ML 2009 Project Abstract
For the Period Ending June 30, 2013

PROJECT TITLE: Assessing the consequences of ecological drivers of change on water quality and habitat dynamics of deep-water lakes with coldwater fish populations
PROJECT MANAGER: Dr. Donald L. Pereira
AFFILIATION: Minnesota Dept. Natural Resources, Division of Fish and Wildlife, Fisheries Research & Policy Manager
MAILING ADDRESS: 500 Lafayette Road
CITY/STATE/ZIP: St. Paul, MN, 55155
PHONE: 651-259-5231
E-MAIL: don.pereira@state.mn.us
WEBSITE: http://www.dnr.state.mn.us/fisheries/management/research.html
FUNDING SOURCE: Environment and Natural Resources Trust Fund
LEGAL CITATION: ML 2009, Chap. 143, Sec. 2, Subd. 5C.

APPROPRIATION AMOUNT: $825,000

Overall Project Outcome and Results

We designed a long-term lake monitoring program that incorporates a synoptic view of lakes, including understanding historic and current lake conditions along statewide gradients of nutrients, climate, ecoregion, and land use. Twenty-four lakes and their associated watersheds were established as sentinel systems to serve as focal points of collaborative long-term monitoring, research, and environmental education. The research funded here focused primarily on the 7 deep-water sentinel lakes with coldwater fish populations. With our project partners, we examined current and forecasted relationships among resident lake biota, water quality, and lake habitat features, and extrinsic factors including watershed inputs, climate, and invasive species. Key deliverables include:

- U.S. Geological Survey developed biophysical water quality models to predict responses in the distribution of temperature and oxygen in Carlos, Elk, and Trout lakes based on current conditions. In Phase 2, models will be used to simulate the consequences of land-use change and climate dynamics on lake ecosystems, including sensitive cold-water fish communities.
- St. Croix Watershed Research Station provided a reconstruction of the historical water quality and diatom communities of seven sentinel lakes. Results provide a context for interpreting future community-level shifts based on land-use changes and climate trends.
- A data visualization tool has been developed that enables interested scientists and others to interact with SLICE data. Improvements are planned to make the tool more user-friendly and provide greater access to databases currently managed by DNR, PCA, and other partners.
- Analysis of zooplankton collections from 24 sentinel lakes suggests that zooplankton will be a sensitive indicator of current and changing lake conditions. Data collected thus far has allowed us to focus sampling on specific times and components of the zooplankton community.
- Our understanding about cisco behavior and population status in Minnesota lakes has been greatly enhanced. We developed and refined sampling techniques, and now have baseline information to understand climate and land use impacts to cisco lakes.

Project Results Use and Dissemination

The information gathered during the SLICE project has been invaluable to fisheries and lake managers in a number of ways. First, the ability to collect water quality, zooplankton, fisheries, and historical lake data over consecutive years from a suite of lakes has been foundational for the implementation of a long-term monitoring program for Minnesota lakes. That information will provide researchers and managers with a wide variety of specialties and interests to focus on specific metrics that are most likely to reflect change from various stressors. The ability to identify those metrics and their response to specific stressors will enable managers to quickly respond and develop best management practices in lakes facing environmental changes. Second, techniques developed and refined during the project have strongly influenced our basic understanding of the ecology and behavior of cisco population in Minnesota. Understanding how cisco populations, vulnerable to both biotic (i.e. invasive species) and abiotic (i.e. climate change) stressors, respond to change will be important for the management of not only cisco but other cold and cool water species as well. Third, by including partners with differing discipline backgrounds and expertise, e.g., USGS, St. Croix Watershed Research Station, et al., the project was able to provide unique and holistic insights into how lake ecosystems function now and in the future (models), as well as how they may have in the past (sediments).

A great deal of the information gathered that has been analyzed and disseminated has been for a scientific audience. Two peer-reviewed publications have been produced (citations below) and a number of presentations have been made at scientific meetings at the national, regional, and state level. We fully expect that several additional peer-reviewed publications will be forthcoming.

For the general audience, SLICE maintains a web presence on the Minnesota Department of Natural Resources' website (http://www.dnr.state.mn.us/fisheries/slice/index.html). The data visualization tool that has been developed will enable both scientists and members of the public to interact with a number of databases, allowing them to see firsthand the data that is being collected. The ability for others to interact with the data should encourage the development of new questions about how aquatic systems function and eventually provide researchers and managers with new means to study those systems.

Finally, Phase 1 (2009-2013) laid much of the key groundwork for Phase 2 (2013-2016), and the monitoring and research efforts summarized above continue. A summary of renewed and new activities can be found at: http://www.lccmr.leg.mn/projects/2013/work_plans/2013_05a.pdf.

Journal Publications as of August 2013:

Ahrenstorff, T.D., T.R. Hrabik, P.C. Jacobson, and D.L. Pereira. 2013. Food resource effects on diel movements and body size of cisco in north-temperate lakes. Oecologia DOI:10.1007/s00442-013-2719-3

Valley, R.D., and S. Heiskary. 2012. Short-term declines in curlyleaf pondweed in Minnesota: potential influences of snowfall. Lake and Reservoir Management 28:338-345.

Trust Fund 2009 Work Program Final Report

Date of Report: 21 September 2013
Date of Next Status Report: Final Report
Date of Work Program Approval: June 16, 2009
Project Completion Date: 30 June 2013

I. PROJECT TITLE: Assessing the consequences of ecological drivers of change on water quality and habitat dynamics of deep-water lakes with coldwater fish populations.

Project Manager: Dr. Donald L. Pereira
Affiliation: Minnesota Dept. Natural Resources, Division of Fish and Wildlife, Fisheries Research & Policy Manager
Mailing Address: 500 Lafayette Road
City / State / Zip: St. Paul, MN, 55155
Telephone Number: 651-259-5231
E-mail Address: don.pereira@state.mn.us
FAX Number: 651-297-4916
Web Site Address:
http://www.dnr.state.mn.us/fisheries/management/research.html

Location: Statewide. See Attachment B for a map

Total Trust Fund Project Budget:	**Trust Fund Appropriation**	**$825,000**
	Minus Amount Spent:	**$825,000**
	Equal Balance:	**$0**

Legal Citation: ML 2009, Chap. 143, Sec. 2, Subd. 5C.

Appropriation Language: $825,000 is from the trust fund to the Commissioner of Natural Resources to assess the consequences of large ecological drivers of change on water quality and habitat dynamics of deep water lakes with coldwater fish populations. This appropriation is available until June 30, 2012, at which time the project must be completed and final products delivered, unless an earlier date is specified in the work program.

II. FINAL PROJECT SUMMARY AND RESULTS

We designed a long-term lake monitoring program that incorporates a synoptic view of lakes, including understanding historic and current lake conditions along statewide gradients of nutrients, climate, ecoregion, and land use. Twenty-four lakes and their associated watersheds were established as sentinel systems to serve as focal points of collaborative long-term monitoring, research, and environmental education. The research funded here focused primarily on the 7 deep-water sentinel lakes with coldwater fish populations. With our project partners, we examined current and forecasted relationships among resident lake biota, water quality, and lake habitat features, and extrinsic factors including watershed inputs, climate, and invasive species. Key deliverables include:

- U.S. Geological Survey developed biophysical water quality models to predict responses in the distribution of temperature and oxygen in Carlos, Elk, and Trout Llakes based on current conditions. In Phase 2, models will be used to simulate the consequences of land-use change and climate dynamics on lake ecosystems, including sensitive cold-water fish communities.
- St. Croix Watershed Research Station provided a reconstruction of the historical water quality and diatom communities of 7 sentinel lakes. Results provide a context for interpreting future community-level shifts based on land-use changes and climate trends.
- A data visualization tool has been developed that enables interested scientists and others to interact with SLICE data. Improvements are planned to make the tool more user-friendly and provide greater access to databases currently managed by DNR, PCA, and other partners.
- Analysis of zooplankton collections from 24 sentinel lakes suggests that zooplankton will be a sensitive indicator of current and changing lake conditions. Data collected thus far has allowed us to focus sampling on specific times and components of the zooplankton community.
- Our understanding about cisco behavior and population status in Minnesota lakes has been greatly enhanced. We developed and refined sampling techniques, and now have baseline information to understand climate and land use impacts to cisco lakes.

III. PROGRESS SUMMARY:

PROGRESS SUMMARY AS OF 12/31/2012

The departure of the project coordinator in March of 2012 required DNR Fisheries Research to shift work responsibilities of two research biologists (Brian Herwig and Jeffrey Reed) to coordinate and report remaining project deliverables. Despite the interruption, all but the amended projects (zooplankton database development and a web-based data visualization tool) are scheduled to be completed by the June 30 2012 deadline.

Zooplankton database and Data Visualization Tool

Internal service level agreements (SLA's) with the State's Office of Enterprise Technology have been developed and a technical committee has been drafted to provide guidance for the development of these tools.

Progress Summary

Since October 2011, progress on nearly all deliverables focused mainly on further data analysis, model development and refinement and completing final reports.

Continued progress was made in the inclusion of zebra mussel effects into the in-lake model for Lake Carlos.

The St. Croix Watershed Research Station has completed diatom reconstruction and submitted a draft final report. Complete results from this study will be provided in the final report to the LCCMR. Similarly, cooperators have completed work on zooplankton sampling and evaluations (J. Hirsch, DNR Division of Ecological and Water Resources) and assessing cisco populations (T. Hrabik, University of Minnesota – Duluth). Final reports for these components of the project have been completed and will be incorporated into the final report to the LCCMR in June 2013.

PROGRESS SUMMARY AS OF 10/30/2011

Despite the disruptions from the State Government Shutdown in July 2011, we are on schedule to finish the project as outlined in this work program by the scheduled date of June 30 2012. In fact, with cost savings in other areas, we have the capability of enhancing one deliverable (zooplankton database) and adding another (web-based data visualization tool) pending LCCMR approval of an amendment request.

Zooplankton database

Specifically, we propose to move $30,950 from various unspent budget categories into an internal service level agreement with the State's Office of Enterprise Technology (OET) to build enhancements of the zooplankton database that this appropriation initially funded that would enhance staff, partner, and constituent access to data. As it stands now, the zooplankton database is functional but access to data is cumbersome. OET estimates it would take 324 hours @ $80/hr ($25,950) for the programming work and we would reserve $7,000 for a student worker to migrate offline zooplankton data (690 spreadsheets) from the sentinel lakes recorded with the outdated zooplankton counting program (See Result 4)

Data visualization tool

We propose to move an additional $32,950 from unspent budget categories into an internal service level agreement with OET to build an automated data visualization web-application for SLICE datasets that resemble those of another successful long-term monitoring program, the Upper Mississippi Long-term Resource Monitoring Program (http://www.umesc.usgs.gov/data_library/fisheries/graphical/fish_front.html). This web-application would use "High Charts" http://www.highcharts.com/demo/ to display time series data from measured indicators via menu choices. This would enhance staff, partner, and constituent access to data and thus the frequency it will be used to influence lake management and present data in an understandable way (See Result 4).

Progress Summary

Progress on deliverables continues with most work since April 2011 involving the last year data collection on the sentinel lakes for this study. For Results 1 and 3, USGS staff continued to collect high resolution flow and chemistry data in addition to meteorological data from the super sentinel lakes (Carlos, Elk, and Trout) that will be important for building a robust predictive model of future lake conditions. Progress continues on building the lake model for the super sentinel lakes. The model on Carlos will include potential impacts of zebra mussel expansion on water quality and fish habitat.

Dating of sediment cores in the cold-water sentinel lakes is nearly complete according to the St. Croix Watershed Research Station (Result 2). Early results indicate an increase deposition of inorganic and organic sediments in most lakes following Euroamerican settlement. Diatom reconstructions of historical water quality are underway.

Progress continues on isotope analysis of groundwater-surface water interactions, patterns of zooplankton communities, cisco behavior habitat use and hydroacoustic assessement tools, and PCA/DNR cooperative lake reporting (Result 4). Activities are focused now on incorporating 2011 data into analyses then moving quickly into final reporting. We are on track to produce final reports of each of these deliverables including an overall final report that weaves all results together by the scheduled project completion date.

PROGRESS SUMMARY AS OF 4/15/2011

Progress on deliverables continues with most work since October 2010 focused on data processing and analysis. Initial datasets for development of the predictive water quality models in Carlos, Elk, and Trout have cleared QA/QC procedures and are published in accessible water quality databases. Model development is underway. Sediment cores have been collected and dated on most of the seven cored sentinel lakes. Diatoms are currently being prepared for identification and reconstruction of historical water quality regimes. Population estimates of cisco have been completed by UMD for the seven sentinel lakes and information on diets, prey availability, and movement patterns are currently being analyzed. All zooplankton data collected to date has been analyzed and summarized.

Of greatest intangible importance is the number of outside partners that SLICE is attracting, which effectively leverages this investment by the ENTF several fold. We expect that a continued commitment to maintaining this long-term monitoring infrastructure will continue to attract interdisciplinary partners and result in efficient use of monitoring data sets; ultimately leading to better water resource management decisions. We are tracking partner efforts at http://www.dnr.state.mn.us/fisheries/slice/investigations.html. Below is a brief bulleted summary:

- Several independent coldwater fisheries investigations funded by USGS, DNR Game and Fish Fund, and Federal-Aid reimbursement dollars
- Three undergraduate research projects funded by UMD's Undergraduate Research Opportunities program
- National Science Foundation (NSF) funded research to support research conducted by Oklahoma State University to reconstruct historical zooplankton

communities and offer further insight into how much water quality conditions have changed over time in the sentinel lakes.

- Baseline surveys of deepwater benthic invertebrate communities funded by the DNR Game and Fish Fund
- Zooplankton data from the sentinel lakes going to Carleton College Math Department for use in undergraduate senior research projects.

PROGRESS SUMMARY AS OF 10/30/2010

We recently completed our 3rd year of data collection for the first phase of SLICE and preliminary analyses are currently underway. Notable updates since the last progress report include completion of hydroacoustic and experimental gillnet surveys of cisco in the seven cold-water sentinel lakes, field data collection for calibration of lake mixing models in the super-sentinel lakes, and updated software applications for more efficient processing of zooplankton data. Regarding the zooplankton software application: given the difficulty of finding open-source programming code for this application (and hence a difficult search for a contractor to write the program from scratch), we will proceed with publishing this code as open-source for other researchers. Also, preliminary findings suggest groundwater may play a significant role in the water budgets of many of our sentinel lakes. Under Result 4 Deliverable 1, we submit an amendment request to fund analytical chemistry work for determining the contribution of ground water to sentinel lake hydrological budgets.

PROGRESS SUMMARY AS OF 4/15/2010

The biggest accomplishment that has occurred since this project commenced in July 2009 is the building of infrastructure and formalization partnerships to support outcomes for this project and others into the future. Interagency and joint-powers agreements between partners were drafted and approved, thus establishing compliancy of data and budget practices for this project and forming a template for future amendments or extensions. All water data being collected complies with state and federal quality control/assurance policies and are being housed in publically available databases for use in other future projects or assessments. In addition, standard aquatic plant, zooplankton, and fisheries assessments have occurred since 2008 and will continue through 2011. DNR Web pages were recently developed that describes the SLICE program, data collection efforts, and expected outcomes (see http://www.dnr.state.mn.us/fisheries/slice/index.html and pages therein).

IV. OUTLINE OF PROJECT RESULTS*:*

Result 1:

Establish 24 sentinel lakes and their associated watersheds as focal points of collaborative long-term monitoring, research, and environmental education

Description:

In the original submitted proposal, we identified only 7 lakes with cold-water habitat that would be considered in this project. Although, the focus remains on understanding dynamics of lakes with cold-water habitat, we must consider a wider range of lake habitat conditions in order to simulate possible changes to lake habitats and biotic communities as they become warmer and more productive. The wide geographical spread and gradient of productivity and other disturbances among our cool and warm-water sentinel lakes affords us a better ability to make comparisons.

Result 1 mostly involves project initiation activities and sets the stage for the deliverables listed in Results 2, 3, and 4. Result 1 also lays the ground work for long-term partnerships and monitoring after this work program is completed in 2012. Specifically Result 1 focuses on building interdisciplinary partnerships to conduct intensive monitoring of several physical, chemical, and biological parameters in 24 sentinel lakes, distributed across the 4 major ecoregions of the state. Efforts will be made to compare and model differences between cold-water and cool-warm water lake habitats and indicators that are particularly sensitive to these differences. In addition, we will establish meteorological and water quality sensors and flow gaging stations (See Attachment C) built and managed by the USGS in 3 "super" sentinel lakes that span a range of watershed conditions but still harbor cold-water fish populations. Data from these lakes will be housed in the National Water Inventory System (NWIS) database and be used to facilitate predictive watershed and lake nutrient modeling discussed in Result 3.

Summary Budget Information for Result 1: Trust Fund Budget: $269,968
Amount Spent: $269,968
Balance: $0

Deliverable	**Completion Date**	**Budget**
1. Network of 24 sentinel monitoring and research sites	July 2009	$0
2. Flow, climate, and water quality monitoring systems in Carlos L., Douglas Co.; Elk L., Clearwater Co.; and Trout L., Cook Co.	June 2013	$269,968

Result Completion Date: 30 June 2013

Result Status as of 15 April 2010:
Continuous temperature data from temperature-sensor logger chains deployed through the ice-free season of 2009 in Trout and Elk were processed for quality assurance and formatted for upload into the USGS National Water Information System database (http://waterdata.usgs.gov/nwis). Additional equipment to measure continuous dissolved oxygen will be installed in all lakes by the end of April 2010. Continuous lake level data and flow and outflow data from 2009 were processed for five sites on Lake Carlos (two inflow site, one outflow site , and two lake level sites) and three sites on Elk Lake (one outflow, one lake level, and one inflow).

Water level loggers were installed in three locations in Lake Carlos in late March, 2010, for the 2010 ice-free season. One transducer was installed in Trout Lake in April, 2010, for the 2010 ice free season. Inflow and outflow discharge data were collected in March and April during these same sampling trips to Lake Carlos and Trout Lake.

Water quality data will be collected on a bi-weekly basis in the three super-sentinel lakes from ice-out through November by USGS and PCA staff. These data will be housed in STORET and can be accessed through PCA's Environmental Data Access Site (http://www.pca.state.mn.us/data/edaWater/index.cfm)

Result Status as of 30 October 2010**:**

Significant amounts of data were collected from the Super Sentinel Lakes during FY2010 (Tables 1.1 and 1.2). A more detailed work summary can be found in Appendix A. All three lakes were monitored for influent and effluent nutrient loads, internal nutrient concentrations, lake levels, and physical and chemical field parameters. Inflows, outflows and ambient lake stations at two depths were sampled monthly by USGS for nutrients, major ions, chlorophyll-a, and particulate carbon and nitrogen. Continuous lake level data were recorded at 15-minute intervals using pressure transducers deployed at all three lakes shortly after the loss of ice cover. Continuous water temperature data from thermistors deployed at multiple depths were collected at 15-minute intervals between May-October in all three lakes. At each monthly sampling, profile data were collected for dissolved oxygen, pH, temperature, chlorophyll-a in vivo fluorescence, and specific conductance. Data from these multiple sampling efforts were coupled with ambient lake monitoring data collected by the Minnesota Pollution Control Agency (MPCA). Together, the combined monitoring data provide 9-11 lake profiles for each lake from May through October. Deuterium and Oxygen-18 data were collected from Elk Lake to characterize groundwater inflows to the lake. Sampling included lake surface water, spring inflows from two locations on opposite sides of the lake, and mini-piezometer groundwater samples adjacent to the spring sites at the edge of the lake.

Continuous temperature data from all 24 Sentinel Lakes has been processed and uploaded to a website to facilitate data sharing among the project partners (http://mn.water.usgs.gov/projects/sentinel_lakes/map.html).

Issues and Needs:

1. Continuous four parameter data platforms are not deployed because of safety issues and overall need assessment. Propose use of sondes at fixed depths with limited use of data platforms on remote lakes.

2. Meteorological data is being collected from nearby airport station on an hourly basis. We will determine whether data will be sufficient for modeling.

3. Lake staff gages need to be tied to a fixed datum so that transducer data can be reconciled with lake bathymetry data. A RTK GPS unit may be only option because of the remote nature of some of the sites and the lack of nearby

benchmarks - (nearest benchmark is 3-4 miles away for Carlos and Trout). We will work with DNR Division of Ecological and Water Resources to verify, rectify, or replace elevation benchmarks.

Plans for 4/15/2011 Reporting Period:

1. Reconfigure thermistor chains for deployment during winter, under ice.
2. Survey lake staff gages.
3. Continue researching data platform options.
4. Meet with Lee Engel (MPCA) to determine water balance approach using isotope data for Elk Lake.
5. Assess results of MN DNR zebra mussel survey.
6. Begin building lake model (Result 3).

Table 1.1. 2010 Chemical sampling status in the super sentinel lakes

Lake Name	Sample Type	Mar	Apr	May	June	July	Aug	Sep	Oct
Lake Carlos	Lake- Below Lake Le Homme Dieu			x	x				
	Lake- West of Kecks			x	x		x		x
	Outflow (Long Prairie)		x		x	x	x	x	x
	Inflow (Lake Darling)		x		x	x	x	x	x
	Inflow (Le Homme Dieu)		x			x	x		
	Temp-DO Profile			x	x	x	x		x
	Continuous Lake Level	x	x	x	x	x	x	x	x
Trout	Lake			x	x	x	x		x
	Marsh Lake Outlet		x		x	x	x		x
	Tributary		x		x	x	x		x
	Trout Outlet		x		x	x	x		x
	Temp-DO Profile			x	x	x	x		x
	Continuous Lake Level		x	x	x	x	x	x	x
Elk	Lake			x	x	x	x		x
	West Spring (Spring 1)			x		x	x		x
	East Spring (Spring 4)					x	x		x
	Outlet		x		x	x	x	x	x
	Temp-DO Profile			x	x	x	x		x
	Continuous Lake Level					x	x	x	x

Table 1.2. Summary of total sampling effort in super sentinel lakes through October 2010.

Data Type	Lake Carlos	Elk Lake	Trout Lake
Lake water quality (samples & profiles)	10 dates (North)/ 9 dates (South)	11 dates	11 dates
Inflow/outflow water quality samples	6 dates	6 dates	5 dates
15-minute temperature profiles	May-October	May-October	June-October
15-minute water level data	March-October	July-October	April-October
Algal growth bioassays	June & August	June & August	June & August
O18-Deuterium isotope samples (ground water)		July & August	

Result Status as of 15 April 2011**:**
Several changes to the Sentinel Lakes data collection plan were necessary after a review of ongoing monitoring and following an initial survey of the three super sentinel lakes. Changes were made to adjust water quality sampling to in-lake conditions with the objectives of filling data gaps in MPCA's sampling regime and constructing a database capable of supporting CE-QUAL-W2 model development.

To achieve these objectives, USGS collected water quality samples necessary to create a bi-weekly data set of relevant nutrient, carbon, and major ion constituent concentrations. The effort was designed to provide coordinated inflow and outflow sampling linked with in-lake sampling. These efforts were coupled with collection of continuous water quality data necessary for model calibration. Continuous data were collected using smaller buoy-based installations to minimize hazards and increase flexibility in sampling. The decision not to deploy data collection platforms resulted in cost savings that are balancing out increased labor and analytical costs. These sampling efforts combined to provide a dataset capable of supporting model development and calibration.

USGS has acquired two large pontoon data platforms capable of deployment if needed to augment the buoy-based deployments of continuous water quality monitors. Plans to deploy shore-based meteorological data sensors are also taking place as planned.

All water quality field and laboratory data from 2010 has been received, checked, and uploaded to the USGS NWIS web where it is available to cooperators. Under ice water samples were obtained for the three Super Sentinel Lakes in March, 2011. Tables 1 and 2 summarize data collected by USGS for 2010 and to date for 2011. All three lakes were monitored for influent and effluent nutrient loads, internal nutrient concentrations, lake levels, and physical and chemical field parameters. Inflows, outflows and ambient lake stations at two depths were sampled monthly by USGS for nutrients, major ions, chlorophyll-a, and particulate carbon and nitrogen through November, 2010 and again in March, 2011. Pressure transducers to obtain continuous lake level data recorded at 15-minute intervals were removed prior to ice cover and were reinstalled at Lake Carlos in March, 2011, and will be reinstalled at Elk and Trout Lakes shortly after the loss of ice cover. Thermistor chains to monitor continuous water temperature data at different depths were deployed under the ice in all three lakes. Each month, profile data were collected for dissolved oxygen, pH, temperature, chlorophyll-a in vivo fluorescence, and specific conductance. Data from these multiple sampling efforts were coupled with ambient lake monitoring data collected by the Minnesota Pollution Control Agency (MPCA). Together, the combined monitoring data provide 9-18 lake profiles for each lake from May through November.

A preliminary zebra mussel survey was conducted under the ice at Lake Carlos in March 2011 near the inflow from Le Homme Dieu. Zebra mussel colonies were found at depths ranging from 1 meter to 9 meters. A more comprehensive survey is planned for Lake Carlos later this spring.

Continuous temperature data from all 24 Sentinel Lakes continues to be processed and uploaded to a web as it is received.
(http://mn.water.usgs.gov/projects/sentinel_lakes/map.html)

Table 1.1 2010-2011 Chemical Sampling Status

Lake Name	Sample Type	2010									2011
		Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Mar
Carlos	Lake- Below Lake Le Homme Dieu			x	x				x		
	Lake- West of Kecks			x	x		x		x	x	x
	Inflow (Lake Darling)		x		x	x	x	x			x
	Inflow (Le Homme Dieu)		x			x	x				x
	Inflow (Lake Geneva)					x					
	Outflow (Long Prairie)		x		x	x	x	x			x
	Profile			x	x		x		x	x	x
	Transducer	x	x	x	x	x	x	x	x	x	x
	Thermistor chain			x	x	x	x	x	x	x	x
Trout	Lake			x	x	x	x		x		x
	Inflow (Marsh Lake Outlet)		x		x	x	x		x		x
	Inflow (tributary)		x		x	x	x		x		
	Outlet		x		x	x	x		x		x
	Profile			x	x	x	x				x
	Transducer		x	x	x	x	x	x			
	Thermistor chain				x	x	x	x			x
Elk	Lake			x	x	x	x			x	x
	West Spring inflow (Spring 1)			x	x	x	x				x
	Inflow (Siegfried Creek)				x						x
	East Spring inflow (Spring 4)					x	x				
	Outlet		x		x	x	x	x			x
	Profile			x	x	x	x			x	x
	Transducer					x	x	x		x	
	Thermistor chain			x	x	x	x	x		x	x

Table 1.2 Summary of total sampling effort through November 2010.

Data Type	Lake Carlos	Elk Lake	Trout Lake
Lake profiles	12 dates (North)/ 9 dates (South)	16 dates	18 dates
Lake water quality samples	10 dates (North)/ 12 dates (South)	11 dates	11 dates
Inflow/outflow water quality samples	5 dates	5 dates	4 dates
15-minute continuous temperature profiles	May-November	May-November	June-October
15-minutes transducer (water level) data	March-November	July-November	April-October
Algal growth bioassays	June & August	June & August	June & August
O18-Deuterium isotope samples		July & August	

Result Status as of 30 October 2011**:**
Significant amounts of data were collected from the Super Sentinel Lakes during FY2011 (Tables 1.1 and 1.2). All three lakes were monitored for influent and effluent nutrient loads, internal nutrient concentrations, lake levels, and physical and chemical field parameters. Inflows, outflows and ambient lake stations at two depths were sampled monthly by USGS for nutrients, major ions, chlorophyll-a, and particulate carbon and nitrogen. Continuous lake level data were recorded at 15-minute intervals using pressure transducers deployed at all three lakes shortly after the loss of ice cover. Continuous water temperature data from thermistors deployed at multiple depths were collected at 15-minute intervals between May-September in all three lakes.

At each monthly sampling, profile data were collected for dissolved oxygen, pH, temperature, chlorophyll-a in vivo fluorescence, and specific conductance. Data from these multiple sampling efforts were coupled with ambient lake monitoring data collected by the Minnesota Pollution Control Agency (MPCA). Together, the combined monitoring data provide 6-8 lake profiles for each lake from May through September. In addition to monthly profile data, water quality sondes were deployed at multiple depths from June through September to track algal biomass and oxygen metabolism in the epilimnion, metalimnion, and hypolimnion of each of the three lakes.

Plans for Final Reporting Period:

1. Meet with MN DNR project manager in December 2011 to provide a status report on modeling effort.
2. Pull thermistor chains for Lake Carlos and establish winter deployment.
3. Use SeaCat 19v2 profiler to conduct synoptic surveys of dissolved oxygen, conductivity, chlorophyll-a, and temperature in Lake Carlos and Elk Lake.
4. Develop zebra mussel density estimates.
5. Continue building lake model.

Table 1.1. 2010 and 2011 Chemical Sampling Status

Lake Name	Sample Type	2010									2011				
		Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Mar	Apr	May	June	July
Lake Carlos	Lake- Below Lake Le Homme Dieu			x	x				x						
	Lake- West of Kecks			x	x		x		x	x	x		x	x	x
	Inflow (Lake Darling)		x		x	x	x	x			x		x	x	x
	Inflow (Le Homme Dieu)		x			x	x				x		x	x	x
	Inflow (Lake Geneva)					x									
	Outflow (Long Prairie)		x		x	x	x	x			x		x	x	x
	Profile			x	x		x		x	x	x		x	x	x
	Transducer	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Thermistor chain			x	x	x	x	x	x	x	x	x	x	x	x
	Continuous water quality sondes												x	x	x
	Weather station													x	x
Trout	Lake			x	x	x	x		x		x		x		x
	Inflow (Marsh Lake Outlet)		x		x	x	x		x		x		x		
	Inflow (tributary)		x		x	x	x		x				x		
	Outlet		x		x	x	x		x		x		x		
	Profile			x	x	x	x				x		x		x
	Transducer		x	x	x	x	x	x					x	x	x
	Thermistor chain				x	x	x	x			x	x	x	x	x
	Continuous water quality sondes												x	x	x
	Weather station														x
Elk	Lake			x	x	x	x			x	x	x		x	x
	West Spring inflow (Spring 1)			x	x	x	x				x			x	
	Inflow (Siegfried Creek)				x						x			x	
	East Spring inflow(Spring 4)					x	x							x	
	Inflow(Ga-Gwa-Dash Creek)													x	
	Inflow (unnamed tributary)													x	
	Outlet		x		x	x	x	x			x	x		x	x
	Profile			x	x	x	x			x	x			x	x
	Transducer					x	x	x		x		x	x	x	x
	Thermistor chain			x	x	x	x	x		x	x	x	x	x	x
	Continuous water quality sondes												x	x	x
	Weather station													x	x

Table 1.2. Summary of total sampling effort through August 2011.

Data Type	Lake Carlos	Elk Lake	Trout Lake
Lake profiles	19 dates (North)/ 13 dates (South)	33 dates	18 dates
Lake water quality samples	13 dates (North)/ 15 dates (South)	16 dates	16 dates
Inflow/outflow water quality samples	8 dates	6 dates	5 dates
15-minute continuous temperature profiles	May 2010-August 2011	May 2010-August 2011	June 2010-August 2011
15-minutes transducer (water level) data	March-November 2010 March-August 2011	July-November 2010 April-August 2011	April-October 2010 May-August 2011
Algal growth bioassays	June & August 2010	June & August 2010	June & August 2010
O18-Deuterium isotope samples		July & August 2010 June 2011	

Result Status as of: 12/31/2012

Summary of Data Collection Efforts

Data collection for each super sentinel lake consisted of continuous temperature data from multiple depths for the major sub-basin in the lake during the ice-free season as well as continuous, multiple-parameter water quality sonde data collected from fixed depths during the ice-free season. Meteorological (MET) data platforms deployed at each lake provided continuous meteorological data to complement the continuous water quality data necessary to populate the individual lake water quality models. MET data collection included wind speed and direction at the surface of the lake, air temperature, net radiation, rainfall, and photosynthetically-active radiation (PAR). Continuous water quality sonde data collection included three parameter data: temperature (Temp), dissolved oxygen (DO), and specific conductance (SC). Routine water quality data were collected once a month by the USGS. Data collection was scheduled to complement the data collection by the Minnesota Pollution Control Agency with the end result being a set of bi-weekly water quality profile data. Profile data included the three continuous parameters (DO, Temp, SC) with the addition of pH and chlorophyll *a* in vivo fluorescence (IVF). Data were collected at multiple depths to characterize the upper, middle, and bottom zones of each lake.

USGS ambient water quality sampling coincided with monthly field data collection. All water quality samples were analyzed for the standard sentinel lakes water quality parameters with the addition of compounds necessary for water quality model calibration. These additions included dissolved and particulate nutrients, major ions, and biological parameters including algal biomass. Table 1 provides a general summary of the USGS data collection efforts including lake profile field data and discrete water quality samples.

Table 1.3. Summary of water quality and discharge data collected by USGS during the Phase 1 Sentinel Lakes Study.

Data Type	Lake Carlos	Elk Lake	Trout Lake
Lake profiles	19 dates (North)/ 13 dates (South)	33 dates	18 dates
Lake water quality samples	13 dates (North)/ 115 dates (South)	16 dates	16 dates
Inflow/outflow water quality samples	8 dates	6 dates	5 dates
15-minute continuous temperature profiles	May 2010-August 2011	May 2010-August 2011	June 2010-August 2011
15-minutes transducer (water level) data	March-November 2010 March-August 2011	July-November 2010 April-August 2011	April-October 2010 May-August 2011
Algal growth bioassays	June & August 2010	June & August 2010	June & August 2010
O18-Deuterium isotope samples		July & August 2010 June 2011	

Surface water inflows and outflows and associated constituent concentrations were also measured during each monthly field sampling. Additional inflow and outflow data were collected during periods of high flow associated with spring run-off and mid-summer rain events. Perennial inflows and outflows at all three lakes were estimated using site-specific discharge rating curves and continuous water level data. The continuous water level data were collected by USGS using pressure transducers at fixed locations with known elevations.

Site-specific discharge data were used along with water level data to calculate water budgets for each lake. Discharge data were combined with constituent concentrations to estimate influent nutrient loading and nutrient budgets for the three study lakes.

Data Reporting to MN DNR

Discrete water quality data and water level transducer data were processed according to USGS protocols and provided to the MN DNR and to the MPCA for inclusion in Sentinel Lake Reports. These reports are available at the following URL:
http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/sentinel-lakes.html

Discrete water quality data were also published in manuscript and database format as part of the Minnesota Water Science Center Annual Data Report 2010 and 2011. Data can be accessed through an interactive web portal at the following URL:
http://wdr.water.usgs.gov/adrgmap/

The database of record for all water quality data, water level data, and discharge data is the National Water Information System, or NWIS. NWIS data are available for download using the NWIS web interface. This interface for Minnesota data is available online at the following URL:
http://waterdata.usgs.gov/mn/nwis/qw

Continuous temperature data from USGS thermistor chains were provided to MN DNR as EXCEL data files. In addition to this data delivery, the USGS developed and continues to maintain an interactive, web-based data portal for all continuous temperature data collected from the Minnesota Sentinel Lakes. This data portal includes an interactive map of sites and data download capabilities. The tool is available at the following URL:
http://mn.water.usgs.gov/projects/sentinel_lakes/map.html

These multiple publications and online database portals provide open access to all data collected by the USGS for the Sentinel Lakes Project.

Result 1 is nearing completion and complete results are expected in the final report to the LCCMR.

Final Report Summary:

Summary for Result 1, Deliverable 1: *Network of 24 sentinel monitoring and research sites.*

We established 24 sentinel lakes and their associated watersheds as focal points of collaborative long-term monitoring, research, and environmental education. In the original proposal, 7 lakes with cold-water habitat were identified and considered in this project. Although, the focus remained on understanding dynamics of lakes with cold-water habitat, we considered a wider range of lake types and lake habitat conditions in our overall monitoring program.

Result 1 involved project initiation activities and set the stage for the deliverables listed in Results 2, 3, and 4. Result 1 also laid the ground work for long-term partnerships and monitoring after this work program was completed in 2013. Specifically Result 1 focused on building interdisciplinary partnerships to conduct intensive monitoring of several physical, chemical, and biological parameters in 24 sentinel lakes, distributed across the 4 major ecoregions of the state and we did so.

Summary for Result 1, Deliverable 2: *Flow, climate, and water quality monitoring systems in Carlos L., Douglas Co.; Elk L., Clearwater Co.; and Trout L., Cook Co.*
We have provided to LCCMR the final report "Assessing the Water Quality of Deepwater Lakes with Coldwater Fish Populations" authored by Erik Smith and Richard Kiesling.

Result 2: Reconstruct post-European to present water chemistry, sedimentation and erosion

Description:
To complement modern sampling and inform modeling of future lake responses, we will partner with the Science Museum of Minnesota (Lead: Dr. Mark Edlund) to comprehensively evaluate post-European colonization changes in lake conditions and evaluate major environmental events that coincided with these changes using analysis of biogeochemical signals preserved in sediment cores the seven cold-water sentinel lakes. The sediment record of a lake faithfully preserves chemical and biological clues or proxies that can be used to reconstruct the environmental history of a lake and its watershed. With any environmental assessment programs such as the SLICE, it is important to have a basic understanding of natural fluctuations within the system. Reliable long-term data sets, on the order of 30 - 50 years, are generally not available for most regions of the country, let alone most lakes in Minnesota. Using paleolimnological techniques and quantitative environmental reconstructions, we can estimate past environmental conditions and natural lake variability. In Minnesota, paleolimnological techniques, especially diatom-based analyses, have been used throughout the state to quantitatively reconstruct historical environmental conditions, including nutrient concentrations (Ramstack et al. 2003; Edlund and Kingston 2004), inform TMDLs and nutrient reduction targets (Edlund et al. 2009), and to develop nutrient criteria specific to ecoregion and lake-type (Heiskary and Wilson 2008). These successes have been based on paleolimnological analysis of only about 200 of Minnesota's 13,000 lakes. Although lake environmental histories vary across the wide range of ecoregions and land uses in Minnesota, major periods of change are generally associated with initial Euroamerican settlement and land clearance, post-WWII changes in agricultural practices, (sub)urbanization, and climate change, although other site-specific land uses (e.g., lakeshore development, damming) have also been identified as drivers of change.

Summary Budget Information for Result 2: **Trust Fund Budget: $90,000**
Amount Spent: $90,000
Balance: $0

Deliverable	**Completion Date**	**Budget**
1. Reconstruct historical water quality and habitat conditions in the seven coldwater sentinel lakes.	Oct. 2011	$70,000
2. Report explaining how past landuse and major environmental cycles (wet/dry, warm/cool) of the recent past shaped current water quality and habitat conditions in each sentinel lake	June 2013	$20,000

Result Completion Date: 30 June 2013

Result Status as of 15 April 2010:
Sediment coring sites have been selected for the seven cold-water sentinel lakes including Elk, Carlos, Ten Mile, Cedar, White Iron, Trout, South Twin lakes. Coring sites represent discrete depositional basins in the deepest region of each lake or broad plateaus where comformable deposition of sediments is likely to occur. Previous coring efforts on two of the lakes have been consulted to assist with core site selection and field sectioning (Bradbury et al. 1993; Engstrom 1995). Sediment cores from two of the sentinel lakes have been recovered to date. The remaining six cold water sentinel lakes will be cored during Spring of 2010.

An 82 cm core was recovered from 26.63 m depth in Carlos Lake on 22 October 2009. The core was sectioned in its entirety in 1.0 cm intervals. All core sections were subjected to loss on ignition analysis (Dean 1974) to determine percent content of organics, carbonates, and inorganics. Results indicate that sediments deposited below 35 cm are primarily carbonate (60-65% dry weight) and secondarily made up of inorganics (20-25% dry weight) and organics (10-15% dry weight). Above 35 cm core depth sediment constituents change rapidly with decreasing carbonate content and increasing inorganic content. These changes are consistent with lake response to Euroamerican settlement in many lakes across Minnesota. Organic content remains at approximately 15% dry weight to 20 cm core depth, before increasing to 30% dry weight at the core surface. The Carlos Lake core is currently being dated using alpha spectroscopy methods to determine the 210-Pb inventory. Based on the earlier core analyzed from Carlos Lake (Engstrom 1995) we anticipate the large shift in core geochemistry at 35 cm to mark the onset of Euroamerican settlement in the region (1860-1880 AD).

A 1.74 m long core was recovered from 19.82 m water depth in Elk Lake (Clearwater County) on 21 January 2010. The core was sectioned in 0.5 cm intervals to a depth of 30 cm. The Elk Lake core is currently being analyzed by loss on ignition analysis to determine organic, carbonate, and inorganic content in preparation for radioisotopic dating.

Result Status as of 30 October 2010**:**
Sediment coring sites have been selected for the seven cold-water sentinel lakes including Elk (Clearwater), Carlos (Douglas), Ten Mile (Cass), Cedar (Morrison), White Iron (St. Louis, Lake), Trout (Cook), South Twin (Mahnomen) lakes. Coring sites represent discrete depositional basins in the deepest region of each lake or broad plateaus where comformable deposition of sediments is likely to occur. Previous coring efforts on two of the lakes have been consulted to assist with core site selection and field sectioning (Bradbury and Dean 1993; Engstrom 1995). Sediment cores from all seven of the sentinel lakes have been recovered to date.

An 82 cm core was recoved from 26.63 m depth in Carlos Lake on 22 October 2009. The core was sectioned in its entirety in 1.0 cm intervals. All core sections were subjected to loss on ignition analysis (Dean 1974) to determine percent content of organics, carbonates, and inorganics. Result indicate that sediments deposited below 35 cm are primarily carbonate (60-65% dry weight) and secondarily made up of inorganics (20-25% dry weight) and organics (10-15% dry weight). Above 35 cm core depth sediment constituents change rapidly with decreasing carbonate content and increasing inorganic content. These changes are consistent with lake response to Euroamerican settlement in many lakes across Minnesota. Organic content remains at approximately 15% dry weight to 20 cm core depth, before increasing to 30% dry weight at the core surface. The Carlos Lake core has been dated using alpha spectroscopy methods to determine the 210-Pb inventory and establish a date-depth chronology for the core. Similar to the earlier core analyzed from Carlos Lake (Engstrom 1995) we confirmed the large shift in core geochemistry at 35 cm (dated 1849.2 AD) to mark the onset of Euroamerican settlement in the region (1860-1880 AD). Fifteen core depths have been chosen for microfossil analysis and diatom slides have been prepared.

A 1.74 m long core was recovered from 19.82 m water depth in Elk Lake (Clearwater County) on 21 January 2010. The core was sectioned in 0.5 cm intervals to a depth of 30 cm. The Elk Lake core was taken to the University of Minnesota Limnological Research Center (LRC) and subjected to whole core logging for magnetic susceptibility, core splitting and imaging, and subsampling in 1-cm increments to 100 cm core depth. Subsamples were examined under the scanning electron microscope and showed good diatom preservation. The Elk Lake core is currently being analyzed by loss on ignition analysis to determine organic, carbonate, and inorganic content in preparation for radioisotopic dating.

A 1.54 m long sediment core was recovered from 20.4 m of water in Trout lake (Cook County) on 08 June 2010. The core was sectioned in the field to a depth of 30 cm and the subsamples and remaining core returned to the laboratory for 4degC storage. The core had a slight color change at 132 cm core depth where it transitioned form a dark brown gyttja above to a lighter brown-gray below. There was abundant gammarids and mysids in the Trout Lake core. The Trout Lake core underwent intitial description and analysis at the LRC to determine magnetic susceptibility, core splitting and imaging, and subsampling in 1-cm increments to 100 cm core depth. The Trout Lake core is currently being prepared for loss-on-ignition analysis in preparation for radioisotopic dating. Analysis of subsamples with scanning electron microscopy showed high abundance of microfossils but relatively high breakage of diatoms

A 1.78 m long sediment core was recovered from South Twin Lake in Mahnomen County on 10 June 2010 from 7.75 m of water depth. The core was field-sectioned to 30 cm depth in 1-cm increments and returned to the lab for cold storage. The core had a slight color change at 80 cm core depth where it transitioned form a brown-gray above to a gray below. The core likely has a very high carbonate content and we have some initial concerns about diatom preservation that we will address with core subsampling. The core was brought to the LRC for initial analysis and sampling using whole core logging for magnetic susceptibility, core splitting, core imaging, and subsampling in 1-cm increments to 100 cm. Smear samples studied with the scanning electron microscope showed heavy dissolution of diatom microfossils that may hinder diatom analysis efforts. Loss on ignition analysis should be completed in about one month in preparation for radioisotopic dating.

Cedar Lake in Morrison County was cored on 06 August 2010 where a 1.66 m core was recovered from 26.11 m of water. The core was field sectioned to 36 cm depth in 1-cm increments. Further core analysis took place at the LRC where the remaining core was subject to whole core logging for magnetic susceptibility, core splitting and imaging, and subsampling in 1-cm increments to 100 cm in preparation for loss on ignition analysis and eventual radioisotopic dating. The core proved to be very interesting as initial analysis suggests the sediment record in Cedar Lake is varved with light and dark band couplets likely representing the annual record of lake productivity. This uncommon core feature may prove valuable in future studies if historical lake response at annual resolution is of interest. Subsamples of couplets were analyzed under the SEM and showed that the light bands likely represented carbonate rich summer sedimentation, whereas dark bands represent winter productivity. Diatom preservation was excellent in this core.

A 1.32 m long core was recovered from 37.8 m of water at Ten Mile Lake in Cass County on 06 August 2010. The core was field sectioned to 36 cm in 1-cm increments. Coring and sectioning was hindered by the extreme depth of Ten Mile Lake and subsequent temperature and pressure changes after core recovery. The core had very high levels of methane that during degassing disturbed the top 15 cm of the core. A return visit with a short gravity core or freeze corer will be necessary to recover an undisturbed sediment record especially at the core top. The remaining core was tranferred to the LRC for whole core magnetic susceptibility logging, core splitting and imaging, and further subsampling in 1-cm increments to 100 cm core depth. Survey under the scanning electron microscope showed high diatom abundances and good diatom preservation in the core. Loss on ignition analysis will be completed in the next month before the core enters the radioisotopic dating queue.

White Iron Lake, located on the border of St. Louis and Lake Counties, was cored on 07 August 2010; a 1.17 m long core was recovered from 10.21 m water depth. The core was field sectioned in 1-cm increments to 18 cm core depth. Further analyses and subsampling occurred at the LRC where the remaining core underwent whole core logging for magnetic susceptibility, core splitting and imaging, and was subsampled to 100 cm depth in 1-cm increments. The scanning electron microscope showed abundant diatoms and good preservation. The core will next be analyzed by loss on ignition and Pb-210 dating.

Core material from this project was also provided to Dr. Larry Wieder (Univ of Oklahoma), who is utilizing the SLICE lakes to explore genetic changes in zooplankton populations. Material from Elk Lake and Trout Lake was sent to Dr. Wieder for ephippia isolation and germination to test the feasibiity of these lakes as systems to explore genetic response of biological communities to historical water quality shifts.

Result Status as of 15 April 2011**:**
Sediment cores of 1-1.5 m length have been recovered from seven sentinel lakes that support cold-water cisco populations including: Elk (Clearwater County), Carlos (Douglas), Ten Mile (Cass), Cedar (Morrison), White Iron (St. Louis, Lake), Trout (Cook), and South Twin (Mahnomen). All cores have been sliced into 1-cm increments and analyzed for loss on ignition to determine the relative contribution of organics, carbonates, and inorganics in each core level. Many of the lakes show increased inorganic deposition (Carlos, Elk, South Twin, Cedar,) and some show increased deposition of organics (Carlos, Cedar, Ten Mile, South Twin) following Euroamerican settlement – potential signs of increased erosion and increased lake productivity in the post-settlement era, respectively. Pb-210 dating has been completed on four (Carlos, Trout, White Iron, South Twin) of the seven cores, and generally show the Euroamerican settlement horizon to be between 19-36 cm below the modern sediment surface. Diatom samples are being prepared from all dated cores and will analyzed to generate a record of biological change in each sentinel lake. Of great interest is the recovery of what appears to be a varved sediment record in Cedar Lake (Morrison). True sediment varves are like growth rings on trees, they record an annual record of biological and chemical lake functions that can be analyzed to give high-resolution insights into interannual lake productivity patterns.

An 82 cm core was recovered from 26.63 m depth in Carlos Lake on 22 October 2009. The core was sectioned in its entirety in 1.0 cm intervals. All core sections were subjected to loss on ignition analysis (Dean 1974) to determine percent content of organics, carbonates, and inorganics. Results indicate that sediments deposited below 35 cm are primarily carbonate (60-65% dry weight) and secondarily made up of inorganics (20-25% dry weight) and organics (10-15% dry weight). Above 35 cm core depth sediment constituents change rapidly with decreasing carbonate content and increasing inorganic content. These changes are consistent with lake response to Euroamerican settlement in many lakes across Minnesota. Organic content remains at approximately 15% dry weight to 20 cm core depth, before increasing to 30% dry weight at the core surface. The Carlos Lake core has been dated using alpha spectroscopy methods to determine the 210-Pb inventory and establish a date-depth chronology for the core. The core showed a monotonic decline in Pb-210 inventory. Similar to the earlier core analyzed from Carlos Lake (Engstrom 1995), we confirmed the large shift in core geochemistry at 35 cm (dated 1849.2 AD) to mark the onset of Euroamerican settlement in the region (1860-1880 AD). Fifteen core depths have been chosen for microfossil analysis and diatom slides have been prepared.

A 1.74 m long core was recovered from 19.82 m water depth in Elk Lake (Clearwater County) on 21 January 2010. The core was sectioned in 0.5 cm intervals to a depth of 30 cm. The Elk Lake core was taken to the University of Minnesota Limnological Research Center (LRC) and subjected to whole core logging for magnetic susceptibility, core splitting and imaging, and subsampling in 1-cm increments to 100 cm core depth. Subsamples were examined under the scanning electron microscope and showed good diatom preservation. The Elk Lake core has undergone loss on ignition analysis to determine organic, carbonate, and inorganic content in preparation for radioisotopic dating. Percent organics rise from 10% at the core bottom to 30% near the core top. Inorganics are found at 20% of dry weight from 99 cm to 36 cm depth and then rapidly increase upcore to 40-50% dry weight. Carbonate behave in contrast to inorganics and make up about 60% of dry weight from 99 cm to 36 cm, then drop to about 20% dry weight to the core top. The Elk Lake core is currently being analyzed for by alpha spectroscopy for 210-Pb inventory. Material from this core was also provided to Dr. Charles Umbanhowar (St. Olaf College, Northfield) who has interest in the longer environmental record preserved in Elk Lake. He picked and sent in charcoal from two core depths for 14-C AMS analysis with results showing that 60-63 cm represents approximately 1770 AD and 92-96 cm represents approximately 1240 AD.

A 1.54 m long sediment core was recovered from 20.4 m of water in Trout lake (Cook County) on 08 June 2010. The core was sectioned in the field to a depth of 30 cm and the subsamples and remaining core returned to the laboratory for 4degC storage. The core had a slight color change at 132 cm core depth where it transitioned form a dark brown gyttja above to a lighter brown-gray below. There was abundant gammarids and mysids in the Trout Lake core. The Trout Lake core underwent initial description and analysis at the LRC to determine magnetic susceptibility, core splitting and imaging, and subsampling in 1-cm increments to 100 cm core depth. The Trout Lake core has undergone both loss-on-ignition analysis and radioisotopic dating. The composition of sediments in Trout Lake has remained very consistent through time with a makeup of 70% inorganics, 10% carbonates, and about 20% organics. The dating and sediment accumulation model for Trout Lake shows that below 19 cm core depth, sediments were deposited pre-Euroamerican settlement (<1870 AD). The sediment accumulation rates of Trout have changed little with time and show a very slight increase from 1900-1970 AD. Analysis of subsamples with scanning electron microscopy showed high abundance of microfossils but relatively high breakage of diatoms. Slide preparation for diatom samples is underway.

A 1.78 m long sediment core was recovered from South Twin Lake in Mahnomen County on 10 June 2010 from 7.75 m of water depth. The core was field-sectioned to 30 cm depth in 1-cm increments and returned to the lab for cold storage. The core had a slight color change at 80 cm core depth where it transitioned from a brown-gray above to a gray below. The core likely has a very high carbonate content and we have some initial concerns about diatom preservation that we will address with core subsampling. The core was brought to the LRC for initial analysis and sampling using whole core logging for magnetic susceptibility, core splitting, core imaging, and subsampling in 1-cm increments to 100 cm. Smear samples studied with the scanning electron microscope showed heavy dissolution of diatom microfossils that may hinder diatom analysis efforts. Loss on ignition analysis and radiometric dating are complete on this core. As suspected, carbonates are the major constituent of the South Twin core ranging in abundance from 70% dry weight (30-99 cm) to 50% dry weight from 30 cm to surface. Organics generally increase in content upcore from 12% to 25% of the core dry weight. Inorganics similarly increase in content upcore from about 18% dry weight from 36 to 99 cm to 27% above 30 cm core depth. The date-depth model resulting from analysis of the 210-Pb inventory suggests that the Euroamerican settlement horizon is near 36 cm (1886 AD), where the inflection in core geochemistry occurs. Sedimentation rates in South Twin are only slightly accelerated after Euroamerican settlement. Samples are currently being prepared for diatom analysis.

Cedar Lake in Morrison County was cored on 06 August 2010 where a 1.66 m core was recovered from 26.11 m of water. The core was field sectioned to 36 cm depth in 1-cm increments. Further core analysis took place at the LRC where the remaining core was subject to whole core logging for magnetic susceptibility, core splitting and imaging, and subsampling in 1-cm increments to 100 cm in preparation for further analyses. The core proved to be very interesting as initial analysis suggests the sediment record in Cedar Lake is varved with light and dark band couplets likely representing the annual record of lake productivity. This uncommon core feature may prove valuable in future studies if historical lake response at annual resolution is of interest. Subsamples of couplets were analyzed under the SEM and showed that the light bands likely represented carbonate rich summer sedimentation, whereas dark bands represent winter productivity. Diatom preservation was excellent in this core. The Cedar Lake core has undergone loss on ignition analysis. The core is more variable in sediment composition than many of the cores being analyzed in this study. Carbonates dominate the sediment and account for 45-55% of core dry weight below 20 cm depth. Carbonates then decrease upcore to account for only 10% of the dry weight at the core top. Inorganics make up the next greatest portion of the sediment with sediments from 20 cm to 99 cm composed of 20-40% inorganic by weight. Above 20 cm inorganics increase from 40% to 55% dry weight at the core top. The Cedar Lake core is currently awaiting 210-Pb dating.

A 1.32 m long core was recovered from 37.8 m of water at Ten Mile Lake in Cass County on 06 August 2010. The core was field sectioned to 36 cm in 1-cm increments. Coring and sectioning was hindered by the extreme depth of Ten Mile Lake and subsequent temperature and pressure changes after core recovery. The core had very high levels of methane that during transport to shore and sectioning underwent degassing that disturbed the top 15 cm of the core. A return visit with a short gravity core or freeze corer will be necessary to recover an undisturbed sediment record especially at the core top. The remaining core was transferred to the LRC for whole core magnetic susceptibility logging, core splitting and imaging, and further subsampling in 1-cm increments to 100 cm core depth. Loss on ignition analysis has been completed for the top 100 cm of core. Ten Mile Lake sediments are predominantly inorganics, which make up 55-64% of the core weight with a trend toward higher inorganics upcore. Organics make up the next most abundant fraction of the core with levels increasing from 20-25% of core weight below 25 cm and increasing to about 30% dry weight of organics at the core top. Carbonates decrease upcore from 10-15% dry weight downcore to only 6% dry weight in the disturbed core top. Survey under the scanning electron microscope showed high diatom abundances and good diatom preservation in the core. The Ten Mile Lake core is currently in the radioisotopic dating queue and we will be returning to Ten Mile Lake to recover a short surface core in June 2011.

White Iron Lake, located on the border of St. Louis and Lake Counties, was cored on 07 August 2010; a 1.17 m long core was recovered from 10.21 m water depth. The core was field sectioned in 1-cm increments to 18 cm core depth. Further analyses and subsampling occurred at the LRC where the remaining core underwent whole core logging for magnetic susceptibility, core splitting and imaging, and was subsampled to 100 cm depth in 1-cm increments. The core has been analyzed by loss on ignition and undergone Pb-210 dating. Sediment composition has remained constant over time. White Iron sediments are primarily inorganics, which make up over 65% of the core's dry weight. Organics constitute 22-24% dry weight, and carbonates make up 10-11% of core weight. The date-depth model resulting from Pb-210 analysis shows that sediments below about 35 cm (1895 AD) represent pre-Euroamerican sediment deposition. Sedimentation rates increase slightly in White Iron Lake following Euroamerican settlement and those rates continue upcore. Scanning electron microscopy showed abundant diatoms and good preservation in White Iron Lake and sediments are currently being prepared for analysis.

Core material from this project was also provided to Dr. Larry Wieder (Univ of Oklahoma), who is utilizing the SLICE lakes to explore genetic changes in zooplankton populations. Material from Elk Lake and Trout Lake was sent to Dr. Wieder for ephippia isolation and germination to test the feasibility of these lakes as systems to explore genetic response of biological communities to historical water quality shifts.

References

Dean, W.E. 1974. Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods. J. Sediment. Petrol. 44: 242-248.

Result Status as of 30 October 2011**:**

Progress for Result 2 has included the collection of sediment cores (1-1.5 m length) from all seven sentinel lakes that support cold-water cisco populations including: Elk (Clearwater County), Carlos (Douglas), Ten Mile (Cass), Cedar (Morrison), White Iron (St. Louis, Lake), Trout (Cook), and South Twin (Mahnomen). An additional gravity core (45 cm long) was taken in June 2011 from Ten Mile Lake to provide more consolidated surface sediments following disturbance of the original long core by degassing. All cores have been sliced into 1-cm increments and analyzed for loss on ignition to determine the relative contribution of organics, carbonates, and inorganics in each core level. Many of the lakes show increased inorganic deposition (Carlos, Elk, South Twin, Cedar,) and some show increased deposition of organics (Carlos, Cedar, Ten Mile, South Twin) following Euroamerican settlement – potential signs of increased erosion and increased lake productivity in the post-settlement era, respectively. Pb-210 dating has been completed on six (Carlos, Trout, White Iron, South Twin, Cedar, Elk) of the seven cores, and generally show the Euroamerican settlement horizon to be between 19-36 cm. The new surface core from Ten Mile Lake is currently in the dating queue. Diatom slides have been prepared for five of the seven lakes and microscopical analysis is underway. Two lakes (Cedar, South Twin) may require some modified microscope counting efforts as these high carbonate systems show some evidence of downcore diatom dissolution.

Result Status as of: 06/30/2012

Work on all aspects of Result 2 is now complete and comprehensive results will be incorporated into the final LCCMR report.

Final Report Summary:
We have provided to LCCMR the final report summary, "Result 2, Reconstruct historical water quality and habitat conditions in the seven coldwater sentinel lakes" authored by Mark Edlund and Joy Ramstack.

Result 3: Utilize watershed and lake mixing models to forecast future water quality conditions in deep lakes with cold-water fish populations given different climate change and land-use scenarios.

Description:
The ability to project the potential outcomes of a range of large scale drivers of change such as watershed land use alterations or climate change is needed to proactively manage Minnesota lakes. A number of regional and state-wide lake modeling studies have illustrated the potential linkages between climate change, lake morphology, and fish habitat in the form of temperature and dissolved oxygen

distributions for Minnesota and the north-central United States (e.g., see summaries in Stefan et al. 1995; De Stasio et al. 1996; Fang et al. 1999). These models have documented the relative importance of lake-basin geometry, ice-free season, thermal stratification, dissolved oxygen stratification and wind-driven mixing to the development of sustainable fish habitat in deep-water lakes of the region. However, the potential trophic-dynamic response to simultaneous changes in climate and land-use is less well understood, as is the response of specific lakes to these historical and hypothetical changes. Questions also remain as to how the complex food webs that support fish guilds within these modeled systems will respond to the predicted physical changes in fish habitat (De Stasio et al. 1996).

The USGS (Dr. Richard Kiesling) will develop predictive tools to evaluate the trophic response of three sentinel lakes ("super" sentinel lakes) to current climate and watershed land-use conditions. We will accomplish this by developing watershed-loading models coupled with in-lake water quality models. Calibrated lake models will be used to forecast changes to water quality and deep-water thermal habitat conditions under changing climate and land-use scenarios. Where data are sufficient, models will be used with historic land use and climate data to provide historical benchmarks for comparison with output from scenario models.

By the conclusion of the study, we will outline the steps needed to take this result from a highly technical exploration to something in a more usable format for land use planners and policy makers. Interactive web-tools may be a promising mechanism by which local planners, policy makers, and even educators and students could "plug-n-play" different land use and climate change scenarios and evaluate the potential consequences of policy decisions on water quality and fish habitat.

Forecasting various scenarios and where to concentrate mitigation measures is not unique to this project and many groups at various scales are currently engaged in developing lake or watershed assessment tools. These groups include the Midwest Glacial Lakes Partnership (a regional subsidiary of the National Fish Habitat Initiative), North Central Lakes Collaborative, NRRI, University of Minnesota Remote Sensing Lab (http://lakesandland.umn.edu/; http://water.umn.edu/cgi-bin/mapserv-3?mode=browse&map=/data/web/water.umn.edu/map/mnlakes2005.map&layer=lakes&year=2005&mapext=184475.144386+4816443.707056+756218.568285+5470451.562617) and DNR Ecological Resources-U of MN (http://www.dnr.state.mn.us/watershed_tool/index.html). The likelihood of more efforts given new clean water legacy amendment funding is high. The need for coordination of these activities for maximum mutual gain with minimum redundancy is obvious. By completion of the LCCMR project, we (lead Ray Valley) will draft a proposal outlining other similar efforts and tools in development and how these efforts can be coordinated or adapted for web tools that focus on watershed-lake links. Modeling efforts coupled with long-term monitoring and recalibration of watershed and lake models could be used to form a strong empirical basis for these tools.

Summary Budget Information for Result 3: ~~**Trust Fund Budget: $41,290**~~
Revised Trust Fund Budget (10/30/2011): $74,240
Amount Spent: $74,240
Balance: $0

Deliverable	Completion Date	Budget
1. Predictive models to form an empirical foundation for the development of watershed best management practices and climate change adaptation policies that will protect the resiliency of coldwater lakes.	June 2013	$41,290
2. Strategies for building future interactive web-applications of these models for state policy makers, educators, and local land use planners.	June 2013	$32,950

Result Completion Date: 30 June 2013

Result Status as of 15 April 2010:

Deliverable 1 (predictive models)
Water quality data collected during 2009 have been received from MPCA and are being compiled into a common database for model calibration. Review of data for use in available models is ongoing. Training of student interns in model procedures is ongoing.

Deliverable 2 (web-applications)
Building user-friendly and web-accessible watershed and lake assessment tools for various user groups will be a process that will likely need to involve many partners external to SLICE. We are currently involved in a collaborative planning effort with other DNR divisions, USGS, NRRI, PCA, and the U of MN Water Resources Center (WRC) to form a watershed consortium that would serve as a think tank on watershed and lake assessment and monitoring issues and be a primary sponsor of efforts such as building interactive web applications and other projects with a watershed focus. During a conference call of partners in February 2010, it was agreed that the U of MN WRC would be the "convener" of such a group with Faye Sleeper as the primary lead on proposals for seed money to start up such a group. We will be working with the WRC and other partners to ensure this proposal moves forward and various funding mechanisms are explored (e.g., Clean Water Legacy, LCCMR 2012 RFP)

Result Status as of 30 October 2010**:**

Deliverable 1 (predictive models)
Water quality data collected by USGS during 2010 has been compiled in a database and will be combined with MPCA water quality data for 2009 and 2010 for use in

model calibration. Project staff received training in CE-QUAL-W2, the program that will be used for lake modeling. Preliminary analysis has been conducted on data to be used in model development including continuous temperature data profile mapping, hypolimnetic oxygen demand calculations, and stable isotope analysis. Collection of background information needed to develop models, including lake bathymetry, watershed terrain information, and historical water quality information, is ongoing.

Deliverable 2 (web-applications)
The need for web-based tools for data visualization and synthesis of status and trends in lake stressors and indicators is becoming more clear as this project progresses. We are currently in the initial phases of project definition and identifying possible contractors for building web applications. Two candidates rise to the top for further consideration: first, building off of prior LCCMR-funding efforts with NRRI on their MN Beaches web data application (http://www.mnbeaches.org/gmap/trends/index.html); or, internal contracting with DNR's Management Information Bureau who has experience building complex web applications within the DNR site (see DNR's fish mapper application http://www.dnr.state.mn.us/maps/fom/index.html and DNR's Watershed Assessment Tool http://www.dnr.state.mn.us/watershed_tool/index.html). We may submit a proposal to LCCMR during the 2012 RFP to fund this work.

Result Status as of 15 April 2011**:**
Deliverable 1 (predictive models)
Model development is currently underway, beginning with processing of bathymetric and watershed elevation data, collection of historic lake levels and meteorological data, and processing of stage/discharge data collected by continuous pressure transducer data to determine lake inflows and outflows. LiDAR digital elevation models that have recently been obtained by the DNR are being used to model terrain around the lakes. Analysis continues on chemistry and temperature profile data collected in 2010 to determine sampling needs to fill data gaps in 2011.

Deliverable 2 (web-applications)
Little movement has occurred with this deliverable since the last progress report. However, future efforts to build data visualization tools should be coordinated with interagency database efforts. Most notably, PCA's merger into a new state repository for water quality data (EQuIS) and the DNR and PCA's cooperative water data system that will serve as a central hub for all water data in the future. Data analysis and visualization options may be available at a reduced cost and could be launched with a modest initial investment for a software programmer to set up and launch the tool. We will continue to research this option.

Result Status as of 30 October 2011**:**
Deliverable 1 (predictive models)
Analyses completed so far include summarizing continuous 15-minute temperature data in contour plots to look at the seasonal patterns in thermocline and mixing trends between the lakes. Temperature data was plotted against wind speed

(collected from nearby airports) to look for relationships between high winds and increased mixing.

We have also calculated basic hypolimnetic oxygen depletion for each of the three lakes using the oxygen profile data from USGS and MPCA. These calculations give us a rate at which oxygen is used in the hypolimnion: an indicator of organic matter accumulation and lake trophic status.

The preliminary analyses we have completed this summer are intended to assist us in developing the biophysical mechanistic models by giving us suitable calibration data.

Deliverable 2 (web-applications)
Amendment Request 10/30/2011
The central hub for Minnesota water data termed the "Watershed Data Integration Project" (WDIP) continues to be developed with clean water and other operational PCA funds. However, WDIP is a water database for housing and retrieving either raw water data or summaries for clean-water assessment work and will not meet multi-indicator (e.g., fish, aquatic plants, zooplankton) data summary needs as outlined here. Rather, we are requesting authorization to reallocate end-of-project funds to build this database and web application. This application will be built in a way that can be "plugged" into WDIP once the database is fully functional (still years away).

The application would resemble what has been built by the USGS for the Upper Mississippi Long-term Resource Monitoring Program but use "High Charts." The State's Office of Enterprise Technology estimates that such a database and web-application could be built for $32,950 (412 hrs @ 80/hr).
Amendment Approved: Approved by LCCMR on December 2, 2011.

Result Status as of: 12/31/2012

USGS has completed development of the three comprehensive water quality models called for in the research addendum. Two of these models (Lake Carlos, Trout Lake) have been calibrated and are ready to be used in assessing alternative climate and nutrient-loading scenarios. Examples of the calibration plots with summaries of the calibration statistics for temperature and dissolved oxygen are provided below in Figures 3.1 and 3.2. Calibration error estimates, presented as average mean error (AME) and residual mean square error (RMSE) are comparable to previously published lake and reservoir models completed by USGS scientists.

The third model (Elk Lake) has been calibrated for water balance and temperature but requires additional work to calibrate the model output for water quality parameters, including dissolved oxygen profiles. It appears that Elk Lake is a more complex system to model than the other two lakes because of site-specific surface wind conditions, apparent large early-season sediment oxygen demands, and large anoxic groundwater inputs with high iron and nutrient concentrations. We are running a number of simulations to evaluate the best options for simulating these complex functions with the CE-QUAL-W2 model. We anticipate having the full water quality calibration completed by August, 2012.

We are working on using the calibrated lake models as tools to evaluate how important nutrient-driven productivity is to oxy-thermal fish habitat. To accomplish this task, we need to test how the trophic response of the three sentinel lakes changes as the model inputs deviate from current climate and nutrient-loading conditions. USGS scientists have developed down-scaled climate data for all three sentinel lake watersheds. We have downloaded these data and are configuring the information for input into the calibrated models. The downscaled climate data are available at the following URL:
http://cida.usgs.gov/climate/hostetlerprojections.jsp

We anticipate that we will have simulated the potential impact of one future climate scenario on the oxy-thermal fish habitat for all three lakes by August 2012. The output from the calibrated lake models coupled with the down-scaled climate model predictions will provide simulated changes to water quality and deep-water thermal habitat conditions under one forecast future climate. Complete simulations and results will be included in the final report to the LCCMR.

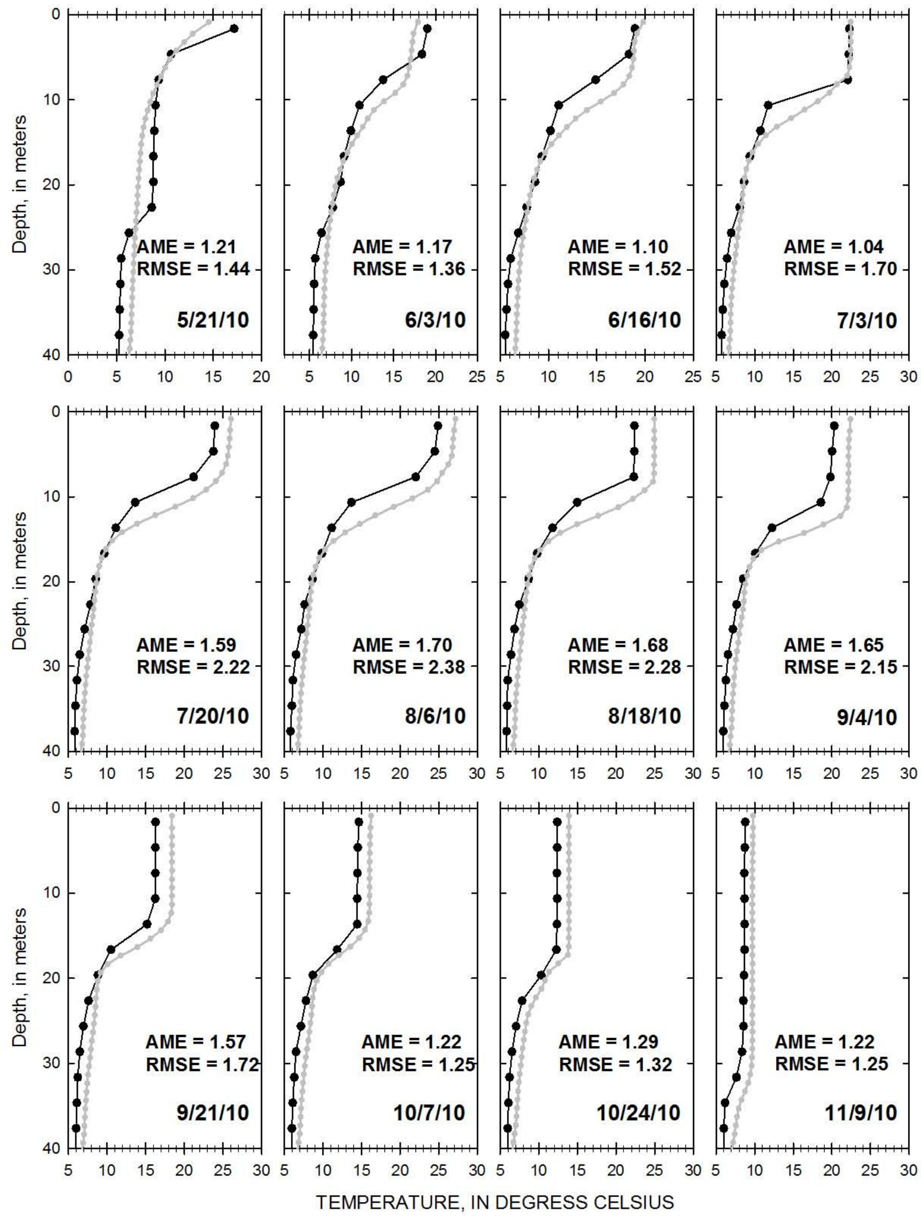

Figure 3.1a. Lake Carlos, North Basin, temperature profiles with calibrated model results for comparison. Average mean error (AME) and residual mean square error (RMSE0 are provided for each profile.

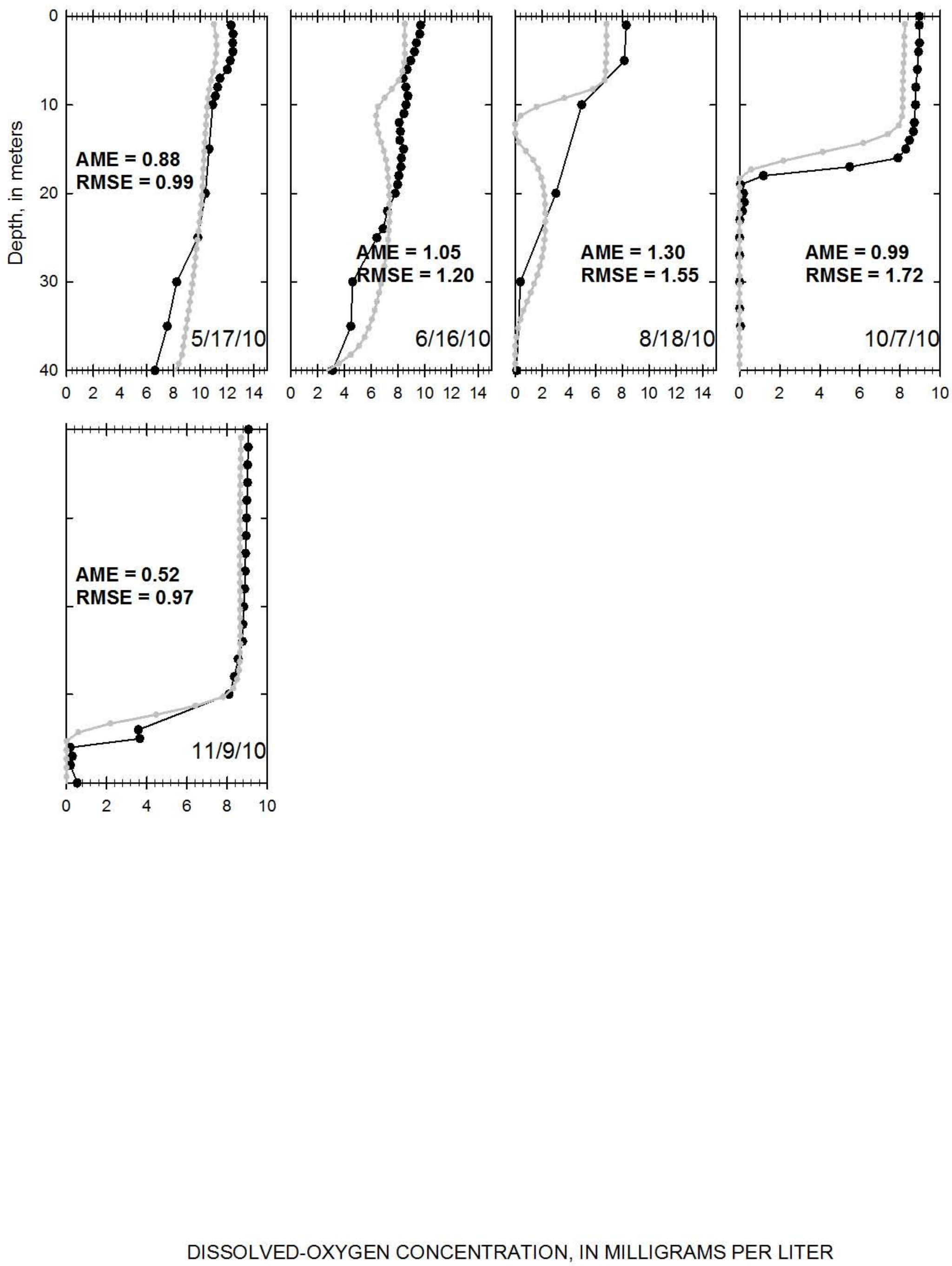

Figure 3.1b. Lake Carlos, North Basin, dissolved oxygen profiles with calibrated model results for comparison. Average mean error (AME) and residual mean square error (RMSE0 are provided for each profile.

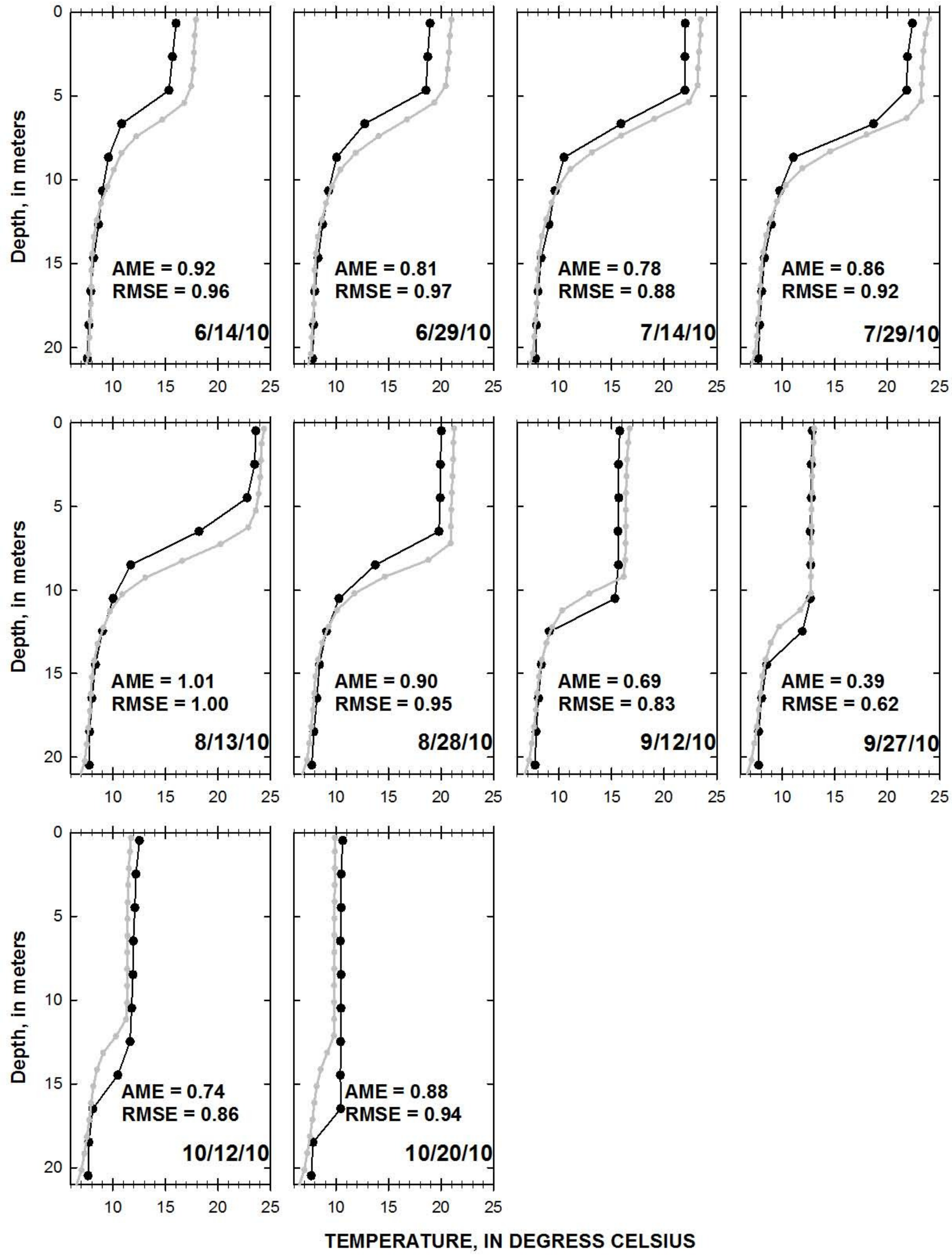

Figure 3.2a. Trout Lake, North Basin, temperature profiles with calibrated model results for comparison. Average mean error (AME) and residual mean square error (RMSE0 are provided for each profile.

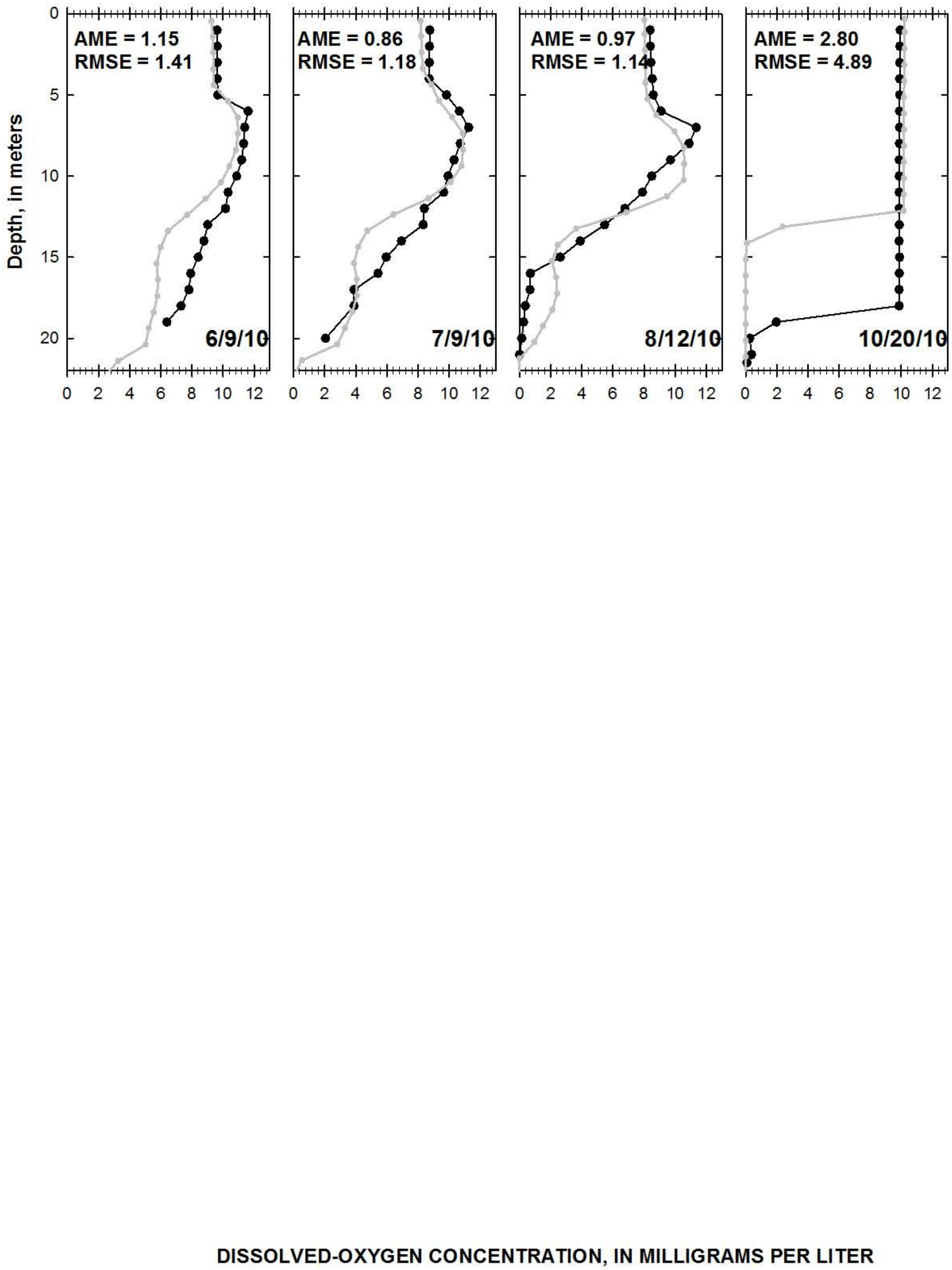

Figure 3.2b. Trout Lake, North Basin, dissolved oxygen profiles with calibrated model results for comparison. Average mean error (AME) and residual mean square error (RMSE0 are provided for each profile.

Zooplankton database and Data Visualization Tool
Internal service level agreements (SLAs) with the State's Office of Enterprise Technology have been developed and a technical committee has been drafted to provide guidance for the development of these tools. Each SLA cost approximately $30,000 and effectively depleted the balance of trust fund dollars, with some funds from other sources (primarily Game and Fish Fund) used to fully fund both SLAs. The zooplankton database SLA has two components. One component will be the design of an actual database for the project (put amount here), and the second component is assembling various sources of data and entering them in to the database. Funds for the Data Visualization Tool (DVT) database have been encumbered and we are in the process of determining if this work will be done by intern IT staff or will be contracted out. We envision that the following data will be directly accessed from the with DVT: all fish assessment data (gill nets, trap nets, nearshore nongame sampling); and basic aquatic plant data. At this time we do not know if the other data sources will be directly available through the DVT, or links will be provided for potential users to download those data from their respective databases. These sources of data include all water quality data gathered on the Sentinel lakes (primarily managed by the MPCA), temperature data (managed by the DNR Div. of Ecological and Water Resources), and the zooplankton data being assembled in the second SLA. We have formed a small committee of biologists and the Fisheries biometrician to advise the IT programmers on what specific data to provide, and the basic summary graphics that will be available to the end user. We envision a final system that is similar in operation to that provided by the USGS LTRMP program based in LaCrosse, WI (see October 2011 summary for URL).

Final Report Summary:

<u>Summary for Result 3, Deliverable 1: *Predictive models to form an empirical foundation for the development of watershed best management practices and climate change adaptation policies that will protect the resiliency of coldwater lakes.*</u>
USGS intended to use the biophysical lake models developed for Carlos, Elk, and Trout lakes to forecast future water quality conditions in deep lakes with cold-water fish populations given different climate change and land-use scenarios. As of the last progress update, USGS anticipated simulating the potential impact of one future climate scenario on the oxy-thermal fish habitat for all three lakes by the time of this final report, but weren't able to use the existing down-scaled daily climate data to develop the sub-daily time-step data required by the model. The available data were inadequate. As a result, USGS will have to use more involved distributional statistics to generate a future climate dataset that is compatible with the CE-QUAL-W2 model. As an alternative for Phase 1 of the project, USGS simulated past climate years using the calibrated model to assess the impacts on oxythermal habitat (details can be found in the report beginning on page 18). During Phase 2, USGS will work to develop the future climate datasets needed to run the lake model simulations. In Phase 2, output from the calibrated lake models will be coupled with the appropriate future climate datasets and used to simulate changes to water quality and deep-water thermal habitat conditions under forecast future climate

conditions and land use scenarios. Full details of the calibrated, validated lake models can be found in the final report provided earlier (report begins on page 18).

Summary for Result 3, Deliverable 2: *Strategies for building future interactive web-applications of these models for state policy makers, educators, and local land use planners.*

Internal service level agreements (SLA's) with the State's Office of Enterprise Technology were developed and implemented. A technical committee of MN PCA and MN DNR staff worked with MNIT staff to develop and fully implement these tools. The zooplankton database had two components, database development and populating the newly developed database; both components were completed as scheduled. While the zooplankton database is for internal use, it will eventually be linked to the Data Visualization Tool (DVT). The DVT was also completed as scheduled. The DVT team has built the tool using the open-source data platform CKAN (ckan.org). The DVT will allow external scientists and interested stakeholders to directly query SLICE data and databases. Currently, basic summary graphics and data of fish catches, zooplankton trends, water temperature and water quality, and aquatic macrophytes are available to query from the beta format for those with a CKAN account. Project managers will continue to work to allow full database accessibility to interested parties. Examples of the end product are provided in Figures 1 and 2.

Figure 1. Opening page of data visualization and database exploration tool for the SLICE program.

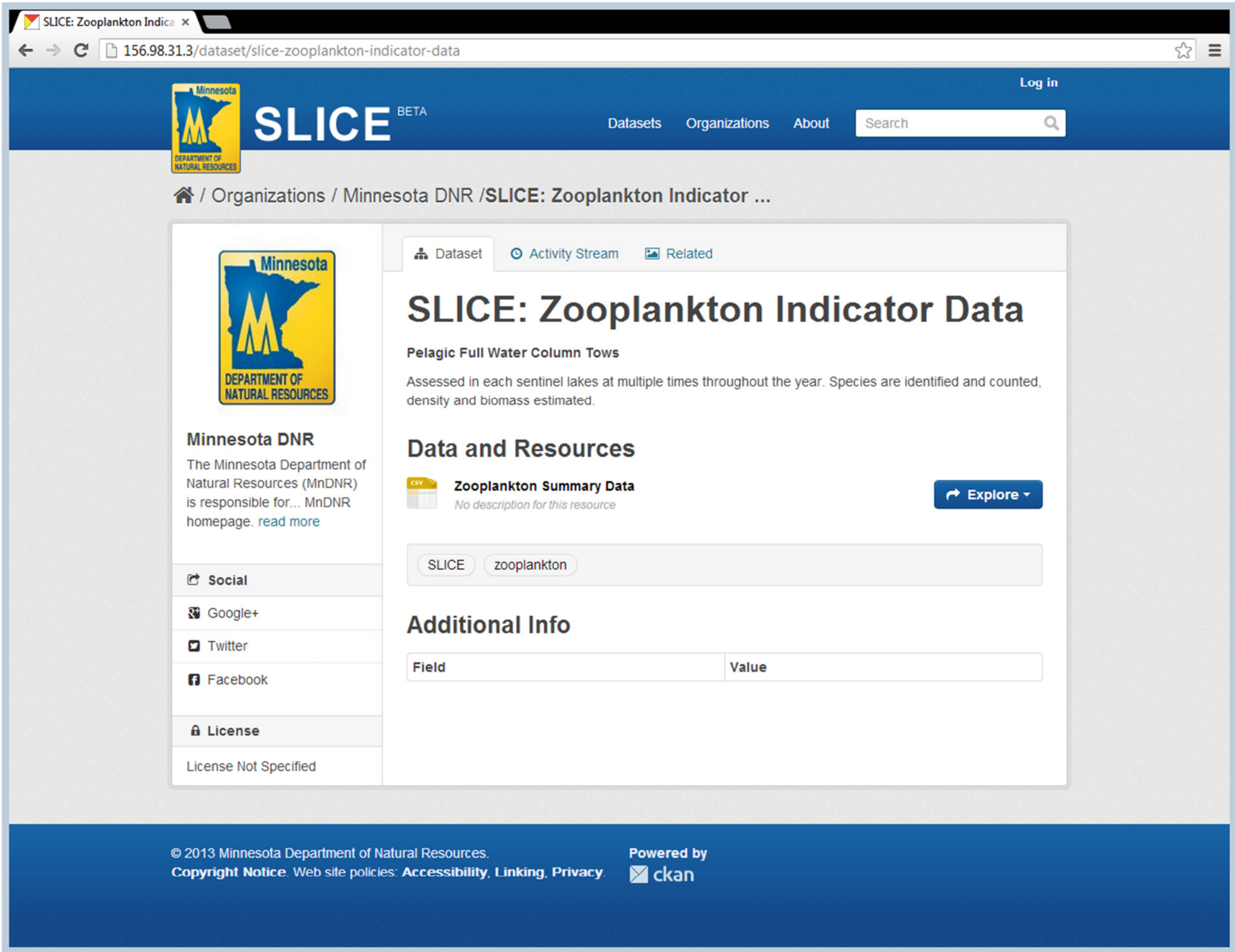

Figure 2. Example of database entry screen for users.

Result 4: Identification of a set of habitat and fish indicators sensitive to human-caused disturbances to serve as an early warning sign of lake ecosystem stress.

Description:
Result 4 is a weave of several in-kind efforts funded by DNR Fisheries operating budgets (the Game and Fish Fund and reimbursement by Federal Sportfish Restoration Dollars) and PCA Environmental Analysis an Outcomes Division operating budgets. Clean Water Legacy funding will contribute a small in-kind contribution from PCA and DNR Ecological Resource budgets during the project period for standard nutrient and biotic assessments in the sentinel lakes. Trust funds will supplement this work. To more clearly describe how Trust funds will be spent, deliverables 1 and 2 are revised from our original submitted proposal.

Deliverable 1 will be mostly funded by DNR Fisheries operating budgets with trust fund supplemental dollars for interns, travel and fleet expenses, water quality assessments in all 24 lakes, and survey equipment and repairs. Again, work will be weighted more heavily in the lakes with cold-water habitat, and basic assessment data will be collected in the other 17 sentinel lakes. Six fisheries research staff are currently focused on collaborating on Deliverable 1. Refer to Valley et al. (2008) for details on this work. It is important to note that the budget in Deliverable 1 will directly benefit the other Results and Deliverables listed in this work program.

Deliverable 2 focuses on the promising potential of zooplankton as being rapid assessment indicators of water quality and habitat conditions. Despite their promise as indicators of changing environmental conditions and their importance to food webs in north-temperate lakes (Rusack et al. 2002, Beisner et al. 2003, and Olden et al. 2006), no studies have examined the linkages of zooplankton populations to environmental conditions in Minnesota inland lakes. We will investigate the sensitivity and robustness of common zooplankton indicators to changes in lake productivity along the gradient of the 24 sentinel lakes. The overall objective of this analysis is to identify which characteristics of pelagic zooplankton communities in Minnesota lakes change in consistent, predictable patterns in response to human disturbance or increased nutrient loading. Trust fund dollars for this deliverable will fund Jodie Hirsch's classified salary at the 10% FTE level. Ms. Hirsch's time will be backfilled by a temporary student worker. Trust fund dollars will also be used to contract with DNR's Management Information System Bureau to write a zooplankton counting program that is necessary to efficiently process the volume of zooplankton data that will be coming in. Jeff Reed and Dr. David Staples in DNR Fisheries will lead the final statistical analysis and report writing. No trust fund budget is requested for their time on Deliverable 3.

Deliverables 3 and 4 focus on better understanding the biology and status Cisco *Coregonus artedi*, a sensitive cold-water indicator species. This work will be led by University of Minnesota-Duluth Associate Professor of Biology, Dr. Tom Hrabik and a TBA M.S. graduate student. Cisco are an important component of the fish community in many Minnesota lakes. They provide a significant forage base for walleyes, northern pike, muskellunge, and lake trout (Ryder and Kerr 1978; Colby et al. 1987). Walleyes grow significantly faster when foraging on energetically rich cisco (Henderson et al. 2004), and more large northern pike are produced when cisco are present (Jacobson 1993). As a dominant planktivore in many lakes, cisco can play an important role in structuring zooplankton communities (Rudstam et al. 1993). Cisco also provide a growing winter sport fishery and are the target of a traditional gill net fishery in Minnesota.

Climate warming has the potential to reduce coldwater fish thermal resources through direct warming in increased hypolimnetic oxygen depletion in stratified lakes from extended periods of stratification (Magnuson et al. 1997; Fang et al. 2004). Cisco are the most common and widespread coldwater cold water fish in Minnesota lakes. Gillnetting assessments found cisco in 648 lakes throughout central and northern portions of the state and across several ecoregions (Minnesota DNR files). The wide distribution suggests that cisco are somewhat more adaptable than other native coldwater fish such as lake whitefish *Coregonus clupeaformis* (sampled in 155 lakes), lake trout *Salvelinus namaycush* (124 lakes) and burbot *Lota lota* (233 lakes). The combination of their wide distribution and cold water preference make cisco an excellent sentinel species and indicator of climate change.

Despite the importance of cisco to Minnesota fisheries and the sensitivity of this species to climate change and eutrophication, relatively little is known about their habitat use and consumptive demand in Minnesota lakes. Furthermore, these pelagic species are difficult to sample with traditional survey gears (horizontal bottom gillnets), thus population status has been difficult to track. Hydroacoustics is an advanced assessment tool that has been proven effective for assessing population status of cisco in the Great Lakes and inland lakes in Wisconsin (Hrabik et al. 2006). Some Minnesota lakes harboring cisco do present some challenges to hydroacoustics (abundant populations of acoustically reflective *Chaoborus* zooplankton) that warrant exploration by a professional well versed in fisheries hydroacoustics. The seven cold-water sentinel lakes represent a wide range of conditions and will be good testing grounds for this technology. Accordingly, we will evaluate hydroacoustics as an assessment tool for cisco in Minnesota lakes while simultaneously exploring basic questions about their habitat use and diet.

Summary Budget Information for Result 4: ~~Trust Fund Budget: $408,922~~
Revised Trust Fund Budget (10/30/2011): $375,972
Amount Spent: $375,972
Balance: $0

Deliverable	Completion Date	Budget
1. Report(s) evaluating a lake monitoring framework for early detection of changes in habitat and fish community status	June 2013	~~$240,822~~ $176,922
2. Assessment of zooplankton indicators.	June 2013	~~$43,100~~ $74,050
3. Evaluation of hydroacoustics to assess the status of cisco populations in inland lakes.	June 2013	$75,000
4. Evaluation of cisco habitat use and behavior	June 2013	$50,000

Result Completion Date: 30 June 2013

Result Status as of 15 April 2010:

Deliverable 1 (lake monitoring framework)
Above, we revise the budget for each deliverable to most closely match spending for those deliverables. Much of the Deliverable 1 budget is to fund the MPCA and MN Department of Health to collect, analyze, and manage water chemistry data from sentinel lakes. Interagency agreements (IA) between DNR and PCA and DNR, PCA, and MDH were executed and are in place to guide current and future project-related expenditures (IA agreements available upon request). Furthermore, four YSI optical dissolved oxygen and temperature meters were purchased instead of the Hach units initially proposed (YSI units offered similar functionality at a lower price).

These units were passed through the PCA to distribute to active citizen volunteers in sentinel lakes South Twin, Cedar, White Iron, and Ten Mile to collect bi-weekly Temp-DO profiles in these lakes. The USGS will be employing high resolution equipment in the other 3 cold water lakes (Carlos, Trout, and Elk) as described in Result 1. High resolution Temp-DO profiles will help us quantify good-growth-habitat-volumes for different thermal guilds of fish in each sentinel lake. Furthermore, more intangibly, by engaging and supporting active citizen groups, we hope to build shared ownership in lake assessment and monitoring. Based on cooperation, these units will stay with citizen volunteers on these lakes for their useful life with DNR or PCA periodically paying for unit maintenance (approximately $125 per year for new optical lenses).

Water quality data will inform analysis of other results and deliverables and many other current and future auxiliary projects. All water chemistry data from 2008 and 2009 have been uploaded to STORET, a publically accessible national water quality database. Furthermore, as an in-kind contribution, the PCA's Water Monitoring Section is partnering with DNR Fisheries to compile comprehensive retrospective lake assessment reports (visit http://www.pca.state.mn.us/water/sentinel-lakes.html to download finished reports). These reports will be important baseline assessments of sentinel lake watershed, water quality, habitat, and fish community conditions from comparison to future conditions. DNR and PCA are following a schedule that will have all 24 reports complete by 2012.

The primary use of the water quality data will go to inform a lake monitoring framework that staff from the DNR Fisheries Research Unit (including the project coordinator Ray Valley) will be drafting. These staff are mostly funded by Game and Fish fund and reimbursement by Federal Sportfish Restoration Act dollars (Study 605, F-26-R-36; Study 605 progress report available upon request). Job 605.6 describes our current approach towards this framework:

Indicator profiles for evaluating lake status are being developed based on current understanding of lake stressor effects. This Job involves synthesizing over 100 possible water quality, zooplankton, aquatic plant, and fish indicators collected in the sentinel lakes to determine how lake conditions vary across gradients of temperature and nutrient levels, two environmental factors likely to be affected by landscape and climate change. Informative indicators will be identified through a basic statistical screening process. After Job 605.6 is completed, other databases will be mined to build and describe empirical models for these indicators. Finally, we will use these models in a risk-based monitoring strategy to define benchmarks and run forecast models to predict the likelihood of lake conditions falling outside of desired ranges.

Deliverable 2 (zooplankton assessment)
Each of the 24 sentinel lakes was sampled for zooplankton monthly from ice-out (April or May) through October 2009. A total of 328 samples were collected by either PCA or DNR personnel. Two replicate vertical tows were taken from each lake on each sampling date at the deepest location. Five of the lakes were sampled at two sites because of larger size and morphology of these lakes. Zooplankton

tows were collected with a standard 80μm mesh Wisconsin zooplankton net from an anchored boat to insure a vertical haul. The net was lowered to within 0.5 meter of the bottom and hauled up at a rate of approximately 0.5 m/sec. Contents were rinsed into sample bottles labeled with date, lake name, site location, and tow depth. Samples were preserved with 100% reagent alcohol and delivered to DNR Ecological Resources personnel for analysis.

All zooplankton samples collected during 2009 have been processed using the following protocol. Each sample was adjusted to a known volume by filtering through 80μm mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5 ml aliquot. A 5 ml aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level) and measured to the nearest 0.01 mm using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (μg/liter), percent composition by number and weight, mean length (mm), mean weight (μg) and total counts for each taxonomic group identified were calculated.

Zooplankton indices from 2008 data and some 2009 data have been calculated and entered into an Excel spreadsheet. These indices include the following: total zooplankton densities (#/liter), total zooplankton biomass (μg/liter), mean cladoceran size (mm), mean daphnia size (mm), daphnia densities (#/liter), daphnia biomass (μg/liter), cladoceran densities (#/liter), cladoceran biomass (μg/liter), and percent calanoids in sample.

The current zooplankton counting hardware and software is outdated and we proposed a budget to upgrade the software. New hardware was purchased during the last year with DNR funds. Division of Ecological Resource IT supervisor Tom Glancy is coordinating this work with the DNR's Management Information System's (MIS) bureau to draft a RFP for potential contractors. MIS will hire and manage an outside contractor to build the application and then bill this project for the work. The application will conform to standards established for other DNR data and report applications, and will lead to greater accessibility by other entities interested in exploring patterns in zooplankton communities.

Deliverables 3 and 4 (cisco assessment)
Activities to date on the evaluation of cisco habitat use and behavior are six fold and include the following:

1. Participated in an organizational meeting with project personnel to coordinate field activities to be conducted at each study lake in 2010.
2. Added Tyler Ahrenstorff, a Ph.D. student in the Integrated Biosciences Program at the University of Minnesota, who will be working on the evaluation of cisco habitat use and behavior as part of his dissertation work.
3. Presented information at a MN DNR fisheries research meeting indicating our approach and methodology for planned sampling on each lake.

4. Established a sampling schedule for data to be collected and used to test hypotheses related to cisco habitat use.
5. Established protocols for sampling zooplankton and fish in each lake for our portion of the project.
6. Selected two undergraduate researchers who will be participating in research and helping to collect and process samples on the project. DNR Interns paid on project funds will also assist with data collection. Accordingly, $15,000 was subtracted from the Deliverable 1 total from the original work program and added to the Deliverable 3 total to reflect the approximate cost of intern salaries focused on this work
7. Purchased several vertical gillnets with project funds ($9,387.38) to sample cisco populations and calibrate hydroacoustic estimates. $10,000 was subtracted from the Deliverable 1 total from the original work program and added to the Deliverable 3 total to reflect the approximate cost of these nets.

Result Status as of 30 October 2010**:**
Deliverable 1 (lake monitoring framework)
Amendment Request 10/30/2010
Preliminary findings suggest groundwater may play a significant role in the water budgets of many of our sentinel lakes. Under the direction of U of MN adjunct professor Dr. Joe Magner, Lee Engel (MPCA Water Quality Specialist) is pursuing Master Thesis research on this question (Target completion date: December 2011) and has been collecting water samples in each sentinel lake since 2008. Currently, this project does not have dedicated funding and Lee is seeking $2,160 to analyze the water samples for ground water isotope signatures (contract with Dr. Tim Griffis at the U of MN Dept. of Soil, Water, and Climate). The connection of surface waters to groundwater plays a key role in lake resilience and is not well understood. Consequently, this ancillary research is also highly relevant to Result 3 of this project and will provide important baseline information for future studies. We therefore request permission from LCCMR to use $2,160 in current project funds to support this work. **Amendment Approved: 11/03/2010**

Other major accomplishments since the last progress report in April includes water quality and zooplankton data collection that was on schedule and is currently being funneled into improved databases for greater accessibility of raw data and data analysis. MPCA is currently in the midst of phasing out STORET and migrating the state's water quality data into EQuiS with an improved Environmental Data Access site that serves as the portal into EQuiS (see http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/storet/storet-program.html). This will result in improved access to raw SLICE datasets by staff, partners, and constituents.

In Deliverable 2 below we discuss progress on updating zooplankton analysis hardware and software. This software update will allow efficient delivery of processed zooplankton samples into a DNR-managed central database and facilitate access to raw and basic summary data by staff and partners.

Finally, we are in the initial phases of discussions with the newly merged DNR Division of Ecological and Water Resources related to building off of their web-based cooperative stream monitoring network (see http://www.dnr.state.mn.us/waters/csg/index.html) that currently manages large, continuous (e.g., readings every several minutes) stream flow data to include data management and delivery of continuous stream and lake temperatures from dozens if not hundreds of temperature data loggers currently deployed in lakes and streams across the state. Obviously, climate change will have a direct effect on water temperatures and the state needs an integrated database that can efficiently deliver information on status and trends in water temperatures to managers, researchers, and policy decision makers. Building such a database and web-based delivery may need additional funding support and may evolve into another Result detailed in a future LCCMR proposal. Such a proposal would likely be in conjunction with proposed web-applications described in Result 3, Deliverable 2 above.

Deliverable 2 (zooplankton assessment)
Each of the 24 sentinel lakes was sampled for zooplankton three times during the 2010 open water season (April/May, July and October) by PCA personnel. In addition, the seven “deep cisco” lakes were sampled monthly from April/May through October. Two replicate vertical tows were taken from each lake on each sampling date at the deepest location. Five of the lakes were sampled at two sites because of larger size and morphology. Zooplankton tows were collected with a standard 80μm mesh Wisconsin zooplankton net from an anchored boat to insure a vertical haul. The net was lowered to within 0.5 meter of the bottom and hauled up at a rate of approximately 0.5 m/sec. Contents were rinsed into sample bottles labeled with date, lake name, site location, and tow depth. Samples were preserved with 100% reagent alcohol and delivered to DNR Ecological and Water Resources personnel for analysis. As of October 20, 2010, 216 samples have been received in the lab and 46 have been processed using the following protocol.

Each sample was adjusted to a known volume by filtering through 80μm mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5 ml aliquot. A 5ml aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting chamber. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level) and measured to the nearest 0.01 mm using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (μg/liter), percent composition by number and weight, mean length (mm), mean weight (μg) and total counts for each taxonomic group identified were calculated.

Zooplankton indices from 2008 and 2009 data have been calculated and entered into a spreadsheet for further data analysis. Zooplankton indices that will be explored include: total zooplankton densities (#/liter), total zooplankton biomass (µg/liter), mean cladoceran size (mm), mean daphnia size (mm), daphnia densities (#/liter), daphnia biomass (µg/liter), cladoceran densities (#/liter), cladoceran biomass (µg/liter), and percent calanoids in sample.

The outdated zooplankton counting system (ZCOUNT) has been replaced with a new program called ZOOPs. A service level agreement between the Division of Ecological and Water Resources and the DNR's Management Information System's (MIS) bureau was developed to hire an outside contractor to write the software program. This project was contracted out to Ken Dunne (a freelance developer represented by the company called "UpNorth-Vet, Inc." which is included in the State's list of approved vendors for IT contracting). The service level agreement was for 250 hours of work (or $20,000) to complete the project. Contract work occurred in August and September 2010 and after thorough testing, the program is now being used to process samples.

The new program ZOOPs is a Microsoft Windows desktop application with a companion PostgreSQL database. The advantages of this new program include the following:

1. The old program (ZCOUNT) is commercial software developed in 1994 and is no longer maintained. It is supported by even older computer hardware that could not be replaced if the system failed.
2. The new program (ZOOPs) is a Microsoft Windows application that is supported by new computer hardware which provides much clearer images for zooplankton identification and more accurate measurements.
3. The new application has a companion PostgreSQL database which produces summary reports. It also calculates and stores zooplankton parameters including those indices that will be tested in the Sentinel Lakes Study.
4. The new application conforms to standards established for other DNR data and report applications, and will provide greater accessibility by other entities interested in patterns in zooplankton communities.

Since the ZOOPs program was developed by an outside contractor, it was decided that the application be written with open source coding, therefore allowing maintenance and future changes to the program by DNR staff if necessary. When searching for the replacement of ZCOUNT, it was realized there is a shortage of specialized programs such as this available to zooplankton researchers. Because of the open source coding status and the lack of available programs, it is recommended that the ZOOPs program be made available to all interested researchers. This could also benefit the DNR as improvements to the program may occur by other researchers using it.

Deliverable 3 (Evaluation of hydroacoustics to assess the status of cisco populations in inland lakes).

In the past 6 months we successfully collected the data set proposed from each of the seven study lakes that contain or were thought to contain cisco. The specific data collected and analyzed for *Deliverables 3 and 4* are outlined in the following paragraphs. These data were collected by Dr. Tom Hrabik, Tyler Ahrenstorff (PhD candidate), Jiethyl Piersak (undergraduate), Kyle Gilles (undergraduate), and MN DNR personnel (Pete Jacobson, Andy Carlson, and several interns). Both undergraduates from the University of Minnesota Duluth received an Undergraduate Research Opportunities Program Award which paid for their summer stipend and some supplies for the project.

We successfully collected hydroacoustic and vertical gillnet data from each of the seven sentinel lakes. The work included extensive preparation and proper execution to not only design the sampling procedure but also to coordinate data collection among multiple collection crews (Pete Jacobson's DNR crew who collected vertical gillnet data and Andy Carlson, a DNR Fisheries Researcher, who collected additional hydroacoustic data with a different transducer on three lakes to compare with our findings). All of the data collected has been stored to computer hard drives and analyses will continue during the next 6 month period, before the next field season begins. Analyses of the vertical gillnetting data show that cisco were only captured in 5 of 7 lakes (Table 4.1). For additional vertical gillnetting results see Appendix B.

Table 4.1. Total numbers of fish caught with vertical gillnets (3/8", 1/2", 3/4", 1-1/4", and 2" bar measure) in the 7 sentinel lakes during the summer of 2010. Species codes are: TLC=cisco, YP=yellow perch, WTS=white sucker, WAE=walleye, BLC=black crappie, LMB=largemouth bass, PRD=pearl dace, RBS=rainbow smelt, LKW=lake whitefish, LKT=lake trout, and RBT=rainbow trout.

	TLC	YP	WTS	WAE	BLC	LMB	PRD	RBS	LKW	LKT	RBT
Ten Mile	337			2					2		
Carlos	565		1	3	2	2					
Elk	45	463									
South Twin	9	248		1	2						
White Iron	76		1	3							
Cedar		719									
Trout							15	65		1	6

Deliverable 4 (Evaluation of cisco habitat use and behavior)

We will be utilizing collected data sets on various abiotic (i.e. temperature, oxygen, and light profiles) and biotic (i.e. zooplankton distributions, cisco diets, and growth) factors from each of the seven sentinel lakes which allow us to evaluate the multi-dimensional niche of cisco as well as their habitat use and behavior. The fact that cisco were absent from samples in two lakes known to previously contain cisco should provide an interesting contrast to allow us to determine critical habitat variables and limiting factors. Temperature, oxygen, and light profiles have been measured in each lake. Zooplankton samples collected with a Wisconsin plankton net (three entire water column samples during the day and three at night in each lake) have been analyzed, and we are part way through analyzing our Shindler-Patalas zooplankton samples (collected from every meter of water during the day and night in each lake). In addition, planktivore and predatory diets from fish caught in all seven sentinel lakes have been analyzed. Scales and otoliths from cisco have also been removed and will be analyzed in the future. To see more of the results from this deliverable please see Appendix B.

Result Status as of 15 April 2011**:**
Deliverable 1 (lake monitoring framework)
In November 2011 an amendment request was approved by LCCMR to allocate $2,160 toward analysis of sentinel lake water samples for stable isotope signatures of groundwater and support Lee Engel's thesis research under U of MN Adjunct Professor Dr. Joe Magner.

Each of the 24 sentinel lakes were visited in the months of May, July, and October over the course of 2008, 2009, and 2010 in order to collect water chemistry data and isotope samples during spring and fall over turn and the mid summer time period when evaporation is highest. By sampling at these key time periods seasonal variations in the lakes isotopic signature will be captured. In order to ensure a good representative sample a composite of the top two meters of lake water was taken. This eliminates large variations form precipitation events within a short duration of sampling.

Stable isotope analysis was conducted for 208 different water samples. Analysis was conducted by the Biometeorology Lab at the University of Minnesota. Analysis was completed January 20, 2010.

Stable isotopes will be compared to the isotopic composition of atmospheric water vapor which has a known isotopic concentration at specific latitudes and air temperatures during the summer of 2011. The deviation in amplitudes of the fractionation of lake water to water vapor will be modeled to predict hydrologic residence time for each lake as well.

Deliverable 2 (zooplankton assessment)
All 216 zooplankton samples collected from the 24 sentinel lakes during the 2010 field season have been processed using the laboratory protocol described in previous progress reports (see results status as of 30 October 2010). Potential zooplankton indices from 2008-2010 data have been calculated and entered into a spreadsheet for further statistical analysis. Zooplankton indices that are being explored include: total zooplankton densities (number/liter), total zooplankton biomass (µg/liter), cladoceran densities (number/liter), cladoceran biomass (µg/liter), Daphnia densities (number/liter), Daphnia biomass (µg/liter), mean cladoceran size (mm), mean Daphnia size (mm) and percent calanoids.

Mean annual zooplankton densities and biomass for the years 2008-2010 are summarized in Table 4.1. The lakes are arranged by landtype and within each landtype by decreasing total phosphorus levels as an indicator of lake productivity. Mean annual densities ranged from 129.46 individuals per liter in Shaokotan Lake to 5.02 individuals per liter in Trout Lake. Mean annual biomass ranged from 1588.75

µg per liter in Shaokotan Lake to 23.36 µg per liter in Bearhead Lake. Within the 7 coldwater lakes, South Twin had the highest zooplankton densities (30.90 individuals/liter) and biomass (55.22 µg/liter) while Trout Lake had the lowest densities (5.02 individuals/liter) and biomass (26.00 µg/liter). Interannual variability in indicators was lowest in summer, especially during August, which provides information about the best time of year to collect samples to minimize natural variability and thus better detect interannual changes in indicators.

Lakes in the shield landtype generally had the lowest densities and biomass while lakes in the prairie landtype had the highest although there was some overlap among landtypes. There appears to be a general trend towards increasing total zooplankton densities and biomass as total phosphorus increased. In addition to total zooplankton densities and biomass, other indices including total cladoceran densities and biomass and total Daphnia densities and biomass were examined by regressions of these indices against total phosphorus and mean chlorophyll.

Initial trends are revealing patterns that are contrary to initial expectations; especially the pattern of increased Daphnia biomass and size with increasing total phosphorous levels. The literature suggests that large Daphnia graze algae efficiently and are thus are associated more often with clear water lakes than turbid ones (Carpenter and Cottingham 1997). Although the complete explanation for these contrary patterns is likely to be complex, the composition of the algal community may be a significant driver of patterns. Rapid assessment algal data collected by PCA in the sentinel lakes will be evaluated as a factor influencing zooplankton community composition and potential grazing. Further, additional indicators such as biomass or density of large Daphnia (i.e., > 1.0 or 1.3 mm) or species composition of copepods may provide additional insight into grazing potential and will be evaluated in 2011-12.

A total of 37 different zooplankton taxa were identified among the 24 sentinel lakes, with two species of copepods (*Skistodiaptomus oregonensis* and *Diacyclops bicuspidatus thomasi*) and 6 species of cladocerans common in all landtypes (Table 4.2). Species common among shield lakes were the calanoid *Leptodiaptomus minutus* and the soft-water cladoceran *Holopedium gibberum*. Species common among prairie lakes included the two calanoid copepods *Leptodiaptomus siciloides* and *Aglaodiaptomus leptopus*. Two of the more uncommon species identified included *Daphnia longiremis* which is a hypolimnetic species and was found only in Carlos and Ten Mile lakes while the calanoid copepod *Onychodiaptomus sanguineus* was present only in Trout Lake.

Table 4.1. Mean summer total phosphorus (μg/liter), mean annual zooplankton densities (number individuals/liter) and biomass (μg/liter) for the 24 sentinel lakes, 2008-2010. Lakes arranged by landtype.

Sentinel Lakes Zooplankton	Lake Type	Mean Summer Total Phosphorus (2000-2009)	Mean Annual Densities (2008-2010)	Mean Annual Biomass (2008-2010)
Prairie				
Artichoke	shallow	248	87.97	636.49
Shaokotan	shallow	167	129.46	1588.75
Madison	deep	78	52.59	245.04
St. James	shallow	52	75.94	134.52
St. Olaf	deep	37	68.23	287.02
Carrie	deep	22	51.89	196.58
Transition				
Peltier	shallow	266	62.21	657.47
Belle	shallow	55	43.80	307.74
South Center	deep	51	21.26	98.81
Pearl	shallow	40	52.31	229.52
Carlos	deep-ciscoe	16	14.60	55.21
Cedar	deep-ciscoe	13	14.08	49.27
Forest				
Portage	shallow	56	86.51	199.91
Hill (south)	deep	37	32.27	154.08
Red Sand	shallow	24	76.23	109.95
Hill (north)	deep	23	14.38	86.23
Elk	deep-ciscoe	17	12.67	36.42
South Twin	deep-ciscoe	17	30.90	55.22
Ten Mile	deep-ciscoe	12	12.58	37.56
Shield				
Echo	shallow	43	33.01	126.18
Elephant	deep	21	15.95	94.96
White Iron	deep-ciscoe	21	9.34	31.45
Tait	shallow	16	17.04	61.46
Bearhead	deep	14	5.53	23.36
Trout	deep-ciscoe	7	5.02	26.00

Table 4.2. Zooplankton taxa identified from the 24 sentinel lakes in 2008-2010. Common taxa (present in 4 or more of the 6 lakes) within a landtype are marked with an X.

Copepods	**Prairie**	**Transition**	**Forest**	**Shield**
Acanthocylcops vernalis				
Aglaodiaptomus leptopus	X			
Diacyclops bicuspidatus thomasi	X	X	X	X
Diacyclops sp.				
Epischura lacustris				
Leptodiaptomus minutus				X
Leptodiaptomus sicilis				
Leptodiaptomus siciloides	X			
Macrocyclops albidus				
Mesocyclops edax	X	X	X	X
Onychodiaptomus sanguineus				
Skistodiaptomus oregonensis		X	X	X
Skistodiaptomus reighardi				
Tropocyclops prasinus mexicanus		X	X	X
Cladocerans				
Acroperus harpae				
Alona circumfibriata				
Alona setulosa				
Alona sp.				
Bosmina longirostris	X	X	X	X
Ceriodaphnia sp.				
Cerodaphnia reticulata		X	X	X
Chydorus sphaericus	X	X	X	X
Daphnia ambigua				
Daphnia catawba				
Daphnia galeata mendotae	X	X	X	X
Daphnia longiremis				
Daphnia parvula				
Daphnia pulicaria	X	X	X	X
Daphnia retrocurva	X	X	X	X
Daphnia rosea				
Diaphanosoma birgei	X	X	X	X
Eubosmina coregoni		X		
Graptoeberis testudinaria				
Holopedium gibberum				X
Leptodora kindti				
Sida crystallina				
Simocephalus sp.				

Deliverable 3 (Evaluation of hydroacoustics to assess the status of cisco populations in inland lakes).

Since the last progress report in October 2010, we have made significant progress towards *Deliverable 3*. Most importantly, we have preliminary hydroacoustic results assessing the status of cisco populations. Of the 7 sentinel lakes, cisco were found in 5 of them (i.e. Carlos, Elk, South Twin, Ten Mile, and White Iron lakes) using vertical gillnetting. Cisco were not captured in Cedar or Trout lakes, and therefore data from these lakes have not been analyzed and will not be collected in 2011. In addition, hydroacoustic data from South Twin Lake has not been analyzed (and will not be collected in 2011) because only 9 cisco were captured in vertical gillnets and the shallow depth of this lake (max depth = 8.5 m) make hydroacoustic data difficult to collect and analyze. Of the 4 sentinel lakes with measureable cisco populations, preliminary data suggests that the highest cisco density by number is in Ten Mile Lake (2624 ± 364 $\#\bullet ha^{-1}$), followed by White Iron Lake (1621 ± 121 $\#\bullet ha^{-1}$), Carlos Lake (1233 ± 197 $\#\bullet ha^{-1}$) and Elk Lake (353 ± 43 $\#\bullet ha^{-1}$). Because cisco sizes vary in each lake, estimates of biomass are highest in White Iron Lake (69 ± 5 $kg\bullet ha^{-1}$), then Carlos Lake (58 ± 9 $kg\bullet ha^{-1}$), Ten Mile Lake (42 ± 6 $kg\bullet ha^{-1}$), and Elk Lake (17 ± 2 $kg\bullet ha^{-1}$).

Deliverable 4 (Evaluation of cisco habitat use and behavior)

Progress has also been made towards Deliverable 4 since October 2010. Notably, we have determined the habitat use (or vertical distributions) of cisco in each of the four sentinel lakes (Figure 4.1). In addition, we have finished analyzing our Schindler-Patalas zooplankton samples (Figure 4.2). Combining our results as of April, 2010, we have finished analyzing the abiotic (i.e. temperature, oxygen, and light profiles) and biotic (i.e. cisco diets and zooplankton distributions) factors which may influence cisco distributions and will help us evaluate their multidimensional niche (Figures in Appendix which is available upon request). It appears that temperature and oxygen have a significant influence on cisco distributions in most lakes (Figure 1); however, there may be other factors driving cisco distributions in other lakes (e.g. Ten Mile Lake). Cisco diets were analyzed by Kyle Gilles who received support from the Undergraduate Research Opportunities Program (UROP) at the University of Minnesota-Duluth. Zooplankton distributions were analyzed by Jiethyl Piersak whom also received support from a UROP award. Logan Jacobson is an undergraduate currently applying for a UROP award to assist with data collection and analyses during the summer of 2011. We are still evaluating the possibility of determining predator distributions and potentially using bioenergetics to evaluate the growth potential for cisco at various depths in the lake. All together, we are gaining considerable knowledge about cisco habitat use and the factors influencing those distributions.

Results for Deliverables 3 and 4 were presented by T. Ahrenstorff in November, 2010, at the annual MN DNR fisheries research meeting at the EPA in Duluth, MN.

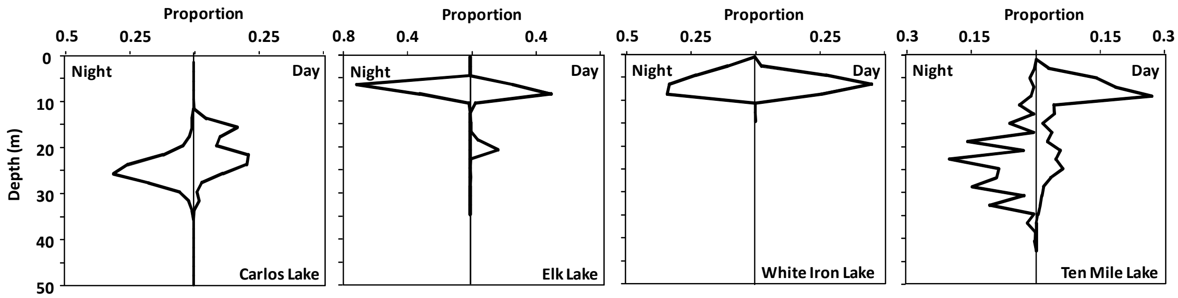

Figure 4.1. Cisco vertical distributions during the day and night in each of the 4 sentinel lakes.

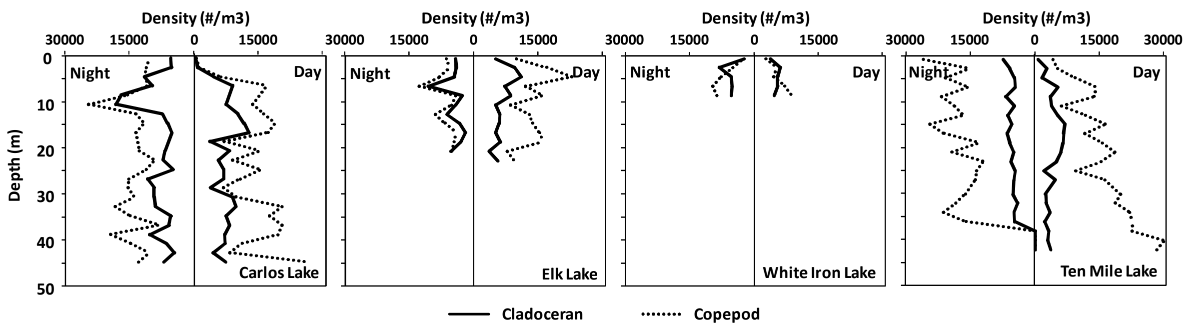

Figure 4.2. Cladoceran and copepod vertical distributions in each of the 4 sentinel lakes. Vertical distributions are separated by species in Appendix which is available upon request.

Result Status as of 30 October 2011**:**

Deliverable 1 (lake monitoring framework)

We are on schedule to produce a report detailing major findings across all results and prescribing key indicator data sets that should be part of SLICE going forward beyond this appropriation. We anticipate that the bulk of the SLICE program will be carried out with DNR and PCA operational lake survey funds. However, we may need LCCMR's ongoing support for specific research investigations and monitoring infrastructure (e.g., data platforms and sensors, data analysis and summary tools). We will follow the RFP process to present those needs to LCCMR.

U of MN Isotope analysis (ground water-surface water interactions and patterns across lakes).

Basic statistical analysis of the isotopic composition was conducted on all 24 individual Sentinel Lakes. Results are being graphically represented for both annual and seasonal variations. Isotopic trends for lakes in the four land use categories have been identified along with variations in the isotopic signature of these lakes depending on their mixing class; well mixed vs. stratified. Seasonal variations are present and more significant in some lakes than others. Annual variations in climate have also shown influences on some well mixed shallow lakes along with the deepest lakes. Results are still being analyzed and will be discussed in future meetings between Lee Engel and Joe Magner. A formal write up explaining trends and conclusions will be drafted by June 30th, 2012.

Deliverable 2 (zooplankton assessment)

Amendment Request 10/30/2011

Recall that LCCMR approved funding to upgrade outdated the ZCOUNT zooplankton assessment system to ZOOPs (summarized in greater detail in the 10/30/2010 Result Status). This has resulted in much more efficient analysis of zooplankton data, electronic storage, and retrieval of data. However, the original project did not leave room for important enhancements that ensure quality control of data entered into the database (e.g., flagging of a daphnia that is 100 cm long) and easy retrieval raw data and summaries by partners and staff. For instance, zooplankton data "reports" have not been written and integrated into the State of Minnesota's central data reporting service (currently titled "DNRnet Reporting Service"). Access to zooplankton data collected with ZOOPs currently requires sophisticated SQL data queries to which only OET staff have access. Our amendment request would reallocate $21,000 of end-of-project savings to writing reports that would grant all DNR employees easy access to the data to use themselves or share with partners or constituents. Data from these reports would feed into the data visualization tool described in Result 3. With approval of the amendment request, the Office of Enterprise Technology could finish enhancements to ZOOPs by the project due date of June 30 2012 at the earliest. However, we request an extension of three months (Sep. 30 2012) to complete this deliverable.

In addition, along the same timelines, we request authorization to spend $7,000 end-of-project money to migrate 690 offline spreadsheets of data from the sentinel lakes collected since 2008 with the old ZCOUNT program into the new database system. This will likely require some relatively time-intensive data manipulation of the ZCOUNT spreadsheets by a student-worker. The Division of Ecological and Water Resources will cover additional costs to migrate these and several thousand additional archived files.

Finally, a meeting was held in August to discuss the Carleton College senior math project. Three Carleton college students under the guidance of math professor Dr. Bob Dubrow will be statistically analyzing the sentinel lakes zooplankton data from 2008-2011. Zooplankton indices data from all 4 years and raw data from 2010-2011 (generated with the new zooplankton counting system) will be the data they will have available for analysis. They are planning on starting this analysis in January 2012 and a completion date is set for May 2012. A second meeting is tentatively planned for later this fall with the students coming to the DNR Ecological and Water Resources Biology Lab so they will have an opportunity to see how the zooplankton data is generated from the new zooplankton counting system.

Amendment Approved: Amendment approved by LCCMR on December 2, 2011.

Deliverable 3 (Evaluation of hydroacoustics to assess the status of cisco populations in inland lakes)

Hydroacoustic data was collected from each of the 4 sentinel lakes (i.e. Lake Carlos, Ten Mile Lake, White Iron Lake, and Elk Lake) with cisco populations during the summers of 2010 and 2011. We estimated cisco density (#/ha) and biomass (kg/ha) in each lake during each year (Table 4.1). Due to differences in the size distribution of cisco between lakes and years (Figure 4.1), determined using vertical gillnets, biomass estimates are better suited for comparisons. Lake Carlos has the highest average biomass (76 ± 12 kg•ha^{-1}), followed by Ten Mile Lake (49 ± 6 kg•ha^{-1}), White Iron Lake (37 ± 3 kg•ha^{-1}), and Elk Lake (22 ± 4 kg•ha^{-1}).

Hydroacoustic data was also collected from Ten Mile Lake during winter and spring of 2011, resulting in data from the summer of 2010, and the winter, spring, and summer of 2011. We will be collecting fall hydroacoustic data in the upcoming weeks. Seasonal density and biomass estimates for Ten Mile Lake are 45 ± 6 kg/ha (2624 ± 364 #/ha) for summer of 2010, 14 ± 1 kg/ha (1000 ± 98 #/ha) for winter of 2011, 40 ± 6 kg/ha (2970 ± 431 #/ha) for spring of 2011, and 53 ± 5 kg/ha (3915 ± 393 #/ha) for summer of 2011. It should be noted that our winter density and biomass estimates are confounded by the fact that we were unable to move while sampling through the ice, resulting in low estimates.

Deliverable 4 (Evaluation of cisco habitat use and behavior)
In the 4 sentinel lakes, we are evaluating cisco habitat use by determining their vertical distribution in each lake during 2010 and 2011 (Figure 4.2). In Carlos and Ten Mile lakes, cisco perform reverse diel vertical migrations characterized by being shallower in the water column during the day and deeper at night. In Elk and White Iron lakes, cisco do not perform any discernable vertical migration and are instead located in similar areas during the day and night.

In order to examine this behavior, or why cisco are distributed differently between lakes, we are comparing observed cisco distributions to various model predictions. Specifically, we will be using foraging, growth, predation, and oxy-thermal niche models to determine which factors are driving cisco distributions (and perhaps density) between each lake. While we have yet to run our model simulations, we have collected all of the data inputs into the models. The lake-specific inputs include light levels, temperature/oxygen conditions, preferred prey distributions, and predator distributions (see Figures in Appendix available upon request).

For Ten Mile Lake, we are examining seasonal changes to the reverse diel vertical migration (Figure 4.3) to determine if there are different drivers seasonally influencing their distributions.

As a result of this collaboration between the University of Minnesota-Duluth and the Minnesota Department of Natural Resources, we have leveraged additional funding for side projects examining zooplankton diel vertical migrations (Jiethyl Piersak; Undergraduate Research Opportunities Program UROP), cisco diet composition (Kyle Gilles; UROP), cisco reverse diel vertical migrations (Logan Jacobson; UROP), cisco synchrony in recruitment events across space (Jared Myers; Michigan State University PhD project), and differences in cisco diel vertical migrations (Tyler Ahrenstorff; NSF Doctoral Dissertation Improvement Grant – pending).

Table 4.1. Cisco density (#/ha) and biomass (kg/ha) estimates for the 4 sentinel lakes from 2010 and 2011.

	Density (#/ha)		**Biomass (kg/ha)**	
	2010	**2011**	**2010**	**2011**
Ten Mile Lake	2624 ± 364	3915 ± 393	45 ± 6	53 ± 5
Lake Carlos	1233 ± 197	1683 ± 250	61 ± 10	91 ± 13
White Iron Lake	353 ± 43	579 ± 100	18 ± 2	26 ± 5
Elk Lake	724 ± 54	1442 ± 146	33 ± 2	41 ± 4

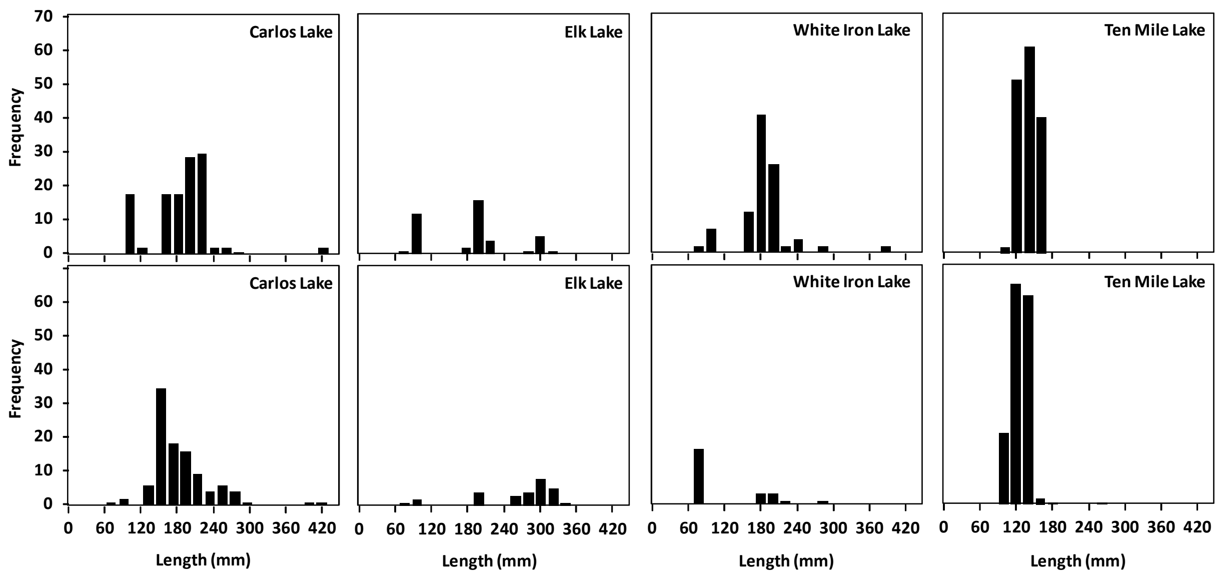

Figure 4.1. Length-frequency distributions for cisco, based on vertical gillnet catch data, in each of the 4 sentinel lakes during 2010 (top row) and 2011 (bottom row).

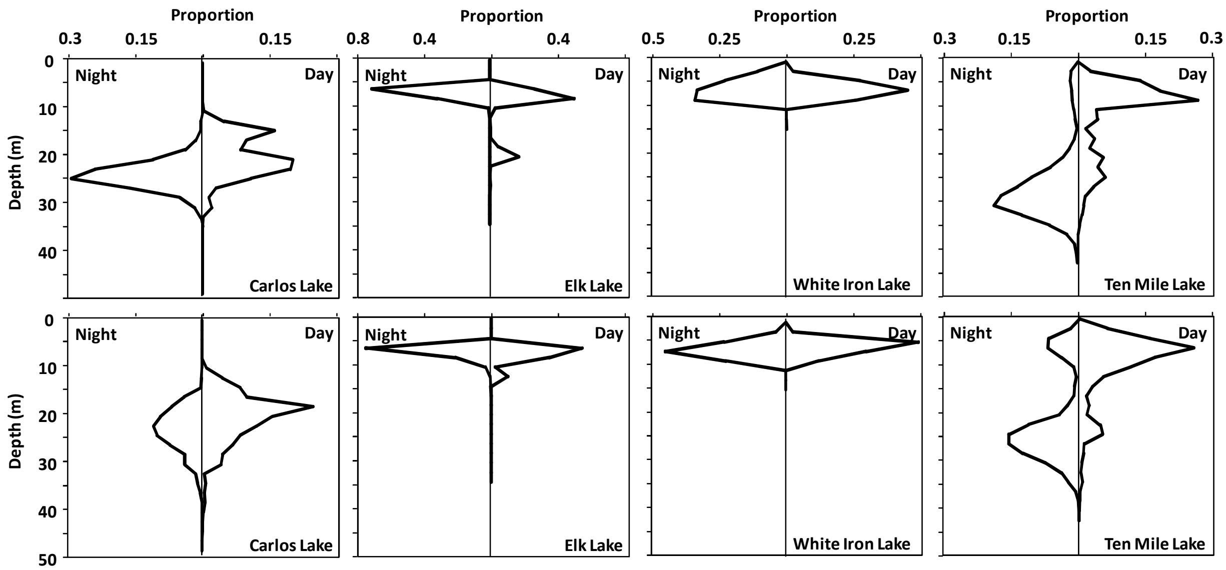

Figure 4.2. Cisco vertical distributions in the 4 sentinel lakes during 2010 (top row) and 2011 (bottom row).

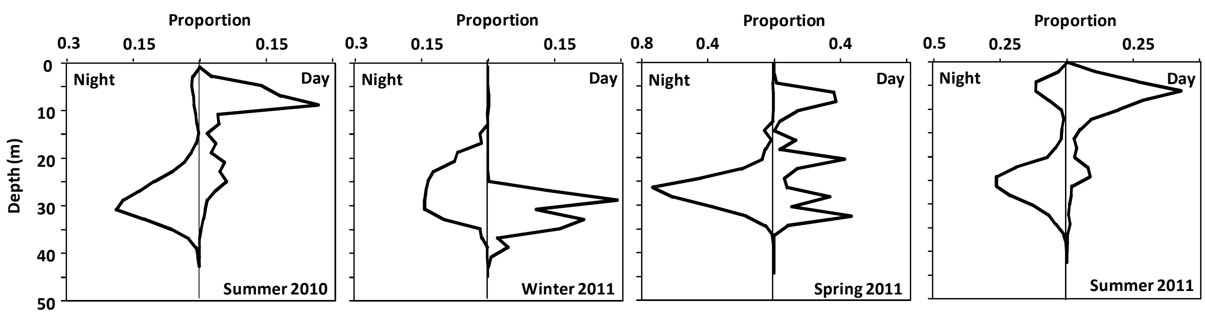

Figure 4.3. Cisco vertical distributions in Ten Mile Lake during the summer of 2010 and the winter, spring, and summer of 2011.

Result Status as of: 12/31/2012

Deliverable 1 (*Lake monitoring framework*)

All work related to the lake monitoring framework is track to be completed as scheduled. Drs. Donald Periera and Richard Keisling presented testimony to the LCCMR for a second phase of funding for the sentinel lakes program.

U of MN Isotope analysis (ground water-surface water interactions and patterns across lakes).

Field work on this project has been completed and Lee Engel's thesis, under the direction of Dr. Joe Magner (University of Minnesota) is in the final editing phase. A full final report, based on the approved thesis will be included in the final report to the LCCMR. The following is a summary of Mr. Engel's work:

Surface water bodies present a challenge in determining how water cycles through them. The use of the stable isotopes of hydrogen (Deuterium expressed as δD) and oxygen ($\delta^{18}O$) can provide hydrologic insight, including possible guidance for TMDL development. Hydraulic residence time is dependent on several factors including: lake volume, watershed size, location within a watershed and climatic variability. Analyzing the stable isotopic composition of lake water δD and $\delta^{18}O$ over time illustrates source water input mixing and evaporative processes. δD and $\delta^{18}O$ were compared to the isotopic composition of atmospheric water vapor which has a known isotopic concentration at specific latitudes and air temperatures. The deviation in amplitudes of the fractionation of lake water to water vapor was modeled to predict hydrologic residence time for each lake. Twenty four lakes throughout Minnesota were sampled over a three year period and residence times were calculated.

Deliverable 2 (zooplankton assessment)
Retooling of the ZOOPS database to allow great accessibility to all partners was approved in October of 2011. The departure of Ray Valley from the SLICE project put this deliverable behind schedule. A May 2012 meeting was held with State IT staff to discuss development needs. As a result, we have two Service Level Agreements (SLA) with MN.IT@DNR (MIS) for the ZOOPS program. The first agreement is for enhancements and bug fixes to the application. The second SLA is for data conversion, to recover data from the ZCOUNT program spreadsheets and migrate it to the ZOOPS database. Both SLAs are in place. Work has not started on enhancements and bug fixes. Preliminary investigation and proof-of-concept for the data conversion has been started.

In April, three Carleton college students under the guidance of math professor Dr. Bob Dubrow presented the findings of their analyses of the zooplankton data collected for the SLICE program from 2008 to 2011.

Deliverable 3 (Evaluation of hydroacoustics to assess the status of cisco populations in inland lakes)
All work on this aspect of the SLICE program has been completed. A final report has been submitted and is undergoing review by DNR staff. The completed report will be available in the final report delivered to the LCCMR in June of 2013.

Deliverable 4 (Evaluation of cisco habitat use and behavior)
Similarly, the evaluation of cisco habitat has also been completed and a final report has been submitted. As is the case with the hydroacoustics evaluation, a completion report will be included in the final report delivered to the LCCMR next June.

Final Report Summary:

<u>Summary for Result 4, Deliverable 1: Report(s) evaluating a lake monitoring framework for early detection of changes in habitat and fish community status</u>

Water quality data is paramount to analysis of other results and deliverables and many other current and future auxiliary projects. All water chemistry data has been uploaded to STORET (http://www.epa.gov/storet/dbtop.html), a publically accessible national water quality database. Furthermore, as an in-kind contribution, the PCA's Water Monitoring Section partnered with DNR Fisheries to compile comprehensive retrospective lake assessment reports (visit http://www.pca.state.mn.us/water/sentinel-lakes.html to download finished reports). These reports contain critical baseline assessments of sentinel lake watershed, water quality, habitat, and fish community conditions for comparison to future conditions.

Synthesis of fish community and fish population metrics, and stressor-indicator relationships using statistical screening techniques utilizing all sentinel lakes data, was funded by the Game and Fish fund and reimbursement by Federal Sportfish Restoration Act dollars (Study 605, F-26-R-36) and is nearing completion. A final report for Study 605 is scheduled to be completed by June 30, 2014. Interim progress reports are available upon request.

On July 1, 2013 we received funding from LCCMR to implement Phase 2 of sentinel lakes program. Staffing adjustments have been made, and the lake monitoring framework has been adjusted to incorporate tiers of sentinel lakes, those sampled more or less frequently, respectively. New lake models have been proposed for 3 shallow lakes with agriculturally-dominated watersheds, and revised sampling plans were developed by subject expert groups that met during fall 2012-spring 2013. This was done for each of the major biological and habitat components being monitored (fish, zooplankton, benthic invertebrates, plants and physical habitat, water quality, and watersheds). Monitoring and research for Phase 2 is currently underway.

Summary for U of MN isotope analysis (ground water-surface water interactions and patterns across lakes) – amendment request for Result 4, Deliverable 1

We have provided to LCCMR the final report "Exploring Hydraulic Residence in Minnesota's Sentinel lakes: Implications for Management" authored by Lee Engel and Joe Magner, summarizing results of an amendment request that directed funds to pay for laboratory services to measure δ^2H (δD) and $\delta^{18}O$ to determine extent of groundwater-surface water interaction and evaporative processes in the 24 sentinel lakes.

Summary for Result 4, Deliverable 2: *Assessment of zooplankton indicators*
A final report, authored by Jodie Hirsch, summarizing the zooplankton assessment and indicator development work follows here:

Deliverable 2 Evaluating potential zooplankton indicators

OBJECTIVE:

1. Identify patterns in zooplankton metrics relative to inherent lake characteristics and stressor gradients. 2. Quantify within lake temporal variation for each metric. 3. Identify patterns in metric variation relative to inherent lake characteristics and stressor gradients. 4. Quantify the minimum detectable difference for each metric and sampling effort needed to detect a range change for each metric, if necessary by lake type or stressor level. 5. Determine potential indicators based on 1-4.

STATUS:

Despite the importance of zooplankton to food chains in north temperate lakes (see Rusack et al. 2002, Beisner et al. 2003, and Olden et al. 2006), few studies have examined the linkages of zooplankton populations to environmental conditions or to fish populations in inland lakes in Minnesota. Westerlund et al. (1998) were unable to link fish community structure with limnetic zooplankton abundance in Minnesota, yet their work provides a baseline for designing a long-term monitoring study and a first comparison for new results. Zooplankton abundance and species composition were found to have no influence on recruitment of yellow perch or black crappie in four Minnesota lakes (Parsons et al. 2004), but large fluctuations in recruitment of all sportfish remain unexplained. Zooplankton variability among lakes is generally greater than variability within lakes (Rusack et al. 2002, Olden et al. 2006). This suggests zooplankton characteristics will respond to changes in lake conditions with a good signal-to-noise relationship during long-term monitoring. In addition, the short generation times of zooplankton allow a rapid response to perturbation. Zooplankton are thus sensitive to environmental conditions in ways that make them potentially valuable leading indicators for changes that will affect sportfish.

PROCEDURES:

Field Methods:

All 24 lakes were sampled monthly from ice-out (April and/or May) through October during 2008 and 2009 by MPCA personnel. During 2010 and 2011, the seven “deep cisco” lakes were sampled monthly while the remaining 17 lakes were sampled three times per year (April/May, July, and October). During 2011, samples were collected in August rather than July due to the state shutdown. Also during 2011, six of the lakes were sampled in November rather than October to coincide with water chemistry sampling on those lakes.
Two replicate vertical tows were taken from each lake on each sampling date at the deepest location. Five of the lakes were sampled at two sites because of larger size and morphology. Zooplankton tows were collected with a standard 13 cm mouth, 80μm mesh Wisconsin zooplankton net, from an anchored boat to ensure a vertical haul. The net was lowered to within

0.5 meter of the bottom and hauled up at a rate of approximately 0.5 m/sec. Contents were rinsed into sample bottles labeled with date, lake name, site location, and tow depth. Samples were preserved with 100% reagent alcohol and delivered to DNR Ecological and Water Resources personnel for analysis.

Laboratory Methods:

Each sample was adjusted to a known volume by filtering through 80μm mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5 ml aliquot. A 5ml aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting chamber. Specimens from each aliquot were counted and measured to the nearest 0.01 mm using a dissecting microscope and a computerized zooplankton counting system. All cladocerans in aliquot were identified to lowest taxonomic level possible (most to species) where copepods were identified to four major groups (cyclopoids, calanoids, copepodites and nauplii) for quantitative purposes. Adult copepods from each sample were further identified under compound microscope, down to species level, for a qualitative lake taxa list.

Data generated included density (number/liter), biomass (μg/liter), percent composition by number and weight, mean length (mm), mean weight (μg) and total count of each taxon identified. These data were automatically recorded from the counting system into the MNDNR zooplankton database.

Potential zooplankton indices were calculated and entered into a spreadsheet for further statistical analysis. These indices included total zooplankton densities (number/liter), total zooplankton biomass (μg/liter), cladoceran densities (number/liter), cladoceran biomass (μg/liter), *Daphnia* densities (number/liter), *Daphnia* biomass (μg/liter), mean cladoceran size (mm), mean *Daphnia* size (mm) and percent calanoids.

Statistical Analyses:
The strength of the relationships between zooplankton measurements and lake productivity were examined with linear regression models. Annual (April-October) and summer (June- August) mean zooplankton densities, mean zooplankton biomass, mean cladoceran densities, mean cladoceran biomass, mean *Daphnia* densities, and mean *Daphnia* biomass for 2008-2011 were each regressed against total phosphorus and mean chlorophyll values for all 24 lakes. The model r-squared values (i.e., the percent of total variation in the statistic explained by the regression model) were used to determine what zooplankton statistics were best explained by lake productivity.

Power Analyses:
Initial power analyses were performed for the zooplankton data to evaluate how noise in the indicators affects the ability to detect temporal changes in indicator values. Noise arises from natural temporal variation in an indicator in addition to sampling and measurement errors. Prospective power analyses were performed for the following statistics calculated from each zooplankton sample replicate: zooplankton biomass and density, cladoceran biomass and density,

Daphnia biomass and density, average *Daphnia* and cladoceran size, and percent calanoids. To simplify analyses, only June data were used to estimate parameters for power analyses.

A series of mixed effect linear statistical models was first fit to each zooplankton statistic to estimate mean indicator values, among-lake variance, temporal variation (referred to as 'process variation'), spatial variation within lake, and measurement error variability. Density and biomass variables were log-transformed to reduce heteroscedasticity and improve normality of residuals. A categorical year effect was first used in each model to determine if there were annual differences in the variables across the state; if no annual differences were detected, an intercept-only model was used. For each indicator, three models with different random effect structures were examined in order to estimate the parameters for power analyses; these are explained below for the Zooplankton Density model.

Model 1 used a sample ID random effect nested within a random lake effect. The sample ID was constructed as a combination of Lake/Sample Date/Sampling Site, and thus represented each unique sampling occasion on each lake. Since there were 2 replicates at each sampling occasion, the residual error standard deviation (in red in model output below) for this model represents measurement error; i.e., the variability among samples taken at the same time and place. The random sample ID standard deviation (in green below) represents a combination of temporal and spatial variation in zooplankton density. The Lake standard deviation (orange) represents variation among the sentinel lakes (largely irrelevant for the power analyses which focus on the power to detect change within a single lake).

```
Model 1 Output:
Linear mixed-effects model fit by maximum likelihood
Random effects:
 Formula: ~1 | Lake
        (Intercept)
StdDev:   0.8840724

 Formula: ~1 | sample.id %in% Lake
        (Intercept)  Residual
StdDev:   0.5525952 0.1991381

Fixed effects: log(Zoop_density) ~ 1
              Value Std.Error DF  t-value p-value
(Intercept) 3.42824 0.1930571 71 17.75765       0
```

Variation among sentinel lakes

Measurement error, i.e. variability among samples taken at the same time and place

Temporal and spatial variability

Model 2 used a Site random effect nested within the random lake effect. For this model, the residual standard deviation represented a combination of temporal and measurement error at a given site within a lake. The random site standard deviation represented spatial variation in zooplankton density between different sites within the same lake over the 4 years of sampling.

```
Model 2 Output:
Linear mixed-effects model fit by maximum likelihood
Random effects:
 Formula: ~1 | Lake
        (Intercept)
```

```
StdDev:   0.6947774

 Formula: ~1 | Site %in% Lake
        (Intercept)  Residual
StdDev: 1.483583e-05 0.4484492
```

Spatial variability between different sites within the same lake over 4 years

```
Fixed effects: log(Zoop_density) ~ 1
               Value Std.Error DF  t-value p-value
(Intercept) 3.354925 0.3246208 40 10.33490       0
```

Model 3 utilized a random Sampling Date effect nested within the random Lake effect. The residual error for this model represents a combination of spatial and measurement error; i.e., the variability of samples taken from a lake on the same day. The Sample Date standard deviation represents temporal variation of samples within a single lake over the 4 years of sampling.

```
Model 3 Output:
Linear mixed-effects model fit by maximum likelihood
Random effects:
 Formula: ~1 | Lake
        (Intercept)
StdDev:   0.8726302

 Formula: ~1 | Date_Sampled %in% Lake
        (Intercept)  Residual
StdDev:   0.5826748 0.2247258
```

Temporal variation of samples within a single lake over 4 years

```
Fixed effects: log(Zoop_density) ~ 1
               Value Std.Error DF  t-value p-value
(Intercept) 3.426777 0.1939094 83 17.67205       0
```

We used the same bootstrapped power analysis method for each indicator so we could compare the signal to noise relationships among the various zooplankton indicators. The intercept value from the statistical model for each indicator was used as the starting point for the power analysis, and 20 years of data were repeatedly simulated with a regression model ($\log_e$ transformed when necessary) with an average annual decrease of sufficient magnitude to lead to a 50% decline in the statistic over 20 years. Both process and measurement error variability was incorporated into the simulated series. For each simulated time-series, a regression model was fit and the p-value for the test for trend different from zero was recorded. We calculated power as the rate at which a statistically significant trend was detected for a 2-sided test with $\alpha = 0.20$ from the simulated time-series.

RESULTS

General:
A total of 37 different zooplankton taxa were identified among the 24 sentinel lakes during 2008-2011, with two species of copepods (*Skistodiaptomus oregonensis* and *Diacyclops bicuspidatus thomasi*) and 6 species of cladocerans (*Bosmina longirostris*, *Chydorus sphaericus*, *Daphnia pulicaria*, *Daphnia retrocurva*, *Daphnia galeata mendotae* and *Diaphanosoma birgei*) common in all ecoregions (Table 1). Species common only among shield lakes were the calanoid copepod

Leptodiaptomus minutus and the soft-water cladoceran *Holopedium gibberum*. Species common only among prairie lakes included the two calanoid copepods *Leptodiaptomus siciloides* and *Aglaodiaptomus clavipes*. Two of the more uncommon species identified included *Daphnia longiremis,* a hypolimnetic-deep water species found only in Carlos and Ten Mile lakes and the calanoid copepod *Onychodiaptomus sanguineus* which was present only in Trout Lake.

Mean annual zooplankton densities and biomass for the years 2008-2011 are summarized in Table 2. The lakes are arranged by ecoregion and within each ecoregion by decreasing total phosphorus levels as an indicator of lake productivity. Mean annual densities ranged from 109.97 individuals per liter in Shaokotan Lake to 4.60 individuals per liter in Trout Lake. Mean annual biomass ranged from 1279.54 μg per liter in Shaokotan Lake to 20.81 μg per liter in Bearhead Lake.

Lakes in the shield ecoregion generally had the lowest densities and biomass while lakes in the prairie ecoregion had the highest although there was some overlap among ecoregions. There appears to be a general trend towards increasing total zooplankton densities and biomass as total phosphorus increases.

<u>Examining temporal and spatial differences in zooplankton communities:</u>

Mean monthly zooplankton densities and biomass were plotted for all lakes by ecoregion to examine temporal (monthly) differences within a lake and also spatial differences among lakes within and between ecoregions (Figures 1-4). These figures visually illustrate monthly differences in zooplankton densities and biomass within a lake and also show that zooplankton communities had different seasonal patterns in different lakes. The shield lakes generally had the lowest densities and biomass while the prairies lakes had the highest. Lakes in the forest and transition ecoregions had values that fell somewhere in between.

Zooplankton biomass in most of the shield ecoregion lakes appeared to peak in June and decline throughout the season, with the exception of Echo Lake where biomass was high in June and again in August. In most lakes, biomass appeared to be lowest during mid-summer, possibly due to predation by young-of-the year fish.

Similar to the shield lakes, June appeared to be the month where zooplankton biomass peaked in most of the forest ecoregion lakes with the exception of Ten Mile Lake where biomass peaked in July and then remained relatively stable throughout the season.

In the transition ecoregion lakes, biomass appeared to peak in May or June in most lakes and decline throughout the season. Peltier Lake was an exception, where biomass peaked in July and remained high throughout the season. Most of this biomass was due to the presence of large *Daphnia pulicaria*.

The zooplankton biomass in the prairie lakes appeared to peak in May or June, and decline in mid-summer. This mid-summer decline could be in response to a decrease in food supply or predation. In early spring, with the release of sediments into these lakes, there is often a pulse of phytoplankton followed by a pulse of zooplankton. By mid-summer, zooplankton have grazed the edible phytoplankton down to a level where zooplankton densities also decline. Low summer zooplankton densities in some lakes could also be caused by young-of –the year fish predation. Some lakes had a smaller secondary peak in September and October. Zooplankton biomass in Shaokotan Lake remained relatively high throughout the season, and similar to Peltier, was due to the presence of large *Daphnia pulicaria.*

<u>Zooplankton indices and lake productivity:</u>

For all zooplankton indices, total phosphorus appeared to be a better fit than mean chlorophyll. All regression r-squared values are summarized in Table 3. The regression with the best fit was total phosphorus vs. summer *Daphnia* densities with an r-squared value of 0.743.

In Figure 5, regressions for the parameters with the four highest r-squared values are plotted: 1) total phosphorus vs. summer *Daphnia* densities, 2) total phosphorus vs. summer *Daphnia* biomass, 3) total phosphorus vs. summer cladoceran biomass and 4) mean chlorophyll vs. summer *Daphnia* densities. Note that the regressions with the best fit all had summer zooplankton values and not annual values. This may suggest that summer zooplankton sampling may be a better tool than annual sampling in describing lake productivity and detecting change over time.

<u>Examining other potential zooplankton indices:</u>

Two additional indices that may prove to be valuable in detecting changes in water quality include the average size of *Daphnia* and the percent calanoids in a zooplankton community. These two indices are illustrated for the seven "deep ciscoe" lakes in Figure 6.

<u>Average size of *Daphnia*:</u>

Early on in this study, it was hypothesized that as nutrient loading increases in a lake, relative abundance of large *Daphnia* should decrease (Harig and Bain 1998). This is based on the fact that large *Daphnia* are efficient grazers of algae and will keep phosphorus levels in check. Among the "deep ciscoe" lakes, Trout had the largest average size of *Daphnia* with an annual average of 1.28mm and the lowest phosphorus value. Trout Lake was the only "deep ciscoe" lake that maintained an average *Daphnia* size close to 1.3 mm throughout the season, which according to Galbraith (1967) is the minimum length of *Daphnia pulex* that lake dwelling rainbow trout selective for and are therefore considered large *Daphnia*. *Daphnia sp.* of this size are also very efficient grazers of algae and contribute to water clarity in lakes.

Among the seven "deep ciscoe" lakes, South Twin Lake had the lowest average size of *Daphnia* with an annual average of 0.81mm but had the third highest phosphorus value. Ten Mile Lake had similar sized *Daphnia* (0.85mm) but lower phosphorus levels. Ten Mile (and Carlos) Lake had populations of the smaller- sized *Daphnia longiremis* which is confined to the hypolimnion of deep lakes. In this case the average size of *Daphnia* may not be the best indicator of lake productivity unless species are evaluated individually.

<u>Percent calanoids in zooplankton community:</u>

It was also hypothesized that as nutrient loading increases, percent composition of calanoids in the zooplankton community should decrease (Gannon and Stemberger 1978). This is based on the fact that most calanoids are grazers of small algal cells which are more common in oligotrophic lakes.

Trout Lake had the highest percentage of calanoids in the zooplankton community and Cedar Lake had the lowest (Figure 6). Cedar Lake also has low phosphorus levels (14 μg/liter) and had the second largest average size of *Daphnia* next to Trout Lake with an annual average of 1.15mm. This presents a problem as one would expect a lake with low phosphorus levels and large-bodied *Daphnia* should also have a large percentage of calanoids in the community. This discrepancy is most likely due to the high densities of the large *Daphnia* in Cedar Lake which contribute to a large percentage of the total zooplankton community. Future analyses will explore whether the percent calanoid index might be better calculated as the percent of calanoids in the copepod community rather than the percent of calanoids in the total zooplankton community.

As with the *Daphnia*, it might be useful to evaluate individual species of calanoids. The percent calanoid index is based on a generalization that all calanoids feed on small algal cells which are typical of lakes with low productivity. It is known that different species of calanoids graze on different sized algal cells and different calanoid species are found in different lake types (Torke 2001).

Some calanoids appeared more ubiquitous such as *Skistodiaptomus oregonensis* which were found in 22 of the 24 sentinel lakes. Others appeared to be more specific to lake type and/or ecoregion, such as *Leptodiaptomus minutus* and *Leptodiaptomus sicilis* which were found mostly in the shield and forest ecoregion lakes while *Aglaodiaptomus clavipes* and *Leptodiaptomus siciloides* were found mostly in the prairie lakes. *Onychodiaptomus sanguineus* was present only in Trout Lake. *O. sanguineus* is described as being a small lake/pond species but has also been found to be a dominant calanoid in the hypolimnion of some deep oligotrophic lakes (Stemberger 1995). Torke (2001) described the calanoids in 499 Wisconsin lakes and concluded that lake productivity and post-glacial history are most likely the main determinants in the distribution of calanoids in Wisconsin, and increasing eutrophication in lakes can change their distribution over time.

Examining individual lakes by ecoregion:

Yearly differences in zooplankton densities, zooplankton biomass, *Daphnia* densities and *Daphnia* biomass were examined in all lakes by plotting the four years of monthly data separately (Figures 7-31). Clearly, some lakes display more year- to- year variation in densities, biomass and monthly patterns than others. At least in the seven "deep ciscoe" lakes where monthly sampling was conducted for four years, the yearly zooplankton fluctuations were greatest during the May and/or June period and least during August or September. This pattern appeared in most of the lakes. Yearly fluctuations in densities and biomass early in the season could be explained by differences in ice out dates, spring temperatures and/or year class strength of fish. Late summer zooplankton samples may be better indicators of change over time than spring or early summer samples due to less year- to-year variation during this period.

These patterns are discussed in the following section along with other noteworthy observations, especially focusing on the different species of *Daphnia* and calanoid copepods, because as discussed above, these two groups may be potential indicators of change among lakes.

<u>Shield Ecoregion:</u>

<u>Trout</u>

Trout Lake had very low total zooplankton densities and biomass and followed similar temporal patterns all four years (Figure 7, Table 2). *Daphnia* densities were also very low, being most abundant during the late summer months and most were large *Daphnia pulicaria*. Trout Lake has an oxygenated hypolimnion where *Daphnia* can migrate into and avoid fish predation during daylight hours. Calanoid copepods made up a high percentage of the zooplankton density. Trout was the only sentinel lake where the calanoid copepod *Onychodiaptomus sanguineus* was found. Other calanoids included *Leptodiaptomus minutus* and *Leptodiaptomus sicilis*, both typical of oligotrophic lakes, and *Epischura lacustris*. The soft-water cladoceran *Holopedium gibberum* was also present in Trout Lake.

<u>Bearhead</u>

Bearhead Lake had very low total densities and biomass, similar to Trout Lake (Figure 8, Table 2). Unlike Trout Lake, *Daphnia* densities tended to peak in June and again in October, and were lowest in mid-summer. The lower numbers in mid-summer could be due to young-of-the-year fish predation. A large portion of the lake is shallow where there is little refuge for *Daphnia* to migrate into during the day to avoid fish predation. The only calanoid species found in Bearhead Lake was the ubiquitous *Skistodiaptomus oregonensis*. The soft-water cladoceran *Holopedium gibberum* was also present in Bearhead Lake.

<u>Tait</u>

Tait Lake had more moderate total densities and biomass when compared to other lakes in the shield ecoregion, but low compared to all sentinel lakes (Figure 9, Table 2). *Daphnia* densities were also low, most likely due to fish predation as it is a shallow lake without a limnetic refuge. The only calanoid species found in Tait Lake was *Skistodiaptomus oregonensis*. The soft-water cladoceran *Holopedium gibberum* was also present in Tait Lake.

<u>White Iron</u>

White Iron Lake had moderate total densities and biomass when compared to other lakes in the shield ecoregion (Figure 10, Table 2). *Daphnia* densities and biomass were also moderate when compared to other shield lakes, and tended to peak in July through September, depending upon the year. Most of these *Daphnia* were *Daphnia galeata mendotae* and the smaller *Daphnia retrocurva*. Calanoid copepods consisted of *Skistodiaptomus oregonensis*, *Leptodiaptomus minutus*, and *Epischura lacustris*. The soft-water cladoceran *Holopedium gibberum* was also present in White Iron Lake.

Elephant

Elephant Lake had moderate total densities but higher total biomass when compared to other lakes in the shield ecoregion (Figure 11, Table 2). *Daphnia* densities and biomass were high compared to other shield ecoregion lakes and did not show any consistent yearly temporal pattern. Large *Daphnia pulicaria* and *Daphnia galeata mendotae* were common and contributed to a large percentage of the total biomass, especially in 2008 and 2009. The only calanoid copepod found was *Skistodiaptomus oregonensis*. The soft-water cladoceran *Holopedium gibberum* was also present in Elephant Lake.

Echo

Echo Lake had the highest total densities and biomass of all the lakes in the shield ecoregion (Figure 12, Table 2). *Daphnia* densities and biomass were also very high especially during 2011 where most were *Daphnia galeata mendotae*. *Skistodiaptomus oregonensis* was the only calanoid present in Echo Lake. The soft-water cladoceran *Holopedium gibberum* was also present in Echo Lake.

Forest Ecoregion:

Ten Mile

Ten Mile Lake had the lowest total densities and biomass of all the lakes in the forest ecoregion (Figure 13, Table 2) and tended to follow similar temporal patterns from year to year. *Daphnia* densities and biomass were also low, and peaked during different times depending upon year, but appeared to be most abundant during the summer months. Ten Mile Lake was only one of two sentinel lakes (Carlos Lake being the other) where *Daphnia longiremis* was found. *D. longiremis* is a deep water species found only in the hypolimnion. In order for this species to thrive, there must be adequate dissolved oxygen below the thermocline throughout the year. Calanoid copepods consisted of *Skistodiaptomus oregonensis, Leptodiaptomus minutus*, *Leptodiaptomus sicilis*, and *Epischura lacustris*.

South Twin

South Twin Lake had moderate total densities and biomass when compared to other lakes in the forest ecoregion (Figure 14, Table 2). *Daphnia* densities and biomass were also moderate compared to the other sentinel lakes in the forest ecoregion. *Daphnia* densities each year followed a similar pattern where they peaked in early summer and again in late summer with very few in July. The larger *Daphnia galeata mendotae* were present during the earlier months where the smaller *Daphnia retrocurva* appeared after July. Two species of calanoids were found in the lake, *Skistodiaptomus oregonensis* and *Epischura lacustris*.

Elk

Elk Lake had low total densities and biomass when compared to other lakes in the forest ecoregion (Figure 15, Table 2). Densities and biomass followed a similar pattern each year while peaking in May or June and decreasing by July with no secondary peak in late summer. *Daphnia* densities and biomass were also low when compared to other forest ecoregion lakes, and peaked at different times each year. In 2011, samples were collected in November rather than October and *Daphnia* densities were quite high compared to other years where samples were collected in October. This could have been the result of a later than average lake turnover date in 2011, causing the second pulse of nutrients, phytoplankton and zooplankton to appear in November. Most of these *Daphnia* were the larger *Daphnia galeata mendotae*. Elk was the only sentinel lake outside of the border ecoregion where the soft-water cladoceran *Holopedium gibberum* was collected. Two species of calanoids were found in the lake, *Skistodiaptomus oregonensis* and *Epischura lacustris*.

<u>Hill (North Basin)</u>

The north basin of Hill Lake had low total densities but moderate biomass when compared to other lakes in the forest ecoregion and both appeared to peak in May or June (Figure 16, Table 2). Most of this biomass during 2008-2010 was due to large *Daphnia pulicaria*, but this species was not present in samples from 2011. The only calanoid found was the ubiquitous *Skistodiaptomus oregonenesis*.

<u>Hill (South Basin)</u>

The south basin of Hill Lake had average total densities but higher biomass compared to the north basin and other lakes of the forest ecoregion (Figure 17, Table 2). *Daphnia* densities and biomass were also higher, especially during June 2008 where large *Daphnia pulicaria* contributed to most of the biomass. Similar to the north basin, *Skistodiaptomus oregonensis* was the only calanoid present.

<u>Red Sand</u>

Red Sand Lake had high total densities and biomass when compared to the other lakes in the forest ecoregion but *Daphnia* densities were very low (Figure 18, Table 2). This lake had more species of smaller cladocerans that are generally associated with aquatic macrophytes. Red Sand Lake does have macrophyte growth throughout the entire lake. Red Sand Lake was the only lake in the forest ecoregion where the calanoid copepod *Aglaodiaptomus clavipes* was found. This species was more common in the prairie and transition lakes. The ubiquitous *Skistodiaptomus oregonensis* was the only other calanoid found in Red Sand Lake.

<u>Portage</u>

Portage Lake had the highest total densities and biomass of all the lakes in the forest ecoregion (Figure 19, Table 2). *Daphnia* densities and biomass were also high compared to other forest ecoregion lakes and consisted mostly of *Daphnia galeata mendotae* which tended to peak in June or July. *Skistodiaptomus oregonensis* was the only calanoid found in Portage Lake.

Transition Ecoregion:

Cedar

Cedar Lake had the lowest total densities and biomass of all the transition ecoregion lakes (Figure 20, Table 2). Densities appeared to peak in spring or early summer and then declined throughout the season. *Daphnia* densities were also low, but most were large *Daphnia pulicaria*. *Skistodiaptomus oregonensis* was the only calanoid found in Cedar Lake.

Carlos

Carlos Lake also had low total densities and biomass, very similar to Cedar Lake (Figure 21, Table 2). Densities tended to peak in May or June and declined by mid to late summer. *Daphnia* densities were also low and tended to peak in mid-summer rather than spring. Carlos Lake was one of only two sentinel lakes where *Daphnia longiremis* was found (Ten Mile Lake being the other one). *D. longiremis* is a deep water species found only in the hypolimnion. In order for this species to thrive, there must be adequate dissolved oxygen below the thermocline throughout the year. Four species of calanoids were found in Carlos Lake; *Skistodiaptomus oregonensis*, *Leptodiaptomus siciloides*, *Leptodiaptomus sicilis* and *Epischura lacustris*.

Pearl

Pearl Lake had higher total densities and biomass when compared to other transition ecoregion lakes (Figure 22, Table 2). *Daphnia* densities were also higher, and the dominant species seemed to vary from year to year. For example, the smaller *Daphnia ambigua* were very abundant in June 2008 whereas in June 2009 most were the larger *Daphnia galeata mendotae*. *Skistodiaptomus oregonensis* was the only calanoid found in Pearl Lake.

South Center

South Center Lake had moderate total densities and biomass when compared to the other transition ecoregion lakes (Figure 23, Table 2). *Daphnia* densities were low although *Daphnia* biomass was relatively higher. This biomass was due to the presence of larger *Daphnia pulicaria* and *Daphnia galeata mendotae* early in the season. *Daphnia retrocurva* was more abundant in August. Four species of calanoids were found in South Center Lake, including *Skistodiaptomus oregonensis*, *Leptodiaptomus siciloides*, *Leptodiaptomus sicilis* and *Aglaodiaptomus clavipes*.

Belle

Belle Lake had higher total densities and biomass when compared with other transition ecoregion lakes (Figure 24, Table 2). *Daphnia* densities and biomass were also relatively high, especially in May and June where large *Daphnia pulicaria* and *Daphnia galeata mendotae* made up most of the zooplankton biomass. Calanoids found in Belle Lake included *Leptodiaptomus siciloides* and *Aglaodiaptomus clavipes*.

Peltier

Peltier Lake had the highest total densities and biomass of all the transition ecoregion lakes (Figure 25, Table 2) and appeared to be more similar to prairie ecoregion lakes. *Daphnia* densities and biomass were also very high throughout the entire season and contributed to most of the total zooplankton biomass. Peltier Lake, along with Shaokotan and Artichoke lakes, had dense populations of the large *Daphnia pulicaria* and also high densities of the blue green algae *Aphanizomenon flos-aquae*. These species are known to co-exist well together in shallow eutrophic lakes since *D. pulicaria* do not graze on *A. flos- aquae* but rather graze on other algal species that compete with *A. flos-aquae* (Lynch 1981). The algae may provide refuge for *D. pulicaria* which generally decrease throughout the season in shallow lakes due to fish predation. The only calanoid copepod found in Peltier Lake was *Leptodiaptomus siciloides.*

Prairie Ecoregion:

Carrie

Carrie Lake had the lowest total densities and second lowest total biomass of all the prairie ecoregion lakes (Figure 26, Table 2). *Daphnia* densities and biomass were moderate when compared with other prairie lakes, although the smaller *Daphnia retrocurva* was the dominant species throughout the season. Interestingly, Carrie Lake was the only lake in the prairie ecoregion where the calanoid *Epischura lacustris* was found. Among the sentinel lakes, *Epischura lacustris* was more common in the deeper lakes of the shield and forest ecoregions. The ubiquitous *Skistodiaptomus oregonensis* was the only other calanoid present in Carrie Lake.

St. Olaf

St. Olaf Lake had moderate total densities and biomass when compared to other prairie lakes (Figure 27, Table 2). *Daphnia* densities and biomass were also relatively moderate where *Daphnia galeata mendotae* and the smaller *Daphnia retrocurva* were the dominant species. *Daphnia* were abundant in early summer, declined during mid-summer and increased again by October. Three species of calanoids were present in St. Olaf Lake, including *Skistodiaptomus oregonenesis*, *Leptodiaptomus siciloides* and *Aglaodiaptomus clavipes*.

St. James

St. James Lake had higher total densities but lower total biomass when compared to the other prairie lakes (Figure 28, Table 2). *Daphnia* densities were also low, with the exception in June 2009 where there were numerous *Daphnia pulicaria* present. Smaller cladocerans were more common otherwise, contributing to the low overall biomass. *Skistodiaptomus oregonensis* was the only calanoid copepod found in St. James Lake.

Madison

Madison Lake had moderate total densities and biomass when compared to other prairie lakes (Figure 29, Table 2*).* *Daphnia densities* were high during May and June, but declined dramatically by July. *Daphnia galeata mendotae* was the dominant *Daphnia* species early in the season. *Leptodiaptomus siciloides and Aglaodiaptomus clavipes* were the two calanoids present in Madison Lake.

Shaokotan

Shaokotan Lake had the highest total densities and biomass of all the sentinel lakes (Figure 30, Table 2). *Daphnia* densities and biomass were extremely high, especially during 2008. Large *Daphnia pulicaria* were very abundant and contributed to most of the zooplankton biomass. Similar to Peltier Lake, the blue-green algae *Aphanizomenon flos-aquae* was abundant and most likely provided a refuge for large *Daphnia pulicaria*. The two calanoids present in Shaokotan Lake were *Leptodiaptomus siciloides and Aglaodiaptomus clavipes.*

Artichoke

Artichoke Lake also had higher total densities and biomass when compared to other prairie ecoregion lakes (Figure 31, Table 2). *Daphnia* densities and biomass were also high, especially during June. Early in the season, during May and June, large *Daphnia pulicaria* contributed to most of the biomass but declined by August with a second peak in October. Similar to Peltier and Shaokotan lakes, the blue-green algae *Aphanizomenon flos-aquae* was present. *Leptodiaptomus siciloides and Aglaodiaptomus clavipes* were the two calanoid copepods present in Artichoke Lake.

Power Analyses:

We are currently in the process of determining what indicators to collect in ongoing monitoring for inference on lake system status, and the initial power analyses give a useful comparison of the strength of noise for each statistic relative to a similar magnitude change to help guide these decisions. Many of the zooplankton indicators had relatively high noise and thus had relatively low power to detect the declines modeled here, though some indicators did show high power to detect a 50% decline over 20 years. For example, measurements of overall zooplankton density tended to be affected by high process variation resulting in relatively poor ability to detect a decline (Figure 32), while measurement of large *Daphnia* density showed lower natural variation and declines were more likely to be detected (Figure 33).

The regression model used in the power analyses, however, may not be the best analysis method to address management or research hypotheses for any given indicator; e.g., it may be more meaningful to test whether zooplankton density is above a certain threshold than to test for a long-term trend in abundance. More appropriate analyses methods are being developed as part of the indicator selection process.

CONCLUSION/RECOMMENDATIONS:

Overall, there appeared to be greater spatial differences in the zooplankton densities and biomass in lakes among ecoregions than in lakes within the same ecoregion. Lakes in the shield ecoregion generally had the lowest densities and biomass while lakes in the prairie ecoregion had the highest, although there was some overlap among ecoregions. There appeared to be a general trend toward increasing total zooplankton densities and biomass as total phosphorus increased.

Regressions with total phosphorus appeared to correlate better than chlorophyll with total zooplankton densities and biomass. The regression with the best fit was total phosphorus vs. summer *Daphnia* densities. The regressions using summer zooplankton values versus annual values had higher r-squared values overall, suggesting that summer zooplankton sampling may be a better tool than annual sampling in describing lake productivity and detecting change over time.

Temporal year-to-year variation within lakes was apparent, especially during the spring season. Yearly zooplankton fluctuations were greatest during the May and/or June period and least during August or September. Therefore, late summer zooplankton samples may be better indicators of change over time due to less year- to-year variation during this period. Early season samples during the spring zooplankton pulse should still be collected for detecting any changes in species composition in lakes over time.

Although the zooplankton community composition in many of the sentinel lakes was similar with common ubiquitous species, there did appear to be some differences, especially in the calanoid and Daphnia spp. among the lakes in the different ecoregions. These two groups have potential to be indicators of change and effort should be made to study these groups more closely. Calanoids should be identified (and quantified if possible) to the species level. The proportion of calanoids in the copepod community (rather than compared to the total zooplankton community) should also be tested as a potential indicator of change.

Table 1. Zooplankton taxa identified from the 24 sentinel lakes in 2008-2011. Common taxa (present in 4 or more of the 6 lakes) within an ecoregion are marked with an X.

	Prairie	Transition	Forest	Shield
Copepods				
Acanthocylcops vernalis				
Aglaodiaptomus clavipes	X			
Diacyclops bicuspidatus thomasi	X	X	X	X
Diacyclops sp.				
Epischura lacustris				
Leptodiaptomus minutus				X
Leptodiaptomus sicilis				
Leptodiaptomus siciloides	X			
Macrocyclops albidus				
Mesocyclops edax	X	X	X	X
Onychodiaptomus sanguineus				
Skistodiaptomus oregonensis		X	X	X
Skistodiaptomus reighardi				
Tropocyclops prasinus mexicanus		X	X	X
Cladocerans				
Acroperus harpae				
Alona circumfibriata				
Alona setulosa				
Alona sp.				
Bosmina longirostris	X	X	X	X
Ceriodaphnia sp.				
Ceriodaphnia reticulata		X	X	X
Chydorus sphaericus	X	X	X	X
Daphnia ambigua				
Daphnia catawba				
Daphnia galeata mendotae	X	X	X	X
Daphnia longiremis				
Daphnia parvula				
Daphnia pulicaria	X	X	X	X
Daphnia retrocurva	X	X	X	X
Daphnia rosea				
Diaphanosoma birgei	X	X	X	X
Eubosmina coregoni	X	X		
Graptoeberis testudinaria				
Holopedium gibberum				X
Leptodora kindti				
Sida crystallina				
Simocephalus sp.				

Table 2. Mean summer total phosphorus (μg/liter), mean annual zooplankton densities (number individuals/liter) and biomass (μg/liter) for the 24 sentinel lakes, 2008-2011. Lakes arranged by ecoregion.

Sentinel Lakes Zooplankton	**Lake Type**	**Mean Summer Total Phosphorus (2010)**	**Mean Annual Densities (2008-2011)**	**Mean Annual Biomass (2008-2011)**
Prairie				
Artichoke	shallow	244	75.64	558.03
Shaokotan	shallow	161	109.97	1279.54
Madison	deep	79	56.66	251.73
St. James	shallow	49	94.79	141.20
St. Olaf	deep	38	65.23	264.00
Carrie	deep	21	45.51	166.84
Transition				
Peltier	shallow	245	55.79	521.96
Belle	shallow	58	38.26	266.98
South Center	deep	51	21.23	97.73
Pearl	shallow	39	46.28	190.12
Carlos	deep-ciscoe	16	13.86	50.89
Cedar	deep-ciscoe	14	12.78	49.27
Forest				
Portage	shallow	56	107.30	199.12
Hill (south)	deep	37	31.45	130.95
Red Sand	shallow	24	71.58	117.36
Hill (north)	deep	23	14.48	73.66
Elk	deep-ciscoe	18	14.50	40.83
South Twin	deep-ciscoe	17	38.05	67.55
Ten Mile	deep-ciscoe	13	12.30	34.64
Shield				
Echo	shallow	42	36.43	165.21
Elephant	deep	25	13.22	76.11
White Iron	deep-ciscoe	21	9.79	31.95
Tait	shallow	16	12.42	44.62
Bearhead	deep	14	5.21	20.81
Trout	deep-ciscoe	7	4.60	23.06

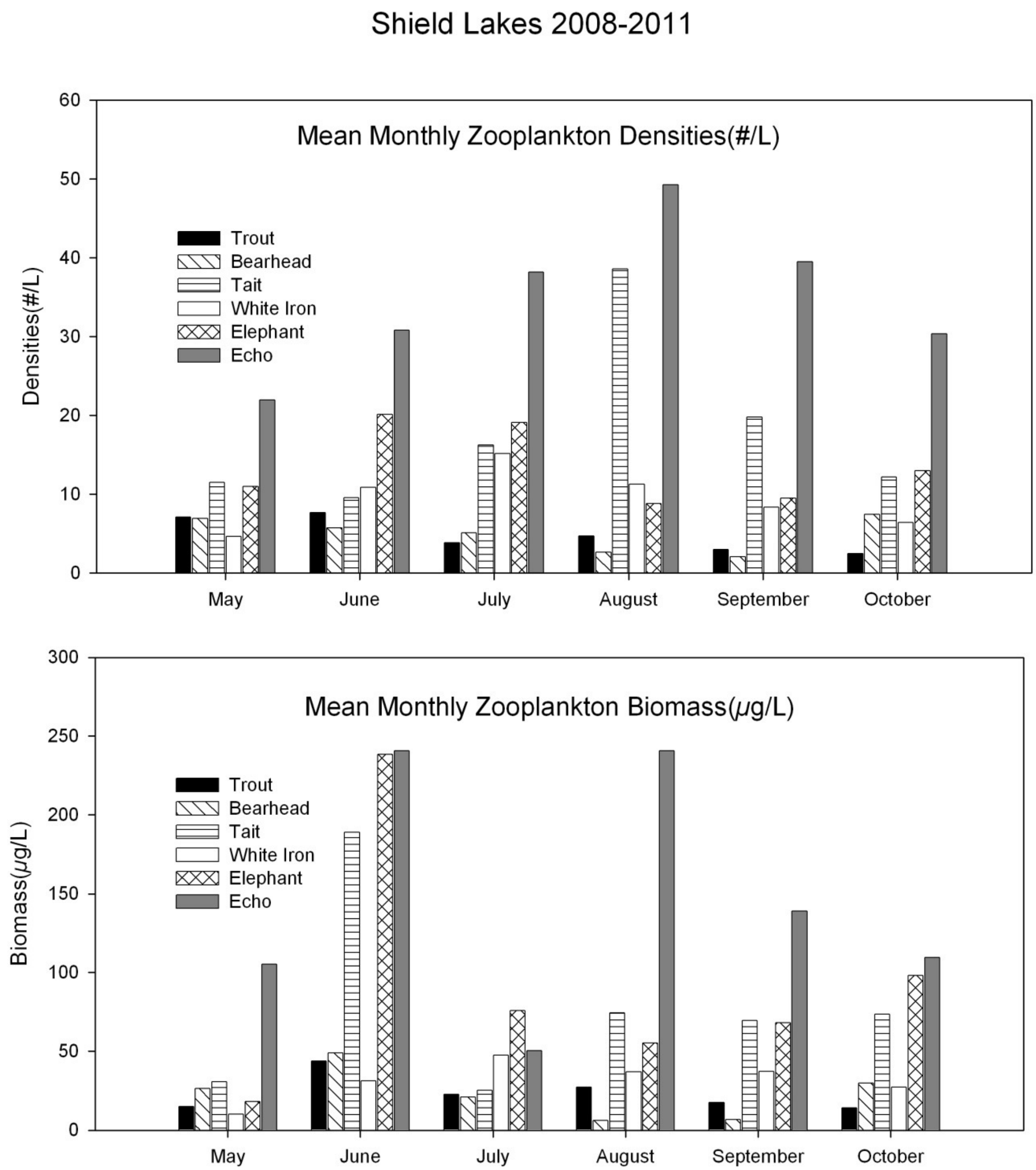

Figure 1. Mean monthly zooplankton densities (#/liter) and biomass (μg/liter) in the sentinel lakes of the shield ecoregion 2008-2011. (Lakes are listed by increasing phosphorus levels).

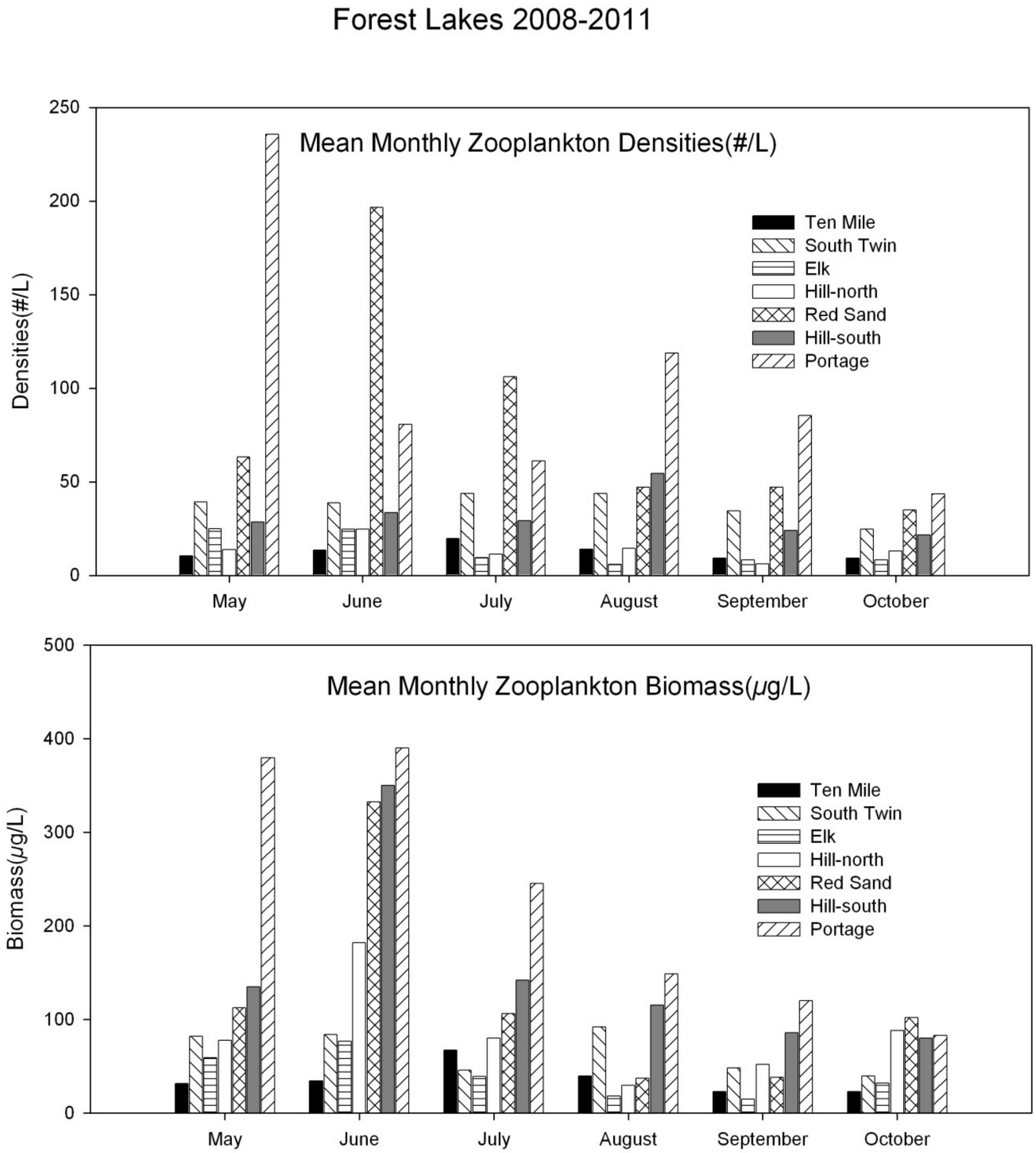

Figure 2. Mean monthly zooplankton densities (#/liter) and biomass (μg/liter) in the sentinel lakes of the forest ecoregion 2008-2011. (Lakes are listed by increasing phosphorus levels).

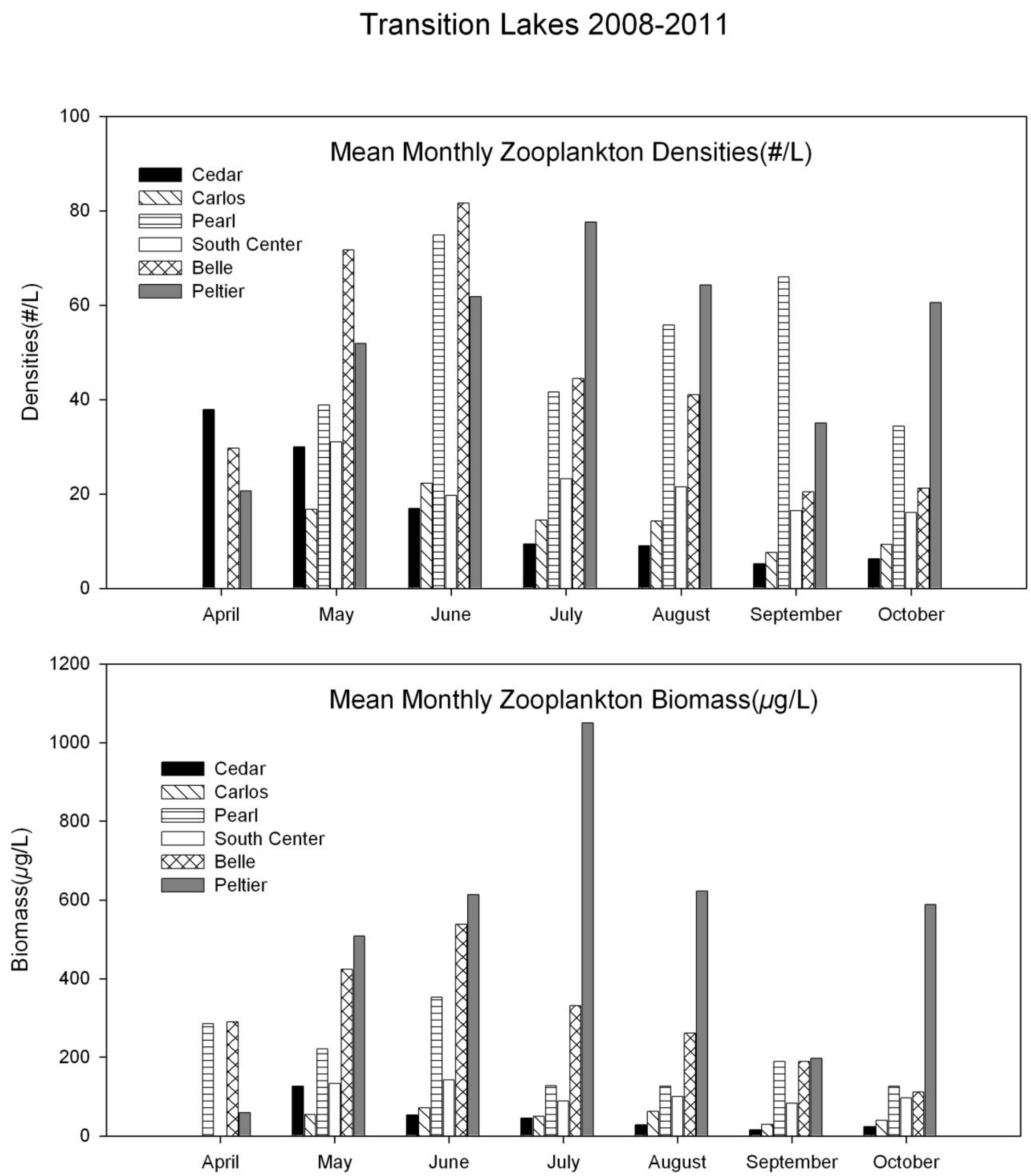

Figure 3. Mean monthly zooplankton densities (#/liter) and biomass (μg/liter) in the sentinel lakes of the transition ecoregion 2008-2011. (Lakes are listed by increasing phosphorus levels).

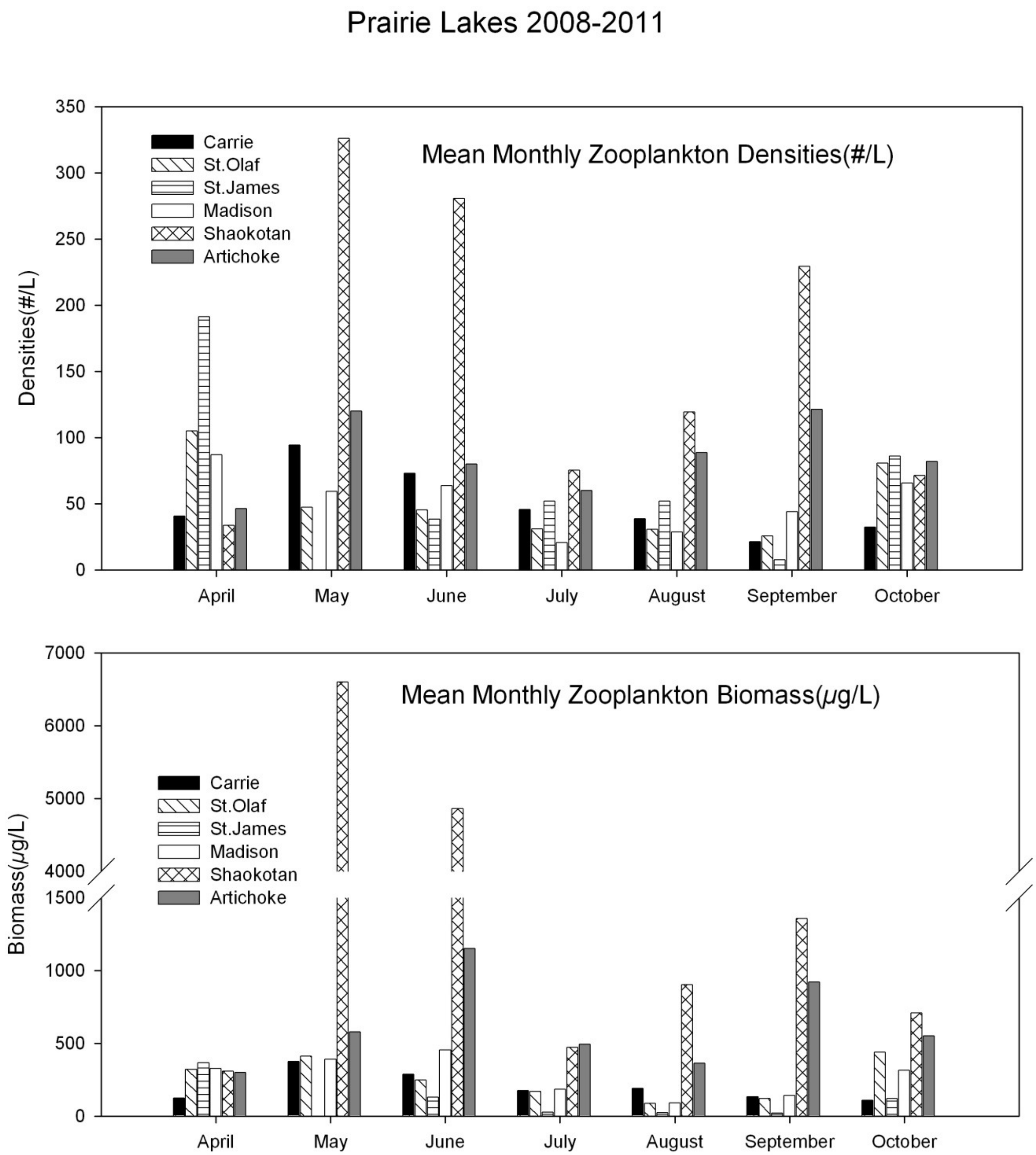

Figure 4. Mean monthly zooplankton densities (#/liter) and biomass (μg/liter) in the sentinel lakes of the prairie ecoregion 2008-2011. (Lakes are listed by increasing phosphorus levels).

Table 3. R-squared values from regressions of zooplankton indices and lake productivity parameters from the 24 sentinel lakes. (Mean annual zooplankton indices calculated from April-October, 2008-2011. Mean summer zooplankton indices calculated from June-August, 2008-2011. Densities measured in number individuals/liter and biomass measured in μg/liter, phosphorus and chlorophyll are summer 2010 values in μg/liter). R-squared values in bold are those best fit regressions shown in Figure 5.

Parameter	**Parameter**	**R-squared value**
Mean annual zooplankton densities	Chlorophyll	0.245
Mean annual zooplankton densities	Total phosphorus	0.287
Mean annual zooplankton biomass	Chlorophyll	0.497
Mean annual zooplankton biomass	Total phosphorus	0.566
Mean summer zooplankton densities	Chlorophyll	0.208
Mean summer zooplankton densities	Total phosphorus	0.266
Mean summer zooplankton biomass	Chlorophyll	0.535
Mean summer zooplankton biomass	Total phosphorus	0.649
Mean annual cladoceran densities	Chlorophyll	0.388
Mean annual cladoceran densities	Total phosphorus	0.418
Mean annual cladoceran biomass	Chlorophyll	0.499
Mean annual cladoceran biomass	Total phosphorus	0.545
Mean summer cladoceran densities	Chlorophyll	0.298
Mean summer cladoceran densities	Total phosphorus	0.305
Mean summer cladoceran biomass	Chlorophyll	0.601
Mean summer cladoceran biomass	Total phosphorus	**0.701**
Mean annual *Daphnia* densities	Chlorophyll	0.581
Mean annual *Daphnia* densities	Total phosphorus	0.637
Mean annual *Daphnia* biomass	Chlorophyll	0.488
Mean annual *Daphnia* biomass	Total phosphorus	0.527
Mean summer *Daphnia* densities	Chlorophyll	**0.652**
Mean summer *Daphnia* densities	Total phosphorus	**0.743**
Mean summer *Daphnia* biomass	Chlorophyll	0.596
Mean summer *Daphnia* biomass	Total phosphorus	**0.706**

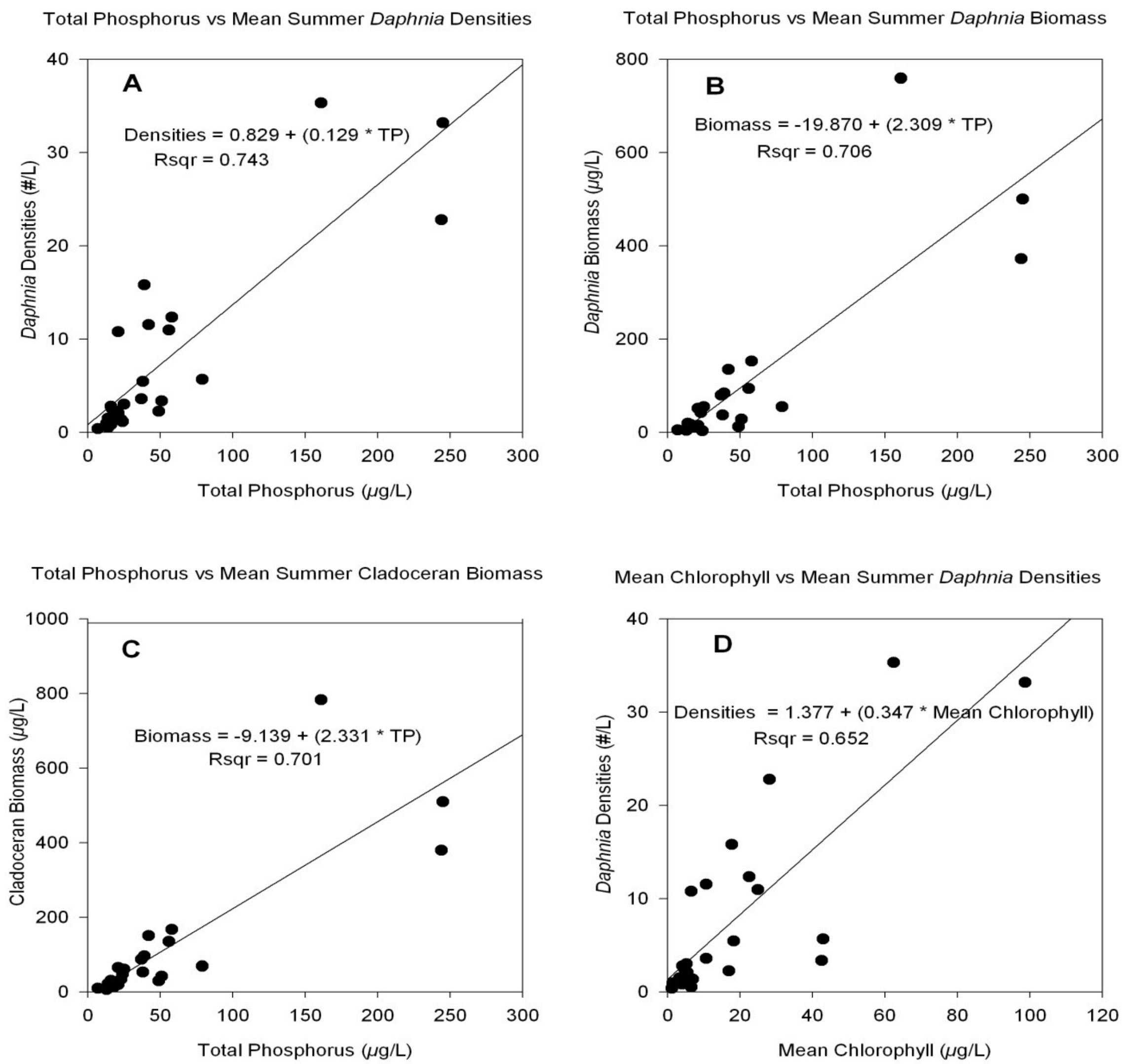

Figure 5. Plots of the four best fit regressions of zooplankton indices and lake productivity parameters from the 24 sentinel lakes, 2008-2011 listed in Table **Z**1. A. Total phosphorus vs. mean summer *Daphnia* densities. B. Total phosphorus vs. mean summer *Daphnia* biomass. C. Total phosphorus vs. mean summer cladoceran biomass. D. Mean chlorophyll vs. summer *Daphnia* densities.

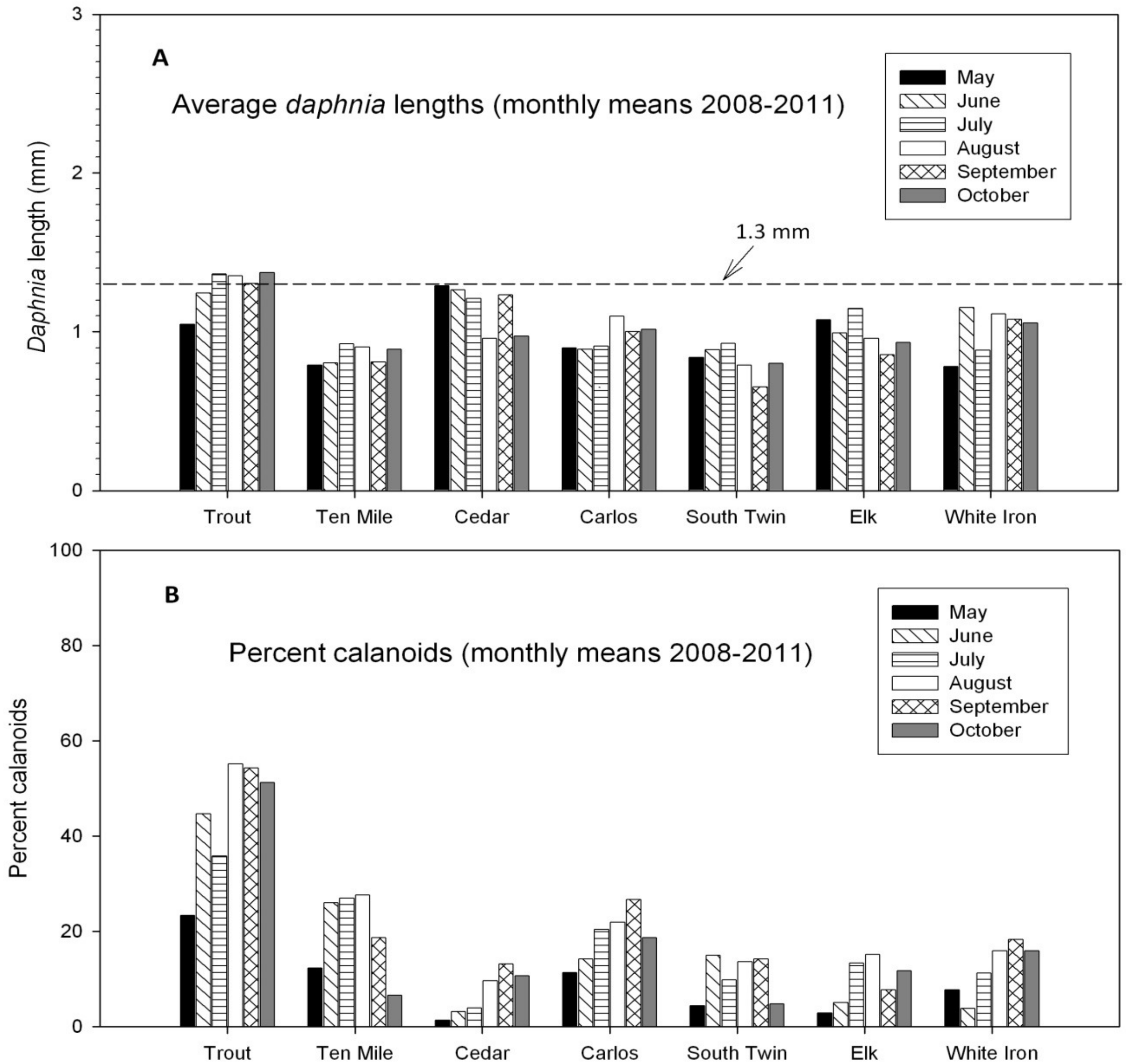

Figure 6. A. Monthly means of the average *Daphnia* lengths (mm) from the seven deep ciscoe lakes, 2008-2011. (1.3mm represents minimum length of "large *Daphnia*" (Galbraith 1967). B. Monthly means of the percentage of calanoids in the zooplankton community from the 7 deep ciscoe lakes, 2008-2011).

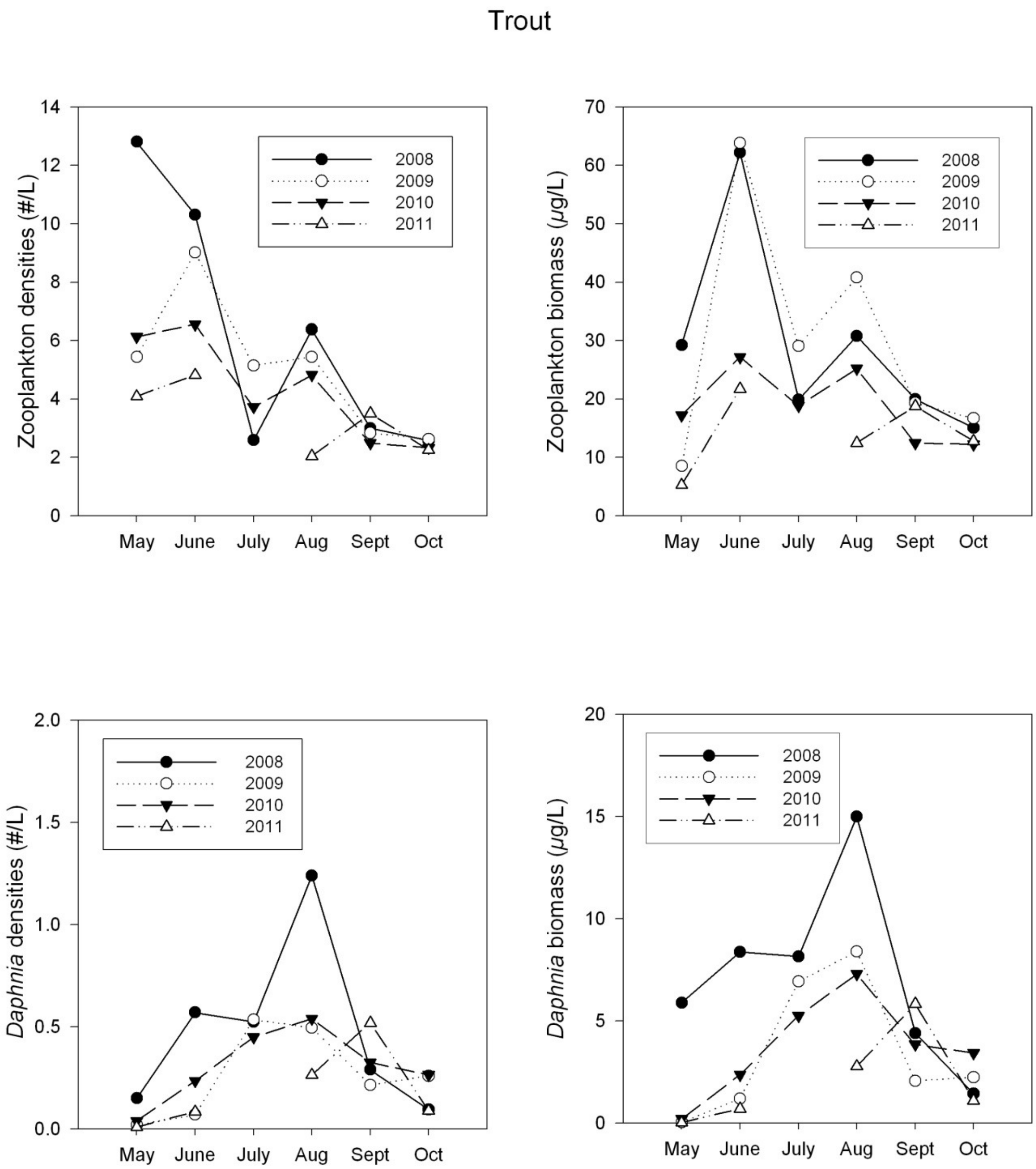

Figure 7. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Trout Lake, 2008-2011.

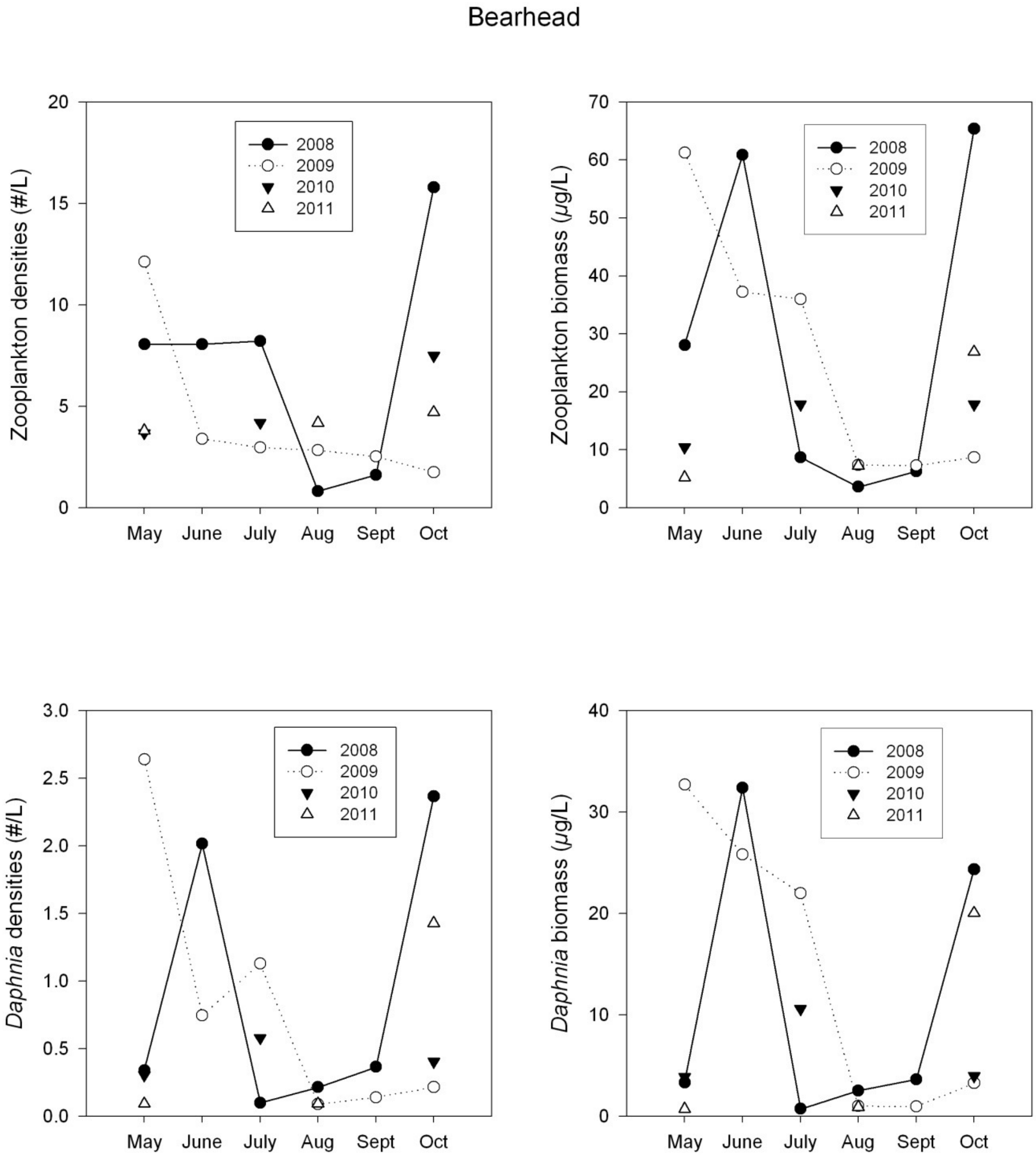

Figure 8. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Bearhead Lake, 2008-2011.

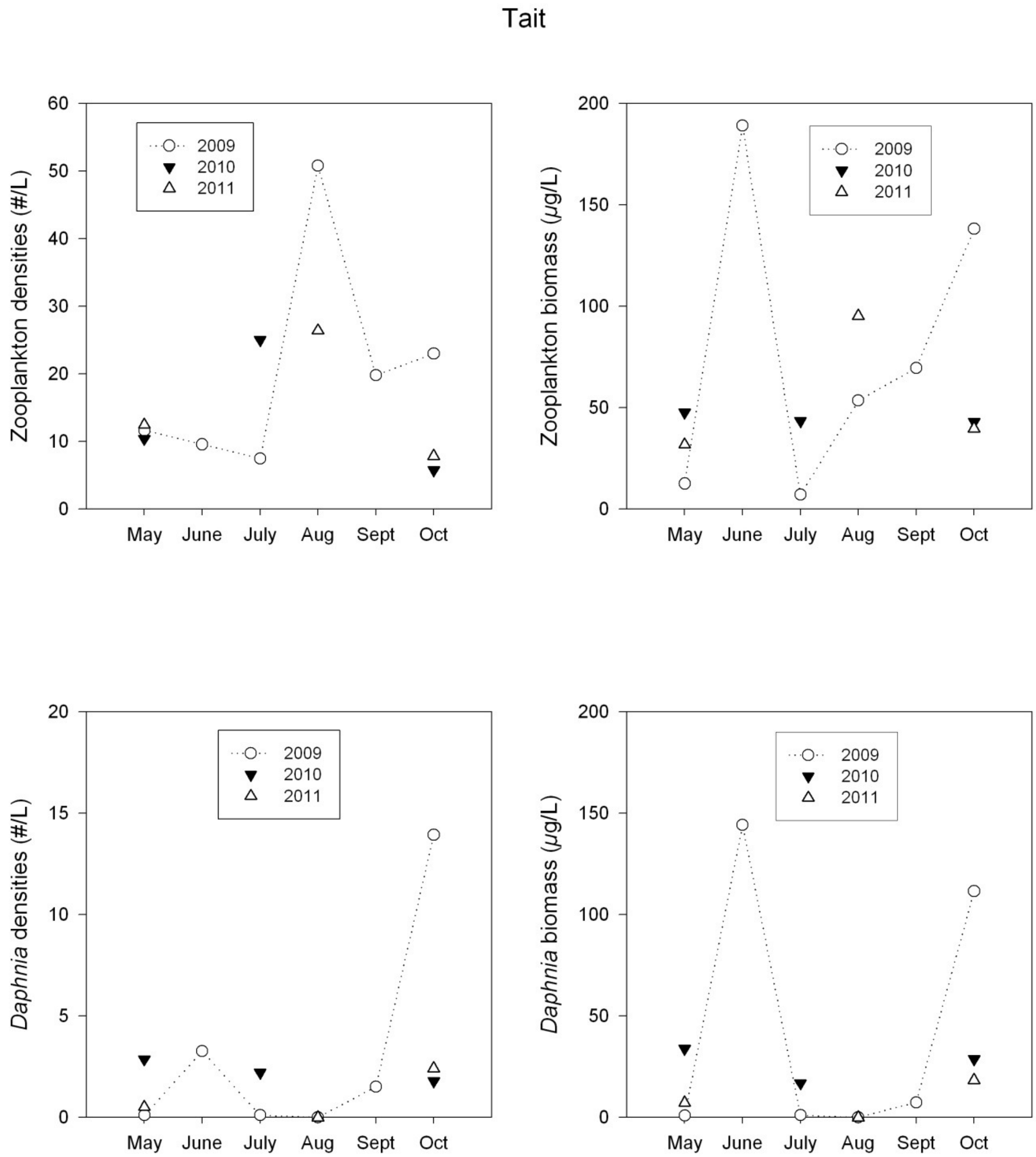

Figure 9. Monthly zooplankton densities (#/liter), zooplankton biomass (µg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (µg/liter) for Tait Lake, 2008-2011.

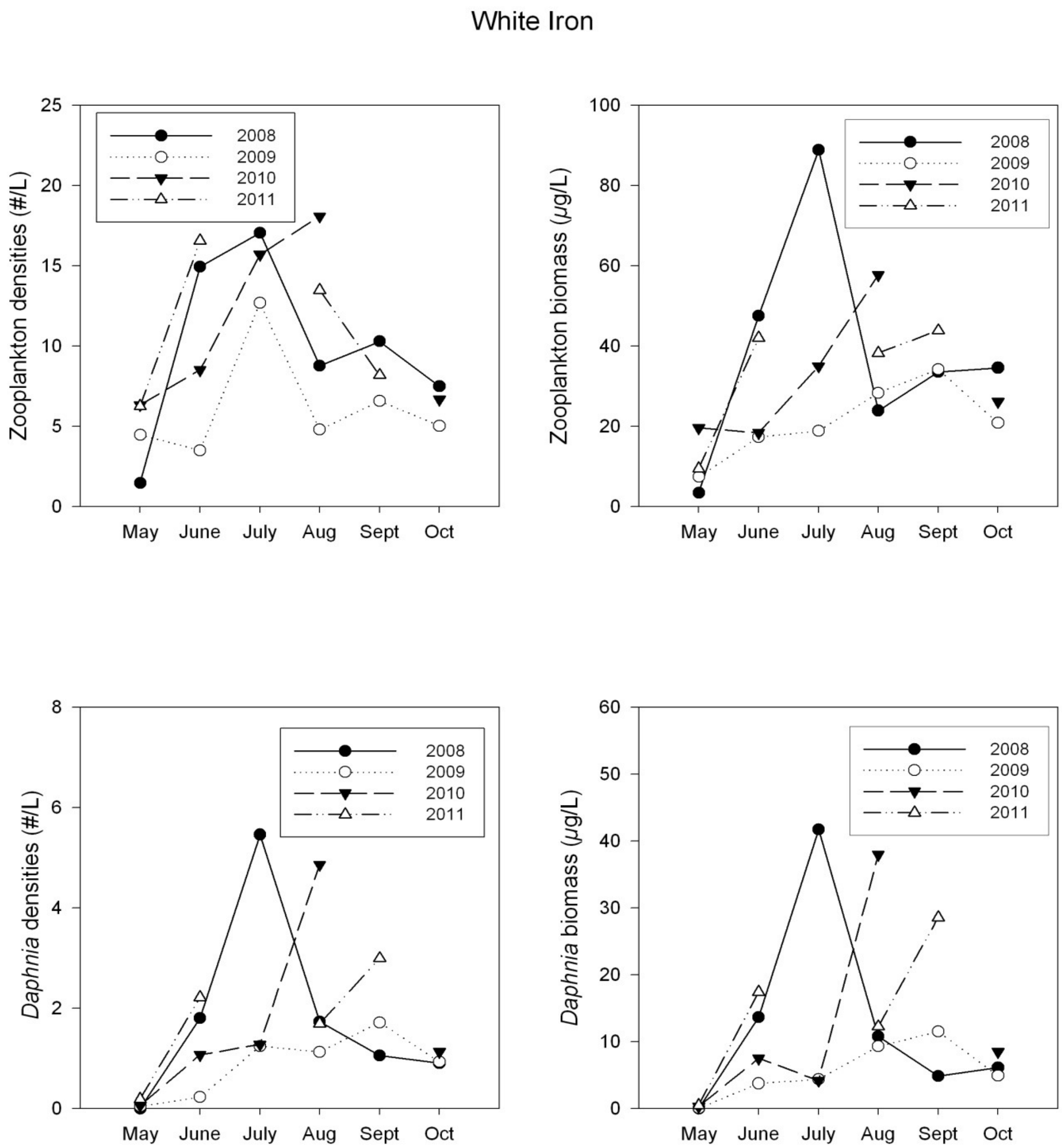

Figure 10. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for White Iron Lake, 2008-2011.

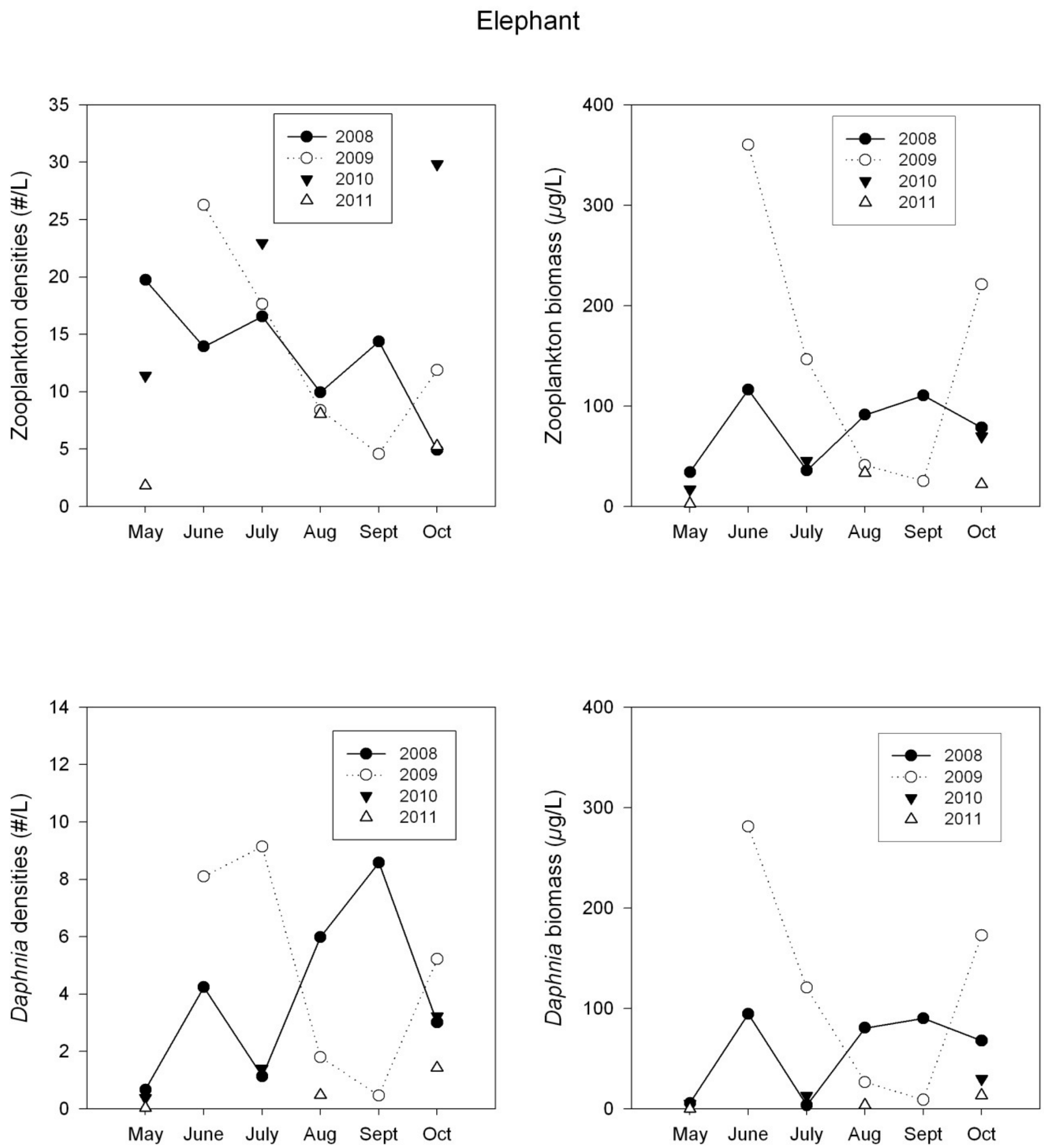

Figure 11. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Elephant Lake, 2008-2011.

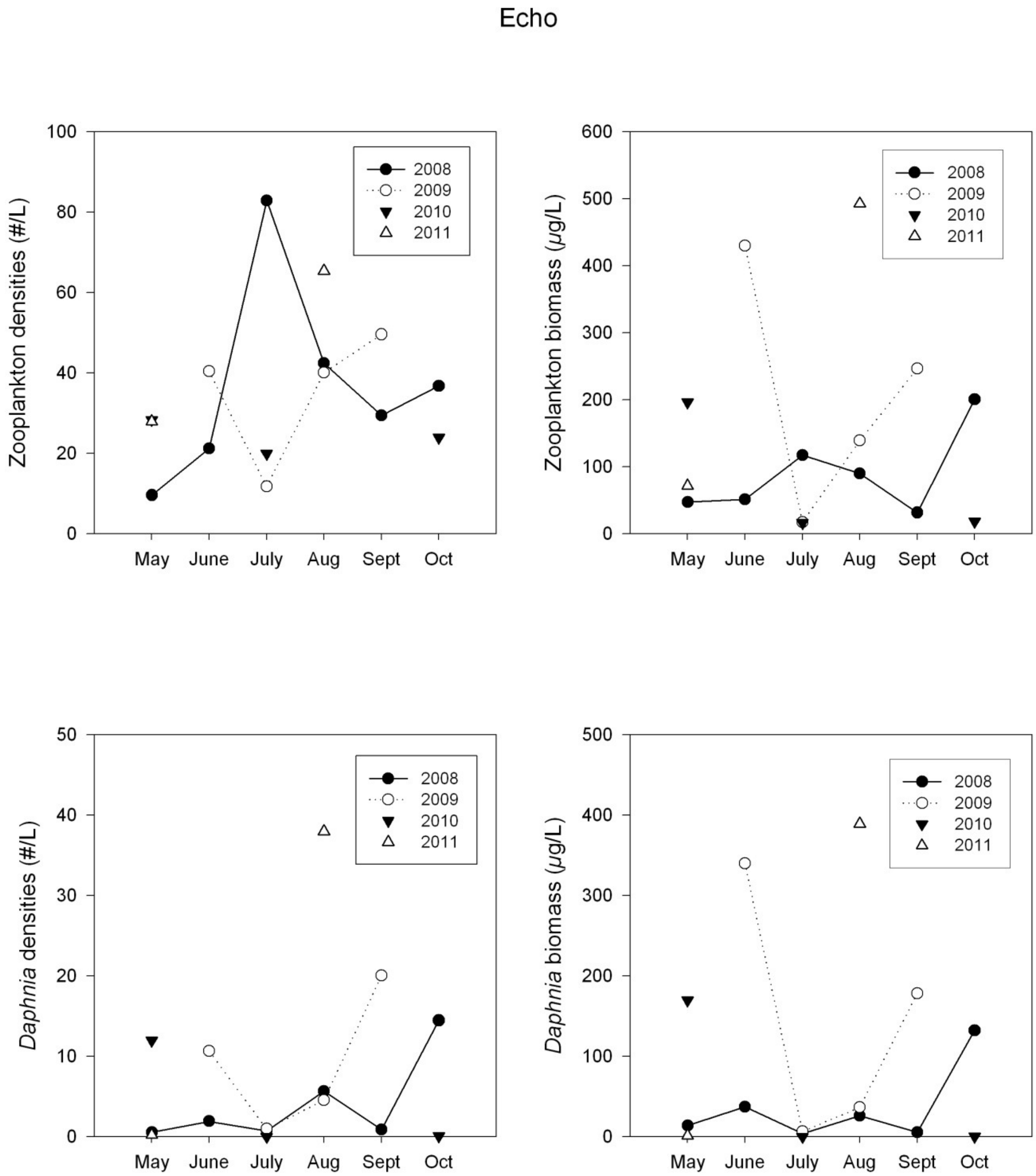

Figure 12. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Echo Lake, 2008-2011.

Ten Mile

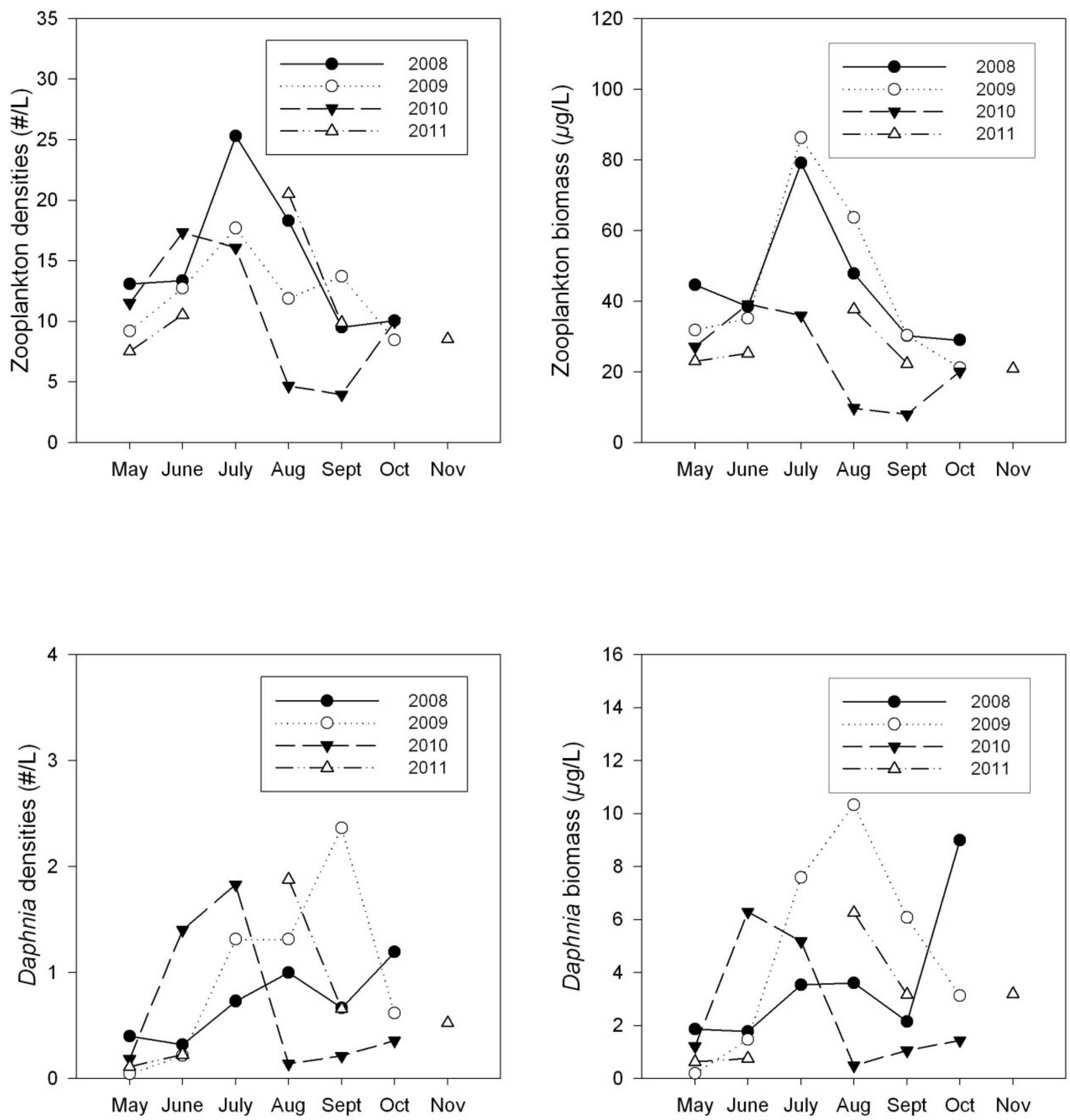

Figure 13. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Ten Mile Lake, 2008-2011.

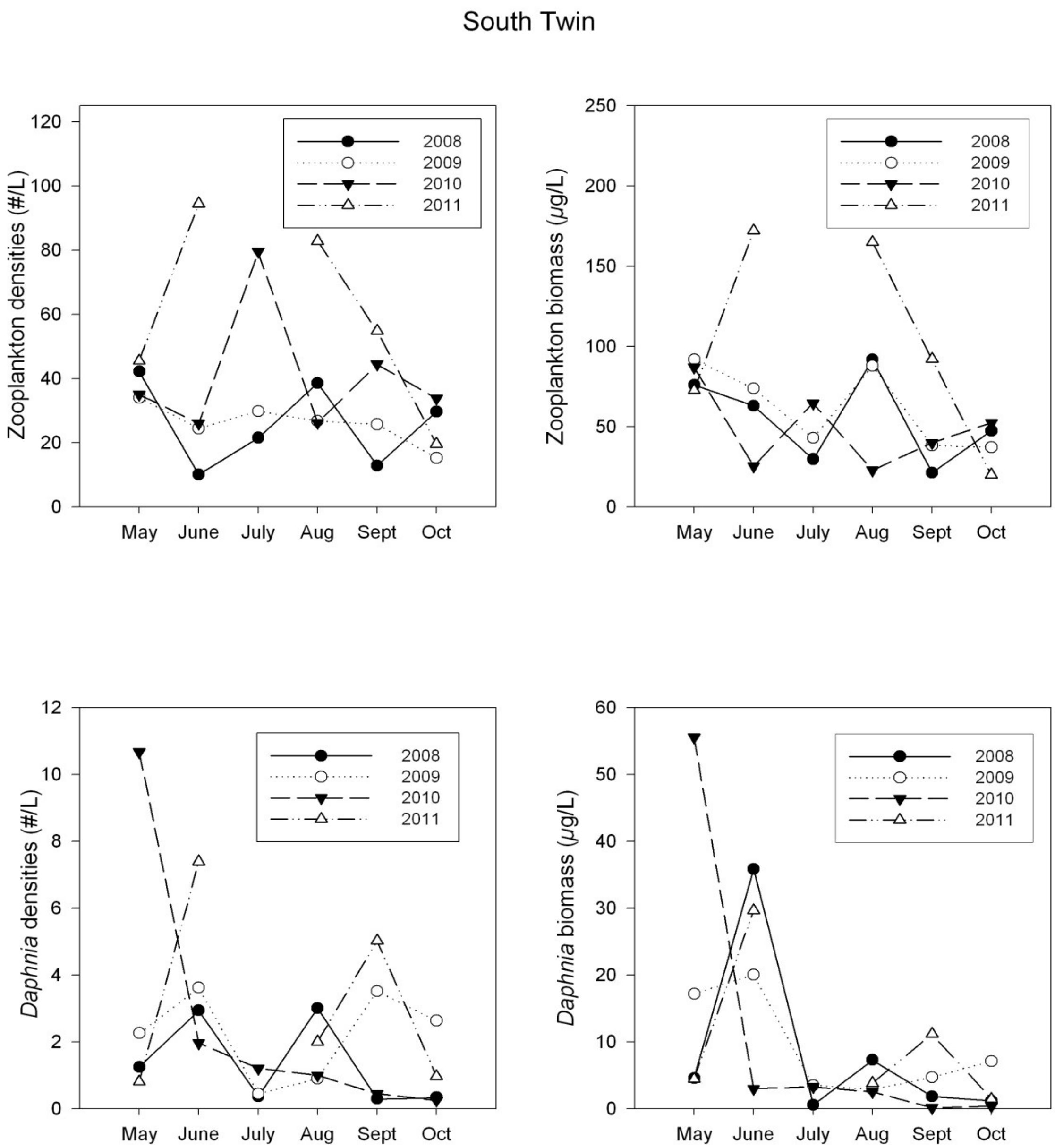

Figure 14. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for South Twin Lake, 2008-2011.

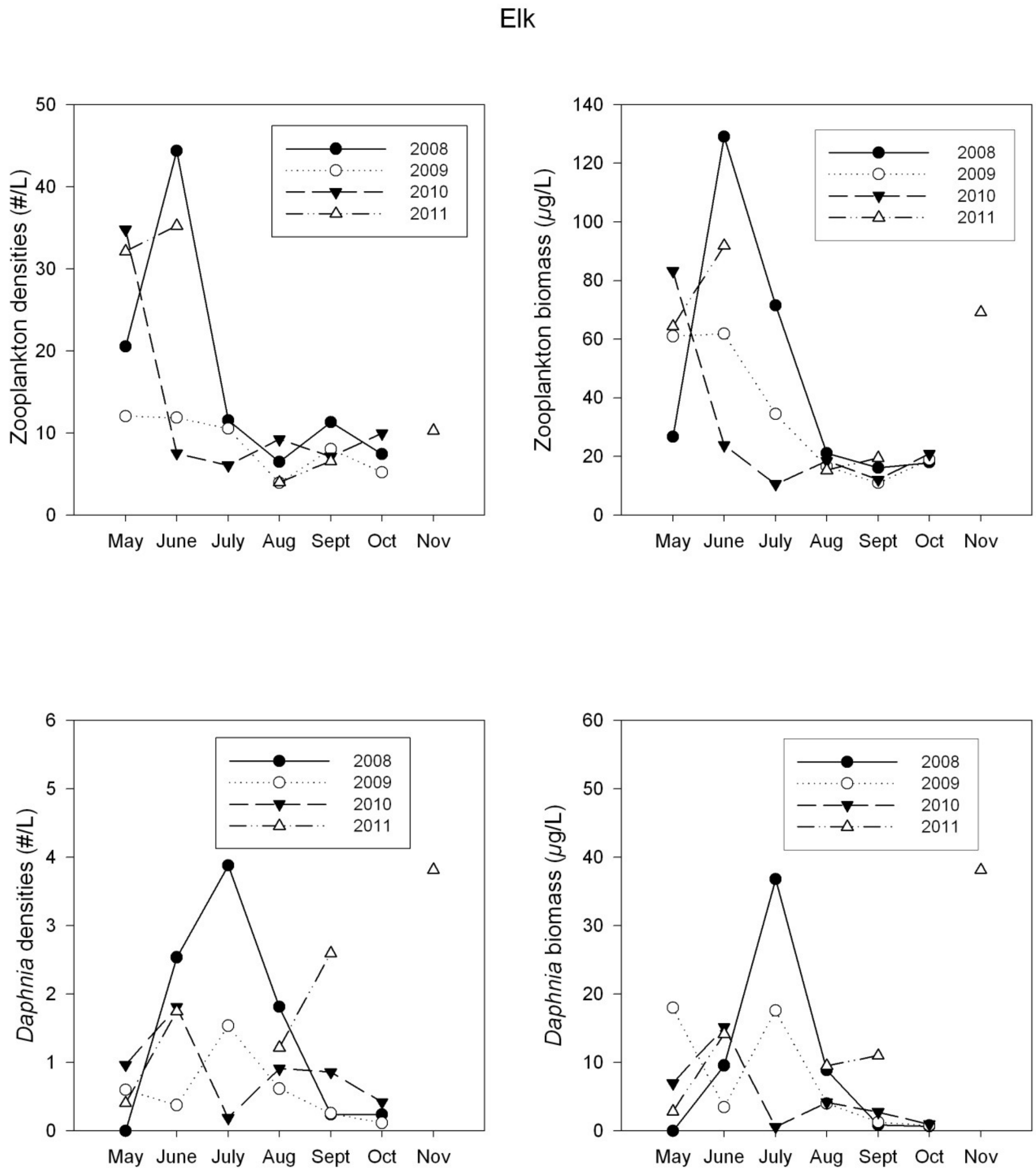

Figure 15. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Elk Lake, 2008-2011.

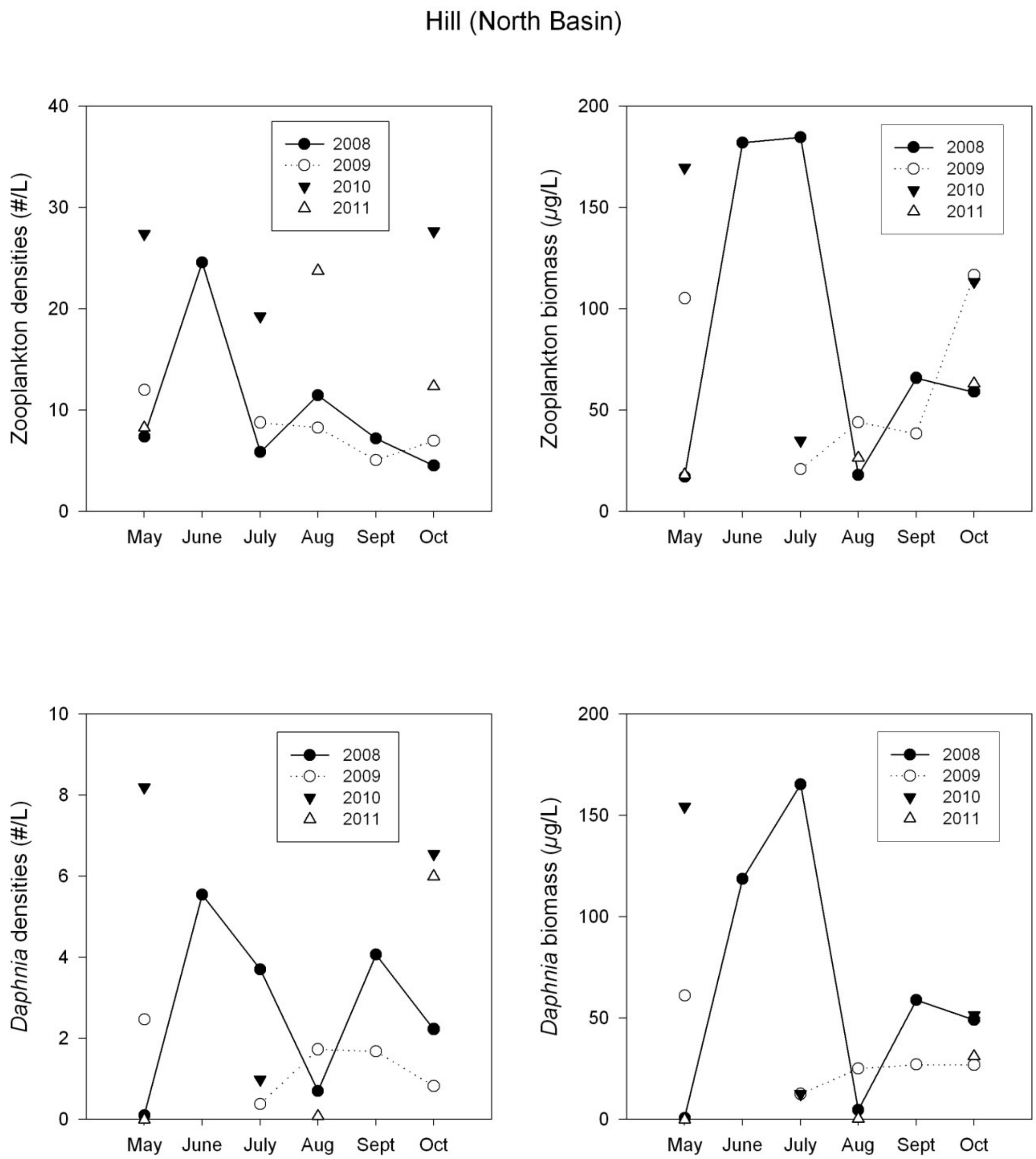

Figure 16. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Hill Lake (north basin), 2008-2011.

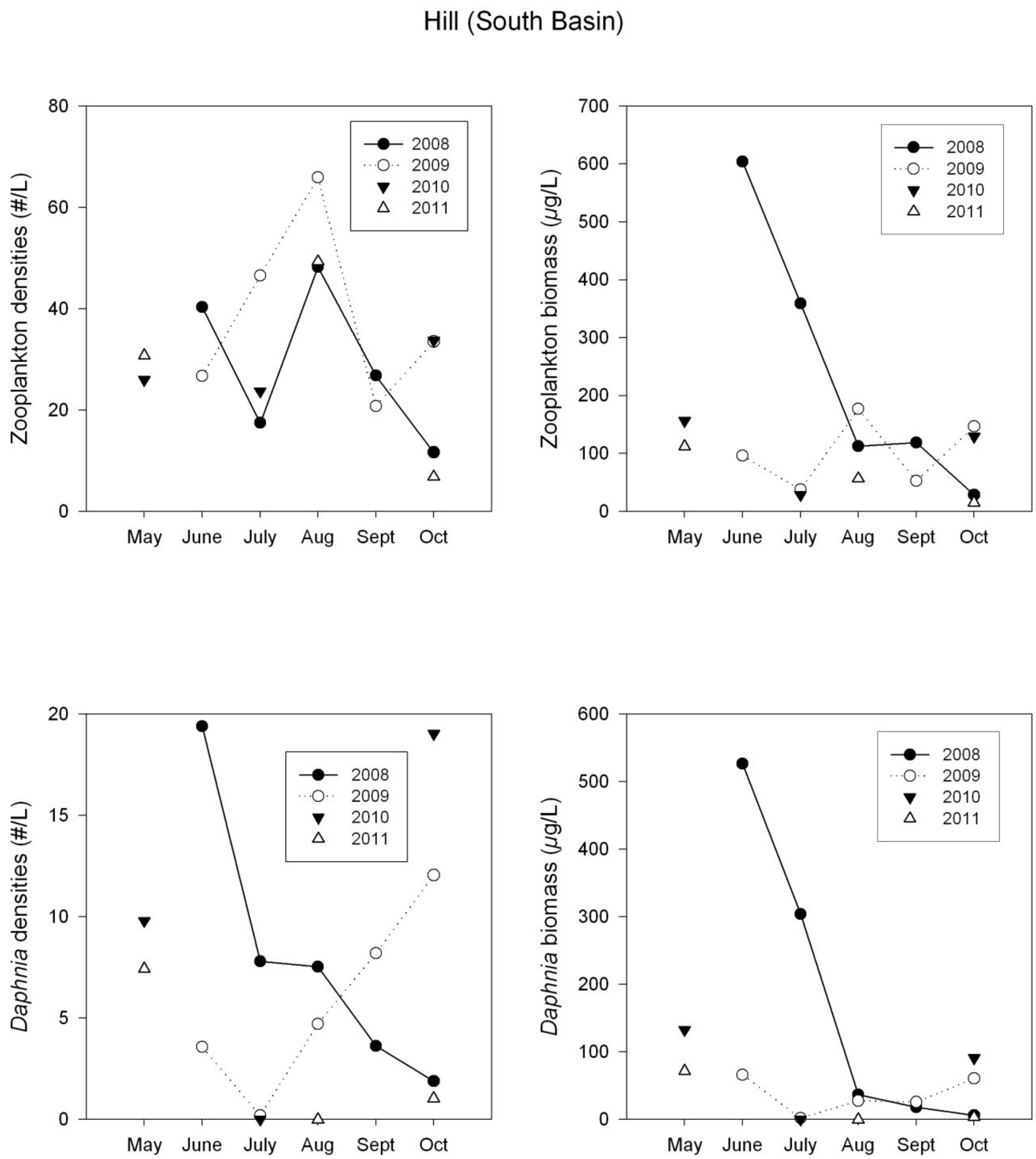

Figure 17. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Hill Lake (south basin), 2008-2011.

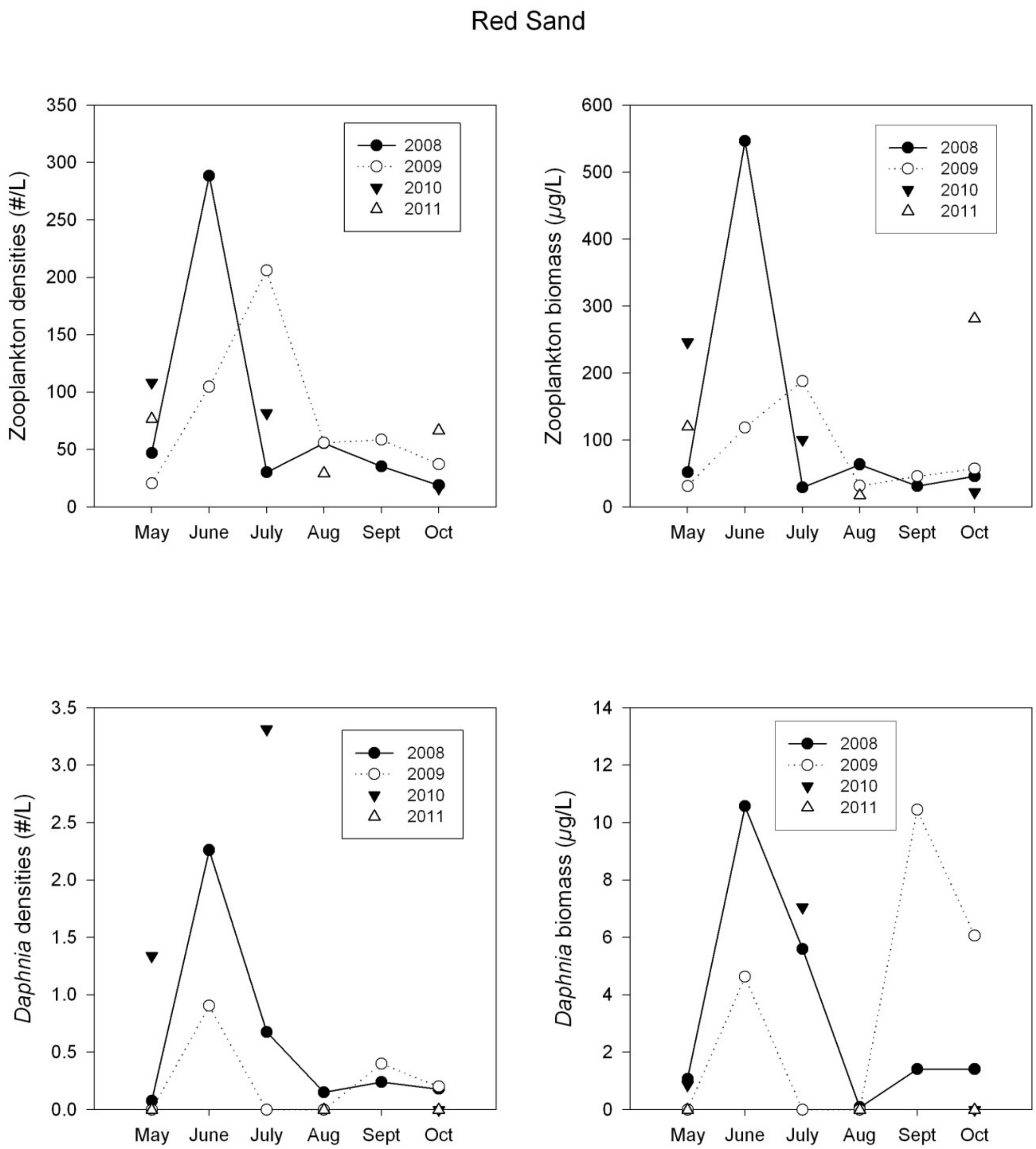

Figure 18. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Red Sand Lake, 2008-2011.

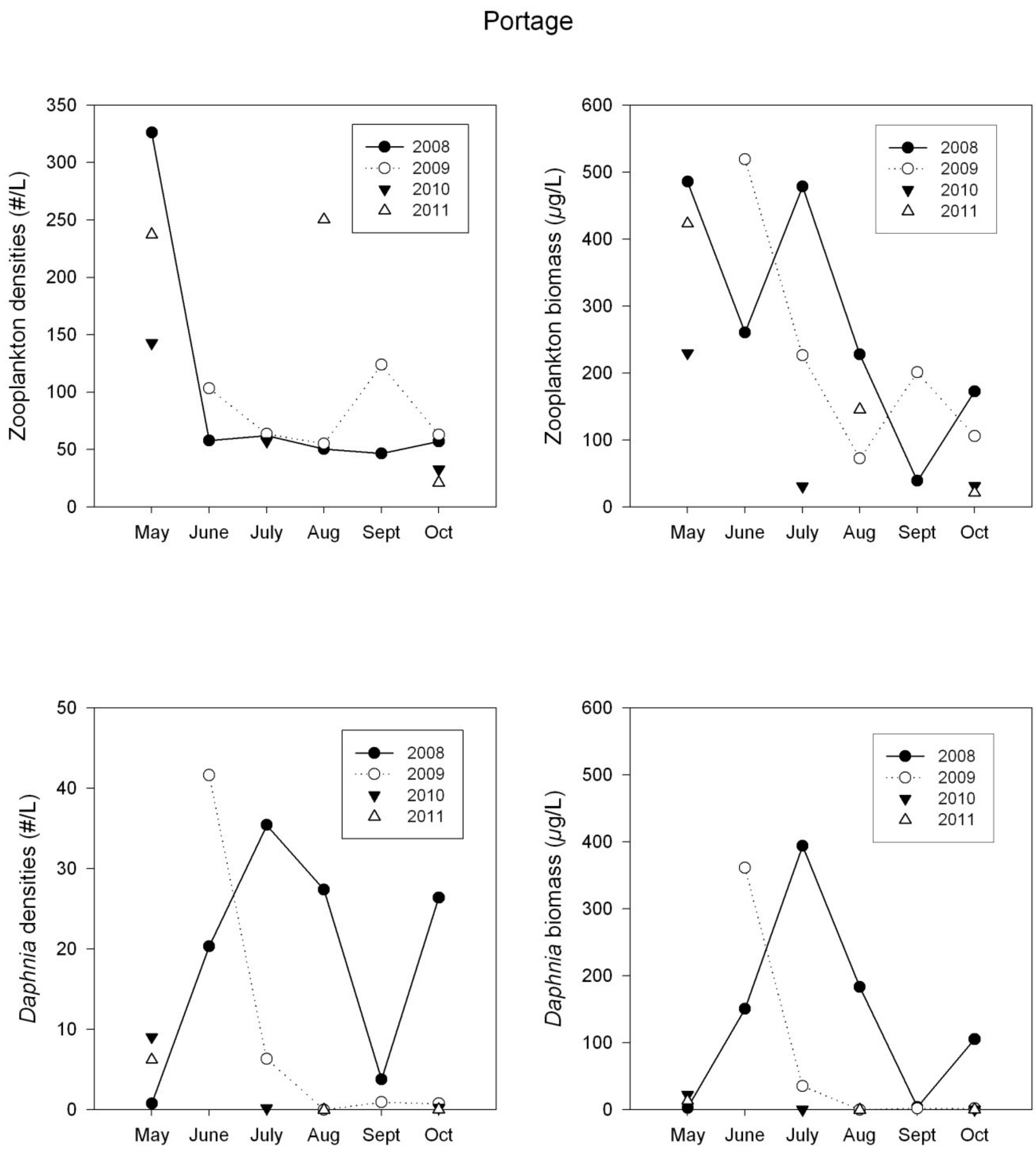

Figure 19. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Portage Lake, 2008-2011.

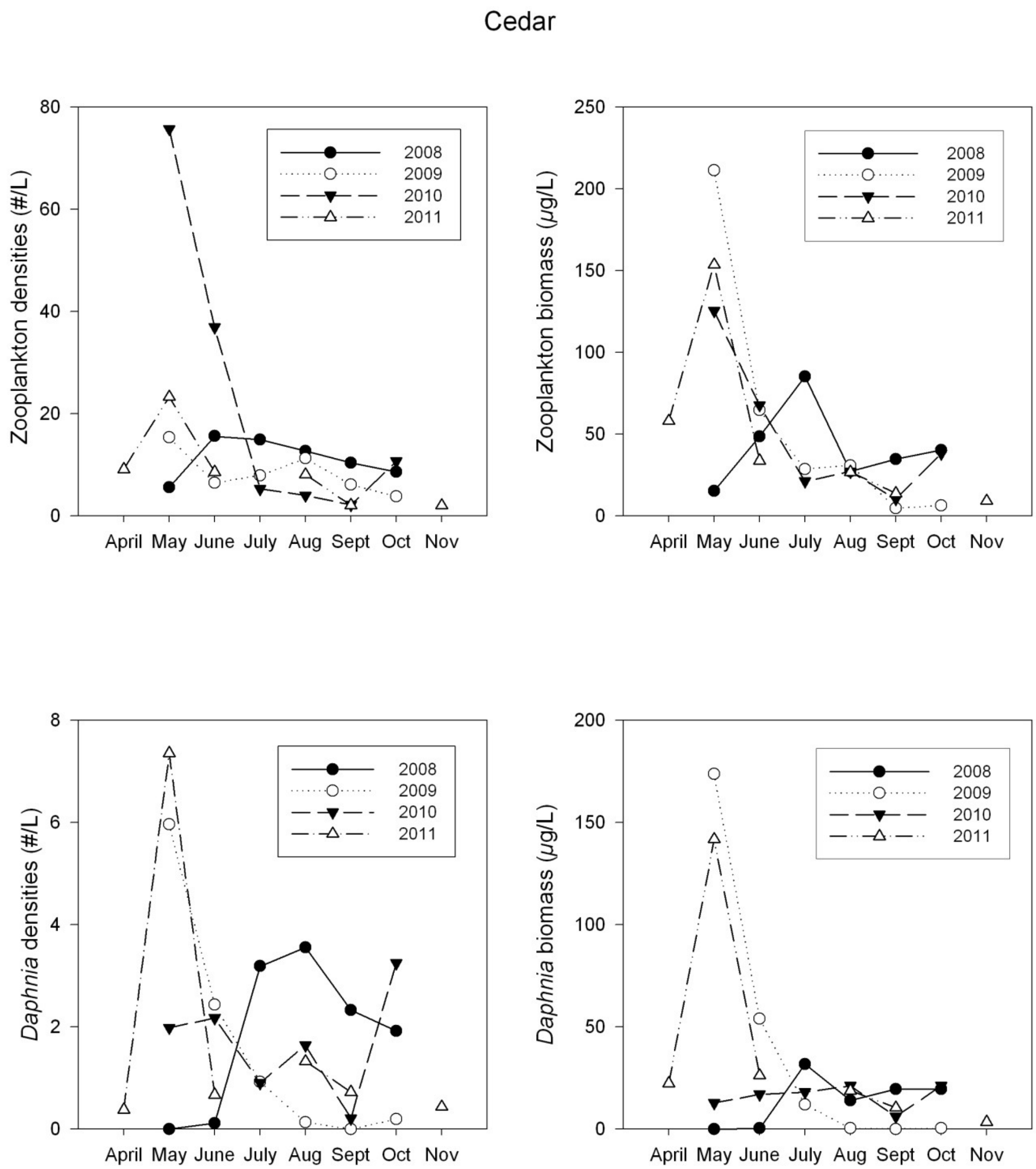

Figure 20. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Cedar Lake, 2008-2011.

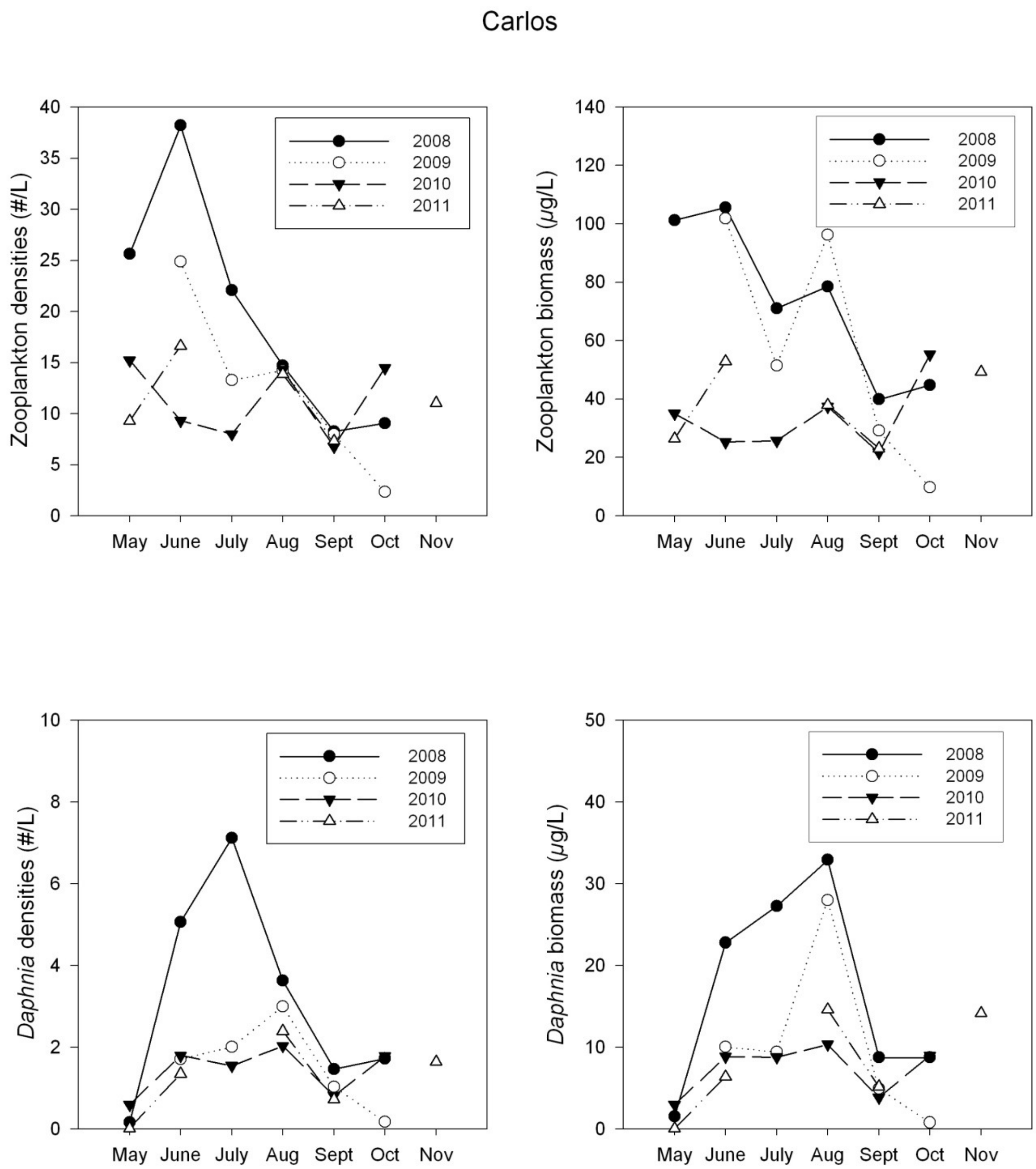

Figure 21. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Carlos Lake, 2008-2011.

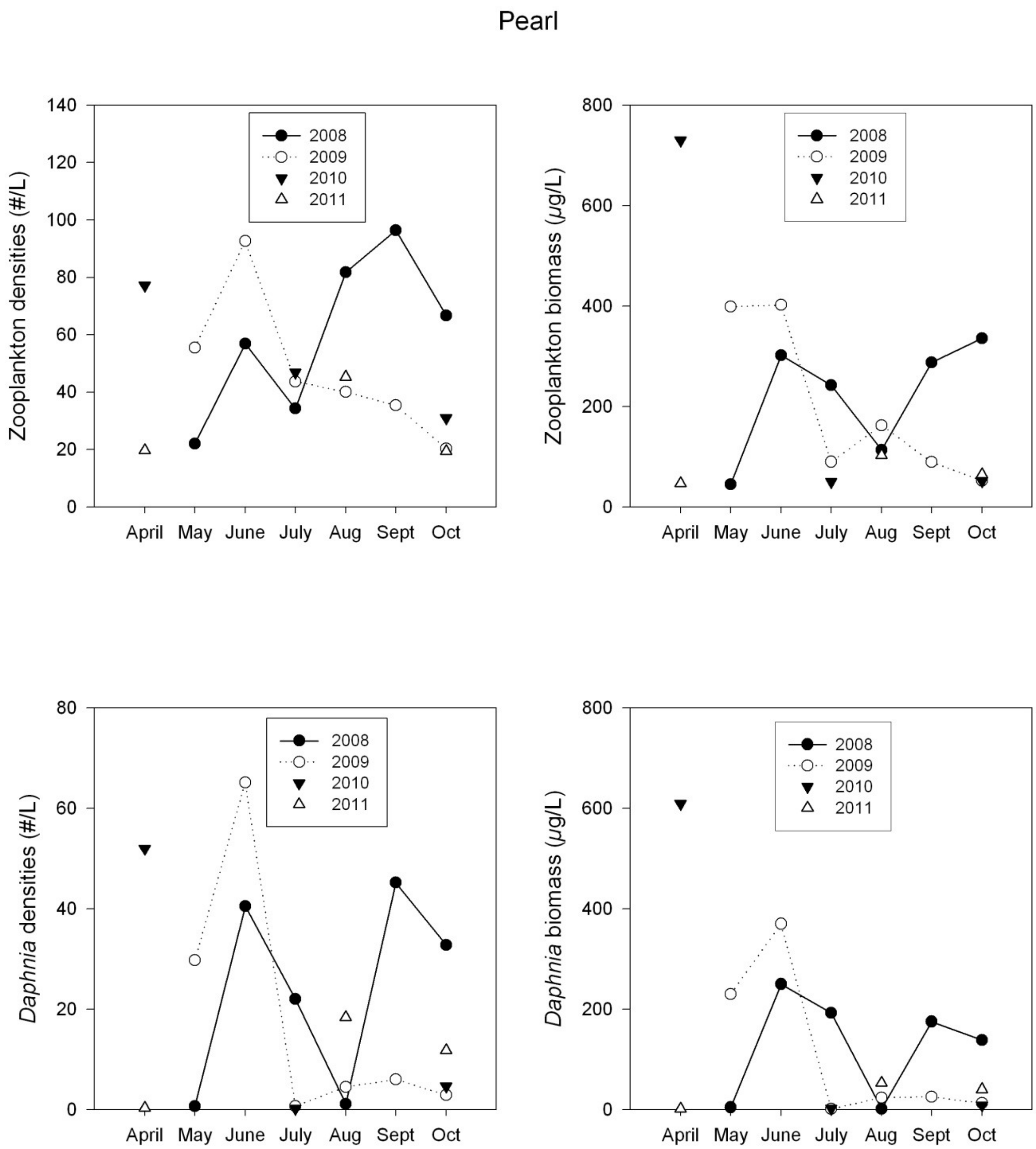

Figure 22. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Pearl Lake, 2008-2011.

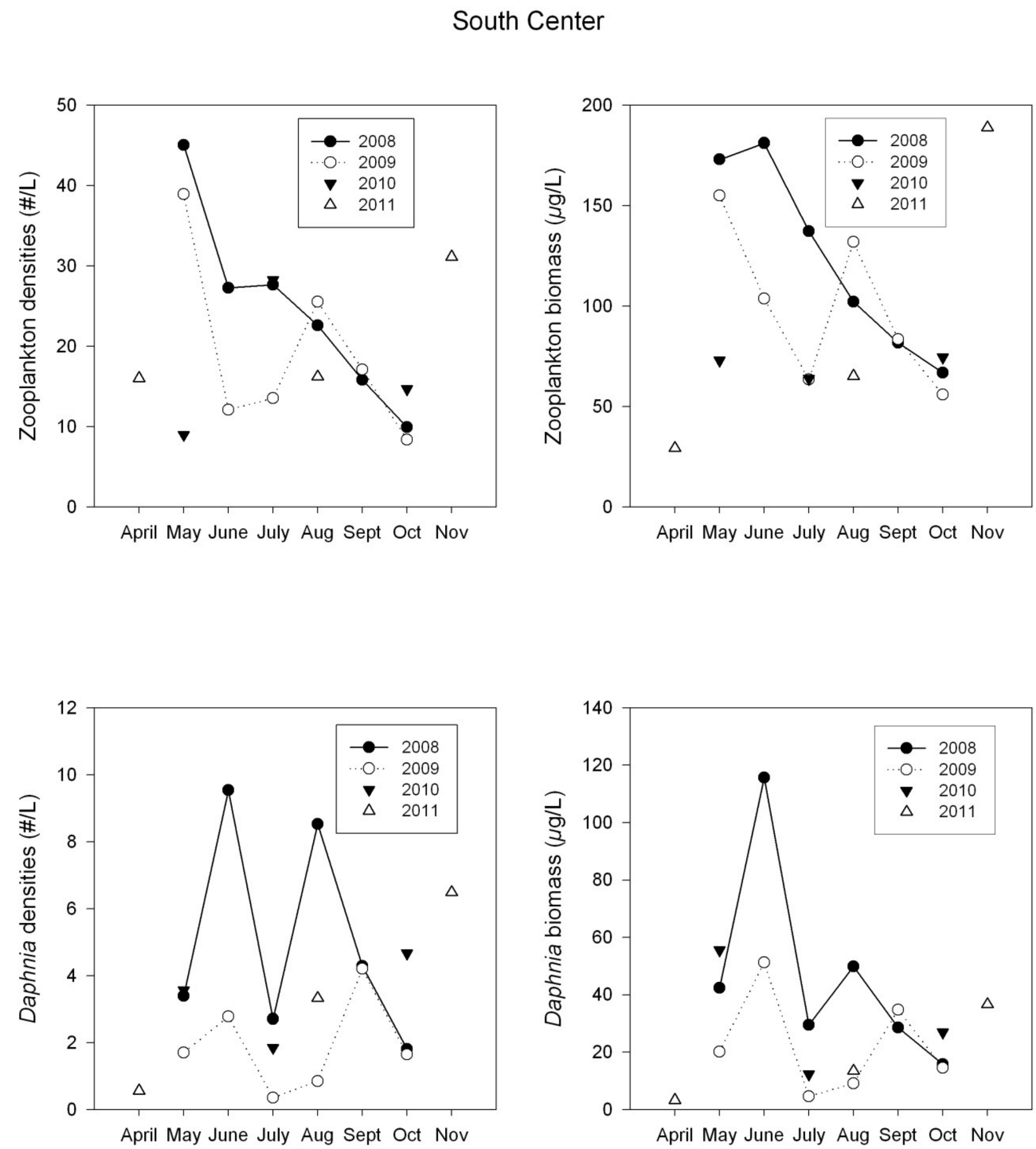

Figure 23. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for South Center Lake, 2008-2011.

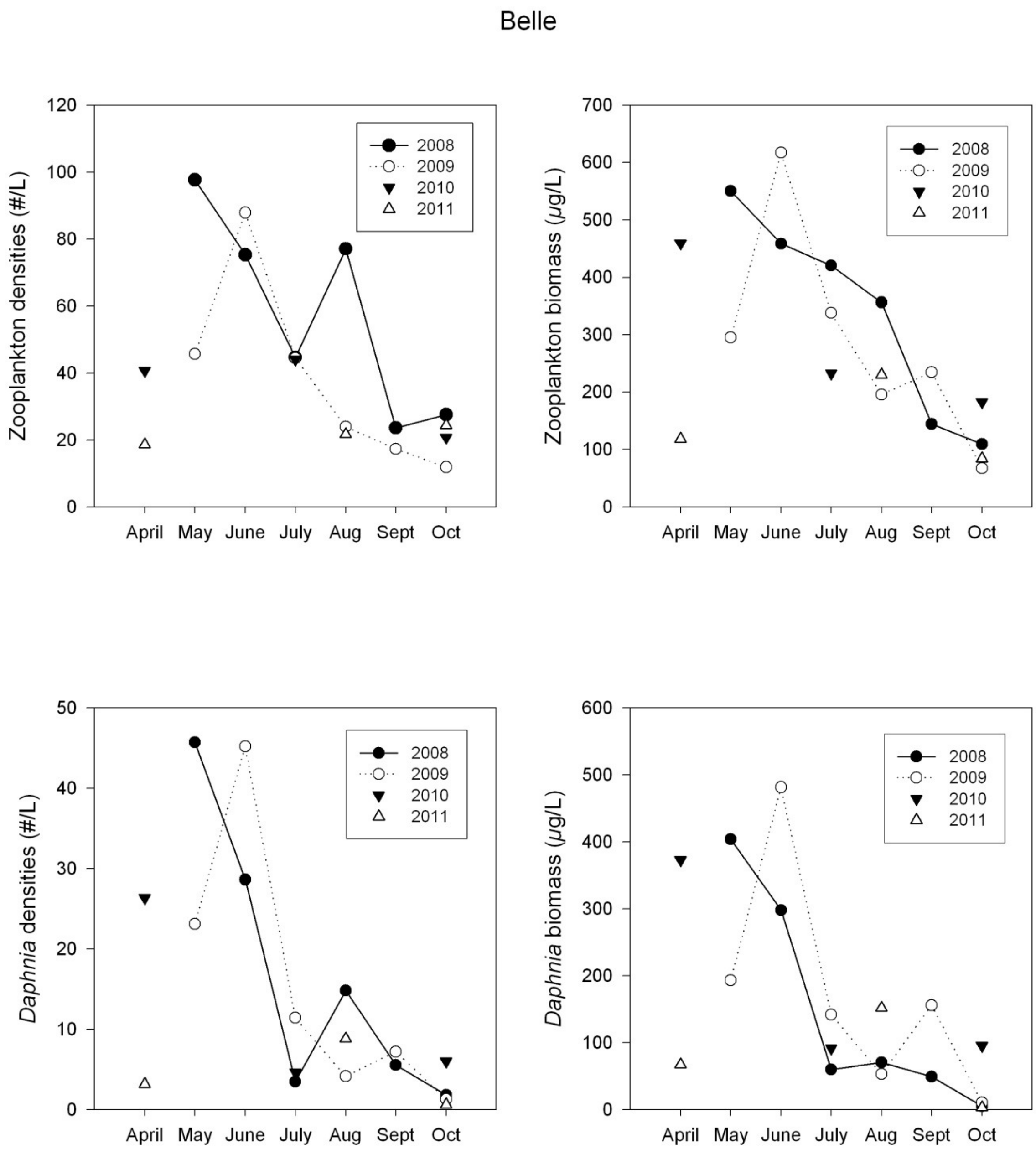

Figure 24. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Belle Lake, 2008-2011.

Peltier

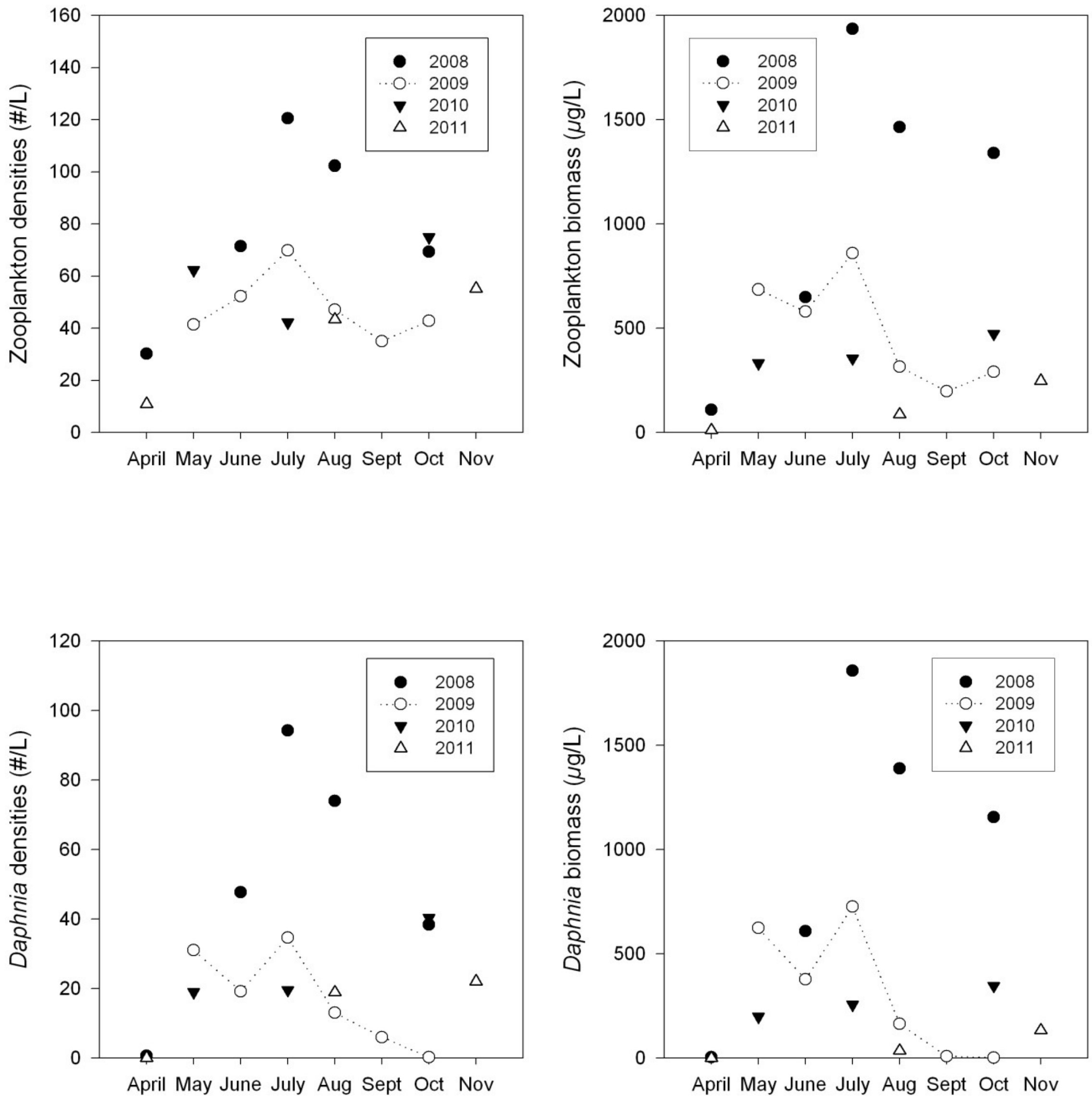

Figure 25. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Peltier Lake, 2008-2011.

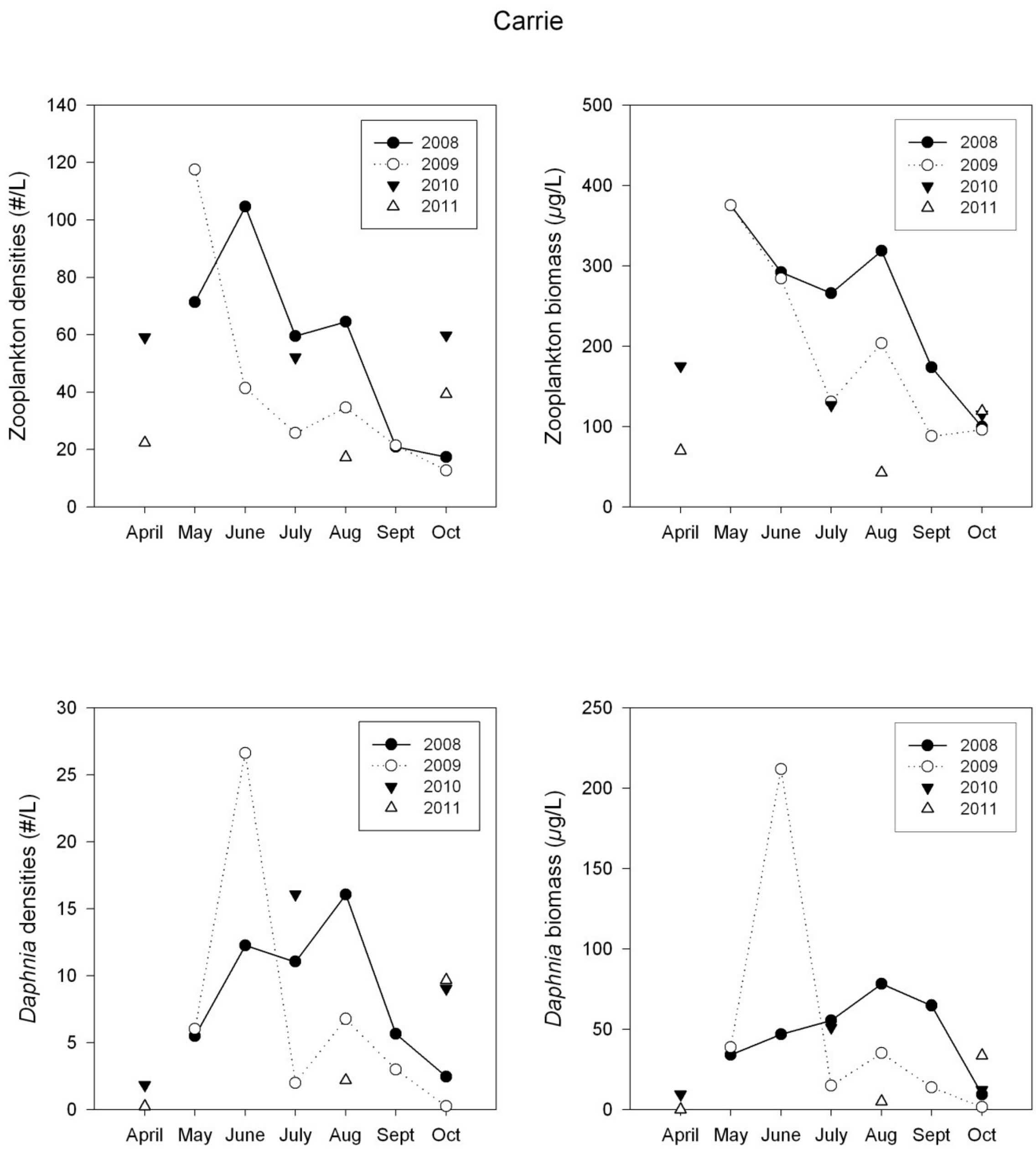

Figure 26. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Carrie Lake, 2008-2011.

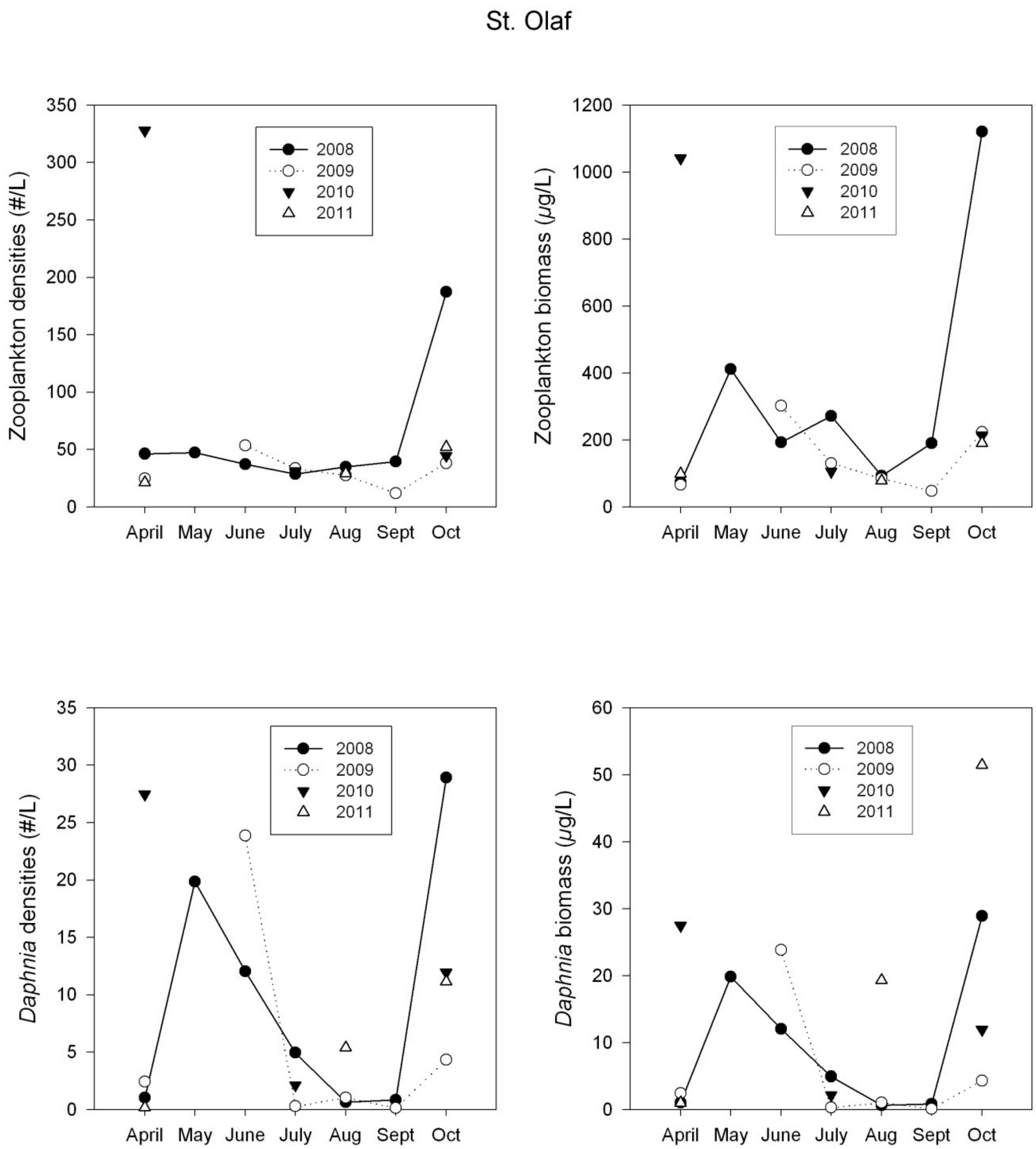

Figure 27. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for St. Olaf Lake, 2008-2011.

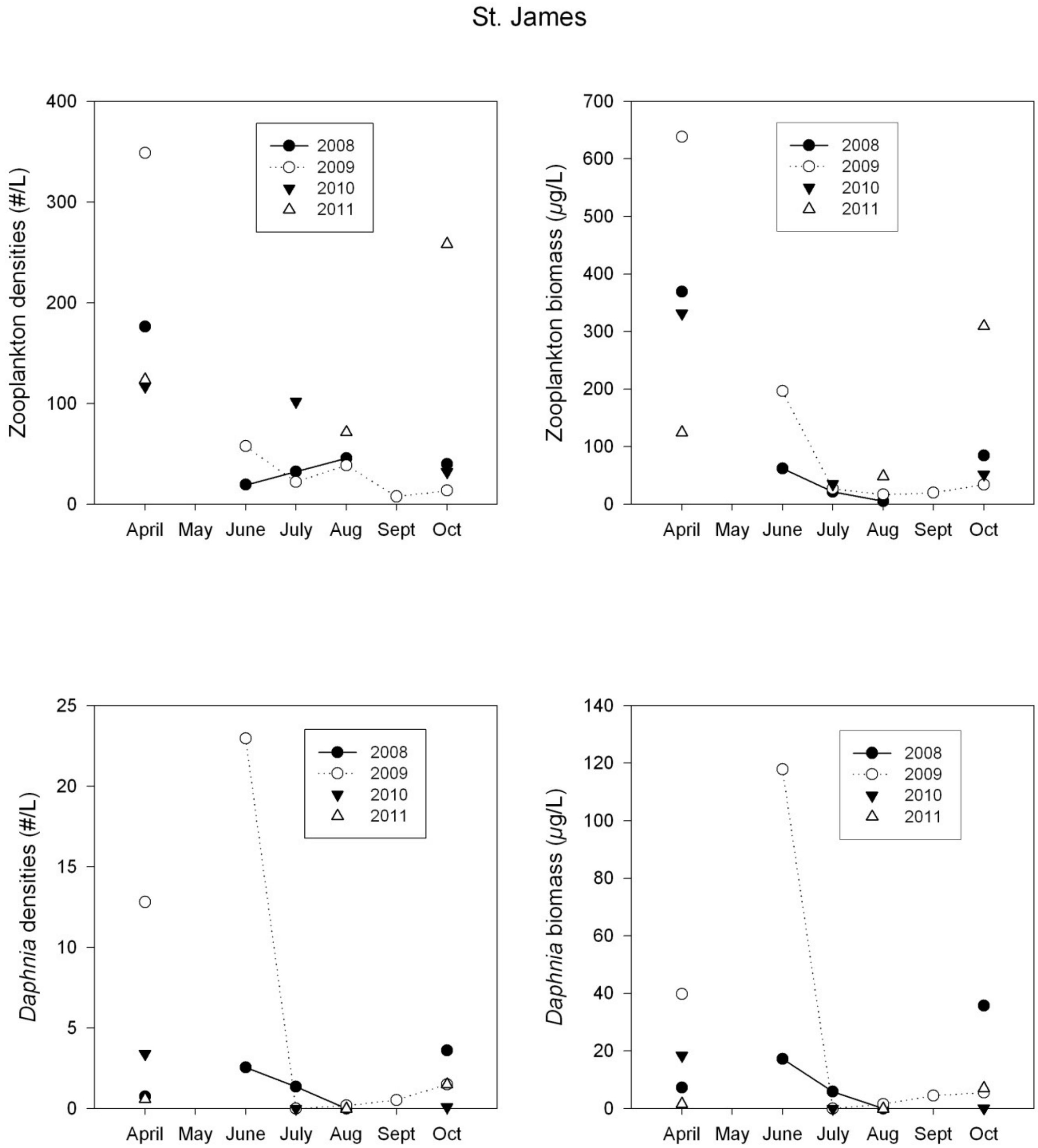

Figure 28. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for St. James Lake, 2008-2011.

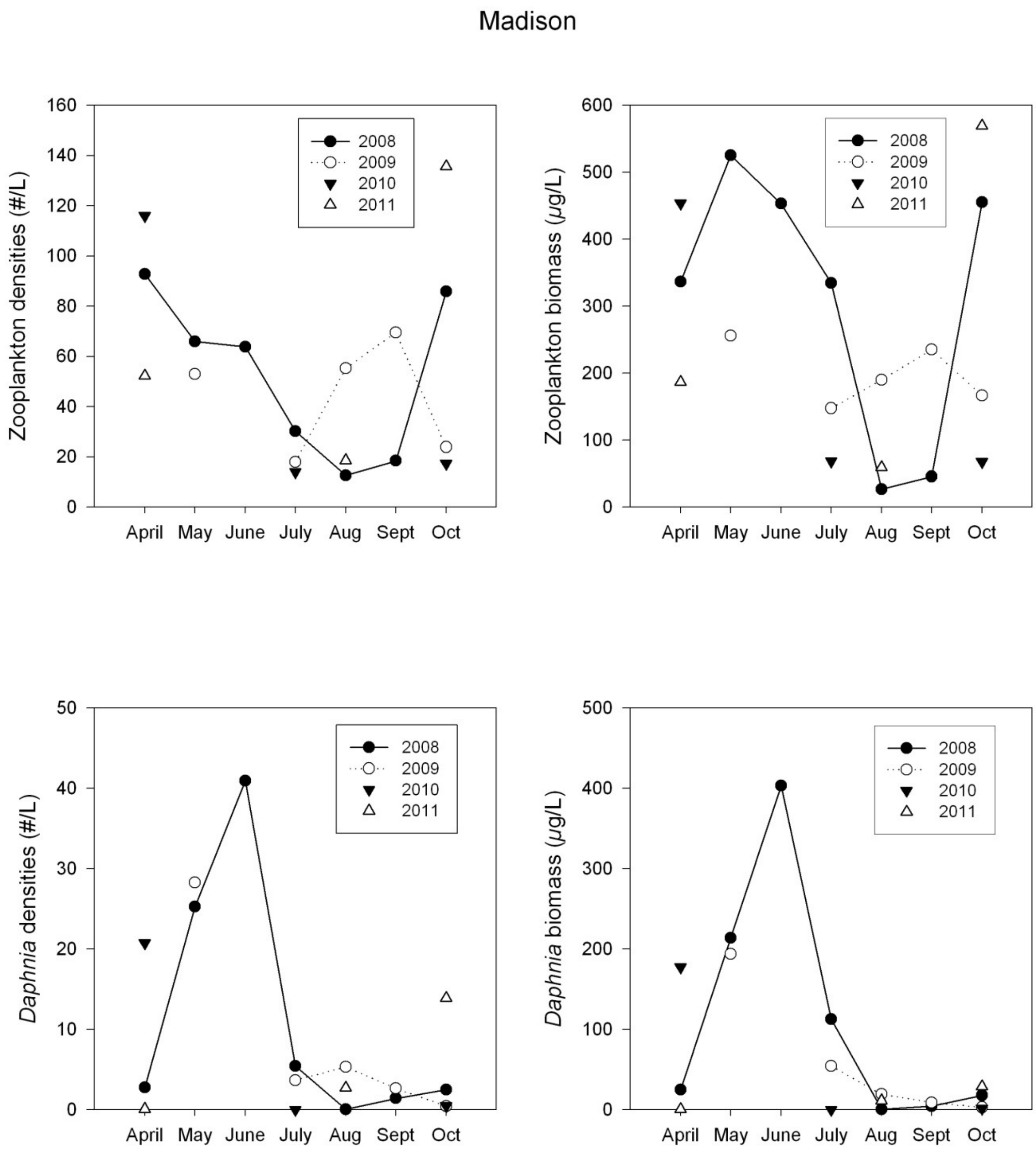

Figure 29. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Madison Lake, 2008-2011.

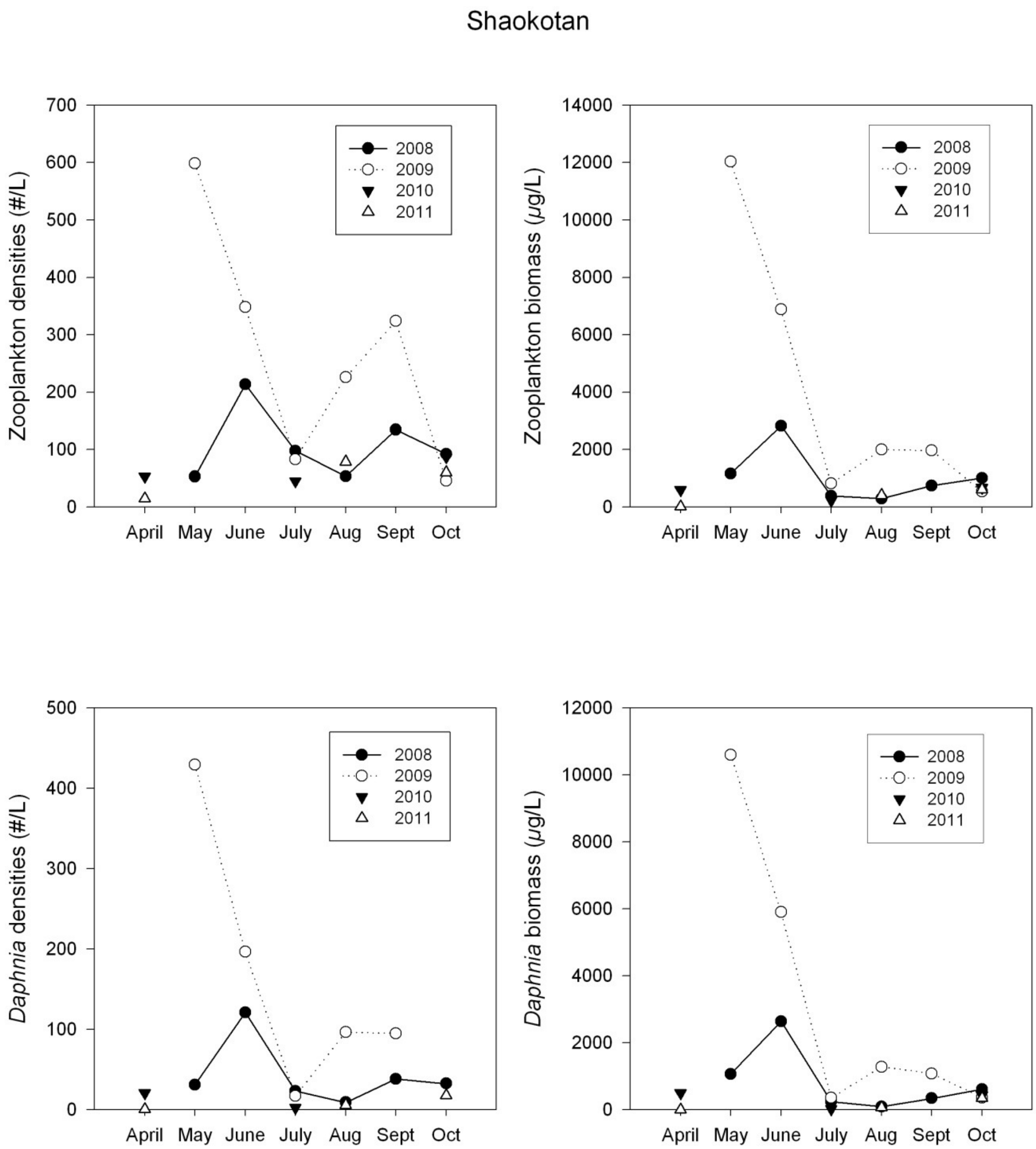

Figure 30. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Shaokotan Lake, 2008-2011.

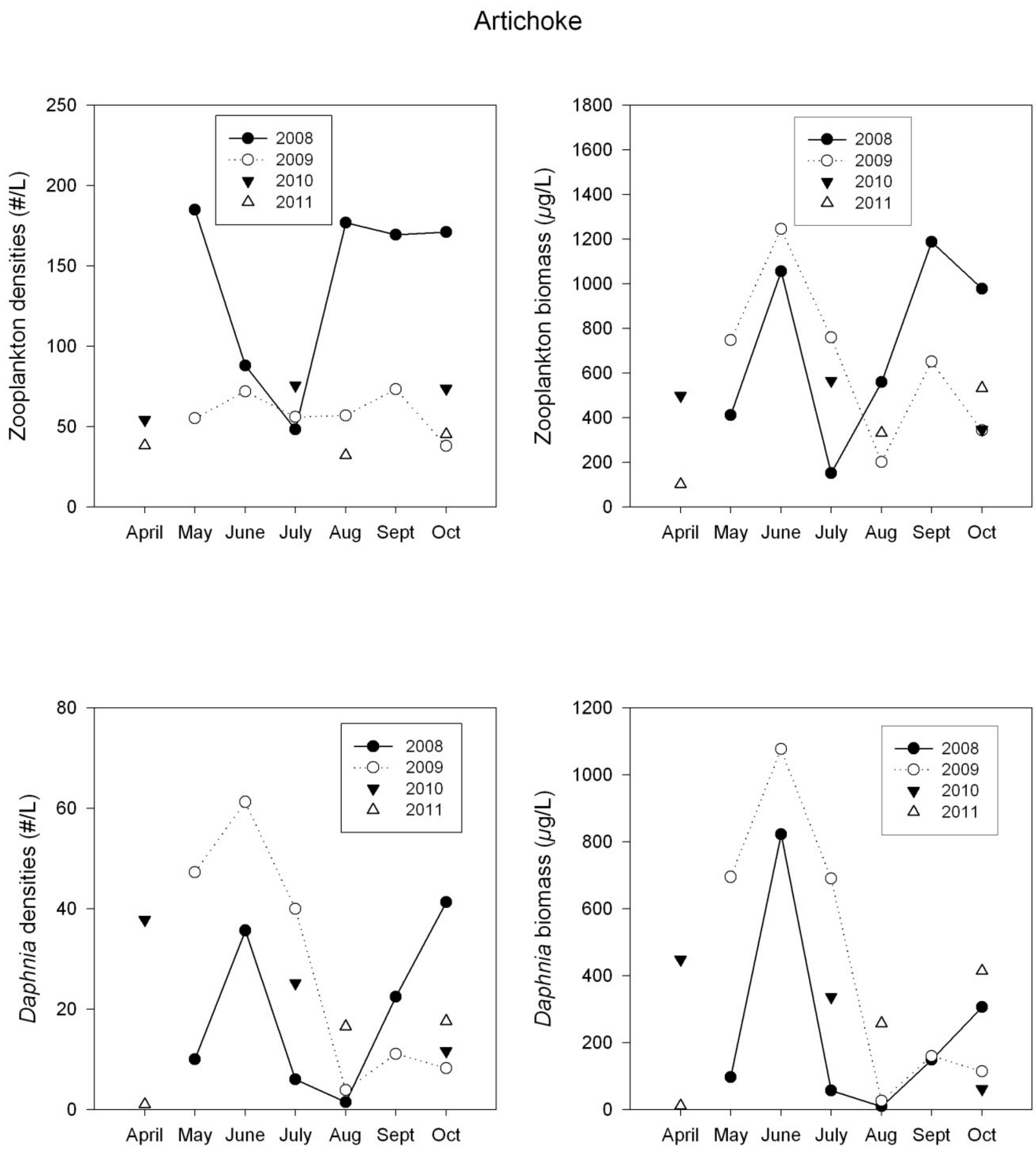

Figure 31. Monthly zooplankton densities (#/liter), zooplankton biomass (μg/liter), *Daphnia* densities (#/liter) and *Daphnia* biomass (μg/liter) for Artichoke Lake, 2008-2011.

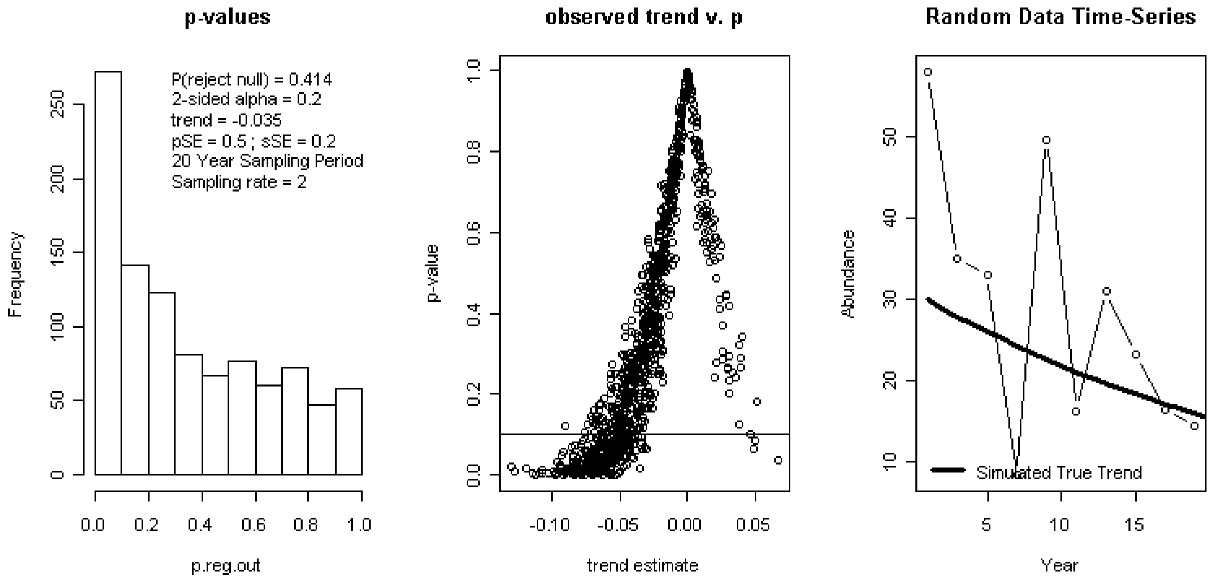

Figure 32. Power analyses results for Zooplankton Density for regression tests for trend on parametrically bootstrapped 20 year time series with annual trend = -0.035, process variability standard deviation = 0.5, sampling error standard deviation = 0.2. Plot 1: distribution of p-values and null hypothesis rejection rate = 0.414; Plot 2: test p-values versus trend estimate; Plot 3: example simulated time-series with underlying deterministic trend (solid line).

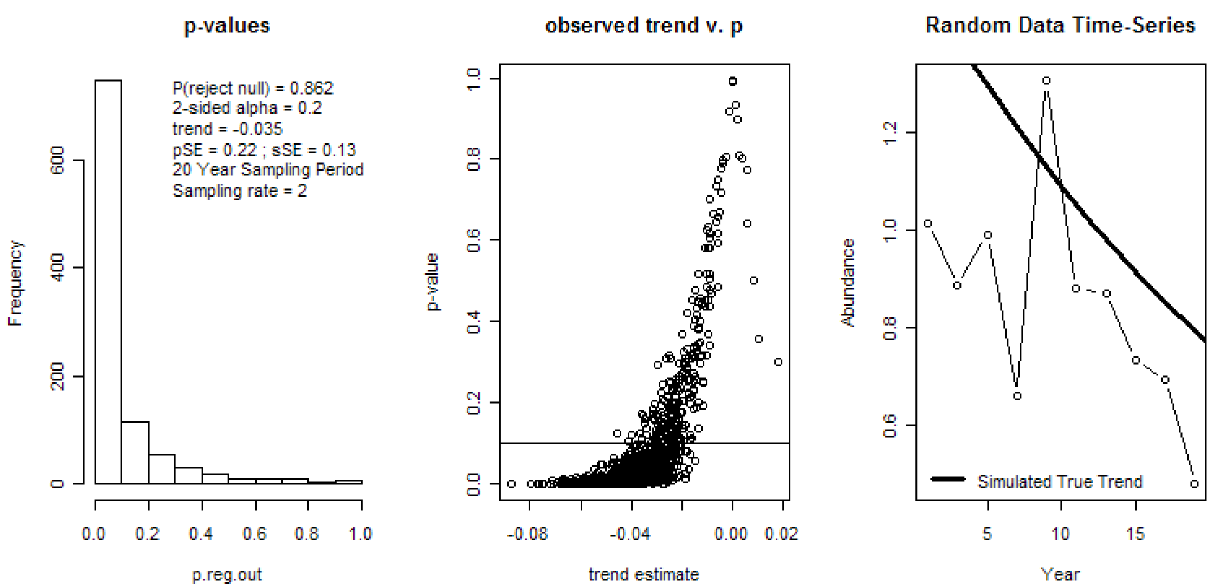

Figure 33. Power analyses results for Large *Daphnia* Density for regression tests for trend on parametrically bootstrapped 20 year time series with annual trend = -0.035, process variability standard deviation = 0.22, sampling error standard deviation = 0.13. Plot 1: distribution of p-values and null hypothesis rejection rate = 0.86; Plot 2: test p-values versus trend estimate; Plot 3: example simulated time-series with underlying deterministic trend (solid line).

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Rusack, J.A., N.D Yan, K.M. Somers, K.L. Cottingham, F. Micheli, S.R. Carpenter, T.M. Frost, M.J. Paterson, and D.J. McQueen. 2002. Temporal, spatial, and taxonomic patterns of crustacean zooplankton variability in unmanipulated north-temperate lakes. Limnology and Oceanography 47: 613-625.

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Westerlund, J.E., P.C. Jacobson, H.K. Van Offelen, and J.K. Hirsch. 1998. Use of Limnetic Zooplankton Sampling in Assessments of Fish Community Structure in Minnesota Bass-panfish Lakes. Minnesota Department of Natural Resources-Section of Fisheries Investigational Report No. 467.

Summary for development of the ZOOPS database – amendment request for Result 4, Deliverable 2.

An internal service level agreement with the State's Office of Enterprise Technology was developed and implemented. Both the ZOOPS database and the migration of data were completed as scheduled. The ZOOPS database will eventually be integrated with the data visualization tool, enabling easy access to the database by those wishing to use the data for research purposes.

Summary for Deliverable 3*: Evaluation of hydroacoustics to assess the status of cisco populations in inland lakes,* and Deliverable 4*: Evaluation of cisco habitat use and behavior.*

Deliverables 3 and 4 focus on better understanding the biology and status of cisco, *Coregonus artedi*, a relatively common and important cold-water indicator species. Despite the importance of cisco in Minnesota lakes, very little is known about their density and their habitat use. In the 7 sentinel lakes thought to contain cisco, only 4 contained robust populations. Using hydroacoustics in 2010 and 2011, cisco densities were variable between lakes from 466±72 #•m^{-3} in White Iron Lake to 3,270±379 #•m^{-3} in Ten Mile Lake. The behavior of cisco was also variable between lakes, with populations performing normal diel vertical migrations, reverse diel vertical migrations, or no migrations at all. Interestingly, cisco populations with a smaller body size migrated to areas of highest foraging potential, despite being in areas sometimes above their thermal preference or in areas of highest predation risk. Cisco populations with a larger body size generally were found in areas near their thermal preference, which put them in areas with less than optimal foraging but lower predation risk. Overall, the results of this study are the first to document the density and behavior of cisco in Minnesota lakes, which is valuable information given the landscape changes (e.g. global climate change) which are likely to occur.

Ahrenstorff, T.D., Hrabik, T.R., Jacobson, P.C., and Pereira, D.L. 2013. Food resource effects on diel movements and body size of cisco in north-temperate lakes. Oecologia 173: 1309-1320.

Additional Budget for Project Coordinator **Trust Fund Budget: $14,820**
Amount Spent: $14,161.69
Balance: $ 658.31

Major coordination activities as of: 15 April 2010
Project coordination during the last year involved an assortment of administrative, logistical, and analytical tasks in order to ensure the proper data was being collected and analyzed by various cooperators, and that progress towards project objectives was being made.

Project communication mechanisms currently include periodic newsletters sent to all SLICE partners and volunteers, a file transfer protocol (ftp) site for file sharing, a password protected online forum for posting discussion topics, files, and collaborative writing, and a SLICE website. A website was launched in September 2009 http://www.dnr.state.mn.us/fisheries/slice/index.html. Finally, I gave a presentation at the annual MN Chapter of the American Fisheries Society Meeting in Nisswa, MN in March 2010.

Information flow and decision making is currently managed through a revised organizational structure that more closely resembles an adaptive management and structured decision making framework (Figure 1). On multiple occasions in 2009, I met with the oversight team to better define team roles and responsibilities. These are described in the appendix of the SLICE Operational Research and Management Plan (http://files.dnr.state.mn.us/fish_wildlife/fisheries/slice/rm.pdf).

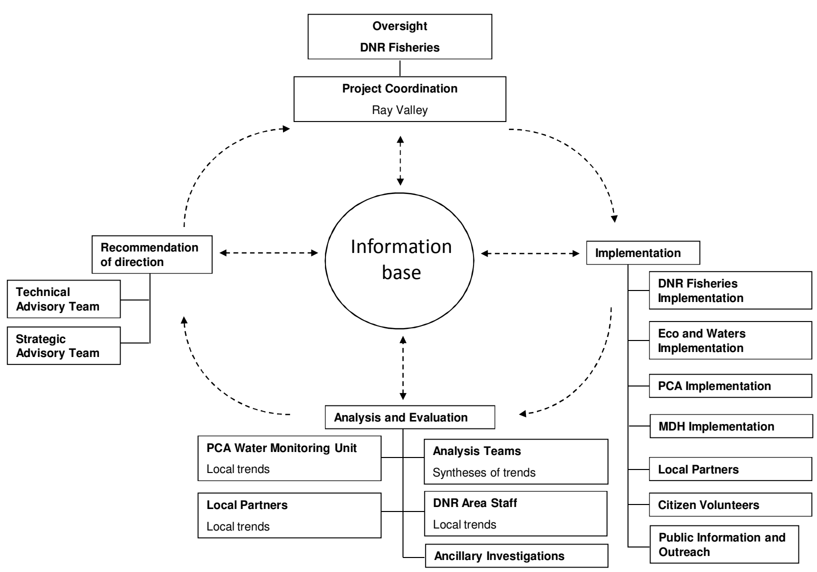


Figure 1. SLICE organizational chart

Major coordination activities as of: 30 October 2010

Coordination activities during the past six months occurred at two levels: ground-level (i.e., making sure proposed work is getting done and is up to standards); and at an organizational level (i.e., sheparding the evolution of SLICE from a pilot project into a well-integrated long-term lake monitoring program). Both levels of coordination have presented their share of challenges, but from our judgment, acceptable progress is being made at both levels. Long-term success at both levels will require technical staff with significant portions of their position description devoted to collecting, analyzing, and disseminating long-term monitoring datasets. With current operating budget shortfalls, this presents arguably the greatest threat to the continued viability of SLICE. The project coordinator, manager, and the SLICE Advisory Team (see Org chart in Figure 1 above) are currently engaged in SLICE Phase 2 (2012-2016) planning efforts that involve contingency planning for various funding scenarios that may result from the State FY12-13 Biennium budget. A meeting is scheduled for January 11th and 12th 2011 to engage in Phase 2 planning efforts.

Major coordination activities as of: 15 April 2011

Much of the coordination activities described in the October 2010 update carry over to the current update. The SLICE Advisory Team composed of representatives from DNR Divisions of Fish and Wildlife, Ecological and Water Resources and MPCA (Water Monitoring Unit) met in January 2011 to debrief from Phase 1 and chart a transition into the operational phase of SLICE, originally planned for 2012. Recommendations from this Advisory Team were carried forward to the SLICE Oversight Team composed of Section of Fisheries Managers for additional guidance. First, the Section of Fisheries and MPCA's Water Monitoring Unit pledged their ongoing support of the SLICE program because it is providing valuable information on the status and trajectory of water and fisheries resources and lending insight into possible cause-effect patterns. Nevertheless, the losses of staff and budget reductions have reduced the capacity of DNR Fisheries to support lake monitoring. Given disruptions due to many early retirements in the Section, budget uncertainties, and analysis bottlenecks, SLICE teams agreed it would be wise to delay Phase 2 implementation until spring 2013. In the interim, a "stop-gap" survey plan was developed for 2012 that will reduce the overall survey load in the sentinel lakes but maintain continuity for important annual datasets. During 2012, intense Section of Fisheries lake survey program planning will be occurring to position the Section for administering an operational SLICE program.

I also presented a talk describing the SLICE program and preliminary results in the Climate Change Symposium at the annual Midwest Fish and Wildlife Conference in Minneapolis, MN in December 2010.

Major coordination activities as of: 30 October 2011
DNR, PCA, and the Superior National Forest plan to continue sampling a reduced suite of data in 2012 with operational budgets. These datasets include seasonal (Spring, Summer, Fall) sampling of water quality, major ions, and zooplankton. Annual sampling of aquatic plants (twice annually in 11 sentinel lakes infested with

curly-leaf pondweed) will continue as well as year-round deployment of temperature logger. Labor intensive game fish sampling will be suspended pending review of methods and indicators, but nearshore fish sampling a la the index of biotic integrity (IBI) funded with clean water funds will continue in order to evaluate the IBI for clean water goals.

Since the last progress report, I have continued active dissemination of program information and findings and have been an invited speaker to several engagements including a talk at a workshop to identify sentinel watersheds throughout the state as a part of clean water research goals on June 30 2011. In September 2011, I was invited to deliver a Water Resources graduate seminar at the U of MN. In October 2011, I delivered a talk at the U of MN Water Resources Conference presenting natural declines in curly-leaf pondweed across our sentinel lake network presumably due to the snowier winters of the past three years. Finally, I will be delivering a lecture to a biology class at University of Hamline in December 2011.

Major coordination activities as of: 12/31/2012
Ray Valley delivered an invited presentation to undergraduate biology students at Hamline University in December (2011). Since the last progress report Ray Valley left his position as project coordinator and public service. A meeting of Fisheries Research staff was conducted in March to assign various aspects of Mr. Valley's coordination workload. Currently, coordination of the project will be the responsibility of research biologists Jeffrey Reed and Brian Herwig.

V. TOTAL TRUST FUND PROJECT BUDGET:

Personnel: $ 76,780*
Contracts: $ 713,682
Equipment/Tools/Supplies: $ 20,738
Acquisition, including easements: $ 0
Travel: $13,800
Other: $

*We are requesting $14,820 from the Trust Fund to temporarily supplement (Rule 10 work assignment) the current Classified 10L DNR salary (MAPE bargaining unit) of the project coordinator (Ray Valley) to a 14L MAPE salary (N.R. Program Coordinator) that is commensurate to the work duties involved with this project. This is equivalent to a 7% FTE. Mr. Valley's salary will return to the level of 10L after the project is completed.

We are also requesting $25,000 from the Trust Fund to pay 10% of Jodie Hirsch's Classified DNR salary. The salary savings will be used to backfill Ms. Hirsch's position with a student worker.

Intern positions are unclassified.

TOTAL TRUST FUND PROJECT BUDGET: $825,000

Explanation of Capital Expenditures Greater Than $3,500:

- Data platforms will be constructed from multiple components costing less than $3,500. Existing USGS platforms will be used whenever possible and equipped with new sensors costing less than $3,500 as needed. Most sensors have an average useful life of approximately three years under continuous operation. Platforms purchased and assembled with trust fund monies will continue to be used for the same water quality monitoring program through its useful life. Collection of physical water quality data for the project will require purchase of one multi-parameter water quality sonde with optical probes for dissolved oxygen (DO) and chlorophyll *a*. The YSI 6600 model V2 is available from the USGS HIF facility for $6,435.00 and matched units are already in service at the USGS MN Water Science Center, allowing sharing of spare parts and components. The instrument purchased with trust funds will be used as a field meter and as a back-up for the other sondes deployed in each lake. The sonde purchased with trust fund monies will be under ownership of the State, but will be used for continued cooperative work with the USGS through its useful life.

VI. PROJECT STRATEGY:

A. Project Partners:

1. DNR Divisions of Parks, Waters, and Ecological Resources
2. MN PCA – Env. Anal. Outcomes Div., Water Monitoring Section (Glen Skuta program manager)
3. US Forest Service – Superior National Forest (Jason Butcher Fisheries program manager)
4. US Geological Survey – Water Science Center (Dr. Richard Kiesling, Limnologist)
5. Natural Resource Research Institute (Dr. Lucinda Johnson)
6. Science Museum of Minnesota (Dr. Mark Edlund)
7. University of Minnesota-Duluth Department of Biology (Dr. Tom Hrabik)
8. University of Minnesota Department of Bioproducts and Biosystems Engineering (Dr. Joe Magner and Lee Engel)

B. Project Impact and Long-term Strategy:

Work outlined in this proposal will lay the necessary ground work for ongoing monitoring and assessment. Work proposed here represents a significant adaptation of DNR Fisheries lake survey program to better assess lake habitat conditions and factors affecting habitat. We expect that equipment utilized, data collected, and models built for the proposed project will continue to be utilized and built upon long after this project expires. Understanding the myriad of factors driving changes to lake habitats will require a long-term adaptive approach. Support from the Environmental Trust Fund will kick-start this effort and help prioritize future monitoring efforts with operating budgets.

C. Other Funds Proposed to be Spent during the Project Period:

Trust fund dollars will supplement at least $508,000 spent during the project period originating from the Game and Fish Fund, USGS cooperative funds, US Forest Service Operating budgets, PCA operating budgets and Clean Water Legacy.

D. Spending History: $120,000 (FY 2009)

VII. DISSEMINATION:

1. PCA has a website providing basic "fact-sheets" on all 24 sentinel lakes. http://www.pca.state.mn.us/water/sentinel-lakes.html
2. Another DNR website on the overall SLICE program is under construction
3. Twenty-four retrospective lake assessment reports
4. Several manuscripts submitted to peer-reviewed journals by project partners
5. Several technical presentations given at state, regional, national, and potentially international symposia. Local outlets include MN chapter of the American Fisheries Society and MN Waters
6. Most water quality data will be housed in EPA's national water quality database STORET (http://www.epa.gov/storet/dbtop.html). GIS data is available at http://deli.dnr.state.mn.us/. Fisheries and aquatic plant data will be housed in a central database and available upon request.
7. A "file transfer protocol" (ftp) site will be maintained by the project coordinator which will house all GIS layers, reports, analyses, and raw data relevant to the project. This information will be available to any interested parties.

Result Status as of: 4/15/10

1. Comprehensive baseline assessment reports for White Iron, Portage, Red Sand, and Peltier are completed and housed at http://www.pca.state.mn.us/water/sentinel-lakes.html
2. SLICE web page constructed and launched http://www.dnr.state.mn.us/fisheries/slice/index.html
3. Valley, R., D. Staples, P. Jacobson. 2010. Preparing for climate change on Minnesota's lake resources through cooperative long-term monitoring and assessment. Oral presentation at the 2010 joint annual meeting of the MN chapters of the American Fisheries Society, Society of Conservation Biology, Society of American Foresters, and the Wildlife Society, Nisswa, MN, March 2010.

Result Status as of: 10/30/10

1. Comprehensive baseline assessment reports for Hill, Ten Mile, Madison, and Shaokotan are completed and housed at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/sentinel-lakes.html
2. Valley, R., D. Staples, P. Jacobson. 2010. Preparing for climate change on Minnesota's lake resources through cooperative long-term monitoring and

assessment. Poster presentation at the annual Water Resources Conference, St. Paul MN.

3. Temporary USGS website established for housing and accessing continuous temperature logger data http://mn.water.usgs.gov/projects/sentinel_lakes/map.html
4. Ongoing new partner investigations utilizing SLICE datasets tracked at http://www.dnr.state.mn.us/fisheries/slice/investigations.html

Result Status as of: 4/15/11

1. Comprehensive baseline assessment reports for Carlos, Cedar, Elk, South Center, and Trout are completed and housed at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/sentinel-lakes.html

2. Valley, R., D. Staples, P. Jacobson. 2010. Preparing for climate change on Minnesota's lake resources through cooperative long-term monitoring and assessment. Poster presentation at the 2011 annual Midwest Fish and Wildlife Conference, Minneapolis, MN, December 2010.

Result Status as of: 10/30/11

1. Comprehensive baseline assessment reports for St. James, are completed and housed at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/sentinel-lakes.html. Belle and South Twin Lakes are soon to be published.
2. Valley. R. 2011. Sustaining Lakes in a Changing Environment (SLICE). Invited talk at the annual Aitkin River and Lakes Fair, Aitkin.
3. Valley, R. 2011. Experience and insight obtained from SLICE and MN Sentinel Lakes Program. Assessment and Selection of Sentinel Watersheds. University of Minnesota, St. Paul. http://sentinel.umn.edu/
4. Valley R. 2011. Sustaining Lakes in a Changing Environment (SLICE) and its so-called sentinel lakes. Invited graduate Water Resources seminar, University of Minnesota, St. Paul.
5. Valley R, S. Heiskary, and C. Tomcko. 2011. Natural short-term declines in curly-leaf pondweed across a network of sentinel lakes: potential impacts of snowy winters. Oral presentation at the University of Minnesota's Annual Water Resources Conference. St. Paul.
6. Sample time-series indicator plots (created manually) and place holder for more sophisticated web data application proposed as amendment on the SLICE web page http://www.dnr.state.mn.us/slice/indicator-graphs.html

Result Status as of: 12/31/12

1. Comprehensive baseline assessments of all sentinel lakes are completed and housed at: http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/sentinel-lakes.html

2. Valley, R. D. and S. Heiskary. 2012. Short-term declines in curlyleaf pondweed in Minnesota: potential influences of snowfall. Lake and Reservoir Management 28:338-345.

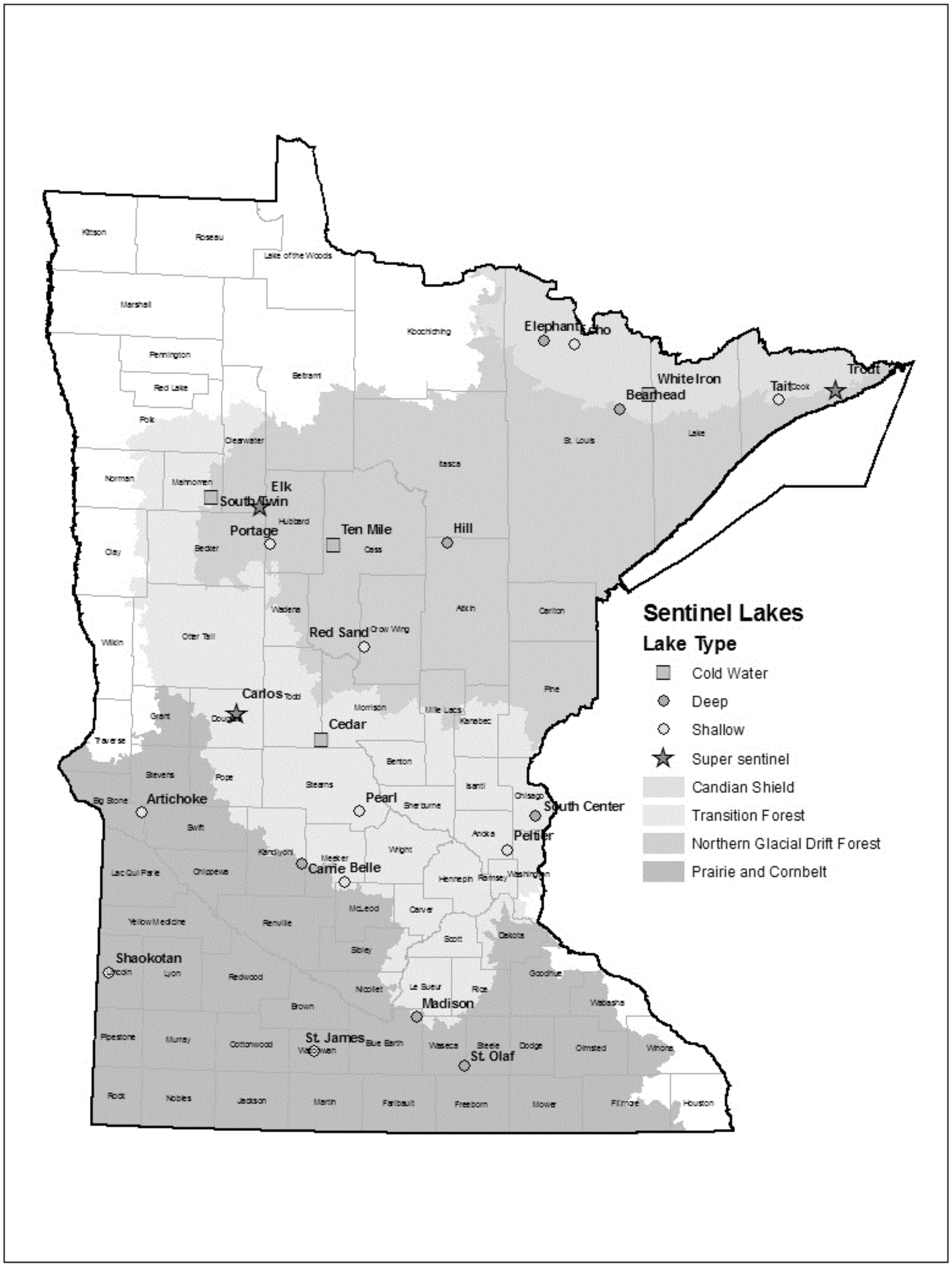
VIII. REPORTING REQUIREMENTS: Periodic work program progress reports will be submitted not later than 15 April 2010 and every October and April thereafter. A final work program report and associated products will be submitted by June 30 2012.

IX. RESEARCH PROJECTS:
See research addendum document

X. ATTACHMENTS

A. Itemized Trust Fund Budget
B. Map of the sentinel lakes

Attachment B



Attachment A: Budget Detail for M.L. 2008 Environmental and Natural Resources Trust Fund Projects

Project Title: Assessing the consequences of ecological drivers of change on water quality and habitat dynamics of deep-water lakes with coldwater fish populations
Legal Citation: ML 2009, Chap. 143, Sec. 2, Subd. 5C
Project Manager: Dr. Donald L. Pereira
M.L. 2011 (FY 2012-13) ENRTF Appropriation: $825,000 - 3 years
Project Length and Completion Date: 30 June 2013

Environment and Natural Resources Trust Fund Budget	**Result 1 Budget**	**Amount Spent Previous**	**Amount Spent this Period**	**Total Amount Spent**	**Balance**		**Result 2 Budget**	**Amount Spent Previous**	**Amount Spent this Period**	**Total Amount Spent**	**Balance**		**Result 3 Budget**	**Amount Spent Previous**	**Amount Spent this Period**	**Total Amount Spent**	**Balance**		**Result 4 Budget**	**Amount Spent Previous**	**Amount Spent this Period**	**Total Amount Spent**	**Balance**		**Total Budget**	**Total Balance**
	Establish 24 sentinel lakes and their associated watersheds as focal points of collaborative long-term monitoring research and environmental education						***Reconstruct post-European to present water chemistry, sedimentation and erosion***						***Utilize watershed and lake mixing models to forecast future water quality conditions in deep lakes with cold-water fish populations given different climate change and land-use change scenarios***						***Identification of a set of habitat and fish indicators sensitive to human-caused disturbances to serve as early warning sign of lake ecosystem distress***							
Budget Item																										
Personnel: wages and benefits																										
Ray Valley (Coordinator 7% FTE - $14820)																				14,142		14,143	658.31			658.31
Jodie Hirsch (Invertebrate Biologist 10% FTE - $25,000)																			25,000	25,000		25,000				
Interns																			21,460	21,460		21,460				
Contracts																										
USGS - Dr. Richard Kiesling	269,968	269,968		269,968									41,290	41,290		41,290										
Minnesota Pollution Control Agency																			40,500	40,500		40,500				
University of Minnesota-Duluth - Dr. Thomas Hrabik																			100000	100000		100,000				
Science Museum of Minnesota - Dr. Mark Edlund							90,000	90,000		90,000																
Internal SLA - Minnesota Information Technology Services													32,950		32,950	32,950			30,950	30,950		30,950				
Minnesota Department of Health																			121,824	121,824		121,824				
University of Minnesota - Dr. Tim Griffis																			2,160	2,080		2,080	80			80
Equipment/Supplies																			22,178	22,178		22,178				
Travel Expenses																			13,800	13,800		13,800				
Column Total	269968	269968		269968	0		90000	90000		90000			74240		32950	74240	0		377872	391933.7		391934.7			825,000	-404

Visual Illustration of Project Outcomes/Impacts

In an effort to engage stakeholders, scientists, and the general public in long-term lake monitoring (and it's environmental and societal significance) we developed a Data Visualization Tool (DVT). The DVT was built using the open-source data platform CKAN (ckan.org). The DVT enables users to interact directly with SLICE data. Currently, basic summary graphics and data of fish catches, zooplankton trends, water temperature and water quality, and aquatic macrophytes are available to query from the beta format for those with a CKAN account. Improvements are planned to make the tool more user-friendly and provide greater access to databases currently managed by DNR, PCA, and other partners. Examples of the current end product are provided in Figures 1 and 2.

Figure 1. Opening page of data visualization and database exploration tool for the SLICE program.

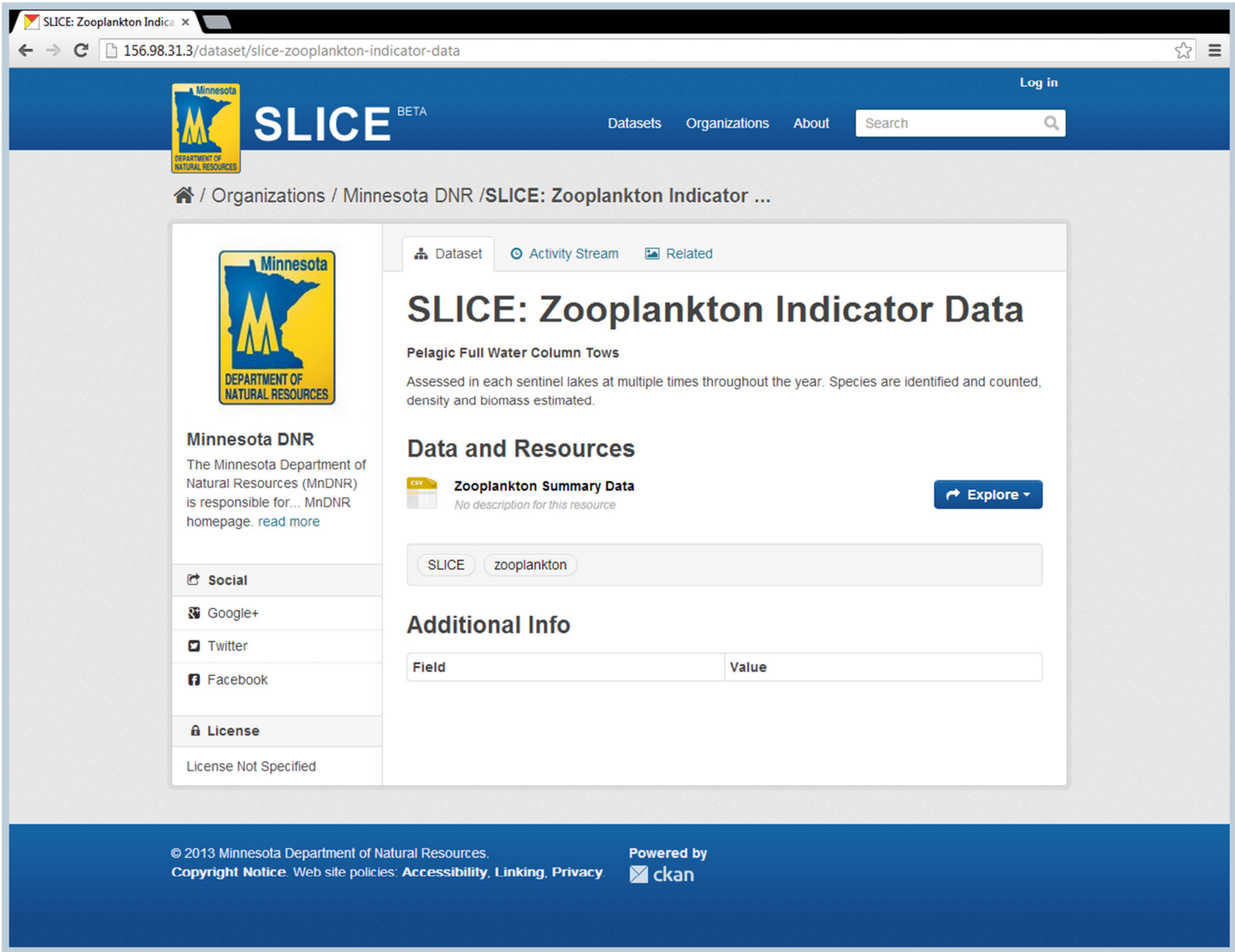


Figure 2. Example of database entry screen for users.