

Using GIS to Map Invasive Aquatic Plants in Connecticut Lakes

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Abstract: The Connecticut Agricultural Experiment Station's (CAES) Invasive Aquatic Plant Program (IAPP) is using GIS to determine the distribution of invasive aquatic plants in Connecticut lakes and ponds. In a first-of-its-kind survey in Connecticut, locations of plant species were recorded using a Trimble GeoXT and then downloaded to ArcGIS 9. Observed plant areas, converted into georeferenced polygons, were also added to the map. These maps are used on CAES IAPP's website (<http://www.caes.state.ct.us/aquaticplants/>) to educate the public on the subject of invasive aquatic plants, to provide baseline data useful in determining how native aquatic plant communities change in response to invasion, and to track the spread of invasive aquatic plants in Connecticut water bodies. GIS models will be used to predict future invasions in Connecticut lakes and ponds by comparing factors such as water chemistry, land use, and sediment type with successful invasions. Ultimately, GIS data will be used in the management of invasive aquatic plants in Connecticut.

Introduction

Invasive species have earned the dubious distinction as the second greatest cause of species extinction, making invasive infestation a great conservation concern (Wilcove et al. 1998). Specifically, invasive aquatic plants are a threat to native aquatic plants and aquatic ecosystem functioning (Vitousek 1996; Mack et al. 2000). Aquatic invasives are also an economic threat, significantly reducing recreation and real-estate values and subsequent tax revenue (Barrett 1989; Bergstrom et al. 1993; Fishman et al. 1999; Pimentel et al. 2000; Rockwell 2003). Furthermore, once invasive aquatic plants become established, they become nearly impossible to eradicate, and increasingly difficult and costly to contain (Leung et al. 2002).

One of the factors that makes control of invasives so costly is that infestations are rarely caught in the early stages, when the population numbers are low. In fact, invasions are usually targeted for control when the plants of concern are widespread and fully entrenched in the ecosystem. Typically, there is no baseline data from plant surveys, which makes it difficult to quantify community changes as a result of invasion, and thus difficult to determine the optimum management approach as well as measure its success. This lack of baseline data is especially true in Connecticut; therefore, the Invasive Aquatic Plant Program (IAPP) of the Connecticut Agricultural Experiment Station (CAES) has been charged with surveying vegetation in the lakes and ponds of Connecticut.

Geographic technology is an integral part of the CAES IAPP. In fact, this program marks the first time that aquatic plant populations are being systematically geo-

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referenced in Connecticut. Geographic technology allows us not only to gather more accurate baseline data, but also allows the CAES IAPP and other researchers to monitor population changes over time. Specifically, Global Positioning System (GPS) units allow us to efficiently collect data in the field and return to those exact locations for further monitoring operations. Geographic Information System (GIS) software allows us to generate geo-referenced maps of plant locations and abundances. These maps are then used to quantify the threat of invasive aquatic plants, and assist in management decisions and future monitoring. The maps are also available for the public to facilitate an understanding of the problem of invasive aquatic plants and to assist in making informed management decisions. Furthermore, GIS software is being used in a watershed analysis to determine the abiotic conditions that facilitate successful invasions.

Methods

Mapping Invasive Aquatic Plants

We used a Trimble Geo XT GPS unit with Microsoft Pocket PC 4.20 and TerraSync 2.50 to map the invasive aquatic plants. We used this unit because of its sub-meter accuracy and its ability to interface with Microsoft Excel and ESRI ArcView. To be consistent with the rest of Connecticut's data layers, we used NAD 1983 State Plane Connecticut FIPS 0600 Feet as the coordinate system for all GIS mapping.

We mapped invasive aquatic plants by first circumnavigating the patches with the boat, while logging points that, in the end, would make up an invasive patch polygon. We also used geo-referenced videography with J.W. Fishers MFG. Inc TOV-1 Towed Video, a Garmin GA 29 receiver and TrakView GPS overlay in order to identify plants too deep to visualize or sample with a 3.7m long rake. We would then make a map in the ArcView (ArcMap) program of ESRI ArcGIS 9.0 that would be used to document the extent of invasion, target invasives for control and to quantify the success of the management (Fig. 1). We downloaded the polygons from the Trimble Geo XT, differentially corrected them in GPS Pathfinder Office 3.0 and exported the data as a shapefile. I then added the polygon data to an ArcView project that contained the lake map obtained from the Connecticut Department of Environmental Protection (CT DEP).

Pre-Treatment Map of Lake Quonnipaug, Guilford, Featuring Locations of *Megalodonta beckii*, *Cabomba caroliniana* and *Myriophyllum spicatum* October 3-6 2005

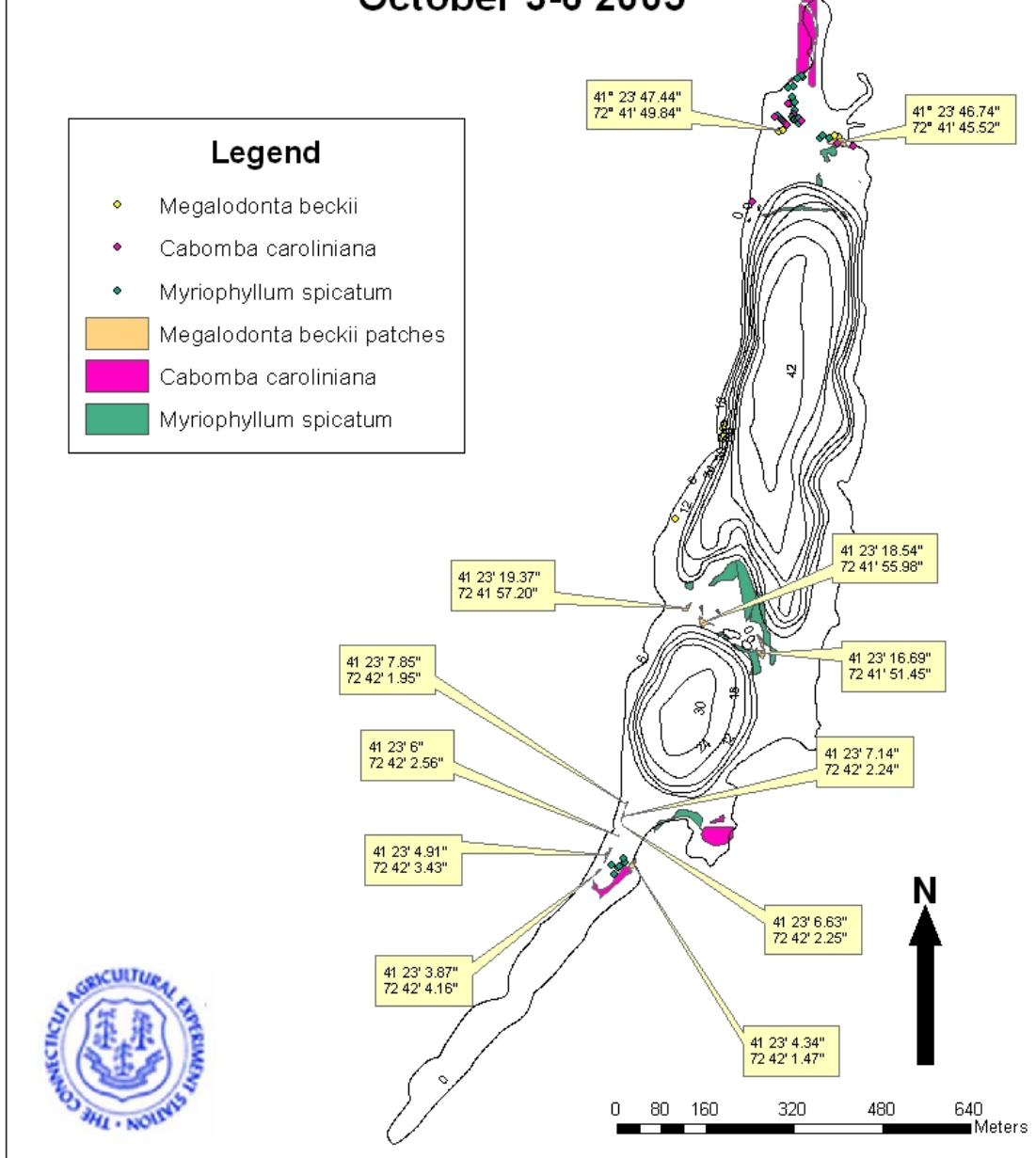


Figure 1: Map of Lake Quonnipaug with the invasive patches of *Cabomba caroliniana* and *Myriophyllum spicatum*, as well as the endangered species *Megalondonta beckii*. The patches were recorded using a Trimble GeoXT with TerraSync software. The map was made in ArcView.

We loaded a GIS topographic map of the lake onto the Trimble Geo XT to facilitate construction of a visual survey map of the remaining patches of invasives that were either too small to circumnavigate or not targeted for management. The topographic map also helped us document the location of native plant species. In the laboratory, the visual survey maps were digitized in ArcView. We created shapefiles in ArcView for each recorded species (using the same species shapefile for all of the lake map projects where the species occurs), and used the editor feature to create polygons that were approximately the same size and location as the ones drawn on the map during the visual survey. The area of each patch was determined with the XTools Pro 3.1.1, a free tool downloaded from the ESRI website (www.esri.com). The plant collection locations were also added to the map after being uploaded from the Trimble Geo XT and differentially corrected in Pathfinder Office. Then we exported the maps as a JPG, inserted it into the website and created hotspots around the plant names in the legend. The hotspots were linked to a map of that species' locations in the lake.

The GPS coordinates of the plant collections were also recorded on the specimen labels of herbaria collection sheets. We recorded the collection locations as point features in a data dictionary developed in Pathfinder Office. In the data dictionary, we noted such attributes as the collector (drop-down menu), depth (numeric), substrate (drop-down menu), weather (drop-down menu), wind direction (drop-down menu) and notes. We also recorded the collected species in a numeric attribute, 1 denoted 'found', 0 denoted was 'not found.'

Quantifying Invasive Aquatic Plant Abundance

The data we gathered during the geo-referenced transect portion of the survey was used to quantify species abundance. We created a data dictionary in Pathfinder Office, which contained the fields of surveyor (drop-down menu), depth (numeric), substrate (drop-down menu), weather (drop-down menu), wind direction (drop-down menu), transect number (numeric), points (numeric), meters from shore (numeric), notes field and plant species (numeric). I used the Trimble Geo XT with the data dictionary to measure and record the location of the transects, which started at the shore (0 meters) and then continued, perpendicular to the shore, at distances of 5, 10, 20, 30, 40, 50, 60, 70 and 80 meters. In lakes less than 100 ha, there was one sample point per 0.4 ha with at least one transect per water body. In larger lakes, sample points were reduced to one point every 0.8 ha. At each point, we sampled native and invasive plants within a 2 m sphere with a 3.7 m rake or grapple (if the water was too deep for the rake). We recorded an abundance value from 1 to 5 (1 = present but rare [1 plant], 2 = occasional [a few plants], 3 = common [more than a few plants], 4 = abundant, 5 = extremely abundant or dominant) of the sampled plant species in the numeric field of each species in the transect point feature of the data dictionary.

After returning to the laboratory, we downloaded the data from the Trimble Geo XT, differentially corrected it, and then added it to the visual survey map in ArcView (Fig. 2). We also exported the data into Microsoft Excel and Systat 11 for statistical analyses.

Ball Pond, New Fairfield 82.5 Acres

Invasive Aquatic Plant Program
Surveyed August 17, 2005
by Roslyn Selsky and
Greg Bugbee

Legend

- ★ Water Sample
- ◆ Transect Points
- Potamogeton pusillus
- Najas minor*
- Nymphaea odorata
- Potamogeton gramineus
- Nuphar variegata
- Potamogeton oakesianus
- Najas guadalupensis
- Ceratophyllum demersum
- Myriophyllum spicatum*
*Invasive

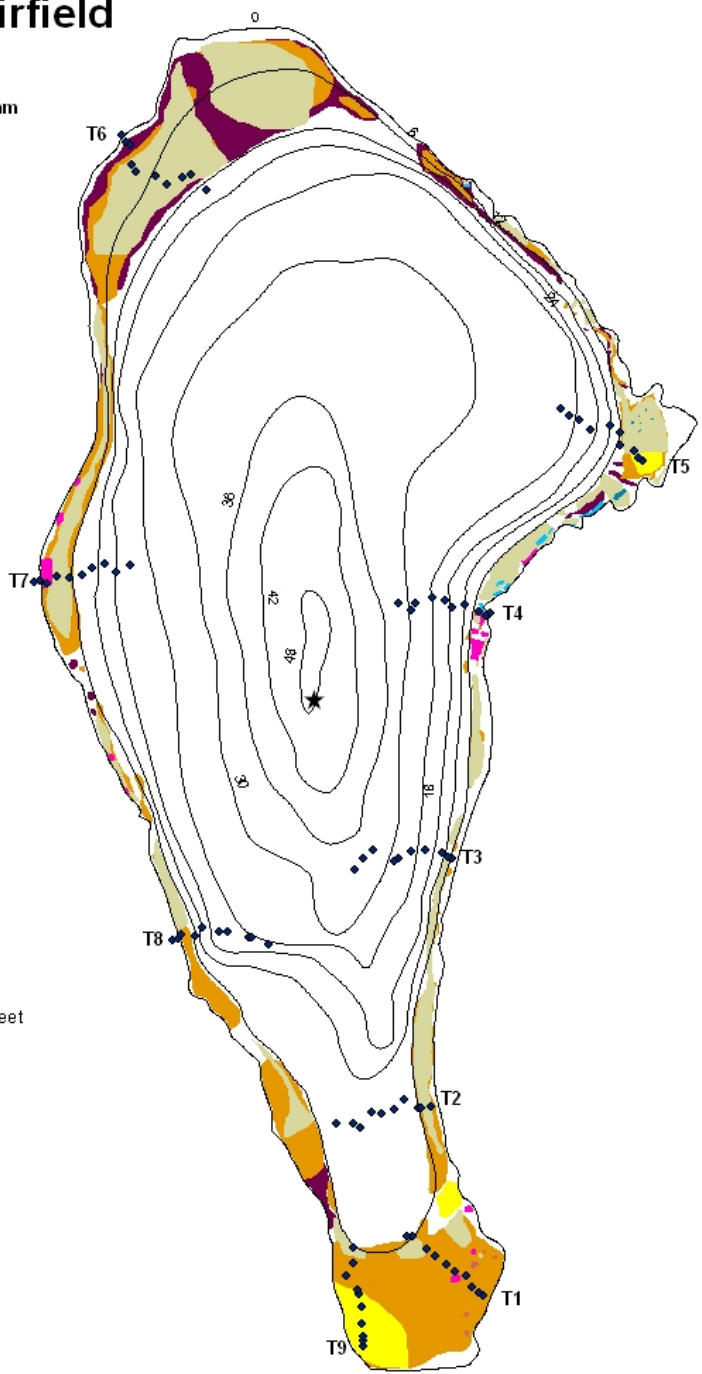
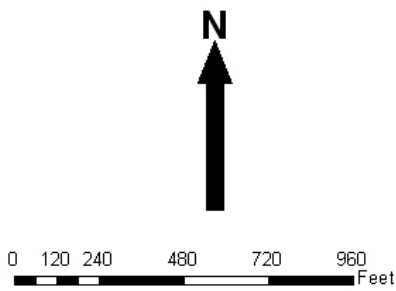


Figure 2: Bathymetry map of Ball Pond with plants recorded during the visual survey and transects. The locations of the transect points were recorded with a Trimble GeoXT with TerraSync software and the map was made in ArcView.

Water Data

In addition to mapping and quantifying plant abundance, we used the Trimble Geo XT to record the location of water sampling sites at each lake or pond. At these sites, we recorded dissolved oxygen and temperature, which was measured on a YSI Model 58 meter. After we downloaded the data from the Trimble Geo XT, we differentially corrected and added it to an ArcView project. If the water body was targeted for management, we would use the ArcView map and Trimble Geo XT to return to the same sampling sites to take additional water samples throughout the year to assess water quality conditions over time.

Watershed Analysis

The watershed analysis began after the survey maps were completed. We are currently using this analysis to determine which abiotic factors affect species richness, including lake perimeter, lake to basin area ratio, land cover, quaternary geology, bedrock, surficial materials, soils, aquifer protection areas, dams, boat launches, roads, leachate and wastewater discharge, major rivers, surface water quality class, open space, sewer service, hydrography, impervious surfaces and population density. We constructed separate map files in ArcView for each lake and pond, and subsequently isolated that lake and its local basin into their own layers.

Using XTools Pro, we calculated a new lake layer and basin layer area, as well as the perimeter of the lake. We determined perimeter of the lake in order to compare lake sizes more accurately, because it is the available littoral zone, which is largely determined by available edge, and not the lake area, that determines available area for plant growth. We also determined the lake and basin areas to calculate the lake to basin ratio.

We created three models in the ArcToolbox, the clip model, hydro model and street model, to aid in the efficiency of the analysis. The clip model (Fig. 3) clipped various shapefiles, which included land cover (lc2002ct.shp), quaternary geology, bedrock, surficial materials, soil, CT DEP, federal and municipal property, sewer service, streets and population (ct_tracts_2000_pop_sp83.shp), to the isolated basin. We then determined the area or length for the desired attribute in all the clipped layers, with the exception of the population layer, using XTools Pro, summed that column and exported the data to Excel with XTools Pro. We modified the population table, which listed the number of people in a census tract, to also contain density. After we had determined the area of the census tracts with XTools Pro, we used the 'calculate values' command in editor mode to determine the density. We then clipped the population layer to the basin with the clip model, and we used the statistics command to average the density if more than one census tract fell into the basin area. Finally, we recorded the population density data in Excel, and we combined the results from the three property layers to reveal the open space in the basin.



Figure 3: Schematic of the clip model, which was used in ArcView to clip various shapefiles to the desired basin.

We created the hydro model (Fig. 4) to clip and buffer the hydrography layers. The hydrography layers were comprised of a Connecticut hydrography layer and projected (NAD 1983 State Plane Connecticut FIPS 0600 Feet) New York, Rhode Island and/or Massachusetts hydrography layers, depending on basin location. We used the hydrography data to gauge the connectivity of water bodies, speculating that more water near a studied lake would translate into greater possibilities for introduction of invasive species. The hydro model had two parts. The first part buffered the lake with the desired distance, and the second part clipped the Connecticut hydrography to the buffered lake. We used the hydro model twice, once with a lake buffer of 1.61 km and then with a lake buffer of 16.09 km. Then we would calculate the area with XTools Pro of the hydrography attribute column, summarize that column and export it to Excel with XTools Pro. If the buffered area extended outside of Connecticut, we would clip the other state's hydrography layer to the buffered lake. If there was any overlap of the two layers, we would isolate that area by clipping the other state's hydrography to the Connecticut hydrography and then subtract it out of the total hydrography area.

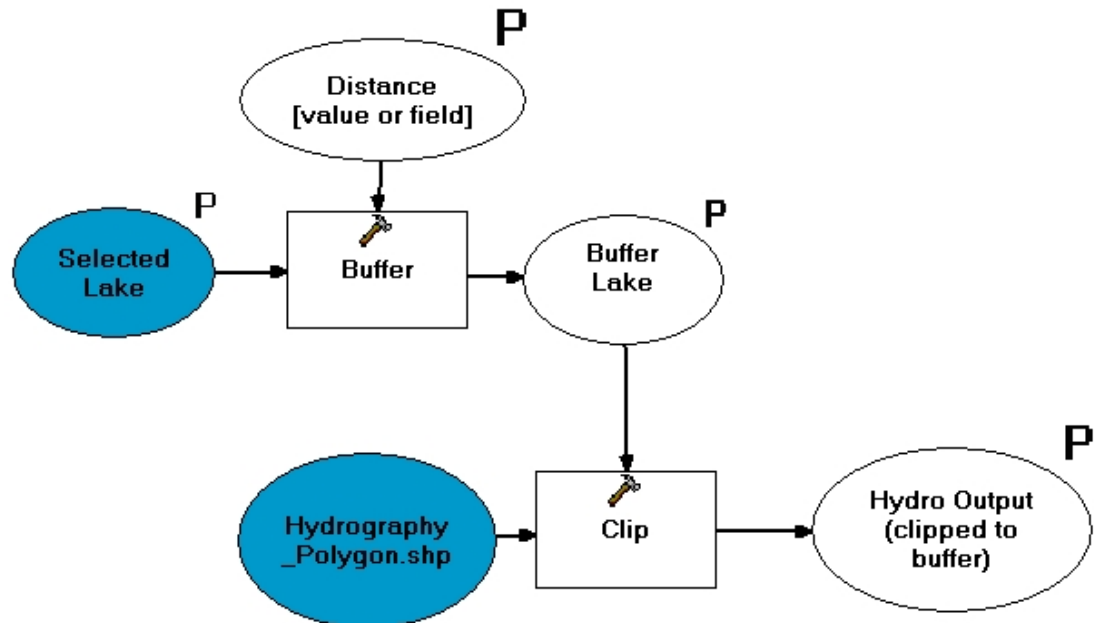


Figure 4: Schematic of the hydro model, which was used in ArcView to determine the hydrography in a 1.61 km and 16.09 km radius of the selected lake.

Similar to the hydro model, we used the street model (Fig. 5) to buffer and clip layers. The street model first buffered the selected lake to 137.16 m. Then the street model clipped the street layer to the buffered lake layer. As with the previous models, we then calculated the length of the street output with XTools Pro, summarized the length attribute and exported it to Excel also with XTools Pro. We used the value of 137.16 m in the street model to determine the area directly around the lake that contained streets, which, as impervious surfaces, would facilitate nutrient run-off into the lake (Brabec et al. 2002).

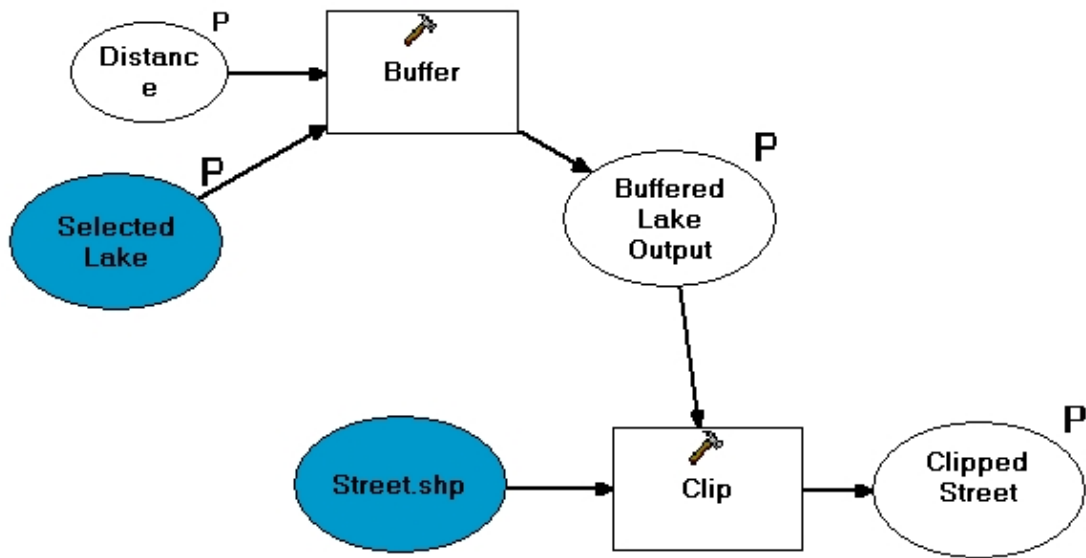


Figure 5: Schematic of the street model, which was used in ArcView to buffer the selected lake and then clip the street layer to that buffer.

We subsequently added the remaining layers in the watershed analysis, which included aquifer protection areas, dams, CT DEP boat launches and major rivers to the map project, and then noted if the feature was present in the selected basin. In addition, we added the leachate and wastewater discharge layer to the project, and recorded the number of discharge sources in Excel. We also added the surface water quality layer to the map project, and recorded the surface water classification, ranging from AA (existing or proposed drinking water supply) to D/B (currently not meeting criteria for target class), in Excel.

Results

Management Results

Maps outlining patches of invasive aquatic species, made with the Trimble Geo XT and ArcView, were successfully used in treatment experiments on two lakes, Bashan Lake in East Haddam (Fig. 6) and Quonnipaug Lake in Guilford (Fig. 1). The pre-treatment survey in Bashan Lake resulted in a precise mapped location of *Myriophyllum heterophyllum* for the herbicide applicators. A post-treatment survey revealed that *M. heterophyllum* had been greatly reduced in the treated areas, from large patches to individual plants (Bugbee et al. 2005). The pre-treatment survey of Quonnipaug Lake not only documented the precise location of the invasives *M. heterophyllum* and *Cabomba caroliniana*, but also the locations of an endangered plant in Connecticut, *Megalodonta beckii*. The precise locations of *M. beckii* were critical because herbicides can not be applied within 61 m of an endangered plant. As a result of our methodologies, CT DEP issued an herbicide permit for *M. heterophyllum* in Quonnipaug Lake, and we were able to schedule a treatment experiment for this summer.

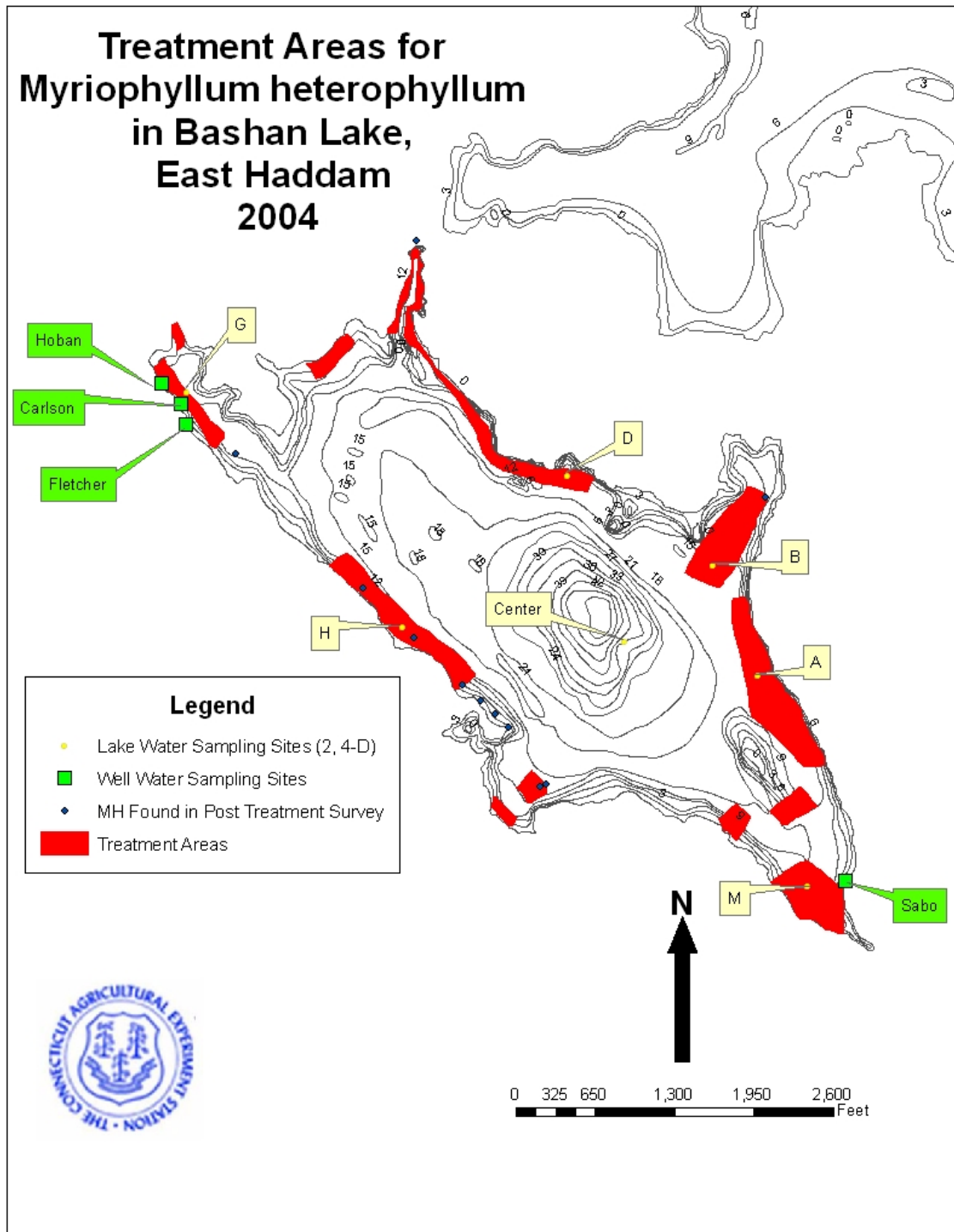


Figure 6: Bathymetry map of Bashan Lake, which shows the location of *M. heterophyllum* (treatment areas) pre-treatment and *M. heterophyllum* post-treatment. The location of *M. heterophyllum* was recorded with a Trimble Geo XT with TerraSync software, and the map was made in ArcView.

Survey Results

CAES IAPP has surveyed 105 lakes, and found that 66 (63%) contained invasive aquatic plants. In total, 95 aquatic plant species were recorded. A number of new populations of invasive plants, as well as a new invasive species in Connecticut, *Glossostigma cleistanthum*, were found. In addition, a number of new populations of endangered plants were documented. An analysis by Capers et al. (manuscript in preparation) of the transect data in the surveyed lakes revealed that high native aquatic plant species richness does not preclude invasion by non-native plants. In fact, invasive aquatic plant species were most often found in lakes with diverse native aquatic plant communities.

One of the ways that the survey data, including the GIS applications, was displayed was through the CAES IAPP's website (<http://www.caes.state.ct.us/aquaticplants/>). Since its unveiling in May of 2005, the website has had 13,844 hits. Users claim that the map pages, which contain ArcView projects of each surveyed lake, are very informative and useful when making management decisions. The CT DEP also used the maps on the website for the 2004 Water Quality Report to Congress (prepared pursuant to Clean Water Act Section 305 (b)). In addition, the maps were used by the CAES IAPP during volunteer monitoring workshops; from 2005 to 2006, 8 workshops were held and 178 citizens attended. The maps were specifically used as an example of aquatic plant mapping, and were used to educate the volunteers about invasive aquatic plants.

Watershed Analysis

While work on the watershed analysis is still ongoing, we successfully applied all three models and created a large dataset with the results. We were also one of the first groups to use the new Connecticut impervious surface layer, and the resulting data will be useful in predicting potential nutrient run-off into water bodies. In addition, government officials and the public will be able to factor our published results of the watershed analysis into their management plans.

Conclusion

In conclusion, GIS is an integral component of the CAES IAPP. The Trimble Geo XT permitted us to efficiently collect data which was used in mapping and statistical analyses. ArcView allowed us to display aquatic plant communities for management studies and education outreach with stakeholders. The GIS methodology developed in this paper was so successful that GIS will be an integral component in the next phase of the CAES IAPP, which includes monitoring of potential native biological control agents.

Acknowledgements

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Data Layers Used in ArcView Projects

1. Aquifer Protection Area Layer- DEP Bureau of Water Management and DEP Environmental and Geographic Information Center. 2004. aquiferprotectionarea.shp
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/apa.htm>
2. Bedrock Geology Layer- U.S. Geological Survey and Connecticut Department of Environmental Protection Geological and Natural History Survey. 2000. bedrock.shp <http://www.dep.state.ct.us/gis/dataguides/dep/layers/bedrock.htm>
3. Dams Layer- DEP Inland Water Resources Division and DEP Environmental and Geographic Information Center. 1996. dam.shp
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/dam.htm>
4. DEP Boat Launch Layer- DEP Environmental and Geographic Information Center. 1996. depboatlaunch.shp
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/boatdep.htm>
5. Connecticut Office of Policy and Management and DEP Environmental and Geographic Information Center. 1997. federalproperty.shp
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/propfed.htm>
6. Open Space Layers- DEP Environmental and Geographic Information Center. 2002. depproperty.shp
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/propdep.htm>
7. Hydrography layer- Connecticut Department of Environmental Protection Environmental and Geographic Information Center. 1995. Hydrography_polygon.shp Hydrography
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/hydro.htm> ; Rhode Island Geographic Information System, University of Rhode Island. Lakes5K.shp “1:5,000 Lakes and Ponds” <http://www.edc.uri.edu/rigis-spf/statewide/state.html#hydrography>; MASSGIS. 2000. Hydrography (1:25,000 and 1:100,000). <http://www.mass.gov/mgis/ftphd.htm> , <http://www.mass.gov/mgis/ftphd100.htm> ; USGS. 1999. National Hydrography Dataset-Medium Resolution. http://nhdgeo.usgs.gov/metadata/nhd_medium.htm ; USGS. 1999. National Hydrography Dataset-High Resolution. http://nhdgeo.usgs.gov/metadata/nhd_high.htm
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13. Major Rivers Layer- DEP Environmental and Geographic Information Center. 1995. majorriverlines.shp
<http://www.dep.state.ct.us/gis/dataguides/dep/layers/river.htm>
14. Connecticut Office of Policy and Management and DEP Environmental and Geographic Information Center. 1997. municipalproperty.shp
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15. Population Layer- Natural Resources Management Engineering, University of Connecticut. 2000. ct_tracts_2000_pop_sp83.shp Personal communication.
16. Quaternary Geology Layer- U.S. Geological Survey and Connecticut Department of Environmental Protection Geological and Natural History Survey. 2000. quaternarygeology.shp
<http://www.dep.state.ct.us/gis/dataguides/usgs/layers/quatgeol.htm>
17. Sewer Service Areas Layer- DEP Bureau of Water Management and DEP Environmental and Geographic Information Center. 1998. sewerservicearea.exe
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19. Street Layer- University of Connecticut Center for Geographic Analysis and U.S. Census Bureau. 2002. Street.shp Connecticut Street Network State Plane, TIGER/LINE 2000.
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