

Northwest Montana Lakes Network

2021 Summary Report



*Volunteers & staff on Lake Mary Ronan.
Photo courtesy Whitefish Lake Institute*

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1.0 INTRODUCTION

The Northwest Montana Lakes Network (NMLN), previously named Northwest Montana Lakes Volunteer Monitoring Network (NWMTLVMN), is a citizen science program that grew out of two lake monitoring programs previously underway at the Flathead Basin Commission (FBC) and the Whitefish Lake Institute (WLI). The Flathead Basin Commission, in cooperation with the University of Montana Flathead Lake Biological Station, coordinated the Volunteer Lakes Monitoring Program (VLMP) from 1992-2010. The VLMP trained, equipped, and supported local volunteers who collected data and reported on over three dozen lakes in the Flathead Basin.

The Environmental Protection Agency (EPA) and FBC programs were the baseline models for the Whitefish to Eureka Volunteer Lake Monitoring Program which was initiated in 2007 by WLI in partnership with Montana Fish, Wildlife & Parks (MFWP). The program was established to provide residents an opportunity to collect baseline data to help determine the trophic status of lakes and implement early Aquatic Invasive Species (AIS) detection and prevention in Northwest Montana. In 2010, the Whitefish to Eureka program combined with the FBC program to form the NMLN. The NMLN currently has more than fifty volunteers that monitor a total of fifty locations on forty-one lakes in Flathead, Lake, Lincoln and Missoula counties. The lakes in the program represent diversity in public use, accessibility, and morphology.

The goal of the NMLN is to provide training and equipment to volunteers to collect long-term trend information for program lakes. The program specifically aims to address the question of whether nutrients are on the rise due to anthropogenic activity around the lakes. To address this question and to develop trend information, total phosphorus, total persulfate nitrogen, and chlorophyll (*a*) are collected at the same time each year. Calcium is collected every five years, and alkalinity was collected once in 2012 to gain a better understanding of each lake's suitability for invasive zebra/quagga mussel habitation.

Among the most important parameters monitored by volunteers are Secchi disk depth and temperature; however, volunteers also serve as reporters for any major or sudden changes that are observed in or around their lake. The program relies on citizen involvement for success and provides training and instruction in accordance with WLI's Sampling and Analysis Plan (WLI, 2020). Another goal of the program is to address the growing concern and real threat to lakes from the colonization and infestation of aquatic invasive species (AIS). In response to this threat, NMLN is increasing its effort to provide training for volunteers in early detection monitoring, primarily focused on invasive mussels (zebra and quagga), flowering rush, curly-leaf pondweed and Eurasian watermilfoil (EWM). Prior to 2010, AIS monitoring was not included in the monitoring program. This report provides interpretation and discussion for management purposes.

1.1 2021 Program Updates

As with any long-term monitoring program, consistency and continuity are critical to ensure comparability of data through time. Often as methodology advances, monitoring programs must adapt and improve, while remaining consistent enough to ensure the integrity of the dataset. In 2021, the NMLN program underwent a major advancement in analysis, data communication, and data management. This involved conversion from an older software suite (NCSS) to an open-source computer language R. This enables easy preparation of figures and databases in the future and ensures quality control and assurance by moving away from user interfaces and towards scripted workflow.

In 2021, all the material in this report was transferred to the new nmln.info website and broken down into more manageable, downloadable pdfs. Lake data was separated out into individual pdfs for each lake. These easily accessible links provide more comprehensive information for each lake.

In 2021, all historic volunteer Secchi and temperature data submitted to the program from 1992 (when it was the Volunteer Monitoring Program coordinated by Flathead Basin Commission) to 2021 was incorporated into a spreadsheet and subjected to quality assurance/quality control (QA/QC). WLI then

contracted with Dr. Dan Stich (Associate professor, SUNY Oneonta) and his research student to undertake preliminary statistical analysis and reporting of trends in Secchi depth and surface water temperature for this dataset. This includes a data exploration and QA/QC in R programming language; identification of variables to include (e.g., year, day, lake, lake size, etc) and working hypotheses; fitting statistical models corresponding to hypotheses about specific variables or their combinations; and interpretation of results and model predictions. Historic and current water chemistry data will be incorporated into the analysis as well, and a report on conclusions from modeling work and the open-source code used will be delivered by June 30, 2022. This report will help us to assess and display average relative changes throughout time (which variables are changing the most and which lakes are changing the most) and lake specific analysis over time. The results of these investigations will be made available on the website and to our volunteers.

2.0 DATA COLLECTION METHODS

Current program methods are based on WLI's Sampling and Analysis Plan (SAP) which incorporated methods from Ellis and Craft (2008) and are summarized below. Historically, the FBC VLMP also followed these procedures. To maintain consistency with previous data collection, these methods will continue to be used by the NMLN whenever possible.

2.1 Volunteers

Volunteers are asked to monitor their sample site twice per month at roughly two-week intervals or with at least three days in between sampling events. The ideal monitoring time is between 11:00 am and 3:00 pm, and volunteers are instructed to choose random times within that four-hour period rather than the same time for each sampling event. Volunteers are given GPS coordinates for their monitoring location; these coordinates are usually for the deepest location of the lake. If a volunteer does not have a GPS unit, they are asked to monitor at mid lake or are shown the monitoring location by the program coordinator.

Volunteers are provided with the necessary equipment for lake monitoring, including a four-quadrant Secchi disk, thermometer attached to a bobber and string, and a NMLN volunteer handbook which includes sampling methodology and data forms. Before beginning the Secchi disk measurement, the thermometer is placed in the lake, allowing it to remain submerged while the Secchi disk measurement is taken. The measurement end of the thermometer is 18 inches from a bobber, or lake surface. Once the monitoring site is reached, the boat is positioned so one side faces away from direct sunlight. Sunglasses are removed so that there is consistency across all program lakes. The Secchi disk is lowered on the shaded side of the boat until it disappears. The depth at which the Secchi disk disappears is recorded. The Secchi disk is lowered an additional five feet and slowly pulled toward the surface until the Secchi disk reappears. The depth at which the Secchi disk reappears is recorded, and the two depths are averaged and recorded as the final depth.

Qualitative atmospheric and water condition data are also recorded. Many of these observations are highly subjective. For water conditions, recorded observations are based on viewing the expanse of water in the vicinity of the monitoring site.

In 2011, the program launched an interactive website that allows volunteers to view all program information, download field data forms, and submit data electronically. In 2020, the website was converted to a WordPress site, www.nmln.info, which makes it easier for the program coordinator to control edits and update content. It is also now mobile responsive. Volunteers record data on the Volunteer Standard Report Form (available on the website) which prompts them to fill out information for Secchi depth, temperature, atmospheric weather conditions, qualitative lake data, and AIS. The website also provides information on the program for the public and prospective volunteers, AIS identification information, and sampling protocols. Volunteers that choose not to use the website are

mailed data collection forms and return envelopes. As of 2020, volunteers can conveniently download a report specific to their lake from the website.

2.2 Hydrolab

2.2.1 Historic Methodology (Pre 2011)

A Hydrolab Series 3 H20 was used to collect depth, temperature, dissolved oxygen, and specific conductivity. The H20 model did not have a Surveyor (handheld computer), so all data collected were recorded manually.

2.2.2 Current Methodology

Once per summer (ideally between the middle of July and the middle of August), the program coordinator visits each lake with a Hydrolab MS5 and Surveyor to measure depth, temperature, dissolved oxygen (% saturation and mg/L), pH, specific conductivity, chlorophyll (*a*), total dissolved solids, salinity, oxidation reduction potential, and resistivity. Profiles are taken at the mid-lake deep site. The Hydrolab MS5 is lowered one meter at a time to 14 meters and the values for each parameter are recorded in the Surveyor 4a. Values are recorded every two meters from 14 meters to 30 meters, every three meters from 30 to 45 meters, and every five meters from 45 meters to the lake bottom. Following each sample event, data recorded on the Surveyor4a are downloaded into the program database.

2.3 Description of Hydrolab Parameters

Luminescent Dissolved Oxygen (LDO): Measuring the concentration of oxygen that is dissolved in a waterbody is a general indicator of the diversity of organisms that a lake can support and the overall health of a lake. Because of the biological need for oxygen, LDO may be the most important parameter monitored in lakes. Many organisms, including certain fish and invertebrates, require high concentrations of dissolved oxygen. Oxygen is dissolved into lakes through the atmosphere, and the amount of oxygen increases with wind generated waves. Tributaries are an additional contributor of oxygen to lakes. Water temperature, photosynthesis, respiration, decomposition, and lake depth are all determinate variables in the amount of dissolved oxygen that is available in lakes. LDO is measured in both mg/L and % saturation.

Chlorophyll (*a*): Chlorophyll (*a*) is a molecule that is present in all plant cells. The amount of phytoplankton (algae) can be quantified by analyzing the amount of chlorophyll (*a*) in a water sample. Although algae are a very important producer in the food web, elevated nutrient concentrations can cause excessive plant growth resulting in a decline in water quality. Lakes with high concentrations of chlorophyll (*a*) are less transparent and tend to have higher total nitrogen and total phosphorus loading. Chlorophyll (*a*) analysis is measured by fluorescence and is reported in µg/L.

pH: pH is a measure of the acidity and alkalinity of water and is measured by the concentration of hydrogen ions. The greater the concentration of hydrogen ions, the lower the pH, and vice versa. pH is measured on a scale from 0-14, with 0 being the most acidic and 14 being the most basic. A pH of 7 is typical of tap water and considered neutral. The pH also determines the solubility of nutrients and metals in water and the availability of chemicals for aquatic life. A pH between 6.0 and 9.0 is generally suitable for most aquatic life. pH is measured in logarithmic units (a one-tenth difference represents ten times the actual value).

Specific Conductivity (SpC): Conductivity is a measure of the ability of water to pass an electrical current, and it is therefore a good measure of dissolved solids and salinity. Conductivity values can differ seasonally with temperature and are most often impacted by the composition of tributaries which reflect the geology of their watershed. Common anthropogenic influences on conductivity are road salt, non-

point source pollution (agriculture and stormwater run-off), and industrial effluent. Specific conductivity is measured in mS/cm.

Total Dissolved Solids (TDS): Total dissolved solids concentration is the sum of positively charged and negatively charged ions in the water and is measured by the weight of all dissolved solids in the water. TDS can come from both organic and inorganic inputs, and there is a close relationship between TDS and SpC. Total dissolved solids are measured in g/L.

Oxidation-Reduction Potential (ORP): ORP is a composite measure of the overall intensity of the oxidizing and reducing conditions within a system and reflects the degree of balance between oxidizing and reducing processes. The seasonal and diurnal changes between photosynthesis and respiration determines the oxidation-reduction potential of lakes (Kalff 2002). Oxidation reduction potential is measured in mv.

Salinity: Salinity is a measurement of the concentration of salts that are dissolved in a waterbody and is closely related to specific conductivity except that it is reported in ppt as opposed to mS/cm. Salinity is measured in ppt.

Resistivity: Resistivity is the inverse measurement of specific conductivity and is a measurement of how strongly water opposes the flow of electric current. Resistivity is measured in k \hat{e} -cm.

Table 1. Accuracy, Range and Resolution of Measurements Taken with Hydrolab MS5.

Parameter	Range	Accuracy	Resolution
Depth	0 to 100m	± 0.05 meters	0.01 meters
Temperature	-5 to 50° C	± 0.10° C	0.01° C
pH	0 to 14 units	± 0.2 units	0.01 units
LDO	0 to 20 mg/L	± 0.1 mg/L	0.01 mg/L
Conductivity	0 to 100 mS/cm	± 0.5% of reading	4 digits
Salinity	0 to 70 ppt	± 0.2 ppt	0.01 ppt
Chlorophyll (<i>a</i>)	0 to 500 µg/L	± 3% for level equivalents of 1 ppb	0.01 µg/L
ORP	-999 to 999 mV	± 20 mV	1 mV

2.4 Water Chemistry

2.4.1 Historic Methodology

Integrated water chemistry samples were collected using a 30-meter hose. Chlorophyll (*a*) samples were separated by filtering lake water through 45 µg filters. The vacuum on the filter was kept below 9.0 inches of Hg pressure to prevent cell rupture and loss of chlorophyll (*a*) into the filtrate (Wetzel and Likens, 1991). Because of the difficulty involved in cleaning the hose and the potential for spread of AIS, integrated samples are now collected using a horizontal Van Dorn Sampler that can be easily disinfected. Some of the dissolved oxygen and temperature profiles taken prior to 2010 displayed in the charts were collected by volunteers using handheld Yellow Springs Instruments (YSI) probes.

2.4.2 Current Methodology

Water chemistry samples are collected using a horizontal Van Dorn Sampler at the annual summer visit and include total persulfate nitrogen (TPN), total phosphorus (TP), and chlorophyll (*a*). Total calcium (Ca) is collected every five years (it was last collected in 2020). Alkalinity was collected in 2012. Each sample contains integrated water from the surface to the lake bottom. Therefore, the values for each parameter are representative of the lake vertical profile at the deep site.

The Van Dorn sampler is lowered into the water and 500 mL sample water is collected at each depth. An integrated sample is collected at discrete depths based on the maximum depth of the lake as shown in Table 2. If the lake depth is greater than 30 meters, an integrated sample is collected every five meters to a depth of 30 meters. All integrated samples include a surface sample, and benthos samples are collected approximately 1 meter above lake bottom if the lake has a depth of less than 30 meters. Sample water from each depth is composited in a carboy. The carboy is then shaken so that sample water can mix prior to dispensing.

Table 2. Integrated Sample Depth Intervals.

Lake Depth	Interval at Which Water is Collected for Integrated Sample
1-6 meters	1 meter
7-12 meters	2 meter
13-21 meters	3 meter

All sample bottles are high-density polyethylene (HDPE). HDPE bottles are filled with integrated water samples for TP, TPN, and Ca and immediately put on ice. All samples are collected and preserved according to the specifications outlined by the University of Montana Flathead Lake Biological Station (FLBS) Research Laboratory in Polson, Montana. Labels are printed and filled out in pencil prior to collection in the field, applied to the sample bottle in the field, and covered with tape to prevent water damage. All sampling equipment is rinsed with 10% hydrochloric acid prior to use in the field. All sample bottles are rinsed 3 times with native water before the sample is filled. Water samples are put on ice in coolers in the field and shipped via UPS ground service to the FLBS Research Laboratory. Each shipment contains a standard Chain of Custody (COC) form.

Integrated water samples for chlorophyll (*a*) analysis are collected at all monitoring locations at depth intervals based on maximum depth described above. A vertical opaque Van Dorn and a carboy covered with a sleeve are used to eliminate light penetration. The carboy is gently shaken prior to dispensing each sample to assure thorough mixing of the sample. In 2011, the program made a transition from field filtering chlorophyll (*a*) samples to having the FLBS’s Research Laboratory filter the sample water for better quality control and sampling efficiency. Sample water for chlorophyll (*a*) is dispensed into a 1000 ml brown bottle to exclude light. Samples are immediately put on ice and shipped next day to the laboratory.

2.5 Description of Water Chemistry Parameters

Total Phosphorus (TP): Phosphorus is a nutrient that is used by aquatic organisms for growth. Phosphorus occurs naturally depending on the geologic inputs to a lake. Anthropogenic sources of phosphorus include but are not limited to fertilizer, wastewater, and detergents. Excessive phosphorous concentrations in a lake can cause eutrophication leading to rapid and excessive plant growth that may result in oxygen concentration depletion and fish and invertebrate kills. Lakes that are anoxic at or near the bottom may experience internal loading where phosphorus is released from sediments through a chemical process at the sediment/water interface.

Total Persulfate Nitrogen (TPN): Nitrogen is a nutrient that is used by aquatic organisms for growth. Nitrogen occurs naturally in soil, is produced by decaying plant matter and microorganisms and can enter lakes through the atmosphere. Common anthropogenic sources of nitrogen occur in wastewater, fertilizer, manure, agricultural runoff, and erosion. Excessive nitrogen concentrations in a lake can lead to eutrophication and can be harmful or fatal to fish and invertebrates.

Chlorophyll (a): Chlorophyll (*a*) samples measure the concentration of photosynthetic pigments to estimate phytoplankton biomass.

Total Calcium (Ca): Measuring calcium is one of the major components in determining the hardness of water; however, for the purposes of the program, total calcium was measured to understand which lakes may be suitable for invasive mussel colonization.

Alkalinity: Alkalinity is a measurement of water’s capability of neutralizing an acid. Lakes with higher alkalinity are more suitable for invasive mussel colonization.

2.6 Analytical Methods and Reporting

Analytical methods are listed in Table 3 and represent standard accepted procedures. All analytical reporting from 2010-2014 was done by Energy Laboratories. Since 2015, analytical reporting has been completed by the FLBS Research Laboratory because of their ability to report at lower detection limits. For quality control, two duplicate water chemistry samples and three trip blanks were collected each field season. All the sampling methods outlined in the 2011 SAP are used to collect trip blanks; however, each sample container is filled with deionized water instead of sample water. Field duplicate samples are collected at two sites using methods outlined in the SAP and sent to the laboratory with the site locations omitted from the chain of custody form.

Table 3. Laboratory Analytical Methods and Reporting Limits.

Analyte	Method	Analytical Reporting Limit (2010-2012)	Analytical Reporting Limit (2013-2014)	Analytical Reporting Limit (2015-2021)
Total Persulfate Nitrogen	A4500 N-C	0.05 mg/L	0.04 mg/L	.025 mg/L
Total Phosphorus as P	E365.1	0.005 mg/L	0.001 mg/L	0.0015 mg/L
Chlorophyll (<i>a</i>)	A 10200 H	0.1 mg/m ³	0.1 mg/m ³	0.1 mg/m ³
Calcium	E200.7	1 mg/L	1 mg/L	1 mg/L

3.0 AIS MONITORING METHODS

3.1 Zebra and Quagga Mussels

Monitoring for the presence of zebra and quagga mussels is conducted on each lake between the middle of July and the middle of August. Veliger (mussel larvae) samples are collected using a vertical or horizontal haul method. If the depth of the monitoring location exceeds 7 meters, the vertical haul is used. For all locations less than 7 meters deep, the horizontal method is used. All samples are collected after surface water temperature exceeds 10^o C. Veliger samples are collected near public access sites. If the lake is entirely private samples are collected in the littoral zone near private docks. Because veligers are passive swimmers, they generally end up on the windward side of lakes making these locations ideal for horizontal hauls. Both the vertical and horizontal haul samples are collected using a 30 cm X 120 cm X 64-micron plankton net. Once the haul is complete all samples are split, and each is preserved in a 100 mL bottle with 95% ethanol.

Veliger samples contain a label on the outside of the sample bottle. All samples are sent via UPS to MFWP in Helena. Samples that are awaiting shipment are kept refrigerated. All samples are split by MFWP upon arrival, and a duplicate sample is kept in the event reanalysis is necessary. Microscopy is conducted by the lab that is under contract with MFWP with results reported in two weeks. A catalogue

record is kept and maintained for veliger samples and includes the date, waterbody, location, GPS coordinates, tow data, sampler, and sample ID.

Vertical Haul: Nets are slowly lowered to 7 meters. Then the net is slowly pulled up using a hand-over-hand motion. The net is lifted so the cod end is completely out of the water allowing the water to drain. Water is then sprayed on the net so that the sample can collect in the cod end. The net is rinsed by dipping the net into the water and lifting it up and down, allowing any remaining microorganisms on the net to be rinsed into the cod end. A spray bottle is used to clear the net of microorganisms that remain after rinsing. After sample collection, the cod end is removed, and contents are poured into the sample bottle. 95% ethanol and 5 ml of 5% baking soda solution are added to the sample bottle to preserve the sample.

Horizontal Haul: Nets are tossed with a rope to about 10 feet behind the boat and are sunk to .5 - 1 meter below the surface. The net is towed behind the boat at a slow speed for approximately 60 meters. Once the boat is stopped, the net is quickly removed from the water allowing the water to drain and for the sample to collect in the cod end. The net is rinsed by dipping the net into the water and lifting it up and down steadily, allowing any remaining microorganisms on the net to be rinsed into the cod end. A spray bottle is used to clear the net of microorganisms that remain after rinsing. After sample collection, the cod end is removed, and contents are poured into the sample bottle. Ninety-five percent ethanol and 5 ml of 5% baking soda solution are added to the sample bottle to preserve the sample.

3.2 Environmental DNA (eDNA)

Environmental DNA (eDNA) early detection sample collection is a partnership between WLI and the City of Whitefish outside the NMLN core mission, but since it overlaps with some of the program lakes, data can be collected during summer field visits by the program coordinator. Plankton samples are collected for eDNA analysis using FLBS collection protocols. The FLBS lab performs the analysis by looking for DNA sequences of EWM, northern milfoil (native), curly-leaf pondweed and dreissenid mussels. There were no positive detections from 2013-2021, except EWM was detected in Beaver Lake in 2019.

Table 4. Environmental DNA early detection sampling collection.

Year	# Of Lakes Sampled
2013	25
2014	24
2015	21
2016	8
2017	5
2018	7
2019	4
2020	3
2021	3

3.3 Macrophyte Surveys

Another partnership between WLI and the City of Whitefish included aquatic macrophyte surveys. Lakes were chosen based on proximity to Whitefish Lake and included Blanchard, Dollar, Lost Coon, Murray, Skyles, Smith, Spencer, Tally, Upper Stillwater, Lower Stillwater, Whitefish, and Upper Whitefish Lake depending on the year. Lakes were sampled between August 15th and September 14th. The survey consisted of determining the composition and relative abundance of plant species at each lake along with characterizing the lake substrate to determine areas suitable for plant colonization. Sites were randomly chosen to represent full coverage of the lake. Both ocular surveys and rake throws were used to determine plant dominance. The maximum depth of the rake was 6.1 m. Where lake depth exceeded 7.6 m, the rake was not thrown, and a data point was not recorded. All plants observed at each site were recorded and rated on a scale of 1-5 for density. If any substrate was visible, it was recorded in order of dominance.

Each surveyed point is included on a Google Earth map and color coded to match the color in a pie chart for dominant plant distribution. These maps and charts are included in the lakes' results section beginning on page 15. Only the most dominant or highest density plant at each survey point was used to construct the graphics and tables, except in cases where there were two or more plants observed with equally high density. For example, if observed plants at survey point 1 were: Yellow water lily (density 5), northern watermilfoil (density 3), Mare's tail (density 3), and bladderwort (density 1), only yellow water lily is depicted as dominant. There were several plants observed at many of the survey's sites, and the maps and charts do not represent overall distribution.

4.0 EQUIPMENT MAINTENANCE, CALIBRATION & DECONTAMINATION

The Hydrolab MS5 is sent annually prior to the field season to Hydrotech ZS Consulting for performance testing and evaluation. The Hydrolab is calibrated for dissolved oxygen prior to sampling each day it is used. Depth is calibrated in the field at each monitoring site prior to sampling. When the Hydrolab MS5 is not in use, it is stored with its sensors in its calibration cup with a pH buffer solution. If the Hydrolab MS5 is reporting values outside a specific parameters range, it is sent to for a diagnostic and repaired if necessary.

All sample containers and Van Dorn samplers are rinsed with 10% hydrochloric acid prior to sampling each waterbody. Plankton nets are soaked in vinegar for at least 4 hours and then rinsed thoroughly with fresh water. All plankton sampling nets are inspected by WLI staff for rips or tears. The boat used by WLI staff in sample collection is decontaminated following every sampling event or prior to sampling in another water body. Additionally, volunteers are trained in decontamination protocols and are instructed to clean all equipment that has been in the water.

5.0 RESULTS

Lakes have been organized into small, medium, and large for interpretation and comparability. The website, nmln.info, includes links to all 41 lakes, 50 sites. Each lake link includes a general lake description, a lake map or satellite photo, temperature and dissolved oxygen depth profile charts, a Trophic State Index (TSI) chart, information on fisheries, the current volunteer monitor, a chart with information on nutrient trends and AIS infestations and risk level. There is also a link to water chemistry concentrations comparisons for each lake size class for the last 6 years. Fish distribution records, lake size, and lake elevation data were taken from MFWP's *Montana Fisheries Information System (MFISH)*. Most geologic information was taken from *Trophic Status and Trends in Water Quality for Volunteer Monitoring Program Lakes in Northwestern Montana (Ellis and Craft, 2008)*.

5.1 Volunteers

Secchi Disc

All of the volunteer data collected has been compiled and stored in the program database and can be queried for specific data requests. Secchi data from volunteers and the annual program coordinator's visit is also submitted to NALMS's annual Secchi Dip-In project. Results from the contract with SUNY Oneida mentioned in *Section 1.1 2021 Program Updates* analyzing volunteer Secchi and temperature data trends will be made available in the fall of 2022.

Observations

In 2013, many volunteers began reporting increased wake erosion and more recreational use from wake-board style boats, many of which contain ballast tanks. Volunteers are instructed to take photos to document shoreline erosion. One of the most common observations from volunteers in 2011-2013 was that lake elevations were above average for most lakes throughout the monitoring season. Spring 2011

(April 1 - June 20) ranked 11th highest in recorded history for total precipitation in Kalispell with 6.64 inches. The highest recorded spring precipitation was in 1998 with 8.28 inches. Additionally, Kalispell had the second lowest spring temperatures in 2011 averaging 47.0 °F, only one-tenth of a degree warmer than the historical low average of 46.9 °F. Many volunteers reported less emergent aquatic vegetation than historically observed, likely a result of the colder temperatures and limited sunlight during the spring months. In 2014 and 2015, volunteers observed warmer than normal summer water temperatures with reports of more algae than usual. The summer of 2017 & 2018 included regional forest fires and a flash drought in northwest Montana. 2019, 2020, & 2021 brought lower than average lake levels for most lakes sampled and thus a higher incidence of increased algal blooms reported, especially early season.

5.2 Trophic Classification

All the lakes in the program are classified as oligotrophic, oligo-mesotrophic, meso-oligotrophic or mesotrophic except for Jette Lake, which is classified as eutrophic with historical data suggesting it is borderline hypereutrophic.

Nutrient richness is the basis for the trophic classification of lakes. Oligotrophic lakes tend to be very clear, nutrient poor and typically cold. There is less zooplankton, phytoplankton, algae, and macrophytes, and fish tend to be smaller because of limited food availability. Because there are fewer plants and algae, dissolved oxygen concentrations tend to be higher throughout the water column. Oligotrophic substrate composition usually consists of rocks and gravel and lacks significant accumulation of sediment.

Eutrophic lakes are the contrast to oligotrophic lakes. They are rich in plant nutrients resulting in high productivity. Large amounts of phytoplankton suspended in the water column give the water a cloudy appearance, and Secchi disk depths tend to be much shallower. Eutrophic lakes also tend to have prolific macrophytes growing in the littoral zone. Eutrophic lakes have a thick sediment layer at the bottom which is nutrient rich and provides food for invertebrates contributing to a high production of fish generally with fast growth rates. Mesotrophic lakes fall between oligotrophic and eutrophic and should be monitored closely to determine if they are trending toward eutrophic.

Table 5: General Trophic Classification of Lakes (Wetzel 2001).

Trophic classification	TP mean (range)	TN mean (range)	Secchi mean (range)
Oligotrophic	.008 (.003-.0177)	.661 (.307-1.630)	9.9 (5.4-28.3)
Mesotrophic	.0267 (.0109-.0956)	.753 (.361-1.387)	4.2 (1.5-8.1)
Eutrophic	.0844 (.016-.386)	1.875 (.393-6.100)	2.45 (0.8-7.0)
Hypereutrophic	(.750-1.200)		(0.4-0.5)

5.3 Carlson's Trophic State Index (TSI)

The Carlson's Trophic State Index (TSI) is used in the report to classify the trophic status of each lake. Carlson's TSI uses chlorophyll (*a*), total phosphorus and Secchi depth to determine trophic state. A formula for total nitrogen was later developed and is also used in this report. The TSI is calculated by the formula below. Refer to Table 5 for information on how "No Detect" samples were calculated.

TSI Calculations:

$$\text{TSI}(\text{SD}) = 60 - 14.41 \ln(\text{SD})$$

$$\text{TSI}(\text{CHL}) = 9.81 \ln(\text{CHL}) + 30.6$$

$$\text{TSI}(\text{TP}) = 14.42 \ln(\text{TP}) + 4.15$$

$$\text{TSI}(\text{TN}) = 54.45 + 14.43 \ln(\text{TN})$$

5.4 Aquatic Invasive Species

5.4.1 Zebra and Quagga Mussels

Veliger samples and duplicates from plankton tows were collected at program lakes 2011-2021 and sent to MFWP for microscopy analysis. Select lakes from non-program partnerships also had eDNA samples taken and sent to the University of Montana laboratory. Most program lakes fall within the tolerance threshold for invasive mussel habitation if calcium is analyzed independently. All but six lakes had calcium concentrations that exceeded 20 mg/L. Although there is much variability in calcium concentrations between program lakes, it is evident that the overall risk-based habitat suitability is high. Determining lakes that are most suitable for zebra/quagga mussels will be especially important in making management decisions unique to each lake, especially if an infestation occurs. Alkalinity concentrations for all program lakes meet the minimum requirement of 18 mg/L for zebra/quagga mussel habitation.

5.4.2 Eurasian Watermilfoil

Eurasian watermilfoil (EWM) is a non-native perennial plant that roots to the bottom of water bodies and can grow in water up to 7.5 meters deep in favorable conditions. It forms dense mats at the water's surface shading out native plants and can clog boat motor propellers, decreasing recreational quality. EWM can spread rapidly because it reproduces through stem fragmentation. Pieces the size of postage stamps that have broken off the main stem can reproduce. EWM is most commonly spread overland by boats that have not been cleaned after use in an infested water body.

Montana first discovered EWM in Noxon reservoir in 2007. In 2010, EWM was discovered at Tosten Reservoir, Fort Peck Reservoir, the Jefferson River, and the upper and lower Missouri Rivers. EWM was discovered at Beaver Lake in October of 2011. The isolated patch was estimated to be about 50 square feet in size. A thorough survey of Beaver Lake's littoral zone was conducted in late October of 2011, and no other isolated patches were found. The Flathead County Weed District hired a diver to evaluate the extent of the infestation. After discovering that the patch was too large to remove by hand pulling, several bottom barriers were placed over the infestation to prevent it from receiving sunlight and to help minimize the spread through fragmentation. In 2012, a suction dredge was used to eradicate the majority of the EWM infestation. Additional dredging and surveying in 2013 revealed isolated patches of EWM. A total of 6 lbs. of EWM were removed by Hanson Environmental in 2013. Management of EWM at Beaver Lake became an important component of the Whitefish Lake AIS Management Program – a partnership between WLI and the City of Whitefish. In the summers of 2014 and 2015, Hanson Environmental removed roughly 1 lb. of EWM; in 2017, two plants were removed, and no plants were found in 2018. New EWM plants were discovered in 2019 and were promptly removed. Bottom barriers were again placed over the suction dredged areas to block out sunlight for any remaining plants. A follow up survey, suction dredging, and hand pulling were conducted by the partners in 2020. Because of the real

threat to Whitefish Lake and the watershed, suction dredging will continue indefinitely until there is confidence that EWM has been eradicated.

After EWM was discovered in Beaver Lake, a joint effort between the Flathead County Weed District, MT Department of Agriculture, WLI, the Flathead Basin Commission and Hanson Environmental was made to survey boat ramps at lakes near Beaver Lake. No other infestations were identified. However, these surveys were conducted late in the season, after plants had already started to desiccate. In 2012 and 2013, twenty-four lakes were surveyed for EWM. No infestations were found. In 2013, plankton samples were collected on 25 lakes for eDNA analysis. In 2014, 35 plankton samples from 24 lakes were collected for eDNA analysis. In 2015, 30 plankton samples were collected from 21 lakes for eDNA analysis. In 2016, 13 plankton samples were collected from 8 lakes. In 2017, 28 plankton samples were collected from 6 lakes. In 2018, 25 samples were taken from 7 lakes. In 2019, 34 samples were taken from 5 lakes. Tally, Whitefish, and Blanchard did not test positive for EWM, but one sample collected from Beaver Lake in 2019 did detect Eurasian watermilfoil. This sampling site is near the known infestation of Eurasian milfoil where there have recently been plant removal efforts, so our results are not unexpected.

In 2020 with funding from the City of Whitefish and Flathead National Forest's Resource Advisory Committee (RAC) WLI collected environmental DNA (eDNA) from seven lakes for non-native Eurasian watermilfoil (*Myriophyllum spicatum*) and aquatic invasive zebra and quagga mussels (*Dreissena polymorpha* and *Dreissena rostriformis*). Eurasian watermilfoil and invasive mussels were not detected in any samples collected from Whitefish, Tally, Blanchard, Ashley, Hungry Horse, Beaver or Upper Stillwater waterbodies. Hungry Horse Reservoir, Ashley Lake, Upper Stillwater Lake and Tally Lake were also analyzed for curlyleaf pondweed (*Potamogeton crispus*) and showed no detection.

6.0 DISCUSSION

6.1 Study Results

Seasonal and annual variability are essential factors in determining trends and are the reason it is important for volunteers to provide information on atmospheric weather conditions and qualitative data. Some of the lakes in the program have more than twenty years of historical data while others only have a handful of years. Weather plays an important role in the variability of data collected. As mentioned before, 2011 - 2013 were colder and wetter than average. In 2014 - 2016, many program lakes were much warmer than they were historically. In 2017 and 2018 we had hot, dry summers with a lot of forest fires that could affect lake evaporative rates, temperature, clarity, and nutrient levels. It will be important to continue to maintain consistency in data collection in the future so that trends become apparent in lieu of annual variation.

Nutrient concentrations are generally variable based on lake size. Nutrient concentrations in lakes are influenced by the surrounding landscape; and lakes that drain agricultural areas may be likely to have higher nutrient concentrations than those that drain forested areas. Nutrient concentrations can also be driven by lake depth and morphology. Shallower lakes tend to have higher nutrient concentrations because they are more biologically productive. Because many of the smaller program lakes likely mix and stratify several times throughout the summer (polymictic), they can exhibit higher nutrient concentrations than larger lakes that mix and stratify twice per year (dimictic). Although trophic classification is determined by specific nutrient concentrations, lake size is an important factor in determining the speed at which eutrophication can occur.

Summer profiles have indicated Beaver, Bootjack, Foy, Murray, Lake Blaine, and Jette were found to be anoxic at some depth. Eutrophic lakes that are covered in ice and snow with large quantities of decaying organic matter can exhibit substantial dissolved oxygen losses in the winter. When the organic matter supply for decomposition is large relative to the mass of dissolved oxygen available, there may be fish

and macroinvertebrate kills (Kalff, 2002). In the winter of 2011/2012, Jette Lake had a winter fish kill due to dissolved oxygen depletion.

Lakes with hypoxic hypolimnia tend to be less than 10 m in depth, have high external phosphorus loading, and high algal biomass. Tally Lake is an exception and likely experiences hypoxia because of many complex processes including chemical oxidation of allochthonous humic matter in addition to the high wind energy required to mix this deep lake (Koopal, 2015 pers. comm.).

Program lakes are highly variable in terms of calcium concentration with a range from a low of 4 mg/L to 62 mg/L. Dreissenid mussels need calcium for shell development; however, calcium concentration is not the only relevant factor in determining whether a specific water body is suitable for mussel habitation. The calcium threshold is an indication for the potential of zebra or quagga mussel suitability among program lakes. Literature suggests the calcium threshold for Zebra mussel establishment can be <20 mg/L, however evidence suggests that long term survival, and establishment of zebra mussel colonies requires >28 mg/L, and 12-15 mg/L is the minimum concentration necessary for long term reproduction and growth (Cohen & Weinstein, 2008). This report classified waters with calcium < 20 mg/L as low risk for infestation, calcium 20 mg/L – 28 mg/L as moderate risk for infestation, and calcium >28 mg/L as high risk for zebra mussel infestation (Whittier *et al.*, 2008). Of the 53 monitoring sites that were sampled, 26 ranked as high risk, 20 ranked as moderate risk, and 7 ranked as low risk for calcium-based risk assessment.

Alkalinity, pH, dissolved oxygen, and conductivity are other variables that determine suitability for long term survival of zebra/quagga mussels. Literature suggests that pH values below 7.3 are too acidic to support long term survival of zebra mussels, and levels between 7.4 and 9.4 are within the range for growth with 8.4 as ideal (Benson *et al.*, 2017). Zebra mussels spawn between 12-18° C which is also the ideal temperature for larval development.

6.2 Study Limitations/Challenges

Through the years of the program, there have been challenges and unique situations that have occurred.

2011: The greatest challenge was the inability to begin the field season data collection on schedule because the Hydrolab MS5 that was expected to be used for the field season didn't arrive until October, and WLI's Hydrolab DS5 wasn't always available when needed. WLI's DS5 also needed to be shipped to Hach Environmental several times for repairs. However, Hydrolab profiles were taken on every lake at least once and were taken twice on 24 of the 42 lakes. The program now has the Hydrolab MS5 (and has back use of WLI's DS5).

2012: No summer Hydrolab profiles were taken on any of the Flathead Lake sites due to equipment maintenance issues.

2013: No fall Hydrolab profiles were collected on Flathead Lake, and water chemistry samples were not collected at three of the Flathead Lake sites. Fall Hydrolab profiles were collected at all eight Flathead Lake monitoring sites.

2014: Unseasonably cold weather caused many of the program lakes to freeze in early November. Because of this, fall Hydrolab profiles were not collected on some of the lakes.

2015: Hydrolab equipment repairs and fires prevented summer sampling on some of the program lakes.

2018: The transition from the NCSS software suite to using the open-source computer language R has benefits in preparation of figures and databases and ensures quality control and assurance, but as with any conversion of database platforms, it created some graphic inconsistencies.

2019: During the sampling season, the Hydrolab MS5 began reading unusually high dissolved oxygen numbers, so it was sent in for evaluation. WLI's Hydrolab DS5 was used for the remainder of the season. We reconciled changes in the report's graphic output and style. We also created a mini-report template for existing Lake Association groups to distribute lake specific findings in a more manageable format.

2020: Due to a large-scale blowdown, Smith Lake, north of Whitefish, was inaccessible for sampling in 2020.

2021: High winds on Flathead Lake may have affected Secchi readings for Somers, Conrad Point, Mackinaw Alley, Skidoo and Indian Bay. Lake temperatures were higher for most lakes in 2021 than in 2020, and many volunteers reported higher amounts of algae earlier in the season than ever before.

General limitations: Water chemistry samples are only collected once each year at one site and Hydrolab profiles are only collected once each year at each lake limiting the spatial and temporal data. In addition, each lake is affected by seasonal variability. Data are intended to provide an inter-annual snapshot of summer conditions, hence the importance for consistency in sampling between mid-July and mid-August. The Carlson TSI also only includes one data point for each year except for Secchi depth, wherein all depths collected for the year are averaged then calculated in the TSI equation.

7.0 RECOMMENDATIONS

We recommend more intensive sampling on lakes with unique biological and chemical characteristics, those with native focal fish species, or lakes that have direct surface connection to those waters. Examples include Upper and Lower Stillwater, Upper Whitefish, Smith, Tally, Beaver, Swan, Lindbergh, Holland, Foy's Lake, and Flathead.

Given the increasing pressures on Montana's lakes from AIS, climate change, and increased human development, the need to gather consistent, accurate information on conditions from Montana's lakes has never been greater. Lake volunteer water quality and AIS monitoring programs such as this one are important models for other regions and lake associations. In 2019 WLI initiated a program with funds from the Bureau of Reclamation and distributed through the Upper Columbia Conservation Commission (UC3) that identifies gaps in geographical coverage of lakes in the Upper Columbia River region and engages additional volunteer groups and citizens in long-term stewardship of basin lakes and reservoirs. This program trains Upper Columbia stakeholders in plankton tow net sampling techniques, visual identification of aquatic invasive plant species, and collecting water quality measurements. It also provides those stakeholders with the necessary monitoring and decontamination equipment as well as an outreach messaging consistent with FWP's Clean, Drain, Dry campaign. A large part of this project is to enhance coordination and support among existing monitoring partners within the Upper Columbia Basin as well as supporting and outfitting new monitoring efforts. Incorporating additional partner groups adds to the volunteer base in the region and allows more lakes to be monitored that are a high priority but are not currently sampled. WLI created a new website highlighting all participating partner groups, sampling and decontamination protocols, and background resources for volunteers (ucln.net).

The NMLN program relies on volunteers and project partners for long term success. Continued support is essential for the monitoring efforts to provide scientific data, education and outreach, and AIS early detection monitoring for the currently monitored forty-one lakes in northwest Montana. This information will help citizens and resource managers navigate the complex resource management decision making process.

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9.0 MAP SOURCES CITED

Abbot: *Google Maps*
Ashley: *MFWP*
Bailey: *Google Maps*
Beaver: *MFWP*
Big Therriault: *MFWP*
Blaine: *MFWP*
Blanchard: *MFWP*
Bootjack: *MFWP*
Dickey: *Mark Reller; Constellation Services*
Dollar: *MFWP*
Echo: *Mark Reller; Constellation Services*
Fish: *Google Maps*
Five: *MFWP*
Flathead: *Mark Reller; Constellation Services*
Foy: *MFWP*
Glen: *MFWP*
Halfmoon: *MFWP*
Hanson-Doyle: *Google Maps*
Holland: *Mark Reller; Constellation Services*
Jette: *Google Maps*
Lake of the Woods: *MFWP*
Lindbergh: *Mark Reller; Constellation Services*
Little Bitterroot: *Mark Reller; Constellation Services*
Loon: *MFWP*
Lost Coon: *Google Maps*
Lower Stillwater: *Mark Reller; Constellation Services*
Mary Ronan: *Mark Reller; Constellation Services*
McGilvray: *Google Maps*
Murphy: *Mark Reller; Constellation Services*
Murray: *MFWP*
Peterson: *Google Maps*
Rogers: *MFWP*
Skyles: *MFWP*
Sophie: *Mark Reller; Constellation Services*
Spencer: *MFWP*
Swan: *Mark Reller; Constellation Services*
Tally: *Mark Reller; Constellation Services*
Tetrault: *Google Maps*
Upper Stillwater: *Mark Reller; Constellation Services*
Upper Whitefish: *MFWP*
Whitefish: *Mark Reller; Constellation Services*

10.0 LIST OF ACRONYMS

AIS:	Aquatic Invasive Species
Chl (a):	Chlorophyll (<i>a</i>)
COC:	Chain of Custody
DEQ:	Department of Environmental Quality
DS5:	Data Sonde 5
eDNA:	Environmental Deoxyribonucleic Acid
EPA:	Environmental Protection Agency
EWM:	Eurasian Watermilfoil
FBC:	Flathead Basin Commission
FLBS:	Flathead Lake Biological Station
GPS:	Global Positioning System
HDPE:	High Density Polyethylene
LDO:	Luminescent Dissolved Oxygen
MDA:	Montana Department of Agriculture
MFWP:	Montana Fish, Wildlife and Parks
MS5:	Mini Sonde 5
NMLN:	Northwest Montana Lakes Network
ORP:	Oxidation Reduction Potential
pH:	Parts Hydrogen
SAP:	Sampling and Analysis Plan
SpC:	Specific Conductivity
TDS:	Total Dissolved Solids
TP:	Total Phosphorus
TPN:	Total Persulfate Nitrogen
TSI:	Trophic State Index
VLMP:	Volunteer Lakes Monitoring Program
WLI:	Whitefish Lake Institute