Limnological Survey of Cordley Lake, SE Michigan

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Introduction

Cordley Lake is a single basin kettle lake located in Hamburg Township, Livingston County, MI at 83° 52.4' W and 42° 26.9' N. A field team from the University of Michigan Department of Ecology and Evolutionary Biology sampled the lake on 9 August 2013. Weather conditions at 10 A.M. were sunny (85% clear sky), calm, and air temperature was 20 C.

Sampling apparatus included a Hach HQ30 temperature and luminescent dissolved oxygen (LDO) meter with integral barometer for calibration, a plain white 20-cm Secchi disk, an electric pump system with submersible Tygon™ tubing for water sampling, Millepore™ in-line filter capsules for preparation of filtrate, and a plankton net with 30-cm diameter mouth and 64 µm mesh aperture.

Field Sampling

Temperature and DO were measured at 1-m intervals from surface to 10 m depth. Water samples were collected at 2, 4, and 7 m depth at the central lake sampling site and from 0 m near the main intermittent inlet and outlet (Figure 1). A vertical plankton tow was collected at site V from 5 m depth to the surface and was preserved in 5% formalin. Phytoplankton samples were collected from 0 m and 2 m at the central lake site V and were preserved in acid-Lugol's iodine. Field sampling was completed by noon.

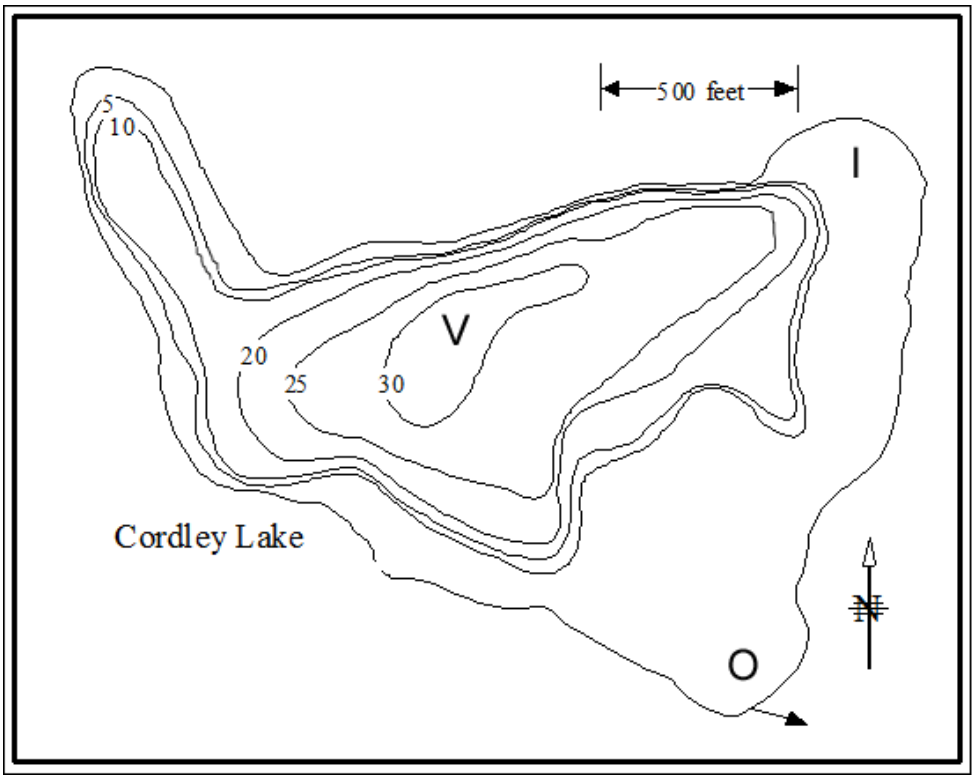


Figure 1. Cordley Lake bathymetry and 2013 sample sites, modified from Fusilier (2010). V= site of vertical profile samples; I= site of main inlet surface water sample; O= site of outlet surface water sample.

Laboratory Analyses

Samples arrived at the Ann Arbor laboratory at 1:30 P.M. Specific conductance at 25 C (K_{25}: Corning Model 441 conductivity meter; 2 point calibration) and pH (Beckman Φ34 pH meter; 2 point calibration) were measured immediately. Three replicate samples from each sampling site were prepared for analysis of chlorophyll *a* (Chl *a*) by filtering 100-ml of raw water through 25-mm diameter Whatman 934-AH glass fiber filters. The filters were folded inside Al-foil envelopes and frozen over silica gel desiccant until analysis. Two replicate samples from 2 m and 4 m were prepared for phycocyanin (PC) analysis by filtering 250-ml of raw water through 25-mm diameter Whatman 934-AH glass fiber filters. These filters were similarly folded inside Al-foil envelopes and frozen over silica gel.

For analysis of total phosphorus (TP), three replicate 40-ml samples of raw water from each sample site were placed in borosilicate screw-cap tubes and 0.4 g of potassium persulfate oxidant was added. For analysis of dissolved phosphorus (DP), triplicate 40-ml of filtrate from 2, 4, and 7 m were similarly treated. Samples were oxidized to orthophosphate at 105 C for 2 h, then cooled and stored sealed until analysis.

Chemical and biological analyses were performed over the subsequent weeks as part of student independent research projects under the supervision of Professor Lehman. Analytes and associated methods were as follows:

1. Acid neutralizing capacity (ANC), or Titration Alkalinity: Gran titration using replicate 50-ml samples and 0.1 N sulfuric acid titrant.
2. Chloride (Cl^-): Gran titration using replicate 50-ml samples and 0.1 N silver nitrate titrant.
3. Calcium (Ca^{2+}): EDTA titration using replicate 50-ml samples. Acidification to pH 5 with 0.1 N sulfuric acid to remove carbonate carbon followed by elevation of pH to pH 12.5 with 5 M sodium hydroxide and addition of CalVer 2 indicator (Hach).
4. Calcium + Magnesium (Mg^{2+}): EDTA titration using 50-ml samples. Addition of pH 10.1 buffer solution and addition of ManVer 2 indicator (Hach).
5. Sulfate (SO_4^{2-}): Barium chloride turbidometric method using 1-cm path length at 420 nm (Genesys 10uv single beam spectrophotometer).
6. DP and TP: Oxidation to orthophosphate using potassium persulfate at 105 C followed by phosphomolybdate blue method using ascorbic acid reductant and spectrophotometry (10-cm pathlength) at 885nm.
7. Soluble reactive silica (SRSi): Silicomolybdate blue method using 5-ml samples and 0.05 N stannous chloride reductant; optical density detected at 660 nm using 1-cm cells.
8. Nitrate (NO_3^-): Second derivative UV spectroscopy scanning from 260 to 200 nm using 1-cm quartz cuvette and a Perkin-Elmer Lambda 25 dual-beam optical bench.
9. Chl *a*: Triplicate 100-ml samples were filtered through Whatman™ AH filters and frozen over silica gel desiccant. Filters were macerated in 90% v/v acetone using a tissue grinder and the resulting slurry was filtered through a Whatman™ GF/D filter.

Extracted pigment fluorescence was detected with a Turner Designs™ TD700 fluorometer equipped with 436 nm excitation filter and 680 nm emission filter.

10. PC: Replicate 250-ml samples were filtered through Whatman™ AH filters and frozen over silica gel desiccant. Filters were macerated in 0.05 M phosphate buffer at pH 7 using a tissue grinder and the resulting slurry was filtered through a Whatman™ GF/D filter. Phycocyanin was detected with a Turner Designs™ TD 700 fluorometer equipped with 600 nm excitation and 640 nm emission filters.
11. Zooplankton species identification: Microscopic inspection with reference *to Fresh-Water Biology Second Edition*[i] and *Fresh-Water Invertebrates of the United States Second Edition*[ii].
12. Zooplankton abundance: Field sample was diluted to 500 ml and 5 replicate 5-ml subsamples were transferred to counting trays and counted at 12-50x magnification. An additional 200-ml was searched for large and rare invertebrates.
13. Phytoplankton identification: Microscopic inspection by inverted compound microscope with reference to *A Guide to the Study of Fresh-water Biology 5th Edition*[iii].
14. Correctness of Analyses: The conductivity check method was used to confirm the completeness and correctness of analyses for major ions. For this technique, a sample is diluted with deionized (DI) water to a K_{25} between 90 and 120 μS. Then published conductivity factors for each ion are multiplied by the calculated concentrations and summed to obtain a predicted K_{25}. The observed and predicted values should be within 2% of each other. Otherwise, important ions may have been overlooked or some of the analyses may be in error.

Citations:

i. Whipple, George C., and Henry B. Ward. 1959 *Fresh-Water Biology*. Ed. W. T. Edmondson. Second ed. New York: John Wiley and Sons.

ii. Pennak, Robert W. 1978. *Fresh-Water Invertebrates of the United States*. Second ed. New York: John Wiley and Sons.

iii. Needham, James G., and Paul R. Needham. 1962. *A Guide to the Study of Fresh-water Biology*. 5th ed. San Francisco: Holden-Day.

Results

Water Chemistry- The vertical distribution of temperature and dissolved oxygen (Fig. 2, Table 1) reveals the existence of a thermocline below 4 m and an associated clinograde oxygen profile from 5 to 7 meters, with near-anoxia below 7 m.

Water samples collected from 2, 4, and 7 m depth were analyzed for major ions (Table 2a) as well as for associated nutrients and pigments (Table 2b). Chemical concentrations are reported in units of moles per liter (M) and equivalents per liter (Eq) to facilitate calculation of charge balance and completeness of analysis. Comparison with overlapping analytes measured from 1993 to 2009 and reported by Fusilier (2010) are summarized in Table 3.

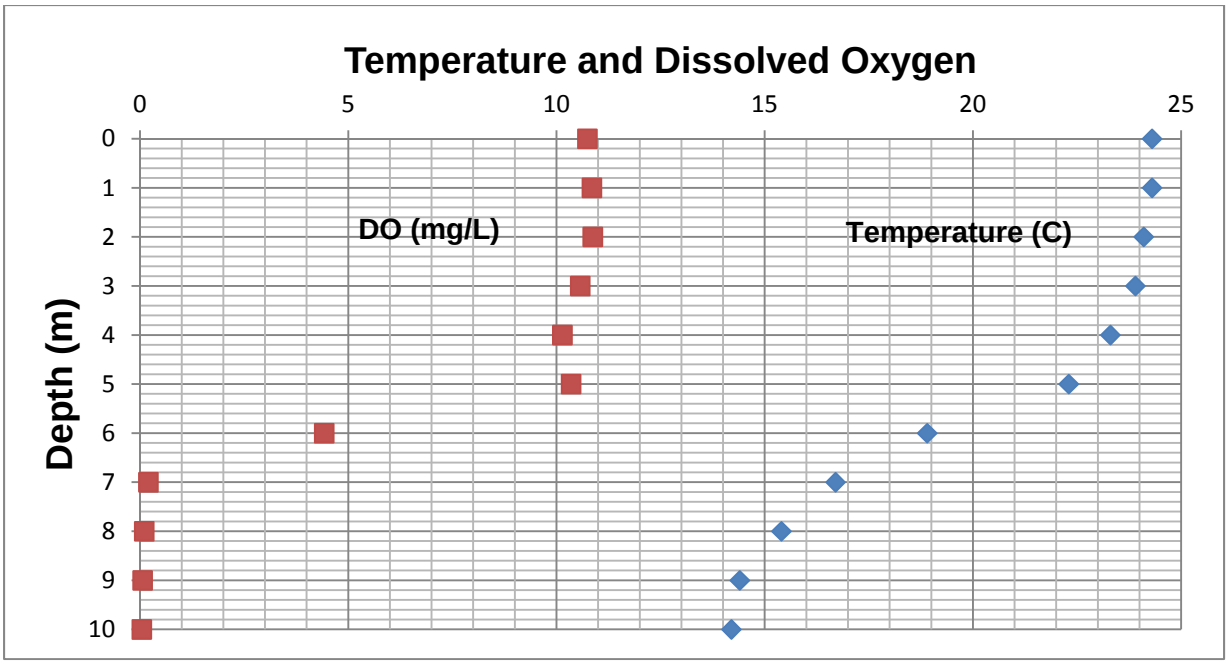


Figure 2: Vertical distribution of temperature (^{o}C) and dissolved oxygen (mg/L)

Table 1: Temperature, DO, and % DO saturation corresponding to data plotted in Fig. 2.

Depth (z) meters	Temperature C	Dissolved Oxygen mg/L	% sat
0	24.3	10.74	133.0
1	24.3	10.85	134.4
2	24.1	10.87	134.2
3	23.9	10.57	130.0
4	23.3	10.14	123.4
5	22.3	10.35	124.5
6	18.9	4.42	49.3
7	16.7	0.20	2.1
8	15.4	0.10	1.0
9	14.4	0.06	0.6
10	14.2	0.04	0.4

Table 2a. Major cations and anions measured in Cordley Lake. nm= not measured.

Site	z m	pH	K_{25} µS	Ca^{2+} mEq	Mg^{2+} mEq	ANC mEq	Cl^{-} mEq	SO_4^{2-} mEq	Cations mEq	Anions mEq
V	2	7.63	590	2.02	1.66	2.28	2.86	0.35	3.68	5.49
V	4	7.58	599	2.02	1.65	2.26	2.89	0.41	3.67	5.57
V	7	7.00	668	2.85	1.66	3.16	2.78	nm		
I	0	7.54	593	2.01	1.62	2.23	2.86	nm		
O	0	7.75	589	1.94	1.67	2.18	2.86	nm		

Table 2b. Pigments, nutrient concentrations, and Secchi disk (SD) transparency measured in Cordley Lake. nm= not measured.

Site	z m	Chl a μg/L	PC μg/L	NO_3^- μM	DP μM	TP μM	SRSi μM	SD m
V	2	4.3	2.1	2.2	0.10	0.28	79.9	3.9
V	4	4.8	4.5	1.1	0.18	0.35	80.8	
V	7	11.8	nm	0.0	0.23	0.76	153.0	
I	0	5.4	nm	nm	nm	0.27	nm	
O	0	4.2	nm	nm	nm	0.18	nm	

Table 3. Mean, minimum, and maximum values for analytes reported by Fusilier (2010) for August to September samples from Cordley Lake from 1993 to 2009, converted to units in common with Tables 2a and 2b.

WEF 2010	Chl a μg/L	pH	K_{25} μS	NO_3^- μM	TP μM	ANC mEq	SD m
Mean	1.9	8.44	515	2.0	0.41	2.12	4.4
Min	0.3	7.9	470	0.6	0.10	1.98	3.0
Max	4.3	8.7	560	5.0	0.97	2.28	7.0

Correctness and Completeness of Analyses- Filtrate from 2-m depth in Cordley Lake was diluted to 0.15X (3.5 ml added to 20 ml DI water). The resulting K_{25} = 90.3 μS. Then, the concentrations of the cations and anions reported in Table 2a were multiplied by the dilution factor (0.15) and the conductivity factors listed in *Standard Methods for the Examination of Water and Wastewater* 15th edition, p. 32. At its measured pH, all of the ANC in Cordley Lake is represented by bicarbonate (HCO_3^-). If one sums the total charge (mEq) from anions (HCO_3^-, Cl, SO_4^{2-}, NO_3^-) and the total charge from cations (Ca^{2+}, Mg^{2+}), it is obvious that anions exceed cations (Table 2a). This is so because we did not analyze for sodium or potassium. By analogy with other surface waters in SE Michigan, almost all of the missing cation balance in Table 2a is sodium. Taking that into account, the predicted K_{25} for the diluted sample is 91.3 μS, or within 1.1% of the measured value.

Biological analyses- The common phytoplankton genera observed in water samples from Cordley Lake are reported in Table 4a, organized by major algal Divisions (algal Divisions are comparable to animal Phyla). Photomicrographs of two representative species are displayed in Table 4b.

Zooplankton from the animal phyla Rotifera and Arthropoda observed in plankton net collections from Cordley Lake are reported in Table 5 along with photomicrographs of the organisms (various magnifications). The one species identified but not depicted in Table 5 is the cyclopoid copepod *Cyclops bicuspidatus thomasi*. It looks superficially similar to *Mesocyclops*. Animal abundances in the lake are reported in Table 6.

Table 4a. Common phytoplankton genera observed in Cordley Lake.

Division	Genus
Cyanophyta	*Anabaena*
	Aphanocapsa
	Microcystis
Chrysophyta	*Dinobryon*
	Mallomonas
Bacillariophyta	*Aulacoseira*
	Diatoma
	Fragilaria
	Navicula
	Synedra
Chlorophyta	*Microspora*
	Oocystis
Cryptophyta	*Cryptomonas*
Pyrrophyta	*Ceratium*

Table 4b. Eukaryotic phytoplankton (microalgae) from Cordley Lake (Kingdom Protista)

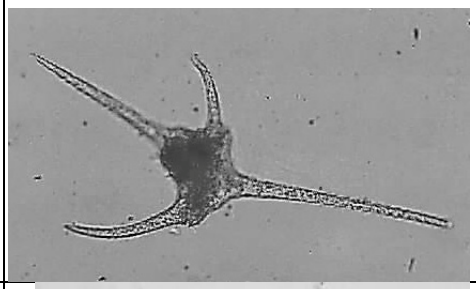
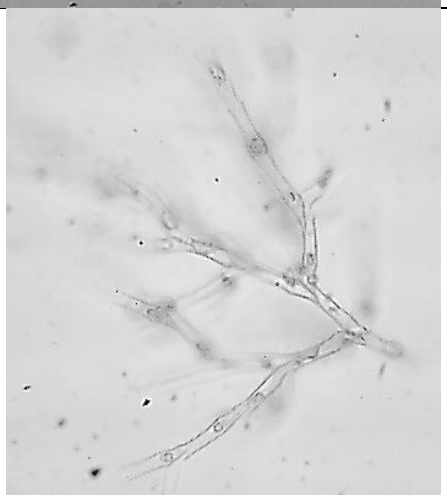
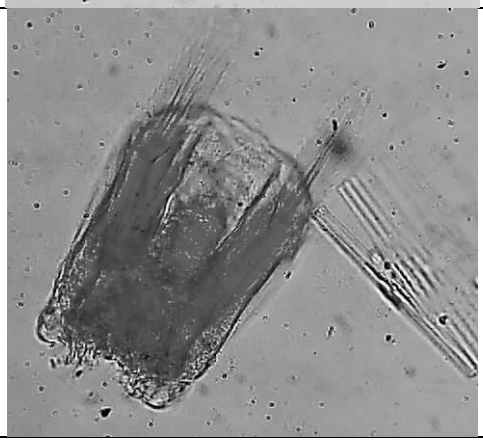
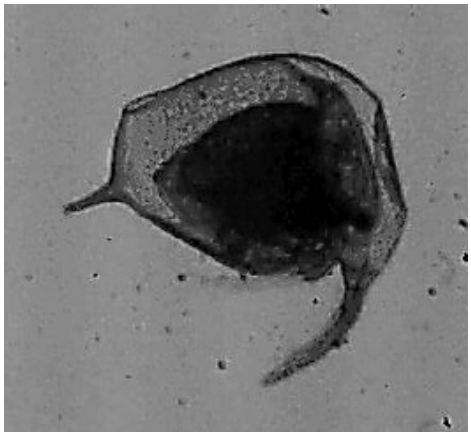
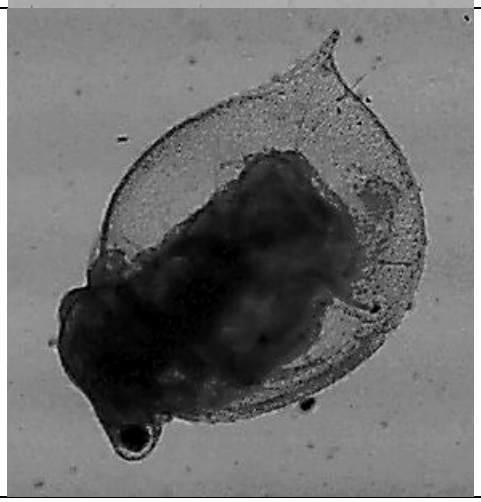
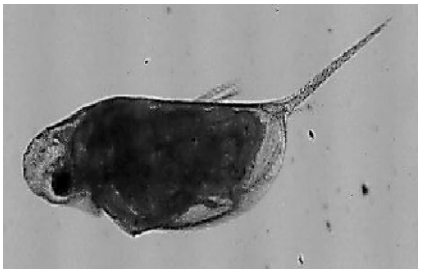
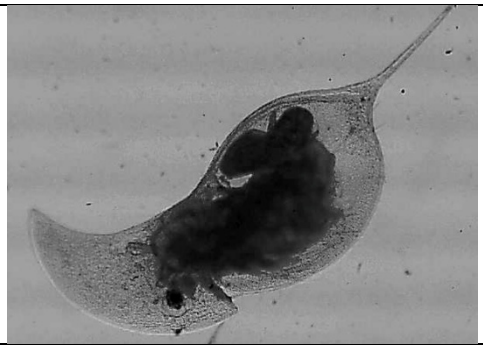
Division: Pyrrophyta Class: Dinophyceae Order: Gonyaulacales Suborder: Ceratineae Family: Ceratiaceae *Ceratium hirundinella*	
Division: Chrysophyta Class: Chrysophyceae Order: Chromulinales Family: Dinobryaceae *Dinobryon divergens*	

Table 5. Zooplankton species observed in Cordley Lake (Kingdom Animalia).

Phylum: Rotifera Class: Monogonanta Order: Ploima Family: Brachionidae *Keratella cochlearis*	
Phylum: Rotifera Class: Monogononta Order: Ploima Family: Brachionidae *Kellicottia longispina* female with egg	
Phylum: Rotifera Class: Monogononta Order: Ploima Family: Synchaetidae *Polyarthra vulgaris*	
Phylum: Arthropoda Class: Crustacea Order: Diplostraca Suborder: Cladocera Family: Bosminidae *Bosmina longirostris*	

Phylum: Arthropoda Class: Crustacea Order: Diplostraca Suborder: Cladocera Family: Sididae *Diaphanosoma brachyurum*		
Phylum: Arthropoda Class: Crustacea Order: Diplostraca Suborder: Cladocera Family: Daphniidae *Ceriodaphnia quadragula*		
Phylum: Arthropoda Class: Crustacea Order: Diplostraca Suborder: Cladocera Family: Daphniidae *Daphnia parvula*		
Phylum: Arthropoda Class: Crustacea Order: Diplostraca Suborder: Cladocera Family: Daphniidae *Daphnia retrocurva*		

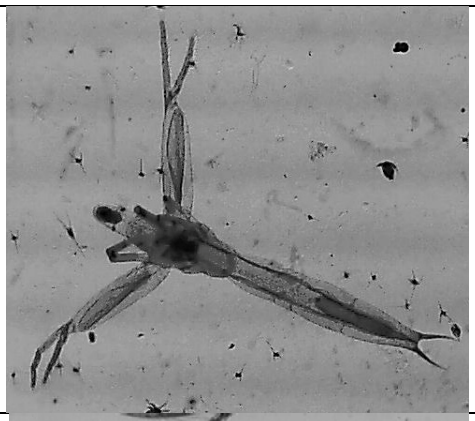
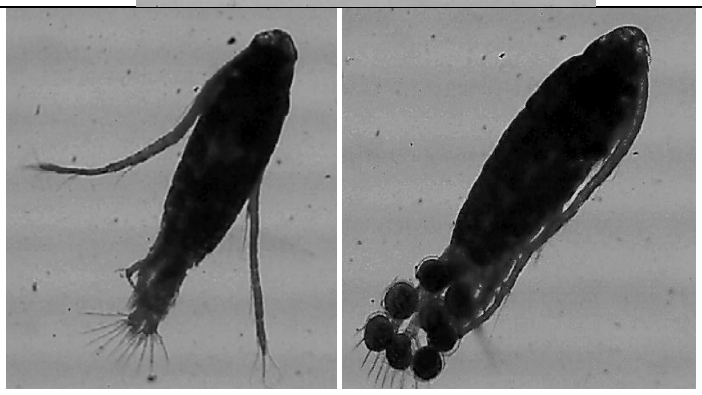
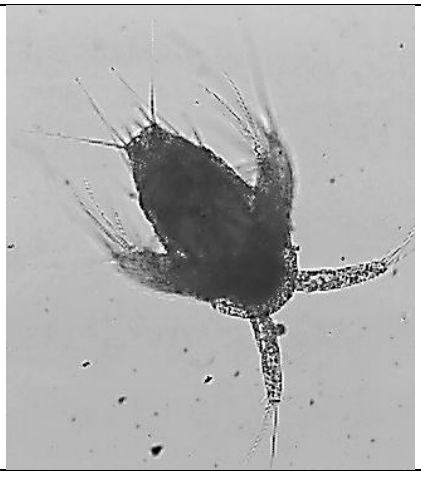
Phylum: Arthropoda Class: Crustacea Order: Cladocera Family: Leptodoridae *Leptodora kindti*	
Phylum: Arthropoda Class: Crustacea Order: Cyclopoida Family: Cyclopidae *Mesocyclops edax*	
Phylum: Arthropoda Class: Crustacea Order: Calanoida Family: Diaptomidae *Diaptomus oregonensis* female with eggs (right), male (left)	
Phylum: Anthropoda Class Crustacea Subclass: Copepoda copepod nauplius larva	

Table 6: Zooplankton abundances in Cordley Lake, expressed as individuals per square meter of lake surface area. *Cyclops* and *Mesocyclops* copepodites (mainly immature stages) are pooled because the species are difficult to distinguish as juveniles.

Taxon	Ind/m^2
Diaptomus oregonensis	63300
Cyclops + *Mesocyclops*	67600
Copepod nauplii	99000
Daphnia parvula	7400
Daphnia retrocurva	11700
Diaphanosoma brachyurum	34700
Ceriodaphnia quadragula	1400
Bosmina longirostris	1400
Keratella cochlearis	83900
Kellicottia longispina	2800
Polyarthra vulgaris	3800

Discussion

Because of its late summer clinograde DO profile, but generally low concentrations of Chl *a* and TP, Cordley Lake should be characterized as mesotrophic rather than oligotrophic or eutrophic. Low levels of PC, Chl *a*, and rarity of colonial cyanobacteria suggest no current existence of cultural eutrophication. However, nitrate concentrations are very low because of assimilation by algae in the epilimnion and denitrification in the hypolimnion. If P concentrations were to increase, the lake is a candidate for nuisance blooms of cyanobacteria (Div. Cyanophyta, aka 'bluegreen algae'). Several species of cyanophytes already exist in the lake (Table 4a), so preemptive watershed management practices would be prudent. Lakeshore residents should thus refrain from application of any fertilizers containing P, and any existing septic fields should be well maintained, or abandoned and residences connected to municipal sewer lines.

The zooplankton community is likewise indicative of a mesotrophic lake with modest levels of planktivory by fish. Fish are visual predators that differentially remove large-bodied crustaceans. Lakes with heavy planktivory tend to be dominated by cyclopoid copepods and rotifers and to have few large *Daphnia* and *Diaptomus*. Because of their body sizes, *Daphnia* and *Diaptomus* dominate the zooplankton biomass of Cordley Lake.

Analyte comparison between Tables 2a/2b and Table 3 reveal statistically different results for pH and K_{25} values. Our pH measurements of 7.00-7.75 are less alkaline than the findings reported by Fusilier (2010), whose range of pH was 7.9 to 8.7. Despite this disparity, our measurements of acid-neutralizing capacity, also known as titration alkalinity (essentially all bicarbonate at these pH values) were not different. Our specific conductance (K_{25}) measurements ranged from 589 to 688 μS, and exceeded Fusilier's reported range of 470 to 560 μS. In the absence of direct comparison between water samples that are split and

measured independently by different laboratories it is not possible to declare these disparities to be the result of systematic calibration errors between labs. Our quality control used conductivity check analysis, but similar analysis cannot be applied to the Fusilier data because too few ions were measured.

Despite the differences observed between pH and K_{25}, our measurements of chlorophyll *a*, Secchi disk transparency (SD), nitrate (NO_3^-) and total phosphorus (TP) overlapped broadly with Fusilier's (2010) measured ranges.

Origin of the chloride salt content of Cordley Lake

The chloride content of Cordley Lake (Table 2a) is high compared to most of the surface waters in the State of Michigan. A more typical value would be 1 mEq. However, Cordley Lake is not out of line with chloride levels in the Huron River drainage. Surveys conducted by a University of Michigan limnology class in 2006 revealed that chloride levels were low in the Huron River at its source in Livingston County (Big Lake, 0.96 mEq) and the outlet of Pontiac Lake (0.80 mEq), but by the time the river had reached Milford its chloride concentration had climbed to 3.10 mEq, slightly higher than that of Cordley Lake. We were not able to determine at that time whether the source of the salt was geological or anthropogenic.

Anthropogenic addition of sodium chloride, mainly as road salt, can have profound effects on lake salinity. Earl Lake in Livingston County contained 12.62 mEq chloride when measured on 6 March 2009; the salt was delivered through storm drain runoff from the salt-encrusted parking lots of several large adjoining retail stores. The fact that historical specific conductance reported by Fusilier (2010) is significantly less than what we measured in 2013 might mean that salt is entering the lake. A seasonal study of chloride content of Cordley Lake could reveal whether salt content rises during the winter and falls during summer. That would suggest anthropogenic inputs.

Cordley Lake water renewal rate and implications for water quality

We did not undertake an independent analysis of Cordley Lake's drainage area, but the lake appears to be predominantly a groundwater recharge lake. If we accept the 4.3 year flushing rate proposed by Fusilier (2010), then residents should understand that any substances they introduce into the lake will remain there for years. For example, if the lake did receive a one-time pulse of road salt it would take almost 10 years for the lake to recover 90% of the way to its pre-perturbation level. Thus any pollutants that are introduced might be introduced quickly, but they will have effects lasting a decade or more.

Conclusion

Water quality of Cordley Lake does not reveal any trend toward deterioration at the moment. Continued prudent action by lakeshore residents to limit nutrient inputs should maintain the lake in its current desirable state. If they are not doing so already, residents should not apply phosphorus-containing fertilizers to their lawns, and they should abandon any septic drain fields that are failing. The low concentrations of nitrate (Table 2b) indicate that the lake is potentially at a tipping point if it were to receive additional phosphorus. Additional phosphorus would stimulate

the types of algae (bluegreen algae or cyanobacteria) that are regarded as nuisance species because they form surface scums and contribute foul odors. The appearance of any such surface bloom should be recognized as a serious alarm.

This report extends lake survey data compiled by Fusilier (2010) with the addition of several chemical analytes (calcium, magnesium, chloride, sulfate, and silica) as well as a biological survey of the lower food web: phytoplankton and zooplankton. The combined data provide a comprehensive baseline of limnological conditions against which future lake conditions can be compared. We are pleased to provide the residents with a detailed 'State of the Lake' assessment for reference purposes, and thank them for letting us increase our skills and understanding of surface waters in Michigan.

REFERENCES

Fusilier, W.E. 2010. Cordley Lake, Hamburg Township, Livingston County, 1993-2009, Water Quality Studies. Unpublished manuscript, 29 p.

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