US Army Corps of Engineers®
Portland District

WATER QUALITY REPORT

ALBENI FALLS DAM
COLUMBIA RIVER BASIN
PEND OREILLE RIVER, IDAHO

Albeni Falls Dam, Lake Pend Oreille, and Pend Oreille River

Water Quality Report
June 2020

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (Corps) Seattle District has been conducting water quality monitoring of Lake Pend Oreille, the Clark Fork River, and the Pend Oreille River since 2005 in order to establish baseline information on the physical, chemical, and biological condition of the lake and rivers. This baseline data allows the Seattle District to define the relationship between Albeni Falls Dam and the water quality in the Pend Oreille River downstream of Lake Pend Oreille. An understanding of the possible impact of Albeni Falls Dam on the water quality in the Pend Oreille River is of paramount importance because of possible future operational changes that may occur at Albeni Falls Dam under the various Columbia River System Operations (CRSO) alternatives.

Water quality data collected in Lake Pend Oreille and the Pend Oreille River is summarized here in order to better understand the limnological functioning of this system. The majority of data discussed in this report is derived from a large-scale water quality monitoring study conducted by the Seattle District from 2005 to 2016. The Seattle District's limnological study was designed to investigate the interaction of physical, chemical, and biological processes in the lake and river to better understand the possible water quality impacts of Albeni Falls Dam operations on Lake Pend Oreille and the Pend Oreille River. Additional water quality data collected in the 1980s through 2000s will be used for comparative purposes only.

This report will focus on summarizing the 2005 to 2016 data to gain an understanding of the current physical, chemical, and biological processes in the lake and river. The scope of this summary is extensive and will include: (1) the fate and transport of nutrients and trace metals in the system, (2) an assessment of the temporal and spatial variability in key water quality parameters, and (3) the biological condition of Lake Pend Oreille.

CONTENTS

EXECUTIVE SUMMARY i
TABLE OF CONTENTS iv
ACRONYMS viii

SECTION 1 - INTRODUCTION 1-1

1.1 STUDY AREA 1-1
1.2 CLIMATE AND GEOLOGY 1-3
1.3 LAND USE 1-4
1.4 CONTAMINANT SOURCES 1-4
1.5 PREVIOUS INVESTIGATIONS 1980S TO 2000S 1-5
1.6 CURRENT INVESTIGATION 2005 TO 2016 1-6
1.7 WATER QUALITY CRITERIA 1-10
1.8 EXISTING 303(D) AND TOTAL MAXIMUM DAILY LOADS 1-11
1.9 DATA ANALYSIS 1-12

SECTION 2 - WATER QUALITY 2-1

2.1 GENERAL DESCRIPTION 2-1
2.2 PHYSICAL CHARACTERISTICS 2-1
2.2.1 Temperature 2-1
2.2.2 Total Dissolved Gas 2-5
2.2.3 Transparency 2-6
2.2.4 Dissolved Oxygen 2-8
2.2.5 Alkalinity, Hardness, and pH 2-11
2.2.6 Specific Conductivity 2-13
2.3 CHEMICAL CHARACTERISTICS 2-13
2.3.1 Nutrients 2-13
2.3.2 Chlorophyll a 2-26
2.3.3 Trophic State 2-27
2.3.4 Major Anions and Cations 2-30
2.3.5 Trace Metals 2-31
2.4 BIOLOGICAL CHARACTERISTICS 2-31
2.4.1 Phytoplankton 2-31
2.4.2 Zooplankton 2-39

SECTION 3 - CONCLUSIONS AND RECOMMENDATIONS 3-1

3.1 CONCLUSIONS 3-1
3.2 RECOMMENDATIONS 3-2

SECTION 4 - REFERENCES 4-1

TABLES

Table 1-1. Water Quality Sampling Locations in Lake Pend Oreille, Clark -Fork River, and Pend Oreille River 2005 to- 2016 1-8
Table 1-2. Chemical Methods and Detection Limits for Lake Pend Oreille, Clark-Fork, and Pend Oreille Rivers Water Quality Analyses 1-8
Table 1-3. Biological Methods and Detection Limits for Lake Pend Oreille, Clark-Fork, and Pend Oreille Rivers Water Quality Analyses 1-9
Table 1-4. Idaho Department of Environmental Quality General Water Quality Standards 1-10
Table 1-5. Idaho Department of Environmental Quality Metals and Ammonia Water Quality Standards 1-11
Table 2-1. Trophic Classification Values for Lake Pend Oreille 2005 to 2016 2-28
Table 2-2. Organization for Economic Co-Operation and Development Trophic State Classification Total Phosphorus, Chlorophyll a, and Transparency Values for Lake Pend Oreille 2005 to 2016 2-30

FIGURES

Figure 1-1. Location of Albeni Falls Dam in the Pend Oreille River Basin Watershed 1-2
Figure 1-2. Locations of Water Quality Monitoring Stations in Lake Pend Oreille and the Clark Fork and /Pend Oreille Rivers 1-7
Figure 2-1. Lake Pend Oreille/Pend Oreille River median water temperature profiles 2005 to 2016 2-4
Figure 2-2. Lake Pend Oreille and Pend Oreille River Transparency and Chlorophyll a for 2005 to 2016 2-7
Figure 2-3. Statistical Summary of Annual Transparency in Lake Pend Oreille and Pend Oreille River for 2005 to 2016 2-8
Figure 2-4. Lake Pend Oreille and Pend Oreille River Median Dissolved Oxygen Profiles for 2005 to 2016 2-10
Figure 2-5. Statistical Summary of Annual Alkalinity in the Lake Pend Oreille Study Area for 2005 to 2016..... 2-11
Figure 2-6. Lake Pend Oreille Study Area Alkalinity Concentrations for 2005 to 2016..... 2-12
Figure 2-7. Lake Pend Oreille Study Area Total Phosphorus Concentrations for 2005 to 2016 2-15
Figure 2-8. Lake Pend Oreille Study Area Data Summary of Annual Total Phosphorus Concentrations by Year for 2005 to 2016..... 2-16
Figure 2-9. Lake Pend Oreille Study Area Soluble Reactive Phosphorus Concentrations for 2005 to 2016 2-17
Figure 2-10. Lake Pend Oreille Study Area Data Summary of Annual Soluble Reactive Phosphorus Concentrations by Year for 2005 to 2016..... 2-18
Figure 2-11. Lake Pend Oreille Study Area Total Nitrogen Concentrations for 2005 to 2016 2-20
Figure 2-12. Lake Pend Oreille Study Area Data Summary of Annual Total Nitrogen Concentrations by Year for 2005 to 2016..... 2-21
Figure 2-13. Lake Pend Oreille Study Area Nitrate+Nitrite Concentrations for 2005 to 2016 2-22
Figure 2-14. Lake Pend Oreille Study Area Data Summary of Annual Nitrate+Nitrite Concentrations by Year for 2005 to 2016..... 2-22
Figure 2-15. Lake Pend Oreille Study Area Ammonia Concentrations for 2005 to 2016 2-23
Figure 2-16. Lake Pend Oreille Study Area Data Summary of Annual Ammonia Concentrations by Year for 2005 to 2016..... 2-24
Figure 2-17. Lake Pend Oreille Study Area Total Nitrogen to Total Phosphorus Ratios for 2005 to 2016 2-25
Figure 2-18. Lake Pend Oreille Study Area Data Summary of Annual Chlorophyll a Concentrations by Year for 2005 to 2016..... 2-27
Figure 2-19. Lake Pend Oreille Summer Trophic State Index Values 2005 to 2016 2-29
Figure 2-20. Lake Pend Oreille Temporal Variation in Phytoplankton Biovolume 2005 to 2016 2-34

Figure 2-21. Lake Pend Oreille Temporal Variation in Phytoplankton Density 2005 to 2016 2-35
Figure 2-22. Lake Pend Oreille 2015 to 2016 Phytoplankton Percent Composition by Biovolume 2-37
Figure 2-23. Lake Pend Oreille 2015 to 2016 Phytoplankton Percent Composition by Density 2-38
Figure 2-24. Lake Pend Oreille/Pend Oreille River zooplankton density by station for 2005 to 2014 2-42

ACRONYMS

Acronym	Description
µg/L	Micrograms per Liter
µS/cm	Microsiemens per Centimeter
ALFCF	Clark Fork Inflow Station
ALFFB	Albeni Falls Dam Forebay Station
ALFLPD	Lake Pend Oreille Deep Water Pelagic Station
ALFLPS	Lake Pend Oreille Shallow Water Pelagic Station
Ca	Calcium
Cl	Chloride
CO_3	Carbonate
Corps	U.S. Army Corps of Engineers
CRSO	Columbia River System Operations
Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
FWPO	Flexible Winter Power Operations
HCO_3	Bicarbonate
IDEQ	Idaho Department of Environmental Quality
K	Potassium
MDEQ	Montana Department of Environmental Quality
Mg	Magnesium
mg $CaCO_3$/L	Milligrams Calcium Carbonate Per Liter
Na	Sodium
OECD	Organization for Economic Co-Operation and Development
SO_4	Sulfate
TDG	Total Dissolved Gas
TMDL	Total Maximum Daily Load
TN:TP	Total Nitrogen to Total Phosphorus Ratios
TSI	Trophic State Index
TSWQC	Tri-State Water Quality Council
USGS	U.S. Geological Survey
WQI	Water Quality Index

SECTION 1 - INTRODUCTION

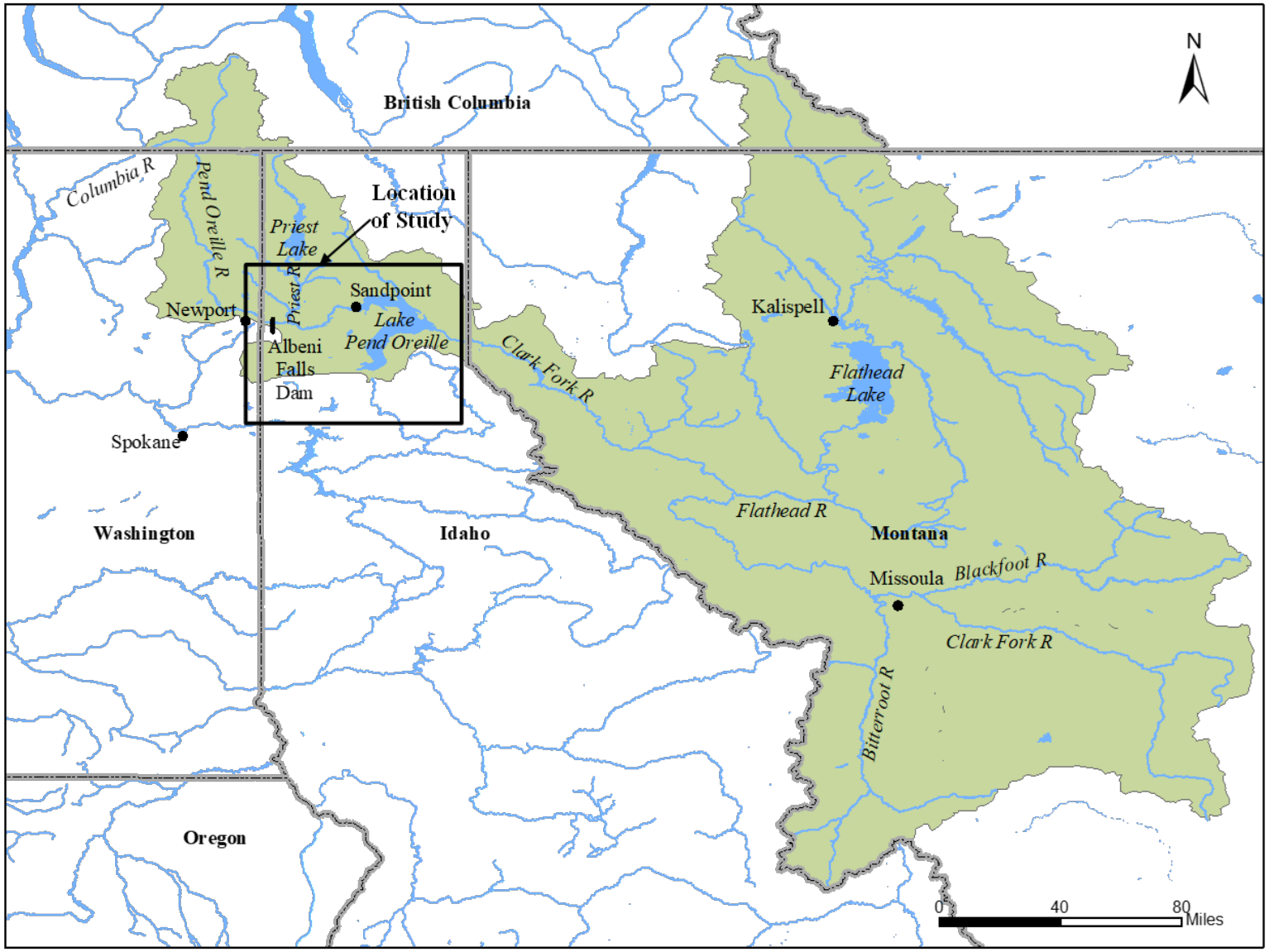
1.1 STUDY AREA

The Clark Fork-Pend Oreille River basin drains about 64,750 square kilometers in southern British Columbia, western Montana, northern Idaho, and northeastern Washington (Figure 1-1). The Clark Fork River originates in the Rocky Mountains of western Montana and flows northwest about 560 kilometers to Lake Pend Oreille. Major tributaries of the Clark Fork include the Flathead, Blackfoot, and Bitterroot Rivers. The Pend Oreille River begins at the outlet of Lake Pend Oreille, flows eastward for about 47 kilometers to Albeni Falls Dam and then flows to the northwest for about 145 kilometers to its confluence with the Columbia River in British Columbia. Major tributaries of the Pend Oreille River include the Priest River (Figure 1-1).

Albeni Falls Dam is a Corps project located near the Washington-Idaho border on the Pend Oreille River at River Kilometer 145. The dam became operational in 1952 and is about 4 kilometers upstream and east of the city of Newport, Washington; 41.8 kilometers west of the city of Sandpoint, Idaho; and 47 kilometers downstream from Lake Pend Oreille (see Figure 1-1). Lake Pend Oreille is a natural lake that is located in a glacially scoured basin in the Purcell Trench in Northern Idaho (Fields, Woods, and Berenbrock 1996). The Clark Fork is the major inflow to the lake, supplying about 85 percent of the surface water inflow to the lake and its outlet arm (Frenzel 1991).

Lake Pend Oreille is the largest and deepest lake in Idaho and the fifth deepest lake in the United States, with a maximum width of about 10.8 kilometers and a maximum depth of about 357 meters (Fields, Woods, and Berenbrock 1996). Although Lake Pend Oreille is a natural lake, Albeni Falls Dam is authorized for regulation of the lake level for flood control, navigation, fish and wildlife conservation, recreation, and power generation. Before the project became operational in 1952, the annual surface elevation of Lake Pend Oreille varied according to seasonal inflows, from an average fall/winter low of about 624.2 meters to an average spring runoff high of about 628.5 meters, with a maximum spring elevation of 631.5 meters recorded on June 9, 1948 (Corps 2000). All elevations are referenced to NGVD29 datum. After reaching a maximum elevation during spring runoff, the lake gradually receded to an elevation of about 624.8 meters by August and reached its minimum elevation of about 624.2 meters by October.

Figure 1-1. Location of Albeni Falls Dam in the Pend Oreille River Basin Watershed



Current Lake Pend Oreille regulating procedures are briefly described below. After the spring runoff period is completed (usually late May to early July), Lake Pend Oreille is maintained in a 0.15-meter summer operation range between elevations 628.5 and 628.6 meters until the end of the summer recreation season. A fall drawdown generally begins after Labor Day and the lake is stabilized at a minimum control elevation for the winter typically by December 1. Historically, the Corps has drafted Lake Pend Oreille to a winter elevation of either 625.1 or 626.6 meters for kokanee (Oncorhynchus nerka) spawning and managed within a 0.3-meter operating band through March. However, since 2011 Lake Pend Oreille regulating procedures have been operating under the flexible winter power operations (FWPO) plan. Under FWPO the lake is held at the winter elevation until kokanee spawning is complete after which the Bonneville Power Administration may use up to 1.5 meters (625.1 to 626.6 meters) of flexibility available in Lake Pend Oreille during the winter instead of holding the winter pool at a constant elevation. This operation may result in Lake Pend Oreille's pool fluctuating up to 1.5 meters during the winter months. Bathymetric data indicates that there is a 6.8 percent reduction in lake surface area and a 1.8 percent reduction in lake volume between the typical full pool and winter pool lake elevations of 628.6 and 625.1 meters (Fields, Woods, and Berenbrock 1996).

1.2 CLIMATE AND GEOLOGY

The climate of the Lake Pend Oreille watershed is influenced by easterly moving weather systems from the Pacific Ocean. Winters are generally cloudy, cool, and wet, with November through March being the wettest months. Most of the snowpack in the mountains falls between November and April. Summers are typically warm and dry, with little rainfall occurring from June through September. Sandpoint, Idaho (elevation 628.5 meters), is the closest long-term (1910 to 2008) weather station to Lake Pend Oreille. The mean annual precipitation at Sandpoint is about 81 centimeters, with an annual snowfall of about 178 centimeters. The mean annual temperature is about 7.8°C, with extremes recorded of -38°C and 40°C (WRCC 2009). Typically, December and January are the coldest and wettest months while July is the warmest and driest month. The first snowfall usually occurs in early November, and heavy snows can occur throughout the winter as can extended periods of melting and freezing. The snow pack generally remains in the area from December through March or April.

The Lake Pend Oreille watershed is dominated by high, forested, northwest-southeast-trending mountain ranges separated by broad valleys. Elevations range from about 600 meters immediately downstream of Albeni Falls Dam to over 3,000 meters in the Rocky Mountains of British Columbia. The topography in the immediate Lake Pend Oreille watershed is characterized by steep mountain slopes that plunge directly into the lake. The mountains rise steeply from the lake to elevations of 1,500 to 2,000 meters, and vegetation is dominated by coniferous forest. The immediate Lake Pend Oreille watershed is dominated by Precambrian-aged low metamorphic grade metasedimentary rocks of the Belt-Purcell Supergroup (Idaho Geological Survey 2002). Sediments in the area are from the Pleistocene glaciation, in which the Cordilleran ice sheet advanced southward along the Purcell Trench from Canada. These glacial advances scoured out the Lake Pend Oreille Basin.

1.3 LAND USE

The Clark Fork–Pend Oreille River watershed is a sparsely populated mountainous area with a majority of the land in the basin being government owned or managed (Maret and Dutton 1999). About 75 percent of the land is covered by forest, while rangeland and agricultural land comprise about 11 and 8 percent, respectively (Beckwith 2002. The Clark Fork–Pend Oreille River watershed experienced rapid growth between 1990 and 2005 (Montana Department of Environmental Quality [MDEQ] et al. 2007). The total population in the watershed was about 375,000 in 2005, with the majority of growth and population (over 310,000) in Montana. Major population centers for each state are concentrated near Missoula and Butte in Montana, near Sandpoint in Idaho, and near Newport in Washington (MDEQ et al. 2007). Population increases in the Lake Pend Oreille nearshore watershed have been occurring rapidly since the 1990s, resulting in increased environmental pressures on the water quality of the lake (Tri-State Water Quality Council [TSWQC] 2004).

The economy of the watershed relies heavily on forest products, mining, hydropower, recreation (tourism), technology, and agriculture. In the past, timber and mining were the main drivers of employment in the region; however, recently tourism and recreation have become more important. In addition, the retail trade and service industry also provide employment opportunities in the watershed (Corps 2000).

1.4 CONTAMINANT SOURCES

Historical and current point source discharges of contaminants that may impact water and sediments in Lake Pend Oreille and the Pend Oreille River exist in the watershed. Extensive mining has occurred throughout the watershed since the late 1800s. Hundreds of hard-rock mines are known to exist in the Clark Fork–Pend Oreille River watershed with these mines and smelters being among the largest in the nation (Maret and Dutton 1999). Copper was the major metal mined but the area also produced zinc, manganese, lead, silver, cadmium, bismuth, selenium, tellurium, and gold (Beckwith 2002). Andrews (1987) estimated that 100 million tons of mining and ore-processing waste were discharged into the headwaters of the Clark Fork and its tributaries from 1880 to 1982. As a result of historical mining and smelting operations in the upper Clark Fork watershed, the area along the Clark Fork from Butte, Montana, downstream to Missoula, Montana, has been designated the largest contiguous Superfund site in the nation.

Elevated concentrations of metals in stream, river, and floodplain sediments have been documented in the Clark Fork–Pend Oreille River watershed far downstream of historical mining and smelting operations (Johns and Moore 1985; Axtmann and Luoma 1991). Sediment metal concentrations in the Pend Oreille River suggest that metal-enriched sediments have been transported as far downstream as the Priest River, just upstream of Albeni Falls Dam (Beckwith 2002). Modeling studies predict that elevated sediment metal concentrations were likely transported from the upper Clark Fork River downstream to Lake Pend Oreille (Axtmann and Luoma 1991). The potential exists for

water quality impacts from possible sediment metal contamination in Lake Pend Oreille and the Pend Oreille River from legacy mining operations.

The nearshore waters of Lake Pend Oreille are likely influenced by contaminant sources immediately surrounding the lake, and discharging directly to the nearshore waters. The deeper open waters of the lake are influenced more by contaminants transported by the Clark Fork River. It is estimated that the Clark Fork River contributes about 80 percent of the nutrient loading to the open waters of Lake Pend Oreille (TSQWC 2004). The communities of Butte and Missoula in Montana, Sandpoint in Idaho, and Newport in Washington discharge secondary treated water to the Clark Fork and Pend Oreille Rivers. In addition to these larger point sources, other sources of contaminants to Lake Pend Oreille and the Pend Oreille River include residential development, urban runoff, and septic systems.

1.5 PREVIOUS INVESTIGATIONS 1980s TO 2000s

Previous water quality studies were conducted on Lake Pend Oreille in the late 1980s and early 1990s by the U.S. Geological Survey (USGS), Idaho Department of Environmental Quality (IDEQ), and the TSWQC (Falter, Olson and Carlson 1992; Frenzel 1991; Hoelscher, Skille, and Rothrock 1993; Falter 2004). In general, these studies concluded the physical, chemical, and biological water quality of Lake Pend Oreille was good and classified the trophic state of the deep water pelagic zone as oligotrophic and the shallow littoral zones as meso-oligotrophic. Trophic state classifies the biological productivity of a lake based on physical, chemical, and biological data (Wetzel 1983). Three water quality parameters are generally used to assess trophic status: total phosphorus, chlorophyll a, and transparency. For Lake Pend Oreille, the shallow nearshore littoral areas of the lake were determined to be the primary area where nutrient enrichment and increased biological productivity were occurring and where a potential water quality concern existed for the lake (Hoelscher, Skille, and Rothrock 1993).

Water quality has been monitored at several deep water pelagic sites and shallow nearshore littoral sites in Lake Pend Oreille since the late 1980s (Falter, Olson and Carlson 1992; Hoelscher, Skille, and Rothrock 1993; Falter 2004; PBS&J 2009). Based on data collected between 1989 and 2009, the general water quality of Lake Pend Oreille is good and the lake is classified as oligotrophic (Woods 2004; PBS&J 2009). Assessment of nearshore water quality data collected between 1989 and 2003 (Falter 2004) and from 2003 through 2007 (PBS&J 2009) indicated no significant trend in nearshore nutrient, chlorophyll a, or transparency levels measured during the summer months. Falter (2004) concluded that nearshore littoral zones maintained a meso-oligotrophic classification between 1989 and 2003. Similarly, data analysis by PBS&J (2009) concluded that nearshore site water quality indicated no trend in decreasing water quality between 2003 and 2007, and that the nearshore areas were classified as oligotrophic.

The Washington State Department of Ecology (Ecology) has been sampling the Pend Oreille River about 3 kilometers downstream of the dam at the Washington-Idaho

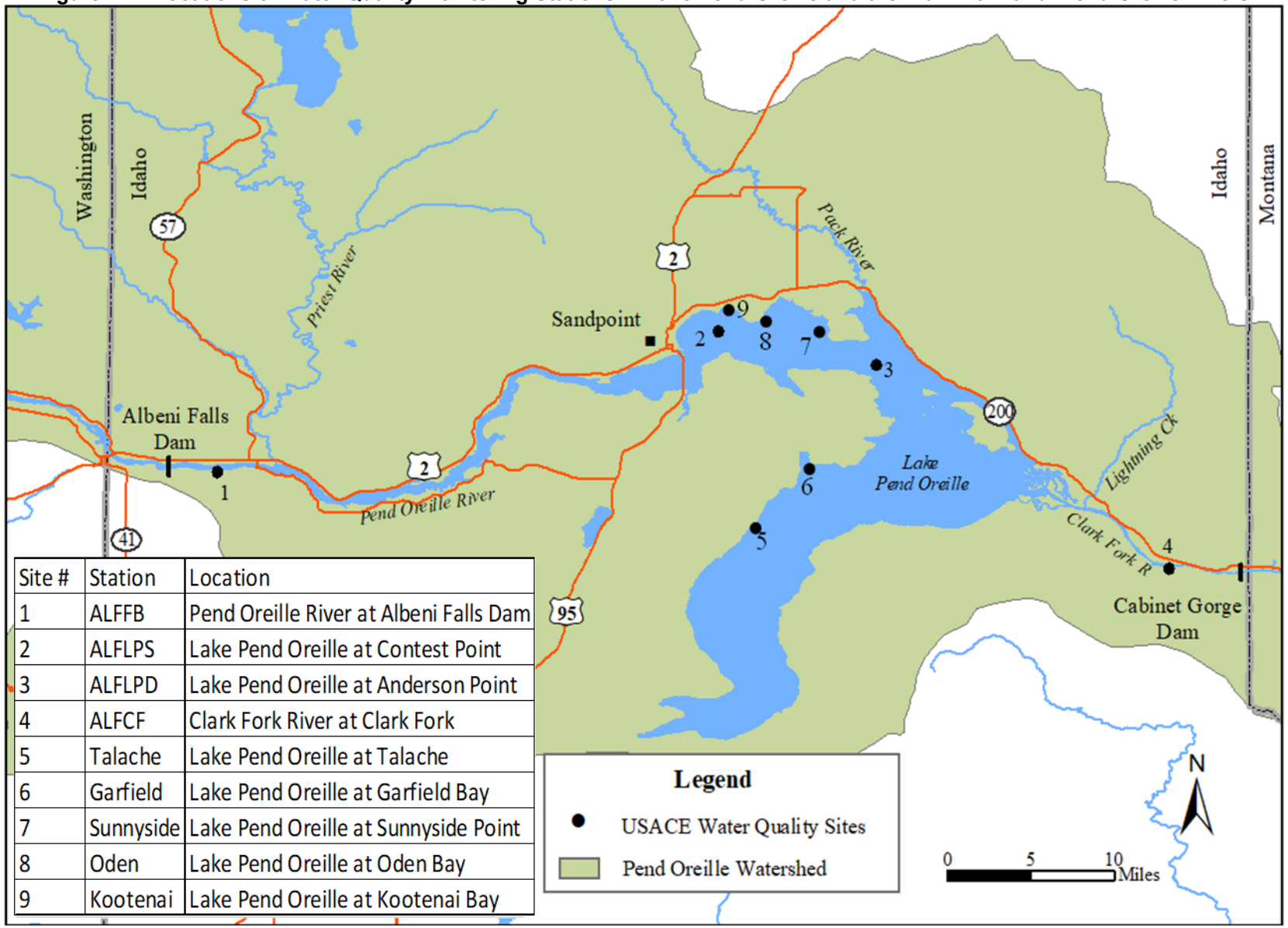
border monthly since 1959 (Ecology 2018a). This long-running sampling program has focused on nutrients (total nitrogen and total phosphorus), temperature, dissolved oxygen, pH, turbidity, suspended solids, and fecal coliform bacteria. Ecology has developed a water quality index (WQI) designed to rate the quality of the water as compared to water quality criteria. The WQI ranges from 1 to 100 with scores below 40 representing poor water quality, scores between 41 and 79 representing moderate water quality, and scores greater than 80 representing good water quality. For nutrients, no specific criteria exist, and the data was compared to expected conditions from similar waterbodies in the region. Based on data collected between January and December from 1993 through 2016, Ecology rated the total phosphorus and total nitrogen concentrations as good with a median WQI score of 95 for total phosphorus and 100 for total nitrogen. Median WQI scores for all other parameters ranged from a low of 68 for temperature to 85 for dissolved oxygen, with moderate WQI values of 73 for turbidity and suspended solids, and 79 for pH. In general, since 1994 the Pend Oreille River immediately downstream of Albeni Falls Dam has had moderate to good water quality with occasional exceedances of water quality standards for temperature and pH.

1.6 CURRENT INVESTIGATION 2005 TO 2016

The Seattle District implemented a water quality monitoring study in 2005 in order to better establish the current state of the physical, chemical, and biological condition of Lake Pend Oreille and the Pend Oreille River from which comparisons to previous studies conducted by the USGS, IDEQ, and TSWQC could be possible. Water quality data presented in this summary was derived from the current Seattle District program. The current Seattle District program consists of two permanent pelagic deep water lake stations, five permanent nearshore shallow lake stations, one permanent lake inflow station, and one permanent downstream river station distributed throughout the Clark Fork/Lake Pend Oreille/Pend Oreille River System (Figure 1-2).

The seven lake stations consisted of one deep water pelagic station (ALFLPD), one shallow water pelagic station (ALFLPS), and five nearshore shallow water stations (Talache, Garfield, Sunnyside, Oden, Kootenai). The Clark Fork inflow station (ALFCF) is located about 5 kilometers upstream of Lake Pend Oreille near the town of Clark Fork, Idaho, while one Pend Oreille River station was located about 47 kilometers downstream of Lake Pend Oreille at the forebay of Albeni Falls Dam (ALFFB). Water quality sampling station locations are summarized in Table 1-1, with general sampling locations shown in Figure 1-2. Water quality parameters of concern, analytical methods, detection limits, and sampling details are presented in Table 1-2 and Table 1-3.

Figure 1-2. Locations of Water Quality Monitoring Stations in Lake Pend Oreille and the Clark Fork and /Pend Oreille Rivers



Site #	Station	Location
1	ALFFB	Pend Oreille River at Albeni Falls Dam
2	ALFLPS	Lake Pend Oreille at Contest Point
3	ALFLPD	Lake Pend Oreille at Anderson Point
4	ALFCF	Clark Fork River at Clark Fork
5	Talache	Lake Pend Oreille at Talache
6	Garfield	Lake Pend Oreille at Garfield Bay
7	Sunnyside	Lake Pend Oreille at Sunnyside Point
8	Oden	Lake Pend Oreille at Oden Bay
9	Kootenai	Lake Pend Oreille at Kootenai Bay

Table 1-1. Water Quality Sampling Locations in Lake Pend Oreille, Clark -Fork River, and Pend Oreille River 2005 to- 2016

Station Name	Station Location	Water Body	Years Sampled	Placement	Latitude (NAD83)	Longitude (NAD83)
ALFLPD	Lake Pend Oreille at Anderson Point	Lake Pend Oreille	2005-2018	Pelagic/Deep	48.258529	-116.361919
ALFLPS	Lake Pend Oreille at Contest Point	Lake Pend Oreille	2005-2018	Pelagic/Shallow	48.27359	-116.506456
Talache	Lake Pend Oreille at Talache	Lake Pend Oreille	2011-2018	Nearshore/Shallow	48.12814	-116.4782
Garfield	Lake Pend Oreille at Garfield Bay	Lake Pend Oreille	2011-2018	Nearshore/Shallow	48.179765	-116.430853
Sunnyside	Lake Pend Oreille at Sunnyside Point	Lake Pend Oreille	2011-2018	Nearshore/Shallow	48.285809	-116.418256
Oden	Lake Pend Oreille at Oden Bay	Lake Pend Oreille	2011-2018	Nearshore/Shallow	48.306811	-116.463957
Kootenai	Lake Pend Oreille at Kootenai Bay	Lake Pend Oreille	2011-2018	Nearshore/Shallow	48.302723	-116.491906
ALFCF	Clark Fork River at Clark Fork	Clark Fork River	2006-2018	River	48.135906	-116.173154
ALFFB	Pend Oreille River at Albeni Falls Dam	Pend Oreille River	2006-2018	River	48.177936	-116.996326
ALFI	Albeni Falls Dam Forebay	Pend Oreille River	2004-2018	River	48.177777	-116.997777
ALQI	Albeni Falls Dam Tailwater	Pend Oreille River	2005-2018	River	48.1775	-117.002222

Table 1-2. Chemical Methods and Detection Limits for Lake Pend Oreille, Clark-Fork, and Pend Oreille Rivers Water Quality Analyses

Parameters	Method Number [1/]	Detection Limit/Unit	Container and Preservative	Holding Time	Water Quality Stations Key [4/]
Total Phosphorus	SM18 4500PF	0.002 mg/L	P/G[2/], 4°C, H2SO4 to pH<2	28 days	A
Soluble Phosphorus	SM18 4500PF	0.001 mg/L	P/G[2/], 4°C, filter immediately	48 hours	A
Total Nitrogen	SM20 4500NC	0.050 mg/L	P/G[2/], 4°C, H2SO4 to pH<2	28 days	A
Nitrate+Nitrite	SM18 4500N03F	0.010 mg/L	P/G[2/], 4°C, H2SO4 to pH<2	28 days	A
Ammonia	SM18 4500NH3H	0.005 mg/L	P/G[2/], 4°C, H2SO4 to pH<2	28 days	A
Alkalinity	SM18 2320B	1.00 mg/L	P/G[2/], 4°C	14 days	A
Hardness	SM18 2340B	0.700 mg/L	P/G[2/], 4°C, HNO3 to pH<2	6 months	B
Calcium	EPA 200.7	0.100 mg/L	P/G[2/], 4°C, HNO3 to pH<2	6 months	B
Magnesium	EPA 200.7	0.100 mg/L	P/G[2/], 4°C, HNO3 to pH<2	6 months	B
Potassium	EPA 200.7	0.500 mg/L	P/G[2/], 4°C, HNO3 to pH<2	6 months	B
Sodium	EPA 200.7	0.500 mg/L	P/G[2/], 4°C, HNO3 to pH<2	6 months	B
Sulfate	SM18 4500SO4E	1.00 mg/L	P/G[2/], 4°C	28 days	B
Chloride	SM18 4500CLC	0.50 mg/L	P/G[2/], 4°C	28 days	B
Aluminum	EPA 200.8	0.003 mg/L	P/G[2/], 4°C[3/]	6 months	B
Arsenic	EPA 200.8	0.003 mg/L	P/G[2/], 4°C[3/]	6 months	B
Cadmium	EPA 200.8	0.0001 mg/L	P/G[2/], 4°C[3/]	6 months	B
Chromium	EPA 200.8	0.0020 mg/L	P/G[2/], 4°C[3/]	6 months	B
Copper	EPA 200.8	0.0010 mg/L	P/G[2/], 4°C[3/]	6 months	B
Lead	EPA 200.8	0.0001 mg/L	P/G[2/], 4°C[3/]	6 months	B
Zinc	EPA 200.8	0.005 mg/L	P/G[2/], 4°C[3/]	6 months	B

Notes:

1/ SM method numbers are from Greenberg, Eaton, and ClesceriAPHA et al. (2000); EPA method numbers are from the U.S. Environmental Protection Agency (EPA) (1983, 1984, and 1992).

2/ P-Polyethylene, G-Glass.

3/ Samples for analysis of total trace metals should be preserved within 24 hours with HNO3 to pH < 2. Samples for dissolved trace metals should be preserved within 24 hours with HNO3 to pH < 2 after filtration.

A = Stations ALFCF, ALFLPD, ALFLPS, ALFFB for all months (2005 to -2016) and Stations Talache, Garfield, Sunnyside, Oden, Kootenai for June to -Sept (2011 to -2016)

B = Stations ALFCF, ALFLPD, ALFLPS, ALFFB for May, July, and October samples (2005 to -2016)

Table 1-3. Biological Methods and Detection Limits for Lake Pend Oreille, Clark-Fork, and Pend Oreille Rivers Water Quality Analyses

Biological Parameters	Method Number [1/]	Detection Limit/Unit	Container and Preservative	Holding Time	Water Quality Stations Key [4/]
Chlorophyll a	SM 1810200H	0.0001 mg/L	P[2/], 4°C, filter, add MgCO3	28 days	C
Phytoplankton	–	–	P/G[2/], 4°C, 1% Lugols	12 months	C
Zooplankton	–	–	G[2/], 4°C, 25% Isopropyl Alcohol	12 months	D

Notes:

1/ SM method numbers are from Greenberg, Eaton, and ClesceriAPHA et al. (2000); EPA method numbers are from the U.S. Environmental Protection Agency (EPA) (1983, 1984, and 1992).

2/ P-Polyethylene, G-Glass.

C = Stations ALFLPD, ALFLPS, ALFFB for all months (2005 to -2016) and Stations Talache, Garfield, Sunnyside, Oden, Kootenai for June to -September (2011 to -2016)

D = Stations ALFLPD, ALFLPS, ALFFB for all months (2005 to -2016)

1.7 WATER QUALITY CRITERIA

IDEQ determines water quality criteria for the Clark Fork River, Pend Oreille River, and Lake Pend Oreille in Idaho. IDEQ has classified waters in the Pend Oreille River watershed as Aquatic Life Use Cold (Cold) waters, which are suitable Primary Contact Recreation and Domestic Well Supply. Lake Pend Oreille and the Clark Fork River inflow are classified as an Aquatic Life Use Cold-Salmonid Spawning (Cold/SS) waters, which are suitable Primary Contact Recreation and Domestic Well Supply (Table 1-4). The state of Idaho's numeric water quality standards are presented in Table 1-5. Criterion maximum concentrations (acute 1-hour average) and criterion chronic concentrations (chronic 4-day average) for metals sampled in Lake Pend Oreille and the Clark Fork and Pend Oreille Rivers are presented in Table 1-5. Total ammonia concentrations shown in Table 1-5 are based on the combined ionized (NH_4+-N – ammonium) and unionized (NH_3-N – ammonia) forms. However, only the unionized form of ammonia (NH_3-N) is toxic to freshwater life. Equations can be used to estimate the concentration of unionized ammonia fraction from measured values of the pH and temperature of the water. In general, the unionized form of ammonia (NH_3) represents an extremely small percentage of the total ammonia nitrogen concentration (Greenberg, Eaton, and Clesceri 1992).

Table 1-4. Idaho Department of Environmental Quality General Water Quality Standards

Parameter/Project	Aquatic Life Use	Standard
Temperature		
Clark Fork River	Cold/SS	Water temperature of 22°C or less with a maximum daily average of no greater than 19°C. During salmonid spawning periods determined by the department a water temperature of 13°C or less with a maximum daily average of no greater than 9°C.
Lake Pend Oreille	Cold/SS	Temperature in lakes shall have no measureable change from natural background conditions.
Pend Oreille River	Cold	Water temperature of 22°C or less with a maximum daily average of no greater than 19°C.
pH		
Clark Fork River	Cold/SS	pH values within the range of 6.5 to 9.0
Lake Pend Oreille	Cold/SS	pH values within the range of 6.5 to 9.0
Pend Oreille River	Cold	pH values within the range of 6.5 to 9.0
Dissolved Oxygen		
Clark Fork River	Cold/SS	Dissolved oxygen concentrations exceeding 6.0 mg/L at all times. During salmonid spawning periods determined by the department a water column one day minimum of not less than 6.0 mg/L or 90% saturation, whichever is greater.
Lake Pend Oreille	Cold/SS	Dissolved oxygen concentrations exceeding 6.0 mg/L at all times. During salmonid spawning periods determined by the department a water column one day minimum of not less than 6.0 mg/L or 90% saturation, whichever is greater. In lakes this standard does not apply to (i) the bottom 20% of water depth in natural lakes where depths are 35 meters or less, (ii) the bottom 7 meters of water depth in natural lakes where depths are greater than 35 meters, (iii) those whaters of the hypolimnion in stratified lakes.
Pend Oreille River	Cold	Dissolved oxygen concentrations exceeding 6.0 mg/L at all times.
Turbidity		
Clark Fork River	Cold/SS	Shall not exceed background turbidity by more than 50 NTU instantaneously or mor than 25 NTU for more than 10 consecutive days.
Lake Pend Oreille	Cold/SS	Shall not exceed background turbidity by more than 50 NTU instantaneously or mor than 25 NTU for more than 10 consecutive days.
Pend Oreille River	Cold	Shall not exceed background turbidity by more than 50 NTU instantaneously or mor than 25 NTU for more than 10 consecutive days.
Total Dissolved Gas		
Clark Fork River	Cold/SS	Shall not exceed 110 percent of saturation.
Lake Pend Oreille	Cold/SS	Shall not exceed 110 percent of saturation.
Pend Oreille River	Cold	Shall not exceed 110 percent of saturation.

Table 1-5. Idaho Department of Environmental Quality Metals and Ammonia Water Quality Standards

Category	Parameters	Acute Water Quality Criteria[1] (µg/L)	Chronic Water Quality Criteria[1] (µg/L)
Nutrients	Ammonia[2]	8110	2540
Dissolved Metals	Aluminum	—	—
Dissolved Metals	Arsenic	340	150
Dissolved Metals	Cadmium	1.3*	0.6*
Dissolved Metals	Chromium	570*	74*
Dissolved Metals	Copper	17*	11*
Dissolved Metals	Lead	65*	2.5*
Dissolved Metals	Zinc	120*	120*

Notes:
1 = IDEQ (2017)
2 = Total ammonia concentration. Based on salmonids present, pH value of 7.8 and temperature of 18C.
* = Value shown based on an average hardness of 100 mg/L as CaCO3 and a Water Effects Ratio of 1.
— = Not Available.

1.8 EXISTING 303(D) AND TOTAL MAXIMUM DAILY LOADS

A nearshore total maximum daily load (TMDL) for nutrients was developed for Lake Pend Oreille in 2002 in response to an increasing trend in nuisance algal growth in the nearshore areas (TSWQC 2002). The TMDL is designed to set target and action levels for total phosphorus concentrations measured in the nearshore waters of Lake Pend Oreille. The TMDL identifies the nearshore waters as the littoral zone of the lake where light can penetrate to the bottom. For the purpose of implementing the TMDL, nearshore waters were determined to be those waters at fewer than 16 meters in depth (TSWQC 2004). The Pend Oreille Lake nearshore TMDL established a lakewide nearshore average total phosphorus concentration of 9 micrograms per liter (µg/L) with an action threshold of 12 µg/L during the summer months of June through September (TSWQC 2004). The 9 µg/L represents an average concentration throughout all the nearshore waters while the 12 µg/L threshold represents an instantaneous concentration at any one location collected during routine monitoring. The June through September timeframe represents the critical summer months when algae growth occurs in the nearshore areas (TSWQC 2004).

The lower Clark Fork River, Lake Pend Oreille, and the Pend Oreille River were identified by IDEQ as water quality impaired and not fully supporting aquatic life in the IDEQ 2014 Integrated Report (IDEQ 2018). The lower Clark Fork River was included in the 2014 IDEQ 303(d) list Category 5 for temperature, Lake Pend Oreille for mercury in fish tissue, and the Pend Oreille River for temperature and dissolved gas. The 303(d) list Category 5 is defined by EPA as waters with one or more beneficial uses being impaired or threatened, and a TMDL is required to address the impairment or threat. The lower Clark Fork River currently has EPA-approved TMDLs for cadmium, copper, zinc, and total dissolved gas (TDG). Lake Pend Oreille has an EPA-approved TMDL for nearshore total phosphorus.

The Pend Oreille River was identified by the Ecology as water quality impaired and not fully supporting aquatic life in the Ecology 2016 Integrated Report (Ecology 2018b). The Pend Oreille River was included in the 2016 Ecology 303(d) list Category 5 for water

temperature and pH, and fish tissue mercury and polychlorinated biphenyls. The Pend Oreille River currently has EPA-approved TMDLs for TDG.

1.9 DATA ANALYSIS

Data analysis consisted of graphing and visual inspection of timeseries data measured at all stations in Lake Pend Oreille during 2005 to 2016. For this analysis, any data below the laboratory reporting limits was used in statistical tests and estimated at one-half the reporting limit. Water quality parameters used for statistical analyses focused largely on nutrients, and included: total phosphorus, soluble reactive phosphorus, total nitrogen, nitrate+nitrite-nitrogen, ammonia-nitrogen, alkalinity, transparency, and chlorophyll a. Phytoplankton data used for these analyses focused on total phytoplankton density, total phytoplankton biovolume, and phytoplankton composition.

Visual inspection of data and trends was conducted using boxplots to summarize water quality data measured at each station during the study. Boxplots display essential characteristics of a dataset, and are useful when comparing copious amounts of data between multiple datasets. Boxplots provide a visual summary of the center of the data (the median shown as a small box inside the larger box), the spread of the data (the interquartile range or larger box height representing 25 to 75 percent of the data), the skewness of the data (where the median box falls in relation to the larger box), and the range of outlier values (the whisker lines emanating from the box representing 10 to 90 percent of the dataset).

SECTION 2 - WATER QUALITY

2.1 GENERAL DESCRIPTION

Retention time, which is the inverse of the flushing rate, refers to the length of time water remains in a water body. Lake volume, inflow, and outflow are important factors in determining the overall retention time in a water body. One can calculate the retention time either by dividing the lake volume by the inflow (filling time) or by the outflow (residence time). In general, high flushing rates allow for the rapid exchange of chemical constituents through the lake. Longer retention times allow for the accumulation and transformations of chemical constituents in sediments and lake water, and their cycling through the ecosystem.

The theoretical residence time of Lake Pend Oreille is about 2.4 years based on historical mean annual outflow volume of 22.6 cubic kilometers and a normal full pool lake volume of 53.9 cubic kilometers (Woods 2004). Theoretical data was based on a 97-year period of record at the USGS gaging station located on the Pend Oreille River at Newport, Washington (see Figure 1-1), about 2.4 kilometers downstream of Albeni Falls Dam. During this 97-year period, outflow volume varied from 11.5 to 34.7 cubic kilometers, resulting in a historical range in residence times from 1.6 to 4.7 years (Woods 2004). During the current 2005 to 2016 water quality study, annual lake residence times ranged from a minimum of 1.65 years in 2011 to a maximum of 2.94 years in 2005.

2.2 PHYSICAL CHARACTERISTICS

2.2.1 Temperature

The temperature-related characteristics of water have a large effect on water quality and the ecology of lakes. As lake water warms in the spring and summer it becomes less dense and floats on top of colder water. In the absence of sufficient energy (i.e., wind or high inflows) to mix the water and equilibrate the temperature, a lake will thermally stratify and form two separate temperature layers. Thermal stratification produces a warm water upper layer, called the epilimnion, and a cold water bottom layer, called the hypolimnion. The transition zone between these two layers is called the metalimnion or thermocline, and is marked by rapid changes in water temperatures from top to bottom. Because of the temperature difference in a stratified lake there is little mixing of water between the epilimnion and hypolimnion until the lake de-stratifies in the fall and winter resulting in a uniform temperature throughout the water column.

The thermal structure in some lakes may be impacted by the temperature of the inflow water resulting in either underflow, when inflow temperatures are colder than the lake's epilimnion and plunge to the deeper layers, or overflow when inflow temperatures are warmer than the lake's hypolimnion and therefore stay in the epilimnion (Wetzel 1975). Although inflow plume routing may be the dominant cause of thermal stratification in some lakes, it is typically more common that a combination of both inflow plume routing and solar heating of the lake surface results in the development of a thermocline. Water

quality study data collected from 2006 to 2016 measured numerous temperature, conductivity, pH, and dissolved oxygen profiles as well as chemical constituents in the Clark Fork River and in Lake Pend Oreille. The data suggests that overflow is the most common inflow water plume routing to Lake Pend Oreille.

Water temperature changes in Lake Pend Oreille and the Pend Oreille River are mainly influenced by atmospheric conditions and weather patterns. Solar heating is sufficient to develop thermal stratification and a thermocline in Lake Pend Oreille during the spring and summer months. In general, the deep water pelagic region of Lake Pend Oreille is completely mixed in the winter months and begins to stratify in April with a strong thermocline developing in June and continuing through October (Woods 2004). Thermocline depths typically range from about 8 to 20 meters. The shallower (fewer than 20 meters deep) regions of Lake Pend Oreille do not thermally stratify for any substantial period of time. Woods (2004) noted that the development of thermal stratification in the deep water pelagic zone of the southern basin of the lake is largely a function of solar radiation. In contrast, the development of thermal stratification in the deep water zone of the northern basin is a function of both solar radiation and inflow plume routing of the Clark Fork. Woods (2004) observed a lack of a strong thermocline development in the large shallow basin near the outlet and contributed this to water column turbulence caused by inflow routing from the Clark Fork.

An extensive water temperature study in Lake Pend Oreille and the Pend Oreille River was conducted by the Seattle District from 2004 through 2006. Temperature strings equipped with automated thermal loggers capable of measuring and logging temperature at hourly intervals were deployed from April through October at several locations from the northern basin of Lake Pend Oreille to Albeni Falls Dam. The temperature loggers were deployed as a string attached to a buoy in a vertical profile starting at the surface (0.5 meter depth) with loggers concentrated in the region of more significant temperature gradients down to about 1 to 5 meters off of the bottom.

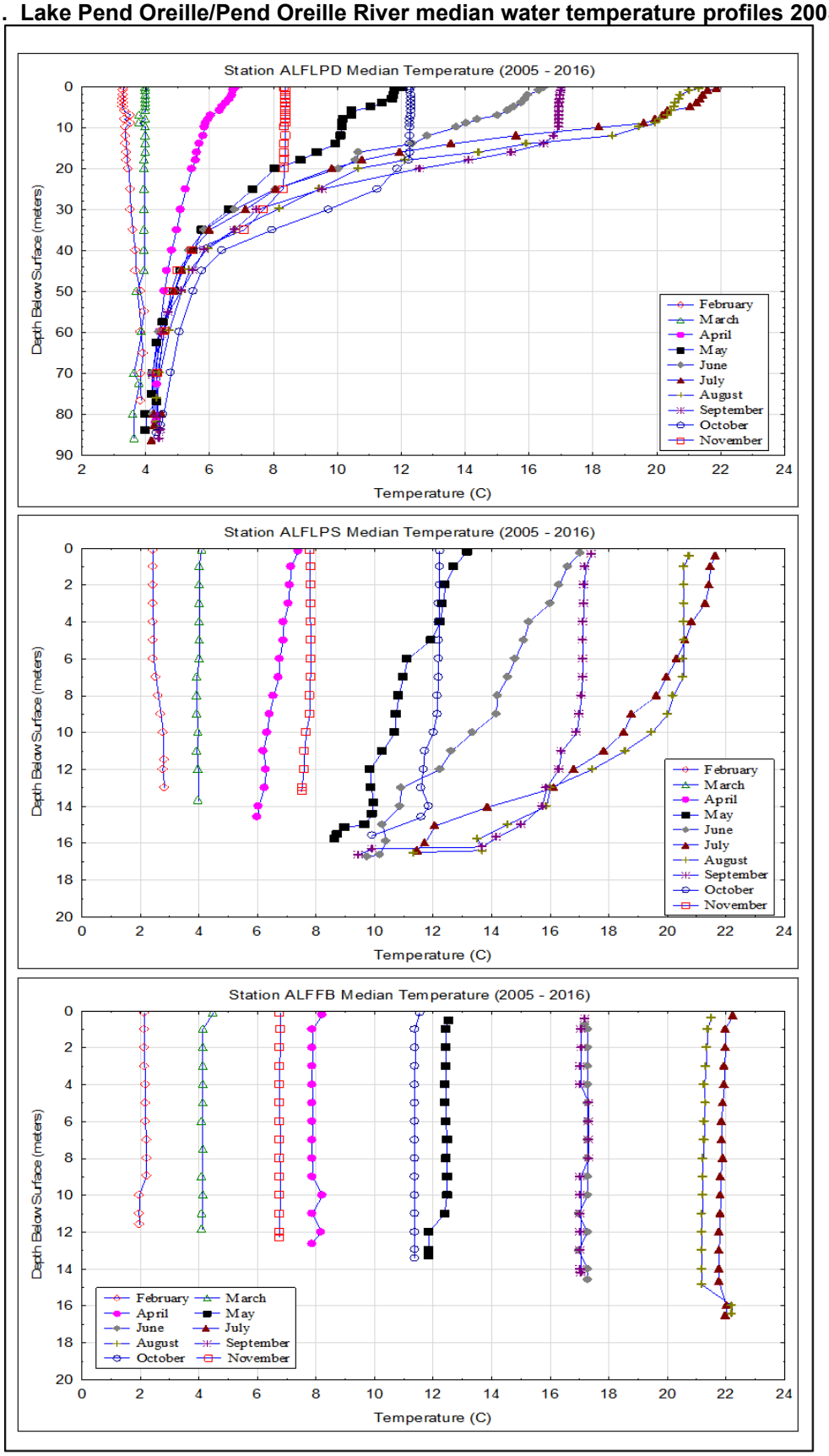
Data collected from 2004 through 2006 shows that the water temperatures in the northern basin of Lake Pend Oreille at both the shallow and deep water pelagic sites were vertically stratified throughout the summer period in contrast to the nearly uniform vertical distribution of temperatures measured downstream in the Pend Oreille River. The temperature conditions at the outlet near the Long Bridge show a vertical variation in water temperatures limited by the shallow depth at this station. Lake Pend Oreille near Hope has colder water temperatures of 5°C or less throughout the summertime at depths greater than about 50 meters. Surface water temperatures in Lake Pend Oreille typically exceed 19°C by the end of June and 22°C by mid-July and reach maximum temperatures in excess of 24°C at the end of July and in early August. Water temperatures in the thermocline region in Lake Pend Oreille exhibit a cyclical pattern consistent with internal seiching activity where a wide range of temperatures are observed cycling between warmer and colder temperatures.

A prominent difference between thermal conditions in the lake and river during the summertime is the occurrence of warmer water temperatures throughout the water column in the Pend Oreille River whereas the warmer water temperatures are limited to

the upper portion of the water column in Lake Pend Oreille. These temperature observations are consistent with the transport of surface oriented water from the lake into the river due to the shallow channel properties in the transitional reach of the Pend Oreille River near Sandpoint. A shallow low water channel acts as a barrier to the transport of much colder subsurface water from Lake Pend Oreille into the Pend Oreille River.

Median water temperature profiles collected in Lake Pend Oreille at stations ALFLPD and ALFLPS, and in the Pend Oreille River at station ALFFB during the study are shown in Figure 2-1. Water temperature profiles at all three stations followed a similar pattern of warming from April through August and cooling in September and October. However, the development of strong thermal stratification only occurred at the deep water station (depth greater than 80 meters) ALFLPD. The shallow water station (depth less than 18 meters) ALFLPS showed very weak thermal stratification while the Pend Oreille River station (depth less than 18 meters) ALFFB showed no stratification. It is likely that water turbulence caused by inflow routing and the shallow depth prevented the development of strong thermal stratification at ALFLPS while water turbulence in the river prevented stratification at ALFFB. The onset of thermal stratification at the deep water lake station ALFLPD varies from year to year likely due to many reasons such as inflow volumes, inflow temperatures, and weather conditions. Thermocline depths at the deep water lake station varied from year to year during the study, but in general ranged from about 10 to 20 meters at ALFLPD. When thermal stratification was present at the shallow lake station ALFLPS, the thermocline ranged from about 6 to 14 meters.

Figure 2-1. Lake Pend Oreille/Pend Oreille River median water temperature profiles 2005 to 2016



2.2.2 Total Dissolved Gas

TDG, water temperature, and associated water quality processes are known to impact anadromous and resident fishes in the Pend Oreille River system. Dams may alter a river's water quality characteristics by increasing TDG levels due to releasing water through the spillways and by altering temperature gradients due to the creation of reservoirs. Spilling water at dams can result in increased TDG levels in downstream waters by plunging the aerated spill water to a depth where hydrostatic pressure increases the solubility of atmospheric gases. Elevated TDG levels generated by spillway releases from dams can promote the potential for gas bubble trauma in downstream aquatic biota (Weitkamp 1980; Weitkamp et al. 2002).

Elevated TDG levels in the Pend Oreille River are largely caused by spill from dams. Although other sources of TDG exist in the watershed (i.e., high water temperatures and high biological productivity) the majority of TDG increases measured in the Pend Oreille River are the result of spills from dams. The State of Idaho's TDG water quality standard states that TDG shall not exceed 110 percent saturation at any point of sample collection or in any single sample. However, the state of Idaho provides an exemption to the TDG standard for flows above the 7Q10 flood.

Albeni Falls Dam is formed by two separate concrete gravity structures, a 10-bay spillway on the left or southwest side of the river, and a powerhouse on the right or northeast side of the river. TDG exchange studies at Albeni Falls Dam in 2003 conducted by Schneider, Yates, and Barko (2007) concluded that Albeni Falls spillway releases resulted in small increases in TDG pressures in the Pend Oreille River. The increase in TDG saturations in the Pend Oreille River during spillway test operations in 2003 ranged from about 0 to 4.1 percent. The small increase in TDG saturations was attributed to the low project head, shallow stilling basin channel, and wide spillway.

The Seattle District has monitored TDG at the forebay and tailwater of Albeni Falls Dam from April through October since 2005. In general, during the high flow spring runoff period, TDG saturations at Albeni Falls forebay exceed 110 percent due to upstream natural and anthropogenic sources. The nearest upstream project that could be a potential source of TDG to the forebay is Cabinet Gorge Dam, located about 90 kilometers upstream on the Clark Fork River at the state line between Idaho and Montana. Parametrix, Inc. (1999), reported that only minor degassing occurred in the Clark Fork–Pend Oreille River system between Cabinet Gorge Dam and Albeni Falls Dam during the 1998 spill season. Therefore, it is likely that Cabinet Gorge Dam is the source of the elevated TDG measured at the forebay. For the Pend Oreille River TDG TMDL, IDEQ identified Cabinet Gorge Dam on the Clark Fork as the source of supersaturated water entering the forebay at Albeni Falls Dam (IDEQ 2008).

Saturations measured in the forebay and tailwater from 2005 to 2016 indicate that spill at Albeni Falls Dam can increase downstream TDG saturations slightly more than predicted from the 2003 spill test. In general, spillway operations from 2005 to 2016 resulted in an increase in downstream TDG ranging from about 0 to 9 percent of forebay saturation depending on the amount of water spilled and the number of spillway

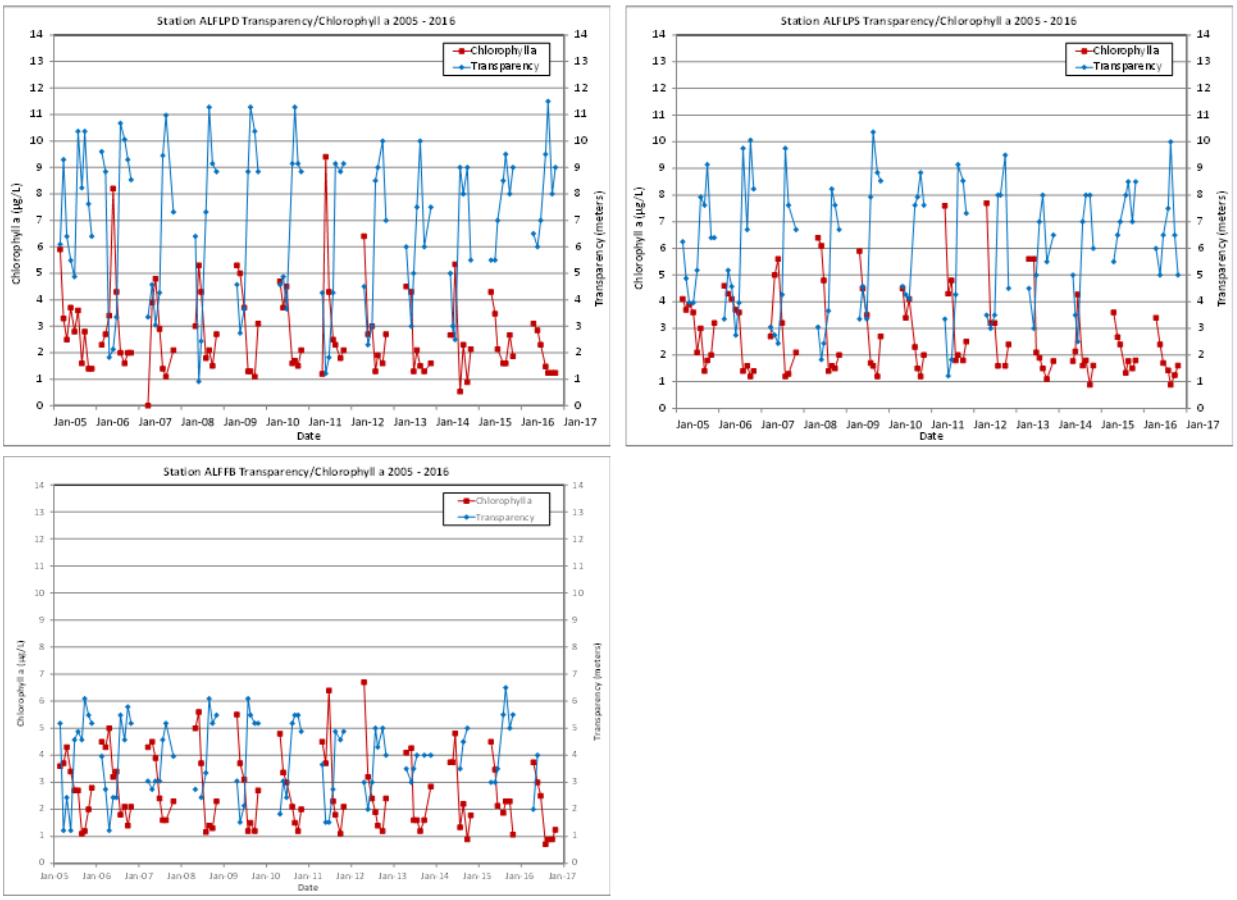
bays operating. Typically, the greatest increase in TDG saturations between the forebay and tailwater occurs when the project is spilling from fewer than eight spillway bays. Forebay TDG saturations and spillway patterns are critical components in determining how much Albeni Falls Dam can spill before the 110 percent TDG criterion is exceeded. Typically, when forebay TDG saturations are less than 100 percent and a uniform spillway pattern is used, spillway releases from Albeni Falls Dam should not exceed the 110 percent TDG criterion.

2.2.3 Transparency

Water transparency was measured in Lake Pend Oreille using a Secchi disk, which is an 8-inch disk with alternating black and white quadrants. The depth at which the disk can no longer be seen in the water is called the Secchi disk depth. This depth is a relative measure of water transparency that can be used to look at changes in water clarity over time and between sampling stations. Water clarity is an important parameter when determining the trophic status of a lake because the amount of algae suspended in the water column (phytoplankton) directly impacts transparency. Other factors that can affect transparency include suspended matter, soil particles, and natural water color.

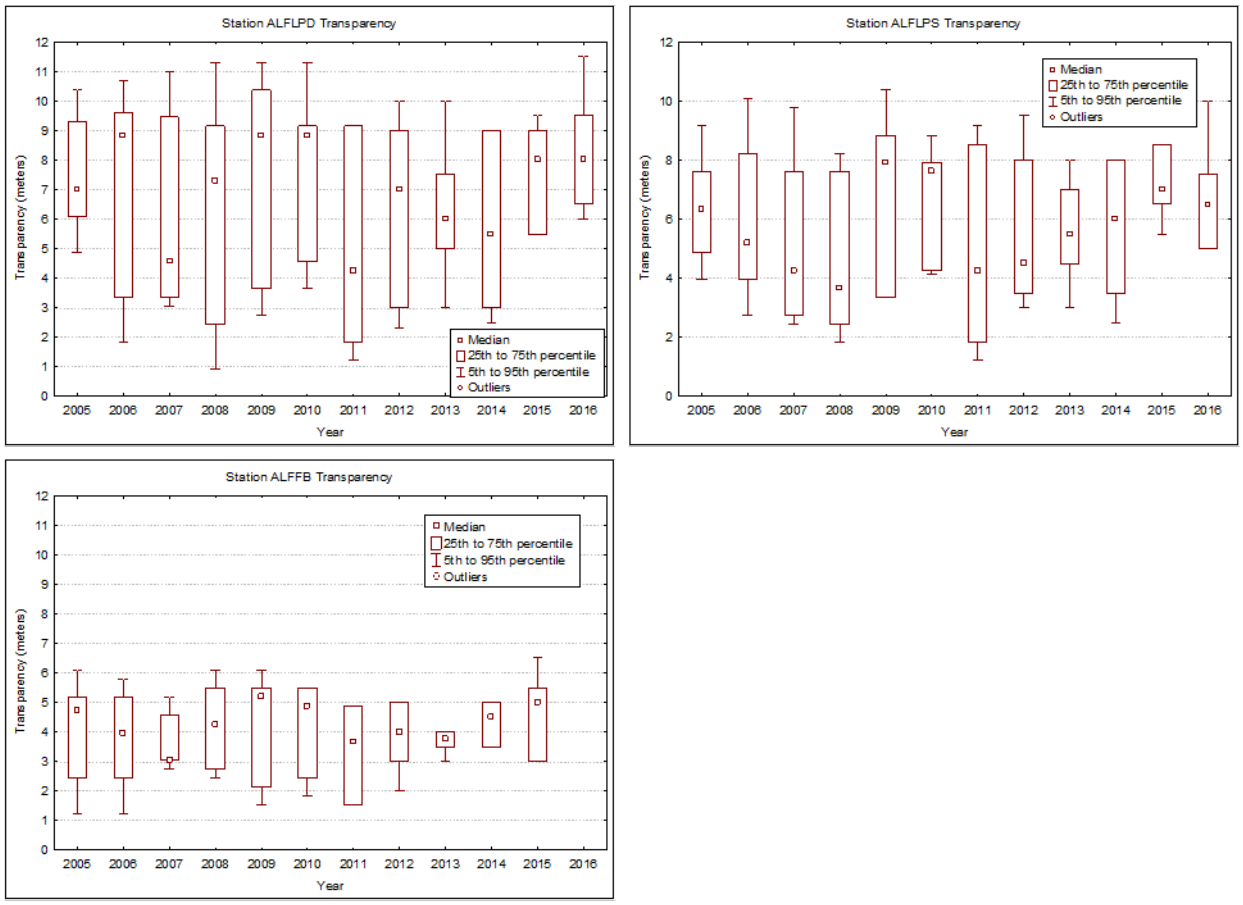
Monthly variations in transparency at water quality stations in Lake Pend Oreille for 2005 to 2016 are presented in Figure 2-2. Timeseries plots show that seasonal trends in transparency were similar at all stations. Transparencies were lowest from April through June, showing the effect of high spring Clark Fork River flows on the overall water clarity in the northern basin of Lake Pend Oreille. Water transparencies increased during the summer months at all stations with maximum water clarity generally in July and August, and slightly reduced water clarity in September and October. The influence of the Clark Fork River on transparencies in the northern basin of Lake Pend Oreille has been documented previously (Woods 2004). The other main factor affecting the transparency of Lake Pend Oreille is phytoplankton growth. Figure 2-2 plots transparency and chlorophyll a together as a time series. A moderately strong negative relationship between transparency and chlorophyll a is apparent at all stations suggesting that in addition to inflow, the reduced water clarity measured at all stations for all years is also likely due in part to the amount of algae suspended in the water column (see Figure 2-2). The seasonal variation of water transparency in Lake Pend Oreille were similar at the deep water (ALFLPD) and shallow water (ALFLPS) stations. Transparencies are moderately reduced in April (3 to 5 meters), greatly reduced in May and June (1 to 3 meters), increasing during the summer to a maximum water clarity (9 to 11 meters) in July and August, and then reducing slightly (7 to 9 meters) in September and October. Transparencies measured in the Pend Oreille River at Albeni Falls Dam followed the same seasonal variation but were substantially lower, ranging from about 1 to 6 meters during the study.

Figure 2-2. Lake Pend Oreille and Pend Oreille River Transparency and Chlorophyll a for 2005 to 2016



A summary of annual (April to October) water transparencies at each station from 2005 through 2016 is presented in Figure 2-3. This boxplot shows the median value, the 25th to 75th percentile range of data, the 10th to 90th percentile range of data, and outlier values. Annual transparency data exhibited both station to station and year to year variations. The median annual transparency was substantially lower in the Pend Oreille River at ALFFB and ranged from 3 meters in 2007 to about 5 meters in 2009. Median annual transparencies were greater and similar at stations ALFLPD and ALFLPS and ranged from about 3 to 4 meters in 2007 to about 8 to 9 meters in 2009. The overall range of data was substantially less in the Pend Oreille River at station ALFFB largely due to the lower maximum transparencies measured at this station.

Figure 2-3. Statistical Summary of Annual Transparency in Lake Pend Oreille and Pend Oreille River for 2005 to 2016



2.2.4 Dissolved Oxygen

The concentration of dissolved oxygen in the water is important for determining the types of organisms which can survive and for regulating chemical processes, such as nutrients released from the sediments. For example, anoxic (no oxygen) conditions at the sediment water interface can result in the release of phosphorus from the sediments into the overlying water. Oxygen is supplied to the water from the atmosphere and from aquatic plants through photosynthesis. Oxygen can be removed from water by the respiration of aquatic organisms and plants, and the decomposition of organic matter in the water and sediments by bacteria.

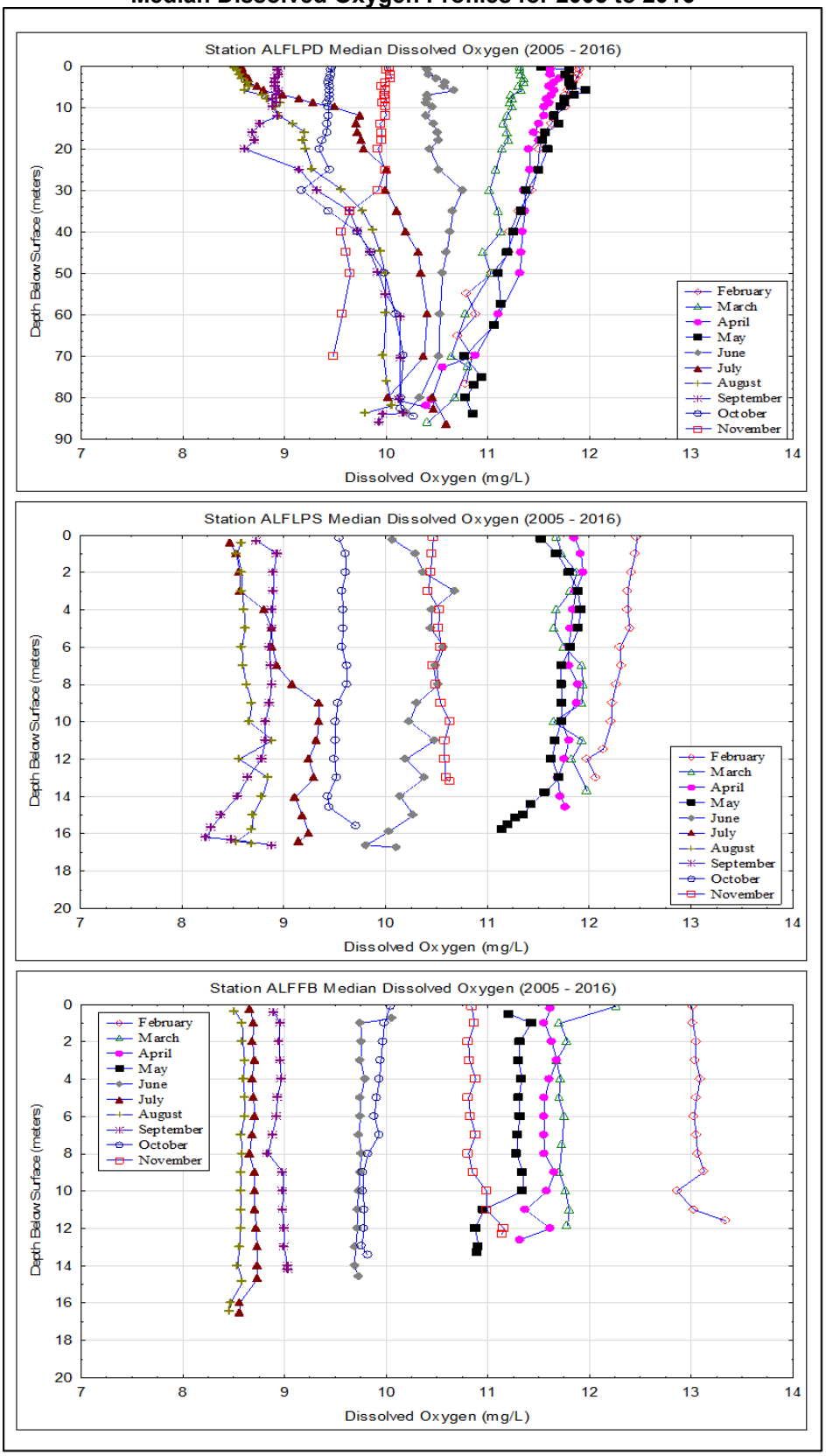
The solubility of oxygen in water is affected by temperature and air pressure. Oxygen solubility increases in cold water and with higher atmospheric partial pressure. The vertical pattern of dissolved oxygen concentration in a lake is controlled by a combination of physical and biological processes. In oligotrophic lakes (low nutrient input and biological productivity) oxygen is typically controlled by physical processes with an orthograde oxygen profile. Dissolved oxygen is at or near 100 percent saturation throughout the water column and the concentration of oxygen is lower in the warmer epilimnion water and increases with depth in the cooler hypolimnion. A highly productive

eutrophic lake is typically controlled by biological process and has an opposite dissolved oxygen profile called a clinograde profile, with oxygen concentrations highest in the near surface epilimnion and reduced oxygen with depth. Biological productivity results in oxygen production near the surface due to photosynthesis and consumption at depth due to decomposition and respiration. When dissolved oxygen concentrations increase or decrease in the metalimnion, the profile is called a positive or negative heterograde, respectively. Increased metalimnetic oxygen (positive heterograde) can be the result of photosynthetic activity by phytoplankton that are adapted to the lower light levels and increased nutrient availability in the metalimnion. Or, if water transparency and nutrient conditions are sufficient, a large population of metalimnetic algae may exist. Decreased metalimnetic oxygen (negative heterograde) is more unusual than increased metalimnetic oxygen, and may result if there is excessive oxygen consumption in the metalimnion, such as from microbial or animal respiration. Typically, an oxygen minima in the metalimnion is possible if water transparency is not sufficient to allow photosynthesis in the stratified layer.

Dissolved oxygen profiles for 2005 through 2016 are presented in Figure 2-4. In general, dissolved oxygen concentrations measured near the surface of all stations were similar and ranged from about 8 to 13 mg/L during the study. The temporal pattern in near surface dissolved oxygen concentrations is largely related to the natural warming and cooling of water in Lake Pend Oreille from spring through fall. Dissolved oxygen concentrations measured near the bottom in the hypolimnion of deep water station ALFLPD were slightly greater than the shallow water station ALFLPS and the river station ALFFB. Hypolimnetic oxygen at ALFLPD ranged from about 9 to 11 mg/L throughout the entire year, while at ALFLPS and ALFFB near bottom dissolved oxygen was slightly less and ranged from about 8 to 11 mg/L. This data shows that Lake Pend Oreille and the Pend Oreille River are well oxygenated throughout the entire water column with very few dissolved oxygen concentrations measured below 8 mg/L.

The vertical patterns of dissolved oxygen concentrations were different between the three stations. In general, vertical profiles at all stations in the spring followed an orthograde profile with relatively constant oxygen concentrations from surface to bottom. For the most part, shallow water station ALFLPS and river station ALFFB continued to display an orthograde profile during the summer and fall with little difference in dissolved oxygen concentrations with depth. However in the summer and fall ALFLPD’s profile generally showed either a metalimnetic decrease in oxygen with an increase in the hypolimnion which is typical of a negative hetrograde profile, or less often a metalimnetic increase in oxygen (positive heterograde) with an increase in the hypolimnion.

Figure 2-4. Lake Pend Oreille and Pend Oreille River Median Dissolved Oxygen Profiles for 2005 to 2016



2.2.5 Alkalinity, Hardness, and pH

Alkalinity is a measure of the buffering capacity of the water to changes in pH. In many freshwater ecosystems, alkalinity is a function of the concentration of bicarbonates, carbonates, and hydroxides (Wetzel 1975). It is likely that Lake Pend Oreille alkalinity is dominated by the carbonate system (HCO_3 and CO_3), as are most aquatic systems in the absence of other, more unique factors. Median annual alkalinity concentrations in the epilimnion ranged from about 80 to 90 milligrams calcium carbonate per liter (mg $CaCO_3$/L) at both ALFLPD and ALFLPS (Figure 2-5). Hypolimnetic median annual concentrations were slightly greater and ranged from about 85 to 95 mg $CaCO_3$/L at both stations. Median concentrations measured the Clark Fork River inflow (ALFCF) and in the Pend Oreille River (ALFFB) were similar to Lake Pend Oreille epilimnetic concentrations ranging from about 80 to 90 mg $CaCO_3$/L. Timeseries plots presented in Figure 2-6 show that concentrations were greatest in the early spring, decreased during the late spring/early summer and increased in the summer and fall at most stations and depths. Based on this data, Lake Pend Oreille would be classified as having moderate alkalinity with an average buffering capacity to pH changes.

Figure 2-5. Statistical Summary of Annual Alkalinity in the Lake Pend Oreille Study Area for 2005 to 2016

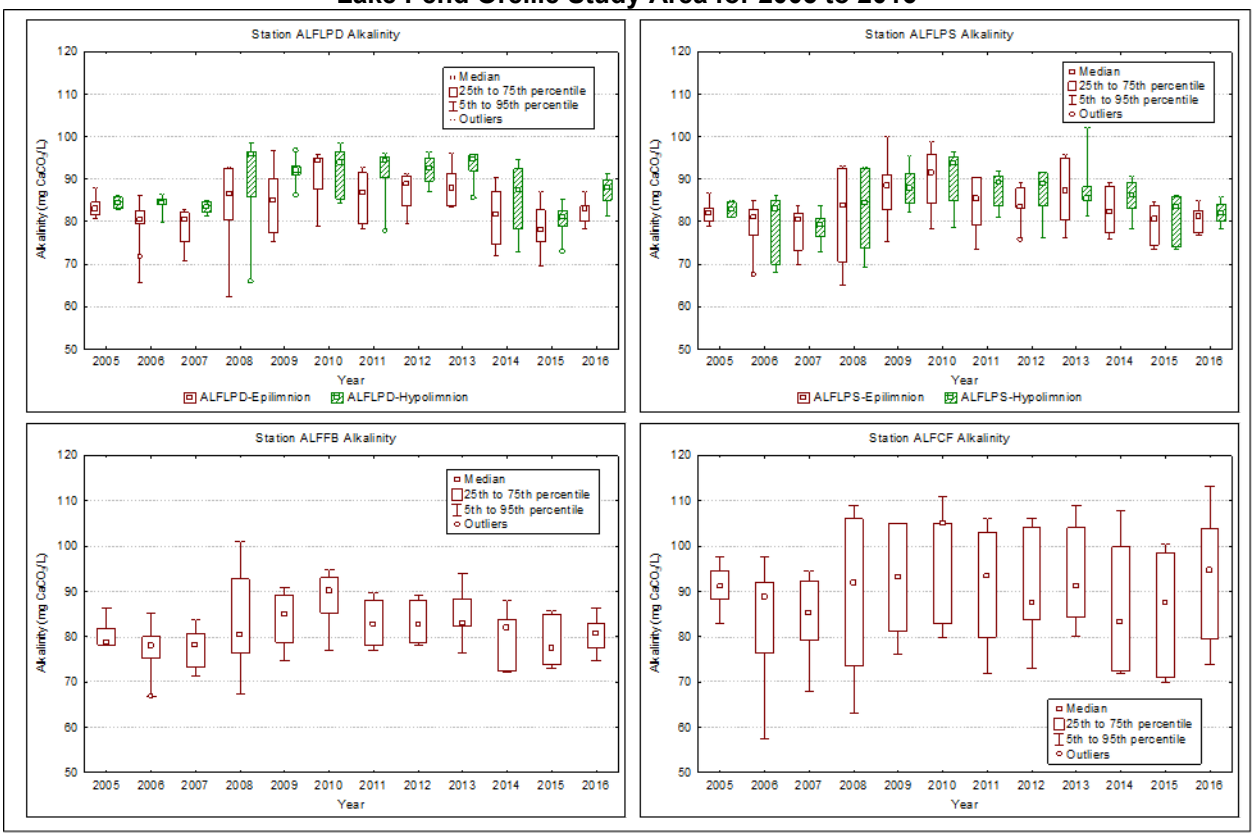
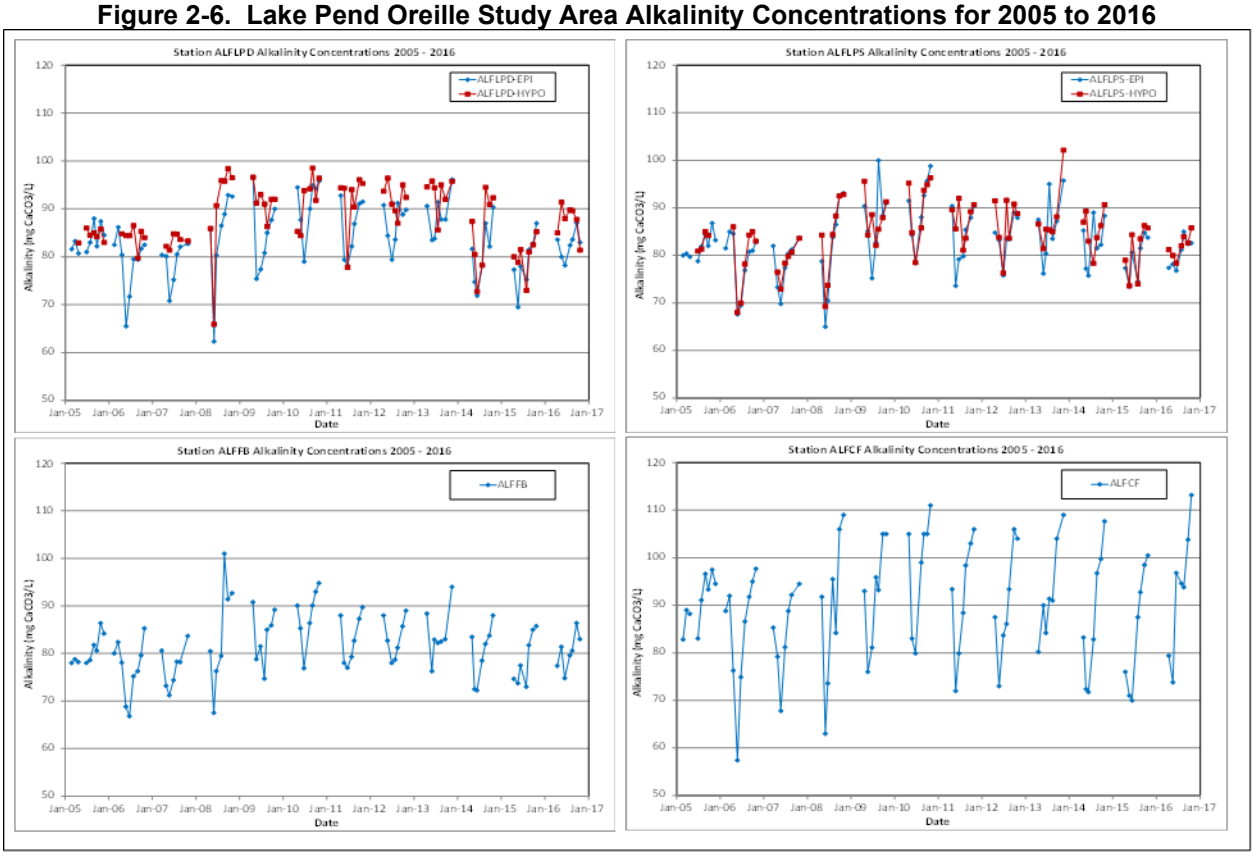


Figure 2-6. Lake Pend Oreille Study Area Alkalinity Concentrations for 2005 to 2016



Hardness is a measure of the amount of calcium and magnesium salts in water that are often combined with either bicarbonate or carbonate, or with anions such as sulfate or chloride (Wetzel 1975). Harder waters have greater concentrations of calcium and magnesium salts. In freshwater, hardness can be important in determining the toxicity of many metals, such as cadmium, chromium, copper, lead, and zinc. Toxicity decreases with an increase in hardness. Therefore, hardness measurements are necessary to calculate water quality criteria for various metals.

For Lake Pend Oreille and the Pend Oreille River, hardness concentrations followed a similar pattern as alkalinity with the greatest concentrations measured in the early spring and late summer/fall. Hardness concentrations in the epilimnion ranged from about 60 to 90 mg $CaCO_3$/L at all stations and depths. These concentrations represent moderately hard which is typical of many freshwater ecosystems in the Idaho Panhandle (Briggs and Ficke 1977).

The parameter pH is a measure of the hydrogen ion activity in the water, and is measured on a base-10 logarithmic scale from 0 to 14 with values less than 7 being acidic, values greater than 7 being basic, and a value of 7 being neutral. Idaho state water quality standards for pH in surface waters are to be in the range of 6.0 to 9.0 (see Table 1-3). Monthly vertical pH profiles collected in the reservoir were generally similar between stations and years, with higher pH values measured near the surface and reduced pH values towards the bottom. In general, a majority of pH values at all stations ranged from about 7.0 to 8.8. In addition, pH values tended to be lowest during April

and May with the greatest pH values measured in July, August, and September. Except for a few outliers, the higher pH values were largely associated with near surface waters in the summer and are likely due to photosynthetic activity of phytoplankton removing carbon dioxide from the water, thereby increasing pH. Conversely, the pH decrease in the hypolimnion may be partly because carbon dioxide is added to the deeper waters by the decomposition of organic matter.

Pend Oreille River pH values downstream of Albeni Falls Dam are of particular concern because the water quality standard for pH in the State of Washington (6.5 to 8.5) is slightly stricter than for Idaho (6.0 to 9.0). Monthly vertical pH profiles collected in the river at Albeni Falls Dam forebay station ALFFB were uniform between the surface and bottom, showing little pH variation. Monthly pH profiles collected in the Albeni Falls Dam forebay (ALFFB) ranged from about 7.2 to 8.7 between 2005 and 2016. Given this, no monthly pH values measured at Albeni Falls Dam exceeded the Idaho standard of 9.0, but several months exceeded the downstream Washington State standard of 8.5. Pend Oreille River pH values in the river were lowest in the spring (April to June) and greatest in the summer and fall (July to October). The higher pH values were uniformly distributed in the water column and are likely the result of photosynthetic activity.

2.2.6 Specific Conductivity

Specific conductivity is a measurement of a solution's ability to conduct electricity and is often used as an indicator of the amount of dissolved ions present since conductivity increases with an increase in dissolved ions. Specific conductivity is the conductivity normalized to a standard temperature (25°C), and is reported in microsiemens per centimeter (µS/cm). During the study, Lake Pend Oreille specific conductivity was variable between stations, depths, and years and ranged from about 100 to 200 µS/cm. Monthly vertical profiles tend to show that specific conductivity increased with depth in Lake Pend Oreille (ALFLPD and ALFLPS) with little to no change with depth measured in the river at ALFLPD. In general, specific conductivity measured at all stations was lowest during the April through June spring runoff period, and greatest during the July through October summer/fall period.

2.3 CHEMICAL CHARACTERISTICS

2.3.1 Nutrients

Phosphorus and nitrogen are the major nutrients required for the growth and productivity of phytoplankton and aquatic plants. The vast majority of lake water quality problems are associated with an overabundance of these nutrients resulting in excessive phytoplankton growth, causing nuisance blooms and resulting decay. The decay of large amounts of phytoplankton can reduce oxygen concentrations to levels that are harmful to many organisms. In freshwater ecosystems, phosphorus is generally the nutrient with the smallest supply to demand ratio for phytoplankton growth. Consequently, phosphorus is often the nutrient limiting productivity in freshwater

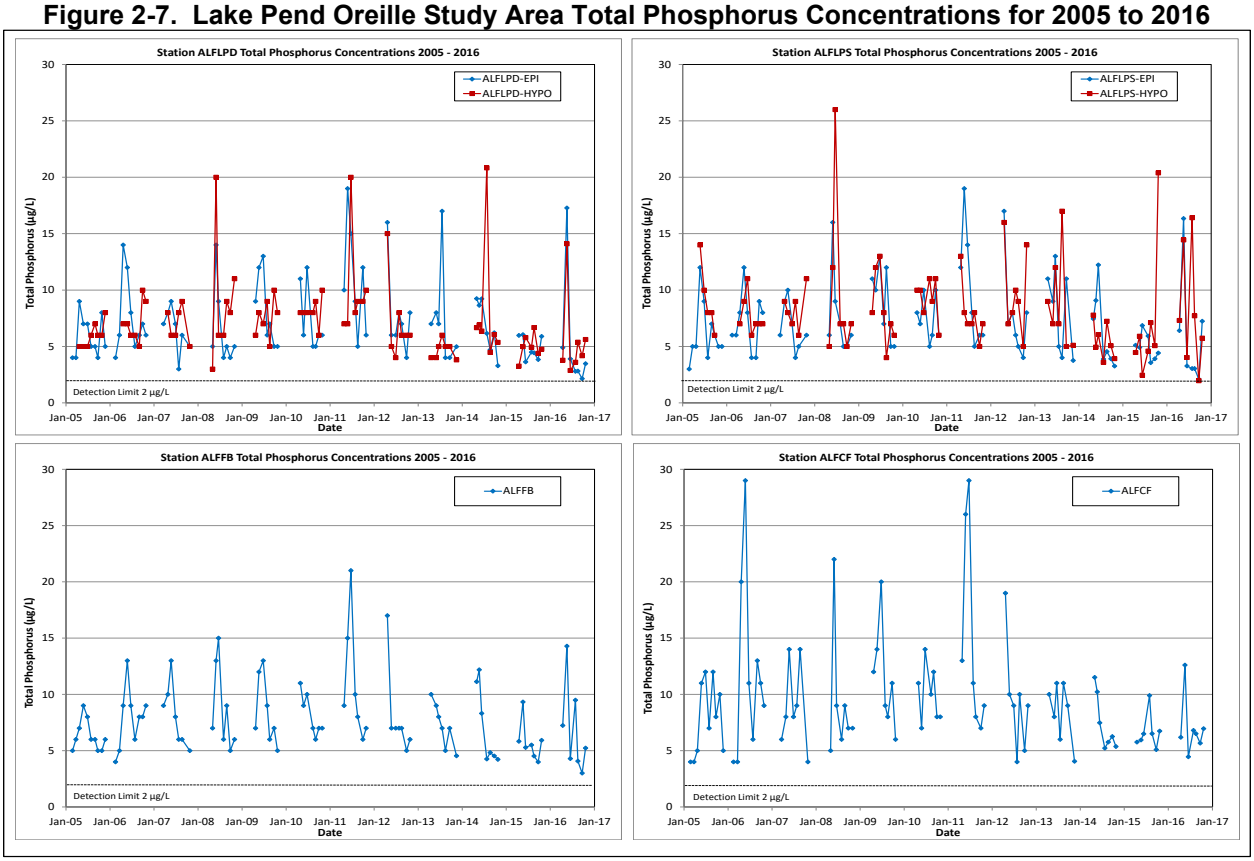
ecosystems and also has relatively limited sources, so it is frequently the nutrient focused on for control of eutrophication. However, in some circumstances nitrogen can be limiting instead of phosphorus, although nitrogen cycling and control of nitrogen sources is more complex. Increased phosphorus and nitrogen inputs to freshwater ecosystems from human activities can be attributed to numerous sources including: the discharge of detergents, runoff containing fertilizers, seepage from failing septic systems, urban runoff and sewage discharges, as well as from nitrogen-based explosives used in mining operations.

2.3.1.1 *Phosphorus*

Phosphorus concentrations were reported as total phosphorus and soluble reactive phosphorus. Total phosphorus represents all forms of phosphorus in water, both dissolved and particulate including all organically combined phosphorus and all phosphate. Soluble reactive phosphorus represents the dissolved form of phosphorus that is readily available for aquatic plant uptake.

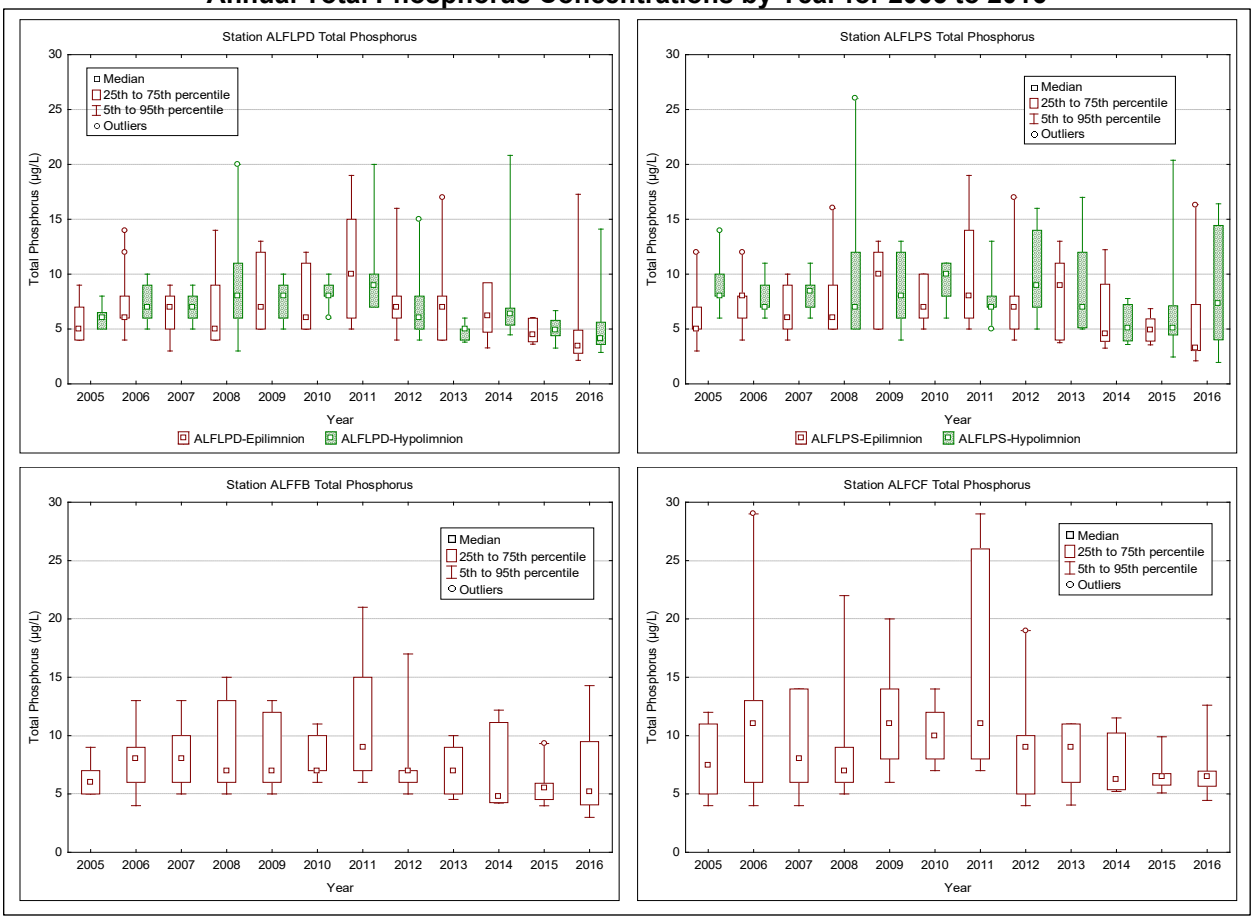
Monthly concentrations of total phosphorus in Lake Pend Oreille, the Clark Fork River, and the Pend Oreille River for 2005 to 2016 are presented in Figure 2-7. Total phosphorus concentrations measured during the study ranged from about 2 to 3 µg/L measured periodically at all stations to about 29 µg/L measured at ALFCF. Total phosphorus followed a similar seasonal pattern at all stations with low concentrations in April, increasing concentrations during high runoff spring conditions in May and June, and decreasing concentrations during the summer and fall. In general, total phosphorus concentrations were greatest at the inflow (ALFCF), and slightly reduced in the lake (ALFLPD and ALFLPS) and outflow (ALFFB). This slight reduction in total phosphorus from the inflow, to the lake, to the downstream river indicates that the Lake Pend Oreille is retaining some total phosphorus. A similar conclusion was made by Woods (2004) who estimated that about 17 percent of incoming phosphorus was retained in the lake, suggesting that Lake Pend Oreille is not an efficient trap for phosphorus.

Figure 2-7. Lake Pend Oreille Study Area Total Phosphorus Concentrations for 2005 to 2016



Boxplots of total phosphorus concentrations for each station for the 2005 to 2016 study are shown in Figure 2-8. Median total phosphorus concentrations in the epilimnion at both ALFLPD and ALFLPS ranged from about 4 to 10 µg/L, while in the hypolimnion concentrations ranged from about 5 to 9 µg/L. Median concentrations in the Pend Oreille River at ALFFB ranged from about 4 to 8 µg/L while at the inflow (ALFCF) they ranged from about 6 to 12 µg/L. The range of concentrations was substantially greater at the inflow, reflecting the higher total phosphorus concentrations measured at this station during the spring runoff May and June time period. In general, the range of total phosphorus concentrations were greater in the hypolimnion at both stations in Lake Pend Oreille.

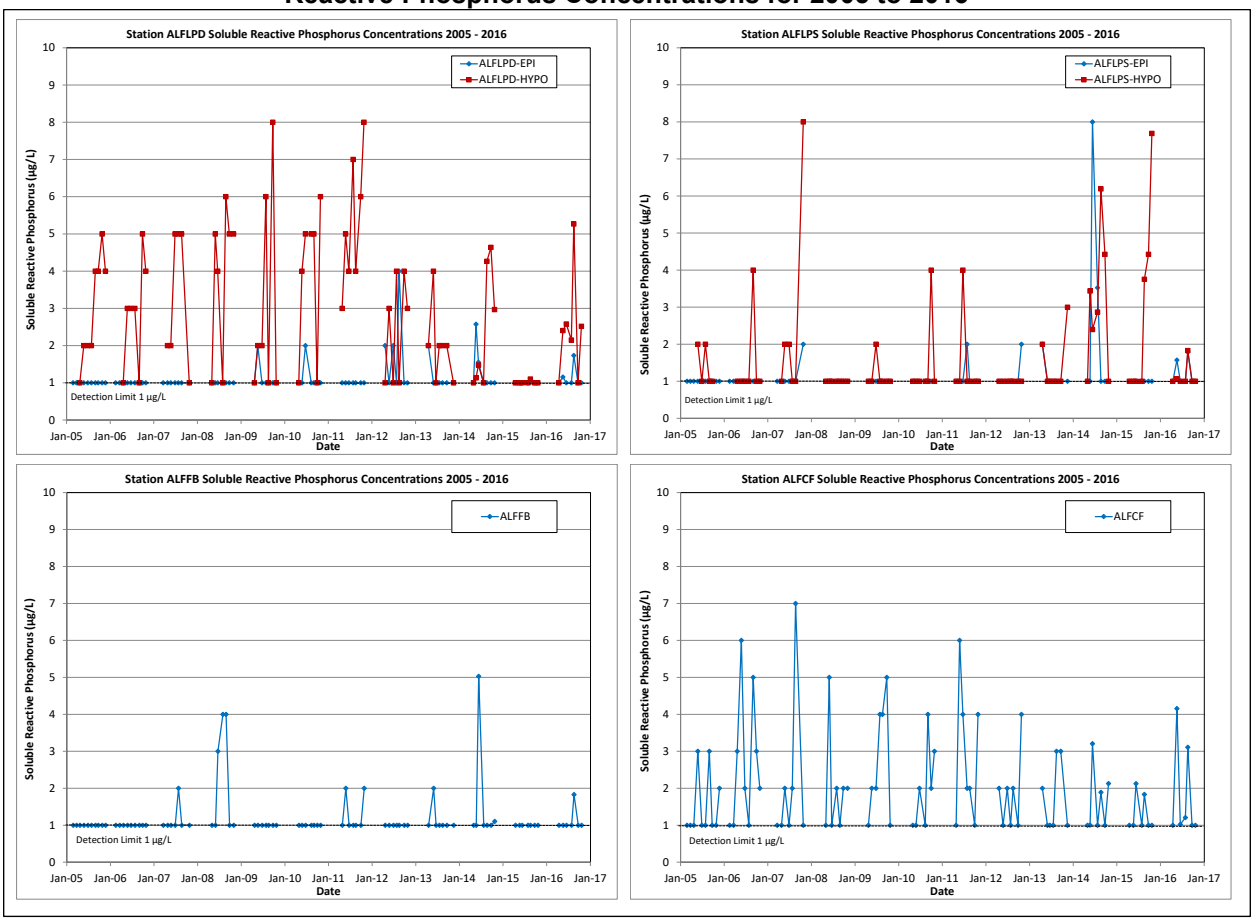
Figure 2-8. Lake Pend Oreille Study Area Data Summary of Annual Total Phosphorus Concentrations by Year for 2005 to 2016



Soluble reactive phosphorus concentrations were low in Lake Pend Oreille, ranging from less than the detection limit of 1 µg/L to a maximum concentration of 8 µg/L (Figure 2-9). Soluble reactive phosphorus concentrations at all stations varied considerably during the 2005 to 2016 study with some years having no soluble phosphorus concentration greater than the detection limit. In general, soluble phosphorus concentrations were greatest at the inflow (ALFCF) and deep lake (ALFLPD) station and decreased down-lake at the shallow lake (ALFLPS) station and down river at Albeni Falls Dam (ALFFB). Additionally, Lake Pend Oreille soluble phosphorus concentrations were greatest in the hypolimnion at both stations. Soluble phosphorus concentrations were greatest during the spring runoff May and June time period at the inflow station and in the epilimnion of Lake Pend Oreille, while concentrations were greatest in the hypolimnion of Lake Pend Oreille in the late summer August and September time period. Patterns in soluble reactive phosphorus can be deceptive because it is consumed by algae as it grows, thereby converting it to algal tissue and reducing apparent concentrations seasonally. The reduction in soluble phosphorus concentrations between the inflow station (ALFCF) and the Albeni Falls forebay (ALFFB) suggests that it is being used by algae in Lake Pend Oreille. The lack of soluble phosphorus moving downstream in the Pend Oreille River is clearly shown in

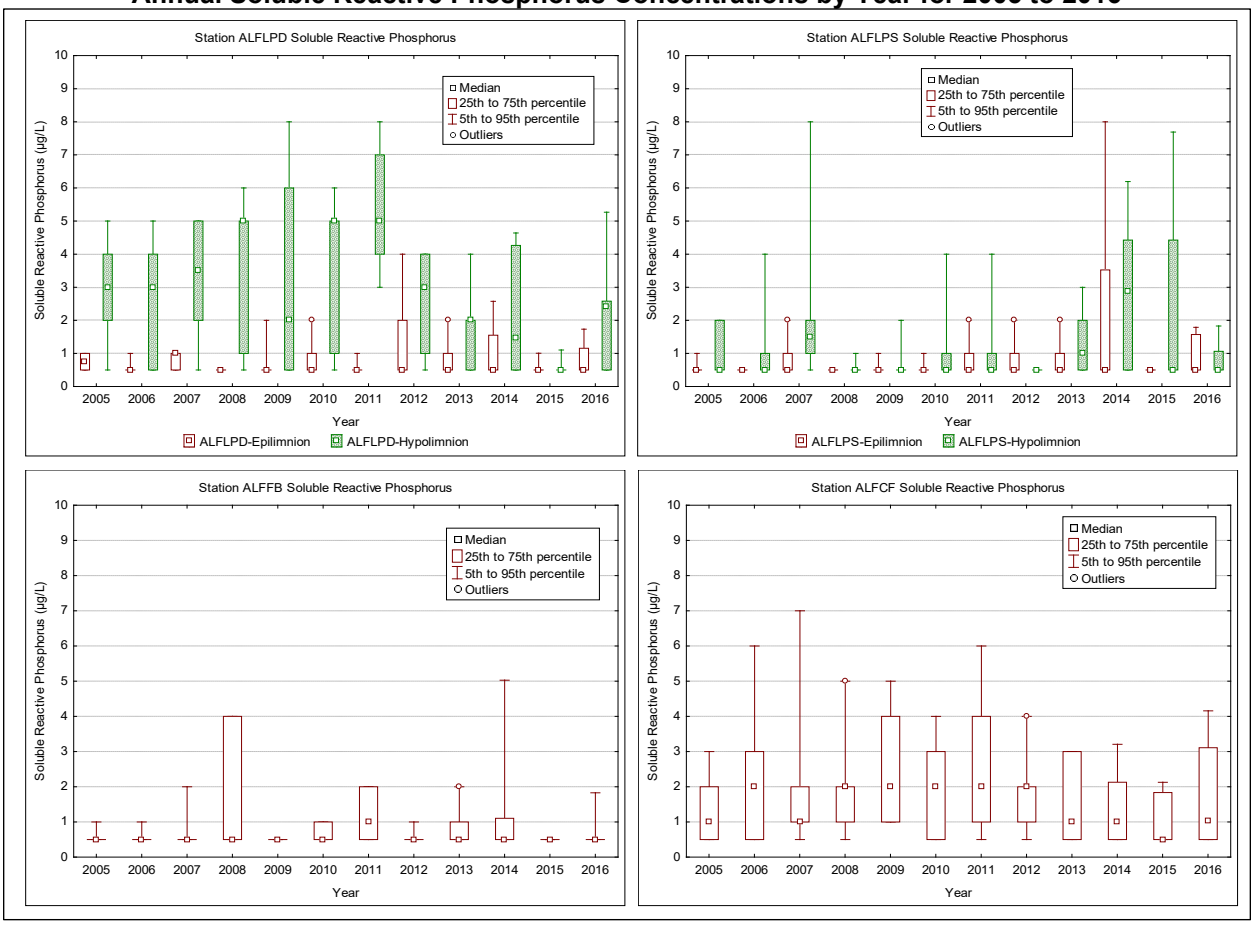
the nearly consistent non-detected soluble phosphorus at the downstream station (ALFFB).

Figure 2-9. Lake Pend Oreille Study Area Soluble Reactive Phosphorus Concentrations for 2005 to 2016



Median soluble reactive phosphorus concentrations were low and were generally less than the detection limit of 1 µg/L at the ALFLPD (epilimnion), ALFLPS (epilimnion and hypolimnion), and ALFFB stations (Figure 2-10). The range of data displayed by the 25th to 75th percentile was greatest in the hypolimnion at ALFLPD.

Figure 2-10. Lake Pend Oreille Study Area Data Summary of Annual Soluble Reactive Phosphorus Concentrations by Year for 2005 to 2016



2.3.1.2 *Nitrogen*

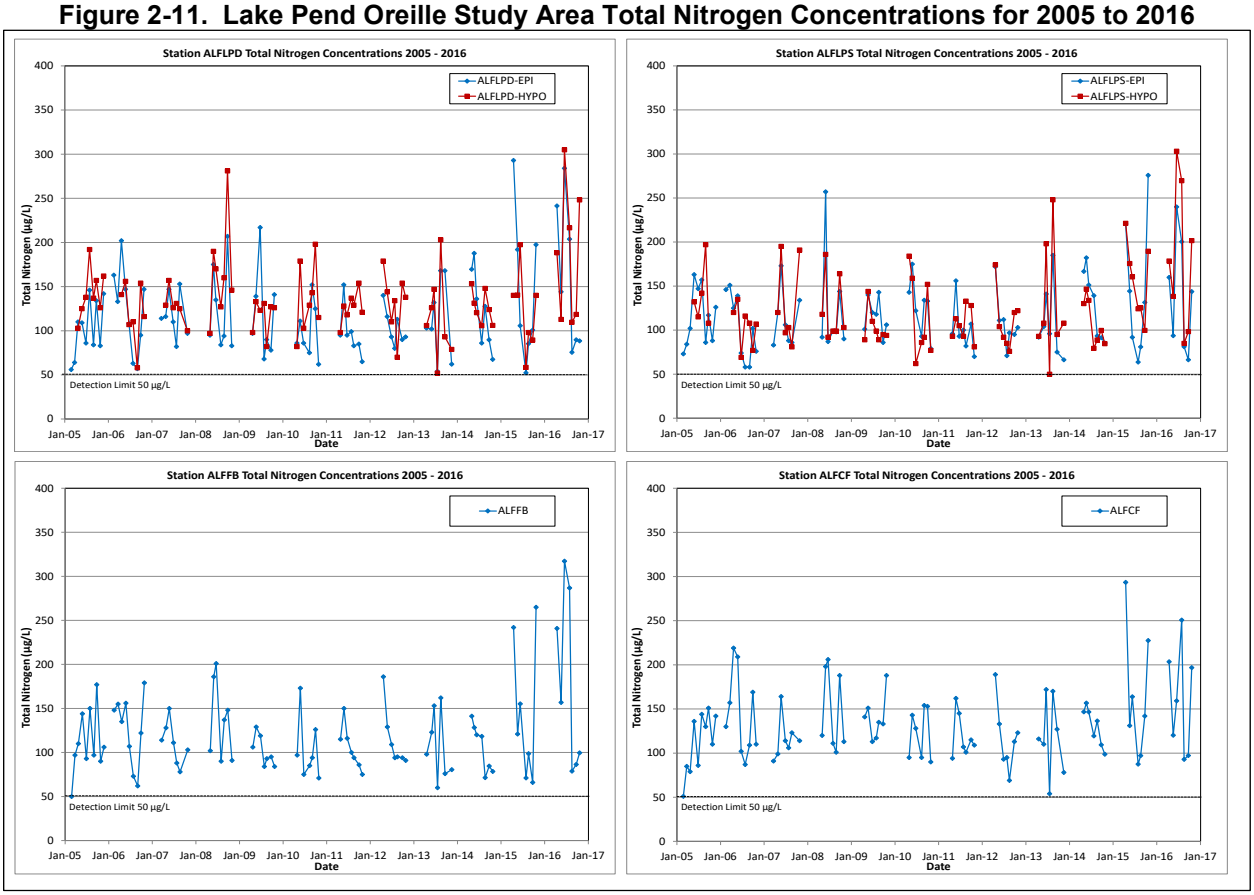
Nitrogen, like phosphorus, is essential for the growth and production of phytoplankton in freshwaters. In freshwater ecosystems, nitrogen exists in many forms including dissolved molecular nitrogen, organic nitrogen, nitrite, nitrate, and ammonia. Sources of nitrogen to freshwaters are varied and include atmospheric inputs via precipitation, nitrogen fixation in the water and sediments, and surface and groundwater inputs. Losses of nitrogen in the freshwater ecosystem include outflow from the system, reduction of nitrate to nitrogen via denitrification and the subsequent release of nitrogen from the water to the atmosphere, and sedimentation of inorganic and organic forms of nitrogen (Wetzel 1975). The most common forms of nitrogen used by freshwater plants for growth are the dissolved forms which includes ammonia-nitrogen and nitrate-nitrogen.

Three forms of nitrogen were measured, total nitrogen (TN-N), nitrate + nitrite-nitrogen (NO_3 + NO_2-N), and ammonia-nitrogen (NH_4^+-N + NH_3-N). The dissolved inorganic forms of nitrogen, ammonia, and nitrate + nitrite are all readily available for phytoplankton growth. Total nitrogen was measured by the persulfate digestion method (see Table 1-2) and includes all inorganic plus organic forms of nitrogen in both

dissolved and particulate forms. Nitrate + nitrite-nitrogen represents dissolved oxidized nitrogen, with nitrite being an intermediate state between ammonia and nitrate. Nitrate is an essential plant nutrient, while nitrite can be a plant nutrient but is generally unstable and is rapidly oxidized to ammonia in oxygenated waters. Ammonia nitrogen is an essential plant nutrient that is often used before nitrate. Ammonia is formed in the natural environment through the fixation of nitrogen gas, excretion by animals, and the decomposition of organic material (plant and animal tissues). Ammonia is reported as the combined ionized (NH_4^+-N - ammonium) and unionized (NH_3-N - ammonia) forms of ammonia. The unionized form of ammonia (NH_3-N) is toxic to freshwater life, and is most prevalent at high pH (greater than about 9.3 pH units). Equations can be used to estimate the concentration of unionized ammonia fraction from measured values of the pH and temperature of the water (see Table 1-4). In general, for pH and temperature values measured in Lake Pend Oreille and the Pend Oreille River the unionized form of ammonia (NH_3-N) represents an extremely small percentage of the total ammonia nitrogen concentration (Greenberg, Eaton, and Clesceri 1992).

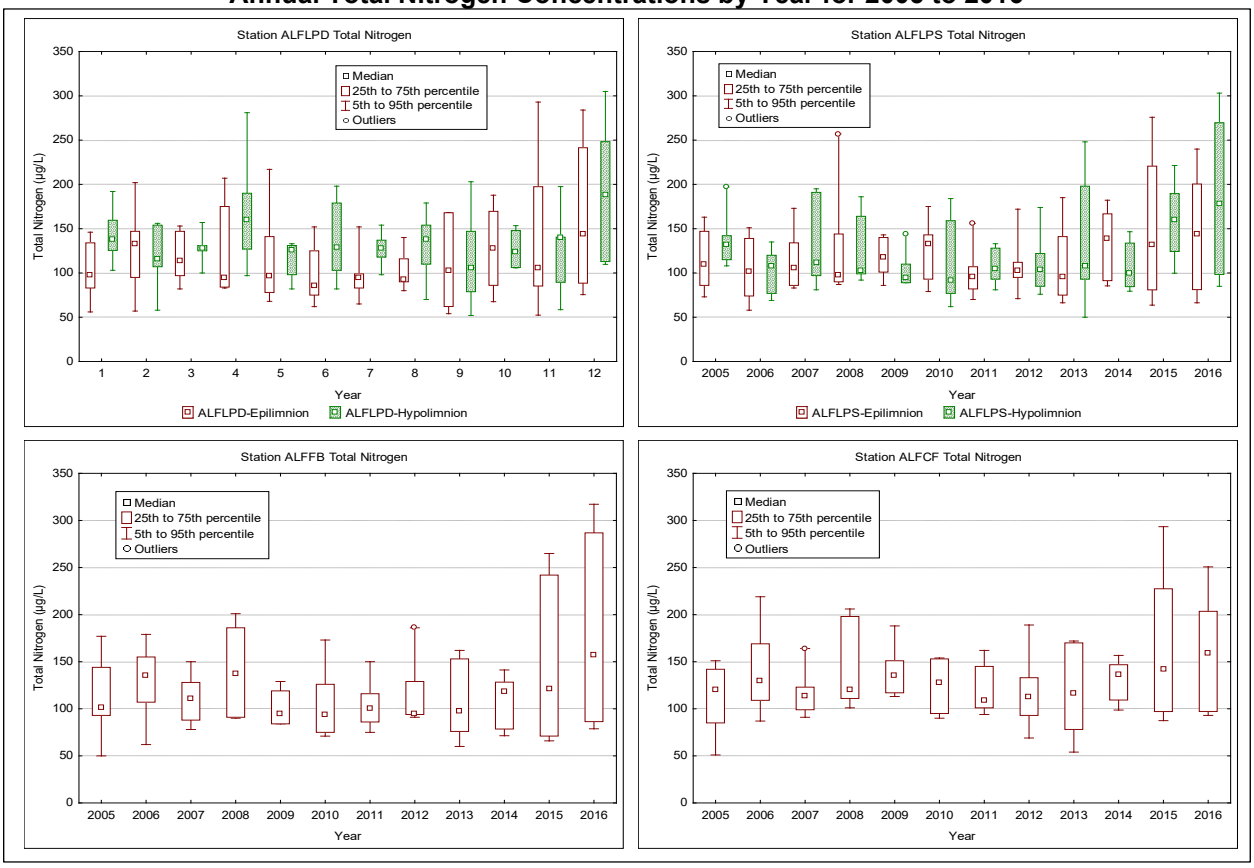
Total nitrogen concentrations ranged from about 60 to 250 µg/L in the epilimnion of both the deep water (ALFLPD) and shallow water (ALFLPS) stations in Lake Pend Oreille, while hypolimnetic concentrations at these stations ranged from about 50 to 300 µg/L at both stations (Figure 2-11). Concentrations were similar at inflow station ALFCF and downstream river station ALFFB. Temporal plots show that total nitrogen concentrations have been increasing at all stations since about 2014. In general, total nitrogen was greatest in both the epilimnion and hypolimnion of Lake Pend Oreille during the May and June spring runoff time and decreased during the summer, with the most pronounced decrease in the epilimnion. A subsequent increase in total nitrogen was often measured at all lake stations in the fall. It is likely that the sharp decreases in epilimnetic total nitrogen measured during the summer are due to the summer growth of algae using nitrate (see nitrate discussion below).

Figure 2-11. Lake Pend Oreille Study Area Total Nitrogen Concentrations for 2005 to 2016



Boxplots of total nitrogen concentrations for each station for the 2005 to 2016 study are shown in Figure 2-12. Median total nitrogen concentrations and the range of data at both ALFLPD and ALFLPS were greatest in the hypolimnion. Total nitrogen median concentrations and the range of the data measured in the epilimnion were similar to inflow (ALFCF) and downstream river (ALFFB) concentrations. A substantial increase in median total nitrogen and the maximum range of the data was measured at all stations in 2015 and 2016. The relative similarity between inflow, lake, and downstream total nitrogen concentrations suggests that Lake Pend Oreille is not an efficient trap for total nitrogen. Woods (2004) made similar conclusions showing that only 15 percent of total nitrogen in the inflow is retained in Lake Pend Oreille.

Figure 2-12. Lake Pend Oreille Study Area Data Summary of Annual Total Nitrogen Concentrations by Year for 2005 to 2016



Nitrate + nitrite-nitrogen concentrations measured at all stations in the lake and river were considerably less than total nitrogen concentrations, suggesting that nitrate is likely not the dominant form of nitrogen in the Clark Fork–Lake Pend Oreille–Pend Oreille River system. Nitrate concentrations at all stations followed similar seasonal patterns with the highest concentrations during the May and June spring runoff time and sharply lower concentrations from July through October (Figure 2-13). The nitrate concentrations were substantially greater in the hypolimnion, suggesting that nitrate in the epilimnion is being used by summer phytoplankton growth. In general, nitrate concentrations in the inflow were greater than concentrations in the epilimnion of Lake Pend Oreille and downstream in the Pend Oreille River. However, nitrate concentrations in the hypolimnion of Lake Pend Oreille were typically greater than inflow concentrations. Given this, Lake Pend Oreille does not appear to be retaining nitrate to a large degree. Boxplots of nitrate concentrations for each station for the 2005 to 2016 study clearly show that median concentrations were greatest in the hypolimnion (Figure 2-14).

Figure 2-13. Lake Pend Oreille Study Area Nitrate+Nitrite Concentrations for 2005 to 2016

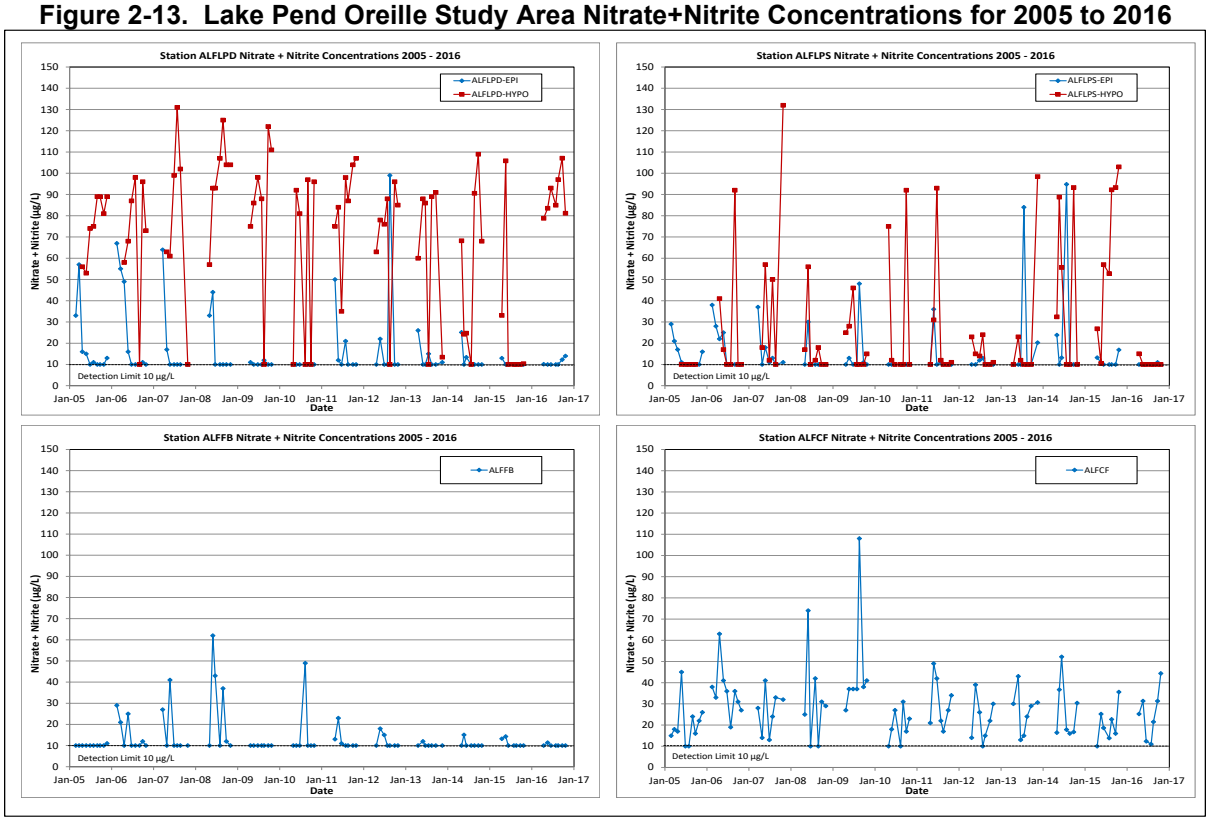
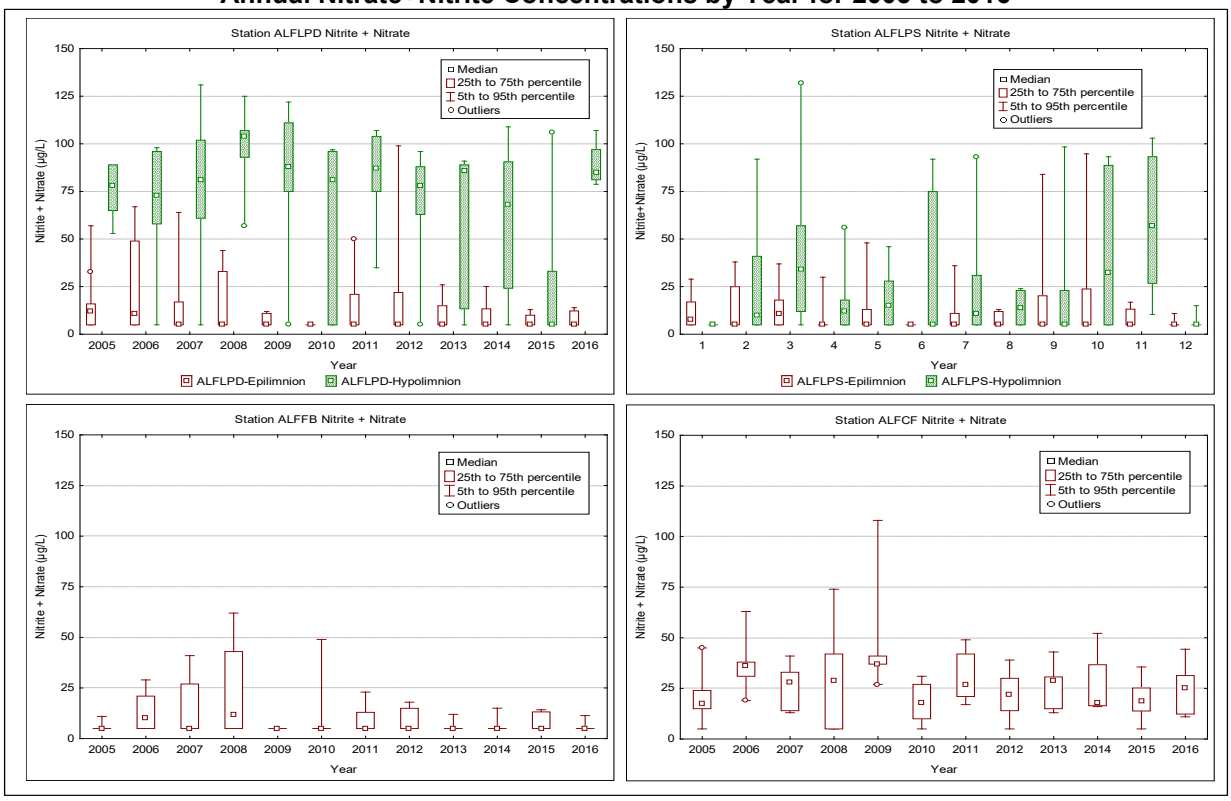


Figure 2-14. Lake Pend Oreille Study Area Data Summary of Annual Nitrate+Nitrite Concentrations by Year for 2005 to 2016



Ammonia concentrations were low at all stations, with the greatest concentrations measured at the inflow (ALFCF) and in the hypolimnion (ALFLPD and ALFLPS) of Lake Pend Oreille. Ammonia concentrations in the epilimnion and in the Pend Oreille River were typically at or near the detection limit of 5 µg/L (Figure 2-15). Similar to nitrate, ammonia concentrations were greatest during the May and June spring runoff time, and sharply reduced during the rest of the year. Median ammonia concentrations were near the 5 µg/L detection limit for stations except the inflow (ALFCF) station (Figure 2-16).

Figure 2-15. Lake Pend Oreille Study Area Ammonia Concentrations for 2005 to 2016

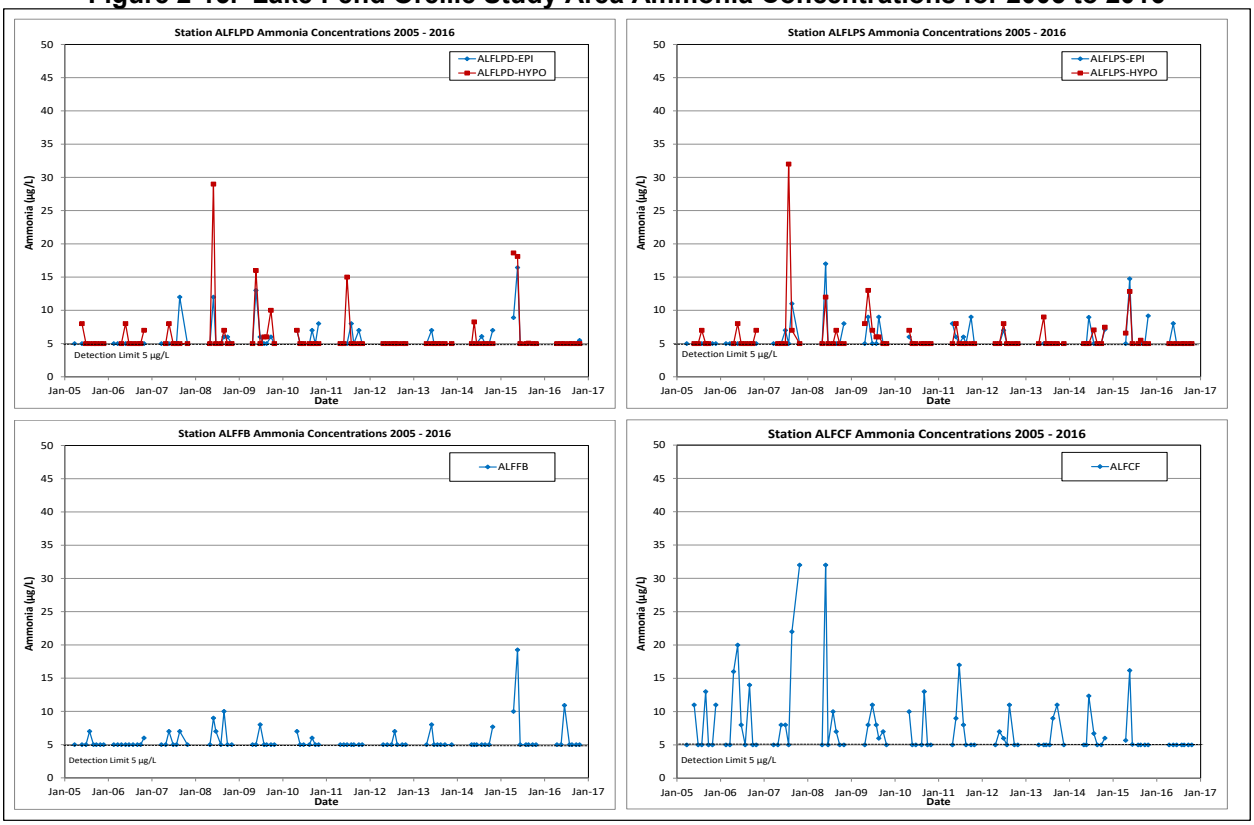
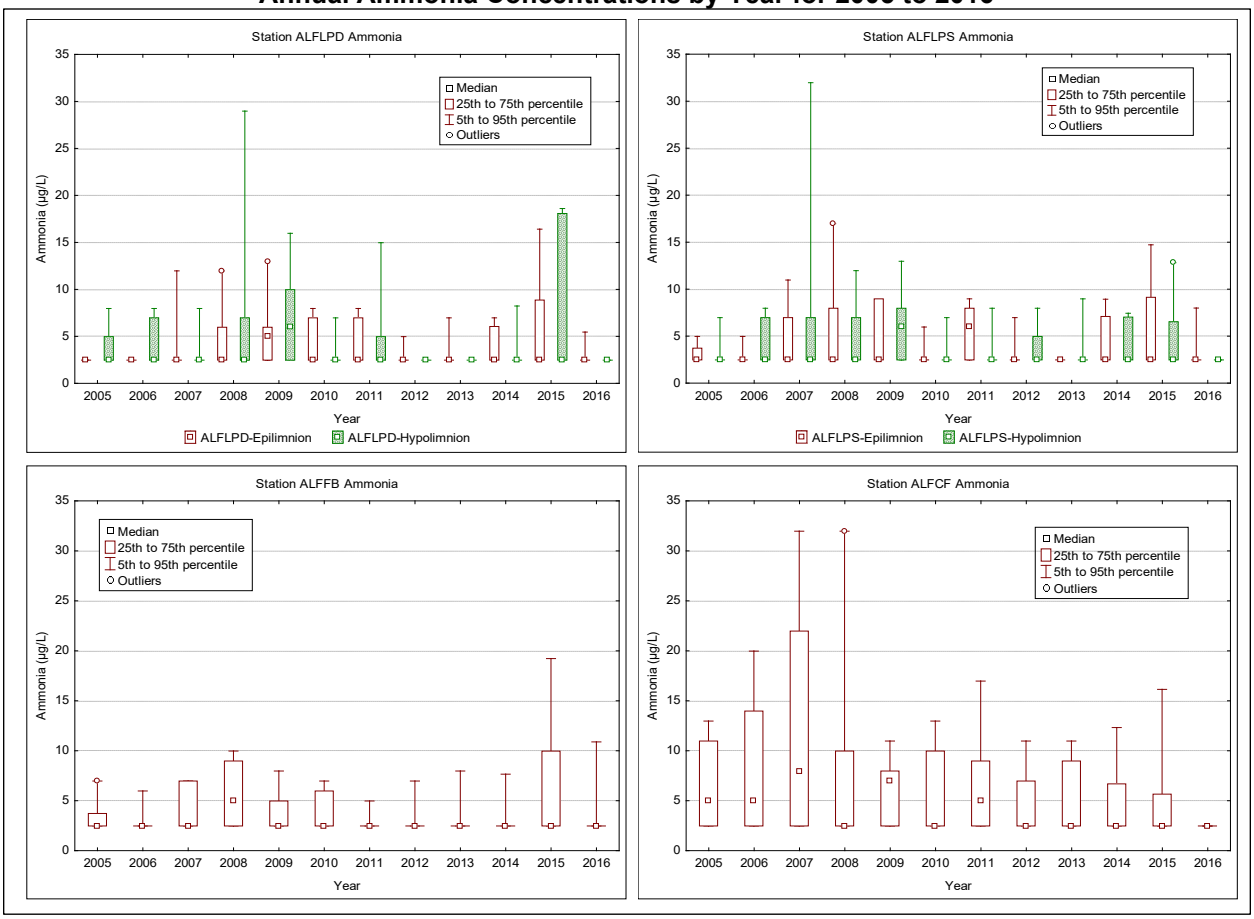


Figure 2-16. Lake Pend Oreille Study Area Data Summary of Annual Ammonia Concentrations by Year for 2005 to 2016

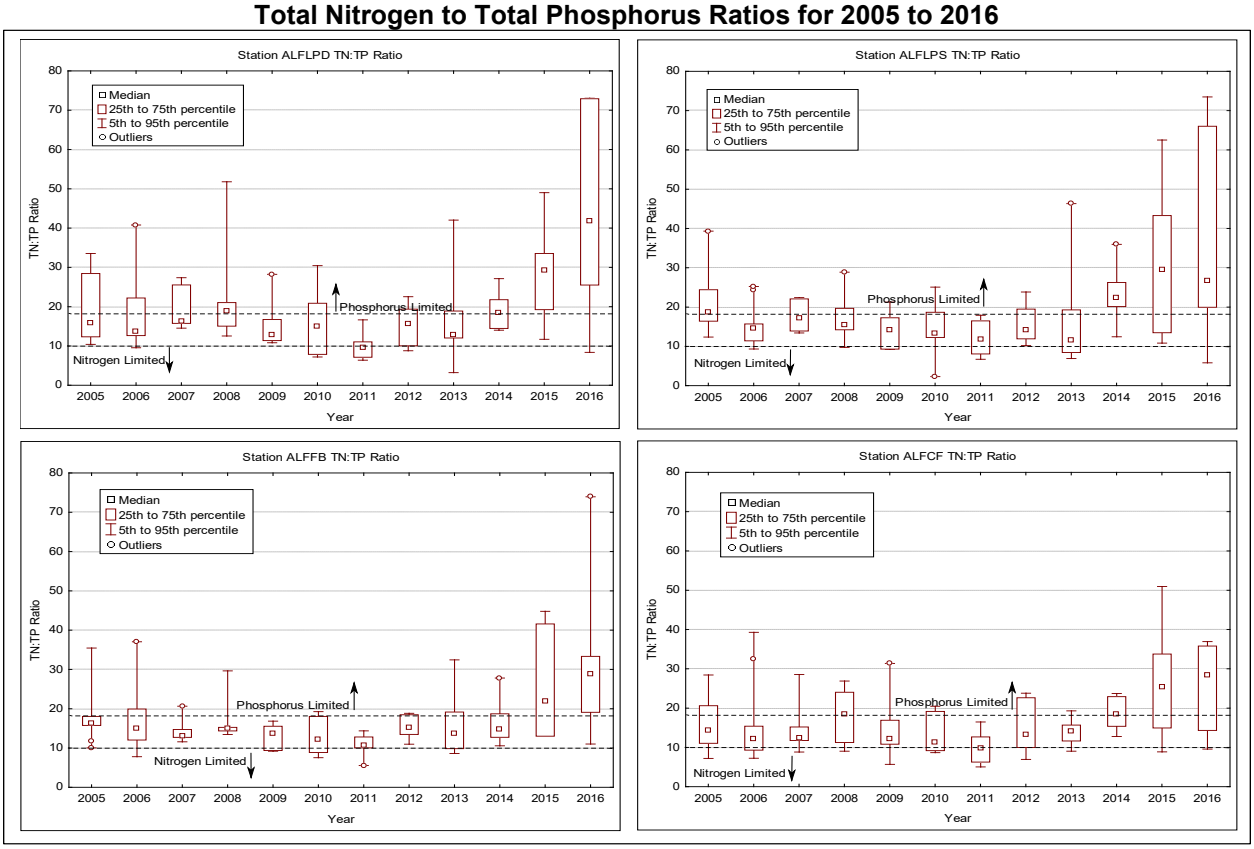


2.3.1.3 *Nutrient Limitation*

Phosphorus and nitrogen are the two major essential nutrients that limit phytoplankton growth in freshwater ecosystems. The limiting nutrient concept maintains that the growth of a plant crop will be limited by the essential nutrient in shortest supply (Ryding and Rast 1989). Total nitrogen to total phosphorus ratios (TN:TP) are often used to determine whether nitrogen or phosphorus is most likely to limit phytoplankton growth. Typically, TN:TP ratios, by weight, greater than 17:1 suggest phosphorus limitation while ratios less than 10:1 suggest nitrogen limitation (Forsberg and Ryding 1980). Ratios between 10 and 17 suggest that either nitrogen or phosphorus could be limiting, or that both nitrogen and phosphorus are limiting (co-limitation). Yearly variations in the TN:TP ratios measured in the epilimnion of Lake Pend Oreille (ALFLPD and ALFLPS) as well as in the Clark Fork (ALFCF) and Pend Oreille (ALFFB) rivers are seen in Figure 2-17. The yearly progression of TN:TP is similar at all stations and from 2005 to 2013 the ratios are generally between 10 and 17 suggesting that phosphorus, nitrogen, or both were limiting phytoplankton growth. From 2014 through 2016 a large increase in the ratio occurred at all stations with values between 25 and 40, suggesting that phosphorus is limiting algal growth. The sharp increase in the TN:TP ratio seen at all stations is due to a concurrent increase in total nitrogen concentrations and decrease in

total phosphorus concentrations measured in the lake. The relatively rapid change in the ratio is interesting and may have an impact on the phytoplankton species and concentrations measured in Lake Pend Oreille.

Figure 2-17. Lake Pend Oreille Study Area
Total Nitrogen to Total Phosphorus Ratios for 2005 to 2016



2.3.1.4 *Nearshore Nutrients*

Summer (June to September) phosphorus and nitrogen concentrations were measured at the five shallow water nearshore stations (Talache, Garfield, Sunnyside, Oden, and Kootenai) from 2011 to 2016. In general, nearshore nutrient concentrations were similar to concentrations measured in the epilimnion at station ALFLPS. Nearshore nutrient concentrations varied seasonally and annually but showed little between station variability.

Nearshore total phosphorus concentrations measured during the study ranged from about 2 to 10 µg/L, with an occasional high concentration (21 µg/L at Talache in July 2013, 23 µg/L at Garfield in July 2011, and 27 µg/L at Oden in June 2012). Total phosphorus followed a similar seasonal pattern at all stations with the highest concentrations during high runoff spring conditions in June and July decreasing concentrations during August and September. Total nitrogen concentrations ranged from about less than the detection limit of 50 to 250 µg/L, with an occasional high concentration (437 µg/L at Sunnyside in June 2011, 370 µg/L at Garfield in August 2013). Total nitrogen tended to be greatest at all stations in June and July. In general,

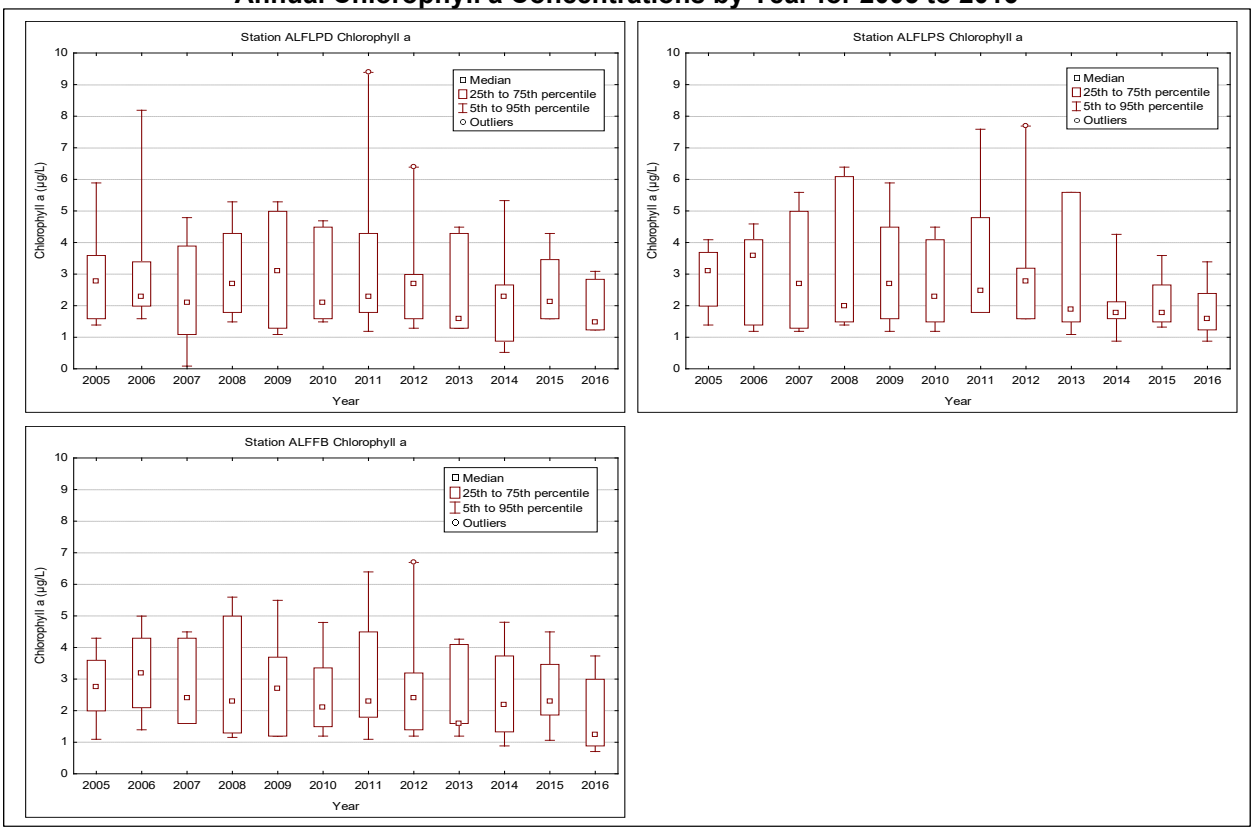
soluble reactive phosphorus, nitrate, and ammonia concentrations were near the detection limits (1, 10, and 5 µg/L, respectively) at all stations.

2.3.2 Chlorophyll a

Chlorophyll a is the primary photosynthetic pigment in all photosynthetic organisms requiring oxygen and is found in all freshwater phytoplankton species. Consequently, measurements of chlorophyll a in the water column are an indirect estimate of the amount of phytoplankton present. Although there are several different forms of chlorophyll present in plants, chlorophyll a is the dominant form and is generally considered an indicator of phytoplankton biomass in freshwater ecosystems (Wetzel 1975).

Temporal variations in chlorophyll a occurred at all stations during the study (see Figure 2-2). Chlorophyll a concentrations ranged from less than 1 to about 9 µg/L at ALFLPD, from about 1 to about 8 µg/L at ALFLPS, and from about 1 to about 6.5 µg/L at ALFFB. In general, chlorophyll a concentrations varied seasonally, with peak concentrations in April and May and an occasional peak concentration in June. Concentrations did not vary much between the two Lake Pend Oreille stations with only small differences in peak chlorophyll a values measured between stations during the study. The negative relationship between transparency and chlorophyll a apparent at all stations during the study suggests that the reduced water clarity measured at all stations for all years is partly due to the amount of algae suspended in the water column (see Figure 2-2). Median chlorophyll a concentrations are presented in Figure 2-18. The overall range of data was similar between stations. However, median chlorophyll a concentrations at all stations were lower in 2014, 2015, and 2016 when compared to other years.

Figure 2-18. Lake Pend Oreille Study Area Data Summary of Annual Chlorophyll a Concentrations by Year for 2005 to 2016



Nearshore chlorophyll a concentrations measured at Talache, Garfield, Sunnyside, Oden, and Kootenai stations from June to September were similar to ALFLPD and ALFLPS summer concentrations. Small between station differences in chlorophyll a were measured for the nearshore stations. Concentrations varied from about 0.6 to 5.6 µg/L, with the greatest concentrations in June and the lowest in August and September.

2.3.3 Trophic State

The biological productivity, or trophic state, of a waterbody can be classified into three general categories: oligotrophic (low productivity), mesotrophic (moderate productivity), and eutrophic (high productivity). Lakes with low nutrient concentrations and low rates of phytoplankton productivity are classified as oligotrophic. Lakes with high nutrient concentrations and high rates of phytoplankton productivity are classified as eutrophic. Mesotrophic lakes have nutrient concentrations and phytoplankton productivity between eutrophic and oligotrophic lakes.

The water quality parameters most often used to assess the trophic state of a lake are total phosphorus, chlorophyll a, and transparency. These three variables have been used by Carlson (1977) and the Organization for Economic Co-Operation and Development (OECD 1982) to develop a trophic state classification system. The general relationship between these three variables and tropic state based on summer mean values and annual mean values are summarized in Table 3-1. Another useful way to

group lakes by trophic classification is with the trophic state index (TSI) which is based on linear regression relationships developed for total phosphorus, chlorophyll a, and transparency in lakes (Carlson 1977). Trophic state indices were computed using equations developed by Carlson (1977) which classify a lake as oligotrophic with a TSI value less than 40, as mesotrophic with a TSI value between 40 and 50, and as eutrophic with a TSI value greater than 50 (Table 2-1). Carlson (1977) recommends using summer TSI values to classify lakes while the OCED (1982) recommends annual values for trophic classification. For this study both summer TSI values and annual OECD values are presented for 2005 to 2016 to provide insight on the trophic state of Lake Pend Oreille.

Table 2-1. Trophic Classification Values for Lake Pend Oreille 2005 to 2016

Trophic State	Trophic State Classification	Total Phosphorus (µg/L)	Chlorophyll a (µg/L)	Transparency (meters)	Carlson Trophic State Index[3]
Oligotrophic	Annual Mean Values Threshold[1]	<10	<2.6	>6	<40
Oligotrophic	Summer Mean Values Threshold[2]	<12	<2.6	>4	<40
Mesotrophic	Annual Mean Values Threshold[1]	10-35	2.6-8.0	3-6	40-50
Mesotrophic	Summer Mean Values Threshold[2]	12-24	2.6-6.4	2-4	40-50
Eutrophic	Annual Mean Values Threshold[1]	>35	>8	<3	>50
Eutrophic	Summer Mean Values Threshold[2]	>24	>6.4	<2	>50

Notes:
1. Based on OECD (1982)
2. Based on Carlson (1977)
3. Carlson (1977)
Transparency TSI= 60-14.41 * ln mean secchi disk (m)
Chlorphyll a TSI= 9.81 * ln mean chl a (µg/L) + 30.6
Total Phosphorus TSI= 14.42 * ln mean TP (µg/L) + 4.15

Lake Pend Oreille would be classified as oligotrophic on the basis of summer TSI values calculated at both the deep water (ALFLPD) and shallow water (ALFLPS) stations (Figure 2-19). Based on summer total phosphorus and transparency TSI values, Lake Pend Oreille would be classified as oligotrophic at all stations. However, chlorophyll a TSI values calculated at both stations fall within the mesotrophic range for some years, such as 2011. Year to year fluctuations in the summer TSI value occurred at every station. For the most part, year to year summer total phosphorus concentrations and transparencies are strongly in the oligotrophic range while chlorophyll a can fluctuate between the oligotrophic and mesotrophic range. Using the OECD (1982) methodology based on annual data, Lake Pend Oreille would be classified as oligotrophic/mesotrophic at both lake stations (Table 2-2).

Figure 2-19. Lake Pend Oreille Summer Trophic State Index Values 2005 to 2016

Table 2-2. Organization for Economic Co-Operation and Development Trophic State Classification Total Phosphorus, Chlorophyll a, and Transparency Values for Lake Pend Oreille 2005 to 2016

OECD (1982) Closed Boundary Annual Mean Values (µg/L)

	ALFLPD			ALFLPS		
Year	Trans	Chl a	TP	Trans	Chl a	TP
2005	7.5	2.9	5.8	6.2	2.9	6.1
2006	7.1	3.2	7.6	6.1	2.9	7.2
2007	6.1	2.3	6.4	5.2	3.0	6.7
2008	6.6	3.0	6.6	4.8	3.4	7.7
2009	7.2	3.0	8.1	6.7	3.0	9.0
2010	7.4	2.8	7.3	6.4	2.7	7.4
2011	5.5	3.4	10.9	5.1	3.5	10.0
2012	6.3	2.8	7.9	5.7	3.3	7.9
2013	6.4	2.4	7.4	5.6	2.8	8.1
2014	6.0	2.4	6.8	5.7	2.0	6.3
2015	7.6	2.5	4.9	7.3	2.2	5.0
2016	8.2	1.9	5.3	6.6	1.8	5.9

	Trans	Chl a	TP
Oligotrophic	>6	<2.5	<10
Mesotrophic	3 - 6	2.5 - 8	10 - 35
Eutrophic	<3	>8	>35

2.3.4 Major Anions and Cations

The chemical composition of the major ions of many freshwater lakes is largely derived from the weathering of soils and rocks in the drainage basin, atmospheric precipitation, and evaporation (Wetzel 1975). The ion balance of most freshwaters is dominated by the major cations calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), and the major anions carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl). Other elements, such as phosphorus and nitrogen, are important biologically but are typically only a minor part of the overall chemical composition of freshwater ecosystems.

The major anions and cations were collected at quarterly intervals in May, July, and October at all stations from 2005 to 2016. Over the course of the study, calcium and magnesium were the dominant cations in Lake Pend Oreille and the Pend Oreille River, and ranged from about 14 to 25 mg/L and 4 to 7 mg/L, respectively. Sodium and potassium concentrations were less, ranging from about 1.5 to 3 mg/L and less than the detection limit of 0.5 to 0.9 mg/L, respectively. Cation concentrations tended to be slightly lower during the spring runoff in May when compared to July and October. Little variation in cation concentrations between stations or depths was noted.

The importance and role of the carbonate system in Lake Pend Oreille was previously described for alkalinity and hardness. After carbonate/bicarbonate, sulfate was the dominant anion with concentrations ranging from about 25.5 to 7 mg/L. Chloride

concentrations were less and typically in the 0.5 to 2.5 mg/L range. Sulfate and chloride concentrations tended to be slightly lower during the spring runoff in May when compared to July and October. Little variation in anion concentrations between stations or depths was noted.

2.3.5 Trace Metals

Samples from the epilimnion and hypolimnion at all stations were analyzed for major trace metals which included aluminum, arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The dissolved form of the metals were measured from 2005 to 2016. Trace metals were collected quarterly in May, July, and October in conjunction with the quarterly anion/cation sampling.

From 2006 through 2015, concentrations of dissolved metals were near or below the laboratory detection limits except for aluminum, with periodic detections of copper and zinc. Dissolved aluminum concentrations were low and ranged from less than the detection limit of 3 µg/L to about 55 µg/L, with one sample at ALFFB (67.2 µg/L) and ALFCF (109.1 µg/L) greater than this range. The highest aluminum concentrations were measured in May and July during years with high spring runoff. Dissolved aluminum concentrations measured at all stations did not exceed IDEQ acute or chronic standards.

Dissolved arsenic, cadmium, chromium, lead, and nickel were consistently below the reported lab detection limits. Dissolved copper and zinc concentrations also tended to be below the laboratory detection limits except for an occasional sample. Dissolved copper ranged from less than detection limit of 1 to 8.1 µg/L, with one sample detected at 16.9 µg/L. Dissolved zinc ranged from less than 5 to 14 µg/L, with one sample detected at 81 µg/L. These periodic detections of copper and zinc were below the IDEQ acute and chronic criteria except for the dissolved copper concentration of 16.9 µg/L measured at the Clark Fork inflow (ALFCF). This concentration exceeded the chronic criteria and likely exceeded the acute criteria due to a lower hardness concentration (78 mg $CaCO_3$/L) in the sample compared to the generalized 100 mg $CaCO_3$/L used for the criteria shown in Table 1-5. Detected zinc concentrations did not exceed IDEQ chronic or acute standards.

2.4 BIOLOGICAL CHARACTERISTICS

2.4.1 Phytoplankton

Phytoplankton are photosynthetic microorganisms that live free-floating in water. Phytoplankton are plant-like, but are not plants. In general, most freshwater phytoplankton can be placed in two classes, algae and cyanobacteria. Numerous types of phytoplankton co-exist in freshwater ecosystems, including free-swimming, free-floating, colonial, and unicellular. Phytoplankton provides the base of the food chain in aquatic environments, and support crucial food-web dynamics up the trophic level to more familiar aquatic organisms, such as fish. Seasonal changes in water temperature and light, as well as nutrient availability play important roles in the natural temporal

variation in phytoplankton species and abundance found in freshwaters. Additionally, human caused impacts such as increased nutrient inputs from both point and non-point sources can greatly impact the natural phytoplankton species composition and abundance found in freshwaters. Increased nutrients can result in blooms which will produce high concentrations of phytoplankton in the water column and on the water surface. Wind and currents can cause phytoplankton blooms to accumulate in certain areas of lakes resulting in surface scums, floating mats and nuisance conditions. Consequently, the abundance, taxonomic diversity, and productivity of phytoplankton are indicators of the health and sustainability of an aquatic ecosystem (Reynolds 1984).

Phytoplankton productivity (biovolume and density) are typically highest in the spring and early summer because of warming water temperatures and the increased availability of nutrients. Phytoplankton levels often decline in the summer as nutrient supplies are depleted, but can increase in early fall due to the breakdown of the thermocline making nutrients from the hypolimnion available to the epilimnion. Phytoplankton productivity levels and the dominant specie composition are important when determining the general biological condition of a lake.

2.4.1.1 *Phytoplankton Characteristics*

Freshwater phytoplankton characteristics and traits that are presented below by division.

Chlorophyta. Chlorophyta are also known as “green algae,” and are a diverse group of algae commonly found in aquatic environments. Green algae are one of the most abundant algal groups in freshwater. Algal cells contain bright green pigments, and can be either unicellular or filamentous. In general, most green algae species are considered part of a healthy aquatic ecosystem and a source of food for zooplankton. However, some filamentous green algae can create water quality problems by forming large, slimy, stringy clouds of algae.

Cyanophyta. Cyanobacteria (commonly referred to as blue-green algae) are a bacteria and not an algae. These unicellular, filamentous, motile, and colonial species are unique in that they are a prokaryotic cell. Although they are prokaryotic, cyanobacteria have internal membranes which function in photosynthesis and contain chlorophyll a. Both filamentous and unicellular species occur in large colonies, all containing mucilaginous sheaths. Consequently, cyanobacteria are not a desirable food source for grazing zooplankton, can form nuisance algae blooms and are generally considered a less desirable and noxious phytoplankton species. In addition, some species of cyanobacteria can produce cyanotoxins which can be harmful to mammals.Bacillariophyta

Dominated by “diatoms,” bacillariophyta are very abundant single-celled organisms that are major photosynthetic producers. Most species are non-motile and they are diverse in form. Diatoms primary characteristic is a silicified cell wall. Though there are species that can produce harmful toxins, diatoms are generally considered valuable to the food chain and functionality of an ecosystem, and are considered to be ecologically

beneficial. Diatoms are commonly abundant during the spring and again during late summer and early autumn.

Cryptophyta. Commonly known as “cryptomonads,” cryptophyta are unicellular algae that usually contain two flagellates of two unequal lengths. This group of algae is very small in size and little is understood about them. These algae are a desirable food source for zooplankton, and considered to be ecologically beneficial. When compared to other algae, cryptomonads can develop during colder periods with lower light intensities.

Chrysophyta. Chrysophyta are more commonly known as “golden algae.” This diverse algal group can be unicellular, colonial, and filamentous. Golden algae are characterized by their yellow-green coloration due to greater amounts of carotenoids versus chlorophylls in their cells. The majority of species possess two flagella.

Pyrrhophyta. Pyrrhophyta are known as “dinoflagellates” and are all unicellular organisms with two flagella. Though most species are found in marine environments, there are a number of species found in freshwater systems. Dinoflagellates tend to bloom in temperate conditions towards the end of summer when stratification is stable and epilimnion nutrients are declining. In marine areas, some species can produce harmful toxins, and are of particular concern to humans as they may cause red tides.

Euglenophyta. Commonly known as “euglenoids,” euglenophyta are a large and diverse group of phytoplankton commonly found in waters high in ammonia and organic matter (Wetzel 1975). Most euglenoids are unicellular, lack a cell wall, and have up to three flagella.

2.4.1.2 *Phytoplankton Abundance and Composition*

Phytoplankton samples were collected in Lake Pend Oreille at stations ALFLPD and ALFLPS, and in the Pend Oreille River at station ALFFB in 2005 and from 2008 through 2016 (2011 had only one sampling date). Collectively, 247 species of phytoplankton representing 7 genera were identified in Lake Pend Oreille and the Pend Oreille River. Of these 247 different species, there were 146 species of bacillariophyta (diatoms), 51 species of chlorophyta (green algae), 20 species of chrysophyta (golden algae), 16 species of cyanophyta (cyanobacteria), 8 species of pyrrhophyta (dinoflagellates), 5 species of cryptophyta (cryptomonads), and 1 species of euglenophyta (euglenoids).

Seasonal and annual variations in phytoplankton biovolume and density are presented in Figure 2-20 and Figure 2-21. Phytoplankton density is a measure of the total number of organisms of each species per milliliter in a sample. Phytoplankton biovolume is a measure of the total volume of organisms of each species in a sample. Because biovolume measurements incorporate both cell numbers and size they can be very different from density measurements, depending on the size of the phytoplankton species. For example, cryptomonads are very small in size and may have large density numbers but small biovolume numbers. Conversely, diatoms, which are generally large in size, may have low densities but high biovolumes.

Figure 2-20. Lake Pend Oreille Temporal Variation in Phytoplankton Biovolume 2005 to 2016

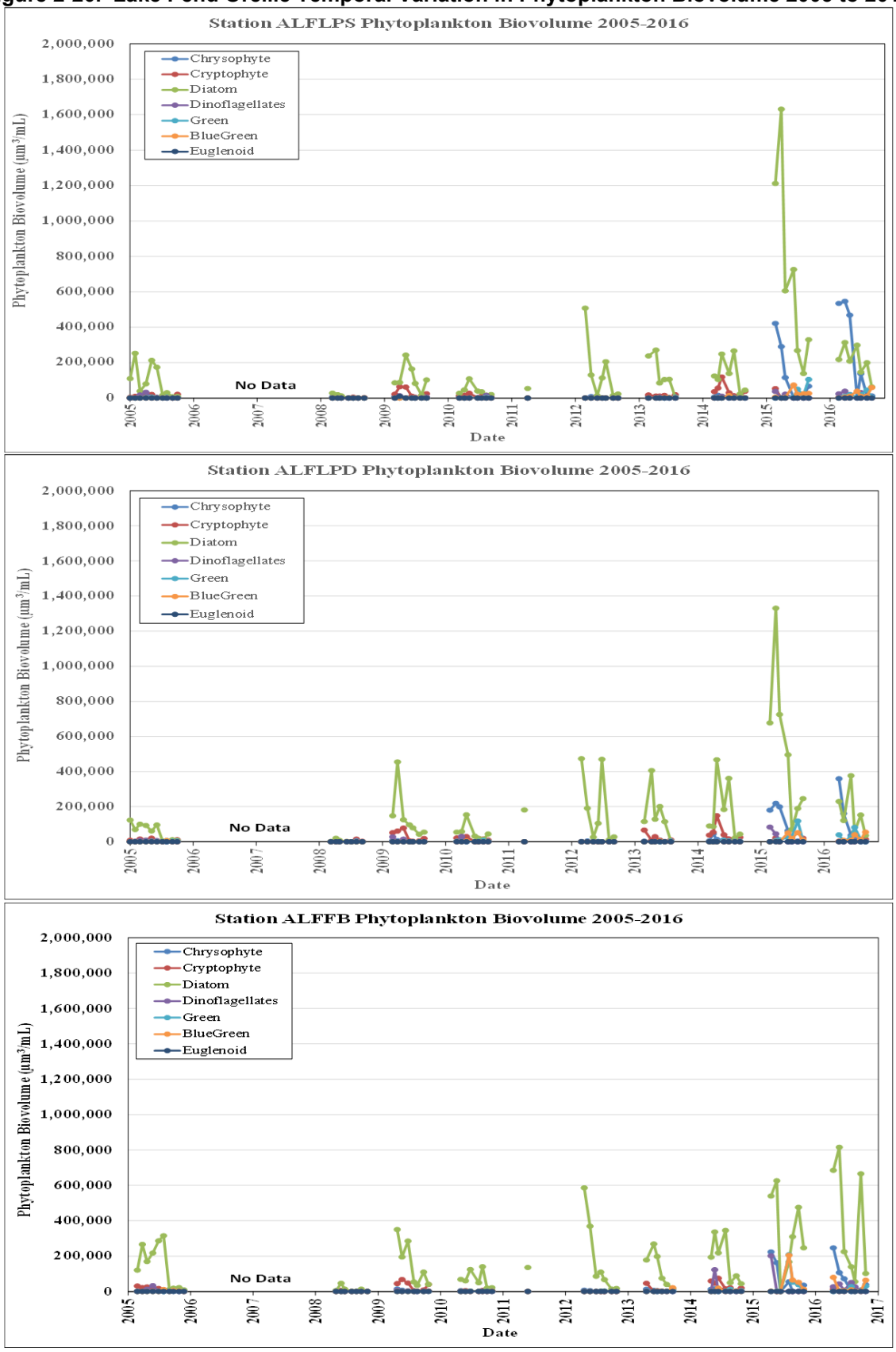
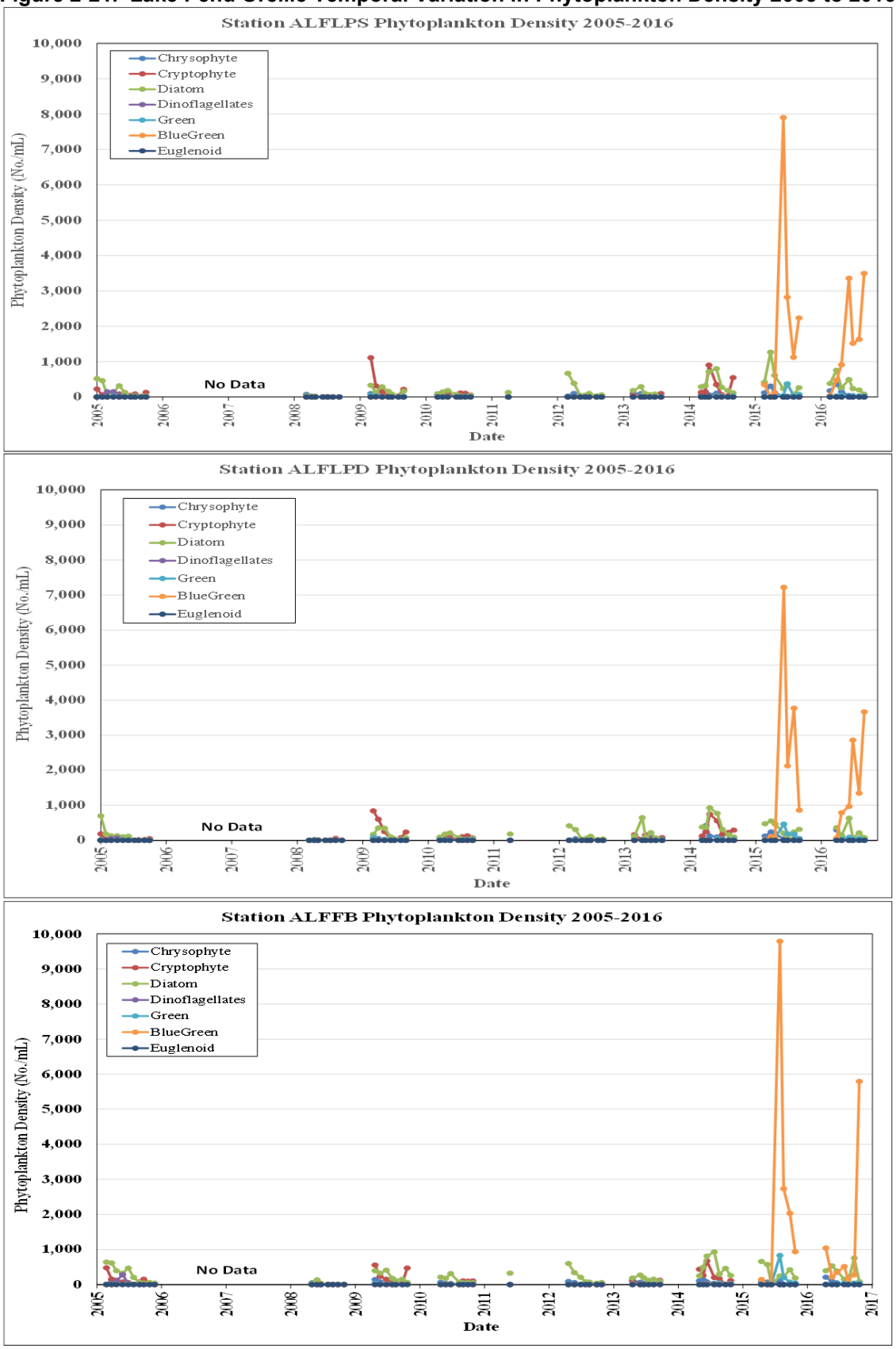


Figure 2-21. Lake Pend Oreille Temporal Variation in Phytoplankton Density 2005 to 2016



A large increase in phytoplankton biovolume and densities were measured at all stations in Lake Pend Oreille and the Pend Oreille River between 2005 and 2016. For the most part, low biovolumes were measured from 2005 to 2013, low to moderate biovolumes in 2014, and a substantial increase in volumes measured from 2015 to 2016 (Figure 3-24). From 2005 to 2014 phytoplankton biovolume seasonal patterns were similar between stations, and biomass was relatively low. In general, biovolumes were greatest in April, May, and June and lowest from July through October. A substantial increase in phytoplankton biovolume was measured at all stations from 2014 to 2016, with the greatest phytoplankton biovolume and numbers measured at the Lake Pend Oreille stations ALFLPD and ALFLPS (Figure 3-24).

Phytoplankton densities followed a similar trend as biovolumes. Densities were low at all stations from 2005 to 2013, increased slightly in 2014, and then increased substantially at all stations from 2015 to 2016 (Figure 3-25). A concurrent shift in the temporal pattern of phytoplankton densities was also measured. From 2005 to 2013, phytoplankton densities were greatest from April through June and lowest from July through October. In 2014, phytoplankton densities increased slightly with the greatest densities measured in June and July and lowest in April, May, August, September, and October. From 2015 to 2016 densities were greatest from July through October and lowest from April through June.

Lake Pend Oreille water column phytoplankton populations were dominated by a mixture of diatoms, cryptophytes, and chrysophytes at all stations from 2005 to 2014 and by diatoms, chrysophytes, and cyanobacteria from 2015 to 2016 (Figure 2-22 and Figure 2-23). In general, from 2005 to 2014 diatoms accounted for about 60 to 100 percent of phytoplankton composition by biovolume and about 30 to 80 percent by total density. Cryptomonads accounted for about 0 to 50 percent by biovolume and 0 to 50 percent by density, crysophytes accounted for about 0 to 10 percent by biovolume and from about 0 to 30 percent by density, while greens and dinoflagellates accounted for about 0 to 5 percent by biovolume and 0 to 25 percent by density with few cyanobacteria and euglenoids measured . From 2015 to 2016, diatoms accounted for about 50 to 70 percent of phytoplankton composition by biovolume and about 20 to 40 percent by total density. Cyanobacteria accounted for about 10 percent by biovolume and for about 50 to 70 percent by density. Crysophytes accounted for about 10 to 30 percent by biovolume and from about 5 to 10 percent by density. Cyanobacteria accounted for about 0 to 40 percent by biovolume and for about 10 to 95 percent by density, while greens and dinoflagellates accounted for about 5 to 10 percent by biovolume and density with few cryptomonads and euglenoids.

Figure 2-22. Lake Pend Oreille 2015 to 2016 Phytoplankton Percent Composition by Biovolume

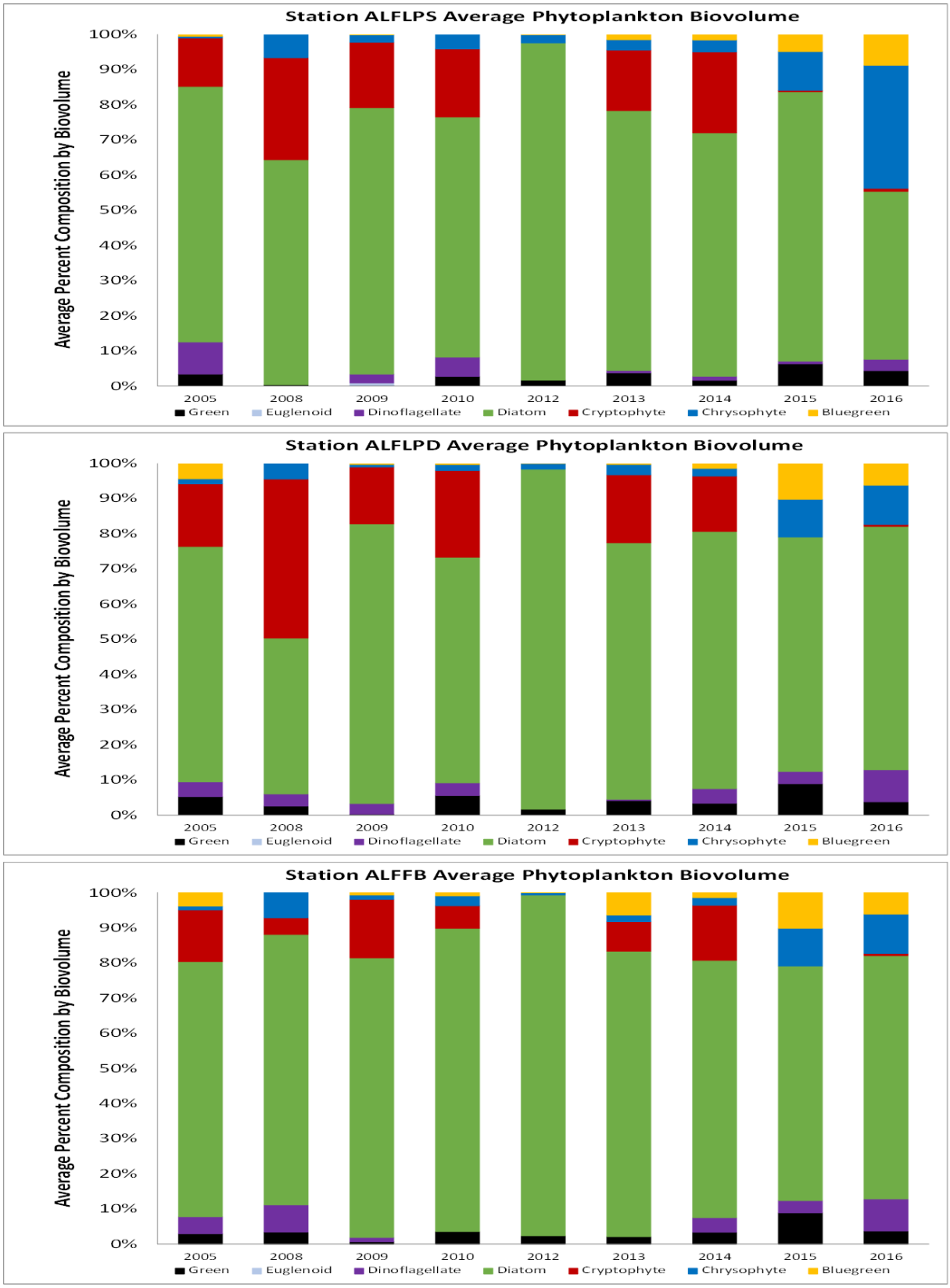
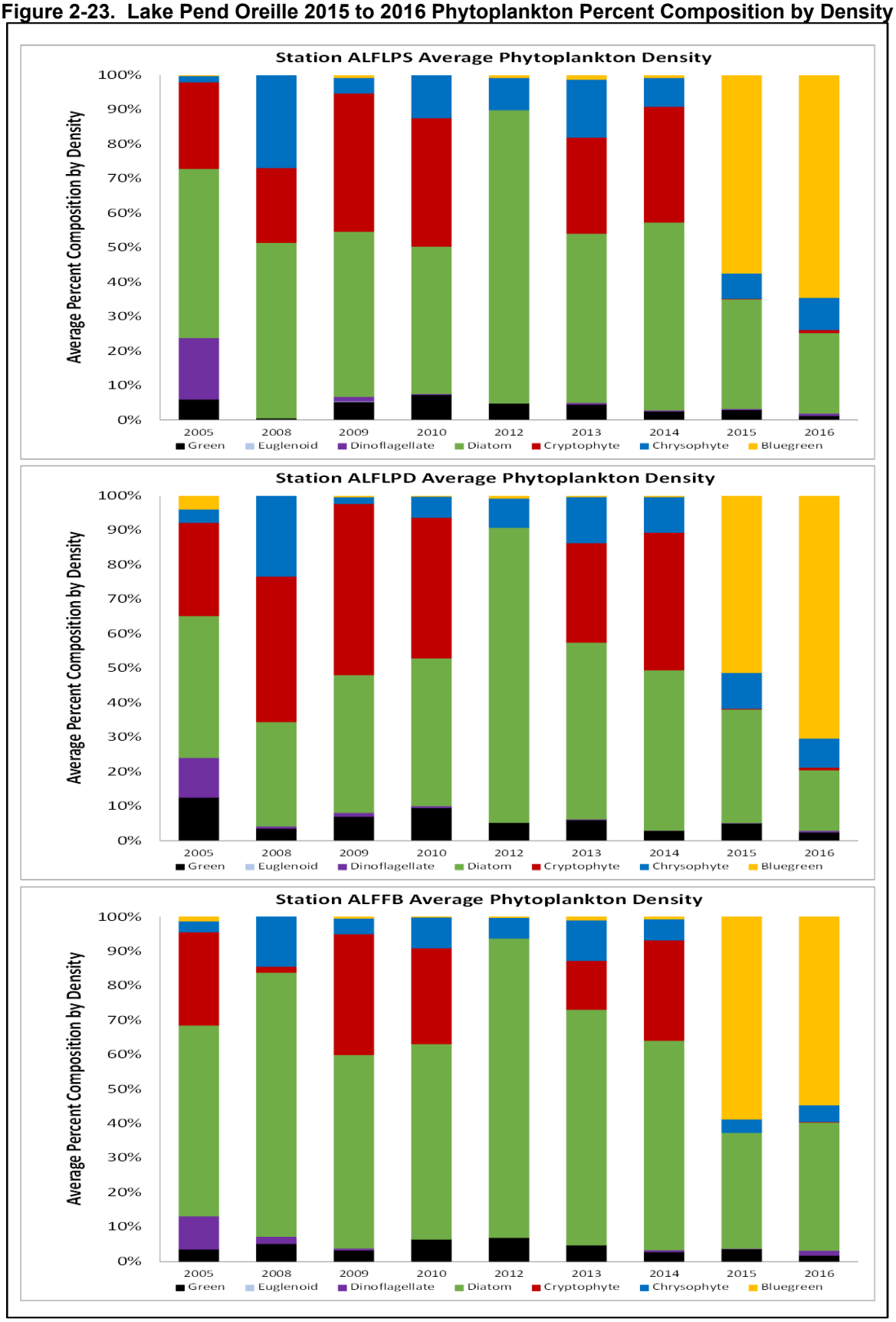


Figure 2-23. Lake Pend Oreille 2015 to 2016 Phytoplankton Percent Composition by Density



Despite low to moderate biovolume and density numbers from 2005 through 2014, species diversity was moderate. From 2005 to 2014, the phytoplankton assemblage was dominated by a mixture of diatoms (*Asterionella Cyclotella*, *Fragilaria*, *Melosira*, *Stephanodiscus*, *Synedra*, and *Tabellaria*), cryptophytes (*Cryptomonas* and *Rhodomonas*), and chrysophytes (*Kephyrion* and *Dinobryon*). During peak blooms, phytoplankton biovolume and density was dominated by a mixture of diatoms (*Cyclotella*, *Fragilaria*, *Melosira*, and *Stephanodiscus*).

A substantial increase in phytoplankton biovolume and density was measured at all stations between 2015 and 2016, with the greatest change in the algal assemblage being a substantial increase in cyanobacteria (Figure 3-24 and Figure 3-25). The large increase in cyanobacteria is interesting, especially since cyanobacteria represented only a minor fraction of the assemblage from 2005 through 2014. From 2015 to 2016 the phytoplankton assemblage was largely dominated by a few diatoms (*Cyclotella* and *Fragilaria*), cyanobacteria (*Aphanocapsa*, *Aphanothece*, and *Planktolyngbya*) and the chrysophyte *Dinobryon*. Based on density, phytoplankton in 2015 and 2016 was dominated by cyanobacteria, while based on biovolume it was dominated by diatoms and chrysophytes. TheCyanobacteria that have been dominating in Lake Pend Oreille and the Pend Oreille River since 2015 (*Aphanocapsa* , *Aphanothece*, and *Planktolyngbya*) are non-heterocystous and cannot fix nitrogen.

The increase in phytoplankton biovolume and density from 2015 to 2016, together with an increase in cyanobacteria, is interesting and may be partly due to an increase in the total nitrogen to total phosphorus ratio in Lake Pend Oreille and the Pend Oreille River. Traditionally, most research has shown a strong correlation between increased phosphorus loading and phytoplankton productivity in freshwaters, as long as the nitrogen to phosphorus ratio is high (Wetzel 1975; Schindler 1978; Anderson, Gilbert, and Burkholder 2002; Welch and Jacoby 2004). However, several recent studies on the impacts of increased nitrogen loadings to oligotrophic lakes have shown an increase in phytoplankton productivity due to greater nitrogen loadings (Bergstrom and Jansson 2006; Hobbs et al. 2016). Changes in species diversity and composition have also been attributed to increased nitrogen to phosphorus ratios. Studies of large shallow temperate lakes in northeast Europe showed that higher total nitrogen to total phosphorus ratios favored the non-heterocystous cyanobacteria that cannot fix nitrogen, such as *Planktolyngbya* (Noges et al. 2008). Studies by Lehman (1976) showed that *Dinobryon* were shown to outcompete other phytoplankton species when phosphorus concentrations are low and the corresponding nitrogen to phosphorus ratios are high because *Dinobryon* possess efficient mechanisms for uptake of nitrogen and low concentrations of phosphorus. Additionally, nitrate enrichment studies on Lake Huron concluded that the diatom *Cyclotella* increases in abundance due to an increased nitrogen to phosphorus ratio (Pappas and Stoermer 1995).

2.4.2 Zooplankton

Zooplankton are microscopic animals found in the water column that are important to the trophic structure of an ecosystem because they feed on phytoplankton and, in turn, are consumed by fish. Zooplankton can be either herbivorous (feeds on phytoplankton),

carnivorous (feeds on other zooplankton), or omnivorous (feeds on both phytoplankton and zooplankton). Water quality conditions can be assessed from the numbers and types of zooplankton species present in the water (Gannon and Stemberger 1978). For example, the presence of certain zooplankton species relative to other species may serve as an indicator of the biological productivity of a water body. However, this generalization may or may not be indicative of site specific water quality conditions, such as those found in Lake Koocanusa. Consequently, zooplankton density and species information should be used in conjunction with phytoplankton data, physical data, and chemical data to determine the overall trophic condition of a lake.

Freshwater zooplankton are usually dominated by three main groups: Rotifers and two subclasses of Crustacea - Cladocera and Copepods. Zooplankton are classified by size, developmental stage, grazing techniques, reproductive characteristics, and/or morphology. The following traits are characteristic of these three main zooplankton groups:

Cladocera. Commonly known as water fleas, these organisms are filter feeders and generally range in size from 0.2 to 3.0 mm. These filter feeders are identifiable by the presence of a large eye and two-valved carapace. Cladocera are an important part of the freshwater ecosystem as they graze on phytoplankton and are a prime source of food for fish. Cladocera have the ability to migrate vertically in the water column on a daily basis. Herbivorous species dominate, although some carnivorous species of Cladocera exist in freshwaters.

Copepod. The second major group of crustacean zooplankton, adult members grow slightly larger than Cladocerans, and range in size from 0.5 to 5.0 mm. These organisms are identifiable by their long teardrop shaped body and antennae. No filtration mechanism exists for feeding and food is seized by mouthparts and brought to the mouth. Both herbivorous and carnivorous species of Copepods exist in freshwater. Some species of Copepods have the ability to migrate vertically in the water column on a daily basis.

Rotifers. A large group of soft-bodied plankton, they are among the smallest of the zooplankton, ranging in size from .002 to 0.2 mm in adult form. The majority of Rotifers have an elongated body shape, with distinguishable head, trunk, and foot regions. Characterized by the division of their body, Rotifers are identified by their wheel-shaped corona. Herbivorous species dominate, although some carnivorous species of Rotifers exist in freshwaters.

2.4.2.1 *Zooplankton Abundance and Composition*

Collectively, 100 species of zooplankton were identified in Lake Pend Oreille and the Pend Oreille River during the 2005 to 2016 study. Of these 100 different species there were 59 species of Rotifers, 27 species of Cladocera, and 14 species of Copepods.

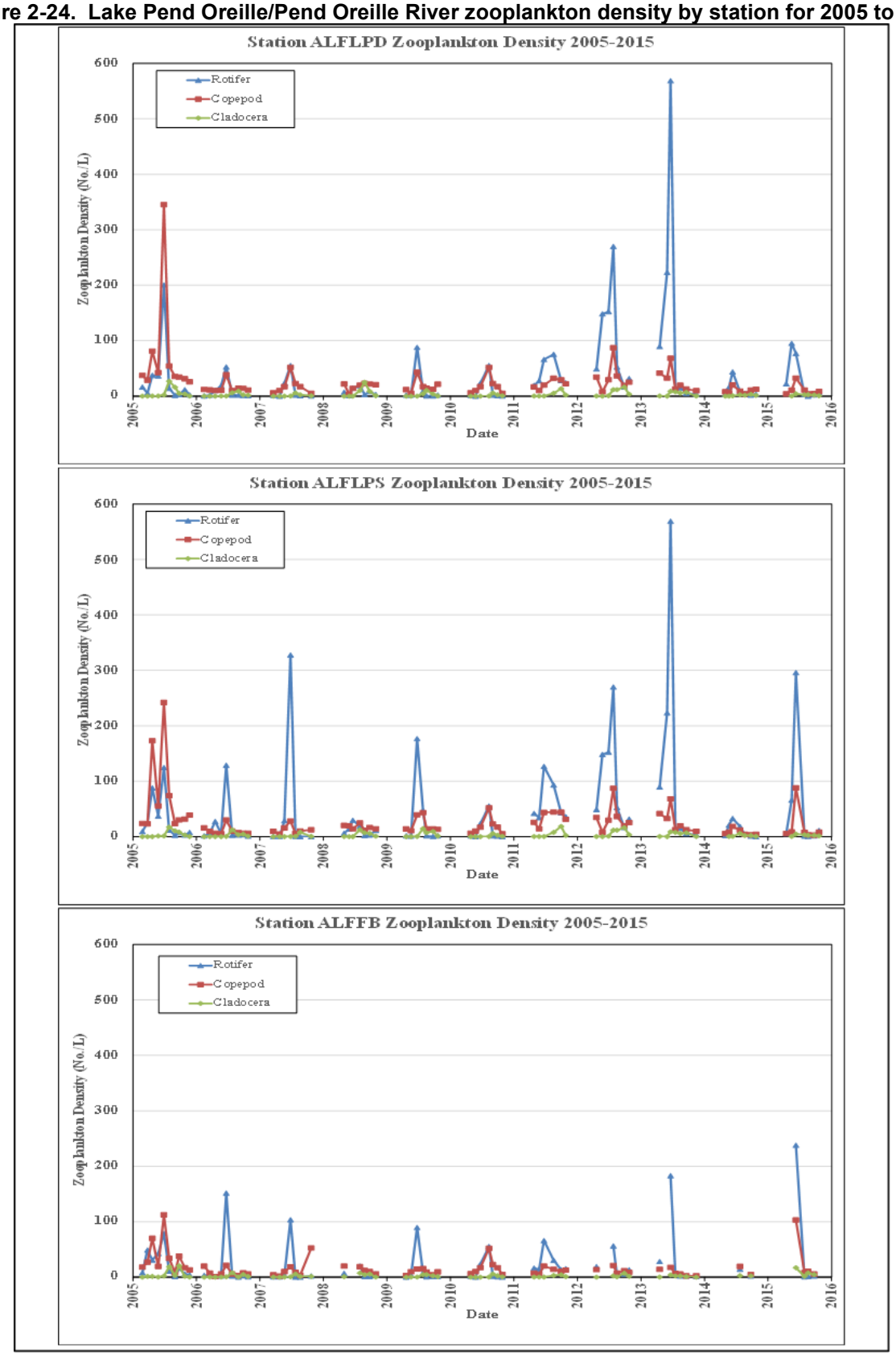
Temporal variations in zooplankton density at all stations in Lake Pend Oreille and the Pend Oreille River are presented in Figure 2-24. Zooplankton density was measured as

the total number of organisms of each species per liter in a sample. Total zooplankton densities varied between years and stations. In general, zooplankton densities were greatest from May through July, depending on the year, at all stations and were greatly reduced during April and August-October. Annual peak zooplankton densities at all stations typically ranged from about 50 to 300 organisms/L, except for a peak of about 600 organisms/L at ALFLPD and ALFLPS in 2013. Rotifers and copepods dominated density measurements at all stations during the study.

The composition of zooplankton was similar between stations; however, seasonal and annual differences were apparent (Figure 2-24). Zooplankton densities from 2005 through 2010 were dominated by copepods and rotifers which accounted for about 40 to 90 percent (copepods) and 5 to 50 percent (rotifers) of the total density depending on the month. However, from 2011 through 2015 rotifers have dominated zooplankton populations accounting for about 40 to nearly 100 percent of the total density depending on the month, with copepod densities ranging from about 5 to 40 percent. Cladocera densities were low (0 to 15 percent) during the entire study. Seasonal differences were apparent at all stations with rotifers dominating during the peak zooplankton season from about May through July. In general, rotifers were dominated by *Keretella, Polyarthra*,and *Synchaeta,* copepods were dominated by *Nauplii*, *Cyclopoid* and *Diacyclops*, while cladocerans were dominated by *Daphnia* and *Bosmina.*

The seasonal succession in zooplankton species seen in Lake Pend Oreille and the Pend Oreille River is likely in response to food source availability, changes in temperature, and grazing by fish. Many zooplankton populations are low over the winter and begin to increase in the spring as food supplies (i.e. phytoplankton) increase and water temperatures rise. As phytoplankton species shift in dominance during the spring, summer, and fall the zooplankton populations will cycle in response to the quality and size of the food (with some phytoplankton species being more palatable than others) as well as due to predation by other zooplankton species (Wetzel 1975). The annual succession in zooplankton species from dominance by larger copepods to dominance by smaller rotifers may be in part a response to the change in algal species and diversity that was measured in Lake Pend Oreille or possibly due to grazing by fish. Abrupt changes in zooplankton species dominance from larger to smaller species were noted in nearby Lake Koocanusa in the late 1980s and believed to have been the result of increased Kookanee grazing (Chisholm et al. 1989, Hamilton et al. 1990).

Figure 2-24. Lake Pend Oreille/Pend Oreille River zooplankton density by station for 2005 to 2014



SECTION 3 - CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

Lake Pend Oreille is the largest and deepest lake in Idaho and the fifth deepest lake in the United States, with a maximum width of about 10.8 kilometers and a maximum depth of about 357 meters. Albeni Falls Dam, located on the Pend Oreille River about 47 kilometers downstream of the lake, regulates the top 3.5 meters of Lake Pend Oreille for flood control, navigation, fish and wildlife conservation, recreation, and power generation. Considerable physical, chemical, and biological water quality data was collected on Lake Pend Oreille and the Pend Oreille River by the Seattle District from 2005 to 2016. Evaluation of the monitoring results yielded the following conclusions.

The water quality of Lake Pend Oreille is good. Lake Pend Oreille would be classified as oligotrophic on the basis of summer TSI values and oligotrophic/mesotrophic based on annual OECD (1982) methods. In general, summer total phosphorus concentrations are low, water clarity is high, and algal growth, as determined by chlorophyll a concentrations, is moderate.

Water temperature changes in Lake Pend Oreille and the Pend Oreille River are mainly influenced by atmospheric conditions and weather patterns. Solar heating is sufficient to develop thermal stratification and a thermocline in the deeper regions of Lake Pend Oreille during the spring and summer months. However, the shallower (fewer than 20 meters deep) northern basin near the outlet does not thermally stratify for any substantial period of time.

A prominent difference between thermal conditions in the lake and river during the summertime is the occurrence of warmer water temperatures throughout the water column in the Pend Oreille River whereas the warmer water temperatures are limited to the upper portion of the water column in Lake Pend Oreille. These temperature observations are consistent with the transport of surface oriented water from the lake into the river due to the shallow channel properties in the transitional reach of the lake to the Pend Oreille River near Sandpoint, Idaho. A shallow low water channel acts as a barrier to the transport of much colder subsurface water from Lake Pend Oreille into the Pend Oreille River.

Dissolved oxygen concentrations in Lake Pend Oreille and the Pend Oreille River ranged from about 8 to 13 mg/L. Both the lake and river were well oxygenated throughout the water column with few dissolved oxygen measurements below 8 mg/L.

Pend Oreille River pH values measured at the forebay of Albeni Falls Dam ranged from about 7.2 to 8.7. The highest values were typically measured in the late summer and fall (July to October) and were occasionally greater than the downstream State of Washington standard of 8.5. These elevated pH values were uniformly distributed in the water column and were likely the result of photosynthetic activity.

Median total phosphorus concentrations in the epilimnion of Lake Pend Oreille ranged from about 4 to 10 µg/L, while in the hypolimnion concentrations ranged from about 5 to 9 µg/L. Median concentrations downstream in the Pend Oreille River ranged from about 4 to 8 µg/L while at the Clark Fork River inflow they ranged from about 6 to 12 µg/L. There was little difference between inflow, in-lake, and outflow phosphorus concentrations suggesting that Lake Pend Oreille is not a sink for phosphorus.

Summer nearshore nutrient concentrations were similar to epilimnetic concentrations measured in Lake Pend Oreille. The majority of nearshore total phosphorus concentrations ranged from about 2 to 10 µg/L, with an occasional measurement greater than 20 µg/L.

An increase in total nitrogen and concurrent decrease in total phosphorus has been measured in the lake since 2014. Given this, TN:TP ratios suggest that phosphorus is the limiting nutrient in the Pend Oreille system.

Lake Pend Oreille water column phytoplankton populations were dominated by a mixture of diatoms, cryptophytes, and chrysophytes from 2005 to 2014, with few cyanobacteria detected. However, from 2015 to 2016 phytoplankton was largely dominated by a few diatoms (*Cyclotella*. and *Fragilaria*), cyanobacteria (*Aphanocapsa*, *Aphanothece*, and *Planktolyngbya*) and the chrysophyte *Dinobryon*.

The increase in phytoplankton biovolume and density in 2015 and 2016, together with a substantial increase in cyanobacteria, may be partly due to an increase in the TN:TP in Lake Pend Oreille and the Pend Oreille River measured during this period. The cyanobacteria species that has been dominating in Lake Pend Oreille and the Pend Oreille River since 2015 (*Planktolyngbya*) is non-heterocystous and cannot fix nitrogen.

Zooplankton densities in Lake Pend Oreille and the Pend Oreille River from 2005 through 2010 were dominated by copepods and rotifers which accounted for about 40 to 90 percent (copepods) and 5 to 50 percent (rotifers) of the total density depending on the month. However, from 2011 through 2015 rotifers have dominated zooplankton populations accounting for about 40 to nearly 100 percent of the total density depending on the month, with copepods densities ranging from about 5 to 40 percent. Cladocera densities were low (0 to 15 percent) during the entire study. Seasonal differences were apparent at all stations with rotifers dominating during the peak zooplankton season from about May through July.

3.2 RECOMMENDATIONS

Annual physical, chemical, and biological water quality sampling of Lake Pend Oreille and the Clark Fork and Pend Oreille Rivers should continue at current sampling locations. Additional research should be conducted on increased nitrogen concentrations in Lake Pend Oreille and potential changes to the phytoplankton assemblage. The sharp increase in cyanobacteria in both the lake and river is of concern and should be investigated. Nearshore phytoplankton should be monitored to

determine if this critical habitat area is experiencing a rise in cyanobacteria. Productivity studies should be conducted on Lake Pend Oreille.

SECTION 4 - REFERENCES

Anderson, D. M., P. M. Gilbert, and J. M. Burkholder. 2002. “Harmful Algal Blooms and Eutrophication: Nutrient sources, Composition, and Consequences.” Estuaries 25:704–726.

Andrews, E. D. 1987. “Longitudinal Dispersion of Trace Metals in the Clark Fork River, Montana.” In Chemical Quality of Water and the Hydrologic Cycle. R.C. Averett and D.M. McKnight, eds. Boca Raton, FL: Lewis Publishers.

Axtmann, E. V., and S. N. Luoma. 1991. “Large-Scale Distribution of Metal Contamination in the Fine-grained Sediments of the Clark Fork River, Montana, U.S.A.” Applied Geochemistry 6(1):77–85.

Beckwith, M. A. 2002. Selected Trace-Element and Synthetic-Organic Compound Data for Streambed Sediment from the Clark Fork-Pend Oreille and Spokane River Basins, Montana, Idaho, and Washington, 1998. Open-File Report 02-336. U.S. Geological Survey.

Bergstrom, A., and M. Jansson. 2006. “Atmospheric Nitrogen Deposition has Caused Nitrogen Enrichment and Eutrophication of Lakes in the Northern Hemisphere.” Global Change Biology 12:635–643.

Briggs, J. C., and J. F. Ficke. 1977. Quality of Rivers of the United States, 1975 Water Year -- Based on the National Stream Quality Accounting Network (NASQAN). Open-File Report 78-200. U.S. Geological Survey.

Carlson, R. E. 1977. “A Trophic State Index for Lakes.” Limnology and Oceanography 22:361–369.

Corps (U.S. Army Corps of Engineers). 2000. Albeni Falls Dam Pend Oreille River, Idaho Water Control Manual. Seattle District.

Ecology (Washington State Department of Ecology). 2018a. Pend Oreille River @ Newport (62A150). Accessed July 12, 2018, https://fortress.wa.gov/ecy/eap/riverwq/station.asp?sta=62A150.

Ecology. 2018b. Washington State water quality assessment. Accessed July 12, 2018, https://fortress.wa.gov/ecy/approvedwqa/ApprovedSearch.aspx.

EPA (U.S. Environmental Protection Agency). 1983. Methods for chemical analysis of water and wastes. EPA-600/4-79-020. Environmental Monitoring and Support Laboratory. Cincinnati.

EPA. 1984. Guidelines Establishing Test Procedures for the Analysis of Pollutants under the Clean Water Act; Final Rule and Interim Final Rule. CFR Part 136. October 26.

EPA. 1992. National Pollutant Discharge Elimination System Stormwater Sampling Guidance Document. EPA 833-B-92-001. Office of Water. Washington, D.C.

Falter, C. M. 2004. Lake Pend Oreille Littoral Periphyton Community: An Updated Trophic Status Assessment 2003. Submitted to the Tri-State Water Quality Council.

Falter, C. M., D. Olson, and J. Carlson. 1992. The Nearshore Trophic Status of Pend Oreille Lake, Idaho. Idaho Water Research Institute, University of Idaho. Moscow, Idaho.

Fields, R. L., P. F. Woods, and C. Berenbrock. 1996. Bathymetric Map of Lake Pend Oreille and Pend Oreille River, Idaho. Water Resources Investigations Report 96-4189. U.S. Geological Survey.

Forsberg, C., and S. O. Ryding, 1980. “Eutrophication Parameters and Trophic State Indices in 30 Swedish Waste Receiving Lakes.” Archiv fur Hydrobiologie 89:189–207.

Frenzel, S. A. 1991. “Hydrologic Budgets, Pend Oreille Lake, Idaho 1989-1990.” In Phase I Diagnostic and Feasibility Analysis: A Strategy for Managing the Water Quality of Pend Oreille Lake. B. Hoelscher, J. Skille, and G. Rothrock, eds. Idaho Department of Health and Welfare, Division of Environmental Quality. Boise, Idaho.

Gannon, J. E. and R. S. Stemberger. 1978. Zooplankton (especially crustaceans and rotifers) as indicators of water quality. Transactions of the American Microscopical Society. 97:16-35.

Greenberg, A. E., A. D. Eaton, and L. S. Clesceri, eds. 1992. Standard Methods for the Examination of Water and Wastewater. 18th edition. American Public Health Association, American Water Works Association, and Water Environment Federation.

Greenberg, A. E., A. D. Eaton, and L. S. Clesceri, eds. 2000. Standard Methods for the Examination of Water and Wastewater. 20th edition. American Public Health Association, American Water Works Association, and Water Environment Federation.

Hobbs, W. O., B. M. Lafrancois, R. Stottlemyer, D. Toczydlowski, D. R. Engstrom, M. B. Edlund, J. E. Almendinger, K. E. Strock, D. VanderMeulen, J. E. Elias, and J. E. Saros. 2016. “Nitrogen Deposition to Lakes in National Parks of the Western Great Lakes Region: Isotopic Signatures, Watershed Retention, and Algal Shifts.” Global Biogeochemical Cycles 20(3):514–533.

Hoelscher, B., J. Skille, and G. Rothrock. 1993. Phase I Diagnostic and Feasibility Analysis: A Strategy for Managing the Water Quality of Pend Oreille Lake. Idaho Department of Health and Welfare, Division of Environmental Quality. Boise, Idaho.

IDEQ (Idaho Department of Environmental Quality). 2008. Pend Oreille River and Lake Total Dissolved Gas Total Maximum Daily Load. Idaho Department of Environmental Quality. June 2008.

IDEQ (Idaho Department of Environmental Quality). 2017. Water Quality Standards. IDAPA 58, Title 01, Chapter 02, Section 58.01.02.

IDEQ. 2018. Idaho's water quality monitoring and assessment information center. Accessed Month Day, 2018, http://www.deq.idaho.gov/water-quality/surface-water/monitoring-assessment/integrated-report.aspx.

Idaho Geological Survey. 2002. Geologic Map of Bonner County, Idaho.

Johns, C., and J. Moore. 1985. Copper, Zinc, and Arsenic in Bottom Sediments of Clark Fork River Reservoirs: Preliminary Findings. University of Montana, Geology Department. Missoula.

Lehman, J. T. 1976. "Ecological and Nutritional Studies on Dinobryoin Ehrenb.: Seasonal Periodicity and the Phosphate Toxicity Problem." Limnology and Oceanography 21(5):646–658.

Maret, T. R., and D. M. Dutton. 1999. Summary of Information on Synthetic Organic Compounds and Trace Elements in Tissue of Aquatic Biota, Clark Fork-Pend Oreille and Spokane River Basins, Montana, Idaho, and Washington, 1974-1996. Water Resources Investigations Report 98-4254. U.S. Geological Survey.

MDEQ (Montana Department of Environmental Quality), Idaho Department of Environmental Quality, Washington Department of Ecology, and the Kalispel Tribe of Indians. 2007. Clark Fork – Pend Oreille Watershed Management Plan: Management Strategies for the Next Decade 2007 – 2017.

Noges, T., R. Laugaste, P. Noges, and I. Tonno. 2008. "Critical N:P Ratio for Cyanobacteria and N2-Fixing Species in the Large Shallow Temperate Lakes Peipsi and Bortsjarv, North-East Europe." Hydrobiologia 599:77–86.

OECD (Organization for Economic Co-Operation and Development). 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Paris, France.

Pappas, J. L., and E. F. Stoermer. 1995. "Effects of Inorganic Nitrogen Enrichment on Lake Huron Phytoplankton: An Experimental Study." Journal of Great Lakes Research 21(2):178–191.

Parametrix, Inc. 1999. Total Dissolved Gas Monitoring Cabinet Gorge and Noxon Rapids Hydroelectric, 1998. Prepared for Water Resources Work Group and Avista Corporation. February.

PBS&J. 2009. Water Quality Status and Trends in the Clark Fork-Pend Oreille Watershed: Time Trends Analysis for the 1984-2007 Period. Prepared for the Tri-State Water Quality Council. January.

Reynolds, C. S. 1984. The Ecology of Freshwater Phytoplankton. Cambridge University Press.

Ryding, S. O., and W. Rast 1989. Control of Eutrophication in Lakes and Reservoirs. Programme on Man and the Biosphere. Cambridge University Press.

Schindler, D.W. 1978. “Factors Regulating Phytoplankton Production and Standing Crop in the World’s Freshwaters.” Limnology and Oceanography 23(3):478–486.

Schneider, M. L., L. I. Yates, and K. L. Barko. 2007. Total Dissolved Gas Exchange at Albeni Falls Dam, 2003. Prepared for the U.S. Army Corps of Engineers, Seattle District. U.S. Army Corps of Engineers Engineer Research and Development Center.

TSWQC (Tri-State Water Quality Council). 2002. A Total Maximum Daily Load (TMDL) for Nutrients for the Nearshore Waters of Pend Oreille Lake, Idaho. February.

TSWQC. 2004. Pend Oreille Lake Nearshore Nutrient TMDL Implementation Plan. Prepared in cooperation with Idaho Department of Environmental Quality, Idaho Soil Conservation Commission, Idaho Department of Lands, Idaho Transportation Department, Bonner County. December.

Weitkamp, D. E., and M. Katz 1980. “A Review of Dissolved Gas Supersaturation Literature.” Transactions of the American Fisheries Society 109:659–702.

Weitkamp, D. E., R. D. Sullivan, T. Swant, and J. DosSantos 2002. Gas Bubble Disease in Resident Fish of the Lower Clark Fork River. Prepared for Avista Corporation. Parametrix, Inc.

Welch, E. B., and J. M. Jacoby. 2004. Pollutant Effects in Freshwater: Applied Limnology. 3rd edition. New York: Taylor & Francis.

Wetzel, R. G. 1975. Limnology. Philadelphia: W.B. Saunders Company.

Woods, P. F. 2004. Role of Limnological Processes in Fate and Transport of Nitrogen and Phosphorus Loads Delivered into Coeur d’Alene Lake and Lake Pend Oreille, Idaho, and Flathead Lake, Montana. Professional Paper 1682. U.S. Geological Survey, National Water Quality Assessment Program.

WRCC 2009. Western Region Climate Center. Historical Climate Information for Sandpoint Idaho 1910 to 2008, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?idsand.