Okanagan Lake Collaborative Monitoring Agreement
2011-2020 Synthesis Report

Prepared for BC Ministry of Environment and Climate Change Strategy,
Environmental Protection Division

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Executive Summary

The British Columbia Ministry of Environment and Climate Change Strategy (BC ENV) in partnership with local municipalities, commissioned a multi-year collaborative monitoring program to sample water quality in Okanagan Lake. Sampling occurred monthly from March to September at four locations from 2011 to 2020. A primary function of the monitoring was 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. Similar to previous years, 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 including phytoplankton and zooplankton biomass with taxonomic identification were also collected. This report summarizes the 2011-2020 findings while highlighting 2020 and sets these recent data within the larger context, including the entire historical dataset (1973-2020).

The results to date indicate that the Armstrong Arm is the most impacted by human activities and watershed degradation. These Impacts include including agriculture, cattle range, logging and septic systems adjacent to the shoreline. This site had the most exceedances and the most parameters trending towards greater exceedances. Weather was the dominant factor on water quality at Okanagan Centre, Kelowna, and Summerland but long-term data still demonstrates human impacts.

Physical

Okanagan Lake is usually stratified from May to November, it mixes in mid-November and then freely mixes over the winter. Secchi depth was highest in late winter and decreased each spring in response to increased phytoplankton activity. Water clarity was typical for Okanagan Lake in 2020 after two years of poor water clarity from the 2017 and 2018 flooding events. Only the Armstrong Arm failed to meet the Secchi depth objective in 2020, as it did in every year to date.

Chemical

Dissolved oxygen (DO) is essential for all aquatic animals and is high throughout Okanagan Lake at all times except in hypolimnion of the Armstrong Arm where DO fell below the water quality objective each summer including 2020; however, there were no fully anoxic conditions in 2019-2020, an improvement over 2016-2018. Silica concentrations were higher during 2017-2018 because of the intense freshets during those years but no long-term trend developed.

Total nitrogen (TN) exceeded the objective at all sites during 2020 as it did in most years. There were significant increasing trends in TN from 2011-2020 at Summerland, Okanagan Centre, and Armstrong Arm, driven in part by a decades-long increasing trend in nitrate in the deep water of Okanagan Lake. This increasing nitrate trend has continued through multiple wet-dry climate cycles and is likely caused by increasing human impacts within the Okanagan region.

Total phosphorus (TP) had a year-over-year increasing trend at all sites except Summerland from 2011-2020, and forms part of a longer-term trend since the mid-2000s. TP includes phosphorus associated with suspended sediment carried into the lake. It increased in Okanagan Lake during wet years such as 2017-2018 and decreased during dry years such as 2019. Dissolved phosphorus

is less affected by freshets than TP and was stable over the past 20 years at all sites, averaging much lower than the 1970s.

The ratio of total nitrogen to total phosphorus (N:P) available to phytoplankton will play a major role in which types of phytoplankton proliferate in a lake. A lower N:P ratio (abundant phosphorus relative to nitrogen) will favour the growth of less desirable cyanobacteria. The N:P ratio failed to meet the objective in the Armstrong Arm in 2020 with a downwards trend (farther from meeting objective).

Biological

Chlorophyll-a was used as a measure of photosynthetic activity in Okanagan Lake. A decreasing north to south trend in the chlorophyll-a data occurred over the course of this study. All sites met the chlorophyll-a objectives during 2020. Chlorophyll-a was lower during 2019 and 2020 compared to the very high 2018 values because of the drier conditions and lower freshet nutrient inputs after 2018. However, a significant increasing trend occurred at all sites from 2011-2020, part of a trend since the mid-2000s. Previous research by ENV had identified a one-year lag between major nutrient inputs and increases in phytoplankton productivity. Productivity in 2021 may be high again after the large 2020 freshet.

Phytoplankton abundance during 2020 was lower than 2018 and consistent with the 2015-2020 data for Okanagan Lake. All sites met the phytoplankton biovolume objective but failed to meet the phytoplankton taxonomy objective during 2020. The Armstrong Arm experienced high densities of cyanobacteria that dominated production during 2020 with over half of observed abundance being composed of potentially toxic taxa on some dates.

Zooplankton biomass met the objective at Kelowna and Summerland in 2020; Summerland has failed to meet the objective in half of the years to date. Kelowna and Summerland both failed to meet the objective of >5% cladocerans in 2020. No significant trends in zooplankton data occurred to date.

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
- Increasing nitrate in hypolimnion of Okanagan Lake since 1970s
- Increasing total phosphorus at all sites except Summerland since early 2000s
- Increasing chlorophyll-a throughout the lake since early 2000s
- Decreasing N:P ratio in the Armstrong Arm
- High densities of potentially toxic cyanobacteria in Armstrong Arm during 2018-2020

Water Quality Objectives, 2011-2020 Values, and Trends for Okanagan Lake

Table 1: Okanagan Lake water quality objectives

Parameter (Nordin, 2005)	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth (growing season average: Apr-Sep)	>7m	>6m	>6m	>5m
Dissolved Oxygen (minimum in bottom waters)	-	-	-	>5 mg/L
TP (mg/L as P) (maximum at spring overturn)	<0.007	<0.008	<0.008	<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%

Table 2: Attainment of Okanagan Lake water quality objectives compared to growing season averages during 2011-2020

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth	7.2	6.7	6.9	3.4
Dissolved Oxygen	9.99	9.99	9.97	3.67
TP (mg/L) 0:10m:	0.005	0.007	0.006	0.011
20-45m:	0.004	0.006	0.005	0.02
Chlorophyll-a (µg/L)	1.71	1.97	2.15	4.15
TN (mg/L) 0-10m:	0.233	0.229	0.229	0.265
20-45m:	0.239	0.255	0.238	0.309
N:P Ratio 0-10m:	53:1	44:1	45:1	32:1
20-45m:	62:1	62:1	57:1	19:1
Algae Taxonomy (% heterocystous cyanobacteria)	11.8%	11.3%	14.4%	30.4%
Algae Biovolume (µL/L)	0.336	0.201	0.656	0.348
Zooplankton Biomass (µg/L)	46.6	69.4	77.2	111.7
Zooplankton Taxonomy (% cladocerans)	4.2%	3.7%	2.2%	6.1%

Legend:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Table 3: Summary of trends compared to attainment of water quality objectives in Okanagan Lake during 2011-2020

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth	-	-	-	-
Dissolved Oxygen	-	-	-	-
TP (mg/L) 0:10m:	-	↑	↑	↑
Chlorophyll-a (µg/L)	↑	↑	↑	↑
TN (mg/L) 0-10m:	↑	-	↑	↑
N:P Ratio 0-10m:	-	-	-	↓
Algae Taxonomy (% heterocystous cyanobacteria)	-	-	-	-
Algae Biovolume (µL/L)	↑	↑	-	-
Zooplankton Biomass (µg/L)	-	-	-	-
Zooplankton Taxonomy (% cladocerans)	-	-	-	-

Legend:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

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

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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 that may result in surface scum depending on type of algae that is blooming
Anoxic	Devoid of oxygen
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
Hypoxic	Very low dissolved oxygen
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
Phytoplankton	Algae that float, drift or swim in water columns of reservoirs and lakes
Plankton	Those organisms that float or swim in water
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
Thermocline	The lake zone of greatest change in water temperature with depth (> 1°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
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
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	Phytoplankton density (cells/mL)	Phytoplankton biomass (mg/m³)
Oligotrophic	0 – 2	1 – 10	<100	> 6	<1000	0-500
Mesotrophic	2 – 5	10 – 20	100 – 500	3 – 6	1000-5000	500-2000
Eutrophic	>5	> 20	500-1000	< 3	>5000	>2000

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

1.0 Introduction

1.1 Overview

The British Columbia Ministry of Environment and Climate Change Strategy (ENV) 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 ENV staff, Okanagan Nation Alliance (ONA; 2011), and Larratt Aquatic Consulting (2012-2019). Okanagan Lake was sampled monthly from March to September from 2011-2020 at four key sites (Figure 1, Table 4).

Table 4: GPS coordinates of sampling sites

Site Name	EMS ID	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°

Note: EMS = Environmental Monitoring System and serves as ENV's database of water quality

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 3). 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 throughout this study.

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

The 2020 data were added to the existing 2011 – 2019 database upon which all the analyses in this report were performed. Water quality objectives were based upon Nordin (2005) (Appendix 1).

Figure 1: Okanagan Basin Watershed with four sampling locations identified

1.2 Weather and Climate Conditions in 2020

The weather during any given year will have a major impact on physical conditions, water chemistry, and biological activity in Okanagan Lake during that and subsequent years. The weather during 2017 and 2018 was very unusual for the Okanagan region. 2017 had the record highest flooding of Okanagan Lake followed immediately by the driest summer recorded. 2018 had a long, cold, and snowy winter followed by a wet spring, that combined to create a very intense freshet and minor flooding throughout the valley (Figure 2). The 2018 spring flooding was followed by a very hot and dry summer in which the Okanagan experienced weeks of intense smoke and ash from wildfires. Weather conditions during 2019 were much closer to the historic normal for the Okanagan while 2020 experienced a large snowpack and very high springtime water levels (Figure 2).

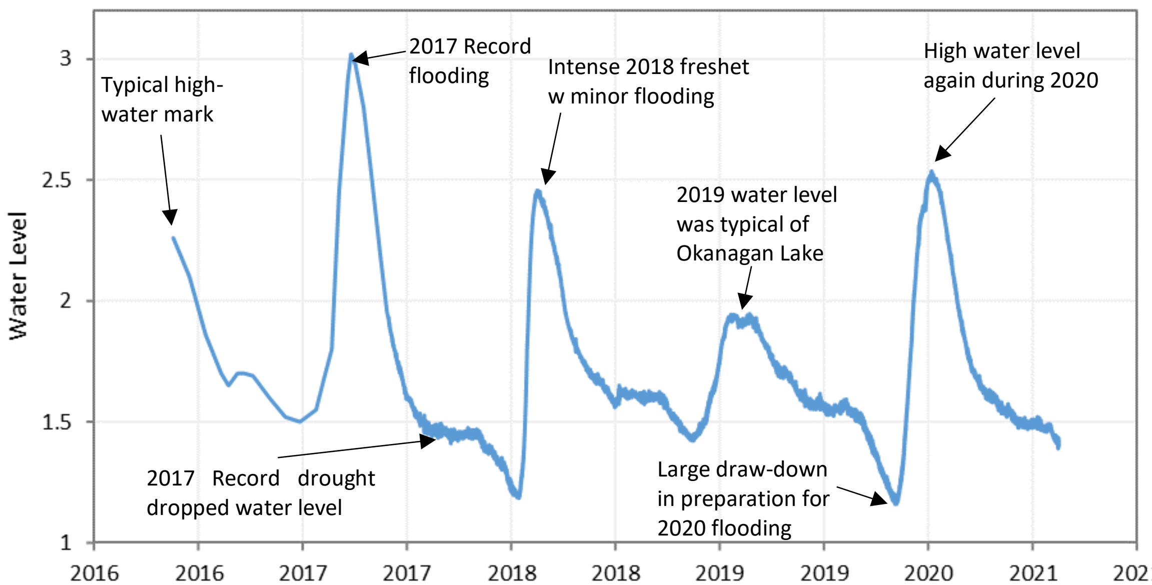

Figure 2: **Water level in Okanagan Lake at Kelowna from Jun 2016 – Jan 2021**
Source: (Water Office, 2020)

2.0 Results & Discussion

2.1 Physical

2.1.1 Temperature

Okanagan Lake is a deep monomictic lake. 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 changes temperature by less than 4 °C annually (Figure 3).

The three main basin sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal behavior while the northern Armstrong Arm site is shallower and reaches a higher surface temperature each summer (Figure 3). 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 2011–2020 temperature data either annually, seasonally, but there was a declining trend in August surface temperatures at Okanagan Centre (Mann-Kendall trend tests).

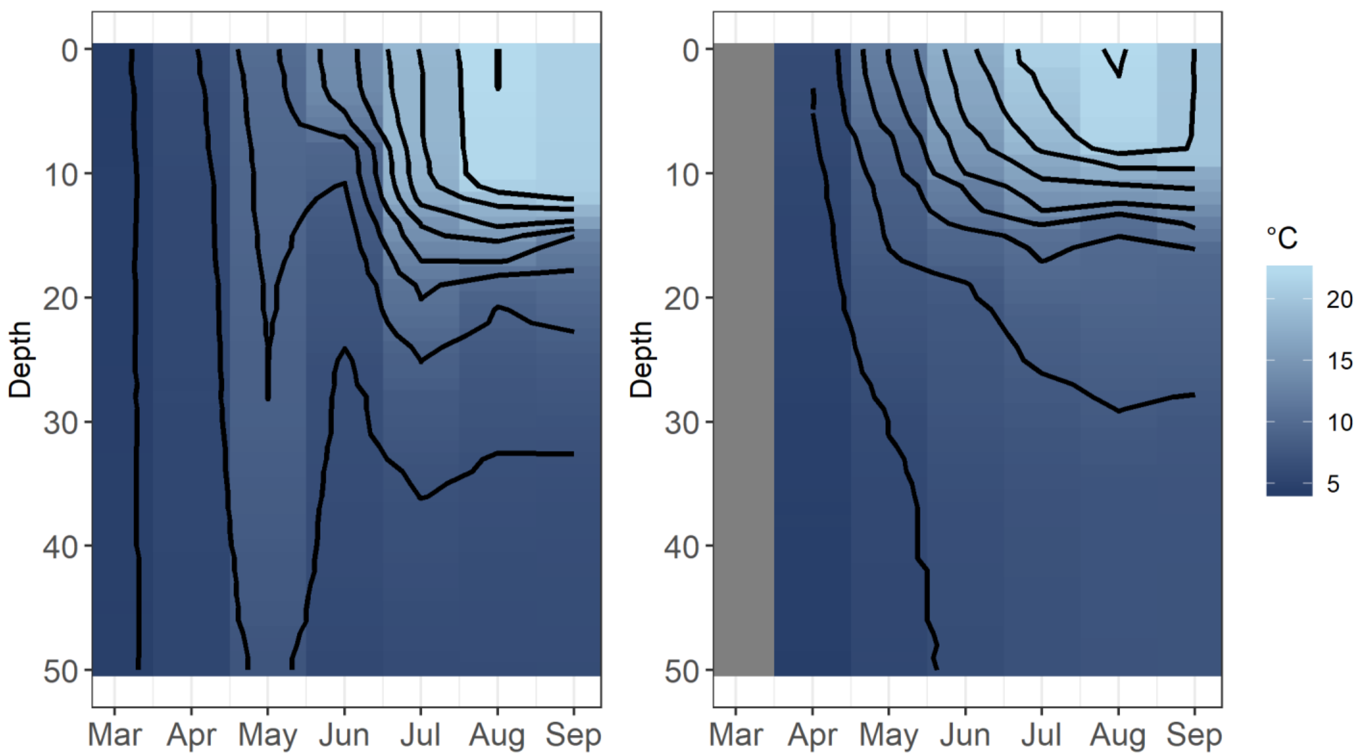

Figure 3: Temperature profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right), 2020

Notes: Lines represent contours of same temperature or dissolved oxygen within the water column through time. Samples not collected during March 2020 at Armstrong Arm because of ice-cover

Surface water temperatures of Okanagan Lake at all four sites were below average throughout most of 2020 with Okanagan Centre and the Armstrong Arm having record cool temperatures in May – June (Figure 4).

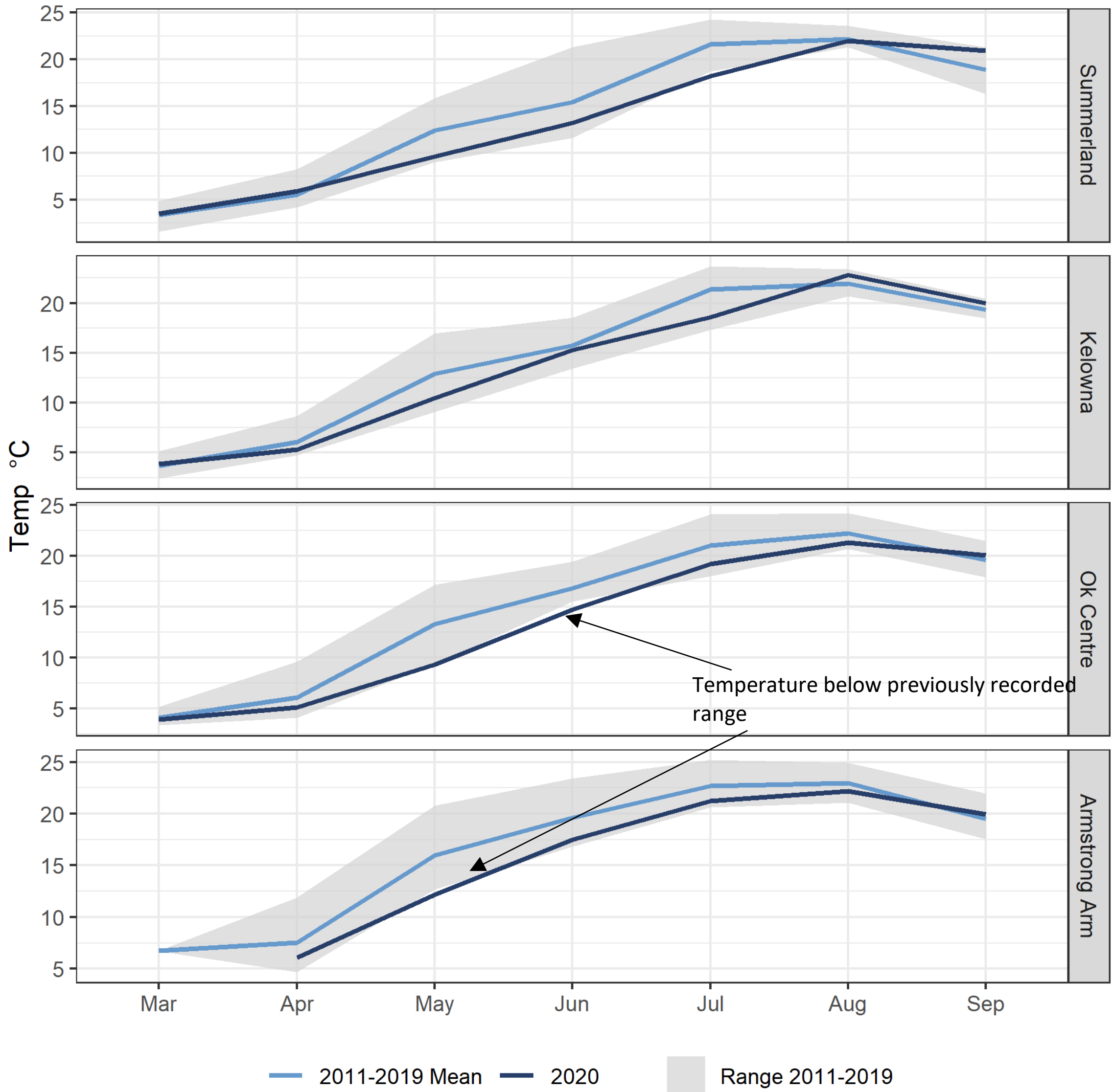

Figure 4: Temperature at Okanagan Lake sampling sites during 2020 compared to 2011-2019

2.1.2 Water Clarity and Secchi Depth

Secchi depth during 2020 ranged from a minimum of only 1.9 m at Armstrong Arm in May to a maximum of 13.4 m at Okanagan Centre in March (Table 5). Secchi depth averages returned to near the 10-year average after the below average water clarity of 2017-2018 (Figure 5, Figure 6). Armstrong Arm was the only site to fail to meet the objective during 2020, as it has in every year of this study (Table 5). The overall average for Okanagan Lake historically has been 6.5-6.6 m and averaged 6.8 ± 3.3 m in 2020 (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 increased spring algal growth and freshet, 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 5).

The Secchi depth in the Armstrong Arm was much lower than at the other sites in Okanagan Lake during all years. This is clearly illustrated in Figure 6. Secchi depth was stable over the past 10 years and there were no statistically significant year-over-year trends in the Secchi depth data from 2011-2020 but there was a significant drop when the 1973-2020 historical data was considered (Mann-Kendall tests, Figure 6). This long-term trend is related to a period of high water-clarity in the years following the installation of nutrient removal systems at wastewater treatment plants; the current lower water clarity likely relates to the cumulative effects of increased population and human activities within the Okanagan watershed over the past 30 years.

Table 5: Growing Season (Apr-Sep) Secchi depth in meters at Okanagan Lake sampling sites, 2020

2020	Site	Objective	Average	StdDev	Max	Min
	Summerland	7.0	8.0	2.3	10.4	5.3
	Kelowna	6.0	6.9	2.3	10.2	4.4
	Ok Centre	6.0	6.5	2.1	10.0	4.6
	Armstrong Arm	5.0	3.2	1.3	4.9	1.9

2011-2020	Site	Objective	Average	StdDev	Max	Min	Trend
	Summerland	7.0	7.2	2.2	12.2	1.9	-
	Kelowna	6.0	6.7	2.2	10.9	1.7	-
	Ok Centre	6.0	6.9	2.0	11.2	3.1	-
	Armstrong Arm	5.0	3.4	1.0	5.6	1.0	-

Legend:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Note: Objective refers to growing season average (Apr-Sep); Coloured shading indicates status of objective during that year with green meaning met objective and red meaning failed to meet objective

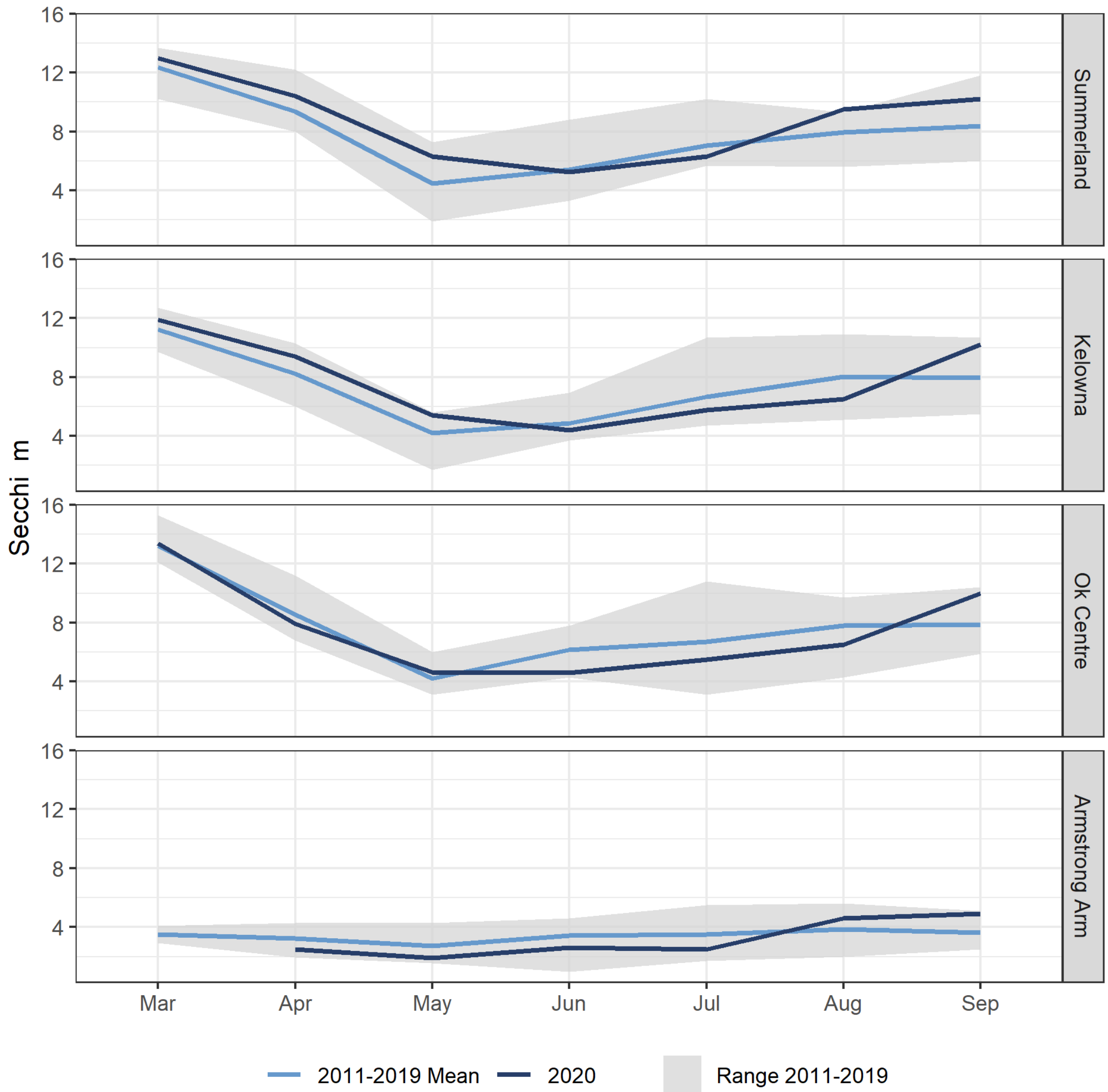

Figure 5: Secchi depth at Okanagan Lake sampling sites during 2020 compared to 2011-2019

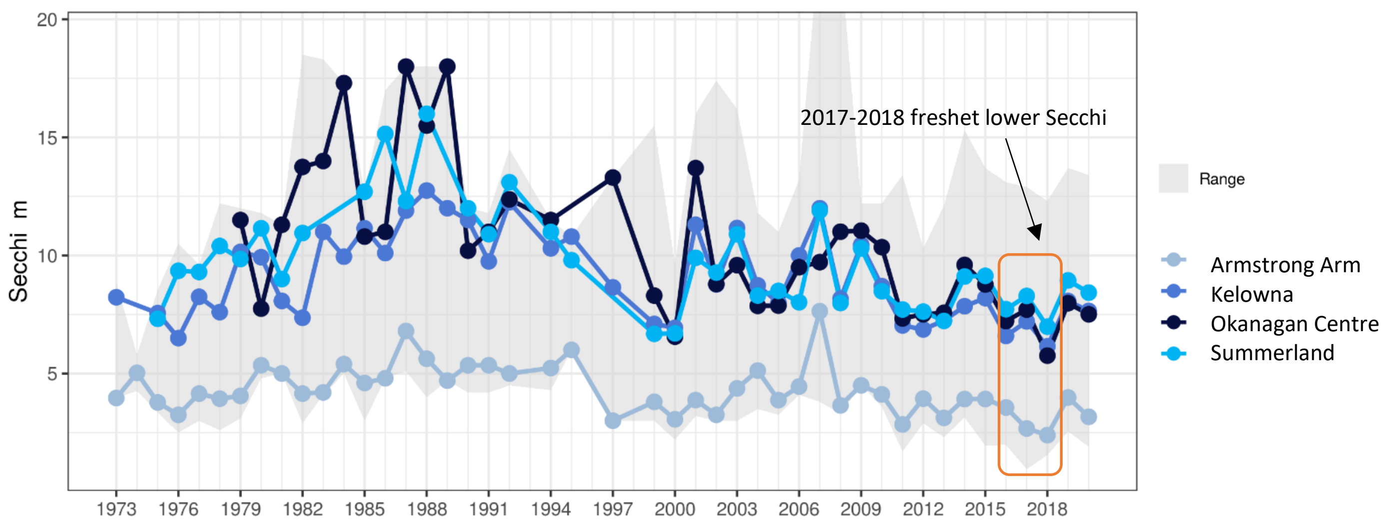

Figure 6: Annual average secchi depth in Okanagan Lake from 1973-2020

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 frequently result from 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

Dissolved oxygen (DO) is essential for all aquatic animals. Low DO will stress fish and possibly preclude them from certain portions of the water column. Hypoxic conditions occur when DO is very low (<2 mg/L) and this has a profound impact on water chemistry through the mobilization of nutrients and metals from the sediment. The three sites (Summerland, Kelowna, and OK Centre) exhibit similar thermal and high dissolved oxygen behavior while the northern Armstrong Arm site is shallower and behaves differently. The later reaches a higher surface temperature and experiences a reduction in dissolved oxygen in the deep water each summer (Figure 7). The reduction in dissolved oxygen is caused by decomposition of organic material in the sediment and deep water and can lead to internal nutrient loading if oxygen becomes depleted. The Armstrong Arm is the only site with a dissolved oxygen objective (>5 mg/L in bottom water), a threshold that it fails to meet every year. By September 2020, the low dissolved oxygen zone (depth below red line in Figure 7) had expanded to 20 m thick but no water below 2 mg/L developed during 2019 or 2020, an improvement over the particularly large 2018 hypoxic zone.

As expected, surface dissolved oxygen concentrations vary throughout the year and have been stable throughout the lake during this study (2011-2020) and over the historical dataset (1973-2020) (Figure 8).

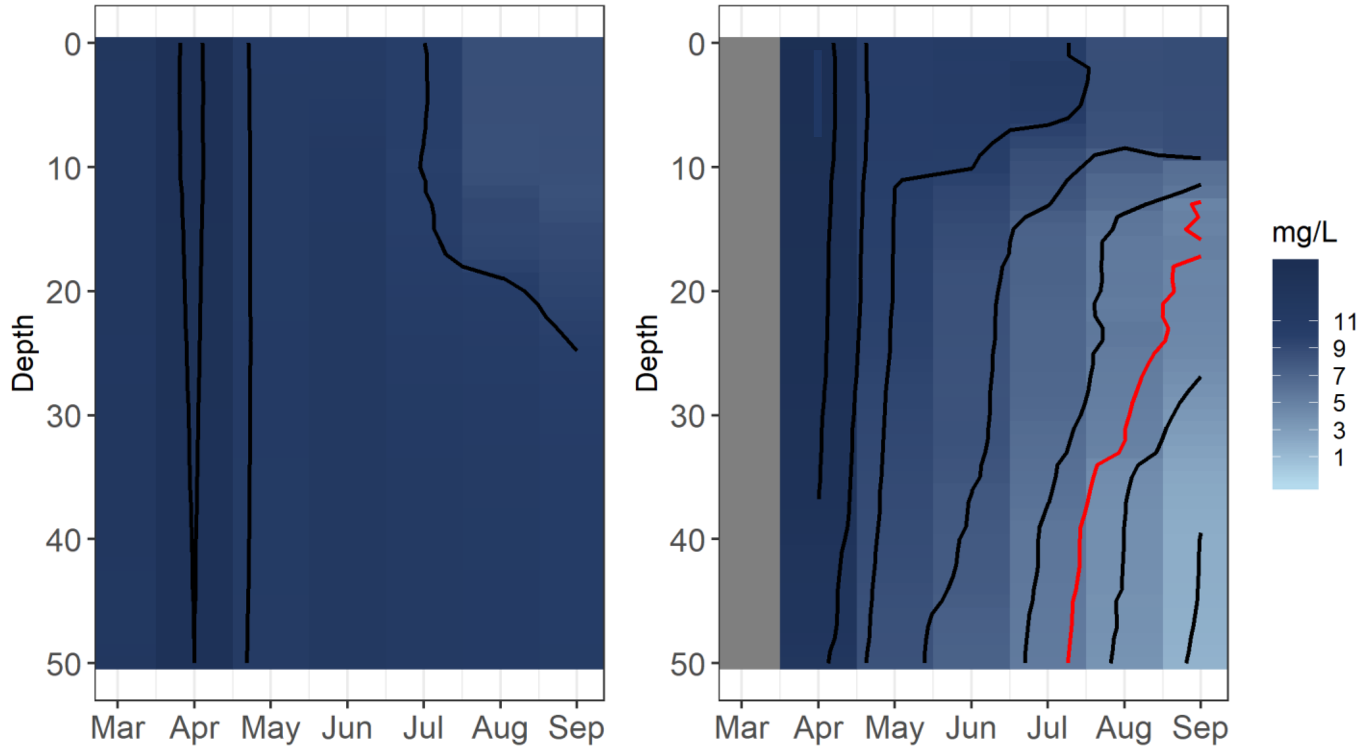

Figure 7: Dissolved oxygen profiles for Okanagan Lake at Summerland (left) and Armstrong Arm (right) during 2020

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.

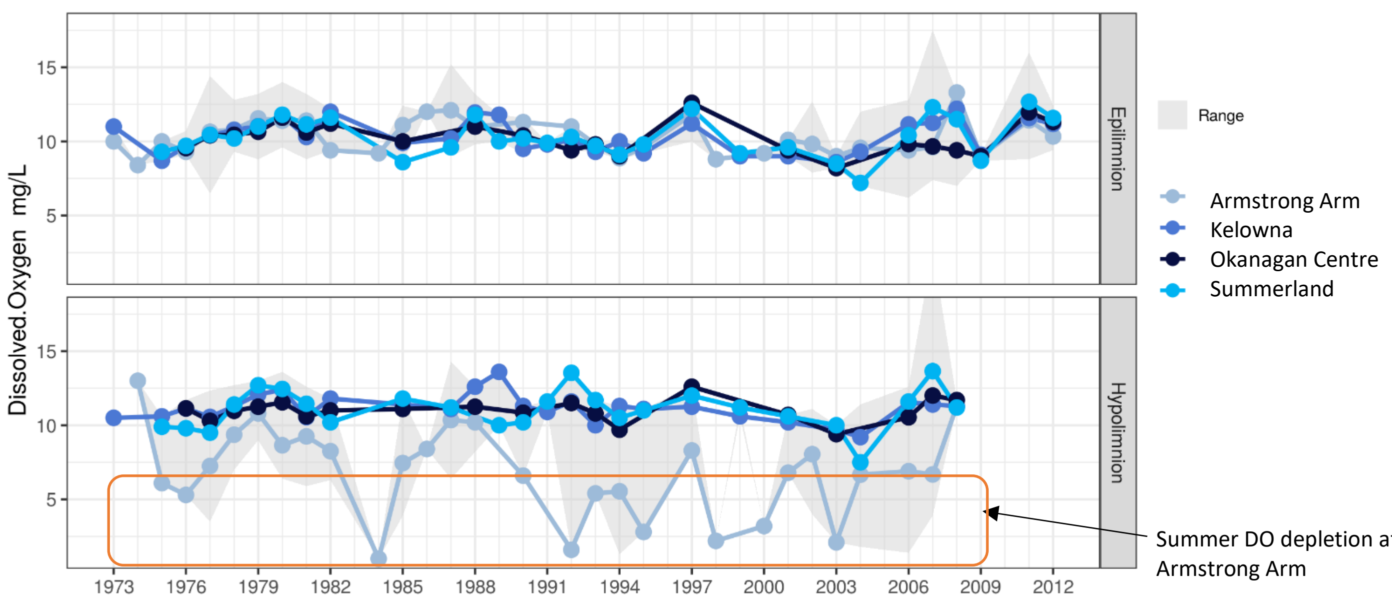

Figure 8: Annual average dissolved oxygen concentrations at Okanagan Lake sampling sites grouped by year, 1973-2012

2.2.2 Silica

Diatoms, a major group of algae in Okanagan Lake, use silica (measured as dissolved silica) as a structural building block for their cell walls. While no objectives for silica concentrations in Okanagan Lake have been set, monitoring continues as silica is a key micronutrient for this important group of algae. Silica sampling shifted to only March and September beginning in 2015 because it did not change significantly over the course of the growing season from 2011-2014. Silica was higher 2017-2018, likely an effect of the flooding and intense freshets during those years, but when looking at the long-term data, there was an increasing trend from the 1970s to 2000 but there was no trend in the silica data since the late 1990s (Table 6, Figure 9). The cause of the change in silica from increasing to stable is not known.

Table 6: Silica concentration in mg/L at Okanagan Lake sampling sites, 2011-2020

2020

Site	Average	StdDev	Max	Min
Armstrong Arm	*No*	*Data*	*From*	*2020*
Kelowna	7.46	0.81	8.19	6.31
Ok Centre	19.07	12.80	30.40	7.73
Summerland	7.54	0.57	8.26	6.87

2011-2020

Site	Average	StdDev	Max	Min	Trend
Armstrong Arm	7.23	1.51	11.80	2.99	↑
Kelowna	7.07	0.65	9.79	5.83	↑
Ok Centre	7.52	3.71	30.40	5.79	-
Summerland	7.04	0.57	8.41	5.75	-

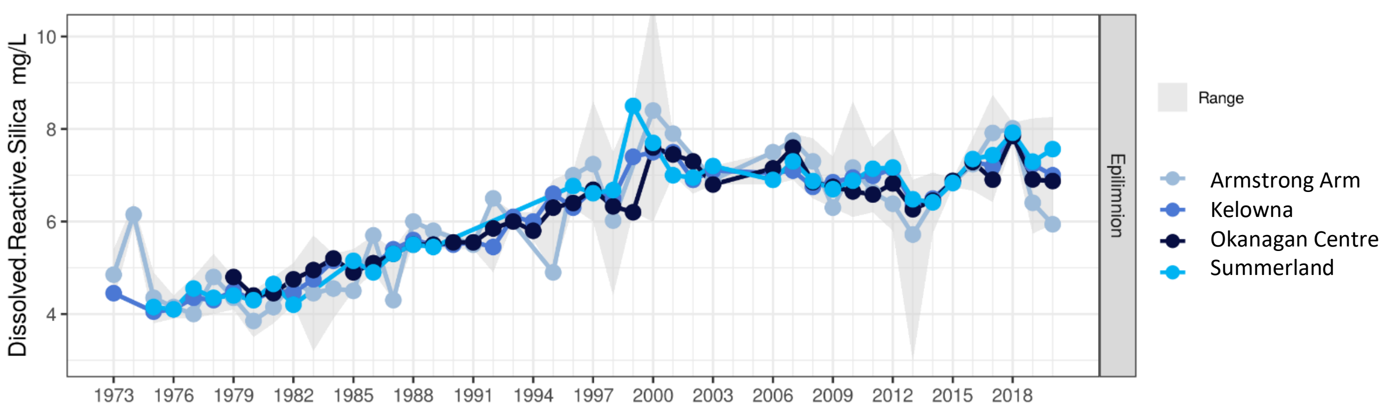

Figure 9: Annual average silica concentration in Okanagan Lake at each sampling site by year with trends highlighted, 2011-2020

2.2.3 Nitrogen and Phosphorus

Nitrogen and phosphorus are the most important nutrients in most aquatic environments. Nutrient limitation occurs when an essential element (typically nitrogen or phosphorus) is in relatively short supply. Algae production is limited by the availability of that nutrient despite potential abundance of other nutrients. In the Okanagan, phosphorus is the main limiting nutrient and its concentration is directly linked to the amount of algae that the lake produces (Nordin, 2005).

Nitrogen
Total nitrogen (TN) averaged 0.251 ± 0.031 mg/L as N in the epilimnion of Okanagan Lake during 2020. The objective for Okanagan Lake was set as a spring value (March sample date[1]) of 0.230 mg/L for the main basins and 0.250 mg/L for the Armstrong Arm. The objective was exceeded at all sites during 2020 as it has in most years (Table 7). TN increased in the Armstrong Arm from 2011-2020 (Mann-Kendall, $p<0.001$) and there were also increasing trends in TN in the hypolimnion at Okanagan Centre and Kelowna[2] (Table 7). However, when comparing the entire 1973-2020 database, there were long-term increasing trends in TN at Summerland, Kelowna, and Okanagan Centre while the higher historical TN concentrations mask the recent trend in the Armstrong Arm (Mann-Kendall tests, Figure 10). 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 7: Total nitrogen in mg/L as N concentration at Okanagan Lake sampling sites, 2011-2020

Site	Depth	Objective	2020	Exceeded in 2020?	% of years exceeding	Trend	Avg	SD	Max	Min
Summerland	<10m	0.230	0.258	Yes	80%	-	0.233	0.056	0.588	0.120
	>20m		0.251	Yes	50%	-	0.239	0.046	0.346	0.030
Kelowna	<10m	0.230	0.297	Yes	60%	-	0.229	0.044	0.502	0.130
	>20m		0.277	Yes	70%	↑	0.255	0.099	0.968	0.100
Ok Centre	<10m	0.230	0.270	Yes	70%	-	0.229	0.068	0.705	0.022
	>20m		0.261	Yes	60%	↑	0.238	0.056	0.463	0.022
Armstrong	<10m	0.250	0.344	Yes	50%	↑	0.265	0.076	0.642	0.181
Arm	>20m		0.299	Yes	80%	↑	0.309	0.079	0.511	0.165

Legend:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

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

[1] The Armstrong Arm sample is typically collected in early April because of ice-cover in that part of the lake
[2] There was a significant increasing trend in TN at Summerland from 2011-2020 when depths were combined as noted in the summary table in Section 3.1

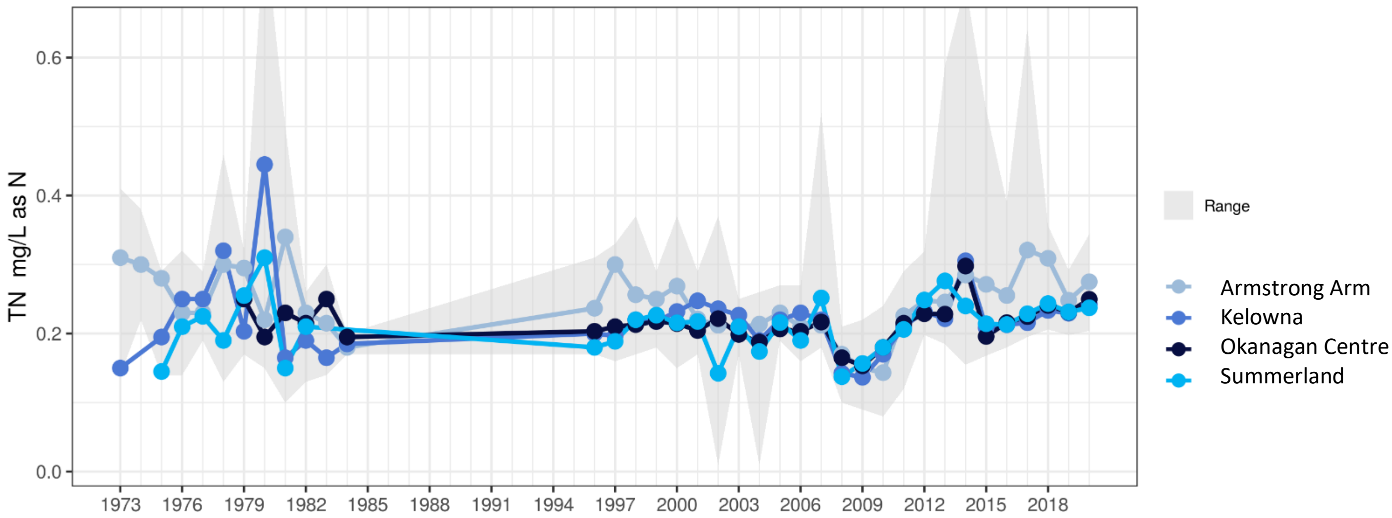

Figure 10: Annual average total nitrogen in Okanagan Lake, 1973-2020

Nitrate increased at all sites from 2011-2020 (Mann-Kendall, $p<0.001$;) Analysis of the entire Okanagan Lake water chemistry database indicates that this trend has been ongoing for decades (1973-2020 dataset; Mann-Kendall, $p<0.001$; Figure 11). This suggests a connection to human activities in the region because the trend has continued through several wet-dry climate cycles.

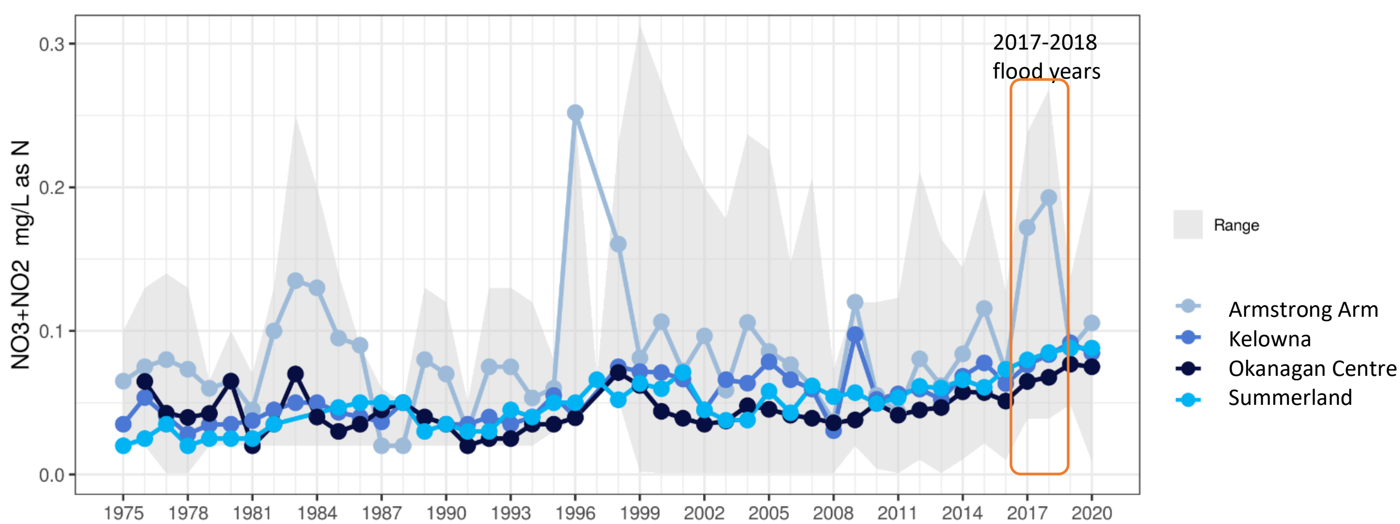

Figure 11: Annual average nitrite (NO_2) + nitrate (NO_3) in mg/L as N in the deep water of Okanagan Lake, 1973-2020

Nitrate is rapidly consumed by algae in the epilimnion each spring and thermal stratification prevents replenishment from the deeper water during the summer (Figure 11). Nitrate increased dramatically each summer in the hypolimnion of the Armstrong Arm because of chemistry associated with the low-DO conditions (Figure 12). For example, nitrate increased from <0.0032 mg/L as N in the epilimnion to 0.203 mg/L as N in the hypolimnion by Sept 2020.

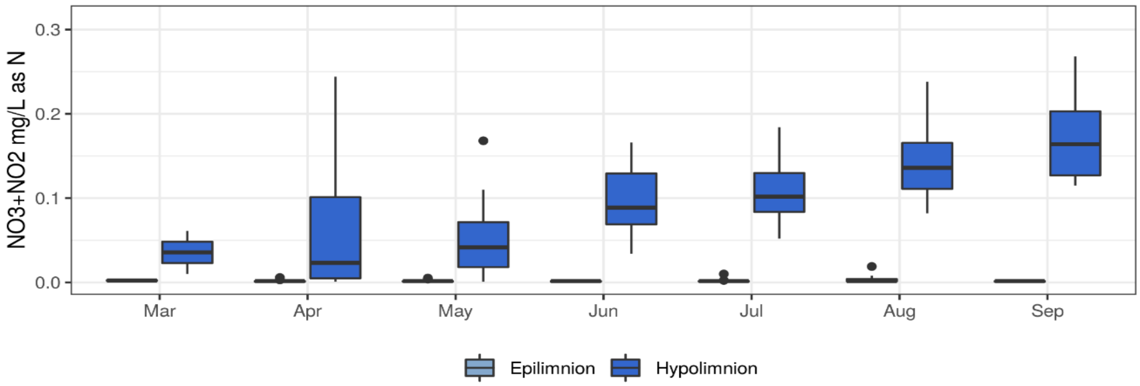

Figure 12: Nitrate + nitrite in Okanagan Lake at Armstrong Arm by month illustrating seasonal accumulation of nitrate in low oxygen hypolimnion, 2011-2020

Phosphorus

Total phosphorus (TP) measures all forms of phosphorus including those that may not be bioavailable. Total phosphorus averaged 0.008 ± 0.006 mg/L as P across Okanagan Lake during 2020 (Table 8). The TP objective for Okanagan Lake applies to the maximum phosphorus concentration at the spring overturn (Nordin, 2005; taken as March[3]). The objectives range from 0.007 mg/L in the south basin to 0.010 mg/L in the Armstrong Arm.

The TP objective was exceeded in the epilimnion and hypolimnion of Armstrong Arm in 2020, as it was in most years from 2011-2020 (Table 8). Increasing trends in TP occurred at all sites except Summerland from 2011-2020 (Table 8), part of a long-term increasing trend in TP since the mid-2000s (Figure 13). TP includes phosphorus associated with suspended sediment carried into the lake and it increases in Okanagan Lake during wet years such as 2017-2018 and decreases during dry years such as 2019 (Figure 13).

Table 8: Total phosphorus (mg/L as P) at Okanagan Lake sampling sites, 2011-2020

Site	Depth	Objective	2020	Exceeded in 2020?	% of years exceeding	Trend	Avg	SD	Max	Min
Summerland	<10m	0.007	0.0054	No	0%	-	0.005	0.002	0.011	0.002
	>20m		0.0043	No	10%	-	0.004	0.001	0.011	0.002
Kelowna	<10m	0.008	0.0056	No	10%	-	0.007	0.005	0.038	0.003
	>20m		0.0050	No	10%	↑	0.006	0.005	0.031	0.002
Ok Centre	<10m	0.008	0.0061	No	0%	↑	0.006	0.003	0.020	0.003
	>20m		0.0057	No	0%	-	0.005	0.002	0.019	0.002
Armstrong	<10m	0.010	0.0160	Yes	60%	↑	0.011	0.009	0.061	0.003
Arm	>20m		0.0106	Yes	70%	↑	0.020	0.010	0.050	0.003

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

[3] The Armstrong Arm spring sample is typically collected in early April because of ice-cover in March

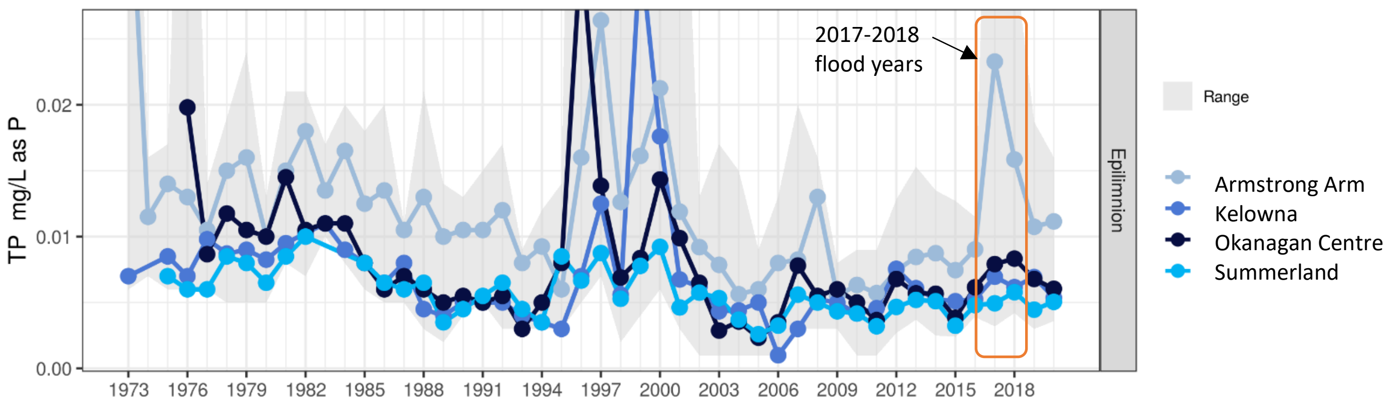

Figure 13: Annual average total phosphorus in Okanagan Lake at the four sampling sites by year from 1973-2020

Note: Decreasing trend from 1973-2005 and increasing trend from 2005-2020

TP experienced minor seasonal variation with a slight increase during freshet in some years at Summerland, Kelowna and Okanagan Centre while there was dramatic variation in the Armstrong Arm over the course of each growing season. TP increased in the hypolimnion during the summer, possibly from phosphorus released from the sediment under low-oxygen conditions while algae productivity reduced surface concentrations over the growing season (Figure 14).

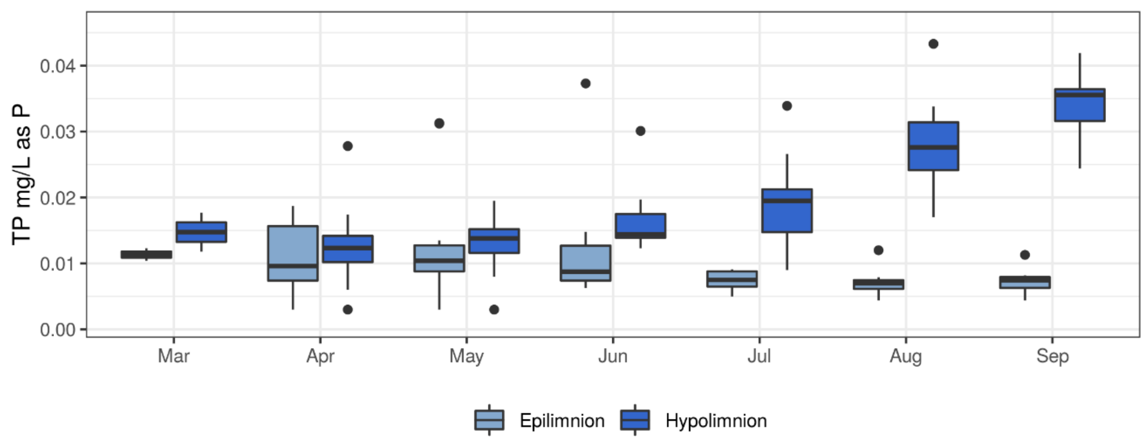

Figure 14: Total phosphorus by month in the Armstrong Arm, 2011-2020

Note: small reduction in eplimnetic TP over the growing season but it does not does drop below detection as nitrate does

Dissolved phosphorus (DP) measures the more bioavailable forms of phosphorus and is a good indicator of potential impacts to biota. Dissolved phosphorus in the epilimnion of the Armstrong Arm increased from 2011-2016 but declined again from 2017-2020 while the hypolimnion continued to increase (Mann-Kendall for 2011-2020 in the hypolimnion, $p<0.001$). DP was stable over the past 20 years at all four sample locations. Summerland, Kelowna, and Okanagan Centre had far lower DP concentrations than the 1970s. Ortho-phosphate measures only the soluble reactive phosphorus fraction of the DP and there were no significant trends in ortho-phosphate data at any of the sites from 2011-2020. However, there was a long-term declining trend since 1998 when orthophosphate sampling began (Mann-Kendall, $p<0.001$, Figure 16).

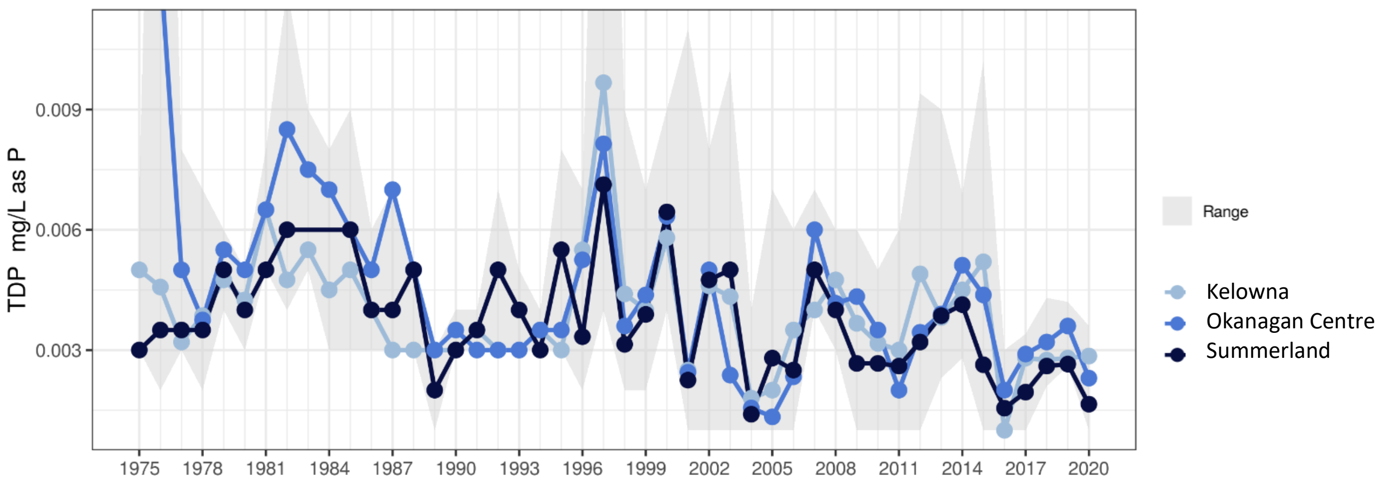

Figure 15: Annual average dissolved phosphorus in Okanagan Lake illustrating declining long-term trend at Okanagan Centre, Kelowna, and Summerland from 1975-2020

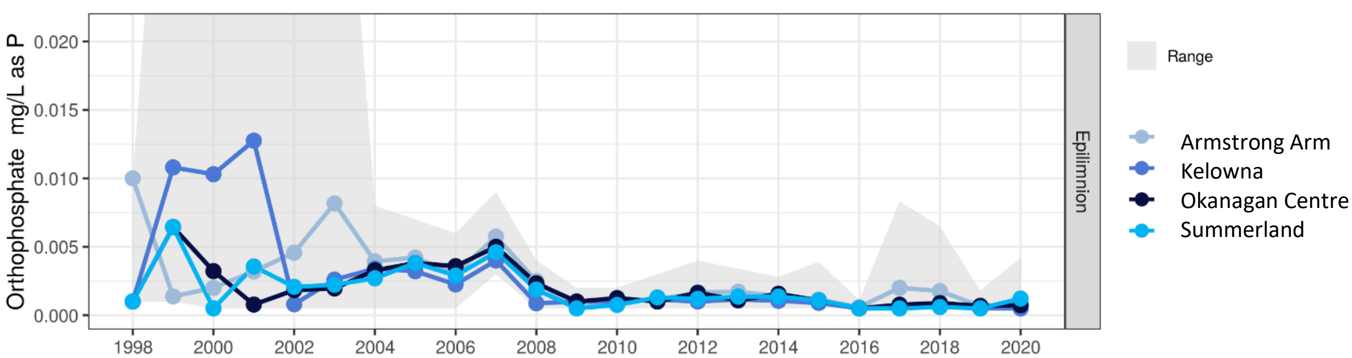

Figure 16: Annual average ortho-phosphate in the epilimnion of Okanagan Lake, 1998-2020

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 total nitrogen to total phosphorus is >25:1 in March samples. The objective was met at Summerland, Kelowna, and Okanagan Centre during 2020 while the Armstrong Arm had higher phosphorus concentrations than the rest of Okanagan Lake and did not meet the objective in 2020 (Figure 13, Table 9). The TN:TP ratio decreased in three places; the Armstrong Arm, the epilimnion at Okanagan Centre, and the hypolimnion at Kelowna from 2011-2020 (Mann-Kendall, $p<0.05$) (Figure 13). The declining TN:TP trend appears to be a short-term effect of the intense 2017-2018 freshets that increased TP during those years. When the historical data was considered, there was a long-term increasing trend in the TN:TP ratio at all sites because of the corresponding long-term decline in TP (Mann-Kendall, $p<0.001$, Figure 13).

Table 9: Ratio of average TN to average TP during spring at Okanagan Lake sampling locations, 2011-2020

Site	Depth	TN	TP	Avg Ratio	Objective	2020	Exceeded in 2020?	% of years exceeding	Trend
Summerland	<10m	0.233	0.0047	53:1	>25:1	48:1	No	0%	-
	>20m	0.239	0.0042	62:1	>25:1	58:1	No	20%	-
Kelowna	<10m	0.229	0.0065	44:1	>25:1	53:1	No	10%	-
	>20m	0.255	0.0056	62:1	>25:1	55:1	No	10%	↓
Ok Centre	<10m	0.229	0.0060	45:1	>25:1	44:1	No	10%	↓
	>20m	0.238	0.0047	57:1	>25:1	46:1	No	10%	-
Armstrong Arm	<10m	0.265	0.0106	32:1	>25:1	22:1	Yes	60%	↓
	>20m	0.309	0.0199	19:1	>25:1	28:1	No	50%	-

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

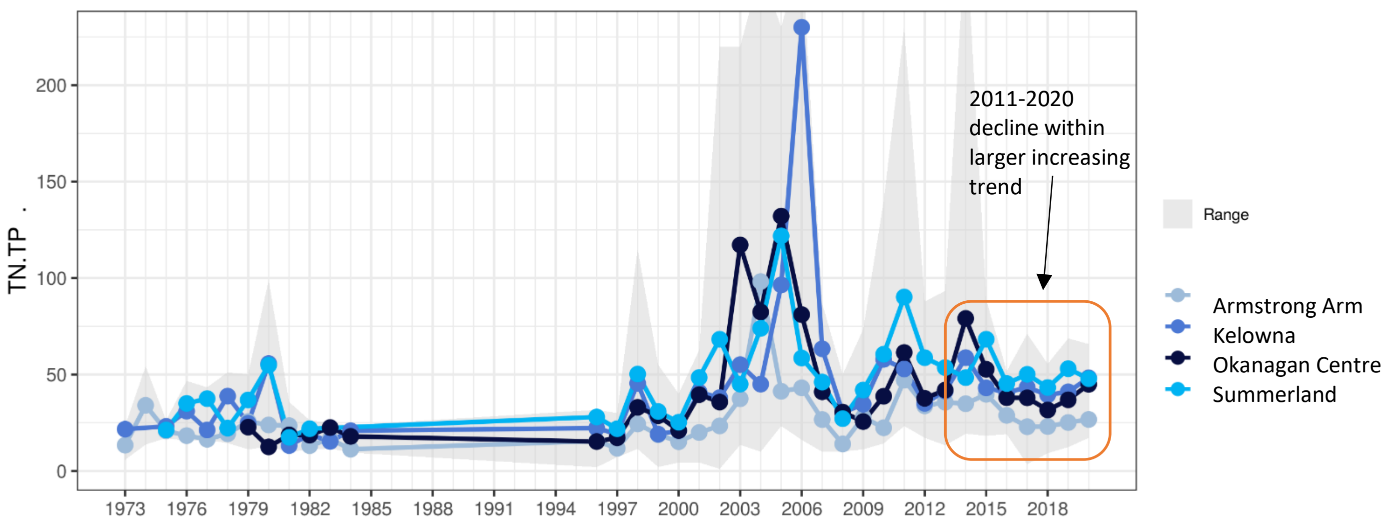

Figure 17: Nitrogen to phosphorus ratio at Okanagan Lake sampling sites 1973-2020

2.3 Biology

2.3.1 Phytoplankton

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. Phytoplankton and zooplankton samples were taken at the Summerland and Kelowna sites during all years with Armstrong Arm added to the analysis program during 2020 because of its high productivity. Preserved taxonomy samples from Armstrong Arm and Okanagan Centre for 2018-2019 were analyzed during 2020. Biomass analysis and taxonomic identification were performed on the taxonomy samples while chlorophyll-a concentrations were monitored at all sites as a productivity metric for phytoplankton abundance.

Chlorophyll-a

Chlorophyll-a is a photosynthetic pigment found in most freshwater algae species. As expected, chlorophyll-a followed an inverse trend to Secchi depth (Figure 5, Figure 18). Chlorophyll-a was lowest in the late winter and peaked in April-May during the increased spring algal growth before decreasing through the summer (Figure 20). During 2020, chlorophyll-a concentrations met the objectives at all sites but the growing season average was very close to the Armstrong Arm Objective (4.7 µg/L, Table 10). The Armstrong Arm failed to meet the chlorophyll-a objective during 2017 and 2018 because of high algal density fueled by nutrients from the flooding during those years (Figure 18). Summer chlorophyll-a concentrations were high in June in the Armstrong Arm, with a maximum of 7.3 µg/L chl-a and were sufficient to colour the entire Arm green (Table 10, Figure 19). While average chlorophyll-a concentrations in the Armstrong Arm have declined over the past three years, they remained higher than pre-2017 and were part of a long-term increasing trend observed at all sites (Mann-Kendall, p=0.005; Figure 18).

In most years, including 2020, there was a north to south decreasing trend in the chlorophyll-a data with the Armstrong Arm having the highest and Summerland having lowest average concentrations (Table 10).

Table 10: Chlorophyll-a in µg/L at Okanagan Lake sampling sites, 2011-2020

Site	Objective	2020	Exceeded in 2020?	# years exceeding	Trend	Average	StdDev	Max	Min
Summerland	4	1.77	N	0	↑	1.71	0.92	4.18	0.10
Kelowna	4.5	2.68	N	0	↑	1.97	0.99	5.40	0.50
Ok Centre	4.5	3.04	N	0	↑	2.15	1.31	6.28	0.25
Armstrong Arm	5	4.67	N	2	↑	4.15	3.79	28.50	0.71

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Note: Based on growing season only (Apr-Sep)

Note: Increase at Ok Centre based on increase between 2015 and 2016

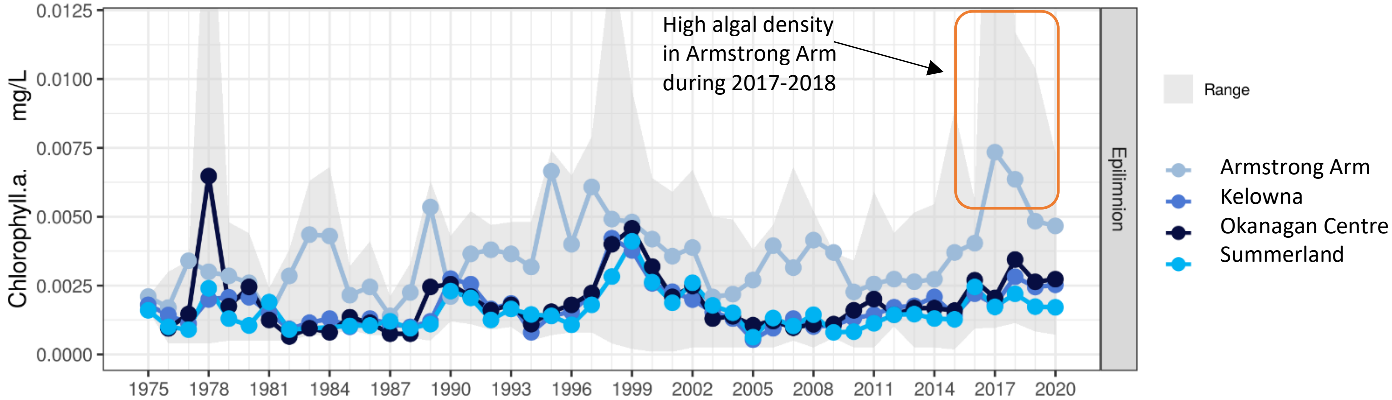

Figure 18: Annual chlorophyll-a concentration at the four Okanagan Lake sampling sites, 1975-2020

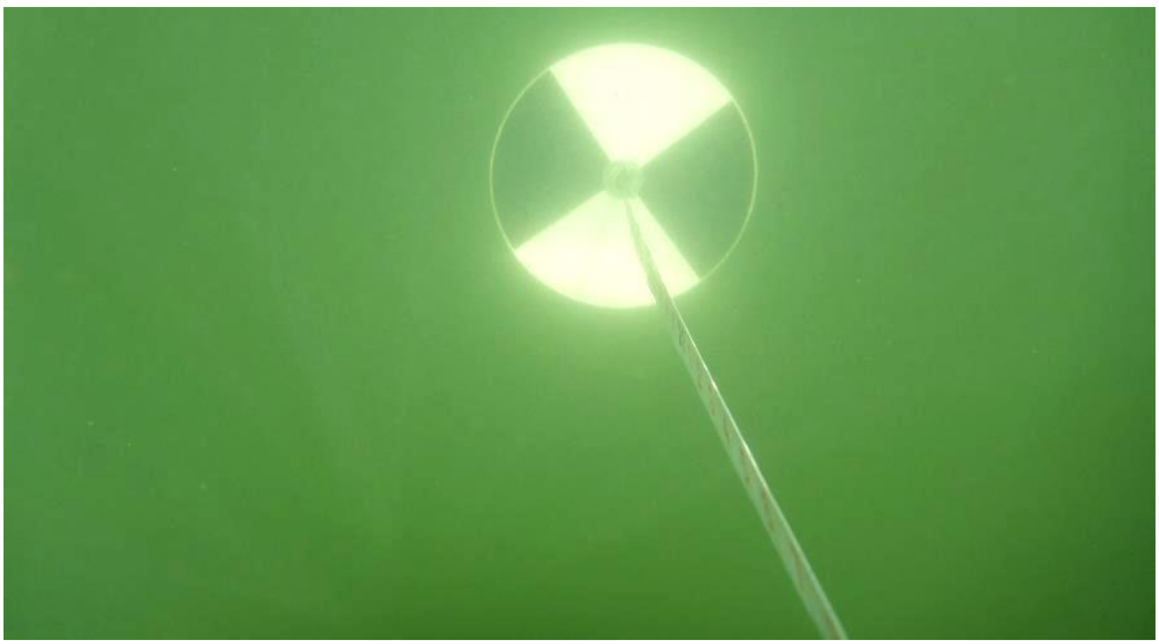

Figure 19: Water colored green with algae at Armstrong Arm in July 2020

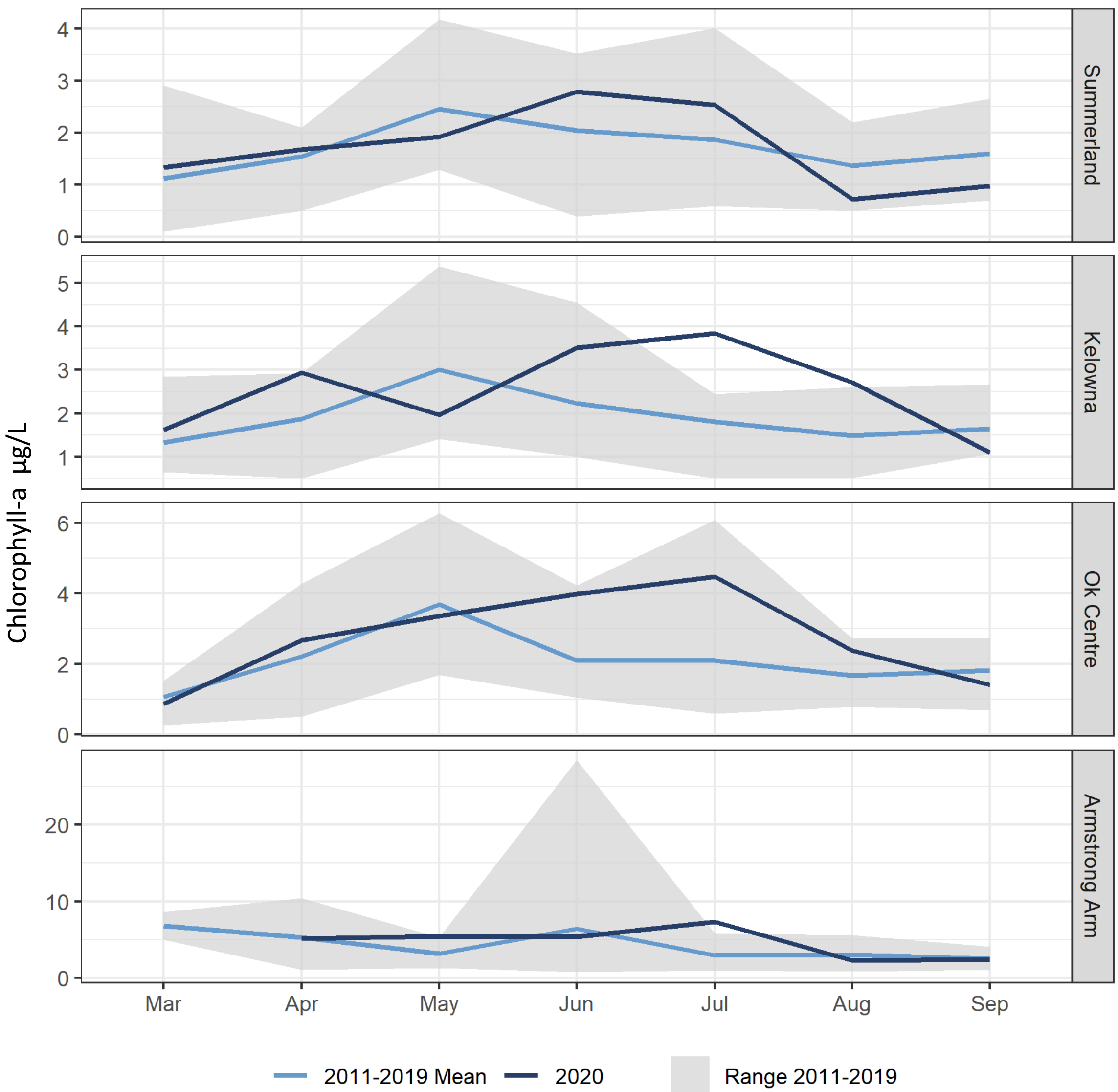

Figure 20: Chlorophyll-a at Okanagan Lake sample sites during 2020 compared to 2011-2019
Note: y-axis scales on this plot are variable depending on the site to highlight seasonal variation. Figure 18 can be used to compare the difference between sites

Biovolume
Phytoplankton biovolume samples were collected as one litre composites from 1-10 m and 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 2015-2020 results are considered here.

All samples from 2020 were below the objective of 0.75 µL/L (Table 11). Samples from the Kelowna site during May - July 2019 showed high densities of diatoms (*Tabellaria sp.*) that increased algae biovolume to a maximum of 2.14 µL/L (185% of objective) and caused a growing season average of 0.82 µL/L for 2019. This was the first and only year that any site did not meet the phytoplankton biovolume objective. Diatom cells are relatively large and will disproportionately affect biovolume compared to very small cyanobacteria cells.

Phytoplankton biovolume increased significantly from 2015-2020 at Summerland (MK test, p=0.004) and at Kelowna (MK test, p<0.001) - a trend that matches chlorophyll-a and is related to increased nutrient delivery from the large 2017 and 2018 freshets (Figure 21). A one-year lag has been observed between wet years and elevated productivity in Okanagan Lake and this effect helps explain why 2019 production was very high despite the much smaller freshet (Figure 21). Productivity remained elevated during 2020 and it is unclear how long it will take Okanagan Lake to return to pre-2017 phytoplankton densities given that 3 of the past 4 years have experienced large freshets with shoreline flooding (2017-2018, 2020). Phytoplankton productivity will likely remain high during 2021.

Table 11: Phytoplankton biovolume in µL/L at Okanagan Lake sampling sites, 2015-2020

Site	Objective	2020	Exceeded in 2020?	# years exceeding	Trend	Average	StdDev	Max	Min
Summerland	<0.75	0.39	N	0	↑	0.336	0.451	2.137	0.021
Kelowna	<0.75	0.25	N	1	↑	0.201	0.165	0.702	0.014
Ok Centre	<0.75	-	-	0	-	0.348	0.353	0.984	0.022
Armstrong Arm	<0.75	0.74	N	0	-	0.656	0.518	1.614	0.084

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Note: Ok Centre = 2018-2019 while Armstrong Arm = 2018-2020

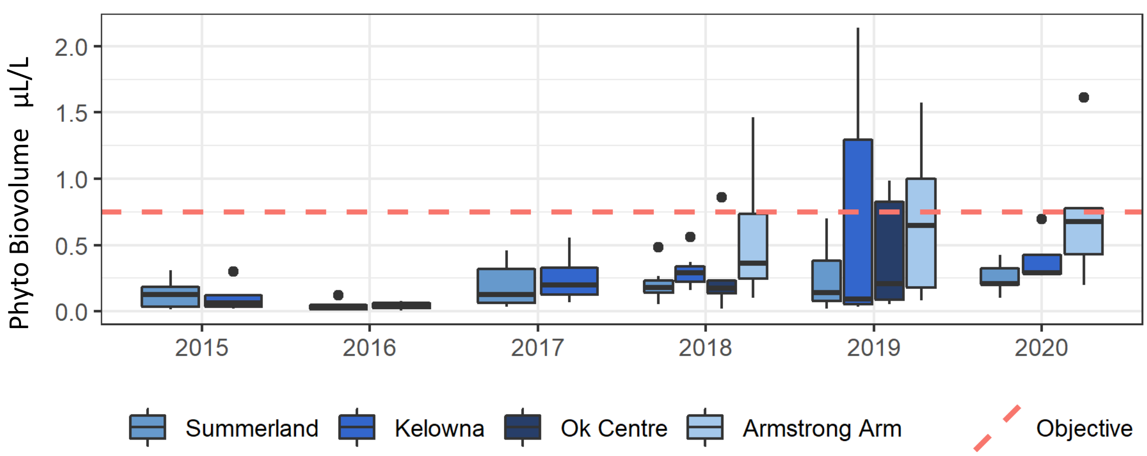

Figure 21: Phytoplankton Biovolume at Summerland and Kelowna, 2015-2020

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 proliferate in the spring and their numbers decrease through the summer. Cyanobacteria were always numerous throughout the growing season in Okanagan Lake, but typically peaked in the late summer. Cyanobacteria dominated the algae counts at 7667 cells/mL in the Armstrong Arm May 2020 sample (Figure 22, Table 12). Algae counts, led by cyanobacteria counts, were high in 2020 throughout Okanagan Lake but still lower than 2018 (Figure 23).

Table 12: Average phytoplankton counts by major algae groups in cells/mL, 2011-2020

	2020 Averages				2011-2020 Averages			
Algae Type	Summerland	Kelowna	Okanagan Centre	Armstrong Arm	Summerland	Kelowna	Okanagan Centre	Armstrong Arm
Diatoms	272	275	-	608	2325	3778	88	294
Greens	569	887	-	908	154	192	566	732
Yellow-Brown	113	103	-	153	315	477	74	142
Cyanobacteria	2213	2837	-	4717	4798	5635	2714	5678
Dinoflagellates	4	7	-	9	10	15	5	25
Euglenoids	2	1	-	3	6	11	0	2
Total Algae	3174	4111	**-**	6398	7612	10112	3448	6873

Note: Okanagan Centre data = 2018-2019; Armstrong Arm Data = 2018-2020

Figure 22: Taxonomic breakdown of algae by major types at Summerland (top) and Kelowna (bottom), 2020

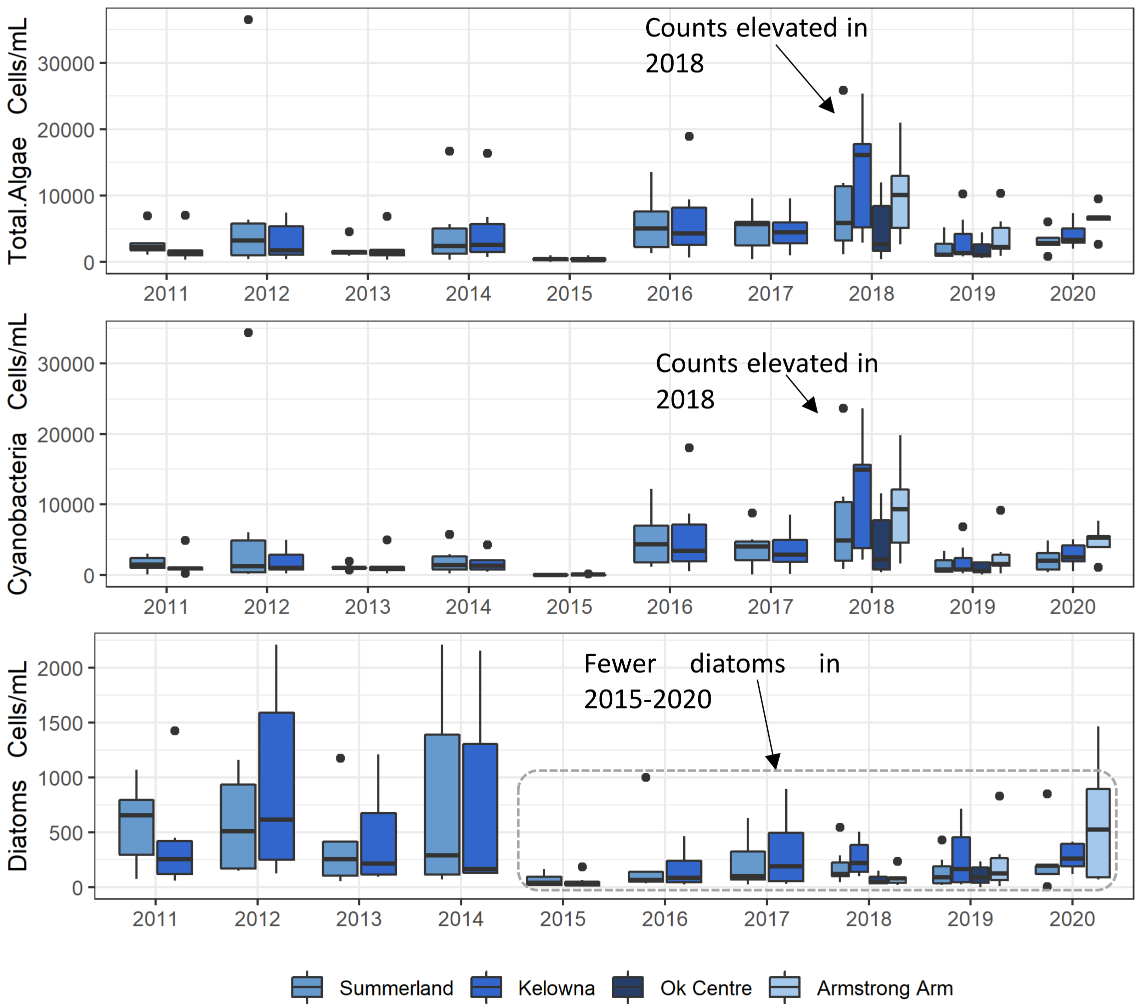

Figure 23: Total algae, cyanobacteria, and diatom counts in Okanagan Lake, 2011-2020

The Okanagan Lake objective for phytoplankton taxonomy states that no more than 5% of total cell counts should be heterocystous cyanobacteria in a given sample. These and other cyanobacteria can produce toxins that are harmful to human health when they are present in high concentrations. The heterocystous cyanobacteria objective was exceeded during most years including 2020, when 1/5 samples exceeded at Kelowna and Summerland and 2/5 samples exceeded in the Armstrong Arm. The maximum percent at Kelowna and Summerland were near the objective at 6% and 5% respectively, but in the Armstrong Arm, up to 57% was comprised of the potentially toxic taxa *Aphanizomenon sp.* and *Dolichospermum sp*[4] (Figure 24). While problematic, these cyanobacteria densities were not high enough to cause acute health concerns. No significant year-over-year trends were detected in the heterocystous cyanobacteria counts from 2011-2020 at Kelowna or Summerland.

[4] Formerly *Anabaena sp.*

Table 13: Percent of total algae counts that were heterocystous cyanobacteria from 2011-2020

Site	Objective	2020 average	Exceeded in 2020?	# years exceeding	Trend	Average	StdDev	Max	Min
Summerland	<5%	1.0%	Y (1/5)	8/10	-	11.8%	26%	92%	0%
Kelowna	<5%	2.5%	Y (1/5)	9/10	-	11.3%	24%	94%	0%
Ok Centre	<5%	-	-	2/2	-	14.4%	23%	86%	0%
Armstrong Arm	<5%	20.8%	Y (2/5)	3/3	-	30.4%	28%	71%	0%

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Note: Ok Centre = 2018-2019 while Armstrong Arm = 2018-2020

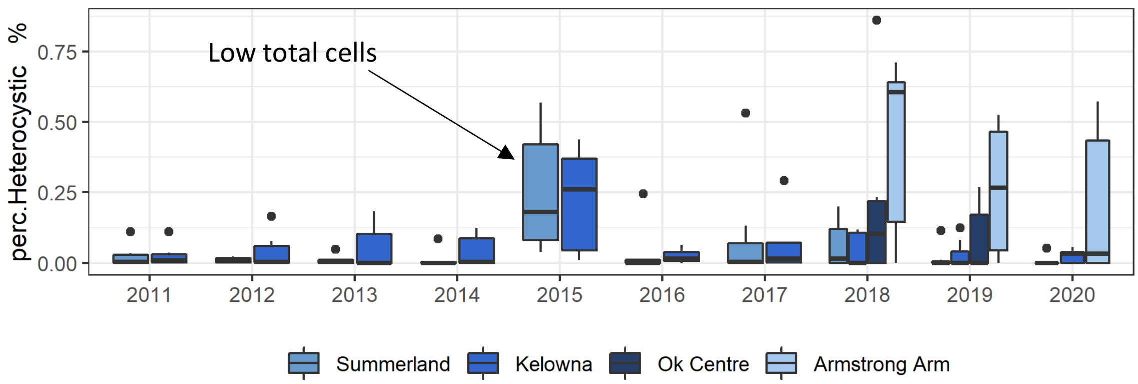

Figure 24: Percent of total algae counts that were heterocystous cyanobacteria, 2011-2020

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.

The Okanagan Lake objective is a growing season average of >50 µg/L (Nordin, 2005). This objective was met at Kelowna and Summerland in 2020. Summerland did not meet this objective in 2016, 2017, or 2019 (Table 14). No significant trends were detected in zooplankton biomass from 2015-2020 beyond the interannual variation.

Table 14: Zooplankton biomass in µg/L at Okanagan Lake sampling sites, 2015-2020

Site	Objective	2020	Met objective in 2020?	# years exceeding	Trend	Average	StdDev	Max	Min
Summerland	>50 µ/L	60 ± 22	Y	3/6	-	46.6	26.3	120.6	6.5
Kelowna		76 ± 19	Y	1/6	-	69.4	36.3	164.1	12.9
Okanagan Centre		-	-	0/2	-	77.2	25.2	123.3	48.3
Armstrong Arm		-	-	0/2	-	111.7	49.9	182.3	43.8

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Note: Ok Centre and Armstrong Arm = 2018-2019

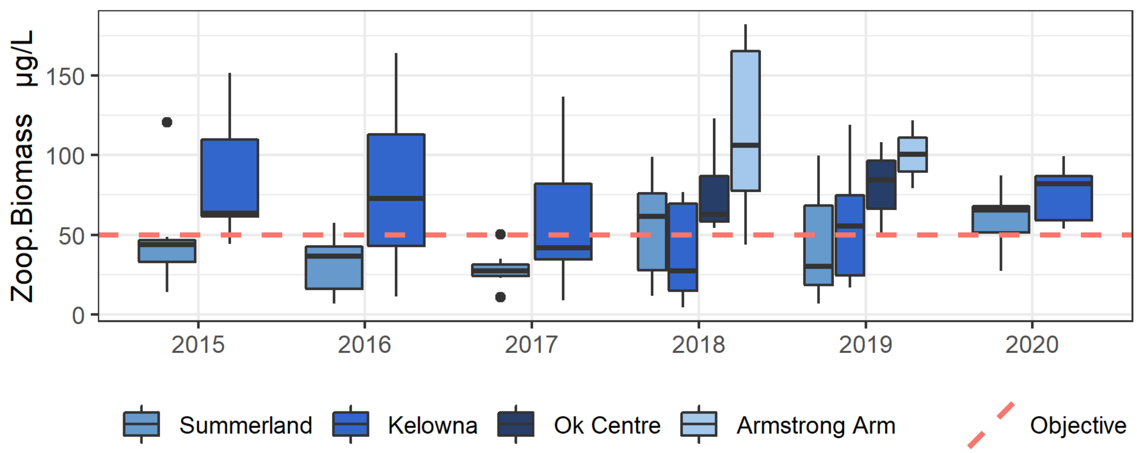

Figure 25: Zooplankton Biomass at the Kelowna and Summerland sampling locations by year, 2015-2020

Notes: There was a change in lab methodology in 2015, preventing comparison with previous years' data

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 69% at Kelowna and 78% at Summerland in 2020 (Table 15).

The objective for Okanagan Lake is a minimum of 5% of the sample counts be cladocerans. 20% of samples at Kelowna and 40% of samples at Summerland met the objective during 2020.

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 were no year-over-year trends in the zooplankton taxonomic data (Table 16).

Table 15: Growing Season average percent cladocerans zooplankton, 2011-2020

Site	Objective	Met objective in 2020?	% of samples exceeding	Trend	Average	StdDev	Max	Min
Summerland	>5% / sample	N	63%	-	4.2%	5.1%	25.5%	0.0%
Kelowna		N	69%	-	3.7%	4.0%	15.1%	0.0%
Okanagan Centre		-	90%	-	2.2%	2.1%	5.1%	0.0%
Armstrong Arm		-	50%	-	6.1%	7.8%	24.1%	0.0%

Legend for years exceeding column:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Note: Ok Centre and Armstrong Arm = 2018-2019

Table 16: Annual average zooplankton densities (organisms/litre) in Okanagan Lake, 2011-2020

	Row Labels	Average of Cladocerans	Average of Copepods	Average of Rotifers	Average of Mysids	Average of Chironomids	Average of Total Zoops
Summerland	2011	4.8	9.1	3.6	0.0	0.0	13.5
	2012	4.8	10.7	0.8	0.0	0.0	12.3
	2013	3.2	8.2	0.3	0.0	0.0	9.0
	2014	3.2	11.3	0.8	0.0	0.0	12.6
	2015	16.5	13.7	7.3	0.0	0.0	23.1
	2016	3.8	7.9	1.5	0.0	0.0	10.0
	2017	2.7	6.6	2.4	0.0	0.0	9.4
	2018	4.0	6.7	1.9	0.0	0.0	9.9
	2019	3.7	8.4	1.9	0.0	0.0	11.1
	2020	4.7	16.1	3.7	0.0	0.0	20.7
Kelowna	2011	3.1	11.9	2.8	0.0	0.0	15.3
	2012	4.1	14.4	1.1	0.0	0.0	16.2
	2013	5.8	11.6	0.5	0.0	0.0	13.0
	2014	3.2	13.3	1.6	0.0	0.0	15.3
	2015	8.1	23.9	5.2	0.0	0.0	30.3
	2016	4.4	13.8	14.0	0.0	0.0	28.4
	2017	7.8	11.7	8.5	0.0	0.0	21.0
	2018	3.0	9.9	5.0	0.0	0.0	16.1
	2019	4.3	9.3	2.3	0.0	0.0	12.4
	2020	5.6	19.8	7.7	0.0	0.0	28.6
Okanagan Centre	2018	2.5	2.2	6.7	0.0	0.0	21.9
	2019	2.2	0.3	3.9	0.0	0.0	18.7
Armstrong Arm	2018	8.7	3.2	7.9	0.0	0.0	28.0
	2019	2.4	0.1	1.9	0.0	0.0	17.3

3.0 Conclusions

This report summarizes the 2011-2020 results and highlights the 2020 findings. This report also extracts trends from the data accumulated by the Okanagan Lake Collaborative Sampling program to date (2011-2020) and compares those to the long-term historical database (1973-2020). Okanagan experienced a large freshet and minor lake-wide shoreline flooding during 2020. The results to date indicate that the Armstrong Arm is impacted by human activities and watershed degradation. This site had the most exceedances and the most problematic trends, that is, trends moving parameters towards greater exceedances and poorer water quality.

Dissolved Oxygen Each year the temperature of Okanagan Lake increases seasonally in the surface waters until the lake becomes thermally stratified, usually in May. This physical dynamic isolates the deep water from the atmosphere and leads to oxygen depletion below the thermocline in Armstrong Arm. The Armstrong Arm therefore failed to meet the dissolved oxygen objective in 2020, as it has in each year of this study, but the thickness of the low-oxygen zone was much smaller during 2019-2020 than the very large hypoxic zone of 2018.

Nutrients
Silica analysis of water samples revealed that the short-term 2011-2018 trend is nested within a long period of stable conditions over the past 20 years.

Total nitrogen increased in the Armstrong Arm from 2011-2020 while increasing trends were noted in the hypolimnion at Okanagan Centre and Kelowna. Total nitrogen exceeded the water quality objectives at all sites during 2020. Nitrate increased significantly in the Armstrong Arm and in the hypolimnion at all sites from 2011-2020. This is part of a decades long increasing trend in hypolimnetic nitrate in Okanagan Lake that has continued through multiple wet-dry climate cycles and is likely caused by increasing human impacts within the Okanagan region.

Phosphorus concentrations were highest in the Armstrong Arm where they exceeded the objective during 2020. There were increasing trends in TP from 2011-2020 at Okanagan Centre, Kelowna, and particularly in the Armstrong Arm where the increase was greatest. The Armstrong Arm is more heavily impacted by human activities and has numerous phosphorus sources and the rise in TP at Okanagan Centre and Kelowna likely speak to the impact of the 2017-2018 freshets on Okanagan Lake. Dissolved phosphorus (DP) and ortho-P represent the more bioavailable forms of phosphorus and were stable at Summerland, Kelowna, Okanagan Centre while DP increased at the Armstrong Arm. Samples from the Armstrong Arm exceeded the nitrogen-phosphorus ratio objective in 2020, with a decreasing trend in that ratio from 2011-2020 at all sites but Summerland because of increased TP over the same time.

Phytoplankton Productivity Chlorophyll-a concentrations increased each spring during the annual spring high algal growth period and then decreased over the summer and into the fall. Chlorophyll-a was high in the Armstrong Arm while at Summerland, Kelowna, and Okanagan Centre chlorophyll-a decreased compared to 2017-2018 but remained above their 2011-2017 averages. Previous research by ENV has identified a one-year lag between major nutrient inputs and increases in phytoplankton productivity so it was expected that 2019 productivity would be high even though there was a normal freshet. However, the high productivity during 2020 indicates that the impacts from 2017-2018 had not faded and were not helped by the large 2020 freshet. Given large freshets in recent years, productivity during 2021 will likely remain high. There was an increasing year-over-year trend detected for chl-a at all sites except Summerland. Chlorophyll-a concentrations in the Armstrong Arm were close to the objective of 5 µg/L but the objective was met at all sites during 2020. Phytoplankton biovolume met the objective at all sites during 2020 and increased at Kelowna and Summerland from 2015-2020.

The taxonomic data indicated that cyanobacteria numerically dominated the phytoplankton samples in 2020, as in every year studied, while overall counts were comparable to previous years and down from the very high 2018 results. Samples from Kelowna and from Summerland exceeded the phytoplankton objective of <5% of algae as heterocystous cyanobacteria during 2020 by 1-2% while the Armstrong Arm samples contained over half heterocystous cyanobacteria during the summer and exceeded the objective by an order of magnitude.

Zooplankton Productivity Zooplankton biomass was stable from 2015-2020. Zooplankton biomass met the objective of >50 µg/L at both Summerland and Kelowna during 2020. Copepods numerically dominated most samples. The water quality objective of >5% of zooplankton as cladocerans was achieved in 1/3 of samples from 2011-2020 at both Kelowna and Summerland.

Table 17 to Table 19 summarize the findings of this report for 2011-2020 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.

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
- Increasing nitrate in hypolimnion of Okanagan Lake since 1970s
- Increasing total phosphorus at all sites except Summerland since early 2000s
- Increasing chlorophyll-a throughout the lake since early 2000s
- Decreasing N:P ratio in the Armstrong Arm
- High densities of potentially toxic cyanobacteria in Armstrong Arm during 2018-2020

Armstrong Arm frequently exceeds most objectives and is the site most at risk of water quality degradation including harmful algae blooms, poor drinking water quality, anoxic 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 in the watershed have impacted this northern-most basin of the lake.

Table 17: Okanagan Lake Water Quality Objectives

Objectives (Nordin, 2005)	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth (growing season average)	7m	6m	6m	5m
Dissolved Oxygen (minimum in bottom waters)	-	-	-	>5 mg/L
TP (mg/L as P) (maximum at spring overturn)	0.007	0.008	0.008	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%

Table 18: Attainment of Okanagan Lake water quality objectives compared to growing season averages during 2011-2020

Objective	**Summerland**	**Kelowna**	**Ok Centre**	**Armstrong Arm**
Secchi Depth	7.2	6.7	6.9	3.4
Dissolved Oxygen	9.99	9.99	9.97	3.67
TP (mg/L) 0:10m:	0.005	0.007	0.006	0.011
20-45m:	0.004	0.006	0.005	0.02
Chlorophyll-a (µg/L)	1.71	1.97	2.15	4.15
TN (mg/L) 0-10m:	0.233	0.229	0.229	0.265
20-45m:	0.239	0.255	0.238	0.309
N:P Ratio 0-10m:	53:1	44:1	45:1	32:1
20-45m:	62:1	62:1	57:1	19:1
Algae Taxonomy (% heterocystous cyanobacteria)	11.8%	11.3%	14.4%	30.4%
Algae Biovolume (µL/L)	0.336	0.201	0.656	0.348
Zooplankton Biomass (µg/L)	46.6	69.4	77.2	111.7
Zooplankton Taxonomy (% cladocerans)	4.2%	3.7%	2.2%	6.1%

Legend:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

Table 19: Summary of trends and the water quality objectives for Okanagan Lake collaborative sampling program (2011-2020)

Objective	Summerland	Kelowna	Ok Centre	Armstrong Arm
Secchi Depth	-	-	-	-
Dissolved Oxygen	-	-	-	-
TP (mg/L) 0:10m:	-	↑	↑	↑
Chlorophyll-a (µg/L)	↑	↑	↑	↑
TN (mg/L) 0-10m:	↑	-	↑	↑
N:P Ratio 0-10m:	-	-	-	↓
Algae Taxonomy (% heterocystous cyanobacteria)	-	-	-	-
Algae Biovolume (µL/L)	↑	↑	-	-
Zooplankton Biomass (µg/L)	-	-	-	-
Zooplankton Taxonomy (% cladocerans)	-	-	-	-

Legend:

Legend:

Achieve objective in >70% of samples	Achieve objective in >25% and <70% of samples	Achieve objective in <25% of samples	No Data/ No Objective

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

4.0 Recommendations

This report concludes the 2018-2020 contract of the Okanagan Collaborative Program. The program originally from 2011-2014 was renewed for 3-years in 2015 and again in 2018. The following recommendations are made for the program moving forward:

- Renew the program for another 3-year term (2021-2023)
- Complete another summary report at the end of the next three-year cycle
- Continue to analyze taxonomy samples in Okanagan Centre and Armstrong Arm
- Consider working with City of Vernon and District of Lake Country for inclusion in this program given their current and future plans for treated effluent disposal

5.0 References

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6.0 Appendices

6.1 Appendix 1: 2011-2020 Sampling Data

All data used in this report can be found in the data transfer file

MoE-Synth-DB.xlsx

6.2 Appendix 2: Statistics and Graphing Overview

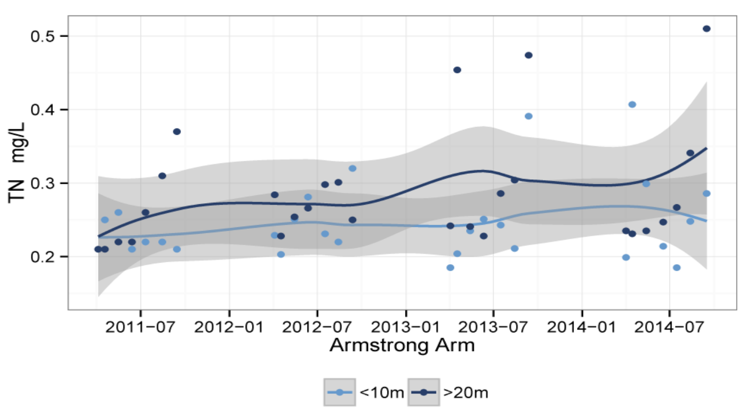
Statistical analyses were performed on data to support interpretations made throughout this report. The use of the word 'significantly' within this report is understood to signify that the claim being made has stood up under statistical analysis. Unless otherwise stated, all statistical analyses were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



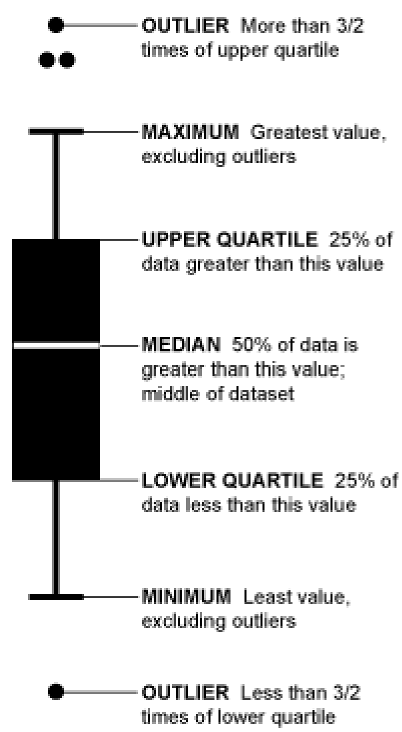
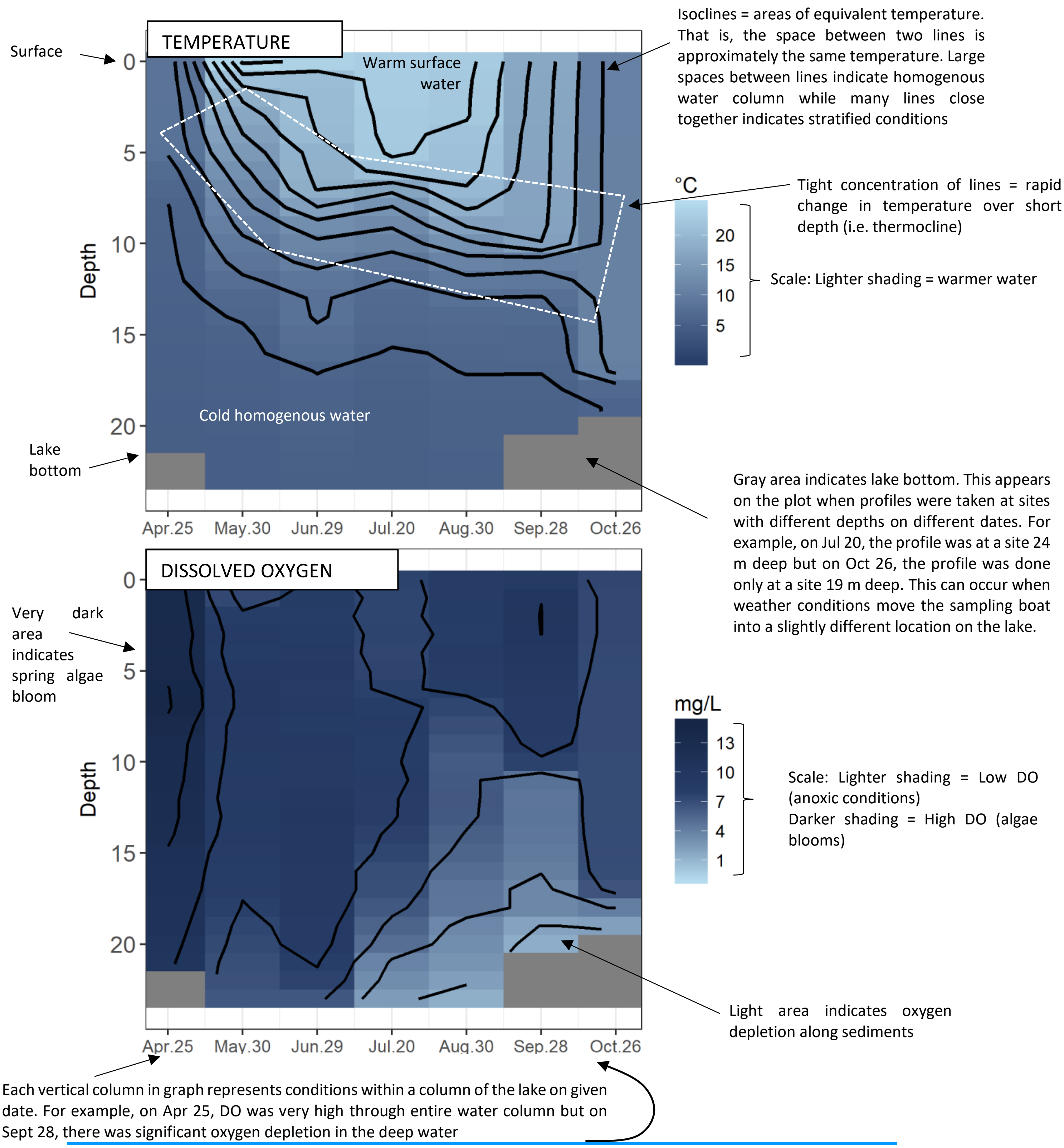


Figure i: Example scatterplot and boxplot
Includes all data for a parameter sorted by depth, LOESS polynomial trendlines and the standard errors of those trendlines are also included. Example boxplot is labeled with key information. Whiskers represent the distance to the highest or lowest point within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

How to Read Temperature/DO Profile Plot

Temperature and dissolved oxygen profiles were routinely collected as part of this study. They are displayed in several locations throughout this report. An example of a temperature graph and a dissolved oxygen graph, descriptions of their key features and how to read them are presented here.



-------------End of Report-------------