Okanagan Lake Collaborative Monitoring Agreement
2011-2014 Sampling Program Synthesis Report

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Prepared for BC Ministry of Environment, Environmental Protection Division

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Executive Summary

The British Columbia Ministry of Environment commissioned a collaborative monitoring program to sample Okanagan Lake monthly at four locations from 2011 to 2014. The purpose of this program was to increase the temporal resolution of water quality data for Okanagan Lake, specifically with the goal of determining trends in nutrient and biological data. Physical metrics such as temperature and dissolved oxygen throughout the water column were measured as well as several chemical parameters including silica, nitrogen, and phosphorus. Biological data ranging from biomass to specific taxonomic identification was also collected.

Physical

Okanagan Lake experienced thermal stratification each year. Dissolved oxygen in the deep water of the Armstrong Arm fell below the water quality objective each summer. Surface dissolved oxygen concentrations decreased from 2011-2014 at all four sample sites on Okanagan Lake. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. The Armstrong Arm secchi depth averaged only 3.4±0.8 m and failed to meet the objective on all dates from 2011-2014. Water clarity was highest at Okanagan Centre averaging 8.2±3.0 m.

Chemical

Silica concentrations were similar throughout the lake averaging between 6.80 and 6.92 mg/L at the four sample sites. Silica decreased from spring to fall each year at the southern three sites but increased from spring to fall in the Armstrong Arm. Silica also decreased year-over-year at all four sites. Dissolved nutrient concentrations were higher in the hypolimnion than the epilimnion of Okanagan Lake during 2011-2014. Total nitrogen averaged 0.25±0.09 mg/L in Okanagan Lake and frequently exceeded the water quality objective at all sites. Total nitrogen increased only in the Armstrong Arm from 2011-2014. Nitrate decreased each year from spring to fall in response to algae activity at the three southern sites. Total nitrogen also increased from spring to fall each year in the Armstrong Arm. Total phosphorus averaged 0.007±0.005 mg/L in Okanagan Lake and dissolved phosphorus increased at all sites from 2011-2014. The Armstrong Arm exceeded the objective in 38% of surface samples. Most samples from the three southern sites achieved the N:P objective but high phosphorus concentrations in the Armstrong Arm resulted in 50% of those samples exceeding the objective.

Biological

Chlorophyll-a was used as a measure of photosynthetic activity in Okanagan Lake. There was an increasing south to north trend in the chlorophyll-a data. Chlorophyll-a averaged from 1.50±0.77 µg/L at Summerland in the south end of the lake to 2.64±1.06 µg/L at the north end of the lake in the Armstrong Arm. All samples achieved the

objective for chlorophyll-a. Chlorophyll-a varied widely throughout the year from a low in March of 0.85±0.27 µg/L to a high in May of 2.89±1.41 µg/L, with the later caused by an annual spring diatom bloom. There were no noticeable year-over-year trends in the chlorophyll-a data. The rest of the biological data (biomass and taxonomy of phytoplankton and zooplankton) was sampled at the Kelowna and Summerland sites only. Phytoplankton biomass averaged 0.0357±0.0578 g/m³ at Kelowna and 0.0223±0.0307 g/m³ at Summerland. The difference between these two sites was not statistically significant, however biomass increased year-over-year at both sites from 2012-2014. Diatoms and cyanobacteria numerically dominated phytoplankton counts. April 2014 counts were much larger than any other sample to date; the reason is unclear. 20% of samples exceeded the phytoplankton taxonomic objective. Zooplankton biomass was well below the objective in all but one sample, averaging 0.0111±0.0113 g/m³ at Kelowna and 0.0084±0.0123 g/m³ at Summerland. Zooplankton biomass also increased year-over-year at both sites from 2012-2014. 46% of samples met the zooplankton taxonomic objective.

Areas of concern

Through this report, we have identified several areas or concern where the Ministry of Environment may wish to pursue further action. These include:

- The secchi depth in the Armstrong Arm was below the objective on all dates from 2011-2014.
- Dissolved oxygen concentrations decreased at all sites from 2011-2014.
- Total nitrogen concentrations frequently exceeded the objective at all sites.
- Total nitrogen and total phosphorus increased in the Armstrong Arm from 2011-2014.
- Dissolved phosphorus increased at all sites from 2011-2014.

Recommendations

We recommend that the existing collaborative monitoring program be renewed for another three year term with some modifications to address the areas of concern. As a part of the funding for the sampling program, we recommend additional funding be secured to re-evaluate trends in the collaborative data against the entire long-term data base on Okanagan Lake. The next report should include the complete MoE dataset to increase the accuracy of the trend analyses. Additionally, it would be valuable to add chloride to the list of parameters analysed during the next term because it provides an estimate of human impacts on aquatic systems.

Potential actions to address areas of concern identified in this study could also include working to increase riparian protection, particularly in the Armstrong Arm and building a nutrient loading profile for Okanagan Lake. This would involve a large sampling and hydrometric involving the major creeks and human point source inputs to Okanagan Lake. A nutrient loading profile would identify the nutrient sources and rank their respective impacts on Okanagan Lake. MoE should work with the municipalities to continue to reduce the nutrient concentrations in treated effluent.

When budget can be obtained to compare the results of the Collobarative monitoring with the entire MoE database on Okanagan Lake, those results could be used to revisit the objectives and reset them with increased accuracy (Table below).

Summary of trends and the water quality objectives for Okanagan Lake collaborative sampling program. Modified from Nordin 2005.

Objective	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth	🟩 -	🟩 -	🟩 -	🟥 -
Dissolved Oxygen	⬜ ↓	⬜ ↓	⬜ ↓	🟥 ↓
TP (mg/L)	🟩 ↑	🟩 -	🟩 -	🟨 ↑
Chlorophyll-a (µg/L)	🟩 -	🟩 -	🟩 -	🟩 -
TN (mg/L)	🟥 -	🟥 -	🟥 -	🟨 ↑
N:P Ratio	🟩 -	🟩 -	🟩 -	🟨 ↓
Algae Taxonomy (% heterocystous cyanobacteria)	🟩 -	🟩 -	⬜	⬜
Algae Biomass (g/m³)	🟩 ↑	🟩 ↑	⬜	⬜
Zooplankton Biomass (g/m³)	🟥 ↑	🟥 ↑	⬜	⬜
Zooplankton Taxonomy (% cladocerans)	🟨 -	🟨 -	⬜	⬜

Legend:

🟩	🟨	🟥	⬜
Always/often achieved objective	Occasionally achieved objective	Never/rarely achieved objective	No Data/ No Objective

↑ = Increasing Trend
↓ = Decreasing Trend
- = No Trend

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Disclaimer: This report is based on research on complex lake systems. Larratt Aquatic Consulting Ltd and its associates have taken necessary steps to ensure accuracy of the information contained within it. No liability is incurred by LAC or the Ministry of Environment for accidental omissions or errors made in the preparation of this report.

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Definitions

The following terms are defined as they are used in this report.

Term	Definition
Algae bloom	A superabundant growth of algae
Anaerobic/anoxic	Devoid of oxygen
Benthic	Organisms that dwell in or are associated with the sediments
Bioavailable	Available for use by plants or animals
Chlorophyll-a	Primary photosynthetic pigment in algae; used as a measure of photosynthetic activity
Cyanobacteria	Bacteria-like algae having cyanochrome as the main photosynthetic pigment
Diatoms	Algae that have hard, silica-based "shells" frustules
Fall overturn	Surface waters cool and sink, until a fall storm mixes the water column
Eutrophic	Nutrient-rich, biologically productive water body
Green algae	A large family of algae with chlorophyll as the main photosynthetic pigment
Light attenuation	Reduction of sunlight strength during transmission through water
Limitation,nutrient	A nutrient will limit or control the potential growth of organisms e.g. P or N
Limnology	The study of the physical, chemical, and biological aspects of freshwater
Littoral	Shoreline between high and low water; the most productive area of a lake
Macronutrient	The major constituents of cells: nitrogen, phosphorus, carbon, sulphate, H
Micronutrient	Small amounts are required for growth; Si, Mn, Fe, Co, Zn, Cu, Mo etc.
Microflora	The sum of algae, bacteria, fungi, *Actinomycetes,* etc., in water or biofilms
Monomictic	“One Mixing”: Describes lakes that are thermally stratified in summer and mixed in winter
Myxotrophic	Organisms that can be photosynthetic or can absorb organic materials directly from the environment as needed
Peak biomass	The highest density, biovolume or chl-a attained in a set time on a substrate
Periphyton	Algae that are attached to aquatic plants or solid substrates
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Photic Zone	The zone in a water body that receives sufficient sunlight for photosynthesis
Plankton	Those organisms that float or swim in water
Reclamation	A restoration to productivity and usefulness
Redox	The reduction (-ve) or oxidation (+ve) potential of a solution
Reducing env.	Devoid of oxygen with reducing conditions (-ve redox) eg. swamp sediments
Residence time	Time for a parcel of water to pass through a reservoir or lake (flushing time)
Riparian	The interface between land and a stream or lake
Secchi depth	Depth where a 20 cm secchi disk can be seen; measures water transparency
Seiche	Wind-driven tipping of lake water layers in the summer, causes oscillations
Thermocline	The lake zone of greatest change in water temperature with depth (> 1^{o}C/m); it separates the surface water (epilimnion) from the cold hypolimnion below
Zooplankton	Minute animals that graze algae, bacteria and detritus in water bodies

Term	Definition
Chl-a	Chlorophyll-a units µg/L
DO	Dissolved oxygen units mg/L
N	Nitrogen units mg/L as N
Ortho-P	Orthophosphate ≈ SRP monomeric inorganic phosphorus units mg/L as N
P	Phosphorus units mg/L as P
MoE	British Columbia Ministry of Environment
DIN	Dissolved inorganic nitrogen = ammonia + nitrate + nitrite units mg/L as N
TDN	Total dissolved nitrogen = ammonia + nitrate + nitrite + dissolved organic N units mg/L as N
TDP/DP	Total dissolved phosphorus units mg/L as P
TN	Total nitrogen: organic + dissolved units mg/L as N
TP	Total phosphorus: organic + dissolved units mg/L as P

Lake Classification by Trophic Status Indicators (Nordin, 1985)

Trophic Status	chlorophyll-a ug/L	Total P ug/L	Total N ug/L	Secchi disc m	primary production mg C/m^2/day
Oligotrophic	0 – 2	1 – 10	<100	> 6	50- 300
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	250 – 1000
Eutrophic	>5	> 20	500-1000	< 3	>1000

Nutrient Balance Definitions for Microflora (Dissolved Inorganic N : Dissolved Inorganic P) (Nordin,1985)

Phosphorus Limitation	Co-Limitation of N and P	Nitrogen Limitation
>15 : 1	<15 : 1 – 5 : 1	5 : 1 or less

Water Quality Objectives for Okanagan Lake – Nordin 2005

Objective	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth (growing season average)	6m	6m	7m	5m
Dissolved Oxygen (minimum in bottom waters)	-	-	-	>5 mg/L
TP (mg/L as P) (maximum at spring overturn)	0.008	0.008	0.007	0.01
Chlorophyll-a (µg/L) (maximum seasonal average)	4.5	4.5	4	5
TN (mg/L as N) (maximum at spring overturn)	0.230	0.230	0.230	0.250
N:P Ratio (spring weighted ratio)	>25:1	>25:1	>25:1	>25:1
Algae Taxonomy (% heterocystous cyanobacteria)	<5%	<5%	<5%	<5%
Algae Biomass (g/m^3) (growing season average)	<0.75	<0.75	<0.75	<0.75
Zooplankton Biomass (g/m^3) (minimum biomass)	>0.050	>0.050	>0.050	>0.050
Zooplankton Taxonomy (% cladocerans)	>5%	>5%	>5%	>5%

Statistics Overview

Statistical analysis were performed on data to support claims made throughout this report. The use of the word ‘significantly’ within this report is understood to signify that the claim being made has stood up under statistical analysis. Unless otherwise stated, all statistical analysis were performed to a confidence of greater than or equal to 95% ($p \leq 0.05$). The ± symbol indicates plus or minus the standard deviation throughout this report.

Water quality data often contains non-detect values for many parameters. Non-detect values were converted to ½ detection limit for all calculations.

Trends were determined through Mann-Kendall linear regression. Mann-Kendall is a non-parametric test for linearity in data. The test produces a Tau-value and a p-value. The Tau value gives the direction of the data and the p-value indicates whether the trend is statistically significant.

Throughout this report the monthly sampling data was grouped seasonally for additional analyses. March, April, and May data were combined as “Spring”; June, July, and August as “Summer”; and September as “Fall”.

Correlations were performed using the Pearson’s Correlation method and all R values reported at Pearson’s Correlation Coefficients.

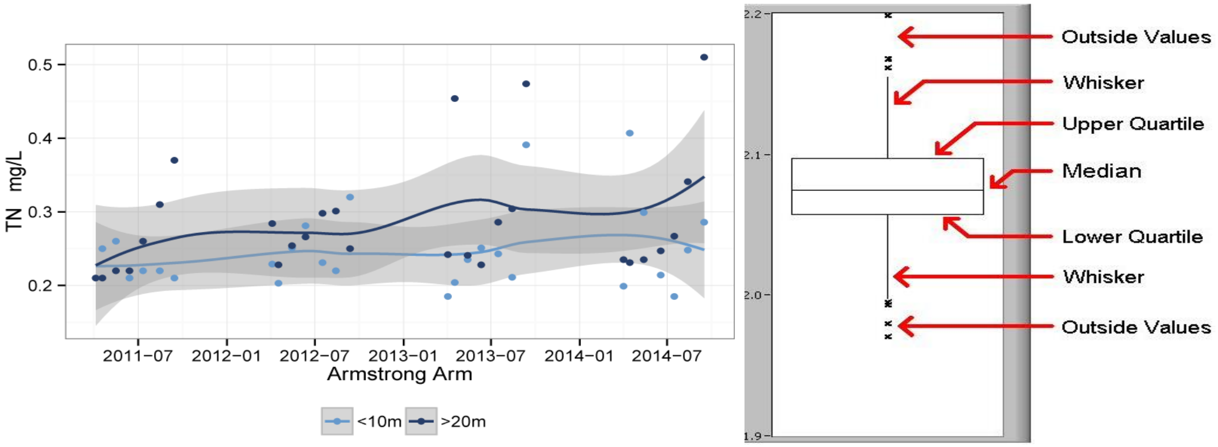


Figure i: Example scatterplot includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within 1.5 * IQR where IQR represents the range between the upper and lower quartiles.

1.0 Introduction

The British Columbia Ministry of Environment (MoE) in partnership with the City of Kelowna, the Regional District of Central Okanagan, and the District of Summerland began a seasonal sampling program on Okanagan Lake in 2011 to increase the temporal resolution of data being gathered. This program was performed collaboratively between MoE staff, Okanagan Nation Alliance (ONA; 2011), and Larratt Aquatic Consulting (2012-2014). Okanagan Lake was sampled monthly from March to September from 2011-2014 at four sites (Figure 1.1, Table 1.1).

Table 1.1: GPS coordinates of sampling sites

Site Name	Site Number	Latitude	Longitude
Summerland	0500454	49.600550°	-119.628030°
Kelowna	0500236	49.861350°	-119.513420°
OK Centre	0500730	50.089900°	-119.478270°
Armstrong Arm	0500239	50.315450°	-119.357180°

Sampling focused on three broad areas at each site: physical, water chemistry, and biological activity. Temperature and dissolved oxygen profiles were taken at each site on each date to build a composite image of temperature and oxygen in Okanagan Lake over time (Figure 2.1.1). Secchi depth, a measure of water clarity, was also recorded for each site.

In addition, a range of parameters were chemically analyzed from samples taken in the epilimnion (1-5-10 m composite) and the hypolimnion (20-32-45 m composite). Chemistry focused on the major nutrients in their various forms.

Biological sampling included basic parameters, such as the chlorophyll-a concentration and biomass, to detailed taxonomic classification of phytoplankton (algae) and zooplankton.

The 2011 – 2014 data were combined into a database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin 2005 (Appendix 1).

Figure 1.1: Okanagan Basin Watershed with four sampling locations identified. 1=Armstrong Arm, 2=Ok Centre, 3=Kelowna, 4=Summerland (Sokal, 2013).

2.0: Results & Discussion

2.1: Physical

2.1.1: Temperature and Dissolved Oxygen

Okanagan Lake is a deep monomictic lake. This means from May to November each year the surface water (epilimnion) is isolated from the deep water (hypolimnion) by a thermocline. The sun warms the epilimnion to over 20 °C each summer while water below 20 m only changes temperature by <4 °C (Figure 2.1.1).

The three southern sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal and dissolved oxygen behavior while the Armstrong Arm site is shallower and behaves differently. It reaches a higher surface temperature and experiences oxygen depletion in the deep water each summer (Figure 2.1.2). Oxygen depletion is caused by decomposition of organic material in the sediment of the lake. Thermal stratification breaks down each November and water freely circulates through the winter. There were no statistically significant trends in the 2011–2014 temperature data either annually, seasonally, or monthly.

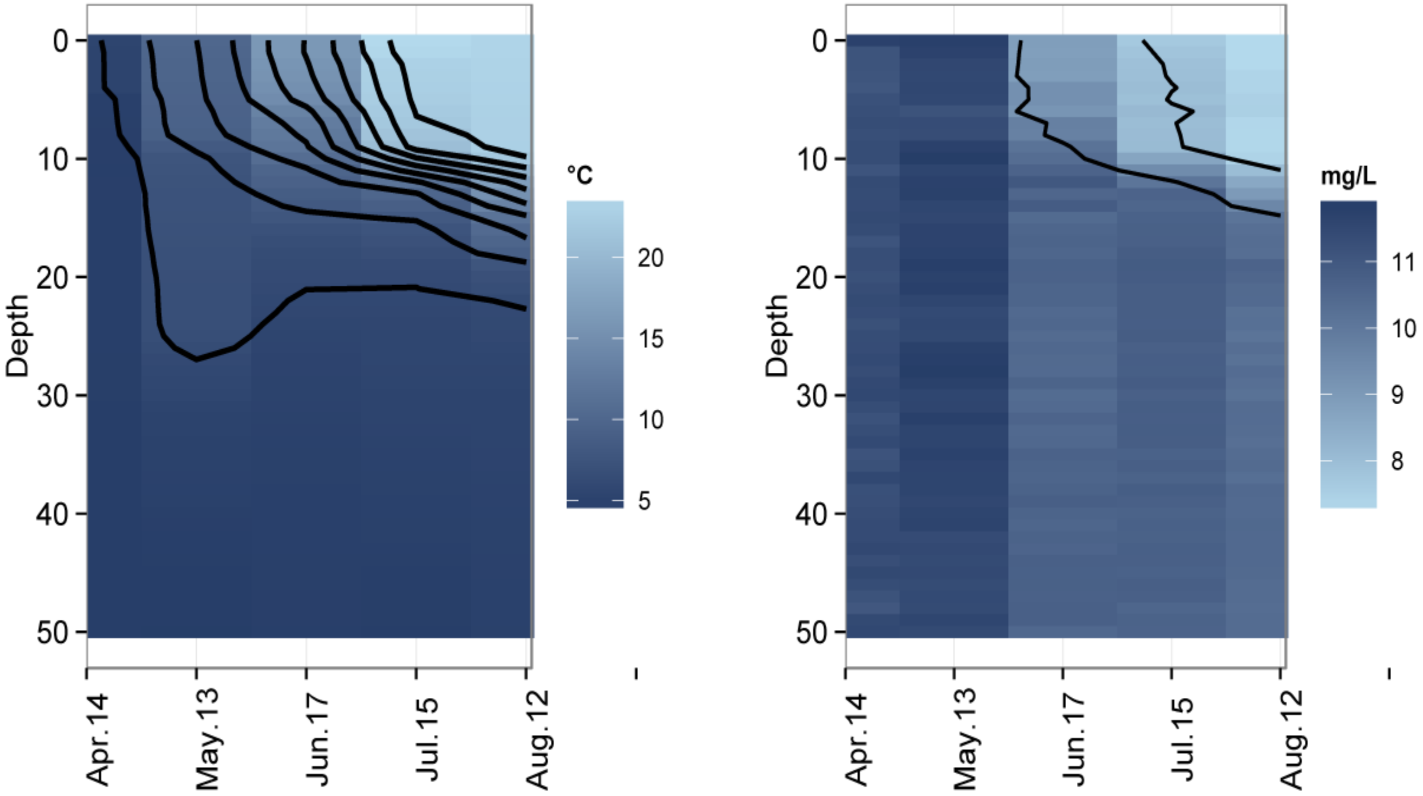


Figure 2.1.1: Temperature and dissolved oxygen profiles for Okanagan Lake at Summerland, 2014. Dissolved oxygen is high throughout the year in the deep water. Lines represent contours of same temperature or dissolved oxygen within the water column through time.

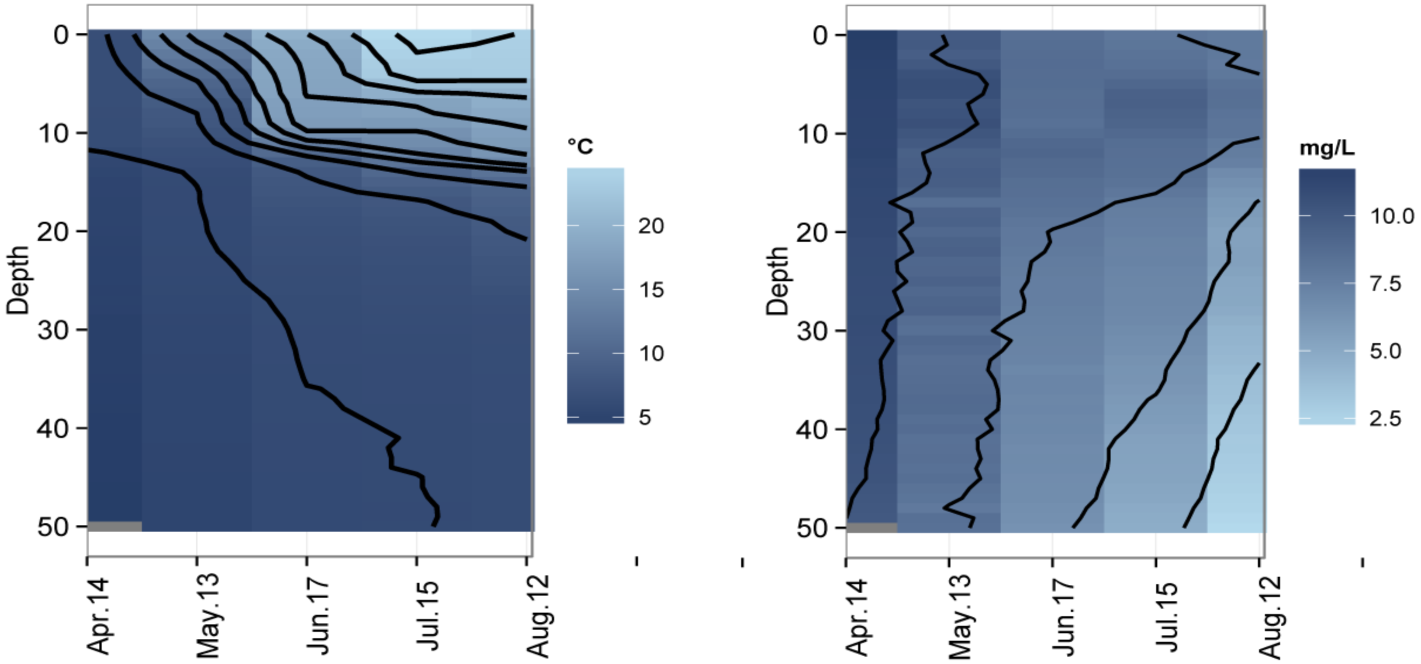


Figure 2.1.2: Temperature and dissolved oxygen profiles for Okanagan Lake at Armstrong Arm in 2014. Dissolved oxygen profile illustrates characteristic oxygen depletion in deep waters of the Armstrong Arm. Lines represent contours of same temperature or dissolved oxygen within the water column through time.

Surface dissolved oxygen concentrations vary throughout the year but have been trending downwards at all sites over the course of the collaborative sampling program (2011-2014; Figure 2.1.3; Mann-Kendall p averaged 0.01±0.007). Colder water has a greater capacity to carry dissolved oxygen than warmer water does, creating a negative correlation with temperature across all sites (R averaged -0.85±0.05), however, there were no significant trends in the temperature data. It is likely that the shift in dissolved oxygen was connected to temperature but the high variability in the temperature data masked any trends.

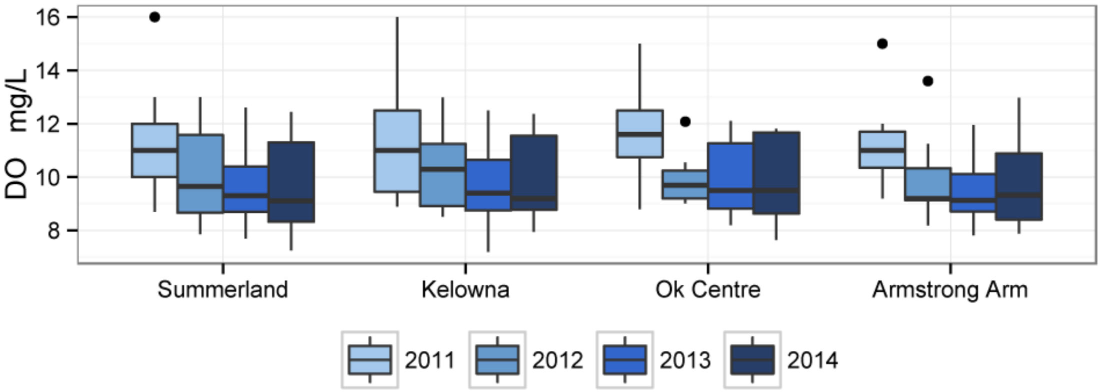


Figure 2.1.3: Surface dissolved oxygen concentrations at Okanagan Lake sampling sites grouped by year, 2011-2014

2.1.2: Water Clarity and Secchi Depth

Secchi depth ranged from a minimum of 1.7 m at Armstrong Arm in July 2011 to a maximum of 15.3 m at Okanagan Centre in March 2014 (Table 2.1.1). The average for Okanagan Lake historically has been 6.5-6.6 m (Andrusak et al., 2006; Nordin, 2005). Secchi depth followed a consistent pattern each year. Maximum secchi depths occurred in the late winter when biological activity was the lowest. During the spring algae bloom, the secchi depth dropped dramatically to the lowest of the year at all sites. As nutrients were used up, algae concentrations diminished and water clarity increased through the summer and into the fall (Figure 2.1.4). The secchi depth in the Armstrong Arm was much lower throughout the year than at the other sites. This is clearly illustrated in Figure 2.1.4. The secchi depth in Armstrong Arm did not meet the objective (>5 m) while the secchi did meet the objective (>6-7 m) at the other sites for all years in the study (Table 2.1.1). There were no statistically significant trends in the secchi depth data either annually, seasonally, or monthly.

Table 2.1.1: Secchi depth in meters at Okanagan Lake sampling sites, 2011-2014

Site	Objective	Average	StdDev	Max	Min
Summerland	7.0	1.0	7.8	13.4	3.2
Kelowna	6.0	2.0	7.4	12.7	2.6
Ok Centre	6.0	3.0	8.2	15.3	3.1
Armstrong Arm	5.0	4.0	3.4	4.9	1.7

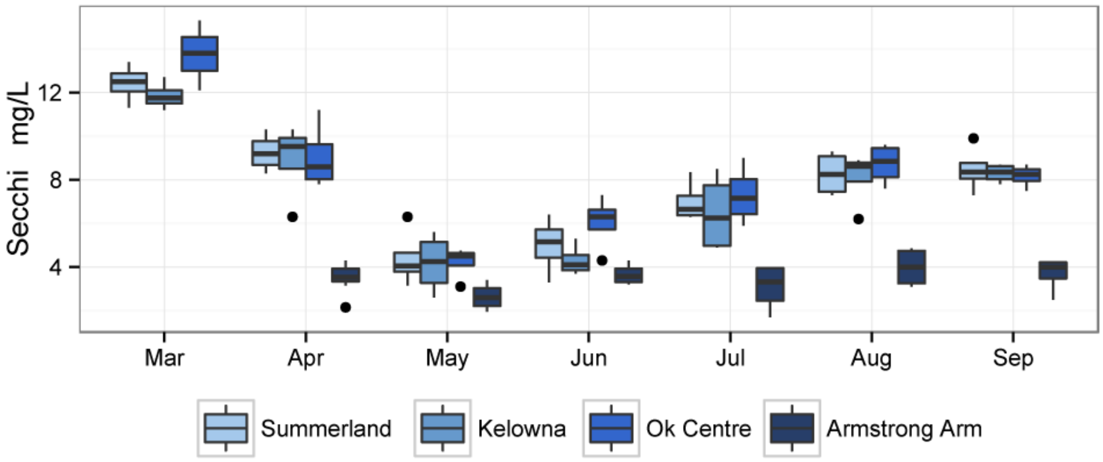


Figure 2.1.4: Monthly secchi depth at each of the sampling sites, 2011-2014. The Armstrong Arm of Okanagan Lake was frozen in March and was therefore not sampled.

2.2: Chemistry

Chemistry sampling focused on nitrogen and phosphorus, the most important aquatic nutrients, and silica, a key micronutrient. Increasing nutrient trends are frequently the result of human activities such as sewage effluent disposal, riparian degradation, agriculture, fertilizer use, storm water, etc. These human-caused impacts are gradual and are easiest to detect as year-over-year trends. As the database grows, it will become easier to separate weather impacts from human impacts.

2.2.1: Silica

Diatoms, a major group of algae in Okanagan Lake, use silica as a structural building block. Silica was not significantly different between the four sites but decreased year-over-year at the three southern sites from 2011-2014 (Table 2.2.1; Figure 2.2.2; Mann-Kendall p averaged 0.005±0.009). Silica concentration in the Armstrong Arm behaved differently from the rest of the lake. At the three southern sites, silica decreased from 7.18±0.64 mg/L in spring to 6.58±0.41 mg/L in summer in response to consumption by the spring diatom bloom (Figure 2.3.4) but silica increased each year from spring to fall in the Armstrong Arm (Figure 2.2.2; T-Test p=0.001). The reason for this difference is not clear from the available data but may indicate that a different algae community exists in the Armstrong Arm than in the rest of Okanagan Lake.

Silica correlated positively with dissolved oxygen and negatively with temperature at Kelowna (R=0.71, R= -0.67) and Summerland (R=0.67, R= -0.63) but not Ok Centre or the Armstrong Arm. Temperature and DO function as proxies for season in this case. Silica was higher in the winter months because biological activity was lower and because some silica is replenished by groundwater inflows and by algal decomposition.

Table 2.2.1: Silica concentration in mg/L at Okanagan Lake sampling sites, 2011-2014

Site	Average	StdDev	Max	Min
Armstrong Arm	6.80	1.17	9.71	2.99
Kelowna	6.92	0.63	9.79	5.83
Ok Centre	6.75	0.65	9.96	5.79
Summerland	6.85	0.48	8.00	5.75

Zooplankton concentrations appeared closely related to the concentration of silica in the lake (Figure 2.2.1). This was likely due to complex interactions between zooplankton feeding patterns and algae growth patterns. The correlation coefficient was only R=0.39 suggesting other factors were involved.

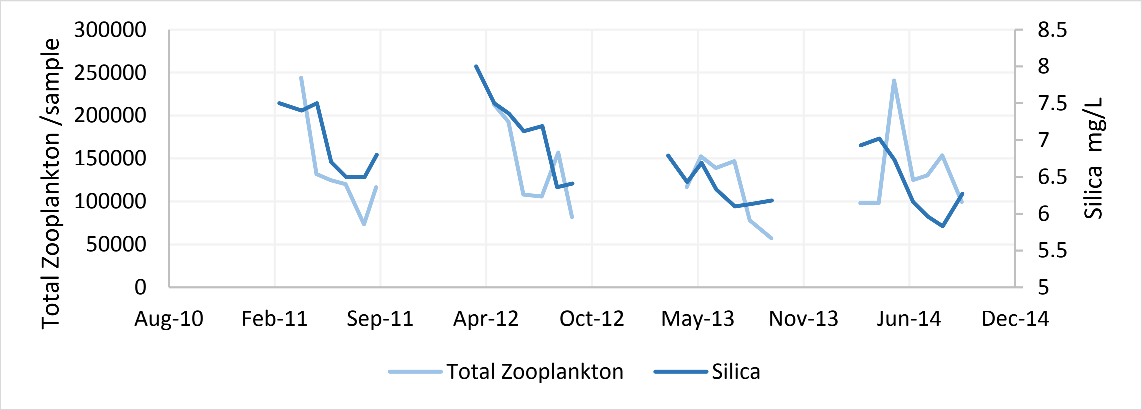


Figure 2.2.1: Zooplankton concentration compared to silica concentration at Kelowna, 2011-2014

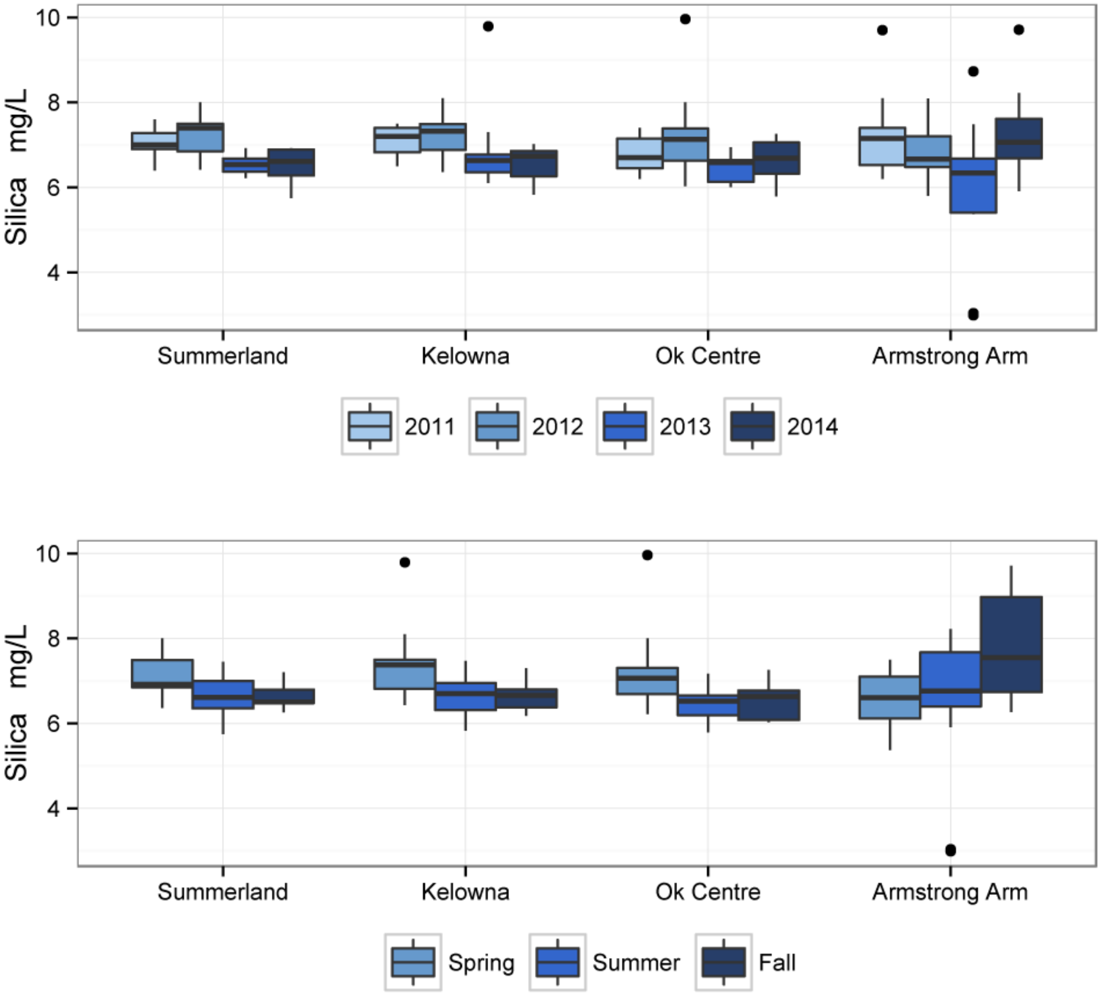


Figure 2.2.2: Silica concentration in Okanagan Lake at each sampling site group by year (top) and season (bottom), 2011-2014

2.2.2: Nitrogen and Phosphorus

Nitrogen and phosphorus are the most important nutrients in most aquatic environments. Phosphorus is the limiting nutrient in the Okanagan and its concentration is directly linked to the amount of algae that the lake produces (Nordin, 2005).

Nitrogen

Total nitrogen (TN) averaged 0.25±0.09 mg/L as N in Okanagan Lake from 2011-2014 (Table 2.2.1). The objective for Okanagan Lake was set as a spring value (March for three southern sites and April for the Armstrong Arm) of 0.230 mg/L for the main basins and 0.250 mg/L for the Armstrong Arm. The objectives were not exceeded in 2011 but were exceeded at all sites in 2012 and 2013. Only Summerland did not exceed in 2014. There were, however, no trends in the nitrogen data for the three southern sites from 2011-2014. TN increased from 0.241±0.047 mg/L in 2011 to 0.279±0.088 mg/L in 2014 (14% increase) in the Armstrong Arm (Mann-Kendall p=0.02). TN also increased each year from spring to fall in the Armstrong Arm (Figures 2.2.4; T-Test p=0.001). There were no year-over-year trends in any of the other nitrogen species. TN was not statistically different between the epilimnion and hypolimnion (2011-2014; T-Test, p=0.07) but there was a difference in nitrate (T-Test, p<0.001). Nitrate correlated negatively to temperature and positively to dissolved oxygen at the three southern sites (R= -0.85±0.08 and R=0.70±0.10 respectively). As with silica, temperature and dissolved oxygen are functioning as indicators for seasonal changes to certain nitrogen species associated with biological activity in the lake. Nitrate is rapidly consumed by algae in the spring and thermal stratification prevents replenishment with the deeper water during the summer (Figure 2.2.3). Average TN values were comparable to those found in the literature (0.17-0.23 mg/L as N; Andrusak et al.,2000).

Table 2.2.1: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2011-2014

Site	Depth	Objective	% Exceeding	Average	StdDev	Max	Min
Summerland	<10m	0.23	50%	0.243	0.083	0.588	0.120
	>20m		25%	0.234	0.064	0.340	0.030
Kelowna	<10m	0.23	50%	0.237	0.062	0.502	0.130
	>20m		75%	0.271	0.153	0.968	0.100
Ok Centre	<10m	0.23	75%	0.240	0.094	0.705	0.180
	>20m		75%	0.240	0.040	0.342	0.190
Armstrong Arm	<10m	0.25	13%	0.245	0.055	0.407	0.185
	>20m		25%	0.285	0.079	0.510	0.210

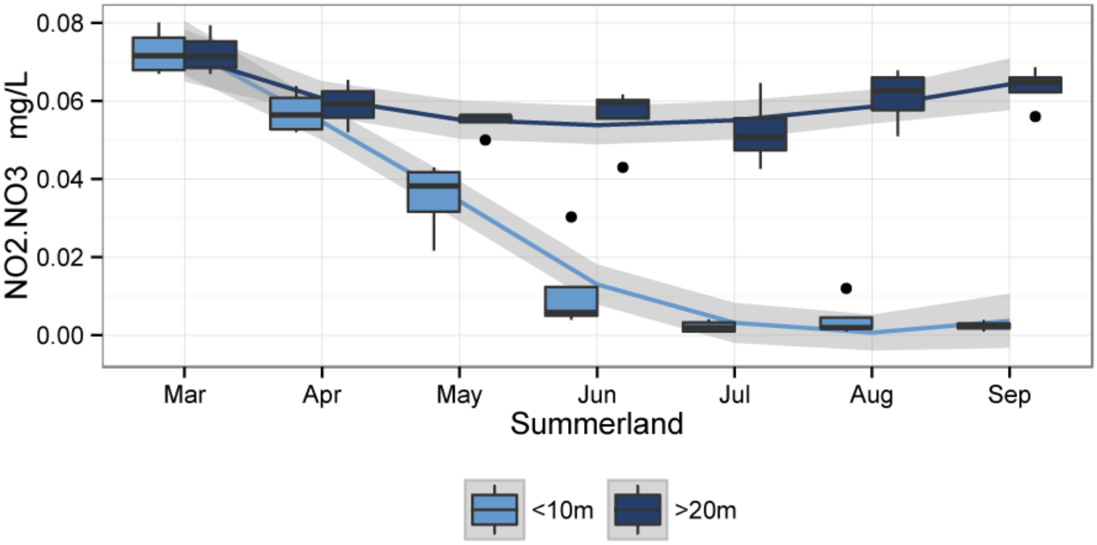


Figure 2.2.3: Inorganic nitrogen species in mg/L as N in the surface and deep water of Okanagan Lake at Summerland by month, 2011-2014

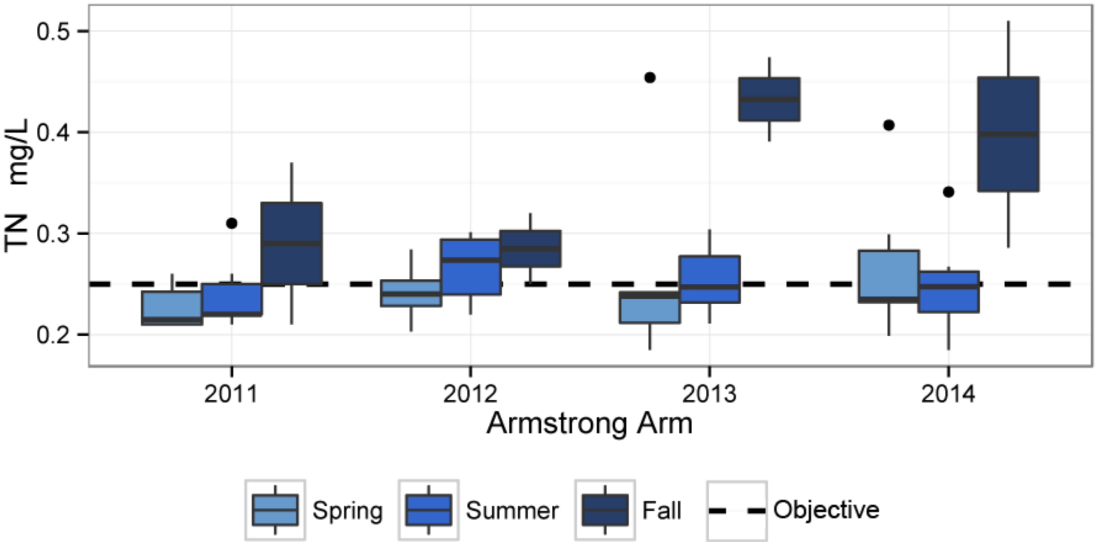


Figure 2.2.4: Total nitrogen in mg/L as N in the Armstrong Arm of Okanagan Lake grouped by season, 2011-2014 (hashed line = Armstrong Arm objective)

Phosphorus

TP measures all forms of phosphorus including those that may not be bioavailable. Total phosphorus (TP) averaged 0.007±0.005 mg/L as P across Okanagan Lake from 2011-2014 (Table 2.2.2). These data were similar to previous studies that indicate a typical range for TP of 0.004-0.010 mg/L (Andrusak et al., 2006). The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at the spring overturn (Nordin, 2005; taken as March for the three southern sites and April for the Armstrong Arm). It ranged from 0.007 mg/L in the south basin to 0.010 mg/L in the Armstrong Arm. The Kelowna site exceeded its objective in 2014 in the hypolimnion sample. TP increased in the Armstrong Arm from 2011 to 2014 (Mann-Kendall p=0.008) and the number of samples exceeding the objective has also increased. All four sample sites in April 2014 exceeded their objective. Phosphorus concentrations were higher in the hypolimnion than the epilimnion (2011-2014; T-Test, p=0.01). This is the normal condition of stratified lakes because P is consumed by microflora in the surface waters and P is released by decomposers in the hypolimnion and substrates.

Table 2.2.2: Total phosphorus in mg/L as P concentration at Okanagan Lake sampling sites, 2011-2014

Site	Depth	Objective	% Exceeding	Average	StdDev	Max	Min
Summerland	<10m	0.007	0%	0.005	0.001	0.008	0.002
	>20m		0%	0.004	0.001	0.006	0.003
Kelowna	<10m	0.008	0%	0.006	0.003	0.014	0.003
	>20m		25%	0.005	0.003	0.011	0.002
Ok Centre	<10m	0.008	0%	0.005	0.002	0.011	0.003
	>20m		0%	0.004	0.001	0.007	0.002
Armstrong Arm	<10m	0.010	38%	0.008	0.003	0.015	0.003
	>20m		75%	0.017	0.008	0.036	0.003

Dissolved phosphorus (DP) measures the more bioavailable forms of phosphorus and is a better indicator of potential impacts to biota. Dissolved phosphorus increased from 2011-2014 across all sites (Figure 2.2.5; Mann-Kendall p averaged 0.004±0.006). Ortho-P measures only the soluble reactive phosphorus fraction of the DP. There were no statistically significant trends in ortho-phosphate data.

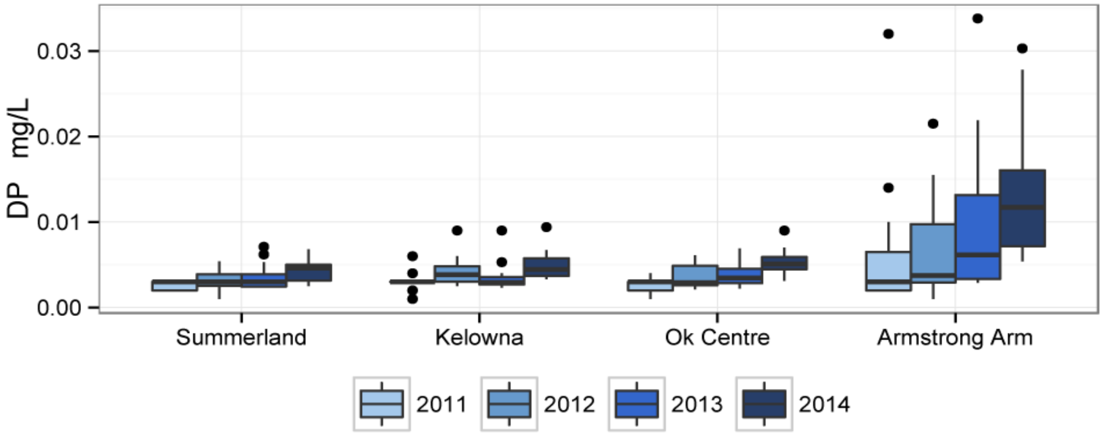


Figure 2.2.5: Dissolved phosphorus in Okanagan Lake at the four sampling sites by year, 2011-2014

N:P Ratio

The ratio of nitrogen to phosphorus is a key factor in determining which types of phytoplankton will proliferate. Many species of cyanobacteria can fix atmospheric nitrogen and are therefore limited primarily by available phosphorus. These algae are more likely to bloom when phosphorus is abundant relative to nitrogen. The Okanagan Lake objective for the spring ratio of nitrogen to phosphorus is >25:1 (Samples from March for the three southern sites and April for the Armstrong Arm). All but one sample from Summerland and Kelowna met the objective while those from Okanagan Centre were always above the objective. The Armstrong Arm had higher phosphorus concentrations than the rest of Okanagan Lake and did not meet the objective in 50% of spring samples (Figure 2.2.5, Table 2.2.3). The N:P ratio decreased in the Armstrong Arm from 2011-2014 (Mann-Kendall, p=0.02). The N:P ratios obtained in this study were higher than those obtained in previous studies with Nordin (2005) citing an Okanagan Lake average of 28:1.

Table 2.2.3: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2011-2014

Site	TN	TP	Avg Ratio	Objective	% Exceeding
Summerland	0.198	0.0040	51:1	25:1	13%
Kelowna	0.233	0.0048	58:1	25:1	13%
Ok Centre	0.248	0.0048	53:1	25:1	0%
Armstrong Arm	0.249	0.0102	31:1	25:1	50%

2.3 Biology

2.3.1 Phytoplankton

Phytoplankton and zooplankton samples were taken only at the Summerland and Kelowna sites. Biomass analysis and taxonomic identification were performed on samples from both sites. Chlorophyll-a concentrations were monitored at all sites as a productivity metric for phytoplankton abundance. Armstrong Arm is shallower and therefore would produce more phytoplankton and zooplankton than the deep basins of Okanagan Lake regardless of human activity

Chlorophyll-a

Chlorophyll-a is the primary photosynthetic pigment in most freshwater algae species (Felip and Catalan, 2000), and in most photosynthetic bacteria. As expected, chlorophyll-a followed an inverse trend to secchi depth (Figure 2.1.4). Chlorophyll-a was lowest in the late winter and peaked in April-May during the spring algae bloom before decreasing through the summer (Figure 2.3.1). Chlorophyll-a concentrations met the objectives for all sites in all years (Table 2.3.1). There was a north to south trend in the chlorophyll-a data with the Armstrong Arm having the highest and Summerland having lowest average concentrations. There were no statistically significant trends year-over-year in the chlorophyll-a data at any site. Average chlorophyll-a concentrations obtained during the collaborative study were lower than historical data found in the literature and may warrant additional investigation with the larger dataset (Andrusak et al., 2000; Nordin, 2005).

Table 2.3.1: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2011-2014

Site	Objective	Average	StdDev	Max	Min
Summerland	4	1.50	0.77	4.18	0.50
Kelowna	4.5	1.60	0.99	5.40	0.50
Ok Centre	4.5	1.71	1.15	5.30	0.25
Armstrong Arm	5	2.64	1.06	5.28	1.05

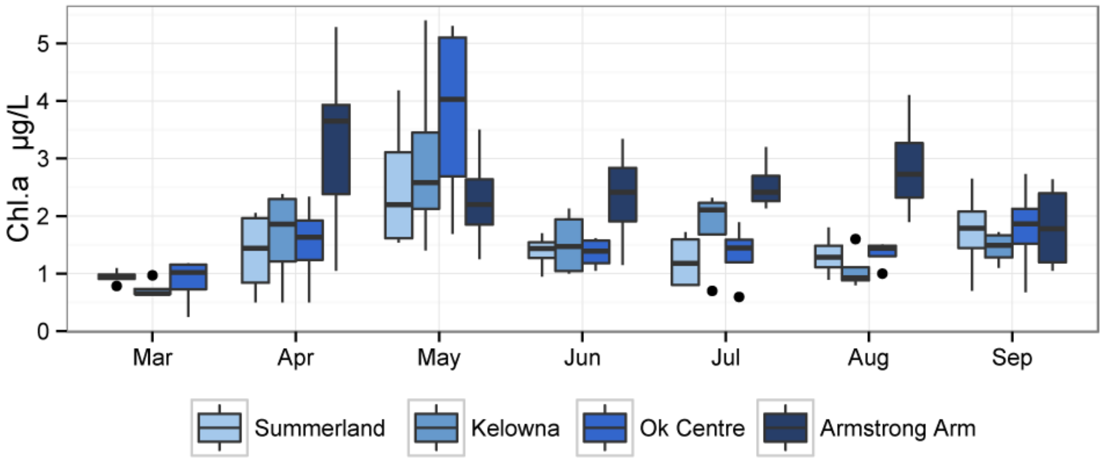


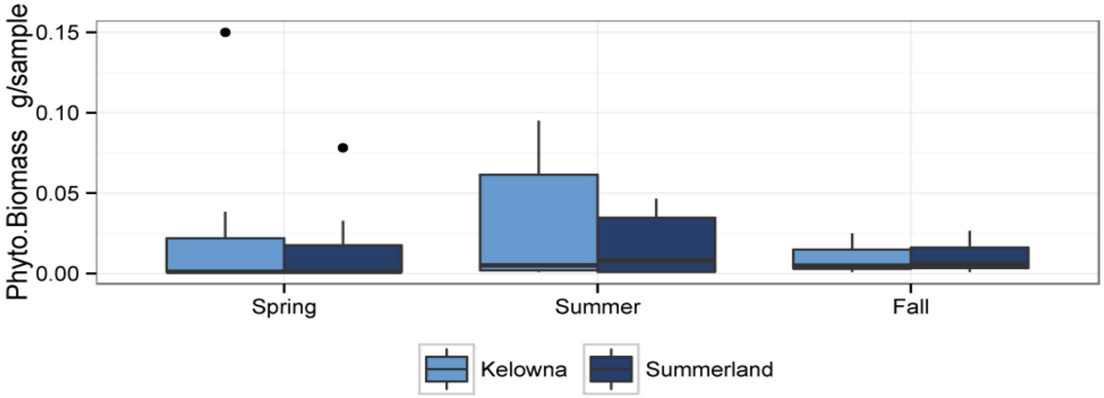
Figure 2.3.1: Monthly chlorophyll-a concentration at the four Okanagan Lake sampling sites, 2011-2014

Biomass

Phytoplankton biomass samples were collected using an 80 µm plankton net from 2012-2014. The net was pulled vertically from 10 m depth to the surface. This concentrated all the organisms in that column of water for ash-free dry mass analysis. Phytoplankton biomass was weakly correlated to zooplankton biomass (R=0.47) because the plankton net also captured any zooplankton within the 10 m water column. The mass obtained was converted to a concentration for comparison to the growing season objective of <0.75 g/m³ (Table 2.3.2). The objective was met at all times. Phytoplankton biomass trended upwards year-over-year due, in part, to very large results in 2014 (Mann-Kendall, p<0.001, Figure 2.3.2). This trend did not correlate well to either total algae counts (R=0.21) or chlorophyll-a (R= -0.07). The reason for this is not clear but may relate to increasing zooplankton biomass.

Table 2.3.2: Phytoplankton biomass in g/m³ at Okanagan Lake sampling sites, 2012-2014

Site	Objective	Average	StdDev	Max	Min	Trend	P-Value
Kelowna	<0.75	0.0357	0.0578	0.2122	0.0014	↑	<0.001
Summerland	<0.75	0.0223	0.0307	0.1106	0.0014	↑	<0.001



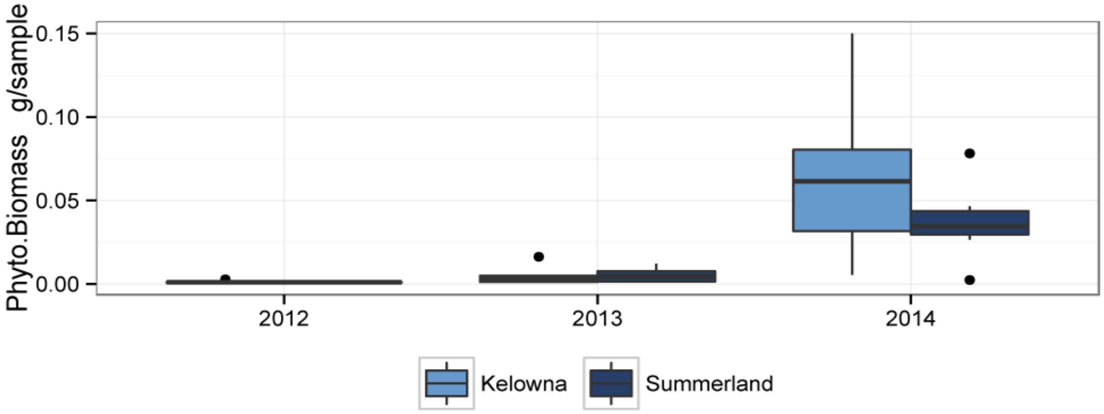


Figure 2.3.2: Algae biomass at the Kelowna and Summerland sampling sites by season (top) and by year (bottom), 2012-2014

Phytoplankton Taxonomy

Algae samples were identified to the species level and then grouped into broad algae types for analysis in this report. Figure 2.3.4 illustrates the major trends in phytoplankton taxonomy in Okanagan Lake. Diatoms bloomed in the spring and then faded as the summer progressed. Cyanobacteria were always numerous in Okanagan Lake but became most intense in the late summer and fall. Algae counts were exceptionally high in April 2014 reaching 207,314 cells/mL of diatoms and 123,393 cells/mL of cyanobacteria at Kelowna. The very high algae counts did not correspond to higher than expected chlorophyll-a or biomass concentrations. There was no obvious explanation for why the counts in April 2014 were so much higher than any other samples, and in the absence of correlations with other algae metrics, these results are suspect.

There were no year-over-year trends in the total algae counts but green algae counts increased at Summerland from 2011-2014 (Mann-Kendall, p=0.049). Algae counts were consistent with the literature if (Andrusak et al., 2000; Rae and Andrusak, 2006; Andrusak et al., 2006).

Table 2.3.4: Average phytoplankton counts by major algae groups, 2011-2014

	2011-2014 Averages*	
Algae Type	**Kelowna**	**Summerland**
Diatoms	1226	972
Greens	124	90
Yellow-Brown	306	165
Cyanobacteria	2899	1711
Dinoflagellates	12	9
Euglenids	12	1
Total Algae	4579	2949

*The April 2014 data increased the averages significantly and were removed for this table

The Okanagan Lake objective for phytoplankton taxonomy states that no more than 5% of total cell counts should be heterocystous cyanobacteria (Order Nostocales). These phytoplankton can produce toxins that are harmful to human health when they are present in high concentrations. A total of 20% of samples exceeded this objective. At Kelowna, one sample in August 2011 and August 2012 exceeded this objective, both with 6% heterocystous cyanobacteria. Samples from Kelowna exceeded the objective from July to September in 2014 reaching 12% heterocystous cyanobacteria. At Summerland, two samples in summer 2011 exceeded the objective to a maximum of 16% heterocystous cyanobacteria. In 2012, one June sample contained 12% and one September sample contained 9%. The July 2014 sample also exceeded the objective at Summerland with 8% of the algae counts as heterocystous cyanobacteria. There were no exceedances in 2013 at either site. The objective exceedances occurred most often in July and August at these sites, while the total cyanobacteria counts increased over the summer but peaked in the fall (Figure 2.3.4). There were no year-over-year trends in the heterocystous cyanobacteria counts from 2011-2014.

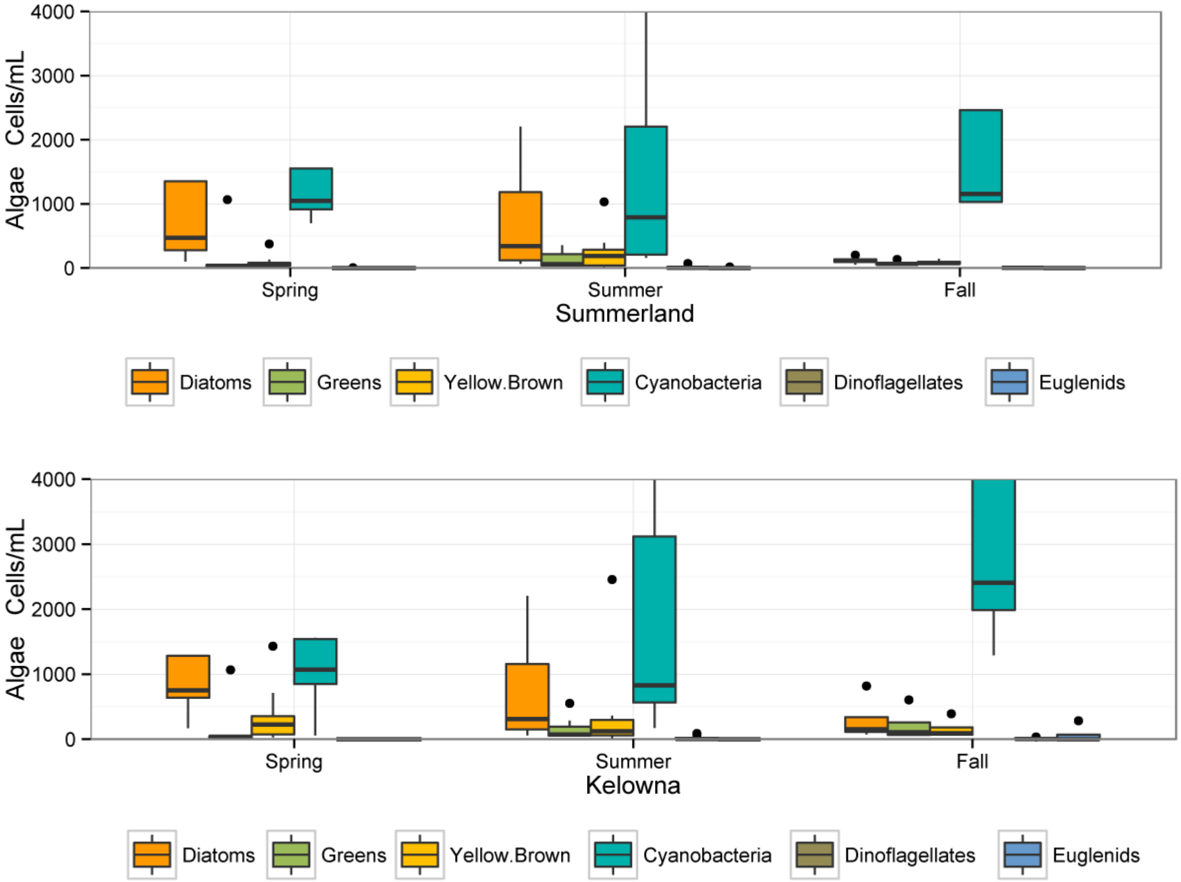


Figure 2.3.4: Taxonomic breakdown of algae by major types at Summerland (top) and Kelowna (bottom), 2011-2014. Cyanobacteria at Kelowna for the fall are off the graph to a maximum of 35,000 cells/mL.

2.3.2 Zooplankton

Biomass

Zooplankton biomass samples were obtained using a 150 µm net lowered to 45 m and raised vertically. The 150 µm net mesh size lets most phytoplankton pass through. Samples were processed in the lab using the same method as the phytoplankton biomass samples. These data were similar to the literature average of 10-30 g/m³ (Andrusak et al., 2000). The Okanagan Lake objective is >0.05 g/m³. This objective was never met at Kelowna and only once at Summerland in August 2014 (Table 2.3.3). A statistically significant difference between Kelowna and Summerland did not occur (2012-2014; T-Test, p=0.28). Zooplankton biomass increased year-over-year at both sites (Mann-Kendall, Table 2.3.3; Figure 2.3.3).

Table 2.3.3: Zooplankton biomass in g/m³ at Okanagan Lake sampling sites, 2012-2014

Site	Objective	Average	StdDev	Max	Min	Trend	P-Value
Kelowna	>0.05	0.0111	0.0113	0.0383	0.0005	↑	0.02
Summerland	>0.05	0.0084	0.0123	0.0540	0.0006	↑	0.03

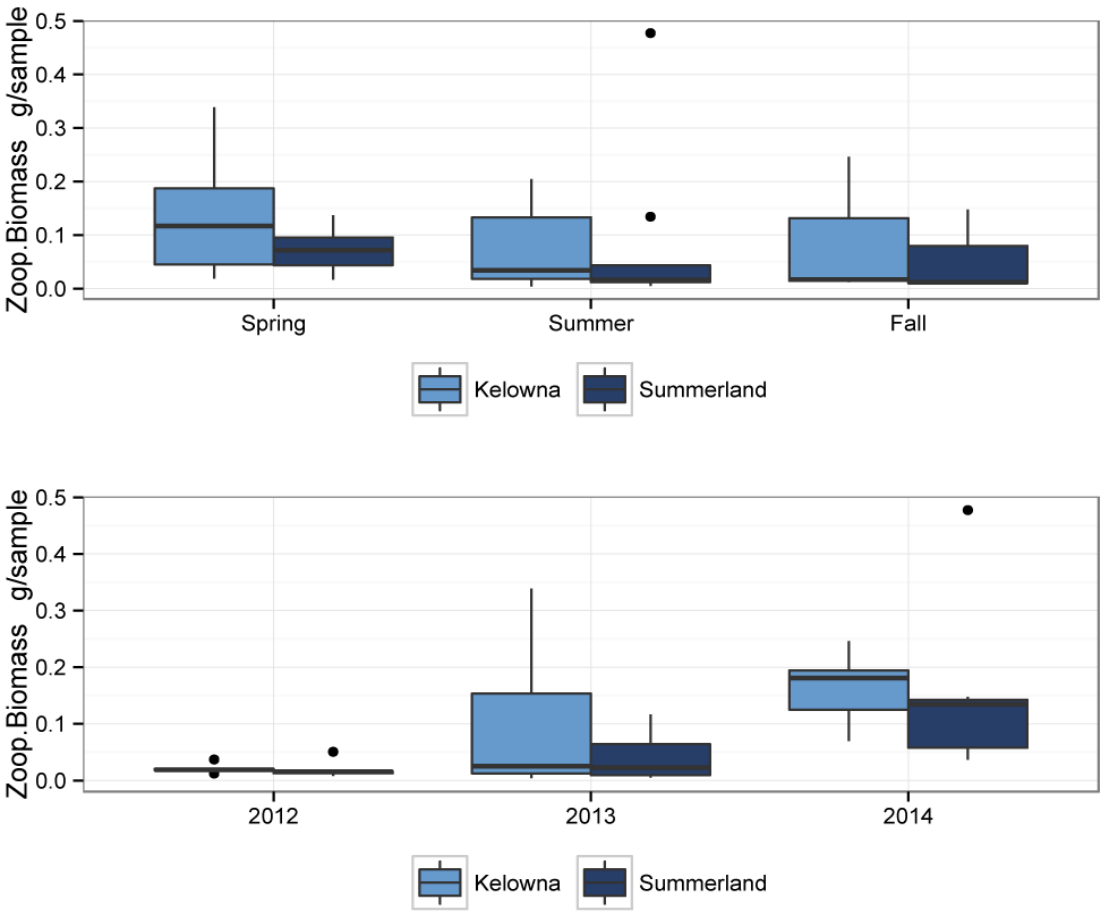


Figure 2.3.3: Zooplankton Biomass at the Kelowna and Summerland sampling locations by season (top) and year (bottom), 2012-2014

Zooplankton Taxonomy

Zooplankton samples were taxonomically identified to the species level and then grouped for analysis in this report. Copepods were the most numerous and averaged 86±34% at Kelowna and 83±39% at Summerland (Table 2.3.5, Figure 2.3.5). The objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. 48% of samples at Kelowna and 44% of samples at Summerland met this objective. The average was 5±5% of zooplankton counts were cladocerans. Mysid shrimp and kokanee salmon prefer to eat cladocerans and their competition may be holding populations below the objective (Andrusak et al., 2000). The average zooplankton abundances were consistent with values found in the literature (Andrusak et al., 2000; Rae and Andrusak, 2006; Andrusak et al., 2006).

Table 2.3.5: Average zooplankton by major taxonomic groups, 2011-2014

Zooplankton Type	Kelowna	Summerland
Copepods	86%	83%
Cladocerans	4%	5%
Rotifers	10%	11%
Mysids	0%	0%
Chironomids	0%	0%
Total Zooplankton	100%	100%

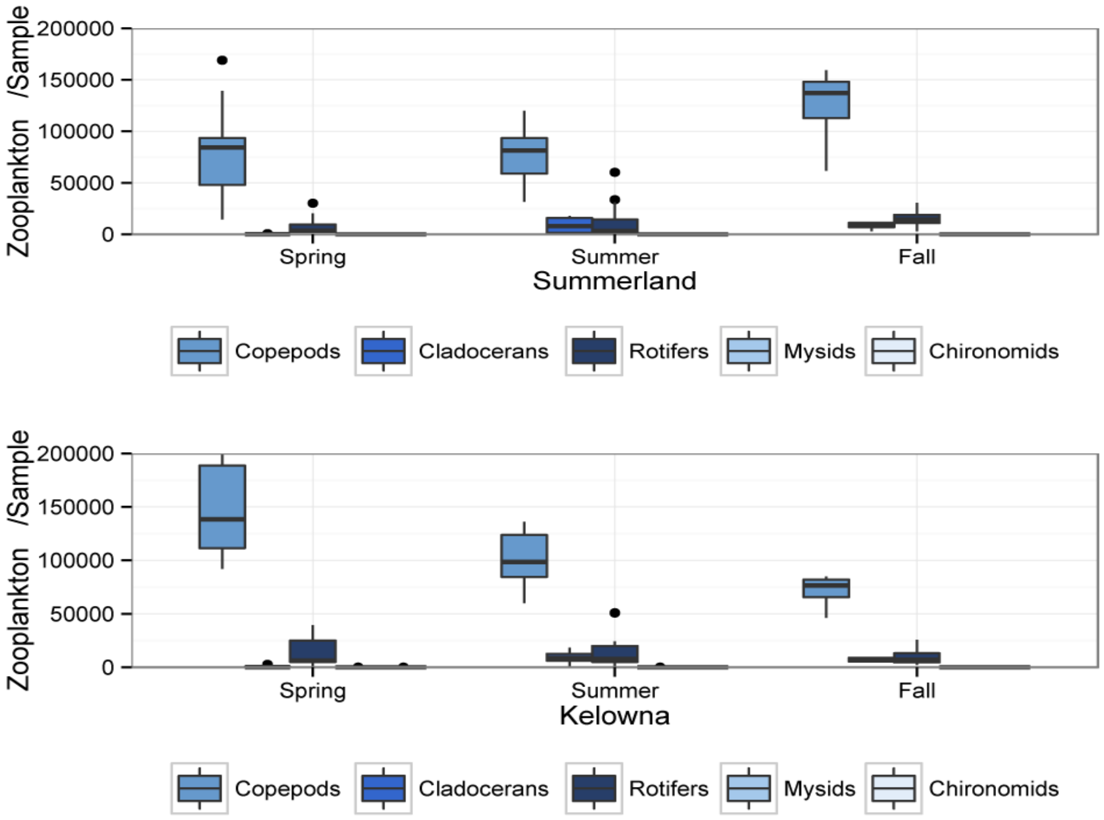


Figure 2.3.5: Breakdown of number of individual zooplankton per sample by major taxonomic types at Summerland (top) and Kelowna (bottom), 2011-2014.

Rotifers are a type of small zooplankton that feed on bacteria and organic detritus. Rotifers can compete with copepods and cladocerans when they also feed on bacteria and detritus. They are common in Okanagan Lake, averaging 11±12% in all samples.

There were no year-over-year trends in the zooplankton taxonomic data. (Figure 2.3.6).

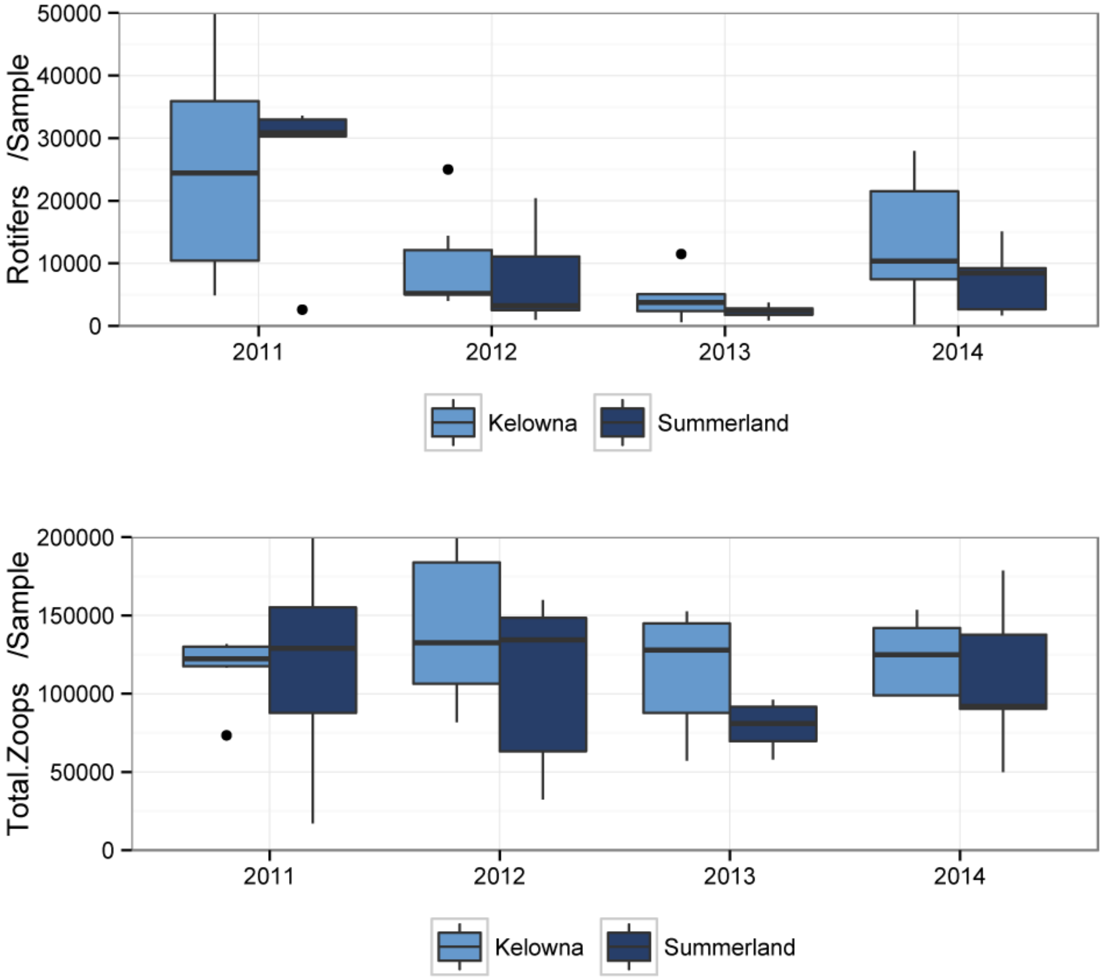


Figure 2.3.6: Rotifer zooplankton (top) and total zooplankton (bottom) counts at Kelowna and Summerland, 2011-2014.

3.0 Conclusions

This report summarizes and extracts trends from the data accumulated by the Okanagan Lake Collaborative Sampling program during its first four years (2011-2014). The data range from physical to water chemistry through to taxonomic.

Each year the temperature of Okanagan Lake increased at the surface until the point where the lake became thermally stratified, usually in May. This physical dynamic isolates the deep water from the atmosphere and led to oxygen depletion below the thermocline in Armstrong Arm. The Armstrong Arm therefore failed to meet the dissolved oxygen objectives each year. Surface water dissolved oxygen concentrations decreased year-over-year throughout the lake from 2011-2014, indicating probable climactic variation.

Chemical analysis of water samples revealed that silica concentrations decreased in the main basins of Okanagan Lake from 2011-2014. Silica increased from spring to fall each year in the Armstrong arm while it decreased seasonally at the three southern sampling sites. Silica is important biologically and its concentration closely mapped to zooplankton counts in Okanagan Lake. Nitrogen increased in the Armstrong Arm from 2011-2014 but not at the other sites. Total nitrogen exceeded the water quality objectives regularly at all sites. Phosphorus concentrations were highest in the Armstrong arm where phosphorus concentrations regularly exceeded the objective. Samples from Ok Centre and Summerland did not exceed the objective while 25% of deep water samples did at Kelowna. Dissolved phosphorus increased year-over-year at all sites. Most samples met the nitrogen to phosphorus ratio but high phosphorus concentrations in the Armstrong Arm caused 50% of samples taken there to exceed the objective.

Chlorophyll-a, the primary photosynthetic pigment in algae, increased each spring during the annual diatom bloom and then decreased over the summer and into the fall. There were no year-over-year trends in the chlorophyll-a data. All samples met the seasonal average chlorophyll-a water quality objective 4-5 µg/L for Okanagan Lake. Phytoplankton biomass increased year-over-year from 2012-2014 at the Kelowna and Summerland sites but met the water quality objective on all dates.

The taxonomic data indicated that diatoms and cyanobacteria numerically dominated the phytoplankton samples. Diatoms were most numerous in spring while cyanobacteria at Kelowna and Summerland dominated in the summer and fall. Algae counts for spring 2014 were unusually high but did not register in the chlorophyll-a samples or the biomass samples. 20% of samples exceeded the phytoplankton objective of <5% of algae as heterocystous cyanobacteria. Objective exceedances occurred in 2011, 2012, and 2014.

Zooplankton biomass increased year-over-year at Kelowna and Summerland from 2012-2014 but remained well below the objective of >0.050 g/m^3 in all samples. Copepods dominated numerically all samples. The Okanagan Lake water quality objective of >5% of zooplankton as cladocerans was achieved in only 46% of samples. Cladocerans averaged 5±5% of zooplankton from 2011-2014.

Table 3.1 summarizes the findings of this report by pairing trends to objective exceedances. Special focus should be paid to parameters that frequently do not meet the objective and for which the data trended in the wrong direction over the course of the sampling program. Armstrong Arm frequently exceeds most objectives and is the site most at risk of water quality degradation including nuisance algae blooms, poor drinking water quality, anaerobic conditions, and further eutrophication. It must be acknowledged that Armstrong Arm is shallower and therefore would be more productive than the deep basins of Okanagan Lake regardless of human activity. However, human activities have impacted this Arm.

Table 3.1: Summary of trends and the water quality objectives for Okanagan Lake collaborative sampling program. Modified from Nordin 2005.

Objective	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth	🟩 -	🟩 -	🟩 -	🟥 -
Dissolved Oxygen	▒ ↓	▒ ↓	▒ ↓	🟥 ↓
TP (mg/L)	🟩 ↑	🟩 -	🟩 -	🟨 ↑
Chlorophyll-a (µg/L)	🟩 -	🟩 -	🟩 -	🟩 -
TN (mg/L)	🟥 -	🟥 -	🟥 -	🟨 ↑
N:P Ratio	🟩 -	🟩 -	🟩 -	🟨 ↓
Algae Taxonomy (% heterocystous cyanobacteria)	🟩 -	🟩 -	▒	▒
Algae Biomass (g/m³)	🟩 ↑	🟩 ↑	▒	▒
Zooplankton Biomass (g/m³)	🟥 ↑	🟥 ↑	▒	▒
Zooplankton Taxonomy (% cladocerans)	🟨 -	🟨 -	▒	▒

Legend:

🟩 Always/often achieved objective	🟨 Occasionally achieved objective	🟥 Never/rarely achieved objective	▒ No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend	

4.0 Recommendations

As part of this report, MoE requested a review of the Water Quality Objectives for Okanagan Lake (Nordin, 2005) and to make recommendations on them as well as to make recommendations on the sampling program moving forward. We have also identified several areas of concern.

The following objectives may require re-evaluation:

- Total Nitrogen (TN) at all sites frequently exceeded the objectives. Nordin based the objectives on the lake average from 1997-2001. Occasional exceedances are therefore less concerning as long as the TN concentrations are not also trending upwards. TN in the Armstrong Arm increased from 2011-2014 and is most concerning.
- Secchi depth and dissolved oxygen objectives for the Armstrong Arm were never met. These objectives were set as goals but the data did not indicate any improvement was occurring during 2011-2014.
- Zooplankton biomass was nearly always below the objective.
- The chlorophyll-a objective is very high; the lake would be in crisis to exceed this objective. The chlorophyll-a data used by Nordin to develop the Okanagan Lake Objectives were higher than the collaborative sampling data and may suggest a period of higher chlorophyll-a in the lake during 1997-2001, the time period of data used by Nordin.

The following areas of concern have been identified that may require further action on the part of the Ministry:

- Chronically low secchi depth in the Armstrong Arm
- Decreasing dissolved oxygen concentrations throughout the lake
- Increasing total nitrogen in the Armstrong Arm
- Increasing total phosphorus in the Armstrong Arm
- Increasing dissolved phosphorus throughout the lake

The following action steps may be considered by MoE to address the areas of concern:

- Include the entire MoE dataset into the trend analyses in the next report to identify long-term trends in the data.
- Build a nutrient loading profile for Okanagan Lake by identifying and sampling major point nutrient sources (e.g., Creeks, WWTP) and comparing to flow volume. This can give perspective on the relative scale of nutrient sources to the lake.
- Increased riparian protection throughout the Armstrong Arm should reduce non-point source nutrient inputs to Okanagan Lake
- Continue to work with the municipalities to continue to reduce nutrient inputs into Okanagan Lake

We recommend the following with regards to the sampling program:

- Renew the program for another 3 year cycle. The 3 year cycle allows more frequent reporting than a longer cycle and allows participants to review the results
- Include funding to re-evaluate trends in data at the conclusion of each contract cycle that includes comparing the collaborative data with the entire MoE data set on Okanagan Lake to look for trends. Those results could be used to revisit the

objectives and reset them with increased accuracy. They would also help identify long-term trends and strengthen our ability to use the data set to detect early warning signs.

- Add taxonomic identification to samples taken in the Armstrong Arm. This part of Okanagan Lake behaves very differently from the rest of the lake. The Armstrong Arm also exceeded most of the objectives most of the time for the parameters that were sampled there and the trend data indicated the conditions there were not improving.
- It may be unnecessary to taxonomically identify phytoplankton and zooplankton to the species level since the objectives and analyses do not take advantage of that level of data resolution. The species-level data is archived and could be investigated to look for subtle shifts in diversity. This analysis may indicate that completing taxonomy to the genus level is adequate for this collaborative program and identifying taxonomy samples to species-level could be completed every 5 years.
- Consider adding chloride to the sampling program as an indicator of anthropogenic impacts. Comparison of chloride concentrations between the four sites may illustrate the level of impact on different parts of Okanagan Lake.
- If an analysis has to be dropped, silica could be considered. Seasonal silica data did not provide additional insight on phytoplankton in Okanagan beyond what was available from the biomass, chlorophyll-a, and taxonomic data.

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