higher nutrient concentrations.

4.5 Zooplankton

The zooplankton community in Elsie Lake Reservoir was comprised of cladocerans, copepods and rotifers (Figure 10). Total crustacean density was 6.1 individuals/L in June; it increased to a peak of 8.7 individuals/L in August, and declined to 1.4 individuals/L in October. The cladocerans were the most abundant of all zooplankton on all dates. They represented 74% of total density in June, rising to 78% in August before declining to 67% of total zooplankton density in October. Twelve cladoceran species were found among all dates but only three were found in greater than trace numbers (>0.1 individuals/L). The relative density of *Eubosmina longispina* declined over the growing season, *Daphnia rosea* increased between June and August and declined thereafter, while the relative density of *Holopedium gibberum* increased (Figure 11). The rare cladocerans included *Alona* sp., *Alonella* sp., *Chydorus sphaericus*, *Ceriodaphnia* sp., *Scapholeberis* sp., *Diaphanosoma* sp. *Sida crystalline*, *Leptodora kindtii*, and *Polyphemus pediculus*. The average copepod densities were always less than 2 individuals/L and they were 23-30% of the total zooplankton densities (Figure 10). Cyclopoid and calanoid copepods were present including *Cyclops* sp., *Cyclops bicuspidatus thomasi, Macrocyclops* sp., *Hesperodiaptomus kenai*, and *Skistodiaptomus oregonensis*. Rotifers were found at very low densities of 0.06 – 0.3 individuals/L across all dates. They were 4.5% of zooplankton density in June; they declined to 0.7% of the total density in August and then increased to 12% in October.

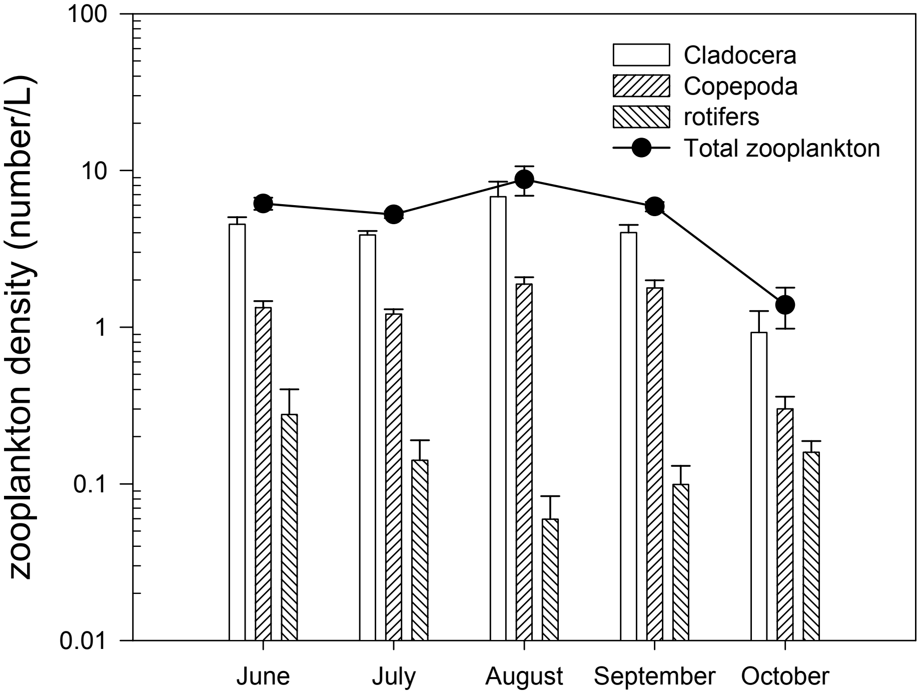


Figure 10. Mean zooplankton density (±se) by month in Elsie Lake Reservoir, 2005.

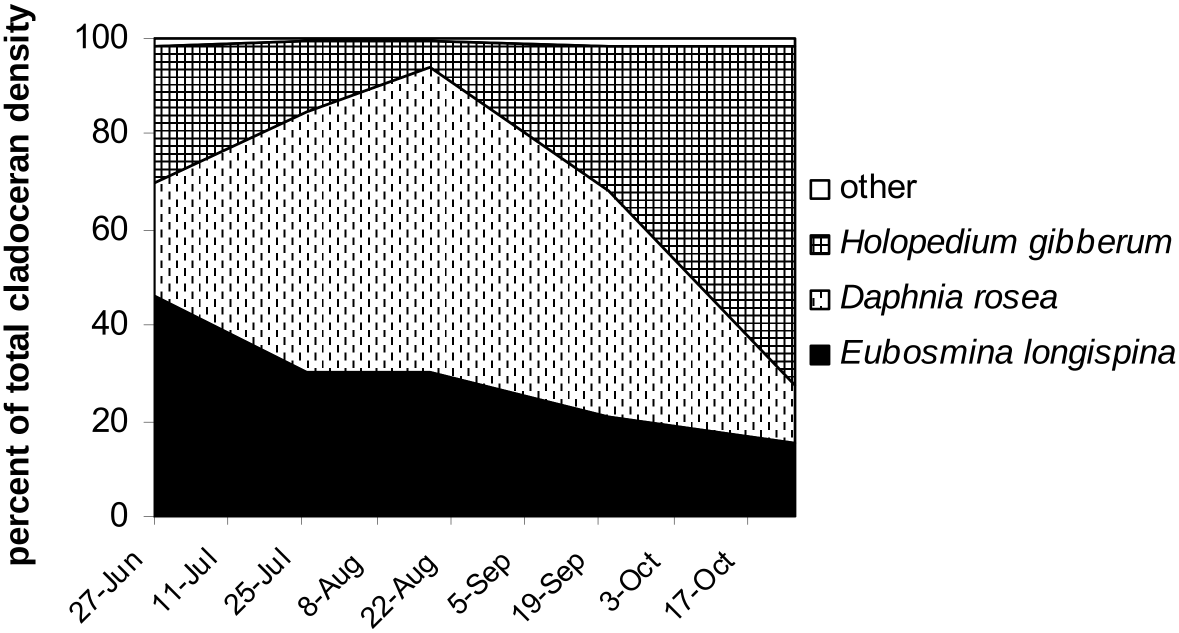


Figure 11. Relative density of cladoceran species, by month, in Elsie Lake Reservoir, 2005.

5 DISCUSSION

5.1 Trophic State

In Table 4, various attributes of Elsie Lake Reservoir are compared to criteria that are commonly used to determine the trophic state of lakes (Wetzel 2001). Using this approach, Elsie Lake Reservoir is classified as ultraoligotrophic among most criteria and oligotrophic among all criteria. This trophic status is the same as that found in many coastal lakes that were examined by Stockner and MacIsaac 1996.

Table 4. Assignment of trophic state in Elsie Lake Reservoir based on criteria defined by Wetzel (2001).

Parameter		**Trophic classification by Wetzel (2001)****				**Elsie Lake Reservoir**	**Status of Elsie Lake Reservoir**
		ultraoligotrophic	**oligotrophic**	**mesotrophic**	**eutrophic**		
TP (µg/L)	mean		8.0	27	84	2.4	ultraoligotrophic
	range	<1 – 5	3 – 18	11 - 96	16 – 386	1.4 – 3.5	ultraoligotrophic
TN (µg/L)	mean		661	753	1875	93	ultraoligotrophic
	range	<1 – 250	307 - 1630	361 - 1387	393 - 6100	40 - 180	ultraoligotrophic
Chl-*a* (µg/L)	mean		1.7	4.7	14.3	0.7*	ultraoligotrophic
	range	0.01 – 0.5	0.3 – 4.5	3 - 11	3 - 78	0.2 – 1.1*	ultraoligotrophic
Secchi depth (m)	mean		9.9	4.2	2.5	10.6	ultraoligotrophic
	range		5.4 – 28.3	1.5 – 8.1	0.8 – 7.0	6 – 13	oligotrophic
Net primary production (mg C m^{-2} d^{-1})	mean						
	range	<50	50 – 300	250 - 1000	>1000	13.9	ultraoligotrophic

*based on sampling in June through October

**based on annual means

Trophic state is a sliding scale related to growth of biota or degree of carbon fixed by plant growth. In most lakes and reservoirs, including Elsie Lake Reservoir, the two critical nutrients that can limit this process are nitrogen and phosphorus. Oligotrophic and ultraoligotrophic lakes and reservoirs are those in which the supply of N and P is low enough to severely limit the growth of phytoplankton, which results in relatively low biomass measured as chlorophyll-a. At the other end of the scale, eutrophic lakes are those receiving relatively high loads of N and P that produce high biomass of algae in the ranges shown in Table 4. Mesotrophic lakes are those having a nutrient load and algal biomass intermediate between oligotrophic and eutrophic states. Of the two nutrients, phosphorus is primarily important because it can theoretically generate 500 times its own weight in algae while nitrogen can only produce 71 times its own weight in algae, meaning that algae are much more reactive to change in P supply than to change in N supply when growth is limited by either nutrient.

A characteristic attribute of eutrophic lakes is they may support blue green algae that can fix their own N (at high energetic cost). A lake becomes eutrophic from high phosphorus loading. As algae respond to this phosphorus supply, the pool of nitrogen can decline, producing nitrogen deficiency among taxa that cannot fix their own nitrogen. Hence, blue greens have a competitive advantage under high P loadings. Because some blue greens can be toxic, are not well assimilated into lake food webs, and can produce obnoxious odour and colour, extreme eutrophication causes waters to be unusable and can be regarded as having very poor water quality.

In oligotrophic lakes and reservoirs in which the supply of both N and P is very low, blue green algae do not have a competitive advantage. Rather, it is the very small sized flagellates of the Chrysophytes and Cryptophytes that are favoured because they can outcompete the larger sized taxa for the available nutrients (Suttle and Harrison 1988, Suttle et al. 1991). This was the case in Elsie Lake Reservoir where the microflagellates dominated for most of the sampling period. Under these conditions, any slight addition of phosphorus can produce limitation of algal growth by nitrogen and vice versa, any slight addition of N can produce limitation by P. Hence, in oligotrophic systems like Elsie Lake Reservoir, the phytoplankton communities are constantly responding to changing N and P deficiency, depending on processes that determine the delivery of nutrients to the euphotic zone. In coastal lakes and reservoirs in which the seasonal return of nutrients to the water column from sediments is negligible, those processes are mainly associated with nutrient transport dynamics in the inflow streams and biogeochemical processes in the forested landscape (weathering, erosion, stage of forest development, soil types, etc.) that determine rates of nutrient transport to those streams.

In Elsie Lake Reservoir, concentrations of the inorganic forms of N and P increased in October compared to concentrations in the summer months. Between the summer and fall, the 39% increase in TP concentration (2.3 μg/L increased to 3.2 μg/L) coincided with a 67% increase in algal biomass (0.6 μg Chl *a*/L increased to 1 μg Chl *a*/L) and a 121% increase in primary production (9.5 mg C m^{-2} d^{-1} increased to 21.0 mg C m^{-2} d^{-1}). The lower biomass response can be attributed to losses associated with senescence, sedimentation, and grazing by zooplankton, which do not affect measurement of primary production. Coincidentally, there was a shift to larger sized phytoplankton taxa in October (e.g. increased biovolume of diatoms and green algae in the microplankton size range) from the relatively small sized taxa (picoplankton and nanoplankton) that were dominant in the summer. This change is consistent with evidence that larger sized taxa become increasingly competitive for phosphorus as the supply concentrations increase (Suttle and Harrison 1988, Suttle et al. 1991). The coincidence of a seasonal shift in phosphorus concentration and algal production suggests that the trophic state of Elsie Lake Reservoir would be highly reactive to modified nutrient loading. Given the known link between nutrient loading, algal production, and food availability for planktivorous and benthivorous fish, we hypothesize that addition of P in the absence of N deficiency would produce a several fold increase in production of organic matter that would contribute to food webs in Elsie Lake Reservoir.

It is reasonable to assume that food webs driven from benthic and pelagic production exist in Elsie Lake Reservoir as they do in other reservoirs (e.g. Johnston et al. 1999, Perrin et al. 2006). What is not clear is the relative importance of each in producing food for fish. Rainbow trout and cutthroat trout are known to be present in Elsie Lake Reservoir (Burt and Robert 2003) but there has been no recent confirmation of the presence of kokanee and Dolly Varden char that may also be present (Regional Consulting Ltd. 2000). Rainbow trout and cutthroat trout mainly feed on emerging benthos and fallout from the forest canopy in other reservoirs (Perrin et al. 2006), and they respond mainly to increased benthic production in fertilized lakes (Johnston et al. 1999). Dolly Varden are likely to be piscivorous and would only be present if there was an abundance of kokanee as forage. Kokanee are planktivorous and if present, they would feed on zooplankton with a preference for the larger size taxa (Thompson 1999). Among the zooplankton taxa that were common in Elsie Lake Reservoir, *Daphnia rosea* is large. This species was found in sizes up to 1.3 mm during fertilization of Wahleach reservoir (Perrin et al. 2006) and they can be larger (Dodson and Frey 1991). It would be expected to be preferred food by kokanee in Elsie Lake Reservoir. *Daphnia* sp. and the other zooplankton species would also be expected to increase in size and abundance due to increased algal production from any nutrient addition that might be considered for Elsie Lake Reservoir. Any nutrient addition treatment that favours the nanoplankton, which was the most productive size fraction in the reservoir, would be a particular benefit to *Daphnia* because that fraction is favoured as forage by the cladocerans (Dodson and Frey 1991, Leibold, 1989). While an increase in zooplankton biomass seems likely from any nutrient addition, the potential response of the whole plankton based food web is highly speculative. Uncertainty about the structure of the fish populations and fish population size must be resolved before decisions on the potential merits of fertilization can be explored.

5.2 Comparison to other lakes and reservoirs in British Columbia

Among measurements to date, Elsie Lake Reservoir supports the lowest phytoplankton biomass and the lowest primary production among lakes and reservoirs in British Columbia (Table 4). The depth integrated Chl *a* concentration (8.1 mg Chl a/m^2) was slightly lower than that in Williston Reservoir (9 mg Chl a/m^2) but several times lower than in other lakes and reservoirs. The average primary production in Elsie Lake Reservoir was 10 times lower than the lowest rate of primary production among lakes and reservoirs that are receiving fertilization treatments and several times lower than that in unfertilized lakes and reservoirs. While Table 5 lists only a few systems for comparison and may not be representative of production among wide ranging ultraoligotrophic lakes and reservoirs in British Columbia, the extremely low biomass and primary production values in Elsie Lake Reservoir are compelling. They indicate extreme effects of trophic depression in a coastal reservoir, where we assume that trophic depression has occurred. The N and P concentrations are among the lowest found anywhere in the world (compared to data in Wetzel (2001)). Small sized phytoplankton are favoured, mainly in the picoplankton and nanoplankton size ranges. They support a classic cladoceran dominated zooplankton community that is known to graze on the small sized phytoplankton. The low zooplankton densities of <10 individuals/L would not be expected to support a highly productive population of obligate planktivors (e.g. kokanee), particularly given the very low water detention time that would favour continual flushing of organisms produced in the pelagic zone. From this evidence, we hypothesize that trout are the favoured fish populations in Elsie Lake Reservoir. Rainbow trout and cutthroat trout are opportunistic and will take food from a diversity of sources, mainly including benthos and terrestrial insects when pelagic production is extremely limited.

Table 5. Comparison of phytoplankton biomass and primary production among lakes and reservoirs in British Columbia.

Lake or Reservoir	Areal phytoplankton biomass (mg Chl *a*/m^2)	Primary production (mg C m^{-2} d^{-1})	Fertilized or not	Reference
Elsie Lake Reservoir	8.1	13.9	No	This report
Williston Reservoir	9.0	33.5	No	Harris et al. (2005)
Okanagan Lake	27.2	72.2	No	Andrusak et al. (2004)
Slocan Lake	26.3	59.3	No	Harris (2002)
Stave Reservoir	28.5	28.5	No	Stockner and Beer (2004)
Alouette Lake	36.8	140	Yes	Reddekopp et al. (2006)
Kootenay Lake	51.5	303	Yes	Harris (2004)
Arrow Lake Reservoir	48.8	262	Yes	Pieters et al. (2001)

5.3 Application of fish production models

Many of the variables measured in this study have been found in past work to be useful predictors of fish standing crop or fish production (e.g. Leach et al. 1987). By considering those that may be most relevant to Elsie Lake Reservoir, estimates of fish yield may be derived.

Perhaps one of the most used models and the one that has generated most heated discussion and controversy is the morphoedaphic index, commonly known as the MEI (Ryder 1965). The MEI is defined as total dissolved solids (mg/L) divided by mean depth (m). Jenkins (1982) applied the MEI to reservoir fish production and found that it explained 62% of variance in fish standing stock in relatively young reservoirs (mean age of 20 years) of the southeastern United States according the equation:

(1) $$\log_{10} TC = 1.759 + 0.713\log_{10} MEI - 0.093\log_{10} MEI^{2}$$

where TC is total fish standing crop (kg/ha) and MEI is total dissolved solids divided by mean depth. When this model is applied to Elsie Lake Reservoir, we find that the reservoir might support a fish standing crop of 93 kg/ha. This value is in the bottom 10% of fish standing crops in reservoirs examined by Jenkins (1982).

Given that Jenkins (1982) data base was somewhat limited in geographic scope and that all except for one fish species in the data base do not occur in British Columbia, we hold little confidence in this estimate. In addition, the average age of the reservoirs examined by Jenkins (1982) was only 20 years, which means that most could have been in stages of trophic upsurge, not trophic depression that is characteristic of Elsie Lake Reservoir. This difference in trophic state also reduces our confidence in application of the Jenkins model to Elsie Lake Reservoir.

In examining the potential importance of many potential predictor variables on fish production in lakes covering a wide range of geographic areas and trophic status, Downing et al. (1990) found that the MEI had no relationship to annual fish production, measured in units of kg/ha/yr. They found that fish production was closely associated with measures or indices of production in the food web. Primary production and total phosphorus concentration were top predictors. A significant (P<0.001) linear primary production model explained 79% of variance in fish production among all lakes according to the equation:

(2) $$\log_{10} FP = 0.6 + 0.575\log_{10} PP$$

where FP was fish production (kg/ha/yr) and PP was primary production (gC/m^2/yr). A significant (P=0.002) linear total phosphorus model explained 67% of fish production among all lakes according to the equation:

(3) $$\log_{10} FP = 0.332 + 0.531\log_{10} TP$$

where FP was fish production (kg/ha/yr) and TP was total phosphorus concentration (μg/L). Downing et al (1990) further showed a strong correlation between fish production and fish standing crop according to the model:

(4) $$\log_{10} FP = -0.42 + 1.084\log_{10} FB$$

where FP was fish production (kg/ha/yr) and FB was standing crop (kg/ha). Equation 4 allowed conversion of production estimates to standing crop estimates when comparing the Downing models to the MEI estimate reported by Jenkins (1982). Application of the primary production model (equation 2) and conversion to standing crop (equation 4) to Elsie Lake Reservoir revealed an estimated rate of fish production of 6.1 kg/ha/yr or 13 kg/ha of fish standing crop, which was seven times less than that estimated by the Jenkins (1982) model. Application of the total phosphorus model (equation 3) and conversion to standing crop (equation 4) to Elsie Lake Reservoir revealed an estimated rate of fish production of 3.4 kg/ha/yr or 7.6 kg/ha of fish standing crop. This standing crop estimate was 58% of that determined from the primary production model.

Further refinement was explored by application of a fish production model developed by Shortreed et al. (2000) that included data from oligotrophic sockeye lakes in British Columbia and Alaska and the lakes reviewed by Downing et al (1990). That model explained 87% of the variance in measured fish production and was described as:

$$FP = 2.97PR^{0.56} \tag{5}$$

where FP was fish production (kg/ha/yr) and PR was primary production (gC/m^2/yr). Application of this model (equation 5) and conversion to standing crop (equation 4) to Elsie Lake Reservoir revealed an estimated rate of fish production of 4.5 kg/ha/yr or 9.8 kg/ha of fish standing crop. These estimates were close to those predicted by the Downing et al. (1990) models.

An important assumption of the Downing et al (1990) and Shortreed et al. (2000) models is that the fish are entirely supported by production from within a lake or reservoir. We have suggested in Section 5.1 that this may not be entirely true for the rainbow trout and cutthroat trout in Elsie Lake Reservoir. They may acquire a substantial portion of their food as fallout from the forest canopy. The models are also largely based on lakes that support planktivorous fish populations. Surveys to date suggest that planktivors are largely absent from Elsie Lake Reservoir although additional work is required to confirm the composition of fish populations in the reservoir. Given these discrepancies between the lakes that were used for the model building and Elsie Lake Reservoir, the fish production models should be used with considerable caution. To put the production values into some perspective, however, the production estimate of 4.5 kg/ha/yr that was determined using equation 5 (Shortreed et al. 2000) for Elsie Lake Reservoir was lower than that from any of the Alaskan and British Columbia oligotrophic lakes that were examined by Shortreed et al. (2000). This comparison implies that production of any planktivorous fish population in Elsie Lake Reservoir would be extremely limited. Our analysis of trophic state suggests that availability of food driven by extremely low nutrient concentrations would be one factor contributing to the low fish production.

6 RECOMMENDATIONS

Given the future intent to apply restoration measures to Elsie Lake Reservoir that may involve nutrient addition, there are two recommendations that result from this study.

First, we have suggested from multiple lines of evidence that an increase in biological production through the pelagic food web to zooplankton is a likely outcome of any future nutrient addition. We have also cited evidence that an increase in benthic production is likely to occur from the same treatment. The potential fish response is where there is substantial uncertainty because the complete fish community structure has not been determined. We do know that rainbow trout and cutthroat trout are present (Burt and Robert 2003), but there is uncertainty whether planktivores are present that might benefit from a fertilization treatment. A detailed fish population survey is required to resolve this question. It is recommended that a hydroacoustic survey be completed in 2006 that will provide information on the size of fish populations, by species, and what habitat is used by each fish species. Fish sampling that will accompany an acoustic survey (e.g. gill netting, trapping, and/or trawling) will provide evidence of fish size-at-age and age structure of the populations. The stomach contents of sampled fish must be examined to provide information on the composition of food that each fish species is ingesting. These latter data will help to identify the source of important food items. Together with the descriptive limnological data from 2005, the description of food composition can be used to construct one or more target food webs for use in designing a restoration strategy. It might reveal opportunities for manipulation of food webs to be explored independently or in combination with fertilization. It is recommended that the fish population and sampling survey be completed at the end of the growing season (e.g. end of September or in October), in 2006.

Since the fish sampling survey will be completed in another year of sampling before treatment is applied, it is recommended that a second year of basic limnology sampling and measurements be completed in that same year. The intent here is to add another set of observations to provide duplicate pre-treatment years of baseline data that can be used in later statistical and ecological analysis to determine the extent of a response to future treatment. The intent is not to redefine trophic state. That information is known from the present study. This recommendation is a study design issue. At least two years of baseline data should be collected for use in future assessment to account for benefits realized from money spent on the restoration activity. This second year of sampling and measurements should include measurement of nutrient concentrations in the inflow Ash River. These latter data are required to provide insight into the extent of nutrient loading from the main inflow, which the 2005 study suggested was important in increasing biological production in the reservoir in the fall.

7 LIST OF REFERENCES

Andrusak, H, S. Matthews, I. McGregor, K. Ashley, R. Rae, A. Wilson, D. Sebastian, G. Scholten, P Woodruff, L. Vidmanic, J. Stockner, G. Wilson, B. Jantz, J. Webster, H. Wright, C. Walters, and J. Korman. 2004. Okanagan Lake Action Plan Year 9 (2004). Biodiversity Branch, Ministry of Water, Land and Air Protection, Province of British Columbia.

APHA. 1985. Standard Methods for the Examination of Water and Wastewater. 16th ed. American Public Health Association, Washington, DC.

Ash River Water Use Plan Consultative Committee (Canada). 2003. Consultative committee report: Ash River water use plan. BC Hydro, Vancouver, BC.

Baxter, R.M. 1977. Environmental effects of dams and impoundments. Ann. Rev. Ecol. Syst. 8: 255-283.

Berman, T. 2001. The role of DON and the effect of N:P ratios on occurrence of cyanobaterial blooms: Implications for the outgrowth of Aphanizomenon in Lake Kinneret. Limnol. Oceanogr. 46: 443-447.

Bothwell, M.L. 1989. Phosphorus-limited growth dynamics of lotic periphytic diatom communities: areal biomass and cellular growth rate responses. Can. J. Fish. Aquat. Sci. 46: 1293-1301.

Brett, M.T. and C.R. Goldman. 1997. Consumer versus resource control in freshwater pelagic food webs. Science. 275: 384-386.

Burt, D.W. and C.B. Robert. 2003. Assessment of fish and fish habitat in the Elsie Lake basin and identification of restoration options. Prepared for Hupacasath First Nations, Port Alberni. Supported by BC Hydro, Bridge Coastal Fish and wildlife Restoration Program. 65pp.

Canter-Lund, H. and J.W.G. Lund. 1995. Freshwater Algae – Their Microscopic World Explored. BioPress Ltd. Bristol UK. 360p.

Carpenter SR, J.F. Kitchell and J.R. Hodgson, 1985. Cascading trophic interactions and lake productivity. BioScience 35: 634-639.

Dodson, S.I. and D.G. Frey. 1991. Cladocera and other Branchiopoda. In. Thorp, J.H. and A.P. Covich. (Ed) 1991. Ecology and Classification of North American Freshwater Invertebrates. Academic Press Inc. New York.

Downing, J.A., C. Plante and S. LaLonde. 1990. Fish production correlated with primary productivity, not the Morphoedaphic Index. Can. J. Fish. Aquat. Sci. 47: 1929-1936.

Grimmard, Y. and H.G. Jones. 1982. Trophic upsurge in new reservoirs: a model for total phosphorus concentrations. Can. J. Fish. Aquat. Sci. 39: 1473-1483.

Guildford, S.J. and R.E. Hecky. 2000. Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? Limnol. Oceanogr. 45: 1213-1223.

Guildford, S.J., F.P. Healey, and R.E. Hecky. 1987. Depression of primary production by humic matter and suspended sediment in limnocorral experiments at Southern Indian Lake, northern Manitoba. Can. J. Fish. Aquat. Sci. 44: 1408-1417.

Harris, S.L 2002. Slocan Lake Primary Productivity Monitoring Program, 2000 & 2001. Report prepared for Redfish Consulting Ltd. Nelson, B.C. 32p

Harris, S.L. 2004. Size fractionated primary productivity in Kootenay Lake, 2004. Prepared for the Kootenai Tribe of Idaho. 18p.

Harris, S.L., A.R. Langston, J.G. Stockner and L. Vidmanic. 2005. A limnological assessment of four Williston Reservoir embayments, 2004. Prepared for the Peace/Williston Fish and Wildlife Compensation Program Report. Prince George, BC. 55p.

Harwood, J.E., R.A. van Steenderen and A.L. Kuehn. 1969. A rapid method for orthophosphate analysis at high concentrations in water. Water Res. 3: 417-423.

Healey, F.P. 1985. Interacting effects of light and nutrient limitation on the growth rate of Synechococcus linearis (Cyanophyceae). J. Phycol. 21:134-146.

Hecky, R.E. and S.J. Guildford. 1984. Primary productivity of Southern Indian Lake before, during, and after impoundment and Churchill River diversion. Can. J. Fish. Aquat. Sci. 41: 591-604.

Hilborn, R. and J. Winton. 1993. Learning to enhance salmon production: lessons from the salmonid enhancement program. Canadian Journal of Fisheries and Aquatic Science 50: 2043-2056.

Hyatt K.D. and J.G. Stockner 1985. Response of sockeye salmon (Oncorhynchus nerka) to fertilisation in British Columbia lakes. Can. J. Fish. Aquat. Sci. 42:320-331.

Hyatt, K.D., D.J. McQueen, K.S. Shortreed, and D.P. Rankin. 2004. Sockeye salmon (*Onchorhynchus nerka*) nursery lake fertilization: Review and summary of results. Environmental Reviews 12: 133-162.

Ichimura, S., T.R. Parsons, M.Takahashi and H.Seki. 1980. A comparison of four methods for integrating ^{14}C-primary productivity measurements per unit area. J. Oceanogr. Soc. Jap. 36: 259-262.

Jackson, T.A. and R.E. Hecky. 1980. Depression of primary productivity by humic matter in lake and reservoir waters of the boreal forest zone. Can. J. Fish. Aquat. Sci. 37: 2300-2317.

Jenkins, R.M. 1982. The Morphoedaphic Index and reservoir fish production. Trans. Am. Fish. Soc. 111: 133-140.

Johnston N.T., M.D. Stamford, K.I. Ashley and K. Tsumura, 1999. Responses of rainbow trout (Oncorhynchus mykiss) and their prey to fertilization of an oligotrophic montane lake. Can. J. Fish. Aquatic. Sci. 56:1011-1025

Joint, I.R. and A.J. Pomroy.1983. Production of picoplankton and small nanoplankton in the Celtic Sea. Mar. Biol. 77(1): 19-27.

Kennedy, R.H. and W.W. Walker. 1990. Reservoir nutrient dynamics. In: Reservoir limnology: ecological perspectives. Edited by K.W. Thornton, B.L. Kimmel, and F.E. Payne. John Wiley and Sons, New York. Pp. 109-132.

Leach, J.H., L.M. Dickie, B.J. Shuter, U. Borgmann, J. Hyman, and W. Lysack. 1987. A review of methods for prediction of potential fish production with application to the Great Lakes and Lake Winnipeg. Can. J. Fish. Aquat. Sci. 44 (Suppl. 2): 471-485.

Levine, S.N. and D.W. Schindler. 1999. Influence of nitrogen to phosphorus supply ratios and physicochemical conditions on cyanobacteria and phytoplankton species composition in the Experimental Lakes Area, Canada. Can.J. Fish. Aquat. Sci. 56: 451-466.

Leibold, M.A. 1989. Resource edibility and the effects of predators and productivity on the outcome of trophic interactions. Am. Nat. 134(6): 922-949.

Mazumder, A. and J.A. Edmundson. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Science 59: 1361-1373.

McQueen D.J., M.R.S. Johannes, J.R. Post, T.J. Stewart, and D.R.S. Lean. 1989. Bottom-up and top-down impacts on freshwater pelagic community structure. Ecological Monographs 59:289-309

Menzel, D.W. and N. Corwin. 1965. The measurement of total phosphorus in seawater based on liberation of organically bound fractions by persulfate oxidation. Limnol. Oceanogr. 10: 280-282.

Murphy, J.A. and J.P. Riley. 1962. A modified single solution method for the determination of inorganic phosphate in natural waters. Anal. Chim. Acta. 27: 31-36.

Ney J.J. 1996. Oligotrophication and its discontents: effects of reduced nutrient loading on reservoir fisheries. American Fisheries Society Symposium 16:285-295.

Ostrofsky, M. L. and H.C. Duthie. 1980. Trophic upsurge and the relationship between phytoplankton biomass and productivity in Smallwood Reservoir, Canada. Can. J. Bot. 58: 1174-1180.

Parsons, T.K., Y. Maita and C.M. Lalli. 1984. A Manual of Chemical and Biological Methods for Seawater Analysis. Pergamon Press, Oxford. 173 p.

Paterson, M.J., D. Findlay, K. Beaty, W. Findlay, E.U. Schindler, M. Stainton, and G. McCullough. 1997. Changes in the planktonic food web of a new experimental reservoir. Can.J.Fish.Aquat.Sci. 54: 1088-1102.

Perrin, C.J. 2005. Limnology of Bouchie and Milburn Lakes: Present status and recommendations for water quality improvement. Report prepared by Limnotek Research and Development Inc. for BC Ministry of Water Land and Air Protection. 49p.

Perrin, C.J. M.L. Rosenau, T.B. Stables, and K.I. Ashley. 2006. Restoration of a montane reservoir fishery using biomanipulation and nutrient addition. North American Journal of Fisheries Management. In Press.

Pieters, R., L.C. Thompson, L. Vidmanic, S. Harris, J. Stockner, H. Andrusak, M. Young, K. Ashley, B. Lindsay, G. Lawrence, K. Hall, D. Sebastian and G. Scholten. 2001. Arrow Reservoir fertilization experiment, year 2 (2000/2001) report. RD 87, Fisheries Branch, Ministry of Environment, Lands and Parks, Province of British Columbia.

Popp, A. and K.D. Hoagland. 1995. Changes in benthic community composition in response to reservoir aging. Hydrobiologia. 306: 159-171.

Power M.E., 1992. Top-down and bottom-up forces in food webs: Do plants have primacy? Ecology 73:733-746.

Reddekopp, S., G. Wilson, K. Ashley, M. McCusker, R. Land, J. Stockner, G. Scholten, P. Woodruff, and D. Dolecki. 2006. The Alouette Reservoir Fertilization Project experimental phase Year 5 (2002) and the monitoring phase (2004 & 2004). Report prepared by Reddekopp Biological for Ministry of Environment. Ecosytems Science Section. Victoria, B.C. 102p.

Regional Consulting Ltd. 2000. Bridge Coastal Fish and Wildlife Restoration Program Strategic Plan. Prepared for BC Ministry of Environment. Fisheries and Oceans Canada., and BC Hydro. 393p.

Rhee, G.-Y. 1978. Effects of N:P atomic ratios and nitrate limitation on algal growth, cell composition, and nitrate uptake. Limnol. Oceanogr. 23:10-25.

Rhee, G.-Y. and I.J. Gotham. 1980. Optimum N:P ratios and coexistence of planktonic algae. J. Phycol. 16:486-489.

Rigler, F.H. 1968. Further observations inconsistent with the hypothesis that the molybdenum blue method measures orthophosphate in lakewater. Limnol. Oceanogr. 13: 7-13.

Ryder, R.A. 1965. A method for estimating the potential fish production of north-temperate lakes. Trans. Am. Fish. Soc. 94: 214-218.

Schallenberg, M. 1993. Effects of impoundment on the oxygen and nutrient dynamics of sub-arctic reservoirs. James Bay Publication Series. North Wind Information Services Inc.

Shortreed, K.S., J.M.B. Hume, and J.G. Stockner. 2000. Using photosynthetic rates to estimate the juvenile sockeye salmon rearing capacity of British Columbia lakes. In: E.E. Knudsen, C.R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser (Ed). Sustainable Fisheries Management: Pacific Salmon. Lewis Publishers. Boca Raton.

Smith, V.H. 1983. Low nitrogen to phosphorus ratios favor dominance by blue-green algae in lake phytoplankton. Science 221: 669-671.

Stables, T.B., G.L. Thomas, S.L. Thiesfeld, G.B. Pauley, and M.A. Wert. 1990. Effects of reservoir enlargement and other factors on the yield of wild rainbow and cutthroat trout in Spada Lake, Washington. North Amer. J. Fish. Management 10:305-314.

Stainton, M.P., M.J. Chapel, and F.A. Armstrong. 1977. The chemical analysis of freshwater. 2nd. ed. Fish. Environ. Can. Misc. Spec. Publ. 25.

Steemann Nielsen, E. 1952. The use of radioactive carbon (^{14}C) for measuring organic production in the sea. J. Cons. Int. Explor. Mer. 18:117-140.

Stockner, J.G. 2005. Phytoplankton populations in Kinbasket Reservoir, Upper Columbia Basin, British Columbia -2005. Report to BC Hydro, Revelstoke, BC.

Stockner, J.G. and K.I. Ashley. 2003. Salmon nutrients: Closing the circle. American Fisheries Society Symposium 34: 3-15. American Fisheries Society, Bethesda, Maryland.

Stockner, J.G and J. Beer, 2004. The limnology of Stave/Hayward reservoirs: with a perspective on carbon production. Prepared for BC Hydro Water Use Plans by Ecologic Ltd. and University of British Columbia, Institute for Resources, Environment and Sustainability, Vancouver, BC. 33 p + App.

Stockner, J.G. and E.A. MacIsaac. 1996. The British Columbia lake enrichment program: Two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management, Vol 12. 547-561.

Stockner, J.G. and K.S. Shortreed. 1985. Whole-lake fertilization experiments in coastal British Columbia lakes: empirical relationships between nutrient inputs and phytoplankton biomass and production. Can. J. Fish. Aquat. Sci. 42: 649-658.

Stumm, W. and J.J. Morgan. 1981. Aquatic Chemistry: 2nd Edition. Wiley and Sons, New York. 780p.

Suttle, C.A., W.P. Cochlan, and J.G. Stockner. 1991. Size-dependent ammonium and phosphate uptake, and N:P supply ratios in an oligotrophic lake. Can. J. Fish. Aquat. Sci. 48: 1226-1234.

Suttle, C.A. and P.J. Harrison. 1988. Ammonium and phosphate uptake rates, N:P supply ratios, and evidence for N and P limitation in some oligotrophic lakes. Limnol. Oceanogr. 33: 186-202.

Thornton, K.W., B.L. Kimmel, and F.E. Payne. 1990. Reservoir limnology: ecological perspectives. John Wiley and Sons, New York.

Thompson, L.C. 1999. Abundance and production of zooplankton and kokanee salmon (*Oncorhynchus nerka*) in Kootenay Lake, British Columbia during artificial fertilization. Ph.D. thesis, Department of Zoology, University of British Columbia, Vancouver, British Columbia, 252 p.

Triton Environmental Consultants Ltd. 1995. Ash River Additional Capacity Study. Report produced for BC Hydro.

Utermohl, H. 1958. Zur Vervollkommnung der quantitativen Phytoplankton methodik. Int. Verein. Limnol. Mitteilungen No. 9.

Vanni, M.J. and D.L. Findlay. 1990. Trophic cascades and phytoplankton community structure. Ecology 71: 921-937.

Wetzel, R.G. 2001. Limnology: Lake and River Ecosystems. 3rd edition. Academic Press. New York.

Yentsch, C.S. and V.W. Menzel. 1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. Deep-Sea Res. 10: 221-231.

8 RAW DATA APPENDICES

Raw data appendices are available on CD or via file transfer from Bridge Coastal Restoration Program.

BRCP REPORT APPENDICES

I. Financial Statement (Statement of income and expenditures-form attached)

Project # 05.As.01

Financial Statement Form

	BUDGET		ACTUAL	
	BCRP	**Other**	**BCRP**	**Other**
INCOME				
Total Income by Source	84,590.00	7,200.00	84,590.00	1,100.00
Grand Total Income	91,790.00		85,690.00	
EXPENSES				
Project Personnel				
Wages				
Consultant Fees	67,840.00	7,200.00	63,594.77	1,100.00
Materials & Equipment				
Equipment Rental	3,225.00		8,140.00	
Materials Purchased	2,175.00		0.00	
Travel Expenses	3,000.00		4,511.82	
Permits	0.00			
Communications	660.00			
Administration				
Office Supplies				
Photocopies & printing				
Postage				
Administration	7,690.00		7,690.00	
Total Expenses	84,590.00	7,200.00	83,936.59	1,100.00
Grand Total Expenses	91,790.00		85,036.59	
BALANCE **(Grand Total Income - Grand Total Expenses)**	0.00		653.41	

II. Performance Measures-Actual Outcomes

There were no performance measures identified for this project. This project provides data and analysis that will support decisions on habitat restoration activities that are being considered for Elsie Lake. Should habitat restoration activities proceed, performance measures will be developed to measure restoration efficacy.

III. Confirmation of BCRP Recognition (newspaper clippings, press releases, newsletters, brochures, photographs of signs/plaques, etc.)

MEDIA ARTICLE

Cash for Ash River

Alberni Valley Times
Wed 01 Mar 2006
Page: 1 / Front
Section: News
Byline: Shayne Morrow
Source: Alberni Valley Times

A group headed by Hupacasath First Nation has attracted increased funding from BC Hydro for habitat enhancement in the Elsie Lake watershed.

Since the late 1990s, the Bridge Coastal Restoration Program (BCRP) has provided funding for restoration work in watersheds affected by hydro development. Hupacasath manager Trevor Jones said it's been a natural fit for the band, but until recently, getting the money was a hit-or-miss proposition.

"Hupacasath were quick out the door to take advantage of the program in the watershed," Jones said Tuesday. But BCRP money was hard to come by until local interest groups banded together, he said.

"We've now created partnerships in a multi-stakeholder group, known as the Alberni Valley Aquatic Resource Group," Jones said.

AVARG includes parties diverse as the Alberni Valley Enhancement Association, personnel from local Fisheries and Oceans Canada operations and the provincial fisheries ministry. The effect has been an expanded centre of gravity for habitat restoration efforts.

"AVARG has become a model for groups in other Hydro jurisdictions," Jones said. And the results are showing, he added. Prior to AVARG, the band was lucky to get funding for one or two projects per year.

"For 2005-06, we've had four projects funded, and another five for 06-07," Jones said.

FEEDING A RIVER

Three of those projects involve assessment and study. But according to AVARG consulting biologist Adam Lewis, one of the programs is simple, hands-on stuff.

Called the Ash River Nutrient Enrichment program, it's just that -- putting more food into the eco-system.

"There are many ways of fertilizing a stream," Lewis explained. "Last year, we started putting in slow-dissolving, pollock-based blocks of nutrient."

Besides adding food for fish and other aquatic life forms, the supplements also raise critical phosphorous and nitrogen levels in the water. When available, coho and chinook carcasses from Robertson Creek hatchery are also introduced back into the watershed, to replicate the effect of historic spawning patterns

"This program takes place in the Middle Ash River, between Elsie and Dickson Lakes," Lewis said. The river is home to both resident and sea-run trout, as well as coho salmon. Total cost of the program is about $27,000 per year, of which BCRP provides about $18,000. The balance comes from the AVARG stakeholders, Lewis said.

ELSIE ON STEROIDS?

The Elsie Lake Productive Capacity Assessment project was fully funded by BCRP, at a budget of $81,000, with Hupacasath providing the boat and sampling crew.

"We're assessing whether putting fertilizer in Elsie Lake would improve salmon capacity," Lewis said. While lake fertilization to increase nutrients is common (nearby Great Central Lake is one beneficiary), it isn't always a good idea.

"Depending on the food-webs within the eco-system, fertilizing a lake can encourage the growth of species that are actually detrimental to the desired species," he explained. You can wind up boosting the population sticklebacks, which prey on juvenile salmonids, or zooplankton, which benefits no one.

"The lake may be producing more biomass of food, but it may be food that the fish can't eat," Lewis said. The good news is, Elsie Lake appears to be an excellent candidate for fertilization, he added.

The fertilizer comes in the form of a phosphorous-nitrogen drip, which is fed into the lake from barge-based tanks over a period of four or five weeks.

HABITAT AVAILABLE

A third study, budgeted at $63,000, is assessing the productive capacity of the tributaries flowing into Elsie Lake.

"What we know is that the Upper Ash River contains a large quantity of habitat," Lewis said. "Fertilizing Elsie Lake would encourage migration of native rainbow and cutthroat trout up into the tributaries."

According to Hupacasath elders, both coho and sockeye salmon spawned in the upper reaches of the Ash prior to construction of the Elsie Lake Dam in the 1950s.

Now the study has turned up a pair of wild cards, with the discovery of both juvenile coho and land-locked sockeye salmon (known as kokanee) in the system.

"We now know kokanee are present in the lake, but nobody is catching them," Lewis said. That raises some interesting scenarios, he explained.

"It's quite possible that the native cutthroat are preying on juvenile kokanee. On the other hand, fertilization would increase the size of the kokanee," he said.

Whether the kokanee are a historic population similar to those found in other B.C. lakes, or a new race created when the dam blocked passage to the lake is another question the scientists will have to wrestle with.

OPENING THE BARRIERS

The $50,000 Ash River Fish Passage Study will deal with both technical and ethical questions, according to Lewis.

"A great way to increase fish production is to link habitat together," he said. Along the Middle Ash are a number of barriers, including Dickson and Lanterman Falls. Increasing fish passage brings into question the wisdom of tampering with the existing eco-balance --especially when it involves a glamour species.

"Upstream of Dickson Falls, the only fish that can pass (according to current wisdom) are summer steelhead, and the province is reluctant to allow salmon passage," Lewis said. And then there's the dam itself.

"There was no barrier there historically, and it's another place where we could look at fish passage," he said. Technically, it's possible, but there are difficulties, such as screening the Ash River turbine intakes to protect migrating salmon smolts.

But restoring coho salmon above the dam, to take advantage of nearly 20 kilometres of Class A spawning habitat, raises another political issue.

The Upper Ash watershed is private timberland owned by Island Timberlands. Should the property be re-designated as salmon spawning habitat, that puts the owner under a whole new set of federal regulations governing harvesting operations, Jones said.

"Hupacasath would like to see salmon in the headwaters for that reason," Jones said.

"Island Timberlands has supported this work from the beginning," he added.

Lewis noted that AVARG has applied to extend the passage assessment for another year, partly as a result of the discoveries.

"Halfway through the project, we found coho, so that changed everything," he said.

"We've realized there are a lot of holes in our knowledge -- especially in the small tributaries on the Upper Ash."

RETURN OF THE KING

For Al Ross (Kaa-nowsh), hereditary chief of Hupacasath First Nation, the AVARG work has been an opportunity to return to his roots, in more ways than one.

"I worked as a fisheries guardian for Tseshaht First Nation for 15 years.

"This has given me a chance to come back," Ross said.

He now serves as acting fisheries manager for Hupacasath, and has been the go-to guy when it comes to field work.

Ross noted that Hupacasath First Nation is actually a coalition of three inland tribes which lived in the Alberni Valley.

"My own people ruled in the Ash River/Elsie Lake area, right where we're working," he said.

IMMEDIATE BENEFITS

AVEA chair Dave Chitty said AVARG has been a boost for his group.

"Any time we can work together with other groups, it's a win-win," Chitty said. "For example, we had anecdotal knowledge of coho above the barriers, and now we have proof."

One of the biggest benefits has been a change in policy by BC Hydro, Chitty said.

"As a result of the Ash River Water Use Plan, Hydro is now required to increase its fish flows during the early fall," he said.

In past years, during the dry season, the utility allowed flows to drop to minimal levels, Chitty explained.

"Now they've moved the flows back closer to historic levels, which improves the migration of species such as steelhead and coho," he said.

Hupacasath First Nation will be hosting an open house at the House of Gathering, from 4-6 p.m. on March 30. Jones said the public will have a chance to check out the BCRP projects and talk to the biologists.

Edition: Final
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OPEN HOUSE

Hupacasath First Nation
5500 Ahahswinis Dr.
Port Alberni, BC
V9Y 7M7

OPEN HOUSE INVITATION

The Hupacasath First Nation invites you to attend an open house and learn all about the exciting fish habitat restoration projects now underway in the Alberni Valley. The Hupacasath are part of AVARG –the Alberni Valley Aquatic Resource Group, which includes the Alberni Valley Enhancement Association, personnel from local Fisheries and Oceans Canada operations and the provincial fisheries ministry. This group has completed four fish habitat restoration projects on the Ash River this year, with the help of the Bridge Coastal Restoration Program (BCRP), who have provided funding for restoration work in watersheds affected by hydro development.

The open house provides an opportunity to learn about fish habitat restoration and the Ash River, and meet the people doing this interesting work. The Open House will be held from 4 pm to 7 pm on March 30, 2006 at the Hupacasath House of Gathering, 5500 Ahahswinis Drive, Port Alberni. Refreshments will be served.

For more information please call 724-4041 and speak to Ness

OPEN HOUSE MINUTES

The Open House was held from 4 pm to 7 pm on March 30, 2006 at the Hupacasath House of Gathering, 5500 Ahahswinis Drive, Port Alberni. Poster boards were prepared for each project.Four members of the general public attended. General questions about the objectives of the work were asked. No follow up actions were identified.

Hosts:	**Attenders:**
Al Ross	Carol Schmidt
Harlan Wright	Female age 45
Jim Lane	Female, age 40
Adam Lewis	Female, age 60
Cedric Robert	

OPEN HOUSE POSTER

Elsie Lake Productive Capacity & Feasibility of Nutrient Enrichment

Figure 1. Map showing the sampling locations (EL1 and EL2) in Elsie Lake Reservoir.

Methods

- Sampled two sites (EL1 & EL2 in Figure 1)
- Collected samples (Figure 2 and Figure 3) from June to October:
  - Water chemistry (pH, TDS, DO, temperature)
  - Water depth (flushing time)
  - Nutrient concentrations
  - Light penetration
  - Chlorophyll *a* concentration
  - Primary productivity
  - Phytoplankton community composition
  - Zooplankton density

Figure 2. Kiyo Masuda (Limnotek) and Allan Ross (Hupacasath First Nation) collecting water samples on Elsie Lake Reservoir, June 27, 2005.

BC HYDRO FISH & WILDLIFE
BRIDGE COASTAL RESTORATION PROGRAM

hupacasath

Background

- Reservoir creation can result in a temporary nutrient increase
  - More nutrients = more fish production
- After ~20 years nutrient levels in reservoirs drop
  - Less nutrients = less fish production, some species cannot survive in these conditions (e.g., kokanee)
- Adding nutrients to an older reservoir = more food for fish
  - This is because invertebrate and algal production on the bottom and in the water column increase when nutrients are added

Results & Conclusions

- All information collected suggests that Elsie Lake Reservoir has very low productivity (see Table 1 for a comparison with other lakes and reservoirs)
  - Low water retention time
  - High water transparency
  - Low concentrations of key nutrients (nitrogen & phosphorus)
  - Fish production models suggest that the fish production is likely among the lowest of low nutrient coastal lakes
- The food web of Elsie Lake Reservoir is likely driven by production on the lake bed rather than production in the water column
- Fertilization will likely increase production on the bottom of the reservoir and in the water column

Acknowledgements

This project was completed by Limnotek Research and Development Inc. and the Hupacasath First Nation under contract to the BCRP. Adam Lewis (Project Manager, Ecofish Research Ltd.) and Trevor Jones (Executive Director of the Hupacasath First Nation) provided guidance. Field Staff included Kiyo Masuda (Limnotek), Tom Tatoosh (Hupacasath First Nation) and Allan Ross (Hupacasath First Nation). Flow data were provided by Cathy Bowie (BC Hydro). Danusia Dolecki completed zooplankton enumerations. John Stockner (Ecologic Ltd.) completed phytoplankton enumerations and biovolume measurements. The final report was prepared by Chris Perrin and Shannon Harris of Limnotek.

Lake or Reservoir	Areal Phytoplankton Biomass (mg Chl a/m ^{2})	Primary Production (mg C/m ^{2}/d)	Fertilized?	Reference
Elsie Lake Reservoir	**8.1**	**13.9**	**No**	**Perrin and Harris (2006)**
Williston Reservoir	9.0	33.5	No	Harris *et al.* (2005)
Okanagan Lake	27.2	72.2	No	Andrusak *et al.* (2004)
Slocan Lake	26.3	59.3	No	Harris (2002)
Stave Reservoir	28.5	28.5	No	Stockner and Beer (2004)
Alouette Lake	36.8	140	Yes	Reddekopp *et al.* (2006)
Kootenay Lake	51.5	303	Yes	Harris (2004)
Arrow Lake Reservoir	48.8	262	Yes	Pieters *et al.* (2001)

Table 1. Comparison of phytoplankton biomass and primary production among lakes and reservoirs in British Columbia.

Recommendations

- To determine if fertilization will be effective, attain a better understanding of fish populations (size and structure) and their habitat use
  - Hydroacoustic survey, gill netting, trawling, and stomach content analysis in 2006 has been proposed to accomplish this
- Continue to build on the 2005 data
  - Collect water chemistry, water depth, nutrient, chlorophyll, primary productivity, phytoplankton, and zooplankton samples again in 2006
- Determine nutrient concentrations entering the reservoir from Ash River

Figure 3. Kiyo Masuda (Limnotek) and Tom Tatoosh collecting water samples on Elsie Lake Reservoir, June 28, 2005.

LIMNOTEK

Ecofish