EVALUATION OF THE MICROBIAL COMMUNITY STRUCTURE'S ABILITY TO ILLUSTRATE CHANGE IN TROPHIC STATUS IN CHRISTINA LAKE

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Abstract

This study uses periphyton abundance and phytoplankton assemblage as bioindicators of productivity to examine the change in water quality in Christina Lake between contemporary and historic data. Phytoplankton data are taken at the South Basin pelagic site in spring and summer and periphyton data from five littoral sites in fall in 2006. The phytoplankton data differed from the historical data with an increase in algal abundance, a decrease in the Shannon-Weaver biodiversity index and taxa evenness. The phytoplankton dominance changed to Oscillatoriales and Ochromonadales in 2006 from Ochromonadales, Pennales, and Centrales in 1992. Periphyton data displayed an increasing trend in chlorophyll concentrations between 1998 and 2006. The analysis indicates the periphyton and phytoplankton biotic community structures may reflect changes in lake productivity. Due to the infrequent monitoring and contrasting signals from secondary parameters, it is not possible to be definitive on findings. Additional monitoring is recommended to further investigate trends.

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Chapter 1.0 Introduction

1.1 Background

Aquatic ecosystem health has been raised as a concern in many of the lakeside communities throughout the Okanagan and Kootenay regions of BC (LaCroix & McLean, 2005). In fact, the environmental impact from shoreline development has been recognized as a global issue requiring attention (Wright, 2004). Resource managers have acknowledged that growing communities require increased safe and affordable methods of wastewater disposal along terrestrial and aquatic interfaces. This issue was raised by the Michigan State Senate’s 2002 Great Lakes Conservation Task Force Report concluding that one of the main issues in Great Lakes water quality is the lack of sufficient riparian management and land use planning (Norton, Gerber, Marans, Meadows, & O’Shea, 2002). The Town of Christina Lake is one example of a lakeside community that requires additional information to sustain the rapid increase in shoreline development, and recreational boaters demand on the lake’s aquatic resources. The study’s intent is to instigate the first stage of the assessment by characterizing the ability of phytoplankton assemblage and periphyton abundance to detect changes in lake productivity.

1.2 Activities and Components of the Program

The proposed study pulls together findings from historical monitoring programs and scientific reports to assess the state of water quality in Christina Lake in 2006. The project responds to the Christina Lake Stewardship Society's request to determine if water quality changes are occurring in Christina Lake. The program also supports the Ministry of Environment's goal of assessing if the 1994 site-specific water quality objectives for Christina Lake are met in 2006. Active community participation assists in ensuring the long-term success of the program. The monitoring program focuses on increasing community awareness while capturing baseline data to be analyzed and reported to the community and land use planners.

Water quality monitoring priorities are established based on the most sensitive designated water use at a specific location. The designated water uses within Christina Lake are:

- Raw drinking water, public water supply, and food processing;
- Aquatic life and wildlife;
- Recreation and aesthetics.

The program goal is to characterize the utility of using phytoplankton species assemblage, and periphyton chlorophyll a to classify productivity within Christina Lake. The source of any changes in productivity is beyond the scope of the study. The first component of an aquatic risk assessment is included within this study through the characterization of water quality and the evaluation of change in productivity within the study area.

The 2006 study expands on the existing data set to detect long-term trends, assess productivity and natural variability in the lake. The most recent comprehensive monitoring program occurred in 1992 and captured monthly nutrients, bacteriology, phytoplankton, and periphyton data. The Ministry of Environment (MOE) conducted a more condensed program from 1999 to 2005 capturing bacteriology, nutrients biannually and periphyton chlorophyll a annually. Ecosystem based characterization did not occur between 1993 and 2005.

Past reports have recommended that future limnology analysis correlate historical deep-station phytoplankton data with current periphyton and phytoplankton abundance and species composition data to provide a more comprehensive understanding of the aquatic ecosystem (LaCroix, & McLean, 2005). Phytoplankton assemblage, periphyton chlorophyll a, water clarity, phosphorus and nitrogen levels are five feasible indicators to assess productivity trends and characterize the current state of the lake's water quality. Each indicator plays a role in understanding a proper functioning aquatic ecosystem. Phytoplankton vary in response to physical and chemical parameters such as light, temperature, and nutrient regimens (Wetzel, 1983). Periphyton are primary producers and a major contributor to nutrient cycling in aquatic ecosystems (Mackie, 2001). By observing and analyzing the structure and functional changes of phytoplankton and periphyton abundance and composition, it is possible to assess the aquatic health and productivity of the system.

1.3 Aquatic Resource Management

Land based development and aquatic recreation around the lake has expanded in the last decade (LaCroix & McLean, 2005). The impact on aquatic ecosystem health remains uncertain. There are no direct discharges into Christina Lake. In spite of the zoning laws there is a potential for septic leakage into the groundwater and lake water. Aquatic based recreation from the influx of houseboats during summer months is also a concern. The accumulation of organic matter can result in nutrient enrichment, and shifts in the phytoplankton and periphyton community structure and abundance. The characterization of changes in water quality in the lake is an environmental, economic and social concern requiring attention.

Shoreline development is a multifaceted component of land use planning. It requires environmental planning that focuses on long-term resource management and sustainability. Sustainability is achieved when resource use “meets the needs of the present without compromising the ability of future generations to meet their own needs." as put forth by the Bruntland Commission in 1988 (Doppelt, 2003). The ideal sustainability framework requires that ecosystem based planning be incorporated into every facet of social, economic and resource community management structure (Doppelt, 2003). This promotes shared responsibility to ensure aquatic resource protection is maintained in Christina Lake. Ideally, findings from the productivity assessment will initiate increased aquatic protection throughout the Christina Lake watershed. Active community participation in water quality data capture and reporting will aid in meeting this goal.

1.4 Aim, research question, and hypothesis

The Christina Lake study will institute a cooperative program between the Christina Lake Stewardship Society and the Province of British Columbia to assess trends and characterize the current level of productivity within the study area. The primary bioindicators proposed are phytoplankton species composition, periphyton chlorophyll a, nitrogen and phosphorus. The field study will focus on assessing if productivity levels have changed within the study area since 1992. The location and composition of shoreline inputs is beyond the scope of this study. This project is designed as a community driven monitoring program to continue into future years to achieve a sustainable aquatic ecosystem in Christina Lake.

1.5 Research Question

To what extent does the biotic community structure reflect changes in lake nutrient productivity?

□**Ho**: The periphyton and phytoplankton population dynamics within the study area imply no change in the productivity level in Christina Lake.

□**H_1**: The change in periphyton and phytoplankton population dynamics within the study area show eutrophication is occurring in Christina Lake.

1.6 Study area

Christina Lake is situated approximately 26 kilometers east of the city of Grand Forks in south-central British Columbia. This lake is renowned for having the warmest summer lake temperature in British Columbia with peaks in July and August of over 25 degrees Celsius (LaCroix, & McLean, 2005). The lake is 18.7 kilometers long with a median width of 600 meters and is characterized as long and narrow with a steep, U-shaped, glacially carved bottom (Cavanagh, Nordin, & Byran, 1994b). The epilimnium layer extends 8-10 meters. Christina Lake and its tributaries are utilized as a water source for irrigation, domestic, commercial and industrial purposes (Christina Lake, 2006).

1.7 Fisheries Information

The fish population has both environmental and socio-economic value in Christina Lake. Christina Lake is home to kokanee, rainbow trout, bass, whitefish, burbot, and carp (LaCroix, & McLean, 2005). In Webster and Wilson’s 2004 study kokanee were caught most frequently with angler species preference evenly divided between kokanee and rainbow trout (Webster, & Wilson, 2005). There is a level of uncertainty around the fish population and health in Christina Lake (LaCroix, & McLean, 2005). Introduced species, over fishing and habitat destruction are possible stressors to the fish population (LaCroix, & McLean, 2005). The Department of Fisheries and Oceans (DFO) uses the Fisheries Act to regulate shoreline structures up to the high water mark to protect this resource. Recreational fishing and fisheries health are within the DFO and MOE mandate for assessment and protection.

1.8 First Nations

The Christina Lake watershed lies within the traditional territory of the Okanagan Nation Alliance. The Okanagan National Alliance (ONA) is the national organization that exercises the collective interests, title and rights on the land for seven Indian Bands throughout the region. The Okanagan Nation has a long established and recognized territorial and cultural claim to the Christina Lake watershed area and takes its responsibility to the protection of this aquatic resource very seriously. Aquatic habitat protection is a concern to the Okanagan Nation Alliance. Government agents permitting development within traditional territory have a legal responsibility to consult and accommodate the First Nations who exercise their rights on the traditional lands in question that are slated for development or augmentation (Hessing, & Howlett, 1997). The ONA was informed of the 2006 aquatic ecosystem assessment and is in support of the program. Future development initiatives within the Christina Lake watershed are to consult with First Nations and respond to their requests on environmental protection.

1.9 Hydrology

The basin's drainage area is 492 square kilometers and the elevation at the lake outlet is approximately 450 meters (Cavanagh et al., 1994a). The majority of the precipitation falls in the winter months in the Christina Lake watershed causing peak flows to occur in May and low flows to occur in October and November. There are 41 inflows into Christina Lake, only a few of which are perennial flows (LaCroix, & McLean 2005). Sutherland Creek, Sandner Creek, McRae Creek, Troy Creek, Parson Creek, Stewart Creek and an unnamed creek are the only identified year-round inflows into the Lake (Christina Lake, 2006). Christina Lake drains into Christina Creek at the south end of the lake. Christina Creek flows join the Kettle River until they connect to the Columbia River near the northern end of the Roosevelt Reservoir in Washington State.

Cavanagh et al. (1994a) assessed the phosphorus loading into Christina Lake from Sutherland Creek and McRae Creek using flow measurements and seasonal phosphorus levels. The flushing rate of the lake is estimated at 4.5 years indicating that plankton and nutrient levels at the two study sites should reflect multi-year historical inputs (Cavanagh et al., 1994a).

1.10 Governance and Socio-Economic Issues

Christina Lake is located in the Regional District of Kootenay Boundary jurisdiction. It is home to 1200 year round residents, swelling to approximately 6000 residents in the summer months (Christina Lake, 2006). The terrestrial/ aquatic interface of Christina Lake is of high interest politically, socially, and environmentally. Many local business owners market the lake’s beauty and recreational value as the main tourist attraction. It is apparent that shoreline land use and aquatic based recreation are the main economic force of this area. Despite the perceived economic benefits of lakefront accommodation, citizens of the area are concerned about the effects of shoreline development and recreational boat use on the lake’s water quality (LaCroix, & McLean, 2005).

Many agencies have interest and governance over the aquatic resources of Christina Lake. Interagency collaboration and planning are required to work towards a functional sustainable vision (Hessing, & Howlett, 1997). The lake’s surface and Crown foreshore is ultimately a provincial responsibility (Hessing, & Howlett, 1997). The

Ministry of Environment grants licenses to nine direct water withdrawals from Christina Lake, six for domestic use and three for waterworks (Christina Lake, 2006). Christina Lake, Sutherland Creek and Moody Creek provide water for the two largest Community Waterworks systems in the community. These are the Christina Waterworks District and the Sutherland Creek Waterworks District. Water quality health is monitored by the Ministry of Environment and the Ministry of Health.

Governments obtain authority to regulate the public and private uses of land through their rights to engage in zoning, planning, and environmental protection (Doppelt, 2003). The land around Christina Lake is a combination of the Town of Christina Lake and the Regional District of Kootenay Boundary. Current zoning bylaws exist within the Town of Christina Lake boundaries. The existing permitting system does not address all land and water interface conservation and protection concerns.

Chapter 2.0 Literature review

2.1 Background

The value of phytoplankton community assemblage and periphyton biomass is examined in this study as a tool to assess aquatic ecosystem health. Aquatic indicators that focus on ecosystem-based community dynamics provide a mechanism to assess the biological integrity of an aquatic system (Schindler, 1978; Rogers, 2002). Biological integrity is commonly defined as the ability to support and maintain a balanced, integrated, and adaptive community of organisms having a species composition, diversity and functional organization comparable to those of natural habitats within a region. (United States Environmental Protection Agency, 2006). The integrity of the system is equated to pristine conditions with minimal disturbance.

Imbalances in community structure and accelerated increases in productivity are the focus of this study. Assessment of trophic status is a method of determining productivity and balance in an aquatic ecosystem. Lakes that are nutrient poor with low organic production and few planktonic algae are classified as oligotrophic. Nutrient-rich lakes high in plankton containing low levels of dissolved oxygen are classified as eutrophic. Natural eutrophication patterns occur in all bodies of water. Changes in trophic status due to natural causes usually take decades (Mackie, 2001). The gradual accumulation of nutrients and organic biomass, accompanied by an increase in production constitutes natural eutrophication (Mackie, 2001). Anthropogenic acceleration, or cultural eutrophication, reduces recreational value and alters aquatic ecosystem balance. The excessive algal and plant growth associated with cultural eutrophication result in reduced water transparency, and possible taste and odour problems in drinking water. Other consequences of accelerated eutrophication include hypolimnetic anoxia, fish kills, and insect infestations.

2.2 Indicator selection

Past data sets indicate the main body of the lake to be oligotrophic (Cavanagh et al., 1994b). Continued plankton community assemblage sampling was recommended by Cavanagh, et al. (1994b), and LaCroix and McLean (2005) to update these findings.

The primary indicators selected for this study are phytoplankton species assemblage, and periphyton chlorophyll a. Phosphorus, nitrogen, temperature, and water clarity provide secondary indicators of assessment to characterize nutrient enrichment within the study area. The availability of baseline data, the number of sample repetitions and the data presentation in historical reports limit the study design.

Phytoplankton

Of the major lacustrine communities, phytoplankton is a good bio-indicator in that they are suspended in the water column, and have limited or no independent locomotion (Mackie, 2001). These minute free-floating microscopic aquatic plants are key components in the aquatic food web and play an active role in nutrient cycles (Wetzel, 1983). Phytoplankton is a main contributor to the overall lake metabolism, and a primary food source for rainbow trout and the zooplankton population. Phytoplankton maintain water quality by cycling nitrates, phosphates, potassium, and metals, converting ammonia to nontoxic forms and removing excess carbon dioxide (Rogers, 2002).

Phytoplankton community structure indicators support the assessment of aquatic impacts and detecting foreign hazards (Rogers, 2002). Lake chemistry alterations are recognized early by phytoplankton, in that they are often the first aquatic group to respond to changes in water quality (Mackie, 2001). Scientific evidence connects phytoplankton abundance and diversity with changes in trophic status, seasonal hydrologic variations, and predatory influences (Schindler, 1978a).

Phytoplankton population dynamics provide information on the rate of productivity of lakes through their role of controlling the synthesis of organic matter that enters the aquatic system (Hecky, & Kling, 1981). Phytoplankton autochthonous primary production rates are central to evaluating this system (Wetzel, 1983). Algal community composition are good indicators of aquatic productivity in that they provide correlations between qualitative and quantitative abundance of algae and available nutrients (Recknagel, 1997; United States Geological Survey, 2004). Community structure and species dominance and an increase in algal cellular bioviolume provide indicators of the ecosystem health of an aquatic system.

Phytoplankton are often the dominant producers in shallow lentic systems and provide the base of most food webs (Mackie, 2001). Phytoplankton functional groups (diatoms, dinoflagellates, chlorophytes, cyanobacteria, cryptomonads) assist in distinguishing nutrient from hydrologically-driven changes in phytoplankton composition. Historical baseline phytoplankton species composition data provides the background conditions necessary to conduct analyses of deviations in relation to differences in environmental functions and patterns in primary production (Wetzel, 1983). External stresses such as chemical and organic shoreline inputs to the aquatic system cause phytoplankton diversity to decline (Brett, & Goldman, 1996).

Analyses and evaluations of seasonal and spatial growth characteristics of phytoplankton are sometimes difficult because of the variety of environmental factors involved, the individual physiological properties of each algal species and the magnitude of change that can occur in both (Wetzel, 1983). Phytoplankton life cycle and response to stressors are fundamental in interpreting findings. For example, often diatoms are dominant in the spring and green algae in the early summer (Munawar, & Weisse 1989). Life cycles emphasize the importance of collecting data in both spring and early summer. Monthly data capture is necessary to ensure all seasonal variations are incorporated into the analysis.

The intensive 1992 Christina Lake limnology study by Cavanagh et al. (1994b) provides the historical baseline for the 2006 study. Historically the phytoplankton population was dominated by the oligotrophic indicators Dinoflagellates, Chloroccocales, and Chrysophytes. Groups that are indicative of eutrophication (blue-greens) were uncommon in the 1992 data set. The 1992 data capture was dominated by *Melosira italica*, *Asterionella Formosa*, *Fragilaria crotonensis, Synedra acus*), the dinoflagellate

Peridinim, various member of the Chlorococcales, the Cryptomonads and Ochromonadales (*Dinobryon and Mallomonas*).

Periphyton

Periphyton is the base of most food webs in the littoral habitat and a source of dissolved and particulate organic matter to the aquatic ecosystem. These epiphytic algal floras are primary transducers of light into biologically based energy and an important food source for invertebrates and some fish. Although attached algal assemblages are the dominant producers in shallow lentic systems, they are often not applied in productivity and impact assessment analysis (Schindler, & Scheuerell, 2002). Periphyton geographical distributions, and population dynamics, respond to both concentrations of chemical and organic inputs and the duration of exposure (Gessner, & Chauvet, 2001). Imbalances in the aquatic ecosystem such as elevated nutrient loads can cause excessive littoral algal growth to proliferate, forming large nuisance growths of biomass that can degrade the habitat for other organisms (Wetzel, 1983).

The periphyton samples are incorporated into the program as a primary bioindicator to capture information on shoreline productivity levels. The periphyton data sets fulfill the project goal of assessing productivity within the littoral study area of Christina Lake (Gessne, & Chauvet, 2001). Land use impacts can cause substantial cumulative impacts to the benthic and riparian habitats of lakes (Schindler, & Scheuerell, 2002). The algal content in the littoral zone provide additional productivity information to the phytoplankton diversity indices in the pelagic study area. Epilithic periphyton reduce some of the challenges of spatial and temporal variation within the pelagic sample sites. The free-floating nature of phytoplankton at pelagic sample sites present limitations on the ability to account for dial and annual variation of hydrologic variables implications on population abundance. Whereas, the epilithic nature of periphyton provides a stationary medium to detect the earliest warning of changing ambient conditions (Cavanagh et al. 1994b; LaCroix, & McLean, 2005).

The Water Quality Objective for periphyton uses chlorophyll a as the measure of aquatic ecosystem productivity. Chlorophyll a concentrations are indicative of the biomass of attached species of algae with a direct relationship between biomass and elevated nutrient inputs (Wetzel, 1983). Values below 3 μg/L are considered indicative of oligotrophic waters and values greater than 15 μg/L are generally considered indicative of eutrophic waters (Resource Inventory Standards Committee [RISC], 1998). Cavanagh et al. (1994b) set the objective at less than 10mg/m2 for littoral lakes and tributary periphyton. The Objective was set to ensure the maintenance of the background oligotrophic conditions are retained (Cavanagh et al., 1994b). The historical chlorophyll a data sets in 1992 indicate that the baseline concentrations were exceptionally low averaging 1.56 mg/m2 at the three shallow sites monitored (Cavanagh et al., 1994a). The ultra-oligotrophic data provided a basis for the water quality objective of 10 mg/m2, which is far below the provincial criterion of 50 mg/m2. Due to the inability to convert mg/m2 to ug/L it is challenging to compare 2006 findings in ug/L to these guidelines and objectives.

Fish as indicators of productivity

Fish population abundance provides some indication of productivity levels in a water body. Fish mobility permits effectively participation in both littoral and pelagic food webs. Natural selection to habituate areas with increased food availability, or nutrient loads, connects fish population abundance with elevated nutrient levels (Schindler, & Scheuerell, 2002).

Temperature and Dissolved Oxygen

Irradiance and water temperature are critical factors in the regulation of seasonal phytoplankton productivity trends (Wetzel, 1983). Lakes that receive additional nutrients often have a stronger connection between temperature and phytoplankton productivity (Mackie, 2001).

The amount of dissolved oxygen (DO) in the lake is related to photosynthesis and respiration rates. Photosynthesis releases oxygen in the daylight hours, the consumption of oxygen during the night results in lower pre-dawn levels. As a lake becomes more eutrophic, this diurnal fluctuation in dissolved oxygen concentration becomes more extreme (Urban Systems, 2001). Dissolved oxygen content in aquatic systems is critical for the maintenance of aquatic life. Lakes that are low in productivity have enough oxygen to support life at all depths throughout the year. Peaks in phytoplankton abundance can cause an increase in oxygen in the euphotic zone (Celewicz – Goldyn, 2003).

Inputs into a lake from sewage and manure can reduce dissolved oxygen levels due to the decomposition process and the demand for oxygen. The deposition of organic matter and decomposition processes consume more oxygen at the bottom of lake as a lake becomes more productive. Lakes that are limited by the amount of oxygen may develop anoxia in the lower hypolimnion during late summer but may still be classified as oligotrophic because of their very low nutrient concentrations (Wetzel, 1983).

Water Clarity

Turbidity is a measure of water clarity or the amount of suspended particulate matter in a water body. The vertical extinction and spectral characteristics of light in lakes can provide indications of productivity within the lake. Both biotic and abiotic factors increase vertical extinction levels (Brett, & Goldman, 1996). Turbidity concentrations increase during freshet due to the inflow of suspended sediment from spring runoff. These increases are usually of low consequence to aquatic life as organisms hold a high tolerance levels for short-term turbidity increases (Mackie, 2001). Elevated levels of turbidity, however, can interfere with the disinfection of drinking water and is aesthetically unpleasant.

Changes in water clarity readings can be caused by increased abundance of free floating algae, erosion of the shoreline or erosion from site development near the lake, and recirculation of bottom sediment from motorboat activity. Secchi depth readings of water clarity provide valuable observations over time. Due to the simplicity of this measurement and its low cost, it is easily adapted into a community monitoring tool.

Nutrients

Lake water quality is strongly influenced by the abundance of nutrients within the watershed system. A moderate amount of nutrients enhances the lake ecosystem by providing a food source for living organisms. Too few nutrients and the lake is unable to sustain life, too many nutrients and the lake suffocates due to the overproduction of life forms. Nutrient runoff from agricultural fertilizers, cattle lands, and wastewater can increase the degree of cultural eutrophication occurring in a waterbody.

Phosphorus and nitrogen concentrations signal the amount of nutrients in the waterbody from natural and anthropogenic input sources. The rate at which phosphorus loads enter freshwater systems varies with land use, geology, morphology of the drainage basin, soil productivity, human activities, and pollution. In some systems, phosphorus uptake by phytoplankton occur rapidly thereby presenting challenges to accurately measure nutrient levels (Wetzel, 1983). The only forms of biologically available phosphorus are total dissolved phosphorus, orthophosphate and soluble reactive phosphorus. These indicators provide a better gauge of trophic status within the lake than total phosphorus.

Nitrogen is second to phosphorus in importance for plant and algae growth (Wetzel, 1983). Nitrogen may enter a lake from precipitation, surface runoff or groundwater sources. Beneficial algae and plants depend on the inorganic nitrate and ammonium forms of nitrogen. If the inorganic forms of nitrogen exceed 0.3 mg/l in spring, there is adequate nitrogen to sustain summer algal blooms (Wetzel, 1983). Obtrusive blue-green algae use nitrogen gas dissolved in lake waters as a nitrogen source (Wetzel, 1983).

2.3 Data assessment

Trophic status is a good method of assessing changes in lake productivity and often reflects land use impacts to water quality (Mackie, 2001). Table 1 provides guidance in the interpretation of water quality data and identifying the trophic status of a lake.

Table 1 Trophic status analysis (Mackie 2001)

Chl a (ug/L)	**Total P (ug/L)**		**Total N (ug/L)**	**Secchi Depth (m)**
Trophic Status	Growing season mean	At spring overturn	At spring overturn	Growing season mean
Oligotrophic	0-2	1-10	<100	>6
Mesotrophic	2-5	10-20	100-500	3-6
Eutrophic	>5	>20	500-1000	<3

The nitrogen-to-phosphorus weight ratio is another method of characterizing lake productivity by assessesing if a waterbody is nitrogen or phosphorus limiting (Bulgakov, & Levich, 1992). The principle states that the yield of any organism will be determined by the abundance of the substance that, in relation to the needs of the organism, is least abundant in the environment (Wetzel, 1983). Historical nitrogen to phosphorus weight ratios obtained for Christina Lake indicate that phosphorus is the nutrient most likely to limit algal and non-rooted vascular plant growth (Cavanagh et al., 1994a). Additional inputs of phosphorus into the lake can result in a change of this ratio and an increase in the growth of phytoplankton.

2.4 Current Guidelines

Phosphorus and chlorophyll a are the two main parameters used to measure and regulate water quality in British Columbia lakes. Phosphorus levels are the primary measure of nutrient content and productivity level. Chlorophyll a is used to gauge productivity by measuring phytoplankton and periphyton biomass in a body of water (MOE, 1999). Guidelines are set for phosphorus and chlorophyll a to outline health risk to support and maintain specific uses of the environment (Canadian Council of Ministers of the Environment [CCME], 2001). The CCME (2001) requirements for guideline formation and World Health Organization’s (2003) recommendations to include biodiversity indicators in water monitoring present questions on the Province of British Columbia’s reliance on phosphorus and chlorophyll a to adequately assess the aquatic ecosystem health of a water body.

2.5 Guideline Formulation

The Province of BC’s nutrient guidelines reflect historical assessment levels, which are representative of the water quality in the province in the early 1980s (Nordin, 1985). Total phosphorus and chlorophyll a are currently the main nutrient level indicators. The phosphorus guideline is set at a maximum of 10 µg/L for drinking water, 10 µg/L for recreation, and 5-15 µg/L to protect aquatic life. The chlorophyll a guideline is set at a maximum of 100 mg/m^2 for aquatic life and 50 mg/m^2 for recreation. The phosphorus and chlorophyll a values are formulated based on chronic exposure. Although phosphorus is not directly toxic to freshwater aquatic life, the values are included due to their broader influence on conditions that affect aquatic life (Nordin, 1985; Hart, Maher, & Lawrence, 1999).

British Columbia’s phosphorus and chlorophyll a guidelines drew from past monitoring observations in lakes and rivers throughout the province. Limnology formulas were used to identify the physical and biological relationships influencing aquatic productivity and algal growth (Environment Canada, 2005). The connection between algal biomass, water clarity, and oxygen depletion was also incorporated into the criteria (Nordin, 1985). Although this process provides some information on the thresholds necessary to maintain balance within the system it does not incorporate an ecosystem approach to water quality assessment.

The present guideline construction and follow up do not fulfill the provincial requirements to assess aquatic health. Nordin (1985) incorporated past research on algal abundance to formulate the provincial guideline. The foundation of the guideline came from Reckhow’s (1978) connection of phosphorus levels to water clarity and Rast, Jones and Lee’s (1983) connection of phosphorus to hypolimnetic oxygen depletion. These formulae were combined with the findings from provincial water quality studies focusing on phosphorus loads and cholorophyll a levels. Nordin (1985) reviewed representative studies with excessive problem algae and derived the numerical limits necessary to balance aquatic productivity, recreation and drinking water sensitivity. Nordin’s (1985) formulation of phosphorus and chlorophyll a criteria in British Columbia is not based on aquatic toxicological data requirements. Freshwater guidelines are required to include a minimum of two chronic fish, two chronic invertebrate, and one freshwater vascular plant or algal species toxicity test results in the formation process. This requirement was not met in the guideline development process by Nordin (1985) or in follow up studies. The guideline report acknowledges that very few attempts are made to quantify algal biomass levels that would cause impairment of water use (Nordin, 1985).

2.6 Limitations of Guidelines

Total phosphorus and chlorophyll a indicators do not characterize aquatic health hazards. Firstly, orthophosphate is a better indicator of the nutrient loads available for algal growth than total phosphorus (Mackie, 2001). Secondly, guidelines representing the hazards of algae and nutrient loads should include phytoplankton and periphyton species composition data to assess aquatic ecosystem health and the cyanobacteria content in the water.

Toxicity of indicator species

The current productivity guidelines do not reflect toxicity test requirements as specified by CCME (2001). Freshwater cyanobacteria (blue-green algae) are capable of producing toxins. At least 46 species of cyanobacteria have shown toxic effects in vertebrates (World Health Organization [WHO], 2003). Toxic metabolites from freshwater algae have scarcely been investigated. Yet toxicity hazards are recognized for freshwater species of Dinophyceae and also the brackish water Prymnesiophyceae and ichthyotoxic species (*Peridinium polonicum*), which have been detected in European lakes (World Health Organization, 2003). It is unclear the frequency of occurrence of cyanotoxins associated with certain cyanobacterial taxa in recreational waters (WHO, 2003).

It is known that cyanobacteria blooms thrive in high phosphorus areas. The World Health Organization (2003) specified cyanobacteria risk as moderate at 50ug/l chlorophyll a. The cyanobacteria risk increases 100-fold with scum at 5000ug/l chlorophyll a and 1000 fold if wind sweeps scums from 100m into 10m at 50 000 ug/l chlorophyll a (WHO, 2003). Guidelines and monitoring protocol are required to identify the toxicity level in water bodies with possible eutrophic concerns linked to cyanobacteria blooms.

The abundance of cyanobacteria in a waterbody provides a cautionary threshold to detect aquatic risk (Cavanagh et al., 1994b; Schindler, 1978a). Cyanobacteria (blue-greens) have adverse effects on livestock, domestic animals, and humans. Acute impacts to human health from the presence of cyanobacteria in freshwater was first documented in 1931 (WHO, 2003). The common mode of exposure is through drinking water or dermal absorption during recreational activities (WHO, 2003). Toxin-producing Cyanobacteria include *Anabaena*, *Aphanizomenon*, *Oscillatoria*, *Microcystis,* and *Lyngbya* (WHO, 2003). *Anabaena* and *Aphanizomenon* interfere with nerve function and have almost immediate effects when ingested. *Microcystis* and *Oscillatoria* produce hepatotoxins (liver toxins) known as microcystins. *Oscillatoria* and *Lyngbya* produce dermatoxins, which cause skin rashes (WHO, 2003). Species identification is essential to recognize these risks in a waterbody (Carmicheal, Bose, Evans, Hyde, & Pfau 1989). The current Christina Lake Water Quality Objective for phytoplankton is based on dominant and non-dominant groupings prohibiting the identification of critical species necessary to capture true health risks.

2.7 Application: Christina Lake Water Quality Objectives

Cavanagh et al. (1994b) created Water Quality Objectives for Christina Lake from the phytoplankton community structure found in historical datasets. The Water Quality Objectives are designed to prevent specified detrimental effects from occurring with respect to a designated water use. In the case of Christina Lake, certain baseline characteristics are well below the BC water quality guidelines. The Christina Lake Water Quality Objectives were designed to augment present water quality guidelines to ensure natural water quality borders were maintained (Cavanagh et al., 1994a). Christina Lake Water Quality Objectives also include suspect indicators such as cyanobacteria and other parameters connected to eutrophication. Table 2 outlines the site-specific Water Quality Objectives for Christina Lake.

Table 2 Water Quality Objectives for Christina Lake (Cavanagh et al. 1994b)

Parameter	**Objective**	**BC Guideline**
Pelagic phytoplankton	Stable community structure not dominated by blue-greens (less than 10% of cells in any sample), dominant genera (greater than 10% of cells) should include *Melosira, Asterionella, Fragilaria, Synedra, Peridinium, Dinobryon*, and *Mallomonas*	None
Zooplankton	Stable community structure dominated (greater than 10% of cells) primarily by *Bosmina longirostris, Epischura nevadensis* and *Kellicotia longispina*	None
Periphyton	Stable community structure dominated (greater than 50% of cells) primarily by pennate diatoms, less than or equal to 10 mg/m^2 for periphyton	None for community composition, chlorophyll a limit of 50 mg/m^2
Dissolved oxygen	8 mg/L minimum at any site and depth	9 mg/L min
Turbidity	Mean value less than or equal to 1 NTU	Mean less than or equal to 1 NTU
Total Phosphorus	Less than 7 ug/L	Less than (mean) 10ug/L

The Water Quality Objectives were constructed to assess the change in lake productivity using phytoplankton species indicative of natural aquatic community structure. Cavanagh et al. (1994b) set targets requiring a stable community structure not dominated by blue-greens (less than 10% of cells in any sample). The dominant genera (greater than 10% of cells) should include *Melosira, Asterionella, Fragilaria, Synedra,* *Peridinium, Dinobryon,* and *Mallomonas* (Cavanagh et al., 1994a). These species were selected due to their historical presence in the lake and role as indicators of low productivity. Alterations in the species composition that fail to meet the outlined Objectives indicate excess hazards presenting aquatic risk to the ecosystem.

2.8 Natural and Geologic Considerations

Natural events such as storms and floods, changes in rainfall patterns, and sedimentation can alter ecosystem structure and functioning. Hydrologic events and weather conditions are captured through the Ministry of Environment's River Forecast Center, and personal communication with local residents. Meteorological indices assist in differentiating long-term trends and seasonal variation. Hydrologic factors such as heavy precipitation events and high wave activity provide additional information to understand deviations from trends within the data set.

Reference to local geology can improve a biomarker's ability to outline relationships and shifts in the aquatic community. The calcium and magnesium required for phytoplankton growth originate from rock weathering. Nevers and Whitman (2004) identified a correlation between hard water and elevated total phytoplankton counts. Site-specific phytoplankton biomarkers derived from historical data sets aid in reducing the uncertainty from geologic variation in water quality assessment.

Chapter 3.0 Study Design

3.1 Methods

The study is intended to work with the Province of British Columbia's historical monitoring program as designed by Cavanagh, et al. (1994b) and Vic Jensen, Senior Biologist for the Ministry of Environment. The program addresses the provincial requirement to complete attainment monitoring to determine if past Water Quality Objectives are being attained. The baseline dataset was captured in 1992 and Water Quality Objectives were formulated in 1994 (Cavanagh et al., 1994a). The project goal is to assess phytoplankton species composition and periphyton chlorophyll a ability to assess if changes in productivity are occurring in Christina Lake.

3.2 Study Sites

Figure 1 displays the location of both the physical, nutrient and phytoplankton pelagic and periphyton littoral sites. Sample sites in the 2006 study follow the historical site location and frequencies used in the 1992 monitoring program by Cavanagh et al. (1994a). The two historical pelagic sites in the 2006 study are Christina Lake @ North Basin E215758 and Christina Lake @ Christina 200078. These two sites are renamed North Basin site and South Basin site respectively throughout the study. The original names follow the Provincial Environmental Monitoring System database codes and names.

The North Basin pelagic site is located in the mid-to-north section of the lake with little development along the foreshore. The South Basin pelagic site is located in the center of the southern most developed portion of the lake. Study sites follow a block design as defined by Swartz (2005). The South Basin site is the only site providing the phytoplankton abundance and species assemblage data. Although this presents a limitation in the data set, it is unavoidable due to the funding limitations of the program.

The periphyton sample sites are located in areas with suitable access to representative algae around the lake. Historical sites were incorporated into the 2006 study design when possible. The study sites captured in 2006 are Christina Lake at English (E246104), Christina Lake at Tambelln (E24186), Christina Lake at Troy Creek (E246192), Christina Lake at Trapper Creek by year (E246191) and Christina Lake at Treadmill (E246191). The site names are consistent with the provincial Environmental Monitoring System database.

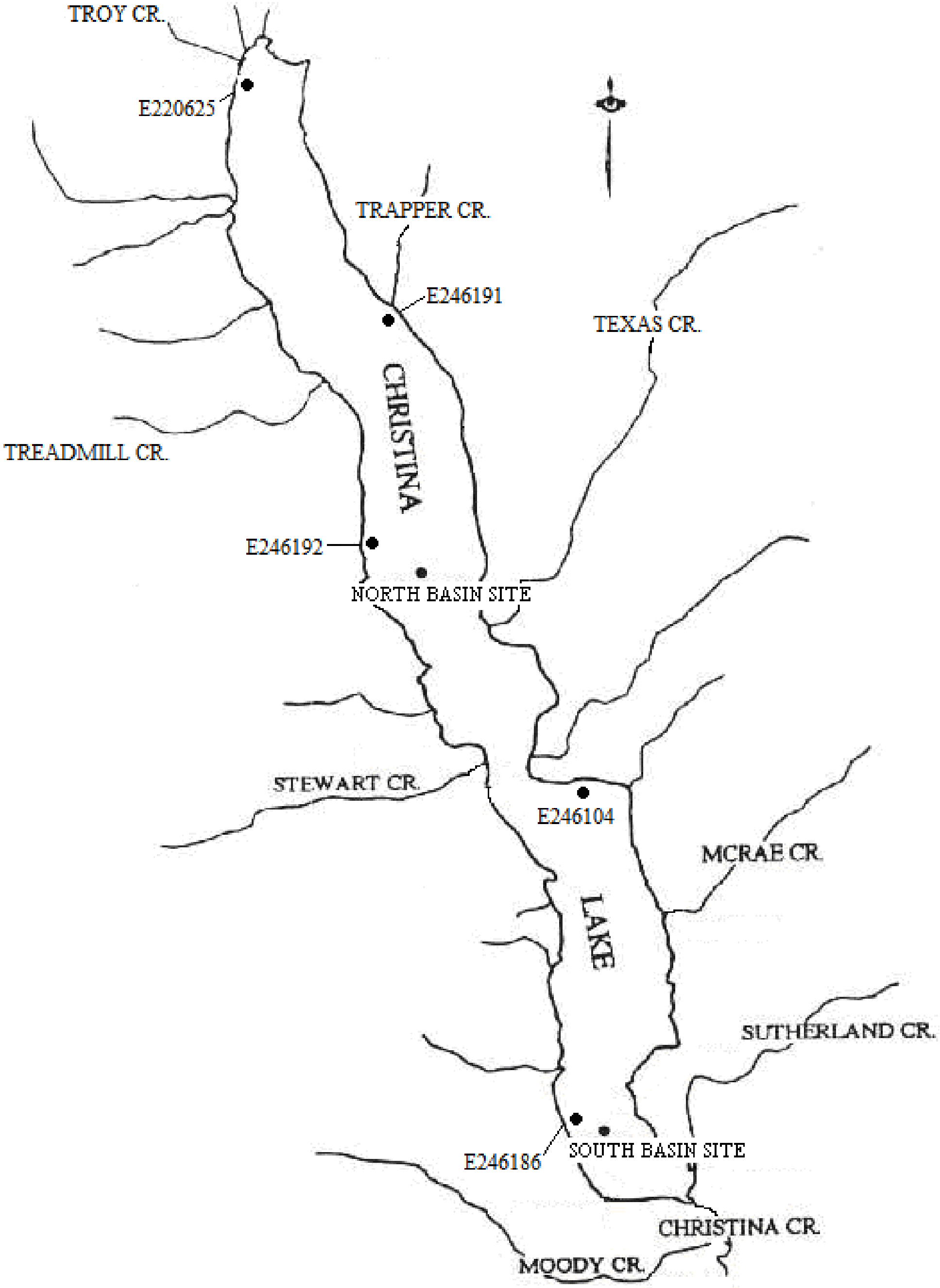

Figure 1 Christina Lake Historical Monitoring Sites

3.3 Indicators and Assessment Techniques

This study uses a range of primary and secondary bio-indicators of productivity to examine the change in water quality in Christina Lake between contemporary and historic data. The primary indicators are periphyton chlorophyll a, and phytoplankton species assemblage and abundance. Secondary indicators include total phosphorus, orthophosphate, total nitrogen, nitrite, nitrate, total Kjeldahl nitrogen, temperature, dissolved oxygen, and water clarity. Due to sporadic and infrequent monitoring and the seasonal variation among parameters, water quality trends over time in Christina Lake are difficult to ascertain.

Primary Indicators

Phytoplankton

Phytoplankton species composition and biomass data are obtained at the South Basin site in the spring and early summer of 2006. Samples are taken with the Van Dorn Sampler from an eight meter depth to the surface in conjunction with nutrient samples at the South Basin site on April 4th and June 22nd 2006. A taxonomist identified the phytoplankton species composition using the methods outlined in Fraser Environmental Service Methods Manual (1994).

Four methods of assessment are applied to interpret data sets. The first method is to assess the phytoplankton abundance by comparing the total number of cells captured in the 1992 data to the 2006 data set. These values are reviewed to determine if there is a trend in the biological data.

Secondly, species total and dominance are charted and compared to historical data to assess biodiversity. Species abundance and productivity indicators are plotted to determine the relationship between the 2006 data set and the historical 1992 data set. Phytoplankton community composition is presented as the percentage contributed by each of Greens, Chryptophytes, Chrysophytes, Cyanophytes (blue greens), and Diatoms.

Thirdly, the Shannon Weaver biodiversity index and taxa evenness compute the relationships between total species and abundance to define biodiversity. This index uses the number of species and the evenness of the species to assess diversity. The species evenness specifies if the cell count is uniform with the number of species in the sample. This is a common method of measuring entrophy in the system (Mackie, 2001). Changes in diversity are useful to assess comparable samples along a spatial contamination gradient or with historical data (Wetzel, 1983). The Shannon Weaver biodiversity index and taxa evenness formulae are outlined in Figure 2.

Biodiversity Index (H')

$$H' = -\sum_{i=1}^{S} p_i \ln p_i$$

Taxa evenness = H'/ln (S)

n_i: The number of individuals in each species; the abundance of each species.

S: The number of species

N: The total number of all individuals

p_i: The relative abundance of each species, calculated as the proportion of individuals of a given species to the total number of individuals in the community:

Figure 2 Shannon Weaver biodiversity index (Maryland Sea Grant 2006)

Phytoplankton findings are compared to the Christina Lake Water Quality Objectives, scientific research and historical reports to interpret findings. From these comparisons the changes in successional communities are evaluated to assess functional impacts to the community.

Periphyton

Periphyton abundance is a primary bio-indicator of the lake's productivity. Five replicates were randomly taken from natural substrate at each of the five study sites. Methods followed the provincial Ministry of Environment's protocols outlined in RISC (1998). Historical periphyton chlorophyll a data sets are available for 1998, 1999, 2000, and 2001 at shoreline sites around Christina Lake. The 2006 periphyton data set follows the same monitoring protocol, and locations as the 1998 to 2001 data. Bivariant linear regression formulae are applied to assess the relationship of periphyton chlorophyll a and time at each of the shoreline sites. JMP software is used to compute and display findings.

All chlorophyll a data are compared to the Resource Inventory Standards Committee (2005) guidelines and the 1994 Water Quality Objectives (Cavanagh et al. 1994b). This assessment analyzes the variation from historical data sets and aides in identifying trends in productivity.

Secondary Indicators

Nutrients, water clarity, temperature and dissolved oxygen provide secondary indicators of productivity. Nutrients grab samples follow the same technique as phytoplankton samples but are collected monthly at three depths in the water column from surface to the maximum depth of 45 meters at the North Basin site and from surface to the maximum depth of 20 meters from the South Basin site monthly from April to October. Depth ranges are dependent on limnion seasonal fluctuations determined by temperature gradients. Water column samples are collected using a Van Dorn bottle and analyzed for total Kjeldahl nitrogen, total nitrogen, nitrate + nitrite, orthophosphate, total phosphorus, and dissolved phosphorus. Dissolved oxygen, and water temperature are taken using a Hydrolab at one-meter intervals from the surface to one meter from the lake bottom on all sample dates in the 2006 monitoring program.

3.4 Funding and Data Capture

The Christina Lake Stewardship Society and the Ministry of Environment staff supplied the boat and all funds associated with the field data capture. Parameters are listed with site locations, methods, and frequency in Table 3. Fraser Environmental Inc. and Maxxam Laboratories in Vancouver completed laboratory analysis.

Table 3 Sampling Regimes

			South Basin	**North Basin**	**Periphyton sites**	**Total**
Parameter	**Unit**	**Method**	**200078[11]**	**E215758[1]**	**5 sites[2]**	**# of samples**
Temperature	Celsius	Field	7	7		14
Dissolved Oxygen	mg/L	Field	7	7		14
Water Clarity	m	Secchi	7	7		14
Nitrogen (total)	ug/L	Lab	7	7		14
Nitrate + Nitrite (dis)	ug/L	Lab	7	7		14
total Kjeldahl N	ug/L	Lab	7	7		14
Ortho-Phosphate (dis)	ug/L	Lab	7	7		14
Phosphorus (total)	ug/L	Lab	7	7		14
Phytoplankton	Tax id	Lab	2			2
Periphyton	Chloropyll a	Lab			25	25

Community Participation

The project is designed to enable collaboration with the Christina Lake Stewardship's commitment and interests to build an annual water quality monitoring program that will be adaptable to changes in provincial support. In addition to assisting with the collection of field samples, the Christina Lake Stewardship Society distributed

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[1] Notes: 1 Sample dates for the South Basin and North Basin site were April 4, May 25, June 22, July 26, August 22, September 23, and October 16, 2006. 2 The sample date for the periphyton sites was August 22, 2006. [1]

information, and educated the community and tourist population on aquatic stewardship and lake health. This is a fundamental part of the 2006 Christina Lake monitoring program.

3.4 Quality Assurance

The goal of quality assurance and quality control is to identify and implement sampling and analytical methodologies in order to limit the introduction of error into analytical data. Quality assurance (QA) is a means to ensure that samples are collected and analyzed adequately with little to no errors. Quality control (QC) methods consist of sampling protocols, training of personnel, use of calibrated equipment, the use of quality control samples (blanks, reference samples, spikes, and replicates), and diligent record keeping. Table 4 outlines the quality assurance and quality control samples taken in the 2006 Christina Lake monitoring program.

Table 4 Summary of quality assurance and control sample type measures (RISC, 1998)

QA/ QC Description	Accuracy Test
Field replicates	Sampling + environmental + analytical precision
Spiked samples	Analytical accuracy
Field blank	Contamination bias and imprecision introduced during sample handling in the field and laboratory;
Trip blank	Contamination (bias and imprecision) introduced by the container, preservative and/or during transportation;
Equipment blank	Contamination (bias and imprecision) introduced through improper cleaning techniques

3.5 Limitations of Methodology

The lack of data sets determining seasonal variation for the study presents challenges in data interpretation. Ideally findings are compared to a broader range of data from more than five representative years of consistent sampling incorporating seasonal and annual variations. Additional phytoplankton species composition monitoring sites in the north end of the lake are required to reduce some of the biases within the 2006 study design. Furthermore, the data gap between 1993 and 2005 present uncertainty in determining the incremental trends in the phytoplankton assemblage and abundance results. Additional phytoplankton species composition sample dates at the South Basin site are necessary to confirm findings. Likewise, periphyton community species composition analysis is required to provide a complete assessment of the aquatic ecosystem health within the littoral zone. A more comprehensive study throughout all seasons at pelagic sample sites, inflowing streams and sediment analysis is required to provide a thorough assessment of the aquatic community structure.

Statistical challenges

Randomization required to complete many tests correlates the responses between any pair of units as equal. Therefore sample dates taken closer together in time are more highly correlated than measurements far apart in time. The inability to randomize time restricts the number of statistical applications that can be applied to the data set. Data can be correlated; it is called autocorrelation when it is in a time series. Autocorrelation can alter the computation of proper p-values and standard errors of effect sizes (Swartz, 2005).

4.0 Chapter 4 – Results

4.1 Phytoplankton

Phytoplankton data from the 2006 monitoring program compares findings with the baseline 1992 data set and historical trends outlined in the Christina Lake Water Quality Objectives document. Cavanagh et al. (1994b) characterized the phytoplankton community structure of Christina Lake in 1992 to consist of diatoms (particularly *Melosira italica*, *Asterionella Formosa*, *Fragilaria crotonensis*, and *Synedra acus*), the dinoflagellate *Peridinim*, and various members of the Chlorococcales, the Cryptomonads and Ochromonadales (*Dinobryon* and *Mallomonas*). The Water Quality Objective requires the 1992 community structure be maintained. The Objective set in 1994 also required a stable community structure not dominated by blue-greens (less than 10% of cells in any sample).

The phytoplankton 2006 data set did not meet the Water Quality Objectives. Table C in the Appendix show differences in dominant species at the South Basin site in 2006 from those reported in 1992. *Lyngbya limnetica* of the order Oscillatoriales dominated the 2006 data set with 506.8 of 645.1 (79%) of the total identified cells in the sample in April 2006 and 14% in June 2006. The Chrysophyte *Dinobryon divergens,* held 53% of the cells in June 2006 with 509.6 cells of the 962.5 total cells identified. The lists of all species and cell counts are included in the Appendix in Table C.

The phytoplankton data in 2006 may indicate changes in species composition from those found in 1992. The taxa richness increased from 27 and 21 species in 1992 to

44 and 42 species in 2006. The species composition changed from Ochromonadales, Pennales, and Centrales in 1992 to Oscillatoriales and Ochromonadales in 2006. Algal abundance increased from 222 cells/mL and 262 cells/mL in 1992 to 645 cells/mL and 962 cells/mL in 2006. The Shannon-Weaver biodiversity index decreased from 2.191 and 2.083 in 1992 to 1.462 and 1.994 in 2006. The taxa evenness decreases from 0.665 and 0.684 in 1992 to 0.386 and 0.534 in 2006. The large difference between the biodiversity index and the taxa evenness indicates the number of species is unequally distributed among algae taxa within the sample set. The percent dominance of sub groups in 1992 was 49% and 58% as compared to 66% and 79% in 2006. These indices may display signs of a decrease in biodiversity in Christina Lake in 2006 from 1992. A decrease in phytoplankton biodiversity is an indication of eutrophication in a lake system (Wetzel, 1983; Mackie, 2001). These observations do not support the hypothesis of no change in productivity level over the span of the study. A summary phytoplankton data analysis is displayed in Table 5.

Table 5 Comparison of the 1992 and 2006 phytoplankton data sets at the South Basin site.

Site	South Basin site			
Date	May 5, 1992	June 3, 1992	April 4, 2006	June 22, 2006
# Species	27	21	44	42
Species Abundance	222	262	645	962
Dominance	Diatoms	Greens	Blue Green	Chrysophytes
Dominance %	49	58	79	66
Shannon Weaver Index	2.191	2.083	1.463	1.994
Taxa evenness	0.665	0.684	0.386	0.534

The grouping of phytoplankton assemblages provides a comparison of changes in the aquatic community structure. The 2006 phytoplankton data present ratios indicative of eutrophication as compared to the 1992 data set's oligotrophic assemblage. The 2006 April phytoplankton data capture identified the eutrophic indicator, blue-greens, to be dominant with 79%, diatoms and greens held 12% and 5% of the cells identified respectively. In June of 2006 Chrysophytes held 66%, blue-greens 15%, diatoms 9%, and greens 7% of the cells identified. Whereas in 1992 the oligotrophic indicators diatoms, greens and Chryptophytes were dominate in the sample population as shown in Figure 3.

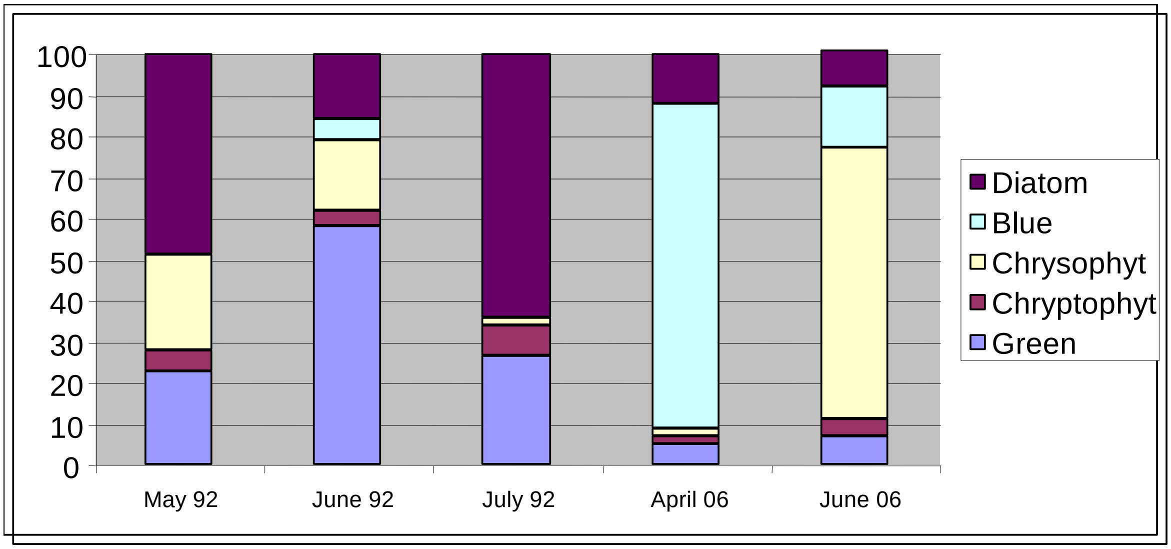

Figure 3 Phytoplankton assemblage percentages in 1992 and 2006 at South Basin Site

Table 6 Summary of phytoplankton percent and total cells identified in 1992 and 2006.

	May 1992 cells/mL	May 1992 %	June 1992 cells/mL	June 1992 %	April 2006 cells/mL	April 2006 %	June 2006 cells/mL	June 2006 %
Greens	50	23	152	58	34	5	70	7
Chryptophytes	11	5	11	4	10	2	36	4
Chrysophytes	52	23	44	17	12	2	632	66
Blue Greens	0	0	13	5	509	79	141	15
Diatoms	109	49	41	16	80	12	83	9
Total	222		263		645		963	

Table 6 provides a comparison of 1992 and 2006 ratios in sub-groups of total cells per milliliter and percentages within the available datasets. The species composition changes may be reflective of increased productivity (Wetzel 1983).

Phytoplankton Data Trends

Blue-green abundance and total cellular abundance are two of the indicators of productivity change. The relationship between the 1992 and 2006 data sets are displayed in Figure 4 and Figure 5.

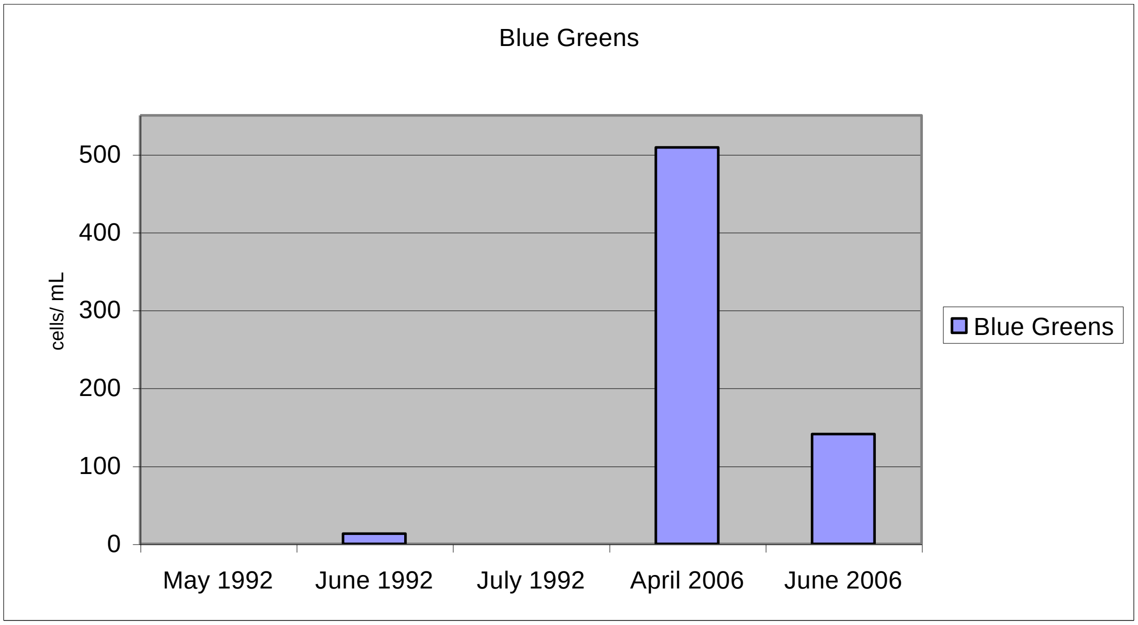

Figure 4 Summary of fit of Phytoplankton blue-green abundance (cells/mL) at the South Basin site by date

Blue-green abundance is reflective of productivity changes within a lake (Mackie, 2001). Figure 4 compares the blue-green abundance in the 2006 data set to the observations in 1992. The increase in blue-greens show some signals of changes in productivity. These observations do not support the hypothesis of no change in productivity level over the span of the experiment. Additional phytoplankton species composition data capture is required throughout all seasons to further investigate the trend.

The abundance of phytoplankton in the samples differed in the 2006 data set from the historical 1992 findings. The total number of phytoplankton cells in April and June 2006 were 645.1 and 962.5 respectively. The total numbers of cells in the May, June, and July 1992 data sets were 222.1, 262.6 and 150.9 respectively. An increase in total abundance is often indicative of increased productivity within the lake (Schindler, 2002; Mackie, 2001). Figure 5 illustrates the trends within the available data.

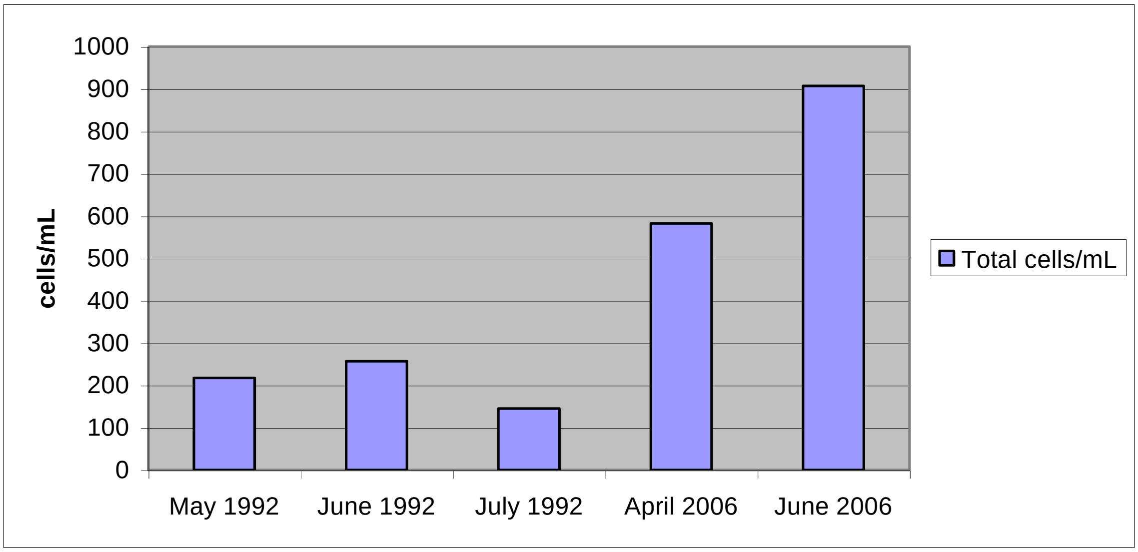

Figure 5 Summary of Phytoplankton abundance (cells/mL) at the South Basin site

The analysis displayed in Figure 5 phytoplankton species abundance at the South Basin site in 1992 and 2006 based on total number of cells per milliliter and time. This data does not support the hypothesis of no change in productivity level over the span of the experiment. Due to the small data set additional phytoplankton sample dates are required to further assess the biological significance of findings.

4.2 Periphyton

Periphyton chlorophyll a measurements were taken at five shoreline sites on August 22 in the 2006 monitoring program. Historical chlorophyll a measurements were captured in 1998, 1999, 2000, 2001 and 2006. Cavanagh et al. (1994b) set the chlorophyll a Objective for Christina Lake to be less than or equal to 10 ug/L for periphyton. This is based on a 30-day mean. No mean periphyton chlorophyll a values exceeded this objective.

Patterns in the chlorophyll a concentration distributions from 1998 to 2006 held similar increasing trends within each sample site. Periphyton chlorophyll a measurements ranged from 3.7 ug/L to 7.7 ug/L in 2006. Table 7 displays the annual mean chlorophyll a data from 1998 to 2006.

Table 7 Periphyton mean chlorophyll a from 1998 to 2006 in ug/L.

Sample Site	Site #	1998	1999	2000	2001	2006
CL at ENGLISH	E246104	0.48	1.96	1.15	1.81	7.73
CL at TAMBELLN	E246186	1.36	2.93	0.68	3.39	3.79
CL at TREADMIL	E246192	4.11	4.59			6.91
CL at TRAPPER	E246191		1.83	1.54	3.69	6.932

Periphyton Data Trends

The data from periphyton sites may be indicative of an increasing trend in productivity from 1998 to 2006. Linear regression analysis is applied to the periphyton mean chlorophyll a findings. Each data point represents the mean of 5 samples providing additional strength to the periphyton chlorophyll a relationships at the four sample sites. This observation does not support the hypothesis that no change in productivity is occurring in Christina Lake.

Table 8 Summary of fit of periphyton chlorophyll a (ug/L) at site Christina Lake at English Bay E246104

Linear Fit	
Average = -1626.71 + 0.81 Year	
Summary of Fit	**Values**
Slope	0.81
R Square	0.75
Standard error	0.26
p-value	0.05

Table 8 displays the strength of the relationship between periphyton chlorophyll a data and time at site Christina Lake at English Bay (E246104). The amount of chlorophyll a in the growing season is estimated to have increased 0.81 ug/L per year (standard error of 0.26) over the span of the study. The r-squared value of 0.75 indicates that 75 percent of the variation in chlorophyll a biomass is connected with time. The p-value for testing if the true slope is zero is 0.05 implying there is a 5% probability that the relation between the variables found in the sample is by chance. These observations do not support the null hypothesis of no change in productivity level over the span of the study.

Table 9 Summary of fit of Periphyton Chlorophyll a (ug/L) Christina Lake at Christina Lake at Treadmill Creek (E246192) by year

Linear Fit	
E246192= -681.46 + 0.34 Year	
Summary of Fit	**Values**
Slope	0.34
R-Square	0.99
Standard error	0.01
p-value	0.02

Table 9 displays the strength of the relationship between periphyton chlorophyll a data and time at site Christina Lake at Treadmill Creek (E246192). Statistically, the high r-squared value of 0.99 indicates chlorophyll a is increasing with time within the sample set (p=0.02). The amount of chlorophyll a in the growing season is estimated to have increased 0.34 ug/L per year (standard error of 0.01) over the span of the study. These observations do not support the null hypothesis of no change in productivity level over the span of the study.

Table 10 Summary of fit of Periphyton Chlorophyll a (ug/L) Christina Lake at Trapper Creek by year (E246191)

Linear Fit	
E246191 = -1546.91 + 0.77 Year	
Summary of Fit	**Values**
Slope	0.77
R Square	0.94
Standard error	0.13
p-value	0.03

The littoral periphtyon site Christina Lake at Trapper Creek (E246191) showed similar characteristics to sites Christina Lake at Treadmill Creek (E246192) and Christina

Lake at English Bay (E246104). Table 10 displays findings of 94 percent of the variation in chlorophyll a biomass is connected with time within the data set ($p = 0.03$). The amount of blue-greens in the growing season is estimated to have increased 0.77 ug/L (standard error of 0.13) per year over the span of the study. The periphyton chlorophyll a data at site Christina Lake at Trapper Creek does not support the null hypothesis of no change in productivity level over the span of the study dates.

Table 11 Summary of fit of Periphyton Chlorophyll a (ug/L) at Christina Lake at Tambelln (E246186) by year

Linear Fit

E246186 = -552.97 + 0.28 Year

Summary of Fit	**Values**
Slope	0.28
R Square	0.41
Standard error	0.19
p-value	0.24

The Christina Lake at Tambelln (E246186) data displayed an increasing trend in chlorophyll a data over time as displayed in Table 8. The periphyton chlorophyll a data at site Christina Lake at Tambelln is not within the confidence interval to delineate a trend ($p=0.24$). The mean chlorophyll a value increased incrementally from 1998, 1999 and 2001. The mean chlorophyll a value of 0.68 ug/L at Christina Lake at Tambelln in 2000 did not support the trend. Although the reduced chlorophyll a findings in 2000 occurred at all sites, the values at Tambelln created a greater variance within the linear regression analysis. This could be due to a number of factors, which include increased wave activity at the site, partial dewatering of the site in low flows, or physical disturbance to the site.

4.3 Water Clarity

Community members recorded secchi depth readings at the South Basin site and North Basin site bimonthly. The changes in spring and fall secchi depth readings from 1993 to 2006 may indicate the clarity in Christina Lake has decreased. Due to the inconsistent findings and the sharp decrease in spring observations it is questionable to consider the 2006 observations reflective of a long-term trend. Figure 6 displays the changes in secchi depth readings from 1993 to 2006.

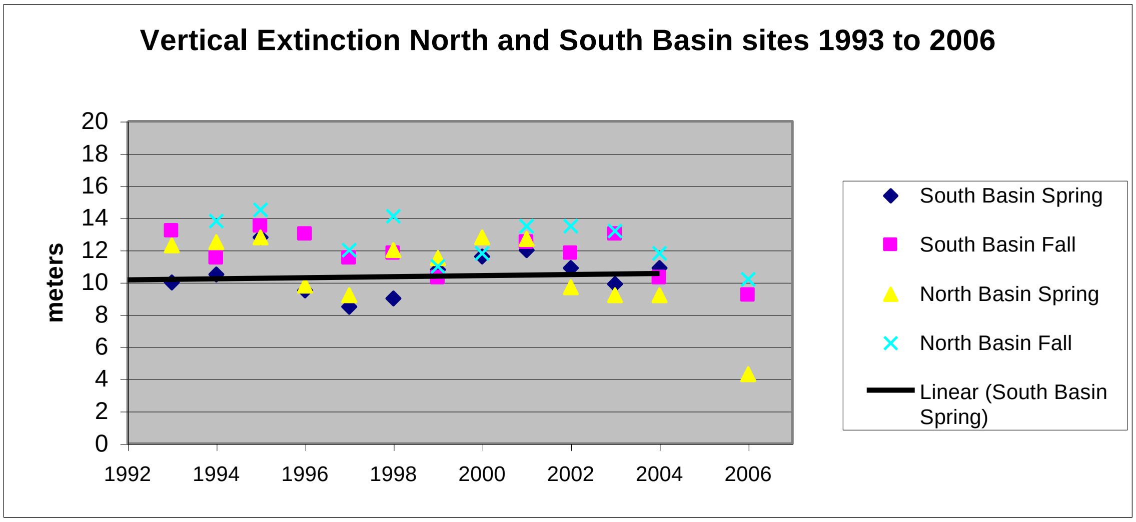

Figure 6 Annual spring and fall extinction depths at the North Basin site and South Basin site

Figure 6 provides additional information on the trends in water clarity in the lake. The historical mean secchi depth readings observed in 1992 exceed 10m. Historical data sets up to and including 1992 showed secchi depth readings typical of oligotrophic waters in Christina Lake (Cavanagh et al., 1994b). The secchi depth readings in the 2006 sampling program ranged from 3 meters to 9.9 meters at the South Basin site. The individual values are a better representation of water clarity as the parameter is seasonally dependent. The linear trend in water clarity spring and fall data from 1993 to 2004 at both the North and South Basin sites are displayed in figure 6. There does not appear to be a trend of decreasing or increasing water clarity within the data set.

Mackie (2001) outlines the limits for correlating secchi depth readings with trophic levels. Values greater than 3 meters are indicative of oligotrophic conditions. This limit was achieved on all sample dates, representing oligotrophic conditions during all sample dates. The high water event in spring of 2006 could account for the decrease in water clarity displayed in figure 6 (Wetzel 1983). Additional turbidity and decreased water clarity is often connected with bank erosion and rapid inflows from creeks and surface water (Mackie 2001). The exceptionally high water level from precipitation and a rapid snowmelt in 2006 could also contribute to these factors (Wetzel, 1983). Additional bimonthly monitoring is required to determine if these observations are part of a short-term event or a long-term trend.

4.4 Nutrient Results

Phosphorus

Overall, average total phosphorus levels in 2006 did not differ significantly from those in the historic data sets. A summary of the 1992 and 2006 data findings are in Table 12 and in Table A and B in the Appendix. The range of total phosphorus at spring overturn based on a 20-year data set presented in Cavanagh et al. (1994b) is 3ug/L to 8ug/L. The overall mean for phosphorus during this 20-year data period is 6.5 ug/L. The mean excluding questionable data from 1983 to 1986 is 5.6 ug/L (Cavanagh et al. 1994b). The 2006 total phosphorus mean is 4 ug/L.

Table 12 Summary of 1992 and 2006 phosphorus data at depths from the South Basin and North Basin site.

	South Basin				N	North Basin				N
	1992	2006	2006	2006		1992	2006	2006	2006	
Parameter (ug/L)	Mean	Max	Min	Mean		Mean	Max	Min	Mean	
Total Phosphorus	4	4	1	2	7	4	4	1	2	7
Orthophosphate		6	1	3	7		6	0	3	7
Dissolved Phosphorus	2	4	0	2	7	2	6	0	4	7

Wetzel (1983) and Mackie (2001) list total phosphorus values between 4-10 ug/L to represent oligo-mesotrophic conditions in a lake. The historical datasets, pre 1992, and the 2006 total phosphorus findings are within the oligo-mesotrophic range. All total phosphorus levels are below the Christina Lake objective of mean spring overturn total phosphorus concentrations less than 7 ug/L and the provincial guideline less than (mean) 10ug/L. Phosphorus levels do not appear to follow a trend from 1992 to 2006. Historical annual phosphorus observations during spring overturn at the South Basin site are graphed in figure 7. The lack of phytoplankton abundance and species composition presents information gaps on the relationship between the elevated total phosphorus levels from 1996 to 2000 and algae productivity.

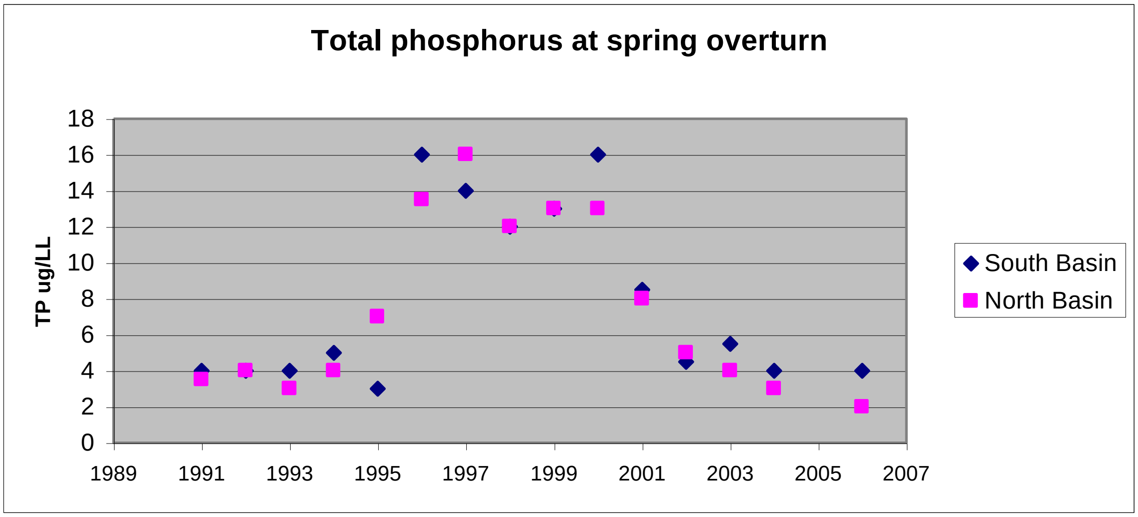

Figure 7 Phosphorus at spring overturn at the South Basin site from 1993 to 2006

Total dissolved phosphorus and average dissolved orthophosphate values are taken at the South Basin site and the North Basin site. No provincial guidelines or objectives exist for orthophosphate. Ideally, orthophosphate concentrations should be 10 ug/L or less at spring turnover to prevent summer algae blooms (Mackie, 2001). The average orthophosphate at sites both the South Basin site and the North Basin site for 2006 was 3ug/L.

Nitrogen

Mean annual total nitrogen, ammonia, total Kjeldahl nitrogen, and nitrate results at spring overturn are displayed in the Appendix in Table A and Table B. The 1992 data set combined with the 1979 Crozier report indicated that the lake was ultra-oligotrophic (Cavanagh et al., 1994b). Figure 8 compares displays trends in data from 1993 to 2006. Overall, nitrogen data did not differ greatly in 2006 from historic findings.

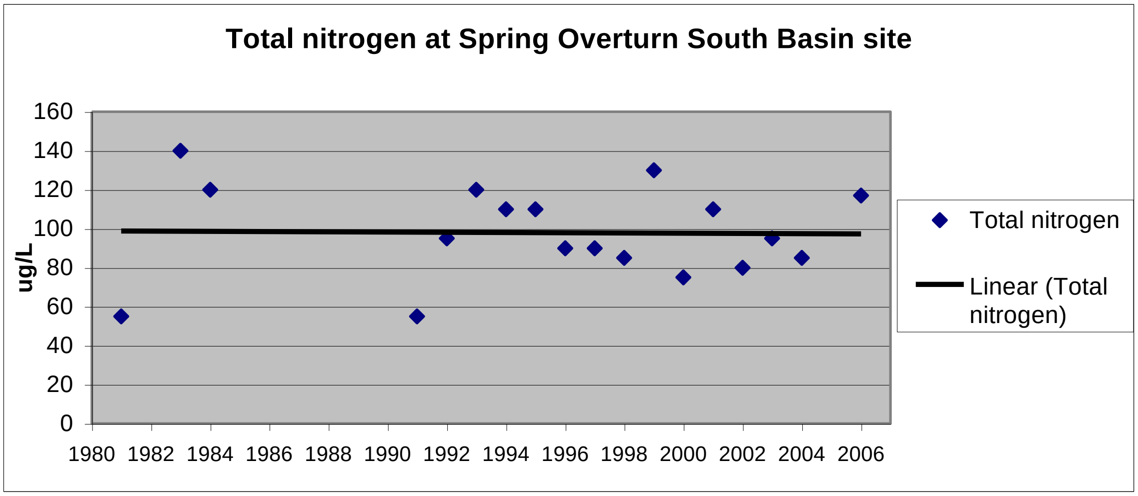

Figure 8 Total nitrogen at spring overturn at the South Basin site from 1981 to 2006

The water quality objective set in 1994 requires the maximum desirable total nitrogen value at spring overturn to be less than 200 ug/L. This was achieved in all samples at both the North Basin and South Basin site. Table 13 displays a summary of available data for 1992 (mean) and 2006 (mean, minimum, and maximum) nitrogen data. There may be a difference between the North Basin and South Basin site spring overturn total nitrogen trends with observations of 70 ug/L and 117 ug/L respectively in 2006. Additional phosphorus data capture at both the North and South Basin sites are required to assess trends.

Table 13 Summary of 1992 and 2006 nitrogen data from the South Basin and North Basin site

	South Basin				N	North Basin				N
	1992	2006	2006	2006		1992	2006	2006	2006	
Parameter	Mean	Max	Min	Mean		Mean	Max	Min	Mean	
Nitrate plus Nitrite (ug/L)		2	0	1	7	2	14	1	7	7
Total Nitrogen (ug/L)	120	117	67	92	7	100	107	67	85	7
Total Kjeldahl N (Calc)	95	117	67	89	7	80	90	57	77	7

Figure 9 illustrates the differences in the north and south basin site total nitrogen data findings from 1993 to 2006 at spring overturn. These data sets provide some indication of nutrient loads within the Christina Lake. The difference in total nitrogen data in the South Basin to the North Basin sites could be from one or a combination of sources including land use, inflowing creeks in the south basin, surface water flows, or the natural hydrologic regime.

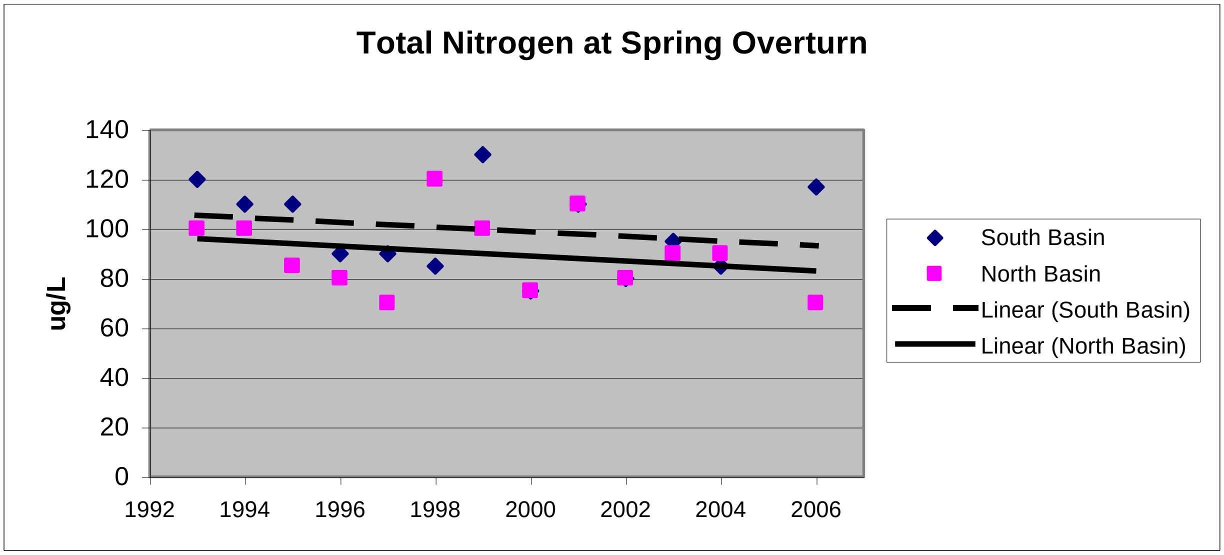

Figure 9 Comparison of the South Basin and North Basin site total nitrogen (TN)

4.5 Hydrology Observations

Although no scientific water level data exists personal communication with local residents indicate that water levels were exceptionally high during the spring of the 2006 Christina Lake monitoring program (B. LaCroix personal communication, December 15, 2006). The data interpretation in the discussion incorporates this factor as a possible explanation for unique observations.

4.6 Temperature and Dissolved Oxygen

Water temperature and DO are measured at the South Basin site and North Basin site monthly. The surface water temperature ranged from 5.3 degrees Celsius on the first sample date, April 4, to a maximum of 26.4 degrees Celsius in July 2006. This varied from the 1992 historical data set of minimum of 4 degrees Celsius and max of 25 degrees Celsius from May to October. The temperature dependent variability of phytoplankton growth is nutrient specific and species specific (Rhee, & Gotham, 1981). Phytoplankton growth has a greater dependence on nutrients at lower temperatures (Rhee, & Gotham, 1981). Present data sets do not allow for an adequate assessment of changes in temperature trends. Factors such as climate change require more frequent data capture over a series of ten to twenty years to assess temperature trends. Seasonal variability and sample frequency make it difficult to assess long-term trends in temperature with the available data.

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Dissolved oxygen (DO) concentrations were measured through the water column at the two deep lake sites monthly from May to October. Percent dissolved oxygen saturation was calculated and dissolved oxygen profiles reviewed. The maximum dissolved oxygen concentration throughout the water column occurred on July 26th at a depth of 8m with a value of 13.6 mg/L for the months recorded. All values exceeded the Water Quality Objectives set by Cavanagh et al. (1994b) of 8 mg/L minimum. This is above the water quality guidelines limit of 9 mg/L for the protection of salmonids. Cavanagh et al. (1994b) observations indicate that all values during 1991 and 1992 exceeded the 8mg/L objective. From the oxygen profiles provided in the Cavanagh et al.

(1994b) report dissolved oxygen levels did not appear to have a significant change in 2006.

Table 14 displays the temperature and dissolved oxygen profile at the South Basin site on June 22, 2006. The increase in dissolved oxygen abundance from the ten meter depth to the two meter depth could be from the abundance of phytoplankton in the euphotic zone (Mackie 2002). Phytoplankton proliferates as temperatures increases in the spring. Additional datasets before and after spring overturn will aid in further assessing the relationships between temperature, dissolved oxygen and phytoplankton species composition and abundance.

Table 14 Temperature and dissolved oxygen profile for June 22, 2006 at South Basin site ranges

Depth	Temp (^{o}C)	DO mg/L
0	18.7	11.5
2	16.6	12
4	14.4	12.6
6	12.2	13.2
8	9.9	12.9
10	8.3	12.8
12	7.2	12
14	6.3	12
16	5.9	12.1
18	5.5	11.7
20	5.2	11.5
24	5	11

4.7 Quality Assurance

The quality assurance requirements were achieved throughout the 2006 monitoring program. Ten percent of the monitoring program consisted of quality control samples including field replicates for all parameters analyzed and field blanks for each sample site. Equipment blanks were taken for one periphyton chlorophyll a sample and one nutrient sample. All other quality control samples were taken by the provincial auditor to ensure the laboratory accuracy under the requirements specified by the Resource Inventory Standards Committee (1998).

5.0 Conclusions and Discussion

5.1 Discussion

Overview

The study aims to determine if phytoplankton and periphyton population dynamics illustrate a change in productivity is occurring within the study area. Secondary indicators water clarity, nutrients, dissolved oxygen and temperature are incorporated to assist in the assessment. Due to the sporadic and infrequent monitoring and contrasting signals from secondary parameters, it is not possible to be definitive on findings.

Primary Indicators

The primary bioindicators in the Christina Lake 2006 study may provide some signs of the initial stages of lake eutrophication. Based on the phytoplankton and periphyton sampling data the lake productivity may have increased within the study area. The analysis of emerging trends is restricted to individual parameters, as the differences in sample frequency do not allow for statistical comparison of findings. Although the statistical analysis displays an increase in productivity for some parameters, the number of years of background data creates uncertainty in the strength of results. Additional monitoring capturing annual and seasonal trends is recommended to further assess findings.

Phytoplankton

Phytoplankton species composition provides the most comprehensive diagnostic overview of current conditions within the study area. Population dynamics display important information on productivity within the aquatic system. Wetzel (1983) indicated that an observable shift in species composition at any time of year may precede detectable changes in water chemistry and therefore, may serve as an early warning of deterioration in water quality. The phytoplankton assemblage may display changes in productivity levels within the study area.

The shift in community structure within the South Basin is shown by univariate analyses and may be considered altered at the community level with a loss of diversity, reduced richness, increased abundance, and increased dominance of eutrophic indicator species. These observations do not support the null hypothesis that no change in productivity is occurring within the study area in Christina Lake.

The presentation of data from phytoplankton species composition compares the south pelagic site samples in April and June of 2006 to the May, June and July samples taken in 1992. The phytoplankton bioindicator of aquatic health required blue-green algae to make up less than 10% of the population at each sample site (Cavanagh et al., 1994a). The historical 1992 data set demonstrated phytoplankton species assemblage typical of oligotrophic conditions (Cavanagh et al., 1994a). The increase of blue-greens from 0%, 5%, and 0% in May, June and July of 1992 to 79% and 15% in April and June 2006 displays a trend in productivity within the data sets. The shift of dominance to blue-green algae in 2006 may indicate signs of eutrophication. Likewise, the phytoplankton abundance increase from 217 cells/mL, 257 cells/mL, and 145 cells/mL in May, June and July of 1992 to 582 cells/mL and 907 cells/mL in April and June of 2006 may indicate signs of eutrophication. The annual incremental increase in species abundance is indistinguishable with the available data set. The biological relevance of these findings requires further monitoring of both annual and seasonal phytoplankton assemblage.

Based on the classification scheme of Cavanagh et al. (1994b), which utilized the maximum of 10 per cent abundance of cyanophytes as an indicator of changes in productivity, Christina Lake is classified as exceeding the objectives. The increase in cyanophytes from 0%, 13% and 0% in May, June, and July in 1992 respectively to 79% and 15% in April and June of 2006 may indicate changes are occurring in the aquatic ecosystem structure. The increase in abundance of cyanophytes in the 2006 data set may signify trophic changes within the study area. Cavanagh et al. (1994a) set the phytoplankton bioindicator of aquatic health to require cyanophytes to make up less than 10% of the population. Blue-greens are typical of eutrophic conditions and provide an indication of changes in aquatic dynamics (Wetzel, 1983). The abundance of blue-greens in the 2006 does not support the null hypothesis of the phytoplankton and periphyton population displaying no changes in productivity within the study area.

Scientific literature relates an increase in phytoplankton total abundance with an increase in productivity (Santos et al., 2003; Schindler 1978). The total number of phytoplankton cells in April and June 2006 were 645.1 and 962.5 respectively. The total numbers of cells in the May, June, and July 1992 data sets were 222.1, 262.6 and 150.9 respectively. The relationship between cellular biovolume and time showed a statistically significant increase ($p<0.05$). Additional data sets capturing species cellular abundance at monthly intervals are recommended to further explain findings.

The Christina Lake water quality objectives were formed based on aquatic health limits in scientific literature and historic Christina Lake and regional data sets. The historical reports provide additional confidence in the 1992 data to be indicative of baseline conditions. The Christina Lake water quality objectives are based on this historical data and analysis. The required dominant genera *Mallomonas, Peridinim, Synedra acus, Fragilaria crotonensis*, and various members of Chlorococcales were either not present or accounted for less than 1% of the population in the 2006 data set. The dominant species in the 2006 data sets was *Lyngbya limnetica.* This blue-green algae *Lyngbya limnetica* made up 79% of the population in spring and 14% of the population in early summer. The quantities of *Lyngbya limnetica* observed during the 2006 study are high enough to be considered strong algal blooms (Wetzel 1983). These elevated counts may be indicative of eutrophication.

There are several possible explanations for the contrasting signals between phytoplankton assemblage data and nutrient data. One is blue-green algae’s unique characteristic to promote growth independent of outside sources of nutrients or growth factors (Allen & Arnon 1955). Allen and Arnon (1955) found the growth of *Anabaena* *cylindrical*, a filamentous, nitrogen fixing member of the Myxophyceae, can produce in 6 days under favorable conditions. Common requirements for the growth of algae require inorganic forms of nitrogen to support summer algae blooms (Schindler, 1978b). Allen and Arnon (1955) found blue-green algae capacity for growth with molecular nitrogen to be of the same order of magnitude as the growth of vigorously growing green algae with nitrate nitrogen. It is recommended to explore the relationships of total nitrogen, nitrite, nitrate, ammonia, dissolved and particulate organic nitrogen and the abundance of blue-green algae in Christina Lake in more detail.

The oligotrophic indicator, *Dinobryon divergens*, accounted for 56% of the algae assemblage during the June sample set in 2006. Celewicz – Goldyn (2003) showed that *Dinobryon divergens* was very abundant in the eutrophic Lake Rosnowskie Duze. This study concluded the high numbers of the oligotrophic indicator in this eutrophic waterbody may be attributed to the high level of oxygenation in the surface layer and the low concentrations of nutrients after cyanoprokaryotic blooms. The elevated dissolved oxygen, low nutrient levels and temporal pattern of *Dinobryon divergens* in the Lake Rosnowskie Duze study hold similar characteristics to the values recorded in the 2006 Christina Lake study. Additional pelagic phytoplankton sites and sampling frequency are required to capture incremental relationships in species composition to further study this connection.

The rare high water event in spring of 2006 presents another aspect of consideration in interpreting productivity trends. Contrary to the common increase in phosphorus and nitrogen during spring freshet, scientific studies have found that rainfall events reduce algal abundance. Pfiester's (1992) study concluded that heavy rainfall and subsequent increase in lake volume appeared to have a real effect in diluting and diminishing algal counts. Therefore the heavy spring rainfall and elevated water level may have masked an even larger shift in phytoplankton abundance. This information, together with the phytoplankton assemblage analysis, does not support the null hypothesis that the periphyton and phytoplankton population dynamics within the study area imply no change in the productivity level in Christina Lake. Additional monitoring is required to further assess the relationship between precipitation and phytoplankton assemblage.

Periphyton

Another primary goal of the study is to assess the relationship between periphyton abundance and time. Stream ecologists often consider elevated littoral productivity levels as an early sign of cultural eutrophication occurring in a waterbody (Wetzel, 1983). Scientific literature suggests that external inputs can change the intensity and stability of ecological interactions in restricted spatial locations (Schindler, & Scheuerell 2002). Disturbance and environmental change such as land use inputs are captured through littoral zone monitoring of periphyton abundance.

Christina Lake water quality objectives developed by Cavanagh et al. (1994b) are considered in the analysis but are not the main focus in the interpretation of findings. Due to the different methodologies employed to capture data in the 1992 data set, it is not used as the baseline for the analysis. The 1992 data set was captured on plexi glass in moored shallow near shore waters. Natural substrate was used from 1998 to 2006 to eliminate human disturbance problems associated with artificial techniques (Hamala, Duncan, & Blinn, 2004). Further evaluation of appropriate periphtyon thresholds, in relation to reference sites within the region, are required to improve the evaluation of periphyton abundance and community structure limits at Christina Lake.

The linear regression analysis applied to three of the periphyton sample sites display an increasing trend in chlorophyll a concentrations from 1998 to 2006 ($p<0.05$). Annual data sets from 1998 to 2001 increased the confidence of information of incremental changes in productivity. The comparison of four sample sites adds strength to the relationship between productivity and time in different areas of Christina Lake. These observations do not support the null hypothesis that the periphyton and phytoplankton population dynamics within the study area imply no change in the productivity level in Christina Lake.

One exception to the elevated periphyton chlorophyll a observations occurred at Christina Lake at Troy Creek, E220625. The average at this site in 2006 was 0.73 mg/m3. There is no historical data for this site. Field notes assist in deriving possible explanations for this isolated low periphyton chlorophyll a record. The site’s close proximity to Troy Creek inflows could cause the periphyton sample to be reflective of the creek’s water quality. Another possible explanation is the high wave activity could remove periphyton from the rocks at the sample site. Additional annual sample sets are recommended to further investigate the relationship between the Christina Lake at Troy Creek (E220625) periphyton site and the observations at the other four sites.

Secondary Indicators

A number of different trophic status indicators are incorporated to help address some of the uncertainty from data gaps and inconsistent observations. Fish abundance, water clarity, phosphorus, nitrogen, temperature and dissolved oxygen provide information to verify plankton observations and decipher trends. The contrasting signals between datasets indicate that additional monitoring of all secondary parameters should occur in conjunction with future periphyton and phytoplankton monitoring.

Fish Abundance

Andrew Wilson, Senior Fisheries Biologist with the Ministry of Environment provided an overview of 2006 fisheries data and interpretations at the Christina Lake Stewardship Society annual meeting. The fish abundance and spatial preference to habituate areas with increased nutrient loads connects fish population abundance with elevated nutrient levels. Fish possess the mobility to effectively participate in both littoral and pelagic food webs. The fish preference to the south basin versus the north basin provides some information of increased productivity in the nutrient loads within Christina Lake (Wilson, 2006).

Water Clarity

Water clarity appeared to have decreased at both the North Basin site and the South Basin site in 2006. Both the North Basin and South Basin site values may indicate changes in nutrient levels are occurring in the Lake. Secchi depth readings characterized water clarity as oligotrophic to mesotrophic in 2006 with a mean measurement of 7.7 meters and 9.14 meters at the South Basin and the North Basin site respectively. Historical readings characterized Christina Lake as oligotrophic with the mean measurement at all deep sites to have exceeded 10 meters. Likewise, the Christina Lake Water Quality Objectives outlined secchi depth parameters not to exceed an annual mean of 10 meters. Although these findings are not statistically significant the readings provide additional information on the state of water quality in Christina Lake. The decrease in water clarity observed through secchi depth readings could be reflective of the landslide and high water levels in the spring of 2006. Regular bimonthly extinction depth readings are required in upcoming years to further assess findings.

Another explanation for the reduced water clarity was the extreme high water and landslide in late spring. This event could account for the low secchi depth observations in May. In conjunction with monthly phytoplankton assemblage and nutrient data, additional biweekly secchi depth readings are recommended to help decipher if the 2005 and 2006 reduction in clarity is part of a long-term trend.

Nitrogen

It is difficult to detect if the nitrogen levels in the lake depict cultural eutrophication. Anthropogenic nitrogen inputs can come from fertilizer and animal wastes on agriculture lands, human waste from sewage treatment plants or septic systems. Regional District representatives have cautioned the community that anthropogenic nutrient inputs from shoreline septic systems and recreational boaters are a potential hazard to water quality within Christina Lake (Regional District of Kootenay Boundary, 2006).

Long-term nitrogen trends could not be distinguished from the available data sets. The nitrogen values do not appear to be symbiotic with the influx of blue-greens in the 2006 data sets. One possible explanation for the difference is the connection between nitrogen and phytoplankton growth rates. As phytoplankton abundance increases nitrogen assimilation by plants is also increased thereby reducing the instantaneous nitrogen values captured in the sample data (Wetzel, 1983). Another aspect is the ability for lakes to compensate for nitrogen deficiencies by fixing atmospheric gases (Schindler, 1978a). For example, the dominant *Oscillatoria* species can promote growth without outside sources of nutrients. Nitrogen fixation could account for part of the disconnecting signals between indicators. Total nitrogen, nitrate, nitrite and total Kjeldahl nitrogen and dissolved oxygen data is required in conjunction with the future recommended phytoplankton assemblage data capture to further assess this relationship.

Phosphorus

The historical phosphorus values and the 2006 data did not display a trend over time, thereby eluding variation from the interpretation of increased productivity within the phytoplankton and periphyton findings. The average total phosphorus during spring overturn in 1992 and 2006 was 4 ug/L at the South Basin site and the orthophosphate measurements were below detection limit on the phytoplankton sample dates. Additional data sets are required to further assess the relationship between nutrients, phytoplankton and periphyton bioindicators in Christina Lake.

A literature search and review of past studies with low level phosphorus in freshwater lakes provide possible explanations for the contrasting signals in phytoplankton, periphyton and phosphorus observations within the study. One possible explanation is the challenge of detecting gradual changes in low level phosphorus. The detection limits of 1 ug/L for orthophosphate, and 2 ug/L for total phosphorus in Christina Lake with an average of 2 ug/L of total phosphorus in 2006 presents questions of the accuracy of the laboratory results. This is demonstrated on October 8, 2006 when the orthophosphate was reported as 2 ug/L and total phosphorus was reported as below the 2 ug/L detection limit. Yet, the percentage of total phosphorus occurring as orthophosphate is probably considerable less than 5 per cent in most natural waters (Wetzel, 1983).

The small data set presents challenges in assessing the biological confidence of results. Increasing the frequency of phosphorus and phytoplankton data sets during the spring and summer months could assist in characterizing the relationships between nutrients and phytoplankton assemblage findings. Likewise, an assessment of the relationships between phosphorus and algae, zooplankton and the fish population in lakes of different trophy may provide additional information. The relationships between population dynamics within the food web could explain the possible eutrophication trends.

As lakes become more productive, the primary effecting agent is increased loading of phosphorus. Likewise, a small increase of phosphorus, being the limiting nutrient in Christina Lake, could result in a large increase in algal abundance. The small increase in phosphorus necessary for the phytoplankton bloom observed in the 2006 study might not be captured in the data set due to the uptake of phosphate by the phytoplankton population. Likewise, Wetzel (1983) explains that in the initial stages of increased productivity the instantaneous concentrations of phosphorus usually decrease and are quite variable. One of the challenges of investigating the sources of variation in phosphorus and phytoplankton abundance is the difficulty to accurately measure the amount of phosphorus in natural populations of phytoplankton (Schindler, 2002). A combination of these explanations could account for differences between the primary indicators and phosphorus values captured in the 2006 study.

5.2 Interpreting Source of Change

Natural eutrophication is a slow process spanning decades (Mackie, 2001). Any changes in productivity levels within a water body that demonstrate trends beyond this process suggest cultural alterations to the system. The source of these changes is difficult to identify, particularly in water bodies with primarily non-point source inputs. A detailed assessment of the relationship between land use and recreation impacts on water quality is required to differentiate natural and cultural eutrophication sources and implications.

5.3 Management implications

In order to adopt sustainable water resource management, there is a need to learn about the linkages between aquatic health and the environmental, economic and social systems. Provincially, policies and legislation regarding land use and development near lakes are set out in the Provincial Planning Act and through the local and regional Official Plans and zoning by-laws. The creation of the Watershed Management Plan provides a mechanism to report changes in water quality and mitigate impacts to the Lake. A lake plan has no legal authority. The Watershed Management Plan gains strength if added to the town's Official Community Plan. The union of the two documents will ensure enforceability and long-term commitment by the region.

Similar to the Natural Step ideology the continuity of the Christina Lake Stewardship group is critical to maintaining a proactive stance rather than a reactive regulatory framework (James, & Lahti, 2004). The microbial community can be modified from its natural homeostasis by a number of mechanisms directly related to land development, and residential practices. Combinations of these mechanisms can dramatically impact these fragile ecosystems over a relatively short time. Public consultation enabling the community to contribute to their community vision for both commercial and public recreational areas will ensure local commitment to the program. Likewise, the Ministry of Health's mandate to achieve source protection of water could be linked with an infrastructure component of the Watershed Management Plan.

5.4 Conclusion

The phytoplankton assemblage, and periphyton chlorophyll a data suggest that cultural eutrophication may be occurring in Christina Lake. Additional monitoring is needed to see whether this hypothesized eutrophication is in fact real or due to an inadequate data set. This study aids in advancing scientific understanding of the benefits of including plankton community dynamics as a bio-indicator of productivity levels in freshwater aquatic assessments within the southern interior of British Columbia.

Community leadership on aquatic assessment and protection is a fundamental part of the Christina Lake water monitoring program. The water monitoring project structure incorporates community participation in order to work with a long-term aquatic program goal that continues beyond the length of 2006 assessment. This provides an avenue for data and reports to be made available for public review and comment. Aquatic issues and potential solutions should be a joint process between users and resource managers. Collaborative environmental planning involving stakeholder ownership and participation is essential to securing the long-term protection and conservation of Christina Lake.

The ideal regulatory and monitoring framework implements an ecosystem objective approach as opposed to a water quality guideline concept (Doppelt, 2003). In order to capture the variability and complexity of aquatic ecosystems, guidelines should be based on community structure and population dynamics as opposed to individual species. The addition of site specific and issue-based criteria allows biomarkers to highlight potential risk from the natural biological population structure. Similarly, area specific trigger levels, representing adverse biological effects, aid in alarming resource managers to adjust industrial permits and land use practice protocols to reduce allowable inputs to the system.

The 2006 Christina Lake study provides evidence that phytoplankton community structure and periphyton abundance are valuable biomarkers of environmental stressors and representation of the level of risk to ecosystem health. This shift in focus in aquatic resource assessment and protection follows the new paradigm of systems thinking. As described by Capra (1996), “The new mathematics…is one of relationships and patterns. It is qualitative rather than quantitative and thus embodies the shift of emphasis that is characteristic of systems thinking – from objects to relationships, from quantity to quality, from substance to pattern.”

6.0 Recommendations

6.1 Tools to achieve sustainability

The optimum water quality protection program combines a balanced mix of regulatory and informational tools. The 2006 water quality study captured phytoplankton, periphyton, water clarity and nutrient data to aid in determining if productivity is increasing in Christina Lake. The water monitoring project successfully incorporated community participation to work with the long-term aquatic program goal to continue beyond the length of 2006 assessment. Continued research and learning about the relationships between phytoplankton and periphyton assemblage and their influence on ecological system will provide useful information for decision-makers for the sustainable development of the Town of Christina Lake.

6.2 Assessment Recommendations

Lake Monitoring Sites

Baseline data capture is recommended to continue at the two historical pelagic sites, the South Basin site and the North Basin site. These sites will assess the trends in water quality of the lake in different sections and provide a possible control site to aid in distinguishing land development impacts from natural processes. Monitoring is recommended to commence immediately after ice melt (pre-freshet) and continue monthly into the fall. Additional phytoplankton sample dates and sites are valuable to assist in developing indicators from measurements of biomass and composition to define lake conditions, and then conduct analyses of seasonal, regional, inter-annual deviations in relation to differences in environmental factors and patterns of primary production (Wetzel 1983). In addition to phytoplankton assemblage and abundance, water temperature, dissolved oxygen, water clarity, turbidity, and nutrients (total nitrogen, total organic nitrogen, ammonia, total phosphorus, total dissolved phosphorus and orthophosphate), are recommended to be monitored at the two pelagic sites. Periphyton chlorophyll a and species assemblage monitoring at minimum at the five historical sites should continue annually.

Monitoring of Christina Lake inflows provide useful information on the quality of the water flowing into the lake and may assist in identifying land use impacts. Inflows are to be monitored at the same frequency as the pelagic samples to determine the extent of variation between inflows and lake water quality. A monthly assessment of fisheries abundance and zooplankton species assemblage are recommended if funding is available.

Lake Water Quantity Data Capture

Climate change and increased demands on water resources throughout the Christina Lake drainage could have an impact on water levels in the lake over the long-term. Such demands include an increasing population with greater necessities for water, and resort developments with high irrigation requirements. Long-term hydrometric monitoring stations on the main inflows Moody and Sutherland Creek and the Christina Creek outflow are essential to understand the relationships between water demand, water quality and water availability of the Lake. An inventory of groundwater wells within the Christina Lake watershed should be combined with existing water licenses and quantities utilized for surface water and their impacts assessed cumulatively and in relation to Global Climate Change.

Lake Foreshore

A fluorometry study is recommended to identify possible nutrient inflows from shoreline land use. Conductivity, pH, nutrients and bacteriology samples will aid in assessing areas with perceived hits from fluorescence monitoring. This will provide a means of identifying new areas of concern and reconfirm hot spots that were identified previously in the 1978 study.

Lake Macrophytes

Aerial photography of the lake is recommended once every 5 years to assess the expansion of the macrophyte beds present in Christina Lake. The Eurasian Water Milfoil study should be continued to monitor, map and eradicate Eurasian water milfoil within the lake. Ideally, community members could be involved in the identification, mapping, and removal of the Eurasian water milfoil population.

Lake Sediments

Lake sediment monitoring is recommended to aid in identifying possible contaminants entering the lake. Such contaminants include oils and greases from motorboat activities and pesticides and herbicides potentially used on the surrounding agricultural lands, and residences. Future sediment sampling should continue at minimum at the South Basin site. Sediment samples should be analyzed at minimum for phosphorus, nitrogen, hydrocarbons, and pesticides.

Soil Holding Capability and Groundwater Monitoring

Soil holding capability could be assessed to outline the variability of soils along the shoreline. This information, along with residential dwelling locations, aids in determining the best site for monitoring groundwater inflows. Groundwater sampling could be incorporated to determine if it is causing a significant nutrient input to the lake.

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Appendices

Year	Month	TP	TDP	TN	KN	NO3	NH3	N: P
1973	May	6					<10	
1978	April	6	<3		95		8	16:1
1981	April	8	5.5	55	55		16	7:1
1983	March	9.5	5	140	140		<5	15:1
1984	April	10.5	5	120	70	<20	<5	11:1
1986	April	8	3		70		<5	9:1
1988	April	7.5	3.5		105		<5	14:1
1990	March	3	<3		90		<5	30:1
1991	May	4	<3	55	50		<5	14:1
1992	May	4	<3	95	90		6.5	39:1
1993	March	4	3	120	90		5	24:1
1994	March	5	4	110	110		5	30:1
1995	April	3	3	110	90		<5	22:1
1996	April	16	17	90	100		<5	37:1
1997	March	14	13.5	90			5	6:1
1998	March	12	9	85			5	6:1
1999	March	13	10.5	130			5	10:1
2000	April	16	12.5	75			5	5:1
2001	April	8.5	6.5	110			5	13:1
2002	March	4.5	3.5	80			5	18:1
2003	April	5.5	5.5	95	85		5	17:1
2004	May	4	2.5	85	80		5	21:1
2006	April	4	4	117	117			32:1

Appendix 1 Annual nutrient levels at spring overturn for the South Basin site (ug/L)1

Year	Month	TP	TDP	TN	KN	NO3	NH3	N:P
1991	May	3.5	<3		55	<5	5.5	16:1
1992	April	4	<3		80	<4	<5	20:1
1993	May	3	5	100	80		8	33:1
1994	April	4	3	100			5	25:1
1995	March	7		85				12:1
1996	April	13.5	15.5	80			<5	6:1
1997	April	16	13.5	70				4:1
1998	March	12	8.5	120			7	10:1
1999	March	13	10	100			5	8:1
2000	March	13	13	75			5	5:1
2001	April	8	5.5	110			5	14:1
2002	April	5	5.5	80			5	16:1
2003	March	4	2.5	90	85			23:1
2004	April	3		90	85			30:1
2006	May	2	<2	70	70			35:1

Appendix 2 Annual nutrient levels at spring overturn for the North Basin site2.

			May 5 1992		**June 3 1992**		**July 8 1992**		**April 4 2006**		**June 22 2006**	
Group	**Order**	**Species**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
Green	Chlorococcale	Ankistrodesmus sp.			4	1	3	2	3		8	1
Green		Ankistrodesmus falcatus	5	2								
Green		Botryococcus braunii			127	48						
Green		Crucigenia crucifera									3	
Green		Crucigenia tetrapedia							3		3	
Green		Crucigenia sp.					1	1				
Green		Dictyosphaerium									3	
Green		Elakatothrix gelatinosa	1	1					3			
Green		Elakatothrix sp.			8	3	1	1				
Green		Lagerheimia sp.									3	
Green		Nephrocytium limneticum	19	9			34	23			3	
Green		Nephrocytium sp.			3	1						
Green		Oocystis sp.			5	2					3	
Green		Pediastrum					1	1				
Green		Selenastrum sp.							3			
Green		Sphaerocystis schroeteri	25	11	6	2	1	1				
Green		Tetraedron									3	
Green	Ulothricales	Ulothrix sp.							3		6	1
Green	Volvocales	Chlamydomonas sp.									3	
Green		Eudorina elegans							3		22	2
Green		UID							11	2	11	1
Green	Zygnematales	Arthrodesmus sp.							3		3	
Green		Cosmarium									3	
Green		Spondylosium planum							6	1	3	
Chrypto	Cryptomonadales	Chroomonas acuta	10	5	11	4	10	7	8	1	28	3
Chrypto		Cryptomonas ovata									3	
Chrypto		Cryptomonas sp.	1	1	1		1	1	3		6	1
Chryso	Dinokontae	Ceratium hirundinella									3	
Chryso		Dinoflagellate										
Chryso		Peridinum inconspicuum									11	1
Chryso		Peridiumun sp.	3	1			1	1			3	
Chryso		Peridiumn/Glenodinium							3			
Chryso	Ochromonadales	Dinobryon bavaricum	3	1	27	10			3		50	5
Chryso		Dinobryon divergens	43	19	17	6					510	53
Chryso		Dinobryon of sertularia							3			
Chryso		Dinobryon sp.					1	1	3		45	5
Chryso		Mallomonas sp.	4	2	1		1	1			3	
Chryso		Synura uvella							3			
Chryso	Rhizochrysidales	Diceras phaseolus									3	

Blue-greens	Oscillatoriales	Lyngbya limnetica							507	79	134	14
Blue-greens		Lyngbya Subtilis			13	5						
Blue-greens		Oscillatoria									3	
Blue-greens	Nostocales	Anabaena			1				3		3	
Diatom	Pennales	Achnanthes minutissima							3		3	
Diatom		Achnanthes sp	1	1	1							
Diatom		Amphora ovalis							3			
Diatom		Amphora sp			1							
Diatom		Asterionella sp			1		1	1				
Diatom		Asterionella formosa	34	15					8	1	56	6
Diatom		Ceratoneis arcus			1				3			
Diatom		Cocconeis placentula							3			
Diatom		Cocconeis sp.	1	1	1				3			
Diatom		Cymbella sp.	1	1							3	
Diatom		Diatoma elongatum							3		3	
Diatom		Diatoma sp.							3			
Diatom		Diploneis sp.?							3			
Diatom		Epithemia turgida							3			
Diatom		Epithemia									3	
Diatom		Eunotia sp.							3			
Diatom		Fragilaria construens			1							
Diatom		Fragilaria crotonensis	1	1					8	1		
Diatom		Fragilaria spp.					1	1	3		6	1
Diatom		Fragilaria pinnata			4	1						
Diatom		Gomphonema spp.	1	1			1	1	3			
Diatom		Meridion circulare							3			
Diatom		Navicula spp.	1	1	1				3		3	
Diatom		Nitzschia sp.			1				3			
Diatom		Pimularia									3	
Diatom		Pleurosigma/Gyrosigma							3			
Diatom		Rhopalodia					1	1	3			
Diatom		Synedra ulna							3			
Diatom		Synedra spp.	6	3	5	2	1	1	3		3	
Diatom		Synedra acus										
Diatom		Tabellaria fenestrata							3		3	
Diatom		Tabellaria flocculosa									3	0
Diatom		Tabellaria sp	1	1	1							
Diatom	Centrales	Cyclotella sp	1	1					3		3	0
Diatom		Melosira sp							22	3		
Diatom		Melosira Italica	62	28	25	10	94	62				
		Totals	222		263		151		645		963	

Appendix 3 Summary of 1992 and 2006 phytoplankton data from South Basin site in percent and cells/mL.