Houghton Lake Management Feasibility Study

Prepared for the Houghton Lake Improvement Board

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Houghton Lake Management Feasibility Study

Executive Summary

This management plan was produced in response to concerns about problems resulting from the proliferation of Eurasian watermilfoil in Houghton Lake. The goals of the evaluation and resulting plan were to evaluate the Eurasian watermilfoil population in the lake and present possible options for Eurasian watermilfoil management. The plan reviews existing data on Houghton Lake derived from previous studies of the lake; presents results of surveys of the aquatic vegetation, the distribution and abundance of milfoil weevils, and water quality in the lake; discusses Eurasian watermilfoil control methods and presents several alternative strategies for using these techniques to manage Eurasian watermilfoil in Houghton Lake.

Previous studies agree that Houghton Lake has long supported abundant aquatic plant growth. Recent aquatic plant problems in the lake are associated with the replacement of a diverse native plant community by the exotic plant, Eurasian watermilfoil (*Myriophyllum spicatum* L.). In 2001, Eurasian watermilfoil could be found in approximately 10,800 acres of the lake. Eurasian watermilfoil was common or dense in approximately 5,300 acres. 21 other aquatic plants were encountered during vegetation surveys. None of these plants was as abundant as Eurasian watermilfoil.

Surveys detected the milfoil weevil, *Euhrychiopsis lecontei*, in 39 percent of sampling locations throughout Houghton Lake. Weevil populations tended to be clumped, with weevils detected in groups of adjacent sampling locations. Weevil populations exceeded the threshold at which weevils are expected to begin impacting Eurasian watermilfoil in a few areas of the lake. Overall, weevil survey results indicate that only a few areas have significant weevil populations.

Water quality measurements taken in September 2001 indicate that Houghton Lake is mesotrophic. Nutrient concentrations are low, yet algae and aquatic plants grow abundantly. The lake is receiving a steady supply of nitrate from its seven tributaries, particularly Spring Brook Creek.

The goal of all proposed management options is to reduce the abundance of Eurasian watermilfoil as much as possible (depending on the approach chosen), while promoting the survival and/or recovery of desirable native plants. There are several feasible options for achieving this goal in Houghton Lake. Strategies potentially capable of meeting management goals include whole-lake fluridone applications, use of the milfoil weevil or integrated management strategies using both the weevil and herbicides. Advantages of each strategy are discussed in detail.

A budget of $1,000,000 per year for at least five years is recommended to initiate management of Eurasian watermilfoil in the lake. This budget will provide adequate funds for any of the management options, and will provide the flexibility to switch management strategies if the preferred strategies cannot be implemented for regulatory reasons or do not succeed.

Houghton Lake Management Feasibility Study

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Houghton Lake Management Plan

Introduction

This management plan was produced in response to concerns about problems resulting from the proliferation of Eurasian watermilfoil in Houghton Lake. The goals of the evaluation and resulting plan were to evaluate the Eurasian watermilfoil population in the lake and present possible options for Eurasian watermilfoil management.

Previous studies agree that Houghton Lake has long supported abundant aquatic plant growth. Recent aquatic plant problems in the lake are associated with the replacement of a diverse native plant community by the exotic plant, Eurasian watermilfoil (*Myriophyllum spicatum* L.).

Description of Houghton Lake

Morphometry/Hydrology

Houghton Lake is large shallow lake. The lake has a surface area of 20,044 acres and a maximum depth of 21 feet (U. S. Environmental Protection Agency 1975). The average depth of the lake has been variously reported as being 7.6 feet (U. S. Environmental Protection Agency 1975) or 8.5 feet (Pecor, et al. 1973b). As part of this study the volume was recalculated (Table 1), based on digitization of the Michigan Conservation Department map (Figure 1), which was based on soundings taken in May 1954 and contours revised in October 1962. The calculated volume of the entire lake is 172,463 acre-ft. This value agrees well with the value of 170,000 acre-ft calculated by Pecor, et al. (1973a). The average depth calculated from these data is 8.6 feet. The volume of the top ten feet on the lake (typically used to calculate fluridone dose rates in Michigan) is 146,339 acre-ft.

Table 1. Houghton Lake Volumes

Depth Layer (feet)	Volume (acre-ft)
0 – 4	74,472
4 – 8	54,462
8 – 10*	17,405
10 – 12*	12,059
12 – 16	11,704
16 – 20	2,352
20 – 21	9
Total	172,463

*10' contour data interpolated.

Houghton Lake receives water from 4 major tributaries plus a number of minor tributaries and drains. The outflow from the lake becomes the headwaters of the Muskegon River, which flows west across Michigan to enter Lake Michigan at Muskegon. Average annual outflow from the lake into the Muskegon River is 156.7 cfs. Pecor, et al. (1973a) calculated a water budget for the lake and concluded that the hydraulic residence time of the lake during 1972 was 1.2 years.

The nearest U.S.G.S. gauging station downstream from the lake is located at Evart, Michigan, about 50 miles downstream from the outlet of the lake. At the location of the gauge, the Muskegon River drains 1,433 mi^2; thus the Houghton Lake watershed (see below)

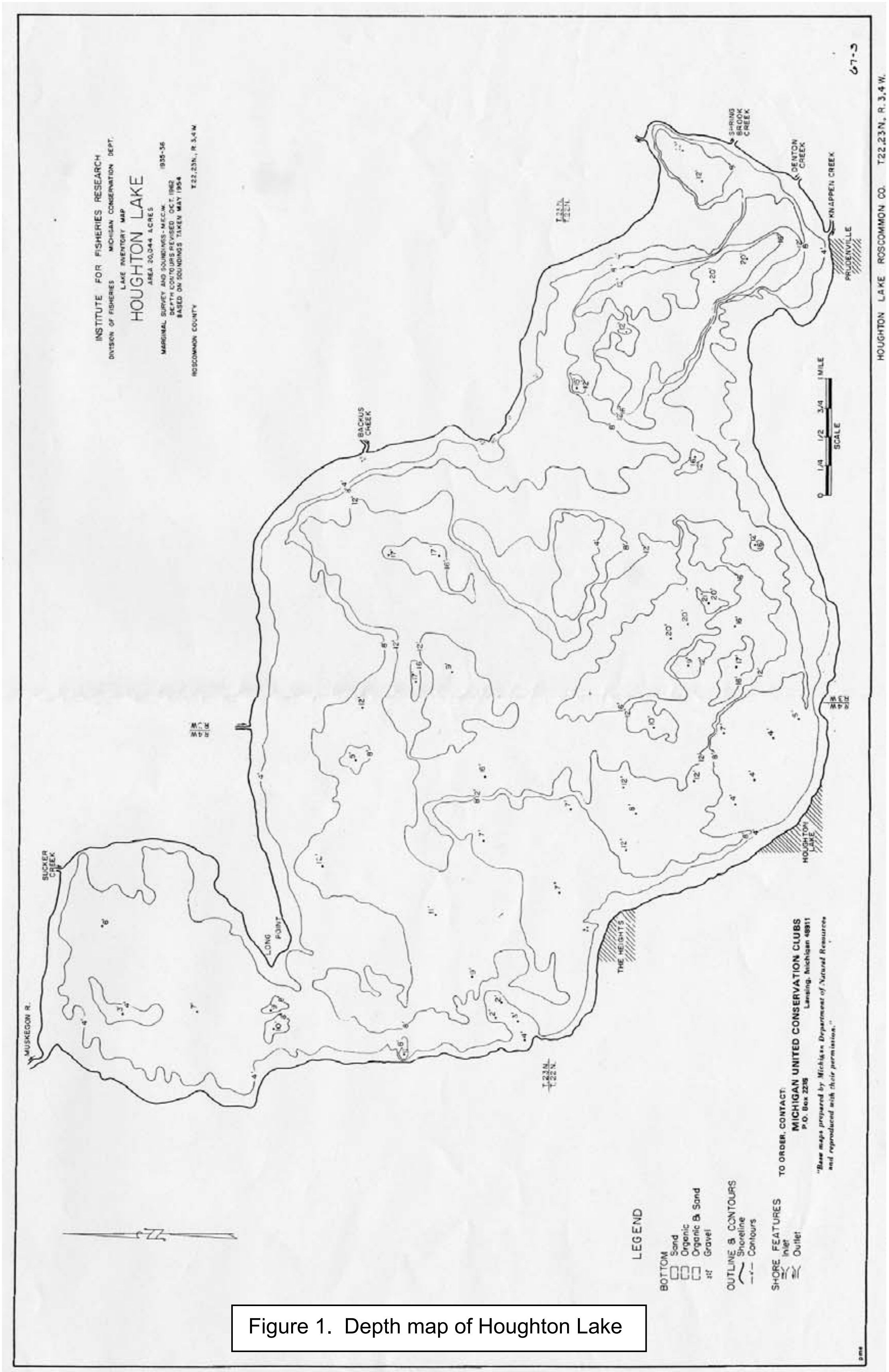
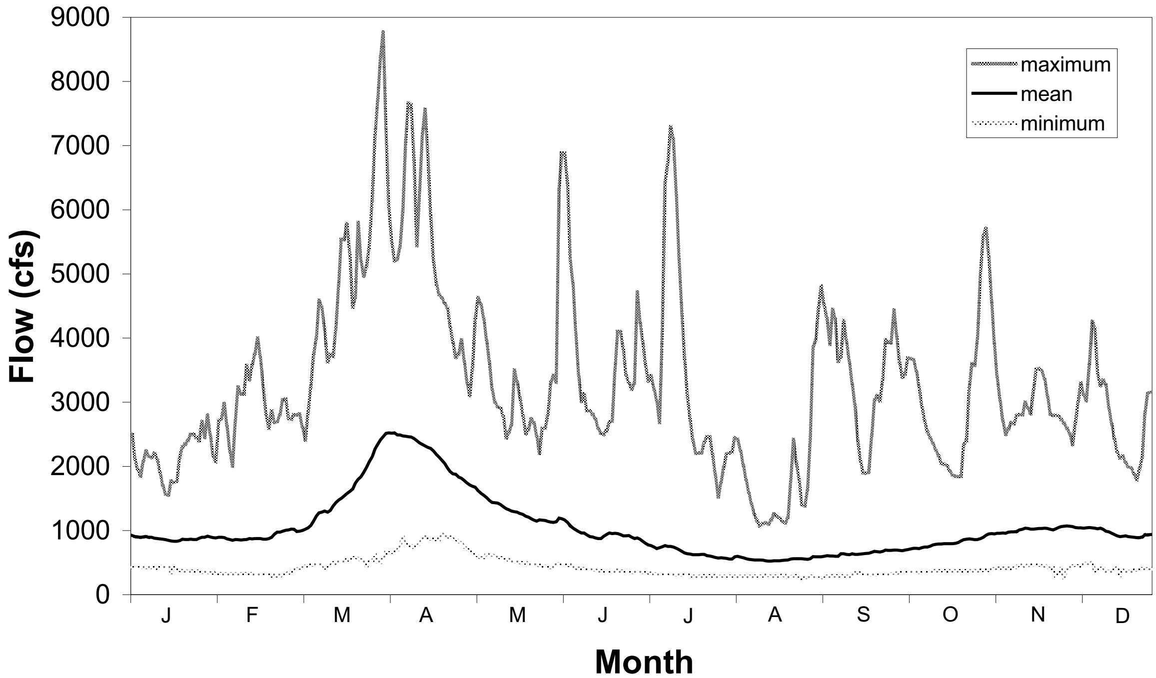


Figure 1. Depth map of Houghton Lake

represents only about 15 percent of the area drained by the river at that point. The average, maximal and minimal flow rates observed Evart during the 70-year period from 1930 through 1999 are plotted in Figure 2. The average annual flow is 1045 cfs. Streamflow varies seasonally, with a seasonal maximum average flow of approximately 2500 cfs in the spring (March-April). Maximal and minimal flow rates are considerably higher and lower, respectively, than the average flow rates. Maximum flows can reach 9000 cfs in the springtime, or 7000 cfs at other times of year. Minimum flow rates are only 500 cfs during much of the year and 1000 cfs in the spring.

Figure 2. Flow of the Muskegon River at Evart, Michigan, approximately 50 miles downstream from the outlet of Houghton Lake.



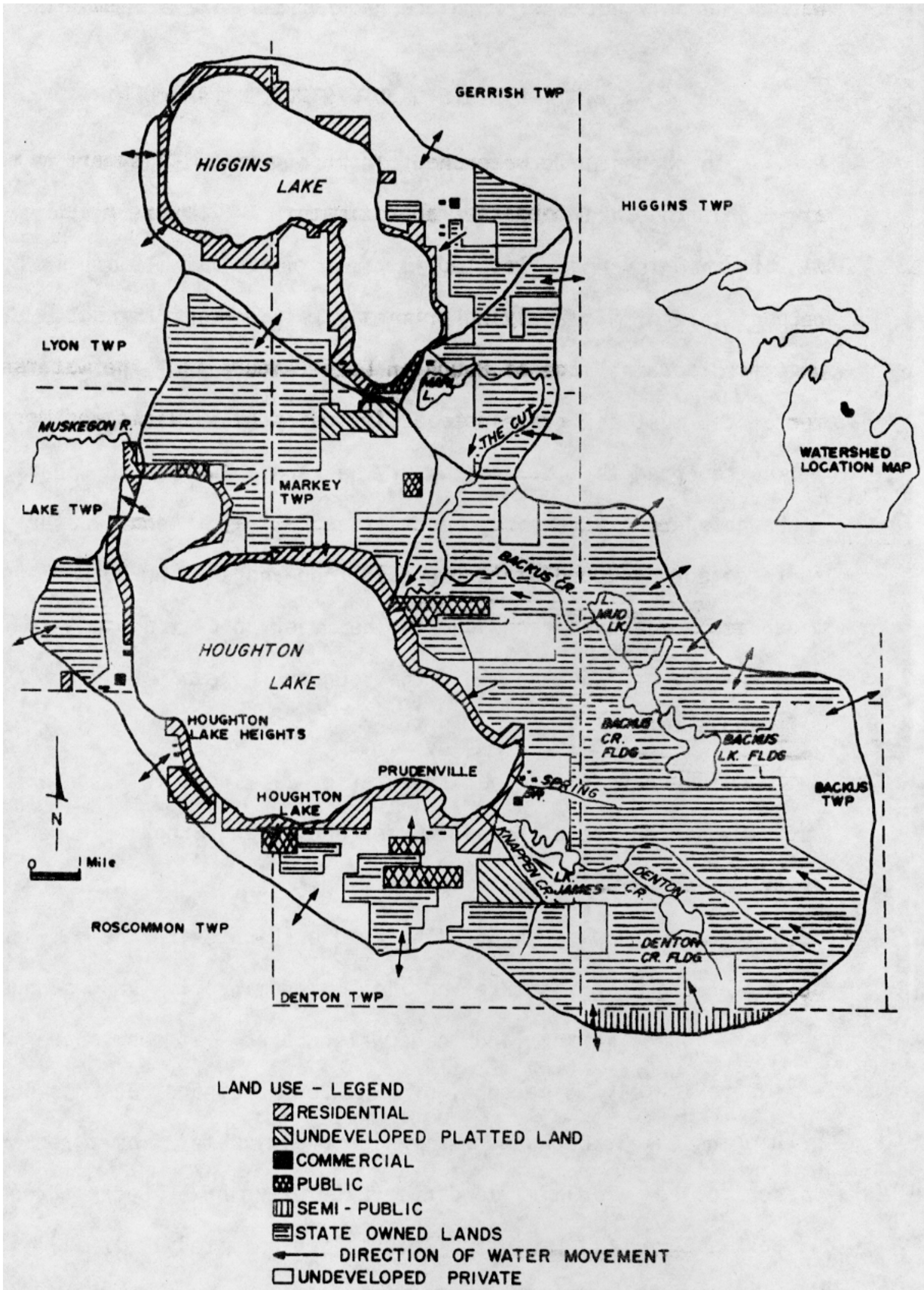
Translating these seasonal variations in flow to Houghton Lake, the outflow and hydraulic residence time vary considerably from season to season and from year to year. During an average year, outflow of approximately 2.5 times the seasonal average is expected in the spring; thus the short-term hydraulic residence time of the lake will be reduced to approximately 5.8 months. During a wet year, spring flows can reach almost nine times the season average. Peak flow rates would reduce the short-term hydraulic residence time to approximately 1.6 months. Conversely, flow during a dry year can be less than one-half that during an average year. Dry-year flow rates would result in short-term hydraulic residence times of approximately 16 months in the spring and over 4 years during the summer.

Watershed

The Houghton Lake watershed includes the immediate drainage area around the lake, as well as the watersheds of Higgins Lake and Denton Creek (Figure 3). The entire watershed (including the lake itself) encompasses 218 mi^2, whereas the immediate drainage, Higgins

Lake and Denton Creek watersheds are 54, 95, and 38 mi^2, respectively (Pecor, et al. 1973a). The lake accounts for the remaining 31.3 mi^2.

Figure 3. The Houghton Lake watershed (from Pecor, et al. 1973a).



Much of the watershed is state-owned land, including state parks and recreation areas, and over 20 percent of the watershed is water. Water quality in runoff from developed areas was poor, but the volume of urban runoff was lower than expected. Nutrient export from the developed parts of the watershed was lower than in most other developed areas where it has been evaluated, presumably due to sandy soils which limit surface runoff even from developed areas (Pecor et al. 1973a). As the result of the large fraction of undeveloped land and low nutrient export rates from developed areas, only 6 percent of the annual phosphorus load and 3 percent of the annual nitrogen load were derived from cultural sources during 1972 (Pecor et al. 1973a).

Water Quality/Nutrient Budgets

Houghton Lake is generally classified as eutrophic or meso-eutrophic (Pecor, et al. 1973b, U. S. Environmental Protection Agency 1975). Although the lake has fairly high nutrient concentrations and productivity, characteristic of a somewhat eutrophic lake, as of 1972, it had not experienced the adverse conditions usually associated with eutrophication (Pecor et al. 1973b).

Pecor et al. (1973b) conducted a detailed study of the water quality of Houghton Lake. Alkalinity and pH measurements identify Houghton Lake as being a moderately alkaline lake with an average pH of 8.2 and an alkalinity of approximately 92 mg $CaCO_3$/L. The total amount of dissolved material in the water is moderate, as indicated by an average conductivity of 193 μmhos/cm^2. The Secchi disk depth in the lake averaged 6.5 feet. Total phosphorus concentrations were moderate, averaging 21 μg P/L. Chlorophyll *a* concentrations in the lake ranged from 5.6 to 12.4 mg/L during 1972. Dissolved oxygen concentrations remained high at all locations throughout the entire ice-free season. Most of the lake remained well oxygenated under the ice, but a minimum dissolved oxygen of 4.3 mg/L was measured near the bottom in one isolated deep (15 foot) basin. Even during the period when dissolved oxygen was low near the bottom, near-surface dissolved oxygen concentrations remained high.

A detailed study conducted by the Michigan DNR examined nutrient loading to Houghton Lake in 1972 (Pecor, et al. 1973a). Table 2 lists the quantities of phosphorus and nitrogen loading from various sources in the watershed. Most of the phosphorus and nitrogen input to the lake came from natural sources, rather than from developed areas. Major tributaries were the most important sources of phosphorus, whereas direct precipitation was by far the largest source of nitrogen. Direct precipitation on the lake surface was also a major source of phosphorus, accounting for nearly as much phosphorus as provided by the major tributaries. Drainage

Table 2. Sources of phosphorus and nitrogen loading to Houghton Lake, 1972.

Source	**Phosphorus** (lbs/yr)	**Nitrogen** (lbs/yr)
Residential drainage	352	4,220
Shallow groundwater	155	3,430
Forest & Marsh drainage	849	19,100
Major tributaries	3,290	91,100
Precipitation	3,280	135,600
Deep groundwater	28	23,500
Total	**7,950**	**277,000**

Source: Pecor, et al. 1973a.

from residential areas and shallow groundwater (including septic inputs) were very minor sources of nutrient loading to the lake.

A second, much less detailed study of nutrient loading to Houghton Lake conducted by the U.S. Environmental Protection Agency (1975) calculated somewhat higher nutrient loads, primarily due to much higher estimated inputs from septic systems and residential drainage. As the U.S. Environmental Protection Agency study was much less detailed and thorough than that of Pecor et al. (1973a) and failed to take into account a number of unique features of Houghton Lake identified by them, it is likely that the U.S. Environmental Protection Agency study overestimates nutrient inputs to the lake.

Despite considerable additional development around the shore of Houghton Lake since 1972, the impact on the nutrient budget of the lake has probably been minor. Land use changes in the watershed are constrained by the large amount of state-owned land and open water. Counteracting the impact of additional development, septic systems around the lake have been replaced by municipal sewer systems that do not discharge nutrients into the lake. All of the residential shoreline areas around the lake are now served by sewer systems. Properties more than ¼ to ½ mile from the lake remain on septic systems, but the septic systems serving these properties probably contribute relatively little nutrient loading to the lake.

Plankton

The phytoplankton (microscopic plant) community of the lake was dominated by *Polycystis* and *Lyngbya* in September and by *Fragilaria*, unspecified flagellates and *Polycystis* on November of 1972 (U.S. Environmental Protection Agency, 1973). This phytoplankton community is characteristic of a shallow, moderately eutrophic lake. A more detailed study of the diatom and chrysomonad component of the phytoplankton (Pecor et al. 1973b) found seventeen common species and concluded from the species composition that the Houghton Lake phytoplankton community was indicative of a shallow, alkaline, eutrophic lake with little organic enrichment and substantial wave action. No problematic algal blooms were noted by either study.

The zooplankton (microscopic animal) community of the lake was examined from 1971 through 1973 by Pecor, et al. (1973b). The two rotifer genera *Keratella* and *Polyarthra* accounted for approximately 90% of the zooplankton. Copepods made up 7% of the zooplankton, with nauplii of *Cyclops* and *Diaptomus* accounting for most of the organisms encountered. Cladocerans made up only 3% of the zooplankton, and included *Bosmina* and lesser numbers of *Daphnia* and *Chydorus*. Pecor et al. (1973b) suggested that the strong dominance of small zooplankton is an indication of intense predation by fish.

Benthos

Pecor, et al. (1973b) examined the benthos of Houghton Lake as part of their evaluation of water quality. Due to its shallowness, the benthos of Houghton Lake is dominated by organisms characteristic of littoral areas of large lakes. Both the productivity and diversity of the benthos were high. Approximately 87 percent of the benthos consisted of scuds (*Hyalella azteca*), midges (Chironimidae), fingernail clams (*Pisidium* spp.) and worms (oligochaeta). Many benthic organisms intolerant of low dissolved oxygen concentrations were present. Dense weedbeds supported the greatest density of benthic organisms.

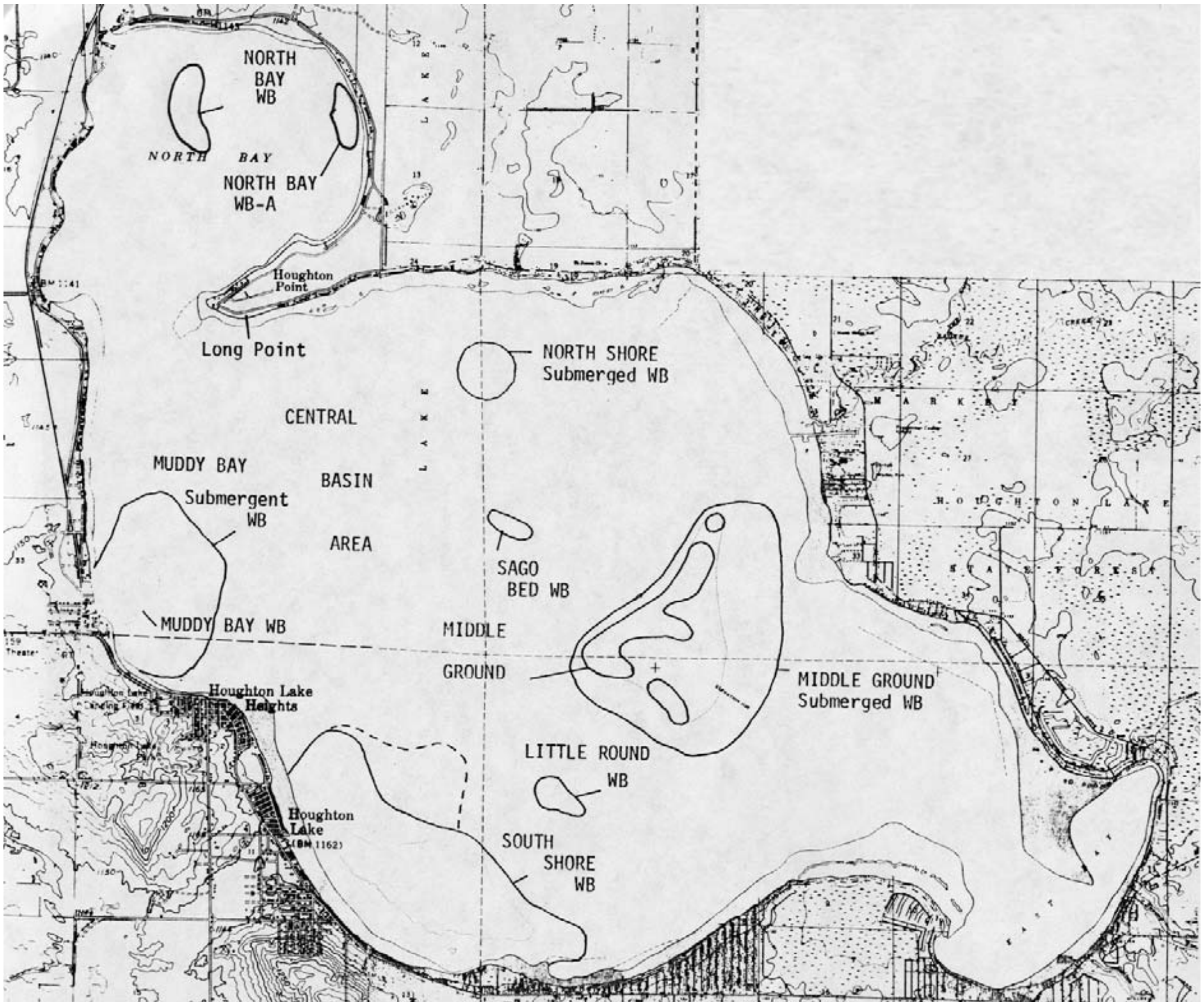
Aquatic Plants

Previous studies agree that Houghton Lake has long supported abundant aquatic plant growth and a diverse community of aquatic plants (Table 3). Evenson, et al. (1973) evaluated the aquatic vegetation of the lake as part of a study of waterfowl use of the lake. They measured a total plant standing crop of 901 pounds per acre (1.01 metric tons per hectare), averaged over the entire lake. Weedbed areas averaged 2,410 lbs/A (2.70 mt/H) and open water areas averaged 600 lbs/A (.67 mt/H). Eight weedbeds were delineated: (1) the South Shore weedbed, (2) the Middle Ground weedbed, (3) the Muddy Bay weedbed, (4) the North Bay weedbed, (5) The North Bay weedbed A, (6) the North Shore weedbed, (7) the Sago [pondweed] bed, and (8) the little round weedbed (Figure 4). In all, these weedbeds occupied approximately one-sixth (17%) of the total area of the lake. The macroalga muskgrass (Chara spp.) dominated many of the beds, and *Elodea* (Canadian pondweed - *Elodea canadensis*) was the most dominant higher plant in the South Shore, Middle Ground, and Muddy Bay weedbeds. Watermilfoils (*Myriophyllum* spp.) were the dominant submersed plants (excluding *Chara,* which is an alga) only in the North Shore weedbed; otherwise they were at most only moderately dominant.

Table 3. Aquatic plants found in Houghton Lake.

Common Name	Scientific Name
Submersed Plants	
Bladderwort	*Utricularia vulgaris*
Coontail	*Ceratophyllum demersum*
Canadian pondweed	*Elodea canadensis*
Alpine pondweed	*Potamogeton alpinus*
Clasping leaf pondweed	*P. richardsonii*
Curlyleaf pondweed	*P. crispus*
Flat-stemmed pondweed	*P. zosteroformis*
Floating leaf pondweed	*P. natans*
Large leaf pondweed	*P. amplifolius*
Ribbon leaf pondweed	*P. epihydrus*
Robbins pondweed	*P. robbinsii*
Sago pondweed	*P. pectinatus*
Small pondweed	*P. pusillus*
Variable pondweed	*P. gramineus*
Whitestem pondweed	*P. praelongus*
Muskgrass	*Chara sp.*
Naiad, water nymph	*Najas sp.*
White water crowfoot	*Ranunculus .*
Eurasian watermilfoil	*Myriophyllum spicatum*
Northern watermilfoil	*M. sibiricum*
Water marigold	*Megalodonta (Bidens) beckii*
Water Stargrass	*Zosterella (Heteranthera) dubia*
Wild Celery	*Vallisneria americana*
Emergent Plants	
Hard-stem bulrush	*Scirpus acutus*
Threesquare bulrush	*S. americanus*
Pickerel weed	*Pontedaria cordata*
Northern wild rice	*Zizania aquatica*
Spatterdock	*Nuphar variegatum*
White water lily	*Nymphaea tuberosa*

Figure 4. Houghton Lake weedbeds (from Evenson, et al. 1973)



Studies of the aquatic vegetation of Houghton Lake conducted during the last decade have expressed increasing concern about the expansion of Eurasian watermilfoil. Bonnette (1996) describes the aquatic vegetation of Houghton Lake in 1996. By 1996, watermilfoil had become the second most dominant submersed plant in the lake and was dense enough in several locations to be a cause for concern. *Elodea* (Canadian pondweed - *Elodea canadensis*) was more abundant and more widespread than watermilfoil. Several other native species were nearly as abundant as watermilfoil, although not as widespread. Continuing concern about the expansion of Eurasian watermilfoil led to a study by the Aquest Corporation in 1999 (Pullman 2000). This study mapped the distribution of Eurasian watermilfoil throughout the lake and determined that Eurasian watermilfoil could be found in nearly 10,000 acres of the lake.

Recent aquatic plant problems in the lake are associated with the replacement of a diverse native plant community by the exotic plant, Eurasian watermilfoil. Studies prior to 1999 did not differentiate between northern watermilfoil and Eurasian watermilfoil, so it is impossible to determine exactly when Eurasian watermilfoil was introduced to the lake, but watermilfoil was not reported as particularly abundant prior to 1996. The distribution pattern described by Bonnette (1996), with watermilfoil forming dense canopied beds at the lakeward and western edges of the south shore weedbed suggests that Eurasian watermilfoil was probably well established in the lake and expanding by 1996. It is not clear whether it was also present during the surveys conducted in the 1970s.

Wild rice was once an important component of the aquatic vegetation of Houghton Lake. A decline of wild rice appears to have begun in 1989 (Bonnette 1996). The cause of the decline is a hotly debated topic. Factors proposed as contributing to the decline include loss of mats of accumulated wild rice detritus (Bonnette 1996), fungal diseases and/or water level changes.

Fish

Houghton Lake is among the most important fishing resources in Michigan. The lake has been stocked with smallmouth bass, northern pike, walleye, yellow perch and bluegill (Schrouder 1993). Studies by the Michigan DNR provide a fairly comprehensive picture of fish populations in the lake. A detailed study of fish populations in the lake during 1955 (Crowe and Latta 1956) estimated that the lake supported 3 to 4 million fish, or 135 to 198 legal-sized fish per acre. The catch in 1955 consisted of 62.9 percent panfish, 18.3 percent gamefish and 18.9 percent roughfish. A less extensive study in 1972 (Pecor et al. 1973b) found similar results and compared growth rates of fish from Houghton Lake from 1922 until 1972 with each other and with the state average. Growth rates of bluegill, pumpkinseed, rock bass and black crappie were consistently higher than the state average, at least by the time fish reached their fourth year. Largemouth and smallmouth bass also grew at rates greater than the state average. The length of these fish species at different age classes did not appear to have changed from 1939 until 1972. Walleye, yellow perch and northern pike in Houghton Lake were all growing at rates below the state average. Growth rates of walleye and yellow perch had been poorest in the 1950s and improved since then, whereas the growth rates of northern pike were found to be stable over time. Another study in 1993 (Schrouder 1993) found a composition of the fish community and growth rates that were similar to those from previous studies.

DNR fisheries personnel insist that Houghton Lake fish populations have not yet begun to show stunting or other impacts likely to result from the expansion of Eurasian watermilfoil (see below). Since the Eurasian watermilfoil invasion is apparently relatively recent, pronounced impacts would not be expected. If Eurasian watermilfoil is unmanaged, these impacts are likely to gradually manifest themselves over time.

Waterfowl

Houghton Lake is an important resource for waterfowl, particularly migrating ducks and coots. Evenson, et al. (1973) evaluated the use of Houghton Lake by waterfowl and the diets of waterfowl using the lake. Aquatic plant materials were an important part of the diet for all of the waterfowl species examined except Goldeneye, at least seasonally. Plant materials were a major part of the diet in both spring and fall in greater scaup, ringed-necked ducks, ruddy ducks, and widgeons and coots. Buffleheads and lesser scaup ate significant amounts of plant material in the fall. Plant species found in significant quantities in waterfowl diets included naiad, *Elodea*, clasping-leaf pondweed, small pondweed, variable pondweed, wild celery, wild rice, and muskgrass.

Management History

Water levels are controlled by an outlet structure. In 1982, the maximum legal lake levels were set at 1138.1 feet above Mean Sea Level (MSL) in the summer and 1137.6 feet above MSL in the winter.

Fishery management began as early as 1921 and has included stocking of the lake with smallmouth bass, northern pike, yellow perch, bluegills and walleye (see above). In addition to stocking Houghton Lake with various fish species, the Michigan DNR developed two large marsh areas on the northwestern side of the lake in 1965 and 1969 that were initially operated as northern pike spawning marshes (Schrouder 1993). These marshes are diked off from the lake and the water level in them maintained by pumping. Due to a lack of natural access to these areas, fish were to be trapped and transferred in and out of them. Northern pike production in these marshes was not as good as expected and they were found to have little impact on pike populations in the lake (Schrouder 1993). Their operation as spawning marshes was discontinued in 1978 and they are presently maintained about a foot above the lake level and used for waterfowl management.

Swimmers' itch treatments were conducted in various parts of the lake since 1944 (Novy et al. 1973). These treatments applied relatively high doses of copper sulfate to kill the snails that serve as intermediate hosts for the swimmer's itch parasites. Copper from the treatments has accumulated in deep soft sediments, but not in most other locations or in most organisms living in the lake.

Recreational Use of the Lake

Houghton Lake is very heavily used for a variety of recreation and is a major resource drawing users from the entire state of Michigan and beyond. Users of Houghton Lake support a local economy that is heavily dependent on tourism. The local year-around population of approximately 11,000 residents swells to near 30,000 during the summer vacation peak from Memorial Day through Labor Day. During the annual TIP-UP TOWN U.S.A.® winter festival held the 3rd & 4th weekends of January 40,000 to 50,000 people visit the area on weekends.

Ecology of Eurasian Watermilfoil

Biology of Eurasian watermilfoil

Eurasian watermilfoil (*Myriophyllum spicatum* L.) is an aquatic plant native to Europe and Asia (Aiken et al. 1979). The exact timing and location of its introduction into North America are unclear: Couch and Nelson (1985) suggest that it arrived in the Washington D.C. area during the 1940s and that it was probably intentionally introduced. Documentation of the spread of Eurasian watermilfoil across North America was initially confused by its similarity to the native North American species northern watermilfoil (*M. sibiricum=M. exalbescens*). At present, Eurasian watermilfoil has spread to 45 states and several Canadian provinces (U.S.G.S. nonindigenous aquatic species database).

As an exotic plant, Eurasian watermilfoil in North America presumably lacks the natural population controls that limit growth within its home range. When Eurasian watermilfoil invades North American lakes, it usually spreads throughout suitable habitat in the lake. Often it first becomes established in water slightly deeper than that occupied by native plant species. From this foothold, it spreads into native plant beds, replacing native aquatic plants (see below). The extent of coverage appears to be related to the trophic status of the lake, with the greatest coverage of Eurasian watermilfoil developing in eutrophic lakes, though lakes of all trophic states usually develop at least some areas of dense Eurasian watermilfoil (Smith and Barko 1990).

Natural declines of Eurasian watermilfoil are common ten to twenty years after the plant becomes widespread (Carpenter 1980a). Certain types of management, particularly large-scale mechanical control, appear to prolong the dominance of Eurasian watermilfoil (Smith and Barko 1990). Declines have been reported from reservoirs along the Tennessee River (Bates and Smith 1994, Smith and Barko 1996); Lake Wingra, Wisconsin (Carpenter 1980a); Currituck Sound, North Carolina (Davis and Brinson 1983); the Chesapeake Bay (Bayley et al. 1968); and the Kawartha Lakes, Ontario (Painter and McCabe 1988). In general, causes of natural Eurasian watermilfoil declines are poorly understood, perhaps because declines result from a variety of different causes (Chambers et al.1994). Typically, declines do not reduce Eurasian watermilfoil abundance to the point where management becomes unnecessary (Smith and Barko 1990).

When Eurasian watermilfoil becomes dominant it causes a variety of problems (detailed below). In recognition of these impacts, Massachusetts, Minnesota, New Hampshire, Vermont, Washington and Wisconsin have initiated Eurasian watermilfoil management programs.

Replacement of Native Plant Species

Invasion of a lake by Eurasian watermilfoil typically results in the replacement of much of the original native plant community by Eurasian watermilfoil (cf: Boylan et al. 1999, Lillie 1986, Madsen et al. 1991, Nichols and Mori 1971). In many cases this results in a substantial reduction in diversity. Boylan et al. (1999) provide detailed, long-term documentation of the expansion of Eurasian watermilfoil in Lake George, New York, and the resulting progressive reduction in abundance of native plants and the diversity of the aquatic plant community.

Eurasian watermilfoil also invades areas that previously supported little or no native plant growth. Initial establishment of Eurasian watermilfoil is often on the deep edge of existing aquatic plant beds. Once Eurasian watermilfoil has established a foothold in these areas, it spreads into existing plant beds, replacing the native species in them. In Houghton Lake, the most prominent Eurasian watermilfoil beds during 1996 occupied the lakeward edge of and an area just west of the south shore weedbed (Bonnette 1996). Since then, it has spread throughout the lake to occupy previously vegetated areas and areas that had not been vegetated.

Water Quality

The dense canopy formed by Eurasian watermilfoil results in greater fluctuations in water chemistry than in native plant communities. Matted Eurasian watermilfoil stems at the water surface inhibit surface water circulation. During the day, oxygen produced by photosynthesis in this layer saturates the surface water and oxygen bubbles escape into the atmosphere. Beneath the canopy, dissolved oxygen concentrations are often lower than those found in native plant beds. At night, oxygen consumption can lead to relatively low dissolved oxygen concentrations under the Eurasian watermilfoil canopy. These processes result in exaggerated vertical and temporal dissolved oxygen fluctuations in dense Eurasian watermilfoil, compared with native plant beds (Honnell et al. 1993).

Dense Eurasian watermilfoil beds have a similar effect on pH. During the day, pH increases due to carbon dioxide removal by photosynthesis. At night, respiration releases carbon dioxide, lowering the pH. Concentration of photosynthetic activity near the surface produces sharp vertical pH gradients similar to vertical gradients of dissolved oxygen. Variations in pH are further magnified by the ability of Eurasian watermilfoil to increase pH to a greater extent than most native plants (Smith 1994).

Dense plant beds can also influence the cycling of phosphorus and other important nutrients (Prentki et al. 1979). Flowing water entering plant beds slows down, which reduces its ability carry suspended sediments. This can lead to increased sedimentation and the accumulation of rich sediments in plant beds. Aquatic plants also release nutrients into the water when they die and begin to decay (Carpenter 1980b). Since most phosphorus and nitrogen in the plants is derived from the sediments via root uptake (Barko and Smart 1981, Best and Mantai 1978, Carignan and Kalff 1980, Carignan 1982), the cycle of growth and decay leads to a net movement of nutrients from the sediments into the water (Barko and Smart, 1980, Landers 1982, Smith and Adams 1986). Plants can also promote the direct release of phosphorus from sediments by increasing pH through photosynthesis, which leads to increased rates of phosphorus release (James et al. 1995). Relative to other plant species, characteristics of Eurasian watermilfoil are likely to result in increased nutrient transfer (Nichols and Shaw 1986), since Eurasian watermilfoil has an unusually high rate of shoot turnover during the growing season (Adams and McCracken 1974) and is capable of raising pH more than other plant species (Smith 1994).

Impacts On Fish and Invertebrate Communities

Both fish and invertebrates are typically more abundant and diverse in aquatic plant beds than in adjacent open water regions (Wiley et al. 1984; Kilgore et al. 1989). Populations of benthic invertebrates beneath submersed vegetation can be more than 100 times larger than those in non-vegetated openings within plant beds (Miller et al. 1989). Eurasian watermilfoil provides a better habitat for invertebrates (Pardue and Webb 1985) and for fish (Kilgore et al. 1989) than the open water of the littoral zone, but not as good habitat as a mixed community of native plant species (Keast 1984). Excessive growth of Eurasian watermilfoil leads to a variety of undesirable impacts on fish populations, including obstruction of predation, altering feeding success and behavior, and covering spawning areas (Engel 1995). Production of forage fish and invertebrates increases directly with increasing macrophyte biomass, whereas largemouth bass production and their condition are maximal at intermediate levels of macrophyte biomass (Colle and Shireman 1980; Wiley et al. 1984). Small fish hide in vegetation, while adult fish remain along edges of vegetation or in open channels within plant beds (Engel 1988). Reduced predation success by largemouth bass in dense macrophyte beds contributes to diminished bass production (Savino and Stein 1982; Engel 1987).

Invertebrate and fish communities in Eurasian watermilfoil beds differ slightly from those associated with other submersed macrophytes. Dvorak and Best (1982) found that Eurasian watermilfoil had the poorest invertebrate fauna of 8 morphologically distinct plant species. Eurasian watermilfoil beds in Lake Opinicon, Ontario, supported significantly fewer benthic and foliar invertebrates per square meter than did mixed beds of pondweeds (*Potamogeton* spp.) and wild celery (Keast 1984), but much of the difference can be attributed to the three-fold higher biomass of the pondweed-wild celery community. In addition, fish abundance in the pondweed-wild celery community during daytime feeding periods was 3 to 4 times greater than in Eurasian watermilfoil beds. Impacts of replacement of native plants by Eurasian watermilfoil are likely to be greatest when Eurasian watermilfoil invasion results in a large change in total plant biomass (Smith and Barko 1990).

Impacts On Waterfowl

There is limited evidence that replacement of native plants by Eurasian watermilfoil can negatively impact waterfowl. In Seneca Lake, New York, overwintering diving ducks were found to suffer from increased weight loss when beds of wild celery (*Vallisneria americana* Michx.) and native pondweeds were replaced by Eurasian watermilfoil (R. Ryan, personal communication).

Interference With Recreation

In most cases, replacement of native plants by Eurasian watermilfoil dramatically increases the extent to which aquatic plants interfere with aquatic recreation. Compared with native plants, Eurasian watermilfoil concentrates its biomass at and near the water surface (Honnell et al 1993, Smith and Barko 1990). The concentrated dense mass of shoots makes it difficult or impossible to boat, swim, water ski, or even fish in Eurasian watermilfoil-dominated areas.

Interference with recreation can lead to a reduction in income derived from individuals using affected lakes for recreation. Reduction in recreation value can also depress the value of lakefront and other nearby properties.

Eurasian Watermilfoil Control Techniques

A number of different techniques have been successfully used to control Eurasian watermilfoil. These techniques vary in terms of their efficacy, rapidity, and selectivity, as well as the thoroughness and longevity of control they are capable of achieving. Each technique has advantages and disadvantages, depending on the circumstances. Techniques that work for other aquatic plants may or may not be appropriate for controlling Eurasian watermilfoil. Likewise, the “best” technique for controlling Eurasian watermilfoil varies from place to place, depending on a number of factors, including the morphometry and hydrology of the lake, the spatial distribution of Eurasian watermilfoil, and the other aquatic plant species present.

Selectivity is a particularly important characteristic of control techniques. Nearly all aquatic plant control techniques are at least somewhat selective, in that they affect some plant species more than others. Even techniques such as harvesting that have little selectivity within the areas to which they are applied can be used selectively, by selecting only certain areas in which to apply them. Selectivity can also occur after the fact, as when a technique controls all plants equally but some grow back more rapidly. One facet of selecting an appropriate aquatic plant control technique is matching the selectivity of the control technique with the goals of aquatic plant management. When controlling Eurasian watermilfoil, for example, it is typically desirable to use techniques that control Eurasian watermilfoil with minimal impact on most native plants.

Physical

Physical control strategies include such things as water level drawdown and bottom barriers. Although these can be quite effective, their use is limited to special circumstances. Successful use of water drawdown for controlling Eurasian watermilfoil typically requires drawing down water levels sufficiently to expose the entire Eurasian watermilfoil population. Most effective control of Eurasian watermilfoil is achieved when drawdown exposes Eurasian watermilfoil plants to freezing conditions during the winter. Drawing down the water level to expose only part of the Eurasian watermilfoil population may control shallow Eurasian watermilfoil, but often results in expansion of Eurasian watermilfoil into deeper water, particularly if low water levels are maintained into the start of the growing season.

Benthic barriers control aquatic plants by covering bottom sediments with a barrier that renders rooted plant growth difficult or impossible. Use of benthic barriers is usually confined to relatively small areas of waterfront associated with individual properties, boat launches or bathing beaches. In Michigan, benthic barriers are normally limited to 1600 ft^2 in size.

Mechanical

Mechanical control uses cutting, dredging or maceration to eliminate aquatic plant growth. The most commonly used mechanical control technique for Eurasian watermilfoil in Michigan is mechanical harvesting, using machines that cut plant stems and pick up the cut fragments for disposal. Mechanical controls, such as rotovating (underwater rototilling), that disturb bottom sediments are illegal in Michigan. The advantages of mechanical control include immediate removal of plants from cut areas and the removal of organic matter and nutrients.

Most mechanical control techniques have little inherent selectivity, in that they control whatever plants are in the areas to which they are applied. Where a mix of Eurasian watermilfoil and native species exists, harvesting favors the plant species that grow back most rapidly following harvesting. In most cases, Eurasian watermilfoil recovers from harvesting much more rapidly than native plants. Thus, repeated harvesting hastens the replacement of native species by Eurasian watermilfoil and often leads to dense, monospecific beds of Eurasian watermilfoil in frequently harvested areas. For this reason, harvesting is not generally recommended as a primary Eurasian watermilfoil control method.

Harvesting has a number of negative impacts. Harvesting stirs up bottom sediments and shakes off loosely attached materials from plants, thus reducing water clarity. Many invertebrates and small fish are removed with the cut material (Mikol 1985). After harvesting, Eurasian watermilfoil typically grows back more rapidly than native plants; thus, repeated harvesting often reduces native plant abundance and creates nearly pure beds of Eurasian watermilfoil.

In Michigan, harvesting does not require a permit.

Chemical

Chemical control uses chemical herbicides to reduce or eliminate excessive aquatic plant growth. Herbicides have the advantage that they are economical and very effective. Modern aquatic herbicides have been extensively tested to ensure that they can safely be used in the aquatic environment. Among other things, these tests ensure that they are low in toxicity to humans and aquatic animals and that and they are not overly persistent or bioaccumulated in fish or other organisms.

A permit is required to use any herbicide in a Michigan waterbody larger than 10 acres.

Systemic Herbicides

Systemic herbicides are translocated throughout plants and thereby kill entire plants. Fluridone, 2,4-D, and trichlopyr are systemic herbicides that can effectively control Eurasian watermilfoil. As of September 2001, trichlopyr has not yet been labeled for aquatic use, although the USEPA is expected to issue an aquatic label soon. 2,4-D and trichlopyr are readily used to control Eurasian watermilfoil in localized areas. Fluridone is poorly suited to localized applications, owing to its solubility and slow action; therefore it is typically applied to very large areas of lakes, or to the entire lake. In Michigan, nearly all fluridone treatments are whole-lake treatments.

Whole-lake fluridone applications are by far the most effective means of controlling Eurasian watermilfoil. Successful fluridone treatments yield a dramatic reduction in the abundance of Eurasian watermilfoil, often reducing it to the point that Eurasian watermilfoil plants are difficult to detect following treatment. Factors essential to the success of whole-lake fluridone applications include: accurate volume measurements, water exchange rates low enough to allow sufficient contact time, and a fluridone dose rate sufficient to control the strain of Eurasian watermilfoil present in the lake. When all of these factors are adequately evaluated prior to treatment, failure of a whole-lake fluridone application is unlikely.

Applied properly, 2,4-D can also yield major reductions in the abundance of Eurasian watermilfoil, but long-term reductions are more difficult to achieve using 2,4-D than using whole-lake fluridone applications. In order to achieve long-term reductions using 2,4-D, it is necessary to treat a large fraction of the Eurasian watermilfoil present. Treatments must be very even and dose rates accurate. Under the best of circumstances, some areas will probably need to be treated repeatedly before the Eurasian watermilfoil in them is controlled. Also, the difficulty of finding and treating areas of sparse Eurasian watermilfoil makes it likely that Eurasian watermilfoil will be reestablished from plants surviving in these areas.

Contact Herbicides

Contact herbicides kill above-sediment parts of plants, but are not translocated to belowground plant parts and rarely kill entire plants. The contact herbicides available for controlling Eurasian watermilfoil include diquat (tradename Reward) and endothall (tradenames Aquathol and Hydrothol). Plants recover relatively rapidly after treatment with contact herbicides. Under ideal conditions, Eurasian watermilfoil can recover in as little as four weeks. For this reason, contact herbicides are used to provide short-term relief from excessive Eurasian watermilfoil populations while awaiting the opportunity to use a long-term control technique.

Biological

Biological controls reduce aquatic plant growth using other organisms that consume aquatic plants or cause them to become diseased. Most modern biological controls are highly specific, impacting only the target plant. Selectivity is typically achieved by using insects or other control organisms that only affect the target species. The use of generalist herbivores that eat a wide variety of plants is generally regarded as excessively risky. Indeed, most of the horror stories concerning biological control gone awry involve the use of herbivores with broad feeding preferences that attack non-target organisms after being released into the environment.

In general, biological controls produce slower, less complete control of target plants than mechanical and chemical control techniques. Biological controls are also less predictable than other types of controls: it is common for them to work in some instances and fail in others. Reasons for success or failure are often unknown.

On the positive side, biological controls offer the potential to provide highly specific, long-term control of exotic species at a very reasonable cost. Most successful efforts to achieve biological control of exotic species use control organisms imported from the original home of the pest. When these "classical" biological controls succeed, they disperse themselves from a few introduction locations and establish self-maintaining populations, yielding widespread long-term control at a very low cost.

Milfoil Weevil

The milfoil weevil is commercially available for use in controlling Eurasian watermilfoil under the tradename Middfoil™. The weevil, *Euhrychiopsis lecontei*, is a native North American insect that consumes Eurasian watermilfoil. The milfoil weevil eats virtually nothing but Eurasian watermilfoil and spends most of its life on the Eurasian watermilfoil plant. The only other plant fed on by the milfoil weevil is northern watermilfoil (*Myriophyllum sibiricum*), which is a native, North American watermilfoil that is very closely related to Eurasian watermilfoil. Although the weevil eats northern watermilfoil, weevil feeding has little effect on it (Sheldon and Creed 1995); thus the weevil has almost no impact on non-target aquatic plants.

The milfoil weevil was discovered following a natural decline of Eurasian watermilfoil in Brownington Pond, Vermont (Creed and Sheldon 1993). The weevil has apparently caused declines of Eurasian watermilfoil in several other water bodies, including Fish Lake, Wisconsin, (Lillie 1996) and McCullom Lake, Illinois, and Cenaiko Lake, Minnesota (Newman and Biesboer 2000). The strategy for using the weevil to control Eurasian watermilfoil involves introducing large numbers of weevils to augment natural populations of the weevil. The decline in Brownington Pond occurred at a weevil density of 3 to 4 per stem (Creed and Sheldon 1995), though Newman and Biesboer (2000) report that the decline in Cenaiko Lake, Minnesota occurred at a density of 1.6 weevils per stem. More recently, Newman et al. (2001) have suggested that densities as low as 0.25 weevils per stem may be sufficient to initiate a decline in Eurasian watermilfoil abundance.

Weevils have a much greater impact on Eurasian watermilfoil than would be expected solely due to the amount of Eurasian watermilfoil actually consumed. For one thing, weevil larvae burrow in the stem, consuming the vascular tissue and interrupting the flow of sugars and other materials between the upper and lower parts of the plant (Creed and Sheldon 1994). Holes where the larvae burrow into and out of the stem allow disease organisms a foothold in the plants and allow gases to escape from the stem, causing the plants to lose buoyancy and sink (Creed et al. 1992). There is less light deeper in the water, so sinking reduces the ability of the plants to photosynthesize. Reduction in the buoyancy of plants also makes residual Eurasian watermilfoil less visible and problematic than a similar amount of unaffected vegetation.

Concerns about the use of the weevil as a biological control agent relate to whether introductions of the milfoil weevil will reliably produce reductions in Eurasian watermilfoil and whether the resulting reductions will be sufficient to satisfy users of the lake. It is not clear why weevil populations naturally achieve a population density sufficient to control Eurasian watermilfoil in some waterbodies but not in others. Without an understanding of the factors limiting natural weevil populations, it is impossible to predict where and when weevil introductions are likely to succeed. Also, like most biological controls, weevils do not eliminate their food source; thus a moderate residual population of Eurasian watermilfoil is expected even when weevils are successful. To date, too few weevil introductions have been followed long enough to determine with any certainty what fraction of weevil introductions will successfully control Eurasian watermilfoil or exactly how large residual populations of Eurasian watermilfoil will be. Weevil control of Eurasian watermilfoil is also very slow compared with other techniques, and residents of lakes accustomed to the rapidity of herbicides are unlikely to be sufficiently patient to wait for weevils to work.

Use of the milfoil weevil in Michigan lakes requires only a statewide permit from the Michigan Department of Agriculture, which has already been issued. In Michigan, no additional permit is required to use milfoil weevil in an individual waterbody.

<u>Other Insects</u>

In addition to the milfoil weevil, there are a number of other herbivorous insects known to impact Eurasian watermilfoil. These include a moth (Johnson et al. 1998, 2000) and a midge (Kangasniemi and Oliver 1983, MacRae and Ring 1993). At present, none of these organisms is being used as an operational biological control for Eurasian watermilfoil.

<u>White Amur</u>

The White Amur or grass carp is an herbivorous Asian fish. White amur consume relatively large quantities of aquatic plant material and can provide effective aquatic plant control. The most appropriate applications for white amur are in the south, where they are used to control hydrilla and other plants high on their feeding preference list. Even in these applications, white amur tend to produce all-or-nothing aquatic plant control: it is extremely difficult to achieve a stocking rate of white amur sufficient to selectively control nuisance species without eliminating all submersed vegetation. They are not particularly appropriate for Eurasian watermilfoil control because Eurasian watermilfoil is low on their feeding preference list; thus, they eat most native plants before consuming Eurasian watermilfoil. In order to prevent breeding of these exotic fish, sterile, triploid fish are often used for aquatic plant control. White amur are illegal in Michigan.

Disease-Causing Organisms

A number of diseases of Eurasian watermilfoil have been described, and there have been several attempts to use disease-causing organisms to control Eurasian watermilfoil (c.f., Smith et al. 1989). At present, none of these organisms is being used as an operational biological control for Eurasian watermilfoil.

Current Conditions in the Lake

Aquatic Plant Communities

Methodology

ReMetrix LLC conducted an analysis of aquatic vegetation in Houghton Lake using three different approaches: 1) a point-grid survey using physical collection of plants in the field, 2) a new hydroacoustic technique for quantifying bottom coverage and density of submersed vegetation, and 3) acquisition and analysis of high-resolution satellite imagery.

Each survey method has different strengths and weaknesses. Physical sampling of vegetation along a lake-wide grid of survey points permits identification of species present but usually provides only qualitative evaluation of plant abundance (i.e., cover and biomass). Hydroacoustic survey is the newest form of assessment for submersed aquatic vegetation. Through sophisticated analysis of georeferenced echosounder data, bottom cover and height of plants can be quantified (see below for further description). This allows calculation of plant biovolume, a combination of coverage and height information that estimates the percentage of the water column at any given point occupied by submersed vegetation. These measurements of plant abundance are quantitative in nature, and because they are georeferenced, can be repeated in an objective manner in future assessments. However, hydroacoustic measurements alone cannot currently determine which species are present in the vegetation scanned by the echosounder. Analysis of remote-sensed imagery provides a complete picture of lake surface and near-surface conditions. The latest in high-resolution satellite imagery can depict features as small as a few feet in length. For large systems like Houghton Lake, the entire water body can be captured in a single picture. Due to its digital georeferenced format, this imagery can be analyzed in GIS (Geographic Information Systems) to precisely quantify areas of lakes with near-surface and topped-out growth of submersed vegetation. In many cases, lake water quality limits image analysis of submersed plant to evaluation of near-surface growth, but high water clarity can result in discrimination to depths as much as 10-15 feet. Species-level discrimination with satellite image analysis is usually not possible.

Point-Grid Field Survey

A grid of survey points on the lake was created in GIS software using digital georeferenced remote-sensed imagery of Houghton Lake from ReMetrix archives as base information. The spacing of grid points was set at 300 meters. Some additional points were added to provide better lake coverage. Overall, more than 900 individual sites around the lake were targeted for survey. Once grid points were established, their coordinates were input into GPS units (Global Positioning System) used to navigate to these individual survey sites on the lake. Field maps were also created by overlay of survey point locations onto existing imagery.

Once mobilized to the field, ReMetrix aquatic scientists navigated to each of the survey points using GPS. At each site, a double-sided collection rake was used to uproot plants and pull them to the surface for species identification. At a minimum, two rake throws were taken at each site with a goal of at least 6 feet of bottom dragged in each throw. Relative abundance of each species collected was also recorded using the a-b-c-d ranking system adopted by the state of Michigan (a = rare – < 3% cover, b = sparse – 3 to 20%, c = common 20-60%, and d = dense - >60%). Plant architecture was also noted (bottom growing, in the water column, topped out). Samples of less common species that were difficult to identify in the field were collected in plastic bags, placed on ice, and returned to the laboratory for identification.

All plant information was recorded in the field using a differential GPS (DGPS) unit equipped with a datalogger and an extensive pre-loaded data dictionary for efficient data entry. Final vegetation data was returned to the laboratory upon completion of the survey where it was compiled and analyzed by ReMetrix GIS analysts. Maps of distribution and abundance were developed for each species identified during the survey. Other map products developed included overall evaluations of lake vegetation density and architecture independent of species, a species diversity map noting number of different species collected and identified at each survey site, and projections of whole-lake fluridone treatment effects on plant density and architecture in year of treatment.

Hydroacoustic Vegetation Assessment

ReMetrix currently uses an advanced hydroacoustic approach to perform assessments of submersed aquatic vegetation. This system, originally termed the Submersed Aquatic Vegetation Early Warning System or SAVEWS, was developed through research by the U.S. Army Engineer Research and Development Center at the Waterways Experiment Station in Vicksburg, Mississippi (Sabol and Melton 1995, Sabol and Burczynski 1998). Research continues through the joint efforts of the US Army ERDC, BioSonics Inc., and ReMetrix LLC. ReMetrix fully integrates the hydroacoustic approach with remote sensing and mapping techniques for full assessment of aquatic ecosystems.

The current hydroacoustic study of Houghton Lake was conducted using a scientific-grade 420 KHz digital echosounder directly linked to a differential GPS through a high-end laptop computer and accompanying software. This system measures the hydroacoustic signatures of bottom and plants and ties this information to a constant flow of DGPS information. This raw data is saved and returned to the laboratory where specialized software uses custom algorithms to process echosounder data and calculate bottom coverage and geometry of submersed plant communities. The result is a collection of literally thousands of georeferenced datapoints at 2-3 meter intervals along each survey transect (Figure 5). Each

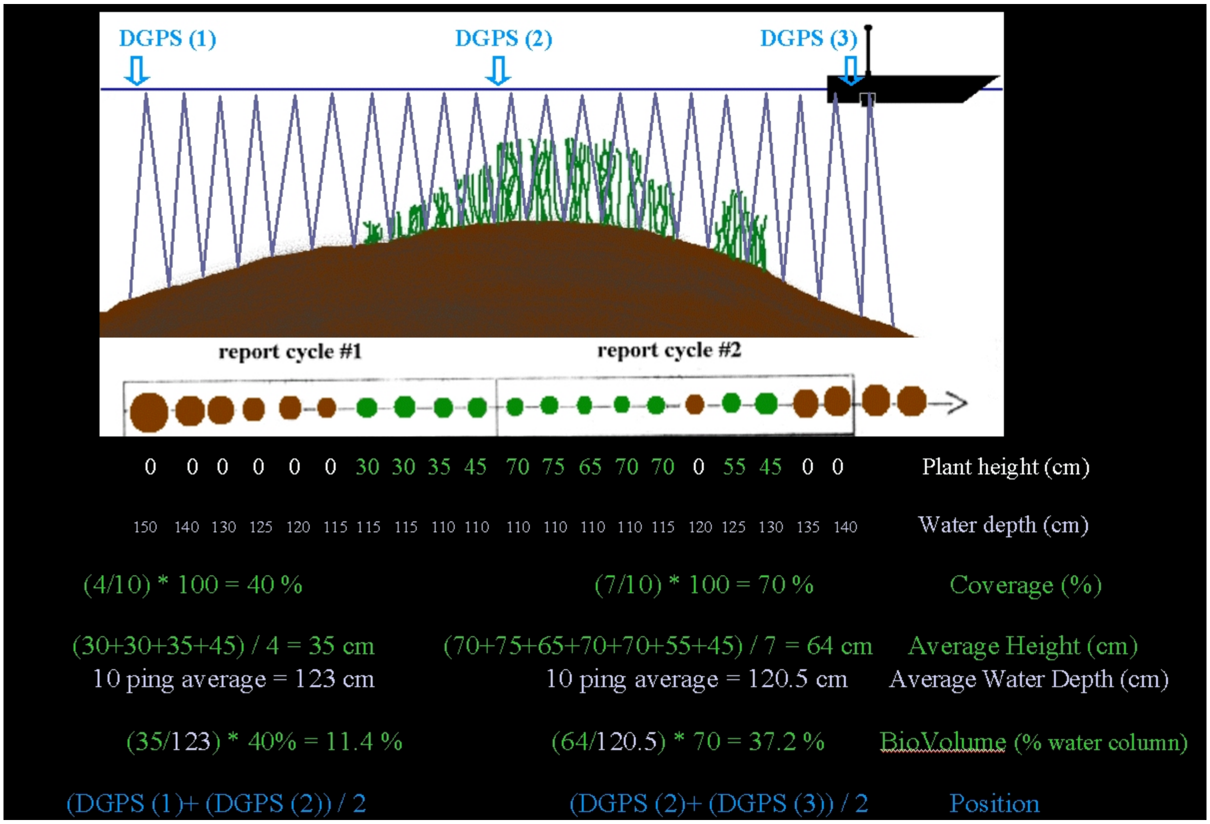


Figure 5. Schematic representation of hydroacoustic assessment of submersed aquatic vegetation with sample data.

data point or report contains information on mean plant height, bottom coverage of vegetation, and water depth. Plant height and bottom coverage data can be combined with water depth information to produce a new metric called plant biovolume, a representation of the fraction of the water column filled with submersed vegetation. For example, in 6 feet of water with a mean plant height of 3 feet and milfoil bottom coverage of 100%, milfoil biovolume would equal 50%. If plant height was reduced to 1.5 feet in this example, biovolume would decrease to 25% despite no difference in bottom coverage by plants. Biovolume calculations allow quantification of how much of the water column is affected by nuisance plant growth resulting in reduced navigation, habitat quality, etc. All hydroacoustic measurements and resulting calculations can be input directly into GIS for further analysis and map production. More information on the design of the echosounder hardware and software can be found in the references cited above.

The 2001 hydroacoustic survey of Houghton Lake was performed on July 24. A complete hydroacoustic survey of lake vegetation was not feasible under the budgetary and time constraints of this project. Therefore, the focus of the survey was collection of several whole-lake transects of hydroacoustic data to develop baseline information for the lake that could be referenced in future hydroacoustic assessments and assist in evaluation of any management action.

Six transects of data were collected during the hydroacoustic survey: one on the north bay of the lake, four within the main central basin of the lake, and one in the easy bay of the lake (Hydroacoustic Transects – map in Appendix B). During field data collection, the ReMetrix survey team took rake samples to verify the presence of vegetation. Species delineation was not a focus of the final analysis, but results of point grid measurements were used to roughly correlate hydroacoustic vegetation measurements with species present. The positions of areas with distinct changes in plant community architecture or bottom type were also recorded as supplementary datapoints using the navigational GPS units to assist laboratory interpretation.

The current processing software also cannot accurately separate bottom and plant signatures from surface noise in areas where dense plant canopies approach the surface. In evaluating this data, ReMetrix scientists used field notes, supplementary GPS data, and visual interpretation of echosounder output to assist delineation and extrapolate appropriate values for coverage and biovolume. Bottom coverage in areas with dense near-surface or topped-out vegetation was estimated at 100%. Average depth of near-surface plant canopies was set at 1 or 2 feet based upon field notes on canopy architecture.

Final graphs were developed showing changes in plant height, water depth, bottom coverage of vegetation, and biovolume of vegetation along the length of each hydroacoustic survey transect. Extrapolated results in areas with near-surface growth were noted on each graph along with calculations of average bottom coverage and biovolume for the specific transect (corrected to account for extrapolated data).

Satellite Image Analysis

With 4-meter ground resolution, multispectral imagery from the IKONOS satellite (Space Imaging LLC) represents an excellent source of high-resolution satellite data for detection of aquatic vegetation. The multispectral sensor on this satellite captures information in four spectral bands: visible red, visible green, visible blue, and near infrared. With careful contrast adjustment, these bands can be analyzed to detect not only emergent, floating, and topped-out submersed vegetation, but in areas with good water quality, also the canopy of submersed plants below the surface.

IKONOS imagery of Houghton Lake was initially acquired on August 6, 2001. Upon receipt of this imagery, ReMetrix scientists determined that much of this image data was unacceptable for proper analysis of submersed vegetation due to a combination of cloud cover and surface water characteristics. ReMetrix requested a quick turnaround on a second acquisition. This second image acquisition occurred on September 22 and 30, 2001. While these collection dates were removed from the time of field sampling by almost 2 months, late September is an excellent time to capture conditions of near-peak plant biomass since widespread submersed plant senescence usually does not occur until November. ReMetrix collected a similar image on October 18, 2000 with excellent results. Not all of the

September 2001 collected imagery was of sufficient quality for analysis. Almost all of the September 22 data was affected by wind streaks on the lake. However, the vast majority of the September 30 scene, covering about 95% of the lake's surface area, was clean and served as the backbone of the analyzed image set. Most of the lake's east bay (~1,000 acres) was only in the September 22 scene. Therefore, ReMetrix used a clean section of the August 6 imagery of the east bay for its analysis.

ReMetrix scientists used contrast-adjusted true (red, green, blue) and false color (near infrared, red, green) composites of IKONOS data to detect submersed vegetation in Houghton Lake. User-interactive feature mapping was used to select pixels known from 2001 field survey results to represent submersed vegetation. Two vegetation classes were created: topped-out and submersed. Once the classification was complete, the areas of classified pixels were calculated in GIS.

Results and Discussion

Point-Grid Field Survey

The ReMetrix survey team started its 2001 field effort on July 23 and completed all field activities on August 1. 912 total sites were studied during the 2001 survey. A map with the distribution of these points is provided in Appendix A. The irregularity of site position in the southern part of lake was due to technical problems with navigational GPS units. Table 4 presents the results of physical collection of vegetation from these 912 survey sites around Houghton Lake. With a survey grid having 300-meter spacing, each survey site represented approximately 22 acres of the lake (total acreage ~ 20,050). Overall, submersed vegetation was found at 705 (or 77.3%) of the 912 survey sites. No vegetation was found at the remaining 207 sites. These results indicate that the total vegetated area of the lake (i.e., area with any amount of aquatic plant growth) is 15,500 acres.

Eurasian watermilfoil (EWM) was found at 490 of the 912 sites (53.7%). Therefore, the total area of Houghton Lake with any level of EWM growth is approximately 10,800 acres. Density measurements indicate that 243 of the 490 sites with EWM (49.6% of EWM sites or 26.6 % of 912 total sites) had common or dense coverage of the plant (i.e., > 20% bottom coverage). Therefore, approximately 5,300 surface acres of the lake have common or dense levels of EWM growth. A map of EWM distribution and abundance (Figure 6 – full version in Appendix A) shows that sites with the densest

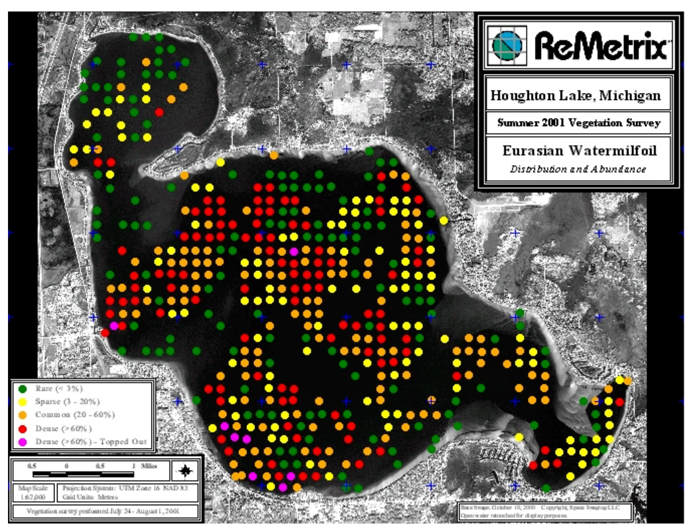


Figure 6. Distribution and abundance of Eurasian Watermilfoil. Red or pink = dense, orange = common, yellow = sparse, green = rare. Full version in Appendix A.

Table 4. Species of submersed aquatic plants found during point-grid survey of Houghton Lake, Michigan conducted from July 24-August 1, 2001. For each species, the number of sites where the plant was found at particular densities is noted: Dense (D) - >60% cover, Common (C) – 20-60% cover, Sparse (B) – 3-20% cover, and Rare (A) - <3% cover. The number of sites where the species was present is also noted as a total and as a percentage of the 912 sites surveyed in the study.

Species	Number of Survey Sites					
	Dense (D)	Common (C)	Sparse (B)	Rare (A)	TOTAL	% of Survey Sites
Eurasian Watermilfoil	113	130	104	143	490	53.7%
Elodea	15	33	106	143	297	32.6%
Muskgrass	15	41	105	103	264	28.9%
Clasping-leaved Pondweed		11	71	75	157	17.2%
Thin-leaved Pondweed	1	4	30	77	112	12.3%
Naiad	1	2	27	53	83	9.1%
Whitestem Pondweed		15	24	31	70	7.7%
Wild Celery		2	19	35	56	6.1%
Variable-leaved Pondweed			8	28	36	3.9%
Coontail		2	11	20	33	3.6%
Water Stargrass	1	5	3	19	28	3.1%
Nitella	3	1	6	8	18	2.0%
Water Marigold			6	5	11	1.2%
Illinois Pondweed			2	6	8	0.9%
Buttercup				8	8	0.9%
Large-leaved Pondweed			1	4	5	0.5%
Flatstem Pondweed			1	4	5	0.5%
Northern Watermilfoil			1	3	4	0.4%
Robbins' Pondweed		1	1	2	4	0.4%
Curly-leaved Pondweed		1		2	3	0.3%
Floating-leaved Pondweed				2	2	0.2%
Bladderwort				1	1	0.1%

growth are primarily found in the main central basin of the lake, but various densities of EWM are also found scattered throughout areas of the lake's north and east bays. Overall, besides EWM, 21 other types of submersed aquatic plants were collected and identified (Table 4). The most common plants found besides EWM were *Elodea* (32.6% of sites*)* and muskgrass (28.9% of sites). Clasping-leaved and thin-leaved pondweeds were found at 17.2% and 12.3% of survey sites, respectively. All other species collected were found at less than 10% of survey sites (Table 4).

Distribution and abundance maps of all species collected are found in Appendix A along with separate maps showing cumulative vegetation density and plant community architecture (all species included) in 2001 and projected values in year of whole-lake fluridone treatment. The results of the grid survey have also been tabulated using standard Michigan DEQ procedures for species coverage calculation (Appendix A). Since vegetation surveys conducted according to DEQ recommendations normally sample only the potentially vegetated zone of the lake, whereas the grid used here sampled areas too deep and too shallow to support vegetation, only grid points where some vegetation was present are included in the analysis. According to this calculation, the total cumulative vegetation cover was 39.5 percent (including muskgrass). Native aquatic plants accounted for 17.6 percent of this, and Eurasian watermilfoil had a calculated cover value of 21.9 percent.

Hydroacoustic Vegetation Assessment

Table 5 and associated individual transect graphs (see Appendix B) show the results of hydroacoustic measurements of submersed vegetation along six lake-wide transects of Houghton Lake on July 24, 2001. Transect 1 running through the north bay of the lake had the least amount of bottom coverage and plant biovolume (9.1% and 3.8% respectively). A comparison with point data showed that the most abundant species along transect 1 were EWM, clasping-leaf pondweed, and naiad. Bottom coverage of vegetation along transects 2-5 in the main basin of lake was 41-45% with percent biovolume ranging from 13.6 to 23.1%.

Table 5. Transect averages for bottom coverage and biovolume (i.e., portion of water column occupied by plants) of vegetation determined from hydroacoustic assessment of Houghton Lake, Michigan conducted July 24, 2001. Averages are corrected to reflect extrapolated data in dense near-surface or topped-out stands where hydroacoustic signal was disrupted. Transect length analyzed is also provided. Location of survey transects and graphical representation of results shown in separate map and associated graphs (Appendix B).

Transect ID	Bottom Coverage	BioVolume	Transect Length (meters)
1	9.1%	3.8%	2,898
2	41.6%	21.9%	8,417
3	45.2%	21.4%	8,117
4	41.6%	13.6%	8,924
5	45.7%	23.1%	5,494
6	36.1%	14.0%	4,190

As indicated by higher biovolumes, transects 2, 3, and 5 had the most near-surface or topped-out vegetation (light green on graphs – Appendix B). If results of all 4 transects are taken as a representative average of the main basin of the lake, mean plant cover and percent biovolume would be 43.5% and 20.0% respectively. As indicated by point survey results, EWM represents the vast majority of this plant coverage and biovolume. Only along the western ends of transects 3 & 5 does *Elodea* represent a significant fraction of the quantified vegetation. Transect 6 through the east bay of the lake also showed significant cover and biovolume. The western end of the transect shows a dense bed of primarily EWM. The remainder of vegetation detected in transect 6 is a mixture of EWM, pondweeds, and *Elodea*.

Bottom-growing vegetation, such as naiad along transect 1, was underquantified in this particular hydroacoustic analysis. Due to relatively rough water on the day of survey (up to two-foot waves), vertical oscillation of the hydroacoustic transducer required a lower sensitivity setting in interpretation software. Therefore, coverage by bottom-growing vegetation (less than 1.5 feet in height) has been left undetected in this analysis. However, it should be noted that re-analysis of raw echosounder output from this survey is feasible if future studies require a more complete picture of plant growth near the sediment surface in specific areas of the lake.

Satellite Image Analysis

Maps with base composite images and associated classification can be found in Appendix C. Analysis of true- and false-color IKONOS images of Houghton Lake detected 3,127 acres of submersed vegetation and 49 acres of topped-out submersed growth (total detected: 3,176 acres or 15.8% total lake coverage). This result represents acreage detected for the western 95% of the lake from the September 30 scene. With data from the August 6 collection, the eastern 5% of the lake (east bay – 950 acres) had no detectable submersed vegetation due to limitations in water clarity and/or atmospheric conditions. Also, classification of approximately 2,000 acres near the western shore of the lake was limited due to haze and/or surface wave action at the time of the September 30 collect. Both of these problems resulted in some level of underestimation of the acreage of detectable vegetation for the whole lake. This issue is unfortunately not an uncommon one in the analysis of IKONOS imagery of lake systems. Space Imaging, the provider of IKONOS data, will not guarantee less than 20% cloud cover in any collected imagery and does not currently consider low levels of surface reflectance from wave action (i.e., levels that often prevent submersed vegetation classification) as grounds for reacquisition of image data.

Due to confusion with open water, classification of submersed vegetation is often limited to areas with common or dense growth of plants. In the classified section of the image (i.e., western 95%), 172 field survey sites showed common levels of submersed growth (20 – 60% cover) and 134 sites showed dense levels of submersed growth (>60 % cover). Based on those levels and the mean of each cover class (common mean = 40% cover, dense mean = 80% cover) and assuming each site represents approximately 22 acres of the lake, 3,872 acres of the western 95% of the lake would be covered by submersed plant growth in these classes. By this calculation therefore, 18% of the submersed vegetation (common or dense) in this area of lake was not detected by satellite. This difference is likely due to a combination of limitations in water clarity, problems with haze in westernmost areas of the lake, and plant architecture. On this last point, 16 field sites showed dense levels of bottom-growing muskgrass or naiad, and 43 sites showed common levels of growth of these plants. Sites dominated by these plants are often not detected in satellite analysis due to depth of growth or confusion with sediment signatures. Using the mean levels from before, as much as 660 acres of submersed cover dominated by muskgrass or naiad may not have been detected in this analysis. This number is very close to the 695.5-acre difference between the total submersed coverage area for the western 95% of the lake (3,872 acres) and satellite-detected coverage (3,176 acres).

Areas with detected submersed vegetation agree well with an overlay of the distribution of 2001 field survey sites having common and dense levels of EWM (Figure 7 – full version in Appendix C). Using the mean cover values as before, the total bottom coverage of these EWM classes would be 3,133 acres, a number very close to the classified submersed total of 3,176 acres. This result suggests that the vast majority of the vegetation detected by satellite consisted of EWM.

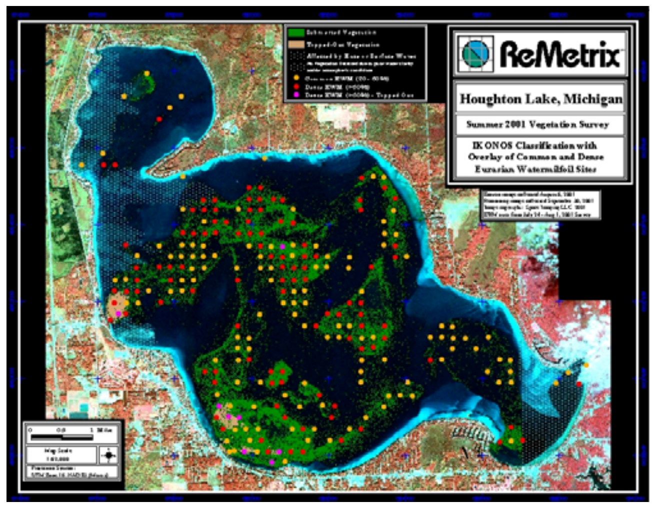


Figure 7. Classification of IKONOS satellite image with overlay of 2001 field sites found with dense and common Eurasian Watermilfoil. Red or pink = dense, orange = common. Full version in Appendix C.

Milfoil Weevil Abundance

Methodology

The abundance and distribution of the milfoil weevil in Houghton Lake was evaluated by sampling plant stems at approximately half of the sampling grid locations used to evaluate aquatic plant populations. Weevil samples were collected from grid intersections along every other east-west grid line. At each sampling location, six 30-cm long terminal stem segments were collected, provided that sufficient Eurasian watermilfoil was present. Stem segments were returned to the laboratory, and the number of weevil eggs, larvae, pupae and adults on each 30-cm stem segment were counted under 10-30x magnification. Where Eurasian watermilfoil was sufficiently dense near the surface, the number of stems in a 0.1 m^2 quadrat was counted 30 cm below their terminal end (to provide an estimate of the number of 30-cm terminal stems per square meter).

Results and Discussion

Eurasian watermilfoil samples for weevil population measurements were collected from 109 grid locations. Weevils were found in 43 of 109 (39%) of the weevil sampling locations at densities from less than 0.25 to more than 1 weevil per stem (see Appendix D). The remaining 61 percent were below the detection threshold of 0.17 weevils per stem. Most areas of the lake had few (<0.25 weevils per stem) or no weevils. Locations with higher weevil densities tended to occur in clusters. Weevil density was above 0.25 to 0.5 weevils per stem (the approximate threshold for impact on Eurasian watermilfoil) in several parts of the lake, mostly in parts of the south shore weedbed and along the northern shore of the lake. Weevils achieved a density in excess of 1 weevil per stem in only two areas of the lake, one in the south shore weedbed and one near the eastern shore of the lake.

The approximate number of weevils per square meter was calculated for locations where a Eurasian watermilfoil stem count had been made (Appendix D). Scarcity of areas where stems could be collected from the surface resulted in sparse coverage for this measurement; nonetheless a pattern similar to the weevil-per-stem data emerges. Substantial weevil densities occurred primarily along the southern edge of the south shore weedbed, and in a few other isolated locations. In these cases, high weevil densities were produced where weevils were found in at least moderate abundance on dense Eurasian watermilfoil.

The results presented here provide a relatively detailed picture of weevil distribution. The clumped distribution of weevils in Houghton Lake suggests that controlling Eurasian watermilfoil in the lake using weevils will require raising the weevil density throughout significant portions of the lake above the threshold for control, a value that is unknown, but may be in the range of one-quarter to several weevils per stem (see Newman and Biesboer 2000). Determining which parts of the lake have exceeded the control threshold is probably more promising than attempting to calculate the total number of weevils required for control, since the location of weevils in the lake matters. At present, only a few areas in the lake have achieved high enough numbers of weevils per stem to begin to impact Eurasian watermilfoil. Most areas of the lake are well below the threshold for weevil impact.

The results of this survey are not directly comparable to those obtained by EnviroScience as part of the MiddFoil™ process. These samples were collected from a uniform sampling grid, which covered the entire lake. In contrast, MiddFoil introduction sites are typically selected in areas deemed suitable for weevil establishment and an effort is made to intentionally select particular Eurasian watermilfoil stems showing varying degrees of weevil damage (Stems are NOT collected randomly). Thus, the results presented here probably yield weevil numbers that are more representative of weevil density in the entire lake, whereas MiddFoil surveys are more sensitive and more readily able to detect low numbers of weevils. It is recommended that future weevil surveys continue to sample plant stems randomly from a grid that covers a substantial portion of the lake, both to allow comparisons with weevil abundance in 2001 and to provide a more accurate picture of the weevil population in the entire lake.

Water Quality

<u>Sampling</u>

Waters samples were collected from Houghton Lake, Roscommon Co., MI, and its tributaries on September 22-23, 2001. Water samples were collected at 13 sites distributed around the lake (Table 6, Figure 8). Four of the sites in the main body of the lake were located in dense weed beds. At each site, water was collected at the surface and just above the sediments using a Van Dorn bottle sampler. We also collected water samples from 7 tributary streams and one outlet stream (Muskegon River) by filling sample bottles just beneath the water surface. Water samples were kept on ice until they were returned to the MWRC laboratory in Mount Pleasant where they were logged in and processed.

Temperature, oxygen, and conductivity profiles were measured at 4 open water and 3 weed bed sites using a Hydrolab Surveyor 3 instrument pack. We also used the Hydrolab to measure temperature, oxygen and conductivity at all stream sites. We measured pH using a hand-held meter; however, the meter was operable only for the first open water site on Sept. 22. Light profiles were measured at 2 open water and 2 weed bed sites using a Licor photometer. Transparency was measured at open water sites in the North Bay, Main Body and SE Bay of the lake using a Secchi disk. Aquatic plant species, sediment composition, and weather conditions were noted at all sites (see field notes in Appendix E).

In the laboratory, water samples were filtered for Total Dissolved Phosphorus (TDP) and Nitrate/Nitrite ($NO_3 + NO_2$). Alkalinity was measured with an acid titration and pH was recorded. Total Phosphorus (TP), TDP, Ammonium (NH_4) and Nitrate were measured using standard colorimetric procedures. Turbidity was measured with a Hach Turbidometer. Chlorophyll a was extracted from 500-1000 ml of water and measured on a Bechman Spectrophotometer.

Table 6: Geographic Coordinates (decimal minutes) for Sampling Sites in Houghton Lake, MI.

Location	Northing	Easting
North Bay Sites		
Site 9	N 44 23.216	W 84 46.192
Site 10	N 44 22.275	W 84 47.026
Main Body, Open Water		
Site 11	N 44 21.530	W 84 45.446
Site 12	N 44 19.172	W 84 43.578
Site 13	N 44 19.491	W 84 40.758
Site 16	N 44 19.160	W 84 43.732
Site 21	N 44 20.968	W 84 42.535
Main Body, Weed Beds		
Site 17	N 44 18.863	W 84 45.290
Site 18	N 44 20.571	W 84 46.998
Site 19	N 44 21.501	W 84 43.695
Site 20	N 44 21.884	W 84 43.985
Southeast Bay		
Site 14	N 44 18.936	W 84 38.361
Site 15	N 44 18.917	W 84 39.562

Water Quality Evaluation

One can accurately assess the productivity and ecological health of a lake by carefully measuring water quality parameters. The concentration of nutrients and oxygen as well as the abundance of plant life are particularly useful for determining productivity status. Lakes that have low nutrients, high oxygen, and low plant abundance are considered *oligotrophic* (low productivity), whereas lakes that have high nutrients, low oxygen, and high plant abundance are considered *eutrophic* (highly productive).

Houghton Lake may be classified as a ***well-buffered, well-mixed lake*** based on water quality measurements collected on September 22, 2001 (Tables 7, 8). Houghton Lake had circumneutral water (pH = 7.5-7.9) with a moderately high buffering capacity (alkalinity = 1.7-2.1 meq/L). Calcium carbonate was not present in the water. Ions dissolved in the water produced conductivity values (202-211 μohms/cm) typical of many Michigan lakes. The small difference in temperature (<1°C) between surface and bottom indicates that Houghton Lake mixes frequently. Mixing was particularly complete in the shallow North Bay (Tables 7, 9). Only the weed bed at site 17 showed thermal stratification – a quick drop in temperature with depth (Table 9). There was plenty of oxygen at all sample locations except deep at site 17. Here, the low dissolved oxygen reading (5 mg/L) most likely results from decomposition of plant material and may be stressful to fish species.

Table 7: Average Water Chemistry Measurements (surface and bottom) for inflowing streams and four locations in Houghton Lake, MI (September 2001)

Site	Location	Depth (meters)	Temp. (deg. C)	Cond@25C (uohm/cm)	pH	Alkalinity (meq/L)	DO (mg/L)	Turbidity (NTU)	NO3+NO2 (ug/L)	NH4 (ug/L)	TP (ug/L)	TDP (ug/L)	Chlorophyll (ug/L)
Inflow Streams	Surf. Avg	0.0	15.8	241	7.8	1.89	5.8	2.6	79.2	4.8	4.6	1.3	4.6
	stdev.		1.1	71	0.3	0.29	1.8	1.4	60.4	2.8	2.4	0.5	2.1
North Bay	Surf. Avg	0.0	16.1	205	7.8	1.78	8.9	2.0	39.7	2.4	1.5	0.0	3.4
	stdev.		0.2	6	0.1	0.03	0.2	0.2	10.4	0.0	1.0	0.0	1.2
	Bottom Avg.	1.5	16.1	204	7.8	1.76	8.7	1.3	35.9	3.8	2.1	0.0	3.8
	stdev.	0.0	0.2	5	0.1	0.06	0.3	0.2	2.6	2.3	0.4	0.0	0.0
Main, Open	Surf. Avg	0.0	17.4	209	7.5	1.69	8.7	1.7	32.3	6.6	3.8	0.8	5.2
	stdev.		0.4	2	0.2	0.18	0.3	0.5	5.8	8.0	4.1	0.6	1.6
	Bottom Avg.	3.8	16.6	210	7.8	1.92	7.9	2.7	31.6	6.8	5.5	1.2	6.7
	stdev.	1.0	0.1	2	0.1	0.06	0.4	1.3	8.3	7.0	6.9	1.0	2.8
Main, Weed	Surf. Avg	0.0	17.5	202	7.9	1.79	9.7	2.6	27.7	2.1	3.9	0.0	9.9
	stdev.		1.0	11	0.1	0.18	1.0	2.7	6.1	1.2	4.5	0.0	11.3
	Bottom Avg.	2.0	16.3	210	7.8	1.80	7.5	10.1	29.8	3.1	12.2	0.8	19.6
	stdev.	0.9	0.2	14	0.1	0.09	1.8	17.3	7.4	2.3	19.3	0.7	32.5
SE Bay	Surf. Avg	0.0	17.2	211	7.9	2.10	8.8	1.5	26.1	2.8	2.2	0.3	5.1
	stdev.		0.1	0	0.1	0.37	0.2	0.4	1.3	0.1	1.2	0.2	0.1
	Bottom Avg.	4.5	16.3	210	7.8	1.86	8.0	2.3	24.2	3.9	6.2	0.3	6.1
	stdev.	2.1	0.1	4	0.0	0.03	0.3	0.9	1.7	0.3	6.4	0.2	2.8

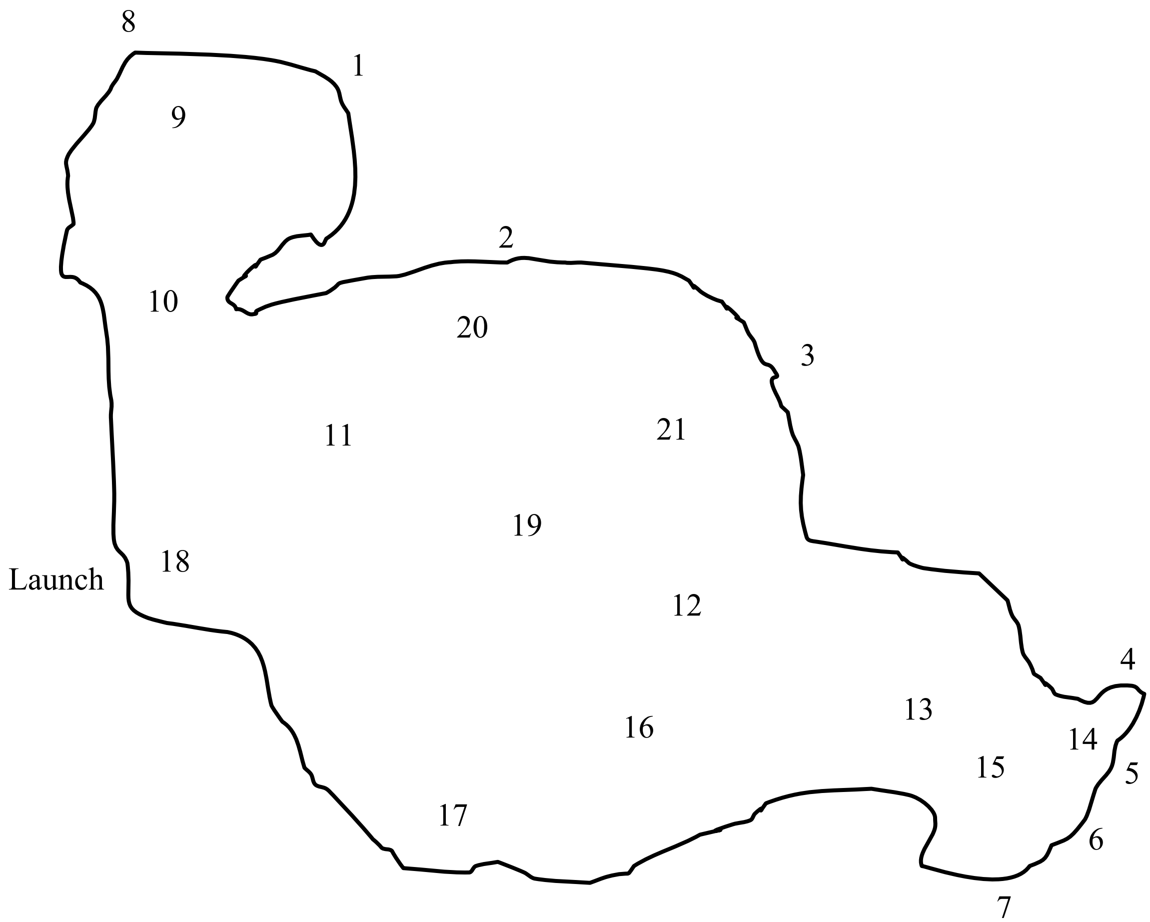


Figure 8: Water Quality Sampling Sites on Houghton Lake, Roscommon Co., MI
Stream Sites: 1-8
North Bay Sites: 9-10
Main Body Open Water Sites: 11-13, 16, 21
Main Body Weed Beds: 17-20
Southeast Bay Sites: 14-15

Table 8: Physical and Chemical Measurements at Open Water and Stream Sites in Houghton Lake, MI (September 2001)

Location	Depth (meters)	Temp. (deg. C)	Cond@25C (uohm/cm)	pH	Alkalinity (meq/L)	DO (mg/L)	Turbidity (NTU)	NO_3+NO_2 (ug/L)	NH_4 (ug/L)	TP (ug/L)	TDP (ug/L)	Chlorophyll (ug/L)	Sediments
Stream Sites													
Site 1	0.0	15.38	234	7.89	1.80	3.23	4.10	59.08	7.07	6.78	1.64	5.89	grass
Site 3	0.0	15.90	240	7.74	2.00	6.73	1.40	44.65	2.62	1.70	<0.30	2.65	Sand/organic
Site 4	0.0	16.30	223	7.42	1.52	4.10	1.30	83.5	8.88	4.70	1.48	7.17	organic
Site 5	0.0	13.88	378	8.21	2.40	5.82	2.40	197.9	2.65	5.61	0.66	1.67	Sand/detritus
Site 6	0.0	17.04	194	8.01	1.80	7.36	2.10	35.04	5.58	1.89	<0.30	6.14	Sand
Site 7	0.0	16.18	177	7.53	1.84	7.41	4.50	55	2.14	7.10	<0.30	4.3	Sand/detritus
Site 8	0.0	16.91	223	7.60	2.04	7.59	2.00	13.77	4.27	2.18	0.38	7.3	Fine organics
North Bay Sites													
Site 9	0.0	15.98	209	7.85	1.80	9.04	2.10	47.01	2.35	2.27	<0.30	4.24	organic /sand
Site 9	1.5	15.90	207	7.71	1.80	8.91	1.45	37.73	2.16	1.76	<0.30	3.77	
Site 10	0.0	16.22	201	7.65	1.76	8.75	1.80	32.31	2.41	0.80	<0.30	2.55	Clay
Site 10	1.5	16.22	200	7.84	1.72	8.50	1.20	34.12	5.45	2.34	<0.30	3.82	
Main Body, Open Water													
Site 11	0.0	16.64	208	7.11	1.56	8.48	1.30	31.69	2.42	<0.30	0.54	2.64	
Site 11	3.0	16.42	208	7.74	1.92	7.98	1.50	28.86	2.37	0.37	0.38	3.57	
Site 12	0.0	17.67	210	7.54	1.48	8.98	1.40	37.09	3.18	1.47	<0.30	6.6	Organic Muck
Site 12	2.5	16.66	211	7.96	1.96	7.41	3.70	44.55	4.8	3.51	2.34	10.87	
Site 13	0.0	17.63	211	7.61	1.88	8.65	1.60	28.15	2.39	1.18	0.29	4.89	clay
Site 13	4.5	16.71	212	7.75	1.96	8.38	1.20	22.15	2.76	2.13	<0.30	4.76	
Site 16	0.0	17.37	210	7.49	1.68	8.33	2.50	25.43	20.93	2.76	<0.30	5.42	clay/organics
Site 16	4.5	16.63	211	7.74	1.96	7.89	3.10	28.74	19.22	3.85	0.49	6.95	
Site 21	0.0	17.55	207	7.56	1.86	8.82	1.85	39.02	4.2	9.88	1.50	6.24	clay/organics
Site 21	4.5	16.67	208	7.82	1.82	7.68	3.90	33.88	4.92	17.56	1.76	7.25	
Main Body, Weed Beds													
Site 17	0.0	19.00	200	7.90	2.00	10.94	6.60	36.61	3.89	10.61	<0.30	26.57	rich organic
Site 17	1.0	16.04	227	7.58	1.80	5.09	36.00	39.54	6.4	41.04	1.27	68.34	
Site 18	0.0	17.10	187	7.89	1.76	9.94	1.20	22.95	1.28	1.65	<0.30	6.53	organic
Site 18	1.5	16.31	192	7.90	1.68	9.44	1.75	21.7	1.37	2.32	<0.30	2.82	
Site 19	0.0	17.21	209	7.70	1.56	9.33	1.50	25.93	1.82	1.49	<0.30	4.23	
Site 19	3.0	16.53	209	7.75	1.88	7.82	1.20	28.51	1.68	3.55	<0.30	4.59	
Site 20	0.0	16.71	210	7.98	1.84	8.46	0.95	25.41	1.43	1.96	<0.30	2.18	
Site 20	2.5	16.45	212	7.79	1.84	7.55	1.50	29.45	2.78	1.71	0.26	2.46	
Southeast Bay													
Site 14	0.0	17.11	211	7.80	1.84	8.95	1.20	25.12	2.89	1.38	<0.30	5.01	organic
Site 14	3.0	16.31	207	7.85	1.88	7.82	1.60	23.02	4.09	1.65	0.28	4.12	
Site 15	0.0	17.28	211	7.99	2.36	8.68	1.75	26.98	2.74	3.02	0.26	5.2	organic
Site 15	6.0	16.23	212	7.79	1.84	8.21	2.90	25.43	3.68	10.68	<0.30	8.05	

Table 9: Light, Temperature and Chemistry Profiles at Open Water and Weed Bed Sites in Houghton Lake, MI (September 2001)

Open Water						Weed Beds					
Depth (m)	Temp. C	pH	DO (mg/L)	Light ($ue/m^2/s$)	Conductivity (umhos/cm)	Depth (m)	Temp. C	pH	DO (mg/L)	Light ($ue/m^2/s$)	Conductivity (umhos/cm)
Site 10						Site 17					
0.0	16.22	8.60	8.75	153.70	201	0.0	19.00		10.94		200
0.5	16.22		8.62	93.56	201	0.5	16.94		9.09		210
1.0	16.22		8.59	86.78	200	1.0	16.04		5.09		227
1.5	16.22	8.40	8.50	57.74	200						
	extinction coefficient=			0.643							
Site15						Site 18					
0.0	17.28		8.68		211	0.0	17.10		9.94	243.2	187
0.5	17.26		8.82		210	0.5	16.87		9.71	167.4	189
1.0	17.26		8.78		208	1.0	16.45		9.42	142.5	192
2.0	17.14		8.75		212	1.5	16.31		9.44	51.8	192
3.0	16.97		8.72		213						
4.0	16.55		8.64		208		extinction coefficient=			1.092	
5.0	16.37		8.38		218						
6.1	16.23		8.21		212						
Site 16						Site 19					
0.0	17.37		8.33		210	0.0	17.21		9.33	1010	209
0.5	17.34		8.23		210	0.5	17.15		8.95	624.2	212
1.0	17.36		8.20		210	1.0	16.94		8.84	212.7	211
2.0	17.16		8.32		211	2.0	16.55		8.23	44.47	208
3.0	16.73		8.14		211	3.0	16.53		7.82	5.303	209
4.0	16.63		8.07		211						
4.5	16.63		7.89		211		extinction coefficient=			1.783	
Site 21											
0.0	17.55		8.82	406.90	207						
0.5	17.55		8.77	257.30	212						
1.0	17.45		8.11	195.50	208						
2.0	17.22		8.52	90.02	210						
3.0	16.9		8.43	23.08	211						
4.0	16.68		7.77	14.39	214						
4.5	16.67		7.68	3.56	208						
	extinction coefficient=			1.013							

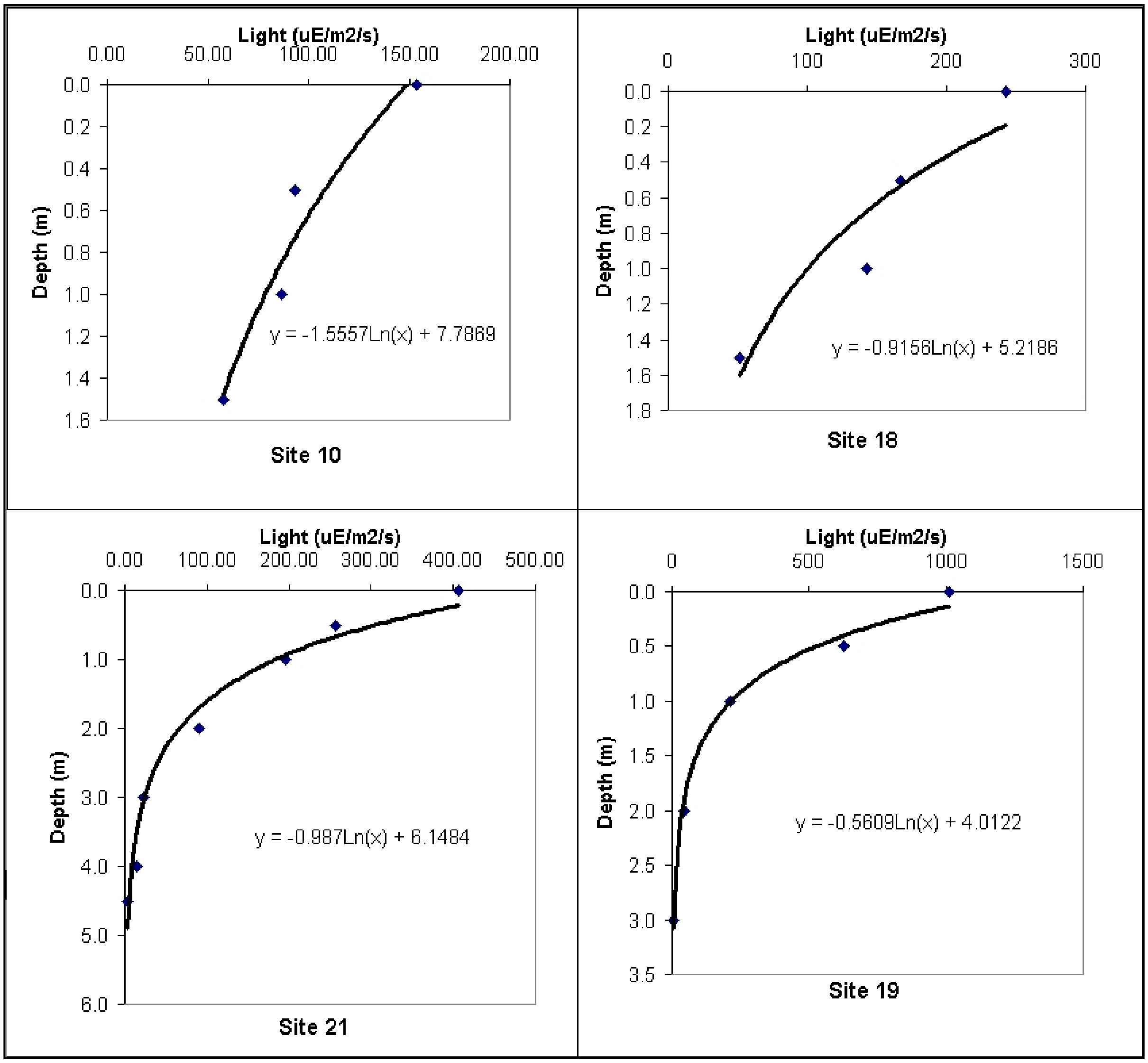


Figure 9: Light Profiles for Open Water (Sites 10, 21) and Weed Beds (Sites 18, 19) in Houghton Lake, MI (September 2001)

Nutrient concentrations were generally low throughout Houghton Lake. Total phosphorus (TP) concentrations were low (<10 µg/L) at all sites except at the bottom of sites 17 and 21 (Table 8). TP concentrations are usually less than 10 µg/ L in oligotrophic lakes (Wetzel 1983). Low dissolved phosphorus measurements (0-2.3 µg/L) in all samples indicate that most of the phosphorus was bound up in particles. This was especially true at site 17 where particles were visible in the water sample and turbidity values exceeded 10 NTU (Table 8). Houghton Lake should be classified as ***oligotrophic*** based on its TP concentration.

Inorganic nitrogen (nitrate and ammonium) is usually present in low concentrations (<1000 µg/L) in natural waters and rarely exceeds 10,000 µg/L (Lind, 1985). On September 22, 2001, the concentration of nitrate and ammonium in Houghton Lake was low at all sampling locations, never exceeding 50 µg/L (Table 8). Nitrogen is an important nutrient for plant growth, and low levels may result from actively growing algae and aquatic plants.

Algal abundance is best estimated by measuring the chlorophyll *a* concentration in water samples. Chlorophyll *a* was moderate (2-10 µg/L) at most sample sites (Table 8). Exceptionally high chlorophyll values at site 17 suggest that the particles collected in the water sample were living algal cells. The moderate algal abundance in Houghton Lake clouds the water and reduces transparency to 1.8 m in North Bay and 2.8-3.0 m in the rest of the lake. These are typical Secchi disk values for a moderate to highly productive lake (Wetzel 1983). Light diminishes quickly in the lake water and has an extinction coefficient of 0.64-1.0 in the open water and 1.1-1.8 in the weed beds (Table 9, Figure 9). Houghton Lake should be considered ***mesotrophic*** based on its chlorophyll *a* values and moderate Secchi depth.

The dense beds of rooted aquatic plants (particularly Eurasian Milfoil) are spots of high productivity. Within these beds, surface water is calm and warm. Algae grow profusely on the surface of the plants and eventually fall off into the water providing food for small invertebrates. Fish species are prevalent in and around the weed beds (see field notes). However, if oxygen levels decrease within the weed bed, fish may move toward the perimeter or leave the weed bed altogether.

The seven inflowing steams/canals contribute nutrients, dissolved ions and sediments to Houghton Lake. Average stream nitrate concentration (particularly site 5) was higher than that of Houghton Lake (Table 7). Average stream conductivity was 241 µohms/cm, 24% higher than that sites in Houghton Lake. Three of the streams contributed cool water to the lake, and four had sandy sediment at their mouths (Table 8). This sediment may eventually end up in Houghton Lake. Site 5 (Spring Brook Creek) was particularly interesting. It had cold water (14°C) with high ion concentrations (cond. = 378 µohms/cm), lots of nitrate (197 µg/L) and low oxygen (5.8 mg/L). This stream may be a good brook trout habitat, but the high nitrate concentrations indicate human impact upstream.

<u>Conclusions</u>

Water quality measurements taken in September 2001 indicate that Houghton Lake is ***mesotrophic***. Nutrient concentrations (especially TP) are low, yet algae and aquatic plants grow abundantly in the open water of the lake. The lake is receiving a steady supply of nitrate from its seven tributaries, particularly Spring Brook Creek.

Goals of Aquatic Plant Management in Houghton Lake

Controlling Eurasian watermilfoil

Aquatic plant problems in Houghton Lake have resulted from the proliferation of the nonindigenous aquatic plant Eurasian watermilfoil. Given the potential of this exotic plant to aggressively expand and replace native vegetation and the problems associated with its dominance, the aim of management should be reduce Eurasian watermilfoil to a relatively low abundance throughout Houghton Lake. Strategies used to manage this species should therefore be capable of reducing Eurasian watermilfoil abundance lakewide. The Eurasian watermilfoil population should be maintained at a sufficiently low abundance that large monospecific beds of Eurasian watermilfoil are not present and native plants dominate the vegetation of the lake.

Maintaining Native Plant Diversity and Abundance

Native aquatic plants are a valuable and important component of the Houghton Lake ecosystem. The strategy for managing Eurasian watermilfoil should ensure that, in the long term, native plant diversity and abundance are preserved. Since Eurasian watermilfoil itself has the potential to dramatically reduce native plant abundance and most control techniques are not perfectly selective, short-term reductions in native plant populations may be tolerated as control techniques reduce Eurasian watermilfoil abundance to maintenance (low) levels. Once Eurasian watermilfoil is under control in the lake, every effort should be made to maintain native plant abundance and diversity. There is no evidence that native plant populations were causing problems for the Houghton Lake ecosystem or for users of the lake prior to the invasion of Eurasian watermilfoil; therefore control of native plants is not recommended as a plant management goal at this time.

Options for Managing the Aquatic Plant Problem in Houghton Lake

Option 1—Whole Lake Fluridone Treatment

Fluridone treatment would produce the most rapid, effective Eurasian watermilfoil control. A successful fluridone treatment would eliminate *at least* 80% of the Eurasian watermilfoil in the lake. (Fluridone treatments are warranted to control at least 80% of the Eurasian watermilfoil in the lake—see below.) Most fluridone treatments eliminate more than 80% of the Eurasian watermilfoil. Removal of Eurasian watermilfoil would be rapid. Fluridone would most likely be applied in the spring, and control would be achieved by midsummer. Because the entire lake would be treated, the treatment would control Eurasian watermilfoil in all parts of the lake, including parts where surveys may not have detected it and where it is too sparsely distributed for convention herbicide treatments to be practical. Fluridone produces sufficiently rapid control that there would be little or no need to pick up rafted plant material, either during the year of treatment or in subsequent years.

Fluridone is capable of providing extremely reliable control of Eurasian watermilfoil, though there have been a few fluridone failures using the "6 bump 6" protocol dictated by the Michigan DEQ. Success of a whole-lake fluridone treatment of Houghton Lake will be dependent upon: (1) conducting the application when water exchange rates are sufficient low to allow adequate contact time, and (2) using a treatment protocol sufficient to control the strain of Eurasian watermilfoil present in the lake.

Successful fluridone treatment at the concentrations used in Michigan requires a contact time of at least six to eight weeks. The average long-term hydraulic residence time of the lake, 1.2 years, is long enough that Eurasian watermilfoil control using fluridone should be readily achieved under average conditions. During an average year, flows are several times the long-term average during the spring, decreasing to rates near the annual average by mid May. Using the standard Michigan DEQ protocol, the success of fluridone treatments decreases when treatments are delayed longer than mid May. Ideally, the flow rate at the outlet of the lake should be measured and the initial fluridone application conducted once the flow rate has dropped sufficiently to ensure adequate contact time. In the absence of actual outlet flow measurements, flow at Evart could be monitored and treatment conducted once the weekly average flow rate at Evart has dropped below 1500 cfs. If flows exceed 1500 cfs, the treatment should be delayed as long as possible, but not beyond late May. An absolute high-flow cutoff of 4000 cfs is recommended. Should flow rates exceed this limit past the middle of May, fluridone treatment should be delayed until the following year.

Given the expense of whole-lake fluridone treatment of Houghton Lake, Eurasian watermilfoil plants from the lake should be tested prior to treatment to determine whether a standard fluridone application conducted using the MI-DEQ "6-bump-6" protocol will adequately control them, and tested after application to determine whether plants have received an adequate dose to kill them. The manufacturer of Sonar offers proprietary (patent pending) plant testing under the tradenames PlanTest™ and EffecTest™. If patent restrictions allow, the manufacturer of Avast may be able to provide similar testing. In the absence of test results indicating otherwise, this report assumes that the Eurasian watermilfoil in Houghton Lake can readily be controlled by a fluridone treatment conducted according to the standard Michigan DEQ protocol.

Success of a whole-lake fluridone treatment should be warranted by the manufacturer of the herbicide. The normal warranty specifies that fluridone will eliminate at least 80 percent of the Eurasian watermilfoil present prior to treatment. If less than 80 percent of the Eurasian watermilfoil is eliminated, the manufacturer will replace the herbicide used in the application (the customer is normally responsible for the cost of reapplication.) If this option is selected, bidders should be required to provide a written warranty specifying the percentage of Eurasian watermilfoil control that is guaranteed, what measure will be used to evaluate control, and what remedies will be provided if the warranted control is not achieved. As a starting point, it would be reasonable for the warranty to guarantee at least an 80 percent reduction in Eurasian watermilfoil coverage measured in 2001, as calculated by MI-DEQ methods from surveys of the same vegetation grid points used in the 2000 and 2001 surveys.

The major drawbacks of a whole-lake fluridone treatment involve possible impact on non-target aquatic plants and concerns about possible impacts of large-scale aquatic plant removal. Although low rate fluridone treatments, such as those allowed in Michigan, are quite selective, some non-target plants in Houghton Lake would be adversely affected. The impact of reducing or removing these plant species depends on their abundance and the likelihood that they will recover following treatment (see maps of projected effects in year of treatment – Appendix A). The non-target plant species of greatest concern are *Elodea* (Canadian pondweed - *Elodea canadensis*), naiad (*Najas* spp.) and water marigold (*Megalodonta beckii*). *Elodea* is very abundant in Houghton Lake; in fact it was probably the most abundant aquatic plant in the lake prior to the expansion of Eurasian watermilfoil. At present it remains very abundant in the lake, growing densely under Eurasian watermilfoil in many locations. *Elodea* is quite susceptible to fluridone, and is often severely reduced or eliminated by even low rate fluridone treatments. Anticipating that a whole-lake fluridone treatment might dramatically reduce the amount of *Elodea* in the lake, reintroduction of this species in the year following treatment is recommended. Naiad would probably be eliminated during the year of treatment, but spontaneous recovery from seed is likely in subsequent years. Water marigold is highly susceptible to fluridone, and would probably be eliminated from the lake by a whole-lake fluridone treatment. Water marigold would probably not return to the lake after fluridone treatment unless planted. It is moderately abundant in Houghton Lake, and its elimination would have little impact on habitat quality but would reduce the diversity of the plant community on the lake.

The Fisheries Division of the Michigan Department of Natural Resources has consistently opposed whole-lake fluridone treatments because of their concern that extensive plant removal could have an adverse impact on fish populations, even if the plants removed are Eurasian watermilfoil. To date, neither their own studies nor those conducted by others have supported the DNR Fisheries Division's concerns. Indeed a study of the effects of whole-lake fluridone treatments on fish conducted by a DNR biologist (Schneider 2000) found that most detectable impacts of fluridone treatment on fish populations were positive. It should be noted that the lakes studied by Schneider were treated with higher doses of fluridone than currently allowed by the Michigan DEQ. Similarly, a study of food web impacts of fluridone treatments conducted by biologists from Michigan State University found that food web impacts of whole lake fluridone treatments did not appear to be particularly harmful.

Despite the initial success of whole-lake fluridone treatments, Eurasian watermilfoil will recover in the lake and additional treatments will be required in the future. The cost of a whole-lake fluridone treatment is high initially, but decreases after the initial treatment until the treatment must be repeated. The Michigan DEQ imposes the restriction that whole-lake fluridone applications occur no more frequently than once every three years. For budgeting purposes, it was assumed that a fluridone application would be required every four years. If fluridone applications are highly successful, they may not need to be repeated this often.

Option 2—Milfoil Weevil

The milfoil weevil (tradename: MiddFoil™) could be used to control Eurasian watermilfoil in Houghton Lake. Compared with herbicides, the weevil produces only a moderate degree of control. If the weevil alone is used, it is likely that the lake will continue to support a fairly sizeable population of Eurasian watermilfoil. It is difficult to specify exactly how large the remaining population of Eurasian watermilfoil would be, but it is reasonable to assume that Eurasian watermilfoil will not be reduced below 20 percent of the current population. Weevils reduce the buoyancy of plants, so the remaining Eurasian watermilfoil will probably be less visible and interfere less with recreation than current watermilfoil beds. There are substantial advantages to spreading introductions over a number of years, to reduce the risk that a one-year weevil project might encounter conditions that are unfavorable to weevil establishment. If weevils are used, the introduction of several hundred thousand weevils each year for 4 to 5 years is recommended.

The main drawback of this approach is the uncertainty concerning its success and longevity. Milfoil weevil management projects have simply not been followed long enough to provide a reliable estimate of the long-term effort and cost required to maintain Eurasian watermilfoil control. Introduced weevil populations may be self maintaining in the long term, but the apparent inability of weevils to achieve sufficiently high population densities to control Eurasian watermilfoil on their own raises questions about the likelihood that weevils will achieve long term control without occasional reintroduction.

If weevils are used to control Eurasian watermilfoil in Houghton Lake, performance guidelines should be established in advance and the progress of control monitored to ensure that guidelines are met. As a starting point, it is recommended that Eurasian watermilfoil be reduced by at least 30 percent by the third year (from the first introduction), 50 percent by the fourth year, and 70 percent by the fifth year. Reductions should be calculated by comparing the number of acres occupied by Eurasian watermilfoil at a density of common or dense. Failure to achieve targeted reductions shall trigger a reevaluation of the strategy used to control Eurasian watermilfoil.

Since it would take several years for the weevil to control Eurasian watermilfoil in the lake, rafts of plant material would continue to collect along the lakeshore for a number of years. If this option were selected, it would be desirable to include removal of this plant material as part of the management program. The budget for removal assumes that harvesters will be used to remove floating rafts of plants and other equipment will be used to remove plant material that has washed up on the beach. During calm periods when plants rafts are not being formed, harvesters can be used to cut boat lanes through the larger Eurasian watermilfoil beds. If possible, contract harvesting companies and existing local equipment should be used. Using contractors and existing equipment provides flexibility, necessary since the need for plant pickup is expected to decrease as management succeeds. If sufficient contractors do not exist or existing local equipment is inadequate, it may be necessary to purchase harvesters or other equipment to remove plants.

Option 3—Simultaneous Integrated Management

An integrated approach would use a combination of several control techniques to manage Eurasian watermilfoil in Houghton Lake. One possible integrated approach would rely on herbicides to provide rapid Eurasian watermilfoil control in critical areas, while using the weevil to achieve long-term control. This option would provide more rapid initial control of Eurasian watermilfoil in high-priority areas than using the weevil alone. Still, large-scale control will be relatively slow, and removal of rafted plant material will be required, as described under Option 2, though to a slightly lesser extent.

Herbicide applications used as part of this strategy would be spot applications in areas where rapid control is particularly desirable. At present, the best herbicide for controlling Eurasian watermilfoil in this sort of application is 2,4-D. Once trichlopyr (tradename Renovate) receives an aquatic label, it could be substituted for 2,4-D, though it will be more expensive. Due to well setbacks, a contact herbicide such as diquat would be used to control Eurasian watermilfoil in canals and other areas within 250 feet of the shore. The budget provided for this option includes sufficient funding for approximately 2000 acres of 2,4-D application the first year of management, declining thereafter. The locations to be treated with herbicides should be selected to provide relief where it is most needed. Presumably these areas would include canals, affected shoreline areas, nearshore areas of the south shore weedbed, boat lanes through extensive Eurasian watermilfoil beds, and other areas as necessary.

Concerns about the long-term success of this option would be those described for using the weevil alone. Herbicide applications included in this strategy are designed to provide short-term relief and are not large enough to achieve long-term reductions in Eurasian watermilfoil. Long-term Eurasian watermilfoil control would depend on the weevil. Performance criteria similar to those recommended for the use of the weevil alone should be established, and failure to meet these criteria should result in the reevaluation of the Eurasian watermilfoil management strategy. The same criteria recommended for weevil evaluation could reasonably used for this option as well.

As with most Integrated Pest Management approaches, successful integrated management of Eurasian watermilfoil in Houghton Lake would require that a greater amount of effort be expended monitoring plant and weevil populations and directing future control efforts than would be required using herbicides or weevils alone. Monitoring of weevil populations and impact would be required to ensure that the weevil is succeeding and to identify areas where herbicides are needed. The most difficult part of implementing an integrated Eurasian watermilfoil control strategy would be adjusting the treatment areas to gradually reduce reliance on herbicides and expand areas controlled by the weevil.

In particular, as in Option 2, specific performance guidelines should be established in advance. If these performance guidelines are not achieved, the Eurasian watermilfoil management strategy should be changed. In this case, herbicide treatments are expected to speed the initial control of Eurasian watermilfoil.

The primary drawback of this approach centers on the same concerns about long-term success of the weevil that were described under Option 2. Additionally, weevils and herbicides have not yet been used together this way. There are no obvious technological barriers to implementing this sort of simultaneous integrated control, but careful monitoring and intelligent decision-making would be paramount to the success of this option.

Option 4—Sequential Integrated Management

It would also be possible to initially control Eurasian watermilfoil using a whole-lake fluridone application to initially get Eurasian watermilfoil under control and then use the milfoil weevil to control areas where Eurasian watermilfoil recovers following herbicide treatment.

Success of this approach would depend on both the factors listed for Option 1 (fluridone alone) and those listed for Option 2 (weevil alone). The initial fluridone application should be warranted as described under Option 1. Following the initial fluridone application, it will be necessary to identify areas where Eurasian watermilfoil has become reestablished in order for weevils to be introduced into these areas.

As with the other integrated approach, successful integrated management of Eurasian watermilfoil in Houghton Lake would require that a greater amount of effort be expended monitoring plant and weevil populations and directing future control efforts than would be required using herbicides or weevils alone. Monitoring of Eurasian watermilfoil populations, weevil populations and weevil impact would be required to identify areas where the weevil should be introduced and to ensure that the weevil is succeeding.

If this option is implemented, monitoring of Eurasian watermilfoil and weevil populations should be conducted to ensure that weevils are successfully becoming established and Eurasian watermilfoil is being adequately controlled. If the Eurasian watermilfoil population exceeds a preset threshold despite weevil introductions, fluridone treatment should be repeated. A re-treatment threshold of 40 percent of the Eurasian watermilfoil abundance in 2001 is recommended. If Eurasian watermilfoil exceeds this threshold despite weevil introductions, fluridone application should be repeated.

Initial concerns about non-target impact would be the same as for Option 1. In the long run, use of the weevil would make reestablishment of fluridone sensitive species such as water marigold much easier to achieve. If this option were selected, it would be desirable to replant non-target plant species eliminated by the initial fluridone treatment, once it is clear that the weevil is successfully controlling Eurasian watermilfoil.

Monitoring Recommendations

Whichever management option is implemented, monitoring of conditions in the lake should be continued, both to direct management efforts and to document the success or failure of management in meeting stated goals. A vegetation survey, conducted according to the protocol used in 2000 and 2001, should be conducted at least once a year. Results of this survey will document the abundance of Eurasian watermilfoil and desirable native vegetation and will indicate where management is needed. If an integrated management strategy that requires selection of locations in which management efforts will be focused is used, additional monitoring of vegetation throughout the growing season will be required. This can be accomplished by visual evaluation of plant beds, without conducting additional whole-lake vegetation surveys. Water quality monitoring should be conducted at least once a year, according to the 2001 protocol. If funds permit, monitoring of phytoplankton and zooplankton should be added.

Recommendations for Adopting an Overall Management Strategy

Management options very in terms of their rapidity, extent of Eurasian watermilfoil control, risk of failure, and non-target impact (Table 10). Based on the information provided above and local considerations, it is recommended that the Management Options be ranked in order of desirability. Initially, management will proceed using the first ranked option. If the first choice cannot be implemented, due to regulatory restrictions, or the first choice fails, as indicated by failure to meet the performance standards described above, the second choice will be implemented, and so forth.

Table 10. Comparison of Eurasian Watermilfoil Management Options

Option	Extent of Control	Risk of failure	Rapidity	Non-Target Impact
Fluridone	Nearly Complete	Low	Rapid	Moderate
Weevil	Moderate	Moderate?	Slow	None
Simultaneous Integrated	Variable	Low	Moderate	Low
Sequential Integrated	Variable	Low to Moderate	Rapid	Moderate

It is recommended that a budget of $1,000,000 per year be established for management of Houghton Lake for an initial period of five years. This amount will allow flexibility in adjusting to changing conditions in the lake or to problems implementing individual management options. Each management option has a risk of failure, and it is prudent for the budget to provide sufficient funds so that alternate approaches can be selected if problems arise. For example, failure of the Michigan DEQ to issue a permit for a whole-lake fluridone treatment would necessitate adopting a strategy that does not use fluridone. Likewise, if the weevil does not meet performance guidelines, it will be necessary to switch to a strategy that is dependent on herbicides. Budget allocations for implementing each of the management options follow.

Budget Estimates for Management Options

	Fluridone	Weevils Alone	Simultaneous	Sequential
Year One (2002)				
Herbicides				
Fluridone	$1,750,000			$1,750,000
2,4-D, etc.			$700,000	
Weevils		$350,000	$300,000	
Flotsam removal		$288,000	$144,000	
Planning & Evaluation	$60,000	$60,000	$100,000	$60,000
Startup expenses[1]	$75,000	$75,000	$75,000	$75,000
Total (Year 1)	**$1,885,000**	**$773,000**	**$1,319,000**	**$1,885,000**
Year Two (2003)				
Herbicides				
Fluridone				
2,4-D, etc.	$92,000		$551,250	
Weevils		$350,000	$300,000	
Flotsam removal		$227,000	$152,000	
Planning & Evaluation	$63,000	$63,000	$105,000	$105,000
Total (Year 2)	**$155,000**	**$640,000**	**$1,108,250**	**$105,000**
Year Three (2004)				
Herbicides				
Fluridone				
2,4-D, etc.	$193,000		$464,000	
Weevils		$350,000	$300,000	$50,000
Flotsam removal		$159,000	$152,000	
Planning & Evaluation	$67,000	$67,000	$111,000	$111,000
Total (Year 2)	**$260,000**	**$576,000**	**$1,027,000**	**$161,000**
Year Four (2005)				
Herbicides				
Fluridone				
2,4-D, etc.	$406,000		$304,000	
Weevils		$350,000	$300,000	$150,000
Flotsam removal		$84,000	$126,000	
Planning & Evaluation	$71,000	$71,000	$117,000	$117,000
Total (Year 4)	**$477,000**	**$505,000**	**$847,000**	**$267,000**
Year Five (2006)				
Herbicides				
Fluridone	$2,128,000	$2,128,000[2]		$2,128,000[2]
2,4-D, etc.			$213,000	
Weevils		$200,000	$250,000	$200,000
Flotsam removal		$88,000	$88,000	$88,000
Planning & Evaluation	$75,000	$75,000	$123,000	$123,000
Total (Year 5)	**$2,203,000**	**$2,491,000**	**$674,000**	**$2,539,000**
Grand Total	**$5,000,000**	**$5,000,000**	**$5,000,000**	**$5,000,000**
Cost Per Year	**$1,000,000**	**$1,000,000**	**$1,000,000**	**$1,000,000**

[1]Repayment of loan from Roscommon County to conduct feasibility study.

[2]Only if needed.

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Appendices

Appendix A

Final Maps: Houghton Lake, Michigan - Summer 2001 Vegetation Survey

Tabulation of Summer 2001 Vegetation Survey of Houghton Lake using standard Michigan DEQ format

Appendix B

Hydroacoustic Transects for Vegetation Assessment – July 24, 2001

Appendix C

Satellite Base Imagery and Classification *[Included in final report.]*

Appendix D

Maps of Milfoil Weevil Abundance

Appendix E

Field Notes from Water Quality Study

Appendix F

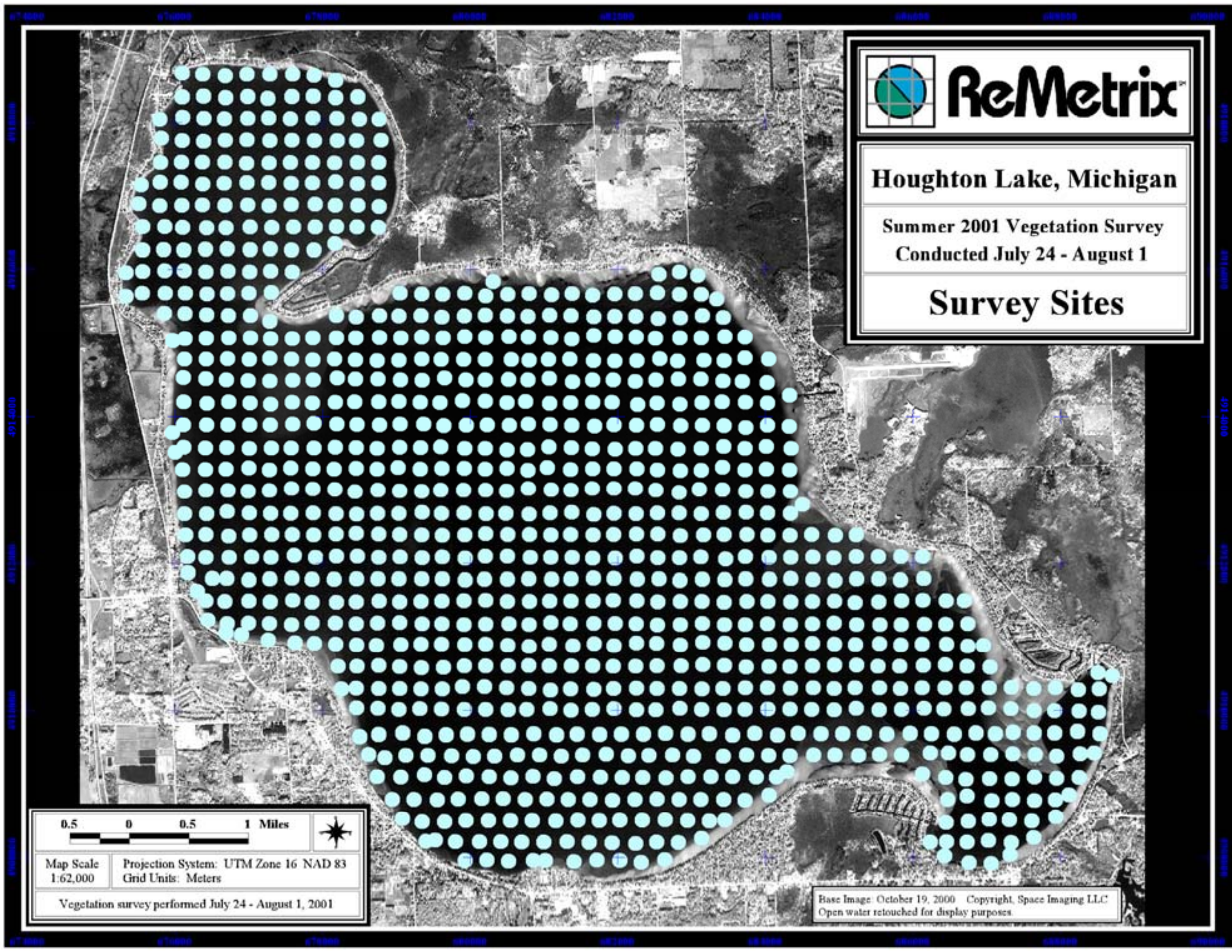
Contact Information

Appendix A

<u>Final Maps: Houghton Lake, Michigan - Summer 2001 Vegetation Survey</u>

Survey Sites
Eurasian Watermilfoil – Distribution and Abundance
Elodea – Distribution and Abundance
Muskgrass – Distribution and Abundance
Clasping-leaved Pondweed – Distribution and Abundance
Thin-leaved Pondweed – Distribution and Abundance
Naiad – Distribution and Abundance
Whitestem Pondweed – Distribution and Abundance
Wild Celery – Distribution and Abundance
Variable-leaved Pondweed – Distribution and Abundance
Coontail – Distribution and Abundance
Water Stargrass – Distribution and Abundance
Nitella – Distribution and Abundance
Water Marigold – Distribution and Abundance
Illinois Pondweed – Distribution and Abundance
Buttercup – Distribution and Abundance
Large-leaved Pondweed – Distribution and Abundance
Flatstem Pondweed – Distribution and Abundance
Northern Watermilfoil – Distribution and Abundance
Robbins' Pondweed – Distribution and Abundance
Curly-leaved Pondweed – Distribution and Abundance
Floating-leaved Pondweed – Distribution and Abundance
Bladderwort – Distribution and Abundance
Number of Submersed Species
Vegetation Density (All Species) – Summer 2001
Vegetation Density (All Species) – Projection of Fluridone Effects in Year of Treatment
Plant Architecture (All Species) – Summer 2001
Plant Architecture (All Species) – Projection of Fluridone Effects in Year of Treatment

<u>Tabulation of Summer 2001 Vegetation Survey of Houghton Lake using standard Michigan DEQ format</u>



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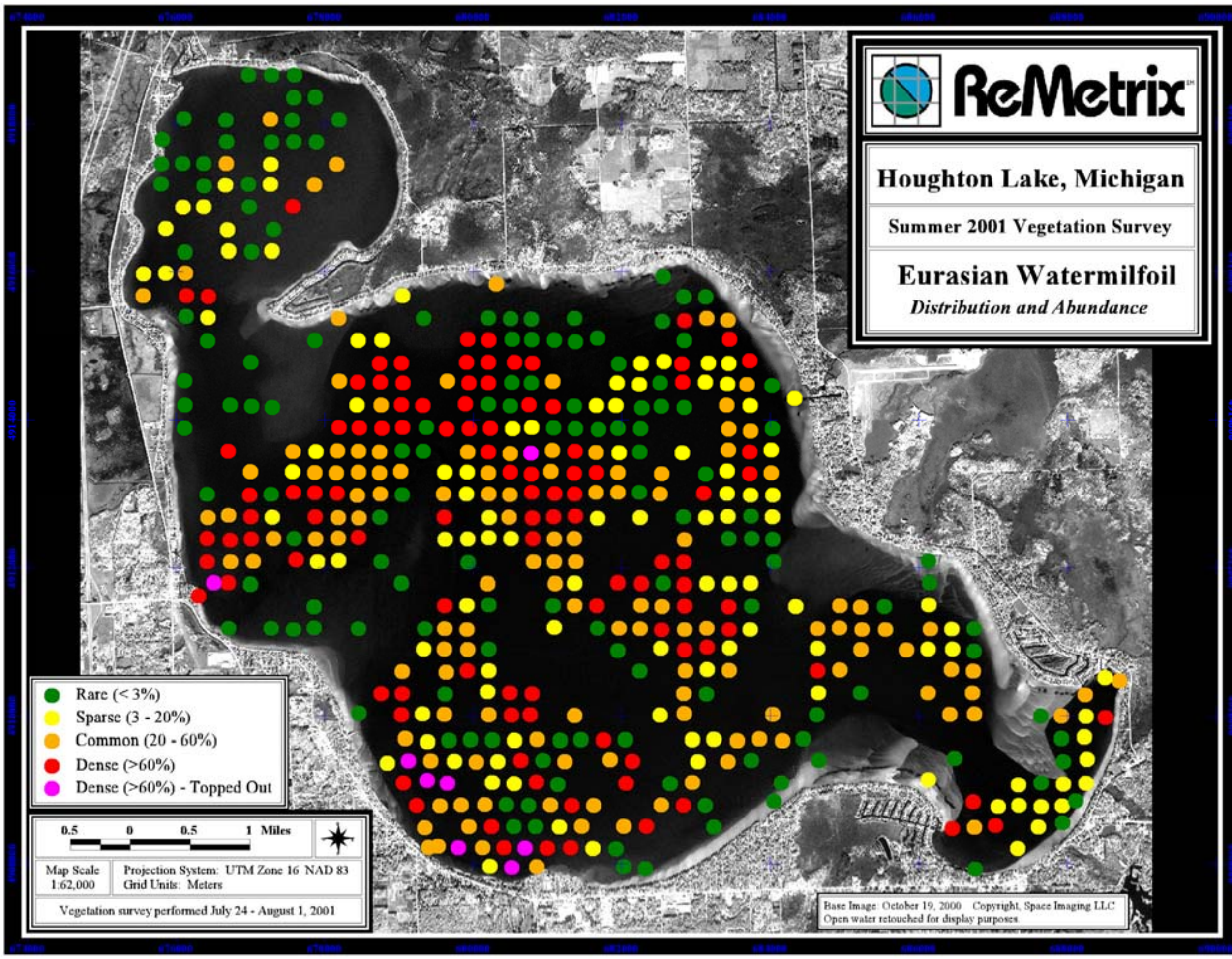

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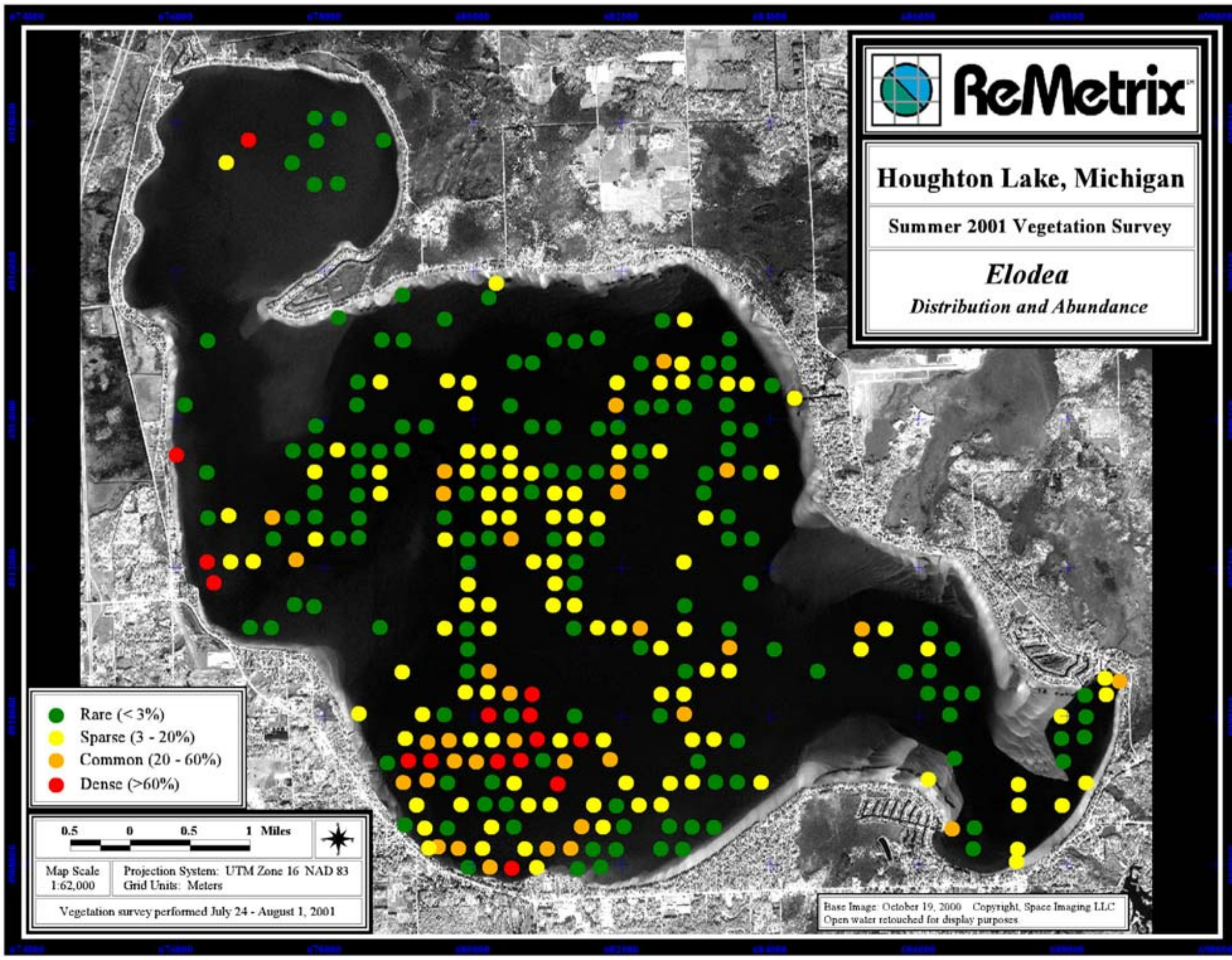

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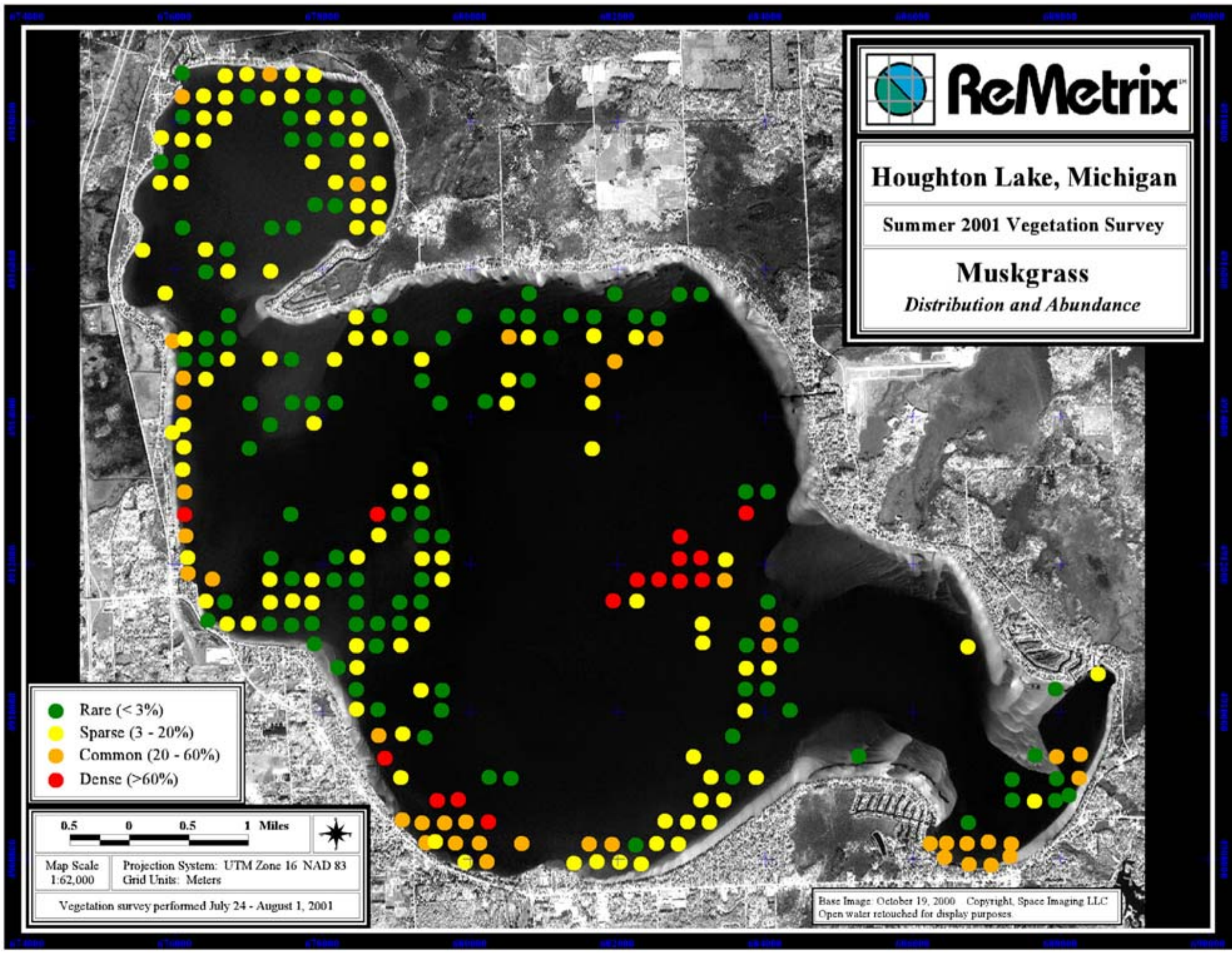

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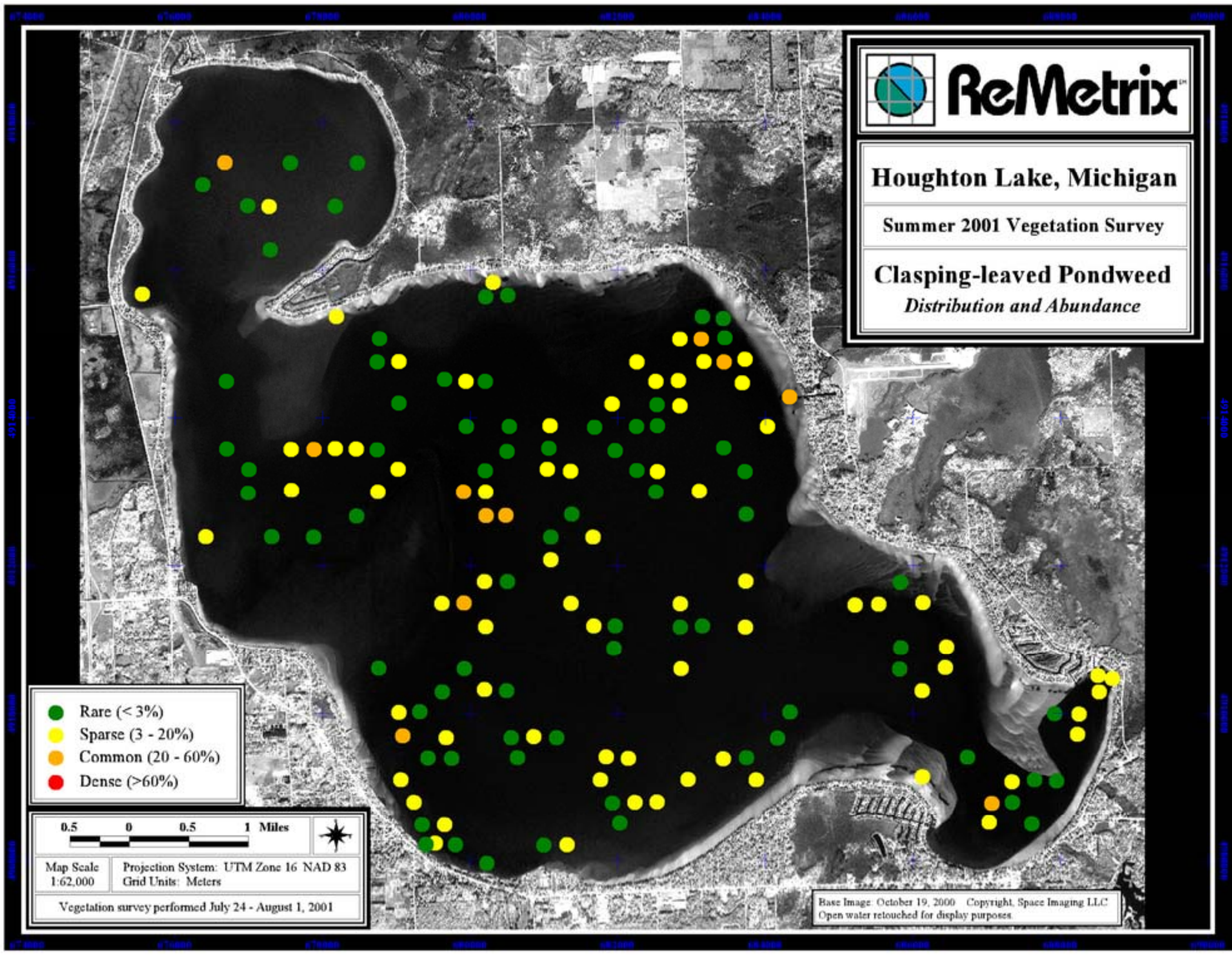

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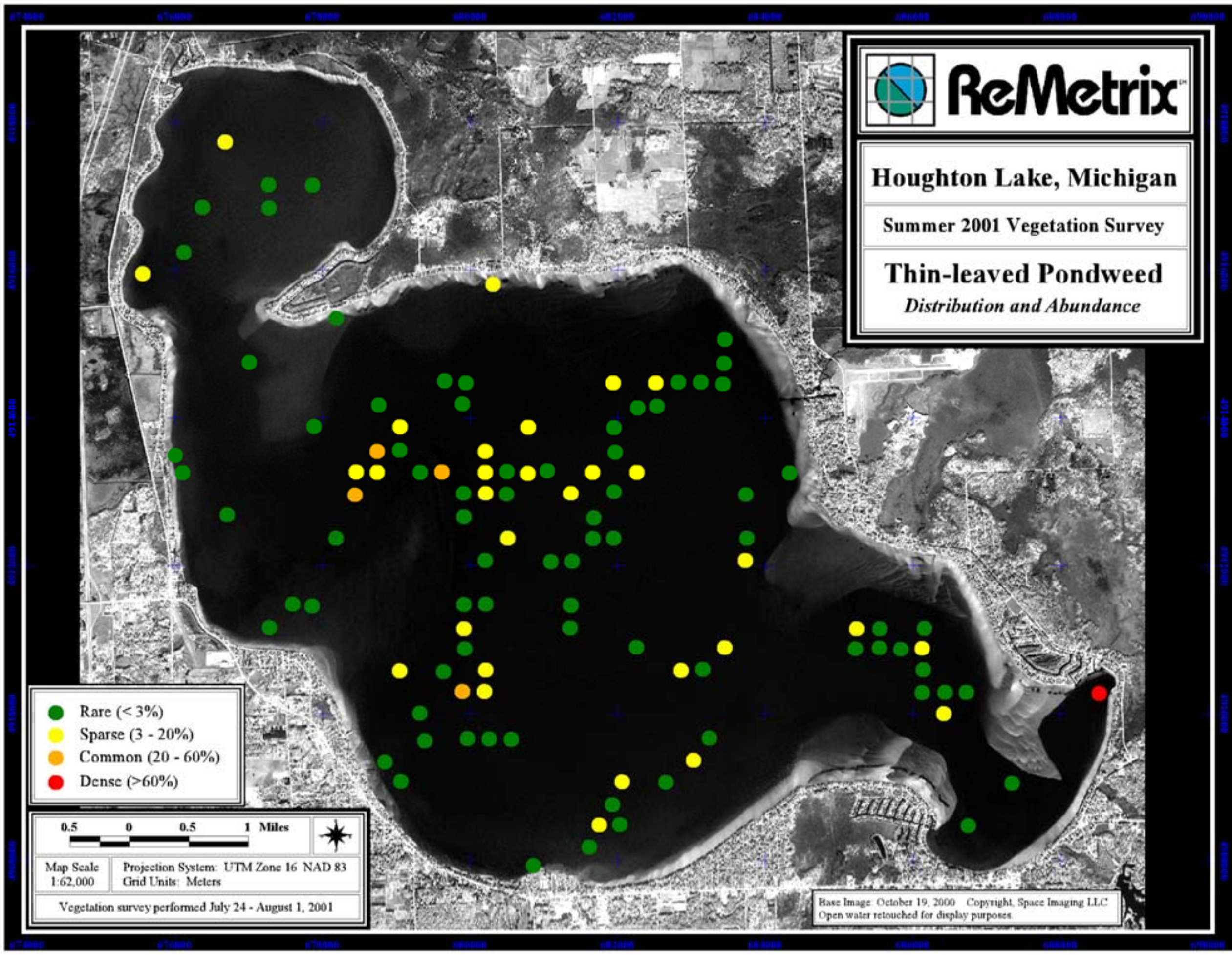

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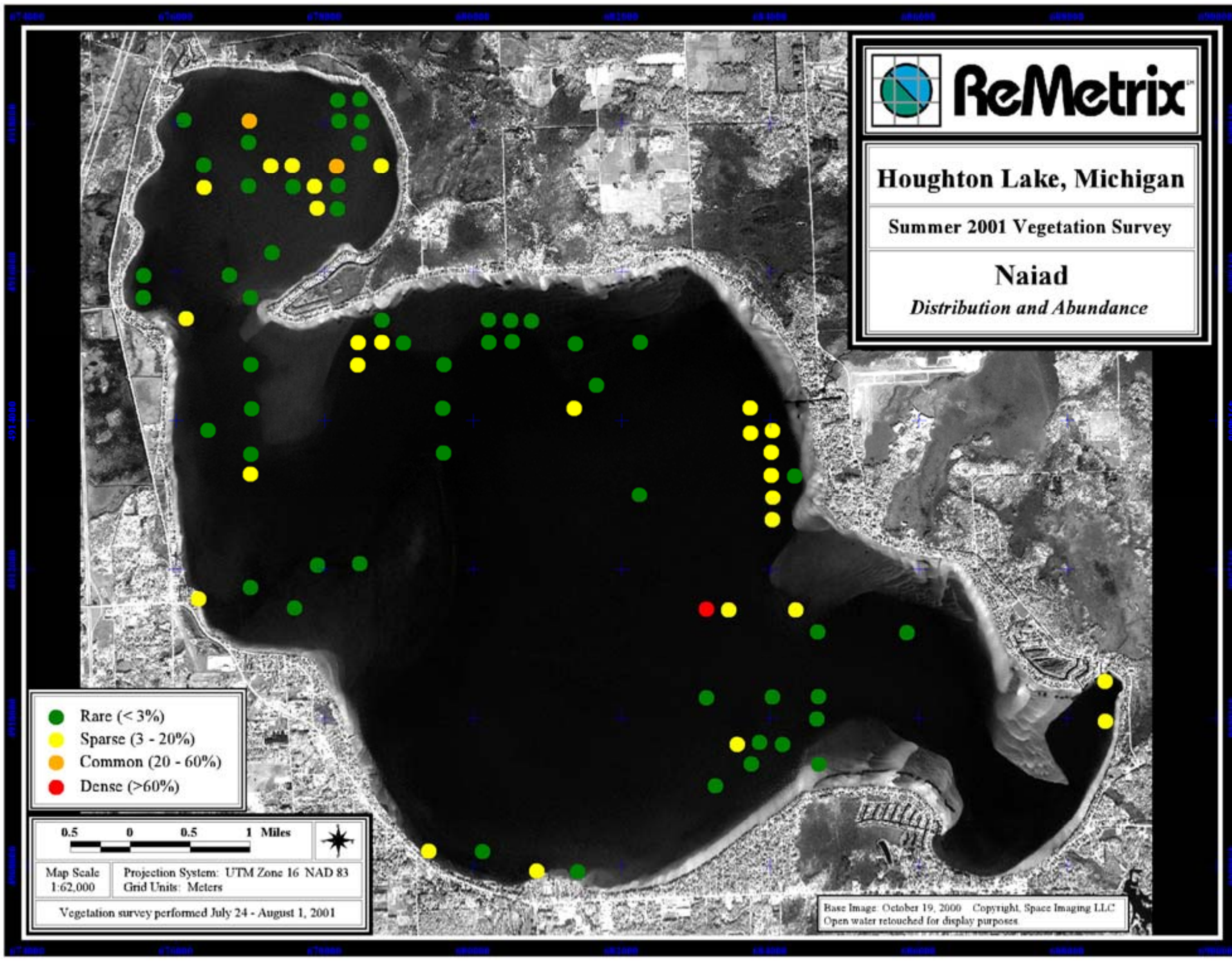

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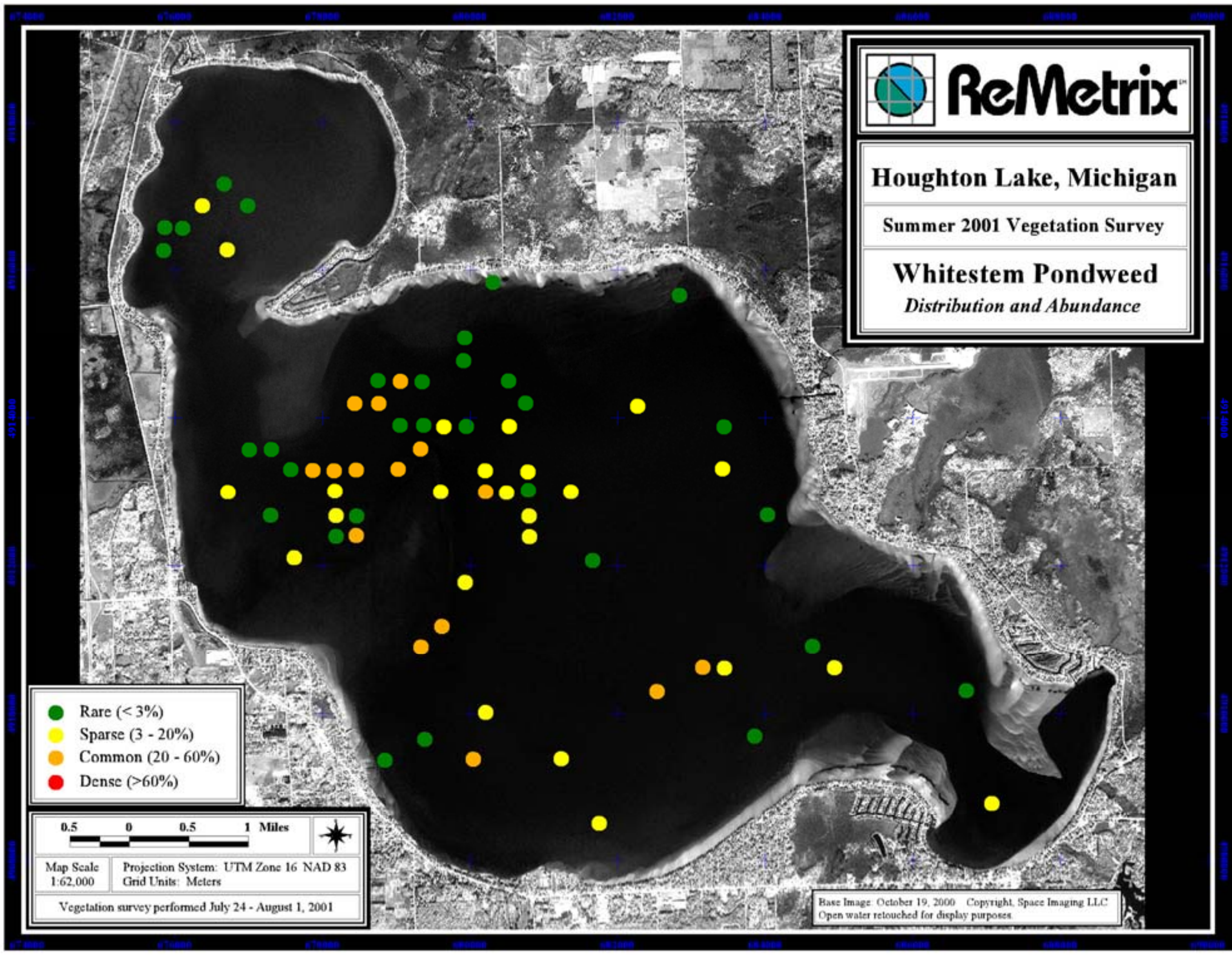

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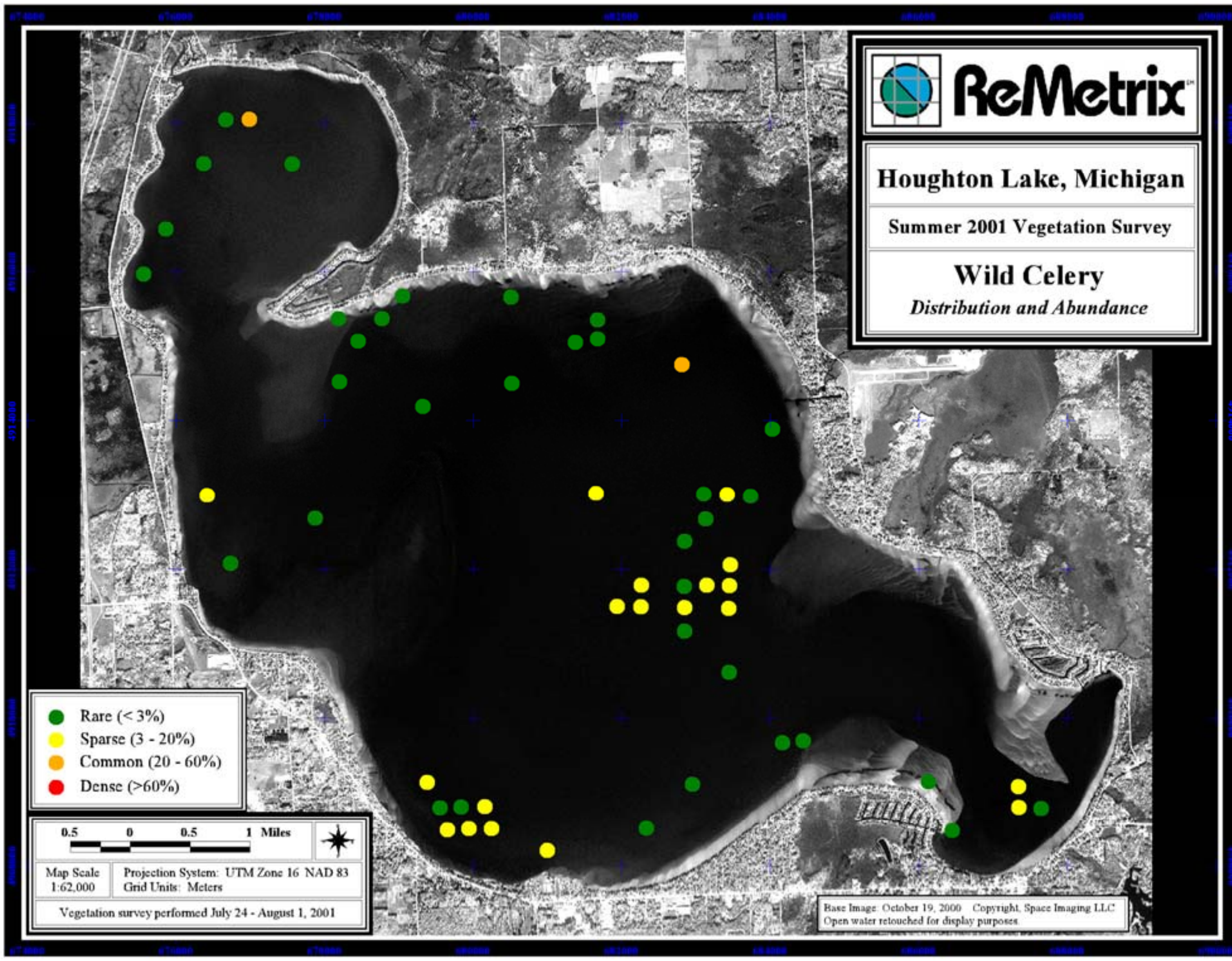

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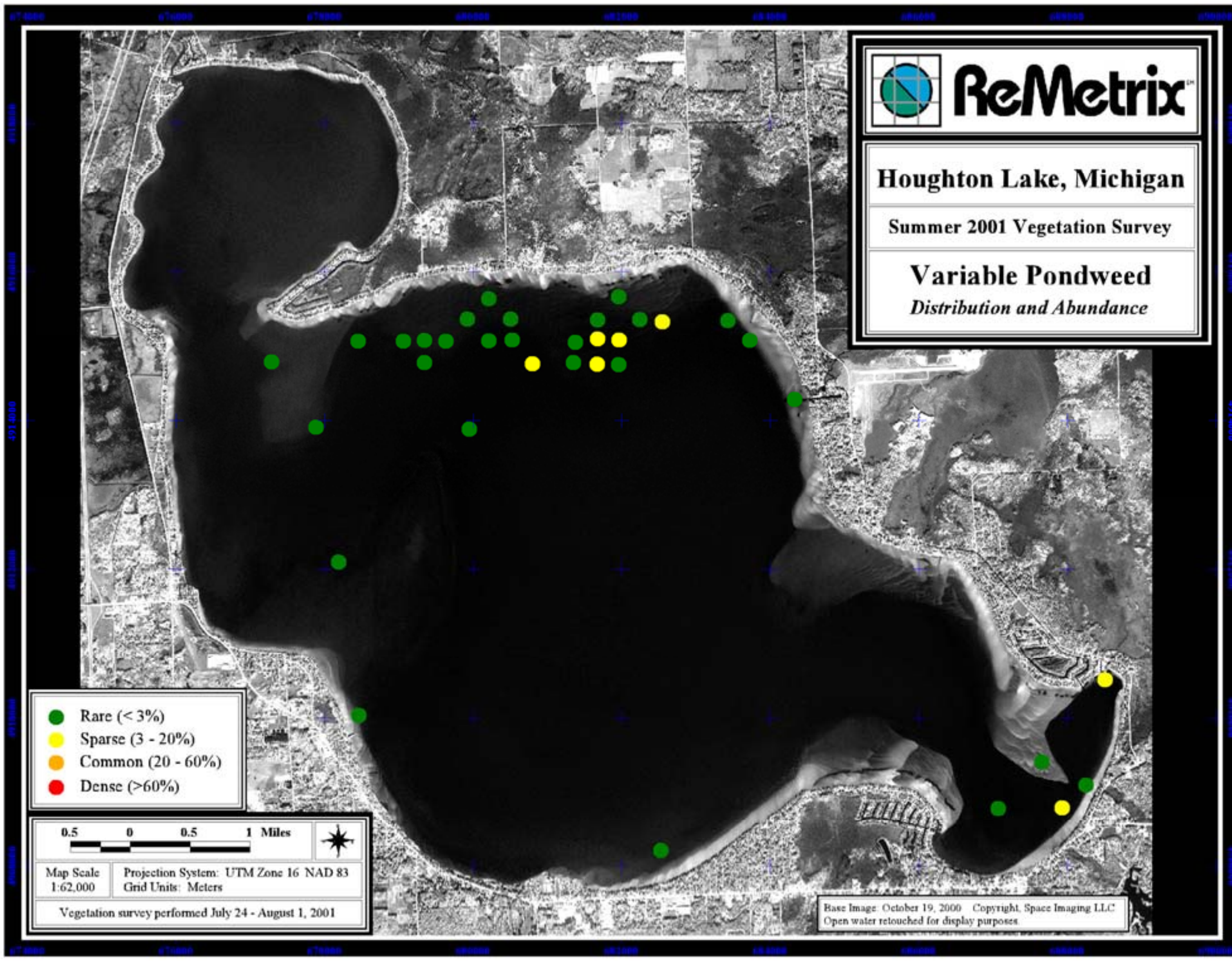

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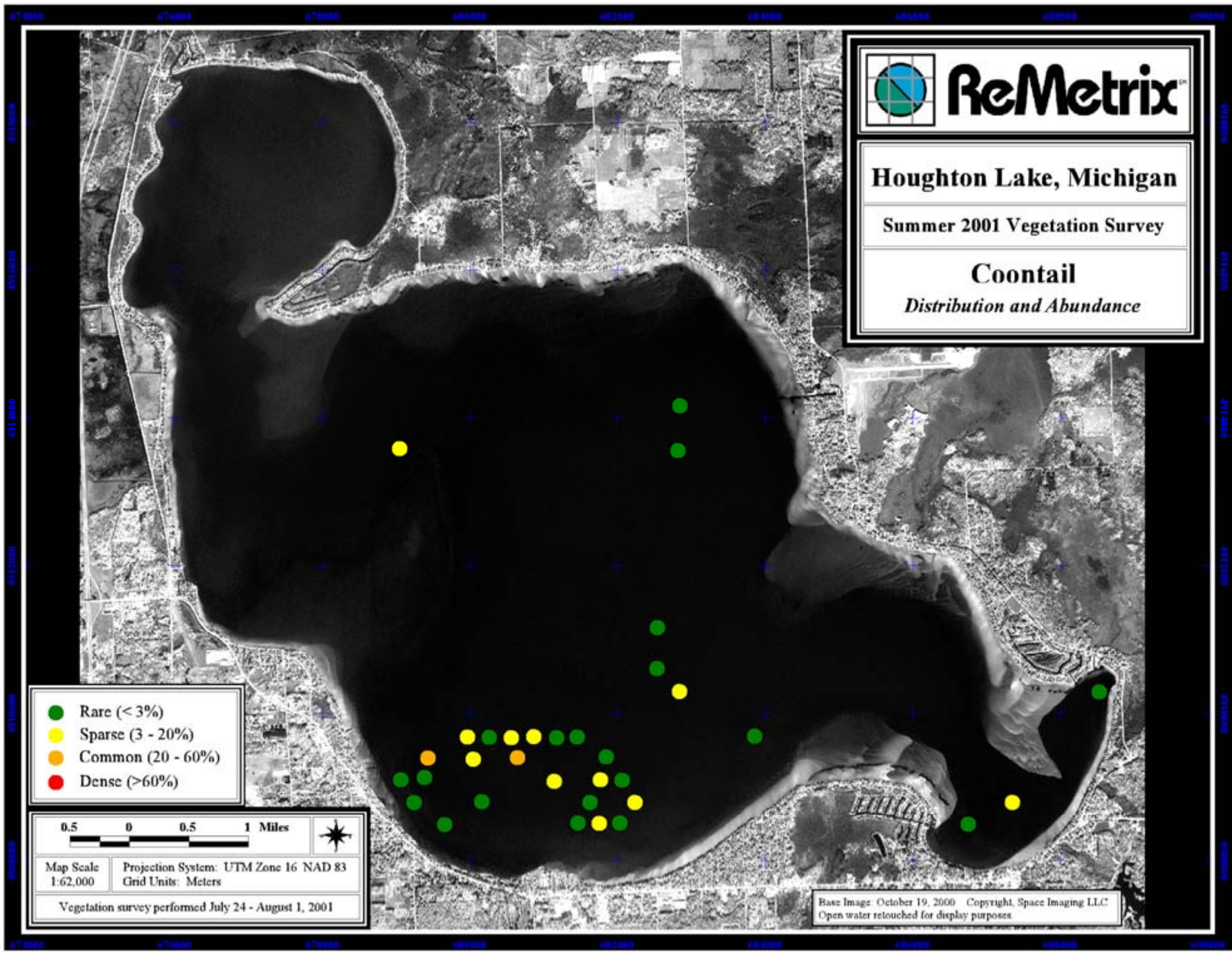

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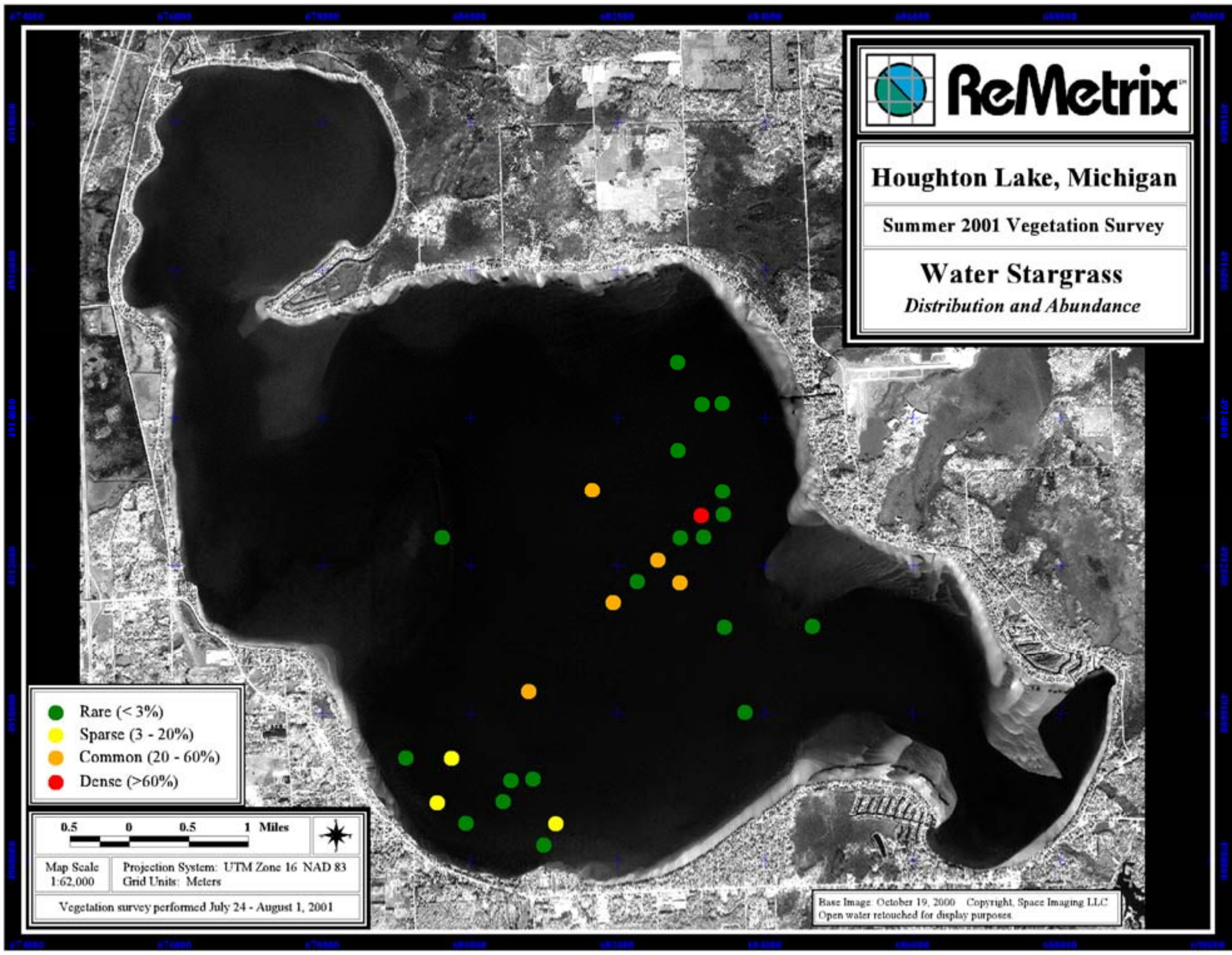

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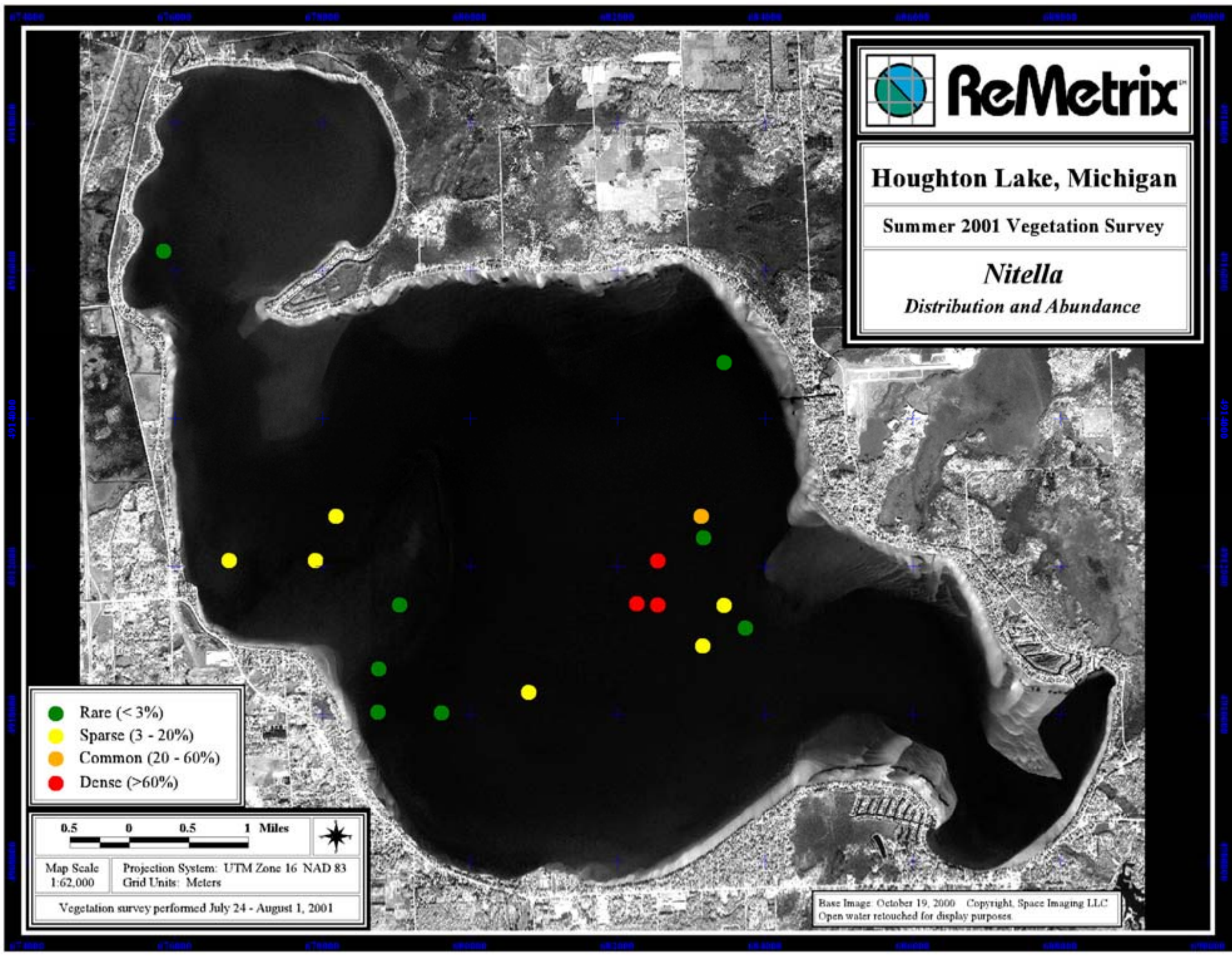

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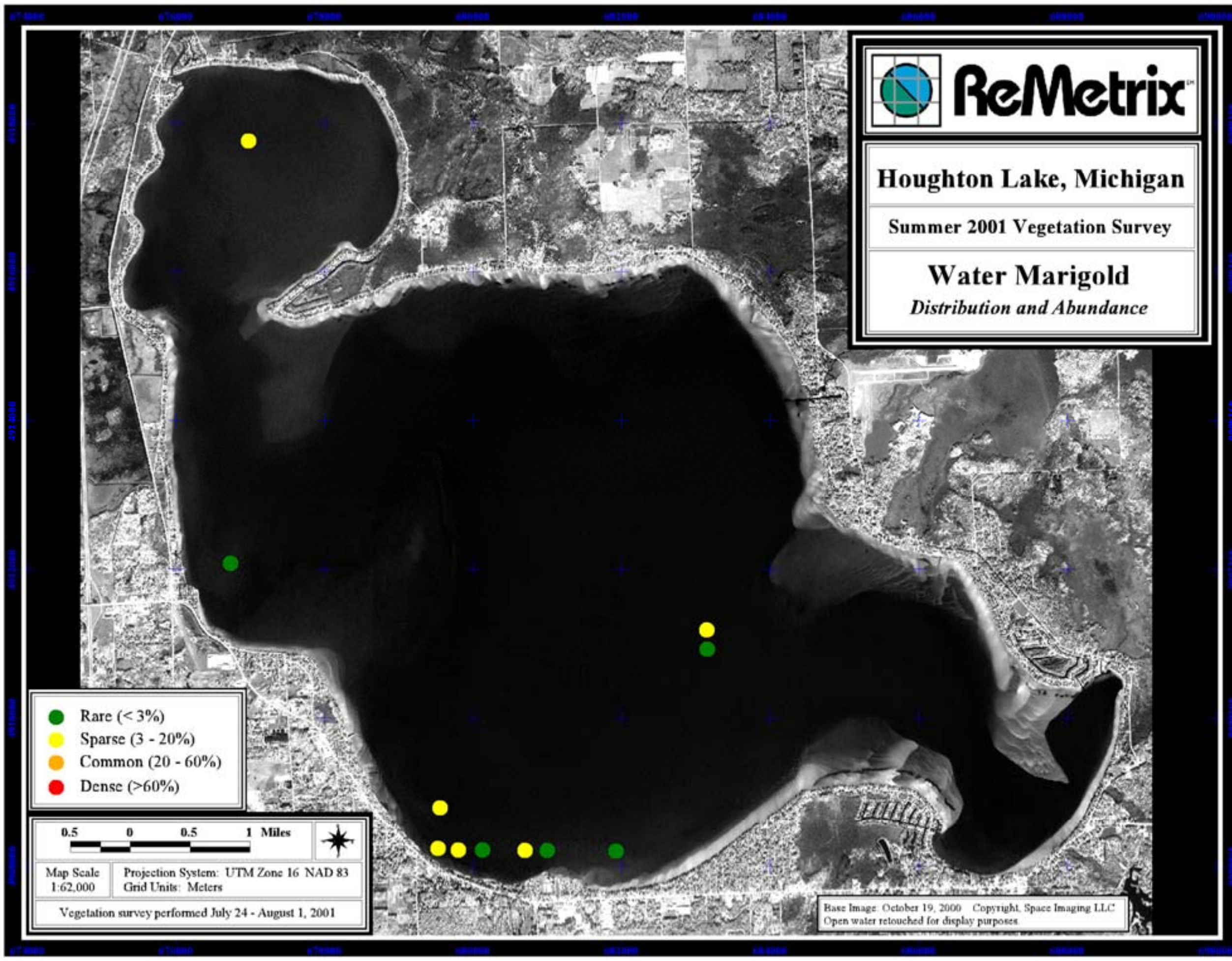

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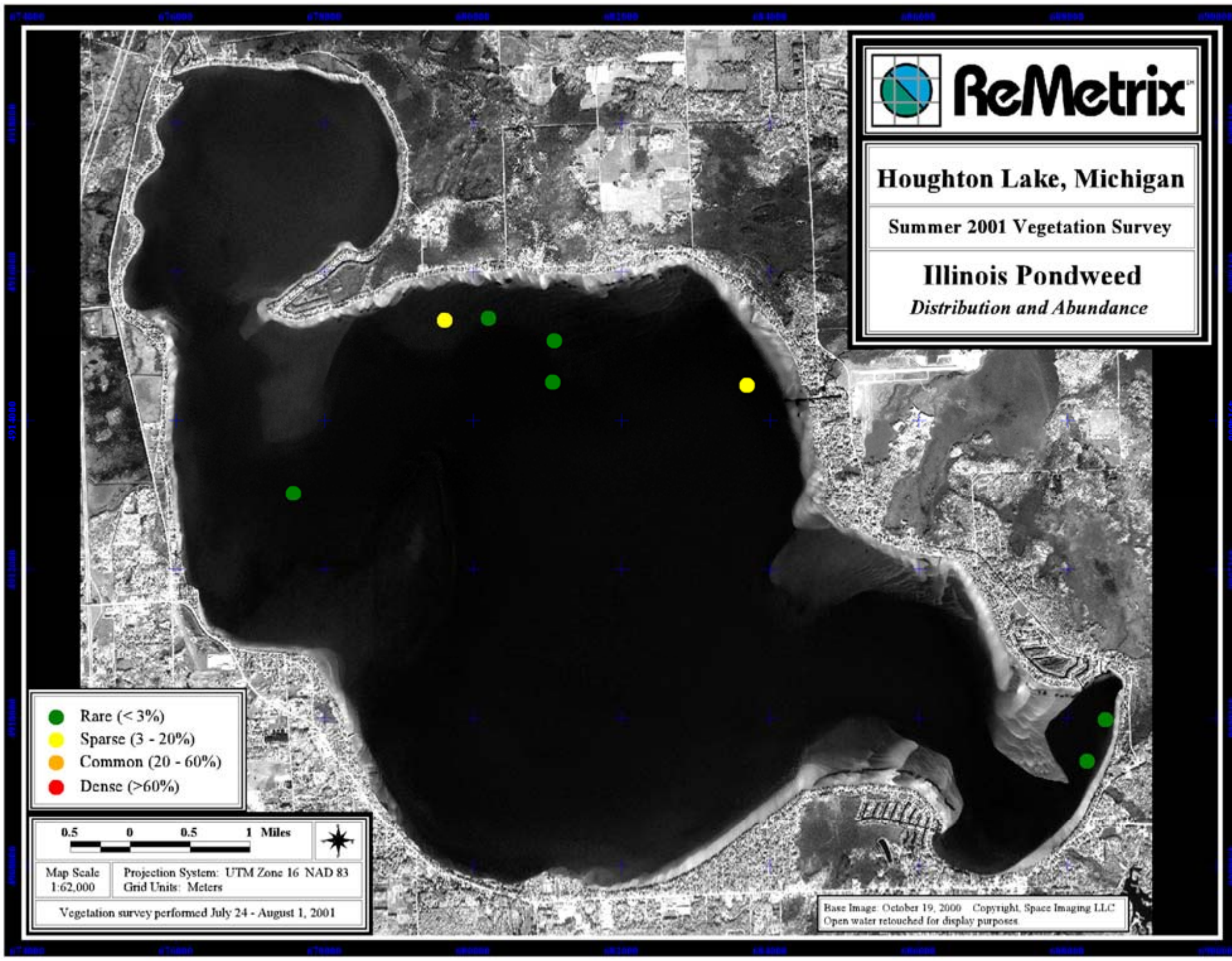

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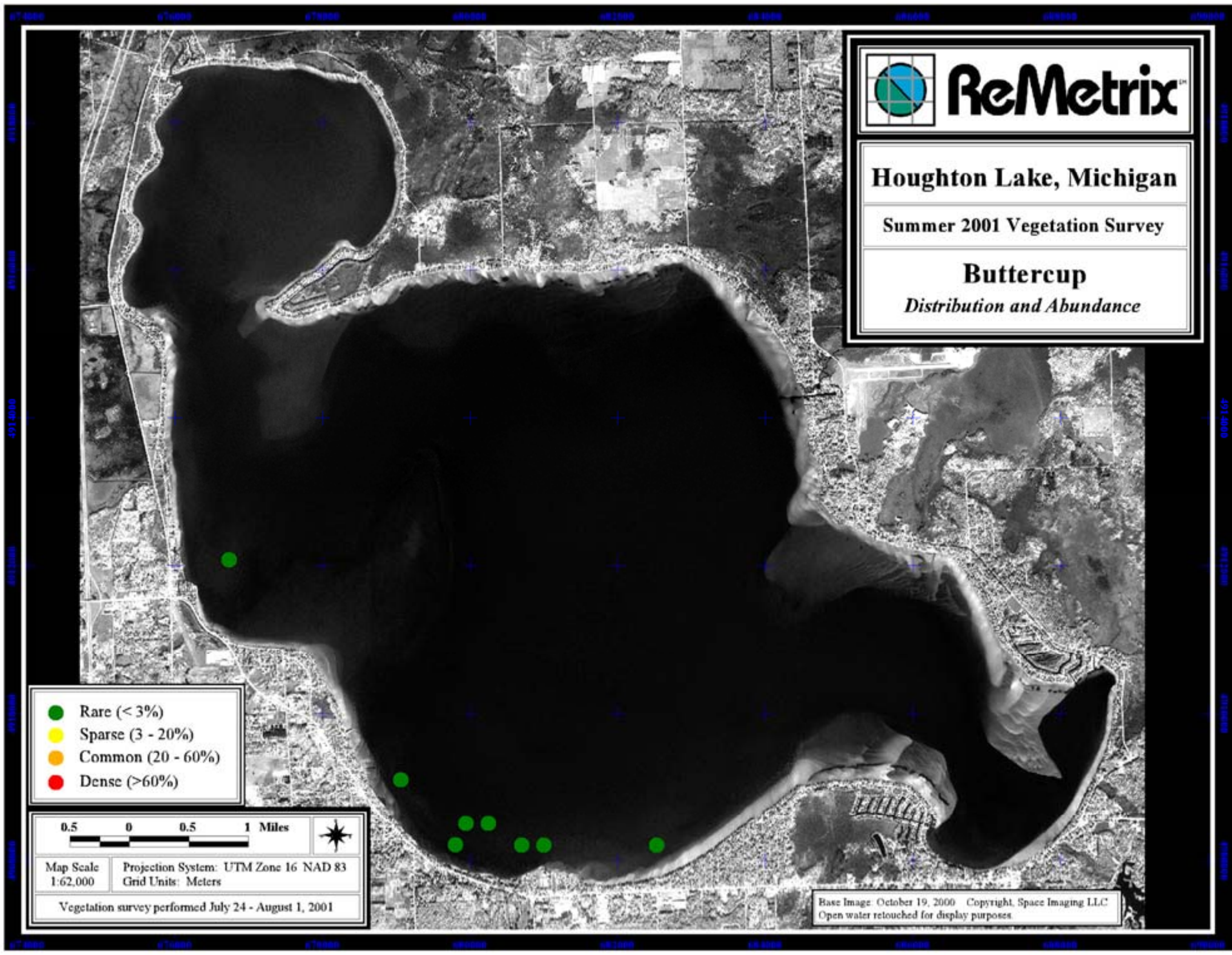

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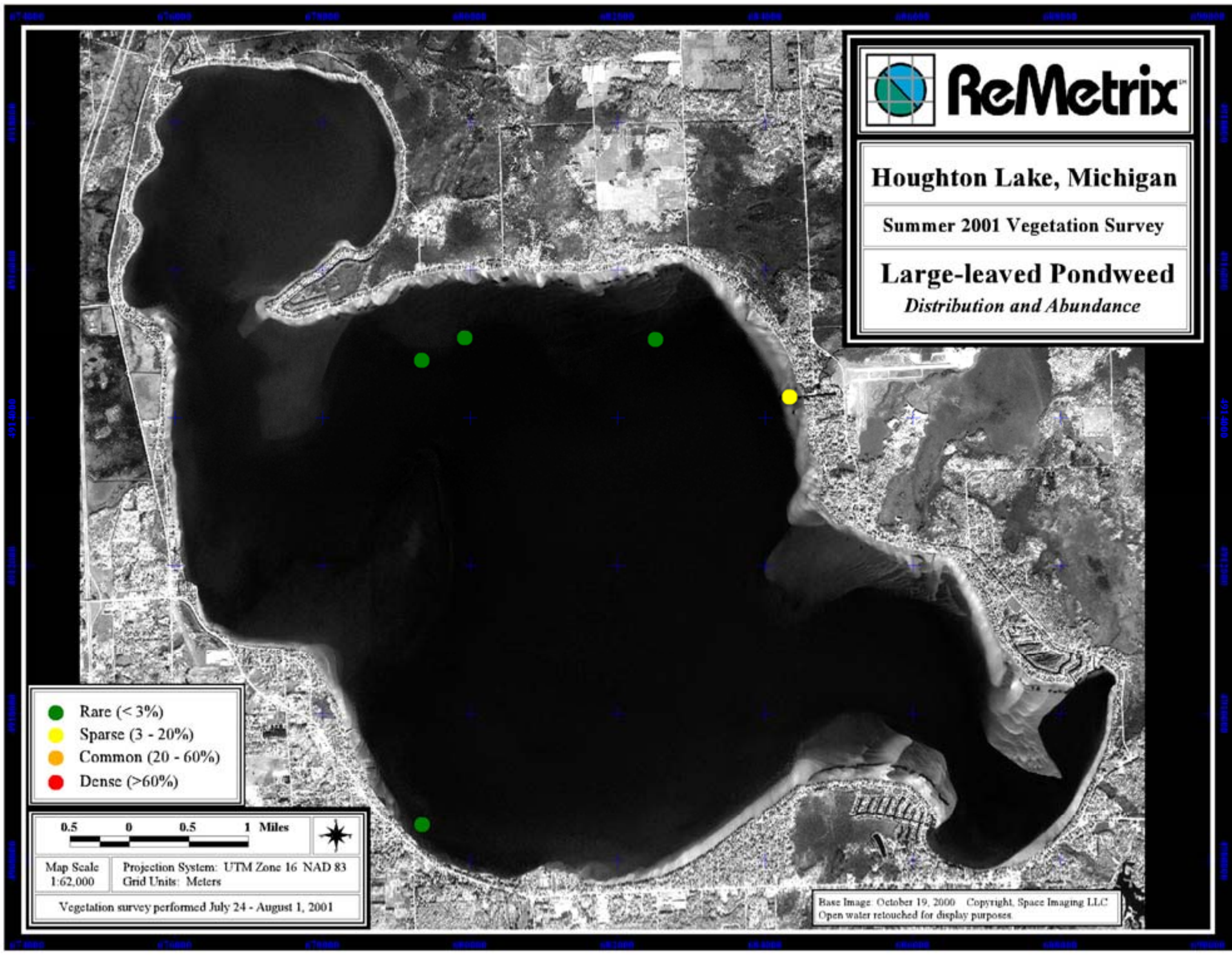

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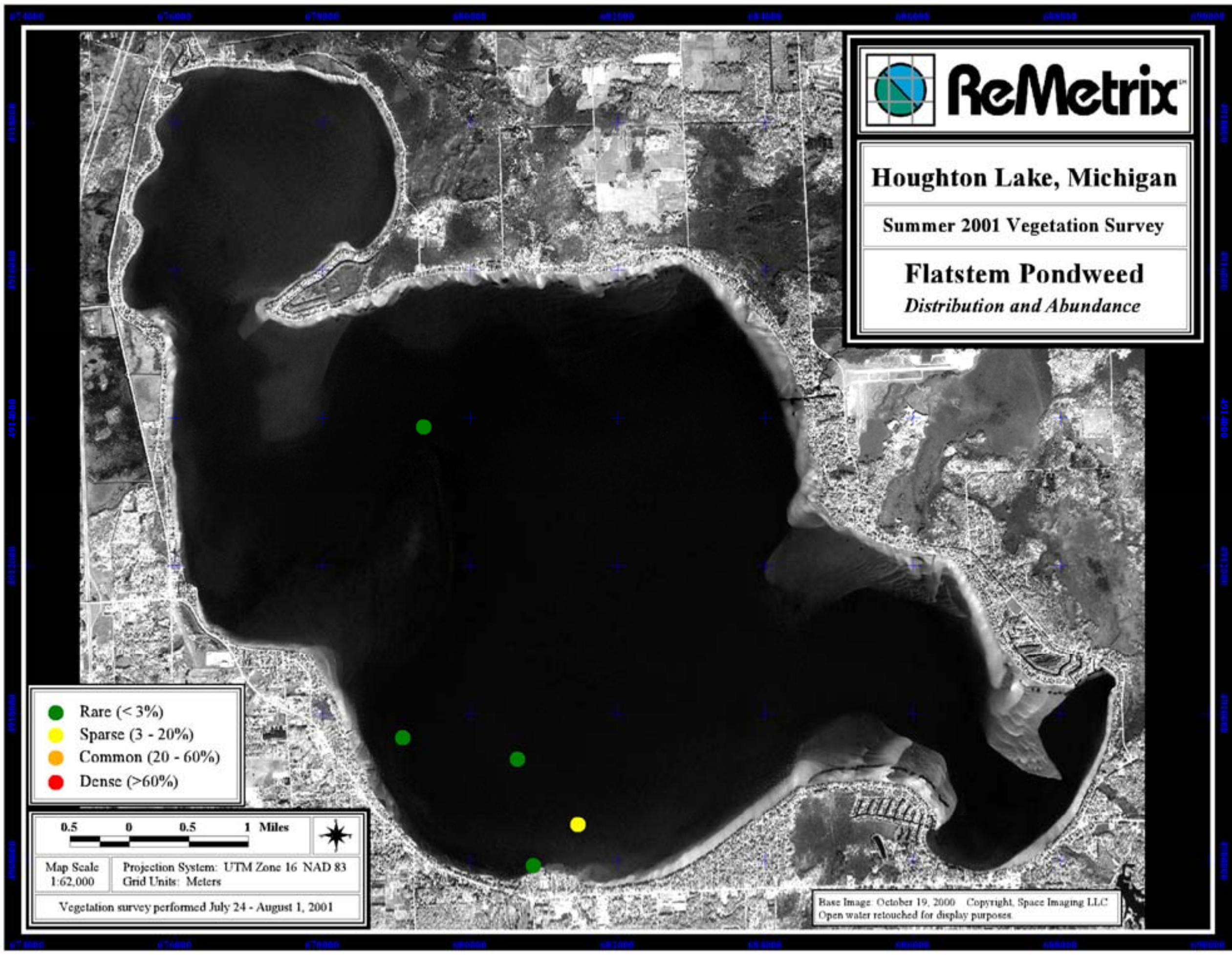

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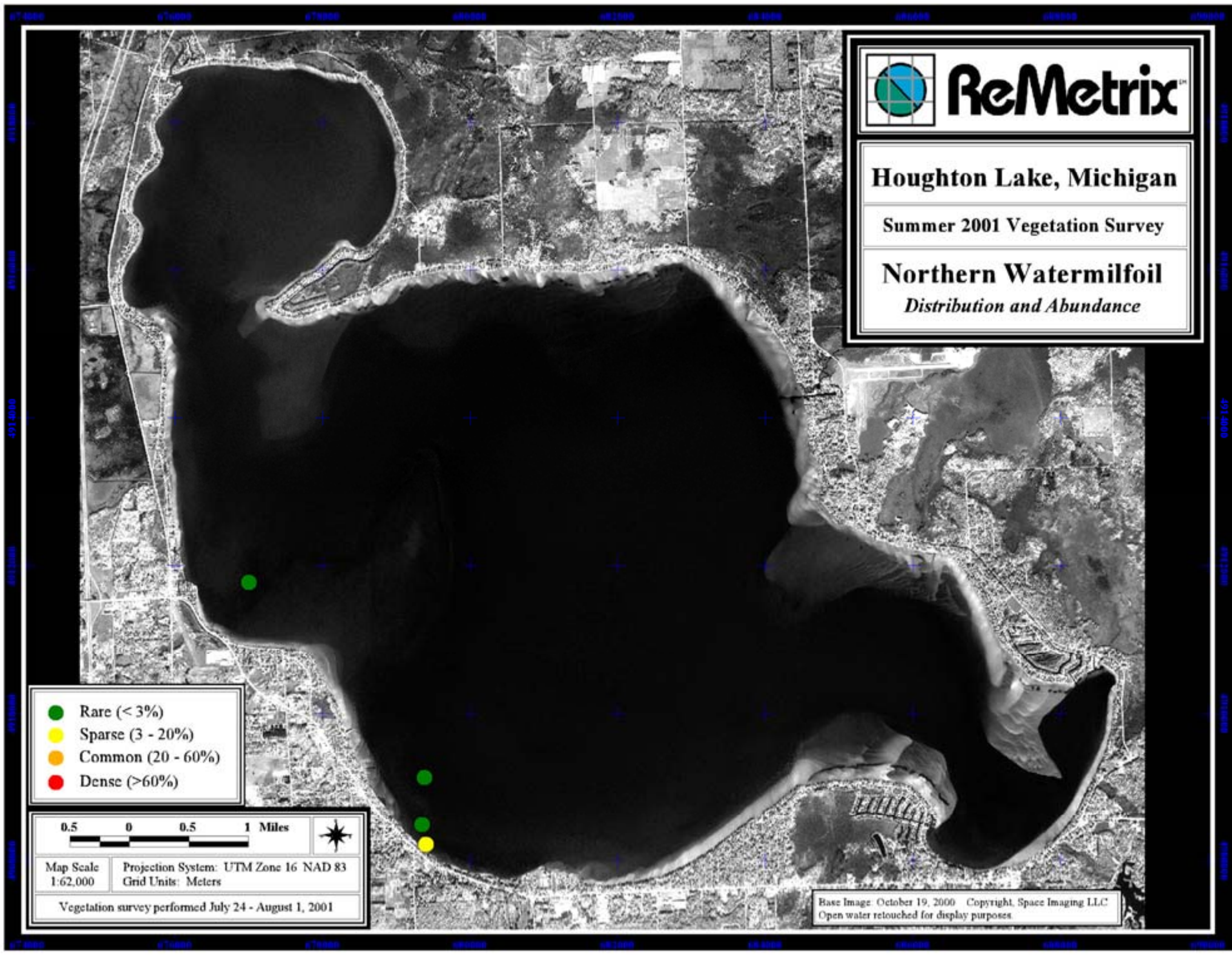

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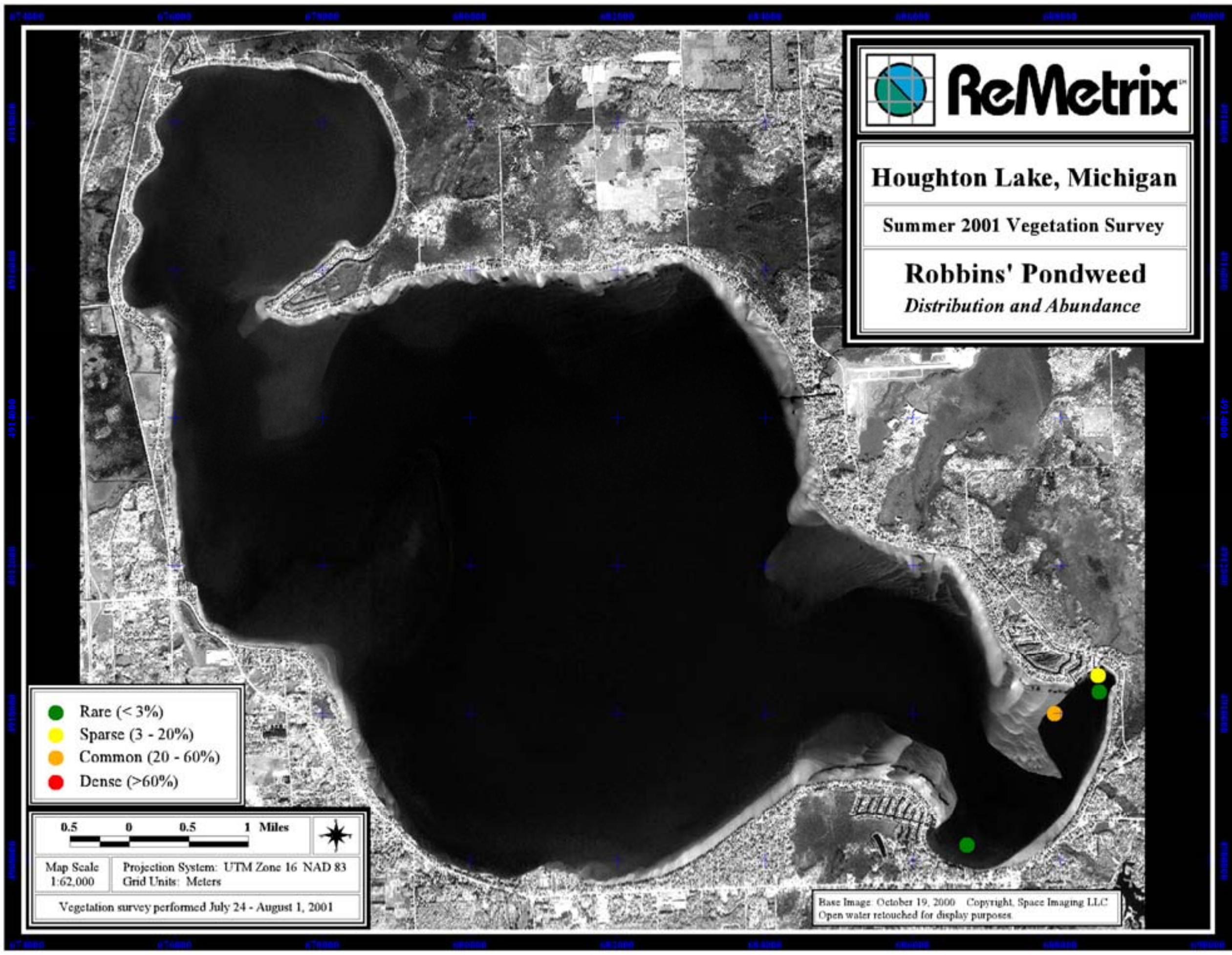

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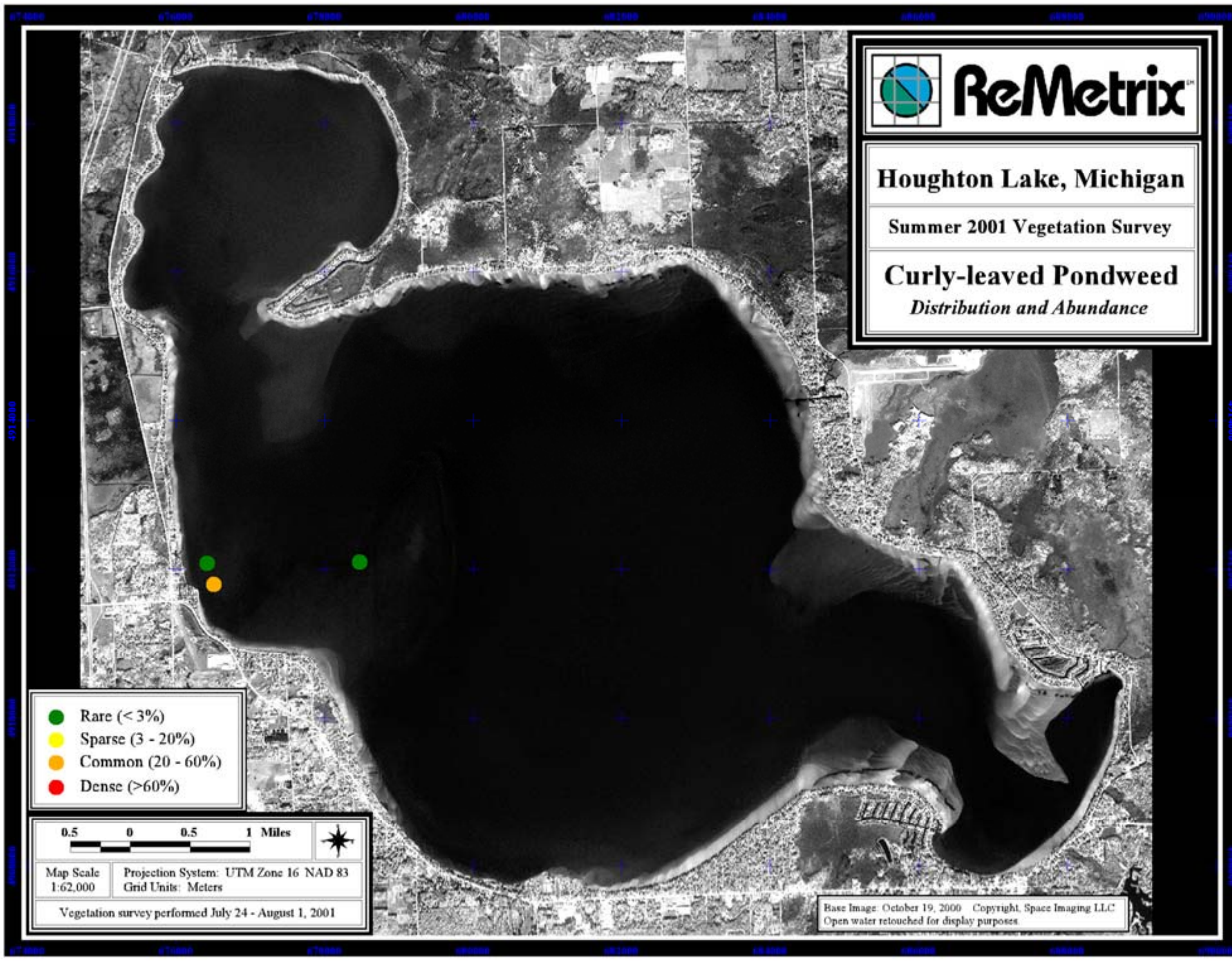

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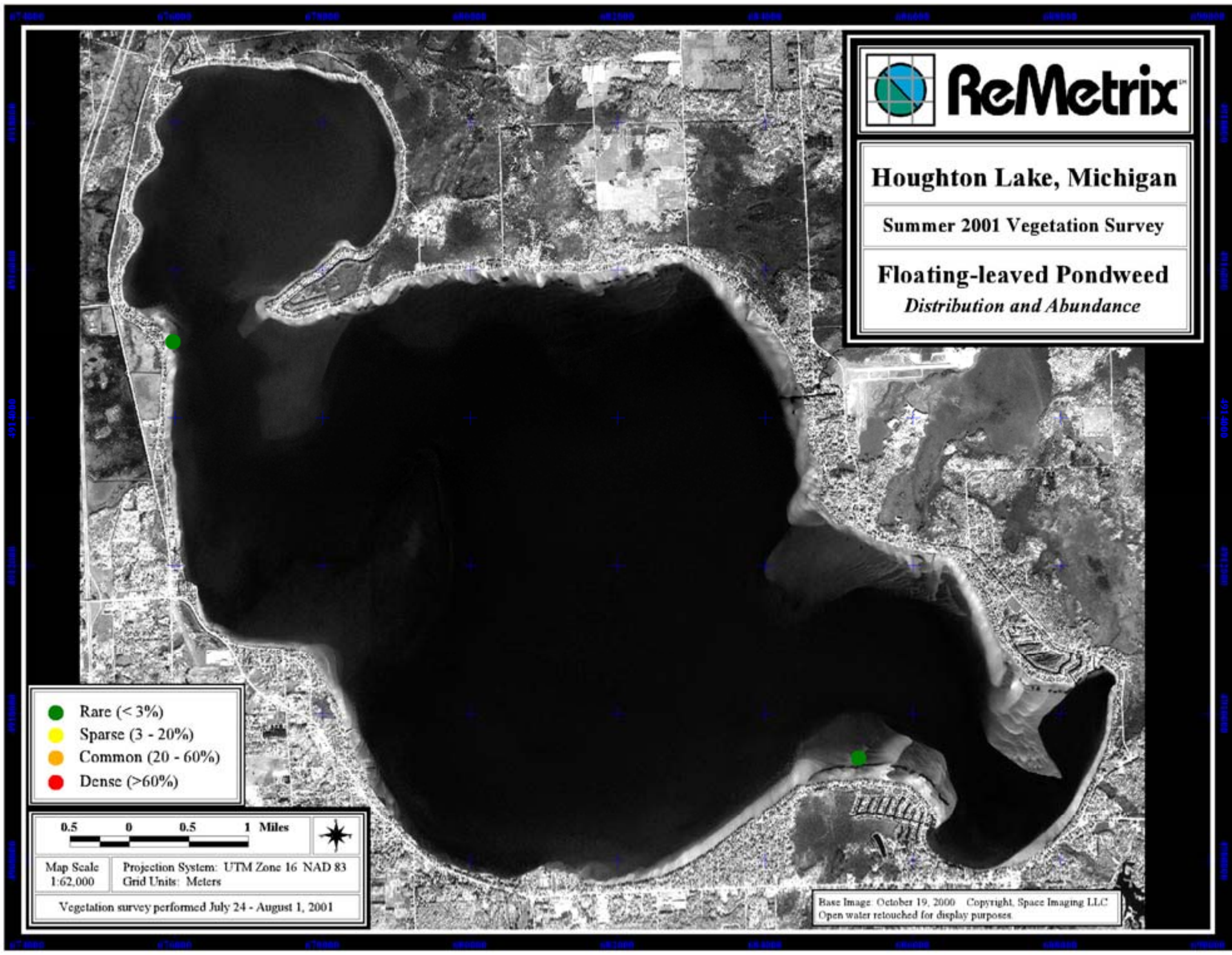

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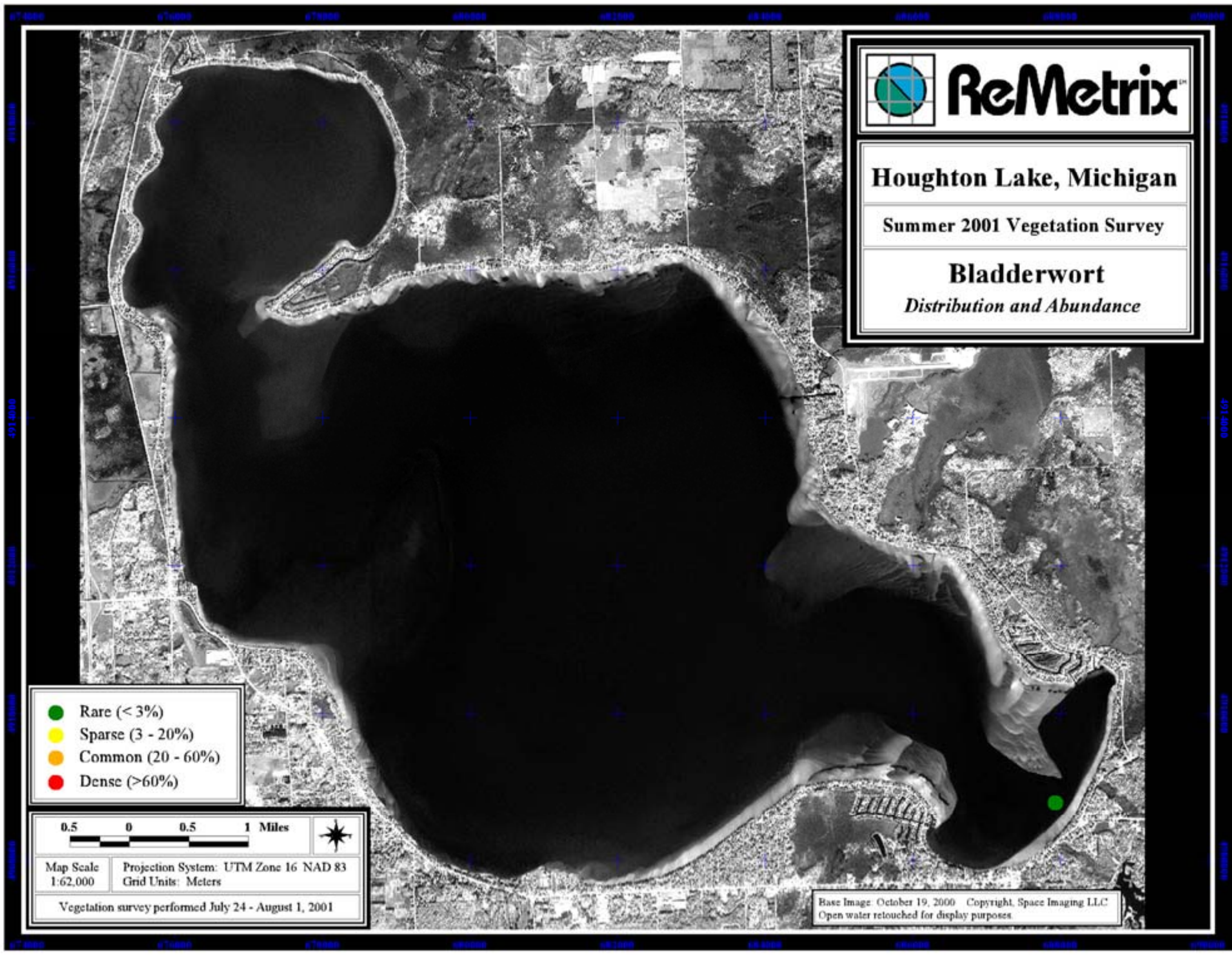

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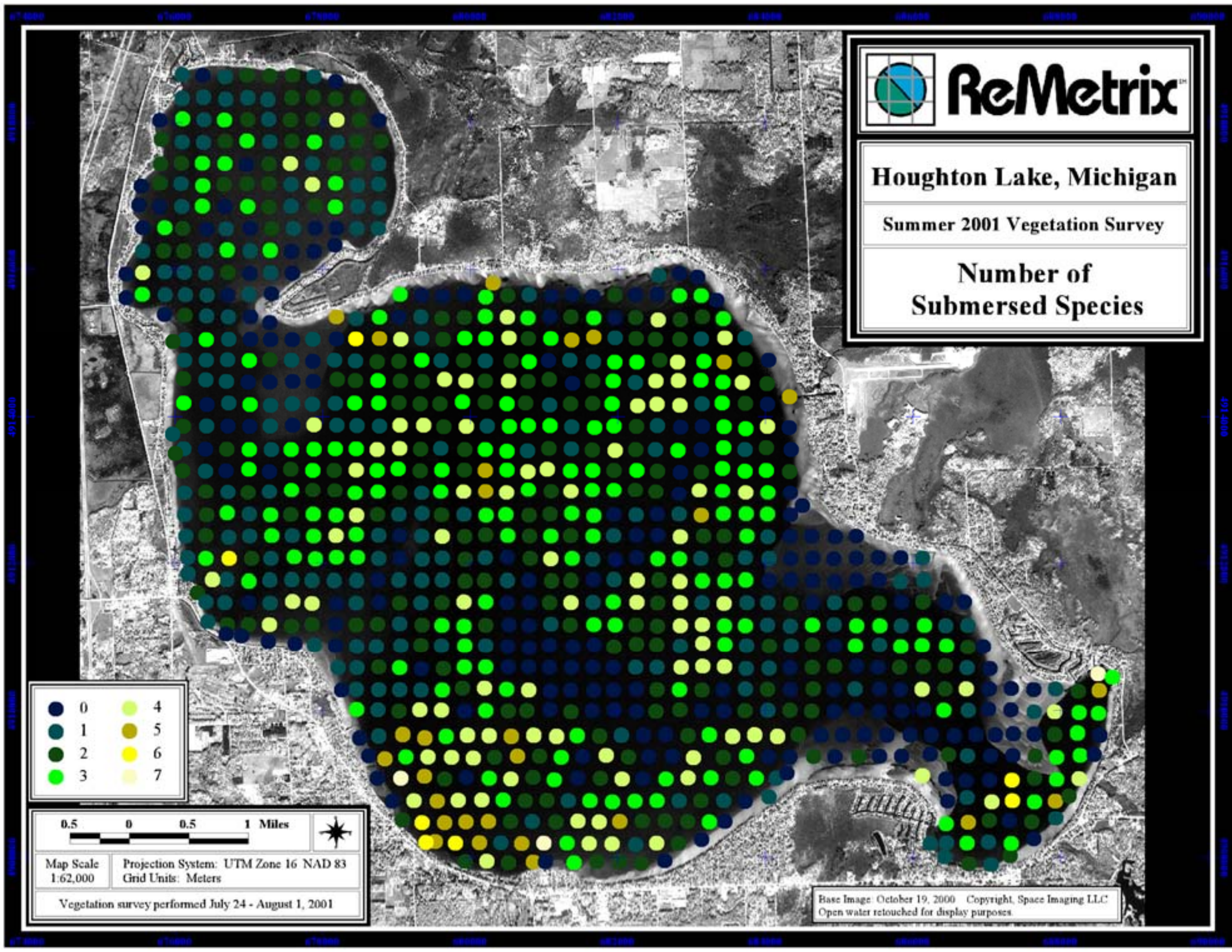

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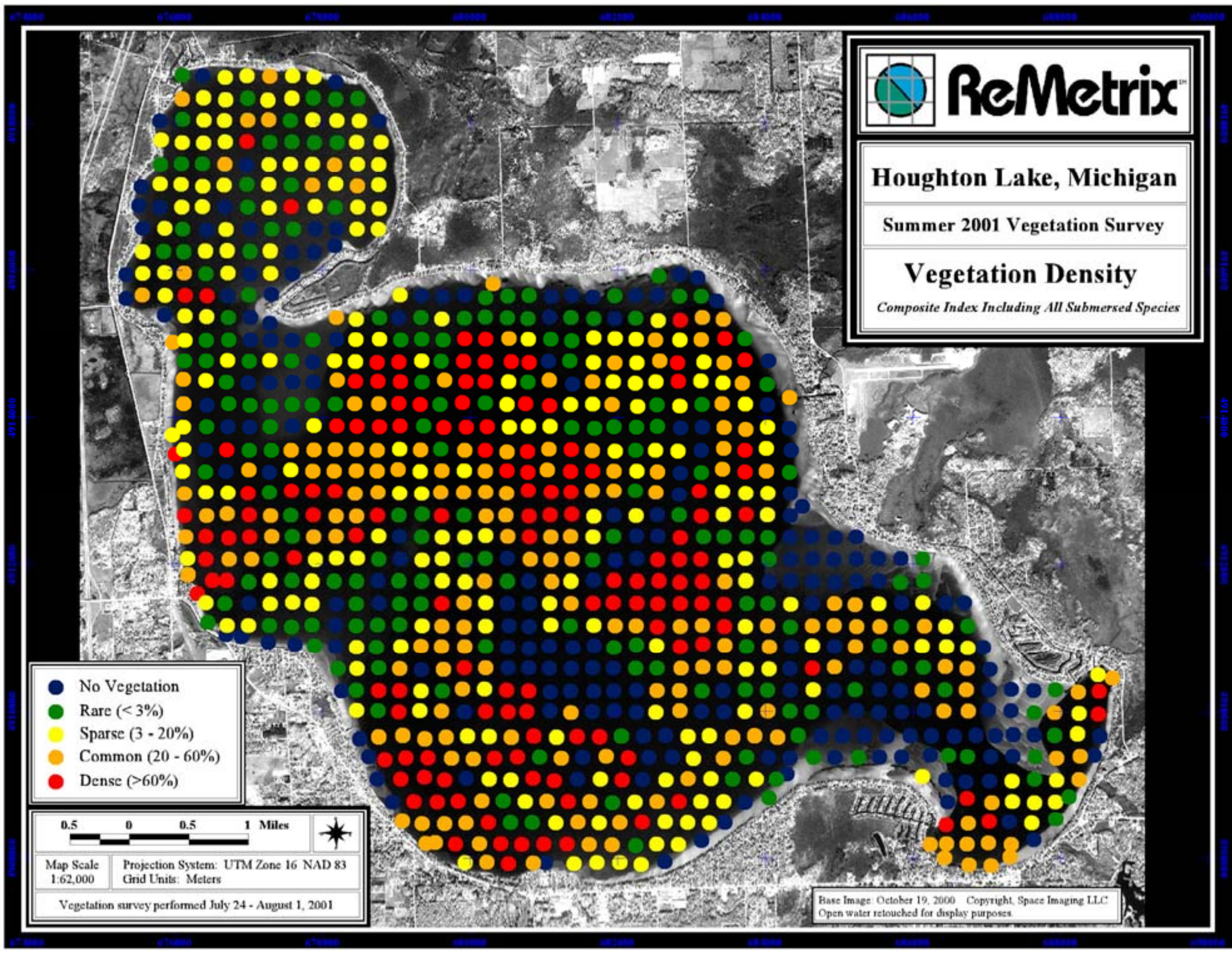

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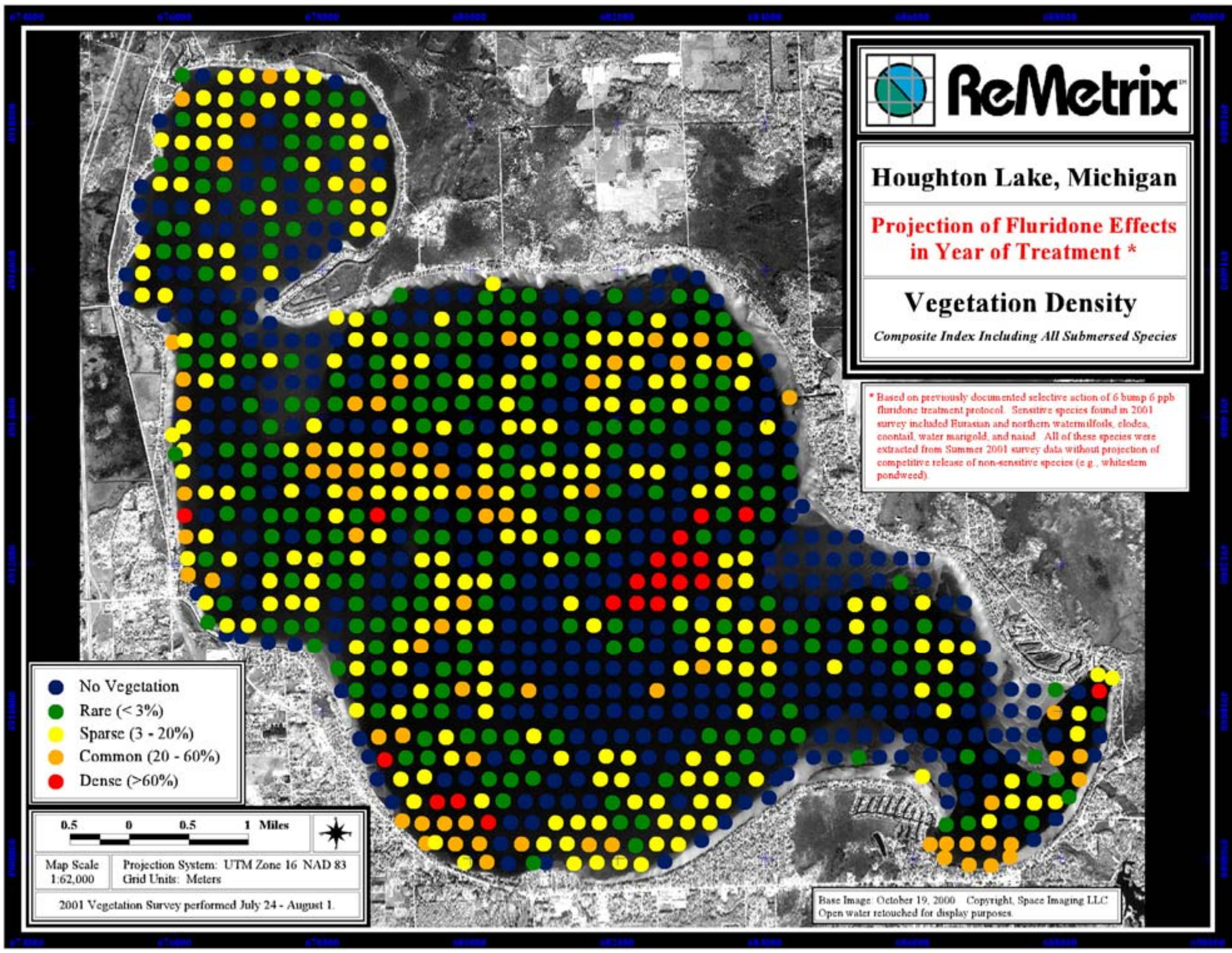

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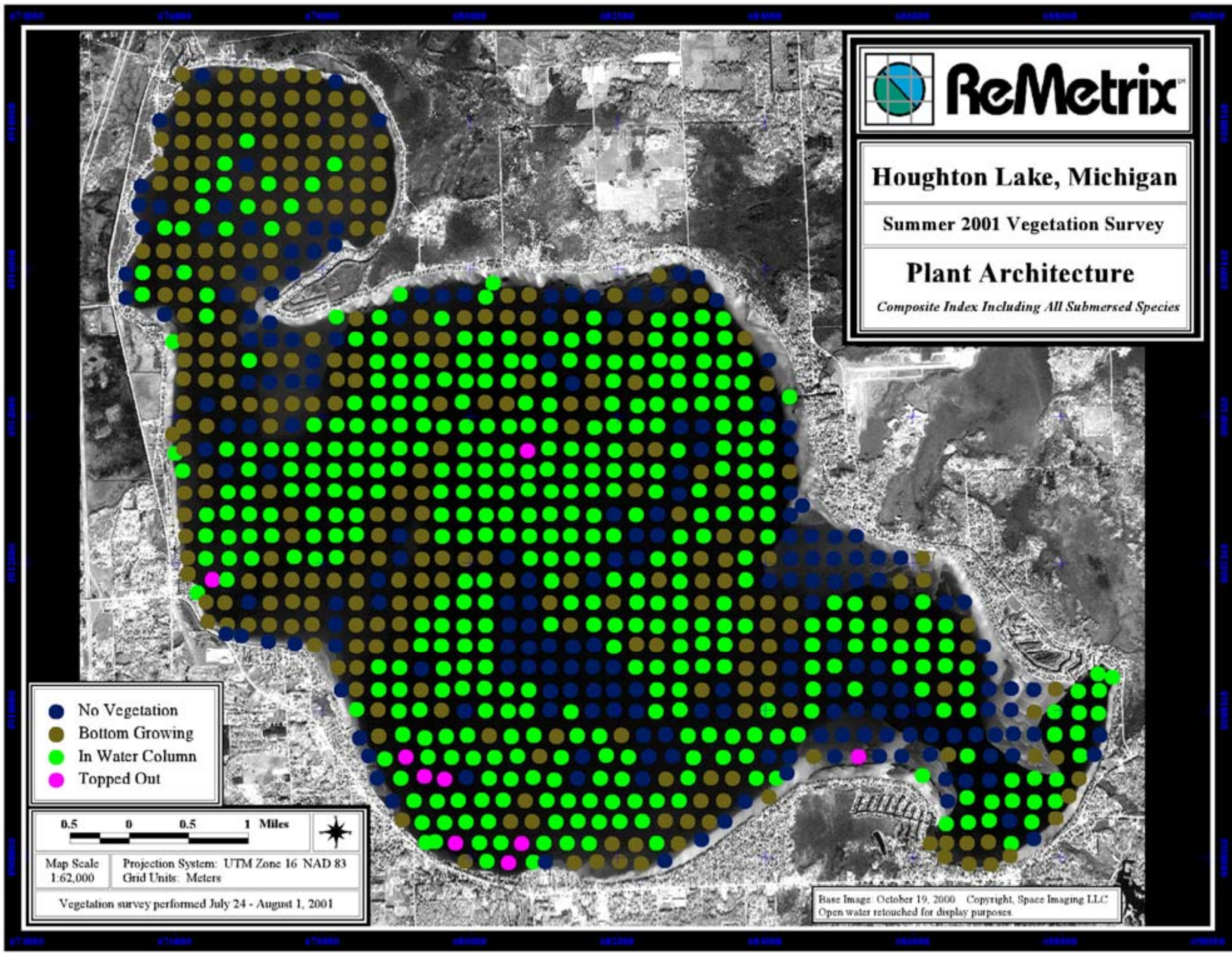

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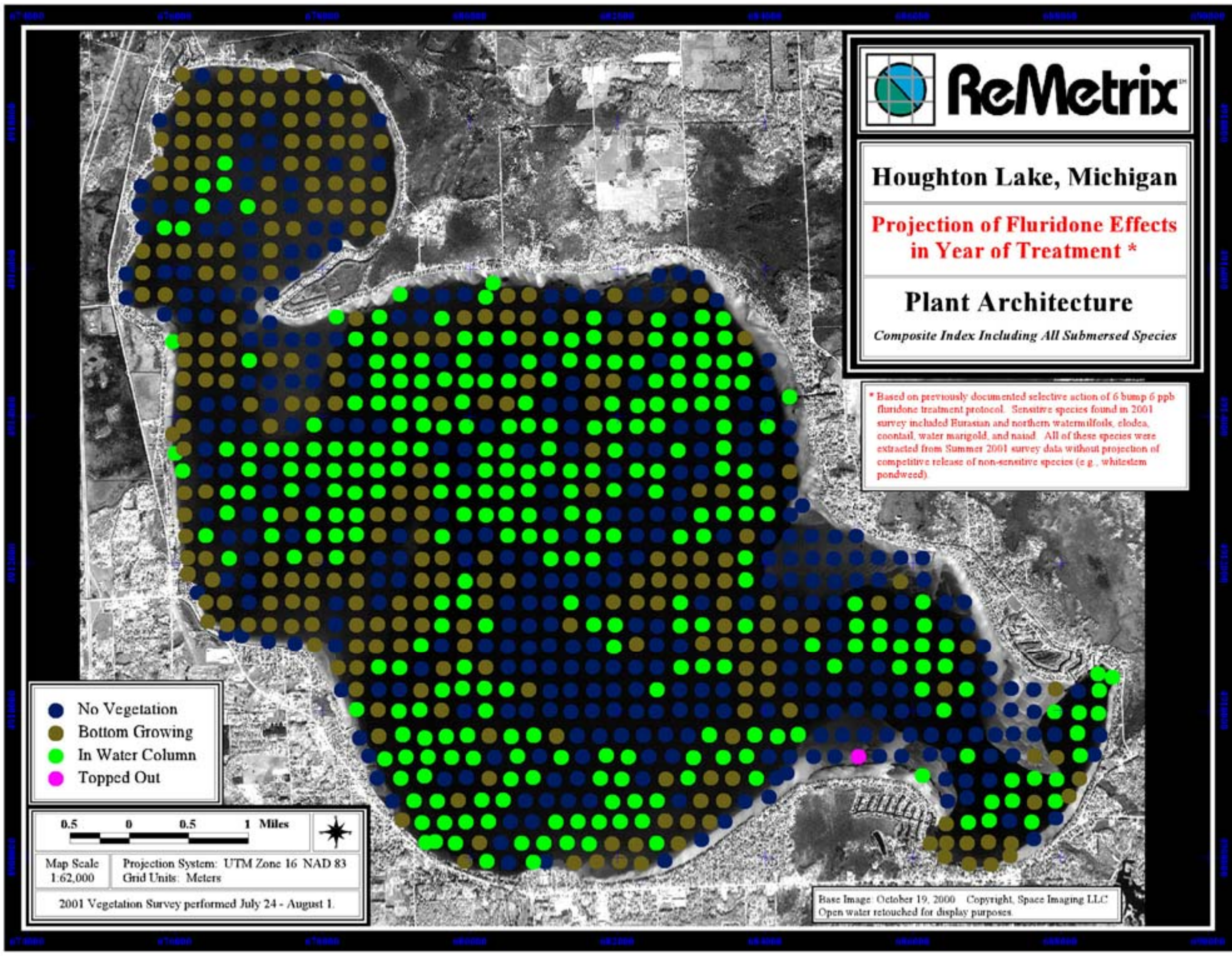

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Houghton Lake Vegetation Survey

Survey Date July-August 2001
Vegetated AVAS 705

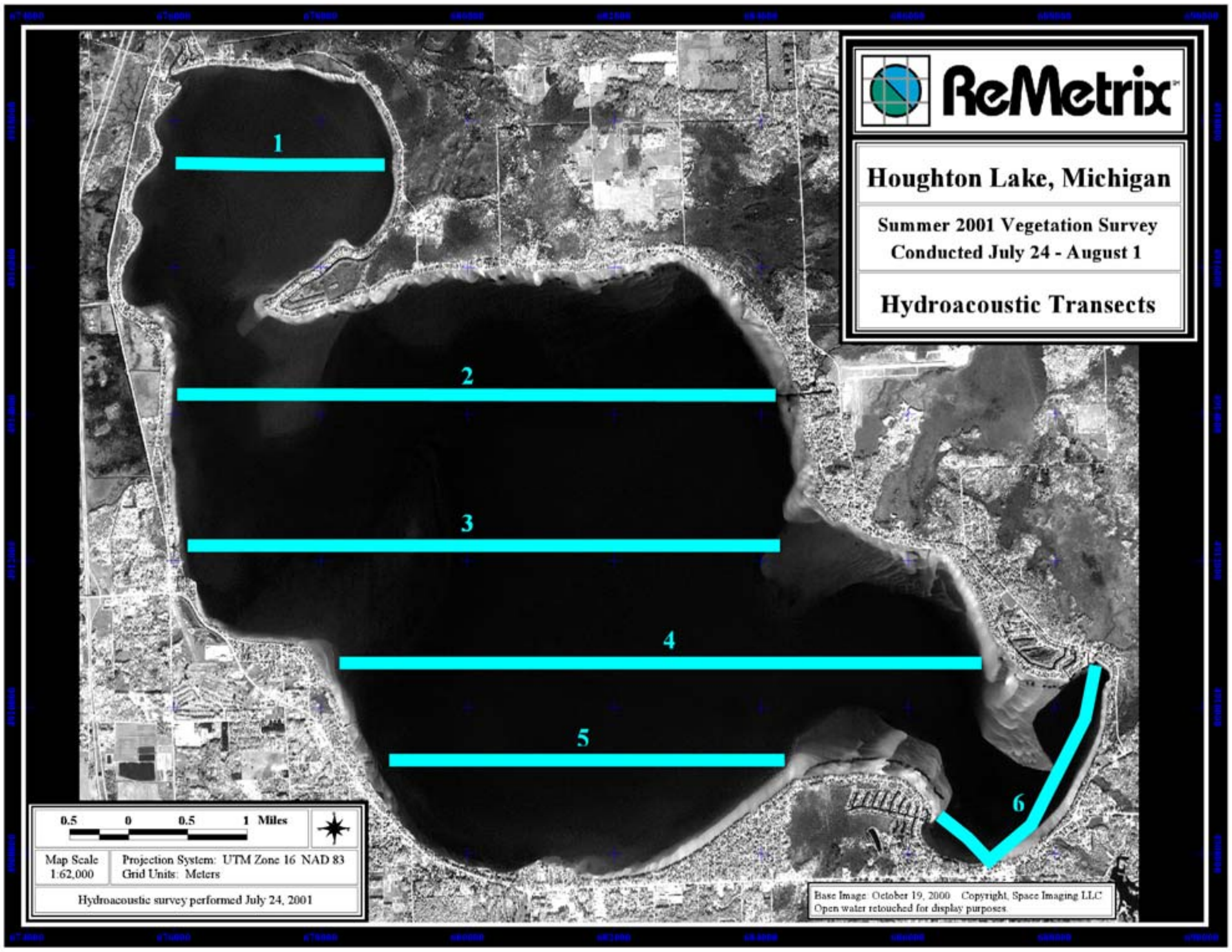
Species		# of AVAS in cover category				Total
No.	Name	A	B	C	D	Cover
1	Eurasian watermilfoil	143	104	130	113	21.88
2	curly leaf pondweed	2		1		0.06
3	muskgrass	102	105	41	15	5.66
4	thinleaf pondweed	77	30	4	1	0.88
5	flatstem pondweed	4	1			0.02
	mediumleaf pondweed					
6	Robbins pondweed	2	1	1		0.07
7	variable pondweed	28	8			0.15
8	whitestem pondweed	31	24	15		1.24
9	Richardson's pondweed	75	71	11		1.74
10	Illinois pondweed	6	2			0.04
11	largeleaf pondweed	4	1			0.02
12	American pondweed					
13	floating leaf pondweed	2				0.00
14	water stargrass	18	3	5	1	0.47
15	wild celery	35	19	2		0.43
16	arrowhead (submersed)					
17	northern watermilfoil	3	1			0.02
18	green watermilfoil					
19	variable-leaf watermilfoil					
20	coontail	20	11	2		0.30
21	elodea	143	106	33	15	5.28
22	bladderwort	1				0.00
23	bladderwort (mini)					
24	buttercup	8				0.01
25	naiad	53	27	2	1	0.69
26	brittle naiad					
27	water marigold	5	6			0.09
28	nitella	8	6	1	3	0.49
29						
30	water lily					
31	spatterdock					
32	water shield					
33	duckweed					
34	giant duckweed					
35	watermeal					
36	arrowhead					
37	pickerelweed					
38	arrow arum					
39	cattail					
40	bulrush					
41	iris					
42	water willow					
43	purple loosestrife					
44						
45						

Total Cumulative Cover 39.5
Native Cumulative Cover 17.6

Appendix B

<u>Hydroacoustic Transects for Vegetation Assessment – July 24, 2001:</u>

Map of Positions of Six Hydroacoustic Transects
Graphs of Vegetation BioVolume, Bottom Coverage, Mean Plant Height and Water Depth for each transect (total of 6)



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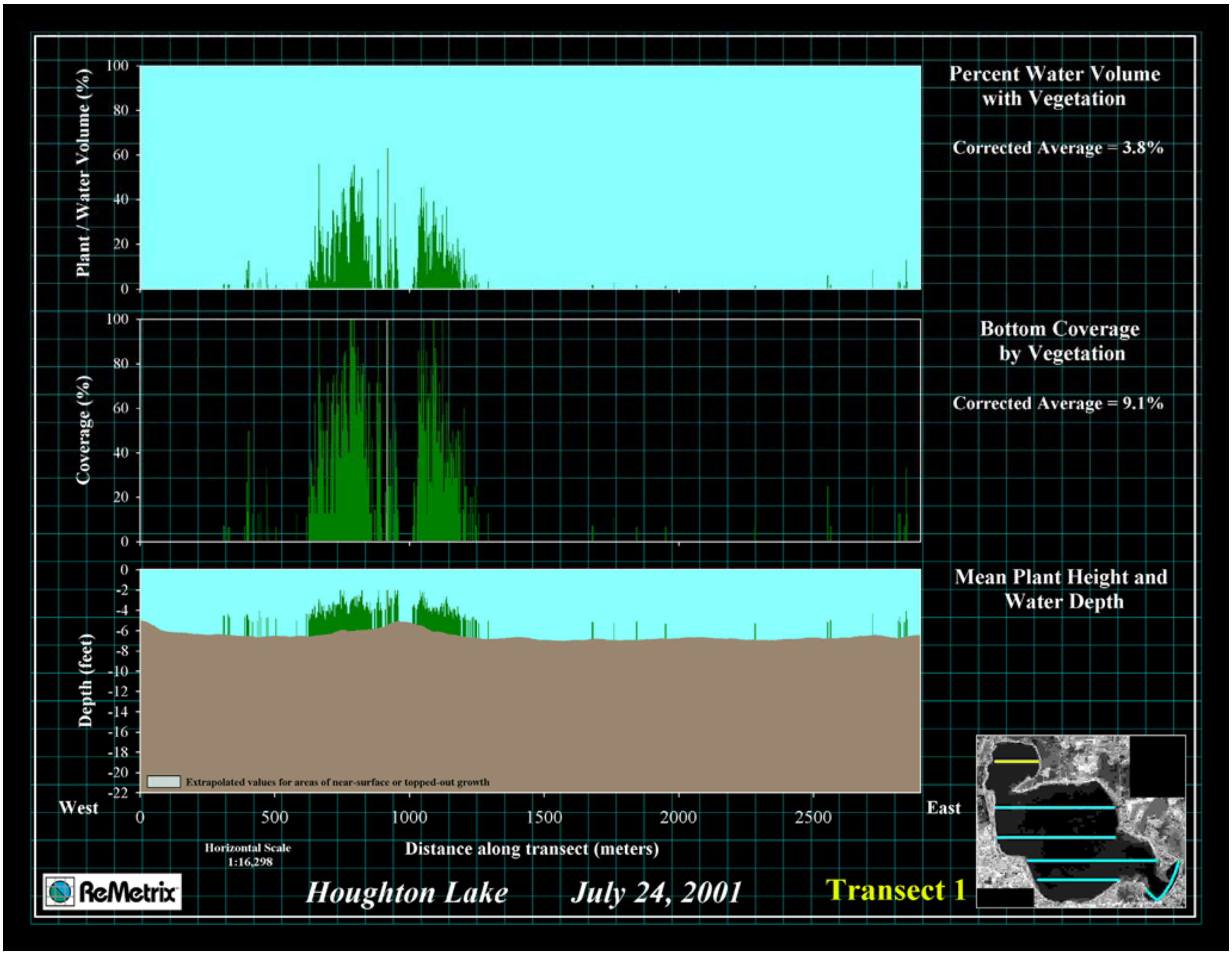

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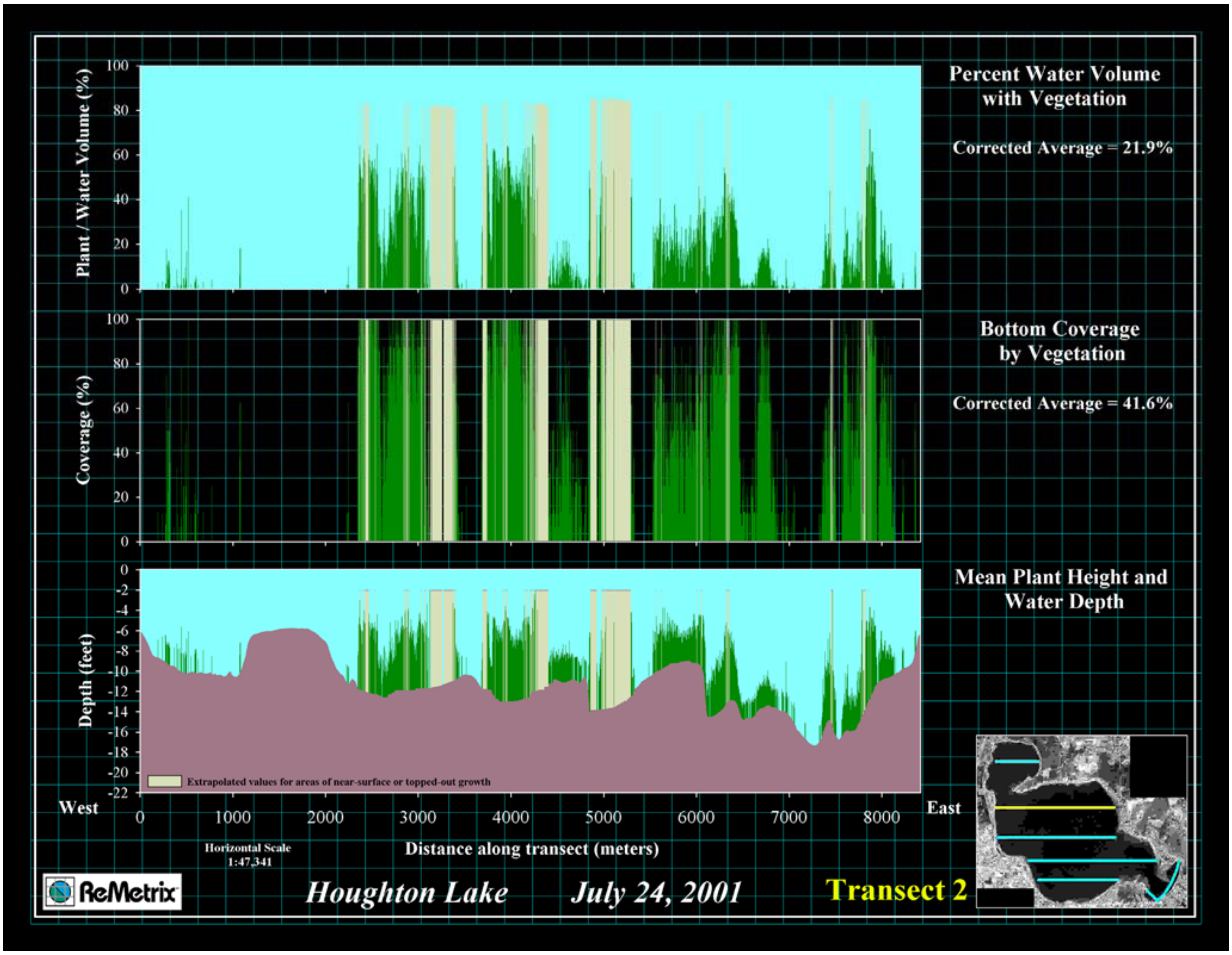

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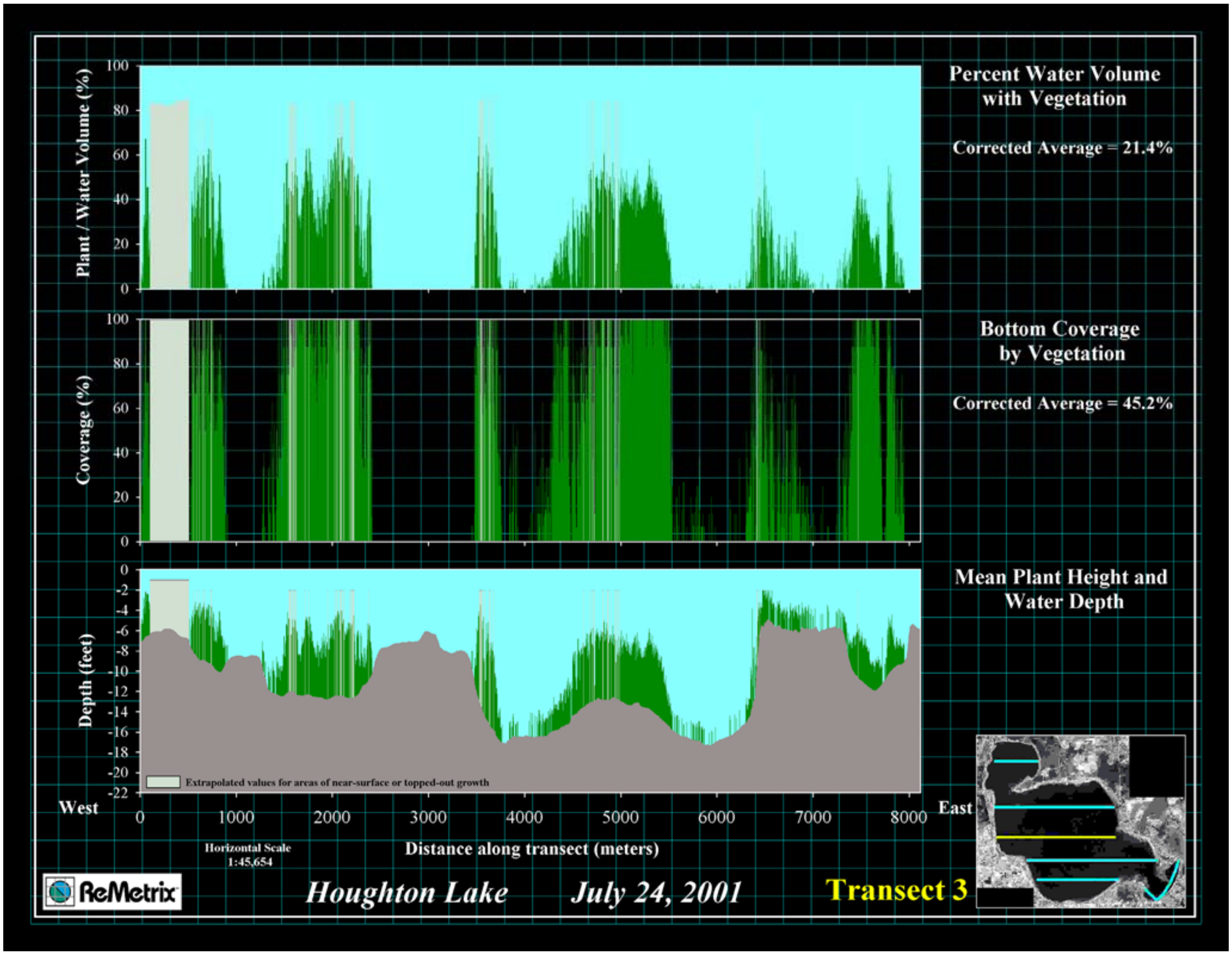

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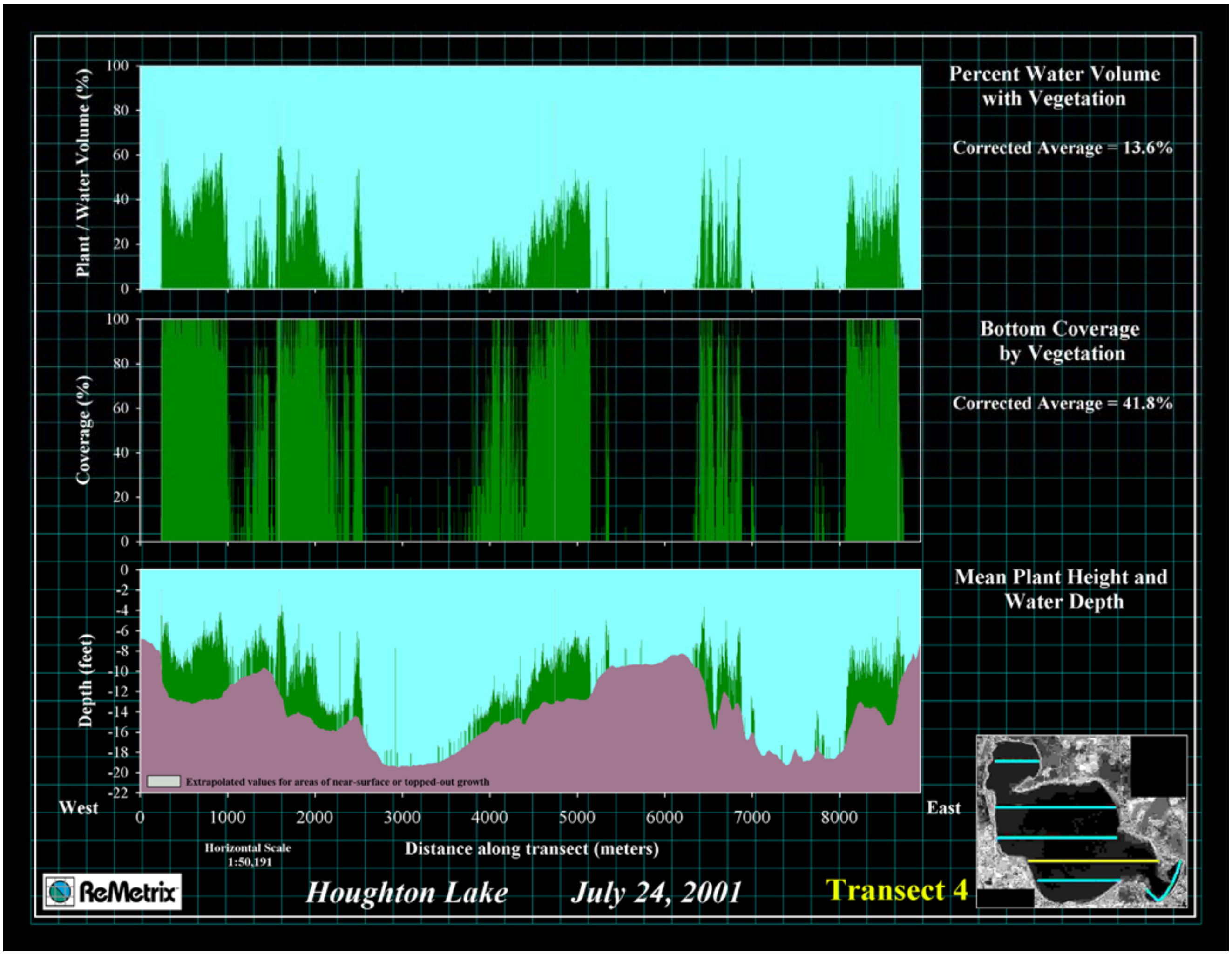

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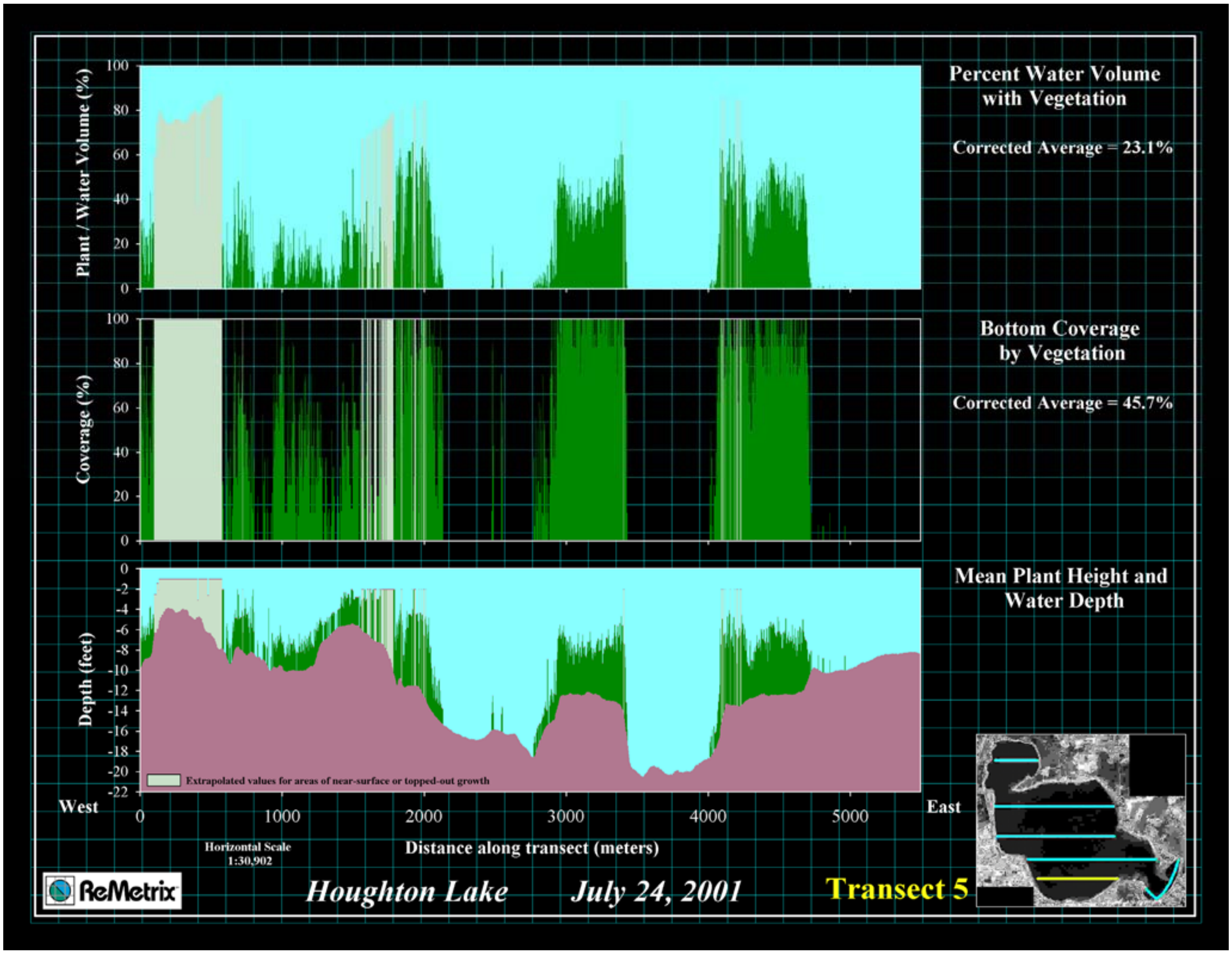

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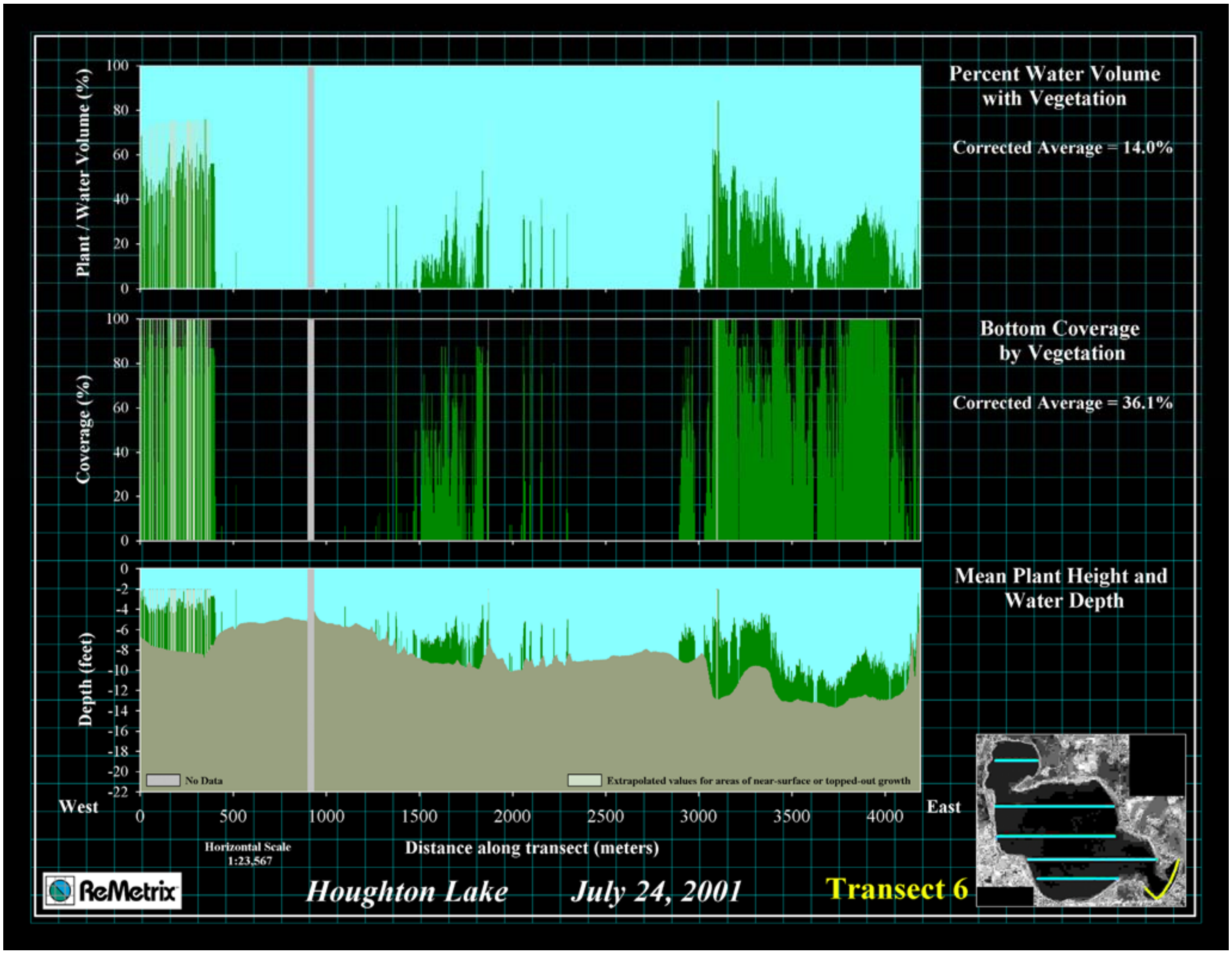

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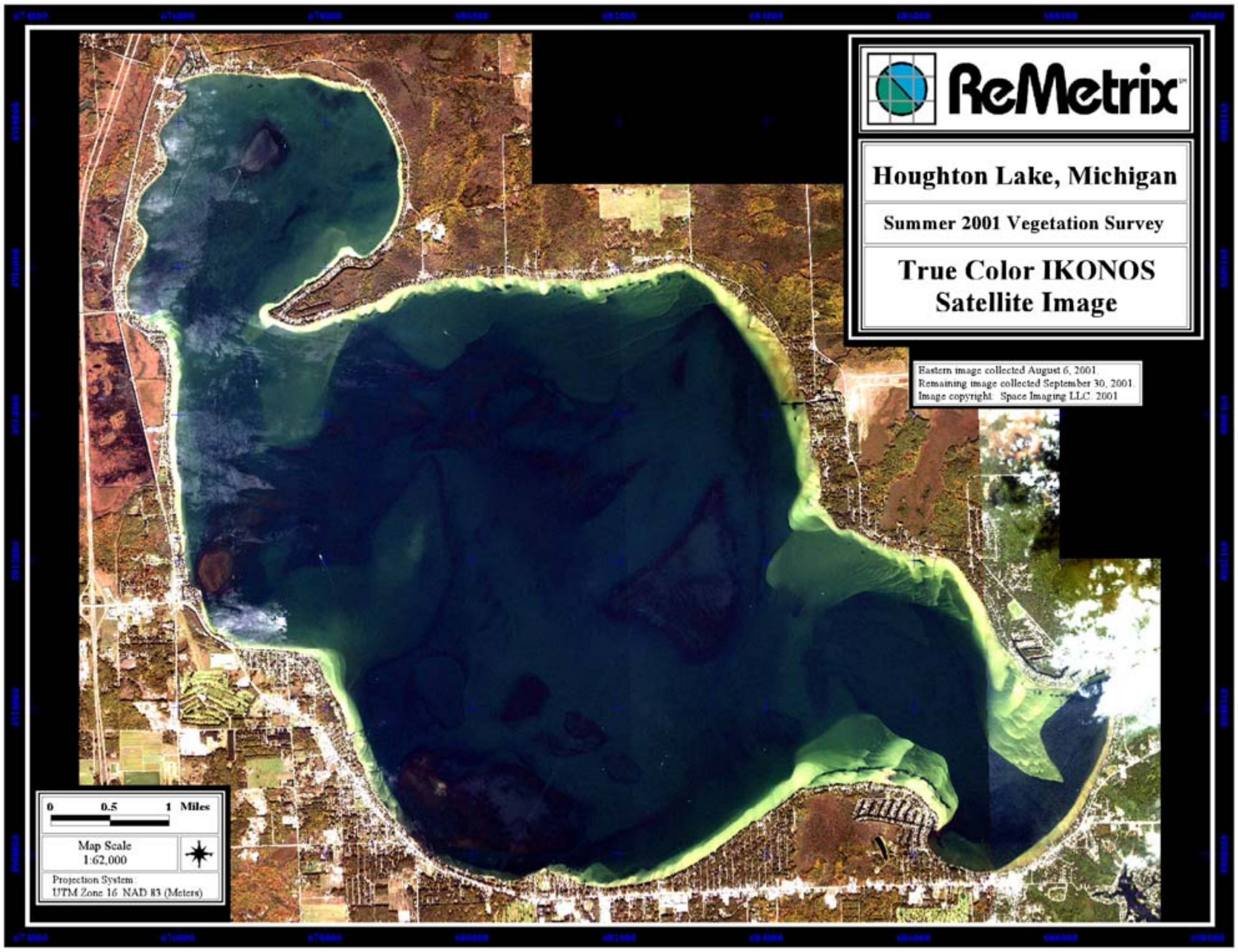
Appendix C

<u>Satellite Base Imagery and Classification*</u>

True Color IKONOS Satellite Image of Houghton Lake, Michigan
False Color IKONOS Satellite Image of Houghton Lake, Michigan
Classification of IKONOS Satellite Image of Houghton Lake, Michigan
IKONOS Classification with Overlay of Common and Dense Eurasian Watermilfoil Sites

- Imagery Acquisition Dates: August 6 and September 30, 2001



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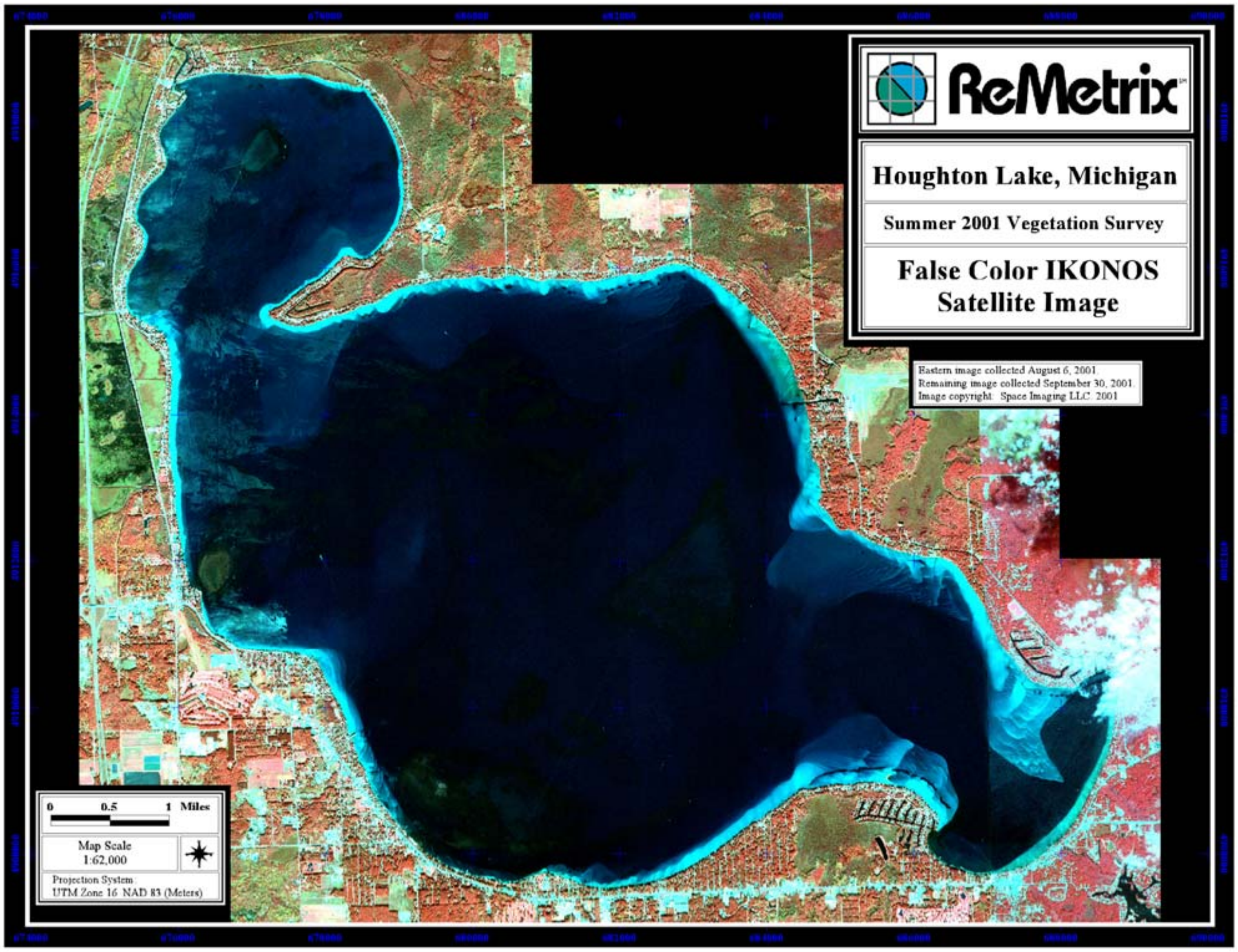

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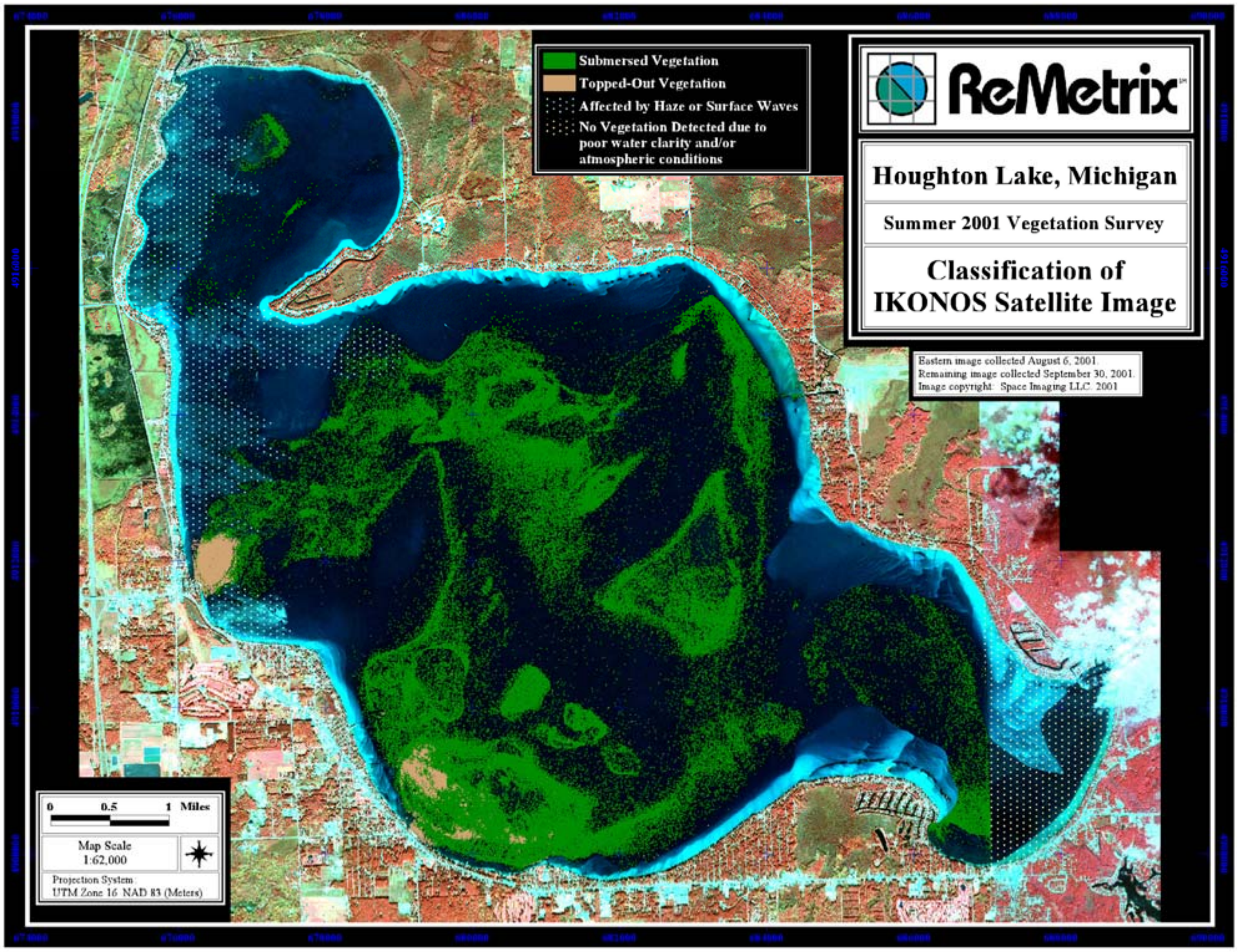

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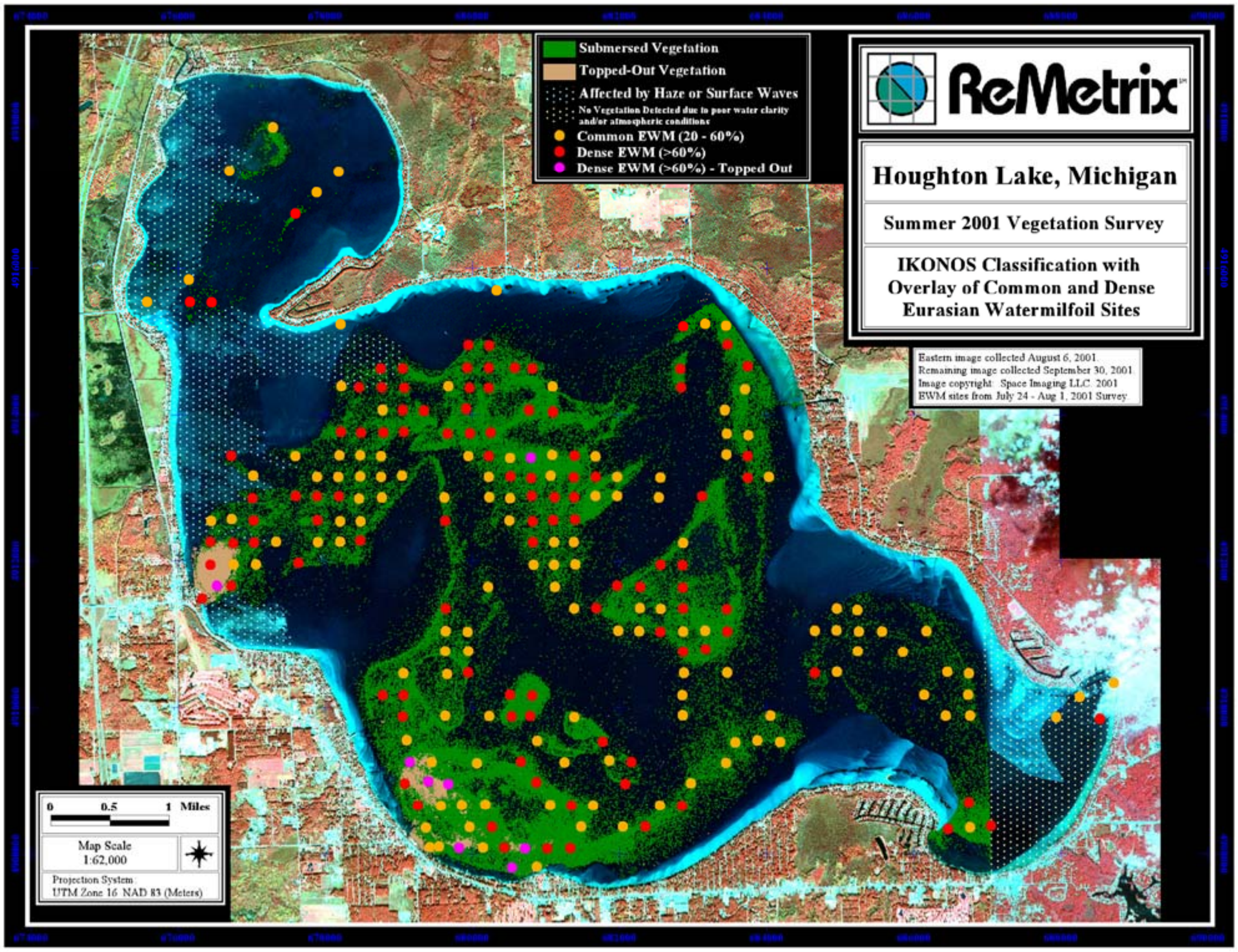
Final Report



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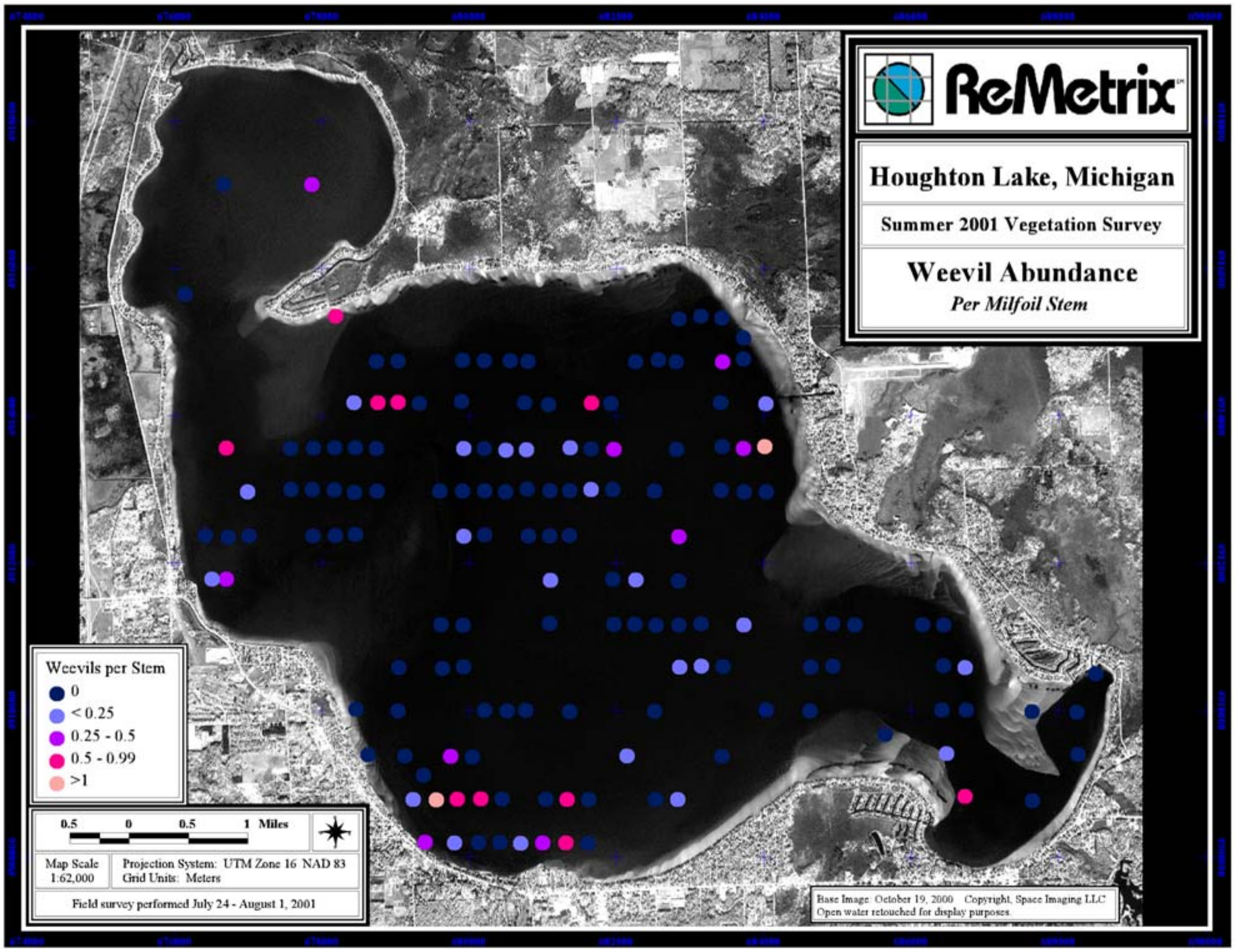
Appendix D

Maps of Milfoil Weevil Abundance

Weevil Abundance per Milfoil Stem
Weevil Abundance per Square Meter



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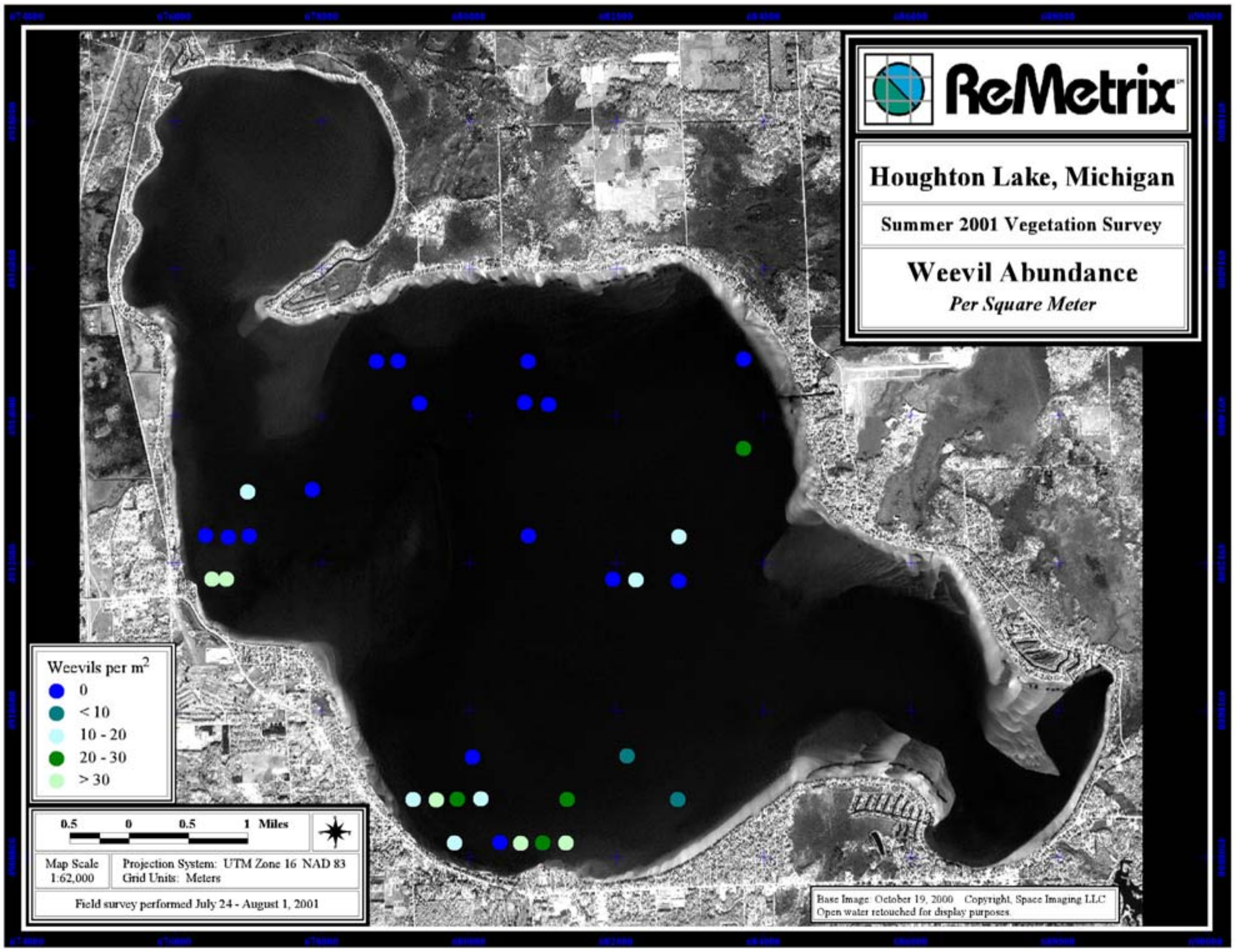

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Appendix E

Field Notes from Water Quality Study conducted by Michigan Water Research Center at Central Michigan University

THE MICHIGAN WATER RESEARCH CENTER
CENTRAL MICHIGAN UNIVERSITY

Houghton Lake Field Notes
23 September 2001

Inflowing Streams
Site 1: Sucker Creek @ Houghton Lake Drive 3:13 pm
The creek is not currently flowing. No water is in most of the channel upstream of the road and only a little water remains in a few holes. Samples were taken from the hole downstream of the road, but these should not be considered indicative of water quality during periods of the year when the creek is flowing. A variety of emergent macrophytes are found in the river channel.

Site 2: 3:32 pm
No water exists here now. No water samples collected. The creek appears to be little more than a roadside ditch that drains a swamp on the north side of the road.

Site 3: The Cut River (labeled Bachus Creek on our map) 3:55 pm
The Cut was hard to follow below E. Houghton Dr. because so many canals have been dredged to accommodate boaters. The sample was taken off the bridge to ensure that it was representative of the river and not stagnant canal water or in-flowing lake water (which may influence water in the river or channel south of here if the mouth is dredged. The end of Markey Road provides access to the canal area.

At E. Houghton Lake Bridge, the river was about 1.5 meters deep at maximum. Emergent Bur reeds and grasses lined the banks. Recent rains have swollen the river, resulting in flooded vegetation up to 30 feet from the banks. Despite this, the river is clear, though slightly tannin-stained. The thalweg has many macrophytes including *Vallisneria* and *Potamogeton sp*. Substrate is sand and organic material.

Site 4: 4:33 pm
The light rain that was falling since I arrived just turned to a steady downpour. This site appears to be nothing more that a canal. It is not marked on the Delorme Atlas. I assume that some tiny 1st order stream pours into the canal somewhere upstream from here. Most of the water in the canal may come from the lake depending on the water level, wind and seiche, etc. There appears to be no current here at all, but the tannin–stained water is evidence of some input from surrounding wetlands. Aquatic plants are diverse and abundant.

Site 5: Spring Brook Creek 5:04 pm
A nice little cold-water creek with good flow to it. Narrow (6-15') and shallow (8" max) near the bridge. Small fish are abundant (chubs?). Probably holds brook trout. Substrate is sand and detritus.

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Site 6: Denton Creek 5:17 pm
Still raining hard. The creek has cement seawalls on both sides. Substrate is sand. Milfoil and water lilies grow in the creek. No fish apparent.

Site 7: Knappen Creek 5:34 pm
Still raining hard. Overland flow entering at road crossing had discolored margins of the river with turbid rainwater. Samples were taken away from turbid area in the thalweg (<0.3 m deep). This creek isn't built up with seawalls like Denton Creek, but it is similar in size. Most of the creek bottom is sand with detritus in depositional zones. A few small minnows were seen under the bridge.

Outflowing Stream
Site 8: Muskegon River @ old 27 2:33 pm
Sediments were rich in organic matter. Abundant macrophytes, water lilies and pickerel weed, along margins with milfoil in thalweg. River barely flows here and water is clear despite the light rain that has been falling for a couple of hours. Water spiders and aphids were abundant in pickerel weed. Hydrolab readings were taken from the bridge over thalweg. Water bottles were filled at the edge of emergent vegetation.

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North Bay: Open Water Sites
Site 9: 9:53 am
Sun is just starting to burn off the thick fog. Not rooted macrophytes, just organic sediments with some sand and *Cladophora*. Some Eurasian Milfoil segments were observed drifting.

Site 10: near constriction in lake 10:21 am
Depth here was less than 2 m. Rooted vegetation was fairly sparse. Sediment was mostly clay. Saw some broad-leafed pondweeds.

Main Body Open Water Sites
Site 11: 11:14 am
This site was deeper than North Bay sites with abundant, but not excessively dense, macrophytes -- lots of broad-leafed *Potamogeton sp.* and *Myriophyllum*. Some adult Chironomids were observed. Filamentous green algae found amongst macrophytes. This area is not as open as some other main body locations.

Site 12: 1:33 pm
We found the sunken island north of here, but it was fairly weedy, so we decided to use this as our #12 open water site. The weeds here were sparse and diverse—*Elodea,*

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Potamogeton, Myriophyllum. Weather was now partly cloudy. Saw a flock of ~ 40 cormorants headed to this site. Sediments were organic muck.
Site 16: Deep Hole 3:01 pm
No weed growth present. Not stratification apparent. Clay bottom.

Site 21: Deep Hole 3:45 pm
As deep as site 16, but with abundant Milfoil growing. Some clumps of Milfoil reach 6 feet from the surface. Growth is not excessively dense here though. Clay/organic sediments were present.

Site 13: Deep Hole 4:08 pm
No macrophytes present. Clay bottom. Cloudy sky.

Main Body Weed Sites
Site 20: 11:51 am
Area due east of site 11 was quite weedy. This site has dense stands of Milfoil with almost nothing else, but the plants do not reach the surface.

Site 19: 12:18 pm
Extremely dense *Myriophyllum* bed with no other species present. Not sure it was where 19 was supposed to be, but it was an excellent weed site. Some Chironomids were active. Sun was bright and no clouds or fog overhead.

Site 17: 1:08 pm
There was a *very dense* Milfoil monoculture here, also abundant Chironomids and young fish, mostly Centrarchids. Observed two large fish feeding (bass?). Some dragonflies present, mating. Weeds here reached surface and in some nearby areas formed what appeared to be a very dense green carpet. Fish were more abundant here than at previous sites. Bottom was rich organic matter.

Site 18: 2:33 pm
Site 18 was located just off weed bed in front of launch due to the fact that we saw no comparable weed bed at map location for site 18 on the way in. Here, there was dense Milfoil with few other plants (some *Potamogeton*). Sediments were organic.

Southeast Bay
Site 15: Open Water, Deep Hole 4:40 pm
No rooted macrophytes here. Looks like a good migration route for fish—the hole was in a channel between a shallow sandbar with a steep drop-off and another steep drop-off. Sediments mostly fine organics with coarse organic matter also appearing. Decomposing wood and leaves came up on the anchor.

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Site 14: Open Water Site 5:01 pm
Myriophyllum was present, though not dense. Water was 3.5 m deep with macrophyte tips at least 1.5 m from surface. Sediments were organic.

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Appendix F

<u>Contact Information:</u>

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