The Aquatic Macrophyte Community of Onondaga Lake: Field Survey and Plant Growth Bioassays of Lake Sediments

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ABSTRACT

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Onondaga Lake, located in the Syracuse metropolitan area of upstate New York, has been heavily impacted by domestic and industrial waste effluents, resulting in a lake with high salinity, low light availability, and a highly calcareous, nutrient-poor sediment. These factors appear interrelated in reducing the cover, distribution and diversity of aquatic plants between 1940 and 1990. A quantitative survey in 1991 found that only 13% of the littoral zone had any aquatic plants. The plant community was dominated by *Potamogeton pectinatus* (11%), with four other submersed aquatic plants found: *Ceratophyllum demersum, Heteranthera dubia, Myriophyllum spicatum,* and *Potamogeton crispus.* Aquatic plants were found less often than expected on the calcium-carbonate oncolite sediments, which are formed from precipitated calcium carbonate, compared to other sediment types in the lake. Laboratory studies were developed to evaluate the role of sediments in limiting plant growth. These studies showed that Onondaga Lake sediments supported less growth than a reference sediment, but no differences among Onondaga Lake sediment types (oncolite, silt, sand or organic) were found in plant growth bioassay studies.

Key Words: sago pondweed, *Potamogeton pectinatus,* sediment limitation, plant growth, submersed aquatic macrophyte, oncolite.

Throughout the 1800s, Onondaga Lake was an important fishery and tourist location. However, beginning as early as 1880, industrial and domestic waste effluents greatly reduced water quality (Saroff 1990). Domestic effluents discharged into the lake resulted in increased algal growth and decreased water clarity (Saroff 1990). Industrial discharges of mercury and $CaCl_2$ (chiefly from chlor-alkali ("Solvay") soda ash production) resulted in increased salinity and calcium supersaturation (Effler and Driscoll 1985, 1986, Effler 1987). Calcium supersaturation resulted in calcium carbonate precipitation, which further decreased water clarity and led to the formation of calcium carbonate concretions, or oncolites (Effler 1987, Dean and Eggleston 1984). While the sediments of most north temperate lakes are predominately clay or sand, Onondaga Lake sediments are composed predominantly of precipitated calcium carbonate, which is a poor plant rooting and nutrient medium. Salinity reached a peak of 3.0 ppt in the early 1980s, at which time the last Solvay process plant suspended activities (Effler 1987). By 1990, lake salinity had dropped to approximately 1.5 ppt (Saroff 1990).

Aquatic macrophytes are an important constituent in lake ecosystems. They produce food for other aquatic organisms, serving as the base of an aquatic food chain; and also provide habitat areas for insects, fish of all age classes, and other resident aquatic and semi-aquatic organisms. The littoral zone, and the vegetation that defines it, are a prime area for the spawning of most fish species, including many species important to sport fisheries. Aquatic vegetation also serves to anchor soft sediments, stabilize underwater slopes, and remove suspended particles and nutrients from overlying waters. All of these factors indicate the importance of natural littoral vegetation to the health of lake ecosystems (Carpenter and Lodge 1986).

The absence of littoral vegetation from a lake may result in reduced diversity, as well as reduced production of desirable fish species (Savino and Stein 1989). Loss of vegetation may contribute to silt resuspension, turbidity, and increased algal productivity. In addition to the biological and ecosystem changes, loss of vegetation reduces the aesthetic and recreational value of a lake.

Few quantitative or observational data have been recorded for aquatic macrophytes within Onondaga Lake (Saroff 1990). Historical species richness estimates are difficult to determine; however, some of the historical references are summarized (Table 1). Apparently, up to fifteen species were present in Onondaga Lake before 1940. For a eutrophic lake in New York State, fifteen species of littoral vascular plants is typical (Madsen et al. 1993).

A systematic study was initiated in 1991 which included a field survey of the presence and frequency of aquatic plants and laboratory experiments of factors affecting plant growth. The objectives of the field study

Table 1. Historical references to aquatic macrophyte species in Onondaga Lake, compared to this survey.

Species	This Survey	McMullen (1991)	NYSM[1]	Personal Observations
Carex viridual		X		
Ceratophyllum demersum	X			X[2]
Chara sp.				X[4]
Cyperus odoratus		X		
Heteranthera dubia	X	X	X	
Juncus pelocarpus		X		
Myriophyllum spicatum	X			X[2, 5]
Najas flexilis		X		
Najas marina		X		
Nitella sp.				X[4]
Nuphar luteum		X		
Nymphaea odorata		X		
Phragmites communis		X		
Polygonum amphibium			X	
Potamogeton crispus	X			
Potamogeton pectinatus	X	X	X	X[2, 3]
Potamogeton robbinsii		X		
Ruppia maritima		X		
Sagittaria rigida		X		
Scirpus americanus		X		
Scirpus validus		X		
Typha angustifolia		X		
Zannichellia palustris			X	

Notes: [1]Listing of voucher specimens in the New York State Museum noted by Bruce Gilman (Madsen et al 1993); [2]Jay Bloomfield and Jim Sutherland, pers. comm., NYS DEC Field Notes for 31 May 1990.; [3]Stone and Pasko 1946.; [4]Dean and Eggleston 1984.; [5]Identified at site as *Myriophyllum sibiricum*, later revised to *M. spicatum*..

were to determine the diversity and distribution of aquatic macrophytes in the lake and correlate the distributions with environmental factors (e.g., depth and sediment type). Although salinity, light availability, and sediment characteristics are all suggested as limiting plant growth, initial laboratory studies focused first on the role of sediments. The purposes of these experiments were to evaluate 1) the potential of Onondaga Lake sediments to grow plants relative to a fertile sediment, 2) the potential of various sediment types to support plant growth, and 3) the relationship between the existing plants and sediment distribution. Two sediment bioassays were performed. In the first, differences in the ability of visually-defined sediment types (oncolite, sand, silt and organic) to support plant growth were compared with a fertile pond sediment. In the second, sediments supporting high, medium and low cover of plants in the lake were brought to the laboratory and bioassayed to see if these abundances could be related to sediment fertility.

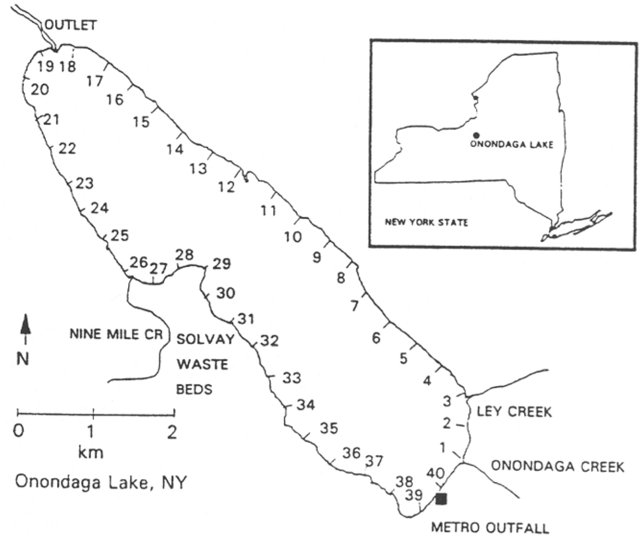

Figure 1.–Location of vegetation survey transects in Onondaga Lake, New York, June 1991.

Materials and Methods

Field Studies

The distribution of submersed littoral vegetation was examined using 40 transects placed in a stratified-random manner around Onondaga Lake (Latitude 43°06'54"N, Longitude 76°14'34"W), perpendicular to the shoreline (Fig. 1). The lake's shoreline was subdivided into 40 segments of approximately 400 m each, and the transect randomly placed within this segment using a random number generator for location. Each transect was 100 m long, divided into 1-meter segments, and extended from the shore to no greater than 5 m deep. At each 1-meter interval, a 0.1 m^2 quadrat was placed (Madsen et al. 1989). Cover of each species within the quadrats was estimated, based on a Daubenmire scale by SCUBA divers knowledgeable in aquatic plant identification (Daubenmire 1959, 1968). In addition, the surficial sediments were visually characterized by six physical (predominantly particle size) classes (gravel, sand, silt, organic, oncolite and carbonate) for each quadrat. Oncolites are small nodules or concretions of calcium carbonate (Dean and Eggleston 1984), while the carbonate class is predominantly carbonate crusts or continuous sheets with virtually no free particles. The visual estimates were also standardized by taking three core samples per transect, which were analyzed for particle size and carbonate content (Madsen et al. 1993). The survey was performed in late June 1991. Data were analyzed for frequency of species occurrence (presence or absence) in all quadrats using a Chi-square analysis of a two-by-two table. Voucher specimens were collected and archived in the Rensselaer Fresh Water Institute herbarium in Bolton Landing, NY. Taxonomic nomenclature and identification follows that of Fassett (1957).

Laboratory Studies

The effect of sediment composition on macrophyte growth in the Onondaga Lake littoral zone was evaluated in a series of greenhouse bioassay experiments (Madsen et al. 1993). *Potamogeton pectinatus* obtained from Wildlife Nurseries in Oshkosh, WI was used in all experiments. *Potamogeton pectinatus* was selected because it is the dominant plant in Onondaga Lake.

Experimental studies were conducted during 1991 using 20 large (1,200 liter) growth tanks (95 cm wide by 155 cm long by 85 cm deep) in a greenhouse at the Lewisville Aquatic Ecosystem Research Facility (LAERF), Lewisville, TX (Latitude 33°04'45"N, Longitude 96°57'33"W). Filtered well water was amended with 220 g of $CaCl_2$ (per 1,200 L tank of water) to correspond to the chemical composition of Onondaga Lake water in 1989 (salinity 1.2 ppt, Madsen et al. 1993). Water temperature was maintained at 25 ± 2°C. Plants were grown in 1.25 liter containers of experimental sediment, with six replicates of each sediment treatment. Replicates were randomly assigned to tanks, with no more than one pot of each treatment in a given tank. After a six-week growth period, containers were harvested and the plant shoot material was dried at 55°C to a constant weight.

Two sediment experiments were performed concurrently (Table 2). In the first ("Sediment Class", Table 2), the ability of different Onondaga Lake sediment classes (that were visually classed in the field, as above) to support plant growth were compared. The four sediment types from Onondaga Lake examined were oncolite, organic, sand and silt. The carbonate and gravel sediment types were not utilized due to the difficulty in collecting those types. A silt sediment with an apparent high organic fraction ("organic") was utilized as a potentially fertile Onondaga Lake sediment. For the four basic sediment types assayed, a standard site was selected to collect each of the sediments needed. In the second experiment ("Sediment Fertility", Table 2) additional sediments were selected based on the existing cover of plants: high (mean cover 32%), medium (mean cover 9%), and low (mean cover 0.001%). Three sites of each of these cover classes were selected for sediment trials, based on transect percent cover estimates, for a total of nine additional sediments bioassayed. The results of each cover class were averaged. A locally-available (e.g., LAERF) fertile sediment was also used as a reference to potential plant growth. Therefore, 14 different sediments were assayed. Data was analyzed using ANOVA, with a Bonferroni Significant Difference test to evaluate differences between the means of each treatment.

Results and Discussion

Field Studies

Oncolites cover much of the littoral zone in Onondaga Lake, including most of the eastern and northwestern shores, and sandy material is mixed in with oncolites in much of this zone (Fig. 2). Silts occur primarily on the southwestern shoreline. The surficial sediment map corresponds well to previous work by Dean and Eggleston (1984).

Five species of submersed macrophytes were observed in Onondaga Lake during the 1991 survey (Table 1). No species of either floating-leaved or emergent plants were observed, although these growth forms are typical of the transition from the littoral zone to wetlands. The absence of these species may be related to high salinity, as well as shoreline changes associated with urbanization and wave scouring of unstable sediments, but no direct tests have been performed.

The frequency of the five submersed species around the lake is evidenced by the number of transects at which each was observed (Table 3). Of the five species observed, *P. pectinatus* was common and had localized areas of high cover, *Heteranthera dubia* was present at

Table 2.–Experimental setup of the two sediment assay experiments.

Experiment	Sediment Type	Onondaga Lake Transect Site	Number of pots utilized
Sediment Class	Lewisville	Lewisville, TX	6
Sediment Class	Gravel	(Not Used)	0
Sediment Class	Sand	Transect 3	6
Sediment Class	Silt	Transect 40	6
Sediment Class	Oncolite	Transect 11	6
Sediment Class	Organic	Transect 20	6
Sediment Class	Carbonate	(Not Used)	0
Sediment Fertility	High Cover	Transect 39	6
Sediment Fertility	High Cover	Transect 19	6
Sediment Fertility	High Cover	Transect 14	6
Sediment Fertility	Medium Cover	Transect 22	6
Sediment Fertility	Medium Cover	Transect 9	6
Sediment Fertility	Medium Cover	Transect 30	6
Sediment Fertility	Low Cover	Transect 7	6
Sediment Fertility	Low Cover	Transect 23	6
Sediment Fertility	Low Cover	Transect 38	6
Total Assayed			84

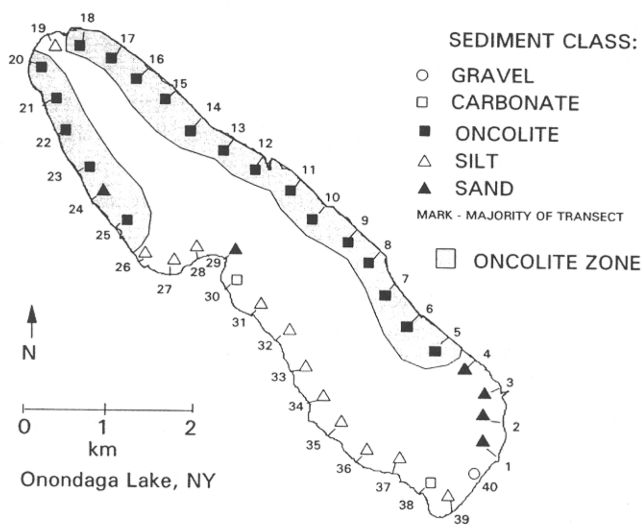

Figure 2.–Surficial sediment types of Onondaga Lake, June 1991.

many transects, and the remaining three species were infrequently observed, or rare, and never common or with high cover at any transect.

Individual sites (transects) exhibited very limited diversity. The number of species at each site ranged from 0 to 3 (Fig. 3), with an average of slightly more than 1 species per transect (mean = 1.3 species). *Potamogeton pectinatus* was the most common, occurring at 68% of the transects. The remaining species occurred in the following order (% of transects with this species): *H. dubia* (25%), *C. demersum* (18%), *P. crispus* (13%) and *M. spicatum* (5%) (Table 3).

Plants were observed in only 13% of the quadrats surveyed. *Potamogeton pectinatus* was the most common (11%). *Heteranthera dubia* occurred in only 2% of the quadrats; all of the other species were rare, occurring in less than 1% of the quadrats. All five species were present in depths of 0 to 2 m. In water depths of between 2 and 3 m, only *H. dubia* and *C. demersum* were observed, and beyond a depth of 3 m, only *H. dubia* was found (Table 3).

Transects without aquatic macrophytes were largely restricted to those areas with the greatest fetch, or exposure (Fig. 3). These sites were predominantly in the southeastern and northwestern areas of the lake. *Potamogeton pectinatus* was present at all but one of the transects with vegetation. *Ceratophyllum demersum* was found predominantly along the western shore, with *H. dubia* found predominantly on the eastern shore. *Myriophyllum spicatum* was found at two nearly adjacent sites northwest of the marina on the northeastern shore. *Potamogeton crispus* was distributed sparsely around the entire lake.

In most locations, existing *P. pectinatus* populations (e.g., patches) were very small. However, two locations, northwest of the outlet and northwest of Onondaga Creek, had large beds of *P. pectinatus*. These two sites had silt sediments. The total areal coverage of *P. pectinatus* was much less than expected for this type of lake.

Sediment characteristics play a major role in the distribution of aquatic plants within Onondaga Lake. Gravel sediments were the least likely to support aquatic plant populations, followed closely by oncolite-dominated sediments (Fig. 4). Both of these types had significantly less frequent occurrences of plants than expected, as determined by a Chi-square test ($p<0.05$). With the exception of areas near transect 40, all gravel sediments were found at the waters edge, where wave-induced turbulence and water level changes combine to severely limit aquatic plant growth. Sand, silt and carbonate-type sediments were more likely to support plant populations than average, with from 18 to 21% of those quadrats containing at least one plant. These data suggest that plants have difficulty in establishing and remaining on oncolite sediments, with fewer problems establishing on other sediment types. It may be that oncolites, like the gravel sediments, are highly disturbed from wave action, or more prone to instability. In the greenhouse experiments (following) plants grown on oncolite sediments produced similar shoot mass to those grown on other sediment types from

Table 3.–Depth distribution and frequency of macrophyte species in Onondaga Lake at the 40 survey transects. Numbers indicate raw frequency of occurrence, as the number of transects in a specific depth interval at which this species was found.

Species	Depth Range(m)					
	0<1	1<2	2<3	3<4	4<5	Total
Ceratophyllum demersum	5	3	1	0	0	7
Heteranthera dubia	3	8	4	1	1	10
Myriophyllum spicatum	1	1	0	0	0	2
Potamogeton crispus	3	3	0	0	0	5
Potamogeton pectinatus	22	12	0	0	0	27
Total Occurrences	**34**	**27**	**5**	**1**	**1**	

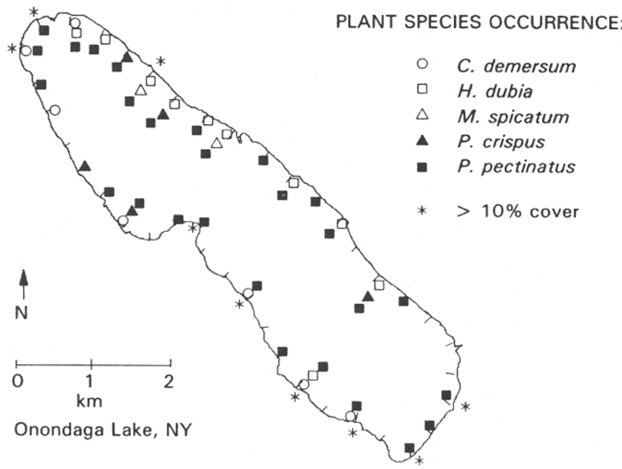

Figure 3.–Distribution of aquatic plant species in Onondaga Lake, June 1991.

Onondaga Lake, which may be attributed to lack of disturbance from waves.

Laboratory Studies

Growth of *P. pectinatus* on the fertile reference sediment was significantly higher (≥ 2X, $p<0.05$) than growth on the Onondaga Lake sediments (Fig. 5). Analyses indicated that the sediments were highly calcareous, and low in both nitrogen and phosphorus (Madsen et al. 1993). Therefore, improvement in water clarity or quality alone will not improve plant growth. Sediment degradation is directly related to the input of $CaCl_2$ into the lake, and resulting calcium carbonate deposition.

Sediments from sites with high, medium, and low percent plant cover showed significant differences ($p<0.05$) in their ability to support plant growth (Fig.

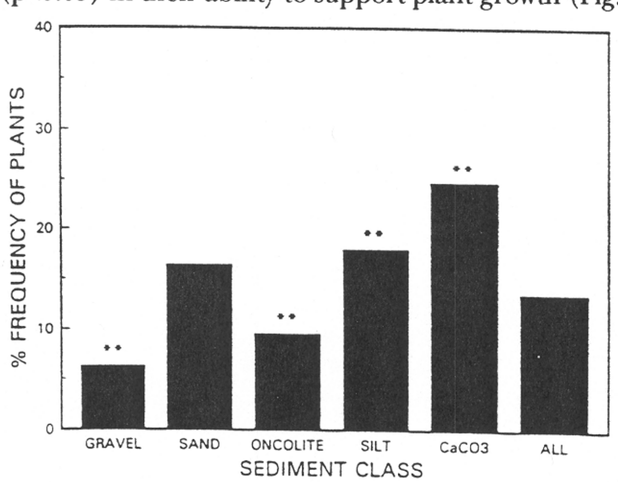

Figure 4.–Frequency of plant occurrence versus sediment type from the field survey. "ALL" indicates the frequency of plants at all quadrats. Asterisks indicate a significant difference from the mean at the p<0.05 level using a Chi-square two-by-two comparison.

5). Sediments from areasof high plant cover had significantly greater growth (grand mean shoot mass 3.7 g) than those from low plant cover areas (grand mean shoot mass 2.1 g); with sediment from areas of medium plant cover, supporting growth intermediate to the two extremes (grand mean shoot mass 2.9 g). Sediment fertility ranges, based on plant growth, were greater within a given sediment class in Onondaga Lake than between sediment classes.

Conclusions

In summary, the plant community of Onondaga Lake exhibited low species richness and percent cover, with plants poorly distributed around the lake. Plant growth was limited by both sediment fertility, as indicated by sediment bioasssays, and stability, as inferred from distribution data. In addition, salinity and poor light availability may also impede the growth of plants. In order to restore a healthy native plant community in this lake, restoration must address all of these limiting factors, not just one. To address the relative importance of sediment, salinity and light availability factors, additional studies should be performed. Sites which had significant plant growth typically were protected from wind-generated waves, which may have allowed plants to colonize undisturbed. Stabilizing sediments with wave protection is one mechanism that might be employed in encouraging the recolonization of the plant community.

Management Recommendations

The paucity of aquatic macrophytes in Onondaga Lake mean that there is little or no littoral habitat for fish and other organisms. Restoration of Onondaga Lake must include steps to restore littoral habitat areas. Expensive approaches include reduced input of saline water and diversion of treated sewage effluent from the lake. These restoration approaches would have broader impacts on improving lake water quality, but may not significantly improve plant colonization. However, other approaches should be examined. Oncolite sediments can be stabilized by building wavebreaks, which will allow plants to grow undisturbed. Fish spawning and nursery areas should also be evaluated. Transplants of desirable native aquatic plants, both submersed and emergent, should be tested on both a pilot scale, and in significant numbers. It is possible to restore or recreate a stable littoral community in Onondaga Lake.

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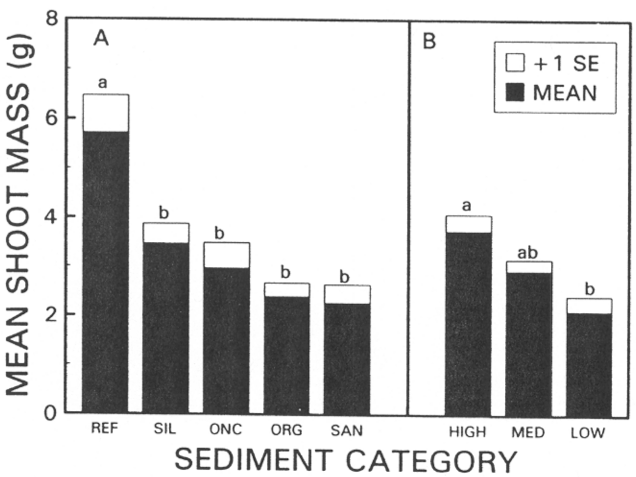

Figure 5.–(A) Growth of *Potamogeton pectinatus* on a reference (REF) and Onondaga Lake sediments in a greenhouse experiment. Onondaga Sediment classed: SIL (silt), ONC (oncolite), ORG (organic), SAN (sand). (B) Growth of *P. pectinatus* in greenhouse with sediments from sites with high, medium and low percent plant cover. Plant cover class sites: HIGH (high, 32% cover), MED (medium, 9% cover), LOW (low, 0.001% cover). Means of *in situ* cover class sites include all replicates of the three sites collected per cover class. Different letters indicate a significant difference at the $p<0.05$ level using a Bonferroni significant difference test, ANOVA.

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