AQUATIC ECOSYSTEM RESEARCH
A Freshwater Conservation Company

TWIN LAKES

Historical Data Analysis and Lake Management Plan

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EXECUTIVE SUMMARY

Aquatic Ecosystem Research was engaged by The Twin Lakes Association and The Town of Salisbury to compose a CTDEEP AIS grant, which would obtain funding to analyze historical lake data and to leverage those analyses to compose a holistic lake management plan. The grant was awarded to The Town of Salisbury and Aquatic Ecosystem Research was subsequently hired to undertake the project, which included the following important features:

- Analysis of historical data from both lakes including:
  - Water quality data (2004 – 2015)
  - Plant community (2004 – 2015)
  - Algal community (2004 – 2015)
  - Fish Community (1992 – 2014)
- Review of the current plant management protocol.
- Review of the rare-species data.
  - Budgetary planning for future survey requirements.
- Site inspection to determine potential recreational enhancement projects.
- Long term lake management planning with:
  - A strategic approach to plant management.
  - Recreational enhancements.
  - An assessment of the sediment-accretion in the "between-the-lakes" channel.
  - A review of database and recommendations for database improvement.
  - A schedule of rare species surveys.
  - Water quality monitoring protocol.
  - Plant survey protocol.

Summary Findings:
The proceeding is a summary of the important findings from the suite of analyses that were undertaken during this study.

- Database Results
  - AER found that the current water quality data collection protocols are not sufficient to provide a complete picture of the state of the Twin Lakes system for the following reasons.
    - There is no consistency in the timing of water quality sampling events; samples were taken at temporally asymmetrical points during the years.
    - Vertical profiles of oxygen and temperature were not developed throughout the full water volume (25m) of East Twin Lake.
      - The maximum depth analyzed for oxygen and temperature was 20m and that depth of assessment was not consistent from year to year.
    - Assessments of hypolimnetic waters of East Twin Lake were not taken near the sediment surface. Instead, those samples were taken at the maximum depth of the oxygen/temperature profile, which was never at the ultimate depth of the lake.

        - Water quality sampling ceased in West Twin Lake in 2011. And, it appears as though the 2010 and 2011 sampling events are redundant in regards to those data SOlitude provided.
        - ***These findings make it impossible to assess nutrient fluxes and develop internal nutrient budgets for the lakes.***
    - AER found that the plant community surveys were taken post herbicide treatment in most years. Pretreatment surveys only occurred in 2004 and 2005.
        - In 2005, a single pretreatment survey was conducted. No post-treatment survey was conducted in that year.
    - AER found that vegetation data was collected using a presence/absence strategy, which makes the calculation of species abundances and coverages difficult.
- Water Chemistry Results
    - East Twin Lake was assessed as a hard water lake in the early-mesotrophic to mesotrophic trophic state.
        - Average total phosphorus = 20µg/L.
        - Average alkalinity = 124.35mg/L.
        - Average Secchi depth = 5.69m.
        - Average N:P ratio = 25.79.
    - West Twin Lake was assessed as a hard water lake in the mesotrophic to lake mesotrophic trophic state.
        - Average total phosphorus = 60µg/L.
        - Average alkalinity = 114.68mg/L.
        - Average Secchi depth = 3.87m.
        - Average N:P ratio = 50.69.
    - There were some significant changes in the water chemistries of East Twin Lake.
        - East Twin Lake (2004 – 2015):
            - Nitrate has decreased significantly over the years.
                - Reason unknown.
            - Alkalinity has decreased significantly over the years.
                - Potentially climate related.
            - Ammonia has increased significantly over the years.
                - Potentially related to internal or external loading.
    - There was no significant overall change in the water chemistry of West Twin Lake between 2004 and 2011.
        - There was however, a significant increase in dissolved phosphorus over the years.
            - Potentially related to internal nutrient loading.
    - East Twin Lake's community was dominated by blue-green algae (Cyanophyta), which is common in hard water lake-systems where calcium carbonate is the major available carbon source.
        - Total cell counts have increased significantly in the epilimnion since 2004.
            - Biomass of algae remained unchanged in the epilimnion, which suggests there are more, smaller cells.
        - The difference in cell densities of the epilimnetic and metalimnetic algal communities of East Twin Lake has become

larger since 2004, which suggests that more algal cells are present in the epilimnion.
        - Potentially related to changes in the thermal structure of the lake.
    - There were no significant trends in water chemistry that correlated with the observed changes in the algal community of East Twin Lake.
- Vegetation Results
  - Twenty and 26 aquatic macrophyte species were detected in East and West Twin Lake, respectively.
    - Rare species detected by SOlitude include *Megalodonta beckii* and *Myriophyllum sibiricum.*
      - AER also found *Potamogeton strictifolius.*
  - Analytical results suggest:
    - East Twin Lake
      - That there was no change in *M. spicatum* abundance since 2004.
        - Recall that only post treatment data were available.
        - Recall that abundance was calculated using presence/absence data.
      - There was no change in vegetation coverage since 2004.
      - There was a significant increase in vegetation encounters since 2004.
        - This suggests that plant community productivity may be increasing.
      - Community diversity and richness have not changed significantly since 2004.
      - Dominant species include *Potamogeton amplifolius* and *Vallisneria americana.*
      - Lily species covered 9.5 acres of East Twin Lake; this coverage was principally located in the northern section of the lake.
    - West Twin Lake
      - There was a significant reduction in the contribution of *M. spicatum* to the plant community since 2004.
      - Community diversity has diminished significantly since 2004.
      - AER determined that dense and sparse coverage of lilies was 18.6 and 16.6 acres, respectively.
- Fish Community Results
  - There was a significant change in the holistic fish community since 1992.
    - Black Crappie, Golden Shiner, and Creek Chubsucker populations have decreased significantly.
    - Rock Bass population has increased significantly.
    - There was no change in richness or diversity.
- Watershed Results
  - The watershed is 4,681ac for both lakes.
  - The total surface area to watershed ratio is 5.4.

    - AER found that 55.4% of the watershed is comprised of forested areas and wetlands, which is below the theoretical 80% that makes a lake system resilient to water chemistry changes.
    - AER found that 9.1% of the watershed is residentially developed, which is below the maximum tolerance of 25%.
- Sediment Analysis
    - There was a total of 47.50yd^3 of soft removable sediment in the between-the-lakes channel.

Recommendations

Aquatic Ecosystem Research has developed a priority approach to the management of the Twin Lakes system. The proceeding initiatives are described in depth in the recommendations section of this document; they are listed here. This approach is organized by tiers and includes:

- Tier 1 – High Priority
    - Inspect and respond approach to the management of *M. spicatum.*
    - Water quality monitoring program reconfiguration.
    - Rare plant survey.
    - Development of a LakeSmart Program.
- Tier 2 – Lower Priority
    - Boat lane creation in East Twin Lake.
    - Lily and sediment management in West Twin Lake.
    - General debris removal.
    - Other rare species surveys.
        - Schedule outlined in document.

INTRODUCTION

East Twin (Lake Washining) and West Twin (Lake Washinee) Lakes are hydrologically connected water bodies located in the Town of Salisbury, Connecticut. East Twin Lake, the larger of the two, has a surface area of approximately 569 acres, a maximum depth of 80 feet, and an average depth of 32.5 feet (Canavan & Siver 1995, CT DEEP 2012). The lake holds approximately 26 million cubic meters of water, is roughly oval in shape, and partially divided by a long, narrow island extending out near the northwest shoreline where it is connected to the mainland by a causeway (fig. 1).

The smaller West Twin Lake has a surface area of approximately 290 acres, a maximum depth of 21 feet (CT DEEP 2012), and a volume of approximately 3.2 million cubic meters. The deeper regions are located in circular basin at the south end of the lake. Extending from the northwest section of the basin in a northerly direction and separated by a former railroad bed (SCC 2009) is a long, shallow arm, much of which is less than 6 feet in depth (fig. 2).

The watershed area for both lakes is 4,681 acres (SCC 2009) and is situated within the State's Marble Valley geological region (Bell 1985, Canavan and Siver 1995). The Marble Valley bedrock is largely comprised of metamorphosed limestone or marble, which greatly influences chemistry of lakes in this region (Canavan and Siver, 1994).

HISTORICAL DATA

Water Quality 1930 to 2000:

East Twin Lake has been included in several statewide water quality surveys dating as far back as the late 1930s (Deevey 1940). Subsequent surveys occurred in the mid-1970s (Frink and Norvell 1984), in the late-1980s (CT DEP 1991), and early 1990s (Canavan and Siver 1994, 1995). A review of the compilation of these data in Canavan and Siver (1995) suggested that the lake's early-mesotrophic to mesotrophic status had not changed significantly over the prior 60 years. Most Secchi transparency measurements ranged from 13 to 20 feet (4 to 6 meters) and most surface total phosphorus concentrations fell in the 10 to 20µg/L range. Notably, different conditions were observed in July of 1992 when Secchi transparency was reported at 9.5 feet (2.9 meters) and surface total phosphorus concentrations at 40 µg/L.

Similar historical data has could not be located for West Twin Lake.

Water Quality After 2000:

Since the 1990s survey, data has been inconsistently collected between 2004 and 2015 from a variety of sources including SOlitude Lake Management and Connecticut Department of Energy and Environmental Protection. AER compiled and summarized trends gleaned from past monitoring in our December 5, 2016 report. Important findings include:

- A significant increase in the amount of late season phosphorus in the hypolimnion (bottom waters) since 2004 with maximum concentrations observed in September-October.

- Significant shifts in the algal community including a fourfold increase in algal cells concentrations (averaging 45,000 cells per mL) occurring after 2012, a decrease in algal diversity, and increase in relative abundance of cyanobacteria (or blue-green algae)

Other important observations conveyed in that memo regarding data collections during that period of time included the inconsistent fashion and the decreasing scope of water quality data collected over time.

Aquatic Plant Data and Management:
An aquatic invasive plant management program, using the aquatic herbicide diquat (Reward®), has been in place since 2004 at the request of the Town of Salisbury and Twin Lakes Association. Historical aquatic plant data collected by SOlitude Lake Management, who also applied the herbicides, for East and West Twin Lakes correspondingly goes back to 2004. At that time 21 transects in East Twin Lake and 10 in West Twin Lake were established to determine dominant species and coverages with particular interest in percent coverage of the invasive plant *Myriophyllum spicatum* (Eurasian Watermilfoil). Similar work continued annually at both East and West Twin Lakes up through 2015 with the exception that most assessments occurred only in the fall rather than spring and fall as was the original protocol. The same number of transects were used throughout the twelve year span.

Plankton Data:
Phytoplankton data have been collected from East Twin Lake from 2004 through 2015 by SOlitude Lake Management. Data included identifications of important taxa, cell enumerations, and biomass of phytoplankton taxa. Phytoplankton community data were not collected from West Twin Lake.

Fisheries Data:
The Connecticut Department of Energy and Environmental Protection has developed a formidable database on fisheries in East Twin Lake using electrofishing techniques. Data used in this assessment goes as far back as 1992. Subsequent studies were conducted in 1996, 1998, 1999, 2002, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011, and 2014.

In West Twin Lake electrofishing data were collected during the years of 2000, 2003, 2011, and 2014.

Other Ecological Studies:
AER's library of work relative to East and West Twin Lakes also includes studies on CT State-listed vertebrates and invertebrates conducted in ca. 2010 and the comprehensive 2009 Salisbury Natural Resource Inventory (SCC 2009).

PURPOSE

The purpose of this document is to compile and analyze all data collected since 2004 and determine important ecosystem trends. Using those findings, management recommendations will be made and relevant methodologies provided.

METHODOLOGY

Lakes:
East Twin and West Twin Lakes were included in this study and data from those lakes were used in the analyses. Data sets for each lake varied in size and scope; a complete discussion of the data sets will be presented in later sections of this report.

Existing Data Sources:
Data were obtained from a variety of sources including the databases of SOlitude Lake Management, CTDEEP, and other published sources.

Database and Storage:
All data were tabulated in to Excel ® spreadsheets and stored on AER servers to ensure that data were available to the client or other lake management entities. The following datasets were created and included:

- Water Quality Database:
  - Temperature and dissolved oxygen profiles (2004 – 2015).
  - Water chemistry (2004 – 2015 complete; historical where available).
- Algal Community Database:
  - Genus level identification (2004 – 2015).
  - Cell enumerations with volumetric corrections.
- Plant Community Database:
  - Species level identification (2004 – 2015).
  - Presence/absence data collection technique.
  - Transect study data structure.
  - Total vegetative cover (%).
- Fisheries Database:
  - Species level identification (1992 – 2014).
  - Species counts per unit effort.
  - Percent above stock size.
  - Percent above quality size.
- Sediment Database:
  - Evaluated in the area between the lakes.
  - Water depth.
  - Soft sediment depth.
  - Refusal depth.
  - Transect study structure.
- Rare Species Database
  - Species level identification.
  - Date of last species-specific survey.
- Watershed Database
  - Cover types (i.e. deciduous forest, wetland, etc.)
  - Relative percent cover of each class.

Data Collection Techniques:
Most of the proceeding data sets were not collected by AER; the descriptions of the protocols were provided by the agency or entity that collected those data. Therefore, Aquatic Ecosystem Research accepts no liability in regards to the actual data

collection protocols and dataset reliability; we can only present the protocols that were provided to us by the group that collected those data. No Quality Assurance Program Protocols (QAPPs) were available for the collection of historical data. Where AER collected data, which will be denoted, we do accept liability for those data sets.

Water Quality –
Water chemistry samples were collected from the deepest parts of East Twin (fig. 1) and West Twin Lakes. Surface samples were collected using a grab technique at a depth of 0.5m; A Van Dorn Bottle was used to collect samples for water chemistry analysis at specific layers (i.e. epilimnion, metalimnion and hypolimnion) when the lakes were stratified. All samples were stored at 3C prior to delivery to the analytical laboratory. Water samples were analyzed for pH, alkalinity, Total Kjeldahl Nitrogen (TKN), ammonia, nitrate, dissolved phosphorus, and total phosphorus. Water clarity was measured using a standard Secchi disc. Temperature and dissolved oxygen profiles were developed with a YSI Model 55 meter. The depths of samples collected for water chemistry analysis varied during over the years and the timing of sampling events were not standardized.

Algal Community –
Phytoplankton data were only collected in East Twin Lake at the deepest section of the lake. Phytoplankton samples were collected at the surface and thermocline using a Van Dorn Bottle. Water Resource Services identified phytoplankton genera under 40 – 100X magnification; samples were concentrated, enumerated using standard techniques, and corrected to be representative of the entire sample volume. These samples were taken during the water quality sampling events; therefore, their periodicity was non-standardized from year to year.

Vegetation –
Vegetation surveys were conducted late in the season of each year in both lakes between 2004 and 2015. SOlitude Lake Management was to conduct pre and post-treatment surveys; however, the two annual surveys for each lake were only conducted in 2004. Furthermore in 2005, only a single pre-treatment survey was conducted. In all years after 2005, SOlitude Lake Management only conducted post treatment surveys. Twenty-one and ten transects were established in East Twin and West Twin Lakes, respectively (figs. 1 and 2). Length and the number of points per transect varied among transects. The plant community was assessed visually at each point after sampling with a grapple or long-handled rake. Water depth, species presence, and total vegetative cover were logged at each point.

Fish Survey –
Electrofishing was conducted at semi-regular intervals between 1992 and 2014 by the CTDEEP at night during May or June using a 17-foot aluminum Jon-boat equipped with a Coffelt VVP-15 control unit, which was powered by a 6500W Honda generator. The electrode array consisted of six 2m long anodes (63.5 mm braided stainless steel cables) mounted from two booms extending approximately 2m ahead of the boat's bow. The boat hull served as the cathode. Electrofishing was done in a pulsed DC mode (80pps, 60% pulse width) at 200-400 volts and 3-9 amps depending on water conductivity.

Electrofishing consisted of slowly moving along the shoreline in water less than 1.5m deep with the current being controlled via a foot pedal on the boat's bow. Typically, six

600sec zones were sampled in different shoreline areas of the lakes. Abundant species such as sunfish (*Lepomis spp.*), Yellow Perch (*Perca flavescens*) and Alewives (*Alosa spp.*) were sampled in predetermined zones (i.e. zones 1, 3, 5), whereas Largemouth Bass (*Micropterus salmoides*) and other less common species were sampled throughout all six zones.

Visual Inspection –
The Twin Lakes were visited on July 17th 2016 by AER for the purposes of evaluating potential recreational enhancements, qualitatively assessing the state of *Myriophyllum spicatum*, to examine potential recreational impediments imposed by lily-species populations, and to provide a professional opinion about the status of the Twin Lakes.

On that date, the entirety of the two water bodies were visually inspected by slowly motoring around the entirety of the littoral zone and georeferencing notable features. Furthermore, the whole populations of the lily species were quantified by mapping the extent of each patch with GPS/GIS technologies. Finally, an aquatic macrophyte species inventory was established by sampling the plant community with a grapple at numerous locations and visual identification following Crow and Helquist 2000.

Sediment Survey –
During the site visit that took place on July 17th 2016, the small channel that connects East and West Twin Lakes was evaluated for sediment accretion. The proceeding survey method was designed to determine whether there was sufficient sediment in the area to consider a dredging program that would enhance lake connectivity and recreational access.

Three transects were established in the channel that connects the two lakes. The northern and southern most transects were 30m in length and the central transect was 10m in length (fig. 4). All three transect were sampled three times at 1m intervals perpendicular to the transect line. The perpendicular sample locations were positioned at 1/5th the linear length of each transect resulting in 51 total sample points. At each sample point, three data values were collected to evaluate the total sediment volume. The first variable collected was water depth. The second variable collected was the depth of the soft sediment and the third variable collected was the depth to refusal. All depths were measured using a calibrated rod capable of penetrating sediment to hard bottom (refusal). To correct for varying water level, which is an inherent problem with sediment surveying approaches, a static structure was used as a reference point. AER selected the northern most bridge as the static structure and the height of this bridge in comparison to the surface of the water was used to correct the other collected variables.

Data collected during this initiative were compiled and the sediment profiles along those transects were developed; additionally, the total sediment volume of the channel was calculated. These calculations were used to determine whether sediment removal was necessary.

Rare Species –
Rare species surveys were conducted by a variety of agencies/companies; those data were obtained by AER and consolidated into a database, which included the specific name of each species and the date of last survey. These data were collected to

schedule future rare species surveying that will be in concordance with state-mandated lake management permitting protocols.

Watershed –
The watershed was analyzed using the most recently available aerial orthographic data available from the CTDEEP. Those data were input to AER's global information system software and the various cover types were tabulated. Using those data, the relative percent cover metrics were calculated for each cover type. Finally, those data were represented in a graphical form.

Data Analytics –
A variety of data analysis protocols were used to examine the state of the lakes. Each of those protocols was specific to a dataset; therefore, this section will be structured to describe the statistical techniques applied to each dataset.

Water Quality:
Data were compiled from the most complete data set and organized by lake, year, month, and depth. The resulting data sets were 112 and 45 rows in length for East Twin and West Twin Lakes, respectively. The most complete data sets for East Twin and West Twin Lakes were 2004 – 2015 and 2004 – 2011, respectively. The variables that were evaluated in each lake were pH, alkalinity, Total Kjeldahl Nitrogen (TKN), ammonia (NH_4^+), nitrate (NO_3^+), dissolved phosphorus (free PO_4^{+3}), and total phosphorus (P). The aforementioned variables were measured in the epilimnion, metalimnion, and hypolimnion of East Twin Lake. Those same variables were examined in the epilimnion and hypolimnion of West Twin Lake. Secchi depth was also measured in both lakes during each sampling event.

All variables in both lakes were evaluated for their mathematical structure and normality. Means, standard deviation, and confidence intervals were calculated for each variable; normality of variables were evaluated using the Shapiro-Wilks' Test.

To evaluate whether the water clarity (Secchi depth) of each lake has changed since 2004, General Linear Models (GLM) were employed. Models were built from raw data over a lake-specific time frame (2004 – 2015 for East Twin and 2004 – 2011 for West Twin); the significance of each model compared to random was calculated using the F-statistic.

Nutrient parameters in each lake were evaluated in a multivariate space using a Three-way Multivariate Analysis of Variance (MANOVA) to account for complex statistical interactions among the organizing variables year, month, and depth. Pillai's trace was used to calculate the multivariate F-statistic and p-values, respectively. Following the calculation of multivariate significance, individual variable influences on the overall model were calculated from their individual F-statistics. The interactions among organizing variables and the nutrient variables that were realized from this analysis were year, month, depth, year x month, year x depth, month x depth, and year x month x depth resulting in a complete valuation of the Twin Lakes system.

To confirm results from the multivariate analyses, AER conducted statistical subsampling protocols on the aforementioned data sets. PERMANOVA was used with 499 permutations to determine whether the results of the holistic tests where reliable.

Algal Community:

The algal community was only evaluated in East Twin Lake because those data were not available for West Twin Lake; cells were enumerated at the genus level between 2004 and 2015 during each sampling event. We used general linear models to determine whether any apparent changes in the algal community were indeed significant. Additionally to examine the influence of lake chemical features on the state of the algal community, we constructed two data sets. The first data set was comprised of the water chemistry variables in each layer of the lake (i.e. epilimnion, metalimnion, and hypolimnion). The second data set was constructed from the algae-group cell counts, richness, and Shannon's Diversity Index, which is calculated using $[-\Sigma(p_i * \ln(p_i)) - (S-1/2N)]$, where p_i is the fraction of the community each genus is representative of, S is the total lake algae richness, and N is the total abundance at each point. Shannon's Diversity Index describes the relative evenness of the community where the number of genera and how abundant each genus is in relationship to all others. Those data sets were organized by month and year for analytical purposes. All data sets were 34 rows in length. Two analyses were conducted using Canonical Correspondence Analysis (CCA) to evaluate the influences of water quality variables on the state of the algal community in the epilimnion and metalimnion. Canonical Correspondence Analysis leverages two data sets; the first data set is the constraining data set (i.e. environmental variables) and the second data set is the response data set (i.e. algal community).

The first analysis to be undertaken was intended to examine how specific genera respond to the measured environmental variables. The constraining data set was comprised of the water chemistry variables, which were listed in previous sections, organized by year and month. The response data set was comprised of the genus level cell counts organized by year and month. The full model was constructed using a Monte-Carlo permutation test with 999 permutations. To evaluate the independence and strength of each canonical axis, Analysis of Variance (ANOVA) was used. Total variance explained was calculated by taking the sum of all constrained eigenvalues from independent axes and dividing that value by the total inertia. The second analysis was conducted in the same manner except the response data set that was used included group level cell counts (i.e. green, blue green, etc.) instead of genus level cell counts.

Plant Community

The plant community of the Twin Lakes was examined each year between 2004 and 2015. Pre-treatment surveys were conducted in May of 2004 and 2005; no other pre-treatment surveys were conducted. Post-treatment surveys were conducted between August and September of all years from 2004 to 2015, except 2005 when only a pre-treatment survey was conducted. Twenty-one and 10 transects were established in East Twin and West Twin Lakes (figs. 1 and 2), respectively; the same transects were evaluated every year but there was no standard transect length. The data collected at each point in each transect included a presence/absence assessment of each species (i.e. 0 or 1), richness, diversity, total cover, and *M. spicatum* encounters. To analyze these data, they were first consolidated in to the following data sets: 1) Total Incidences by Year, 2) Species Incidences by Year, 3) Percent Species Incidences by Year, and 4) Species Percent Contribution to Community by Year. Using those data, graphical representations were created and General Linear Models (GLM) was used to evaluate various important aspects of the plant community between 2004 and 2015.

Fish Community
Fish data were analyzed using a permuted version of MANOVA (Multivariate Analysis of Variance) to determine if there have been significant changes in the fish community of East Twin and West Twin Lakes. Individual species trends were realized using General Linear Models.

SUMMARY RESULTS

Database –
We found that the water quality database was inconsistently collected and that the full vertical profile of East Twin Lake was never entirely examined. Furthermore, the evaluation of West Twin Lake's water quality ceased after 2011 for reasons that are unknown to Aquatic Ecosystem Research. For both lakes, the water quality sampling events were never temporally standardized and sampling events occurred at different intervals in many years. The result is numerous data gaps from year to year; and due to the lack of fidelity in the vertical water chemistry assessment in East Twin Lake, it is impossible to develop highly reliable nutrient, oxygen, or temperature models.

Aquatic Ecosystem Research also found that the vegetation dataset used a presence/absence approach that was executed among numerous transects following plant management. The issue with this strategy is that there is no true ability to analyze biomass or cover of aquatic macrophytes. Usually presence absence metrics take advantage of a geo-grid applied to the whole lake, which affords the ability to extrapolate total species cover. Transect techniques usually implement some biomass assessment (i.e. g/m^2 or rank order) to calculate the whole-lake productivity metrics. The approach used in the Twin Lakes is not inherently incorrect; its shortcoming is in the ability to apply the results to the whole lake community and the technique's ability to evaluate changes in the plant community. In fact, the principal issue is that surveying only occurred post plant management in most years; therefore, it is impossible to determine difference between herbicide and ecosystem effects on the plant community dynamics.

Water Quality –
East Twin Lake's water clarity did not vary significantly between 2004 and 2015 or over the summer season. The average water clarity between 2004 and 2015 was 5.69m. East Twin Lake is classified as early-mesotrophic or mesotrophic based on commonly used indices and is enriched with oxygen (i.e. >5.0mg/L) throughout most of its vertical profile for the majority of the season, which is important for the lake's biota. Aquatic Ecosystem Research did find that the water chemistry of the lake has changed significantly since 2004; the principal variables controlling the multivariate model were a significant reduction in nitrate concentration, a significant negative trend in alkalinity, and a significant increase in ammonia concentration. Unfortunately, Aquatic Ecosystem Research was unable to determine any reliable mechanisms for the aforementioned patterns; more monitoring under a standardized sampling program is necessary to fully resolve those patterns. Furthermore, the monthly variation in water chemistry variables was found to be in line with "normal" behavior of deep northern dimictic lakes. Finally, Aquatic Ecosystem Research did not find any change in the monthly water quality patterns since 2004.

West Twin Lake's water clarity did not vary significantly between 2004 and 2011 or over the summer season when yearly assessments were conducted. The average water clarity for West Twin Lake was 3.87m and the lake is classified as mesotrophic to late-mesotrophic based on commonly used metrics. The water chemistry of the lake was not found to vary significantly from 2004 to 2011 and the water chemistry variables were found to oscillate "normally" over the season when compared to other northern dimictic lakes. Unfortunately, Aquatic Ecosystem Research was unable to determine the current state of the lake's water quality or any trends extending to 2015 because the sampling of West Twin Lake ceased after 2011.

Algal Community –
Our results suggest that the algal community of East Twin Lake has changed significantly since 2004 and that this change is directly related to changes in the pelagic algal cell density. We also found that cyanobacteria (i.e. blue green algae) were the dominant constituents of the algal community in all years, which is normal for hard water systems where bicarbonate is the dominant form of carbon in the water column. Furthermore, the detected changes in the algal community could not be related to any water chemistry changes in a complete multivariate model. Additionally, the vertical structure of the algal community has also changed significantly where the cell density is becoming greater in the epilimnion compared to metalimnion. Despite those changes, there was no change in the overall biomass productivity of the algal community. The reasons for the aforementioned changes are therefore not immediately clear because the density of cells did not vary in relationship to the chemical characteristics of the lake and total productivity did not change. Therefore, Aquatic Ecosystem Research hypothesizes that there has been a shift in the thermal structure and vertical mixing of the lake that is causing the changes in cell distribution in the vertical water column. Examination of this phenomenon is beyond the scope of this study because the dataset is incomplete and a change associated with thermal structure is most likely related to climatic changes, which are not directly in the control of The Twin Lakes Association.

Plant Community –
Twenty aquatic macrophyte and one macroalgae species were detected in East Twin Lake between 2004 and 2015. The yearly surveys also confirmed the presence of two state listed species: 1) *Megalodonta beckii* and 2) *Myriophyllum sibiricum*. Aquatic Ecosystem Research also found *Potamogeton strictifolius*, which is also a state listed species. *Potamogeton ogdenii* was not found during the yearly surveys or by AER. As discussed in methods section, a pre and post herbicide treatment survey was only done in 2004; between 2006 and 2015 only post- treatment surveys were conducted and in 2005 only a pre-treatment survey was conducted. Therefore, it was impossible to obtain a true view of the state of the plant community and determine the impact of the herbicide treatments on the plant community. When post treatment survey data were compared among years we did not find any significant change in the abundance or incidences of *Myriophyllum spicatum*. Furthermore, AER did not find any change in community richness or community diversity in post-treatment survey data. Those data – however – do suggest that there has been a significant increase in the total plant abundance. Finally, Aquatic Ecosystem Research was able to determine that the most common aquatic plant species were *Chara spp., Potamogeton amplifolius,* and *Vallisneria americana.*

Twenty-six aquatic macrophyte species and one macroalgae were detected in West Twin Lake. The yearly surveys also confirmed the presence of two state listed species: 1) *Megalodonta beckii* and 2) *Myriophyllum sibiricum*. However, SOlitude and Aquatic Ecosystem Research were unable to find the other two rare species in West Twin Lake that are thought to be present. The same issues encountered in the East Twin Lake vegetation dataset were also found in the West Twin Lake data. When post treatment data were compared over the years, AER found a pattern that suggests the total abundance of *M. spicatum* is decreasing in a significant fashion; however, the total incidences of *M. spicatum* encounters did not change between 2004 and 2015. Furthermore, community diversity diminished significantly but the trend was subtle; the dominant species in West Twin Lake were *Potamogeton amplifolius, M. spicatum,* and *Vallisneria americana.*

In both lakes, the lily-species (principally *Nymphaea odorata*) covered a total area of 44.7ac (fig. 5). The total acreage of lily-species were asymmetrically distributed between the two lakes. East Twin Lake contains 9.5ac, most of which is present in the section of the lake north of Isola Bella (fig. 6). There is no major encroachment of that lily-volume on recreational access; however, there is a significant density of lilies at an important tributary/wetland inlet (fig. 6). West Twin Lake contains 35.2ac of lily cover, most of which is not significantly impacting recreation (fig. 7). However, there are lily patches encroaching on the rowing lane. More critically, there are significant patches of lilies at the northern end of West Twin Lake that are compromising some residence's recreational access and are extending into the outlet stream leading to the dam that may be impacting out flow of the lake system (fig. 7).

Fish Community –
East Twin Lake was the only lake with a dataset large enough to undertake a full fish community analysis. Those data extended from 1991 to 2015 at irregular intervals and were conducted following CTDEEP protocols. The multivariate analysis of the fish community as a function of year found that there was a significant change in the overall structure of that community. The higher-order community metrics (i.e. total catch/effort, species richness, and diversity) were found not to have varied significantly since 1991; however, there was a notable negative trend in total catch/effort since 1991. The significance detected in the multivariate model was controlled by changes in four species population sizes: 1) Black Crappie, 2) Golden Shiner, 3) Rock Bass, and 4) Creek Chubsucker. All of the aforementioned species, except Rock Bass, decreased in catch/effort since 1991. Rock Bass exhibited a significant increase in catch/effort. In general, the fish community appears to be diminishing in total productivity for reasons that are not evident from this study. Reasons for those changes may include increased fishing pressure, changes in the plant community, or some unintended effect from fish stocking events.

Watershed Analysis –
Our analysis of land use cover types indicated that forested or wooded areas, residential development, and agricultural land accounted for 55.4%, 9.1%, and 11.4% of the total watershed, respectively.

Sediment Analysis of Between-Lakes Channel –
Aquatic Ecosystem Research found that the main channel between the lakes contained 47.5yds^3 of soft sediments. Our analysis did not include the heavily vegetated wetland that is east of the main channel; we assume that there is significant

sediment accretion in that area but that it would not be advantageous to dredge that area. The main channel is not an area that dredging would be recommended at this point due to the complications of dredging that area and due to the limited accretion.

COMPLETE ANALYTICAL RESULTS

Data Base –

Overall, those data collected over the years on the Twin Lakes were fairly complete. However, there were some significant issues with the water quality data set. Before describing issues with the water quality data set, it should be noted that all data were not statistically "normal", which means that the data structure is not meeting one assumption of most statistical approaches. That is usually the case for environmental data and can be accounted for by using statistical resampling-techniques such as bootstrapping or permutation tests. Within the water quality database there were the following issues:

1) Data Consistency
    a. Water quality data was not measured in a consistent manner from year to year. There were multiple inconsistencies with the water quality data collection protocol. They are:
        i. Dissolved oxygen and temperature profiles were never developed through the full water volume of East Twin Lake. The maximum depth the lake is 25m and SOlitude Lake Management only developed the temperature and dissolved oxygen profiles to a depth between 10 and 20m.
            1. This structural feature of the current water quality monitoring protocol does not afford the ability to construct a complete lake oxygen budget or assess the flux of nutrients from the sediment surface.
            2. Hypolimnetic (bottom) nutrient tests were also not taken close to the sediment surface; instead they were taken at a depth of 20m. This further complicates developing a nutrient budget for the lake.
        ii. The intervals at which nutrients, algae, and thermal/oxygen profiles were assessed differed from year to year.
            1. This structural feature of the current water quality monitoring protocol makes comparing chemical features from year to year difficult. Essentially, the strategy for analyzing the lakes water quality is not standardized.
            2. There are currently 3 yearly examinations of water quality. This means that there are large gaps in the dataset, which further complicates developing nutrient budgets and ecologically relevant trends in the system.
        iii. West Twin Lake water quality appears to be redundant (i.e. use of same data) for the years 2010 and 2011.
2) Reduction of Water Quality Monitoring Scope
    a. Throughout the years, the scope of the water quality monitoring program has been reduced. Initially, the program spanned four months and two lakes. Since its inception, the number of visits per year has been reduced to 3, the number of variables collected has been reduced by 2, and all monitoring of West Twin Lake ceased after 2011.

b. From an ecological perspective, this compromises data value in management decision-making; and, from a budgetary perspective there should have been reductions in project cost that coincided with the reductions in project scope unless there were changes in treatment costs.

Water Quality –

East Twin Lake chemistry and water clarity:

Between 2004 and 2015 the average pH, alkalinity, Total Kjeldahl Nitrogen, ammonia, nitrate, dissolved phosphorus, and total phosphorus were 7.92, 124.35mg/L, 0.41mg/L, 0.03mg/L, 0.05mg/L, 10µg/L, and 20µg/L, respectively. Over that same time frame, the water clarity average was 5.69m and the average nitrogen to phosphorus ratio was 25.79. These findings suggest that East Twin Lake is early-mesotrophic or mesotrophic (Carlson 1977, CTDEP 1982) where hard-water macrophytes (June-Wells et. al 2013, 2016) and carbonate based algal communities will dominate (Sharpiro 1977, Kortmann 2014).

Yearly dissolved oxygen averages for East Twin Lake were found to be between 7.0 and 10.0mg/L from 2004 to 2015. Furthermore, average dissolved oxygen was found to above 5.0mg/L in most months where assessments were conducted. This is a critical feature because many fish species experience population productivity impairments when oxygen is below 5.0mg/L (EPA 1993). As previously noted, the whole vertical profile of the lake was never resolved between 2004 and 2015, which makes yearly comparisons of dissolved oxygen patterns impossible. Pending a more resolved assessment, it does appear that the majority of East Twin Lake's water is enriched with oxygen; at least to a depth of 10-15m. It is important to restructure the data collection protocol to incorporate the full vertical profile of East Twin Lake so a more complete view of the oxygen dynamics is achieved.

When the water quality of East Twin Lake was analyzed for yearly trends using a Three-way MANOVA and 499 permutations we found that water quality had changed significantly between 2004 and 2015 ($F=14.26$, $R^2=0.09$, $p=0.001$, Table 1). The factor with the biggest impact on the multivariate model was nitrate ($F=13.38$), which decreased from detectable levels between 2004 and 2007 to yearly concentrations below detectable limits of the quantitative test (Tables 1 and 2). The reason for this change is not immediately clear but may be associated with more rapid assimilation of nitrogen by algae and macrophytes or less external nitrogen loading. The secondary factor influencing the MANOVA model was alkalinity ($F=8.88$, Table 1); this variable exhibited a significant linear decrease between 2004 and 2015 (Table 2), which suggests that acidic inputs to the lake are reducing the buffering capacity of East Twin Lake's water. The tertiary variable that influenced the multivariate model was the change in the ammonia concentration of East Twin Lake (Table 1). While there is no clear pattern evidenced by the yearly averages, higher ammonia concentrations were detected in later years, which may be a result of increased blue green algae density or higher rates of decomposition in the sediments of the littoral zone.

Aquatic Ecosystem Research's results did not find that there was a significant water quality difference among months when MANOVA was conducted with 499 permutations (Table 1). However, individual regression indicated that some variables were indeed varying in a significant manner throughout the summer season in East

Twin Lake. The reason for a non-significant finding is not immediately clear but may be related to the data structure or size of the data set. Despite the insignificant finding of the permuted test, there were some expected relationships among the water chemistry variables and the month of sampling. The acidity of the lake (i.e. pH) decreased from May to October (F=16.64), the ammonia concentration of the lake increased (F=9.73) over that same time period (Tables 1 and 3). We were also able to resolve the patterns of increasing dissolved and total phosphorus concentrations throughout the summer season (F's= 8.050 and 10.340, respectively – Tables 1 and 3). These types of findings are expected because of the influence of thermal stratification on the availability of dissolved oxygen at different lake strata. During the summer months the pH of a temperate dimictic lake decreases due to the use of oxygen by lake biota, which leads to higher concentrations of carbon dioxide in the hypolimnion; furthermore in The Twin Lakes system, algae leverage bicarbonate carbon sources, which further alters the bicarbonate-buffering system of the epilimnion and results to a more acidic condition (Table 3). Ammonia and phosphorus (both total and dissolved) are generally elevated later in the season due to internal loading from the sediments of the hypolimnion (deep waters). Reduced deep-water oxygen resulting from thermal stratification alters oxidative-reductive condition of the hypolimnion and deep-water sediments resulting in a release of phosphorus from mineral particles (i.e. iron-bound phosphorus). Internal ammonia loading is a result of altered metabolic activities of microbes. Bacteria decomposers will use oxygen to complete their energy harvesting activities, but when oxygen is limited microbes will use other inorganic sources for their terminal electron receptor (i.e. nitrate/nitrite), which results in an enrichment of ammonia.

We also found a statistical difference among layers of the lake (Table 1). This finding was to be expected because East Twin Lake is a temperate, dimictic lake that is thermally stratified during the summer months. The thermal impediment to mixing (i.e. RTRM Profile or Thermal Stratification) that occurs during the warmer months (i.e. mid-summer) results in two distinct water volumes that are not interacting. Therefore, chemical parameters such as pH, alkalinity, ammonia, and phosphorus variables, which are all associated with the state of aqueous oxygen, will vary between the top and bottom layers of the lake. Our results suggest that there are lower pH (F=116.89), higher alkalinity (F=8.12), higher ammonia (F=9.73), and higher dissolved/total phosphorus concentrations (F's=6.87 and 7.82, respectively) in the hypolimnion compared to the epilimnion (Tables 4 and 5); in fact, there is a semi-linear increase or decrease, whichever is relevant to the specific variable, from the epilimnion through the metalimnion to the hypolimnion (i.e. from top to bottom of the lake). These are normal findings for a temperate dimictic lake and those expected patterns were resolved for East Twin Lake.

The final statistically significant result found during our analysis was that of month x depth. This two-way analysis evaluates the relationships among variables while co-varying the controlling variables month and depth (i.e. interrelated patterns). Essentially, it looks at the statistical relationships among epilimnetic, metalimnetic, and hypolimnetic variables as the season progresses and evaluates how different those variables are exact time periods (i.e. months). Our analysis found that as the summer season progresses the variables pH (F=5.73), alkalinity (F=4.82), ammonia (F=5.57), dissolved phosphorus (F=7.32), and total phosphorus (F=13.116) are increasingly different among layers as the season progresses from May to October (Tables 1,6,7). This result confirms the statistical findings of the one-way analyses of

depth and month that were previously reported; it also further suggests that thermal stratification is influencing the relative nutrient characteristics of East Twin Lake.

Aquatic Ecosystem Research also conducted year by month, year by depth, and year by depth by month analyses all of which did not detect differences in water chemistry variables in relation to the control-variables (i.e. year, month, and depth). The analysis of year by month evaluated whether monthly water chemistry parameters have changed significantly since 2004. The analysis of year by depth examined whether there were significant changes in lake strata since 2004. And, year by depth by month evaluated whether there were differences in monthly water chemistry variables – organized by strata – since 2004. All of the aforementioned analyses did not detect any significant differences, which suggests that the aforementioned relationships have been relatively stable during the timeframe of this study (Table 1).

Secchi depth (i.e. water clarity) was analyzed using a two-way ANOVA. There were no differences detected among Secchi depth readings over the study timeframe (i.e. 2004 – 2015) or among months (May – October). Those findings suggest that water clarity has been relatively stable since 2004 and that it oscillates around the average of 5.69m in a statistically insignificant fashion (Table 8).

West Twin Lake chemistry and water clarity:
Between 2004 and 2011 the average pH, alkalinity, Total Kjeldahl Nitrogen, ammonia, nitrate, dissolved phosphorus, and total phosphorus were 8.11, 114.68mg/L, 0.40mg/L, 0.02mg/L, 0.04mg/L, 10µg/L, and 60µg/L respectively. Over that same time frame, the water clarity average was 3.87m and the average nitrogen to phosphorus ratio was 50.69. These findings suggest that West Twin Lake is mesotrophic or late-mesotrophic (Carlson 1977, CTDEP 1982) where hard-water macrophytes (June-Wells et. al 2013, 2016) and carbonate based algal communities will dominate (Sharpiro 1977, Kortmann 2014).

Yearly dissolved oxygen averages for West Twin Lake were found to be between 6.0 and 8.5mg/L from 2004 to 2011. Furthermore, average dissolved oxygen was found above 5.0mg/L in most months where assessments were conducted. As noted above this is a critical feature of lakes because many fish species experience population productivity impairments when oxygen is below 5.0mg/L (EPA 1993). Also and as previously noted, sampling of West Twin Lake ceased after 2011, which does not allow for a full contemporary analysis of the oxygen conditions in this lake. Pending a more resolved assessment, it does appear that the majority of West Twin Lake's water is enriched with oxygen, at least to a depth of 4-5m. It is important to restart the water quality monitoring program in West Twin Lake to determine the nutrient dynamics of that system and to quantify the relationship between East Twin and West Twin Lakes.

West Twin Lake's water quality data was analyzed for yearly trends using a three-way MANOVA framework and 499 permutations. The multivariate model explained 3% of the total variance (r^2=0.031) and found that there were no statistical differences among the year spanning from 2004 to 2011 (F=2.43, p=0.108, Tables 9 and 10).

The three-way MANOVA analysis also evaluated the monthly changes in water quality and determined that there are significant summer season differences among months (F=28.35, p=0.001, Table 9). Overall, the water quality variables explained 36% of the total variance (r^2=0.360) and monthly alkalinity (F=27.098) was the factor that

contributed to the overall model significance (Tables 9 and 11). No other variable was found to have a strong effect on the multivariate model. The monthly trend in alkalinity decreased from May to October (Table 11), which suggests that acidic inputs to the lake throughout the summer shifted the buffering capacity of the lake in a significant fashion; another possible reason for this shift in alkalinity is that the change is a result of bicarbonate use by blue-green algae or macrophytes, which would alter the bicarbonate buffering system and diminish the buffering capacity of the lake.

The analysis of differences in water chemistry by depth did not find an overall significant difference (F=3.77, p=0.060, Table 9); however, the individual regression of pH found that it had a strong influence on the model despite the lack of the overall model significance (Tables 12 and 13). The acidity of West Twin Lake's epilimnion and hypolimnion differed significantly; this finding is common to temperate dimictic lakes due to thermal stratification, oxygen depletion in the hypolimnion, and increased carbon dioxide in the hypolimnion. Here we will not provide an exhaustive review because the topic was covered in previous sections but suffice to say that this result is normal and to be expected. No other variables had strong influence on the multivariate model.

Evaluating the year x month relationship among water quality variables in multivariate space indicated that there was a significant change in monthly water chemistry variables between 2004 and 2011 (F=8.145, p=0.007, Table 9). The multivariate model explained 10% of the total data variance (r^2=0.103) and a single variable, alkalinity (F=8.980), had a strong influence on the overall model. This result suggests that the buffering capacity of West Twin Lake's waters has not only changed significantly between 2004 and 2011, it has also changed when any given month is compared across years (Tables 10 – 13).

The other analyses that were conducted under the three-way MANOVA model did not detect any differences (Table 9). We did not find any significant differences in the year x depth analysis, which suggests that the relationship between lake-layers (i.e. epilimnion and hypolimnion) has not changed throughout the years (Tables 12 – 15). Furthermore, the trends in the month x depth water quality patterns have not changed. And finally, the year x depth x month relationships have not changed in any appreciable manner (Tables 9 and 12 – 15).

Aquatic Ecosystem Research also evaluated the water clarity pattern of West Twin Lake by year and month. The water clarity of the lake has not changed in any appreciable manner since 2004 and does not oscillate in a significant fashion when monthly averages are compared (Table 16).

Algal Community –
Qualitative Algae Community Assessment:
From 2004 to 2008 phytoplankton samples collected from surface waters had relatively low total cell concentrations, with greater diversity and richness than those observed after 2008 (figs. 8 – 10). Total cell concentrations neared 10,000 cells per mL only in samples collected in the summer of 2005 and otherwise were approximately 5,000 cells per mL or less. Cyanophyta (cyanobacteria or blue-green algae) were the dominant taxa in most samples and always in samples collected in June thru September (fig. 11). Other important taxa, particularly in samples collected in

May, included Chrysophyta (golden algae), Chlorophyta (green algae), and occasionally Bacillariophyta (diatoms).

Samples collected at the thermocline during that same time period generally exhibited characteristics similar to their corresponding sample from surface waters. Total cell concentrations were generally ≤5,000 cells per mL with the exceptions August 2004, July 2005 and September of 2008 when concentrations were 6,400, 6,700, and 9,400 cells per mL, respectively (fig. 12). Cyanobacteria were often the dominant taxa, particularly in samples collected in months other than May when golden algae, green algae, and/or diatoms were dominant or codominant (fig. 13).

Samples collected in September of 2008 exhibited a notable difference between the samples collected at the surface and thermocline. During this month, the cyanobacteria concentrations at the thermocline of 8,360 cells per mL was over 7 times greater than the concentration observed at the surface. In all other paired sampling events, surface and thermocline concentrations were similar or surface concentrations were slightly higher (figs. 8 and 12).

In the period from 2009 to 2011, phytoplankton samples collected in surface waters differed some from those collected during the prior period (i.e. 2004 – 2008). Changes included an increase in the frequency of cell concentrations nearing or exceeding 10,000 cells per mL with some reaching 12,000 cells per mL (fig. 8). Diversity and richness also decreased because cyanobacteria populations were often >90% of the surface community, particularly in the summer and fall (figs. 9,10,11). Whereas species richness would regularly range from 10 to 15 in surface samples collected from 2004 to 2008, richness values observed in surface samples during the 2009 – 2011 period were ≤8.

Characteristics of corresponding samples from the thermocline continued to be similar to those collected at the surface. Richness and diversity were lower than that observed from 2004 to 2008; cyanobacteria cell concentrations were modestly higher in summer and fall months (figs. 13,14,15).

From 2012 to 2015, several of the surface cell concentrations in the months of September and October were higher than those observed during the previous periods; cell concentrations ranged from 40,000 to 50,000 cells per mL (fig. 8). It is important to note that there were no samples collected in the fall in 2015. For those years when fall surface samples were collected, the flora was highly dominated by cyanobacteria (fig. 11), which would collectively comprise >98% of the total and were largely from the small-celled colonial taxa *Aphanocapsa spp.* and *Gomphosphaeria spp*. Richness and particularly diversity continued to drop, with diversity reaching near-zero values after May 2010 (figs. 9 and 10).

During this period there were notable differences between the samples collected at the thermocline vs. those collected in surface waters. The highest cell concentration in the thermocline throughout the twelve-year period was observed in July of 2012 (fig. 12); the community was dominated by cyanobacteria cells enumerated at 33,000 per mL (fig. 13), which was three times greater than the cell concentration at the surface (fig. 11). In September of the same year, thermocline concentrations were still high (approximately 27,500 cells per mL) but only half of that observed at the surface (figs.

13 and 11). In October of 2013 and 2014 there was great disparity between concentrations in surface waters vs. those at the thermocline.

Quantitative Algal Assessment:
There were evident changes in the algal community in our qualitative assessment. However, it was not clear whether those changes were "real" and statistically significant. To address this concern AER undertook a series of statistical protocols to further understand the dynamics of the algal community. We approached this problem by first determining whether there were significant trends in the populations of the various algal groups; we then overlaid the algal data with the environmental data to determine what – if any – environmental characteristics might be responsible for changes in the algal community.

We first analyzed the algae community of the epilimnion using General Linear Models; we attempted to determine if each group, including other community features, changed in a significant manner in relationship to each year and month. Total cell count was found to have increased significantly between 2004 and 2015 ($F=5.156$, $p=0.030$, Table 17) suggesting that the algal community has become more dense in the surface waters of East Twin Lake. Additionally, the analysis found that there is a significant increase in total algae cell count as the summer season progresses from May to October ($F=12.92$, $p=0.001$, Table 17). This suggests that as each summer season progresses, that the algal community of the epilimnion becomes more dense; this finding is common for temperate lakes. However, the yearly increase in cell density is not normal for lakes without some external or internal pressure (i.e. nutrient enrichment). We also found that there was a significant decrease in yearly algae diversity ($F=33.95$, $p<0.001$, Table 17) in East Twin Lake and that the diversity of the algal community did not vary significantly monthly during the summer season ($F=0.064$, $p=0.799$, Table 17). This result suggests that the algal community is becoming less diverse and that one group is becoming dominant in that community by outcompeting the other groups. The reason for this change is not clear from this analysis but could be related to some environmental perturbation such as local climatic conditions. Since total cell abundance is directly related to the prevalence of the Cyanophyta (i.e. blue green algae), which have increased between 2004 and 2015 ($F=5.782$, $p=0.022$, Table 17), the decreases in diversity since 2004 is a result of the increased blue green algae cell density. We also found that the Cyanophyta increased significantly throughout the summer season ($F=12.99$, $p=0.001$, Table 17) but blue green algae cell abundance did not affect monthly algal community diversity. Overall, these results suggest that the state of the Cyanophyta group is controlling total algae cell abundance and the diversity of the algal community in each year. Furthermore, the blue green algae group is dominant in East Twin Lake and increasing in yearly cell density, which is diminishing the diversity of East Twin Lake's algal community. There was not a significant change in the total richness of the algal community as it relates to year ($F=3.485$, $p=0.071$) or month ($F=2.924$, $p=0.097$, Table 17).

Due to the aforementioned findings, the theoretical biomass of the epilimnetic algal community was calculated in each month of each year following an approach provided by Ken Wagner of Water Resource Services (Wibraham, MA). This metric allowed for the assessment of whether the increase in cell density since 2004 also was expressed as an increase in total algal biomass. Biomass increases would further support the hypothesis that some external pressure is altering the state of the algal community, which might cause recreational and ecological impairment in the future. When AER

regressed the algae biomass vs. year, no significant trend was found (F=0.155, p=0.697, Table 17). This suggests that the community composition has shifted since 2004 but that there was no increase in the total productivity of the algal community. This result is important when considering the lack of any change in year-by-year water clarity of East Twin Lake since 2004. We also found that there was not a significant increase in algal biomass of the epilimnion throughout the summer season (i.e. May to October, Table 17). Again, we found an increase in the monthly cell density but that increase was not expressed as an increase in biomass, which further suggests that the shift exists in the composition of the algal community not its overall productivity. The reasons for the change in the composition are not immediately clear but the productivity has been relatively stable yearly and monthly in East Twin Lake's epilimnion since 2004.

To further resolve changes in the algal community of the epilimnion, each group's cell density (i.e. cell count) was analyzed for both yearly and monthly trends. Diatoms were not found to vary in any significant fashion yearly (F=0.038, p=0.846, Table 17) or monthly (F=0.062, p=0.804, Table 17). The Charophyte group also did not exhibit significant yearly (F=3.789, p=0.060, Table 17) or monthly (F=0.001, p=0.977, Table 17) trends. Additionally, the Chlorophyte group did not exhibit significant yearly trend (F=1.584, p=0.218, Table 17) but did increase in a significant manner during the summer season (F=6.982, p=0.013, Table 17). The Chrysophyte group also lacked a yearly (F=0.705, p=0.407, Table 17) trend but their cell density decreased in significant manner (F=6.352, p=0.018, Table 17) as the summer season progressed. The Cryptophyta did not exhibit significant relationships with year (F=0.024 p=0.879, Table 17) or month (F=0.407, p=0.528, Table 17). Euglenophyta did not show a significant yearly trend (F=0.605, p=0.443, Table 17) in the epilimnion of East Twin Lake; however, their cell density did increase significantly during the summer season (F=10.96, p=0.002, Table 17). Finally, the Pyrrophyta cell counts have decreased significantly (F=6.593, p=0.015, Table 17) year-to-year between 2004 and 2015 without any significant summer season trends (F=1.209, p=0.280, Table 17).

Following the analysis of the epilimnetic algal community we evaluated the trends in the metalimnion using General Linear Models (GLM). Total algal cell density was not found to have increased significantly in the metalimnion as a function of year (F=3.406, p=0.070, Table 18) or month (F=3.211, p=0.082, Table 18), which suggests that the algal community at this stratum was relatively stable between 2004 and 2015. Furthermore, we were unable to detect any significant changes in the algal diversity of the metalimnion between 2004 and 2015 (F=2.958, p=0.095, Table 18) or during the summer season (F=0.040, p=0.843, Table 18), which suggests that the proportional cellular contribution of each group to the metalimnetic community has not varied appreciably within the summer season or yearly since 2004. However, we did detect a subtle shift in the algal richness (i.e. the number of species) of the metalimnion as a function of year (F=4.605, p=0.038, Table 18), which suggests that the total number of genera has decreased in a significant fashion since 2004. The reason for this trend is not immediately clear but could be associated with the loss of minor community constituents, which would not affect the total cell density or diversity of the metalimnion algal community. However, this pattern was not realized as a function of the summer season; therefore, we can assert that this trend is probably due to a loss of minor community constituents or possibly related to sampling error. Cyanophyta (i.e. blue green algae) dominate the metalimnetic algae community on a cell-by-cell basis and the aforementioned community features are directly tied to oscillations in the blue

green algae populations. Analyzing the Cyanophyte group specifically, we found that the density of that group has increased significantly since 2004 (F=3.930, p=0.050, Table 18). However, the positive trend is not as striking as the trend found in the epilimnion because the statistical significance was controlled by a spike in a cellular abundance during a single year (i.e. 2012), which suggests that some environmental feature caused an increase in the density of Cyanophytes during 2012. Therefore, it is AER's opinion that the Cyanophyta of the metalimnion have been relatively stable with subtly increasing cell density in later years (m=654.80, r^2=0.052, Table 18). Finally, the examination of the blue green algae group during the summer season showed a distinct increase in density as the season progressed, which is expected because that is a common feature of all pelagic algal communities in hard water systems where the Cyanophyta take advantage of lower nitrogen to phosphorus ratios and elevated water temperatures; those conditions favor blue green algae populations later in the summer season.

To determine whether there was any shift in the biomass production of the metalimnetic algal community during the summer since 2004, AER again regressed the total biomass of the algal community at this stratum against year and month. Our analysis did not detect any significant shift in the yearly (F0.010, p=0.921, Table 18) metalimnetic algal community productivity. This finding suggests that while there have been some oscillations among genera that there has been no "real" change in the overall production of algae in the metalimnion since 2004. Furthermore, no significant trend was detected in the summer season dynamics (F=1.857, p=0.182, Table 18) of the metalimnetic algal community productivity. We would expect to see an increase in productivity as the season progresses due to changes in nutrient concentrations or thermal structure of a lake; however, this was not the case. The productivity of the algal community at the metalimnion stratum did not exhibit productivity changes as the summer progressed despite the shifts in specific genera or total cell count.

To further resolve the characteristics of the metalimnetic algal community, the other algal groups were analyzed in relation to year and month using General Linear Models. We were unable to find any significant oscillations in the diatom group of the metalimnion as a function of year (F=1.961, p=0.170, Table 18) or month (F=0.072, p=0.790, Table 18). Charophytes were not found to be present in the metalimnion in any year or month between 2004 and 2015. The green algae (Chlorophytes) were also found to have no significant relationships with year (F=0.928, p=0.342, Table 18) or month (F=0.851, p=0.363, Table 18). The Chrysophyte group did not exhibit any yearly trends (F=0.005, p=0.974, Table 18) in the metalimnion but diminished significantly in that water volume (F=7.756, p=0.008, Table 18) as the summer season progressed (i.e. May to September). The Euglenoids did not exhibit any significant yearly trend (F=2.921, p=0.097, Table 18) but increased significantly in the metalimnion (F=13.660, p<0.001, Table 18) throughout the summer months. The Pyrrophyta did not exhibit any yearly (F=3.700, p=0.063, Table 18) or monthly (F0.986, p=0.328, Table 18) in the metalimnion.

The preceding analyses did not examine whether any changes in the water chemistry of East Twin Lake were having an impact on the structure of the algal communities of the epilimnion or metalimnion. To examine the influences of environmental factors on the state of the algal community – of both layers – we used Canonical Correspondence Analysis (CCA). To do this, two data sets were created: 1)

Environmental (Constraining) and 2) algae groups (Response). The multivariate model of each analysis (i.e. epilimnion and metalimnion) was built with a forward selection process (α=0.05) and 999 permutations. The total variance explained by the model was calculated by taking the sum of all constrained axes divided by the total inertia. Individual environmental variables were evaluated in multivariate space and their relative influence was determined from their F-statics averaged over 999 permutations. The environmental variables included year, month, and the layer specific chemical features including pH, alkalinity, TKN, ammonia, nitrate, dissolved phosphorus, and total phosphorus. The algae variables included the Bacillariophyta, Charophyta, Chlorophyta, Chrysophyta, Cryptophyta, Cyanophyta, Euglenophyta, Pyrrophyta, Total Cell Count, Richness, and Shannon's Diversity Index.

Firstly, the epilimnetic community was analyzed in the aforementioned fashion. The analytical protocol resolved 9 constrained axes and explained 74.5% of the total variance. Examining the individual axes, it was determined that the first three resolved axes were found to be significant and independent. However, the examination of the individual variables did not resolve any strong relationships among those variables and the overall community structure except for the previously detected yearly and/or monthly trends (Table 19). Secondly, we analyzed the same constraining variables in relation to the metalimnetic algal community. That model resolved 8 constrained axes and accounted for 73.9% of the total variance. The first three canonical axes were found to be significant and independent. Again, examination of the individual variables did not resolve any strong relationships among the environmental variables and the algal community structure except the previously detected relationship between cell count and month (Table 20). Those findings suggest that the measured chemical features of East Twin Lake are not oscillating in a fashion that is affecting the algal community structure of the epilimnion or metalimnion. However, the changes in the algal community that were detected in regards to total cell counts and individual group cell counts could be related to changes in other variables that were not measured such as thermal structure or other chemical features (i.e. iron/manganese).

The final analysis of the algal community that was undertaken compared the total cell counts of the epilimnion and metalimnion. This analysis was undertaken by taking the difference between the cell counts of the epilimnion and metalimnion as a function of year and developing a mathematical model that most suitably represented the trend in those data. The ultimate model was found to be a fourth-order polynomial that accounted for 73.7% of the total variance in those data. This model suggests that between 2004 and 2012 that the algal communities of the epilimnion and metalimnion were similar, varying between -2000 and 2500 cells (fig. 16). However after 2012, the difference grew exponentially; the epilimnion was much denser in algal cells compared to the metalimnion (fig. 16). The reason for this change after 2012 is not immediately clear but AER believes that there may have been some change in the thermal structure of the lake, which lead to a redistribution of the algal community. More examination is necessary to determine what influence thermal structure is having on the state of the algal community.

Plant Community –
Between 2004 and 2015 twenty aquatic macrophyte species were detected in East Twin Lake (Table 21). Two of those species are listed by the state of Connecticut as threatened or endangered. The state listed species that were detected between 2004 and 2015 were *Megalodonta beckii* and *Myriophyllum sibiricum*. Two state listed

aquatic macrophytes were not detected by the surveys that occurred between 2004 and 2015; the species that were not detected during that period were *Potamogeton ogdenii* and *Potamogeton strictifolius*. Despite the fact that those species were not detected by the yearly surveys, *P. strictifolius* was found by AER during their site visit in July of 2016; however, the distribution of that species was not quantified.

Potamogeton amplifolius (12 – 26% of the community) and *Vallisneria americana* (10 – 25% of the community) were found to be the dominant macrophyte species in East Twin Lake. The macroalgae *Chara spp.* was also found to be a dominant constituent of the aquatic plant community (20 – 30%). *Myriophyllum spicatum* accounted for between 3 and 18% of the macrophyte community.

When AER examined specific portions of the vegetation data set as a function of year it was noted that the relative contribution of *M. spicatum* to the plant community has not varied appreciably (F=0.003, p=0.963, fig. 17) since 2004. Since the only consistent vegetation data set was from post treatment surveys, it is difficult to determine whether there has been a significant change in the contribution of *M. spicatum* to the community structure in the absence of herbicide treatments. However, there was a subtle increase in the number of *M. spicatum* encounters (F=3.557, p=0.092, fig. 18) between 2004 and 2015. AER also examined whether total plant abundance had changed since 2004; we found that there was no change in the average vegetation coverage (F=1.998, p=0.191, fig. 19) and a significant increase in average vegetation encounters (F=11.680, p=0.008, fig. 20) since 2004. These results suggest that the plant community may be increasing in yearly productivity. However, because data were collected on a presence/absence basis, it is not possible to determine whether those trends are "real". Furthermore, community diversity (F=0.040, p=0.846, fig. 20) and species richness (F=3.021, p=0.116, fig. 21) have been stable since 2004. Finally, AER determined that the most productive zone of East Twin Lake is between 0.5 and 3m (fig. 22).

Between 2004 and 2015, twenty-six aquatic macrophyte species and the macroalgae *Chara spp.* were detected in West Twin Lake (Table 21). Two of those aquatic plant species are listed as threatened by the State of Connecticut. The state-listed species in West Twin Lake are *Megalodonta beckii* and *Myriophyllum sibiricum*. It should be noted that the state documents do not indicate specific zones known to contain the rare species in West Twin Lake, but they are certainly present. It is currently unknown whether the other state listed aquatic macrophyte species are present in West Twin Lake because they were not detected during AER's visit.

Potamogeton amplifolius (15 - 66% of the community) and *Vallisneria americana* (25 – 59% of the community) were found to be the dominant macrophyte species in West Twin Lake. Furthermore, the lily-species *Nymphaea odorata* comprised a significant portion of the aquatic plant community (13 – 22%). The macroalgae *Chara spp.* was also found to be a dominant constituent of the aquatic plant community (30 – 62%). *Myriophyllum spicatum* accounted for 16 to 22% of the macrophyte community.

When AER examined specific portions of the vegetation data set as a function of year it was noted that the relative contribution of *M. spicatum* to the plant community has diminished (F=14.98, p=0.004, fig. 23) since 2004. Since the only consistent vegetation data set was from post treatment surveys, it is difficult to determine whether there has been a significant change in the contribution of *M. spicatum* to the

community structure without the treatments. However, there was a notable but non-significant decrease in the number of *M. spicatum* (F=2.296, p=0.164, fig. 24) encounters between 2004 and 2015. AER also examined whether total plant abundance had changed since 2004; we found that there was a subtle (F=2.673, p=0.137) increase in the total number of vegetation encounters since 2004 (fig. 25) suggesting that the plant community productivity may be increasing. Furthermore, community diversity was found to have decreased (F=7.052, p=0.026, fig. 26) since 2004 but this might be a statistical anomaly because the decrease was subtle. Plant species richness was found to be stable (F=0.888, p=0.371, fig. 27) between 2004 and 2015. Finally, AER determined that the most productive zone of West Twin Lake is between 1.0 and 3m (fig. 28).

During AER's visit to the Twin Lakes in July of 2016 an assessment of the total lily-coverage was conducted. The results suggest that lilies cover 9.5 acres in East Twin Lake (fig. 6). In West Twin Lake there was 16.6 and 18.6 acres of sparse and dense lily coverage, respectively (fig. 7). Recommendations for lily-species management will be presented later in this report.

Fish Community –
East Twin Lake was sampled by CTDEEP during the years of 1992, 1996, 1998, 1999, 2002, 2003, 2004, 2005, 2006, 2007, 2009, 2010, 2011, and 2014. Twenty species were detected during those surveys. Multivariate Analysis of Variance found that the community as a whole has changed significantly (F=3.504, p=0.030, Table 22) since 1992. However, the overall multivariate model was controlled by changes in the Black Crappie (F=39.729, p<0.001, fig. 29), Golden Shiner (F=14.886, p=0.002, fig. 30), Rock Bass (F=9.024, p=0.011, fig. 31), and Creek Chubsucker (F=8.853, p=0.012, fig. 32) populations (Table 22). The variables Total Catch/Effort (F=3.840, p=0.074), Species Richness (F=2.697, p=0.127), and Shannon's Diversity (F=1.673, p=0.220) did not exhibit any significant trends (Table 22). Those results suggest that the higher-order features of the community (Fish Productivity, Diversity, etc.) have not changed appreciably but that some individual species populations have changed significantly, which resulted in a significant multivariate trend. In regards to the individual variables, there were some interesting relationships that will be described in the proceeding text. Despite the finding that Total Catch/Effort did not exhibit a trend that differed statistically from random, the visual trend is that of notable decreasing catch/effort since 1991 (fig. 33). Conversely, fish community diversity (Shannon's, fig. 34) and richness (fig. 35) have remained unchanged. The reason for the trend in catch/effort in concordance with the lack of notable changes in diversity/richness is not immediately clear but could be associated with increased recreational fishing or other anthropogenic impacts; it is impossible – however – to determine what is causing the changes in total catch/effort because that information was beyond the scope of this management planning document and further investigation would be necessary. Specifically, the Black Crappie, Golden Shiner, and Creek Chubsucker populations have diminished significantly since 1991 (Table 22) and were found to have extremely limited populations during later years of that study. Conversely, the Rock Bass population has increased significantly from 50 caught/effort to 200+ caught/effort since 1992 (fig.31). Unfortunately, AER cannot determine the causes of the aforementioned changes due to the complexity of the study necessary to further resolve these trends and because of the multiple fish stocking/recreational fishing activity variables that are currently not available.

In West Twin Lake, 15 species were detected between 2000 and 2014 and the lake's fish community was surveyed in 2000, 2003, 2011, and 2014. We were unable to statistically analyze the fish community due to dataset requirements (i.e. number of response variables vs. number of sampling events) associated with ethical analytical protocols. However, we found that the community is dominated by Bluegill (average catch/effort=459) and Yellow Perch (average catch/effort=127). Furthermore, 11 species were detected on average and the Shannon's Diversity Index average was 1.29. Finally, average total catch/effort was 728.

Watershed –
Periodic assessments of the watershed, including land use cover, are important because of the important influence the watershed has on lake water quality. Field et.al. (1996) were able to correlated lake trophic condition with watershed forest cover and lake ionic levels to the degree of urban-residential land cover in the watershed. Siver et.al. (1999) showed that Connecticut lakes in watersheds that have remained ~80% forest cover tended not to experience water quality changes while those with watersheds that exceeded 25% residential changed the most over the last 100 years.

As reported earlier, the collective watershed for East and West Twin Lakes is 4,681 acres. The combined surface area of East Twin and West Twin Lakes is 859 acres so the combined watershed to lake surface area (WS/SA) is 5.4. Using the sub-watershed areas and surface areas for East Twin and West Twin Lakes separately, watershed-to-surface-area ratios were calculated to be 4.6 and 7.1, respectively. These ratios – separate and collective – were low in comparison to other lakes in Connecticut based on Canavan and Siver (1994) who reported on a 60-lake survey where WS/SA range of 1.8 to 391.3.

Aquatic Ecosystem research conducted a basic watershed analysis using GIS technologies and found 10 different distinct cover-types (fig. 3). Our analysis of land use cover indicates that forested or wooded areas, including forested wetlands, are 55.4% of the entire watershed and less than the theoretical 80% threshold discussed in Siver et.al. (1999). Residential development in the watershed is 9.1%; well under the theoretical 25% threshold (fig. 3). We also found that 11.4% of the watershed is agricultural land cover. This feature is worth noting because agricultural land use can be a significant exporter of nutrients.

Based on this assessment, it may be important to consider opportunities to protect undeveloped lands on the lake and within the watershed. Finally, it may be prudent to see if appropriate best management practices for the agricultural activities in the watershed are being implemented.

Volumetric Sediment Analysis –
The small channel that connects East Twin and West Twin lakes was surveyed to examine the accumulation of soft sediment. Adjacent to this channel is a densely vegetated wetland that appears to be encroaching into the channel, which might make navigation difficult in the future (fig. 4). That vegetated area is to the east of the main channel. This survey found that there was a nominal amount of accumulated sediment in the main channel; the total volume of sediment in the main channel was found to be 47.50yd^3. That total volume was asymmetrically distributed among the three transects that were established and examined by AER. The first transect (green) was found to contain 21.35yd^3 of soft, removable, sediment that exhibited that highest

accretion volumes at the eastern edge (fig. 36). The second transect (purple) was found to contain 12.14yd^3 of sediment, which as asymmetrically distributed along the eastern side of that transect (fig. 37). The third transect (orange) contained 14.01yd^3 of removable sediment, which had accumulated on the western side of that area (fig. 38).

RECOMMENDATIONS

This section will cover the specific recommendations for the ongoing management of the Twin Lakes Ecosystem. The recommendations will be presented in a priority-based manner and, where necessary, a fully resolved protocol will be cited. Those full protocols will be presented in the Appendix section of this report for ease of separation from the main text of this report.

Tier 1 Management Initiatives (High Priority) –

Plant Community Management:
It is the opinion of Aquatic Ecosystem Research that plant management be continued in the Twin Lakes system. However, AER also believes that broad-scale herbicide treatments should not be continued. We propose an *Inspect and Respond* approach to the management of *M. spicatum*. The reason we propose additional temperance is because aquatic macrophytes provide numerous ecosystem services including buffering water chemistry to nutrient inputs, enhancing the oxygen concentration of the water body, and providing habitat to numerous aquatic species. And despite the fact that a plant is not native to a region, it is still a constituent of the ecosystem and providing ecosystem services. Therefore, we propose the following approach to herbicide use decision-making process:

- Each year the areas of interest, which are outlined in figures 39 and 40, should be examined and patches of *M. spicatum* should be quantified using GPS/GIS technologies.
    - The Twin Lakes Association should then prioritize the patches that were mapped during the aforementioned inspection and treatment should proceed following a prioritization treatment areas.
        - The following conditions should be considered when choosing *M. spicatum* patches to treat with herbicides.
            - The patch is large (i.e. >0.4ac).
            - The patch impairs recreational access or activities.
            - The patch (or set of patches) might compromise the diversity characteristics of the holistic plant community.
    - The purpose of changing the plant management protocol in this way is to return choice to the Twin Lakes Association by allowing them to choose what is treated. Under the current approach to plant management, the management company chooses what to treat.
    - We expect this change in protocol to reduce the overall treatment acreage and cost of herbicide applications.
- AER also encourages The Twin Lakes Association to continue to promote other physical plant management techniques to manage resident swim areas for non-target plant species or small patches of *M. spicatum*.
    - Diver Assisted Suction Harvesting is an approach that is well suited for removing small patches of nuisance aquatic macrophytes.

        - Given the yearly costs associated with owning, insuring, and staffing the diver assisted suction harvester that The Twin Lakes Association currently houses at O'Hara Marina; it may be advantageous to develop a relationship with a local company that executes that type of work and build a customer base for undertaking yearly swim area maintenance.
            - If this program is developed, the first-year cost of the program might be offset if the suction harvester currently owned by The Twin Lakes Association is sold.
        - Aquatic Ecosystem Research expects that by developing a relationship with a diver assisted suction harvesting company and providing a customer base that the costs of suction harvester maintenance/insurance/staffing could be removed from The Twin Lakes Association budget and that customer cost could be reduced over time as more people take advantage of the program.
- Aquatic Ecosystem Research also recommends that The Twin Lakes Association promote the use of benthic barriers in resident swim areas because the one-time cost of the benthic barrier – including yearly maintenance – could offset the long term costs of yearly diver assisted suction harvesting to the resident.

Water Quality Monitoring:
As previously discussed, the current water quality monitoring protocol is not satisfactory and is likely expensive. Currently, The Twin Lakes Association is paying for an incomplete chemical evaluation of their water body. More concerning, the water quality monitoring program is a directive of CTDEEP and a requirement of the herbicide treatment permit. If the CTDEEP analyzed the water quality dataset and took exception to the incomplete design of the program, future permits might not be approved. Aquatic Ecosystem Research proposes a new water quality monitoring program to be implemented in both lakes.

- The implemented water quality monitoring program should include:
    - Full vertical profiles of:
        - Temperature
        - Dissolved Oxygen
        - pH
        - Specific Conductance
    - Water Clarity
    - Algal Assessments
    - Nutrient Analyses
    - Metal Analyses
    - All of the aforementioned should be conducted every month over a 6 or 8-month period during the summer season.
- A full description of AER's proposed water quality monitoring program is outlined in **APPENDIX A.**

Rare Plant Survey:
The last time a rare plant survey was conducted in the Twin Lakes system was in the year 2000. Some plant species distributions can change significantly in as little as 5 years in systems where disturbances are common (i.e. lakes with recreational activity

and herbicide treatments). The CTDEEP has taken note of the age of the rare plant survey and may require such a survey before future permits are awarded.

- Aquatic Ecosystem Research recommends that – at minimum – a rare plant survey is conducted in East and West Twin Lakes to resolve the distribution of:
    - *Megalodonta beckii*
    - *Myriophyllum sibiricum*
    - *Potamogeton strictifolius*
    - *Potamogeton ogdenii*
- Aquatic Ecosystem Research also recommends that a full qualitative/quantitative plant community survey be conducted because this type of survey has not been conducted. A complete qualitative/quantitative aquatic macrophyte survey includes:
    - Qualitative mapping of all aquatic macrophyte species.
    - Quantitative mapping of non-native and rare species.
        - Total acreage and distributions.
    - Mathematical descriptions of all species distributions.
    - Plant community models in relationship to depth and light.
    - **A full description of a qualitative/quantitative plant survey is available in APPENDIX B.**

LakeSmart Program:
A LakeSmart Program is a community-directed initiative designed to develop and cultivate stewardship and a sustainable living ethic on and near a lake. Several programs serve as models in New England and include the Maine LakeSmart Program, perhaps one of the first of its kind and the flagship conservation program of the Maine Lake Society. The Connecticut Federation of Lakes (CFL) also developed a LakeSmart Program and provides a list of best management practices (BMPs) for lake associations and homeowners that are in the interest of enhancing lake recreational quality. Programs such as these are pledge programs, i.e. participants sign pledges that they are implementing a number of BMPs at home and practices in the watershed that are in the interest lake protection. These programs often include rewards for participants such as plaques or attractive signage that can be displayed to signify their contribution to the LakeSmart Program.

AER recommends that the Twin Lakes community consider promoting the existing CFL LakeSmart Program or customizing the program for their specific lake management needs. The CFL program groups BMPs into one of four categories:

- **Managing Waste**
    - For lake areas where on-site sewage treatment or septic systems are the prevailing waste management option, community commitment to this category is vital from both a lake and a human health perspective. BMP commitments in this category should include:
        - Regularly scheduled pump-out, inspection and maintenance if necessary of the on-site septic system. Schedules will vary on level of use, number of residents at a home, etc.
    - Clean up after pets in a timely manner to prevent waste runoff from a property.
    - Do not use storm drains or the lake to dispose of yard waste like leaves and other debris.

- **Waterfront and Watershed Landscaping**
    - It is well known that appropriate lakeside landscaping and landscaping practices help protect the water quality and other environmental aspects of lakes. This holds true for properties on and near the lake. Some potential BMPs residents might pledge to follow could include:
        - Reduce or eliminate use of chemical fertilizers and pest control products particularly when other options are available.
        - Create a vegetated buffer on the lakeshore or around the perimeter of a property to reduce pollutant-laden storm water runoff.
        - Use trees, shrubs and groundcovers that are native to New England to improve odds of successfully establishing the "buffer gardens."
- **Managing Storm Water**
    - Storm water management is one of the primary ways a homeowner can commit to a healthier lake. Pollutants such as fertilizers are most often "carried" to the lake by storm water. If you reduce storm water coming off your property, you reduce pollutants being carried to the lake. Some possible measures a homeowner could implement to reduce storm water include:
        - Properly installed rain gardens can be an attractive way to reduce storm water export from your property. The University of Connecticut NEMO Program provides a mobile phone app that provides guidance on how to design, install and maintain a rain garden and can be found at http://nemo.uconn.edu/tools/app/raingarden.htm.
        - Install rain barrels to collect and store roof gutter runoff.
        - Reduce impervious surfaces on the property and create more areas where runoff can infiltrate into the groundwater.
- Aquatic Ecosystem Research can help the Twin Lakes Association to develop their LakeSmart Program.

Tier 2 Management Initiatives (Secondary Priority) –

Boat Lane Creation:
The tributary entering the northern end of East Twin Lake currently houses dense stands of *Nymphaea odorata* and other plant species. The incursion of plants into this tributary inlet has compromised flow and recreational access to the adjacent wetland. Aquatic Ecosystem Research recommends that a boat lane be constructed through the lilies to the wetland with the use of a hydrorake. The proposed boat lane is 33ft wide and 328ft long. The total surface area to be managed with the hydrorake is 10,758ft^2 (fig. 6). To conduct this project the following will be necessary:

- The area of the proposed boat lane is in close proximity to areas thought to contain populations of the rare macrophyte species. Therefore, it will be necessary to conduct a survey of the proposed boat for rare species and provide the results to the CTDEEP.

- Permission to conduct hydroraking will also have to be obtained from the Division of Land Acquisition and Management.
- Salisbury Inland Wetlands Commission may also have to approve the project.

Lily and Sediment Management West Twin Lake –
The lily patches are currently a management necessity in West Twin Lake. There are two areas where lilies are an issue. The following lily management initiatives are recommended.

- Rowing Lane
    - Lilies are prevalent along the western shoreline of West Twin Lake and are encroaching on the rowing lane used by Salisbury School and other recreational rowers.
    - Aquatic Ecosystem Research recommends that a hydrorake be used to manage portions of the lily patches shown on (fig. 7) encroaching on the rowing lane.
        - To undertake this project permission from the CTDEEP Division of Land Acquisition and Management and The Town of Salisbury might be necessary.
            - West Twin Lake is not owned by The State of Connecticut but permission may still be necessary.
            - Salisbury Inland Wetland Commission may also have to approve the project.
- Northern Section and Outlet Area
    - There is significant sedimentation and lily encroachment at the outlet of West Twin Lake (figs. 7,40). The scope of this project could be very large. Therefore, Aquatic Ecosystem Research has divided the project in to the following phases:
        - North Western Area
            - There is significant sediment accretion and lily encroachment in this area. This project only includes areas that are part of West Twin Lake proper; areas further west or part of the channel leading to the dam are part of the second phase. AER recommends that a hydrorake be used to manage lilies and sediment in the northwest area of West Twin Lake to restore recreational access and water flow. (figs. 7,40)
                - Permission to undertake from CTDEEP Land Acquisition and Management and Salisbury Inland Wetland Commission might be necessary.
- Outlet Channel
    - The area extending from the northwestern limit of West Twin Lake to the outlet dam has accreted significant volumes of sediment that has lead to the populations of lily-species to expand. Furthermore, the stream leading to the dam has become choked with debris in some areas. Therefore, Aquatic Ecosystem Research recommends the following projects be undertaken:
        - General clean-up to remove debris.

- A hydroraking initiative in the area just northwest of the West Twin Lakes outlet to manage lilies/sediment and to create an area of enhanced water flow to the dam.
    - This project may require permission from CTDEEP Division of Land Acquisition and Management and Salisbury Inland Wetlands Commission.
- An investigation of the entire channel to determine the feasibility/necessity of further channel management.

General Lake Debris Removal:
Debris can tend to accumulate under the Isola Bella causeway underpass and in the channel connecting East and West Twin Lakes. Aquatic Ecosystem Research recommends that these areas be cleared of debris on a yearly basis.

RARE SPECIES SURVEY SCHEDULE

The Twin Lakes system contains 17 known state-listed species. With the presence of this many rare species there can be some complications in lake management permit acquisitions. To resolve the issue with tracking the historical surveys of rare species, Aquatic Ecosystem Research has developed the following schedule for The Twin Lakes Association. We have divided the rare species in to groups, provided their last known survey dates, and developed a schedule for future surveys.

Aquatic Macrophytes:

- Last survey conducted in the year 2000.
- Recommended survey schedule:
    - 2017
    - 2022
    - 2027

Aquatic Invertebrates:

- Last survey conducted in the year 2015.
- Recommended survey schedule:
    - 2020
    - 2025
    - 2030

Semi-Aquatic Vertebrates/Invertebrates:

- Last survey conducted in the year 2011
- Recommended survey schedule:
    - 2021
    - 2031
    - 2041

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APPENDIX A

A critical element to successful lake management programs is consistent and statistically robust water quality monitoring. An effective program allows lake managers and lake community stakeholders to: 1) develop essential baseline datasets; 2) detect trends and/or changes in water quality over time; and 3) determine if an implemented lake management strategy is effective or not.

The most important seasons to monitor water quality in lakes of the Northeast are spring, summer and fall. These seasons provides insights into spring freshet conditions, peak productivity, and conditions at fall turnover. AER recommends either a six (6) or eight (8) month monitoring program covering those seasons, i.e. monthly visits from May through October or from April through November.

During each visit AER staff would launch a boat onto East Twin and West Twin Lakes and anchor at the deepest site on each lake. Once anchored, the following data would be collected in the field with YSI Professional water quality monitoring equipment:

- Temperature profiles (profiles denotes that measurements are taken at the surface and at one meter intervals until the lake bottom is reached)
- Dissolved oxygen and percent saturation oxygen profiles
- Conductivity and specific conductivity profiles
- pH profiles

Secchi transparency would also be measured with a 20 cm diameter black and white Secchi disk.

In addition, water samples would be collected with a Van Dorn horizontal water sampler near the surface at one meter depth, at the thermocline or the depth of increased oxygen concentration, and at one meter from the bottom. Water samples would be collected for the following laboratory analyses:

Surface (1 m depth)	**Thermocline**	**Bottom (1 m above bottom)**
Total phosphorus	Total phosphorus (optional)	Total phosphorus
Total nitrogen	Total nitrogen (optional)	Total nitrogen
Total Kjeldahl Nitrogen (TKN)	TKN (optional)	TKN
Nitrate	Nitrate (optional)	Nitrate
Nitrite	Nitrite (optional)	Nitrite
Ammonia	Ammonia (optional)	Ammonia
Alkalinity		Alkalinity
Iron		Iron
Manganese		Manganese
Chlorophyll-*a*	Chlorophyll-*a* (optional)	
Phycocyanin	Phycocyanin (optional)	
Algal identification & enumeration	Algal identification & enumeration	

In addition, a concentrated plankton sample would be collected with a 10 µm mesh plankton net and also used for algal identifications, in particular for rarer taxa. A photographic record of important phytoplankton taxa would also be created.

Note the option for full nutrient analyses for samples collected at the thermocline. Also note that biological analyses (chlorophyll-*a*, phycocyanin, and algae) are not recommended as options for samples collected at the bottom. Similarly, analyses of alkalinity, iron, and manganese are not recommended for samples collected at the thermocline.

All data would be entered into Excel spreadsheets and stored on AER servers.

APPENDIX B

RECOMMENDATIONS: AQUATIC INVASIVE PLANT MANAGEMENT

The following are recommendations for the assessment of the aquatic plant community and aquatic invasive plant management.

Pretreatment Assessment:
In a going forward basis, Aquatic Ecosystem Research is recommending an *"inspect and respond"* approach to aquatic invasive plant treatments. Inspections and assessments of aquatic invasive plants performed during a given year should be the basis of herbicides or other aquatic plant management options in the following year. This may reduce unnecessary applications of herbicides or other treatments and provide more cost effective management.

Qualitative Plant Mapping:
Aquatic Ecosystem Research is recommending both qualitative plant mapping and quantitative plant community modeling for East and West Twin Lakes. First, a qualitative plant mapping would be conducted by slowly motoring throughout the entirety of the littoral zone on East and West Twin Lakes. Plants will be identified visually following Crow and Hellquist (2000) after a sample is collected with a grapple tied to a 20m line. This type of survey is used to develop a species inventory and to determine each species' general location. Species ranges will be logged on blank lake maps using dead reckoning and then georeferenced in ARCMAP®; a qualitative aquatic plant distribution map will be created from those data.

Quantitative Plant Community Modeling:
A more quantitative modeling of the East and West Twin Lakes' plant communities would be conducted using a random block design method. To develop statistical models, 48 geo-referenced points will be established at depths ranging from 0.1-6.0m in both East and West Twin Lakes. These points will be organized by depth; six depth classes will be created (0-1, 1-2, 2-3, 3-4, 4-5, and 5-6m) and each class will contain between 6 and 10 points. At each point the boat will be anchored, oriented perpendicular to the nearest shoreline, and the depth measured off the front of the boat using a weighted drop line. The plant community will be sampled using a grapple tied to a 20m line. At each point, four grapple tosses (two to each side of the boat) will be conducted by throwing the grapple parallel to the nearest shore out to the full length of the line. Plant species will be identified on site following Crow and Hellquist (2000) and their abundance evaluated using a rank abundance technique. The abundance of each species will be evaluated by two independent observers and given a rating of 1 - rare, 2 – present but not abundant, 3 – abundant but not dominant, 4 - dominant, or 5 – dense monoculture.

Those data will be compiled in an Excel Spreadsheet® and various abiotic/plant community parameters calculated. Light availability at the sediment-water interface will be calculated at each point using the following formula: $I_z = e^{(-kz)} * I_o$, where I_z is light intensity at depth z, e is Euler's number, k is the attenuation coefficient of light in water multiplied by the Secchi depth, z is the depth, and I_o is the solar constant (340 w/m2). Point diversity will be calculated using Shannon's Diversity Index $[-\Sigma (p_i * \ln(p_i)) – (S-1/2N)]$ where p_i is the fraction of the community each species is representative of, S is the total lake richness, and N is the total abundance at each point. Point richness will be calculated by counting the number of species encountered at each point. Total

point abundance will be calculated by taking the sum of all species' rank abundance values at each individual point. Finally, the relative contribution of each species to the community will be calculated by taking the sum of each individual species' rank abundance values across all points, dividing it by the total rank abundance of all species at each point, and multiplying that quotient by 100.

These statistics will then be used to develop the plant community models. General Linear Models (GLM) will be employed to determine which mathematical models best fit those data. Models will be assessed using Akaike Information Criteria (AIC); in each case the model with the lowest AIC will be chosen (i.e. best fit). Those analyses will be conducted in R for the following variables as they relate to depth and light availability: 1) Total Point Abundance, 2) Diversity, and 3) Richness.

TABLES

Table 1: Three-way MANOVA results of East Twin Lake water chemistry. *Bold indicates significant findings.*

Three-Way MANOVA of East Twin Water Quality					
Multivariate Model Results (permutations = 499)					
Control Variable(s)	*Sum of Squares*	*Mean Square*	*Model F*	*R-squared*	*p*
Year	0.022	0.022	14.26	0.094	**0.001**
Month	0.001	0.001	0.81	0.005	0.454
Depth	0.033	0.033	21.63	0.142	**0.001**
Year x Month	0.005	0.005	3.39	0.022	0.070
Year x Depth	0.000	0.000	0.22	0.001	0.705
Month x Depth	0.013	0.013	8.24	0.054	**0.008**
Year x Depth x Month	0.001	0.001	0.43	0.003	0.559

Individual Variable Regressions (p-value)							
Variable	*Year*	*Month*	*Depth*	*Year x Month*	*Year x Depth*	*Month x Depth*	*Year x Depth x Month*
pH	0.205	**<0.001**	**<0.001**	0.934	0.098	**0.003**	0.232
Alkalinity	**0.004**	0.343	**0.005**	0.120	0.565	**0.030**	0.569
TKN	0.103	0.311	0.404	0.168	0.140	0.676	0.708
Ammonia	**0.020**	**0.002**	**0.055**	0.226	0.638	**0.020**	0.498
Nitrate	**<0.001**	0.647	0.546	0.931	0.145	0.382	0.390
Dissolved Phosphorus	0.571	**0.006**	**0.010**	0.317	0.301	**0.008**	0.241
Total Phosphorus	0.499	**0.002**	**0.006**	0.261	0.465	**<0.001**	0.392

Table 2: Yearly averages of water quality parameters (i.e. whole lake) for East Twin Lake since 2004.

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East Twin - Water Chemistry Averages by Year								
Year	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
2004	7.83	126.67	0.27	0.00	0.04	7.13	11.42	27.45
2005	8.05	132.50	0.14	0.06	0.12	2.58	6.17	43.11
2006	7.71	125.78	0.67	0.06	0.13	5.50	9.82	81.45
2007	8.04	137.67	0.46	0.01	0.25	3.54	11.87	59.46
2008	8.08	118.89	0.34	0.00	0.00	43.67	78.11	4.41
2009	7.95	123.78	0.36	0.01	0.00	4.26	10.58	33.61
2010	8.11	123.89	0.36	0.02	0.00	5.37	15.30	23.24
2011	7.92	120.67	0.42	0.00	0.00	5.22	14.58	28.96
2012	7.90	116.83	0.47	0.00	0.00	0.00	3.89	120.00
2013	7.65	118.11	0.77	0.02	0.00	12.33	22.78	33.87
2014	7.67	121.11	0.44	0.11	0.00	10.89	15.56	28.36
2015	8.17	118.33	0.45	0.09	0.00	9.50	19.83	22.52

Table 3: Monthly averages of water quality parameters (i.e. whole lake) for East Twin Lake since 2004.

East Twin - Water Chemistry Averages by Month								
Month	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
May	8.00	128.60	0.42	0.01	0.05	5.71	9.48	49.93
June	8.09	119.39	0.34	0.02	0.02	10.61	19.89	17.75
July	7.86	124.71	0.54	0.02	0.09	2.49	8.05	78.62
August	7.95	125.08	0.40	0.03	0.09	7.53	15.75	30.79
September	7.84	121.67	0.40	0.05	0.02	16.49	33.97	12.35
October	7.57	123.67	0.18	0.09	0.00	19.13	37.36	4.79

Table 4: Yearly epilimnetic water chemistry averages (i.e. surface waters) for East Twin Lake since 2004.

East Twin - Epilimnetic Water Chemistry Averages by Year								
Year	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
2004	8.08	122.50	0.28	0.00	0.00	1.83	2.25	125.56
2005	8.33	125.00	0.18	0.05	0.06	0.50	4.25	57.06
2006	8.00	119.67	1.00	0.07	0.16	4.67	6.00	193.89
2007	8.38	117.00	0.43	0.00	0.52	2.20	7.60	125.00
2008	8.39	114.33	0.43	0.00	0.00	40.33	59.33	7.30
2009	8.34	119.33	0.30	0.00	0.00	5.03	7.63	39.30
2010	8.29	120.67	0.47	0.00	0.00	3.33	9.90	47.14
2011	8.38	113.67	0.37	0.00	0.00	0.00	3.67	100.00
2012	8.10	112.00	0.43	0.00	0.00	0.00	0.00	NA
2013	7.93	112.00	0.40	0.00	0.00	7.33	10.67	37.50
2014	7.90	113.33	0.22	0.08	0.00	5.00	7.00	31.43
2015	8.30	110.00	0.49	0.10	0.00	6.00	9.00	53.89

Table 5: Yearly hypolimnetic water chemistry averages (i.e. deep waters) for East Twin Lake since 2004.

East Twin - Hypolimnetic Water Chemistry Averages by Year								
Year	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
2004	7.38	135.00	0.32	0.00	0.13	13.00	14.75	30.00
2005	7.55	142.50	0.17	0.08	0.25	3.25	6.75	62.59
2006	7.32	130.67	0.67	0.07	0.16	6.60	10.47	78.98
2007	7.52	128.67	0.53	0.02	0.13	5.70	16.33	40.82
2008	7.68	120.67	0.30	0.00	0.00	51.00	97.67	3.07
2009	7.48	127.33	0.37	0.03	0.00	4.20	12.60	29.10
2010	7.76	129.33	0.30	0.07	0.00	9.67	27.37	10.96
2011	7.46	124.67	0.40	0.00	0.00	15.67	35.33	11.32
2012	7.52	125.50	0.43	0.00	0.00	0.00	9.33	46.43
2013	7.39	121.33	0.77	0.06	0.00	26.00	51.67	14.84
2014	7.50	123.33	1.10	0.14	0.00	22.33	29.00	38.05
2015	7.80	125.00	0.45	0.10	0.00	14.50	16.00	27.81

Table 6: Monthly epilimnetic water chemistry averages (i.e. surface waters) for East Twin Lake since 2004.

East Twin - Epilimnetic Water Chemistry Averages by Month								
Month	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
May	8.13	122.50	0.42	0.02	0.10	4.43	6.88	75.58
June	8.25	114.67	0.35	0.02	0.00	9.65	24.53	14.10
July	8.19	118.57	0.51	0.02	0.13	2.21	4.38	145.71
August	8.26	115.50	0.50	0.04	0.03	3.08	5.25	101.43
September	8.28	112.50	0.37	0.03	0.02	11.23	11.78	32.67
October	8.13	122.50	0.42	0.02	0.10	4.43	6.88	75.58

Table 7: Monthly hypolimnetic water chemistry averages (i.e. deep waters) for East Twin Lake since 2004.

East Twin - Hypolimnetic Water Chemistry Averages by Month								
Month	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
May	7.71	126.30	0.39	0.02	0.04	6.99	10.06	43.04
June	7.80	122.17	0.37	0.03	0.05	12.17	19.25	21.73
July	7.40	129.43	0.70	0.02	0.07	2.43	7.38	105.08
August	7.45	135.25	0.48	0.03	0.24	13.50	19.00	37.50
September	7.30	131.83	0.46	0.07	0.03	26.32	61.50	7.97
October	7.17	131.67	0.34	0.18	0.00	44.23	89.07	3.78

Table 8: Monthly water clarity for each year including the yearly averages for East Twin Lake since 2004.

East Twin - Water Clarity by Month (m) and Yearly Averages (m)							
Year	May	June	July	August	September	October	Year Average
2004	7.86	8.53	6.40	7.70	NA	NA	7.62
2005	4.48	NA	4.66	4.36	7.16	NA	5.17
2006	5.27	NA	7.41	5.55	NA	NA	6.08
2007	4.97	NA	5.18	NA	7.35	NA	5.83
2008	3.81	NA	3.07	NA	6.30	NA	4.39
2009	4.30	NA	6.90	NA	4.90	NA	5.37
2010	7.32	5.85	NA	NA	NA	5.64	6.27
2011	5.79	NA	7.53	NA	3.84	NA	5.72
2012	5.85	NA	6.04	NA	3.87	NA	5.25
2013	6.71	5.64	NA	NA	NA	4.17	5.51
2014	NA	7.01	5.79	NA	NA	3.20	5.34
2015	NA	6.86	NA	3.96	5.18	NA	5.34

Table 9: Three-way MANOVA results of West Twin Lake water chemistry. *Bold indicates significant findings.*

Three-Way MANOVA of West Twin Water Quality					
Multivariate Model Results (permutations = 499)					
Control Variable(s)	*Sum of Squares*	*Mean Square*	*Model F*	*R-squared*	*p*
Year	0.003	0.003	2.43	0.031	0.108
Month	0.041	0.041	28.35	0.360	**0.001**
Depth	0.005	0.005	3.77	0.048	0.060
Year x Month	0.012	0.012	8.14	0.103	**0.007**
Year x Depth	0.001	0.001	0.62	0.008	0.422
Month x Depth	0.000	0.000	0.03	0.000	0.944
Year x Depth x Month	0.001	0.001	0.42	0.005	0.533

Individual Variable Regressions (p-value)							
Variable	*Year*	*Month*	*Depth*	*Year x Month*	*Year x Depth*	*Month x Depth*	*Year x Depth x Month*
pH	0.094	0.106	**<0.001**	0.841	0.796	0.663	0.339
Alkalinity	0.105	**<0.001**	0.062	**0.004**	0.445	0.821	0.496
TKN	0.442	0.353	0.758	0.630	0.746	0.877	0.843
Ammonia	0.154	0.060	0.961	0.060	0.922	0.921	0.903
Nitrate	0.234	0.206	0.724	0.958	0.959	0.661	0.996
Dissolved Phosphorus	**0.035**	0.407	0.632	0.955	0.829	0.847	0.701
Total Phosphorus	0.492	0.358	0.389	0.715	0.618	0.455	0.868

Table 10: Yearly averages of water quality parameters (i.e. whole lake) for West Twin Lake between 2004 and 2011.

West Twin - Water Chemistry Averages by Year								
Year	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
2004	8.20	115.00	0.33	0.00	0.00	4.86	8.13	40.62
2005	8.21	120.00	0.15	0.07	0.05	5.00	11.88	16.74
2006	7.84	116.50	0.67	0.06	0.16	7.02	9.52	87.22
2007	8.28	111.17	0.58	0.00	0.07	5.32	38.43	16.87
2008	8.21	109.67	0.17	0.01	0.00	41.67	378.17	0.45
2009	7.91	119.33	0.53	0.00	0.00	4.02	12.23	43.60
2010	8.03	106.50	0.50	0.00	0.00	19.30	5.00	100.00
2011	8.03	106.50	0.50	0.00	0.00	19.30	5.00	100.00

Table 11: Monthly averages of water quality parameters (i.e. whole lake) for West Twin Lake between 2004 and 2011.

West Twin - Water Chemistry Averages by Month								
Month	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N;P
May	8.25	125.33	0.19	0.01	0.07	7.48	13.68	18.40
June	8.26	112.75	0.39	0.00	0.00	20.00	46.00	8.48
July	7.97	119.90	0.62	0.01	0.07	4.67	10.74	64.34
August	8.07	104.67	0.30	0.02	0.05	7.33	11.67	29.86
September	8.07	104.75	0.47	0.07	0.00	20.79	283.08	1.66
October	8.03	106.50	0.50	0.00	0.00	19.30	5.00	100.00

Table 12: Yearly epilimnetic water chemistry averages (i.e. surface waters) for West Twin Lake between 2004 and 2011.

West Twin - Epilimnetic Water Chemistry Averages by Year								
Year	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
2004	8.33	112.50	0.35	0.00	0.00	2.50	6.50	53.46
2005	8.43	115.00	0.10	0.07	0.06	2.50	7.00	22.14
2006	7.92	114.67	1.00	0.07	0.17	4.50	7.17	162.79
2007	8.45	108.33	0.50	0.00	0.04	4.03	62.53	8.58
2008	8.27	109.33	0.18	0.00	0.00	48.33	86.67	2.04
2009	8.19	115.33	0.57	0.00	0.00	2.93	8.57	66.15
2010	8.03	107.00	0.40	0.00	0.00	13.60	4.70	85.11
2011	8.03	107.00	0.40	0.00	0.00	13.60	4.70	85.11

Table 13: Yearly hypolimnetic water chemistry averages (i.e. deep waters) for West Twin Lake between 2004 and 2011.

West Twin - Hypolimnetic Water Chemistry Averages by Year								
Year	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
2004	8.08	117.50	0.31	0.00	0.00	8.00	9.75	32.05
2005	8.00	125.00	0.19	0.06	0.05	7.50	16.75	14.48
2006	7.75	118.33	0.33	0.05	0.16	9.53	11.87	41.57
2007	8.11	114.00	0.66	0.00	0.10	6.60	14.33	53.02
2008	8.15	110.00	0.17	0.02	0.00	35.00	669.67	0.25
2009	7.63	123.33	0.50	0.00	0.00	5.10	15.90	31.45
2010	8.03	106.00	0.60	0.00	0.00	25.00	5.30	113.21
2011	8.03	106.00	0.60	0.00	0.00	25.00	5.30	113.21

Table 14: Monthly epilimnetic water chemistry averages (i.e. surface waters) for West Twin Lake between 2004 and 2011.

West Twin - Epilimnetic Water Chemistry Averages by Month								
Month	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
May	8.31	125.17	0.12	0.02	0.05	5.85	11.48	14.95
June	8.35	110.50	0.41	0.00	0.00	19.00	50.00	8.20
July	8.26	112.20	0.97	0.01	0.08	2.40	6.68	156.59
August	8.26	101.00	0.14	0.02	0.05	2.67	6.33	30.00
September	8.21	104.25	0.43	0.07	0.00	26.58	81.88	5.19
October	8.03	107.00	0.40	0.00	0.00	13.60	4.70	85.11

Table 15: Monthly hypolimnetic water chemistry averages (i.e. surface waters) for West Twin Lake between 2004 and 2011.

West Twin - Hypolimnetic Water Chemistry Averages by Month								
Month	pH	Alkalinity (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Nitrate (mg/L)	Dissolved Phosphorus (ug/L)	Total Phosphorus (ug/L)	N:P
May	8.19	125.50	0.25	0.01	0.08	9.12	15.87	20.90
June	8.18	115.00	0.37	0.00	0.00	21.00	42.00	8.81
July	7.67	127.60	0.26	0.01	0.07	7.50	14.80	22.70
August	7.87	108.33	0.46	0.02	0.04	12.00	17.00	29.80
September	7.92	105.25	0.51	0.08	0.00	15.00	484.28	1.06
October	8.03	106.00	0.60	0.00	0.00	25.00	5.30	113.21

Table 16: Monthly water clarity for each year including the yearly averages for West Twin Lake between 2004 and 2011.

West Twin - Water Clarity by Month (m) and Yearly Averages (m)							
Year	May	June	July	August	September	October	Year Average
2004	3.17	4.82	3.66	3.35	NA	NA	3.75
2005	2.71	NA	3.93	4.27	3.08	NA	3.50
2006	4.42	NA	5.94	4.02	NA	NA	4.80
2007	4.12	NA	3.81	NA	3.63	NA	3.85
2008	2.79	NA	3.89	NA	2.49	NA	3.06
2009	3.10	NA	3.90	NA	3.60	NA	3.53
2010	5.03	4.45	NA	NA	NA	3.20	4.23
2011	NA	4.05	3.96	NA	NA	4.21	4.08

Table 17: General Linear Modeling results for the epilimnetic algal community in East Twin Lake. *The t-value and r-squared values express the direction of movement (i.e. negative or positive) for each trend and the quality of model fit (i.e. variance explanation), respectively. Bold values indicate significant results.*

Linear Regression Statistics - Epilimnetic Algal Community of East Twin Lake						
Group/Variable	**Time Frame**	**Estimate**	**t-value**	**F-statistic**	**r-squared**	**p-value**
Bacillariophyta	Year	3.991	0.196	0.038	0.001	0.846
	Month	-9.812	-0.250	0.062	0.803	0.804
Charophyta	Year	-0.692	-1.946	3.789	0.082	0.061
	Month	0.021	0.029	0.001	0.001	0.977
Chlorophyta	Year	-48.980	-1.259	1.584	0.017	0.218
	Month	183.480	2.642	6.982	0.157	**0.013**
Chrysophyta	Year	-44.720	-0.840	0.705	0.001	0.407
	Month	-238.230	-2.520	6.352	0.143	**0.018**
Cryptophyta	Year	-0.096	-0.153	0.024	0.001	0.879
	Month	-0.770	-0.638	0.407	0.001	0.528
Cyanophyta	Year	1593.700	2.405	5.782	0.130	**0.022**
	Month	4208.000	3.604	12.990	0.273	**0.001**
Euglenophyta	Year	0.316	0.778	0.605	0.001	0.443
	Month	2.250	3.311	10.960	0.237	**0.002**
Pyrrophyta	Year	-4.289	-2.568	6.593	0.148	**0.015**
	Month	3.823	1.100	1.209	0.006	0.280
Diversity	Year	-0.161	-5.827	33.950	0.507	**<0.001**
	Month	0.019	0.257	0.066	0.001	0.799
Richness	Year	-0.375	-1.867	3.485	0.072	0.071
	Month	0.667	1.710	2.924	0.056	0.097
Total Cell Count	Year	1499.200	2.271	5.156	0.115	**0.030**
	Month	4148.000	3.595	12.920	0.272	**0.001**
Biomass	Year	-27.210	-0.393	0.155	0.001	0.697
	Month	-106.500	-0.815	0.665	0.001	0.421

Table 18: General Linear Modeling results for the metalimnetic algal community in East Twin Lake. *The t-value and r-squared values express the direction of movement (i.e. negative or positive) for each trend and the quality of model fit (i.e. variance explanation), respectively. Bold values indicate significant results.*

Linear Regression Statistics - Epilimnetic Algal Community of East Twin Lake						
Group/Variable	**Time Frame**	**Estimate**	**t-value**	**F-statistic**	**r-squared**	**p-value**
Bacillariophyta	Year	-21.450	-1.400	1.961	0.026	0.170
	Month	8.659	0.269	0.072	0.001	0.790
Charophyta	Year	NA	NA	NA	NA	NA
	Month	NA	NA	NA	NA	NA
Chlorophyta	Year	-31.690	-0.964	0.928	0.001	0.342
	Month	62.200	0.922	0.851	0.001	0.363
Chrysophyta	Year	1.395	0.032	0.001	0.001	0.974
	Month	-222.770	-2.785	7.756	0.161	**0.008**
Cryptophyta	Year	0.015	0.069	0.005	0.001	0.945
	Month	0.753	1.803	3.249	0.060	0.080
Cyanophyta	Year	654.800	1.982	3.930	0.077	**0.050**
	Month	1347.000	1.992	3.970	0.078	**0.050**
Euglenophyta	Year	1.116	1.709	2.921	0.052	0.097
	Month	4.352	3.697	13.660	0.266	**<0.001**
Pyrrophyta	Year	-1.378	-1.923	3.700	0.070	0.063
	Month	1.523	0.993	0.986	0.001	0.328
Diversity	Year	-0.048	-1.720	2.958	0.053	0.095
	Month	-0.012	-0.199	0.040	0.001	0.843
Richness	Year	-0.392	-2.165	4.605	0.095	**0.038**
	Month	0.665	1.753	3.074	0.056	0.089
Total Cell Count	Year	602.800	1.846	3.406	0.064	0.070
	Month	1201.700	1.792	3.211	0.059	0.082
Biomass	Year	-11.160	-0.100	0.010	0.001	0.921
	Month	-290.800	-1.363	1.857	0.025	0.182

Table 19: Canonical Correspondence results for the epilimnetic algal community of East Twin Lake. *Constrained variance portioning (proportion) shows the quality of the model fit. Variable tests show the most influential environmental factors in the structuring of the algal community.*

Canonical Correspondence Analysis of Epilimnetic Algal Community

Variance Partitioning

	Inertia	Proportion
Total	0.687	1.000
Constrained	0.512	0.746
Unconstrained	0.175	0.254

Individual Axis Influences

	CCA1	CCA2	CCA3	CCA4
Eigenvalue	0.286	0.140	0.056	0.022
Proportion Explained	0.417	0.203	0.081	0.032
Cumulative Proportion	0.417	0.620	0.701	0.733

	CCA5	CCA6	CCA7	CCA8
Eigenvalue	0.006	0.001	0.001	0.000
Proportion Explained	0.009	0.002	0.001	0.000
Cumulative Proportion	0.742	0.744	0.745	0.745

Axis Tests (perm.=999)

	Df	ChiSquare	F	p
CCA1	1	0.286	37.670	**0.001**
CCA2	1	0.139	18.358	**0.001**
CCA3	1	0.056	7.358	**0.004**
CCA4	1	0.022	2.912	0.074
CCA5	1	0.006	0.794	0.423
CCA6	1	0.001	0.162	0.848
CCA7	1	0.001	0.103	0.897
CCA8	1	0.000	0.037	0.977
CCA9	1	0.000	0.012	0.996

Variable Tests (perm.=999)

	Df	ChiSquare	F	p
Year	1	0.082	4.233	**0.040**
Month	1	0.104	5.336	**0.031**
pHE	1	0.002	0.108	0.970
AlkalinityE	1	0.014	0.696	0.656
TKNE	1	0.008	0.415	0.796
NH4E	1	0.006	0.301	0.866
NO3E	1	0.043	2.210	0.245
DphosE	1	0.003	0.175	0.918
TphosE	1	0.009	0.459	0.694
pHM	1	0.016	0.829	0.639
AlkalinityM	1	0.033	1.686	0.263
TKNM	1	0.011	0.544	0.741
NH4M	1	0.012	0.621	0.686
NO3M	1	0.017	0.863	0.565
DphosM	1	0.037	1.890	0.283
TphosM	1	0.021	1.095	0.479
pHH	1	0.001	0.074	0.994
AlkalinityH	1	0.017	0.884	0.557
TKNH	1	0.008	0.415	0.774
NH4H	1	0.006	0.289	0.894
NO3H	1	0.030	1.535	0.323
DphosH	1	0.003	0.177	0.931
TphosH	1	0.030	1.543	0.306

Table 20: Canonical Correspondence results for the metalimnetic algal community of East Twin Lake. *Constrained variance portioning (proportion) shows the quality of the model fit. Variable tests show the most influential environmental factors in the structuring of the algal community.*

Canonical Correspondence Analysis of Metalimnetic Algal Community

Variance Partitioning

	Inertia	Proportion
Total	0.665	1.000
Constrained	0.492	0.739
Unconstrained	0.174	0.261

Individual Axis Influences

	CCA1	CCA2	CCA3	CCA4
Eigenvalue	0.268	0.153	0.053	0.015
Proportion Explained	0.546	0.310	0.107	0.030
Cumulative Proportion	0.546	0.856	0.963	0.993

	CCA5	CCA6	CCA7	CCA8
Eigenvalue	0.002	0.001	0.000	0.000
Proportion Explained	0.005	0.002	0.001	0.000
Cumulative Proportion	0.997	0.999	1.000	1.000

Axis Tests (perm.=999)

	Df	ChiSquare	F	p
CCA1	1	0.268	37.094	**0.001**
CCA2	1	0.153	21.102	**0.001**
CCA3	1	0.053	7.280	**0.001**
CCA4	1	0.015	2.020	0.093
CCA5	1	0.002	0.324	0.646
CCA6	1	0.001	0.127	0.897
CCA7	1	0.000	0.051	0.972
CCA8	1	0.000	0.003	1.000

Variable Tests (perm.=999)

	Df	ChiSquare	F	p
Year	1	0.052	2.693	0.144
Month	1	0.129	6.702	**0.012**
pHE	1	0.004	0.197	0.930
AlkalinityE	1	0.011	0.584	0.713
TKNE	1	0.005	0.278	0.839
NH4E	1	0.006	0.321	0.841
NO3E	1	0.042	2.186	0.233
DphosE	1	0.002	0.096	0.961
TphosE	1	0.016	0.835	0.520
pHM	1	0.019	0.979	0.560
AlkalinityM	1	0.019	0.985	0.463
TKNM	1	0.009	0.461	0.748
NH4M	1	0.004	0.197	0.917
NO3M	1	0.024	1.232	0.450
DphosM	1	0.025	1.319	0.418
TphosM	1	0.034	1.755	0.290
pHH	1	0.001	0.033	0.995
AlkalinityH	1	0.008	0.417	0.798
TKNH	1	0.020	1.035	0.442
NH4H	1	0.013	0.670	0.658
NO3H	1	0.018	0.924	0.528
DphosH	1	0.002	0.111	0.981
TphosH	1	0.029	1.491	0.300

Table 21: Aquatic macrophyte species list for East and West Twin Lakes. Species included in this list summarize those species detected by SOlitude Lake Management.

Species Inventory: East and West Twin Lakes		
Plant Species	East Twin	West Twin
Chara spp.	x	x
Ceratophyllum demersum	x	x
Eleocharis spp.		x
Elodea canadensis	x	x
Isoetes spp.	x	x
Megalodonta beckii	x	x
Myriophyllum sibiricum	x	x
Myriophyllum spicatum	x	x
Najas flexilis	x	x
Najas guadalupensis	x	x
Najas minor		x
Nuphar variegata	x	x
Nymphaea odorata	x	x
Pontederia cordata	x	x
Potamogeton amplifolius	x	x
Potamogeton crispus	x	x
Potamogeton illinoensis	x	x
Potamogeton natans	x	x
Potamogeton praelongus		x
Potamogeton richardsonii		x
Potamogeton robbinsii	x	x
Potamogeton zosteriformes	x	x
Sagitaria spp.		x
Utricularia macrorhiza	x	x
Utricularia spp.	x	x
Vallisneria americana	x	x
Zosterella dubia		x

Table 22: MANOVA results from the analysis of East Twin Lake's fish community. *Bold indicates significant findings.*

East Twin - Fish Community Analyses			
Multivariate Analysis			
Variable	F-statistic	r-squared	p-value
Year	3.504	0.226	0.03
Individual Regressions			
Species	F-statistic	r-squared	p-value
Largemouth Bass	3.767	0.239	0.070
Smallmouth Bass	0.422	0.034	0.528
Brook Trout	0.219	0.018	0.649
Brown Trout	2.539	0.175	0.137
Rainbow Trout	1.383	0.103	0.262
Chain Pickerel	1.679	0.123	0.219
Black Crappie	39.729	0.768	**<0.001**
White Perch	0.336	0.027	0.573
Yellow Perch	7.265	0.377	**0.019**
Brown Bullhead	3.844	0.243	0.074
Bluegill	0.326	0.026	0.578
Pumpkinseed	1.677	0.123	0.220
Readbreast Sunfish	0.043	0.004	0.840
Rock Bass	9.024	0.429	**0.011**
Bridle Shiner	0.477	0.038	0.503
Golden Shiner	14.886	0.554	**0.002**
Banded Killifish	0.669	0.053	0.429
Alewife	0.935	0.072	0.353
Creek Chubsucker	8.853	0.425	**0.012**
White Sucker	3.311	0.216	0.098
Total Catch/Effort	3.840	0.242	0.074
Species Richness	2.697	0.184	0.127
Shannon's Diversity	1.673	0.122	0.220

FIGURES

Figure 1: East Twin Lake orthography map with vegetation transects.

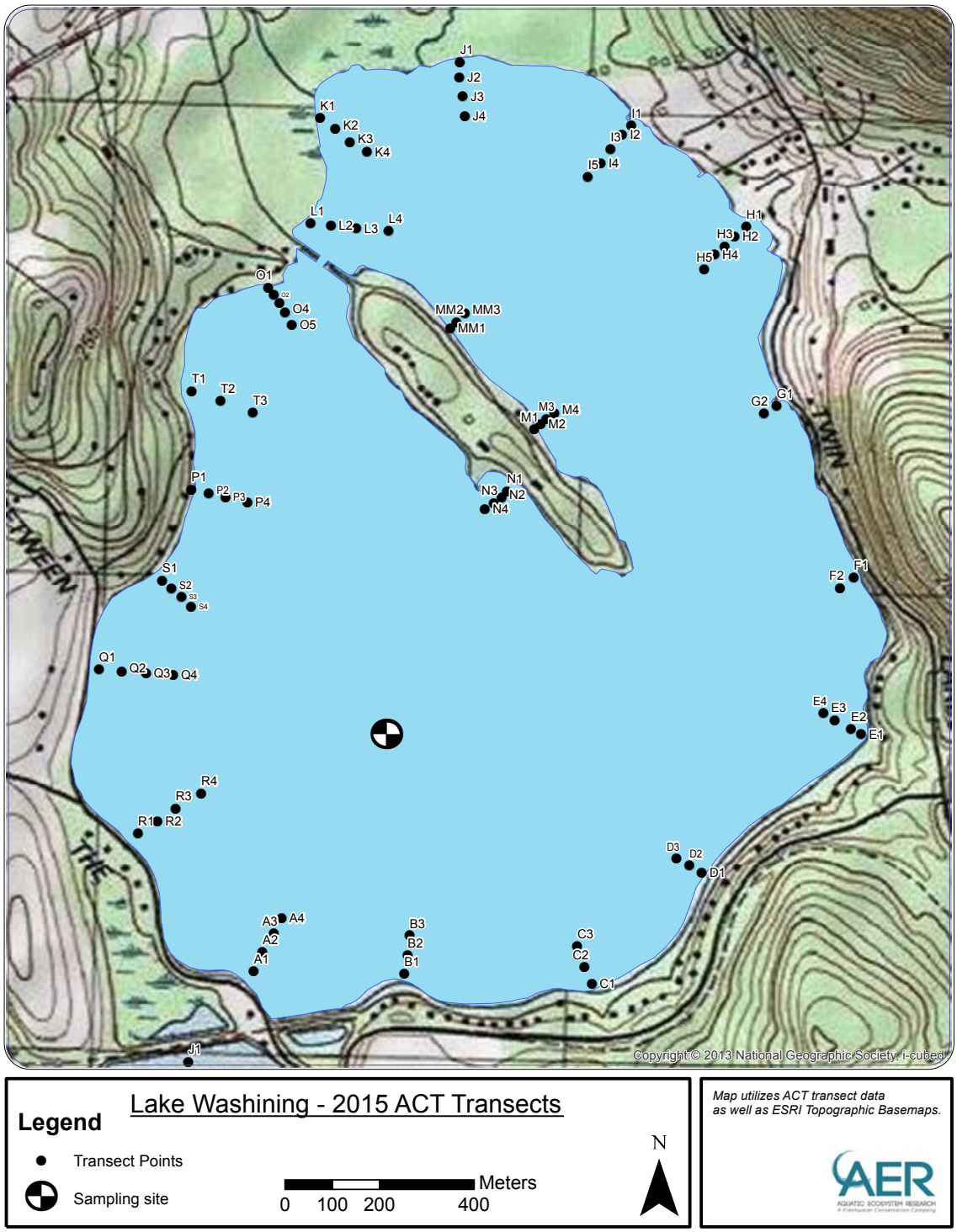

Figure 2: West Twin Lake orthography map with vegetation transects.

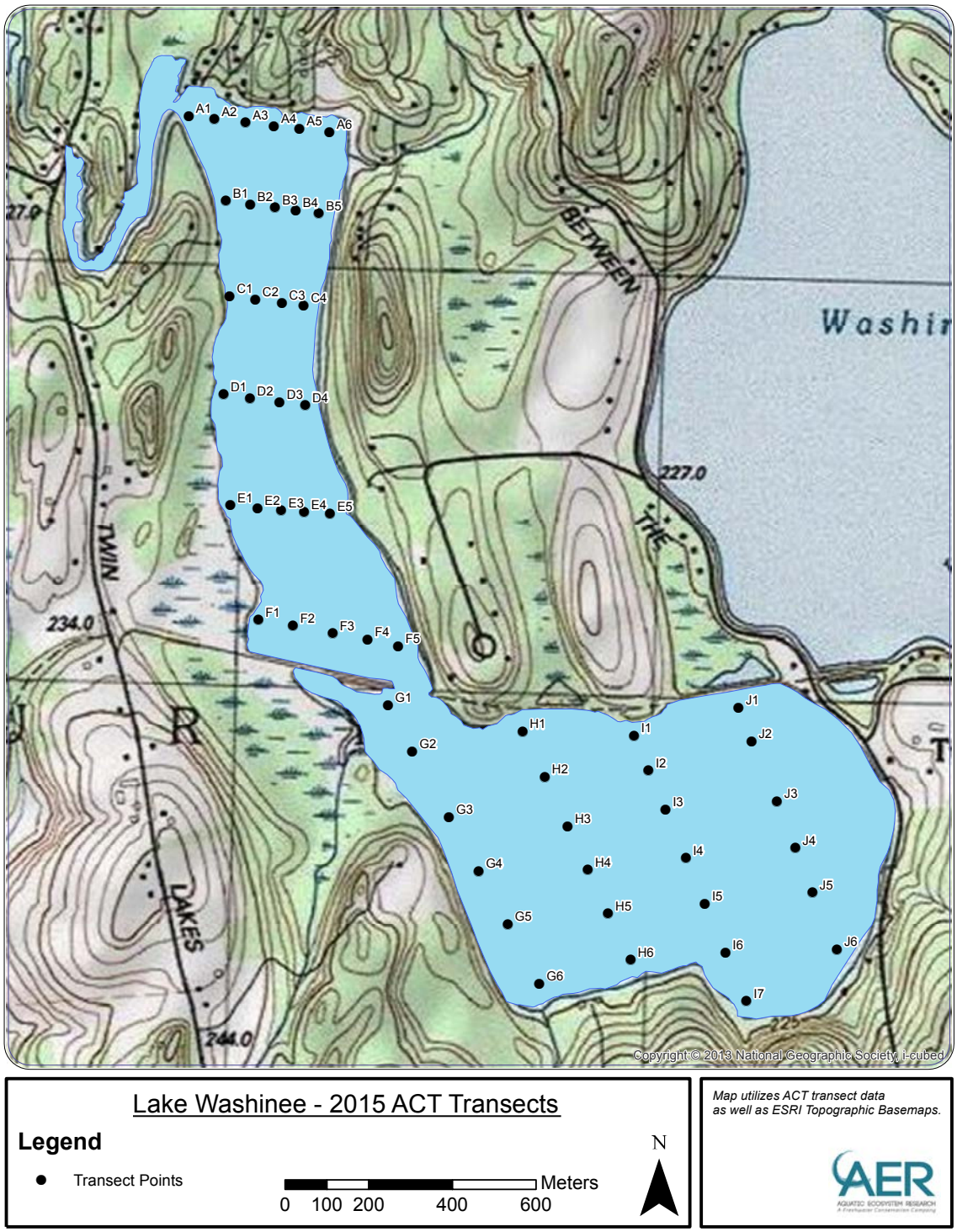

Figure 3: East and West Twin Lakes watershed map with land cover classes.

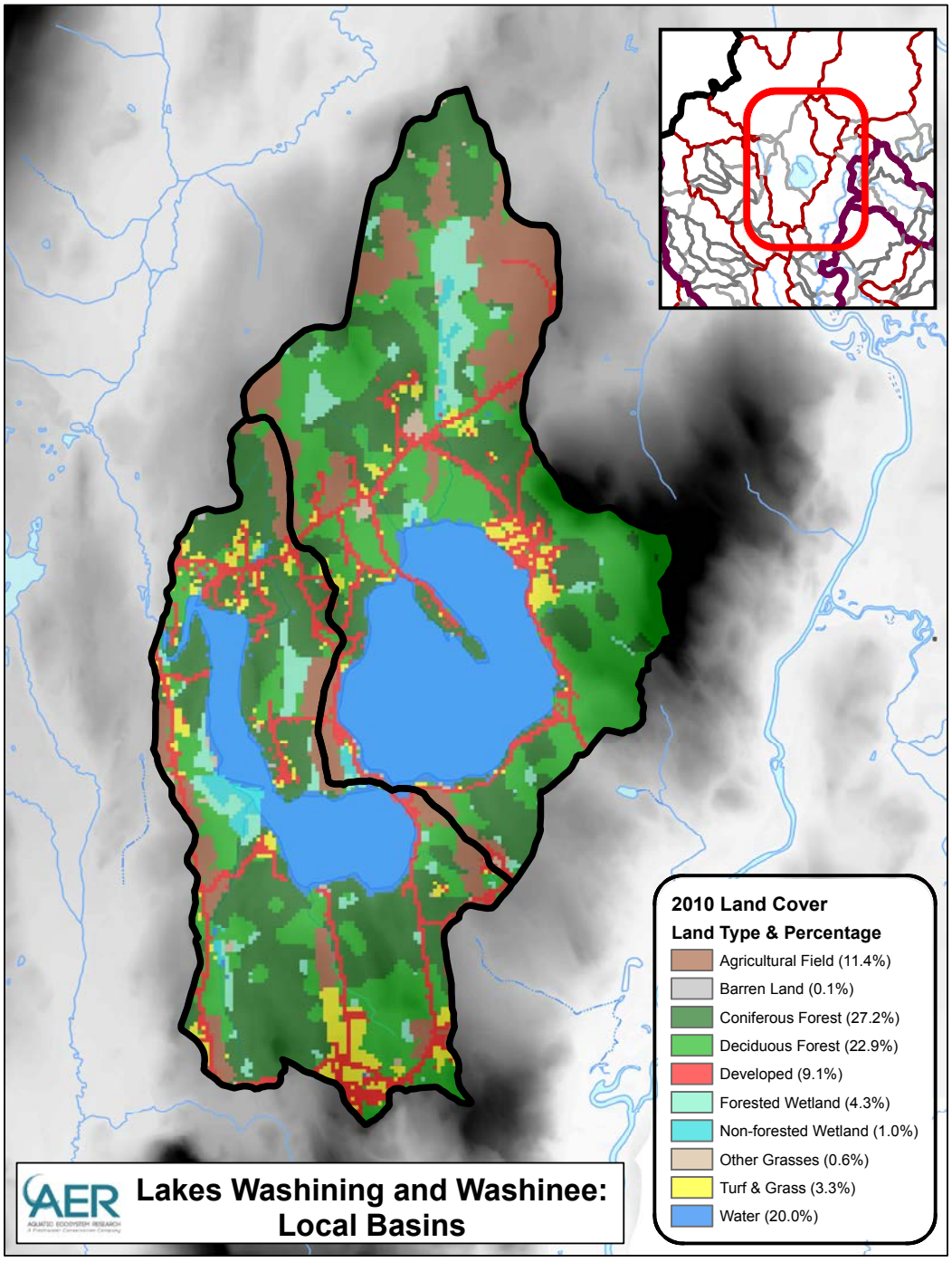

Figure 4: Map of the "between – the – lakes" channel with sediment transects.

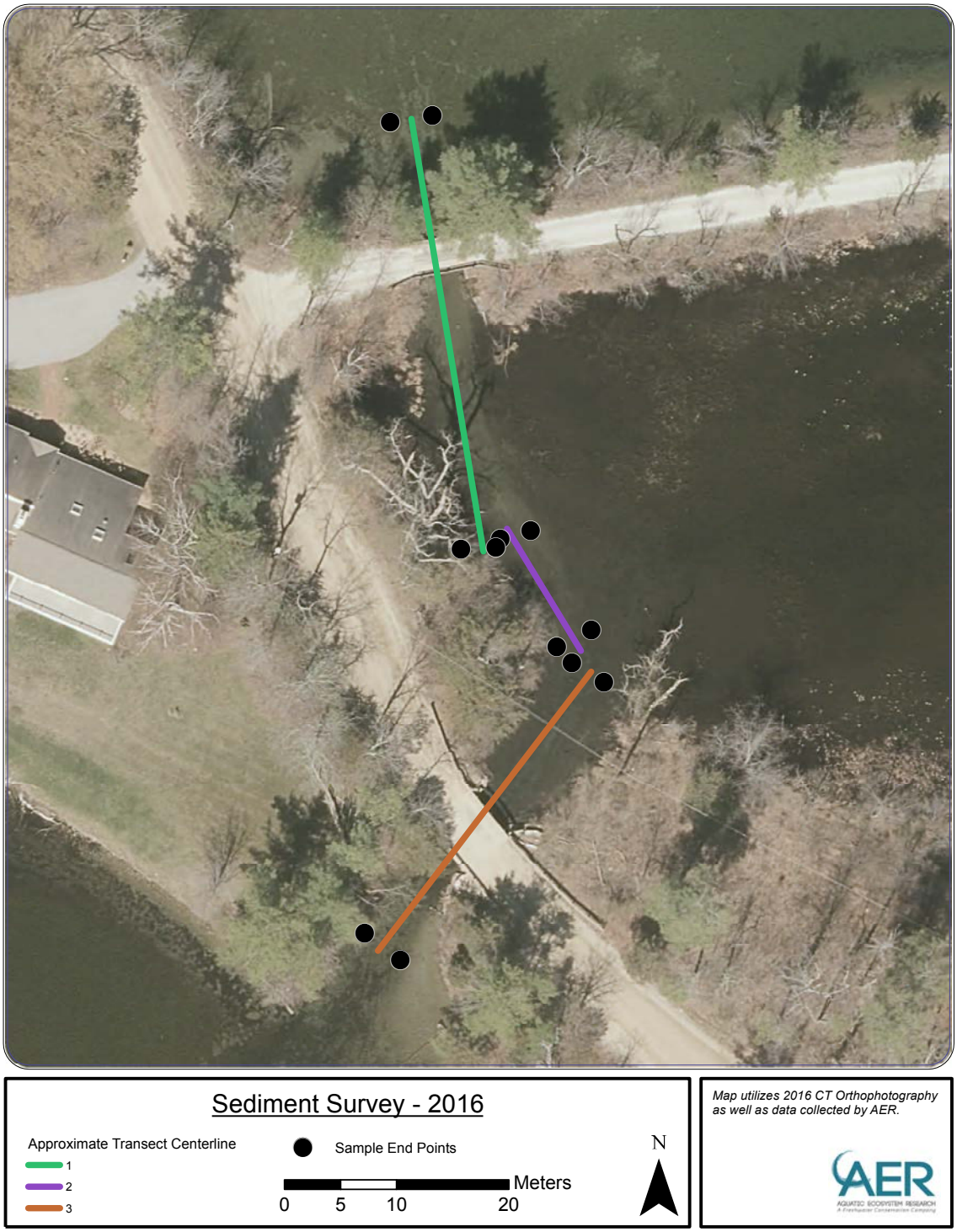

Figure 5: Overview map of lily populations in East and West Twin Lakes.

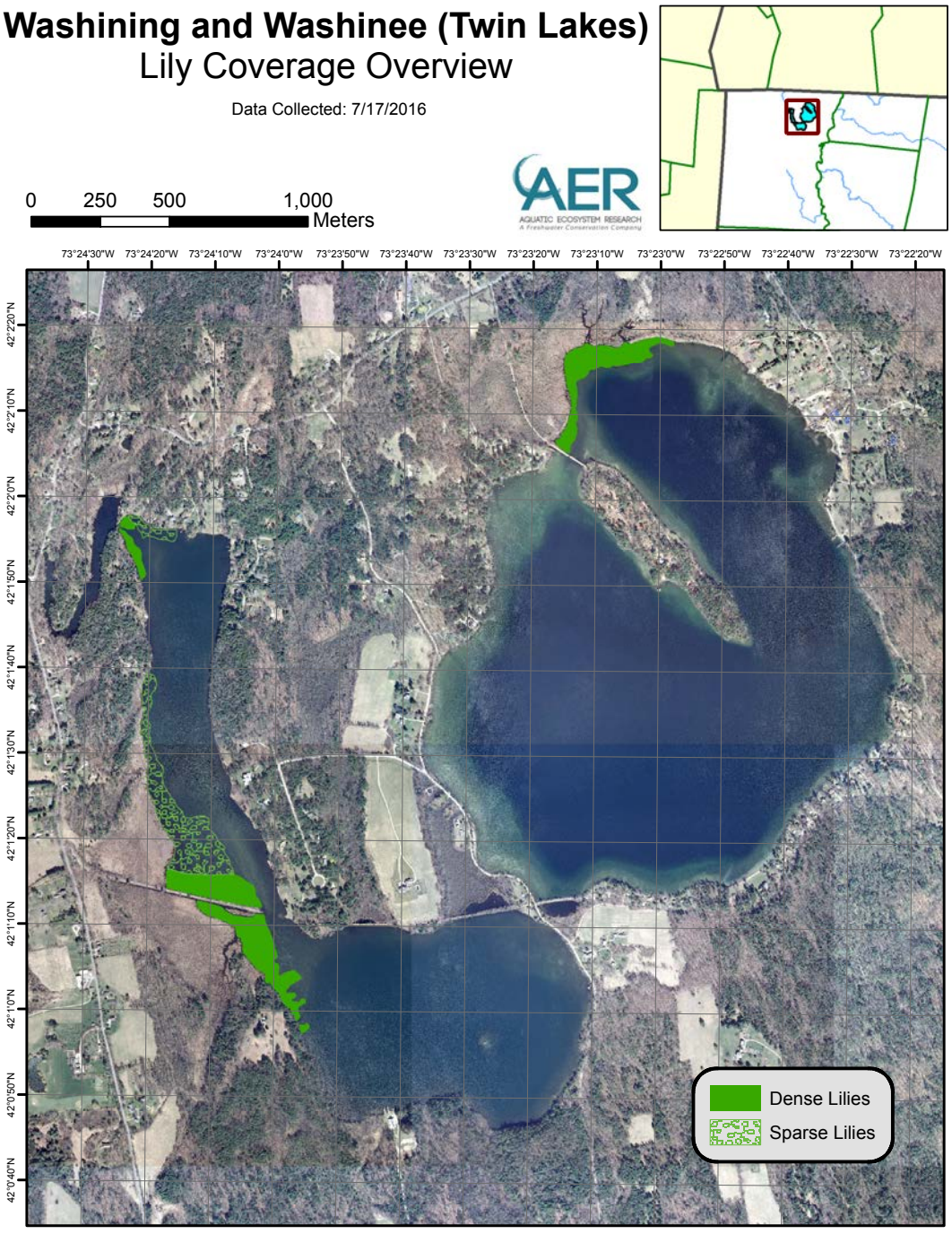

Figure 6: Map of the lily populations in East Twin Lake including the proposed boat lane.

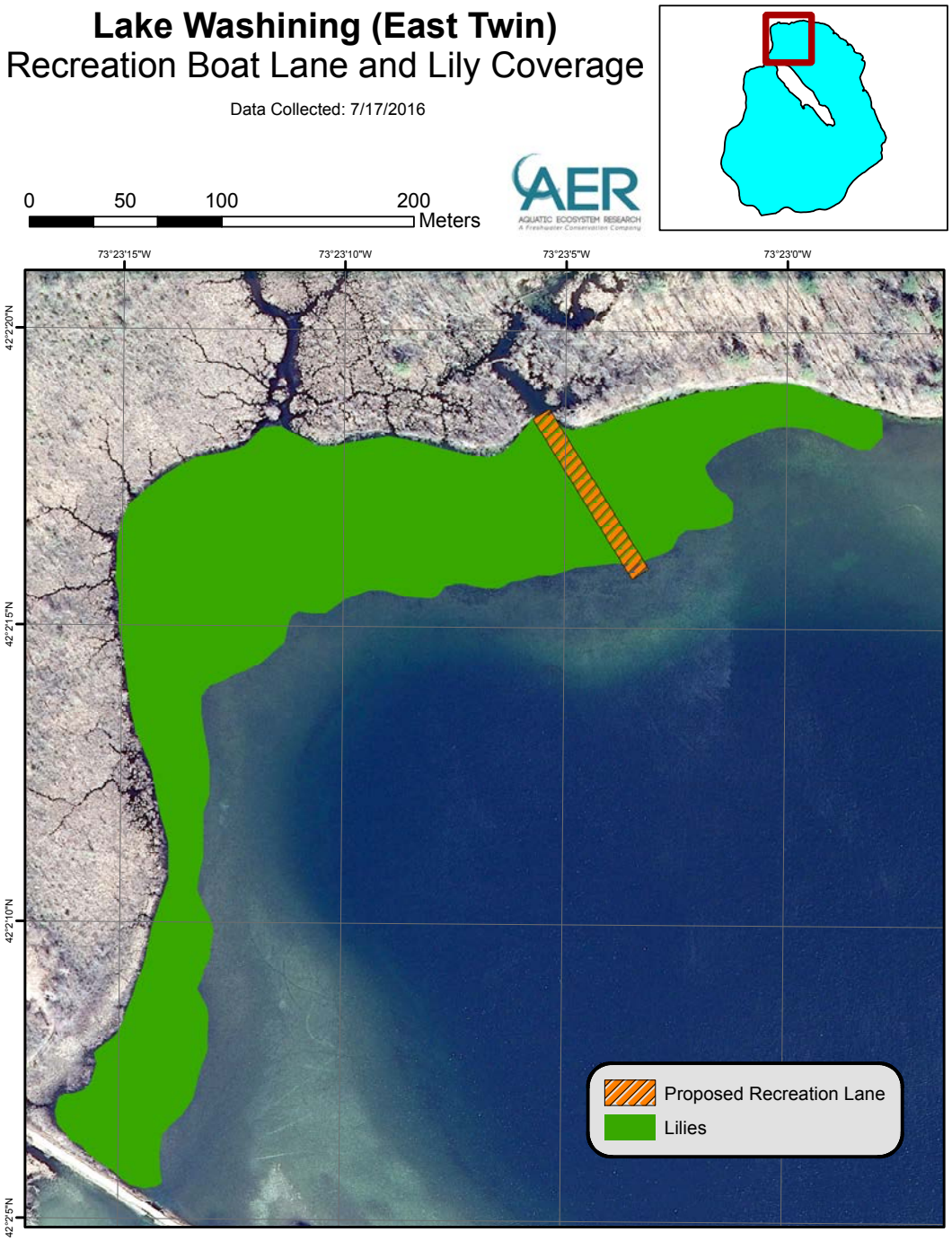

Figure 7: Map of the lily populations in West Twin Lake including the known rowing lane.

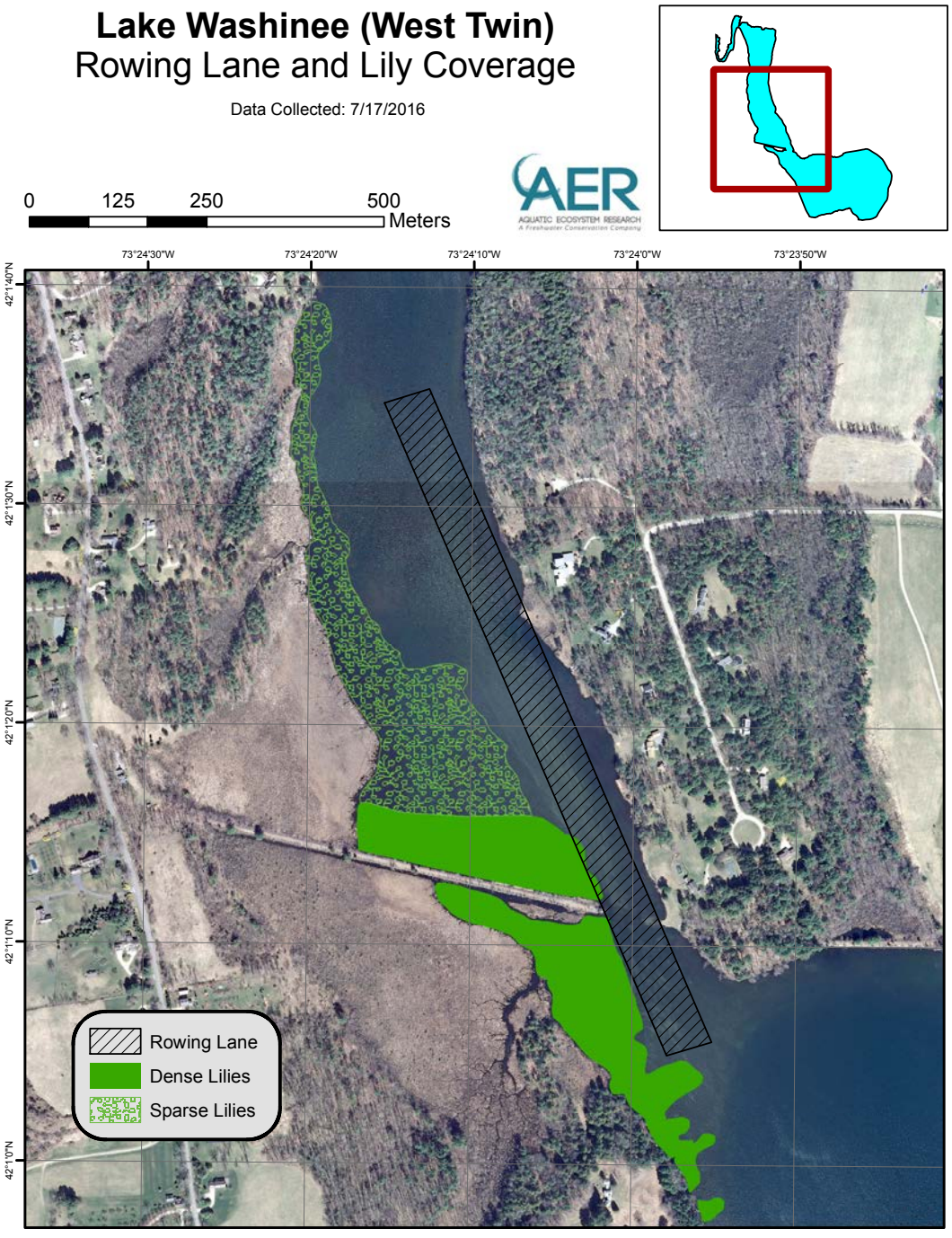

Figure 8: Yearly and monthly surface algal cell concentrations (cells/mL) in East Twin Lake.

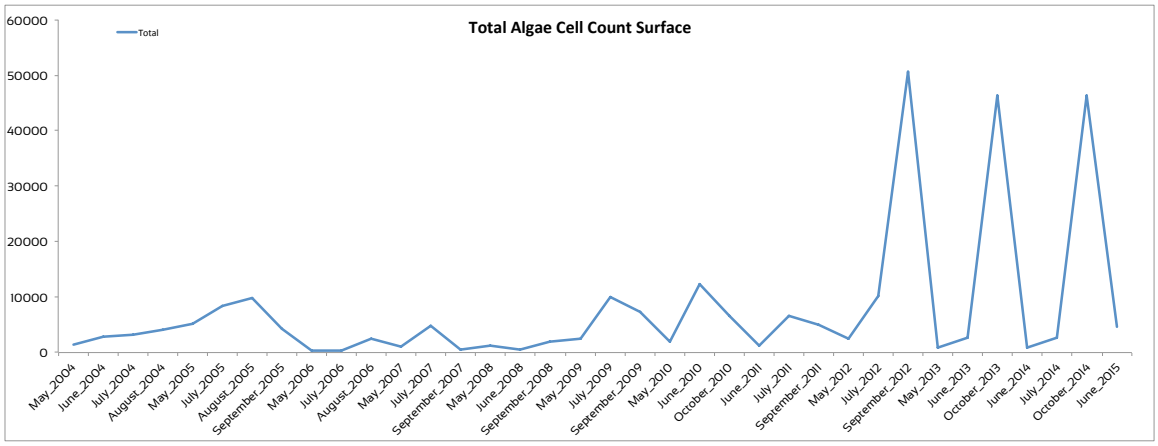

Figure 9: Richness (i.e. number of species) in the surface algal community of East Twin Lake by year and month.

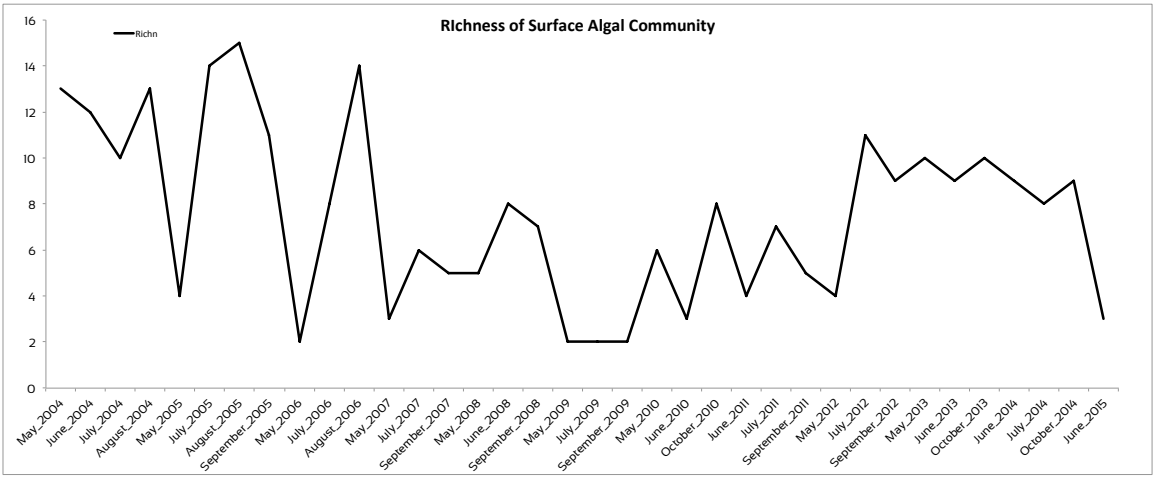

Figure 10: Diversity of the surface algal community of East Twin Lake by year and month.

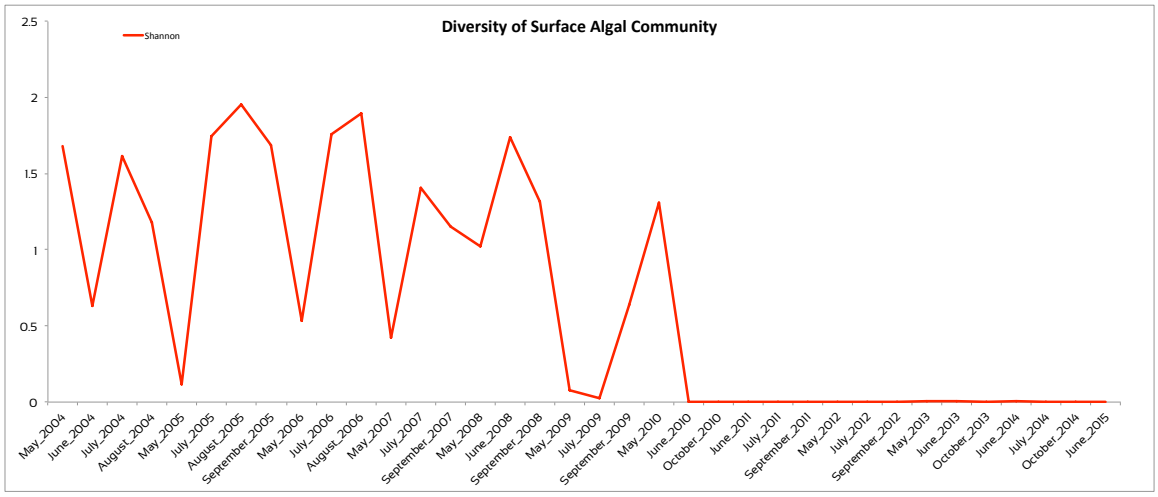

Figure 11: Cell counts by group in the surface algal community East Twin Lake by month and year.

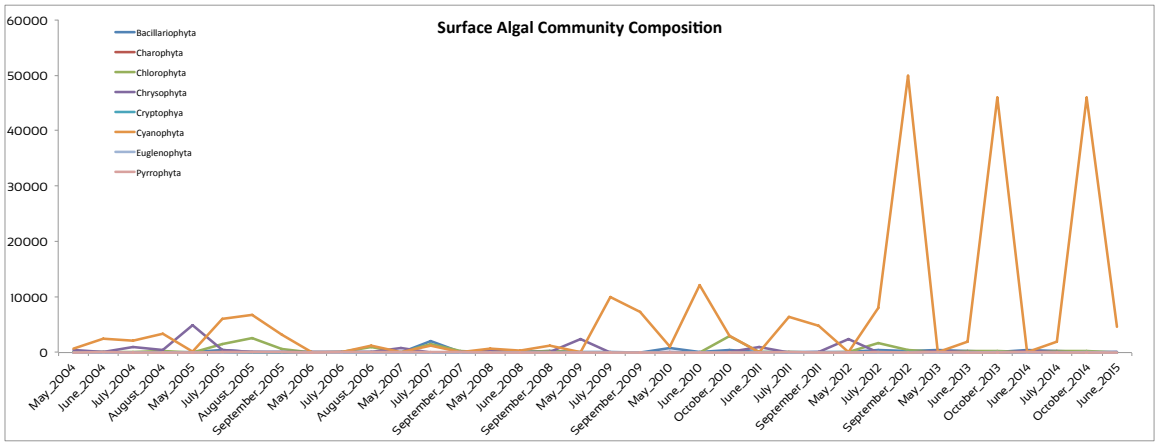

Figure 12: Total cell count in the metalimnetic algal community of East Twin Lake by month and year.

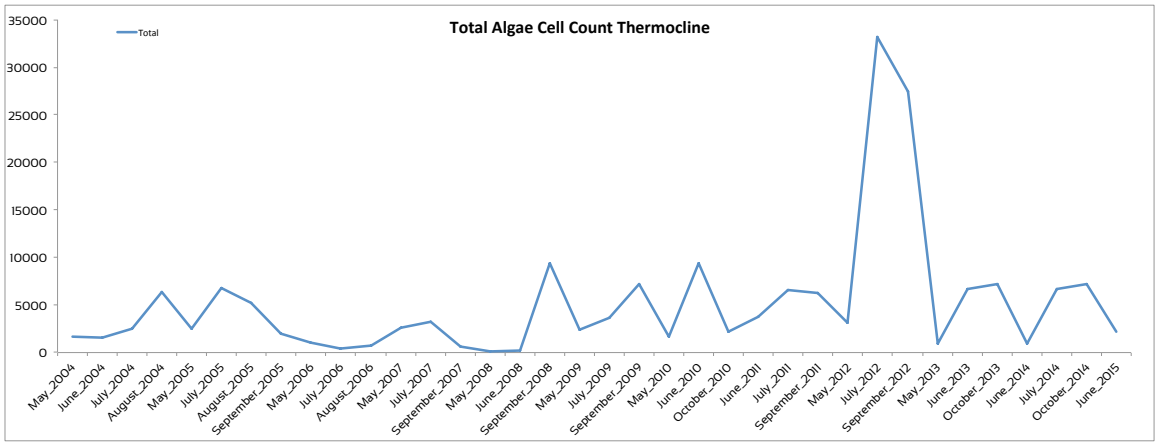

Figure 13: Cell counts by group in the thermocline algal community East Twin Lake by month and year.

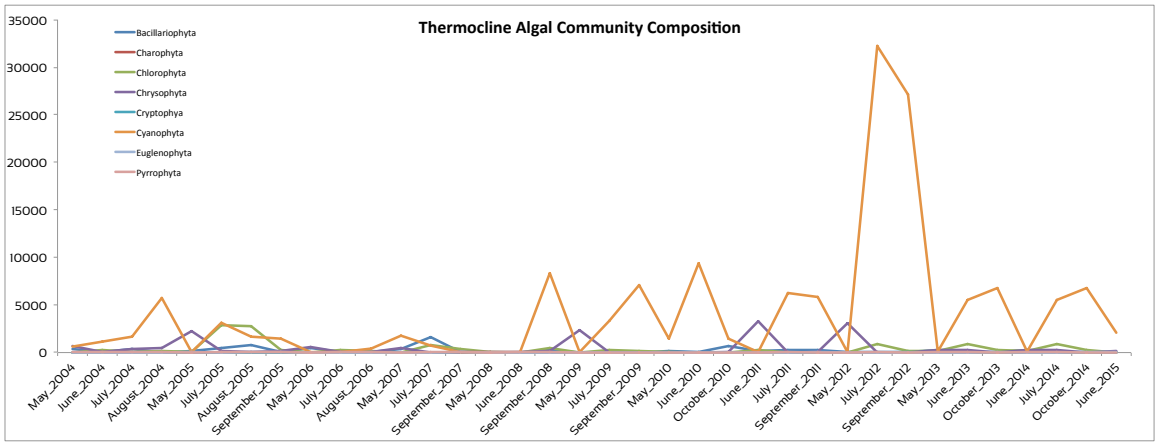

Figure 14: Richness (i.e. number of species) in the thermocline algal community of East Twin Lake by year and month.

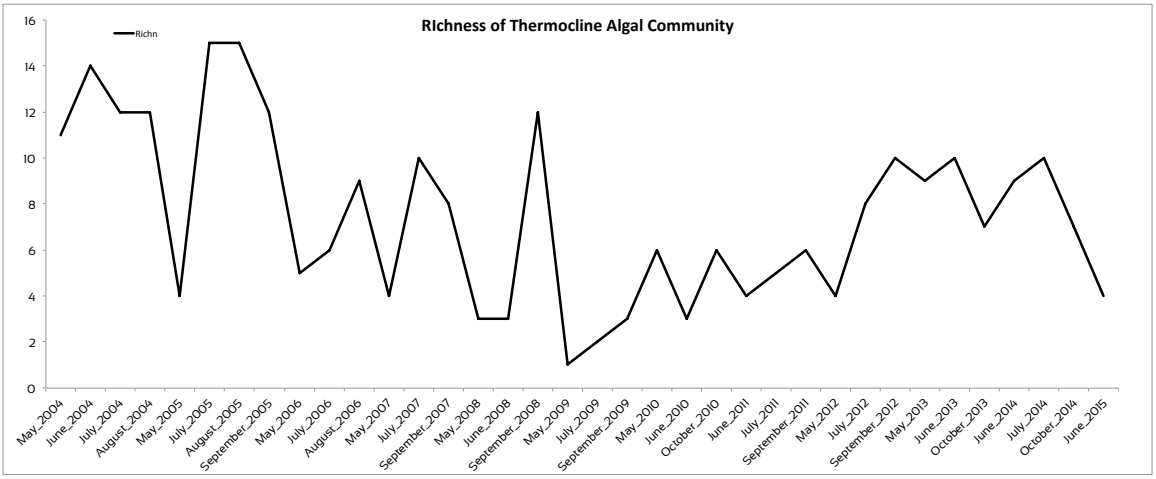

Figure 15: Diversity of the thermocline algal community of East Twin Lake by year and month.

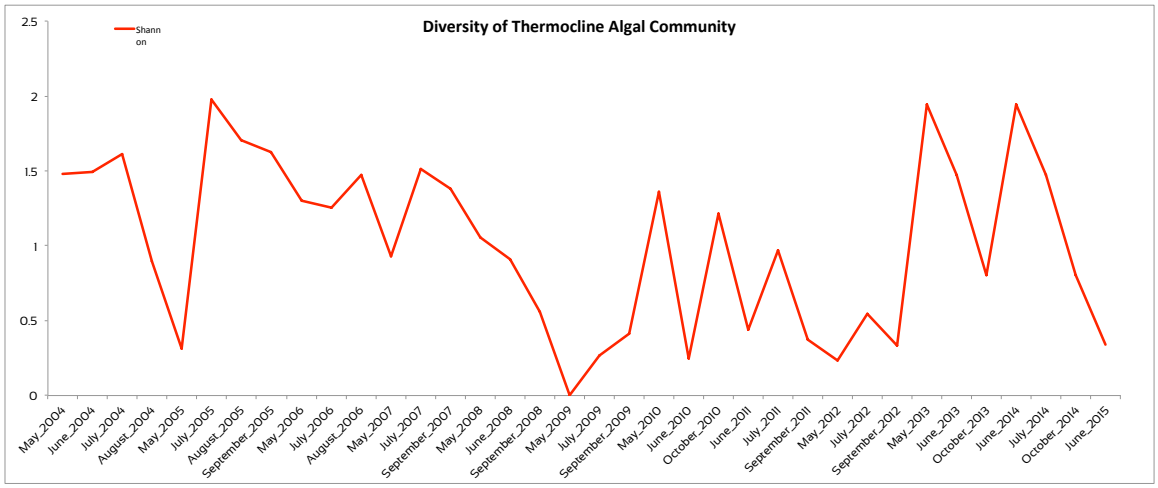

Figure 16: Difference between the algal cell counts of surface and thermocline algal communities by year.

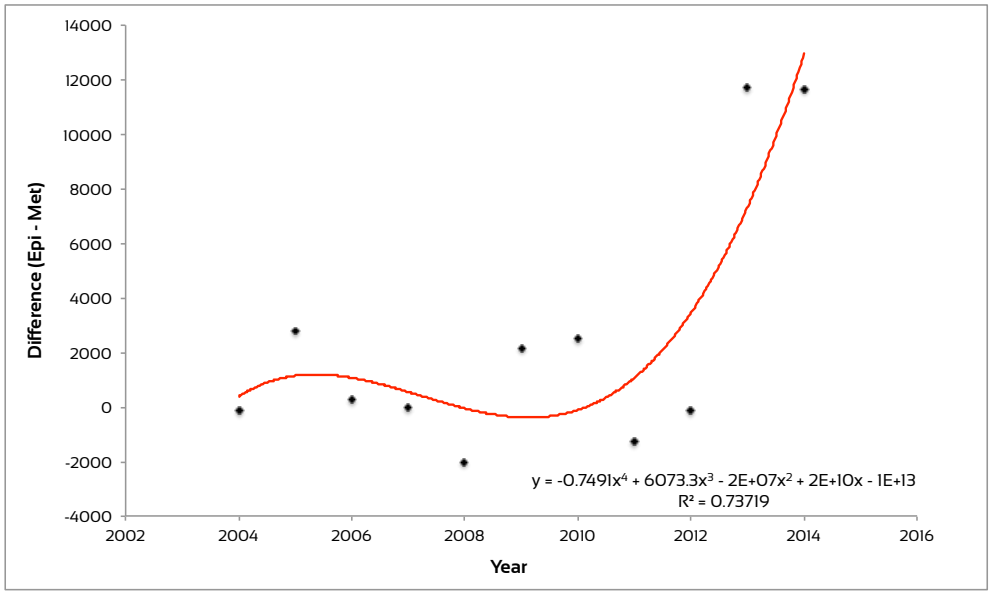

Figure 17: Percent of East Twin Lake's macrophyte community that is *Myriophyllum spicatum*.

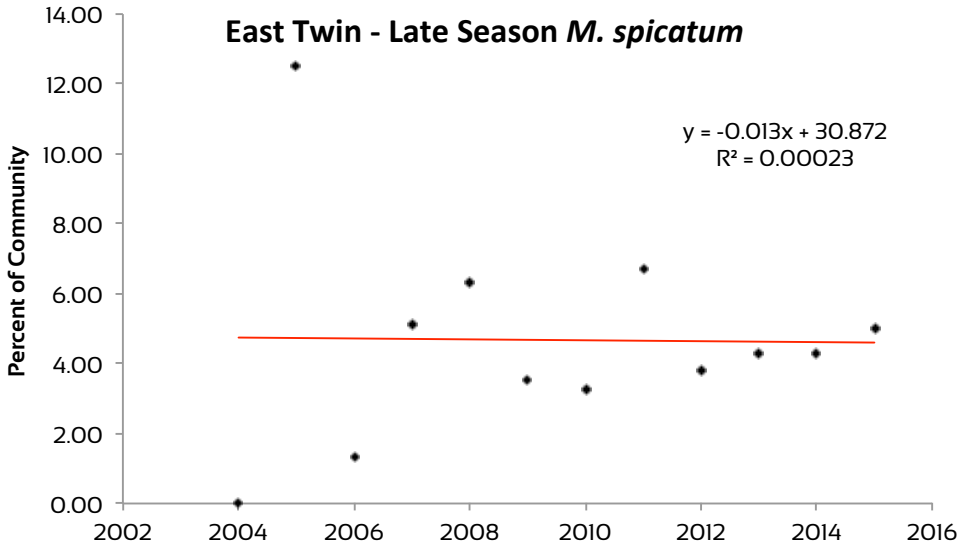

Figure 18: Number of *Myriophyllum spicatum* encounters by year in East Twin Lake.

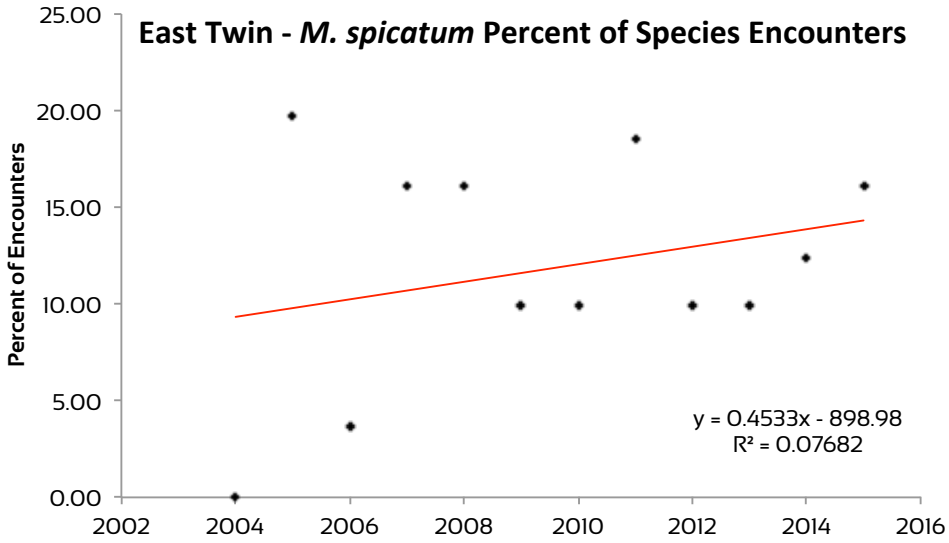

Figure 19: Number of vegetation encounters by year in East Twin Lake.

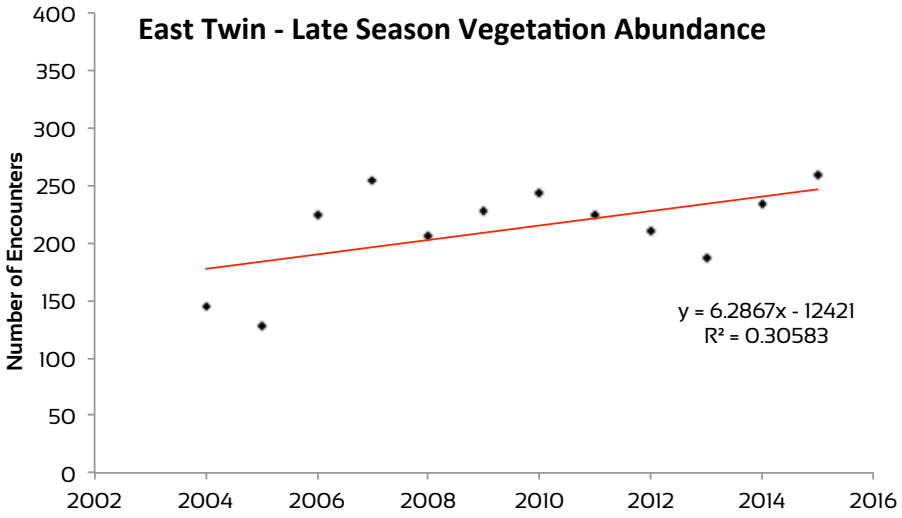

Figure 20: Macrophyte community diversity by year in East Twin Lake.

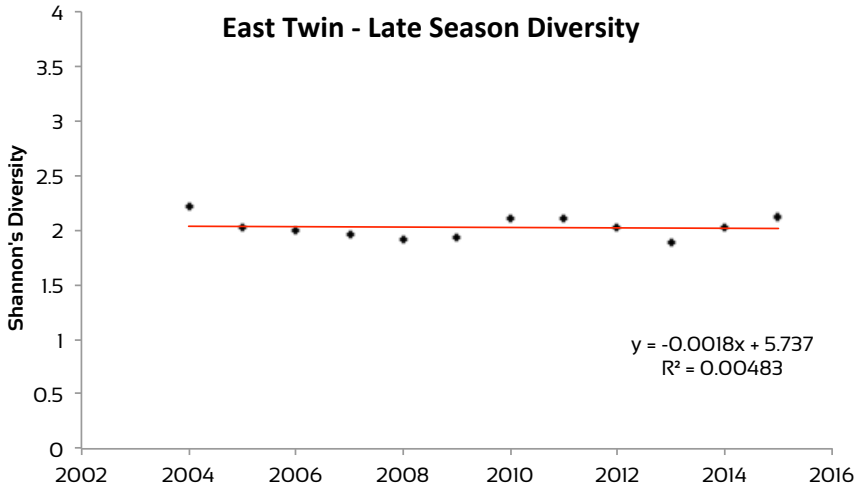

Figure 21: Macrophyte community richness by year in East Twin Lake.

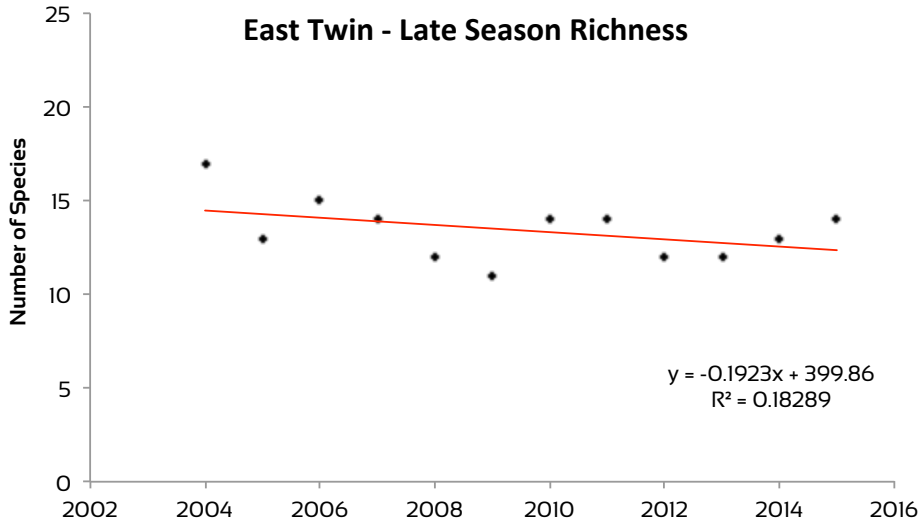

Figure 22: Macrophyte community productivity by depth and year in East Twin Lake.

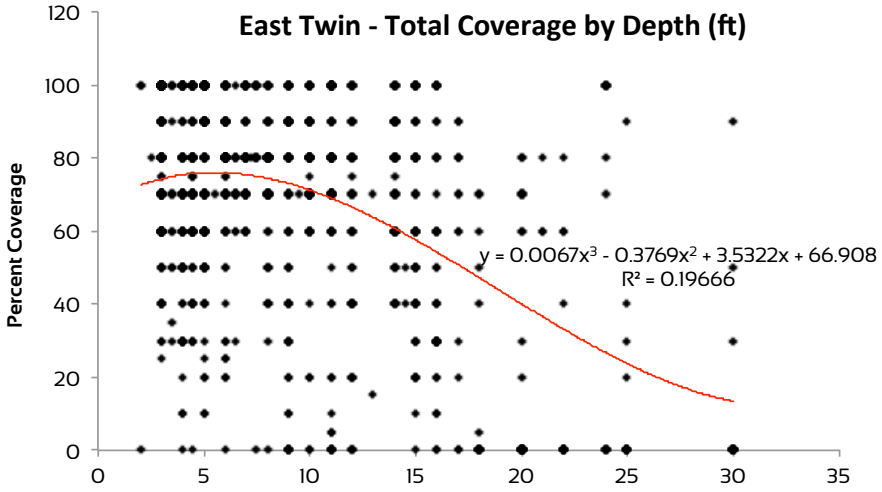

Figure 23: Percent of West Twin Lake's macrophyte community that is *Myriophyllum spicatum*.

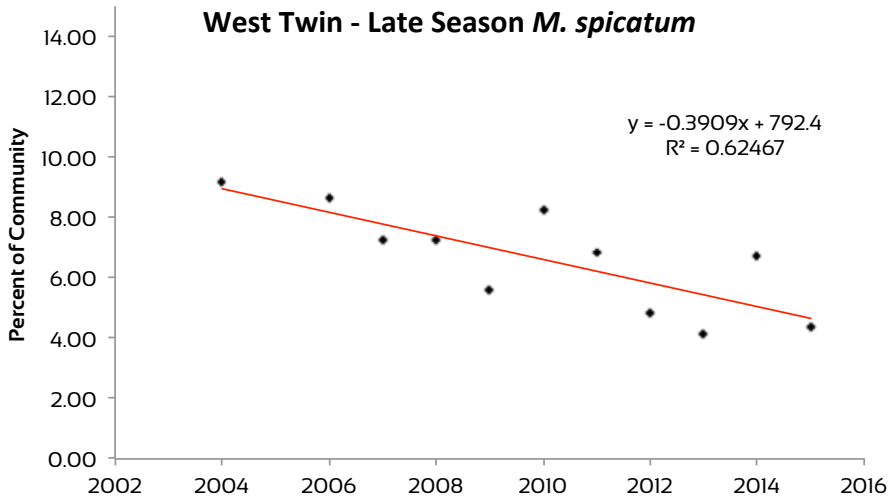

Figure 24: Number of *Myriophyllum spicatum* encounters by year in West Twin Lake.

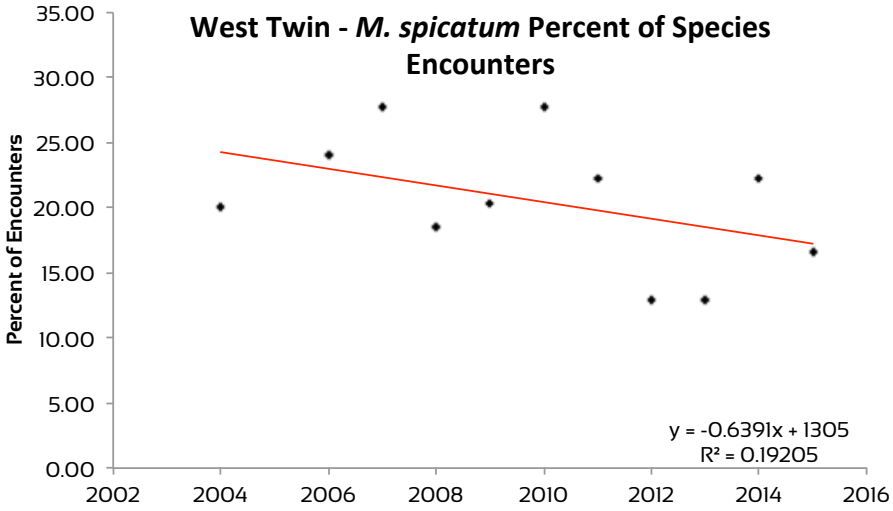

Figure 25: Number of vegetation encounters by year in West Twin Lake.

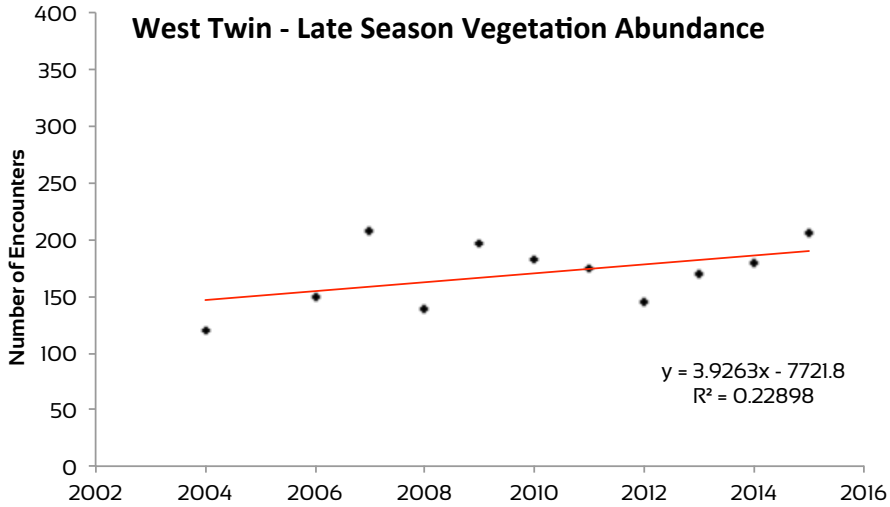

Figure 26: Macrophyte community diversity by year in West Twin Lake.

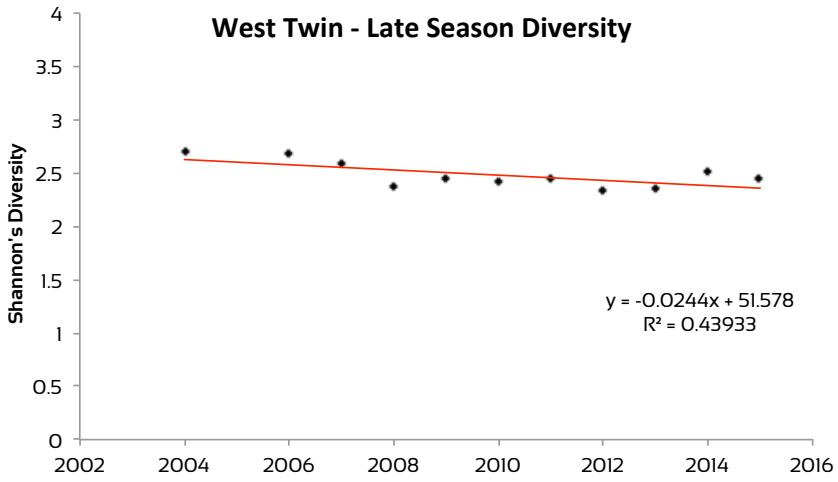

Figure 27: Macrophyte community richness by year in West Twin Lake.

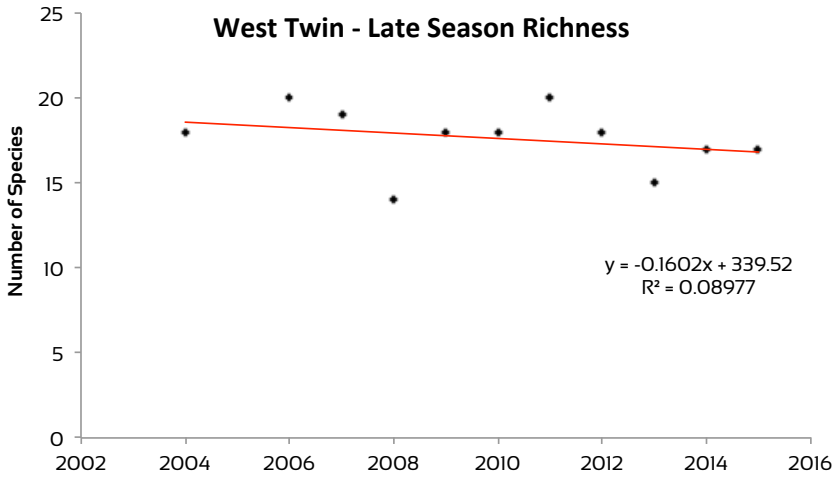

Figure 28: Macrophyte community productivity by depth and year in West Twin Lake.

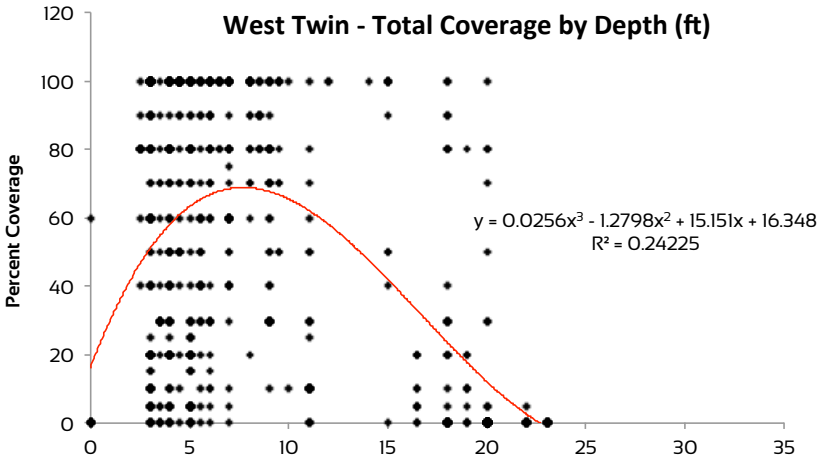

Figure 29: Black Crappie population size (i.e. catch/effort) by year in East Twin Lake.

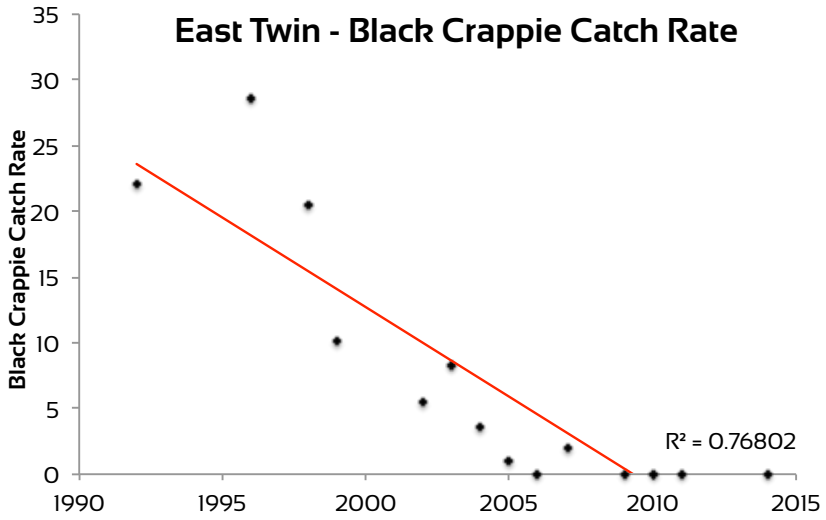

Figure 30: Golden Shiner population size (i.e. catch/effort) by year in East Twin Lake.

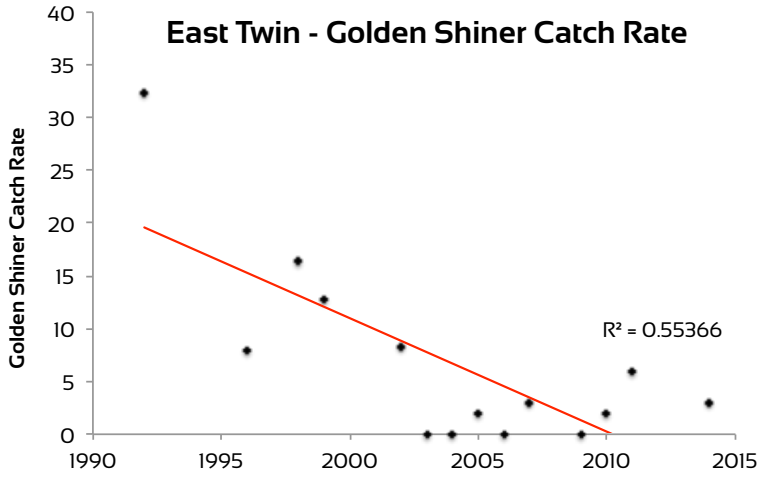

Figure 31: Rock Bass population size (i.e. catch/effort) by year in East Twin Lake.

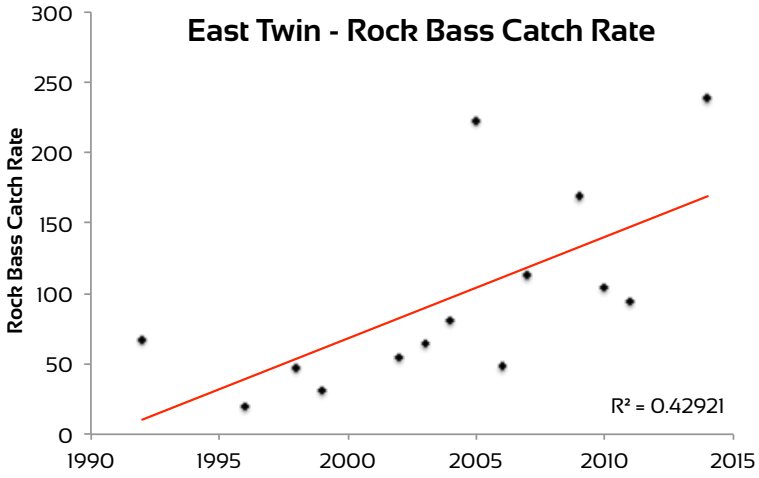

Figure 32: Creek Chubsucker population size (i.e. catch/effort) by year in East Twin Lake.

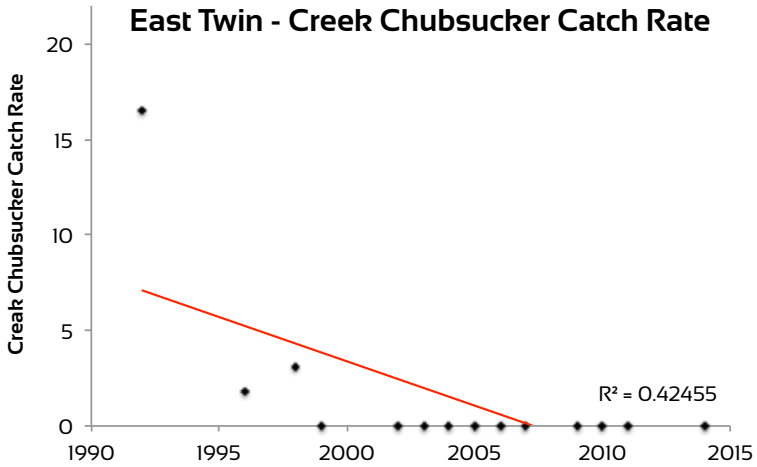

Figure 33: Total catch per unit effort by year of all fish in East Twin Lake.

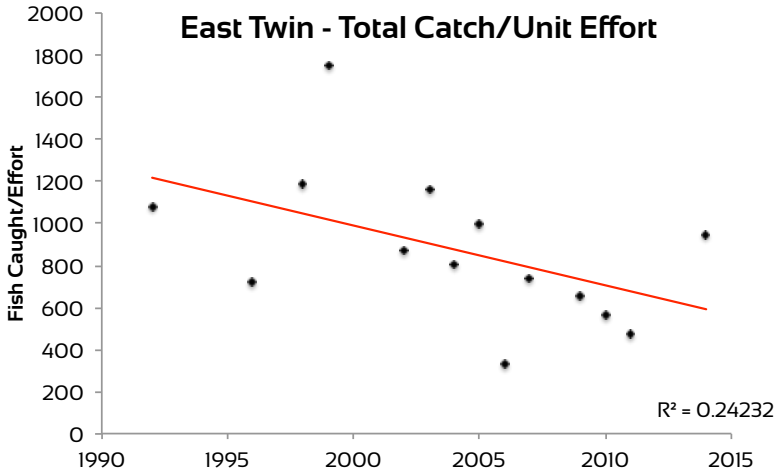

Figure 34: Diversity of fish community by year for East Twin Lake.

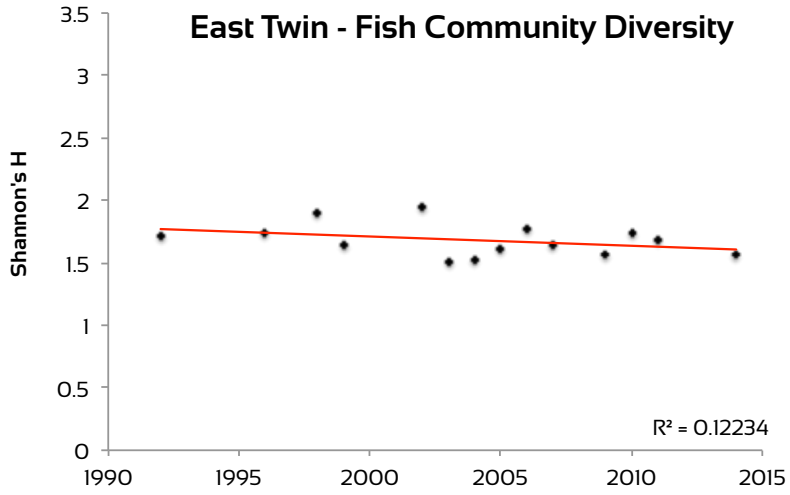

Figure 35: Fish community richness by year for East Twin Lake.

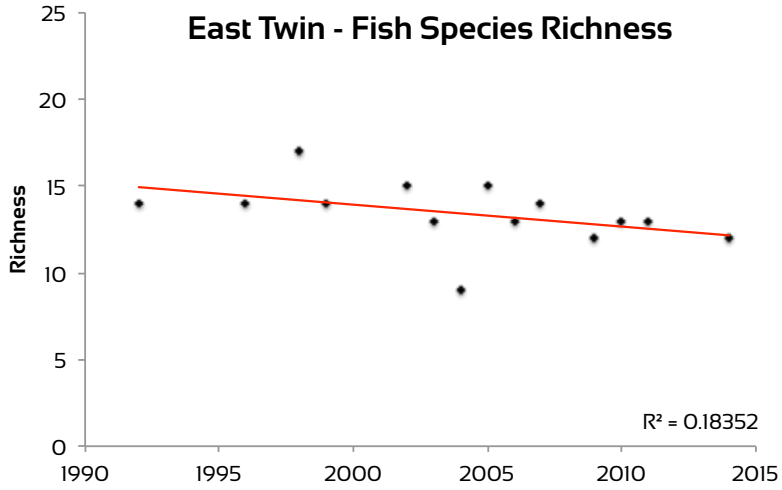

Figure 36: Horizontal sediment profile of transect 1 from the between-the-lakes sediment volumetric analysis.

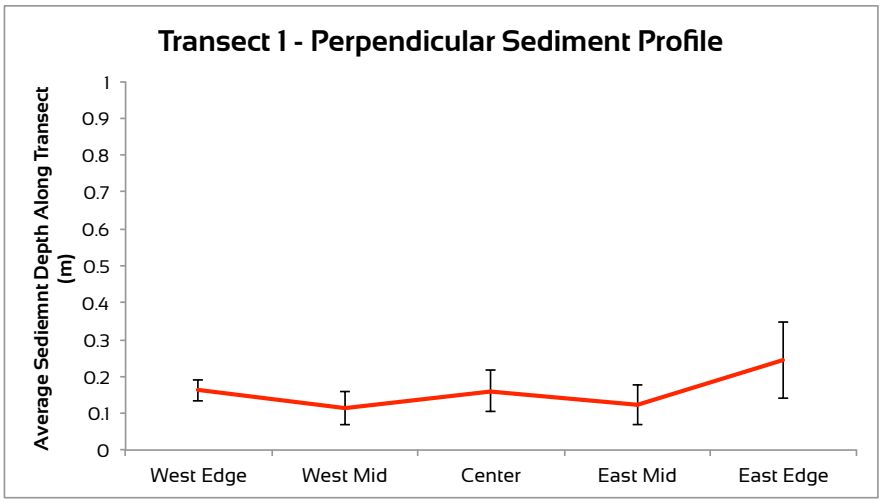

Figure 37: Horizontal sediment profile of transect 2 from the between-the-lakes sediment volumetric analysis.

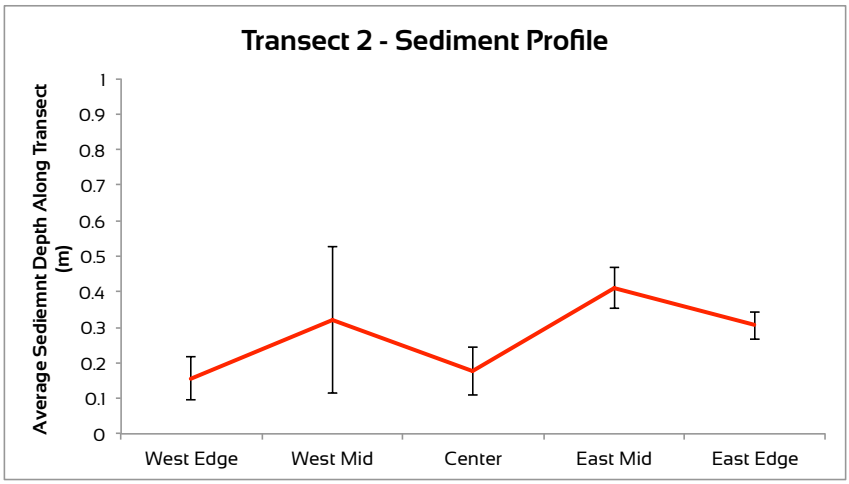

Figure 38: Horizontal sediment profile of transect 3 from the between-the-lakes sediment volumetric analysis.

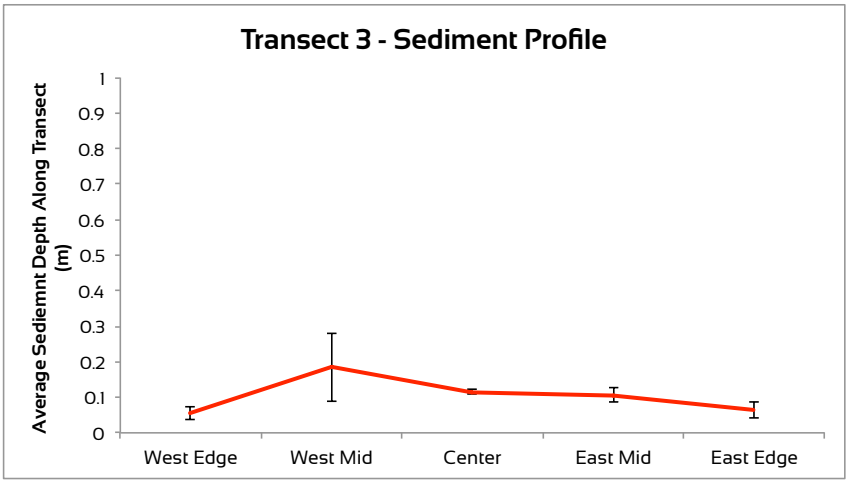

Figure 39: Proposed inspection/treatment areas for East Twin Lake.
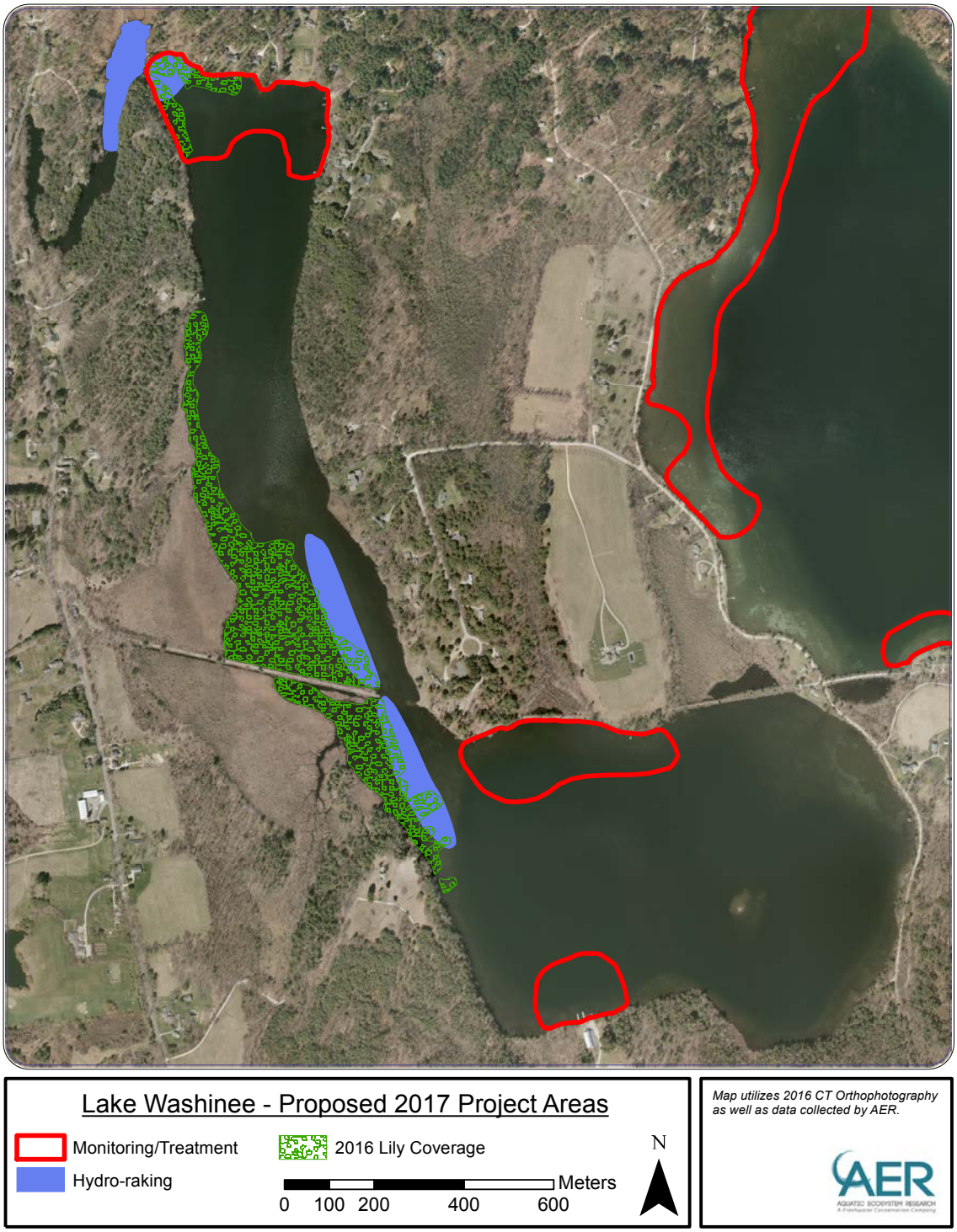
Figure 40: Proposed inspection treatment areas for West Twin Lake.