



DARRIN
Fresh Water Institute

Lake George, New York
Adirondack Field Station at Bolton Landing

Saratoga Lake Aquatic Plant Survey – 2012

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Background

Quantitative aquatic plant surveys were undertaken for Saratoga Lake, New York as part of a cooperative effort between Aquatic Control Technologies (ACT) and the Darrin Fresh Water Institute, and supported by the Saratoga Lake Protection and Improvement District (SLPID). The aquatic plant survey was designed to be comparable to pre-treatment and post-treatment data collected by the author in 2004, and 2007 thru 2011 (Eichler & Boylen 2011) to evaluate a treatment program based on application of the herbicide fluridone (SONAR™) in 2007 and the herbicide triclopyr (Renovate) in 2008 thru 2012 (Figure 1) to control Eurasian watermilfoil (*Myriophyllum spicatum*). In 2011, hand harvesting of Eurasian watermilfoil by SCUBA divers was also conducted by Adirondack Invasives Management (AIM) in an area south of Mannings Cove. The Point-Intercept Rake Toss method presently required by NYS DEC for Tier III Lakes was employed.

The survey area encompassed the entire littoral zone of Saratoga Lake. The assessment was designed to generate the information necessary to review effectiveness of aquatic plant management efforts, meet all permit requirements and provide data for comparison of post-treatment conditions to prior survey information. The project consisted of three components: 1) collection of herbarium specimens throughout the lake for compilation of a species list, 2) point-intercept frequency and depth data for points distributed within the treatment area, and 3) point-intercept frequency and depth data for points distributed within an untreated (control) area of the lake.

Introduction

Survey Site

Saratoga Lake is located in Saratoga County, New York in the towns of Saratoga, Stillwater, Malta and the City of Saratoga Springs. The lake has a surface area of approximately 3765 acres and a surface elevation of 203 ft amsl. Saratoga Lake has a single outlet, Fish Creek, draining to the Hudson River. Average water depth is reported to be 25 ft, with a maximum depth of 95 ft (Mikol and Polsinelli 1985). Hydraulic retention time is reported to be 0.4 years and lake volume is 381,000,000 m³. Transparency via secchi disk in 2003 was reported to be 4.1 m (SLPID 2003). More recently the NYS DEC has reported secchi transparency values of 4.0 m and 3.6 m in 2009 and 2010, respectively (CSLAP 2010).

An aquatic plant survey of Saratoga Lake in 1932 (NYS DEC 1932) indicated that the lake was quite free of “weeds” except in a few protected bays, primarily along the south and west shores. Common species included *Ceratophyllum demersum*, *Elodea canadensis*, *Vallisneria americana* and the pondweeds; *Potamogeton amplifolius*, *P. praelongus*, *P. nodosus*, and *P. friesii*. One exotic species, *Potamogeton crispus* was reported. In 1969, the NYS DEC pesticides unit did a more extensive mapping of aquatic plants in Saratoga Lake. They reported a healthy native plant

community with 13 submersed species, 2 native rooted floating-leaf species, 3 native emergent species and 3 free floating species (Dean 1969). *Myriophyllum spicatum* populations were first confirmed in the mid-1970's and reported to be the dominant aquatic plant species in the lake by the early-1980's (Hardt et al. 1983). Additional data collections by the US EPA Clean Lakes Program reported 14 submersed species, 2 floating-leaved species, 2 emergent species and 3 free floating species in 1981-82 (Hardt et al. 1983). Both *Myriophyllum spicatum* and *Potamogeton crispus* were reported as occurring as dense growth. By 1994, the Saratoga Lake aquatic plant community included 23 submersed species, 3 native rooted floating-leaf species, 2 native emergent species and 1 free floating species (Eichler and Boylen 1995). *Myriophyllum spicatum* was the most common plant species, present in 68 percent of survey points. Two other exotic aquatic plant species were reported, *Potamogeton crispus* and *Trapa natans*.

Nuisance aquatic plant growth has posed problems for Saratoga Lake for the past two decades. Excessive aquatic plant growth is reported to impact water-based recreation, aesthetic quality, environmental issues related to loss of habitat diversity, exclusion of native plant and animal species, and hydrodynamics. Nuisance growth of aquatic plants in Saratoga Lake is mainly attributable to three non-native species: Eurasian watermilfoil (*Myriophyllum spicatum*), Curly-leaf Pondweed (*Potamogeton crispus*), and Waterchestnut (*Trapa natans*), with the majority of effort devoted to the management of Eurasian watermilfoil.

In 1994, an aquatic plant survey of Saratoga Lake was conducted by the Darrin Fresh Water Institute to evaluate ongoing aquatic plant harvesting and lake level drawdown programs for the control of *Myriophyllum spicatum* and *Potamogeton crispus*. Volunteer efforts were also employed to hand harvest scattered growth of *Trapa natans*. These aquatic plant management efforts were instituted in 1984 and continue on an annual basis. Results of the 1994 survey indicated a diverse population of native aquatic plants dominated by the exotic invasive *Myriophyllum spicatum*. While mechanical harvesting provided access to the open waters of the lake for recreational use, this technology was not having an appreciable long-term effect on the density of growth of *Myriophyllum spicatum*. Winter draw-down and the resultant ice scour in shallow waters (depth less than 1 meter) was determined to be negatively effecting the growth of *Myriophyllum spicatum*. In 2000 and 2003, two additional aquatic plant management tools were evaluated on an experimental basis, biological control agents (weevils) and herbicide (SONAR) application. Biocontrol agents, while promising, continue to be experimental. Surveys conducted in 2004 (Eichler and Boylen 2004) indicated that native species richness in the herbicide treated areas had increased, however Eurasian watermilfoil was still dominant. A three year herbicide cycle was initiated in 2007 with fluridone (Sonar) treatment of the southern margin of the lake in the area of Browns Beach. Triclopyr (Renovate) herbicide was applied in 2008 and 2009 on the eastern and western margins of the lake, respectively. In 2010, four discrete areas were treated with triclopyr; the sunken islands on the west side of the lake, the area just north of the Kayadeross Creek, and two plots at the southern end of the lake. In a post-treatment survey, 28 species were observed lake-wide in 2010 (Eichler and Boylen 2010). Eurasian watermilfoil was the seventh most widely distributed plant (22% of survey points), an increase from ninth in 2009. Common native species included *Ceratophyllum demersum* (62%

of survey points), *Najas guadalupensis* (48%), *Elodea canadensis* (46%), *Vallisneria americana* (43%), *Zosterella dubia* (30%), *Potamogeton zosteriformis* (23%), *Potamogeton perfoliatus* (16%) and *Najas flexilis* (8%).

Average number of species per sample point was greater in 2010 (3.47 ± 0.12) than in 2009 (2.74 ± 0.12) or 2008 (2.47 ± 0.12).

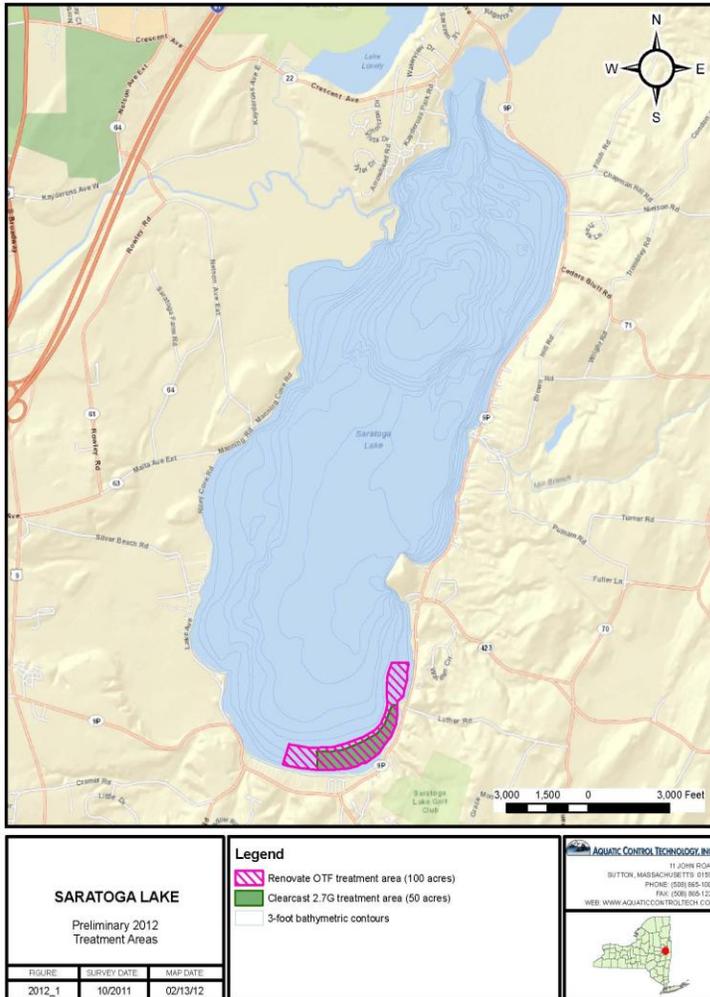
Exclusion of survey points outside the littoral zone may have accounted for this change.

In 2011, three areas were treated with triclopyr. Two of the sites were bays adjacent to Snake Hill, one to the north encompassing about 10 acres and the other to the south including about 35 acres were treated. The remaining site centered on the shoal area off Franklins Beach, encompassing about 55 acres. In August of 2011, the aquatic plant community of Saratoga Lake included 23 submersed species, 3 floating-leaved species, 2 floating species and 3 emergent species for a total of 31 species. Native species were dominant in 2011.

Common native species in the untreated or control areas included *Ceratophyllum demersum* (61% of survey points), *Najas guadalupensis* (50%), *Vallisneria americana*

(46%), *Elodea canadensis* (42%), *Zosterella dubia* (31%), *Potamogeton zosteriformis* (21%), *Potamogeton perfoliatus* (16%), *Chara/Nitella* (13%), *Najas flexilis* (9%), *Potamogeton illinoensis* (6%) and *Potamogeton pusillus* (6%). Eurasian watermilfoil showed some signs of decline in the previously treated portions of the survey, reported for 18% of survey points a decrease from 21% of survey points reported for 2010.

In 2012, a 100 acre area at the southeastern margin of the lake in the area of Browns Beach was treated with triclopyr (Renovate OTF) and imazamox (Clearcast 2.7G) was applied in a 50 acre sub-area.

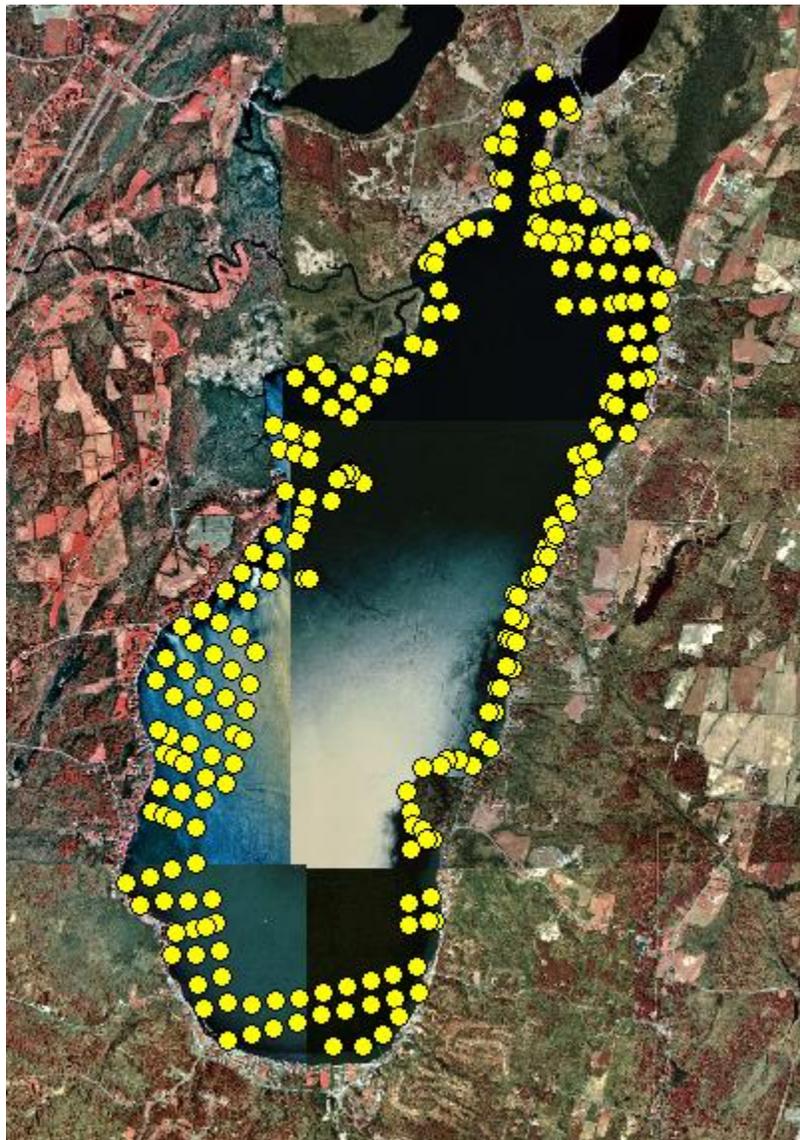


Treatment area maps courtesy of ACT, Inc., Sutton, MA.

Methods

Species List and Herbarium Specimens. As the lake was surveyed, the occurrence of each aquatic plant species was recorded and adequate herbarium specimens collected. The herbarium specimens were pressed, dried, and mounted (Hellquist 1993) at the Darrin Fresh Water Institute Laboratory in Bolton Landing, NY, where they became part of the permanent collection.

Figure 1. Distribution of point intercept survey points for Saratoga Lake aquatic plant survey.



Point Intercept Survey. The frequency and diversity of aquatic plant species were evaluated using a point intercept method (Madsen 1999). At each grid point intersection, all species located at that point were recorded, as well as water depth. Species were located by a visual inspection of the point and by deploying a rake to the bottom, and examining the plants retrieved. A differential global positioning system (Garmin GPSmap 168) was used to navigate to each point for the survey observation. Point intercept plant frequencies were surveyed on August 25 and 26, 2011, at the time of maximum aquatic plant abundance. Based on an 80 m grid and excluding nearly all points outside the littoral zone, a total of 294 points were surveyed for Saratoga Lake in 2012. The point intercept method allows a large number of discrete observations in a short period of time facilitating statistical analysis and comparisons. Point intercept methods also allow for production of distribution maps for all species listed (Figure 1).

Results and Discussion

In August of 2012, the aquatic plant community of Saratoga Lake included 20 submersed species, 3 floating-leaved species, 2 floating species and 3 emergent species for a total of 28 species (Table 1). Three exotic species, *Myriophyllum spicatum*, *Potamogeton crispus* and *Trapa natans* were reported. An additional exotic species, Brittle Naiad (*Najas minor*), was reported for the first time in 2011, but absent in 2012. Species richness was quite high, with a large number of species occurring in more than 10% of survey points (Table 2). Eurasian watermilfoil was the fifth most widely distributed plant (26% of survey points), ranked the same as 2011 but an increase from seventh in 2010 and ninth in 2009.

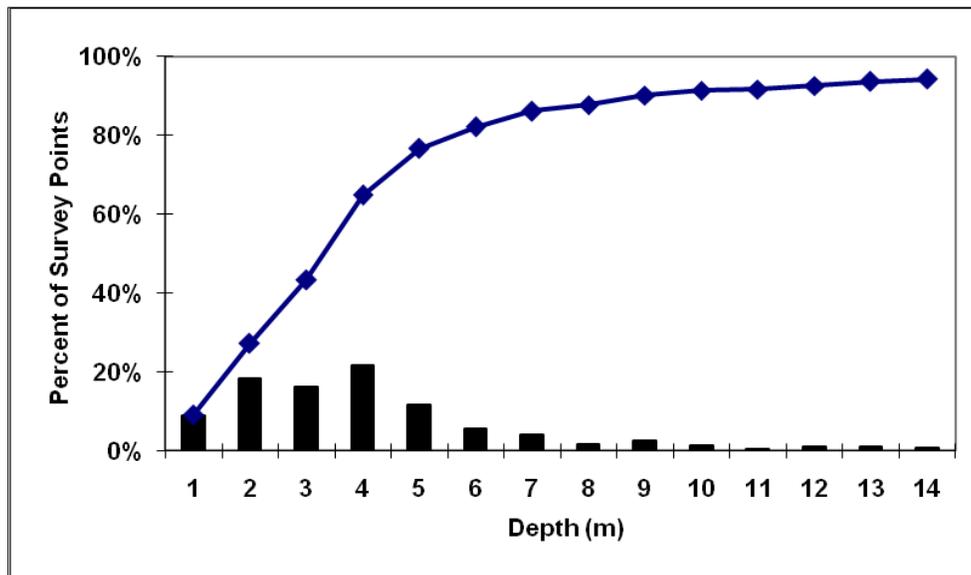
Table 1. Aquatic plant species present in Saratoga Lake in recent surveys.

Species	Common Name	2009	2010	2011	2012
<i>Ceratophyllum demersum</i> L.	coontail	x	x	x	x
<i>Chara/Nitella</i> sp.	muskgrass, chara	x	x	x	x
<i>Elodea canadensis</i> Michx.	elodea	x	x	x	x
<i>Lemna minor</i> L.	duckweed	x	x	x	x
<i>Lemna trisulca</i> L.	duckweed	x	x	x	x
<i>Megalodonta beckii</i> Torr.	water marigold	x	x	x	x
<i>Myriophyllum spicatum</i> L.	Eurasian watermilfoil	x	x	x	x
<i>Najas flexilis</i> (Willd.) Rostk. & Schmidt.	bushy pondweed	x	x	x	x
<i>Najas minor</i> All.	Minor Naiad			x	
<i>Najas guadalupensis</i> (Spreng.) Magnus	Southern naiad	x	x	x	x
<i>Nuphar variegata</i> Engelm. ex Durand	yellow pondlily	x	x	x	x
<i>Nymphaea odorata</i> Ait.	white pondlily	x	x	x	x
<i>Pontederia cordata</i> L.	pickerelweed	x	x	x	x
<i>Potamogeton amplifolius</i> Tuckerm.	largeleaf pondweed	x	x	x	x
<i>Potamogeton crispus</i> L.	curlyleaf pondweed	x	x	x	x
<i>Potamogeton gramineus</i> L.	variable-leaf pondweed	x	x	x	x
<i>Potamogeton illinoensis</i> L.	Illinois pondweed	x	x	x	x
<i>Potamogeton perfoliatus</i> L.	clasping-leaved pondweed	x	x	x	x
<i>Potamogeton praelongus</i> Wulfen	white-stem pondweed	x	x	x	x
<i>Potamogeton pusillus</i> L.	small pondweed	x	x	x	x
<i>Potamogeton richardsonii</i> (Ar. Benn.) Rydb.	Richardsons' pondweed			x	x
<i>Potamogeton robbinsii</i> Oakes	Robbins' pondweed	x	x	x	x
<i>Potamogeton zosteriformis</i> Fern.	flat-stem pondweed	x	x	x	x
<i>Ranunculus longirostris</i> Godron	white watercrowfoot		x	x	
<i>Sparganium</i> sp.	burreed			x	x
<i>Stuckenia pectinata</i> L.	sago pondweed	x	x	x	x
<i>Trapa natans</i> L.	waterchestnut		x	x	x
<i>Typha</i>	cattail	x	x	x	x
<i>Utricularia vulgaris</i> L.	great bladderwort	x	x	x	
<i>Vallisneria americana</i> L.	wild celery	x	x	x	x
<i>Zosterella dubia</i> Jacq.	water stargrass	x	x	x	x

Maximum Depth of Colonization

Maximum depth of colonization by rooted aquatic plant growth extended to a depth of 6 meters. Calculated maximum depth of colonization (MDOC) by macrophytes ranged from 4.3 to 4.9 meters in 2004 (Eichler and Boylen 2004), and was comparable to 1994 records (Eichler and Boylen 1995). Specimens of *Ceratophyllum demersum*, *Najas guadalupensis* and *Myriophyllum spicatum* were found between 5 and 6 meters depth in most years. Thus, 6 meters is the maximum extent of the littoral zone, representing an increase of approximately 1 meter in depth from 1994 estimates (Eichler and Boylen 1995) and comparable to depth records for 2004 (Eichler and Boylen 2004) and 2007 (Eichler and Boylen 2008). Depth distribution of sampling points (Figure 2) was equitable throughout the littoral zone in 2007 thru 2012.

Figure 2. Depth Distribution of Saratoga Lake sampling points in 1 meter depth classes.



Species Richness and Distribution

A total of 24 species were observed in open lake surveys of Saratoga Lake in 2012 and 2011 (Table 1). These results are comparable to previous surveys, where 29 species were observed in 2009, 25 species in 2007 and 2008, 22 species in 1995 and 2010, 21 species in 1982 and 2004 (Hardt et al., 1983) and 20 species in 1969 (Dean 1969). The limited occurrence of *Potamogeton crispus* can be attributed to the timing of the current survey (August), rather than an actual decline in the abundance of this species. *Potamogeton crispus* generally reaches peak abundance in June and July, and then undergoes senescence. *Trapa natans* was observed in the open water survey near the delta of the Kayaderos Creek, and as moderate growth adjacent to the Fish Creek Boat Launch area in 2012. *Najas minor* was reported for the first time in 2011, but was absent from the 2012 survey. Brittle naiad is an annual species which spreads primarily by seeds, and has been expanding its range northward over the last decade, particularly in the Upper Hudson Valley. Species absent from the 2012 survey but present in prior surveys were generally either present in only a single survey year or relatively uncommon in prior surveys (<1% of survey points).

Maps of the distribution of aquatic plant species and groups of species (i.e. Broad-leaf Pondweeds) for Saratoga Lake are included in Appendix A. Eurasian watermilfoil decreased in frequency of occurrence (26% of survey points in 2012, down from 29% of survey points in 2011, and up from 22% of survey points in 2010, 7% of survey points in 2009, 13% of survey points in 2008, 48% of survey points in 2007 and 54% in 2004). *Ceratophyllum demersum* remains the most widespread native plant, present in 54% of survey points. A number of other native species were also commonly observed, including *Zosterella dubia* (36% of survey points), *Najas guadalupensis* (33%), *Vallisneria americana* (33%), *Elodea canadensis* (22%), *Potamogeton richardsonii* (22%), *Chara* (10%), *Najas flexilis* (9%), *Potamogeton zosteriformis* (7%) and *Potamogeton perfoliatus* (6%). A list of frequency of occurrence results for all species observed is provided in Table 2. While the frequency of occurrence of most native species has remained stable since the pre-treatment survey of 2004, there were some exceptions. Two exceptions were *Najas guadalupensis* and *Elodea canadensis*, species present in limited numbers in 2004 prior to treatment but much more abundant in post-treatment surveys in 2007 thru 2012. A related species, *Najas flexilis*, declined in 2007 but returned to pre-treatment levels in 2008, increased in abundance in 2009 and stabilized at 2008 levels afterward. Getsinger et al. (2002) reported declines in *Najas flexilis* and *Elodea canadensis* in the year following fluridone treatment in two Vermont lakes, however these species returned to levels comparable to pretreatment in the following year. Eichler and Boylen (2008) reported similar increases in frequency of occurrence of *Najas flexilis* and *Elodea canadensis* in two Vermont lakes following triclopyr treatments. *Potamogeton crispus* increased in abundance between the pre-treatment survey in 2004 and subsequent post-treatment surveys in 2007 and 2008, but still remained a minor component of the overall population. Frequency of occurrence of *Potamogeton crispus* increased in 2010 to the highest levels recorded in recent surveys. Many of the survey points reporting *Potamogeton crispus* in 2010 were in areas treated in 2011. In 2011 and 2012, *Potamogeton crispus* returned to very limited abundance. *Potamogeton richardsonii* has

expanded its coverage in a number of regional lakes in 2012, however the reason for this expansion is unknown as the current time. All other differences were in the less common species.

Table 2. Percent frequency of occurrence of aquatic plant species in Saratoga Lake. Species in bold are known to be invasive.

Species	Common Name	2009	2010	2011	2012
<i>Ceratophyllum demersum</i>	coontail	61.4%	62.3%	62.9%	54.1%
<i>Chara/Nitella</i>	muskgrass, chara	10.5%	11.9%	8.5%	9.5%
<i>Elodea canadensis</i>	elodea	40.7%	46.3%	26.2%	22.3%
<i>Lemna trisulca</i>	duckweed	2.5%	2.5%	2.4%	1.0%
<i>Megalodonta beckii</i>	water marigold	0.9%	2.0%	0.3%	0.3%
<i>Myriophyllum spicatum</i>	Eurasian watermilfoil	6.8%	22.1%	29.3%	25.6%
<i>Najas flexilis</i>	bushy pondweed	13.6%	7.8%	9.2%	3.0%
<i>Najas guadalupensis</i>	Southern naiad	38.3%	48.0%	41.8%	32.8%
<i>Najas minor</i>	brittle naiad			0.3%	
<i>Nuphar variegata</i>	yellow pondlily	0.3%	0.4%	0.3%	0.3%
<i>Nymphaea odorata</i>	white pondlily	0.3%	0.8%	0.3%	0.3%
<i>Potamogeton amplifolius</i>	largeleaf pondweed	1.2%	2.5%	1.7%	1.6%
<i>Potamogeton crispus</i>	curlyleaf pondweed	3.1%	9.4%	0.7%	2.3%
<i>Potamogeton gramineus</i>	variable-leaf pondweed	1.9%		0.3%	0.7%
<i>Potamogeton illinoensis</i>	Illinois pondweed	4.6%	6.6%	3.1%	4.3%
<i>Potamogeton perfoliatus</i>	Clasping-leaved Pondweed	8.0%	15.6%	11.6%	5.9%
<i>Potamogeton praelongus</i>	white-stem pondweed	3.1%	4.1%	3.4%	4.6%
<i>Potamogeton pusillus</i>	small pondweed	6.5%	5.7%	2.3%	0.7%
<i>Potamogeton richardsonii</i>	Richardsons' Pondweed			0.3%	22.0%
<i>Potamogeton robbinsii</i>	Robbins' pondweed	0.9%	0.4%		0.3%
<i>Potamogeton zosteriformes</i>	flat-stem pondweed	17.3%	22.5%	6.5%	2.6%
<i>Ranunculus longirostris</i>	white watercrowsfoot	0.3%	1.6%	0.3%	
<i>Stuckenia pectinata</i>	sago pondweed	0.3%	0.4%	1.4%	1.0%
<i>Trapa natans</i>	waterchestnut				0.3%
<i>Utricularia vulgaris</i>	great bladderwort	0.3%			
<i>Vallisneria americana</i>	wild celery	31.2%	43.4%	33.0%	33.1%
<i>Zosterella dubia</i>	water stargrass	20.4%	30.3%	35.4%	36.1%

In 2012, *Myriophyllum spicatum* was the fifth most abundant species, present in 27% of all samples collected in the untreated (control) area and 7% of all samples collected in the treated areas (Table 3, Figure 3). Common native species in untreated areas included *Ceratophyllum demersum* (54% of survey points), *Zosterella dubia* (37%), *Najas guadalupensis* (35%), *Vallisneria americana* (34%), *Potamogeton richardsonii* (23%), *Elodea canadensis* (21%), *Chara/Nitella* (9%), and *Potamogeton zosteriformis* (6%). In the treated portion of the survey, Eurasian watermilfoil declined sharply in the year of treatment (7% of survey points, Figure 4).

A number of native species were commonly observed, including *Ceratophyllum demersum* (54%), *Elodea canadensis* (32%), *Zosterella dubia* (25%), *Vallisneria americana* (21%), *Potamogeton praelongus* (14%), *Najas guadalupensis* (11%), *Chara* sp. (11%), *Potamogeton perfoliatus* (7%), and *Potamogeton richardsonii* (7%). With this diversity and distribution of native species, the test for selectivity should be sensitive to a number of species, and the probability of native plant restoration in areas formerly inhabited by Eurasian watermilfoil should be high following management efforts.

Table 3. Percent frequency of occurrence of aquatic plant species in Saratoga Lake.

<i>Species</i>	All	Control	Treated
<i>Ceratophyllum demersum</i>	54.1%	53.8%	53.6%
<i>Chara/Nitella</i>	9.5%	9.3%	10.7%
<i>Elodea canadensis</i>	22.3%	21.1%	32.1%
<i>Lemna trisulca</i>	1.0%	1.1%	
<i>Megalodonta beckii</i>	0.3%	0.4%	
<i>Myriophyllum spicatum</i>	25.6%	27.2%	7.1%
<i>Najas flexilis</i>	3.0%	3.2%	
<i>Najas guadalupensis</i>	32.8%	34.8%	10.7%
<i>Nuphar variegata</i>	0.3%	0.4%	
<i>Nymphaea odorata</i>	0.3%	0.4%	
<i>Potamogeton amplifolius</i>	1.6%	1.8%	
<i>Potamogeton crispus</i>	2.3%	2.2%	3.6%
<i>Potamogeton gramineus</i>	0.7%	0.7%	
<i>Potamogeton illinoensis</i>	4.3%	4.7%	
<i>Potamogeton perfoliatus</i>	5.9%	5.7%	7.1%
<i>Potamogeton praelongus</i>	4.6%	3.6%	14.3%
<i>Potamogeton pusillus</i>	0.7%	0.4%	3.6%
<i>Potamogeton richardsonii</i>	22.0%	23.3%	7.1%
<i>Potamogeton robbinsii</i>	0.3%	0.4%	
<i>Potamogeton zosteriformis</i>	2.6%	2.5%	3.6%
<i>Stuckenia pectinata</i>	1.0%	1.1%	
<i>Trapa natans</i>	0.4%	0.4%	
<i>Vallisneria americana</i>	33.1%	34.1%	21.4%
<i>Zosterella dubia</i>	36.1%	36.9%	25.0%

Figure 3. Distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) in surveyed areas of Saratoga Lake in 2012.

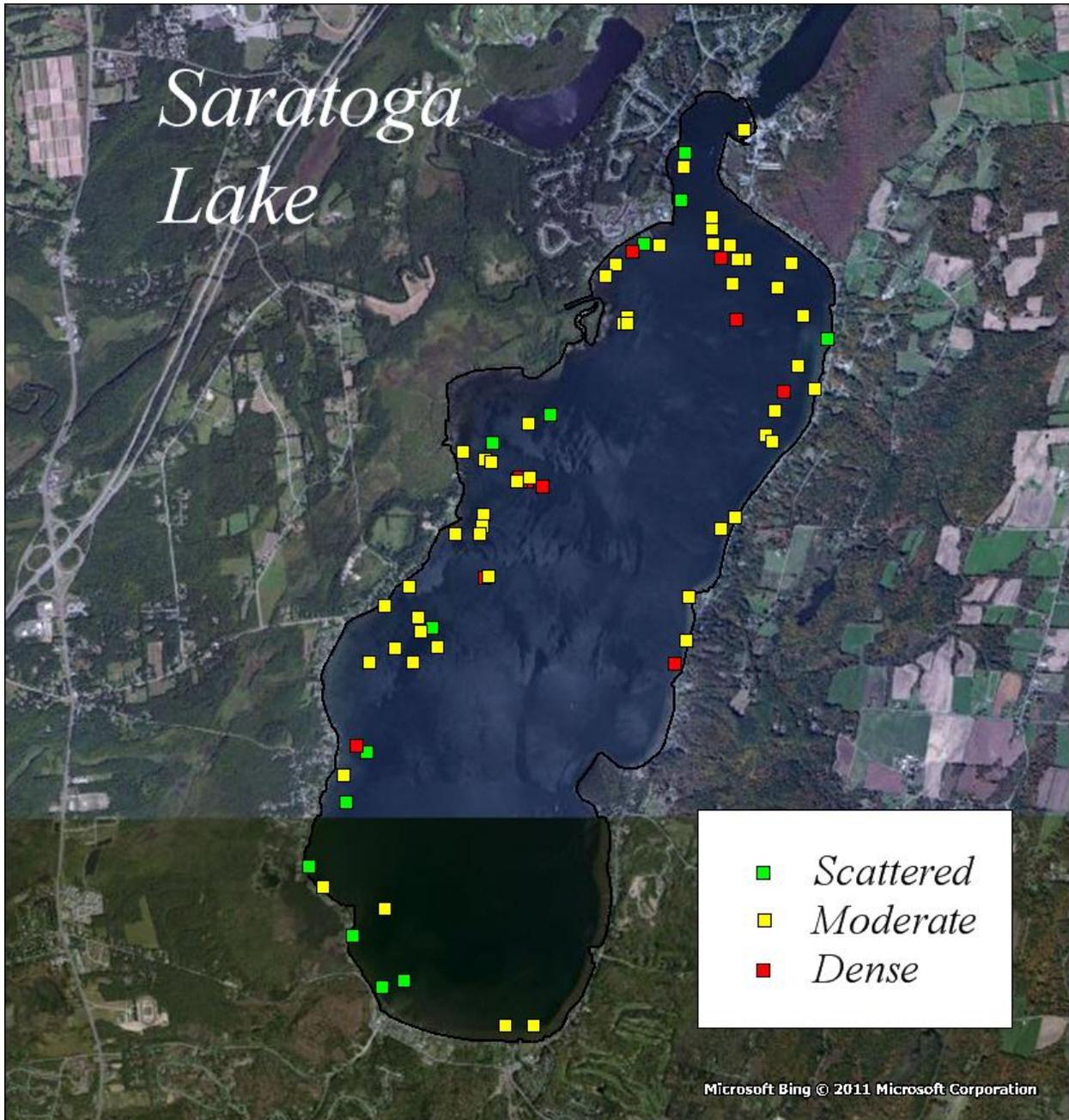
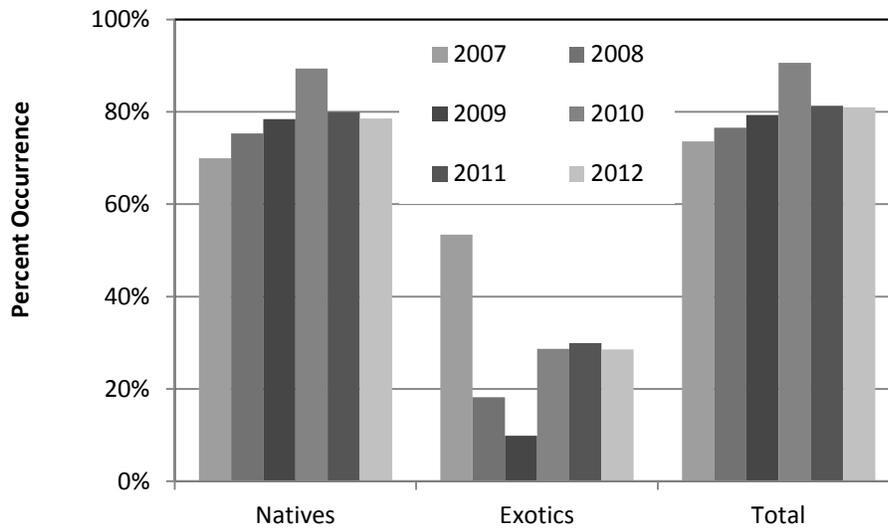


Figure 4. Saratoga Lake frequency of occurrence summaries for all sampling points.



In 2012, 76% of survey points in the control area and 68% in the treated area supported native species. Sixty-seven percent of whole lake points were vegetated by native plant species in 2004, 70% in 2007, 75% in 2008, 78% in 2009, 89% in 2010, 80% in 2011 and 79% in 2012 (Figure 4). In depths less than 6 m, representing the littoral zone, 84% of survey points contained native species and 88% of survey points less than 2 meters depth yielded native aquatic plants in 2012. Eurasian watermilfoil was present in 26% of whole lake survey points, and 31% of survey points within the littoral zone or zone of aquatic plant growth. It is apparent that exotic species, dominated by Eurasian watermilfoil, were clearly more abundant lakewide in 2004, 2007 & 2008 (56%, 53% and 18% of survey points, respectively) than in 2009 (10% of survey points). With only ‘spot’ treatments conducted in 2010 and 2011, Eurasian watermilfoil recovery to 29% and 33% of survey points was reported. With a larger treatment area in 2012, Eurasian watermilfoil declined to 26% of survey points.

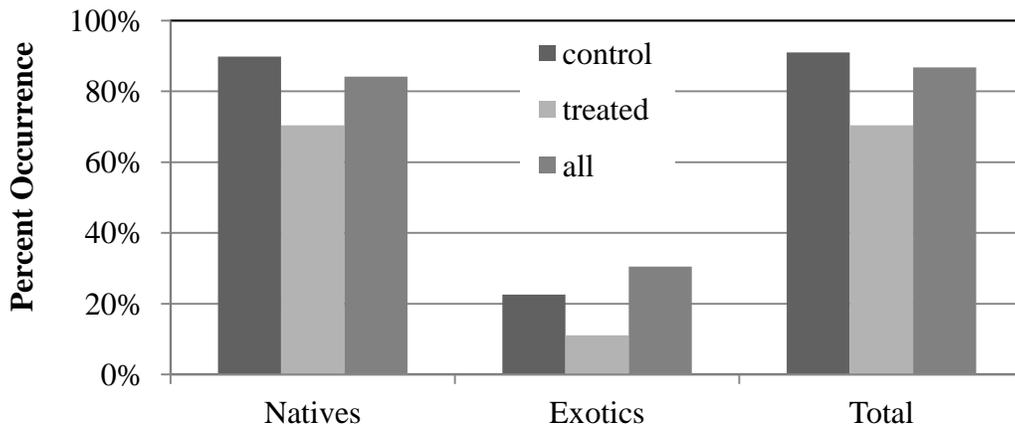


Figure 5. Saratoga Lake frequency of occurrence summaries for sampling points less than 6 meters water depth.

For survey points within the littoral zone, water depth less than 6 m (Figure 5), results are similar to whole lake surveys. The impact of the herbicide treatment for 2009 was less apparent on the relative abundance of exotic species when comparing treated (11% of survey points) and control sites (12%), most likely due to the fact 2009 is the final year of a 3 year program to treat the whole lake. Eurasian watermilfoil declined from 31% of littoral zone survey points within the treatment area in 2008 to 11% of comparable survey points post-treatment in 2009. In 2010, an increase in the frequency of occurrence of Eurasian watermilfoil, to levels comparable to 2008, was observed. Eurasian watermilfoil declined from 40% of survey points in 2010 to 33% of survey points in 2011 as areas supporting the heaviest growth of Eurasian watermilfoil were treated. The decline continued in 2012, with 31% of littoral survey points supporting Eurasian watermilfoil. The expected relationship of greater frequency of occurrence of aquatic plants with shallower water depth is consistent with that reported by Eichler and Boylen (1995) where frequency of occurrence values in the littoral zone ranged from 78 to 90% of survey points.

In 2009, relative abundance of each species was incorporated into the survey effort. All species recorded for each sample point were ranked by relative abundance on a 4 point scale, ranging from present as a trace amount to entirely dominating the sample. Maps of relative abundance for each species are provided in Appendix A. Relative abundance provides a different picture of the abundance of Eurasian watermilfoil (Figure 6). Lake-wide Eurasian watermilfoil was present as dense growth in 2009, but declined to moderate levels in 2010 and remained at or below moderate levels in 2011 and 2012. While frequency of occurrence provides a statistically reliable measure of the aquatic plant population of a lake, combining frequency with relative abundance may provide a clearer picture of the impact of an individual species on the overall population.

Relative Abundance of Eurasian watermilfoil

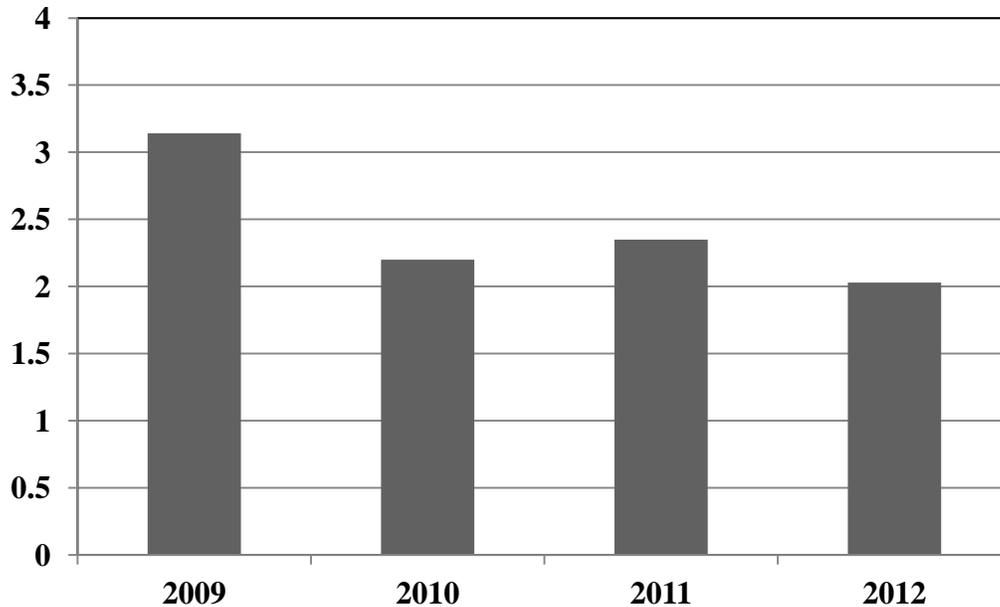


Figure 6. Lake-wide relative abundance of Eurasian watermilfoil in Saratoga Lake.

Species richness results for the point intercept survey are presented in Table 4 and Figure 6. In 2004 whole lake species richness was 2.00 ± 0.10 species per survey point. Whole lake species richness increased steadily from 2.31 ± 0.17 in 2007 to 3.47 ± 0.12 in 2010. In 2011, species richness lake-wide was comparable to 2009 at 2.81 ± 0.11 species per sample and slightly greater than the 2.65 ± 0.12 reported in 2012. Depths less than 2 meters yielded 3.72 ± 0.21 and 3.69 ± 0.25 species per sample point in 2011 and 2012. In comparison, littoral (<6m depth) species richness in 2007 was 2.74 ± 0.20 , and peaked at 3.17 ± 0.12 species per sample point in 2009. In 2011 littoral zone species richness was slightly lower at 3.11 ± 0.11 and this decline continued into 2012 (2.89 ± 0.12). The shallow fringe (<2m depth) species richness also peaked in 2009 at 4.25 ± 0.23 , respectively. Total species richness appears to be closely linked to the relative abundance of Eurasian watermilfoil.

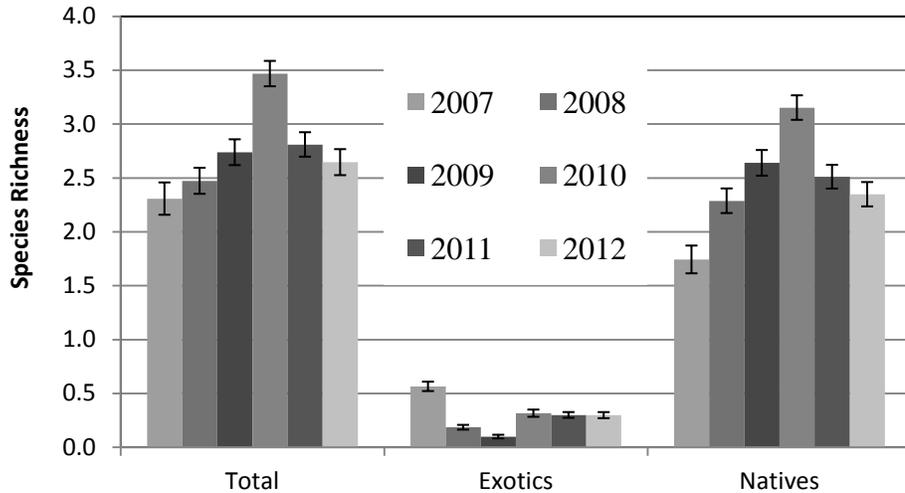
Native species richness was 2.07 ± 0.18 species per survey point in 2007 for the entire littoral zone (depths less than 6 meters), exceeding the 2004 littoral, native species richness of 1.65 ± 0.09 species per survey point, but still less than the 2.66 ± 0.12 species per survey point in 2008 and 3.05 ± 0.12 species per survey point in 2009. Native species richness stabilized in 2010 and 2011 at 2.77 ± 0.13 and 2.78 ± 0.11 species per survey point, respectively. A slight decline in native species richness was observed in 2012 (2.57 ± 0.11). Whole lake native species richness was 1.43 ± 0.08 species per sample in 2004, 1.74 ± 0.19 species per sample in 2007, 2.29 ± 0.11 species per sample in 2008, 2.64 ± 0.12 species per sample in 2009, 3.15 ± 0.11 species per

sample in 2010 and 2.51 ± 0.11 species per sample in 2011. The increase in 2010 may have been a sampling artifact since the majority of sampling points outside the littoral zone were eliminated from the 2010 sampling. In the shallow portion of the littoral zone, depths less than 2 meters, species richness was 2.47 ± 0.18 native species per sample in 2004, and rose steadily to peak at 4.22 ± 0.24 native species per sample in 2009. A slight decline to 3.72 ± 0.24 native species per sample was observed in 2010 and continued in 2011 (3.57 ± 0.21) and 2012 (3.46 ± 0.23). As expected, species richness in the littoral zone and its shallow fringe was higher than whole lake species richness. Lack of a Eurasian watermilfoil canopy in water depths less than 2 meters may also allow for greater species richness. The negative impact of a canopy of Eurasian watermilfoil on species richness of native plants has been well documented (Madsen et al. 1989; 1991). Conversely, species richness increases in areas where Eurasian watermilfoil growth is reduced (Boylen et al. 1996). Species richness in the control area exceeded that in the treated

Table 4. Saratoga Lake species richness for the point intercept survey.

Plant Grouping	Water Depth Class	Statistic	2007	2008	2009	2010	2011	2012
Native plant species	Whole Lake (all depths)	Mean	1.74	2.29	2.64	3.15	2.51	2.35
		N	163	324	324	244	294	279
		Std. Error	0.19	0.11	0.12	0.11	0.11	0.11
	Points with depths <6m	Mean	2.07	2.66	3.05	2.77	2.78	2.57
		N	137	278	278	241	265	272
		Std. Error	0.18	0.12	0.12	0.13	0.11	0.11
	Points with depths <2m	Mean	3.54	3.84	4.22	3.72	3.57	3.46
		N	39	76	76	65	79	74
		Std. Error	0.44	0.22	0.24	0.24	0.21	0.23
All plant Species	Whole Lake (all depths)	Mean	2.31	2.47	2.74	3.47	2.81	2.65
		N	163	324	324	244	294	279
		Std. Error	0.17	0.12	0.12	0.12	0.11	0.12
	Points with depths <6m	Mean	2.74	2.88	3.17	3.04	3.11	2.89
		N	137	278	278	241	265	272
		Std. Error	0.20	0.13	0.12	0.13	0.11	0.12
	Points with depths <2m	Mean	4.31	3.99	4.25	3.89	3.72	3.69
		N	39	76	76	65	79	74
		Std. Error	0.50	0.22	0.23	0.25	0.21	0.25

Figure 7. Saratoga Lake species richness.
Error bars are standard error of the mean.



area, but generally by less than 1 species per survey point. The elimination of Eurasian watermilfoil from many of the survey points in the treated area accounts for the majority of the difference. A sharp decline in exotic species richness was observed following herbicide treatments in 2007, 2008 and 2009 while total and native species richness increased. A slight increase in the lake-wide abundance of exotic species in 2010 occurred in conjunction with a slight decline in total and native species richness. This condition persisted in 2011 and 2012.

Summary

Quantitative aquatic plant surveys were undertaken in 2012 for Saratoga Lake, New York as part of a cooperative effort between Aquatic Control Technologies (ACT) and the Darrin Fresh Water Institute, and supported by the Saratoga Lake Protection and Improvement District (SLPID). The project was designed to obtain data to evaluate aquatic plant management efforts and review potential new strategies. The project included three components: 1) collection of specimens for compilation of a species list, 2) point-intercept frequency and depth data for points distributed in previously treated areas, and 3) point-intercept frequency and depth data for points distributed in herbicide treated areas (southwest end and north of the Kayadeross).

In Saratoga Lake, Eurasian watermilfoil (*Myriophyllum spicatum*) expanded rapidly after an initial invasion in the 1970's. *Myriophyllum spicatum* populations were first confirmed in the mid-1970's and reported to be the dominant aquatic plant species in the lake by the early-1980's (Hardt et al. 1983). In 1994, the Saratoga Lake aquatic plant community contained 23 submersed species, 3 native rooted floating-leaf species, 2 native emergent species and 1 free floating species (Eichler and Boylen 1995). *Myriophyllum spicatum* was the most common plant species, present in 68 percent of survey points. Two other exotic aquatic plant species were reported, *Potamogeton crispus* and *Trapa natans*. *Potamogeton crispus* is seasonally abundant, forming a dense band at the deep margins of Eurasian watermilfoil growth in the spring and early summer. *Trapa natans* has been reported as scattered individuals on the delta of Kayadeross Creek and in Mannings Cove, however it was absent from the 2008 and 2009 surveys, but returned in 2011 and 2012. A number of *Trapa natans* plants have been observed in the area of the Fish Creek boat launch ramp annually since 2010. Herbicide treatments were incorporated into the aquatic plant management program in 2007 to supplement previously employed lake level drawdown and mechanical harvesting. A three year herbicide treatment effort was initiated with fluridone (Sonar) treatment of the southern margin of the lake in the area of Browns Beach in 2007. Triclopyr (Renovate) herbicide was applied in 2008 and 2009 on the eastern and western margins of the lake, respectively. In 2010, three small area treatments with triclopyr were conducted, two at the south end of the lake and one around the sunken islands in the mouth of Mannings Cove. In 2011, three areas were treated with triclopyr. Two of the sites were bays adjacent to Snake Hill, one to the north encompassing about 10 acres and the other to the south including about 35 acres were treated. The remaining site centered on the shoal area off Franklins Beach, encompassing about 55 acres. In 2012, triclopyr was applied to a 100 acre area at the southeast corner of the lake, and imazimox to applied to a 50 acre sub-area.

In August of 2012, the aquatic plant community of Saratoga Lake included 20 submersed species, 3 floating-leaved species, 2 floating species and 3 emergent species for a total of 28 species. Twenty-four of these species were found in the point intercept survey of 2001 and 2012. These results are comparable to previous surveys in 2009 (26 species, Eichler and Boylen 2009), 2007 and 2008 (25 species, Eichler and Boylen 2007), 2004 (21 species, Eichler and Boylen 2004), 1994 (22 species, Eichler and Boylen 1994), 1982 (21 species, Hardt et al. 1983) and

1969 (20 species, Dean 1969). Eleven species were found in samples from the treated area and 22 species were reported in the control samples, however very limited areas were treated in 2011.

Exotic species, dominated by Eurasian watermilfoil, were clearly more abundant lake-wide in 2004 (56% of survey points), prior to the herbicide treatments of 2007 through 2009 (53%, 18% and 10% of survey points, respectively). A slight increase in exotics species abundance (22% and 29% of survey points) was observed in 2010 and 2011, respectively. In 2012, Eurasian watermilfoil was found at 26% of survey points. Eurasian watermilfoil remains a common member of the plant community, but at greatly reduced numbers when compared to previous surveys. Eurasian watermilfoil declined from first to tenth most abundant species by frequency of occurrence between 2007 and 2009, however an increase was reported to seventh in 2010 and fifth most abundant species in 2011 and 2012, respectively.

Native species were dominant in 2012. Common native species in the untreated or control areas included *Ceratophyllum demersum* (54% of survey points), *Zosterella dubia* (36%), *Najas guadalupensis* (33%), *Vallisneria americana* (33%), *Elodea canadensis* (22%), *Potamogeton richardsonii* (22%), *Chara* (10%), *Najas flexilis* (9%), *Potamogeton zosteriformis* (7%) and *Potamogeton perfoliatus* (6%). Eurasian watermilfoil showed some signs of decline in the previously treated portions of the survey, reported for 29% of survey points, unchanged from 2011.

In the treated areas of Saratoga Lake, Eurasian watermilfoil was present in 7% of survey points in 2012. Common native species in the treated areas included *Ceratophyllum demersum* (54%), *Elodea canadensis* (32%), *Zosterella dubia* (25%), *Vallisneria americana* (21%), *Potamogeton praelongus* (14%), *Najas guadalupensis* (11%), *Chara* sp. (11%), *Potamogeton perfoliatus* (7%), and *Potamogeton richardsonii* (7%). With this diversity and distribution of native species, the test for selectivity should be sensitive to a number of species, and native plant restoration in areas formerly inhabited by Eurasian watermilfoil appears to be rapid following management efforts.

Estimates of relative abundance for each species surveyed were incorporated into the sampling protocol in 2009 (Figure 7). A four point scale, ranging from one which indicated a trace amount of a particular species to four indicating clear dominance of the species in a particular sample was employed. On a lake-wide basis, dense growth of Eurasian watermilfoil was reported for 2009, declining to moderate levels in 2010 thru 2012. While frequency of occurrence results provide a statistically reliable way to represent aquatic plant populations, combining relative abundance with frequency of occurrence may provide a better way to characterize the impact of an invasive species on a native plant population.

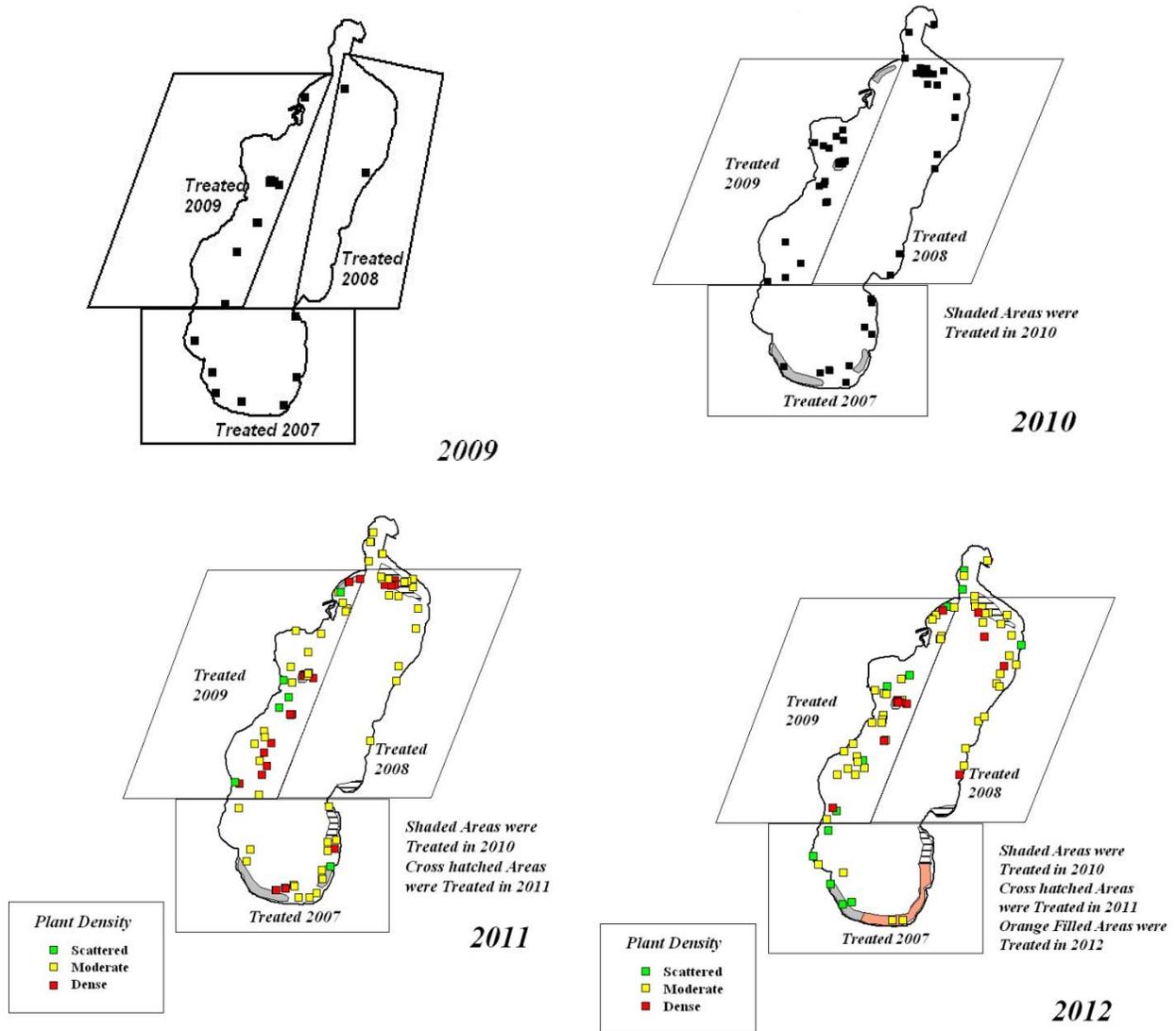
In 2004 whole lake species richness was 2.00 ± 0.10 species per survey point. Whole lake species richness has increased steadily since that time to 3.47 ± 0.12 by 2010. The increase in 2010 may have been a sampling artifact since the majority of sampling points outside the littoral

zone were eliminated from the 2010 sampling. In 2011, whole lake species richness was 2.81 ± 0.11 species per survey point, a decline associated with an increase in the relative abundance of invasive species. Whole lake species richness in 2012 was comparable to 2011. In the shallow portion of the littoral zone, depths less than 2 meters, species richness was 2.47 ± 0.18 native species per sample in 2004, and rose steadily to peak at 4.22 ± 0.24 native species per sample in 2009. A slight decline to 3.57 ± 0.21 and 3.46 ± 0.23 native species per sample was observed in 2011 and 2012. As expected, species richness in the littoral zone and its shallow fringe was higher than whole lake species richness. Lack of a Eurasian watermilfoil canopy in water depths less than 2 meters may also allow for greater species richness. Native species richness lake-wide and in the treatment zone was higher post-treatment in 2007, 2008 and 2009 than during 2004 (pre-treatment). A slight increase in the lake-wide abundance of exotic species in 2010 and 2011 occurred in conjunction with a slight decline in total and native species richness. In 2012, native species richness and the abundance of invasive species was nearly unchanged from 2011.

Principal areas of Eurasian watermilfoil expansion in 2004 were reported in the northeast at Franklins Beach and the southwest in the area of Rileys Cove. Franklins Beach was selected as the control (untreated) area for 2007 while the south end of the lake and Browns Beach area were treated with herbicide (Figure 6). In 2008, the Franklins Beach area was selected for treatment, the west shore including Mannings Cove served as the control, and Browns Beach west across the south end of the lake was assessed 1 year post-treatment. In 2009, the west shore and Mannings Cove areas were treated, the Franklins Beach area was assessed 1 year post-treatment and Browns Beach west across the south end of the lake was assessed 2 years post-treatment. In 2010, spot treatments were conducted at the southern end of the lake and north of the mouth of the Kayadeross Creek. In 2011, spot treatments were conducted to the north and south of Snake Hill and adjacent to Franklins Beach. Substantial reduction in Eurasian watermilfoil frequency of occurrence was observed in the treated area between 2008 (pre-treatment) and 2009 (post-treatment) while the previously treated control areas increased from 2% to 5%. Eurasian watermilfoil declined from 26% of littoral zone survey points within the treatment area in 2008 to 9% of comparable survey points post-treatment in 2009. Eurasian watermilfoil increased in frequency of occurrence lakewide in 2010 (22% of survey points), with principal areas of growth in Mannings Cove and the shoal area offshore from Franklins Beach. In 2011, Eurasian watermilfoil continued to increase in lakewide occurrence (29% of survey points), with persistent growth in the mouth of Mannings Cove and the Franklins Beach area. Eurasian watermilfoil growth was also observed at the deep margin of the littoral zone along the western shoreline and south end of the lake.

Lakewide aquatic plants were found to occur in 87% of survey points in the littoral zone, comparable to prior surveys (range of 88 to 91%), and not indicative of any major change in the aquatic plant population. Eurasian watermilfoil abundance declined from 66% of littoral zone survey points in 2004 to 59% of survey points in 2007, 21% in 2008 and 8% in 2009. With selective treatments in 2010, Eurasian watermilfoil increased to 22% of whole lake survey points, and 29% of survey points less than 6 m water depth, representing the littoral zone or zone

Figure 8. A comparison of the distribution of Eurasian watermilfoil (*Myriophyllum spicatum*) growth in selected areas of Saratoga Lake in 2009 through 2012.



of aquatic plant growth. Following additional small area treatments in 2011, Eurasian watermilfoil abundance increased to 29% of lake-wide survey points. The distribution of exotic species, dominated by Eurasian watermilfoil, in the previously treated areas (29% of survey points) was less than the treated area (40%). A larger treatment area (100 acres) in 2012 produced a decline in Eurasian watermilfoil to 26% of survey points lake-wide, and 7% of survey points within the treatment area. The fact that Eurasian watermilfoil is only slowly recovering after treatment suggests the durability of treatment regimes from 2007 thru 2010.

The difficulty of treating certain areas, particularly small isolated plots such as the sunken islands in the mouth of Mannings Cove, is demonstrated by the resilience of Eurasian watermilfoil at these sites even after repeated treatments.

Eurasian watermilfoil abundance declined from 58% of littoral zone survey points within the treatment area in 2004 to 25% of comparable survey points post-treatment in 2007. In 2008, Eurasian watermilfoil abundance continued to decline to 3% of littoral zone survey points within the treatment area. In the control area, Eurasian watermilfoil abundance increased from 74% of survey points in 2004 to 80% of comparable survey points in 2007. In 2008, Eurasian watermilfoil abundance declined to 26% of survey points in untreated areas. In 2009, the decline in Eurasian watermilfoil abundance continued, with lake-wide frequency of occurrence at 7% of survey points. This decline coupled with what appeared to be sub-lethal effects of the herbicide in the untreated areas, suggest efficacy of the herbicide over a much greater area than anticipated. An increase in Eurasian watermilfoil abundance was observed in 2010 and again in 2011, primarily in areas not treated for 2 years and certain problem sites. Even with the increase, Eurasian watermilfoil abundance in 2011 and 2012 remains at less than half of pre-treatment levels. Lake-wide relative abundance values for Eurasian watermilfoil also declined from dense to moderate levels between 2009 and 2010, and remained at moderate to low levels through 2012. While frequency of occurrence provides a statistically reliable measure of the aquatic plant population of a lake, combining frequency with relative abundance may provide a clearer picture of the impact of an individual species on the overall population.

The littoral zone or maximum depth of colonization (MDOC) by aquatic plants was calculated to extend to a depth of 4.9 meters based on transparency data. *Ceratophyllum demersum* and *Najas guadalupensis*, however were commonly found between 5 and 6 meters depth, with occasional *Myriophyllum spicatum* specimens also encountered, suggesting a littoral zone maximum depth of approximately 6 meters, 1.0 meter greater than reported in 1994. Suppression of canopy formation through mechanical harvesting may allow for light penetration and thus the survival of native plant species in areas of dense Eurasian watermilfoil growth. Changing water clarity may also be a by-product of the invasion of Saratoga Lake by zebra mussels (*Dreissena polymorpha*) in the mid-1990's. Improved water clarity is frequently reported following zebra mussel invasions due to their ability to filter large volumes of phytoplankton from the water column. Reduced Eurasian watermilfoil density in shallow waters as a result of winter draw-down and ice scouring has also provided areas for colonization of native species resistant to winter draw-down. Evidence continues to suggest that a native species, Water Stargrass (*Zosterella dubia*) is replacing Eurasian watermilfoil at the shallow end of its range. The frequency of occurrence of *Zosterella dubia* has increased substantially, reported in 19% of samples in 1994, 47% of samples in 2004 and 44% of samples in 2007 in the control area. In 2008 through 2012, while still quite abundant, the frequency of occurrence of this species appears to have stabilized at 30% to 40% of survey points lake-wide. The operators of the mechanical harvesters continue to report that *Zosterella dubia* has become a prevalent species in their harvested materials. Survey results indicate that this species is found growing densely in waters of 1 to 1.5 meters depth at the inner margins of dense Eurasian watermilfoil growth. The growth habit of this species may

be a consideration in future management efforts. One native pondweed species dramatically expanded its frequency of occurrence from less than 1% of survey points in 2011 to 22% of survey points in 2012. Richardsons Pondweed (*Potamogeton richardsonii*) has been present in Saratoga Lake for many years, but always as a minor component of the aquatic plant population. A similar rapid growth of Richardsons Pondweed was observed in another regional lake in 2012, Hadlock Pond in Washington County. The extremely mild winter of 2011 – 2012 may be responsible for the expansion of this species.

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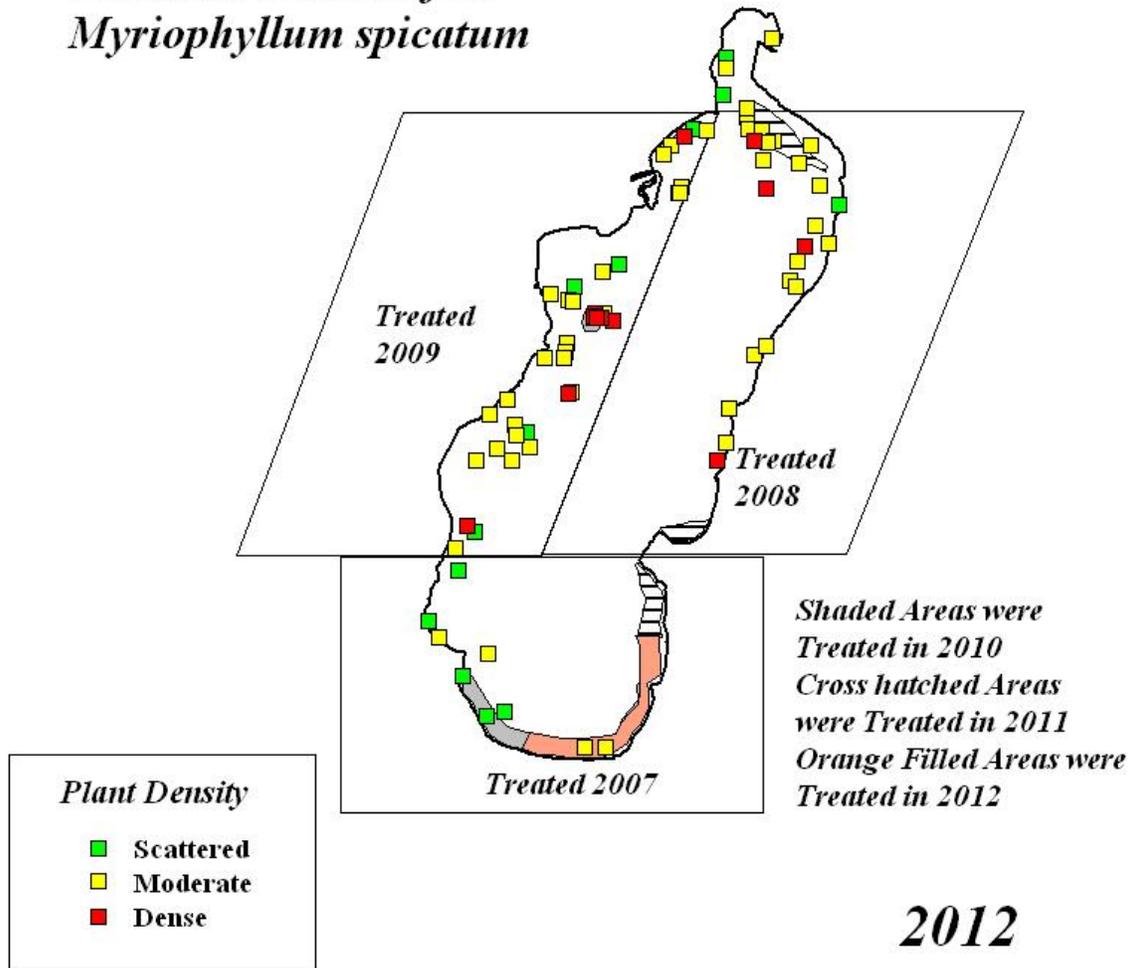
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Appendix A. Saratoga Lake aquatic plant distribution maps

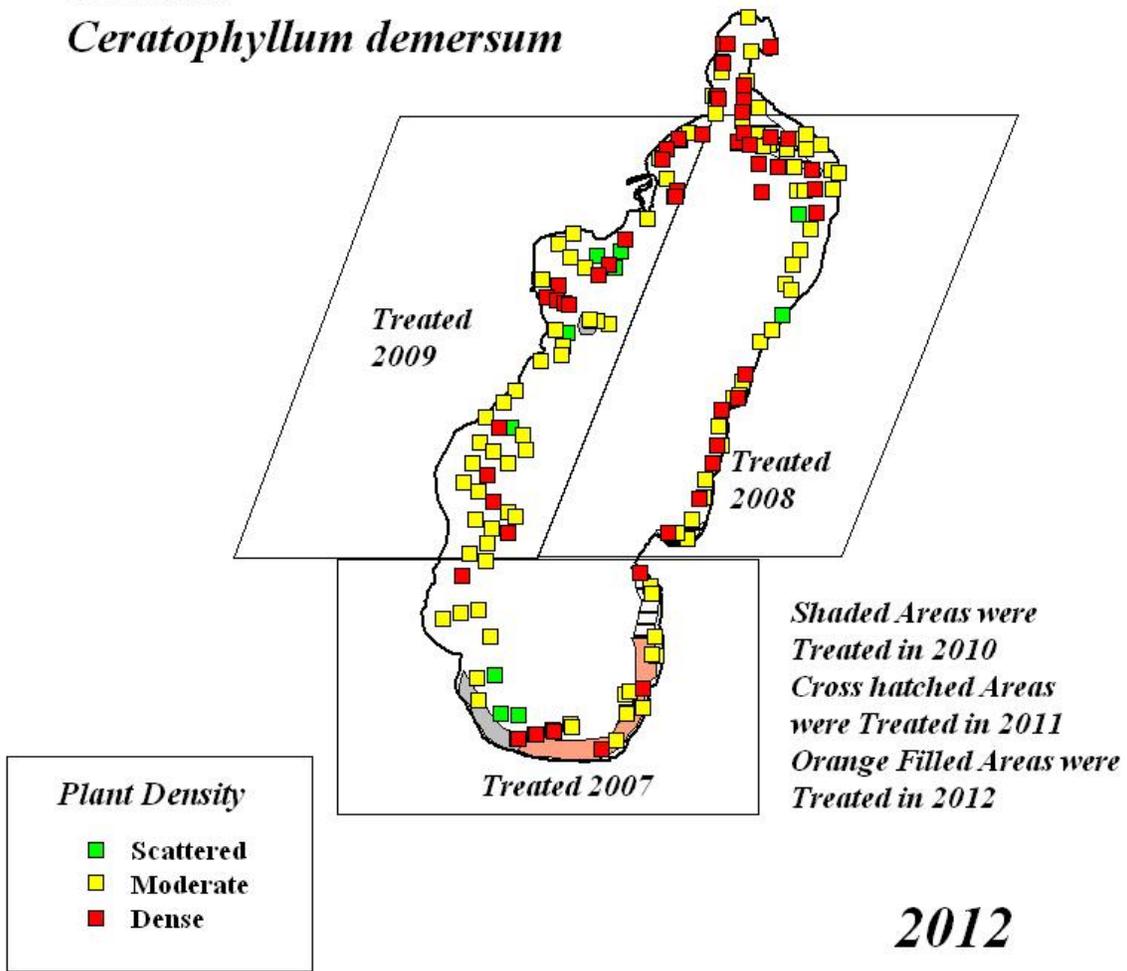
Saratoga Lake

Distribution of *Eurasian watermilfoil* *Myriophyllum spicatum*



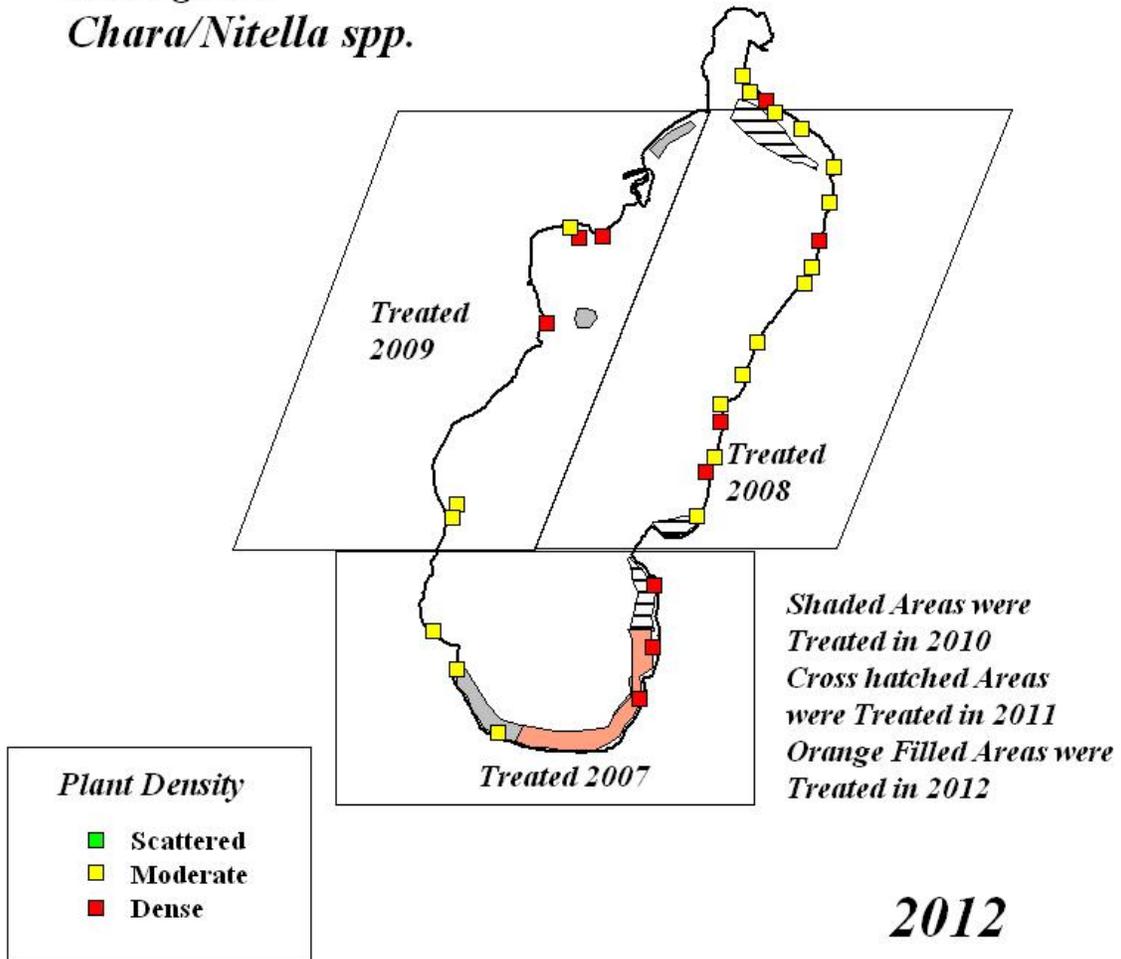
Saratoga Lake

Distribution of Coontail *Ceratophyllum demersum*



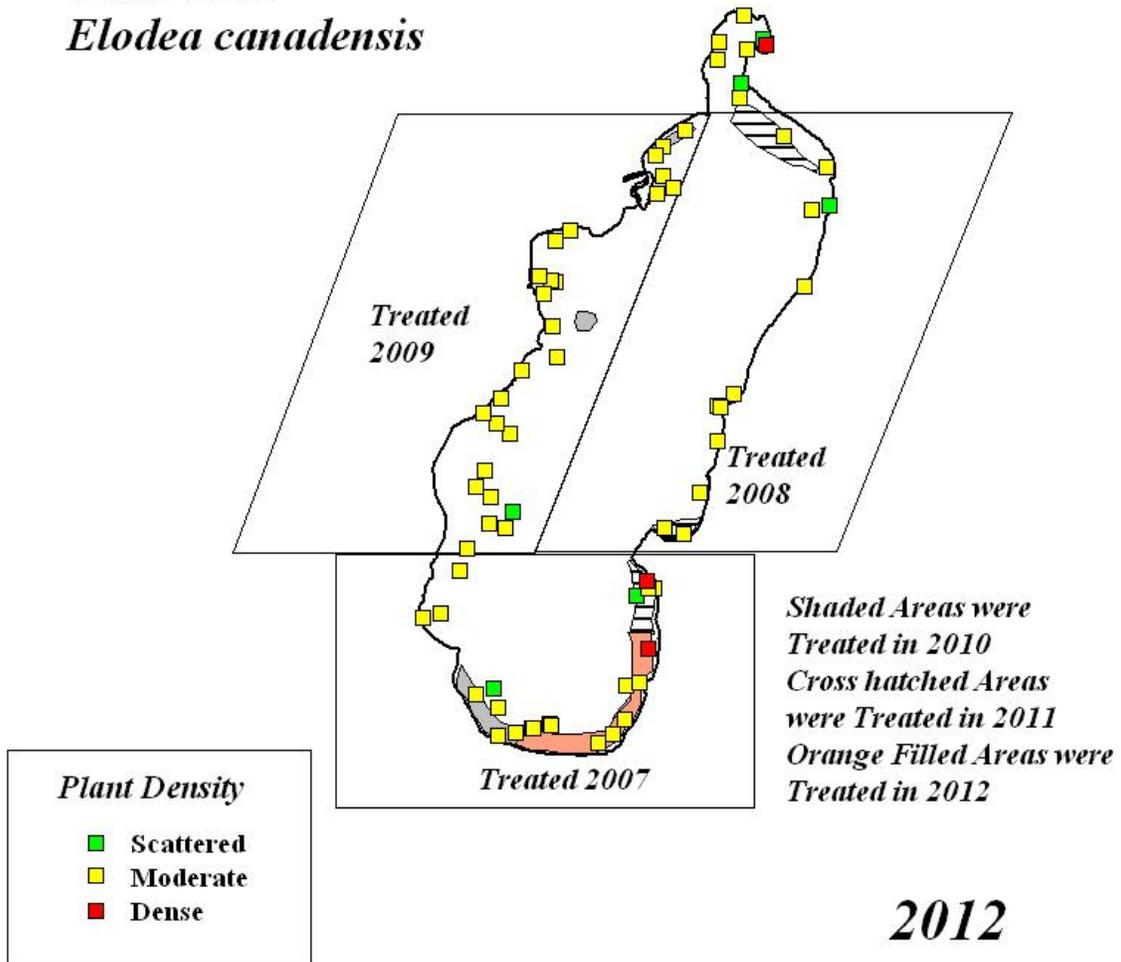
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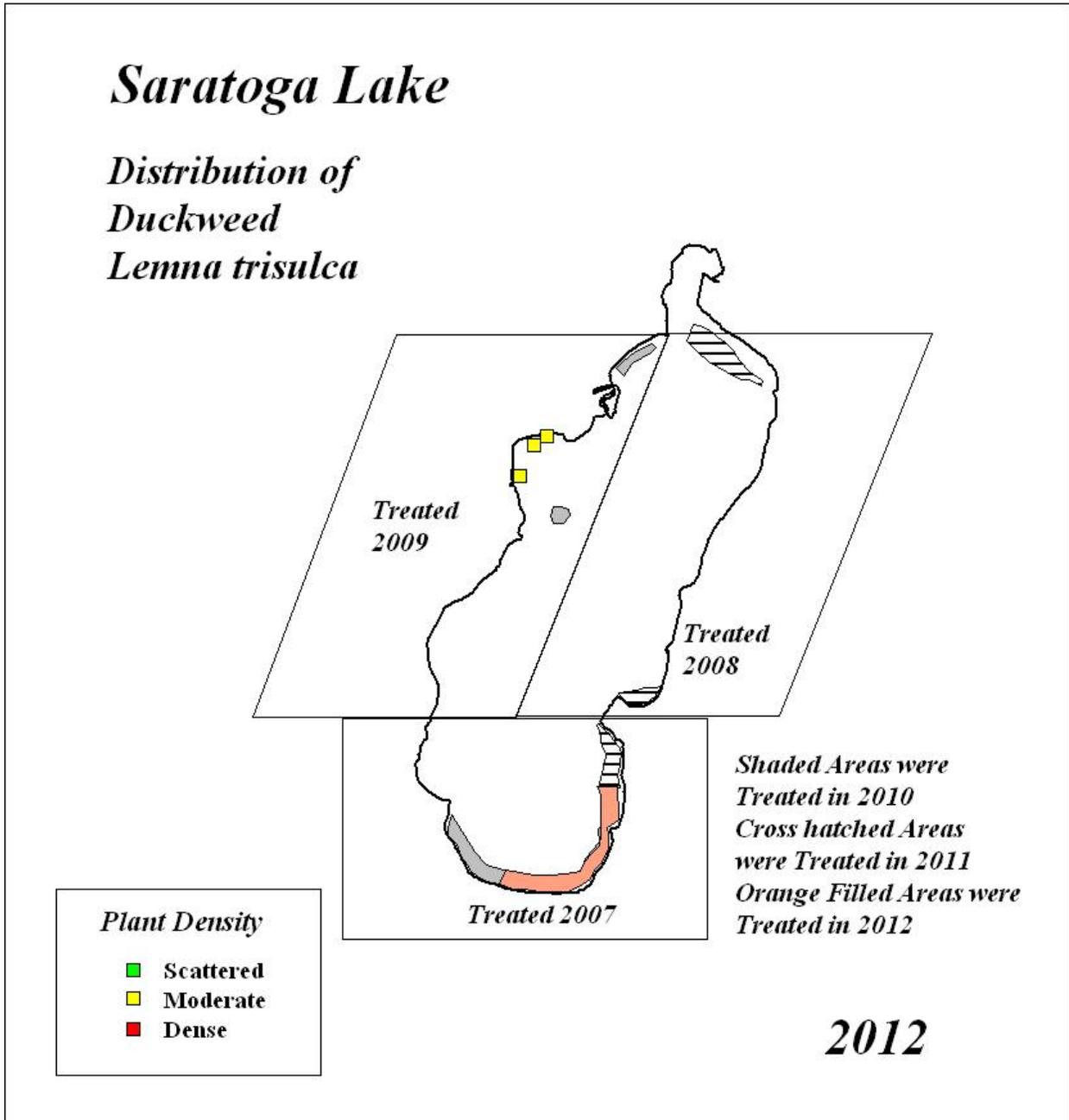
Distribution of Muskgrass *Chara/Nitella spp.*

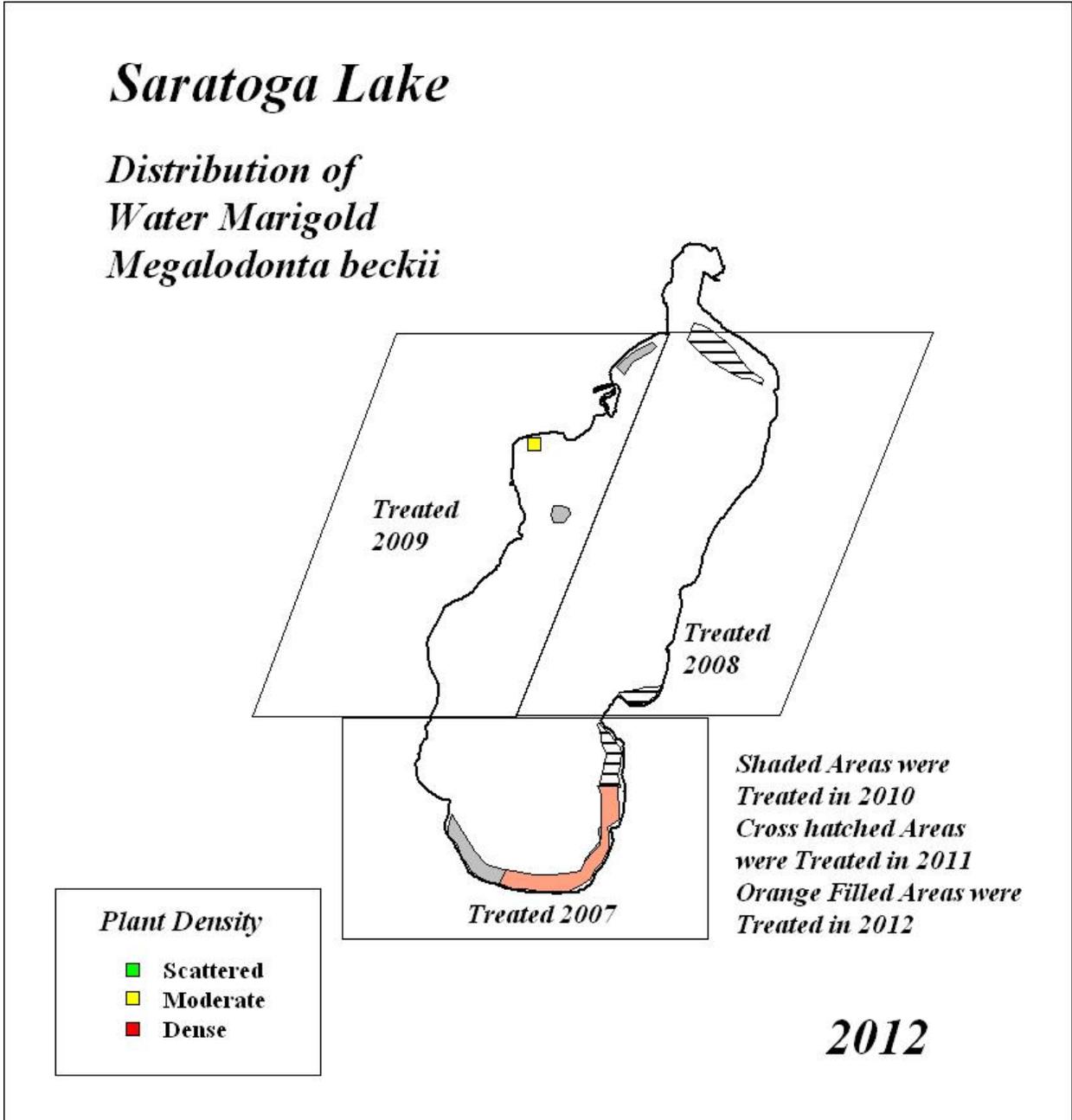


Saratoga Lake

Distribution of *Elodea canadensis*

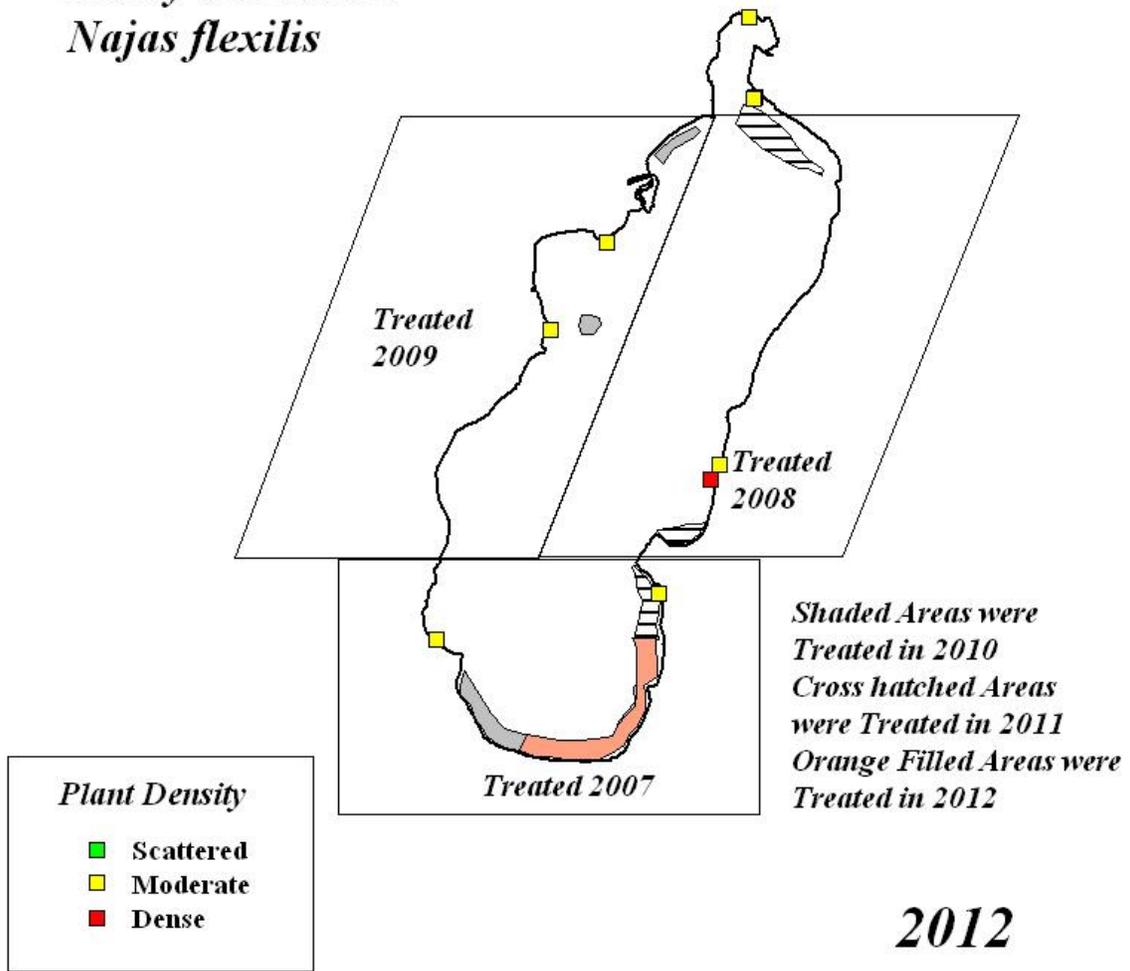






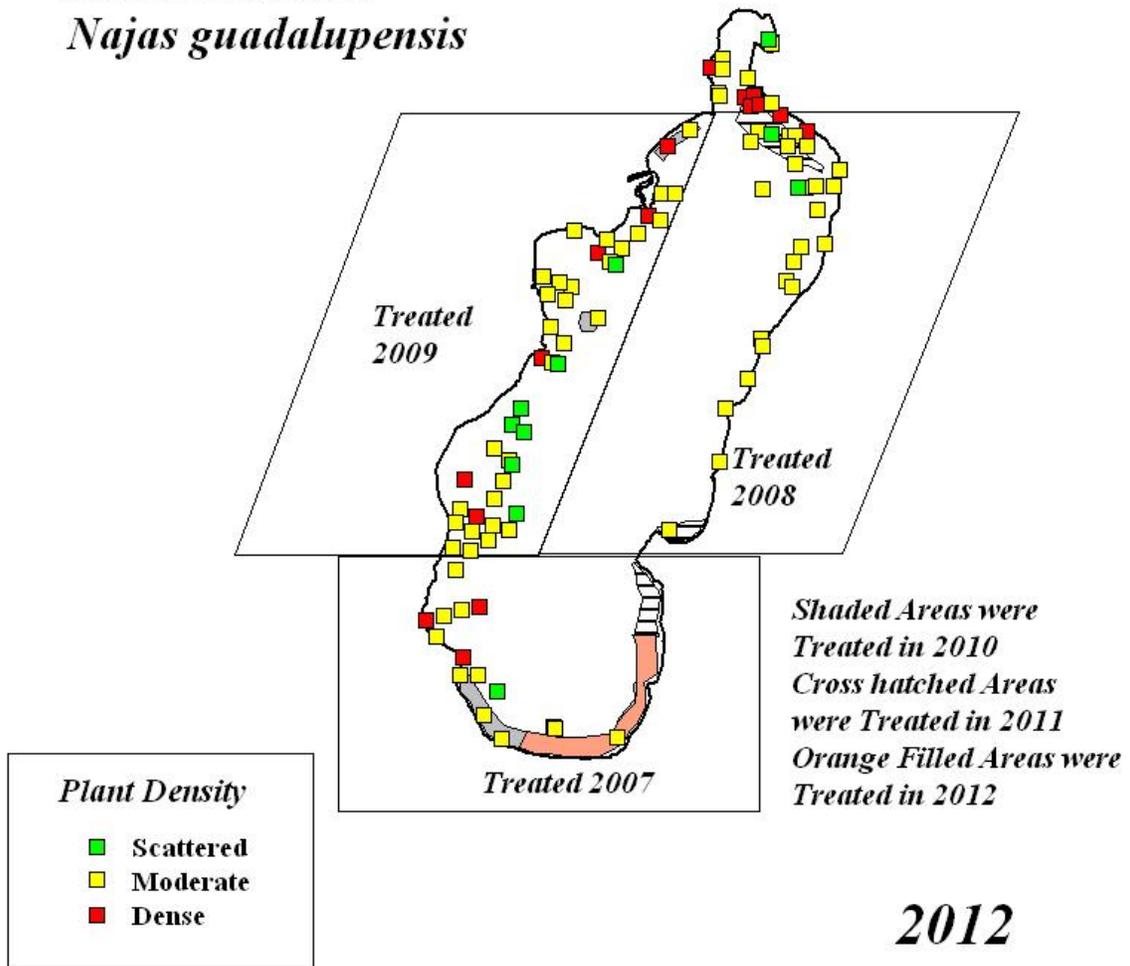
Saratoga Lake

Distribution of Bushy Pondweed *Najas flexilis*



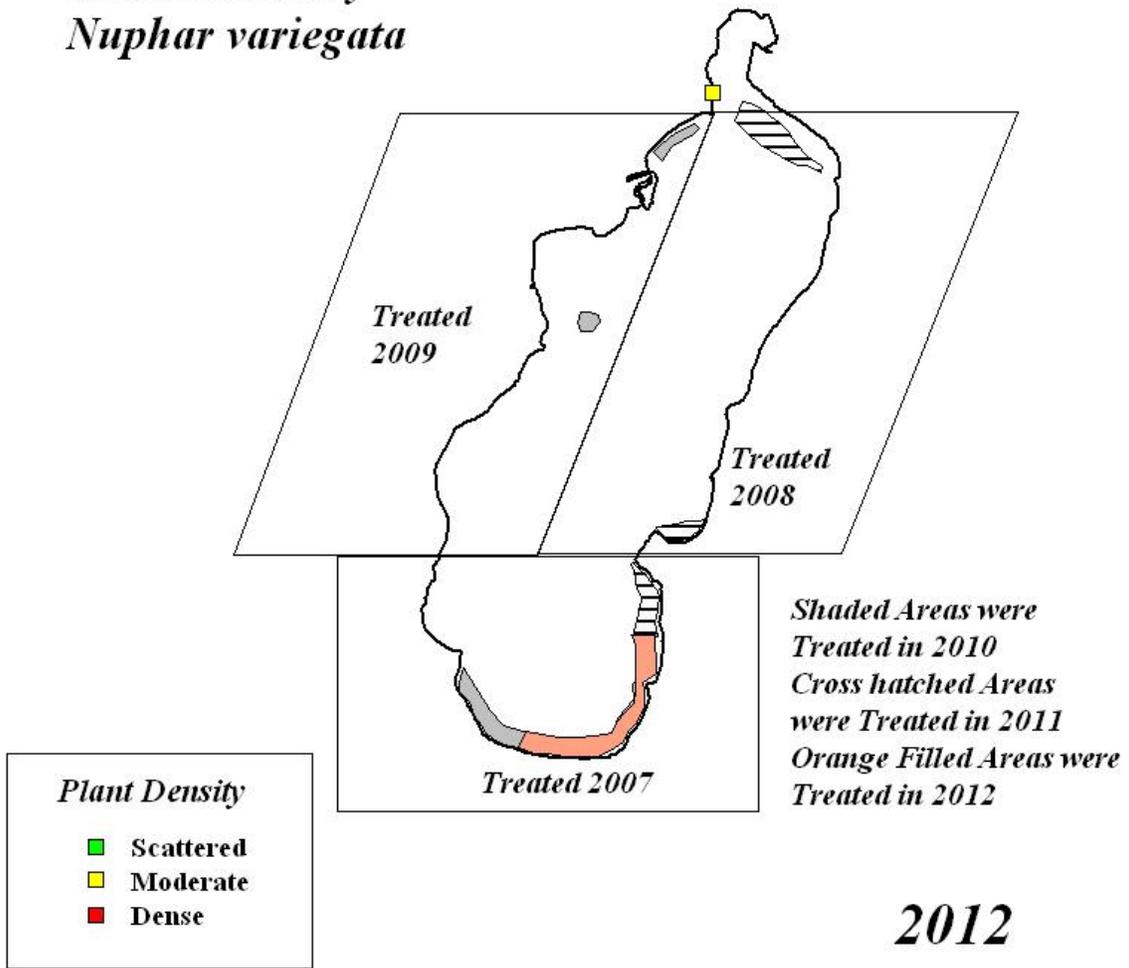
Saratoga Lake

Distribution of Southern Naiad *Najas guadalupensis*



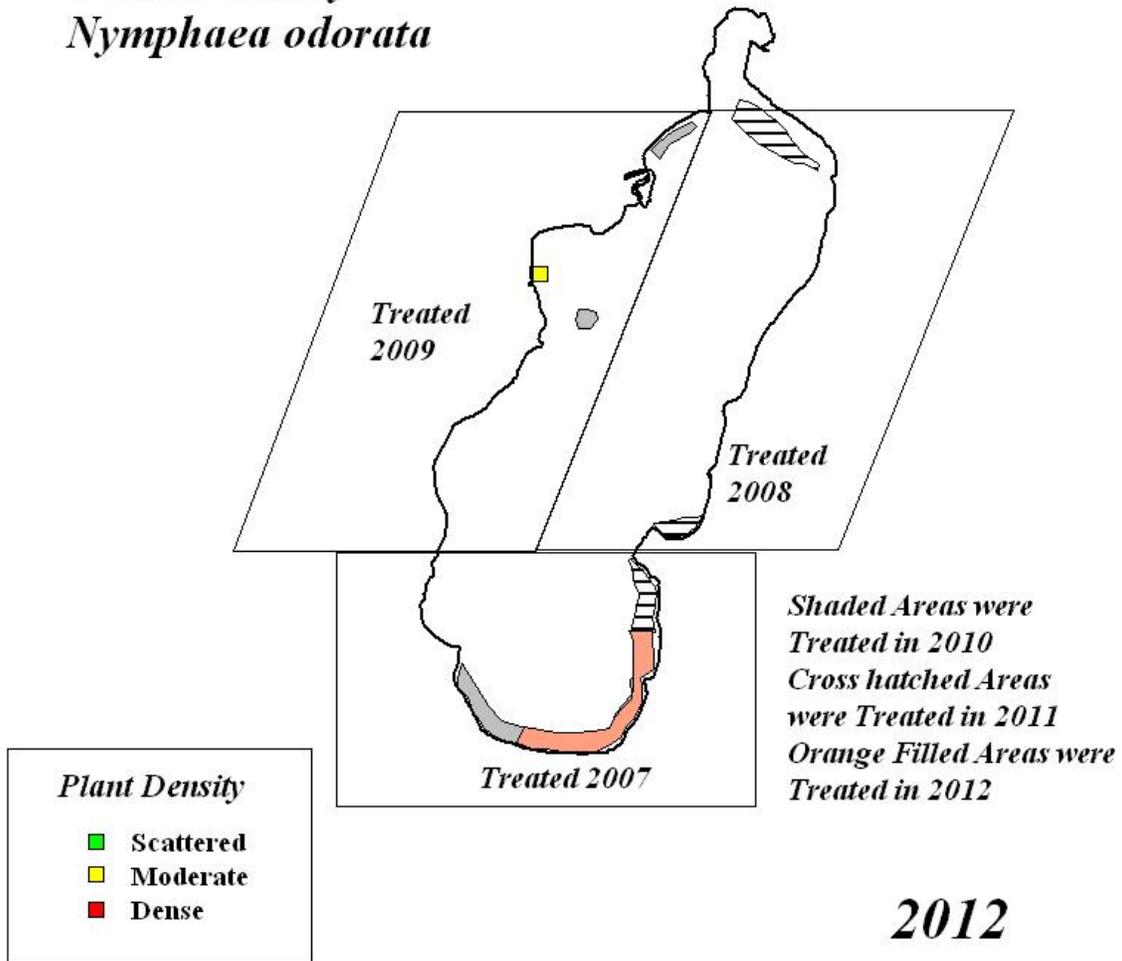
Saratoga Lake

Distribution of Yellow Pondlily *Nuphar variegata*



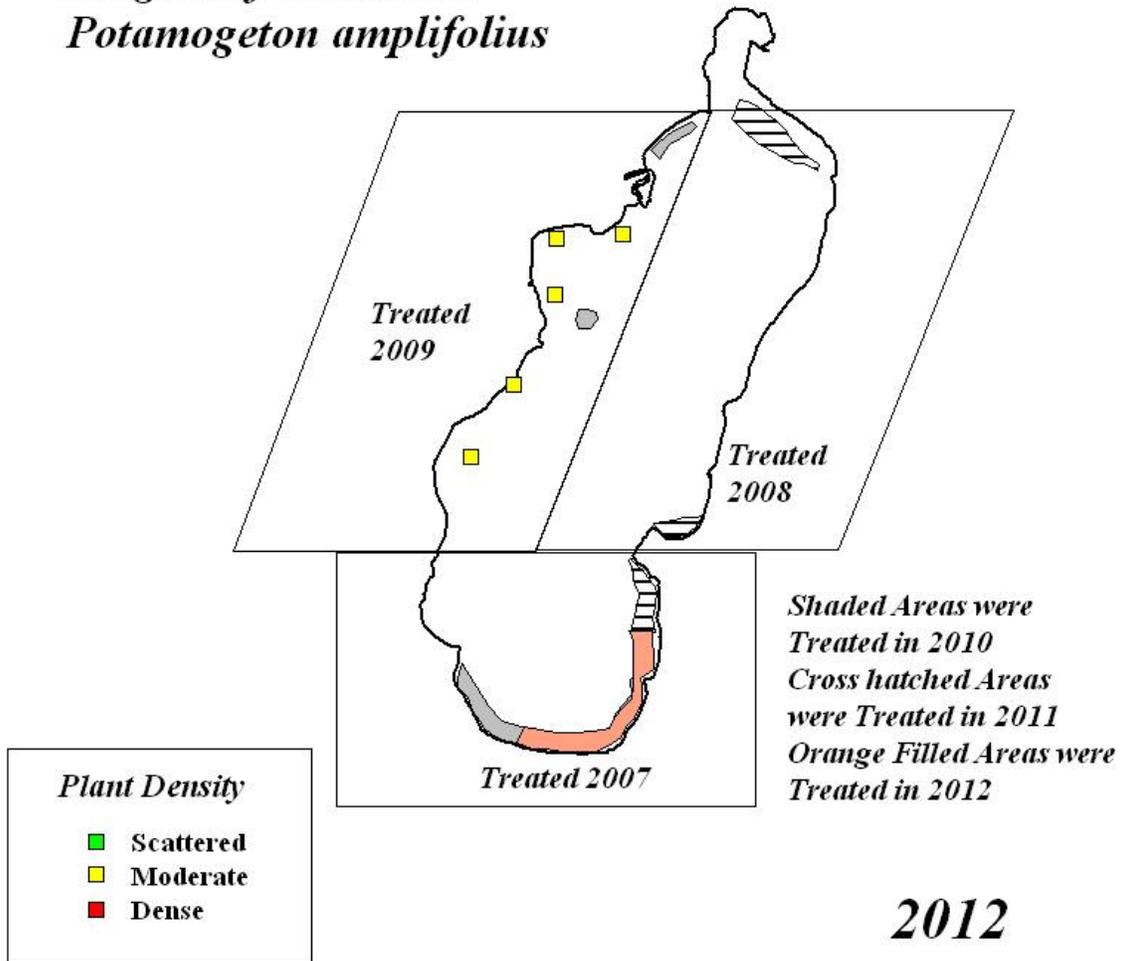
Saratoga Lake

Distribution of White Pondlily *Nymphaea odorata*



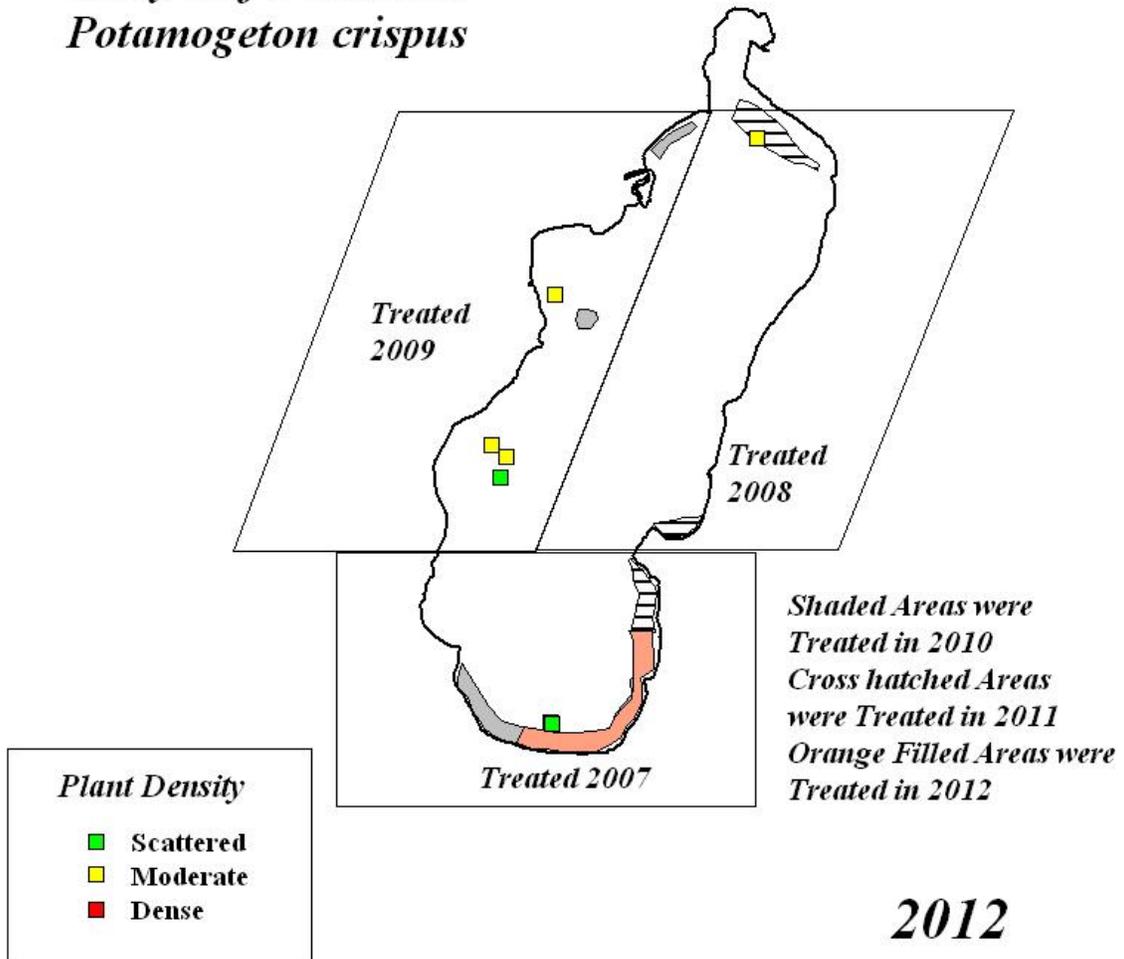
Saratoga Lake

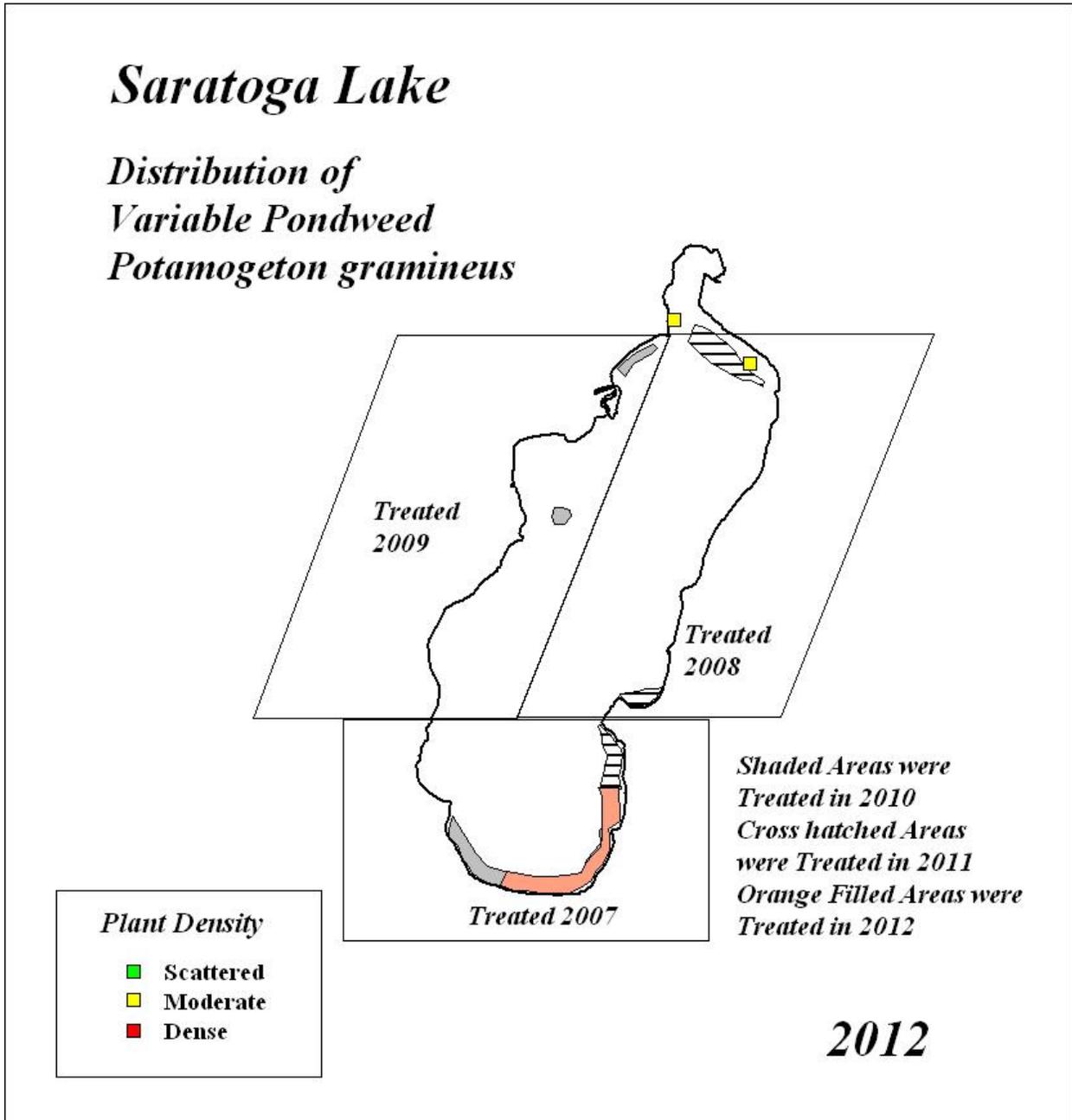
Distribution of Large-leaf Pondweed *Potamogeton amplifolius*



Saratoga Lake

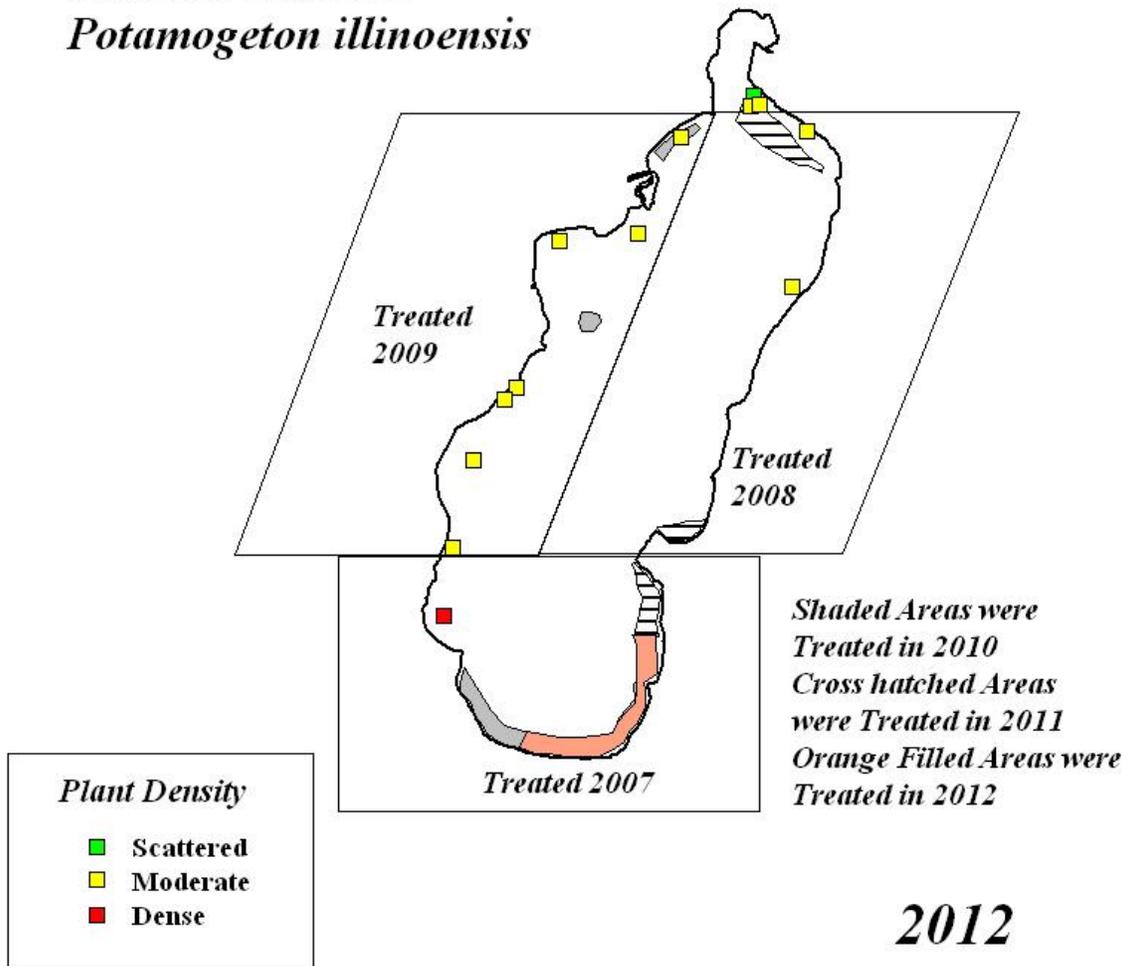
Distribution of Curly-leaf Pondweed *Potamogeton crispus*





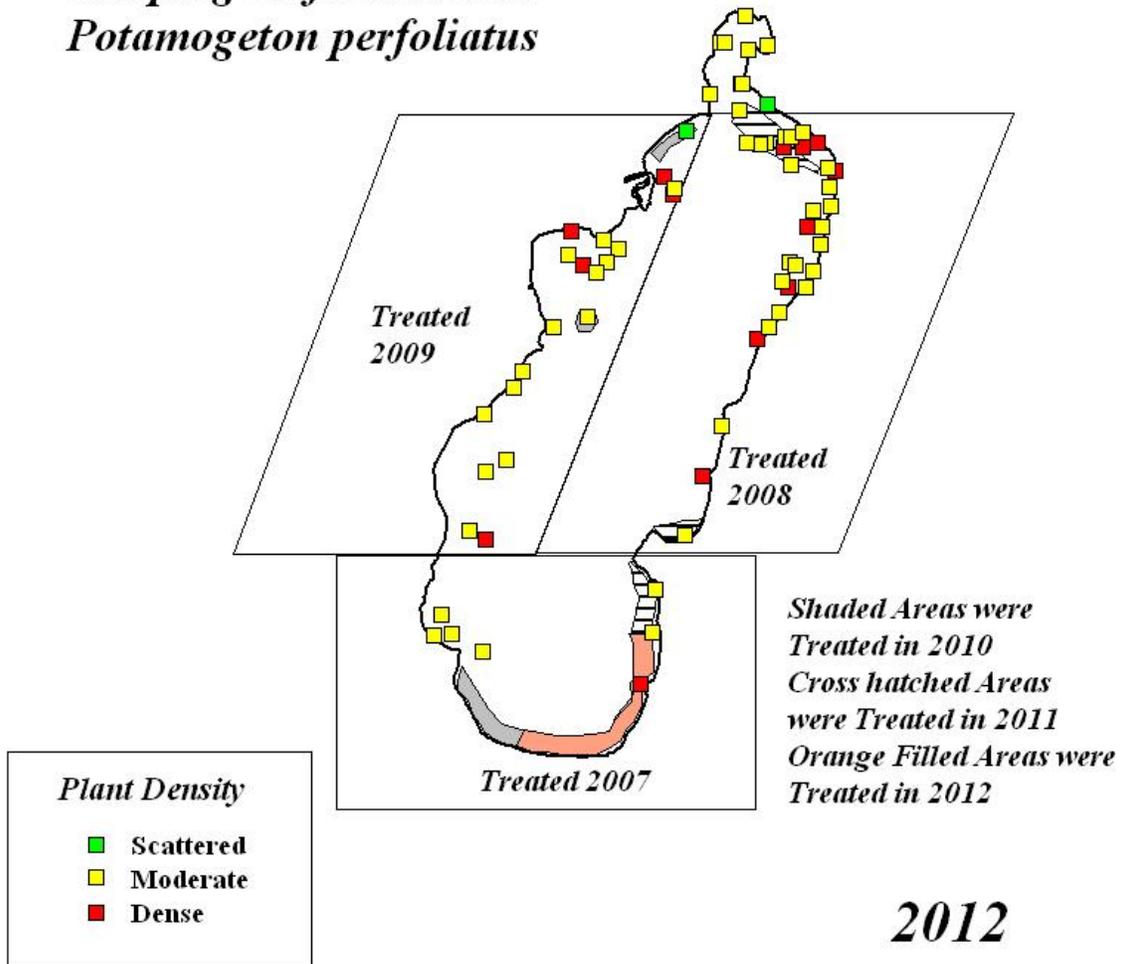
Saratoga Lake

Distribution of Illinois Pondweed *Potamogeton illinoensis*



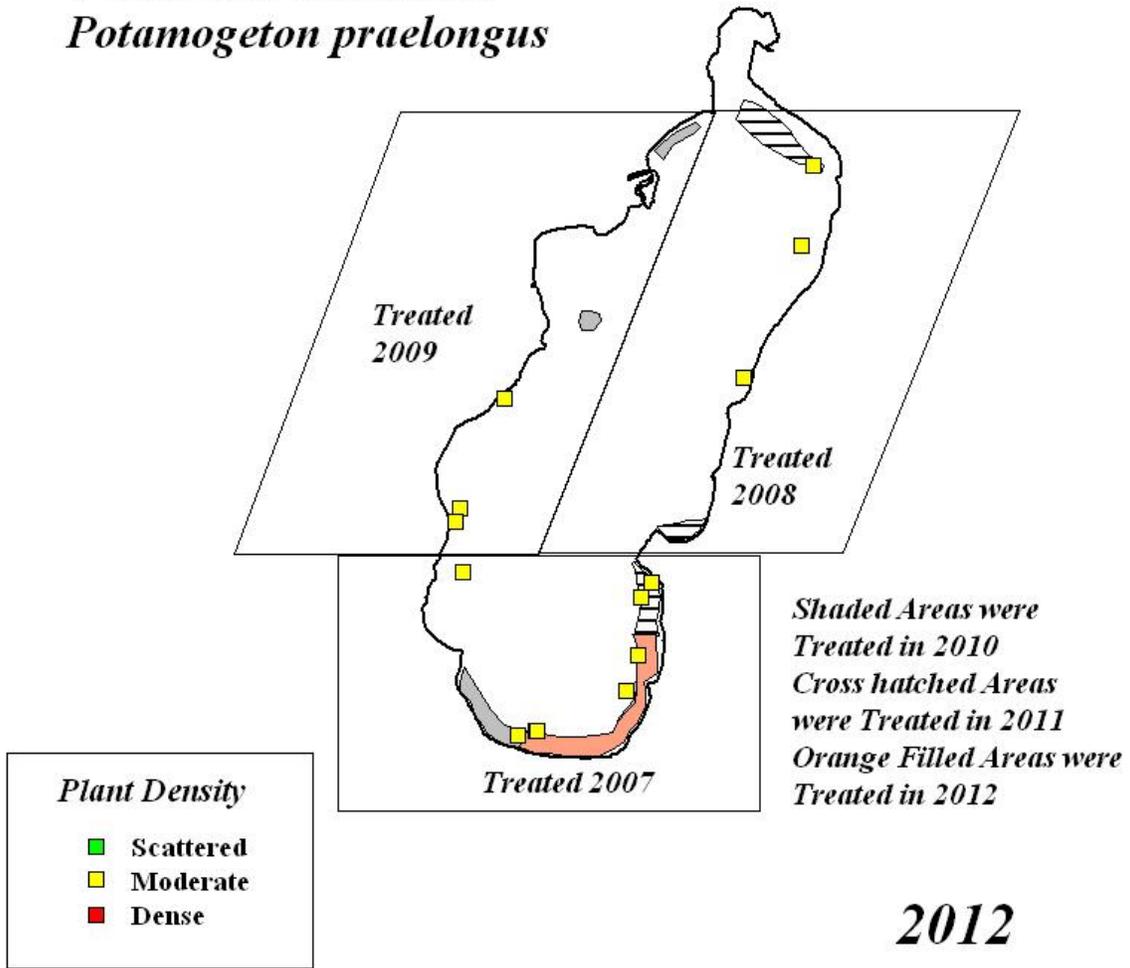
Saratoga Lake

Distribution of Clasping-leaf Pondweed *Potamogeton perfoliatus*



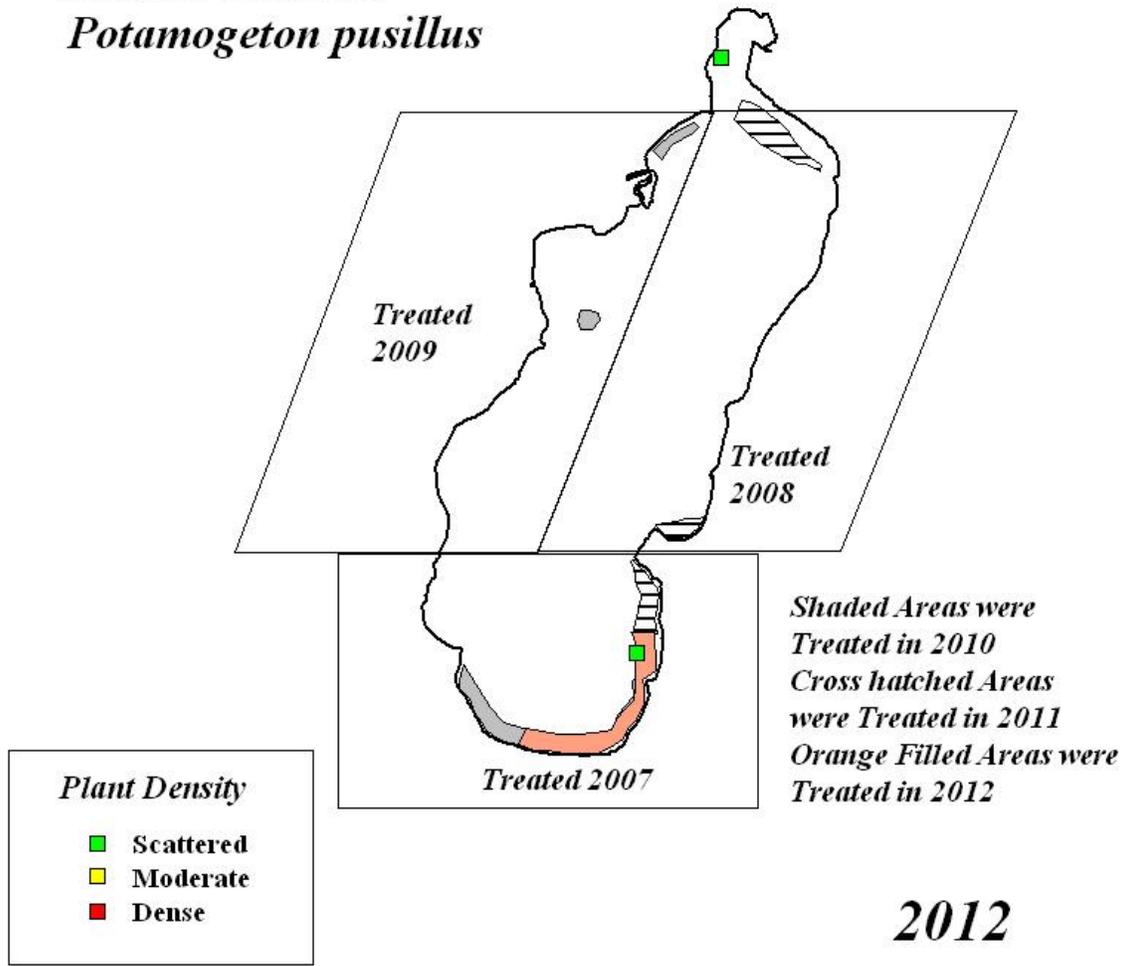
Saratoga Lake

Distribution of White-stem Pondweed *Potamogeton praelongus*



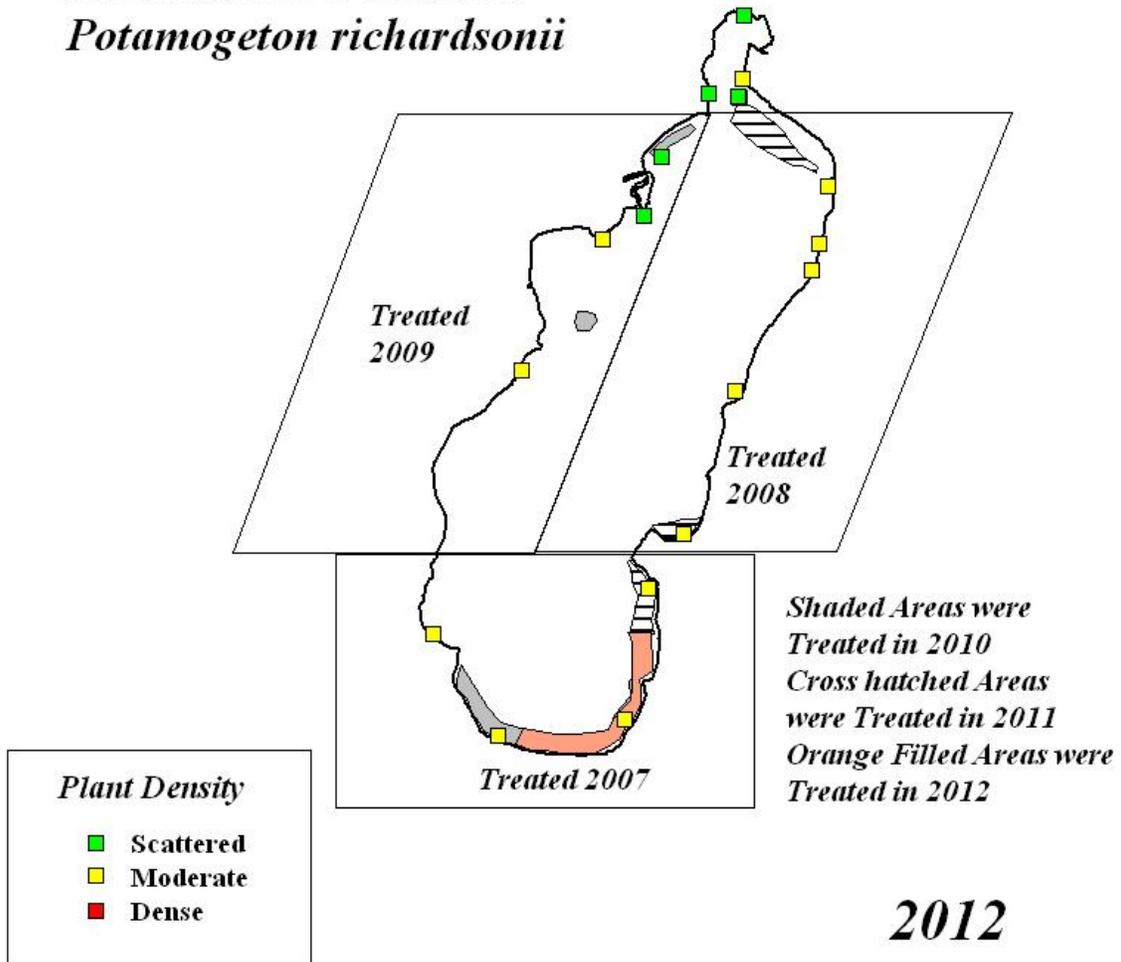
Saratoga Lake

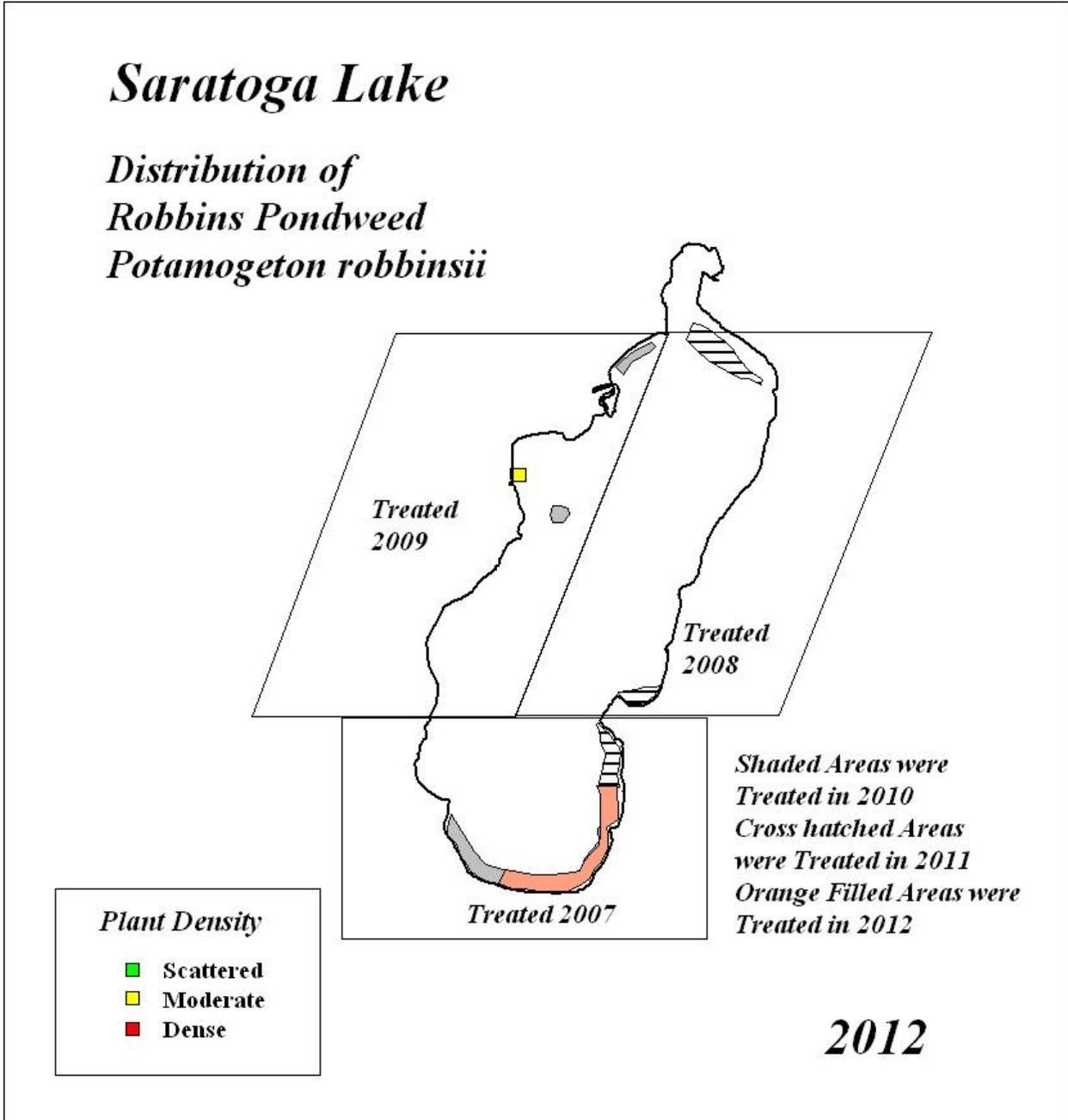
Distribution of Small Pondweed *Potamogeton pusillus*



Saratoga Lake

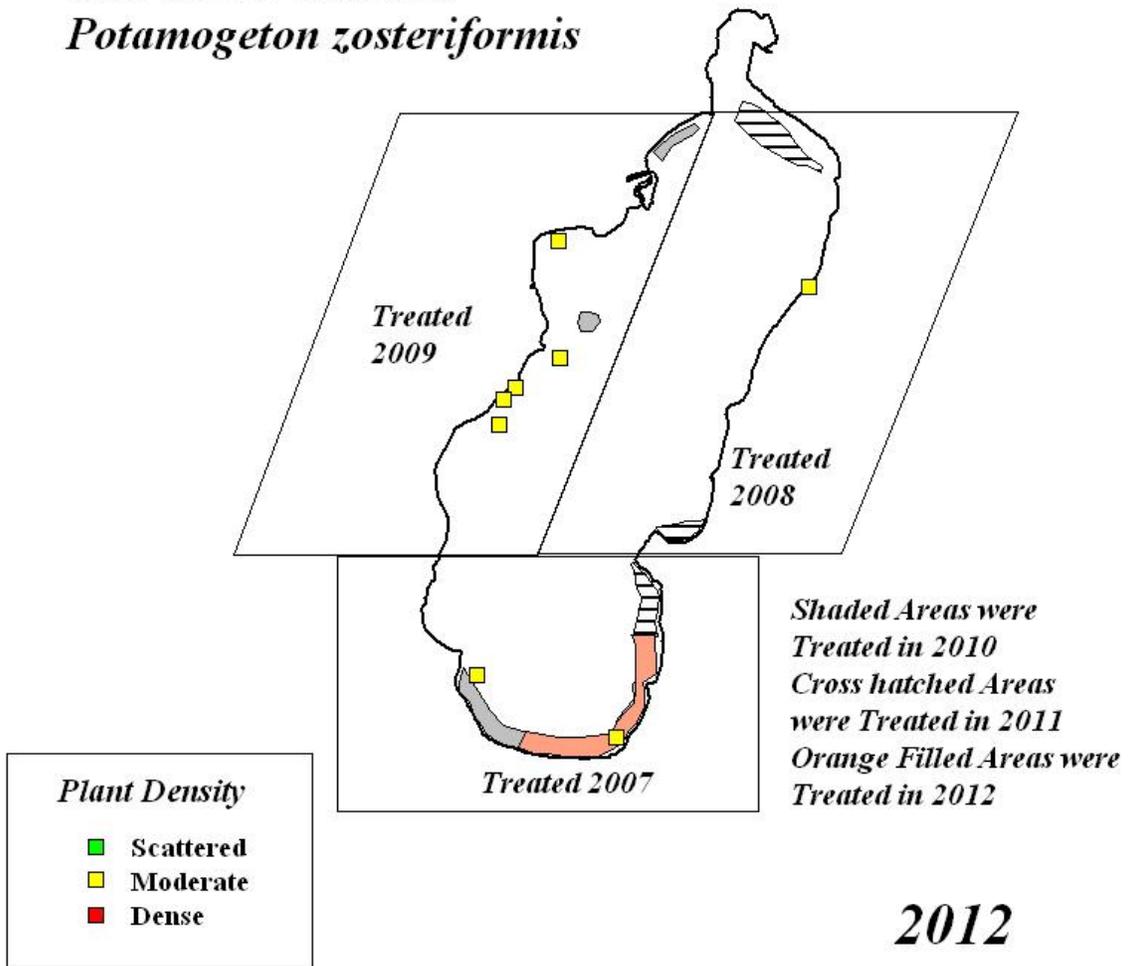
Distribution of *Potamogeton richardsonii*





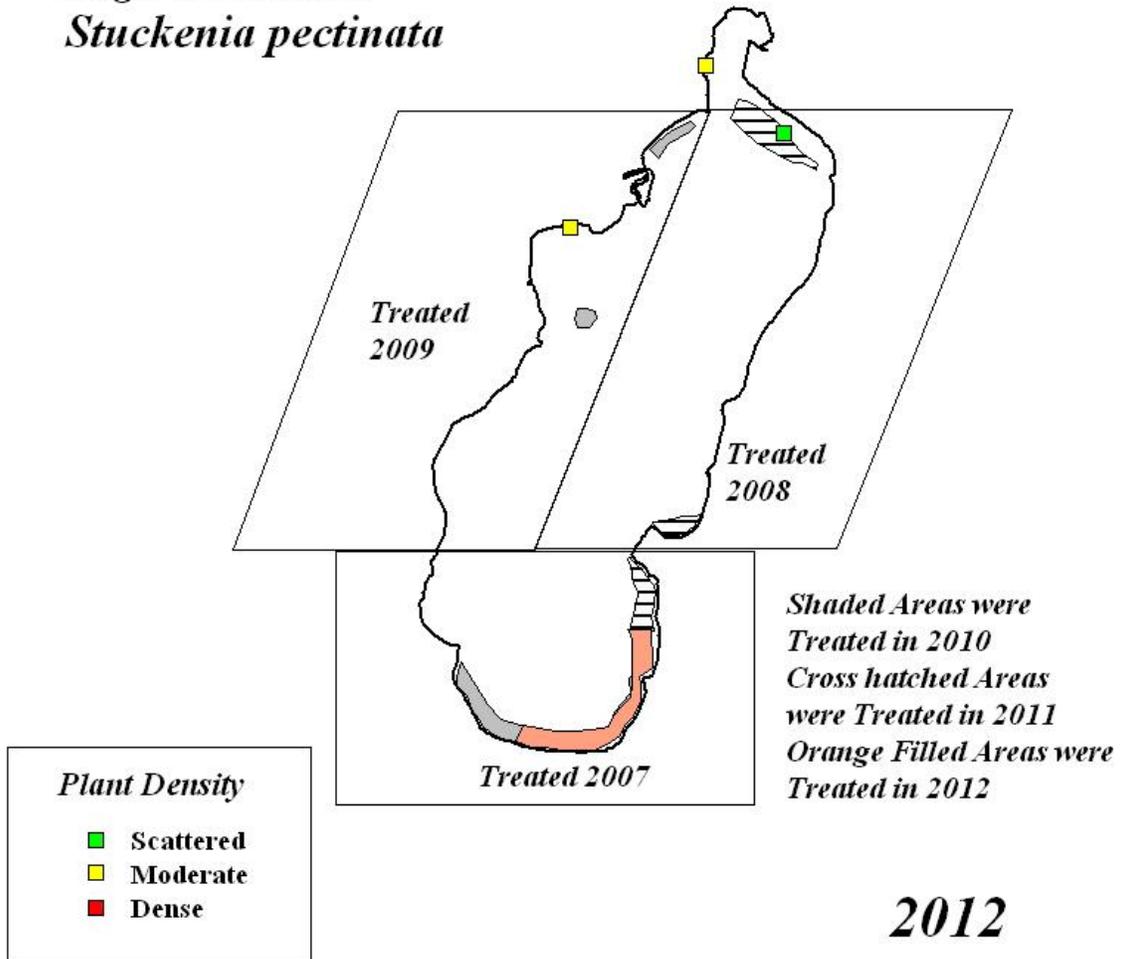
Saratoga Lake

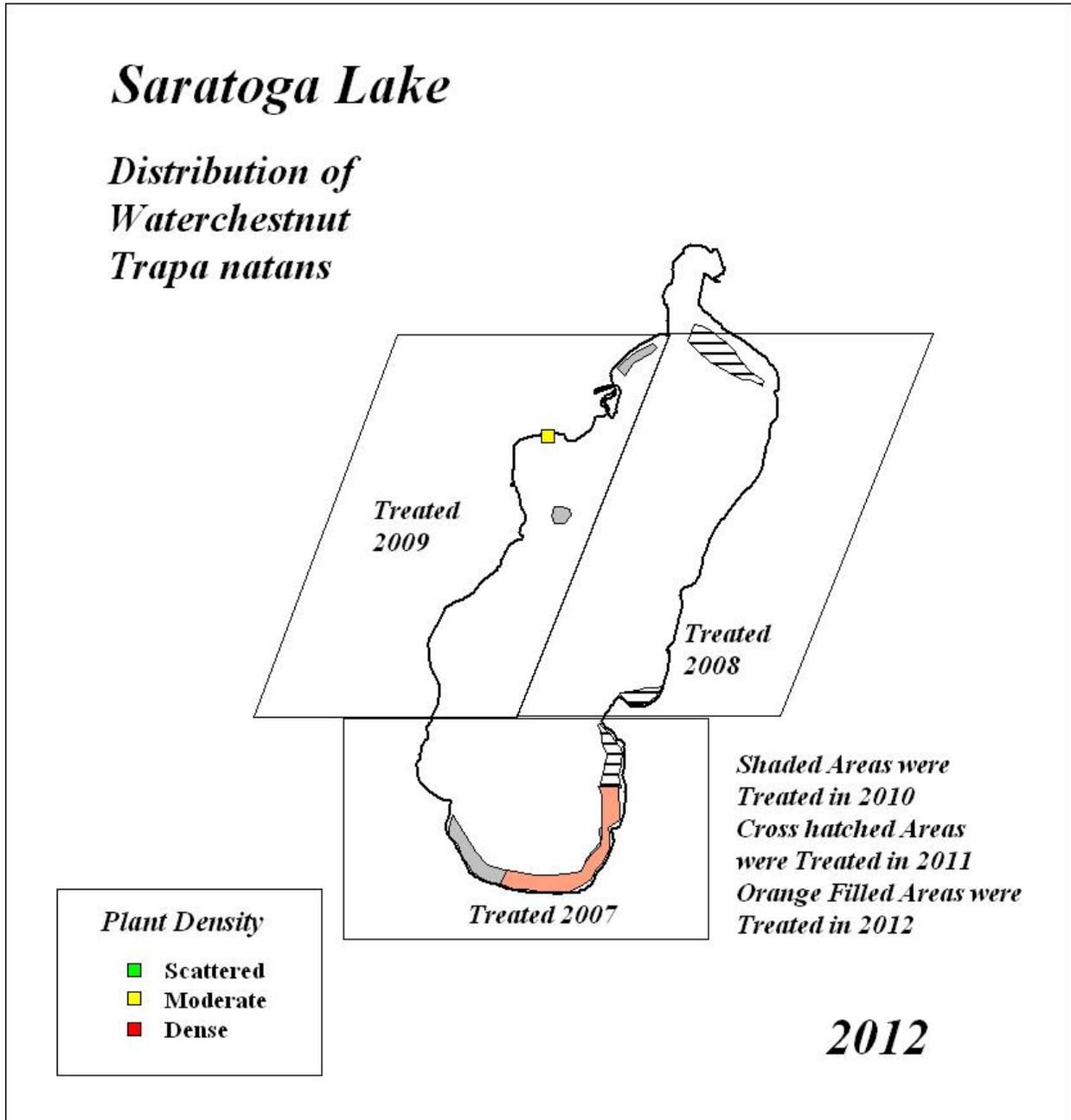
Distribution of Flat-stem Pondweed *Potamogeton zosteriformis*



Saratoga Lake

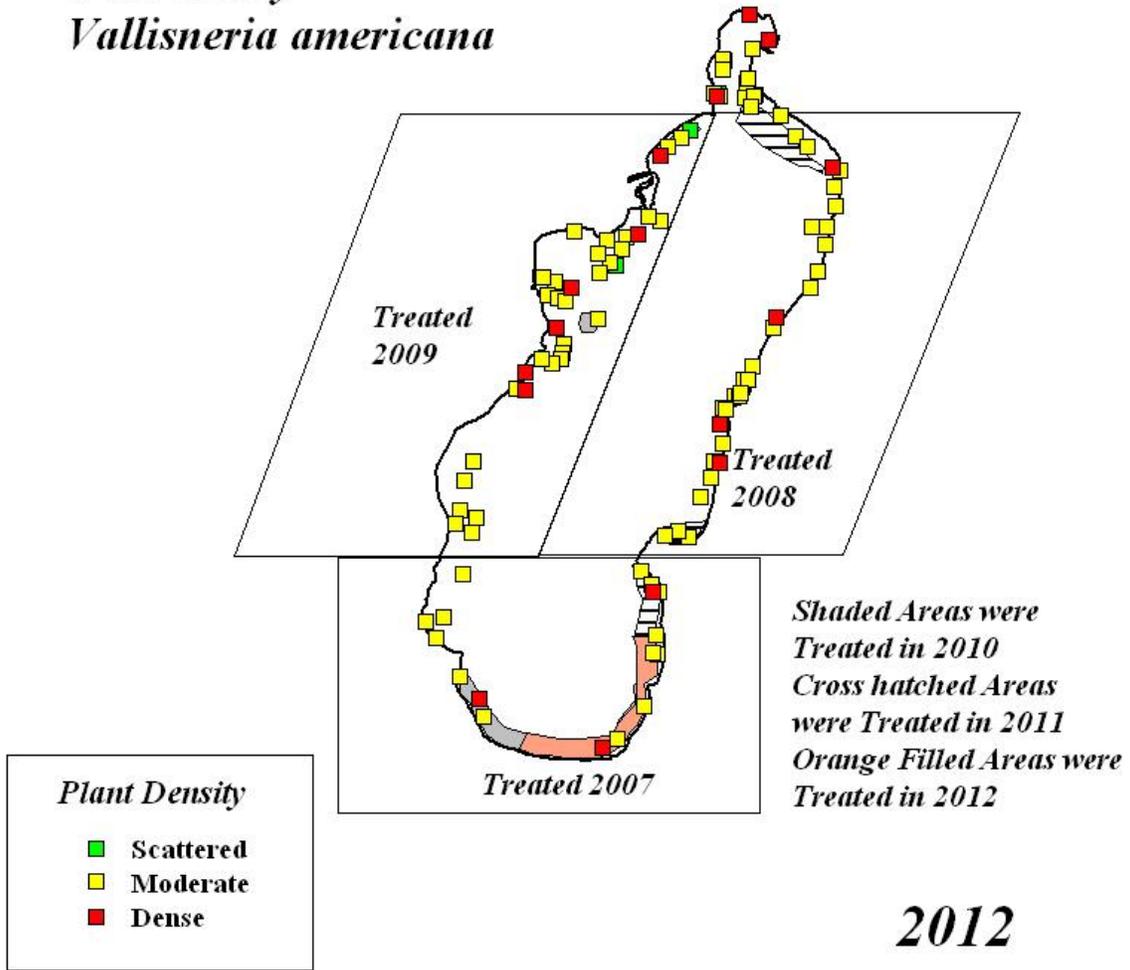
Distribution of Sago Pondweed *Stuckenia pectinata*





Saratoga Lake

Distribution of Wild Celery *Vallisneria americana*



Saratoga Lake

Distribution of Water Stargrass *Zosterella dubia*

