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2010 Onondaga Lake Aquatic Macrophyte Survey

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1. INTRODUCTION

1.1 Background

As part of the Amended Consent Judgment (ACJ), Onondaga County agreed to increase the level of biological monitoring of the Onondaga Lake ecosystem. Appendix D, Section IV, item (4) states that the County will "complement the chemical monitoring program with a biological monitoring effort to assess the densities and species composition of phytoplankton, zooplankton, macrophytes, macrobenthos, and fish".

The Ambient Monitoring Program (AMP) commits to monitoring the macrophyte community once every five years. As described on page 54 of the AMP (dated 7/24/98), "Macrophytes (rooted aquatic plants and algae) will be assessed using standard techniques for monitoring aquatic vegetation. Reference quadrants will be identified and sampled every five years. The sampling program will provide sufficient data for a statistical evaluation of changes."

The AMP program has committed to sampling Onondaga Lake aquatic macrophytes in the years 2000, 2005, and 2010 and collecting annual aerial photographs of the littoral zone to determine plant distribution (when water clarity allows). The first AMP macrophytes sampling effort was completed in 2000. The results of the 2000 baseline effort were detailed in a report submitted to Onondaga County in 2001 (EcoLogic 2001). Those results were also summarized in the 2000 Onondaga Lake Annual AMP report (OCDDS 2001).

1.2 Previous Lake Macrophyte Investigations

Madsen 1991: A survey completed by Dr. John Madsen and colleagues (US Army Corps of Engineers, Madsen et al. 1996a) in late June 1991 provides the only quantitative characterization of the community prior to the first AMP survey in 2000. These investigators examined the distribution of submersed aquatic vegetation along 40 transects located perpendicular to the lake shoreline. Each transect was divided into 1m segments and extended from the shoreline to a water depth of 5 m or a length of 100 m from shore, whichever was shorter. At each 1m segment interval, field personnel placed a quadrat of 0.1 m^2 and estimated the species composition of macrophytes.

Macrophytes were observed in 13.3% of the quadrats surveyed in 1991, and the community was composed of only five species. The typical number of macrophyte species for a eutrophic lake in the New York is fifteen (Madsen et al. 1996a). The researchers noted that numerous chemical and physical factors likely contributed to the reduced flora. Considered among the most significant were sediment texture (particularly the presence of calcium carbonate accretions or oncolites), reduced water transparency, elevated salinity, and low nutrient content of the sediments.

In the 1991 survey, transects without plants were largely restricted to those areas with the greatest wave action. Sediment texture was determined to be a significant determinant as well. Sediments composed of predominantly gravel were the least likely to support macrophytes, followed by oncolites (Madsen et al. 1996a).

OCDWEP 2000: The Onondaga County Department of Water Environment Protection (OCDWEP) initiated the first AMP macrophyte survey in 2000. This survey used a combination of aerial photographs and a field survey to document species composition, percent cover, and biomass. The aerial photographs were digitized and macrophyte beds delineated in ArcView. The field survey used 20 transects located perpendicular to shore and extending to a 6 m depth of overlying water. Data on species composition and percent cover were collected within $1m^2$ quadrats every other meter along each transect. Biomass samples were collected from within a $0.25\ m^2$ quadrat at randomly selected locations along each thirty-meter section of each transect.

Macrophytes were observed in 28% of the quadrats surveyed in 2000, and the community was composed of ten species. The community was dominated by only three species: sago pondweed (*Stuckenia pectinata),* common waterweed *(Elodea canadensis),* and water stargrass *(Zosterella dubia)*. Almost all macrophytes (99%) were located in shallow water, at depths to about 2 m. The maximum depth at which macrophytes were observed was 3.75 m. Similar to the 1991 findings, most macrophytes were found in areas of the littoral zone with low wave energy. The report concluded that there was substantial potential for expansion of macrophyte beds in most of the littoral zone.

OCDWEP 2005: The 2005 Onondaga Lake macrophyte monitoring program combined a lake-wide mapping effort from aerial photos with quantitative in-lake surveys. The methods used in the baseline survey of 2000 were replicated in 2005 to ensure data comparability.

The macrophyte community in 2005 was drastically different from that found in 2000. Species richness had almost doubled since 2000. Two of the newly documented species were listed as New York State endangered species; however, the community was still largely dominated by only a few species. Common waterweed was by far the most abundant species in all areas of the lake. The coverage and biomass of macrophytes was, on average, slightly more than three times greater in 2005 than it was in 2000. The range of percent cover in the lake was within the range expected to be near ideal for largemouth bass production. The percent of subplots with plants also increased about two-fold, and the depth to which plants were growing in the lake had increased significantly since 2000.

1.3 Objectives

The objectives of the 2010 Onondaga Lake macrophyte program included:

- Determine the species composition, abundance, and distribution of the macrophyte community in Onondaga Lake.
- Determine whether significant changes to the community had occurred since 2005.
- Determine if any significant change in the macrophyte community since 2005 can be correlated with changes in water quality or ecological factors.

2. METHODS

Macrophyte distribution and abundance can be determined by several methods. Inventories may be completed using remote sensing techniques such as satellite imagery and aerial photography. Other techniques rely on field sampling to identify species composition and estimate biomass. The 2010 Onondaga Lake macrophyte monitoring program utilized both methods by combining a lake-wide mapping effort from aerial photos with quantitative in-lake surveys. The methods used in the 2000 and 2005 surveys were replicated in 2010 to ensure data comparability.

2.1 August Field Sampling

2.1.1 Strata and Transect Locations

Consistent with other nearshore biological sampling programs of the AMP, a stratified random sampling design was used for the macrophyte monitoring program. This sampling design is appropriate for the Onondaga Lake macrophyte community for several reasons. First, the lake has fairly distinct areas where a combination of factors affecting macrophyte growth can be used to define strata. Second, stratification of samples increased precision by reducing variance within strata, while random selection ensured that the macrophytes were sampled in an unbiased manner.

The lake was divided into five distinct strata as indicated in Figure 1. The selection of the strata was based on substrate type (Auer et al. 1995; Madsen et al. 1996a) and wave energy (EcoLogic 1999). The five strata are:

Stratum 1: *Oncolites, Low Energy* [northwest shore];
Stratum 2: *Wastebeds, Medium Energy* [southwestern shore];
Stratum 3: *Fine Sediment, High Energy* [south end];
Stratum 4: *Oncolites, High Energy* [southeastern shore];
Stratum 5: *Oncolites, Medium Energy* [northeast shore].

In 2000, four line transects were randomly located in each stratum, totaling 20 transects in the entire lake. These same 20 transects were sampled in 2005 and again in 2010. The 20 transects used in the 2000 and 2005 surveys were located using GPS coordinates and site photos one day prior to initiating the 2010 sampling effort.

2.1.2 Species Composition and Cover Sampling

Transects extended from shore to a water depth of 6 m or out to the maximum depth of plant growth, whichever was greatest. Each transect was temporarily marked at the shoreward end with large red plastic jug set at the water’s edge. A brightly colored buoy with six meters of rope attached was anchored at a depth of 6 m perpendicular to the shore and aligned with the red shoreline jug stake to mark the offshore end of each transect. A second brightly colored buoy was deployed at the 3-m depth to further define the transect line. The location and distance to shore at the 3- and 6-meter buoys were recorded using a global positioning system unit and a laser rangefinder, respectively.

Data were collected along transects by one person wading or using SCUBA gear. Sampling began at the shore end of the transect and proceeded out into the lake. Macrophyte species composition and percent cover by species of a 1-m^2 area was visually estimated every 2 m along the entire length of the transect out to 6 m depth. Depth at the deepest point of macrophyte growth along each transect was also recorded. The sampler was accompanied by two other crew members in a rowboat. One member of the crew recorded data relayed by the sampler, and a second crew member guided the boat.

If the field crew was unable to finish an entire transect in a single day due to time constraints or weather, the recorded GPS readings of the 3 and 6 meter points along the transect were used to reset the buoys at a future time to finish off the transect line.

2.1.3 Biomass Sampling

Transects were divided into 30-m intervals starting from shore and ending at a depth of 6 m. A 1-m section was randomly selected for biomass sampling in each of these 30-m intervals. The selected quadrat numbers were kept constant for all transects. The randomly selected quadrats were located at 15, 41, 61, 119, 145, 163, 185, 221, 267, 289, 309, 351, 381, 399, 446, 470, 495, and 531 meters from shore. Biomass was sampled at each of these locations until the end of the transect was reached.

At each pre-selected biomass sample location along the transect, a 0.25 m^2 weighted quadrat (a square made from PVC tubing filled with lead shot) was dropped and allowed to sink to bottom with no assistance. The sampler harvested all macrophytes and filamentous algae within the quadrat. Plants were broken directly at the sediment surface, rolled into a ball while underwater, and brought to the surface. The sample was transferred to a labeled plastic garbage bag(s) on a nearby boat and brought to the Cornell University for processing.

At Cornell University, the entire balled plant mass from each 0.25 m^2 quadrat was separated to individual plant species. Species were washed to aid in separating filamentous algae and to remove sediment and zebra mussels. Clean species were then placed into labeled paper bags. The bagged samples were put in drying ovens at a temperature of 105°C for at least 48 hours. Dry weights were then determined on the entire 0.25 m^2 sample and recorded in an Excel spreadsheet. The Cornell Laboratory did not conduct any wet weights or sub-sampling, in order to reduce sampling error often experienced when wet weights and extrapolation of subsamples are used.

2.2 Analysis of Subplot Data – Community Metrics

A series of standard community measures (metrics) were used to characterize the community structure and composition of macrophytes in Onondaga Lake. These metrics were compared to the same metrics calculated in 2000 and 2005.

Macrophyte community metrics included measures of lake-wide and strata-based percent coverage, biomass, frequency of occurrence, richness, dominance, and diversity. Filamentous algae are not used in the metric calculations for macrophytes and are reported separately where appropriate.

2.2.1 Percent Cover

Percent cover was estimated within each of the 1-m^2 subplots. Cover is the surface area occupied by a vertical projection of foliage and stems of different species of plants and/or filamentous algae to the lake's surface. Percent cover was independently calculated for each species observed in the quadrat. Percent cover averages for each strata and the entire lake were calculated from subplot data. For example; the mean cover of a stratum was based upon the mean of all individual subplots, including those that did not contain macrophytes (where percent cover equaled zero) in that stratum.

Relative percent cover of the individual species was also calculated, based upon each individual species percent cover compared to the total cover of all macrophytes in the area of study (stratum or entire lake).

2.2.2 Biomass

Biomass as dry weight (grams) per square meter was calculated by summing the dry weight of all species in a 0.25 m^2 subplot sample and extrapolating to one square meter. Mean biomass in each strata and the entire lake as well as relative percent biomass for each species were also calculated in this manner.

2.2.3 Frequency of Occurrence

Frequency of occurrence is the percent of subplots in which a plant species was present. This measure helps to distinguish widespread species that do not form large beds, since species that cover an entire quadrat count the same as species represented by a single plant.

2.2.4 Richness, Dominance, and Species Diversity

The character of a community dominated by a few species is very different from one composed of a relatively equal distribution of several different species. Diversity of the macrophyte community was evaluated through three measures: 1) richness, 2) dominance, and 3) Shannon diversity. These metrics were calculated for each subplot containing macrophytes. For example, the mean diversity of a stratum is based upon the mean of all individual subplots containing macrophytes in that stratum.

2.2.4.1 Richness

Richness is the number of individual species in a sample area. Richness was calculated as the number of species per subplot. Mean richness was calculated as the average of all subplots containing macrophytes for each stratum and for the entire lake.

2.2.4.2 Dominance

Dominance was measured as the relative percent cover of the most abundant species in each subplot. Mean dominance was calculated as the mean of all subplots with macrophytes for each stratum and for the entire lake.

2.2.4.3 Species Diversity

The Shannon diversity index (Shannon and Weaver 1949) was selected to quantify diversity. Diversity is a function of both the number of species present (richness) and the equitability of distribution of individuals within these species (evenness) (Washington 1984). Diversity is greatest when high numbers of taxa are represented in near equal proportions. Diversity measures can help determine if disparity occurs between different sites within the same waterbody or if changes occur over time, but they are not particularly useful as a stand-alone values.

Shannon diversity (H) is calculated as the proportion of species *i* relative to the total number of species (*pi*) and then multiplied by the natural logarithm of this proportion (*lnpi*). The resulting product is summed across species, and multiplied by -1 to arrive at the final diversity value. The percent cover of the individual species was used to calculate the relative proportions in the equation. Mean diversity was calculated as the mean of all subplots that contained macrophytes for each stratum and the entire lake.

2.3 Aerial Photograph Interpretation and Analysis

AirPhotoGraphics Inc. of Martinsburg, West Virginia, was contracted to take aerial photographs of the littoral zone. Color aerial photographs of the lake's littoral zone have been taken in late June or early July of the years 2000-2003 and 2005 and in August from 2006 through 2010. Photos were not taken in

2004 due to poor water clarity conditions in June and July of that year. The timing of the flights coincided with high water clarity and sunny, calm conditions.

Photographs were taken from an altitude of 3000 feet from a high-wing twin-engine aircraft with cameras mounted on the underside of the plane. A GPS unit mounted on the plane automatically controlled the timing of the photographs. Three flight lines were flown parallel to the long axis of the lake (i.e., southeast to northwest). Exposures were taken with 60% overlap between exposures. 9" x 9" prints were developed at a scale of approximately 1 inch = 500 ft. The photographs were transferred to digital format, georeferenced and copied to a DVD that was sent to EcoLogic. The georeferenced photographs were imported into ArcGIS and the margins of the macrophyte beds were manually delineated.

The total area (in acres) of the littoral zone with macrophytes was calculated from the digitized files for each year. Areas perceived to be macrophyte beds were judged to contain either dense or sparse growth. When needed, the color and contrast of the digitized images were adjusted to help differentiate the margins of beds. Areas with dense growth had their entire area used in acreage calculation. Sparse areas were assumed to have 30% of the delineated area covered in macrophytes. This 30% assumption was based on several test areas where growth was perceived to be sparse. In these areas, all macrophytes were delineated at high magnification and the total area with macrophytes was calculated.

Prior to 2010, "ground-truthing" has typically been conducted at 10 locations around the lake to verify that aerial photograph interpretations are accurately delineating the density and extent of macrophyte coverage. This was not done in 2010 because the macrophyte survey was underway at the time the aerial photographs were taken, so data collected during the survey could be used as a check of the aerial photograph interpretations. In addition, ground-truthing conducted for the nine surveys conducted from 2000 through 2009 has consistently found strong agreement between the results of the ground-truthing and digitized macrophyte coverage.

3. RESULTS AND DISCUSSION

Aquatic macrophytes are an important component of lake ecology; the rooted plants and algae have major effects on productivity and biogeochemical cycles. Macrophytes produce food for other organisms and provide habitat for aquatic invertebrates, fish, and wildlife, and help to stabilize sediments. The productivity, distribution, and species composition of macrophyte communities are affected by a variety of environmental factors such as light, temperature, sediment composition, nutrient status, and wave energy.

This section focuses first on the results of the 2010 survey (Sections 3.1 and 3.2) and then makes comparisons to the 2000 and 2005 datasets (Sections 3.3 and 3.4).

3.1 2010 Macrophyte Community

3.1.1 Macrophyte Species Composition

Twenty-three species of aquatic macrophytes were identified in Onondaga Lake during the 2010 survey (Table 1). Of these, 18 were of the submersed variety, three were free floating, and one was a floating-leaved species. Twenty of these species were identified in subplots during the August 2010 field survey. Two additional species, not observed during the field survey, were later identified in the biomass samples [stonewort (*Nitella flexilis)* and widgeon grass (*Ruppia maritima)*]. One species [water chestnut (*Trapa natans)*] was observed during the field survey but it was noted outside of sampling subplots. A single rosette of this invasive species was found near Transect 1 in Stratum 5 in about 1.5 m of water.

Coontail (*Ceratophyllum demersum)* was the most common species in 2010, accounting for 30% of the cover, 30% of the biomass, and occurring in 46% of the subplots (Table 2). Common waterweed was also prevalent, accounting for 23% of the cover, 18% of the biomass, and occurring in 35% of the subplots. Water stargrass represented 17% of the cover, 13% of the biomass, and occurred in 33% of the subplots. The fourth most abundant species was southern naiad (*Najas guadalupensis*), which accounted for 11% of the cover, 17% of the biomass, and was found in 22% of the subplots. Eurasian water milfoil (*Myriophyllum spicatum*) accounted for 9% of the cover, 15% of the biomass, and was found in 24% of the sampled subplots. This indicates that Eurasian water milfoil is widely but sparsely distributed in the lake. All other species were relatively uncommon in 2010, individually representing less than 5% of the cover and biomass throughout the lake.

Seven species were collected in every stratum: coontail, common waterweed, Eurasian water milfoil, southern naiad, water stargrass, curly pondweed (*Potamogeton crispus*), and small pondweed (*Potamogeton pusillus*) (Table 3). Straight-leaf pondweed (*Potamogeton strictifolius*) and sago pondweed were found in four strata, three species were found in three strata, two species were found in two strata, and six species were found in only one stratum.

Seven of the species that were documented in the 2010 survey had not been observed in the lake previously. These were muskgrass (*Chara vulgaris*), water moss (*Fontinalis* sp.), stonewort (*Nitella flexilis*), starry stonewort (*Nitellopsis obtusa*), water smartweed (*Polygonum amphibium*), stiff water crowfoot (*Ranunculus longirostris*), and sheathed pondweed (*Stuckenia vaginata*). The genera containing three of these species (muskgrass, stonewort, and stiff water crowfoot) had previously been reported from the lake (once for each genus), but an individual species had not previously been identified. All of the new species were relatively rare in the lake, each accounting for less than 1% of the total plant coverage and biomass except for muskgrass. Muskgrass represented slightly less than 3% of the cover and was 4% of the biomass in the lake.

Straight-leaf pondweed is designated as endangered within New York State. This species is classified in the state's Natural Heritage Program/NYSDEC database as "S1" defined as "critically imperiled in New York State because of extreme rarity (5 or fewer sites, or very few remaining individuals) or extremely vulnerable to extirpation from New York State due to biological factors". Straight-leaf pondweed was found along seven transects in strata 1 through 4 (Table 4). Transects 10, 12, and 16 had the highest relative abundance of this species. Straight-leaf pondweed was first reported from Onondaga Lake during the 2005 survey.

3.1.2 Macrophyte Species Metrics

Measures of richness, diversity, and dominance all showed the same general spatial pattern in 2010 (Table 5). The best values (highest richness and diversity and lowest dominance) all were found in stratum 4, followed by stratum 5 and stratum 1. The poorest values all were associated stratum 3.

3.1.2.1 Macrophyte Species Richness

Mean species richness per subplot varied considerably between the strata, ranging from a high of 3.0 in stratum 4 to a low of 2.1 in stratum 3. Species richness was greatest in strata with oncolite substrate and lowest in areas with fine sediment substrate. Degree of wave action did not appear to be a major factor influencing species richness, since the stratum with the highest richness (stratum 4) and lowest richness (stratum 3) both are classified as high-energy areas of the lake.

3.1.2.2 Macrophyte Species Diversity

Diversity is a measure of the evenness of the distribution of species in a community, with a higher diversity value reflecting more even distribution of species than a low value. Diversity was notably greater (better) in stratum 4 and poorer in stratum 3 than in any other strata. Diversity was also relatively higher in strata 1 and 5 and lower in stratum 2. As was the case with species richness, degree of wave action did not appear to be a major factor influencing diversity, since the stratum with the highest (stratum 4) and lowest (stratum 3) values both are classified as high energy areas of the lake.

3.1.2.3 Macrophyte Species Dominance

High dominance indicates that one species accounts for most of the macrophyte coverage in a sample. A select few species tend to dominate the macrophyte community in Onondaga Lake. As a result, dominance values are relatively high, ranging from 0.65 in stratum 4 (southeast shore, oncolites, high energy) to 0.79 in stratum 3 (south end, fine sediment, high energy), with a lake-wide mean of 0.73.

3.1.3 Macrophyte Cover, Biomass and Frequency of Occurrence

The spatial pattern of percent cover, biomass, and frequency of occurrence of macrophytes differed considerably from that shown by the species-based metrics. The highest values for percent cover, biomass, and frequency of occurrence were all associated with stratum 5, and the lowest values were associated with stratum 2 (Table 6).

3.1.3.1 Macrophyte Percent Cover

Percent cover is the area of a subplot covered in vegetation. Percent cover is probably the most important index to monitor over time as it directly affects the lake's fish community. Moderate percent cover provides essential nursery habitat for larval, young-of-the-year, and juvenile fishes by providing protection from predators while at the same time not limiting the feeding efficiency of predatory game fish. Too little or too much vegetation coverage has the potential to negatively affect a littoral fishery by limiting recruitment of young fish into the adult population or through poor growth of adult fish caused by low foraging efficiency.

The lake-wide mean percent cover in 2010 was 65%. The mean percent cover between the strata ranged from a low of 54% in Strata 1 and 2 to a high of 82% in Stratum 5 (northwest shore, oncolites, medium energy) (Table 6). Highest percent cover occurred in the two eastern strata (4 and 5) of the lake, both of which have oncolite substrate. The three remaining strata all had similar percent cover (54-57%) despite having different substrate and wave energy classifications.

3.1.3.2 Macrophyte Biomass

Biomass, measured as dry weight (g/m^2), ranged from a low of 14 g/m^2 in Stratum 2 (wastebeds) to 79 g/m^2 in Stratum 5 (northeast, oncolites, medium energy), with a lake-wide average of 40 g/m^2 (Table 6). The two eastern strata (4 and 5) had the greatest biomass, and Stratum 1 at the north end of the lake had the third highest biomass. Stratum 3 (south end, fine sediment, high energy) had the second lowest biomass, considerably less than that of Strata 1, 4, and 5, but approximately double that of Stratum 2.

Biomass samples have been collected in other regional lakes using similar methods to those used in this survey. During August 2000 in Conesus Lake, mean biomass of macrophyte beds ranged from 92 to 513 g/m^2 (Bosch and Makarewicz, 2001). In Cayuga Lake from 1987 to 1998, macrophyte biomass at standard monitoring sites varied annually from 30 to 150 g/m^2 in the southwest portion of the lake and 75 to 425 g/m^2 in the northwest section (Johnson et al. 1998a, Johnson et al. 1998b). The results in both Conesus and Cayuga Lake studies were calculated within macrophyte beds only (i.e., areas without macrophytes were not sampled). Biomass in Onondaga Lake during August 2010, calculated only for subplots that contained macrophytes, ranged from 0.008 to 216.0 g/m^2. The range of biomass samples in Onondaga Lake is highly variable but within the range documented in the some other regional lakes.

3.1.3.3 Macrophyte Frequency of Occurrence

The percent of subplots with macrophytes is a good indication of the distribution of macrophytes, as it relies on the presence of macrophytes rather than on the density of macrophyte growth. Overall, 65% of the subplots in the lake contained macrophytes (Table 6). Strata 1, 4, and 5 all had similar values (83-84%) and had the greatest frequency of occurrence. Stratum 2 (wastebeds) had the lowest frequency of occurrence at 34%. Again, wave energy level did not appear to be an important factor in determining frequency of occurrence of macrophytes in subplots in 2010.

3.1.4 Macrophyte Relationship to Depth

The depth to which rooted macrophytes grow is largely a function of water clarity. The maximum depth of growth at the transects ranged from 3.1 m on transect 14 in stratum 2 (wastebeds, moderate energy) to 6.2 m on transects 17 and 20 in stratum 1 (northwest shore, oncolites, medium energy) (Table 7).

The two northern strata (strata 1 and 5) averaged the deepest average growth at 5.9 m and 5.1 m, respectively. The southern end (strata 3) had the shallowest growth at 4.1 m, followed closely by stratum 2 at 4.2 m. The lake-wide mean maximum depth of macrophytes in 2010 was 4.8 m.

Common waterweed and coontail generally grew the deepest, often being the only species encountered past the 4-m depth. Other species that were occasionally found near the deepest extent of growth along the transects were Eurasian water milfoil, southern naiad, and water stargrass. Although macrophytes were found growing past the 6-m water depth, 97% of macrophytes in 2010 were found in 3 m of water or less based on percent cover. Only 0.02% of macrophytes were found growing deeper than 6 m.

3.2 2005 Filamentous Algae Abundance and Distribution

Filamentous algae are a major issue affecting recreational use of Onondaga Lake. Mats of algae historically formed dense layers of growth on nearshore macrophytes during the summer months. This layer may detrimentally affect macrophyte growth and distribution through excessive shading. Algal mats also cause odor problems along Onondaga Lake Park when the mats wash ashore and decay. Distribution of filamentous algae is highly variable, both spatially and temporally. The presence and density of algal mats is controlled by water quality (light, nutrients, and temperature) in addition to wind direction and speed. Wind can cause floating algae to accumulate on macrophytes in certain areas of the lake but can also cause the mats to break up and wash ashore.

3.2.1 Filamentous Algae Percent Cover

The lake-wide mean percent cover of filamentous algae in 2010 was 51%. The mean percent cover among the strata ranged from a low of 25% in stratum 2 (wastebeds) to a high of 64% in stratum 1 (northeast shore, oncolites, low energy) (Table 8). Percent cover of algae did not follow the same spatial pattern as macrophytes, which had the greatest percent cover in Stratum 5 followed by Stratum 4. Stratum 4 actually had the second lowest percent cover of algae. The occurrence of greatest percent cover of algae in low-energy stratum 1 suggests that low-energy areas may be best suited for algal growth.

3.2.2 Filamentous Algae Biomass

Strata 1, 3, 4, and 5 all had similar levels of algal biomass (range 12-15 g/m^2) (Table 8). Stratum 2 (wastebeds) had an algal of biomass zero for plots in which biomass was measured. The whole lake mean algal biomass in subplots was 11 g/m^2.

3.2.3 Filamentous Algae Frequency of Occurrence

The percent of subplots where filamentous algae was found varied considerably among the strata, with high occurrence (77-81%) in strata 1, 4, and 5, moderate occurrence (39%) in stratum 3, and low occurrence (7%) in stratum 2 (Table 8). The lake-wide mean of the percent of subplots containing filamentous algae was 52%.

3.3 Comparison of the 2010 Macrophyte Community to 2005 and 2000

3.3.1 Species Composition

The 2010 survey documented the presence of 23 species of macrophyte in the lake compared to 17 species in 2005 and 10 species in 2000 (Table 9). All of the species found in 2005 but one (arrowhead, *Sagittaria latifolia*) were documented again during the 2010 survey. The arrowhead documented in 2005 was actually noted from outside of the sampling plots, so it is possible that this species occurred in Onondaga Lake in 2010 but was not in the area actually surveyed. Five of the seven species found in 2010 but not in 2005 had never been documented in the lake prior to this survey. Water smartweed and muskgrass (by genus only) were reported historically from the lake (Madsen et al. 1996a).

In 2000, a combination of sago pondweed, common waterweed and to a lesser extent water stargrass dominated the community (Figure 2). In 2005 common waterweed and, to a much lesser extent, coontail were the dominant species. Relative abundance of dominant species shifted again in 2010, with coontail and water stargrass increasing in percent cover and common waterweed declining to third most abundant. Percent cover of Eurasian water milfoil increased slightly from 2005, but still remained below 10% in 2010. The overall contribution of species individually comprising less than 5% of cover in 2010 was twice that found in 2000 and 2005, reflecting the increased number of species in the lake and improving balance in the abundance of species in the lake. Similar trends were seen in biomass and frequency of occurrence (Figure 2).

The overall percent cover of the invasive exotic Eurasian water milfoil increased only 1% from 2005 to 2010, but its percent of the total macrophyte biomass in the lake more than doubled (from 7% to 15%) during this time. However, the frequency of occurrence of this species in subplots only increased 3% (from 21% to 24%) from 2005 to 2010, after increasing from 3% to 21% from 2000 to 2005. These trends suggest that the spread of Eurasian water milfoil in Onondaga Lake has slowed considerably since 2005, but significant biomass of this species can be significant where it occurs. The expanding number of macrophytes species and improved growing conditions now found in the lake may be providing strong enough competition to keep Eurasian water milfoil from becoming overly dominant as it has in some other regional waters. It is also possible the presence in the lake of the milfoil-grazing moth *Acentria ephemerella* could be limiting expansion of this invasive species. This herbivore was found in good numbers on milfoil plants in Onondaga Lake in 2005, but no effort was made to document its presence during the 2010 survey.

The within-strata abundance and distribution of straight-leaf pondweed, the one endangered macrophyte species found in Onondaga Lake, has changed notably since this species was initially reported in 2005. This species was found along 12 transects distributed through all five strata in 2005, but was found along only seven transects distributed within Strata 1 through 4 in 2010. Percent cover of straight-leaf pondweed declined in three of these strata as well, but increased considerably in Stratum 3, improving from a mean of 2.3% in 2005 to 22.1% in 2010. Interestingly, straight-leaf pondweed appears to be most abundant in strata 2 (wastebeds) and 3 (south end) where species richness and diversity are the lowest and dominance is highest. Within the lake as a whole, percent cover of straight-leaf pondweed increased from 0.2% in 2005 to 0.9% in 2010, while percent biomass decreased from 0.3% in 2005 to 0.17% in 2010. The frequency of occurrence (3%) of straight-leaf pondweed in subplots for the entire lake did not differ for 2005 and 2010.

3.3.2 Species Metrics

Mean species richness, diversity, and dominance per subplot all showed significant improvements since the 2000 survey (Figure 3a-c). Mean species richness within subplots has increased by 48-114% among the strata and 74% for the lake as a whole from 2000 to 2010 (Figure 3a). The greatest change has occurred in stratum 4 (southeast shore, oncolites, high energy), and the least change has occurred in stratum 2 (wastebeds). Mean diversity within subplots has increased by 80-368% among the strata and 216% for the lake as a whole from 2000 to 2010 (Figure 3b). The greatest change has occurred in stratum 4, and the least change has occurred in stratum 2. Mean dominance within subplots has decreased by 11-27% among the strata and by 19% for the lake as a whole. Again, greatest change has occurred in stratum 4, and the least change has occurred in stratum 2 (Figure 3c).

3.3.3 Community Composition

3.3.3.1 Percent Cover

All areas of the lake showed a dramatic and statistically significant increase ($p<0.05$) in percent cover of macrophytes from 2000 to 2010 (Figure 4). The greatest overall increase in percent cover since 2000 has occurred in strata 4 and 5 in which percent cover has increased by 69%. However, the greatest increase in percent cover since 2005 occurred in stratum 3 (43% increase) and stratum 2 (37% increase). Mean percent cover for the entire lake increased by a factor of 3.3 (8% to 26%) between 2000 and 2005 and a factor of 2.5 (26% to 65%) between 2005 and 2010. This represents an overall 8-fold increase in percent cover lake wide since 2000.

The ideal macrophyte coverage for aquatic life varies by species and life stage. In Onondaga Lake, largemouth and smallmouth bass are arguably the most important sportfish species. Habitat conditions for largemouth bass are more strongly influenced by macrophyte cover than are smallmouth bass. Wiley et al. (1987) estimated that 36 to 40% macrophyte coverage was optimal for largemouth bass. Stuber et al. (1982) concluded that the ideal percent cover for largemouth bass is between about 40 and 60 percent. These two independently derived relationships seem to agree that approximately 40% to 50% coverage is ideal for largemouth bass. Macrophyte coverage in this range provides the appropriate balance of habitat for the production and protection of fish forage (e.g., invertebrates, small fish) while still allowing largemouth bass to effectively find and capture prey. Percent cover less than this range may result in limited forage production and high predation risk for prey, whereas percent cover above this range can lead to reduced ability for bass to find and capture food due to dense macrophyte growth.

Based upon these relationships, macrophyte coverage in some areas of Onondaga Lake (strata range 54% to 82%, lake average 65%) has now exceeded the ideal range for largemouth bass (Figures 5 and 6). Strata 1, 2, and 3 (54%, 54%, and 57% cover, respectively) are within or only slightly above the optimal range for largemouth bass, but percent cover in stratum 4 (77%) and stratum 5 (82%) far exceeds the optimal range for largemouth bass.

3.3.3.2 Biomass

Biomass values from 2000 to 2010 were variable and showed no specific trend among strata or for the lake as a whole (Figure 7). Most areas of the lake showed increases in biomass from 2000 to 2005 that were generally proportional to the increases documented for percent cover for that same period, but this was not the case when data for 2010 were included. Mean biomass actually decreased from 2005 to 2010 in four of the five strata, the exception being stratum 3, in which biomass more than doubled since 2005 and has increased 6-fold since 2000. The declines in biomass in strata 1, 2, 4, and 5 from 2005 to 2010 were generally small. Overall biomass in these strata in 2010 was still greater than in 2000, except in stratum 2, where mean biomass has shown a consistent slight decline since 2000. Mean biomass for the entire lake showed a statistically significant ($p<0.05$) 3.2-fold increase from 2000 to 2005 and a 20% decrease (not significant) from 2005 to 2010.

3.3.3.3 Frequency of Occurrence

The percent of subplots containing macrophytes was also variable and showed no specific trend among strata (Figure 8). Slight declines in frequency of occurrence were seen in strata 1, 4, and 5 from 2005 to 2010, but frequency of occurrence was still 83-84% and considerably greater than 2000 values in all of these strata. Frequency of occurrence in stratum 2 (wastebeds) declined from 2005 to 2010, falling to 34%, about equal to the 2000 value. Stratum 3 (south end, fine sediment, high energy) was the only stratum to show a consistent increase from 2000 (14%) to 2010 (59%). Lake wide, frequency of occurrence has consistently increased since 2000, but the increase from 2005 to 2010 was only 3% compared to 34% from 2000 to 2005.

3.3.4 Relationship to Depth

The depth to which macrophytes grew in Onondaga Lake increased significantly from 2000 to 2005 (Figure 9). In 2000 the maximum depth that plants were documented growing was 3.7 m, and only three of the twenty transects had growth past the 3-m depth. The maximum depth that plants were observed growing in 2005 increased to 6.75 meters, with 17 of the 24 transects having growth past a depth of 3 m. The mean maximum depth at which macrophytes were present increased in all areas of the lake between 2000 and 2005, with a mean lake-wide increase of 2.3 m.

Such dramatic change was not evident from 2005 to 2010. The depth to which macrophytes grew in 2010 was essentially unchanged from 2005 values in strata 1, 2, and 5, and showed modest but not significant increases in strata 3 and 4. Lake wide, the depth to which macrophytes grew increased from 4.4 m in 2005 to 4.8 m in 2010. The 2010 survey marked the first time that mean maximum depth of plant growth exceeded 4.0 m in all strata.

Although the maximum depth at which macrophytes grow has increased dramatically since the 2000 survey, most macrophytes (97% in 2010) are still found in less than 3 m of water. This is not unexpected since it is in this zone where light easily reaches the lake bottom. In addition, 77% of the total length of all transects surveyed was ≤3 m in depth, indicating the vast majority of the lake's littoral zone is ≤3 m.

The increase in maximum depth of macrophyte growth from 2000 to 2010 would suggest that water clarity has improved over the past 10 years, allowing macrophytes to colonize deeper areas of the lake. Increased light penetration may be one mechanism for the increase in maximum macrophyte depth. However, Secchi disk measurements and LiCor readings collected annually at the South Deep station are do not strongly support this relationship (Figures 10a-d). The mean depth of light extinction and the mean light extinction coefficient have both shown a gradual trend of increasing light penetration since 2000, though 2010 deviated slightly from this trend (Figures 10a and 10b). However, mean Secchi depths at the South Deep station and nearshore sites have shown considerable variability with no notable trend over time (Figures 10c and 10d).

The relatively weak relationship between Secchi depth and LiCor readings to depth of macrophyte growth suggests that light penetration is not the sole factor influencing depth of macrophyte growth in Onondaga Lake. This is illustrated most clearly when mean Secchi depth for the different strata is considered. Strata 2 (wastebeds) has the second highest mean Secchi depth for 2000-2010 (Figure 11), but has the second shallowest mean depth of macrophyte growth among the five strata. Strata 2 also ranks poorest or second poorest in mean percent cover, species richness, diversity, dominance, biomass, and percent of subplots with macrophytes. Conversely, strata 1, 4, and 5 have mean Secchi depths for 2000-2010 similar to those of stratum 2, but consistently have the best values for the aforementioned measures. This indicates that while water clarity and its influence on light penetration is important, other factors such as substrate type, wave energy, and substrate chemistry can also have a major influence on macrophyte community structure and distribution.

3.3.5 Digitized Aerial Photographs

The digitized aerial photographs provide both a whole lake view of macrophyte distribution and a finer temporal resolution with regard to the expansion of beds than do the field surveys. Appendix 10-1 show maps of the digitized macrophyte beds in each stratum and the entire lake since 2000 (note no photos were taken in 2004 due to poor water clarity). The dramatic expansion of macrophytes documented by the field surveys between 2000 and 2010 is apparent when these maps are viewed chronologically. Expansion appears to have occurred in all areas of the lake.

A total of 409 acres of macrophytes were delineated from the 2010 aerial photographs. The overall coverage of macrophytes in 2010 exceeded the previously highest delineated value of 382 acres in 2009 (Figure 12). It should be noted that the aerial photographs were taken in June or early July during 2000 through 2005, and in August during 2006 through 2010. The drop in overall coverage observed between 2005 and 2006 may be the result of seasonal variability in plant growth between June and August. Despite the seasonal differences that may exist when comparing the June and August photographs, it is clear that coverage of macrophytes has steadily increased over both periods. The 409 acres of macrophyte coverage in 2010 represents 53% coverage of the entire littoral zone of the lake. This represents more than a doubling of coverage of the littoral zone since 2006, when monitoring via aerial photographs shifted to August.

In 2010, dense macrophyte growth was found extending in an uninterrupted band from the mouth of Ninemile Creek clockwise to the southeast corner of the lake. In addition, a nearly continuous, narrow band of dense growth extended from just east of the mouth of Ninemile Creek to just south of Tributary 5A for the first time since monitoring began. In 2009, this same area consisted primarily of a continuous band of sparse growth interspersed with some smaller areas of dense growth. The very southern end of the lake also showed some increase in area of dense growth compared to 2009.

As in the past, macrophyte growth appeared to be the least dense along the south and southwest shores. The northwest area (Maple and Willow Bays) and the east shore (Onondaga Lake Park) east toward the mouth of Ley Creek appears to have the most stable areas of macrophyte growth over time (Appendix 10-1-2). The areas from the mouth of Ley Creek south to Harbor Brook, then north and west past the wastebeds to the mouth of Ninemile Creek seem to have the most variability in growth density.

3.4 Comparison of 2010 Filamentous Algae Results to 2005 and 2000

Comparisons of filamentous algae abundance from year to year is complicated by the extreme variability of this type of alga both spatially and temporally. Unlike macrophytes anchored in the sediment, the presence of large amounts of floating algae does not necessarily indicate that the algae originated in the area where found. Waves can break up and re-distribute the algae. Since macrophytes tend to capture and hold floating algae, areas with large amounts of macrophytes would be expected to have increased amounts of algae.

3.4.1 Percent Cover

The percent cover of filamentous algae has increased in all strata from 2000 to 2010 (Figure 13). The greatest increases from 2005 to 2010 occurred in strata 1 and 3, which had increases of 41% and 52%, respectively. The smallest increase occurred in stratum 4, where percent cover increased only about 7%. Percent coverage of filamentous algae for the entire lake increased 3.7-fold since 2005, reaching 51% in 2010. The greatest percent cover of algae in concentrated at the north (strata 1 and 5) and south (stratum 3) ends of the lake.

3.4.2 Biomass

Changes in biomass from 2000 to 2010 have been inconsistent among the five strata (Figure 14). Strata 1 and 2 have shown a declining trend, and Stratum 3 has shown a slowly increasing trend. Strata 4 and 5 both showed an increase in algal biomass from 2000 to 2005 and a decrease from 2005 to 2010. The lake overall has shown a gradual decline in algal biomass. Algal biomass has shown high variability among the subplots during all three surveys, and this variability and the patchy distribution of algae contribute to the inconsistency observed in this measure over time. The difference in results between percent cover and biomass for algae may be attributed to the variability in algal density. When large mats of algae are present, they often cover a high proportion of the area where they are found. However, this coverage may be composed of anything from a thin layer of algae to thick mats that extend from the surface to bottom.

3.4.3 Frequency of Occurrence

The frequency of occurrence of filamentous algae has increased consistently since 2000 in four of the five strata, the exception being stratum 2 (wastebeds) where this measure increased from 2000 to 2005, but declined in 2010 (Figure 15). Frequency of occurrence increased substantially (by about 30%) in strata 1, 3, and 4 from 2005 to 2010. The increase in stratum 5 was relatively small (8%), but frequency of occurrence in 2005 was already high (71%). Frequency of occurrence of algae for the entire lake has increased by 21% between each survey.

3.5 Comparison of Current Macrophyte Results to Historical Information

The composition of the historic macrophyte community of Onondaga Lake is largely unknown. Table 9 lists species found in Onondaga Lake during various quantitative and qualitative surveys since 1991, as well as species known to have occurred historically. Madsen et al. (1996a) completed the first quantitative study of macrophytes in Onondaga Lake during June 1991. These investigators revisited several of their transects in later years and found a trend of increasing species richness and increasing frequency of occurrence for sago pondweed (Madsen et al. 1996b). Species richness at four monitoring transects increased from three macrophyte species, in both 1991 and 1992, to six in 1993. Frequency of occurrence of sago pondweed was 29%, 39% and 44% in 1991, 1992, and 1993, respectively.

In 1991, Madsen, et al. (1996a) used transects at 40 sites that extended either 100 m from shore or to a depth of 5 m, whichever was shorter. Where applicable, the results presented in this section were also analyzed to a depth of 5 m or 100 m from shore, so as to standardize these analyses with those used by Madsen in 1991. Madsen reported his results on a frequency of occurrence basis only.

In 1991, five species of macrophyte were collected; sago pondweed, curly pondweed, water stargrass, coontail, and Eurasian water milfoil (Table 9). Common waterweed was first observed in 1992 (Mark Arrigo personal observation). It was observed at monitoring transects again in 1993 by Madsen et al. (1996a). By 1995, common waterweed had dramatically expanded and became one of the most abundant species in the lake (Arrigo 1995). Ten species of macrophytes were observed in the lake during the 2000 OCDWEP survey, a doubling of richness since 1991. However, the same six species present since 1992 still made up almost 100% of the community. In 2005, the total number of species had increased to 17 but the six core species still made up about 97% of the community based on percent cover and 99% based on biomass. The percent cover of these same six species in 2010 declined to 83%, and their percentage of the biomass declined to 78%.

In the 1991 survey there was an average of 1.3 species documented in each transect (Table 10). The number of species per transect (standardized to the 1999 transect lengths) increased to 3.4 species per transect in 2000 and to 6.0 in 2005. This increase continued in 2010, with 6.8 species found per transect, a 3.8-fold increase from 2000 and a 5.2-fold increase from 1991.

Madsen et al. (1996b) also reported the frequency of occurrence of each species in subplots. This provides a good indication of the amount of the littoral zone with macrophyte growth (although it should not be confused with percent cover). In 1991, only 13% of subplots out to 100 m offshore or to a 5-m depth contained any macrophytes. The percent of subplots with macrophyte growth increased to 61% in 2000 and to 74% in 2005. This increase continued in 2010, with 83% of subplots out to 100 m offshore or to a 5-m depth containing macrophytes, a 1.4-fold increase from 2000 and a 6.4-fold increase from 1991.

4. SUMMARY AND CONCLUSIONS

The macrophyte community of Onondaga Lake has undergone dramatic changes since the baseline AMP survey of 2000. These changes are even more striking when compared to the first quantitative survey of lake macrophytes conducted in 1991 (Madsen et al. 1996b). Since 2000, species richness has more than doubled, and is nearly four times that reported from the 1991 survey. This increase in species richness is due nearly entirely to establishment of native species; only two of the 13 new species documented since 2000 are non-native. Straight-leaf pondweed (*Potamogeton strictifolius*), listed as endangered in New York State, has established a persistent population in the lake. The macrophyte community continues to be dominated by only a few species, but the dominance of these species is declining, with the most prevalent species comprising only 30% of macrophyte cover in 2010, compared with 52% in 2000 and 62% in 2005. Evenness is increasing; the five most common species in 2010 made up 84% of the community coverage compared to 94% in 2000 and 97% in 2005.

Mean diversity within subplots has increased by 80-368% among the strata and 216% for the lake as a whole from 2000 to 2010. Mean dominance within subplots has decreased by 11-27% among the strata and by 19% for the lake as a whole from 2000 to 2010. The greatest change in diversity and in dominance has occurred in stratum 4 (southeast shore, oncolites, high energy), and the least change has occurred in stratum 2 (south end, fine sediment, high energy). These improvements in diversity and dominance reflect the increased number of species in the lake and the increasing contribution of each species to the overall macrophyte community over time.

The percent coverage of macrophytes in 2010 showed a continuation of the large increase seen between 2000 and 2005. Percent coverage increased in all areas of the lake and lake-wide exceeded 60%. This increase in percent cover has resulted in some areas of Onondaga Lake now exceeding the ideal range (40-50%) of cover for largemouth bass. One positive aspect of this increase is that nearly all of it is due to increases in the coverage of native species. Non-native species comprised only about 9% of coverage in 2005, and this figure was unchanged for 2010.

Macrophyte biomass did not show a continuation of the increasing trend found in 2005. Instead, biomass in most areas of the lake showed a slight decline from 2005 but remained above levels found in 2000. Slight declines were seen in Frequency of occurrence of macrophytes in subplots declined slightly in most areas of the lake from 20005 to 2010, but a large increase in stratum frequency of occurrence in stratum 3 resulted in an overall increase on a lake-wide basis. Lake wide, frequency of occurrence has consistently increased since 2000, but the rate of increase has slowed considerably since 2005.

The depth to which macrophytes grew in 2010 was essentially unchanged from 2005 values in much of the lake, but increased in some areas (south and southeast sections). This resulted in a lake-wide increase in the depth to which macrophytes grow from 4.4 m in 2005 to 4.8 m in 2010 and marked the first time that mean maximum depth of plant growth exceeded 4.0 m in all strata.

GIS mapping analysis of digitized aerial photographs were consistent with the characteristics of the in-lake data. A dramatic increase in amount of macrophytes was noted in all areas of the lake between 2000 and 2010. The time series of aerial photographs shows that the observed increase in macrophytes occurred gradually and is therefore not a function of natural annual variability or related to annual weather conditions. Rather, the overall environment (including factors such as water chemistry, water clarity, and sediment stability) within Onondaga Lake has improved and become more conducive to supporting macrophyte growth.

The underlying mechanisms resulting in the increase in macrophyte richness, coverage, biomass, distribution, and depth since 2000 are not well understood. Water clarity may affect maximum depth that plants grow but is unlikely to influence macrophytes to any great extent in the shallower depths where most macrophytes currently grow. Lake salinity does not appear to have decreased significantly since 2000, so is not likely responsible for the documented changes. Upgrades to the wastewater treatment plant have resulted in a dramatic decrease in ammonia-N concentrations in the lake since

2000. Since ammonia is assimilated by aquatic algae and macrophytes for use as a nitrogen source, a reduction in this compound should not result in an increase in plants.

The reduction in ammonia in the lake, however, did allow zebra mussels to greatly expand their presence after 2000 (Spada et al. 2002). Large populations of zebra mussels, by their filter-feeding activities, can increase the amount of light penetrating into the water, and deliver nutrients to the lake benthos. This has been correlated with the increased growth of filamentous algae and other benthic plants in the littoral zones of Saginaw Bay and in other areas of the Great Lakes (Skubinna et al. 1995, Lowe and Pillsbury 1995).

Laboratory analysis of Onondaga Lake sediments by Madsen et al. (1996b) found that although Onondaga Lake is eutrophic, the sediments were highly calcareous, and low in both nitrogen and phosphorus. As discussed above, there does not appear to have been any change in water clarity after zebra mussel expansion in 2000. However, zebra mussels may have increased the amount of carbon and other nutrients reaching the lake's benthic community. This fertilization of the otherwise nutrient-poor sediments could help explain the dramatic increase in macrophyte growth since 2000. Also, during the 2005 survey divers noted macrophytes growing in areas where the bottom was covered in combinations of sediment, live mussels, and mussel shells. Zebra mussels (both live and shells only) may have a stabilizing effect on the otherwise unstable sediments and that could further benefit macrophytes.

Once macrophyte beds become established, they too serve to stabilize sediment by reducing wave energy and trapping suspended sediment so it can settle to the bottom (Petticrew & Kalff 1992). Low rates of settling of suspended sediment stimulate macrophyte growth through the influx of more nutrients in the sediments (Madsen et al. 2001). Organic matter begins to accumulate in established macrophyte beds (Kenworthy et al. 1982), and this initial increase in organic material can enhance macrophyte growth and production. However, continuous accumulation of organic material can actually limit macrophyte growth through nutrient complexation, reduced sediment oxygen levels, or other mechanisms (Barko and Smart 1986). This may explain why some areas of Onondaga Lake actually showed a decrease in biomass from 2005 to 2010, despite increasing percent cover.

Macrophyte beds also produce localized areas of higher water clarity through the settling of suspended sediment, which can further enhance macrophyte growth and reproduction (Doyle 2000). Secchi measurements taken in the open lake may not accurately measure water clarity changes in the littoral zone, especially where macrophyte growth may influence the intensity and spectrum of light reaching the bottom. Different macrophyte species show different growth and reproductive responses under various light conditions (Doyle 2000), so the ultimate depth of light penetration may not be as important to some species as the quality of available light. Thus, as macrophytes have become more established in Onondaga Lake, they have exerted a greater influence on the physical characteristics of the littoral zone and effectively improved conditions for establishment of new species and enhanced growth of macrophytes overall. This process and the other factors previously mentioned help explain some of the many changes observed in the macrophyte community of Onondaga Lake in the past decade.

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TABLES

Table 1. Scientific and common names of macrophyte species that have been documented in Onondaga Lake in the current (2010) survey and past surveys.

Scientific Name	**Common Name**
*Ceratophyllum demersum**	Coontail
Chara sp.	Muskgrass
*Chara vulgaris**	Muskgrass
*Elodea canadensis**	Common waterweed
*Fontinalis sp.**	Water moss
*Lemna minor**	Small duckweed
*Lemna trisulca**	Forked duckweed
*Myriophyllum spicatum**	Eurasian water milfoil
*Najas flexilis**	Slender naiad
*Najas guadalupensis**	Southern naiad
Najas marina	Spiny naiad
*Nitella flexilis**	Stonewort
Nitella sp.	Stonewort
*Nitellopsis obtusa**	Starry stonewort
*Polygonum amphibium**	Water smartweed
*Potamogeton crispus**	Curly pondweed
Potamogeton diversilfolius	Variable-leaf pondweed
*Potamogeton pusillus**	Small pondweed
*Potamogeton strictifolius**	Straight-leaf pondweed
*Ranunculus longirostris**	Stiff water crowfoot
Ranunculus sp.	Water crowfoot
*Ruppia maritima**	Widgeon grass
Sagittaria latifolia	Arrowhead
Sparganium sp.	Bur-reed
*Spirodela polyrhiza**	Greater duckweed
*Stuckenia pectinata**	Sago pondweed
*Stuckenia vaginata**	Sheathed pondweed
Trapa natans	Water chestnut
*Vallisneria americana**	Wild celery
Zannichellia palustris	Horned pondweed
*Zosterella dubia**	Water stargrass

*Note: * indicates presence in the current survey.*

Table 2. Species level macrophyte community results for Onondaga Lake in 2010.

Species	Relative % Cover	Relative % Biomass	% of Subplots with Macrophytes
Ceratophyllum demersum	30	30	46
Elodea canadensis	23	18	35
Zosterella dubia	17	13	33
Myriophyllum spicatum	9.2	15	24
Najas guadalupensis	11	17	22
Stuckenia pectinata	4.2	1.6	6.1
Chara vulgaris	2.6	4.0	3.1
Potamogeton crispus	0.18	0.50	2.9
Potamogeton strictifolius	0.92	0.17	2.9
Potamogeton pusillus	0.19	0.44	1.7
Lemna minor	0.16	0	1.2
Lemna trisulca	0.00028	0.000019	1.2
Fontinalis sp.	0.012	0.093	0.66
Nitellopsis obtusa	0.26	0.0015	0.52
Stuckenia vaginata	0.044	0.098	0.52
Spirodela polyrhiza	0.0035	0	0.38
Ranunculus longirostris	0.0035	0.021	0.28
Najas flexilis	0.0058	0	0.047
Nitella flexilis	0	0.0089	0.047
Polygonum amphibium	0.0012	0	0.047
Ruppia maritima	0	0.00041	0.047
Vallisneria americana	0.058	0	0.047

Table 3. Macrophyte species presence/absence among the five strata in Onondaga Lake in 2010.

Species	Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Potamogeton pusillus	X	X	X	X	X
Myriophyllum spicatum	X	X	X	X	X
Najas guadalupensis	X	X	X	X	X
Ceratophyllum demersum	X	X	X	X	X
Zosterella dubia	X	X	X	X	X
Potamogeton crispus	X	X	X	X	X
Elodea canadensis	X	X	X	X	X
Stuckenia pectinata	X	X	X	X	--
Potamogeton strictifolius	X	X	X	X	--
Ranunculus longirostris	X	X	--	--	X
Stuckenia vaginata	X	--	X	X	--
Lemna minor	X	--	X	--	X
Lemna trisulca	X	--	X	--	--
Spirodela polyrhiza	X	--	--	--	X
Fontinalis sp.	--	--	X	X	--
Chara vulgaris	X	--	--	X	--
Polygonum amphibium	X	--	--	--	--
Najas flexilis	--	--	X	--	--
Nitellopsis obtusa	--	--	--	--	X
Ruppia maritima	--	--	--	--	X
Vallisneria americana	X	--	--	--	--
Nitella flexilis	--	--	--	--	X

Note: X denotes presence; -- denotes absence

Table 4. Distribution of straight-leaf pondweed (*Potamogeton strictifolius*), a New York State-listed endangered macrophyte species, in Onondaga Lake, 2010.

Species	Stratum	Transect	Relative Abundance
Potamogeton strictifolius	04	05	0.13%
		06	0.25%
	03	10	14%
		12	74%
	02	16	11%
	01	18	0.25%
		20	0.0013%

Note: Relative abundance based on percent cover of only that species.

Table 5. Macrophyte species index results for Onondaga Lake in 2010.

Stratum	Richness		Diversity		Dominance	
	Mean	*SE*	*Mean*	*SE*	*Mean*	*SE*
1 Oncolite Low Energy	2.7	0.084	0.51	0.028	0.73	0.014
2 Wastebeds	2.2	0.11	0.46	0.044	0.75	0.021
3 Fine Sed. High Energy	2.1	0.050	0.39	0.018	0.79	0.0094
4 Oncolite High Energy	3.0	0.061	0.71	0.023	0.65	0.011
5 Oncolite Med. Energy	2.9	0.092	0.56	0.028	0.73	0.014
Whole Lake Average	2.5	0.034	0.52	0.012	0.73	0.0058

Note: SE = Standard error. Metrics were calculated using only subplots that contained macrophytes.

Table 6. Macrophyte community-level measures for Onondaga Lake in 2010.

Stratum	% Cover		Biomass (g/m^2)		% of Subplots with Macrophytes
	Mean	*SE*	*Mean*	*SE*	*Total*
1 Oncolite Low Energy	54	3.1	47	13.8	83
2 Wastebeds	54	5.24	14.2	6.2	34
3 Fine Sed. High Energy	57	2.3	30	6.0	59
4 Oncolite High Energy	77	2.5	52	8.3	84
5 Oncolite Med. Energy	82	3.5	79	20	84
Whole Lake Average	65	1.36	40	4.6	65

Note: SE = Standard error. Metrics were calculated using all subplots within each strata and the entire lake.

Table 7. Maximum depth of macrophyte growth along transects and within strata in Onondaga Lake during the August 2010 field survey.

Stratum	Average Maximum Depth (m) of Stratum	Transect	Maximum Depth (m) of Transect
5	5.1	1	5.8
		2	4.5
		3	5.9
		4	4.0
4	4.8	5	4.0
		6	5.0
		7	5.7
		8	4.5
3	4.1	9	4.4
		10	3.2
		11	4.3
		12	4.3
2	4.2	13	4.1
		14	3.1
		15	4.8
		16	4.9
1	5.9	17	6.2
		18	6.0
		19	5.1
		20	6.2

Table 8. Measures of filamentous algae in Onondaga Lake in 2010.

	% Cover		Biomass (g/m2)		% of Subplots with Algae
Stratum	Mean	SE	Mean	SE	Total
1 Oncolite Low Energy	64	3.0	12	4.5	81
2 Wastebeds	25	7.7	0	0	6.8
3 Fine Sed. High Energy	54	2.9	12	3.6	39
4 Oncolite High Energy	33	2.3	13	3.6	77
5 Oncolite Med. Energy	56	3.2	15	4.1	79
Whole Lake Average	51	1.46	11	1.7	52

Notes: SE = Standard error. Metrics were calculated using all subplots within each strata and the entire lake.

Table 9. Species list of aquatic macrophytes observed in Onondaga Lake in current (2010) survey, past studies, and documented historical observations.

Species	2010	2005	2000	1995	1993	1992	1991	Historical
Ceratophyllum demersum	X	X	X	X	X	X	X	1
Chara sp.	--	--	--	--	--	--	--	3
Chara vulgaris	X	--	--	--	--	--	--	--
Elodea canadensis	X	X	X	--	--	--	--	--
Fontinalis sp.	X	--	--	--	--	--	--	--
Lemna minor	X	X	--	--	xx	--	--	--
Lemna trisulca	X	X	--	--	--	--	--	--
Myriophyllum spicatum	X	X	X	X	X	X	X	--
Najas flexilis	X	X	--	--	--	--	--	--
Najas guadalupensis	X	X	--	--	--	--	--	--
Najas marina	--	--	--	--	--	--	--	1,2,4
Nitella flexilis	X	--	--	--	--	--	--	--
Nitella sp.	--	--	--	--	--	--	--	5
Nitellopsis obtusa	X	--	--	--	--	--	--	--
Polygonum amphibium	X	--	--	--	--	--	--	3
Potamogeton crispus	X	X	X	X	X	X	X	2
Potamogeton diversifolius	--	--	--	--	xx	--	--	--
Potamogeton pusillus	X	X	X	--	--	--	--	--
*Potamogeton strictifolius**	X	X	--	--	--	--	--	--
Ranunculus longirostris	X	--	--	--	--	--	--	--
Ranunculus sp.	--	--	X	--	--	--	--	--
Ruppia maritima	X	X	--	--	--	--	--	--
Sagittaria latifolia	--	X	X	--	--	--	--	--
Sparganium sp.	--	--	--	--	xx	--	--	--
Spirodela polyrhiza	X	X	--	--	--	--	--	--
Stuckenia pectinata	X	X	X	X	X	X	X	1,2,3
Stuckenia vaginata	X	--	--	--	--	--	--	--
Trapa natans	X	X	--	--	--	--	--	--
Vallisneria americana	X	X	X	--	--	--	--	--
Zannichellia palustris	--	--	--	--	xx	--	--	5
Zosterella dubia	X	X	X	X	X	X	X	1,2,3,4
Total Number	**23**	**17**	**10**	**6**	**10**	**6**	**5**	**9**

*Notes: * indicates endangered species; "X" indicates presence; "--" indicates absence; "xx" only a few plants found behind experimental wave breaks. Historical presence indicated by note number.*

Sources for surveys by years:
2010 Survey (OCDWEP TBD)
2005 Survey (OCDWEP 2006)
2000 Survey (OCDWEP 2001)
1995 Survey (Arrigo 1995)
1993 Survey (Madsen et al. 1996b)
1992 Survey (Exponent 1998 and Madsen et al. 1996b)
1991 Survey (Madsen et al. 1996a)

Historical Sources:
1. Paine (1865)
2. Bye and Oettinger (1969)
3. NYS Museum voucher specimen (Madsen et al. 1996a)
4. Goodrich (1912)
5. Dean and Eggleston (1984)

Table 10. Comparison of macrophyte community summaries from 1991, 2000, 2005, and 2010.

Year	Study	# Species Observed	# Species/ Transect	% Subplots with Macrophytes
1991	Madsen et al. 1996a	5	1.3	13%
2000	OCDWEP 2001	10	3.6	61%
2005	OCDWEP 2006	16	5.6	74%
2010	OCDWEP 2011	22	6.8	83%

Note: Madsen used transects out to a depth of 5m or 100m in length whichever was shorter. The 2000, 2005, and 2010 results shown here were computed based on these parameters.

FIGURES

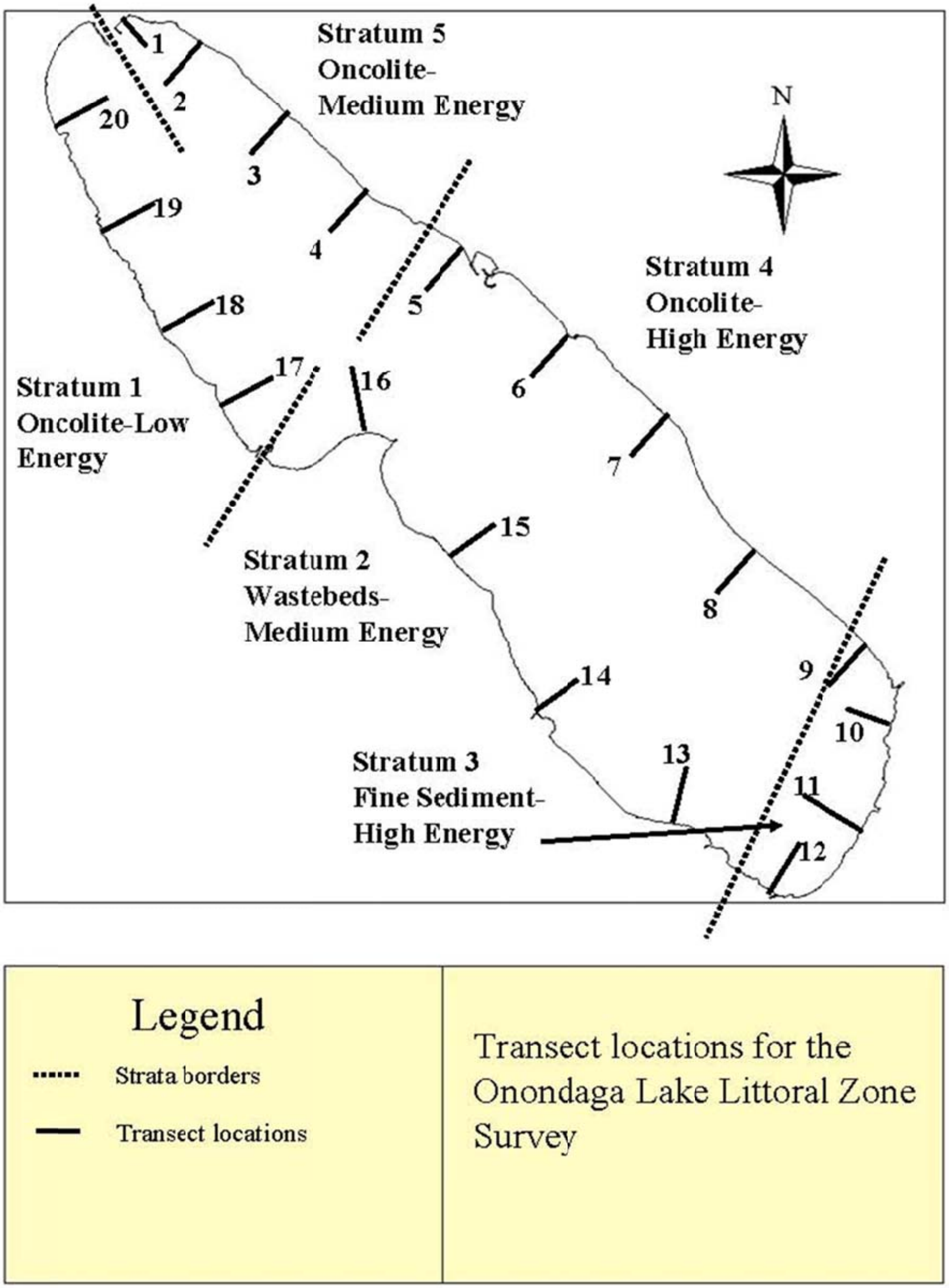


FIGURE 1. Macrophyte survey transect locations in Onondaga Lake, summer 2010.

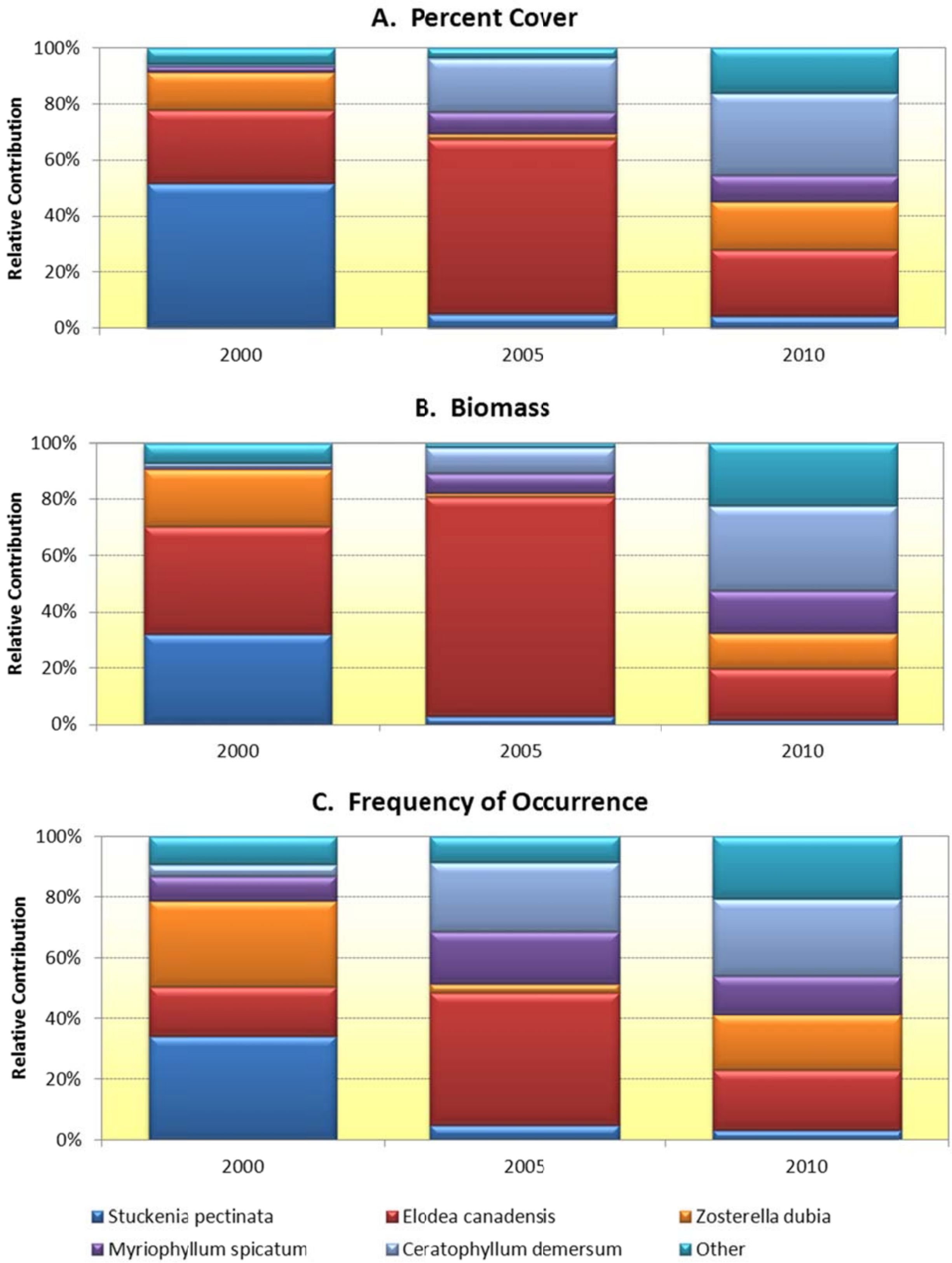


FIGURE 2 (a-c). Relative percent cover, biomass, and frequency of occurrence for species of macrophytes collected in Onondaga Lake in 2000, 2005, and 2010.

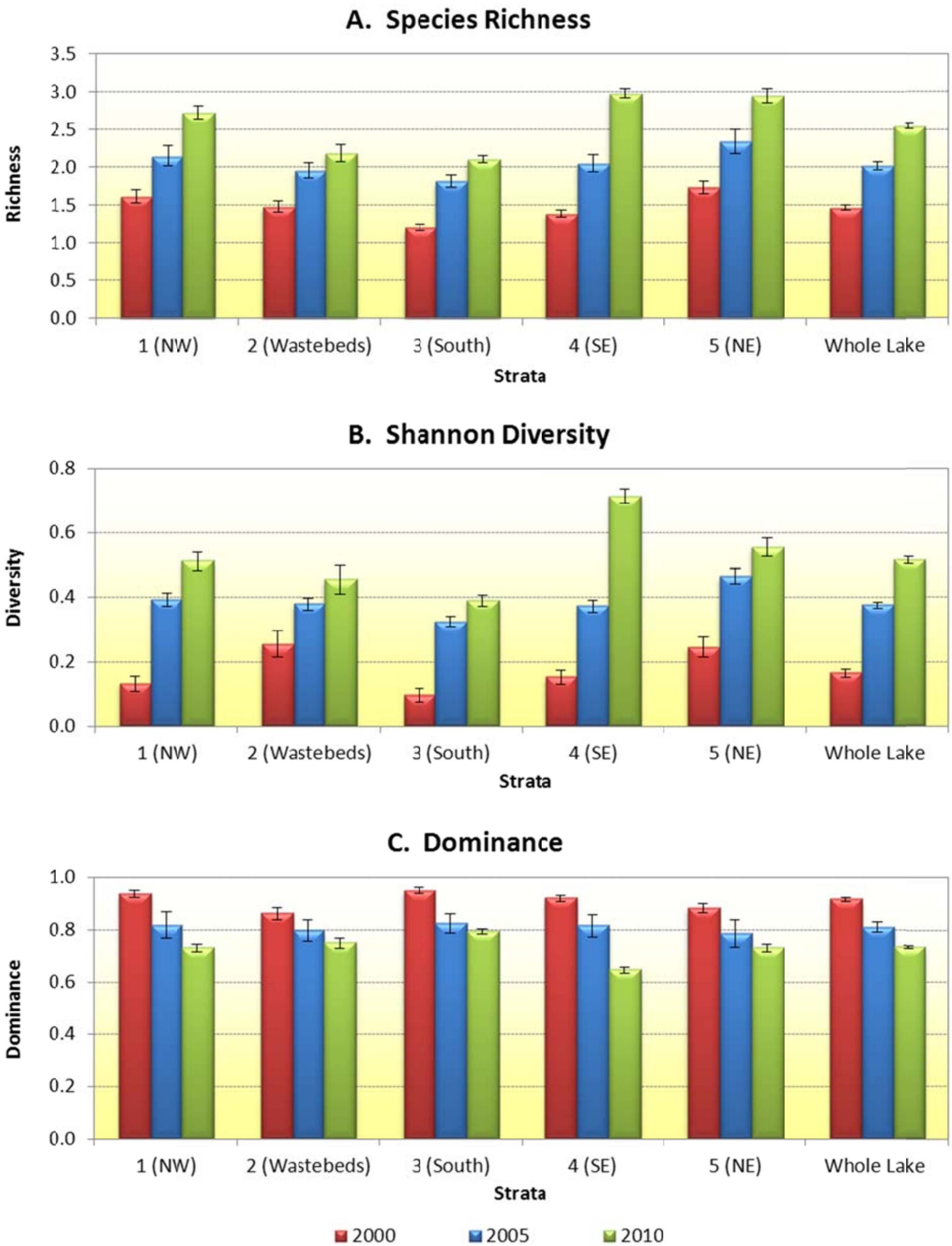


FIGURE 3 (a-c). Mean species richness, Shannon diversity, and dominance of macrophytes within subplots of each stratum and all of Onondaga Lake, 2000-2010.
Note: error bars are standard errors.

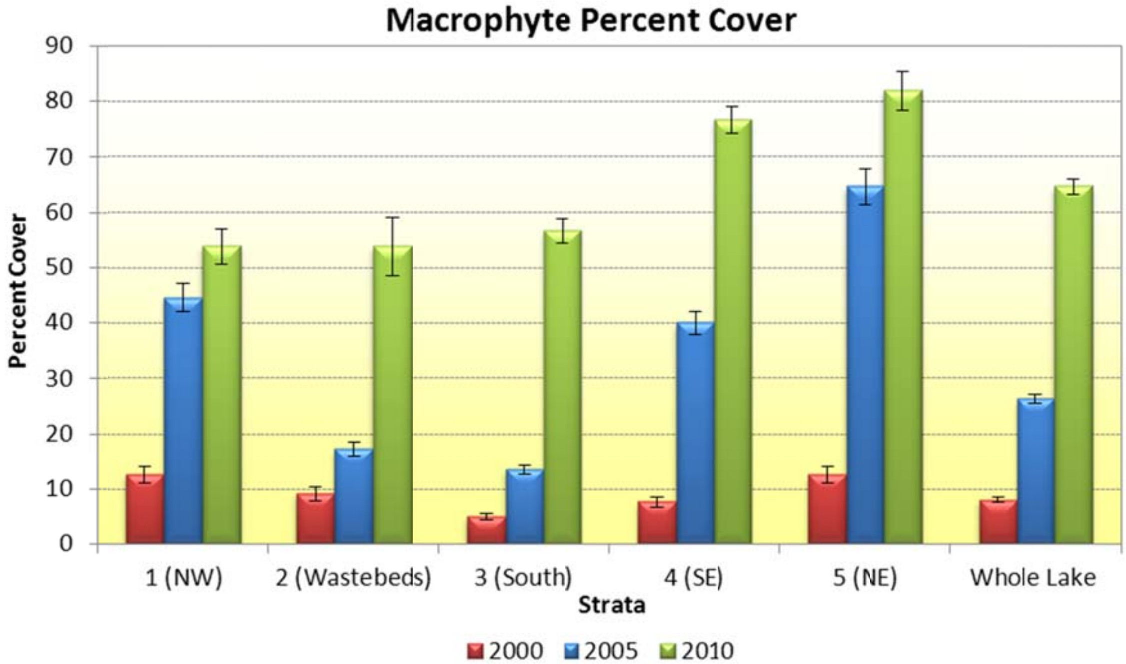


FIGURE 4. Mean macrophyte percent cover in each stratum and all of Onondaga Lake.
Note: Error bars are standard error.

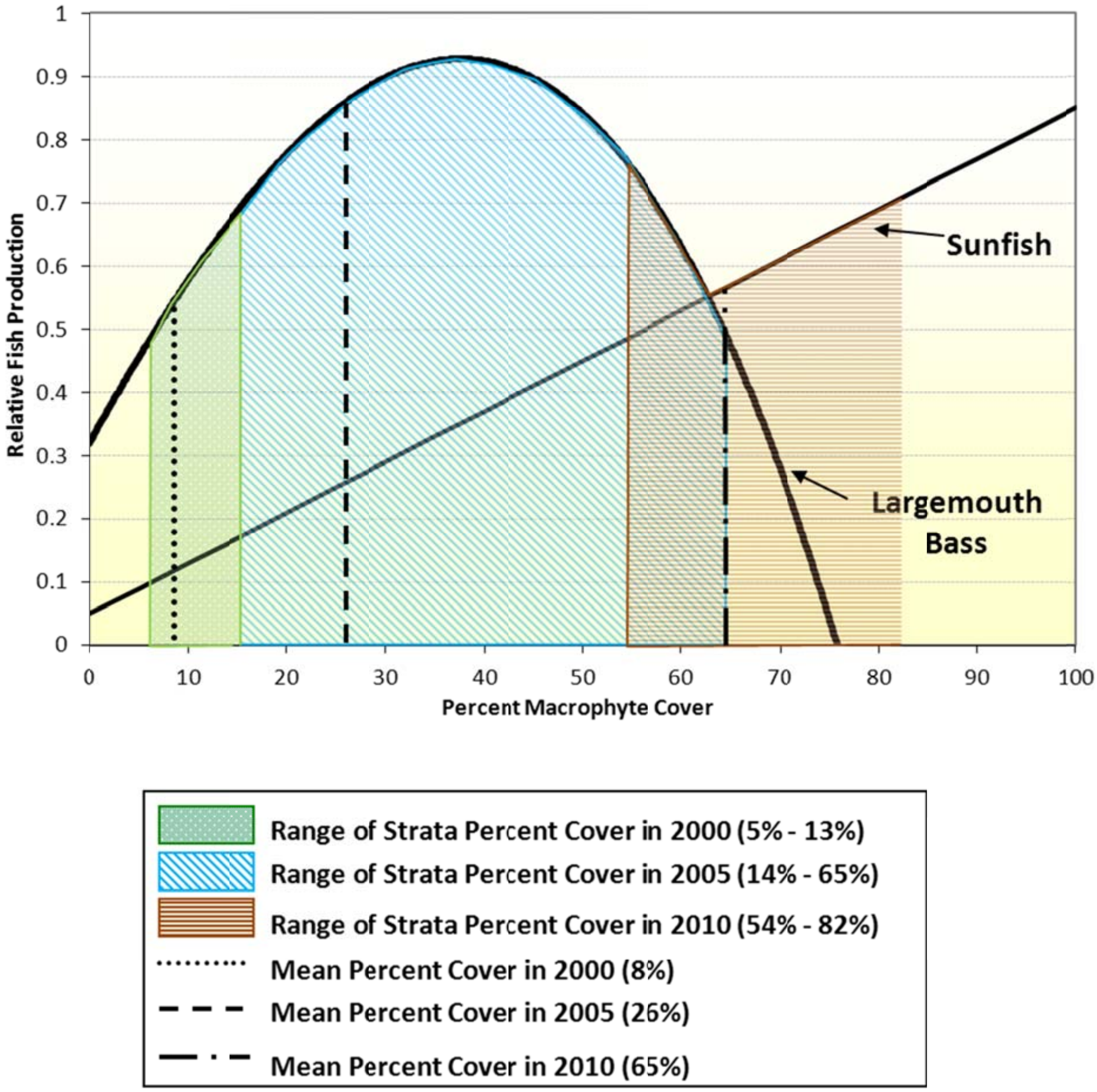


FIGURE 5. Relative production of largemouth bass and sunfish as a function of aquatic macrophyte coverage, based on a trophic model by Wiley et al. (19870. Figure reproduced from Baker et al. (1993).

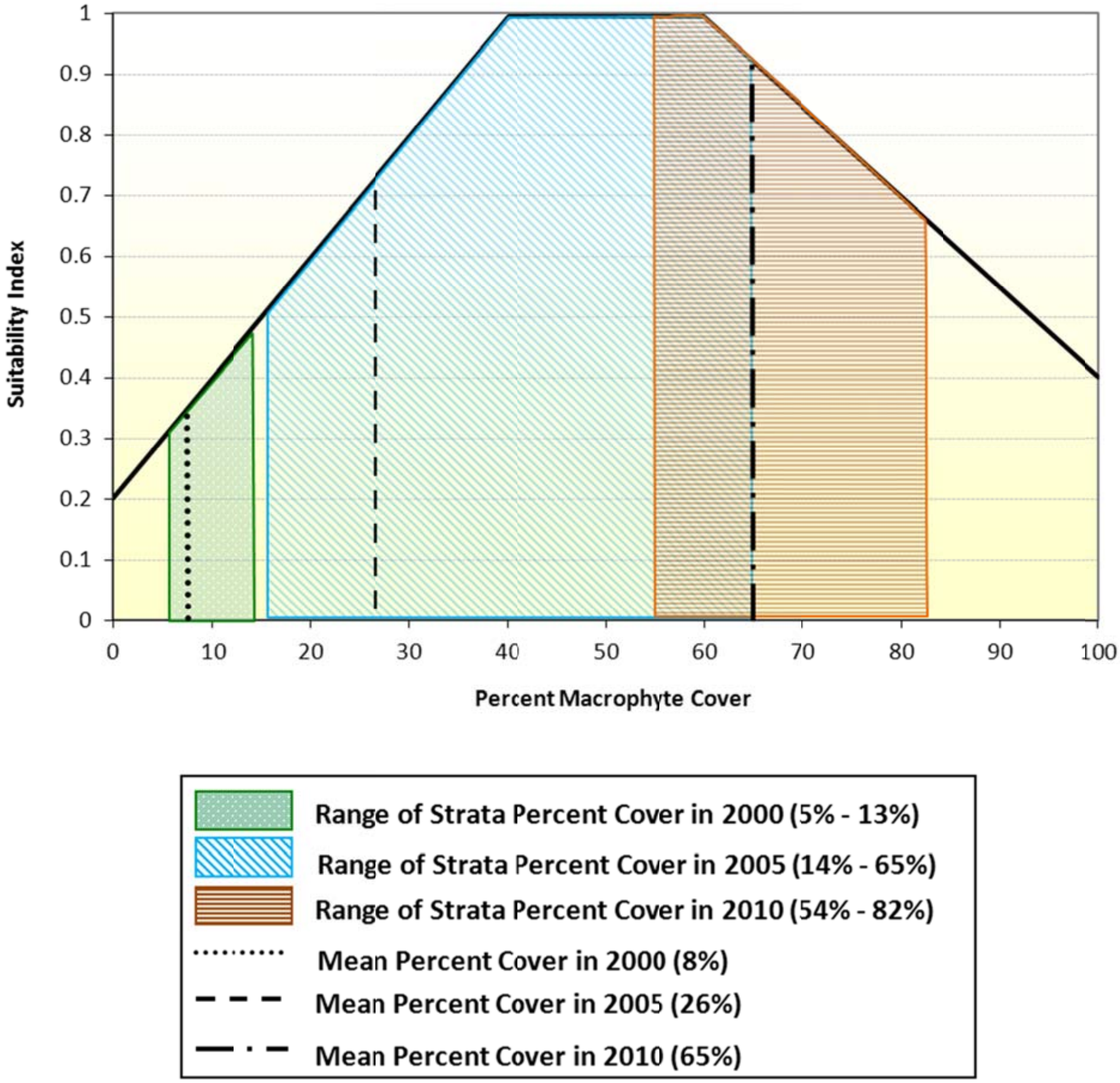


FIGURE 6. Comparison of percent macrophyte cover in Onondaga Lake in 2000, 2005, and 2010 to a percent macrophyte cover suitability index developed for largemouth bass. Reproduced from Stuber et al. (1982).

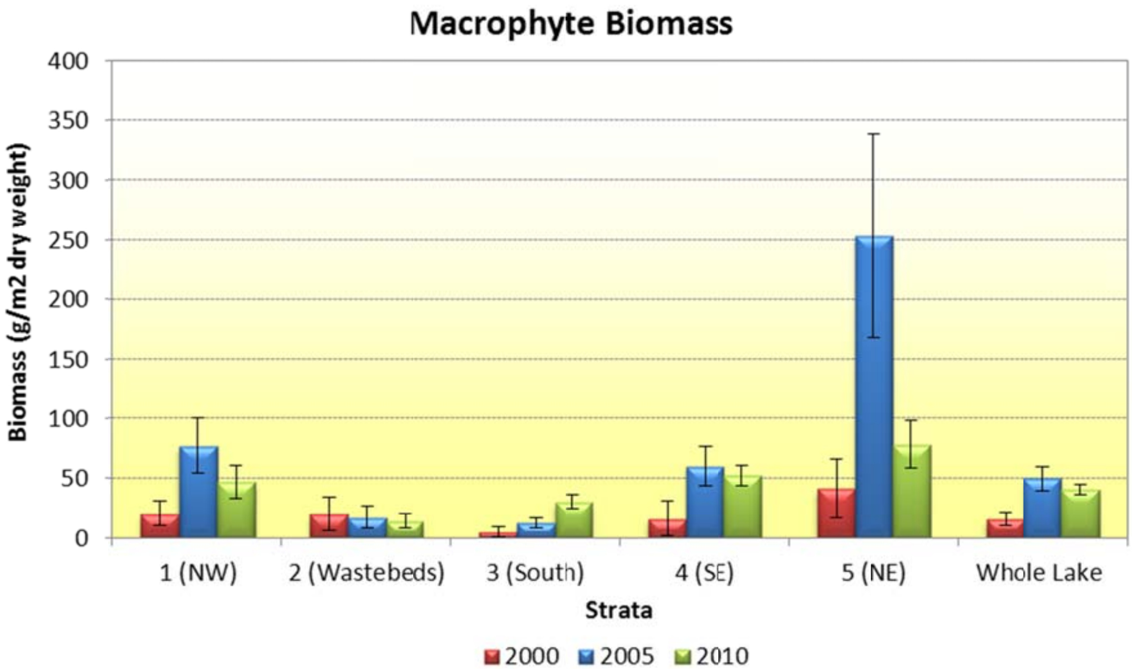


FIGURE 7. Mean macrophyte biomass (g/m^2 dry weight) in each stratum and all of Onondaga Lake.
Note: Error bars are standard error.

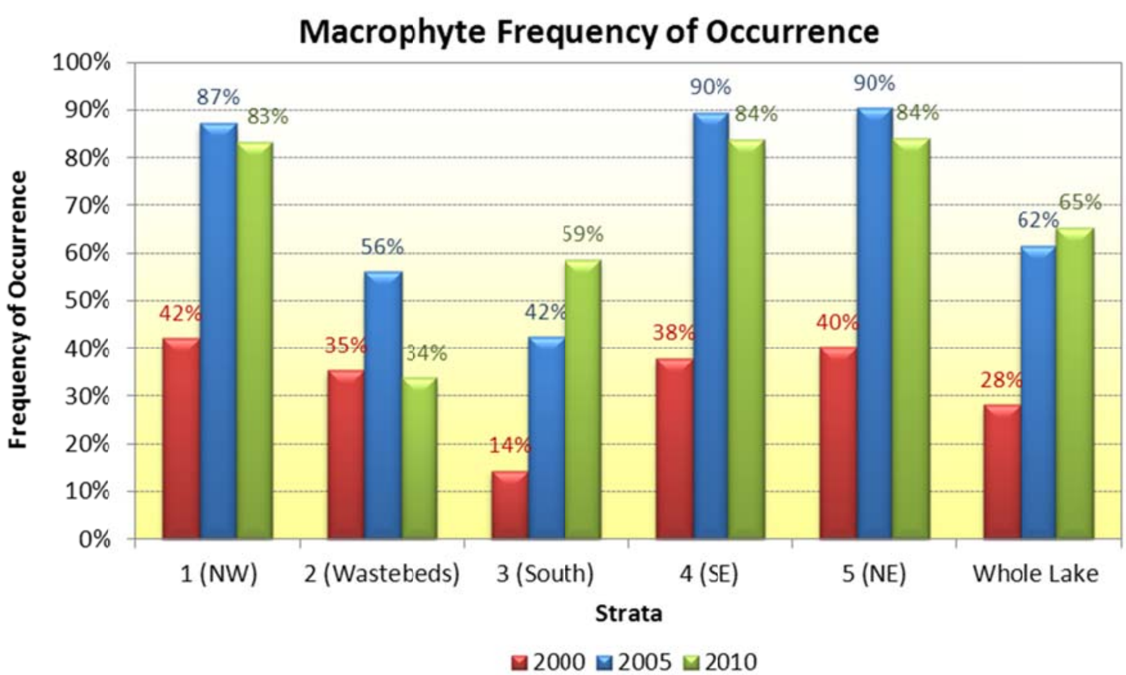


FIGURE 8. Percent of subplots with macrophytes in each stratum and all of Onondaga Lake.

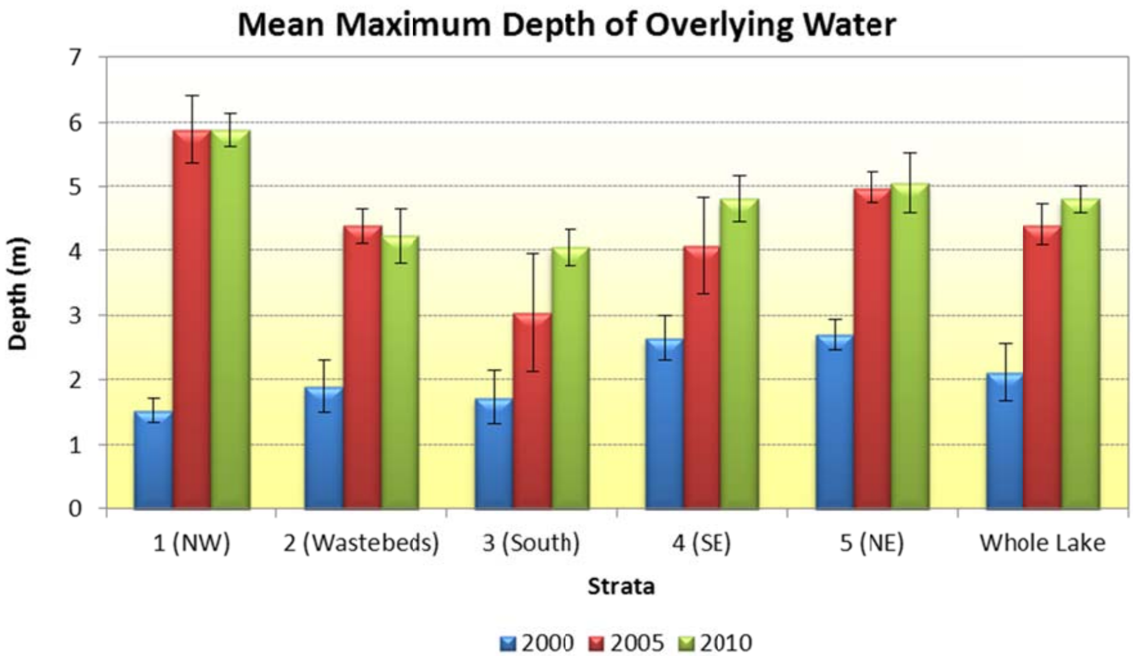


FIGURE 9. Mean maximum depth of overlying water with detected macrophyte growth in each stratum of Onondaga Lake.
<u>Note:</u> Error bars are standard error.

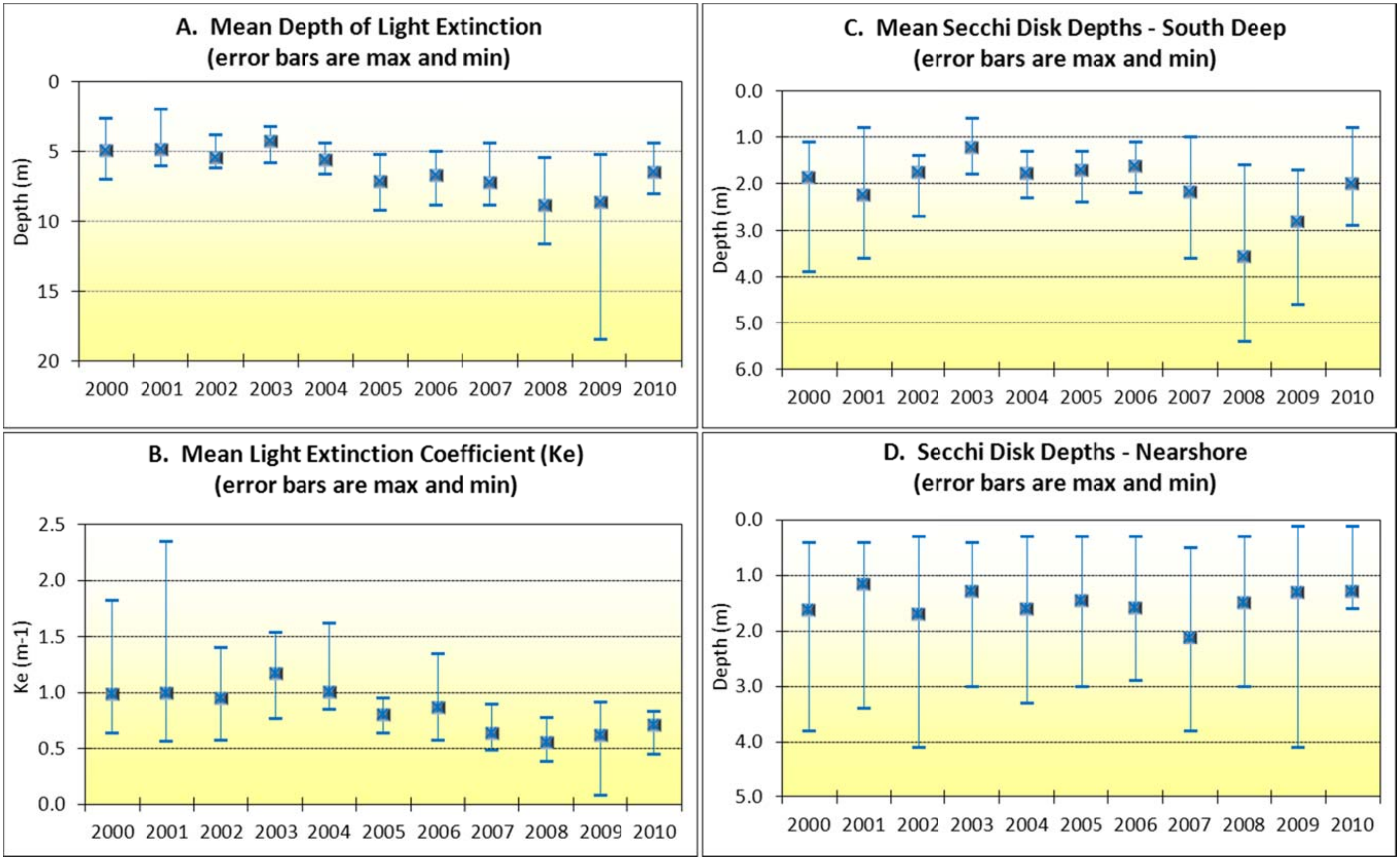


FIGURE 10a-d. Mean depth of light extinction (A), mean coefficient of light extinction (B), mean Secchi depth at South Deep Station (C), and mean Secchi disk depth at nearshore sites (D) from June-September in Onondaga Lake, 2000-2010.

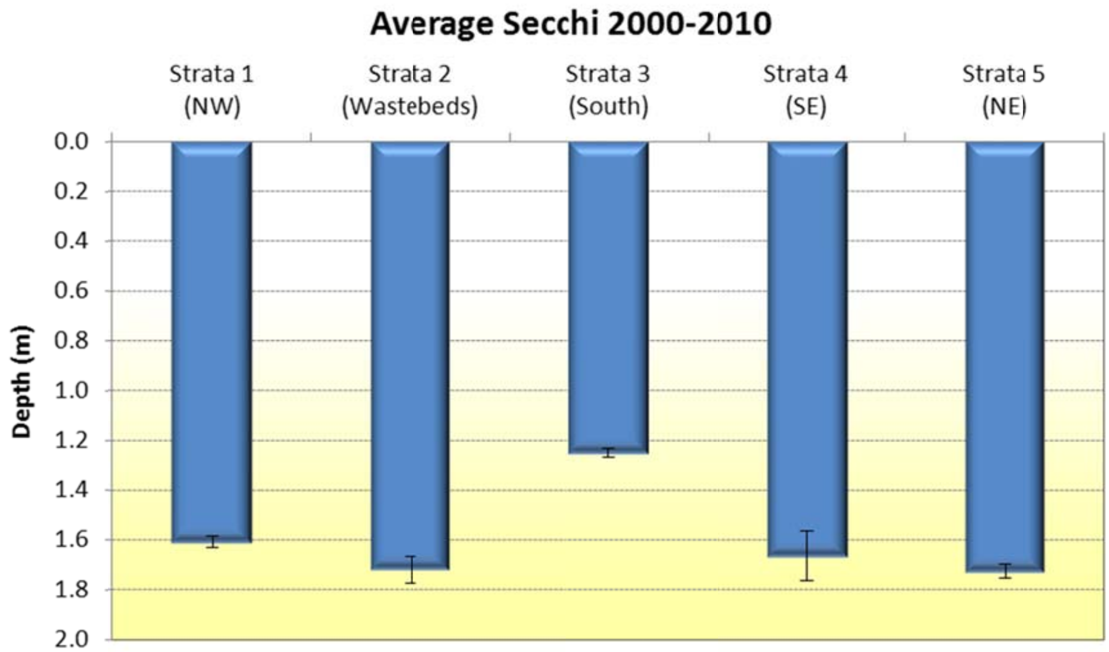


FIGURE 11. Mean nearshore Secchi disk measurements collected from nearshore sites within each stratum from 2000 to 2010.

<u>Note:</u> Error bars are standard errors; there were no nearshore sites in Stratum 2 from 2000 to 2005.

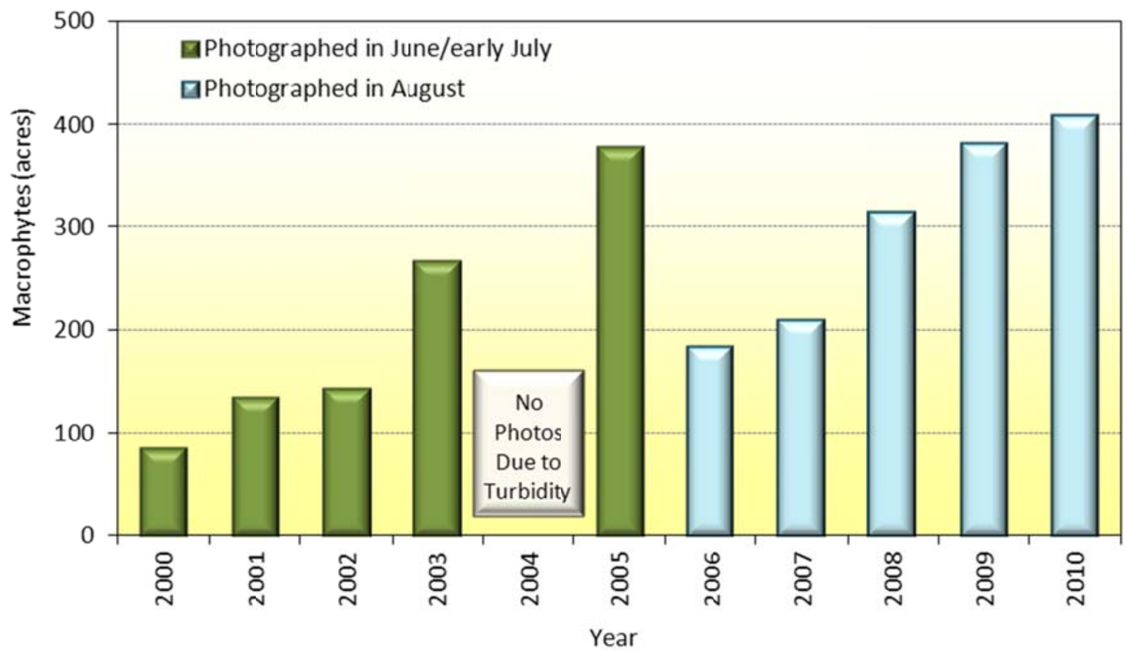


FIGURE 12. Total acreage of macrophytes in Onondaga Lake from 2000 to 2010 based on areas delineated as macrophytes from digitized aerial photographs.

**2006 - 2010 photographs were taken in August, all others were taken in June or early July; this adds an unknown level of variability to the analysis so those five years are depicted separately.*

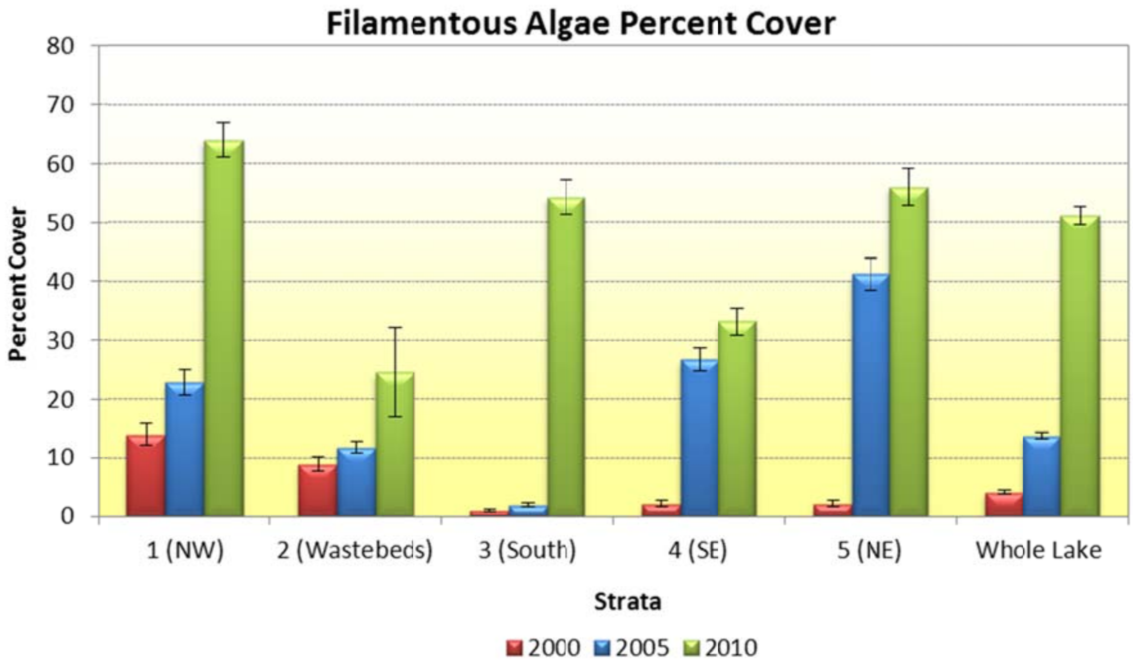


FIGURE 13. Mean filamentous algae percent cover in each stratum and all of Onondaga Lake.
Note: Error bars are standard error.

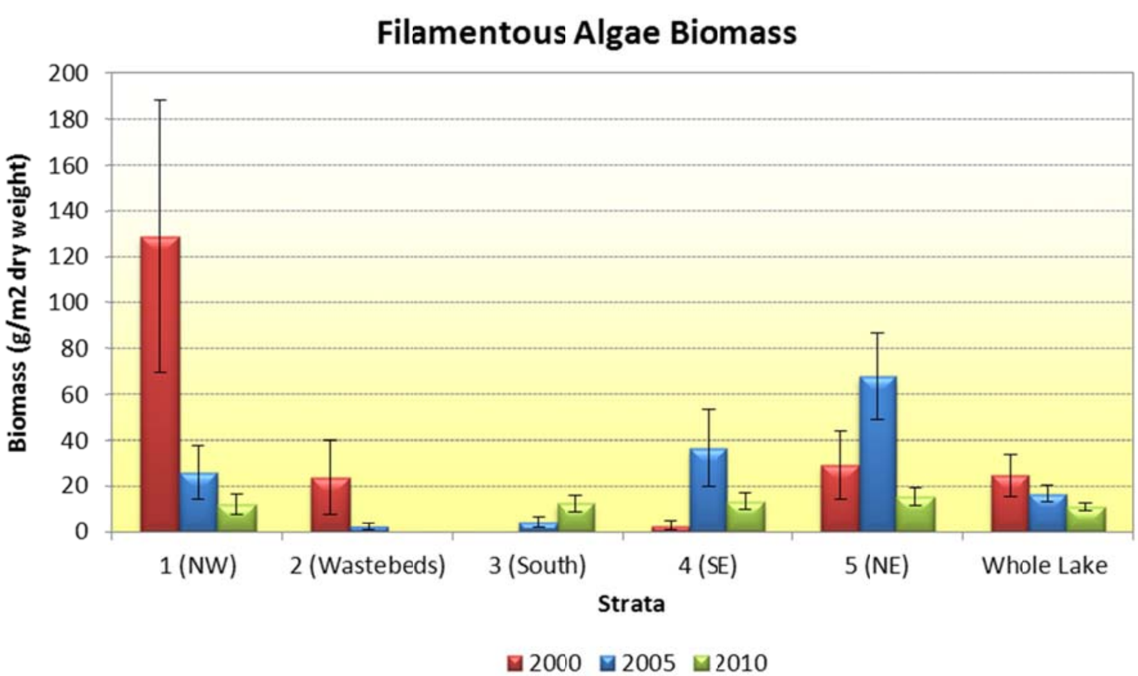


FIGURE 14. Mean filamentous algae biomass (gm2 dry weight) in each stratum and all of Onondaga Lake.
Note: Error bars are standard error.

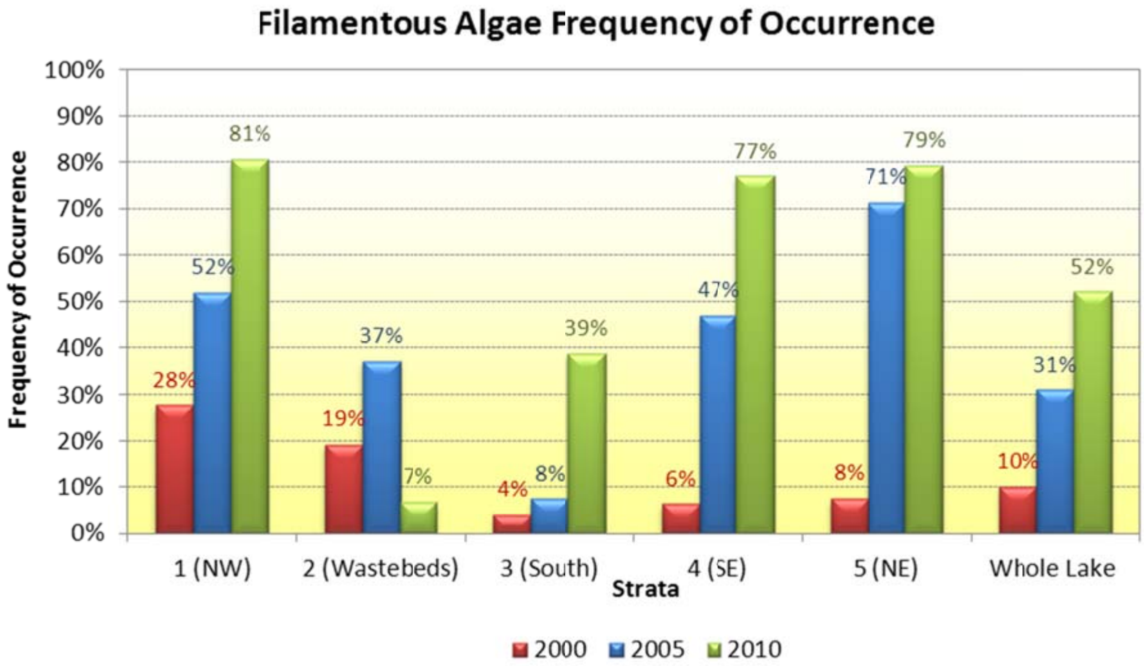
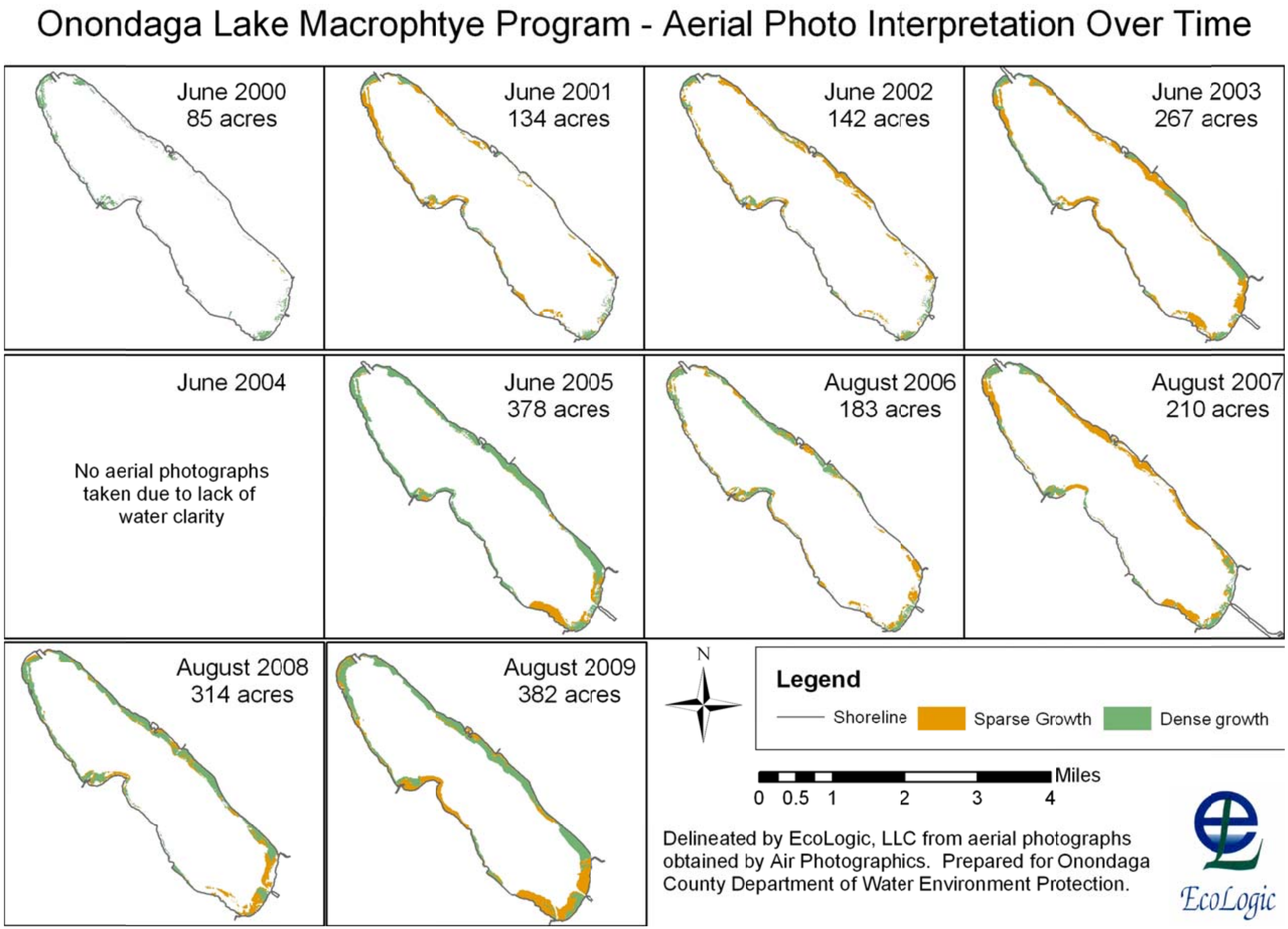
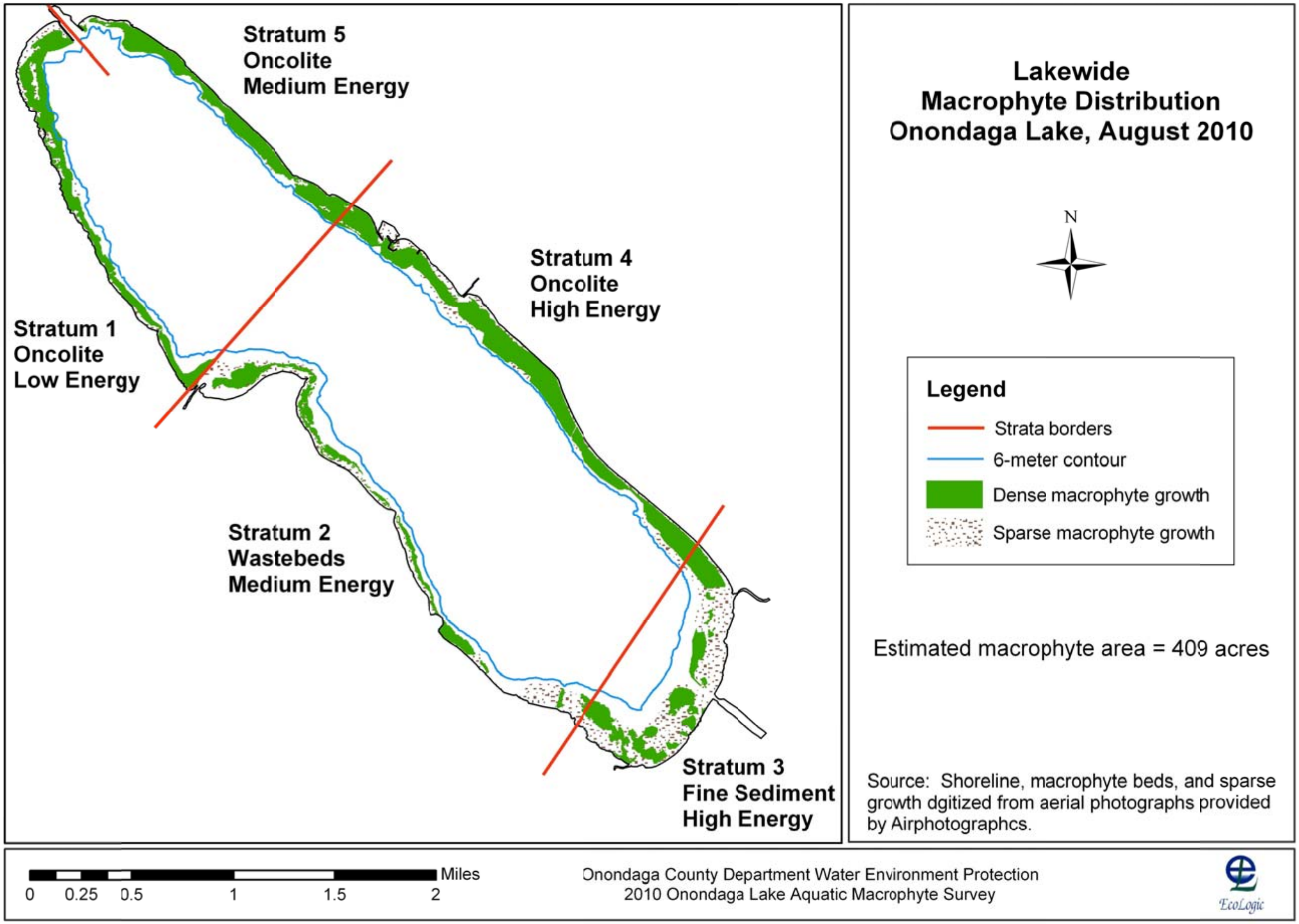


FIGURE 15. Percent of subplots with filamentous algae in each stratum and all of Onondaga Lake.

APPENDICES



Appendix 1. Coverage of aquatic macrophytes in Onondaga Lake from 2000 through 2009 based on interpretation of aerial photographs. Photographs were taken in June or early July in 2000-2005 and in August in 2006-2009.



Appendix 2. Coverage of aquatic macrophytes in Onondaga Lake in August 2010 based on interpretation of aerial photographs.