



"Advancing the Science of Lake Management"

P.O. Box 118
Centralia, WA 98531
Tel: 360-330-0152
Fax: 360-330-0174

Devils Lake 2019 Aquatic Plants Survey Report And Biobase Mapping

Prepared by AquaTechnex, LLC.



Introduction

AquaTechnex was contracted Devils Lake Water Improvement District (DLWID) to provide Biobase Mapping and aquatic plant survey services at Devils Lake. Our mapping and survey efforts in 2019 focused on updating Devils Lake's bathymetric data and aquatic plant identification and presence.

2019 Aquatic Plant Survey

Prior to conducting the aquatic plant identification and presence survey it was known and clarified aquatic plants at the time of survey may have senesced beyond identification or have completely decomposed for the season. However, the importance of finding and identifying any invasive aquatic plants warranted a preliminary inspection of the lake. Upon review of littoral zone of the lake we concluded most of the lake bottom was barren

of aquatic plants. Thus, completing transects and rake tosses would not provide requested aquatic plant data and would require visually searching for remaining plants.

While completing the first pass around the lake plant findings were noted and recorded with a Trimble GPS. A data dictionary with aquatic plant names as features was used to record plant species. Noted plant species included American waterweed (*Elodea canadensis*), Naiad (*Najas spp.*), Water celery (*Valasenaria americana*), Yellow cow lily (*Nuphar spp.*), Water starwort (*Callitriche spp.*), and Parrotfeather (*Myriophyllum aquaticum*). The map following this report on page 4 provides location/distribution of plants around Devils Lake.



All current noted plants are native, except parrotfeather (Image: left). This plant species is listed in the State of Oregon as a Class B invasive noxious weed. Special attention was given to locating all locations still present around the lake. Many fragments of the plant were seen during the inspection. Fragmentation/vegetatively is parrotfeather's mode of reproduction. Wind and current driven fragments spread this plant to new locations. Current population in the lake is low. However, the spread to new locations is quick and expansion will likely double or greater in one year.

Biobase Mapping of Devils Lake

BioBase is a cloud-based platform that automates processing and map creation of spatial data. BioBase processes sonar log files to create detailed bathymetric, submerged aquatic vegetation, and bottom hardness maps. AquaTechnex utilized this technology to generate the following bathymetric, Submerged aquatic vegetation and bottom hardness maps on pages 6 – 10. The Devils Lake Biobase survey report is found at the end of this report or at the following link, <https://noxreportprod.s3.amazonaws.com/48123221-3fc8-47dd-9479-a21ba7242c85/Report.html>.

Submerged Aquatic Plant Map

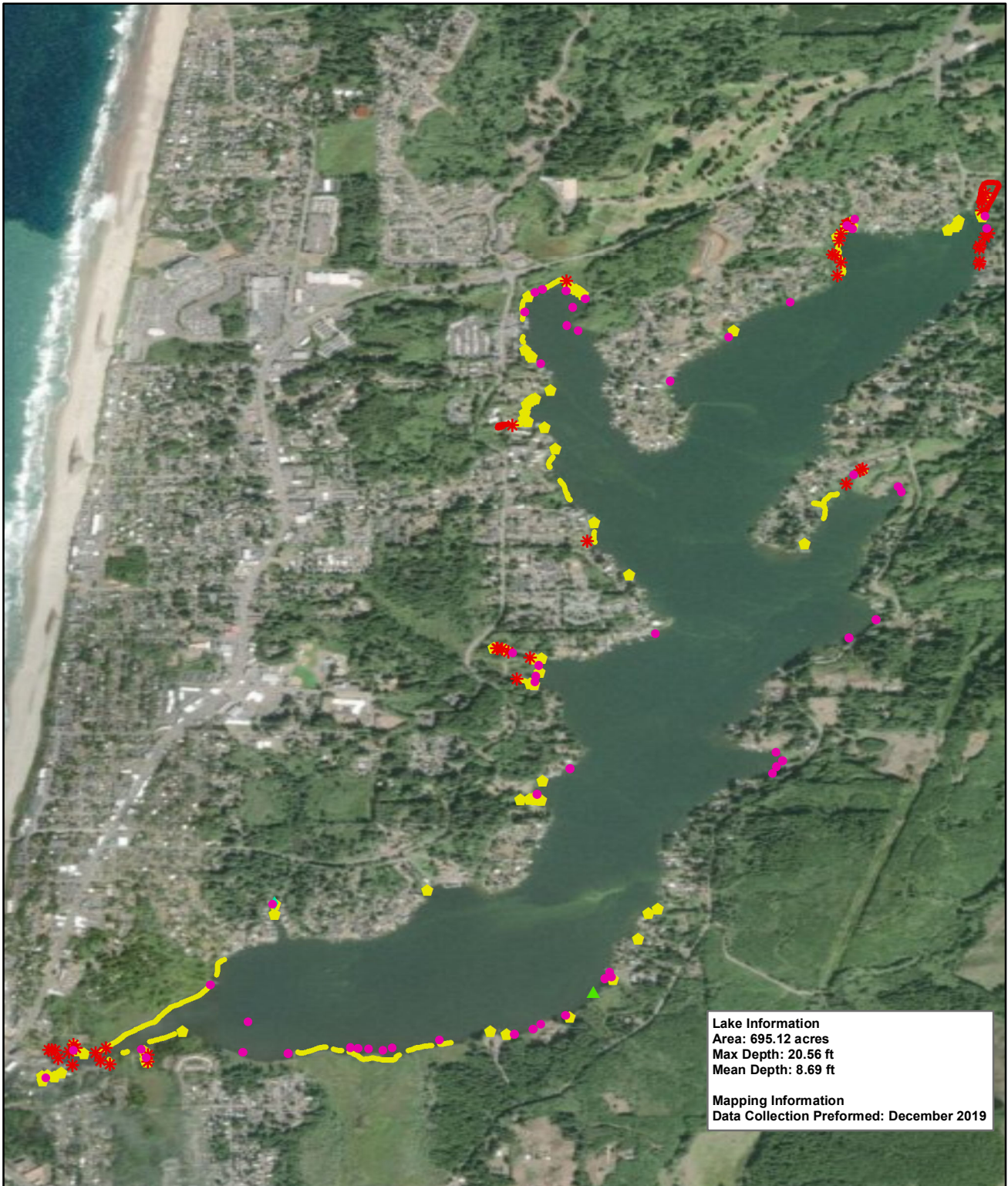
From the biobase report plant data is represented by Veg Avg BV (Average biovolume of the vegetation) and Veg PAC (Percent of the bottom that has plants growing). Biovolume is the amount of the water column (in percent) that is occupied by plants. Sometimes this is described as “how tall the plants are” and is generally a fair description. In the map below, the color scale denotes percentages with red indicating a higher percentage of the water column filled with plants and blue/green indicating very little or no plants at all. During this time of year few submerged aquatic species remain as represented in map below almost entirely blue. See page 5.

Biobase Contour Maps

Two contour maps are provided below. One with blue color shading to depict associated zones of depth and the second with respected depth contours. Devils Lake has an area of 695 acres and volume of 6,042 acre-ft. See pages 6 and 5.

Biobase Composition Map

The composition map provides data on Devils Lake's bottom hardness. The bulk of the lake bottom is depicted soft. Devils Lake near shore areas are shallow and in many areas are wide. AquaTechnex staff frequently had to use oars to free vessels from muck or off wood debris in shallow zones of the lake. During the survey we found near shore areas were mainly soft sediments and organic muck with minimal area being gravel to solid. See page 8.



Lake Information
 Area: 695.12 acres
 Max Depth: 20.56 ft
 Mean Depth: 8.69 ft

Mapping Information
 Data Collection Performed: December 2019

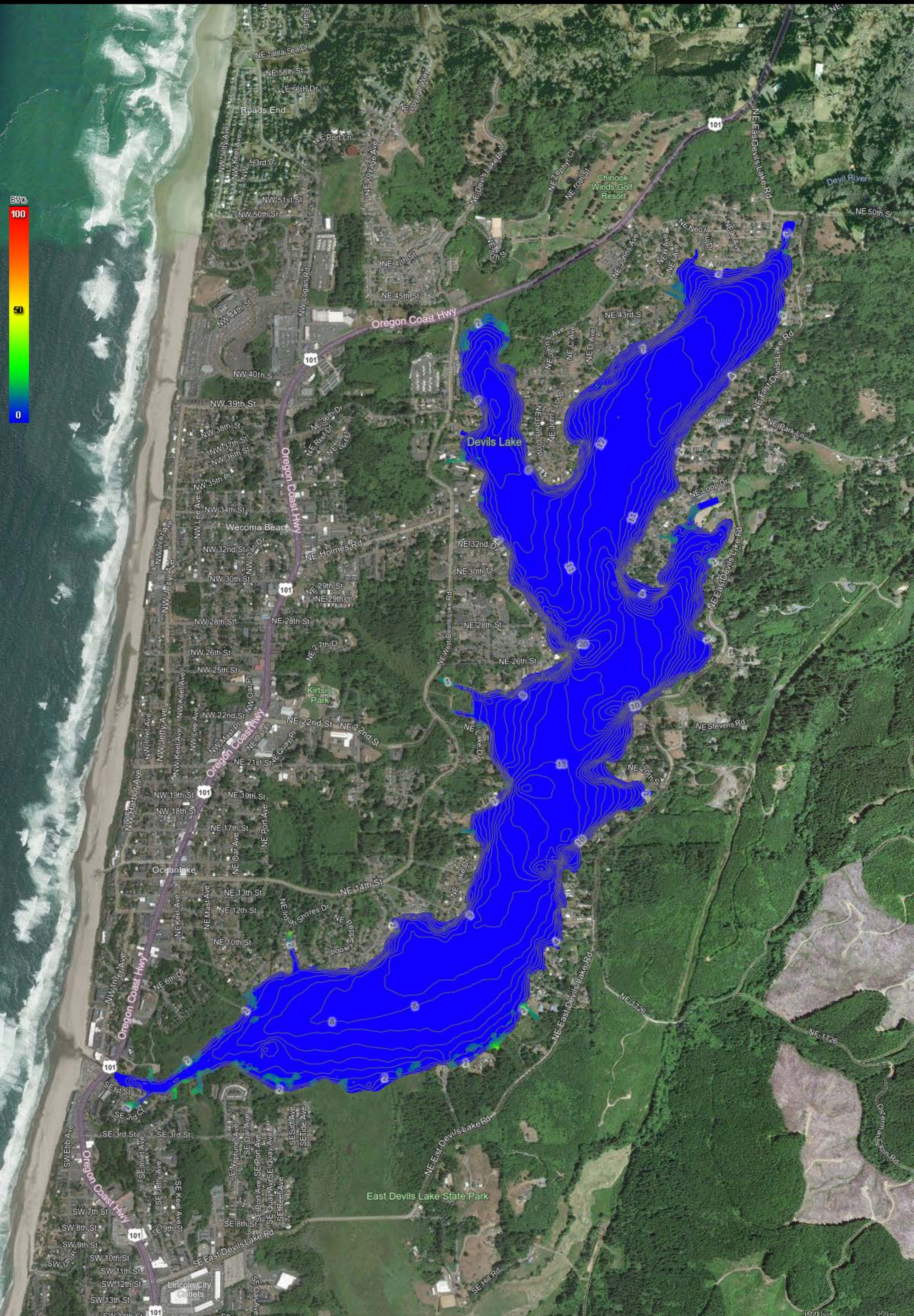
Devils Lake
 Lincoln County, Oregon
 December, 2019

Legend

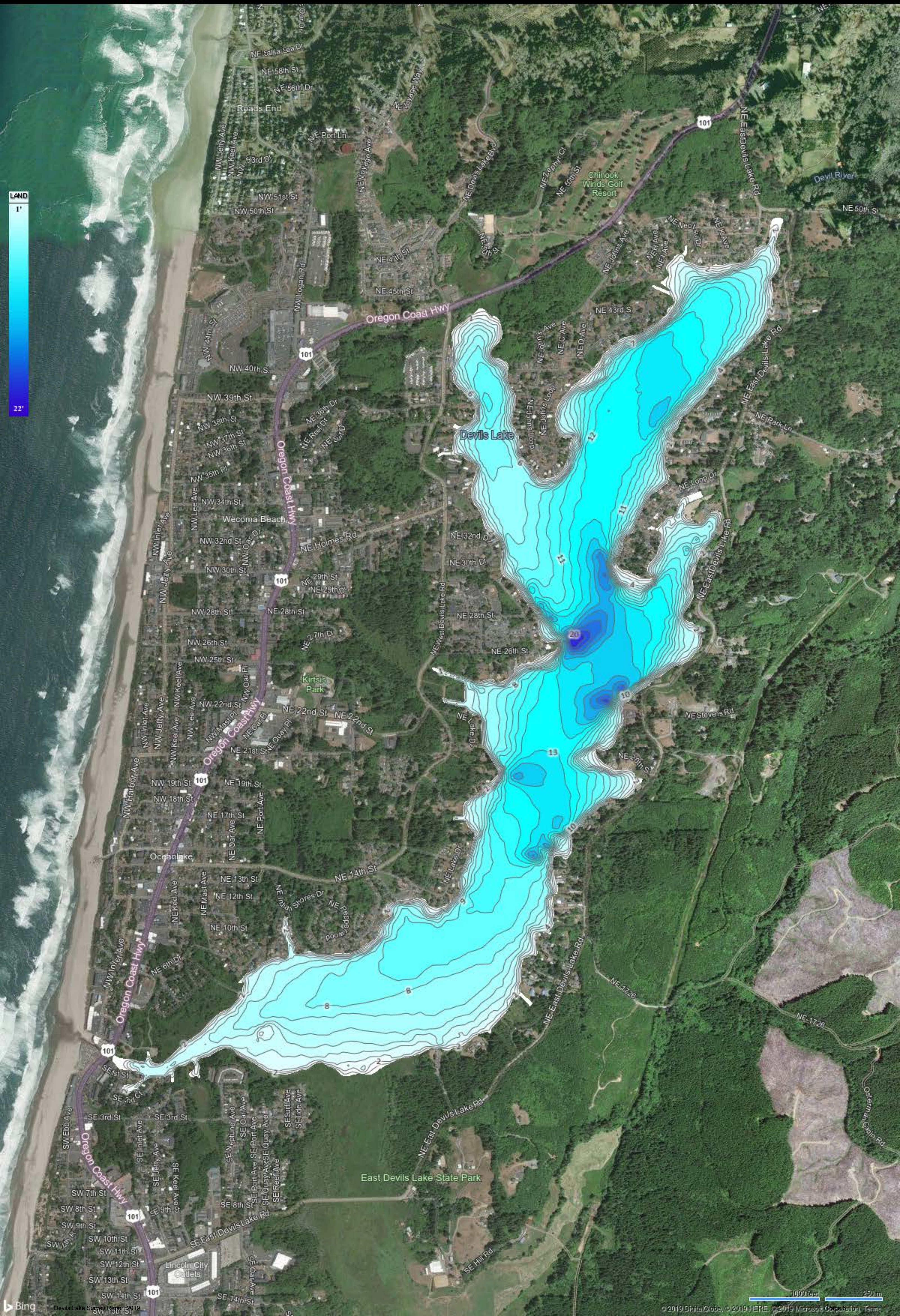
- | | |
|--------------------------|--------------------------|
| ● Najas/Callitriche spp. | * Myriophyllum aquaticum |
| ◆ Vallisneria americana | — Nuphar spp. |
| ▲ Elodea canadensis | ◆ Nuphar spp. |
| — Myriophyllum aquaticum | |

AquaTechnex, LLC
 Washington Office
 Centralia, Washington
 360-249-0192
 www.aquatechnex.com

0 550 1,100 2,200 3,300 4,400
 Feet



1000 feet 250 m



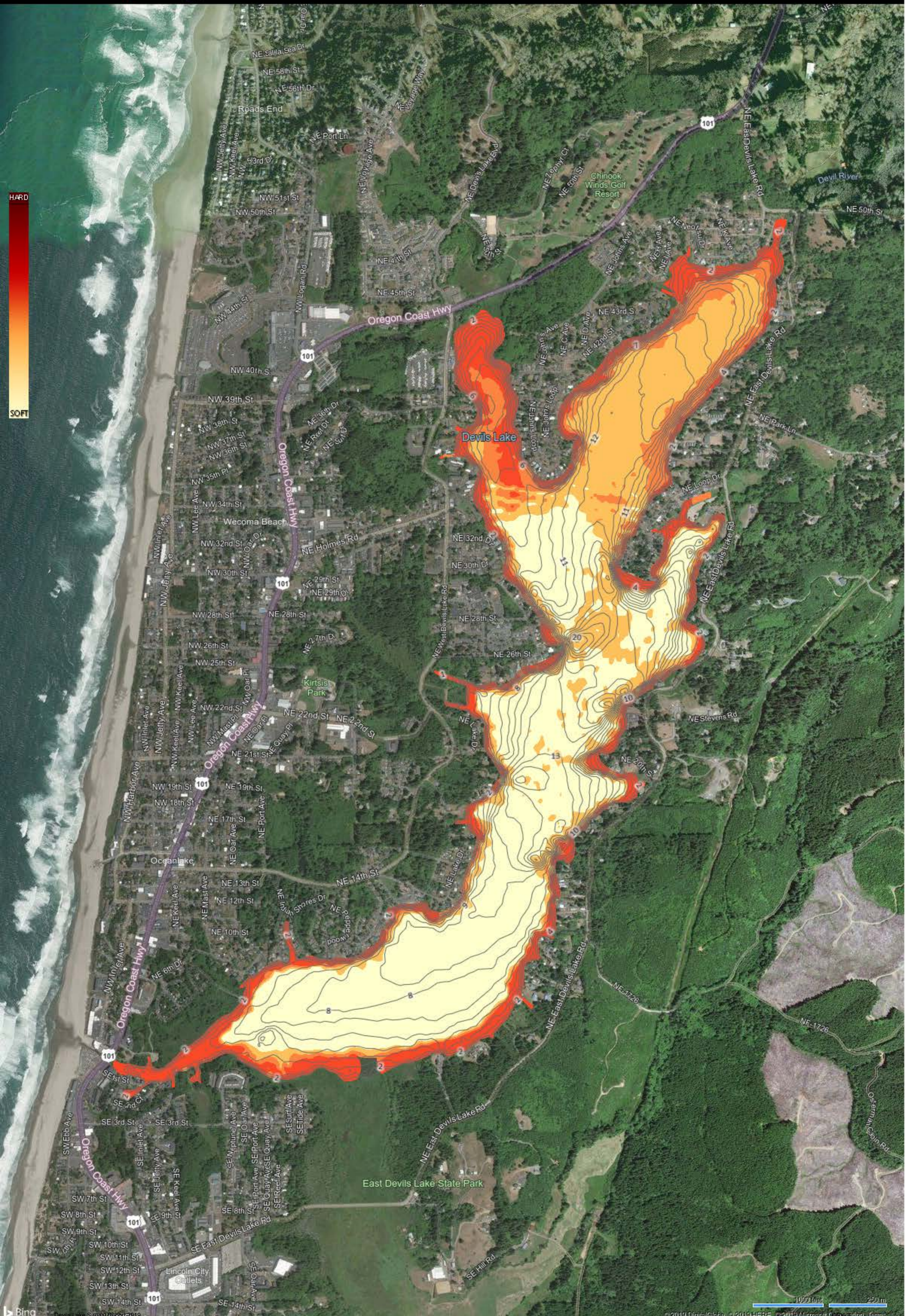
LAND
1'
22'

Devils Lake

East Devils Lake State Park

1000 feet 250 m





Devils Lake, Lincoln Oregon

Generated: 12/11/2019 9:01:25 PM (UTC)

Waterbody Size: 695.12 acres



Data Collector

Kyle Langan

Data Collection Date

12/3/2019 7:48:20 PM (UTC)

Average Water Temperature

45.71° F

Location

Start: 44.96718288,
-124.01456611
End: 44.99650351,
-123.98550700

Survey Size

Area: 694.45 acres
Percent: 99.90% of
waterbody
Volume: 6036.72 acre ft

Est. Waterbody Volume

7453433.86 cu. m
(6042.60 acre ft)

Settings

Track Buffer: 80 m
Grid Cell Size: 16.0 m
Min. BV Detect: 5%
Min. Veg Depth: 0.73 m
Detect: m

Offset Information

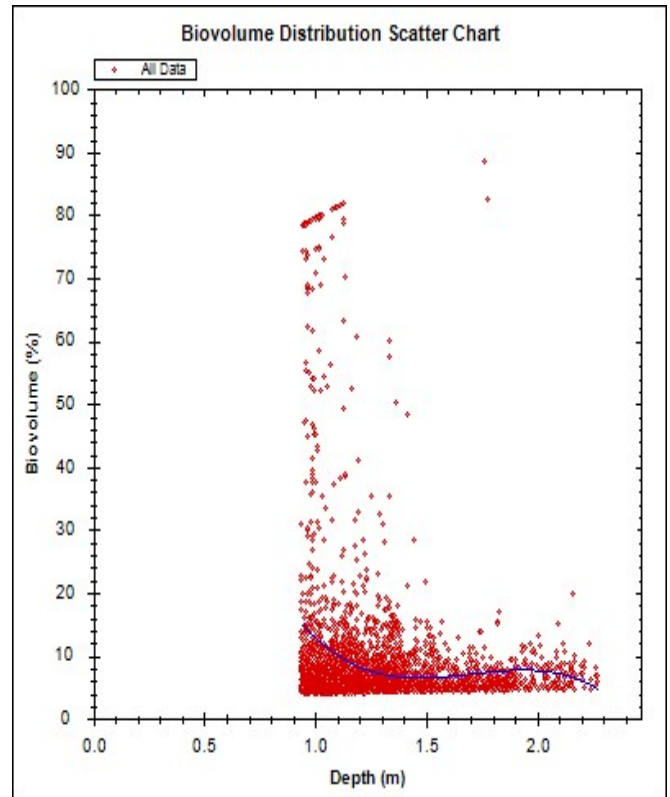
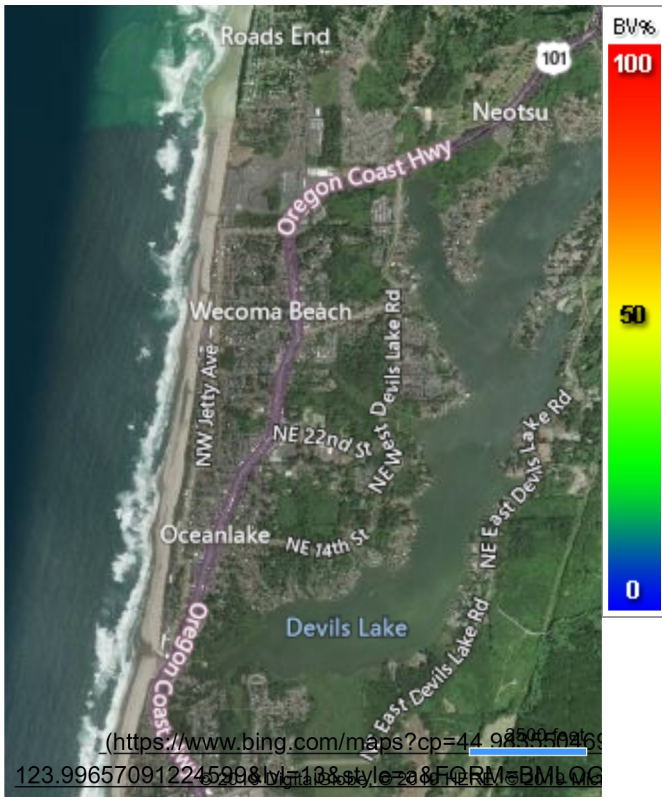
See Below

Survey Summary

	Type	PAC	Avg BVp	SD BVp	Avg BVw	SD BVw	Depth Range	Avg Depth	Distance	No. Points
Full Survey	Point	7.2%	10.6%	±12.0%	0.8%	±4.2%	1.93 - 21.19 ft	7.00 ft	60.34 miles	34591
	Grid	2.2%	8.2%	±4.7%	0.2%	±1.4%	0.19 - 20.56 ft	8.69 ft	-	487

Vegetation Biovolume Heat Map

Biovolume Distribution Scatter Chart



Manual Vegetation Coordinates

Latitude	Longitude	Biovolume %
44.9660792173059	-124.015022836453	
44.9661095809891	-124.01480842528	
44.966276580959	-124.014518970196	
44.9663069445377	-124.014358161816	
44.9665194891384	-124.014122309525	
44.9664435804428	-124.014079427291	
44.9661741037624	-124.014604734665	
44.966606784014	-124.013934699749	
44.9665612388781	-124.013934699749	
44.9666778711313	-124.013677524294	
44.9666399169008	-124.013795450439	
44.9667765520128	-124.01354887759	
44.9669207776113	-124.013479193959	
44.9670004810759	-124.013355907534	
44.9668980051725	-124.013302304741	
44.9667765520128	-124.013350547255	
44.966655098596	-124.013302304741	
44.9667006436575	-124.013136136081	
44.9668145061528	-124.013109334685	
44.9669435500411	-124.013136136081	
44.9670498212604	-124.013045011333	
44.9669928902745	-124.012932445467	
44.9669018005796	-124.012852041277	
44.9668638464973	-124.012712674014	
44.9669777086688	-124.012691232897	
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44.9672320000356	-124.012701953455	
44.9672168184931	-124.012605468427	
44.9671333199375	-124.012535784796	
44.9670687982432	-124.012460740885	
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44.9672244092648	-124.01234628862	
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44.9674255643502	-124.012276604988	
44.9674179736051	-124.012174759681	
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44.967250976958	-124.01201931158	
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44.9675470161357	-124.011971069066	
44.967668467664	-124.011981789625	

44.9677216026268	-124.011820981245
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44.9674976763788	-124.01161729063
44.9674065874855	-124.011569048116
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44.9673791960851	-124.011253165686
44.9675575784507	-124.011247805407
44.967709392793	-124.011349650714
44.9678460253575	-124.011478297418
44.967971271589	-124.011537260491
44.9680319969362	-124.011403253508
44.967971271589	-124.011231724569
44.9678308439775	-124.011156680658
44.9677131881464	-124.011070916189
44.9675651691774	-124.010990511999
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44.9677397556132	-124.01073857887
44.9678915694733	-124.010851144736
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44.9682597164155	-124.010883306412
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44.9676637349817	-124.010320419009
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44.9681761058283	-124.010250735378
44.9682861700796	-124.010347220406
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44.9686391333231	-124.010282897054
44.9685480462424	-124.01047586711
44.9685670227295	-124.010159610629
44.9679711580389	-124.009773670517
44.9679294093253	-124.009602141579
44.9689109026176	-124.009862880836
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44.9676616160949	-124.008574211875
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44.9671329792819	-124.007207318702
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44.9669394139799	-124.006966106132
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44.9687184530488	-123.994744115196
44.9689613508877	-123.994336733966
44.9708285936756	-123.992878737987
44.979047766174	-123.987514761039
44.9791691933489	-123.987922142268
44.9793513336293	-123.988286641263

Biovolume Analysis by Quantity

AOI	0-5%	5-20%	20-40%	40-60%	60-80%	>80%
1	92.82%	6.73%	0.20%	0.09%	0.14%	0.03%

Biovolume Analysis by Depth

Full Survey	Depth	Type	Count	PAC	Avg BVp	SD BVp	Avg BVw	SD BVw
	0-1m	Point	1655	46.3%	17.4%	±19.7%	14.8%	±0.0%
	1-2m		13817	12.2%	7.5%	±2.6%	2.5%	±0.0%
	2-3m		10491	0.3%	6.6%	±1.0%	0.3%	±0.0%
	3-4m		6850	0.0%	0.0%	±0.0%	0.0%	±0.0%
	4-5m		1637	0.0%	0.0%	±0.0%	0.0%	±0.0%
	5-6m		103	0.0%	0.0%	±0.0%	0.0%	±0.0%
	6-7m		12	0.0%	0.0%	±0.0%	0.0%	±0.0%
	7-8m		3	0.0%	0.0%	±0.0%	0.0%	±0.0%
	8-9m		1	0.0%	0.0%	±0.0%	0.0%	±0.0%
	9-10m		22	0.0%	0.0%	±0.0%	0.0%	±0.0%
	0-1m	Grid	361	18.7%	8.8%	±5.2%	1.6%	±4.1%
	1-2m		125	2.8%	6.6%	±1.8%	0.2%	±1.1%
	2-3m		0	0.0%	5.2%	±0.1%	0.0%	±0.0%
	3-4m		0	0.0%	0.0%	±0.0%	0.0%	±0.0%
	4-5m		0	0.0%	0.0%	±0.0%	0.0%	±0.0%
	5-6m		0	0.0%	0.0%	±0.0%	0.0%	±0.0%
	6-7m		0	0.0%	0.0%	±0.0%	0.0%	±0.0%

Glossary

AOI

Area of Interest: Defines the individual transects or contiguous data samples as depicted by the color coding of each trip line. Separate areas of interest can be generated through merging of multiple trips, appending data to a single sonar log or lapses in time (greater than five minutes) within a sonar log.

BVp

Biovolume (Plant): Refers to the percentage of the water column taken up by vegetation when vegetation exists. Areas that do not have any vegetation are not taken into consideration for this calculation.

BVw

Biovolume (All water): Refers to the average percentage of the water column taken up by vegetation regardless of whether vegetation exists. In areas where no vegetation exists, a zero value is entered into the calculation, thus reducing the overall biovolume of the entire area covered by the survey.

PAC

Percent Area Covered: Refers to the overall surface area that has vegetation growing.

Grid

Geostatistical Interpolated Grid: Interpolated and evenly spaced values representing kriged (smoothed) output of aggregated data points. The gridded data is most accurate summary of individual survey areas.

Point

Individual Coordinate Point: A single point represents a summary of sonar pings and the derived bottom and canopy depths. Individual point data create an irregularly spaced dataset that may have overlaps and/or gaps in the data resulting in a increased potential for error.

Additional Waypoints

No Additional Waypoints

Offsets

Trip Name	File Name	Trip Date (UTC)	Manual Offset (ft)	Max Tide (ft)	Min Tide (ft)	Ave Tide (ft)	Start Tide (ft)	End Tide (ft)
DEVIL1.sl2	DEVIL1.sl2	12/4/2019 10:29:32 AM	0.67	0	0	0	0	0
DEVIL2.sl2	DEVIL2.sl2	12/4/2019 12:33:57 PM	0.67	0	0	0	0	0
DEVIL3.sl2	DEVIL3.sl2	12/4/2019 2:54:39 PM	0.67	0	0	0	0	0
DEVIL4.sl2	DEVIL4.sl2	12/4/2019 4:49:22 PM	0.67	0	0	0	0	0
DEVIL5.sl2	DEVIL5.sl2	12/4/2019 6:06:31 PM	0.67	0	0	0	0	0
DEVILS3.sl2	DEVILS3.sl2	12/3/2019 10:04:07 PM	0.67	0	0	0	0	0
DEVILS2.sl2	DEVILS2.sl2	12/3/2019 8:50:11 PM	0.67	0	0	0	0	0
DEVILS4.sl2	DEVILS4.sl2	12/3/2019 11:04:50 PM	0.67	0	0	0	0	0

DEVILS5.sl2	DEVILS5.sl2	12/4/2019 4:53:42 PM	0.67	0	0	0	0	0
DEVILS6.sl2	DEVILS6.sl2	12/4/2019 5:59:28 PM	0.67	0	0	0	0	0
DEVILS7.sl2	DEVILS7.sl2	12/4/2019 6:58:30 PM	0.67	0	0	0	0	0
DEVILS8.sl2	DEVILS8.sl2	12/4/2019 7:33:03 PM	0.67	0	0	0	0	0
DEVILS10.sl2	DEVILS10.sl2	12/4/2019 9:03:20 PM	0.67	0	0	0	0	0
Sonar_2019-12-03_13.48.10.sl2	Sonar_2019-12-03_13.48.10.sl2	12/3/2019 7:48:20 PM	0.67	0	0	0	0	0
DEVILS9.sl2	DEVILS9.sl2	12/4/2019 8:01:09 PM	0.67	0	0	0	0	0

Report URL: <https://noxreportprod.s3.amazonaws.com/48123221-3fc8-47dd-9479-a21ba7242c85/Report.html> (<https://noxreportprod.s3.amazonaws.com/48123221-3fc8-47dd-9479-a21ba7242c85/Report.html>)

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Pacific Rim Design Group

8152 SW Hall Blvd • Suite 101
Beaverton, OR 97008
714.757.3698

Ms. Tina French
Board Chairperson
Devils Lake Water Improvement District
4006 NE West Devils Lake Road
Lincoln City, OR 97367

Sept 6, 2022

Re: Elodia Weed Survey, Devils Lake

Dear Ms French,

Please find attached the final report for the elodia weed survey performed by Pacific Rim Design Group. The attached report addresses the findings of the survey crew that performed the field work, as well as an engineering evaluation of the field data.

The general findings of the report show the condition of the weed coverage in Devils Lake as of August 2, 2022. The report also addresses the origins of the elodia weed as best as can be determined from the available data. In addition, the report provides an estimated growth rate of the weeds as well as the anticipated weed impact to the lake as of August, 2023.

Please note that our data shows that this weed volume issue within the lake is likely to become much worse in terms of 'coverage' of the lake surface as well as the total biomass volume within the lake by this same time next year. Mitigation measures are highly recommended and should be coordinated with the state agencies having jurisdiction. It is recommended that a further survey be conducted in one year to further substantiate the growth, coverage, and impact to the surface and water volume of the lake.

Please let me know if you have any questions regarding the attached report. Copies of the maps in a larger format are available upon request.

Sincerely,



William C. Hagmaier, PE
President



**REPORT AND DOCUMENTATION OF
PHYSICAL SURVEY OF WEED IMPACT AT
DEVILS LAKE, OR**

**A Report to the
Devils Lake Water Improvement District,
Lincoln City, OR
August 28, 2022**

**Pacific Rim Design Group
8152 SW Hall Blvd #101
Beaverton, OR 97008**

General Abstract

Devils Lake is located in Lincoln City, Oregon and is under the management jurisdiction of various State of Oregon authorities, including Oregon Department of Fish and Wildlife and Oregon Department of State Lands. The lake is considered an urban lake with approximately 850 homes and properties surrounding the lake and has a wetted perimeter of approximately 12 miles. The lake has a surface area of 635-685 acres depending on source of data, a volume of approximately 250 million cubic feet and an average depth of approximately 8.2 feet. Due to the shallow average depth of the lake, it is by nature a highly eutrophic lake. A eutrophic lake is by definition, a lake which is rich in nutrients and thereby supports a dense plant population, the decomposition of which kills animal life by depriving it of oxygen.

This lake has a long history of dealing with various weeds; the most recent of which was in the mid to late 1980s when grass carp were introduced into the lake to help mitigate the extent of the weed issues. The Devils Lake Water Improvement District (DLWID) was given permission to stock the lake in 1986 with 10,000 sterile grass carp, and additional 17,000 in 1987, and another 5000 sterile carp in 1993. By 1994 the submerged aquatic plants in the lake were relatively under control and excessive vegetation in the lake was not noticeable until early in 2022. This field evaluation and report were undertaken to document the current presence of aquatic vegetation in the lake as of August 2, 2022.

Introduction

Devils Lake has recently experienced an explosive growth of elodea weed (sometimes called American or Canadian water weed) in all areas of the lake. These weeds have risen to the surface in some areas and are within the top 3 feet of the lake surface in many other areas of the lake. The DLWID requested Pacific Rim Design Group to perform a survey of the lake to document the physical extent of the weeds both horizontally within the lake as well as vertically within the lake. This survey was a physical survey of weed location, heights, and general dispersion within the lake. This survey was not intended to document the variability, or the type, or the density of weeds within the water column of the lake.

Executive Summary

- Elodea weed coverage of the lake bottom is effectively at 100% as of the time of this study. Visual observations combined with weed depth measurements and physical field sampling of weeds at the bottom of the lake provided consistent evidence of weed coverage throughout the lake.
- The surface area (including water depth to 36 inches) of the lake currently affected by elodea weed has been calculated to be 266 acres, which equates to a coverage of 40.1% of the surface. This is a surface measurement as defined by this report and is different than the biomass water volume impact to the lake as noted below. A graphic representation of the weed surface coverage of the lake is shown in Figure 2 of the Appendix.

- The total biomass water volume of the lake currently affected by elodea weed has been calculated to be 116.98 million cubic feet of water, which equates to 48.6% of the volume of the lake. The largest volume of elodea in the lake is currently located in the middle and northern portions of the lake and is only 5' to 6' below the surface at the time of this study. This mass is similar to the lower portions of an iceberg...large but unseen. This mass is now high enough in the water column to receive good sunlight and will likely accelerate in growth over the next year.
- The growth rates of the elodea weed have been calculated in this lake to be between 2.3' to 3.5' per year. The elodea weed was not present in this lake until a very small amount of weed was documented in one location of the lake in December of 2019, during an Aquatic Plant Survey performed by AquaTechnex, LLC. Since that date, the elodea weed has established a substantial presence throughout the lake. Within one year of this study, it is estimated that 85% or more of the lake surface area will have elodea within 36 inches or less of the surface. A graphic representation of the elodea weed cover within 1 year of this study is shown in Figure 2 of the Appendix.

Data Collection

The intent of the survey was to document the extent of the weed coverage in the lake as well as the biomass water volume of weed currently present in the lake with a focus on visual and physical measurement. Sonar bio-mapping of the lake was not included as part of the scope of work for this study. There were various measurement parameters that needed to be resolved to provide a reasonable foundation on which to base the final evaluation of the weed measurements. Neither a 2 dimensional computer map nor a 3 dimensional computer map of the lake was available for the weed survey. Therefore, these maps were created from field measurements correlated to published topographic mapping to provide an appropriate engineering boundary from which the extent of weeds could be evaluated. The following measurement data was determined as critical for the accuracy of the weed measurements.

Measurements Parameters that were Required to be Correlated

The boundary area of the lake had to be created in a CADD based format so that the ultimate calculation of weed coverage had a basis for its area. A map of the lake was created using Civil 3D software from existing 2 dimensional mapping available from Google and USGS mapping data. Once the boundary area was created; the boundary area needed to be backchecked against published data as to the known area of the lake. The boundary of the lake is known to be approximately 632 - 685 acres depending on the data source. The map boundary created by the Civil 3D software and graphic images for use by this study is 670 acres, resulting in a 98% level of correlation. (100% correlation was not possible because of the variable level of the water at different times of historical measurements and the nature of the available graphic data versus the ability of high order LIDAR mapping normally prepared by state and federal agencies with appropriate budgets.) It was determined that for this study a correlation of the boundary with a 98% confidence level was sufficient.

The depth of the lake at multiple locations was field measured with a survey rod and then confirmed versus the published topography maps of the lake. These measurements were necessary so that the depth of the lake and published topography maps could be confirmed as accurate and consistent with actual field measurements. Once the field measurements of depth were correlated with the published maps, this data then allowed the use of field measurements and existing topography maps to be used with confidence to create a 3 dimensional CADD map of the lake. The 3 dimensional map of the lake could then be cross checked for water volume versus the published volumes of the lake as identified by existing state data. The water volume of the lake based on published data is approximately 235-262 million cubic feet depending on the source of the data. The water volume of the lake based on the 3 dimensional map prepared for this report was 249 million cubic feet; resulting in a correlation between the created map and the published data of 95%-100%, which was considered as reliably accurate for the purpose of this study.

Measurement of Weed Depths

The depths of weeds were measured over a period of 10 days from July 20 to August 2. Measurements were made at 85 different radial points around the lake (see Appendix, Figure 1). These points were chosen at random and were approximately 300' to 500' apart. There were some locations around the lake that were so congested with weeds at the surface that the boats could not enter these areas. However, these areas were generally documented as densely populated with weeds and incorporated into the ultimate weed map. At each of the 85 radial points, a maximum of 4 locations were established for individual measurement. These measurements included

- the depth to top of weeds by visual measurement using a survey rod,
- the depth of the actual lake bottom using a survey rod,
- a depth finder reading at random intervals to confirm weed depth correlation with the survey rod measurement,
- a survey measurement of distance to shoreline
- and in locations where weeds were not visible to measure, a depth finder reading was made to document the top of the weeds.

The measurement for the depth of the weeds was based on visual observations to the maximum extent possible with a physical measurement to top of weeds. Where visual observation was not possible, a depth finder was used to map the top of weeds. In order to confirm that the boat depth finders were measuring top of weed and not the bottom of the lake, a number of measurements were made in areas where visual depth could be compared against the depth finder results. These cross correlated measurements are shown on Table 1 in the Appendix at various location around the lake. When the visual survey rod measurements were compared to the depth finder measurements it was shown to have reasonable consistency of depth +/- 6 inches.

Weeds were visibly measurable to a depth of 5' to 5'-6" depending on the location within the lake. In the deeper parts of the lake where weeds could not be visually observed, a depth finder was utilized to determine the depth to top of weeds. The depth finder measurements at these locations were trusted as "measuring the top of weeds" and not the bottom of the lake based on the correlation that was performed in water where weed depths could be visually confirmed and correlated with the depth finder readings as noted above.

Confirmation of Weed Type by Sampling

The purpose of this study was to document the presence of aquatic weeds in the lake; specifically elodea to the extent possible. The field personnel were able to confirm the weeds that were visually encountered were nearly 100% Elodea at all locations other than the west-southwest area of the lake from Regatta Park to the west where Elodea was mixed with other weeds to varying degree. In areas of the lake where weeds were not visually observed, but were indicated by depth finders; a weed cutting blade was used to cut the weeds. These weeds were pulled to the boat and others floated up to the surface. The weeds observed in these cuttings were all elodea as best as could be determined as shown in the picture below. No area of the lake could be found from sampling that did not contain substantial amounts of elodea weed.



Data Analysis

The primary focus of this study was to document the area coverage of the weeds in the lake and the biomass water volume of weed coverage within the lake. The data shown in Table 1 of the Appendix reflects the physical measurements of the weeds based on the visual and depth-finder methodology of data collection noted previously in this report. The field measurement data noted in Table 1 provides both a location and depth for the weeds throughout the full expanse of the lake. This data was utilized by engineers to create a 3 dimension model of the weed surface within the lake using Civil 3D CADD software modeling.

Weed Coverage Area Calculation

The data in Table 1 of the Appendix and resultant modeling indicates that the bottom of the lake is fully covered in weeds to varying depths. This determination was confirmed by both field data measurements as well as physical field sampling. As noted previously, the predominant weed that was found within the

lake at all levels was elodea, although other aquatic vegetation was witnessed in visible proportion in the west-southwesterly arm of the lake.

The project scope included preparation of a map showing the area of the lake that was impacted by the elodea weed. For the purpose of this report, the definition of 'weed impact' to the lake was defined as weeds within the top 36" of the water surface. This depth of 36 inches was utilized as a relative depth where the impact could be seen by recreational users of the lake without generally impacting their activities, whether that was fishing, skiing, kayaking or pleasure boating. Any weed above that level was considered as an impact to the lake. Figure 2 of the Appendix shows this area of impact (weeds within 36 inches of the surface) in pink highlighting. As noted on the map, the area of current greatest impact is the southern portion of the lake, both in the southwest arm of the lake and along the southeastern area and shoreline.

The surface area of the lake as previously noted is 649 acres based on the model that was created for this study. The surface area currently impacted by weeds (shown in pink highlights on the map) is 266 acres, equating to a coverage of 40.1 %. The bottom area of the lake that is currently impacted by weeds was found to be all 649 acres; or 100% coverage as previously noted.

Weed Coverage Volume Calculation

The coverage of weeds within the lake was found to be relatively extensive (basically 100%) from the perspective of bottom coverage, and 'impactful' to the use of the lake in many areas (approximately 40.1% surface impact) with weeds at a visible depth of 36 inches or less. However, the biomass water volume calculation (volume of water with presence of weeds) is a somewhat more detailed evaluation of the weed presence within the lake because it evaluated to full lake and not just the surface area.

The measurement data from the weed survey in Table 1 of the Appendix was used to establish the surface area of the elodea coverage as well as the depth of elodea from the surface. This depth of the elodea creates a 'top surface' for the elodea weeds which has varying heights. The bottom of the lake also has a varying surface. These two surfaces were incorporated into one spatial 3 dimensional figure within the CADD model and the difference between these two 3 dimensional surfaces then allowed the software of Civil 3D to calculate the volume of water impacted by elodea.

The water volume of the lake as previously noted is 249 million cubic feet of water. The volume of water currently impacted by elodea weed (also known as biomass water volume) is 116.34 million cubic feet (coverage by volume = 48.6%). This volume represents the amount of water that is impacted by varying densities of elodea. The actual density or total weight of elodea weed within the lake is beyond the scope of this report and if this calculation is needed, it is best provided by a marine biologist familiar with aquatic plant densities. Regardless of the physical 'density' or weight of the elodea weed; the physical presence of the weed and the physical impact of the weed is documented herewith for further use.

Weed Coverage Projection

As part of this study, a historical evaluation of the elodea weed presence within the lake was also performed. The purpose of this research was simply to provide a documented source, or beginning point, for the spread of the elodea, if that was possible. This information, if available, was anticipated to be able to provide a timeline for the historical spread of the elodea weed.

A report titled as “The Devils Lake 2019 Aquatic Plants Survey Report and Biobase Mapping” prepared by AquaTechnex, LLC was prepared on behalf of DLWID in December of 2019. In that report it was noted that a small presence of elodea weed was found at one location in the southeast portion of the lake approximately 2000 feet east of the Brown Bear State Park boat dock/launch ramp (see Appendix, Figure 3). This weed survey report was a full lake survey and is available for public review. The fact that the elodea weed was found in only one small area in December of 2019; leads to the conclusion that the substantial spread of elodea weed within the lake has basically all occurred within the last 2 years and 7 months.

Elodea weed heights in the southern portion of the lake (southwest arm and southeastern shoreline) appear to range from 6’ to 9’ depending on location and are growing the full depth of the lake in large portions of this area. In essence, this growth and height has all occurred in 31 months. Heights in other portions of the lake appear to vary from 5’ to 8’ depending on location. Elodea can also grow without being rooted as noted in the picture below. There are a variety of floating masses on the lake which may be fully floating or may be partially supported on weeds rooted to the bottom as witnessed by the pictures below.



It appears the elodea established itself initially in the southern portion of the lake and then spread northerly via seasonal winds from the southwest as well as potentially some 'boat transport' during the fishing and boating seasons. Based on the height of the weeds in the southern portion of the lake and given the time duration since first sighting of the weeds, it appears that the weeds can grow from the base of the lake at a rate of 2.3' to 3.5' per year in the shallow waters of this lake.

The main north-south body of the lake currently has weed depths of 5' to 6' below the top of the water surface. Based on the projected weed growth that is evident in the past 2 years, this lake will be substantially impacted for recreational uses to a very large degree by the late summer of 2023 (weeds at 36 inches or less).

Conclusions

The primary conclusions of this study have been incorporated into the Executive Summary at the beginning of this report. These conclusions are based on documented observations and engineering calculations.

It is apparent from this study that the lake has a high content of elodea weeds affecting the lake surface. These weeds are either:

- floating in place,
- floating on top of a fixed weed mass that has risen to the lake surface,
- or are rooted to the bottom of the lake with a top of weed mass at depths that are either currently close to the surface or will be within one year.

Summary Conclusions are as follows:

- The elodea weeds appear to have currently rooted throughout the full bottom of the lake and most of the lakeside docks, public parks, launch ramps, and public swimming areas are affected due to their location in relatively shallow areas where the weed growth has been the highest.
- The elodea weed coverage as defined by this report is weeds within 36" of the surface. The weed coverage in the lake at this time is 40.1% of the lake area, affecting all the shallow water areas as well as a large portion of the southern area of the lake.
- There is a large presence of elodea that is currently unseen covering the largest mass of the lake bottom in the middle areas and northern areas of the lake. This large weed mass is already rooted and has grown to heights of 5'-8'. This large mass is the biggest threat to the lake's future since it has a very large volume, it has already established itself with solid growth, and the weed mass is now within 5'-6' of the surface and receiving much more sunlight. Ultimately this volume of weed will overwhelm the lake without mitigation measures. The current estimate of this biomass water volume in the lake is 48.6% of the total volume of the lake.
- Elodea is known to be able to grow to a height of 15'. More than 90% of this lake has a depth of less than 15', which infers that this lake could be substantially unusable to all activities: (fishing, boating, small craft use, swimming, etc) if the growth of the weeds is left uncontrolled.

- The growth rate of elodea weed has been calculated to be in the range of 2.3' to 3.5' per year in this lake. This growth rate has a significant effect on the full lake and will likely substantially impact the main body of the lake by mid-summer of 2023.
- Any proposed mitigation measures for control of the weeds needs to take into account the very large volume of annual weed growth as well as the large volume of existing weeds in the lake.

APPENDIX

TABLE 1

Devils Lake Weed Survey

Data Collection Date: July 20-Aug 2, 2022

Pacific Rim Design Group

Data Location	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Depth of Weed Below Water Surface
1	84	6.3		1.3	267	8.5		1.9	432	9.2		2.7	546	4.1
2	183	7	4.1	3.6	273	7.8	4	3.5	465	8.8		2.4		
3	45	6.2		1.5	93	8		3.1	246	8.7		1.9		
4	120	7.2		1.7	183	7.2		2.3	321	9.6	4.4	4	891	4.2
5	90	7.4		1.5	177	6.8		1.8	279	7.9		3	786*	5
6	144	8.3		2.6	204	8.9		3.9	309	9.8	4.9	4.4	621	5
7	117	8.5		1.3	228	8.7		1.7	344	9.9		4.6	534	5.1
8	69	9.6		1.9	174	10.5		3	329	9.6		5.3	460	6.9
9	108	8.1		1	153	12.7	6	5.6						
10	57	9.5		1	87	13.4	5.1	5.5					415	10.5
11	63	8.5		0.9	93	9.9		3.5	153	12.6	5	5.8	531	9.5
12	93	7.8		1.1	135	9		1.8	258	9.3		3.9	467	4.8
13	108	5.3		2.1	222	7.5		2.9	412	9.2		4.1		
14	75	8.4		1.9	195	9.4		2.5	248	9.1		4.4	432	4
15	93	9.9		2.2	163	9.8	4	4.3					361	4.3
16	102	7.1		1.1	185	9.2		1.9	265	9.7		4.6	585	5.1
17	96	7.6		1.8	159	8.9		2.4	189	10.5	5.6	5.1	504	6
18	30	6.8		2.1	105	8.2		2.8	173	9.9		4.9	382	11.7
19	189	6.2		0.8	472	7.5		1.1	822	8.6		3.2		
20	348	8.3		1.3	417	8.2		1.6	732	8.3		2.9		
21	333	8.3		1.6	420	8.9		1.5	537	9.2	5.9	5.4		
22	180	9.6		2.3	258	9.5		3.1	373	9.8		5.1	512*	4.8
23	60	8.2		1.1	90	9.3		2.4	195	10.4		5.6	402	4.9
24	84	7.2		1.8	174	8.6		2.3	294	10.1		3.5	577	5
25	69	7.4		1.4	136	8.7		2.1	258	9.8		3.1		
26	135	7.8		1.1	195	9.7		2.6	242	10.1		3.5	564	4.9

* Weed Sampling Performed

Devils Lake Weed Survey

Data Collection Date: July 20-Aug 2, 2022

Pacific Rim Design Group

Data Location	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface
27	55	6.6		1.2	97	8.1		2.1	185	10.5		4.6	615			4
28	105	8.7		1.9	156	9.1		2.2	223	10.6	5.6	5.1	546			4.3
29	105	8.5		1	173	9.1		3.4	216	11.5		5.4	1059*			4
30	81	7.3		1.3	165	9.2		2.5	228	10.1		4.5	514			4.3
31	51	10.3		3.3	152	11.2	5.4	5.2					567			6
32	82	8.7		2.9	154	8.8		2.8	256	9.4		3.8	738			5
33	201	6.1		1.3	389	6.5		2.5	798	8.2	3	3.4				
34	234	5.9		1.5	423	7.2		2.4	868	8.1		3.2				
35	196	5.1		1.3	565	7.1		2.4	846	8.2		3.4				
36	284	4.8		1	538	6.2		2.2	923	8.1		3.4				
37	313	5.4		1.1	595	6.9		2.4	825	8.1		3.3				
41	68	7.9		2.3	112	10.1		4.7					417			7
42	211	7.3		1.4	391	10.6		3.0	453	10.9		4.8	736*			4.8
43	99	8.8		2.6	198	10.4		3.8	276	11.8	5.9	5.4	366			5
44	105	7.4		2.3	183	11.1		1.7	288	12		4.9	349			4.3
45	126	7.2		1.4	213	7.6		2.4	306	8.6		2.4	520			4.1
46	143	7.6		2.2	222	7.6		2.6	312	9.2		3.9	434			4
47	69	9		2.8	153	9.6		3.0	206	10.2	4.9	4.5				
48	93	5.5		2.1	255	10.6		3.5	321	11.7		5.2	445			4
49	25	8.4	3.3	3.6	42	12.9	6.1	5.8					348			8.4
50	87	10.1		3.5	158	11.2	6	5.6					325			10
51	111	8.1		3.6	143	8.9		4.5	174	9.9		5.6	378			7
52	96	8.6	4	3.8	182	9.6		5.1					411			4
53	45	7.1		3.5	133	8.1		4.6	184	9.5		5.4	603*			3.5
54	32	6.3		2.8	110	8.6		3.5	177	9.5		5.2	405			4.5
55	38	7.6		3.4	74	8.1		3.6	145	9.8		5.1	408			5.8
56	48	6.8		3.2	69	7.7		3.7	138	9.9		5.4	510			5.3

* Weed Sampling Performed

Devils Lake Weed Survey

Data Collection Date: July 20-Aug 2, 2022

Pacific Rim Design Group

Data Location	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface	Location Offset from Shoreline	Lake Depth per Field Instrument	Lake Depth per Boat Depth Finder	Depth of Weed Below Water Surface
57	37	9.8		3.4	82	7.9		3.5	162	10	5.9	5.4	657			6
58	51	8.7		2.9	121	8.8		3	171	9.2		4.8	570			3.9
59	68	7.7		2.8	144	8.1		3.9	258	9.2		4.9	430			4.6
60	78	7.9		2.6	123	6.6		3.3	216	9.5		4.9				
61	66	7.1		2.7	111	8.8	5	4.8	177	9.4		5.3	417			4.5
62	25	6.6	5	4.5	153	9.1		3.6	199	9.7		4.9	428			4.4
63	85	5.4		1.3	135	6		2.1	403	9.1		3.5				
64	84	8.8		2.3	153	10.1		3.1	175	11.1	5	4.6	655*			4
65	63	8.1		2.5	93	11.5	5.3	4.9					398			4.2
66	114	8.3		3.1	142	10.4	6.4	6.1					390			5.1
67	85	8	5.1	4.8	114	12.6		6.0					786			6
68	95	7.6		2.9	182	8.1		4.8					822			5.5
69	54	11	4	4.1	101	12	5.5	5.9					943*			7
70	68	9.1		3.5	98	10.3		4	213	10.9		4.8	492			4.5
71	36	7.1		2.4	63	8.4		3.6	99	10.1		5.6	458			4.5
72	78	7		3.5	132	9	5	5.2					391			3.8
73	46	6.1		1.6	103	8.3		3.0	189	9.2		4.9	375			4.2
74	31	8.1		2.6	146	9.6		3.4	193	9.1		5.8	401			3.6
75	78	6.8		2	173	8.6		3.4	216	9.3		5.4	418			3.7
76	68	7.5		3	94	9.6		3.4	167	9.6	6.1	5.5	321			3.8
77	70	7.7		3	104	9.1	5.2	4.8					358			4.2
78	69	8		1	158	8.9		3.0	238	9.2	4.9	5.1	569			4.6
79	93	8.1		0.9	152	8.6		3.6	226	9.1		5.4	453			4.5
80	96	7.1		1.1	219	10.9	4.7	4.2	288	9		5.1	717*			4
81	92	7.1		2.5	192	7		2.6	246	9.1	5.5	5	486			4.1
82	63	8.8		2.4	126	9.1		3.5	202	8.9		5.2	543			4.5
83	122	7.2		2.1	186	9		2.8	277	9		5.1	558			5

* Weed Sampling Performed

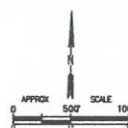
FIGURE 1



FIGURE 1

LEGEND:

 SURFACE DATA POINT LOCATION.



**DEVILS LAKE, OREGON
ELODEA WEED
DEPTH SURVEY MAP**

DATE:
7/27/2022

Pacific Rim
Design Group
4100 Silver Lake Blvd - Suite 100
Bend, OR 97709
734.727.3000

FIGURE 2

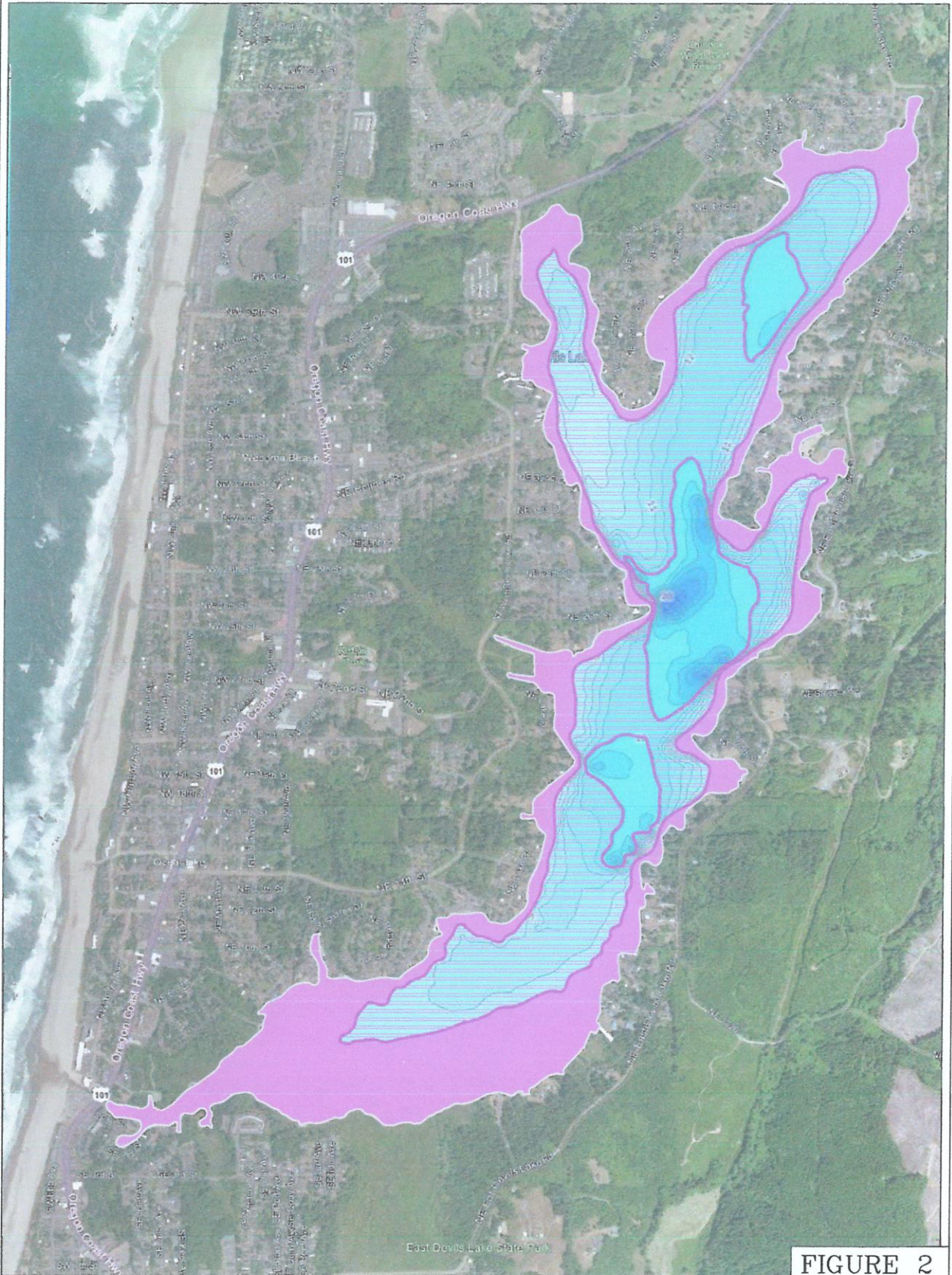
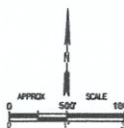


FIGURE 2

LEGEND:

- AREA CURRENTLY IMPACTED BY ELODEA WEED WITHIN 6" TO 36" OF WATER SURFACE. (2,489,444 SF)
- AREA ANTICIPATED TO BE IMPACTED BY ELODEA WEED WITHIN 1 YEAR TO A LEVEL WITHIN 6" TO 36" OF WATER SURFACE. (12,838,796 SF.)



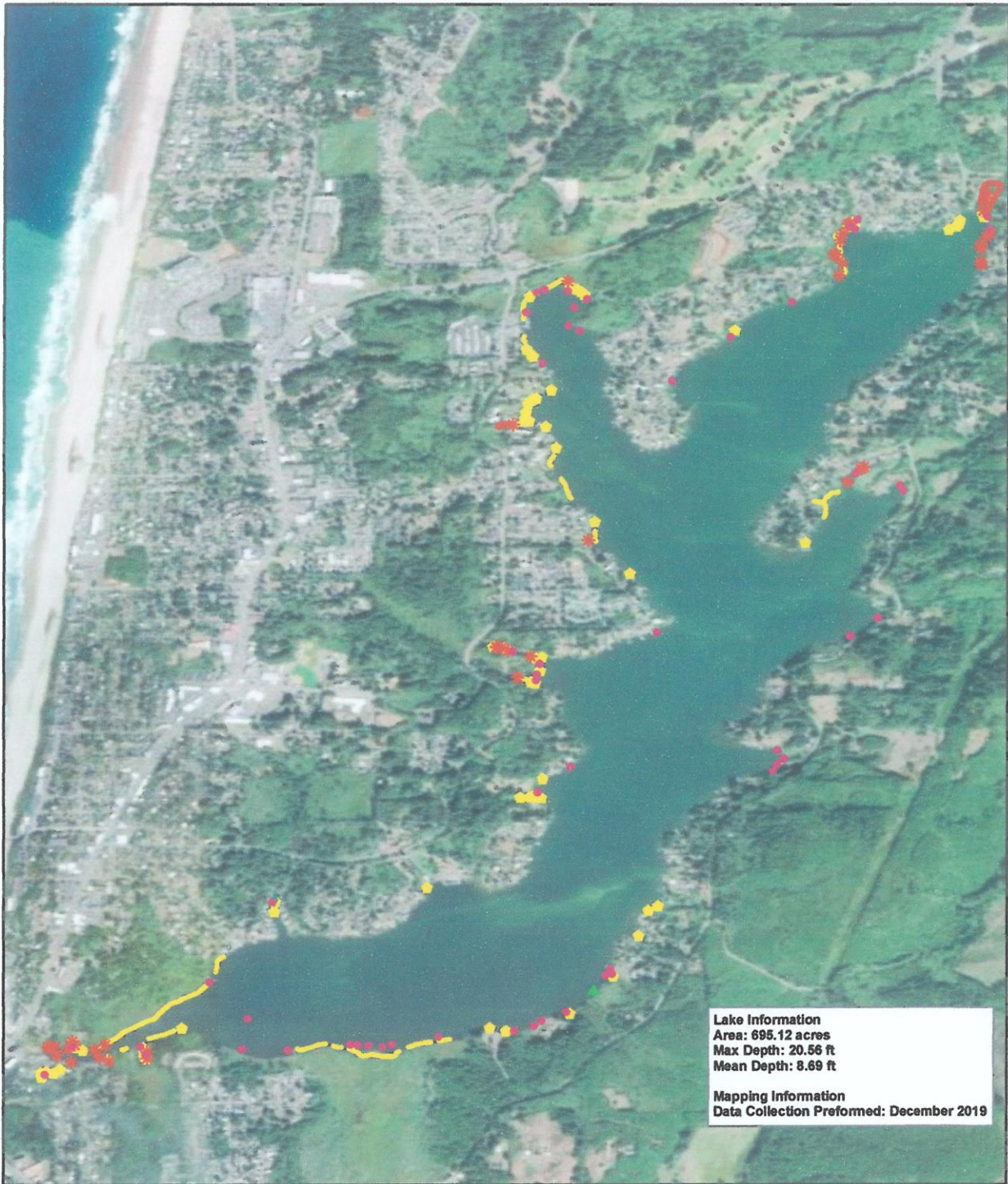
**DEVILS LAKE, OREGON
ELODEA WEED
IMPACT MAP**

DATE:
7/27/2022

Pacific Rim
Design Group

3123 Silver Star - Suite 10
Redwood, CA 95568
707.752.2958

FIGURE 3



Devils Lake
 Lincoln County, Oregon
 December, 2019

Legend

- Najas/Callitriche spp.
- ◆ Vallisneria americana
- ▲ Elodea canadensis
- Myriophyllum aquaticum
- * Myriophyllum aquaticum
- Nuphar spp.
- Nuphar spp.



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 Centralia, Washington
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 www.aquatex.com

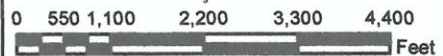
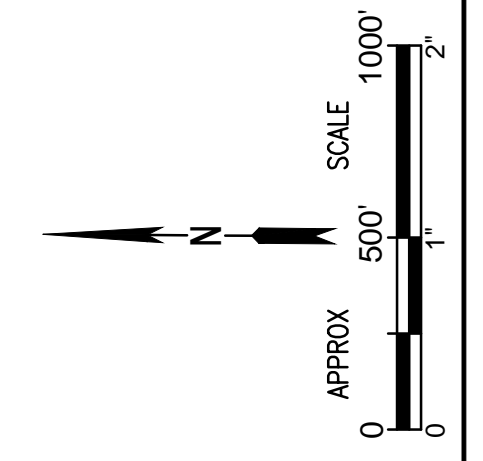




FIGURE 1

DEVILS LAKE, OREGON
 ELODEA WEED
 DEPTH SURVEY MAP

DATE: 7/27/2022
 Pacific Rim Design Group
 8152 SW Hill Blvd • Suite 107
 714.927.9800



LEGEND:
 (X) SURFACE DATA POINT LOCATION.

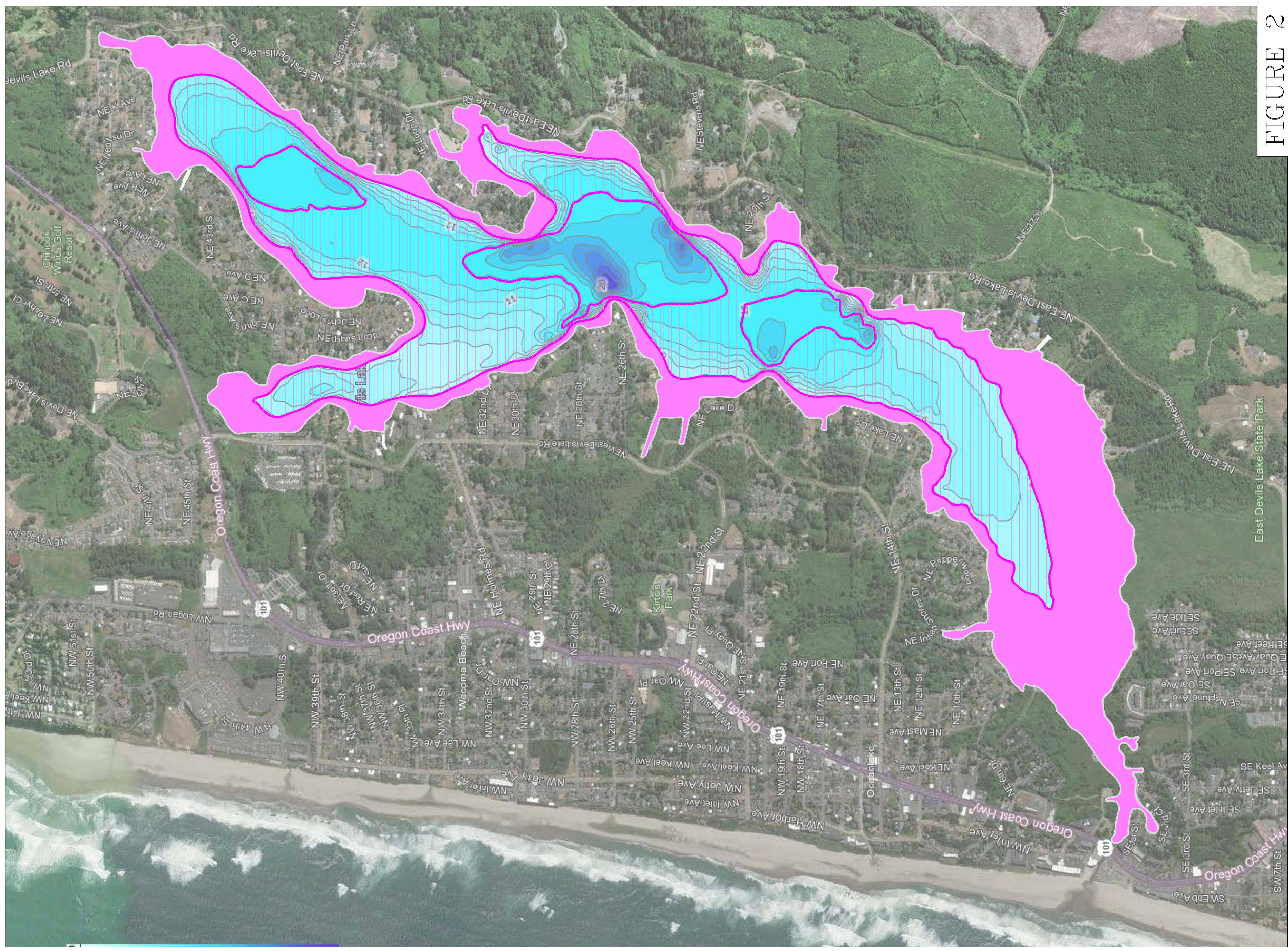
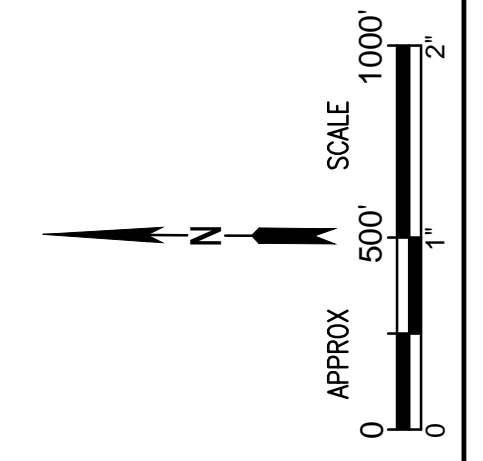


FIGURE 2

DEVILS LAKE, OREGON
 ELODEA WEED
 IMPACT MAP

DATE: 7/27/2022
 Pacific Rim Design Group
 8152 SW Hill Blvd., Suite 107
 714.927.9800



LEGEND:

- AREA CURRENTLY IMPACTED BY ELODEA WEED WITHIN 6" TO 36" OF WATER SURFACE. (2,489,444 SF)
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Effects of Introduced Fishes on Wild Juvenile Coho Salmon Using Three Shallow Western Washington Lakes

by

Scott A. Bonar,
Arizona Cooperative Fish and Wildlife Research Unit
U.S. Geological Survey
104 Biological Sciences East
University of Arizona
Tucson, AZ 85721

And

Bruce D. Bolding, Marc Divens, and William Meyer
Inland Fisheries Research
Washington Department of Fish and Wildlife
600 Capitol Way North
Olympia, Washington 98501-1091, USA

November 2004

Abstract

Pacific salmon declines have been blamed on hydropower, overfishing, ocean conditions, and land-use practices; however, less is known about introduced fish impacts. Most of the hundreds of lakes and ponds in the Pacific Northwest contain introduced fish and many of these water bodies are also important for salmon production, especially coho salmon. Over two years, we examined predation impacts of ten common introduced fishes (brown bullhead catfish *Ameiurus nebulosus*, black crappie *Pomoxis nigromaculatus*, bluegill *Lepomis macrochirus*, golden shiner *Notemigonus crysoleucas*, green sunfish *Lepomis cyanellus*, largemouth bass *Micropterus salmoides*, pumpkinseed *Lepomis gibbosus*, rainbow trout *Oncorhynchus mykiss*, warmouth *Lepomis gulosus*, and yellow perch *Perca flavescens*) and two native fishes (cutthroat trout *Oncorhynchus clarki*, and prickly sculpin *Cottus asper*) on wild juvenile coho salmon *Oncorhynchus kisutch* in three shallow western Washington lakes, all located in different watersheds. Of these species, largemouth bass were responsible for an average of 98% of the predation on coho salmon in all lakes, but total impact to each run varied among lakes and years. Very few coho salmon were eaten by black crappie, brown bullhead catfish, cutthroat trout, prickly sculpin, and yellow perch, while other species were not observed to eat coho salmon. Juvenile coho salmon growth in all lakes was higher than in nearby streams. Therefore, food competition between coho salmon and introduced fishes in lakes was probably not limiting coho salmon populations. Largemouth bass are widespread, present in 85% of lowland warmwater public-access lakes of Washington (n=421). Future research would help identify impact of largemouth bass predation across the region, and prioritize lakes where impacts are most severe. Nevertheless, attempts to transplant or increase largemouth bass numbers in lakes important to coho salmon would be counterproductive to coho salmon enhancement efforts.

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Introduction

Pacific salmon are integral to the aquatic ecosystems, the economy, and both Native American and European culture of the Pacific Northwest. Five species of Pacific salmon have declined in abundance, especially along the southern half of their native range in California, Oregon and Washington. These declines have been drastic, and many salmon stocks are now protected under the U.S. Endangered Species Act.

Salmon declines have been blamed on a combination of overharvest, habitat destruction, presence of dams, climate change, and interactions with hatchery fish (National Research Council 1996; Finney et al. 2000; Kareiva et al. 2000; Finney et al. 2002). While numerous studies have examined the effects of these factors, few have examined the role of introduced fishes in the decline of salmon stocks. Lakes and rivers in the western United States were stocked en-mass with nonnative fishes, including centrarchids, ictalurids, percids and salmonids, during the late 19th and early 20th century, by European settlers and the U.S. Fish Commission (Lampman 1946; Wydoski and Whitney 1979). The introductions and subsequent movement of these fishes were widespread and virtually all lowland lakes and many river systems in the Pacific Northwestern region of the United States now contain some introduced fish. Few were stocked into lakes on the Pacific Coast of Canada; however, there is increasing interest by angling groups to introduce many of these species. Although popular with anglers (Zook 1999), introduced fishes have contributed to declines of native fishes in many regions of the American West (Minckley and Deacon 1991; Gunckel et al. 2002).

Most studies of interactions among introduced fishes and Pacific salmon have been conducted in large deep lakes, reservoirs, or large river systems (Poe et al. 1991; Tabor et al. 1993; Fayram and Sibley 2000; Nowak et al. 2004). However, the most common introduced fishes found in the freshwaters of the Pacific Northwest evolved in warm, shallow waters of the eastern United States and prefer the littoral areas of lakes and ponds. Few of these species develop large populations in deep, cold lakes or reservoirs, or fast-flowing Pacific Northwest streams. Shallow, off-channel sites such as ponds, sloughs, marshes, and the littoral zones of lakes are more suitable habitat for these species. These areas are also important for salmon; these habitats are reported to contribute 15-62% of the total production of juvenile salmon in various watersheds (Bustard 1983; Brown and Hartman 1988; Beechie et al. 1994). In western Washington State alone, over 450 lakes and ponds are accessible to anadromous salmon, providing rearing habitat and migration corridors for their journey to the sea (Washington Department of Fish and Wildlife unpublished data). The vast majority of these lakes and ponds are small and shallow, yet almost no information is available regarding the impacts of introduced fishes on the numerous small salmon runs that use the hundreds of shallow lakes throughout the Pacific Northwest.

The goal of our study was to (1) evaluate the degree to which the most common introduced fishes prey on juvenile salmon in three small shallow western Washington lakes; (2) evaluate effects by season, and size group of predators; (3) calculate number of juvenile salmon removed by predation in each lake; and (4) compare juvenile salmon growth among lakes and nearby

streams to investigate the potential for competition for food to limit juvenile salmon growth. We focused our study on the effects on coho salmon because of their long freshwater residence time as juveniles (usually > 1 year), and their propensity to use lakes and other off-channel habitats to rear.

Methods

Our study was conducted over a 2-year period in three shallow (< 8 m deep), lowland (< 125 m above mean sea level in elevation) western Washington lakes, all located in different watersheds (Table 1). We used a standard combination of gear types to sample the diets, population sizes and growth of introduced and native fishes in each of the lakes once or twice per month, throughout the year. Each sampling year started the first of April and continued to the first of April the following year. During April 1998 to April 1999 (first year) we sampled each lake twice each month during salmon smolt migration and once per month the rest of the year. From April 1999 to April 2000 (second year), we sampled each lake once per month throughout the year. Water temperatures were taken on each sampling date using a Scout II hydrolab. In both the littoral zone and the deepest portion of the lake, we took temperature readings every 0.5 m from the surface to the bottom. For sampling fish, each lake was divided into eight sections. Half of the sections were randomly chosen and sampled during the day and half were sampled at night to provide diel information on diet. By the end of each sampling trip, the entire lake was sampled. Fish were captured in the littoral zones using minnow traps and gill nets set for two hours to minimize mortality, and boat electrofishing to sample the entire shoreline of each section. Deeper areas of the lakes were sampled using vertical and horizontal gill nets, slat traps and minnow traps. In deep areas in the summer, when no fish were captured, hydroacoustic surveys were used to confirm the absence of fish. Additionally, we snorkeled portions of Big Beef Creek approximately 1.6 km below and 0.5 mi km above Lake Symington in midsummer 1999 to identify the distribution of introduced predators in streams adjacent to the lake.

All captured fish were anesthetized and total length was measured to the nearest mm. Weights (g) were taken on the first 100 fish of each species to develop relationships between length and weight. At the start of the study, all fish were either fin-clipped or tagged for population estimates, but after three sampling periods we tagged only largemouth bass using individually numbered anchor tags. The stomachs of up to 30 individuals of each age cohort of each species were pumped during both day sampling and night sampling using gastric lavage to obtain contents. Minimum size of the fish pumped was 75 mm TL. Contents were then stored in a 10% formalin solution buffered with borax and transported to the laboratory, where they were separated into the following 11 groups: insects, zooplankton or other non-crayfish invertebrates; crayfish; salmon fry; salmon smolts; unidentified salmonids; other fish; unidentified fish; amphibians; birds; rodents; detritus, plants or other materials. We captured hundreds of juvenile coho salmon in the three lakes. The only other salmon captured were eight juvenile chum salmon from Long Lake. Therefore, we assumed all salmon in the gut contents were coho. Digested fish material was identified to species using diagnostic bones (Hansel et al. 1988) when present. Salmon fry and smolts represented two distinct length groups in each lake. Regressions of cleithrum (shoulder), dentary (lower jaw) or standard length to total length were used to identify salmon juveniles as either smolts or fry. The sorted stomach contents were blotted on absorbent paper and weighed on an analytical balance to the nearest 0.001 g.

Predation was evaluated using the Wisconsin bioenergetics model (Hanson 1997) to estimate the weight of salmon consumed by each predator group over a one-year period. The Wisconsin

bioenergetics model is an energy balance equation that relates consumption rate to growth, metabolism, water temperatures, and excretion in an individual fish. Population and survival estimates are used to expand the consumption of an individual fish to the population as a whole. Using this model, we calculated consumption rates of salmon by type of introduced species.

Data needed for the model included the thermal experience of predators in each lake; introduced fish diet, growth, survival, gonad growth, population estimates, and energy density; and energy density of the prey. Water temperatures used were those measured at the depth fish were captured. We assumed species captured by boat electrofishing were feeding at the water temperature measured at a depth of 1.0 m in the littoral zone. For those captured by other techniques such as nets or traps, we used the temperature at the depth where the device was set. Diet was the proportion of each diet item by weight for each month. If less than ten fish were caught in a particular month, adjacent months would be combined to obtain a sample size that would be greater than ten. Growth was estimated by examining the movement of cohorts throughout the year from length-frequency histograms and confirmed by monitoring the change in length of tagged fish between sampling periods. Because growth is calculated by changes in fish weight by the model, length data were transformed into weight data using weight-length relationships developed for each species at each lake. Predator population and survival estimates were used to expand the rate of consumption of coho salmon by individual predators to the population as a whole. Survival was calculated using an age-length key and regressing numbers of fish against age (Ricker 1975). Energy is expended for gonadal growth in fishes, and consumption is required to supply this energy. Average growth of gonads of introduced predators and time of spawning was estimated from field observations and the literature (Timmons et al. 1980).

Population sizes of largemouth bass greater than 150 mm total length (TL) were obtained over six sampling events from April 7 to June 18, 1998 using a Schnabel mark-recapture estimate (Ricker 1975). Mark-recapture estimates assume that there is no mortality or recruitment during the sampling period. Therefore, we calculated population sizes before most spawning activity, because we did not want recruitment to seriously affect our estimates. Assumptions of the mark-recapture method also include the marked fish become randomly mixed with the unmarked, tags are not lost, tags are visible to surveyors, there is no difference in mortality between tagged and untagged fish, and that tagged and untagged fish are equally vulnerable to capture. We replaced tagged fish to the sections of each lake where they were captured and allowed at least one week before recapture to ensure they were randomly mixed. The floy tags we used were highly visible to the surveyors, and at the beginning of the study we both fin-clipped and floy-tagged each largemouth bass, and examined each untagged captured fish for evidence of fin clips and wounds under the dorsal to ensure tags loss was minimal. We carefully inserted anchor tags in the dorsal musculature to reduce wounding and associated mortality.

Largemouth bass recruitment in small maritime-influenced shallow western Washington lakes is more stable from year-to-year than largemouth bass in cold inland reservoirs where year class strength can be affected severely by water drawdown, winter mortality of young, and wave action. Therefore, population estimates calculated in 1998 were used to approximate those in 1999.

Consumption rates were calculated by season and then summed to obtain the estimate for the entire year. We subdivided consumption rate by spring (the period of smolt migration), summer, and late fall/early winter because growth rates and available food among these three periods was different. Model default values for predator energy densities were used. Energy densities of prey were either reported in literature provided by the model or were that of a closely related surrogate species provided by the model. We used the following energy densities for prey, expressed as Joules per gram of prey body mass: invertebrates = 3000; other fish = 4186; amphibians = 4000; coho salmon fry = 5765; crayfish = 3000; coho salmon smolts = 5774; birds = 4000; rats = 4000.

Consumption rates calculated the mass of salmon fry or salmon smolts in g per day per individual predator of each cohort. We separated fry and smolts in the diet by using a cutoff of 100 mm TL, which was determined through examination of length frequencies. Numbers of smolts consumed were calculated by dividing total weight of smolts eaten by the average weight of a smolt determined from a length-weight regression equation. To calculate numbers of fry eaten, we first calculated the total length of fry on that particular sampling date. We then converted total length to weight using length-weight regressions and divided total grams of fry consumed by the weight of an individual fry on that date. We transformed numbers of fry consumed into smolt equivalents by multiplying fry numbers by 0.12, a survival rate from fry to smolt estimated for the Big Beef Creek watershed (D. Seiler, Washington Department of Fish and Wildlife unpublished data.). Smolt equivalents (Rand et al. 1993; Ford et al. 2001; Bartron and Scribner 2004) are a common method of expressing numbers of fry in a form that can be compared to smolt numbers. Adding the number of smolts consumed to the number of smolt equivalents consumed provided an estimate of the number of smolts eaten over one year.

We calculated three estimates of the number of coho salmon eaten by each predator species for each lake, for each year. The *low* and *nominal estimates* included only fish that could be positively identified as salmon in the diet and were based on the lower 95% confidence level and the nominal estimate of the largemouth bass population estimate respectively. The *high estimate* was based on the upper 95% confidence level of the largemouth bass population estimate and included both fishes that could positively be identified as salmon, and unidentified salmonid fishes in the diet.

Comparison of the number of juvenile coho salmon eaten by largemouth bass with a measure of juvenile salmon abundance gave an approximation of the impact to the run. We obtained estimates of the juvenile coho salmon smolt outmigration in the Lake Symington (Big Beef Creek) watershed, and the Wildcat Lake (Wildcat Creek) watershed from traps managed by the Washington Department of Fish and Wildlife (Unpublished Data). Lake Symington was located midway between the headwaters of Big Beef Creek and its outlet to Puget Sound, so only a portion of the entire run would have been exposed to the largemouth bass predation in Lake Symington. The trap measuring the number of salmon smolts produced above Wildcat Lake was in place on Wildcat Creek, immediately at the outlet of Wildcat Lake. Trapping data from the Salmonberry Creek watershed, which contained Long Lake, were unavailable. Habitat/smolt production relationships produced for Washington streams (Zillges 1977; Baranski 1989) were used to calculate potential smolt production in Salmonberry and Curley Creeks, which entered and exited the lake respectively. Available habitat was calculated using a combination of air

photos, and ground surveys using standard methods (Zillges 1977; Baranski 1989) for an estimate of low-flow wetted perimeter. All smolts produced in Salmonberry Creek were exposed to competition or predation from introduced fishes and possibly some from Curley Creek were as well. Because estimates of smolt production potential do not actually measure the numbers of juvenile salmon exiting a watershed, but the potential of a watershed to produce salmon smolts, they are prone to more error than trap counts.

Results

Juvenile coho salmon rearing in all three lakes grew much faster than those in nearby streams draining into Puget Sound (Figure 1), suggesting coho salmon populations were not food-limited in the lakes. However, growth was recorded only in the spring because few juvenile salmon were found in the lakes in late summer.

Fish predation was a significant source of mortality of coho salmon juveniles. Over the two-year study, 30,622 fish were sampled and the contents of 10,262 stomachs were pumped and analyzed. Percent of salmon in the diet was highest for largemouth bass (Table 2). Other species primarily targeted insects and zooplankton. Some salmon were found in the diet of black crappie, brown bullhead, cutthroat trout, prickly sculpin, and yellow perch. Although in three instances salmon constituted 5-10% of the total weight of the stomach contents for these fishes, this usually represented one salmon in the diet the entire year for the species. We found no evidence of rainbow trout, bluegill, or pumpkinseed sunfish feeding on any salmon.

While some salmon were eaten by other species, the vast majority of total salmon was eaten by largemouth bass in all three lakes. Percentage of the total catch consisting of largemouth bass in each lake for each year was as follows: Wildcat 1998-99, 81; Wildcat 1999-00, 88; Symington 1998-99, 35; Symington 1999-00, 42; Long 1998-99, 27; Long 1999-00, 35. Therefore, largemouth bass averaged 51% by number of the total catch of fishes over all three lakes during both years. Among the three lakes, an average of 94% of the salmon found in diets each year were in largemouth bass stomachs (Figure 2). When diet was standardized by catch (mean weight of salmon per individual fish of each species \times number of fish of that species in total catch), an average of 98% of the salmon prey from each lake were found in largemouth bass stomachs (Figure 2).

Our bioenergetics analyses concentrated on largemouth bass predation, because the amount of coho salmon eaten by all other species was minimal. Lake Symington contained the smallest largemouth bass population, while Long Lake contained the largest population (Table 1). Density of largemouth bass was highest in Lake Symington but lowest in Long Lake. Most largemouth bass were captured in shallow water of the littoral zones at average depths of approximately one meter, experiencing the thermal regime of this region (Figure 3). Annual survival of largemouth bass did not vary substantially in Long Lake or Lake Symington between years (Table 3). In Wildcat Lake, survival declined by about 26% between years. Examining movement of modal size of largemouth bass cohorts and corroborating this with data from tagged fish provided estimates of largemouth bass growth for the model (Figure 4). Largemouth bass growth was rapid compared to previously reported Washington state averages (Wydoski and Whitney 1979).

The bioenergetic analysis revealed that both the largemouth bass populations in Symington and Long Lakes ate the most coho salmon smolt equivalents. The largemouth bass population in Wildcat Lake ate the fewest (Table 4). Largemouth bass predation varied by season ($P < 0.025$, $F = 9.216$, Table 5). Most occurred in spring when coho salmon smolts were migrating through

lakes to the sea, or coho salmon fry were moving from creeks into lakes. We captured few coho salmon in any of the lakes in summer or early fall (Figure 5). Consequently, predation was usually low at this time of year.

No salmon were found in the diet of age-0 largemouth bass. Of those largemouth bass age-1 and older, we found no evidence that a particular size group or age class of largemouth bass was responsible for more predation on coho salmon than others. Total numbers of smolt equivalents eaten did not differ by age class ($P > 0.25$, $F=0.747$), nor did grams of smolt equivalents eaten per gram of largemouth bass differ among various age classes of largemouth bass ($P > 0.25$, $F = 0.660$).

Almost all of the predation by largemouth bass on coho salmon was likely confined to the lakes. During the mid-summer 1999 snorkel surveys of Big Beef Creek adjacent to the Lake Symington, we saw only a few age-0 largemouth bass, part of the cohort that did not eat any coho salmon in the lakes. Additionally, even though it was mid-July, water temperatures in the Creek were considerably lower than those in the lake, and were much below that needed for optimal feeding of largemouth bass.

Juvenile coho salmon outmigrations were largest in the Big Beef Creek (Lake Symington) watershed, and lowest from the outlet of Wildcat Lake (Table 4). The amount of coho salmon smolt production eaten by largemouth bass also varied considerably among watersheds, from about 5% of the number exiting the system to over twice the number exiting the system. Lake Symington contained the smallest largemouth bass population (Table 1), and was located in the watershed that produced the largest number of coho salmon smolts of the three systems studied. Furthermore, Lake Symington was located midway in the Big Beef Creek watershed, and a substantial portion of the smolts passing through the Big Beef Creek trap were produced below the lake and never exposed to the largemouth bass predation in Lake Symington. Not surprisingly, the amount of smolt equivalents eaten by largemouth bass in Lake Symington compared to the number exiting the Big Beef Creek Trap was lowest in this system.

Long Lake contained the largest population of largemouth bass, and was fed by Salmonberry Creek and drained by Curley Creek. Number of juvenile salmon eaten in this lake, compared to the juvenile coho salmon production potential in the watershed was much greater (Table 4). Wildcat Lake supported the smallest run of smolts because a screen was present at the outlet of the lake to prevent stocked trout from leaving the system. Even though the screen was in place, a few salmon were able to pass around the screen, and both fry and smolts were found above the barrier. The small smolt run exiting the lake was severely impacted by largemouth bass predation (Table 4). For example in 1998-99, the number of juvenile coho salmon smolts passing over the trap at the exit to the lake was only half as many as those that were eaten by largemouth bass in the lake. Because the screen partially blocked salmon migration through the lake and upstream, it was removed in 1999.

Discussion

Juvenile coho salmon growth was higher in the lakes than in several nearby streams and higher than an average for south Puget Sound streams that was recorded in the literature (Rounsefell and Kelez 1938; Kahler et al. 2001; Figure 1). This suggests juvenile salmon were not growth-limited in the lakes we studied, and that food competition with introduced fishes, while possibly occurring, was likely unimportant in contributing to mortality of juvenile coho salmon. This is consistent with data from others (Swales and Levings 1989; Irvine and Johnston 1992; Bryant et al. 1996; Quinn and Peterson 1996) who found that coho salmon rearing in lakes grew faster than those in nearby streams.

We studied the effects of the most widely distributed introduced fishes in Washington's shallow lakes (Zook 1978; Fletcher 1982; Fletcher 1983; Washington Department of Fish and Wildlife 2003). Of these fishes, largemouth bass were the most important predators of coho salmon. Predation on salmon was important in all systems studied. The percent impact to the run was smallest in Lake Symington; however, only a portion of the run that exited the trap passed through the lake. Lake Symington was located midway in the watershed. If only half the salmon production was upstream of the lake, 10-20% of the salmon exposed to predation would have been removed, not 5-10%.

Future research to prioritize where largemouth bass predation is most severe would allow for the maintenance of valuable non-threatening largemouth bass populations for anglers while identifying those largemouth bass populations for potential control that would have a substantial effect on salmon runs. Predation impacts to salmon in our three lakes seemed greatest when there was a small coho salmon run passing through a lake containing a large littoral zone supporting many largemouth bass versus a large run passing through a small lake.

No specific largemouth bass size group (Age-1 and over) was responsible for more salmon predation than other size groups. While rapidly growing young largemouth bass typically require higher food rations, salmon were a small component of their diet. Because consumption of salmon was sporadic, there were no discernable differences in predation on salmon among largemouth bass size classes, even though smaller individuals may have eaten more food per gram body weight overall.

The results of our studies of three shallow lakes were different from those from studies of some large Pacific Northwest rivers and deep lakes where largemouth bass, and a related species, smallmouth bass *M. dolomieu* were less important predators on juvenile salmon. Northern pikeminnow, a native species, were the most important predators in the John Day Reservoir of the Columbia River, responsible for 78% of the total loss of juvenile salmonids (Poe et al. 1991). In large (8966 ha), deep (85 m) Lake Washington, smallmouth bass did not have a large impact on sockeye salmon populations (Fayram and Sibley 2000) in contrast to the significant effects of native cutthroat trout (Nowak et al. 2004). However, our results agree with others who have studied impacts of black basses in shallow systems. Impacts of smallmouth bass in the Hanford Reach of the Columbia River were greater, presumably because of greater habitat overlap among

juvenile salmonids and smallmouth bass (Tabor et al. 1993). In the shallow Tenmile Lake system of Oregon, Reimers (1989) stated that time association between the introduction of largemouth bass (1971) and reduced levels of coho salmon for the next 15 years was dramatic. He further stated that natural production of wild coho smolts was limited to the tributary streams because of high levels of predation in the lakes. Smallmouth bass introductions have been shown to drastically alter littoral zone native fish communities in central Ontario (Vander Zanden et al. 1999; MacRae and Jackson 2001), and removal of smallmouth bass from a New York lake resulted in a significant increase in the abundance of five species of native fishes (Weidel et al. in review). In years past, piscicide was regularly used to clear small and medium-sized Washington lakes of introduced warmwater predators and competitors so stocked trout fry, many of similar size to coho salmon juveniles, could survive. Decreased piscicide use in Pacific Northwest lakes, especially in western Washington, has made it difficult to clear them of introduced fishes, and survival of trout fry stocked into these systems is usually too low to support a viable fishery (Bradbury 1986). Currently most trout fisheries in western Washington are maintained by stocking large catchable trout (>150 mm) because mortality of smaller fry is too large to be cost-effective. In deeper systems, such as Columbia River reservoirs or Lake Washington, there may be more of a spatial separation of largemouth bass and salmon than in shallow lakes, allowing the salmon to avoid largemouth bass predation. In addition the small amount of littoral zone available for establishment of largemouth bass in deep lakes or riverine systems may limit their populations.

Largemouth bass are widespread, present in 85%, of the lowland warmwater public-access lakes of Washington (n=421)(Washington Department of Fish and Wildlife 2003). Because hundreds of these lakes are accessible to anadromous salmonids and are often used as rearing areas and migration corridors, future examination of the effects of largemouth bass predation on juvenile salmon on a landscape scale could help identify the overall impacts of this introduced species.

Whether a decrease in predation on coho salmon juveniles in lakes would translate into larger adult populations is unclear at this time. Kareiva et al. (2000) estimated that modest reductions in first-year or estuarine mortality would reduce population declines in Chinook salmon *O. tshawytscha*. In addition, coho smolt size is positively correlated with subsequent survival (Mathews and Ishida 1989; Holtby et al. 1990; Irvine and Johnston 1992) and those rearing in lakes are consistently larger than those in nearby streams. However, other important mortality factors such as climate conditions affecting ocean survival and the availability of summer low-flow habitat may dampen the benefits of attempting to improve lake survival by removing largemouth bass. Nevertheless, attempts to increase largemouth bass numbers in important coho rearing sites, or transplanting largemouth bass to lakes important to coho salmon would be counterproductive to coho salmon enhancement efforts.

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Table 1. Descriptions of study lakes for introduced fish/salmon interactions project. Fish species are BBH = brown bullhead catfish, BC = black crappie, CH = chum salmon, CT = cutthroat trout, GDS = golden shiner, GS = green sunfish, LMB = largemouth bass, PKS = prickly sculpin, PS = pumpkinseed sunfish, RB = rainbow trout/ steelhead, WM = warmouth sunfish, YP = yellow perch. Population estimate is number of largemouth bass > 150 mm TL.

Lake	Size (ha)	Watershed	Fish Species	Elevation (m)	LMB		Density (fish/ha)	
					Population Estimate	Low 95% C.I.		High 95% C.I.
Symington	24	Big Beef Creek	BBH, BG, CO, YP, LMB, RB, CT, GS, PS, WM	120	338	218	549	14.08
Long	127	Salmonberry/Curley Creeks	YP, BC, BG, LMB, CT, CO, CH, GDS, PKS, BBH	36	922	705	1205	7.26
Wildcat	44	Wildcat Creek	CO, PKS, CT, RB, LMB	116	438	361	533	9.95

Table 2. Percent by weight of stomach contents of fishes captured from three western Washington lakes. Data were separated into two one-year periods, March 1998-March 1999, and April 1999-March 2000.

Predator	N	Prey Item											
		Invertebrates		Non-Salmon Fish		Amphibians		Crayfish		Unidentified		Aquatic Plants, Detritus, And Other	
		(Not Crayfish)	Salmon Fish	Amphibians	Salmon Crayfish	Fish	Salmonid	Birds	Rodents	Salmonid	Birds	Rodents	Other
		Wildcat Lake 1998-99											
Coho salmon	15	99.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Prickly sculpin	162	89.62	2.72	0.00	4.64	0.00	0.19	0.00	0.00	0.00	0.00	0.00	2.84
Cutthroat trout	102	99.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.54
Largemouth bass	1240	16.58	67.27	2.27	1.57	4.09	1.02	4.91	0.00	0.00	0.00	0.00	2.29
Rainbow trout (Incl. Steelhead)	121	86.77	5.79	0.00	0.00	0.00	1.82	3.36	0.00	0.00	0.00	0.00	2.27
		Wildcat Lake 1999-00											
Coho salmon	32	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Prickly sculpin	82	99.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44
Cutthroat trout	58	99.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52
Largemouth bass	971	25.29	57.77	8.76	5.96	1.01	0.97	0.01	0.00	0.01	0.00	0.01	0.24
Rainbow trout (Incl. Steelhead)	66	99.02	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.93
		Long Lake 1998-1999											
Brown bullhead	227	95.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.09
Black crappie	210	88.61	5.29	0.00	2.31	0.00	0.45	0.03	0.00	0.00	0.00	0.00	3.31
Bluegill	329	97.53	0.26	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	2.18
Coho salmon	70	98.87	0.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
Prickly sculpin	96	83.12	3.91	0.00	0.00	11.62	0.77	0.00	0.00	0.00	0.00	0.00	0.57
Cutthroat trout	332	96.58	3.14	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.24
Golden shiner	1	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Largemouth bass	1008	6.34	74.62	2.75	3.09	6.67	1.43	1.42	1.23	0.26	0.00	0.00	2.18
Pumpkinseed	162	99.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51
Rainbow trout (incl. Steelhead)	12	89.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.22
Yellow perch	108	91.59	6.90	0.00	0.00	0.00	1.49	0.02	0.00	0.00	0.00	0.00	0.00
		Long Lake 1999-2000											
Brown bullhead	115	79.38	2.32	0.00	9.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.95
Black crappie	136	69.90	27.49	0.00	0.00	0.00	0.00	2.05	0.00	0.00	0.00	0.00	0.56
Bluegill	372	95.68	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	4.24
Coho salmon	149	99.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23
Prickly sculpin	159	73.44	22.07	0.00	0.00	0.00	0.00	0.12	3.63	0.00	0.00	0.00	0.74

Predator	Prey Item										Aquatic Plants, Detritus, And Other				
	Invertebrates (Not Crayfish)		Non- Salmon Fish		Amphibians		Salmon		Crayfish			Unidentified		Birds	Rodents
	N		N		N		N		N			Salmonid			
Cutthroat trout			333	86.63	12.38	0.29	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.64
Golden shiner			7	40.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	60.00
Largemouth bass			518	17.93	52.95	11.35	4.87	5.33			1.27	3.45	0.00	0.00	2.86
Pumpkinseed			130	98.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.05
Rainbow trout (incl. Steelhead)			15	88.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.23
Yellow perch			447	89.39	6.39	0.15	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	4.03
Lake Symington 1998-1999															
Brown Bullhead			186	90.01	2.22	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	7.51
Bluegill			48	99.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82
Coho Salmon			55	99.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10
Cutthroat Trout			136	95.38	2.07	0.00	0.11	0.00	0.00	0.35	0.00	0.00	0.00	0.00	2.09
Green Sunfish			54	81.74	0.00	17.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.85
Largemouth Bass			432	8.28	27.00	24.37	19.82	11.80		2.56	3.80	0.00	0.00	0.00	2.38
Pumpkinseed			212	93.46	0.28	0.41	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	5.79
Rainbow Trout			12	99.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15
Yellow Perch			165	92.29	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.07
Lake Symington 1999-2000															
Brown Bullhead			191	96.41	0.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.18
Bluegill			26	77.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.12
Coho Salmon			233	98.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.06
Cutthroat Trout			58	88.30	4.94	0.00	6.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45
Green Sunfish			93	99.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66
Largemouth Bass			281	18.39	25.01	19.72	12.59	9.12		0.42	6.93	0.00	0.00	0.00	7.82
Pumpkinseed			187	98.76	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	1.23
Rainbow Trout			4	99.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.66
Yellow Perch			103	94.15	0.28	0.00	1.28	0.00	0.00	0.00	0.46	0.00	0.00	0.00	3.84

Table 3. Survival of largemouth bass in three western Washington lakes. Numbers under age columns indicate number of fish in each age group captured.

Lake	Year	Age			Annual Survival Rate (S)
		1	2	3	
Wildcat	1998-99	802	233	213	0.52
	1999-00	1061	114	71	0.26
Long	1998-99	894	147	312	0.59
	1999-00	266	116	79	0.54
Symington	1998-99	188	129	31	0.41
	1999-00	235	12	25	0.33

Table 4. Number of coho salmon smolt equivalents eaten by largemouth bass in the three study lakes. The *low* and *nominal estimates* included only fish that could be positively identified as salmon in the diet and were based on the lower 95% confidence level and the nominal estimate of the largemouth bass population estimate respectively. The *high estimate* was based on the upper 95% confidence level of the largemouth bass population estimate and included both fishes that could positively be identified as salmon, and unidentified salmonid fishes in the diet. Smolt abundance for Lake Symington was the number of smolts that passed through the Big Beef Creek Trap close to the outlet of Puget Sound in 1998 and 1999, respectively. Smolt abundance for Wildcat Lake was the number of smolts that passed through the trap at the outlet of the lake in 1998 and 1999, respectively. Smolt abundance for Long Lake is the range of smolt production potential for Salmonberry Creek only (low number) that flows into Long Lake to smolt production potential for Salmonberry and Curley Creeks combined (high number). Curley Creek exits Long Lake and flows into Puget Sound.

Number of Smolt Equivalents Eaten by Largemouth Bass					
Lake	Year	Low	Nominal	High	Smolt Abundance
Symington	98-99	1131	1754	3311	22,222 – 20,967
Symington	99-00	603	908	2356	
Long	98-99	1082	1414	2108	3,478-8,404
Long	99-00	2090	2728	4632	
Wildcat	98-99	73	88	461	30-55
Wildcat	99-00	0	0	109	

Table 5. Salmon consumption (numbers) by entire largemouth bass population each day during each season as estimated by the Wisconsin bioenergetics model. Spring–early summer was defined as April 1 – mid-July (14th-20th depending on lake and year). Late summer–early fall was defined as mid-July (14th-20th) – Late October (13th-28th). Late fall–winter was defined as Late October (13th-28th) – end of March (31st). In Lake Symington, 1999, season change between LS/EF and LF/W was September 15.

Lake	Year	Spring-Early Summer	Late Summer-Early Fall	Late Fall-Winter
Symington	98-99	16.047	0.522	0.036
Symington	99-00	7.505	0.000	0.773
Long	98-99	11.252	0.913	0.747
Long	99-00	7.217	5.443	8.858
Wildcat	98-99	0.838	0.000	0.000
Wildcat	99-00	0.000	0.000	0.000

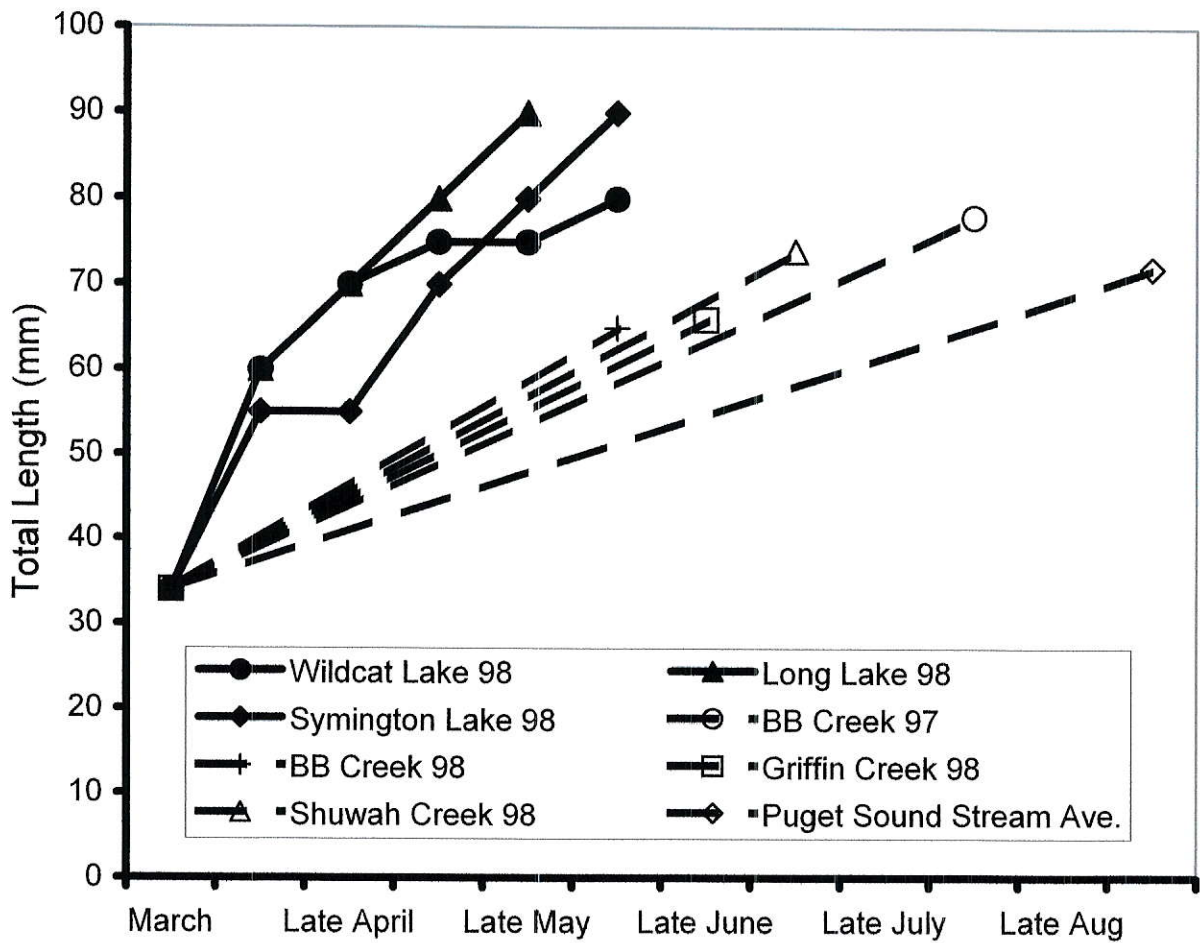


Figure 1. Growth of coho salmon juveniles in the three study lakes and in Puget Sound streams. Coho salmon emerge from the gravel in nearby creeks in March at an average size of approximately 34 mm TL (Sandercock 1991).

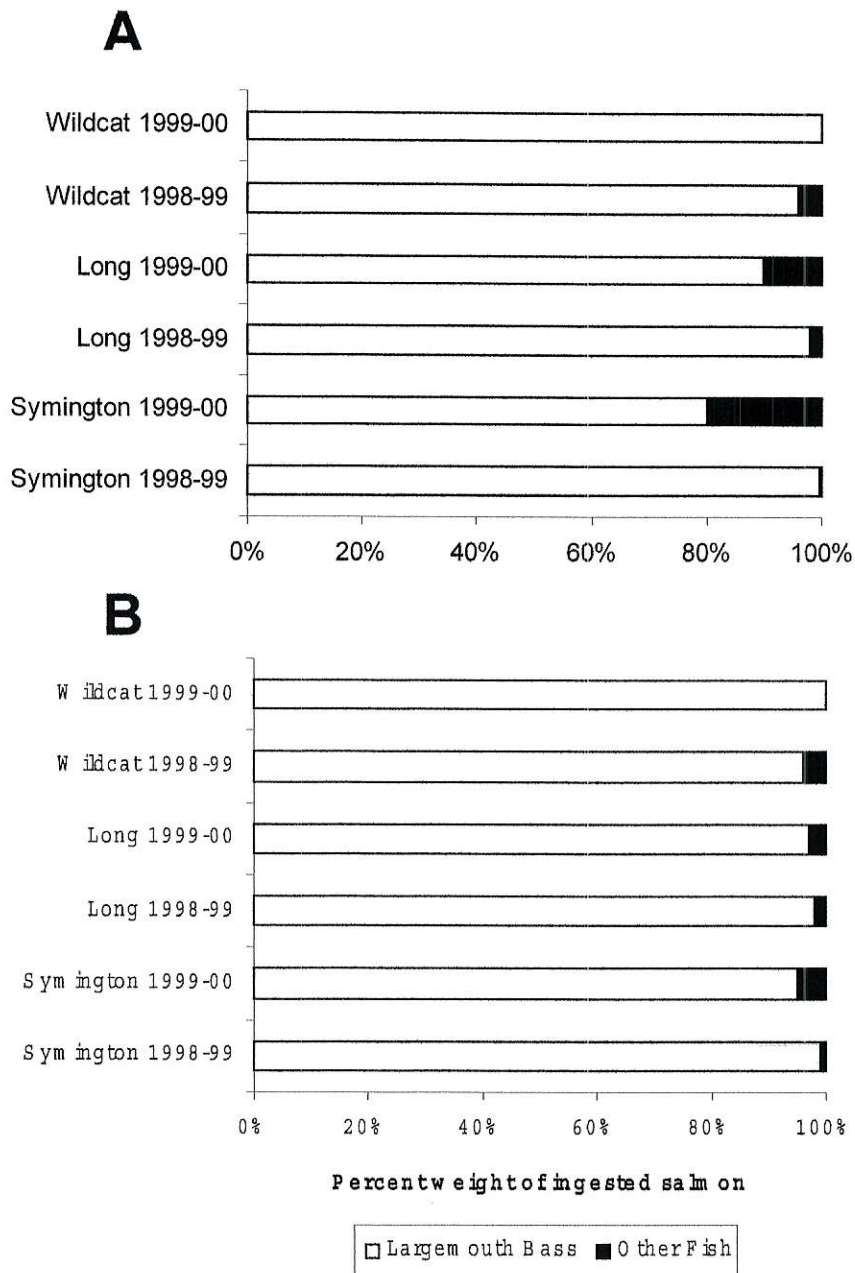


Figure 2. Percent distribution of total salmon ingested recovered from fish diets of various predators (A). Same data standardized by catch (B, mean number of salmon per individual fish of each species x number of fish of that species in total catch). Wildcat 1999-2000 data based on fish identified as salmonids.

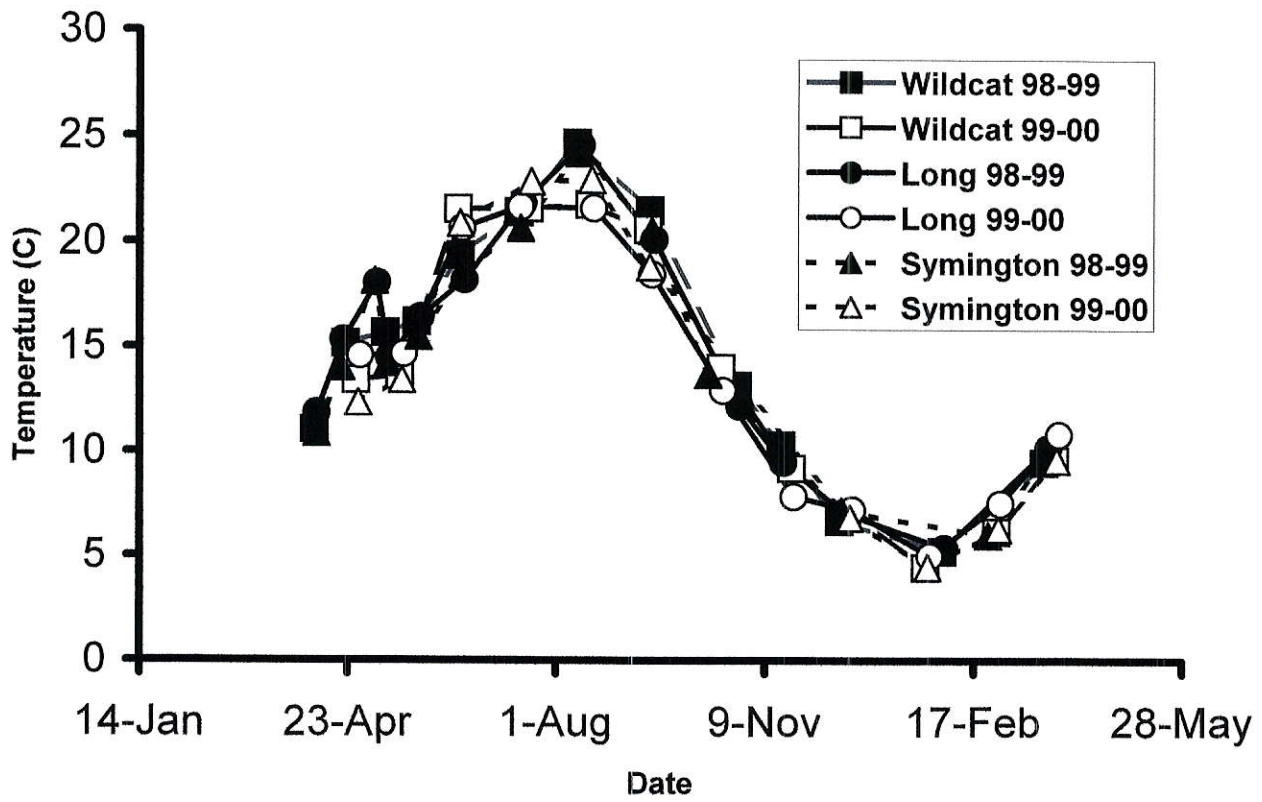


Figure 3. Thermal experience of largemouth bass in three western Washington lakes, April 1998-April 2000.

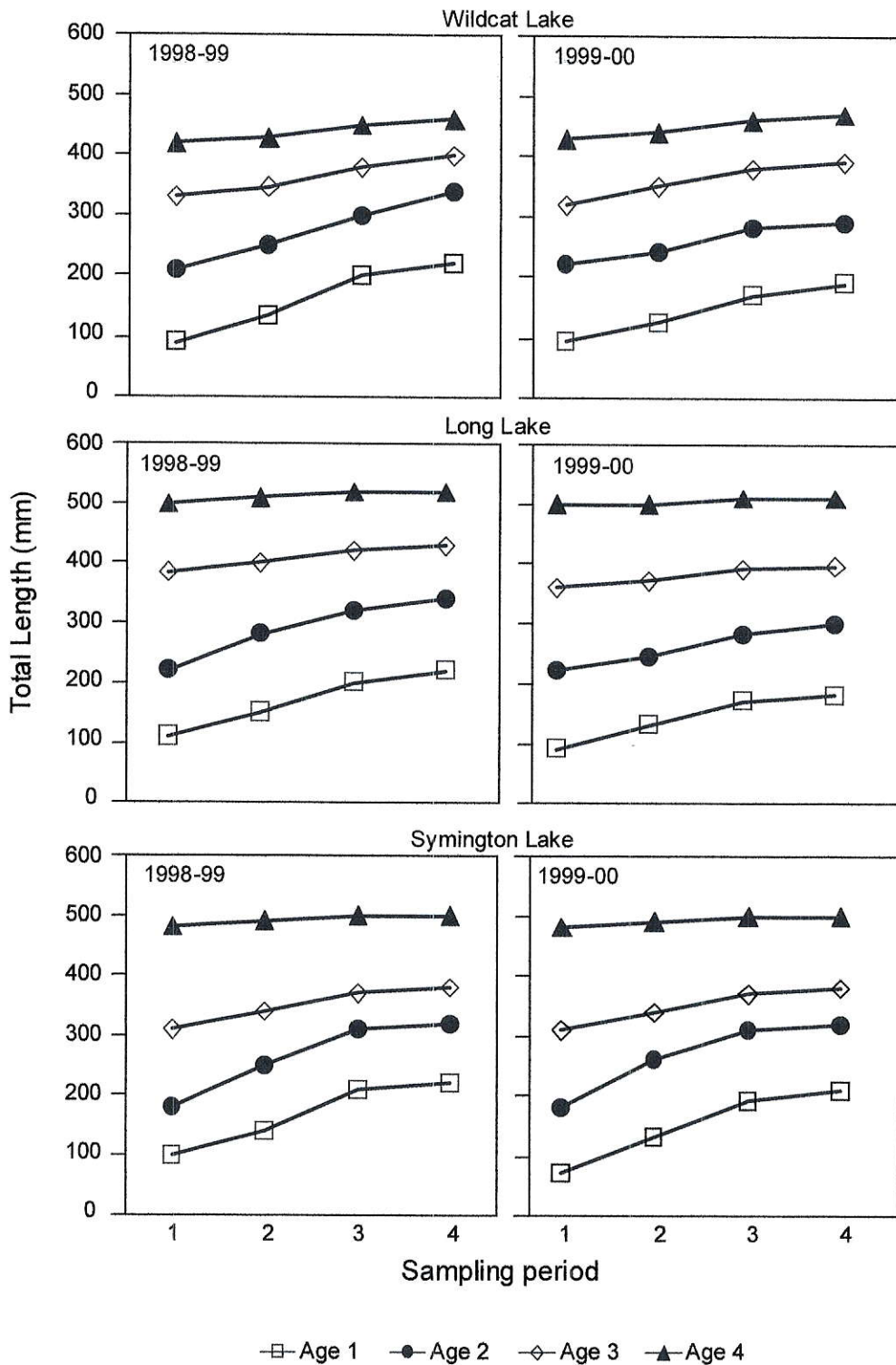


Figure 4. Modal total length of largemouth bass at sampling period 1 (April 7-9, 1998; April 27-29, 1999), period 2 (July 14-17, 1998; July 15-20, 1999); period 3 (October 13-28, 1998; Symington September 15, 1999, Wildcat and Long, October 19-20 1999) and period 4 (March 23-25, 1998; March 28-30, 1999). Age-4 bass include age-4 and older.

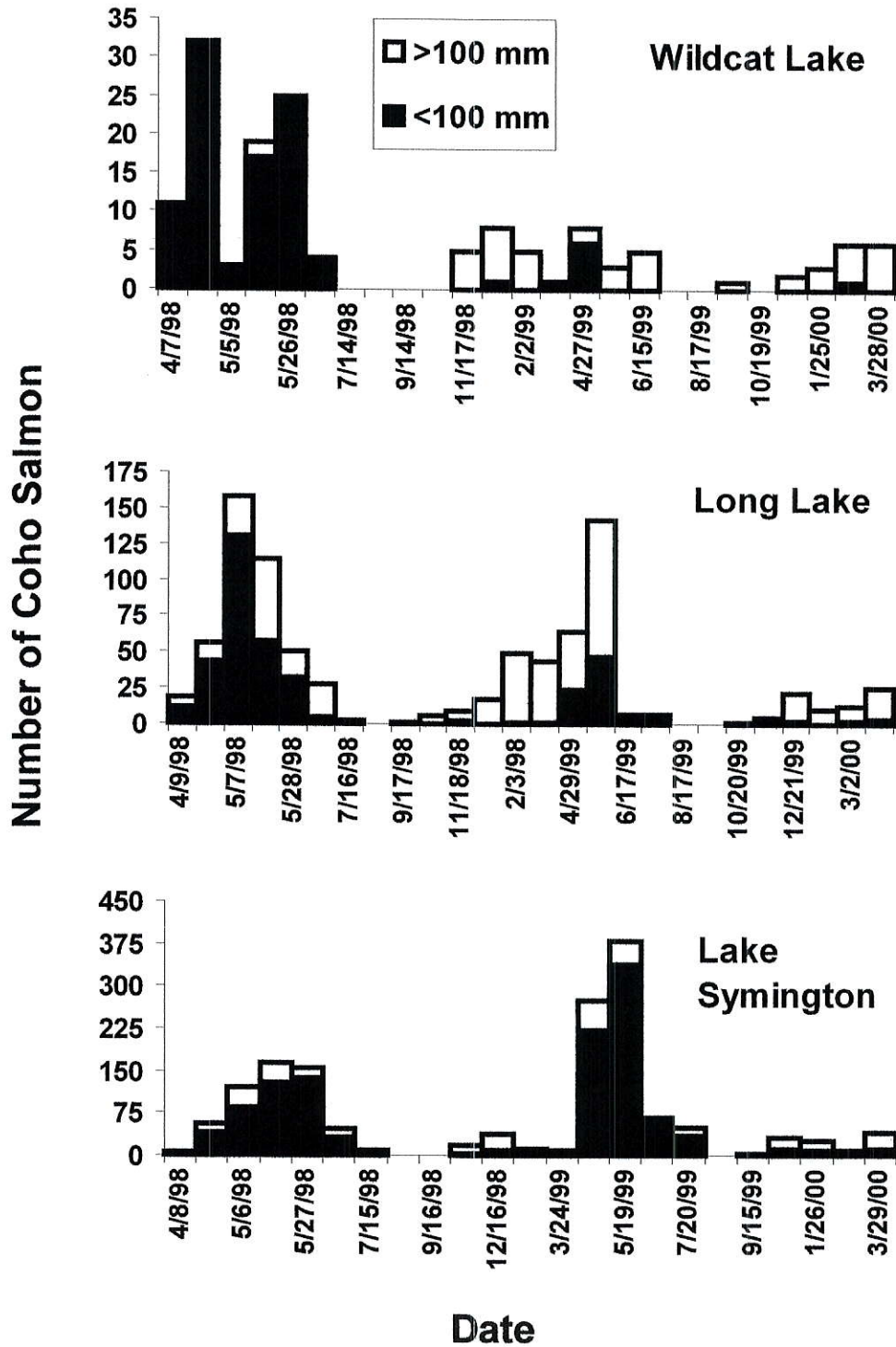


Figure 5. Number of coho salmon captured in each lake by time of year. Effort was similar for all surveys. Coho salmon catch per unit effort was underestimated for the spring, 1998 in Lake Symington. Not all coho salmon electrofished were brought onto the boat for counting and weighing.

This program receives Federal financial assistance from the U.S. Fish and Wildlife Service Title VI of the Civil Rights Act of 1964, Section 504 of the Rehabilitation Act of 1973, Title II of the Americans with Disabilities Act of 1990, the Age Discrimination Act of 1975, and Title IX of the Education Amendments of 1972. The U.S. Department of the Interior and its bureaus prohibit discrimination on the bases of race, color, national origin, age, disability and sex (in educational programs). If you believe that you have been discriminated against in any program, activity or facility, please write to:

U.S. Fish and Wildlife Service
Office of External Programs
4040 N. Fairfax Drive, Suite 130
Arlington, VA 22203

FW: Devils Lake

1 message

josh@dlwid.org <josh@dlwid.org>

Wed, Oct 19, 2022 at 3:34 PM

To: Susan Elworth <susan.elworth@gmail.com>, Bryan O'Doherty <jbo@bryanodoherty.com>

Cc: Tina French <tfrench@northlincolnsanitary.com>

Great news! One more item off the list.

Joshua Brainerd

Executive Director

Devils Lake Water Improvement District

[4006 NE West Devils Lake Road](#)

[Lincoln City, Oregon, 97367](#)

541-994-5330



From: SPANGLER John J * ODFW <John.J.SPANGLER@odfw.oregon.gov>

Sent: Wednesday, October 19, 2022 2:48 PM

To: josh@dlwid.org

Subject: FW: Devils Lake

Josh,

Looks like there will not be a need to consult with NOAA. Please keep this email in your files.

John Spangler

Midcoast District Fish Biologist

[810 SW Alder St., Unit C](#)

[Newport, OR 97365](#)

541-812-8689

Email: John.J.SPANGLER@odfw.oregon.gov

From: SPANGLER John J * ODFW
Sent: Wednesday, October 19, 2022 2:46 PM
To: Kathleen Wells - NOAA Federal <kathleen.wells@noaa.gov>; Lance Kruzic - NOAA Federal <lance.kruzic@noaa.gov>
Subject: RE: Devils Lake

Thanks Kate, Lance,

I'll let the Devils Lake folks know they can proceed with developing their application for stocking grass carp in Devils Lake pending OAR revision approval by the Commission.

From: Kathleen Wells - NOAA Federal <kathleen.wells@noaa.gov>
Sent: Wednesday, October 19, 2022 2:43 PM
To: Lance Kruzic - NOAA Federal <lance.kruzic@noaa.gov>
Cc: SPANGLER John J * ODFW <John.J.SPANGLER@odfw.oregon.gov>
Subject: Re: Devils Lake

That's correct. We only do section 7 consultations with federal agencies i.e., that's what creates a federal nexus.

Kate Wells

Willamette/(Interim) OR Coast Branch Chief

NMFS Oregon Washington Coastal Office

(503)-230-5437

On Wed, Oct 19, 2022 at 2:20 PM Lance Kruzic - NOAA Federal <lance.kruzic@noaa.gov> wrote:

Hi Kate,

Just got off the phone with John Spangler, ODFW, cc'd here. He wants confirmation that no consultation is required for Devils Lake because there is no federal nexus for NMFS. Can you confirm or deny back to John on this? Thanks for your response, lance

--

Lance Kruzic

Fisheries Biologist

Hatcheries and Inland Fisheries

Sustainable Fisheries Division

NOAA Fisheries, NMFS

Roseburg, Oregon

phone : 503-758-3141

lance.kruzic@noaa.gov



Devils Lake Water
Improvement District

STERILE GRASS CARP STOCKING RECOMMENDATION

<<DRAFT>>

ADOPTED ??????, 2022

Board of Directors:

Tina French, Chair

Rob Ellis, Director

Susan Elworth, Director

Keith Fowler, Director

Mitchell Moore, Director

Executive Director: Joshua Brainerd

GRASS CARP GROWTH, ENVIRONMENT AND CONSUMPTION

Water Temperature Affects SAV Consumption

Per discussion with KEO Fish Farm, grass carp reach 12 inches in 1-2 years, which is the recommended initial stocking size for Devils Lake. According to the University of Florida study noted below, grass carp are Juveniles and continue to grow and develop between 1-9 years, after which they are mature Adults. Grass carp consumption of Submerged Aquatic Vegetation (SAV) is primarily determined by the water temperature, the attractiveness of the SAV as a food source, and the age of the carp. Water temperatures around 68 degrees result in high consumption (2-3 times carp body weight per day) while temperature below 60 degrees result in much lower consumption (less than 1 times body weight).

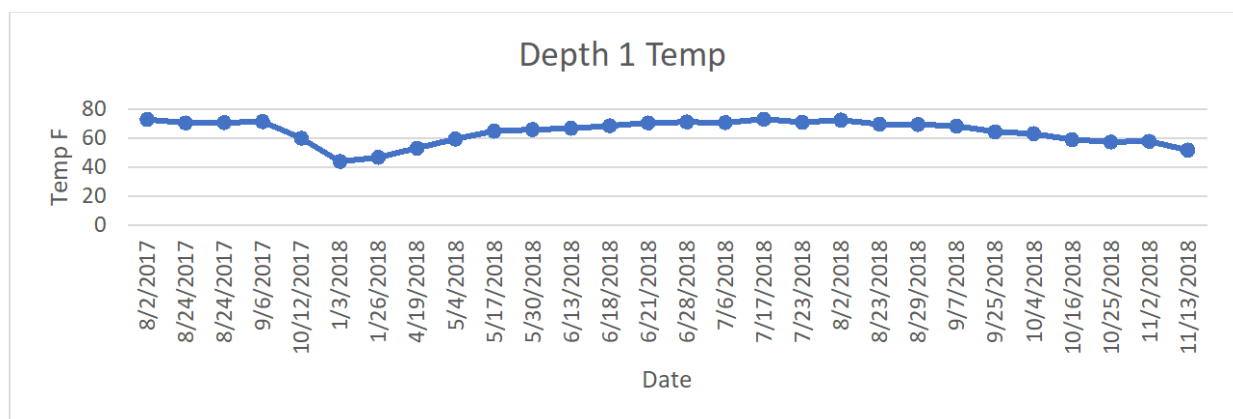
Hydrilla/elodea are favorite SAV sources for grass carp as they are easier for the carp's grinding eating process to break down and consume than SAV such as Milfoil. Grass carp consume more food during the first six years of their life and then consumption slows. In ideal conditions, a newly stocked 12-inch grass carp in 68-degree water with heavy elodea presence can grow 2 inches per month and gain 10 pounds per year until maturity.

Virginia DWR Agency states "Under good conditions a five-pound fish will eat about five pounds of aquatic plants a day! As fish become larger consumption decreases, and a 20-pound fish may eat only four pounds of plants a day. Feeding rates are temperature dependent and slow down drastically below 60°F. Therefore, grass carp are not recommended for trout ponds."

<https://dwr.virginia.gov/fishing/private-pond-management/triploid-grass-carp-stocking-for-aquatic-vegetation-control/>

As the table below shows, Devils Lake water temperature is at or below 60 degrees for approximately eight months of the year. Therefore, we expect significantly less SAV consumption for grass carp in Devils Lake than in the lakes of the South.

Devils Lake Water Temperature Record:



Age and Size Affects SAV Consumption

With respect to range of size and lifespan, that same Virginia DWR guidance states, “The white amur or grass carp is a rapid growing, plant-eating fish native to the large rivers of eastern China and Siberia. They are one of the largest members of the minnow family and fish as large as 110 pounds have been collected from the Yangtze River in China. A more typical size for Virginia waters would be 20 lbs. Life span typically ranges from 5 to 11 years, but fish over 20 years old have been collected in China.”

A University of Florida study states, “In the warm waters of Florida, with abundant food, grass carp grow quickly at around 2 lbs/month or 0.91 kg/month and may achieve weights of 97 lbs (44 kg) (Sutton et al. 2012). Younger fish and female fish grow faster than older or male fish.

The introduction of grass carp is the most effective biological control tool that has been identified for hydrilla. Additionally, although conversion of plant material to protein by the grass carp is not highly effective, it is still the best use for hydrilla. Every 1 lb (0.45 kg) increase in fish weight requires 5-6 lbs (2.3-2.7 kg) of dry hydrilla (Sutton et al. 2012), which - considering hydrilla is 95% water - is a great deal of live plant material.”

https://entnemdept.ufl.edu/creatures/BENEFICIAL/MISC/Ctenopharyngodon_idella.htm

CH2M Hill 1992 Annual Maintenance Stocking Recommendation

In June 1992, CH2M Hill produced a *Devils Lake Monitoring Final Report* for the District. It concluded that grass carp had no negative affect on other fish, that it was effective in reducing weeds, and that the carp appeared to be growing at a rate faster than other areas in the country. However, they noted that initial fish mortality of as much as 50 percent for newly introduced grass carp, especially after long-distance transport. Assuming that to be the case at Devils Lake, and assuming a further 10 percent per year mortality, it would be desirable to provide for annual maintenance stocking of 2,000 fish to achieve sufficient stocking to control the weeds. CH2M Hill’s mean length and weight information for grass carp is charted below.

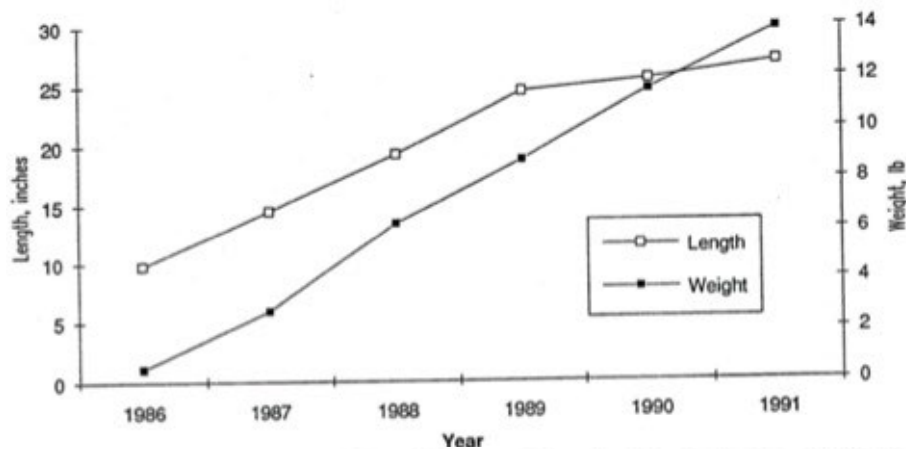


Figure 6. Length and Weight of Grass Carp in Devils Lake, 1986-1991.

The experience of Devils Lake over the past 35 years is long-lived carp that matured at a smaller weight – not unlike Virginia. This smaller weight may be due to the colder water temperature, the lower attractiveness of the available food source at the time, and the decimation of their food sources by overstocking.

Recommendation Stocking Rates Based Upon the Science:

There are numerous articles, studies, and scientific presentations regarding how many grass carp to stock in ponds and lakes. Those generally present stocking recommendations based upon the percentage of SAV in the body of water. Studies generally describe SAV infestation levels as LOW (< 30% SAV volume), MODERATE (30%-60%), and HEAVY (> 60%). Distilling the recommendations from the many studies by governmental fish and wildlife agencies, SAV control experts and scientific papers, the consistent stocking rates recommended based upon SAV infestation level are

LOW – recommend 2-5 grass carp per acre.

MODERATE - recommend 5-10 grass carp per acre.

HEAVY - recommend 10-20 grass carp per acre.

CONCLUSION AND RECOMMENDATION

Devils Lake is cooler than the lakes of the South, its SAV infestation of elodea is HEAVY, and it currently has no productive grass carp. In addition, the grass carp will be trucked from Keo, Arkansas, which may result in a significant mortality from transporting. Accordingly, a HEAVY stocking rate of 15 fish per acre, reviewed for restocking every five or six years appears appropriate. That results in an initial stocking of 10,200 sterile grass carp. Once maintenance level of 15-20% vegetation is achieved, a restocking rate of 3 fish per acre is recommended for continued maintenance of the lake SAV.



Updated Bathymetry and Paleolimnology of Devils Lake, Lincoln County, Oregon

A Report Prepared for
Devils Lake Water Improvement District
Bend, OR

By

J.M. Eilers¹
B.J. Eilers¹
Roger Sweets²
Ann St. Amand³

Through

MaxDepth Aquatics, Inc.
Bend, OR

May 2005

¹MaxDepth Aquatics, Inc., 1972 NE 3rd St., #10, Bend, OR 97701

²Indianapolis University, Indianapolis, IN

³PhycoTech, Inc., St. Joseph, MI

ABSTRACT

A bathymetric map and paleolimnological analysis were conducted on Devils Lake in 1994. New technology and sediment analysis techniques have made it possible to improve on the approaches used in 1994. The Devils Lake Water Improvement District (DLWID) contracted with MaxDepth Aquatics, Inc. to develop a new bathymetric map and to conduct another paleolimnological analysis of the sediments in Devils Lake. The field survey for the lake mapping and sediment collection were carried out in March 2005. The mapping was conducted using 25 m transects and the finished bathymetric map was positioned within a recent satellite Ikonos satellite image of the area. The updated map has a spatial accuracy of about 1 m.

The sediment analysis showed that the sediment accumulation rate in Devils Lake has continued to increase and that the rate of increase appears to be nearly linear. The concentrations of carbon, phosphorus, and nitrogen in the sediment all appear to be increasing as well. The analysis of the diatoms in the sediment core show that Devils Lake underwent a transition circa 1994 following the loss of macrophytes associated with the consumption by the introduced grass carp. The diatoms show a major reduction in taxa that typically grow on other aquatic plants and a corresponding increase in the proportion of planktonic diatoms. An analysis of cyanobacterial akinetes in the sediments shows that there has been a major increase in the density and deposition rate of akinetes in the recent sediments. This indicates that production of blue-green algae has increased.

The results indicate that elimination of the aquatic macrophytes in the 1990s has resulted in an increase in planktonic diatoms and cyanobacteria. To reverse this trend, we recommend actions that will allow macrophytes to return to Devils Lake.

INTRODUCTION

A bathymetric map and paleolimnological analysis were conducted on Devils Lake in 1994 (Eilers et al. 1996). New technology and sediment analysis techniques have made it possible to improve on the approaches used in 1994. The Devils Lake Water Improvement District (DLWID) contracted with MaxDepth Aquatics, Inc. to develop a new bathymetric map and to conduct another paleolimnological analysis of the sediments in Devils Lake. The objective of conducting a new bathymetric survey was to provide a high resolution map of the lake that could serve as a benchmark against which to judge future changes. The purpose of the paleolimnological analysis was to extend the information collected ten years earlier and to determine if trends observed in Devils Lake were continuing and to add to previous analyses by measuring cyanobacterial akinetes and other nutrients in the sediment.

METHODS

The bathymetric survey for Devils Lake was conducted on March 24-25, 2004 at a time when the lake stage was at 8.75 ft MSL. The survey was conducted using transect intervals of 25 m oriented east-west (Figure 1). The soundings were collected with a BioSonics echosounder equipped with a 200 KHz split-beam transducer. Boat speed was set to about 9.5 kph and soundings were done at 5 pings per second, a pulse length of 0.4 sec with a threshold value of -65 dB. Positional data were derived from a JRC DGPS WAAS receiver with a nominal error of about 1 m. The data were stored on board and later processed with BioSonics VBT software. The 10 m grid was generated from the acoustic data using a kriging algorithm; contours were generated from the grid file. The finished map was placed in the landscape using an Ikonos rectified satellite image collected on September 21, 2003 and processed by Spatial Solutions, Inc., Bend, OR. No adjustments were done to the bathymetric map to have it positioned within the landscape image.

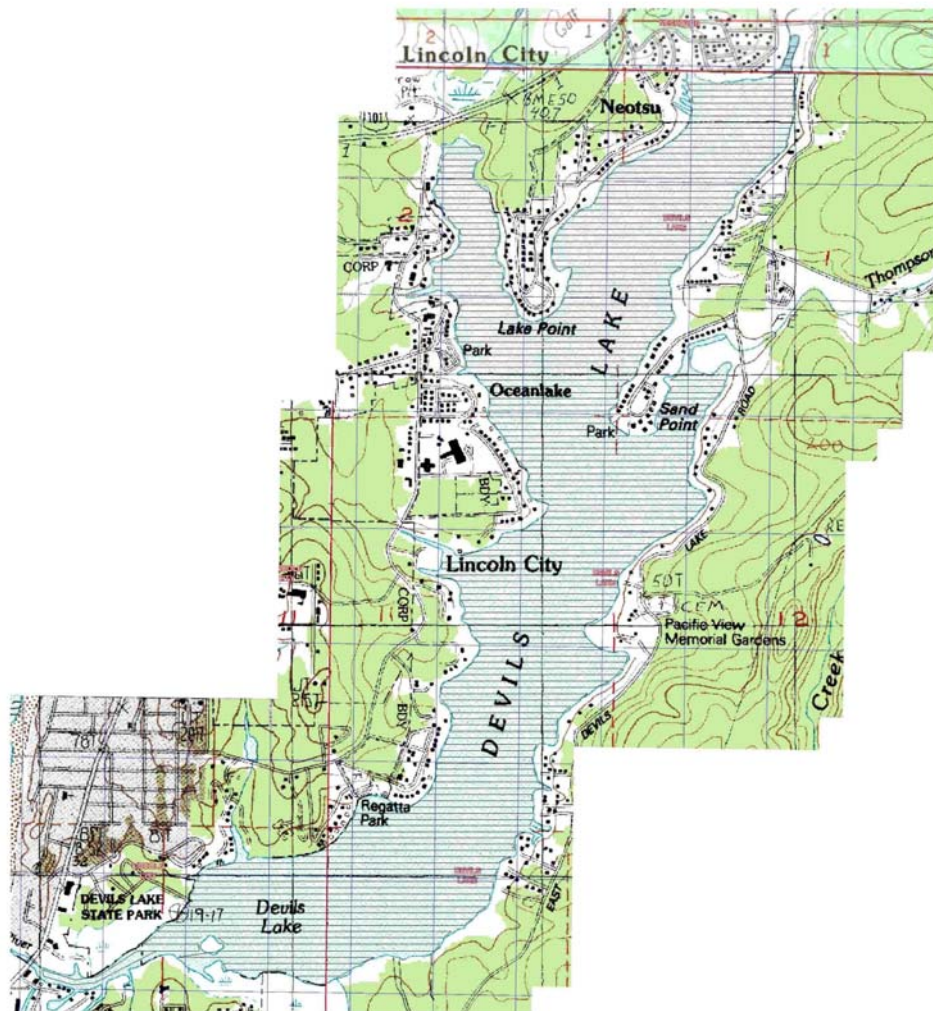


Figure 1. Topographic map of Devils Lake and vicinity showing the survey pattern used to map Devils Lake in 2004.

Two sediment cores were collected from near the center of Devils Lake on March 25-26, 2004. The two cores were inspected on the lake shore and it appeared that core “A” collected on March 25 showed the least degree of disturbance at the sediment-water interface and along the sidewall. Core “A” was located at latitude 44 58’ 49.89” and longitude 123 59’ 29.15” at a lake depth of 3.4 m. The total core length was about 150 cm; the upper 100 cm of the core were sectioned, placed in WhirlPac bags, and refrigerated prior to shipping to the various laboratories.

Sediment intervals 0 to 60 cm from the primary core were shipped to the Soils Laboratory at Oregon State University (OSU) in Corvallis for analysis of percent moisture (Table 1). A selected set of 20 intervals were shipped to MyCore Scientific in Ontario for analysis of ²¹⁰Pb. Additional intervals were shipped to MyCore Scientific to help minimize some of the uncertainties in dating the material. Based on the results of the sediment dating, selected intervals were shipped to PhycoTech for analysis of diatoms and cyanobacterial akinetes. Additionally, the analysts at OSU were directed to use selected intervals for analysis of carbon, nitrogen, and phosphorus.

Table 1. Sediment intervals for analysis of historical changes in Devils Lake. The interval value shown below represents the bottom of the interval.

Core DVA (cm)	Moisture	²¹⁰ Pb Dating	Akinetes	Diatoms	C, N, P
	OSU	MyCore	PhycoTech	University of Indianapolis	OSU
1	X	X	X	X	
2	X				X
3	X	X	X	X	X
4	X				
5	X	X		X	X
6	X		X		
7	X	X		X	X
8	X		X		
9	X	X		X	X
10	X		X		
11	X	X		X	
12	X		X		
13	X	X			X
14	X				
15	X	X	X		
16	X				X
17	X	X			
18	X		X		
19	X	X			X
20	X		X		
21	X	X			X
22	X				
23	X	X	X		
24	X				X
25	X	X	X		
26	X				X
27	X	X	X		
28	X		X		
29	X	X			X
30	X		X		
31	X	X	X		
32	X				X
33	X	X			

Table 1. cont.					
Core DVA (cm)	Moisture	²¹⁰ Pb Dating	Akinetes	Diatoms	C,N,P
34	X	X	X		
35	X				X
36	X	X			
37	X				
38	X		X		X
39	X	X			
40	X	X	X		
41	X				
42	X				X
43	X		X		
44	X				
45	X				
46	X		X		
47	X				
48	X				
49	X		X		
50	X				
51	X				
52	X				
53	X				
54	X				
55	X				
56	X				
57	X				
58	X				
59	X				
60	X				

1. Analytical Methods

The analytical methods selected for application in the Devils Lake study are summarized in Tables 2 and 3 and described below.

Table 2. Summary of analytical analyses used in the Devils Lake study and laboratories associated with the specific analyses.

Analysis	Number	Laboratory	Method
Percent Water	60	MyCore	Gravimetric
²¹⁰ Pb	20	MyCore	Modified Appleby and Oldfield (1978)
C,N	20	OSU	CNS Leco Analyzer
TP	20	OSU	Kjeldahl digestion
Diatoms	20	PhycoTech	Acid digestion, microscopy, 500+ cells per slide
Akinetes	20	PhycoTech	Microscopy

The water content of the sediments was determined by measuring the weight loss of samples dried at 105 °C. Carbon, nitrogen, and sulfur were analyzed using a Leco model CNS-2000 elemental analyzer. Standard Leco operating procedures were followed using sulfamethazine for standardization and a combustion temperature of 1350° C. Copper was analyzed with a Perkin Elmer Optima 3000 DV ICP spectrometer using the radial view. Samples were first digested in a CEM Corporation model MDS-2000 microwave digestion oven. A total digest of the sediment (CEM Corp., 1991) using HNO₃, HF, HCl, and H₃BO₄ was used for the analysis of P.

²¹⁰Pb was analyzed using alpha spectroscopy (Eakins and Morrison 1978), which involves distillation of the sample, HNO₃ and HCl digestion, and plating onto silver prior to counting. Analytical details are presented in Flynn (1968) and Evans & Rigler (1980) with modifications described in Cornett et al. (1984) and Rowan et al. (1995). The sediment ages and accumulation rates were calculated using the constant-rate-of-supply (CRS) model of Appleby & Oldfield (1978). Additional details regarding the sediment dating process are available on www.mycore.ca.

The analysis of the diatoms involved procedures developed over the last several decades. A milliliter of sediment from each interval was digested by a 'cold digestion' method. The sediment is rinsed into a beaker with a minimal amount of distilled water. Typical volumes at this stage are about 10 ml. Two to three times that amount of concentrated sulfuric acid H_2SO_4 is added to the beaker. A saturated solution of potassium permanganate is added at this stage resulting in rapid heating and digestion of organic matter. The permanganate is continually added until no digestion appears to take place. A saturated solution of oxalic acid is then added to 'clear' the solution. The digestate is replaced with water by removing the supernatant after settling through a lengthy series. The final volume of cleaned diatoms is brought to 15 ml. A measured amount is placed on a cover slip using a pipetter; water is sometimes added to gain an efficient and even spread of diatoms on the cover slip. The water is left to dry at low heat and the cover slip is then fixed in Hyrax[®] medium on a slide. The diatoms are counted using both phase and bright-field optics on an Olympus[®] BH-2 microscope. Counts are generally between 400-600 valves. Girdle views are identified. Broken frustules are counted by the protocol of a single identifiable point for each valve. All valves in a colony are counted. Taxonomy is drawn from a wide array of texts, much of which resides on Sweets' extensive photographic documentation. Principal texts referred to are Patrick and Reimer (1966, 1975), Krammer and Lange-Bertalot (1986-1991), and others. In this report a traditional taxonomy is employed that does not include some of the proposed genera of the last 20 years, principally to provide clarity with comparison with a diatom core investigation predating these texts by Whiting (Eilers et al. 1996), other paleoecological investigations from the same region, and also because ecological and paleoecological investigations are performed with slightly different goals than taxonomic investigations that require SEM techniques. For Devils Lake this principally involves subdivisions of the important *Fragilaria* species and some *Navicula* species.

Slides for enumeration of akinete counts were prepared by diluting a 1 mL subsample of the lake sediments to 20 mL. From this diluted subsample, 0.25 mL was permanently mounted in HPMa using a modification of Crumpton (1987) and St. Amand (1990). Cyanobacterial akinetes were counted on an Olympus BMX60 microscope equipped with Nomarski optics and epifluorescence. Cells and colony remnants were visualized using blue-light epifluorescence at 400X. Between 300 to 400 random fields were spread evenly over three slide mounts per sample. In the case of colony remnants, cells per colony were also tabulated. Pollen grains and *Pediastrum* cells were also counted along with the akinetes.

Table 3. Analytical Quality Control and Performance Criteria for the Devils Lake study.

Matrix	Parameter	Method	Precision	Accuracy	Quantitation Limit
Sediment	Water	Gravimetric	± 1.0 °C	± 0.5 °C	0.001 %
	C,N	Leco CNS	± 8 %	± 26 %	1 ppm
	P	TKN digestion; RFA methodology	$\pm 8\%$ of Std. Value	$\pm 26\%$ of Std. Value	1 ppm
	^{210}Pb	Alpha Spectroscopy	$\pm 0.5\%$	± 2.5 %	0.0003 Bq/g
	Diatoms	Microscopy	NA	NA	NA
	Akinetes	Microscopy	NA	NA	NA

RESULTS

1. Lake Bathymetry

The updated bathymetric map shows the general pattern described with the earlier map, but the updated version displays considerably greater details (Figure 2). Devils Lake is shallow and the vast percentage of the lake volume is contained in the upper 4 m (Figure 3). The updated bathymetric map has a slightly greater surface area and is slightly deeper than the 1994 version (Table 4). The improvement in accuracy of the surface area was made possible through the used of the satellite image of the lake. No macrophytes were observed in the echograms gathered during the Devils Lake mapping survey in 2004.

Devils Lake

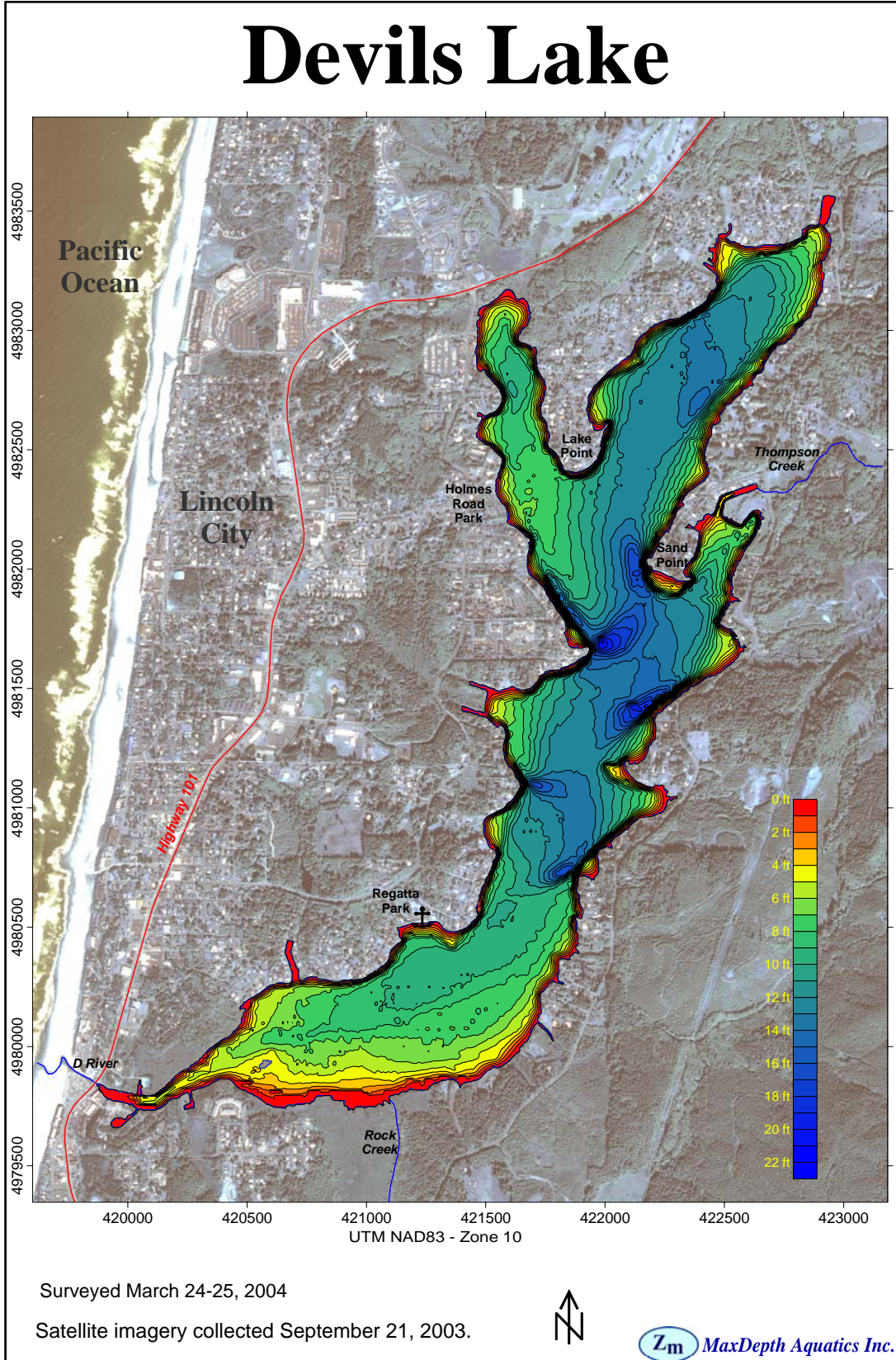


Figure 2. Updated bathymetry of Devils Lake, Lincoln County, Oregon.

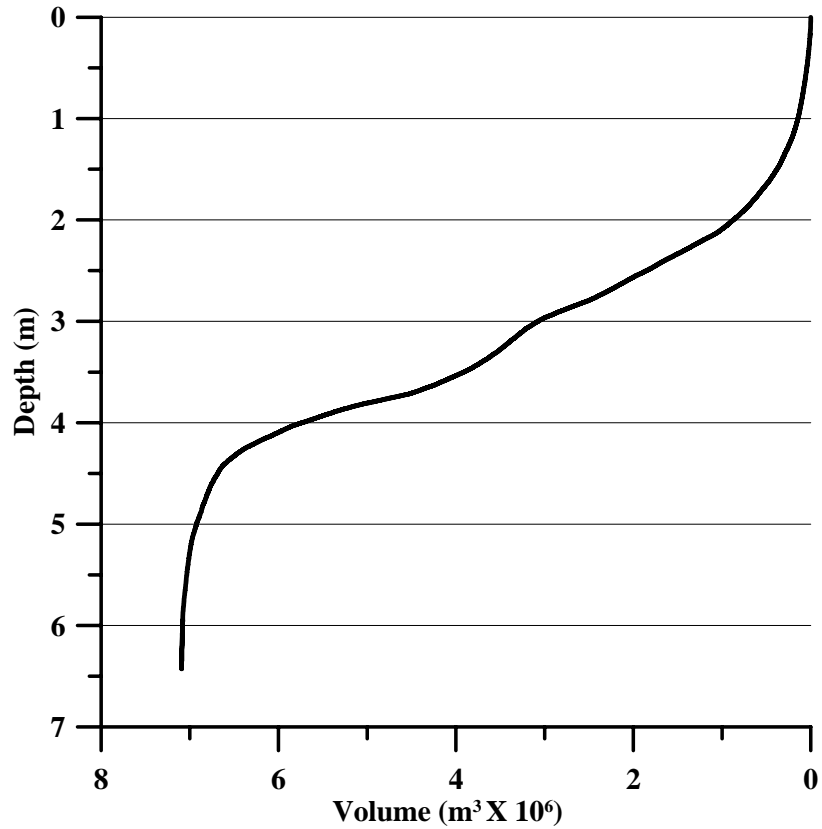


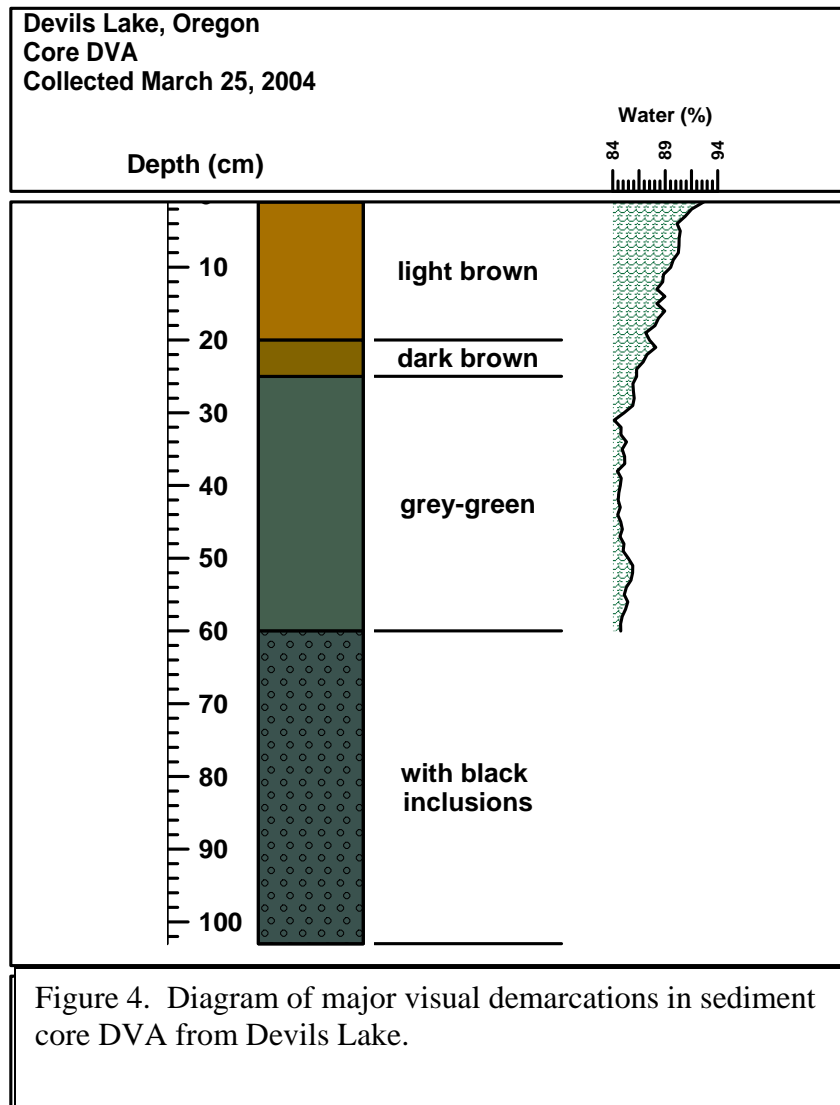
Figure 3. Lake depth versus lake volume for Devils Lake, based on the bathymetry collected in 2004.

Table 4. Comparison between lake morphometry based on surveys conducted in 2004 (this study) and 1994 (Eilers et al. 1996).

Parameter	Unit	2004	1994	Percent Change
Area	ha	277.2	270.7	+2.4
Ave. Depth	m	2.56	2.3	+11.3
Max. Depth	m	6.43	5.8	+10.9
Volume	m ³ X 10 ⁶	7.092	6.14	+15.5

2. Paleolimnology

The sediment in Devils Lake shows high water content in the upper sediments and gradually decrease to relatively moderate moisture levels at a depth of about 60 cm (Figures 4 and 5). The activity of ^{210}Pb in the sediment declined gradually throughout the upper core, and the resulting estimates of sediment age have moderately low levels of uncertainty (Figures 6 and 7). The sediment accumulation rate (SAR) in Devils Lake shows a linear increase ($R^2 = 0.973$) through the period of record (Figure 8). Concentrations of carbon and nitrogen also exhibit fairly linear increases in the sediment (Figures 9 and 10), although the percent of the data explained by the linear regression is somewhat lower than that for SAR. In contrast, the phosphorus concentrations in the sediment exhibit no recognizable pattern (Figure 11).



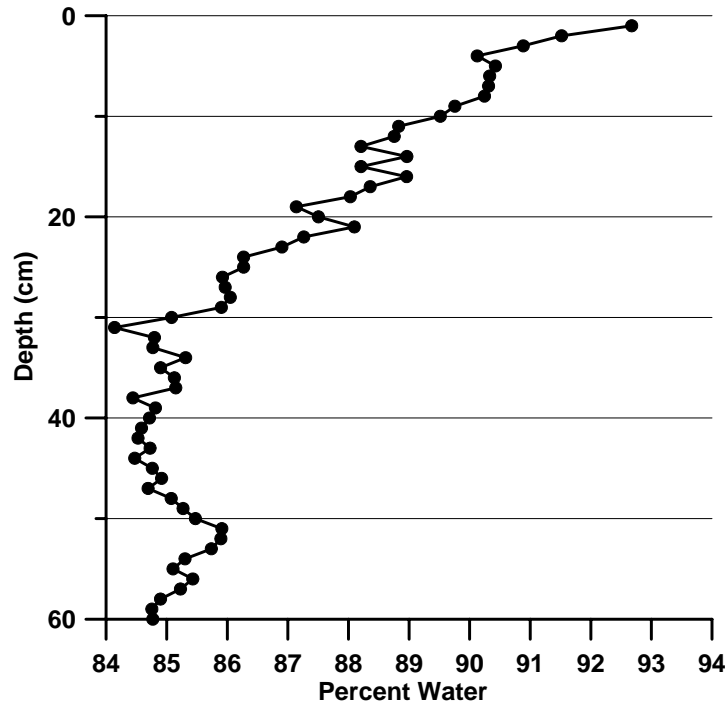


Figure 5. Percent water content in core DVA, Devils Lake.

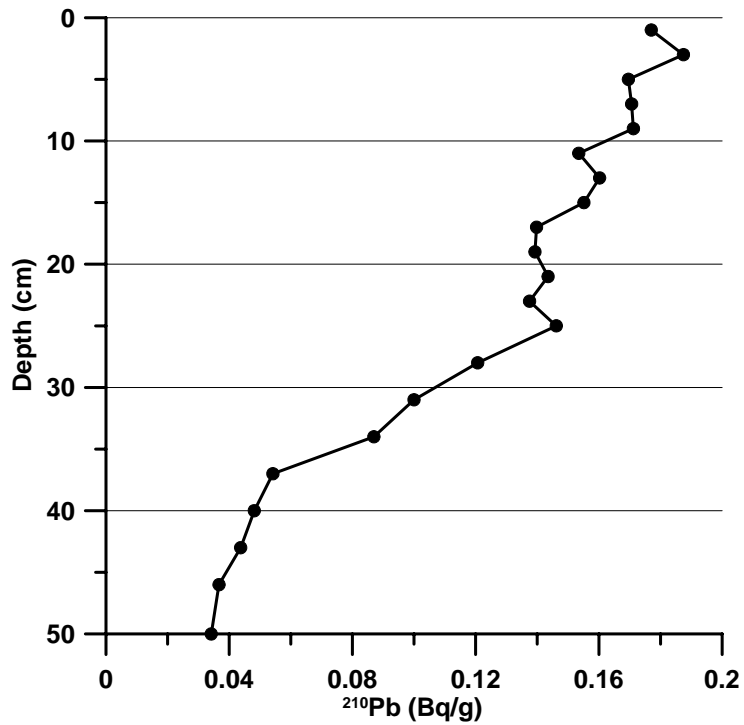


Figure 6. ²¹⁰Pb activity in the sediments of Devils Lake.

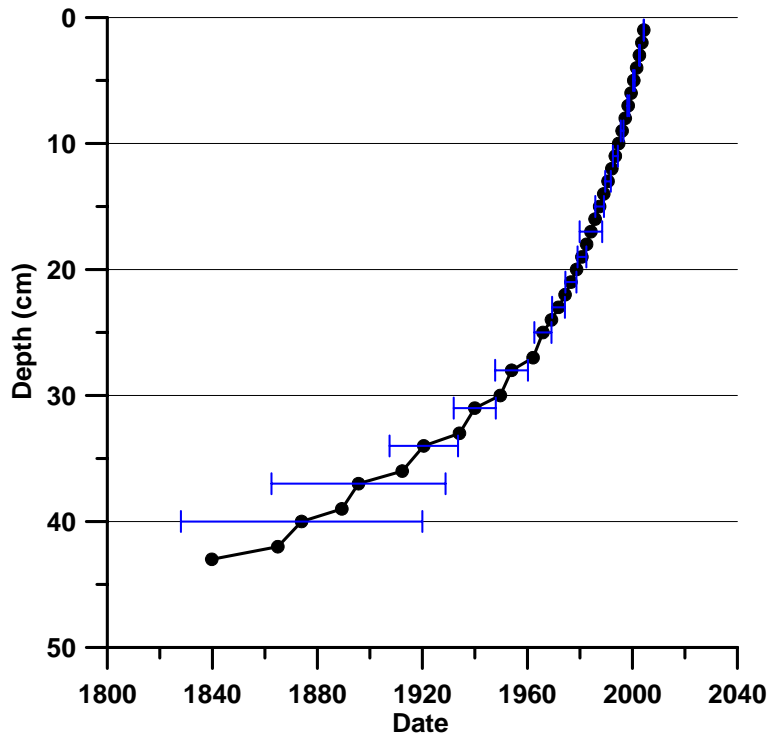


Figure 7. Age of sediments inferred from ^{210}Pb dating. The blue horizontal lines represent the uncertainty in the dates.

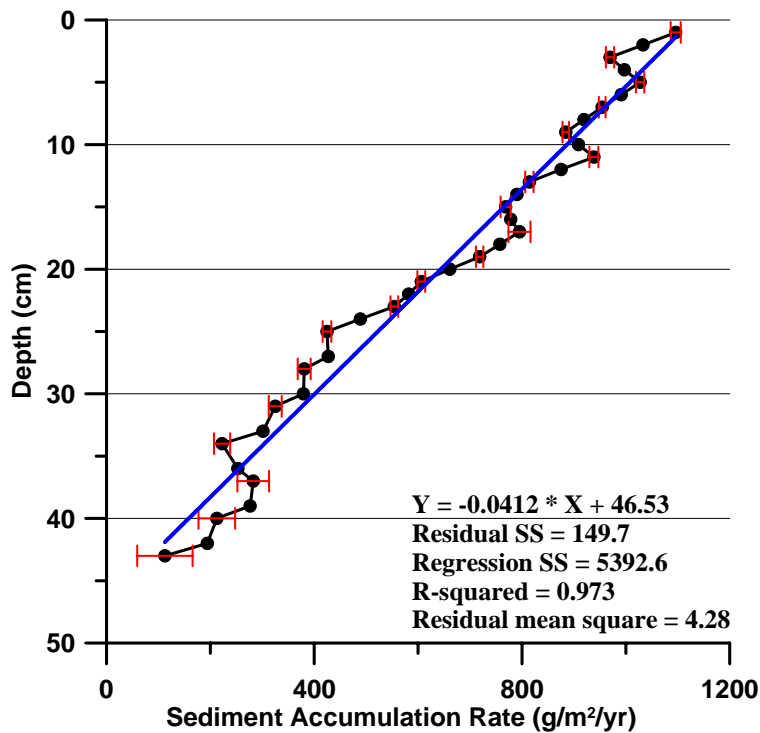


Figure 8. Sediment accumulation rate in Devils Lake based on ^{210}Pb dating. The blue line shows the best-fit linear regression.

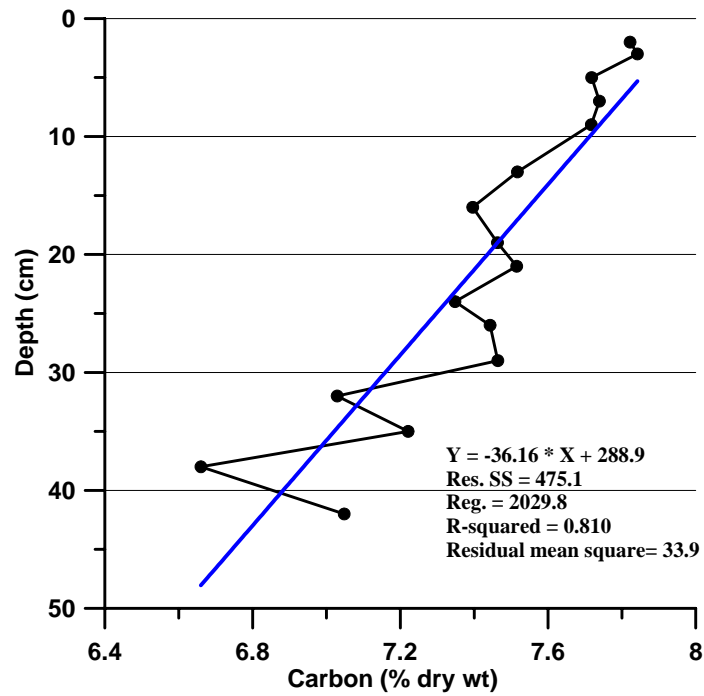


Figure 9. Carbon content in the sediments of Devils Lake. The blue line is the best-fit linear regression.

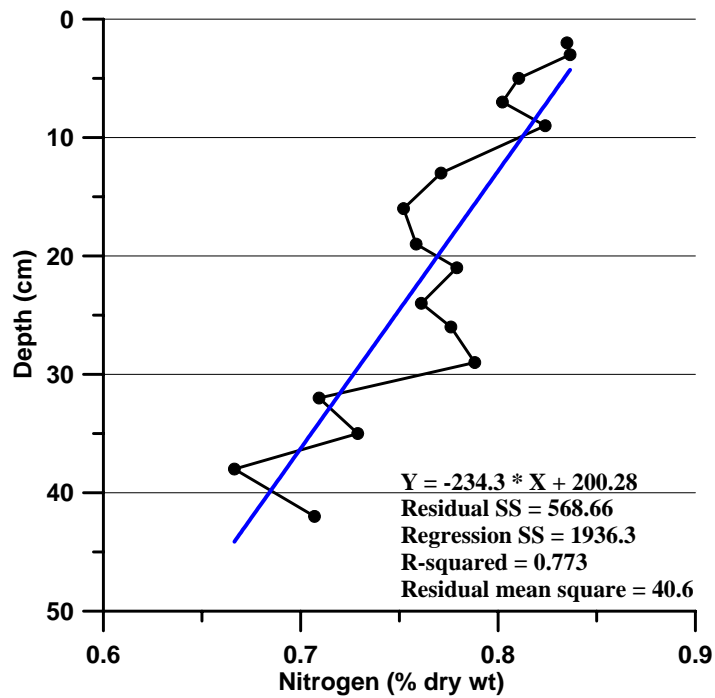


Figure 10. Nitrogen content in the sediments of Devils Lake. The blue line is the best-fit linear regression.

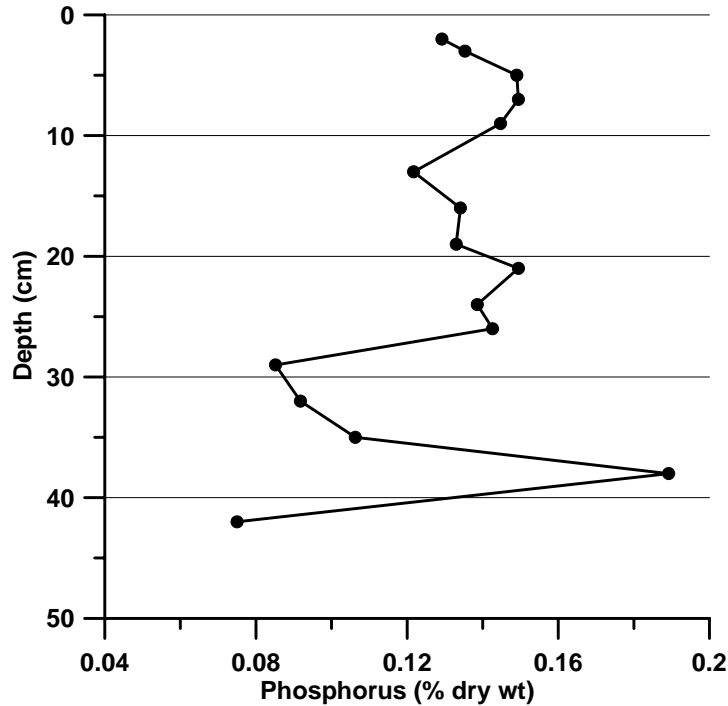


Figure 11. Phosphorus content in the sediments of Devils Lake.

Two components of lake biology were investigated in the sediment core. The first was the cyanobacteria (blue-green algae) akinetes. These resting cells produced by some species of cyanobacteria can be preserved in the sediment for hundreds of years, making it possible to evaluate changes in the abundance of cyanobacteria. All sediment intervals showed some cyanobacteria akinetes in the sediments. However, when we examine the deposition rate of the akinetes (product of SAR X akinete density), it is apparent that there has been a large increase in the amount of both *Anabaena* and *Gloeotrichia* being deposited in Devils Lake (Figures 12 and 13). Both taxa are capable of N-fixation (utilizing atmospheric N as a source of nitrogen for metabolism) and both organisms are commonly found in waters with high availability of nutrients.

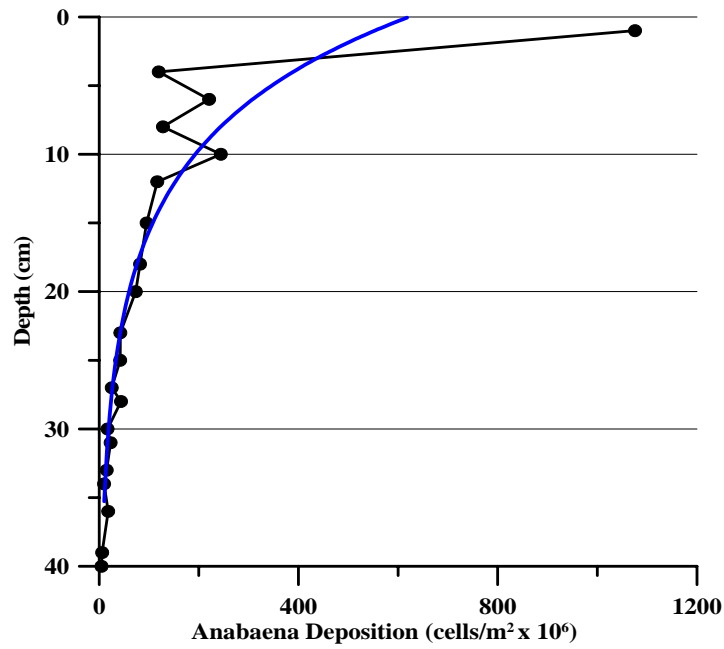


Figure 12. Deposition rate of *Anabaena* akinetes in the sediment of Devils Lake. The blue curve is a logarithmic fit to the observed data.

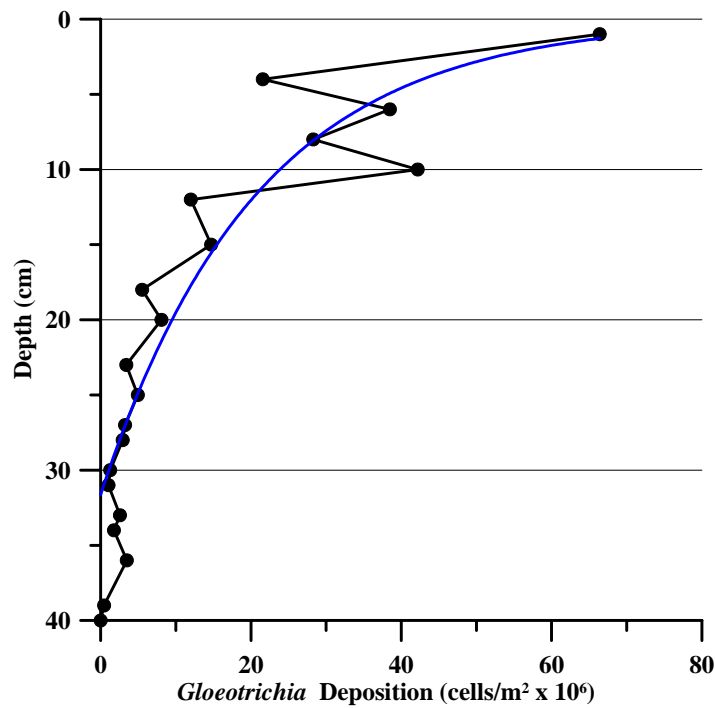


Figure 13. Deposition rate of *Gloeotrichia* akinetes in the sediment of Devils Lake. The blue curve is an exponential fit to the observed data.

There are abundant numbers of diatoms in the sediment samples, but it appears the sediment has been heavily worked as broken frustules are very common. There also appears to be a large amount of fecal material which can be identified as clumps with embedded diatoms. All samples are completely dominated by the many varieties of the common species *Fragilaria pinnata* (particularly the small nominate variety) and *Fragilaria construens* (particularly the small var. *venter*), and by *Fragilaria brevistriata*. These three diatoms account for more than 50% of all 6 interval counts. Nevertheless, as many as 40-50 other species were identified in the counts.

Unfortunately, habitat preferences are known for only a very few diatom species, although broad assumptions can be made for individual genera. Calculations of generic representation (Figure 14) indicate very little change in genera representation across the upper sediments in the core. There is some increase in the representation of *Fragilaria* in intervals 3 and 5, almost certainly leading to the decrease in representation of most (but not all) other genera in those intervals. Response of other genera is generally inconsistent in those two intervals.

Combining less important genera into habitat groupings while retaining genera found at high percentages (Figure 15) suggests more strongly a pattern of change occurring between interval 7 and interval 5. Figure 15 is arranged with planktonic species at the bottom, tychoplanktonic species (including the dominant *Fragilaria*) in the middle, and periphytic species at the top. *Nitzschia* and the small *Navicula* spp. may also be considered tychoplanktonic although with less certainty. The bottom three intervals appear relatively uniform in their representation by genera and habitat; the results for intervals 3 and 5 suggest an expansion of the tychoplankters (and euplankters?) as indicated by the uppermost boundary of small *Navicula* spp. (deep blue); strictly periphytic species appear to retract further in the uppermost interval and euplanktonic species (particularly *Aulacoseira* and *Cyclotella*) expand. In particular, the strongly epiphytic genera *Cocconeis* declines markedly in the upper three intervals. Grouping completely by presumed habitat (Figure 16) again suggests the possibility of subtle changes between intervals 5 and 7 and perhaps further just below the uppermost interval.

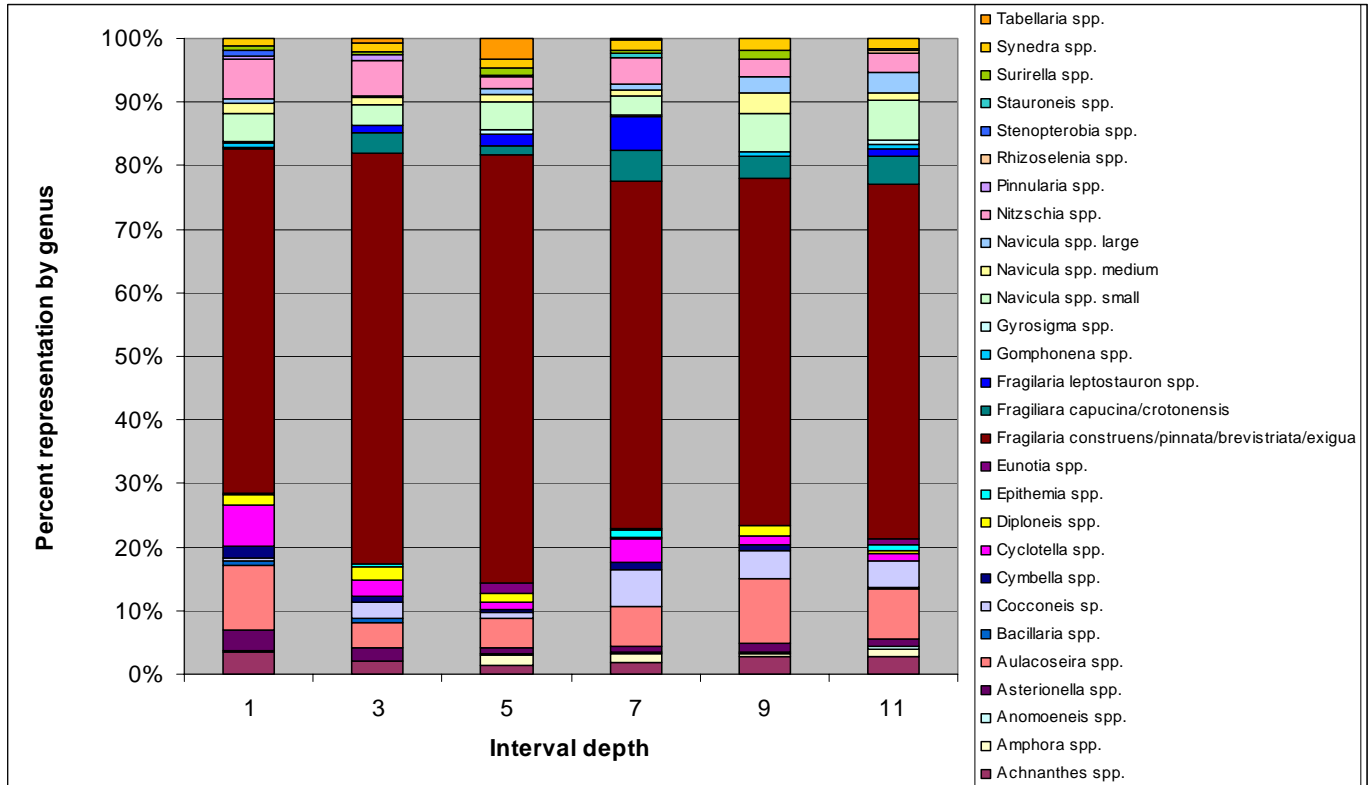


Figure 14. Major diatom taxa in the upper sediments (1 – 11 cm) of Devils Lake.

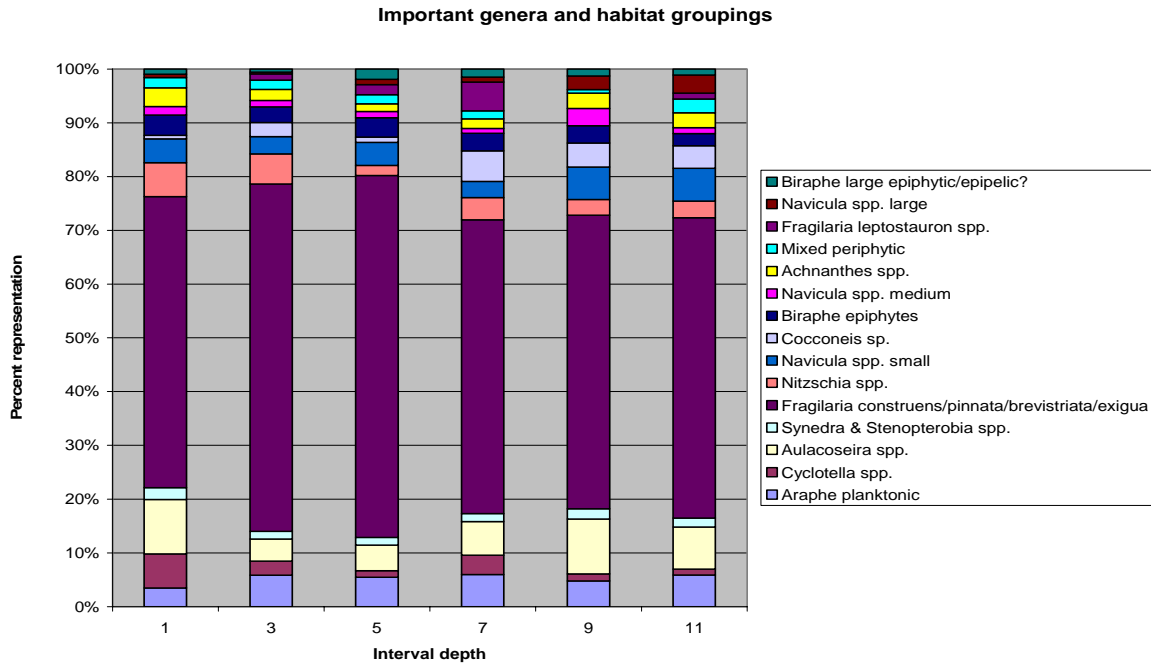


Figure 15. Major genera of diatoms in the upper sediments of Devils Lake grouped by habitat types.

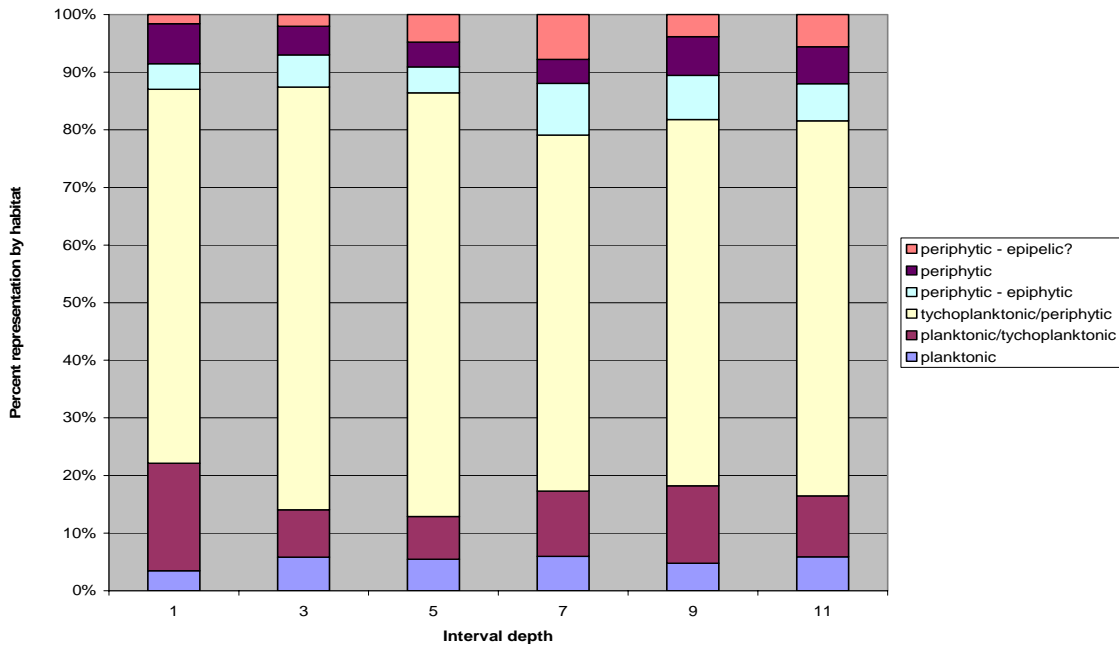


Figure 16. The proportion of diatoms in the upper sediments of Devils Lake grouped by habitat preferences.

DISCUSSION

Identifying habitat preferences of diatoms is problematic as precise data does not exist for many species, or more accurately, has not been collated into a verifiable database since Lowe (1974). Nearly every taxonomic treatise suggests something about habitat preference for a few of the many diatoms covered in such texts (see e.g., Patrick and Reimer 1966 and others).

Diatoms have no active way to remain in the water column. Most euplanktonic forms have spines or are colonial which allows for slower settling. Some can apparently alter their internal specific gravity to change sinking rates. But none can move upward in the water column without the water physically moving them. Most of the planktonic forms are araphid and centric diatoms. Even many of these forms must be able to settle, survive, and await physical resuspension. Such forms are referred to as tychoplanktonic, or, put another way, facultatively planktonic. In freshwaters, the centric genera *Cyclotella* and *Aulacoseira* (formerly often *Melosira*), and the araphe forms *Asterionella* and *Synedra* (many of which are now in the genus *Fragilaria*) are among these.

Many other diatoms have capabilities designed to adhere to substrates, most of the monoraphe and biraphe forms live on surfaces. The raphes themselves (by a mechanism still somewhat unclear) allow these forms to move across surfaces – a further suggestion that these have not evolved to be planktonically productive. The supergenus *Navicula* and many others fall into this category. Other biraphe diatoms do not move along surfaces, but actively adhere to surfaces in rosettes (some *Nitzschias* and some of the araphe *Synedra* for example), or form tubes with many individual frustules, such as *Cymbella*. These periphytic diatoms may adhere to any surface, but many do prefer to live on plants themselves, such as the common epiphyte *Cocconeis*. One generalization is that some of the largest diatoms often live in the mud or on fallen leaves preferentially (*Frustulia* and some *Surirella*).

Unfortunately, there are many exceptions to these general rules – *Fragilaria leptostauron*, closely related to the common Devils Lake presumably tychoplanktonic *Fragilaria* species, prefers the mud. Some large *Surirella* species appear to live a largely planktonic lifestyle. Further, habitat preferences for many diatoms appear to be exactly that – preferences and not obligate. Tychoplanktonic species can grow resting on a surface, and periphytic is frequently means exactly that – attached to any surface. Overall, the scientific knowledge of such preferences remains limited. Nevertheless, many of the generalizations do hold true, particularly regarding the well-known planktonic forms versus those forms with specific functional means of attaching or adhering to a substrate.

There appears to be only minimal evidence from the diatoms in the sediment core of the major changes that have taken place in Devils Lake in the upper 11 cm. There does seem to be a slight increase in the relative abundance of planktonic and tychoplanktonic forms at the expense of strictly periphytic forms in the upper three intervals that were examined,

and particularly in the uppermost interval (Figures 15 and 16). Observationally, there appeared to be a larger number of large diatoms in the lower intervals such as *Epithemia* (frequently broken) and *Surirella*.

Another indication of this is the clear difference in the numbers of *Cocconeis placentula* varieties between the bottom three and top three intervals. These diatoms are relatively important in the lower intervals, rising to above 5 percent. This number seems small, but it is the most important species after the abundant small *Fragilaria* complex (*pinnata*, *construens*, *brevistriata*) and is found at the same or greater levels as *Aulacoseira italica* (tychoplanktonic). In the upper intervals, it is relatively unimportant, passed by the planktonic *Cyclotella* species and the likely tychoplanktonic *Nitzschia angustata*.

Why is this evidence not more clear for such a major change? There may be several reasons. The strong dominance of the small *Fragilaria* complex, one of the most common diatom 'weed' species, particularly in the Northwest sediments can dampen any change. Also, many generally periphytic forms may do quite well living on other substrates. The overall advantage of living on an aquatic plant appears to be simply to be higher in the photic zone. Obligate epiphytes appear to gain a nutrient advantage. Therefore many genera that used to live on the plants now live on the substrates below, with some exceptions.

Another important question concerns the light regime overall – is the light on the sediment surface lesser or greater in the new ecology of Devils Lake? Have the carp changed the nutrient regime at the sediment surface? The effect on diatom primary productivity in the open water will be dependent on the light regime and the suspension of sediments, primarily silica. Do the carp perform the ecological service of sediment resuspension by mechanical action? If so, and average light conditions remain the same, then primary productivity may not be much affected. The sediment samples indicate likely not much change on a quantitative basis, although further analysis is needed to assess this. From a methodological standpoint, the carp may also have the effect of homogenizing the upper sediments to a much greater degree than when the macrophytes were present. This could dilute any paleoecological record in the diatom core.

The most significant change in the diatom community composition is not the small changes observed within the upper 11 cm, but rather in the transition from macrophyte conditions observed in the 1994 study compared to 2004 where no macrophytes were observed. If we compare the diatom communities from these two periods we observe a pronounced shift from a community with a high proportion of epiphytic taxa (eg. *Cocconeis* sp.) to a community dominated more by planktonic (eg *Fragilaria construens* group) and tychoplanktonic species (Figure 17). This transition is fairly rapid and is consistent with the types of changes that might have been occurring in the lake at the time. These changes might have included a great exposure of sunlight throughout the lake bottom, increased sediment disturbance from both wind and fish activity, and greater availability of nutrients.

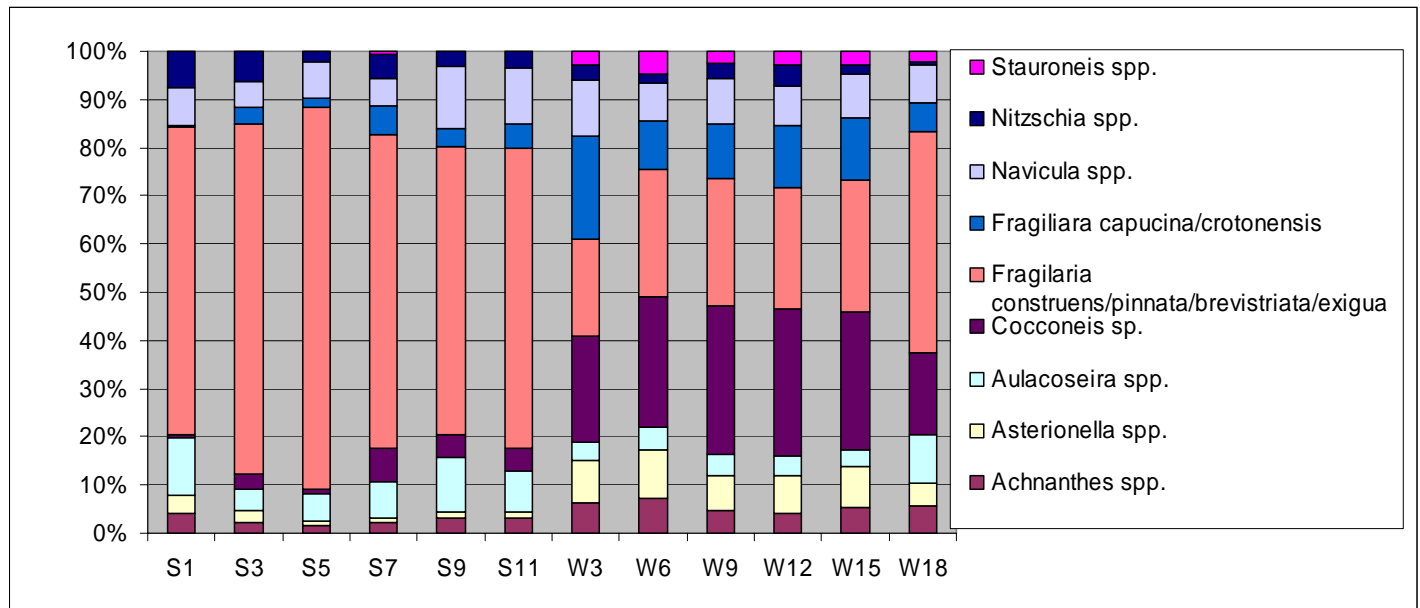


Figure 17. Major diatom taxa measured in the upper sediments of Devils Lake (S1 – S11) compared to results from the 1994 study showing the upper six sediment intervals examined in the earlier study (W3- W18). Sample S11 corresponds to sample depth 11cm from the current study and sample W3 corresponds to a sample depth of 3 cm in the previous study (Eilers et al. 1996).

CONCLUSIONS

The diatom paleoecological record from a short core taken from Devils Lake indicates a small change in the diatom community between intervals 7 cm and 5 cm. This change suggests a slight increase in the number of planktonic and tychoplanktonic diatoms at the expense of strictly periphytic diatoms. This change increases in the uppermost examined interval, where generally planktonic genera (e.g., *Cyclotella*) increase. Some strongly epiphytic forms, such as *Cocconeis placentula* varieties have decreased representation in the upper three intervals. The major change in diatoms appears to be the shift that occurred circa 1994 with the loss of the macrophytes by carp grazing.

The cyanobacteria akinetes gradually increase throughout the sediment core, but both *Anabaena* and *Gloeotrichia* exhibit the greatest increase in deposition rate at 10 cm depth, corresponding to 1995 (+/- 0.7 yr). Thus, both sets of biological indicators identify the period from 1994-1995 as a shift in some major aspect of the lake ecology. This period corresponds with the complete elimination of the macrophytes by the grass carp. A likely scenario is that the elimination of the macrophytes opened up a great portion of the lake to competition among planktonic species. Other factors may be

involved as well, including increased utilization and recycling of nutrients in the sediments from the browsing by the grass carp.

The concentrations of carbon and nitrogen show apparent increases in the sediment, whereas phosphorus concentrations show no trend. The concentration profiles could be an artifact of redox-related reactions in the sediments.

The sediment accumulation rate in Devils Lake is linear and shows no indication of a change in trend line under the current watershed and in-lake activities. The increase in sediment inputs can be derived from both erosional inputs from the watershed and in-lake production of plant biomass. We have no basis for distinguishing the two groups of sediment sources with the available data, although the high degree of disturbance in the watershed is a likely factor to consider.

ACKNOWLEDGEMENTS

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**Estimating Abundance of Grass Carp in Devils Lake and
A Plan for Continued Stocking of Fish**

**A Report to the
Devils Lake Water Improvement District
Lincoln City, Oregon**

**By
Joseph Eilers
MaxDepth Aquatics, Inc.
Bend, Oregon**

September 8, 2015

INTRODUCTION

Grass carp (*Ctenopharyngodon idella*) is a large herbivorous member of the carp family introduced throughout the United States as a method for controlling aquatic plants in lakes. The Devils Lake Water Improvement District (DLWID) applied for and received permission from the Oregon Department of Fish & Wildlife to introduce grass carp into Devils Lake as an experimental program to reduce the extensive growths of aquatic plants, much of which were comprised of invasive taxa. The DLWID introduced 10,000 fish in 1986, 17,050 in 1987 and an additional 5,000 fish in 1993. By 1994, the lake was virtually free of submerged aquatic macrophytes and has remained relatively macrophyte-free since then.

The DLWID has developed a broad strategy for reducing the input of nutrients to Devils Lake with activities that include encouraging the use of more natural vegetated shorelines, implementation of best management practices to reduce urban runoff and development of plans for local sewer districts to reduce inputs from septic systems. However, the District would still like to have the option to continue stocking grass carp as one of its management tools for the lake. This report provides an assessment of the current status of grass carp in Devils Lake and offers a suggested plan for additional stocking should the District receive permission to continue with the experimental stocking program.

ESTIMATION OF GRASS CARP ABUNDANCE IN DEVILS LAKE

A total of 32,050 grass carp have been stocked in Devils Lake, however it is unknown how many grass carp are currently present in Devils Lake. Attempts to quantify the number present when they were abundant were unsuccessful (CH2M-Hill 1992). A project was conducted by the DLWID in 2006, with the aid of local volunteers, to position individuals throughout the lake and make observations of fish presence. The results suggested that the population had declined to between 300 to 1000 grass carp (Paul Robertson, personal communication, April, 2013), although this estimate was considered semi-quantitative at best. Life history information indicate that grass carp have a life span of 10 to 20 years, although this is subject to uncertainty because most of the life history data are derived from studies of the fish in warmer climates. Grass carp have been present in Devils Lake for over 20 years.

I attempted to provide an independent estimate of the abundance of grass carp in Devils Lake using assumptions regarding mortality rates and life history information. Sources of mortality for grass carp in Devils Lake include mortality upon stocking, predation, disease, and escape to the ocean through the D River. The triploid grass carp were

trucked to Devils Lake from a fish farm and released into the lake. Some fish were observed in distress during stocking, although it is unknown how many fish expired during this transition. Many fish are susceptible to predation, especially from piscivorous fish such as bald eagles, cormorant, pelicans, herons and mergansers. Some predation from bald eagles was observed at Devils Lake, but again it was unquantified and likely to have been relatively low. Fish are susceptible to a wide array of diseases and parasites. However, few dead grass carp have been observed in the lake throughout the years. Grass carp are native to rivers and some grass carp have exited the lake through the outlet. However, these fish are intolerant to saltwater and quickly perish in saline environments (Cross 1970). Some dead grass carp have been observed on the beach near the D River, but again it is unclear if these represent just a few individuals or a larger number of grass carp that have exited the lake.

The major difficulty in estimating the current population of grass carp in Devils Lake, besides not having any interim data on abundance, is the lack of information specific to grass carp mortality rates for lakes in the Pacific Northwest. Most of the information generated on mortality rates of grass carp are based on data from southern states. For example, Morrow et al. (1997) and Kirk and Socha (2003) report annual mortality rates in South Carolina of 22 to 39 percent which results in a population survival on the order of a decade. This contrasts sharply with annual mortality rates of 2.0 to 7.7 percent for two lakes in Iowa (Hill 1986). Shireman and Smith (1983) report a maximum age of 21+ years. I selected an annual mortality rate of 10 percent for Devils Lake carp which reflects an intermediate rate of annual mortality as appears to be the case for colder climates.

In the absence of data, a structured approach was taken to estimate the number of grass carp in Devils Lake. Simple models were generated assuming various parameters for annual mortality and death upon stocking. The first model assumed a constant 10 percent annual mortality rate and no mortality on stocking (Figure 1). This model yields the highest estimate for the current population. Two additional models were added that also included a 10 percent annual mortality rate, but also included additional mortality upon stocking. Both of these models yield slightly lower current population estimates for the grass carp. A fourth model was developed that included a high mortality on stocking, increased survivability through years 2 through age 10 and increased mortality rate with increasing age. According to this model, the grass carp would have expired by year 2013, which apparently is not the case. Of course, the assumptions regarding mortality rates shown in Figure 1 could over-emphasize the early decline in the population. In which case, the actual trajectory for the population might be better represented by a relatively stable population followed by a rapid decline as fish approach their maximum lifespan in this environment (Figure 2).

These models for estimating the number of grass carp in the lake suggest that the current population is on the order of 1,000 fish, which is in general agreement with the DLWID observations in 2006. Given the uncertainty in the models, the estimate number of fish could easily be well under 1,000. It's unlikely that the number of fish would be much greater than 1,000 because of the extreme age of the fish.

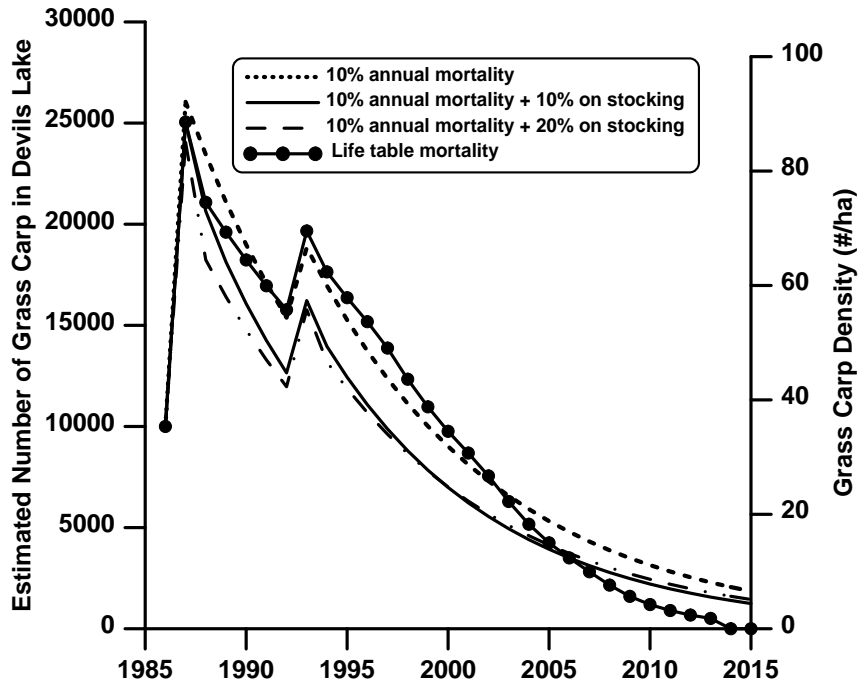


Figure 1. Estimated population of grass carp in Devils Lake under four ranges of assumptions regarding stocking mortality and annual mortality.

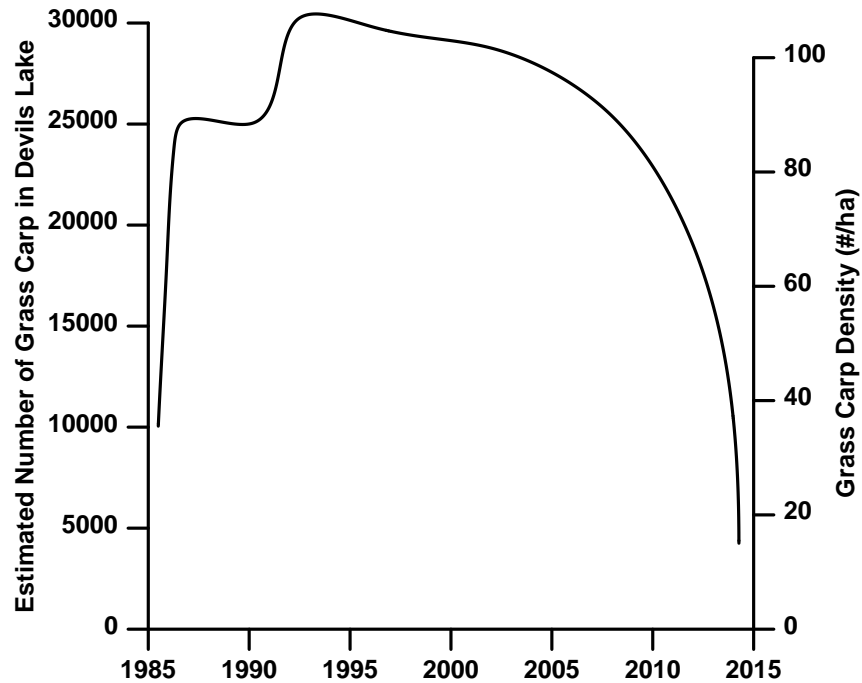


Figure 2. Estimated population of grass carp in Devils Lake assuming low rates of stocking mortality and low annual mortality rates until advanced age of fish.

FACTORS AFFECTING STOCKING RATES OF GRASS CARP

Determining the appropriate stocking density of grass carp has been a challenge for lake managers. Common outcomes are to stock at a density resulting in either complete eradication of submerged macrophytes, such as what was initially done in Devils Lake, or too low to achieve control of the plants. Researchers now recognize that the consumption of aquatic plants by grass carp is a function of a number of factors including feeding preferences for aquatic plant taxa, water temperature, age of fish, bathymetry of lake, and lake-specific mortality factors (cf. Stewart and Boyd 1999). A more recent approach is to use grass carp to suppress macrophyte populations, but not eliminate the plants (Cassani et al. 1996; Hoyer and Canfield 1997). This approach requires that the stocking be done incrementally and that it be done concurrently with a program to monitor the biomass of aquatic macrophytes. This allows the current plant conditions in the lake to inform decisions regarding future stocking practices. A cautious and incremental approach to grass carp stocking is required because of the considerable number of uncertainties with regard to the feeding rate of the grass carp and the longevity of the fish.

The multiple stockings of grass carp from 1986 to 1993 could have resulted in a population exceeding 30,000 fish and a density of over 100 fish/ha. Most stocking

regimes are now based on available macrophytes, either as percent lake coverage or percent biovolume of edible plants. Note that emergent macrophytes such as *Typha* (cattails) or floating taxa such as *Nuphar* (spatterdock) are not consumed by grass carp (cf. Stewart and Boyd 1999). If we assume that the historical coverage of edible macrophytes in Devils Lake was about 60 percent of the lake surface area, then the effective stocking density was over 200 fish/ha of macrophytes. This is an extraordinarily high stocking density based on current recommended rates of stocking. As noted, recommended stocking rates are dependent on a number of factors, including the taxa of macrophytes present in the lake, the annual water temperature, desirability to maintain complex aquatic habitats, age of grass carp, ploidy of grass carp and local recreational preferences.

Food preferences by grass carp vary widely as summarized by Bowers et al (1987), although they reported high preferences for *Potamogeton crispus*, *P. pectinatus*, *P. zosteriformes*, *Elodea canadensis* and *Vallisneria* among 12 Pacific Northwest macrophyte species examined. For macrophytes from Devils Lake, they reported the highest degree of preference for *P. zosteriformes* based on short-term, controlled studies (Table 1). However, preferences only indicate the order in which plants are consumed and all of these species were eventually consumed in Devils Lake. Preferences based on longer-term studies found very different rankings for preference of macrophyte consumption than those reported by Bowers et al. (Stewart and Boyd 1999; Swanson and Bergersen 1988).

Table 1. Grass carp preferences for aquatic macrophytes from Devils Lake, Oregon (from Bowers et al. 1987).

Species	Mean consumption (g)		
	15 °C	20 °C	25 °C
<i>P. zosteriformes</i>	63.2	95.1	104.1
<i>E. canadensis</i>	46.9	66.3	37.1
<i>V. americana</i>	16.7	17.6	29.6
<i>M. spicatum</i>	0	6.3	0.9
<i>C. demersum</i>	0	1.4	0
<i>E. densa</i>	0	0	0

Water temperature is believed to affect the rate at which plants are consumed and the growth rates of grass carp. Secondly, it may affect the longevity of grass carp. Temperature is a predominant factor in the model AMUR/STOCK developed for estimating the desired stocking rate of grass carp (Stewart and Boyd 1999). The model incorporates temperature as a factor strongly affecting the growth of macrophytes an in

the bioenergetics of the fish whereby higher temperatures promote higher rates of plant growth and higher rates of plant consumption. The authors emphasize that key characteristics of plant growth should be considered in establishing stocking rates of grass carp: (1) overwintering level, (2) onset of regrowth, (3) rate of regrowth, and (4) peak biomass in addition to lake temperature regime. Other investigators report on the effects of temperature and in short-term studies the effects of feeding rates were not significant (Bowers et al. 1987). However, Swanson and Bergersen (1988) found that incorporation of daily temperature units (DTU) was necessary to account for variations in consumption of macrophytes by grass carp in coldwater lakes. Most studies indicate that cooler temperatures will slow the growth of macrophytes and slow the consumption of macrophytes by grass carp, although the degree to which this effect is exerted is complex. Some authors indicate that a minimum temperature threshold results in no further consumption of plants by grass carp (Stewart and Boyd [11 °C]; Colle et al. 1978: 14 °C).

STOCKING RATES THROUGHOUT THE UNITED STATES

State fish and game agencies and affiliated university extension services often provide guidance on recommended stocking rates for grass carp, particularly in the southern United States (Table 2). The rates are typically based on stocking triploid fish of 200-300 mm length. Oregon is the only state listed that requires fish also be implanted with PIT tags. Many of the southern states base stocking rates on the need to control hydrilla, an invasive macrophyte. Note that several states recommend use of techniques other than stocking grass carp, such as mechanical harvest or herbicides, when plant coverage is less than 20 percent.

Hanlon et al. (2000) found in a study of 38 Florida lakes that the minimum number of grass carp that can be stocked to yield partial control over macrophyte growth was a stocking density of 10 to 15 fish per acre of lake. Others have found that densities of 4 to 7.5 grass carp per hectare can yield partial control (10 – 40% plant coverage) based on a study of four impoundments in Texas (Blackwell and Murphy 1996). No studies were found that described what is proposed in Devils Lake – namely where macrophytes had been totally eliminated by grass carp and a managed regrowth of macrophytes with modest subsequent restocking of grass carp was implemented (cf. Chilton and Muoneke 1992).

Table 2. Recommended grass carp stocking rates for selected states. Low rates generally correspond to plant coverage of 20-40 percent, moderate of 40-60 percent and high of greater than 60 percent.

State	Recommended Stocking Rate (fish/ha)				Note	Source
	General	Low	Medium	High		
Alabama		8	25-38	38-50	For ponds with bass	Auburn Univ.-Ext
Florida	13	3-8				UF-Ext
Georgia	13-25					GDNR
Kentucky		5-13	13-25	25-50	Don't stock w/ plant cover < 20%	KDF&W
Mississippi		8-13	13-25	30-50		MSU-Ext
Missouri		5-13	13-25	25-50	Don't stock w/ plant cover < 20%	MDoC
New Mexico		8	13	18	Don't stock w/ plant cover < 20%. Low elevation lakes	NMDF&G
Ohio		10-15	15-20	20-25	5-8 for coverage < 20%	OSU-Ext
Oklahoma	13-23				For partial control	OSU
Oregon	55				Maximum density allowed	ODFW
South Carolina	25-100				Preferred rates should be based on plant biomass	SCDNR
Tennessee		< 13	13-25	38-50		TWRA
Texas		13		25	Criteria is 50% plant coverage	TPWD
Virginia		5	13	25		VDGIF
Washington	23-63				Per vegetated acre	WDOE
Southern Regional Aquatic Center		25-30	30-38	>50	8/ha for vegetation cover < 10 %	USDA-SRAC

OPTIONS FOR GRASS CARP STOCKING RATES IN DEVILS LAKE

The choice of an initial stocking density is dependent on whether Devils Lake still has a viable population of grass carp present. If the decision to renew the experimental stocking density is postponed until the current population expires, then macrophytes will begin to regrow. The extent of subsequent macrophyte regrowth would alter the strategy for grass carp stocking considerably. However, the current conditions are that grass carp are present and still exerting macrophyte suppression. The proposed stocking plan is based on current conditions.

I suggest an initial stocking density of approximately 1 grass carp per hectare of lake surface area, which for Devils Lake would result in introduction of 270 fish. This would be roughly equivalent to a stocking rate of 2 fish/ha of potentially available macrophyte habitat. This rate is two orders of magnitude less than the original stocking density of 98 fish/ha used in 1986/87 and supplemented with another 18.3 fish/ha in 1993 for a total of 116 fish/ha. This proposed stocking density is predicated on starting the stocking in 2016. As the number of grass carp currently in the lake die off, control over the macrophyte growth is expected to decline rapidly. Thus, if grass carp stocking can be initiated while macrophyte biomass is low, it greatly reduces the need for a high stocking rate to suppress a plant population that is in a rapid growth phase. The population of grass carp would be slowly raised by continued stocking at the rate of 270 fish every other year. This would continue while monitoring of the extent and density of the macrophytes is conducted to provide information regarding the effectiveness of the carp to suppress, but not eliminate macrophytes. This would result in population increases, whereby the grass carp stocking would eventually be curbed to balance the desire for relatively stable macrophyte extent (Figure 3). One such scenario could involve achieving a modest density of grass carp and then gradually decreasing that level to further experiment with optimal densities of grass carp and macrophytes in Devils Lake (Figure 3, dotted line). Devils Lake Water Improvement District has a relatively stable level of revenue and is financially able to commit to this level of macrophyte monitoring.

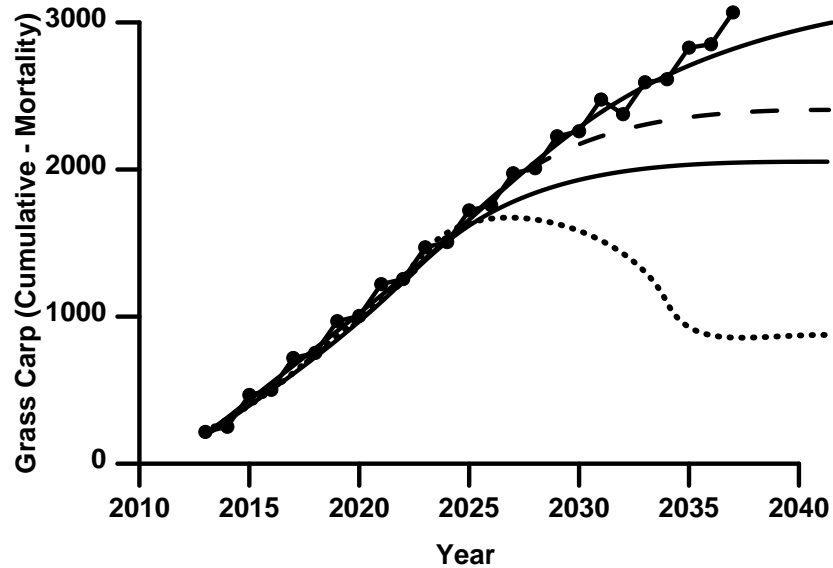


Figure 3. Proposed increase in grass carp in Devils Lake under a stocking rate of 1 fish/ha every other year coupled with a life-stage model for estimated annual fish mortality (solid line with circles). The four curves deviating from this line show possible scenarios for stabilizing the grass carp population in equilibrium with a modest macrophyte density.

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