Okanagan Lake Collaborative Monitoring Agreement
2016 Summary Report
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Prepared for BC Ministry of Environment, Environmental Protection Division

Larratt Aquatic Consulting Ltd. 2605 Campbell Rd. West Kelowna B.C. V1Z 1T1
Phone: 250.769.5444 Email: heather@larratt.net

Executive Summary

The British Columbia Ministry of Environment along with local municipalities, commissioned a multi-year collaborative monitoring program to sample long-term water quality in Okanagan Lake, monthly (March to September) at four locations from 2011 to 2016. A primary function of the monitoring is to determine attainment of Okanagan Lake water quality objectives, along with increasing the temporal resolution of water quality data for Okanagan Lake, specifically with the goal of determining trends in nutrient and biological data. In 2016, parameters such as temperature and dissolved oxygen were measured throughout the water column as well as several chemical parameters including silica, nitrogen, and phosphorus at discrete depths. Biological data ranging from biomass to specific taxonomic identification was also collected. This report summarizes the 2016 findings and analyzes data from 2011-2016 for trends.

Physical

Okanagan Lake experienced thermal stratification in 2016 as it did in each year of study. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. The Armstrong Arm Secchi depth averaged only 3.9 ± 1.3 m and the Summerland Secchi depth averaged 6.8 ± 1.6 m in 2016 and both failed to meet their objectives of >5 m and >7.0 m respectively averaged over the growing season. Kelowna and Okanagan Centre met the Secchi objective of >6.0 m in 2016. Water clarity was highest at Summerland in 2016.

Chemical

Dissolved oxygen in the deep water of the Armstrong Arm fell below the water quality objective each summer including 2016. Surface dissolved oxygen concentrations decreased from 2011-2016 at all four sample sites on Okanagan Lake, likely as a function of increasing summer water temperature. Silica concentrations were similar throughout Okanagan Lake averaging between 7.34 and 7.93 mg/L at the four sample sites. There have been several short-term trends in silica but no long-term trends over the entire 2011-2016 sampling period. Total nitrogen averaged 0.225 ± 0.035 mg/L as N in Okanagan Lake and exceeded the objective at Summerland in the epilimnion sample. Total nitrogen decreased at Okanagan Centre and Kelowna >20 m from 2011-2016. Nitrate decreased from spring to fall in response to algae activity at the three southern sites but increased year-over-year at Summerland >20 m and in the Armstrong Arm from 2011-2016. Total phosphorus averaged 0.007 ± 0.006 mg/L as P in Okanagan Lake during 2016 and increased in the Armstrong Arm from 2011-2016, where it also exceeded the objective in 2016. Dissolved phosphorus increased slightly from 2011-2014 and then leveled off or decreased at the three southern sites. Dissolved phosphorus increased dramatically in the Armstrong Arm from 2011-2015 before also decreasing in 2016. The N:P ratio objective was exceeded in the Armstrong Arm in 2016, and is trending downwards (away from 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 over the course of this study. Chlorophyll-a averaged 2.66 ± 1.25 µg/L at Summerland in the south end of the lake and increased to 3.86 ± 1.01 µg/L at the north end of the lake in the Armstrong Arm during 2016. All sites achieved the objective for chlorophyll-a in all years. There was a weak increasing trend calculated for chl-a at Okanagan Centre because there was a 74% increase in its concentration between 2015 and 2016. The rest of the biological data (biomass and taxonomy of phytoplankton and zooplankton) were sampled at the Kelowna and Summerland sites only. Phytoplankton biovolume averaged 0.050 ± 0.023 µL/L at Kelowna and 0.048 ± 0.040 µL/L at Summerland during 2016. Cyanobacteria numerically dominated phytoplankton counts in 2016. All samples exceeded the phytoplankton taxonomy objective with up to 80% of counted cells being heterocystic cyanobacteria. Zooplankton biomass met the objective in Kelowna (91.6 ± 51.6 µg/L) but not in Summerland (34.8 ± 17.7 µg/L) during 2016. 43% of samples at Summerland and no samples from Kelowna met the objective.

Areas of concern

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

- Chronically low Secchi depth in the Armstrong Arm
- Decreasing dissolved oxygen concentrations throughout the lake
- Increasing nitrate in the hypolimnion at Summerland
- Increasing total phosphorus and dissolved phosphorus in the Armstrong Arm
- Decreasing N:P ration in the Armstrong Arm
- Unusually high heterocystic cyanobacteria concentrations during 2016

Recommendations

We recommend that the existing collaborative monitoring program be continued as is, through the remainder of the current term and a second detailed synthesis report be compiled at the end of the term in 2017. We also recommend that phytoplankton taxonomy results continue to be supplied in “cells/L or cells/mL” for consistency with the historic data.

Water Quality Objectives, 2016 Values, and Trends for Okanagan Lake

Objectives (Nordin, 2005)	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth (growing season average: Apr-Sep)	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 (µL/L) (growing season average)	<0.75	<0.75	<0.75	<0.75
Zooplankton Biomass (µg/L) (growing season average)	>50	>50	>50	>50
Zooplankton Taxonomy (% cladocerans)	>5%	>5%	>5%	>5%

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth (m)	6.8 ± 1.6	6.1 ± 0.7	6.4 ± 0.6	3.5 ± 0.8
Dissolved Oxygen (mg/L)	7.25 (Aug)	8.06 (Aug)	7.43 (Sep)	1.2 (Sep)
TP (mg/L)	0.005	0.005	0.006	0.009
	0.003	0.008	0.003	0.017
Chlorophyll-a (µg/L)	2.66 ± 1.25	2.35 ± 0.57	2.79 ± 0.30	3.86 ± 1.01
TN (mg/L)	0.213	0.213	0.216	0.255
	0.229	0.222	0.192	0.264
N:P Ratio	45:1	41:1	38:1	29:1
	80:1	48:1	57:1	17:1
Algae Taxonomy (% heterocystous cyanobacteria)	80%	78%		
Algae Biomass (µL/L)	0.048 ± 0.040	0.050 ± 0.023		
Zooplankton Biomass (µg/L)	34.8 ± 17.7	91.6 ± 51.6		
Zooplankton Taxonomy (% cladocerans)	5 ± 4%	2 ± 1%		

Legend:

Met objective in 2016	Did not meet objective in 2016	No Data/ No Objective

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 (µL/L)	-	-		
Zooplankton Biomass (µg/L)	-	-		
Zooplankton Taxonomy (% cladocerans)	-	-		

Legend:

Met objective in 2016	Did not meet objective in 2016	No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend

Preferred Citation

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Report prepared by: Larratt Aquatic Consulting Ltd.

Jamie Self: BSc, RPBio
Aquatic Biologist

Heather Larratt: BSc. RPBio
Aquatic Biologist

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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
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
Nutrient limitation	A nutrient will limit or control the potential growth of organisms e.g. P or N
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
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 (> $1^oC/m$); 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
AFDM	Ash-free dry mass
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

Statistics Overview

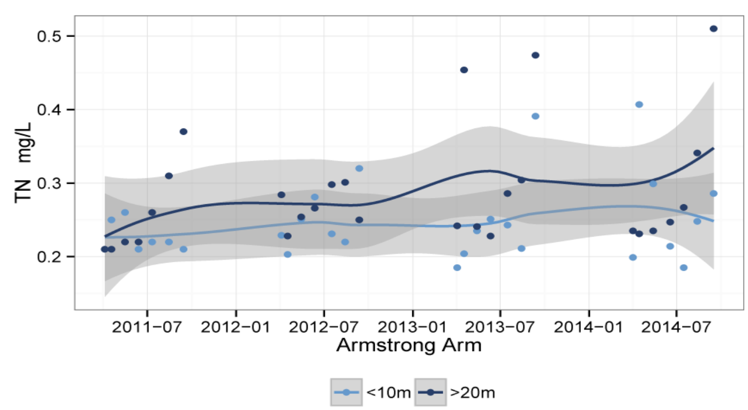
Statistical analyses were performed on data to support claims made throughout this report. The use of the word 'significantly' within this report is understood to signify that the claim being made has stood up under statistical analysis. Unless otherwise stated, all statistical analyses were performed 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.



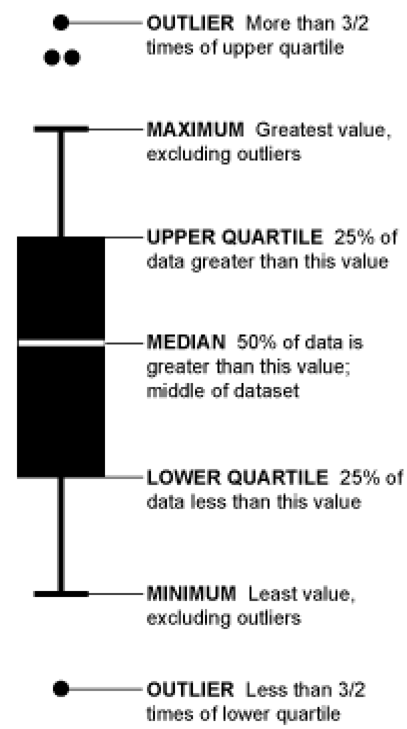


Figure i: Example scatterplot and boxplot
Includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within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

1.0 Introduction

1.1 Overview

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 water quality data being gathered. This program was performed collaboratively between MoE staff, Okanagan Nation Alliance (ONA; 2011), and Larratt Aquatic Consulting (2012-2016). Okanagan Lake was sampled monthly from March to September from 2011-2016 at four key 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 subjects at each site: physical parameters, water chemistry, and biological activity.

Physical parameters including temperature profiles were taken at each site on each date to build a composite image of conditions in Okanagan Lake over time (Figure 2.1.1). Secchi depth, a measure of water clarity, was also recorded for each site.

In addition, dissolved oxygen profiles were taken and 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. Chemistry results were analyzed by ALS Environmental.

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

The 2016 data were added to the existing 2011 – 2015 database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin 2005 (Appendix 1).

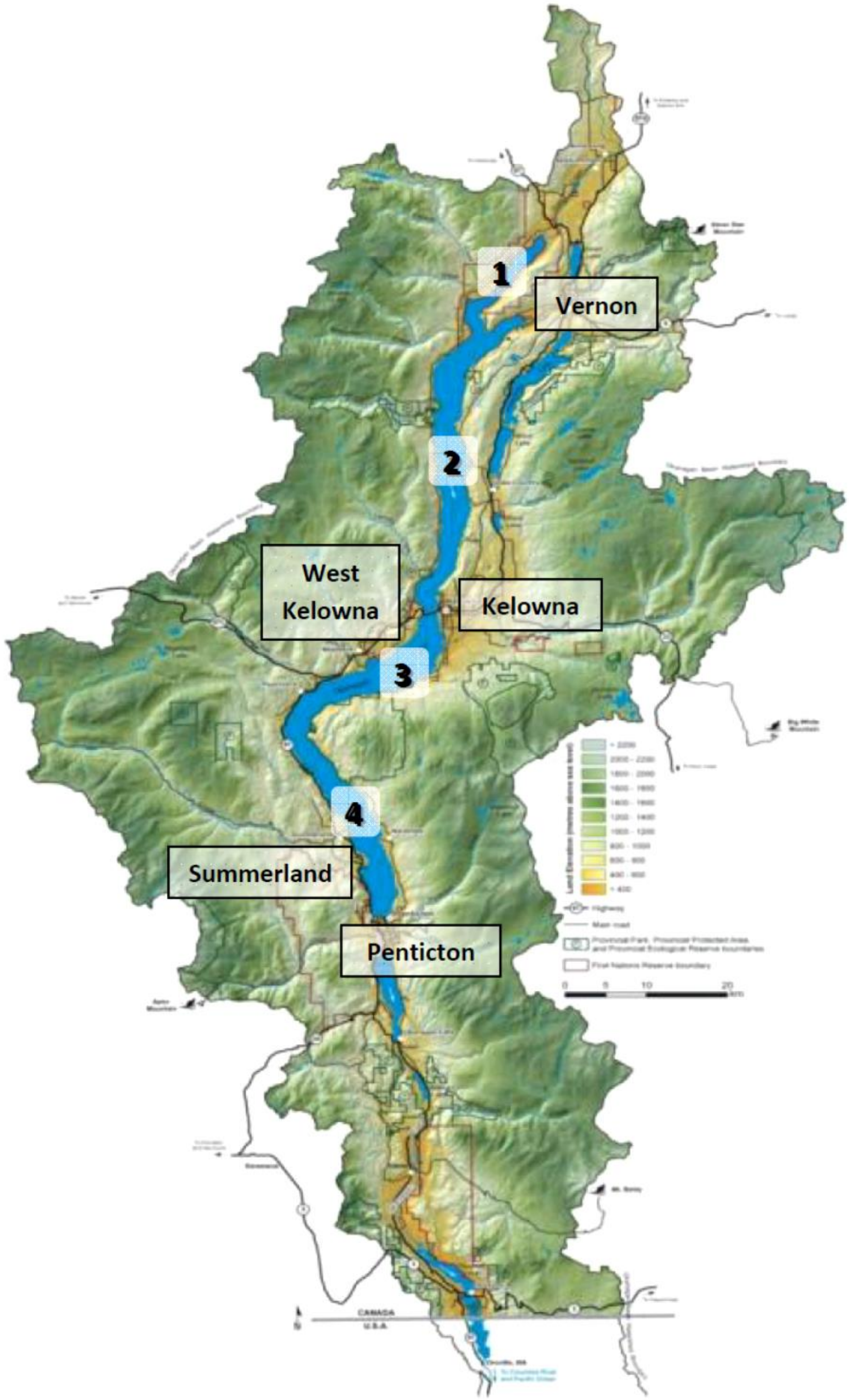


Figure 1.1: Okanagan Basin Watershed with four sampling locations identified. 1=Armstrong Arm, 2=Ok Centre, 3=Kelowna, 4=Summerland (Sokal, 2013)

2.0 Results & Discussion

2.1 Physical

2.1.1 Temperature

Okanagan Lake is a deep monomictic lake. This means from May to November each year, the surface water (epilimnion) is thermally 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 less than 4 °C annually (Figure 2.1.1).

The three southern sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal behavior while the northern Armstrong Arm site is shallower and behaves differently. The later reaches a higher surface temperature and experiences oxygen depletion in the deep water each summer (Figure 2.1.1). Thermal stratification in Okanagan Lake breaks down each November and the water column freely circulates through the winter. There were no statistically significant trends in the 2011–2016 temperature data either annually, seasonally, or monthly.

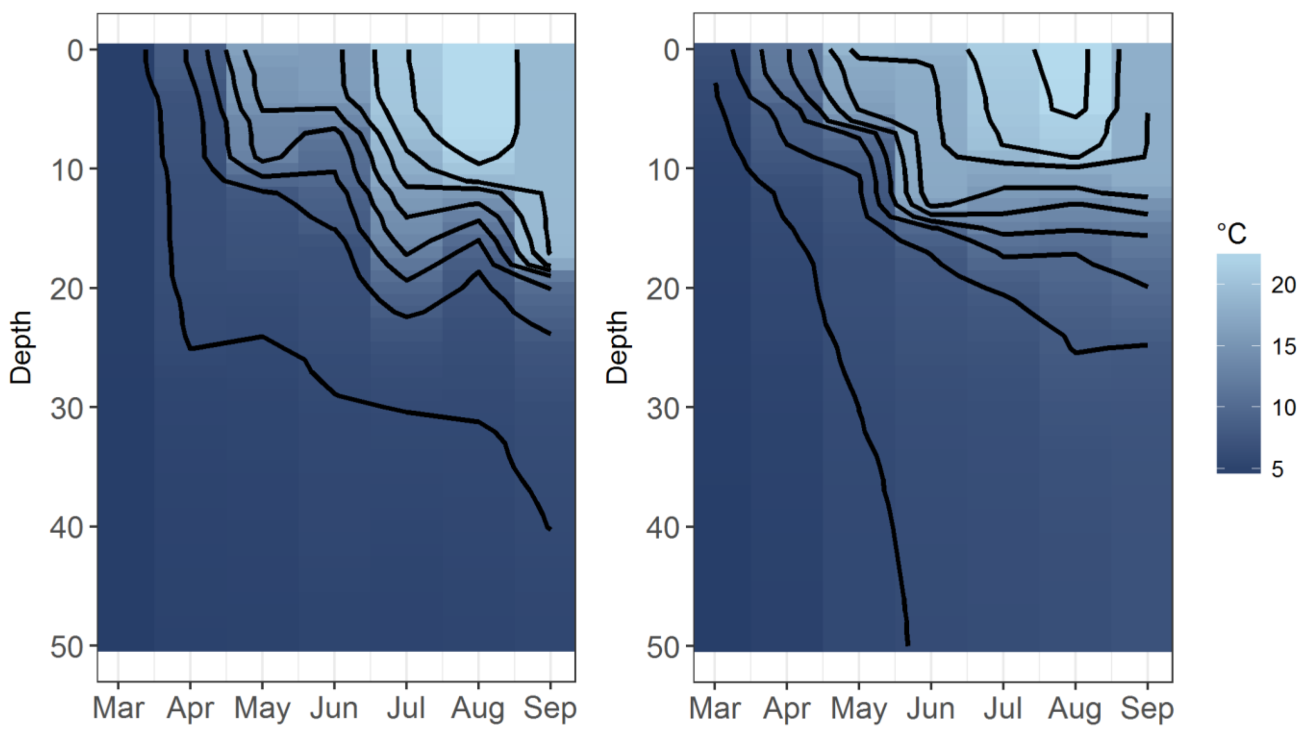


Figure 2.1.1: Temperature and dissolved oxygen profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right), 2016. Lines represent contours of same temperature or dissolved oxygen within the water column through time.

Surface water temperatures of Okanagan Lake at all four sites were above average for the March to May period during 2016 because of the hot and dry spring. Temperatures fell back in line with the average in June as the weather shifted and the effects of El Niño faded (Figure 2.1.4).

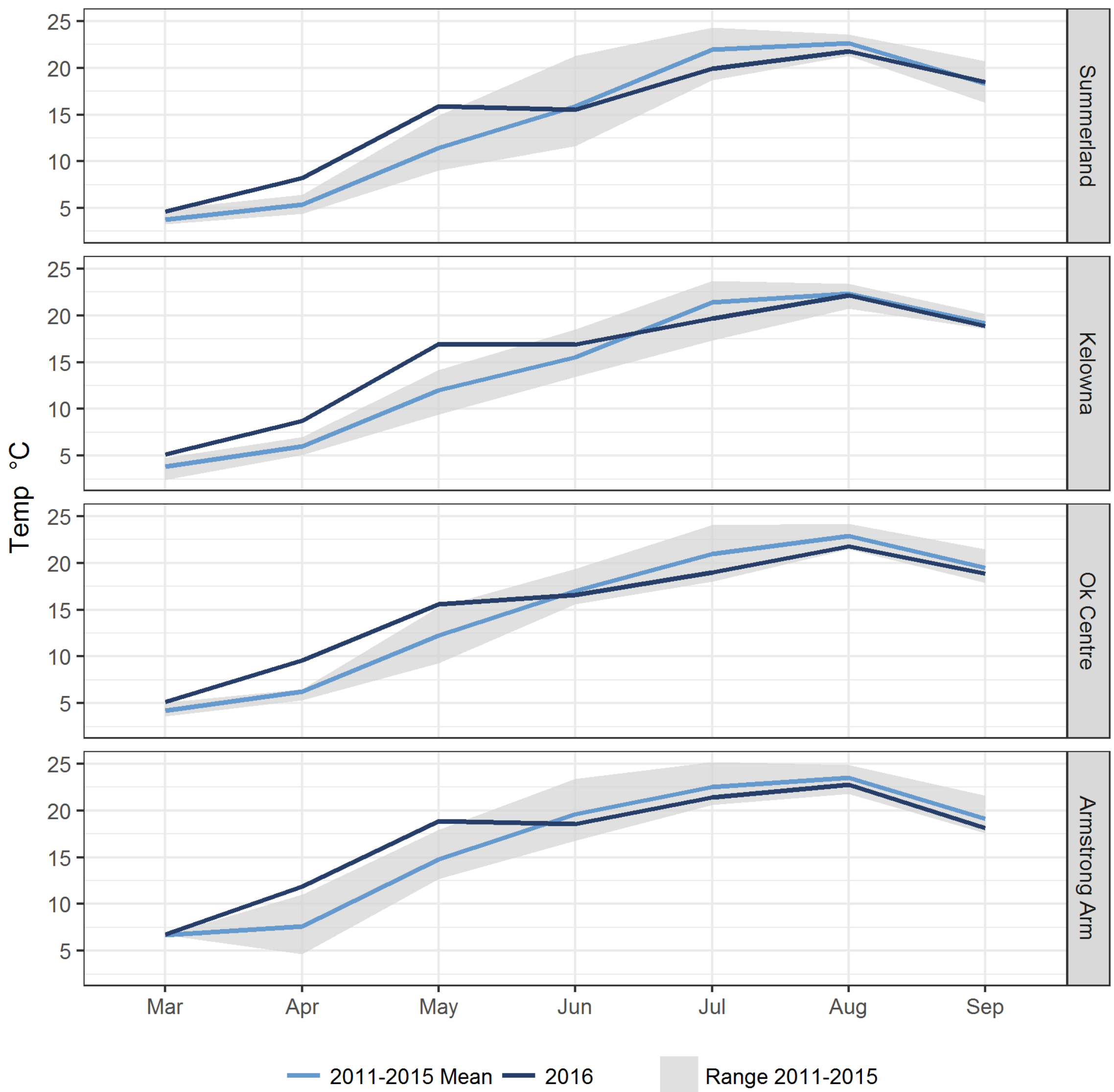


Figure 2.1.4: Surface temperature at Okanagan Lake sample sites by month, 2011-2016

2.1.2 Water Clarity and Secchi Depth

Secchi depth during 2016 ranged from a minimum of 2.0 m at Armstrong Arm in August to a maximum of 13.1 m at Summerland in March (Table 2.1.1). Secchi depth averages were lower at all sites during 2016. The overall 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 2.1.5).

The Secchi depth in the Armstrong Arm was much lower throughout the year than at the other sites in Okanagan Lake. This is clearly illustrated in Figure 2.1.5. The Secchi depth in Summerland and the Armstrong Arm did not meet their respective objectives (>7 m, >5 m) while the Secchi did meet the objective (>6 m) at Kelowna and Ok Centre during 2016

(Table 2.1.1). There were no statistically significant trends in the Secchi depth data either annually, or monthly. A small increasing trend in secchi depth was observed at Kelowna during the summer (June-August) between 2011-2015 but the lower secchi depths during 2016 appear to have broken this trend (Mann-Kendall, p=0.04; Figure 2.1.6).

Table 2.1.1: Growing Season (Apr-Sep) Secchi depth in meters at Okanagan Lake sampling sites, 2016

Site	Objective	Average	StdDev	Max	Min
Summerland	7.0	6.8	1.6	9.1	4.8
Kelowna	6.0	6.1	0.7	7.1	5.4
Ok Centre	6.0	6.4	0.6	7.3	5.9
Armstrong Arm	5.0	3.5	0.8	4.4	2.0

Note: Objective refers to growing season average (Apr-Sep)

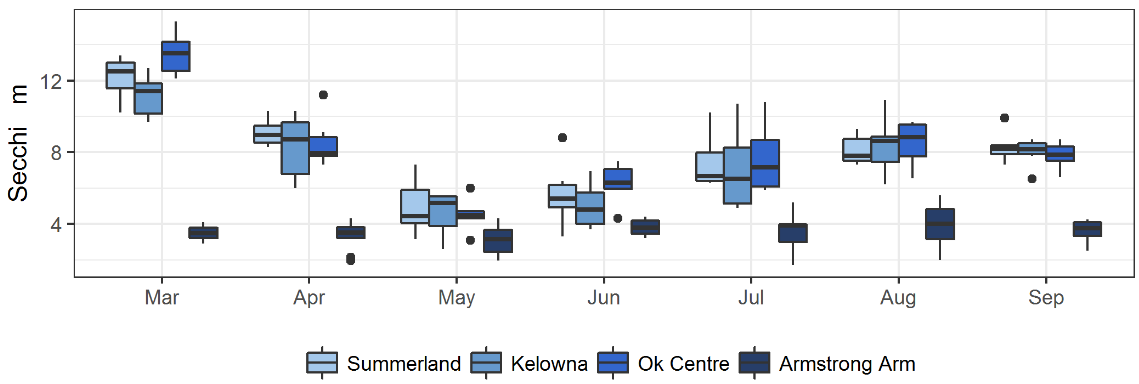


Figure 2.1.5: Monthly Secchi depth at each of the sampling sites, 2011-2016

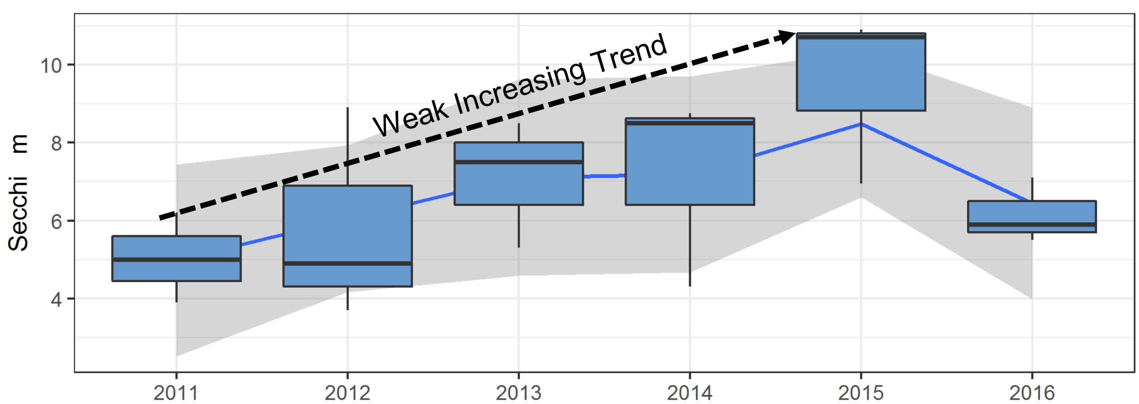


Figure 2.1.6: Secchi Depth at Kelowna during Summer (June-Aug) from 2011-2016

2.2 Chemistry

Chemistry sampling focused on dissolved oxygen, 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 wastewater 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 climatic impacts from human impacts.

2.2.1 Dissolved Oxygen

The three southern sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal and dissolved oxygen behavior while the northern Armstrong Arm site is shallower and behaves differently. The later reaches a higher surface temperature and experiences oxygen depletion in the deep water each summer (Figure 2.2.1). Oxygen depletion is caused by decomposition of organic material in the sediment and deep water. The Armstrong Arm did not meet the dissolved oxygen concentration guideline during 2016.

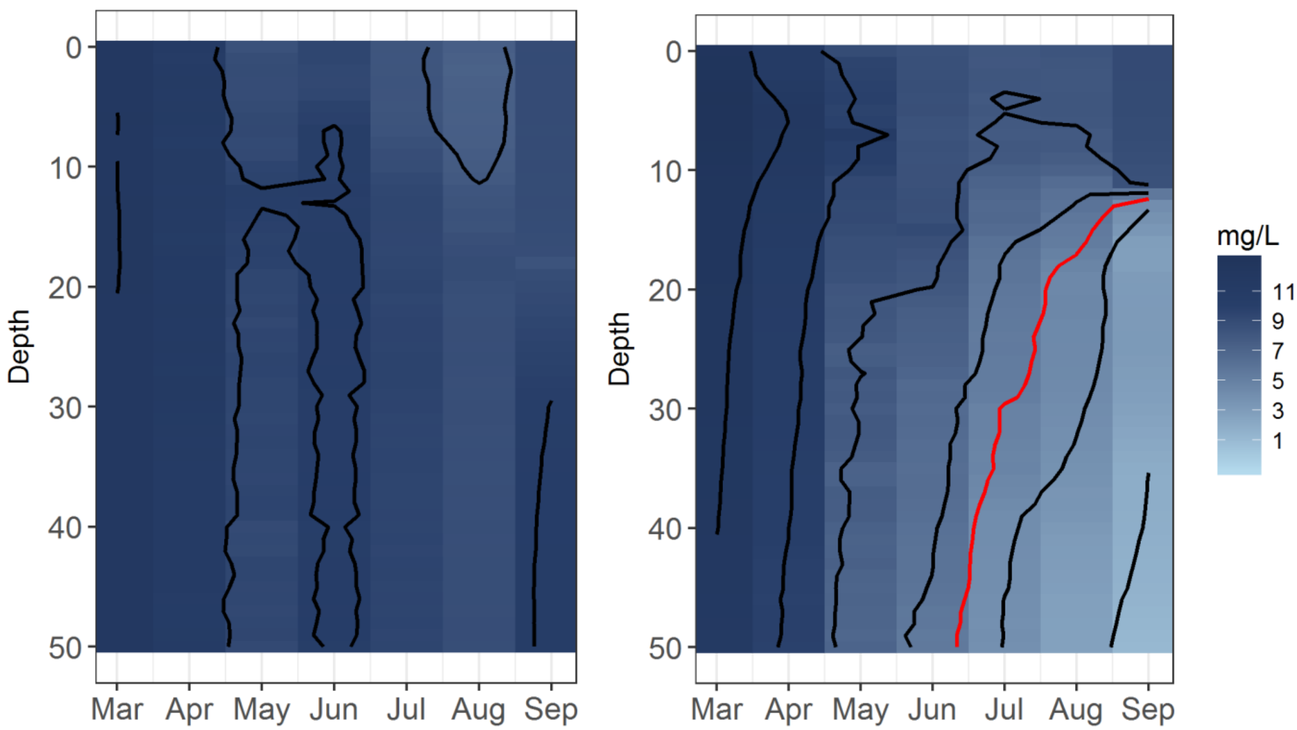


Figure 2.1.2: Temperature and dissolved oxygen profiles for Okanagan Lake at Summerland (left) and at Armstrong Arm (right) in 2016. Dissolved oxygen profile illustrates high dissolved oxygen concentrations at Summerland and characteristic oxygen depletion in deep waters of the Armstrong Arm. Lines represent contours of same dissolved oxygen within the water column through time. Note: The red line on dissolved oxygen plot represents Water Quality Objective; all water below this line does not meet the objective.

Surface dissolved oxygen concentrations vary throughout the year but have been trending downwards at all sites over the course of the collaborative sampling program (2011-2016; Figure 2.1.3; Mann-Kendall $p \leq 0.007$). Colder water has a greater capacity to carry dissolved oxygen than warmer water does, however, there were no significant trends in the temperature data. The shift in dissolved oxygen was probably connected to increased water temperature but the high variability in the temperature data masked any trends.

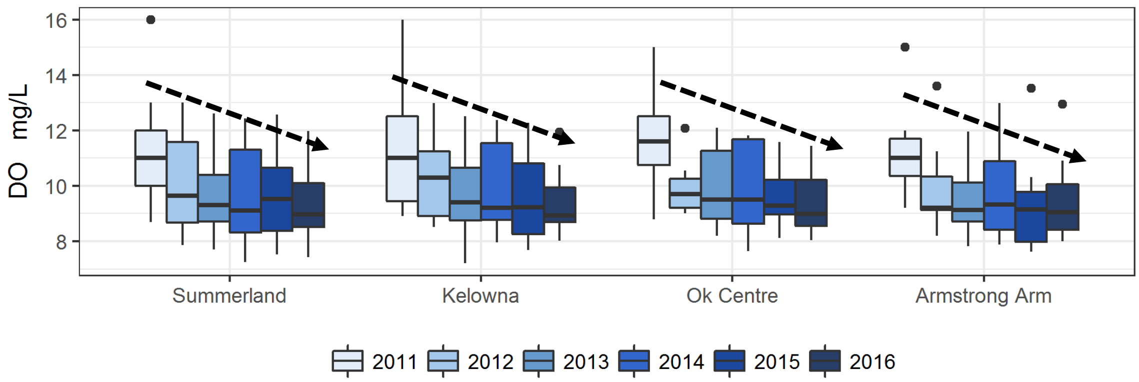


Figure 2.1.3: Surface dissolved oxygen concentrations at Okanagan Lake sampling sites grouped by year with trends highlighted, 2011-2016

2.2.1 Silica

Diatoms, a major group of algae in Okanagan Lake, use silica as a structural building block for their cell walls. Silica was not significantly different between the four sites (Table 2.2.1). There have been several short-term trends in Silica (see arrows in Figure 2.2.1) but no long-term trends over the entire 2011-2016 sampling period. The short-term trends were likely related to cyclical climate patterns (2011-2014 were wet years while 2015-2016 were dry). Silica sampling shifted to only March and September beginning in 2015 because it did not change significantly over the course of the growing season.

Table 2.2.1: Silica concentration in mg/L at Okanagan Lake sampling sites, 2016

Site	Average	StdDev	Max	Min
Armstrong Arm	7.41	0.37	7.88	7.05
Kelowna	7.34	0.35	7.79	6.98
Ok Centre	7.34	0.14	7.49	7.16
Summerland	7.93	1.59	10.2	6.67

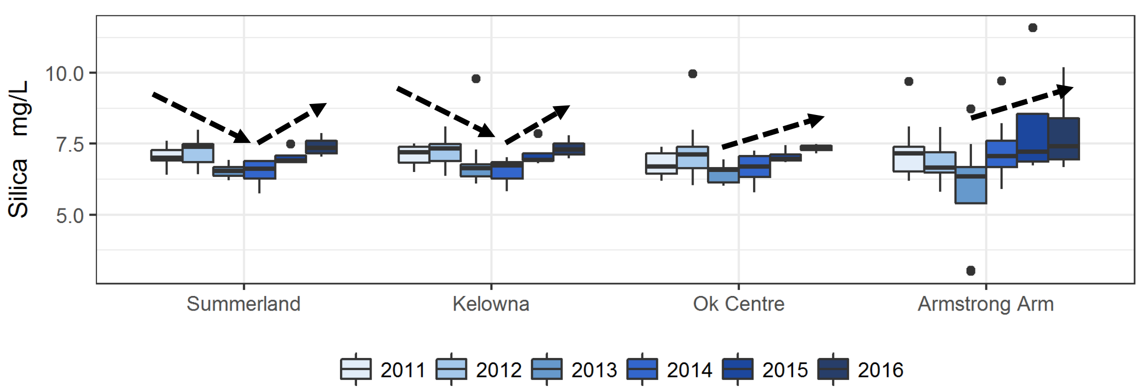


Figure 2.2.1: Silica concentration in Okanagan Lake at each sampling site by year with trends highlighted, 2011-2016

2.2.2 Nitrogen and Phosphorus

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

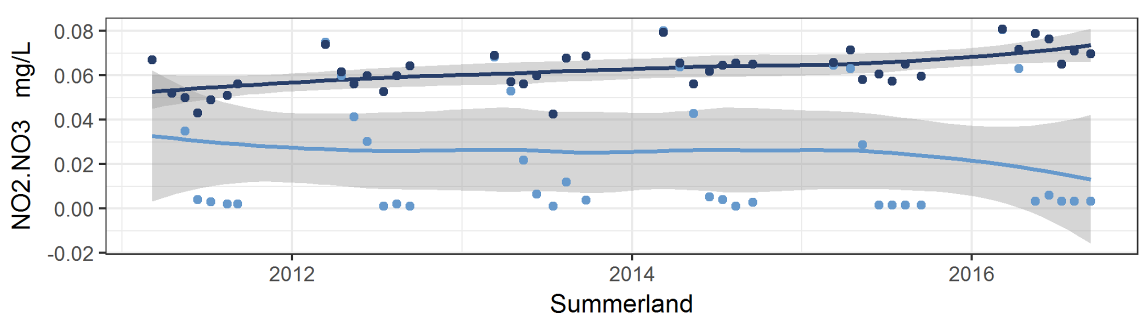
Nitrogen

Total nitrogen (TN) averaged 0.225 ± 0.035 mg/L as N in Okanagan Lake during 2016 (Table 2.2.1). The objective for Okanagan Lake was set as a spring value (March sample date) of 0.230 mg/L for the main basins and 0.250 mg/L for the Armstrong Arm. The objectives were exceeded at only Summerland epilimnion during 2016. TN increased in the Armstrong Arm from 2011-2015 but decreased from 2015-2016 breaking the long-term trend. TN decreased at Okanagan Centre from 2011-2016 (Mann-Kendall, $p=0.003$) but not at Summerland or Kelowna (Table 2.2.2). Nitrate+nitrite increased in the Armstrong Arm at both depths (Mann-Kendall, $p<0.001$) and at Summerland in the hypolimnion from 2011-2016 (Mann-Kendall, $p<0.001$). Nitrate is rapidly consumed by algae in the spring and thermal stratification prevents replenishment with the deeper water during the summer (Figure 2.2.2). Average TN values were comparable to those found in the literature for Okanagan Lake (0.17-0.23 mg/L as N; Andrusak et al.,2000).

Table 2.2.2: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2016

Site	Depth	Objective	Exceeded in 2016?	Trend	Avg	SD	Max	Min
Summerland	<10m	0.230	Yes	-	0.213	0.021	0.253	0.193
	>20m		No	-	0.229	0.012	0.251	0.213
Kelowna	<10m	0.230	No	-	0.213	0.011	0.227	0.197
	>20m		No	↓	0.222	0.012	0.236	0.200
Ok Centre	<10m	0.230	No	-	0.216	0.020	0.246	0.180
	>20m		No	↓	0.192	0.041	0.220	0.103
Armstrong	<10m	0.250	No	-	0.255	0.061	0.389	0.207
Arm	>20m		No	-	0.264	0.015	0.283	0.247

Note: Statistical significance of general trends derived from all data for a site may disappear when depths are split apart due to smaller sample size



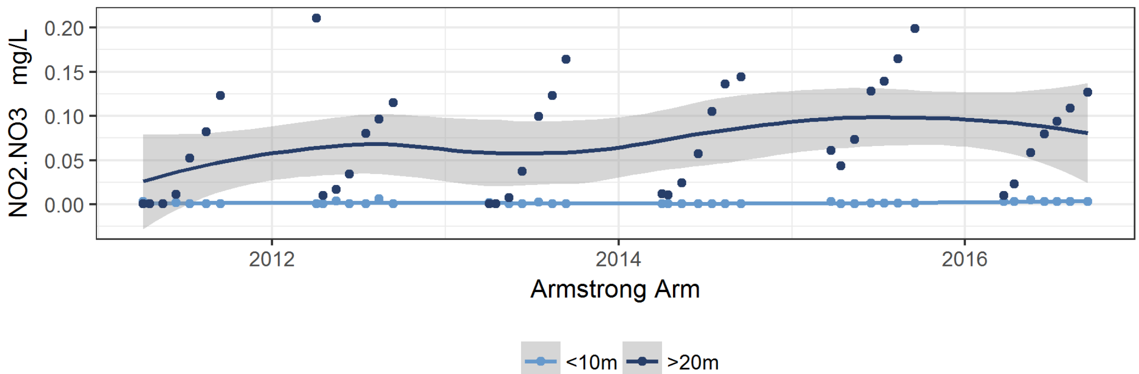


Figure 2.2.2: Nitrite+nitrate in mg/L as N in the surface and deep water of Okanagan Lake at Summerland and in the Armstrong Arm, 2011-2016

Phosphorus

TP measures all forms of phosphorus including those that may not be bioavailable. Total phosphorus (TP) averaged 0.007 ± 0.006 mg/L as P across Okanagan Lake during 2016 (Table 2.2.3). These data were similar to 2011-2015. The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at the spring overturn (Nordin, 2005; taken as March). It ranged from 0.007 mg/L in the south basin to 0.010 mg/L in the Armstrong Arm. The TP objectives were exceeded in the deep sample at Armstrong Arm in 2016. TP increased in the Armstrong Arm from 2011 to 2014, but has been stable over the past three years.

Table 2.2.3: Total phosphorus in mg/L as P concentration at Okanagan Lake sampling sites, 2016

Site	Depth	Objective	Exceeded in 2016?	Trend	Avg	SD	Max	Min
Summerland	<10m	0.007	No	-	0.005	0.001	0.006	0.004
	>20m		No	-	0.003	0.001	0.006	0.002
Kelowna	<10m	0.008	No	-	0.005	0.000	0.006	0.005
	>20m		No	-	0.008	0.010	0.030	0.003
Ok Centre	<10m	0.008	No	-	0.006	0.002	0.012	0.005
	>20m		No	-	0.003	0.001	0.004	0.002
Armstrong	<10m	0.010	No	-	0.009	0.001	0.010	0.007
Arm	>20m		Yes	↑	0.017	0.006	0.026	0.011

Dissolved phosphorus (DP) measures the more bioavailable forms of phosphorus and is a good indicator of potential anthropogenic impacts to biota. From 2011-2016, some short-term trends have emerged, likely related to climate patterns (see arrows in Figure 2.2.3). Dissolved phosphorus increased dramatically from 2011-2015 in the Armstrong Arm (Figure 2.2.3; Mann-Kendall $p<0.001$). Ortho-phosphate measures only the soluble reactive phosphorus fraction of the DP. There were no significant trends in ortho-phosphate data.

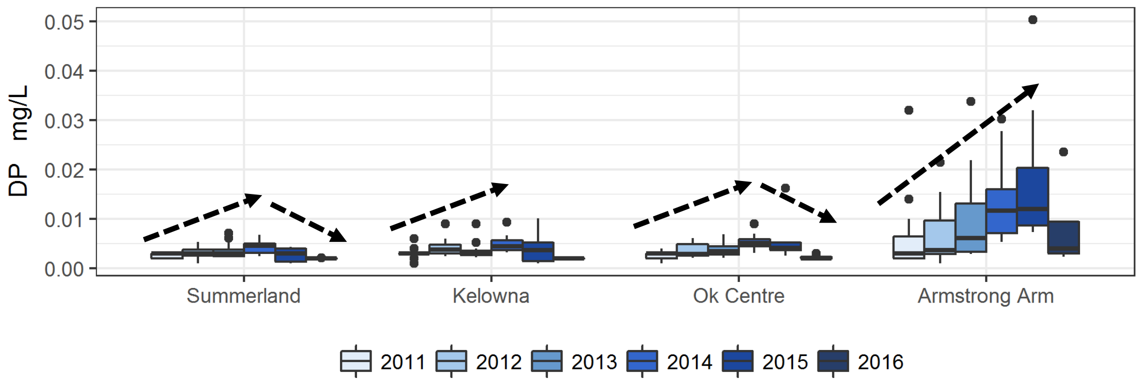


Figure 2.2.3: Dissolved phosphorus in Okanagan Lake at the four sampling sites by year with trends highlighted, 2011-2016

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 in March samples. All three southern sites met the objective in 2016. The Armstrong Arm had higher phosphorus concentrations than the rest of Okanagan Lake and did not meet the objective in 2016 (Figure 2.2.3, Table 2.2.4). The N:P ratio decreased in the Armstrong Arm from 2011-2016 (Mann-Kendall, p=0.018).

Table 2.2.4: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2016

Site	TN	TP	Avg Ratio	Objective	Exceeded in 2016?	Trend
Summerland	0.221	0.0040	62:1	>25:1	No	-
Kelowna	0.217	0.0065	44:1	>25:1	No	-
Ok Centre	0.204	0.0048	47:1	>25:1	No	-
Armstrong Arm	0.260	0.0132	23:1	>25:1	Yes	↓

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. The Armstrong Arm of Okanagan Lake is shallower and has the potential to 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 (Figures 2.1.5 and 2.3.1). 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). During 2016, chlorophyll-a concentrations met the objectives at all sites. Spring chlorophyll-a concentrations were relatively high at up to 3.99 µg/L in April but the seasonal average remained below the objective (Table 2.3.1). In most years, 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, but this did not occur in 2016 because Summerland had a longer lasting spring bloom than at Kelowna. There was a weak increasing trend calculated for chlorophyll-a at Ok Centre because there was a 74% increase in its concentration between 2015 and 2016. No other statistically significant year-over-year trends in the chlorophyll-a data were observed.

Table 2.3.1: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2016

Site	Objective	Exceeded in 2016?	Trend	Average	StdDev	Max	Min
Summerland	4	N	-	2.66	1.25	4.02	0.91
Kelowna	4.5	N	-	2.35	0.57	3.11	1.50
Ok Centre	4.5	N	↑	2.79	0.30	3.28	2.40
Armstrong Arm	5	N	-	3.86	1.01	5.56	2.57

Note: Based on growing season only (Apr-Sep)
Note: Increase at Ok Centre based on increase between 2015 and 2016

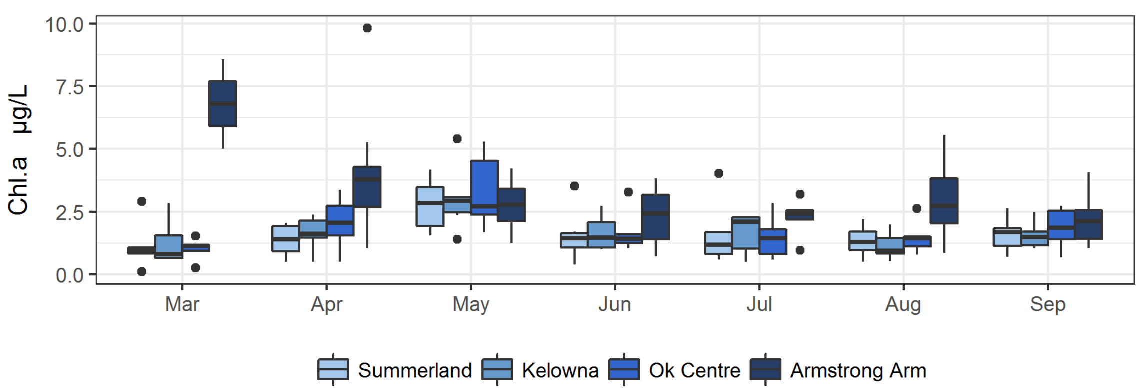


Figure 2.3.1: Monthly chlorophyll-a concentration at the four Okanagan Lake sampling sites, 2011-2016

Biovolume

Phytoplankton biovolume samples were collected as a one litre composite from 1-10 m. The biovolumes were determined taxonomically. From 2011-2014, biomass was determined using ash-free dry mass (AFDM). It is not possible to directly compare the results from the two methodologies and only the 2015-2016 results are considered here. All samples were well below the objective of 0.75 µL/L during 2016 (Table 2.3.2). Phytoplankton biomass decreased relative to 2015 during 2016 but no trends can be determined from only two years of data (Figure 2.3.2).

Table 2.3.2: Phytoplankton biovolume in µL/L at Okanagan Lake sampling sites, 2016

Site	Obj	Apr	May	Jun	Jul	Aug	Sep	Avg	SD
Kel.	<0.75	0.0257	0.0527	0.0745	0.0471	0.0237	0.0763	0.0500	0.0228
Sum.	<0.75	0.0136	0.1224	0.0469	0.0535	0.0200	0.0307	0.0478	0.0396

Note: 2015 report incorrectly stated objective as 750 µL/L, no false exceedances created by error
Note: Growing season average based on Apr-Sep only

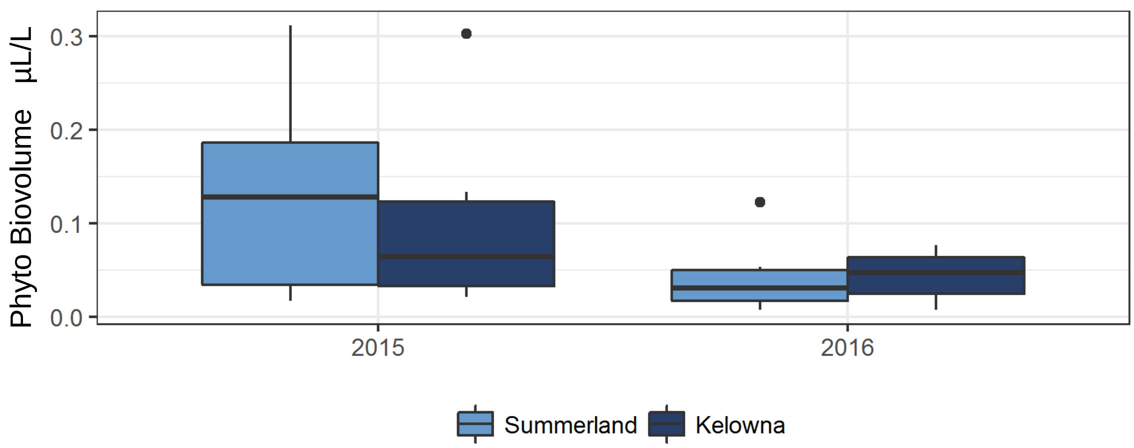


Figure 2.3.2: Phytoplankton Biovolume at Summerland and Kelowna, 2015-2016

Phytoplankton Taxonomy

Algae samples were identified to the species level and then grouped into broad algae types for analysis in this report. Diatoms tend to bloom in the spring and then their numbers decreased as the summer progressed. Cyanobacteria were always numerous in Okanagan Lake, but peaked in the late-summer. Cyanobacteria dominated the algae counts during 2016 at 18,000 cells/mL in Kelowna September samples (Figure 2.3.3, Table 2.3.3).

Algae counts, in particular cyanobacteria counts, were very low in 2015 while chlorophyll-a and biovolume were in line with previous years because cyanobacteria do not use chlorophyll-a as their primary photosynthetic pigment and inflate cell counts without contributing much to the total biovolume. Algae counts were much higher in 2016 and were more in line with previous years (Figure 2.3.4). The lab used to identify algae species changed between 2014 and 2015 and may be a factor in the apparent drop in 2015 algae counts relative to previous years.

Table 2.3.3: Average phytoplankton counts by major algae groups in cells/mL, 2016

Algae Type	2016 Averages Kelowna	Summerland
Diatoms	163	211
Greens	162	111
Yellow-Brown	394	289
Cyanobacteria	5742	5027
Dinoflagellates	28	5
Euglenoids	0	0
Total Algae	**6490**	**5643**

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. All 2016 samples exceeded this objective (7/7 samples at each site (Figure 2.3.5). There were no year-over-year trends in the heterocystous cyanobacteria counts from 2011-2015; 2016 results were unusually high and skewed trends. The cause of the large jump in heterocystic algae counts was not clear.

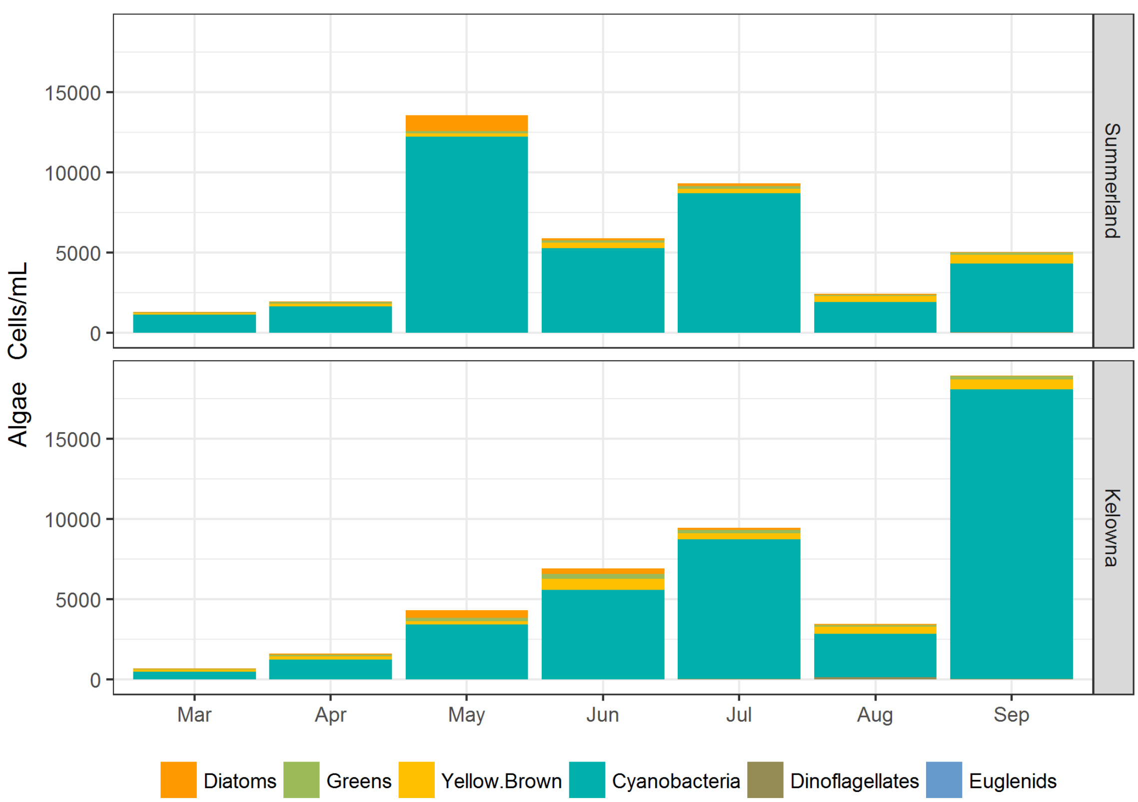


Figure 2.3.3: Taxonomic breakdown of algae by major types at Summerland (top) and Kelowna (bottom), 2016

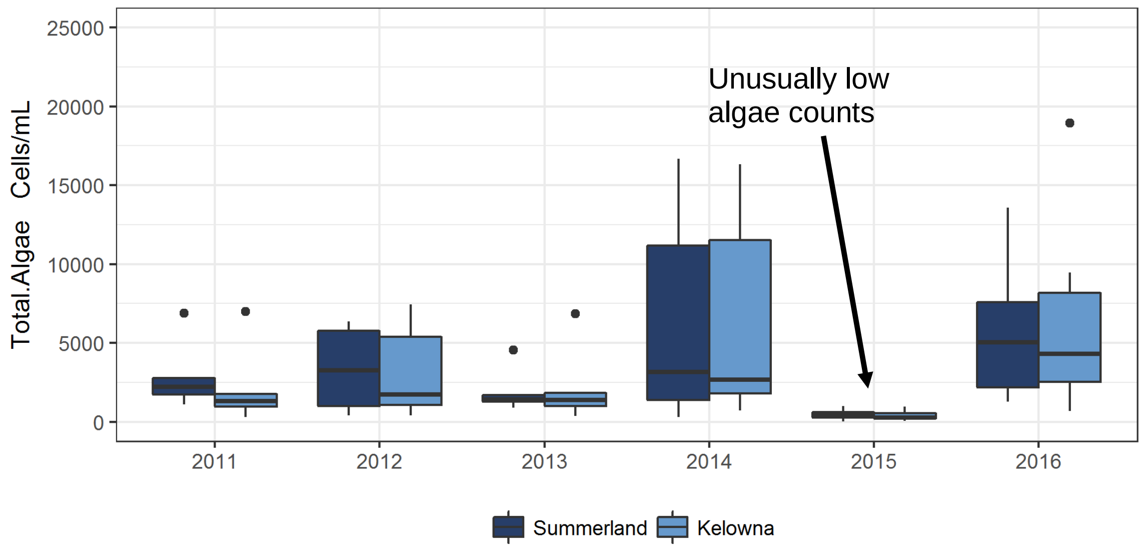


Figure 2.3.4: Total algae counts at Summerland and Kelowna, 2011-2016

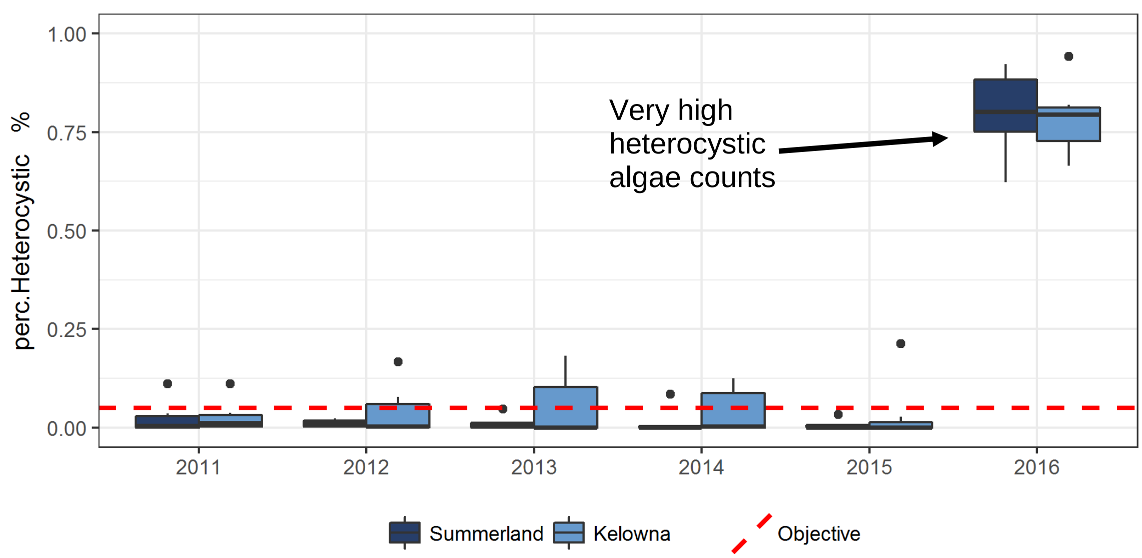


Figure 2.3.5: Percent of total algae counts that were heterocystic cyanobacteria, 2011-2016

2.3.2 Zooplankton

Biomass

Zooplankton biomass samples were obtained using a 150 µm net lowered to 45 m and raised vertically at a rate of approximately 0.5 m/second. The 150 µm net mesh size lets most phytoplankton pass through, while collecting most zooplankton. Samples were identified taxonomically and the biomass was calculated from the abundance. In previous years, AFDM was used to calculate the zooplankton biomass. The change in methodology may be responsible for the apparent change in zooplankton between 2014 and 2015. The Okanagan Lake objective is a growing season average of >50 µg/L (Nordin, 2005). This objective was met at Kelowna but not at Summerland in 2016 (Table 2.3.4). The two years of data using the new analytical method was not sufficient to determine trends in zooplankton biomass (2.3.6).

Table 2.3.4: Zooplankton biomass in µg/L at Okanagan Lake sampling sites, 2016

Site	Objective	Avg	SD	Max	Min	Trend
Kelowna	>50	91.6	51.6	164.1	16.6	91.6
Summerland	>50	34.8	17.7	57.3	6.7	34.8

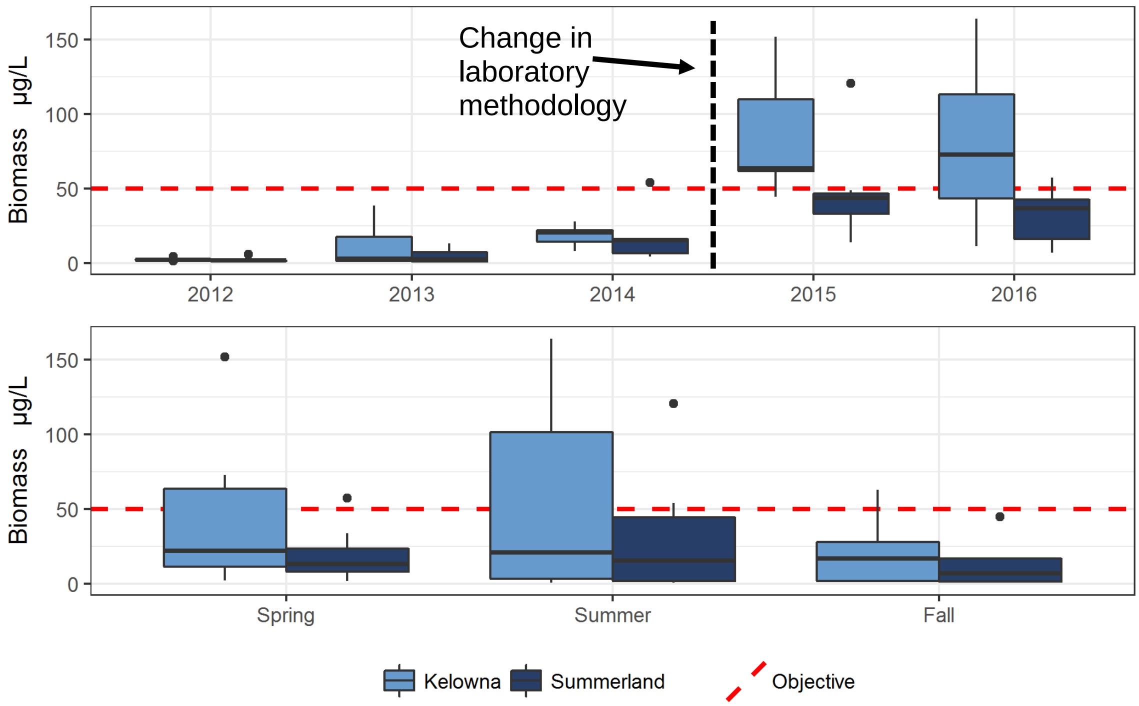


Figure 2.3.6: Zooplankton Biomass at the Kelowna and Summerland sampling locations by year (top) and season (bottom), 2012-2016

Note: In 2015 report, there was an incorrect unit conversion when comparing different sampling methodologies used in 2012-2014 and 2015.

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 49 ± 34% at Kelowna and 79 ± 44% at Summerland in 2016 (Table 2.3.5, Figure 2.3.7). The objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. 43 % of samples at Summerland met this objective but no samples at Kelowna met the objective during 2016. The average was 3 ± 4 % of zooplankton counts were cladocerans. Mysid shrimp and kokanee salmon prefer to eat cladocerans and their consumption 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). There was a large increase in rotifers at Kelowna in 2016 but there were no longer term year-over-year trends in the zooplankton taxonomic data. (Figure 2.3.7).

Table 2.3.5: Average zooplankton by major taxonomic groups, 2016

Zooplankton Type	Kelowna	Summerland
Copepods	49%	79%
Cladocerans	2%	5%
Rotifers	49%	15%
Mysids	0%	0%
Chironomids	0%	0%
Total Zooplankton	100%	100%

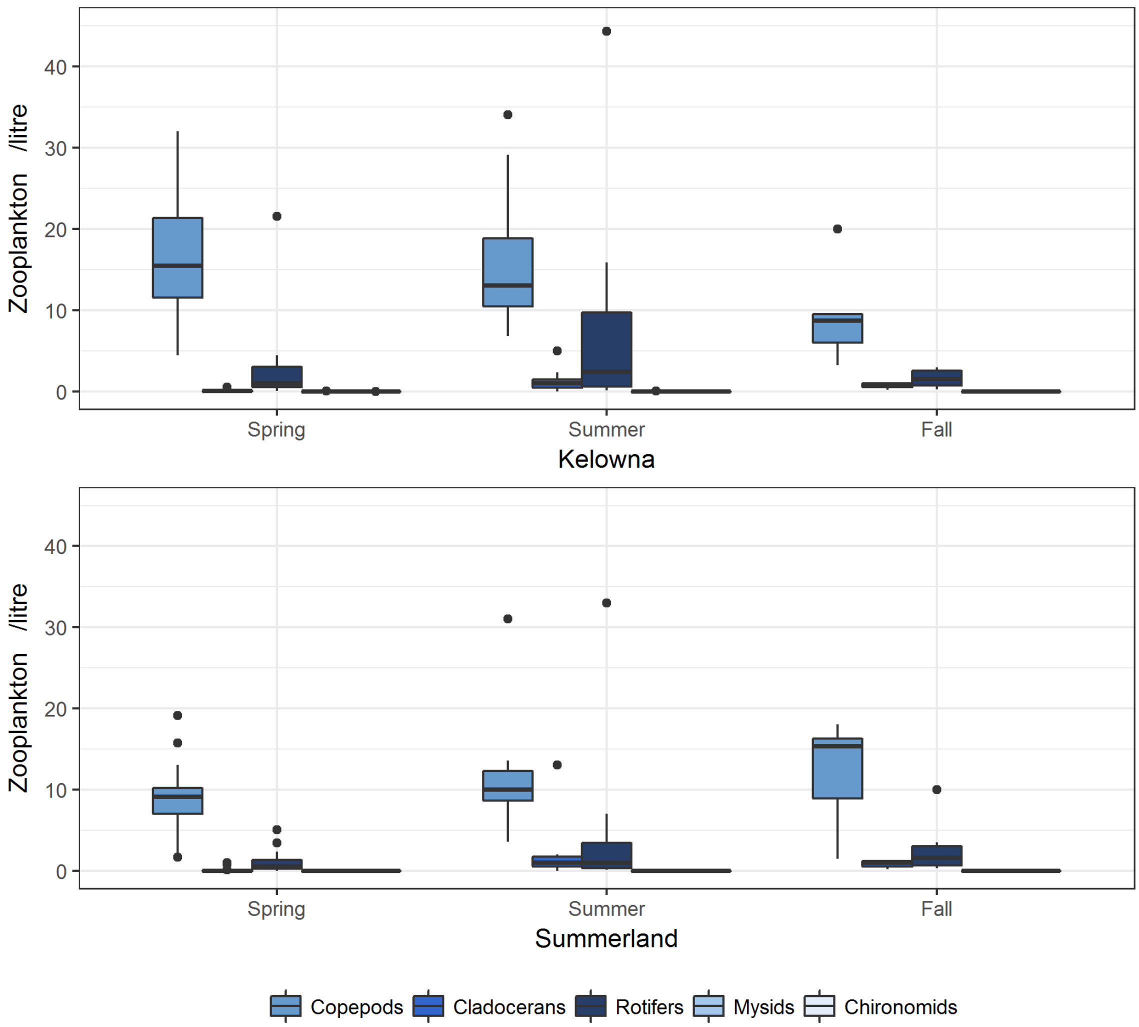


Figure 2.3.7: Breakdown of number of individual zooplankton per sample by major taxonomic types at Kelowna (top) and Summerland (bottom), 2011-2016

3.0 Conclusions

This report summarizes the 2016 results and extracts trends from the data accumulated by the Okanagan Lake Collaborative Sampling program to date (2011-2016).

Each year the temperature of Okanagan Lake increased in the surface waters until the lake became thermally stratified, usually in May. This physical dynamic, isolated 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 objective in 2016, as it has in each year of this study. Surface water dissolved oxygen concentrations decreased year-over-year throughout the lake from 2011-2016, indicating probable climactic variation.

Chemical analysis of water samples revealed no long-term trends in silica concentrations. Total nitrogen has been stable at all sites from 2011-2016 but nitrate+nitrite increased significantly in the Armstrong Arm and in the hypolimnion at Summerland over the same period. Total nitrogen exceeded the water quality objectives at all sites except Okanagan Centre during 2015 but only the Summerland epilimnion samples during 2016. Phosphorus concentrations were highest in the Armstrong Arm where phosphorus concentrations exceeded the objective during 2016, but only in the hypolimnion. Dissolved phosphorus increased slightly from 2011-2014 and then leveled off or decreased at the three southern sites, but it increased steadily in the Armstrong Arm from 2011-2015, before also decreasing in 2016. Samples from the Armstrong Arm exceeded the nitrogen-phosphorus ratio objective in 2016 and there was a decreasing trend in that ratio in the Armstrong Arm from 2011-2016.

Chlorophyll-a concentrations increased each spring during the annual diatom bloom and then decreased over the summer and into the fall. There was a weak increasing trend detected for chl-a at Ok Centre because its concentration increased between 2015 and 2016. All sites met the seasonal average chlorophyll-a water quality objective of 4-5 µg/L for Okanagan Lake. Phytoplankton biovolume met the objective in 2016 as well but a change in methodology in 2015 prevented a trend analysis.

The taxonomic data indicated that cyanobacteria numerically dominated the phytoplankton samples in 2016 while overall counts were similar to previous years. Seven out of seven samples from Kelowna and from Summerland exceeded the phytoplankton objective of <5% of algae as heterocystous cyanobacteria during 2016. The cause of the increase in cyanobacteria during 2016 was not clear from the nutrient data.

Zooplankton biomass was stable from 2015-2016. Zooplankton biomass met the objective of >50 µg/L at Kelowna but not at Summerland during 2016. Copepods numerically dominated most samples. The water quality objective of >5% of zooplankton as cladocerans was achieved in 43% of samples at Summerland but 0% of Kelowna samples in 2016.

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

- Chronically low Secchi depth in the Armstrong Arm
- Decreasing dissolved oxygen concentrations throughout the lake
- Increasing nitrate in hypolimnion at Summerland

- Increasing total phosphorus and dissolved phosphorus in the Armstrong Arm
- Decreasing N:P ration in the Armstrong Arm
- Unusually high heterocystic cyanobacteria concentrations during 2016

Tables 3.1 and 3.2 summarizes the findings of this report for 2016 by pairing trends to objective exceedances. Special focus should be paid to parameters that did not meet the objective and for which the data trended in the adverse 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 likely be more productive than the deep basins of Okanagan Lake regardless of human activity. However, human activities in the watershed have impacted this northern-most basin of the lake.

Table 3.1: Okanagan Lake Water Quality Objectives and 2016 values with exceedances

Objectives (Nordin, 2005)	**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 (µL/L) (growing season average)	<0.75	<0.75	<0.75	<0.75
Zooplankton Biomass (µg/L) (growing season average)	>50	>50	>50	>50
Zooplankton Taxonomy (% cladocerans)	>5%	>5%	>5%	>5%

Objective	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth (m)	6.8 ± 1.6	6.1 ± 0.7	6.4 ± 0.6	3.5 ± 0.8
Dissolved Oxygen (mg/L)	7.25 (Aug)	8.06 (Aug)	7.43 (Sep)	1.2 (Sep)
TP (mg/L)	0.005	0.005	0.006	0.009
	0.003	0.008	0.003	0.017
Chlorophyll-a (µg/L)	2.66 ± 1.25	2.35 ± 0.57	2.79 ± 0.30	3.86 ± 1.01
TN (mg/L)	0.213	0.213	0.216	0.255
	0.229	0.222	0.192	0.264
N:P Ratio	45:1	41:1	38:1	29:1
	80:1	48:1	57:1	17:1
Algae Taxonomy (% heterocystous cyanobacteria)	80%	78%		
Algae Biomass (µL/L)	0.048 ± 0.040	0.050 ± 0.023		
Zooplankton Biomass (µg/L)	34.8 ± 17.7	91.6 ± 51.6		
Zooplankton Taxonomy (% chaldocerans)	5 ± 4%	2 ± 1%		

Legend:

Met objective in 2015	Did not meet objective in 2015	No Data/ No Objective

Table 3.2 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	- (did not meet)	- (met)	- (met)	- (did not meet)
Dissolved Oxygen	↓ (no data/no objective)	↓ (no data/no objective)	↓ (no data/no objective)	↓ (did not meet)
TP (mg/L)	- (met)	- (met)	- (met)	↑ (did not meet)
Chlorophyll-a (µg/L)	- (met)	- (met)	↑ (met)	- (met)
TN (mg/L)	- (did not meet)	↓ (met)	↓ (met)	- (met)
N:P Ratio	- (met)	- (met)	- (met)	↓ (did not meet)
Algae Taxonomy (% heterocystous cyanobacteria)	- (did not meet)	- (did not meet)	(no data/no objective)	(no data/no objective)
Algae Biomass (µL/L)	- (met)	- (met)	(no data/no objective)	(no data/no objective)
Zooplankton Biomass (µg/L)	- (did not meet)	- (met)	(no data/no objective)	(no data/no objective)
Zooplankton Taxonomy (% cladocerans)	- (did not meet)	- (did not meet)	(no data/no objective)	(no data/no objective)

Legend:

Met objective in 2015	Did not meet objective in 2015	No Data/ No Objective
↑ = Increasing Trend	↓ = Decreasing Trend	- = No Trend

4.0 Recommendations

The Okanagan Collaborative Program is currently in the midst of a three year (2015-2017) term. At this time, no changes to the sampling program are recommended. However, we do recommend that phytoplankton taxonomy results continue to be supplied in “cells/L or cells/mL” for consistency with the historic data. It is also recommended that at the end of the current term (2017), a comprehensive multi-year synthesis report be compiled summarizing the status of the program to date and make any necessary recommendations to the program moving forward.

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Appendices

Appendix 1 2016 Sampling Data

All data used in this report can be found in the data transfer file
MoE-Synth-DB.xlsx