Aquatic Invasive Species Survey
of
Selected Lakes in the Ceded Territory
During 2004

by

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and

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INTRODUCTION

The Great Lakes Indian Fish and Wildlife Commission (GLIFWC) is an organization exercising delegated authority from 11 federally recognized tribes in Minnesota, Wisconsin, and Michigan. These tribes retain hunting, fishing, and gathering rights in the territories ceded to the United States through various treaties (Figure 1).

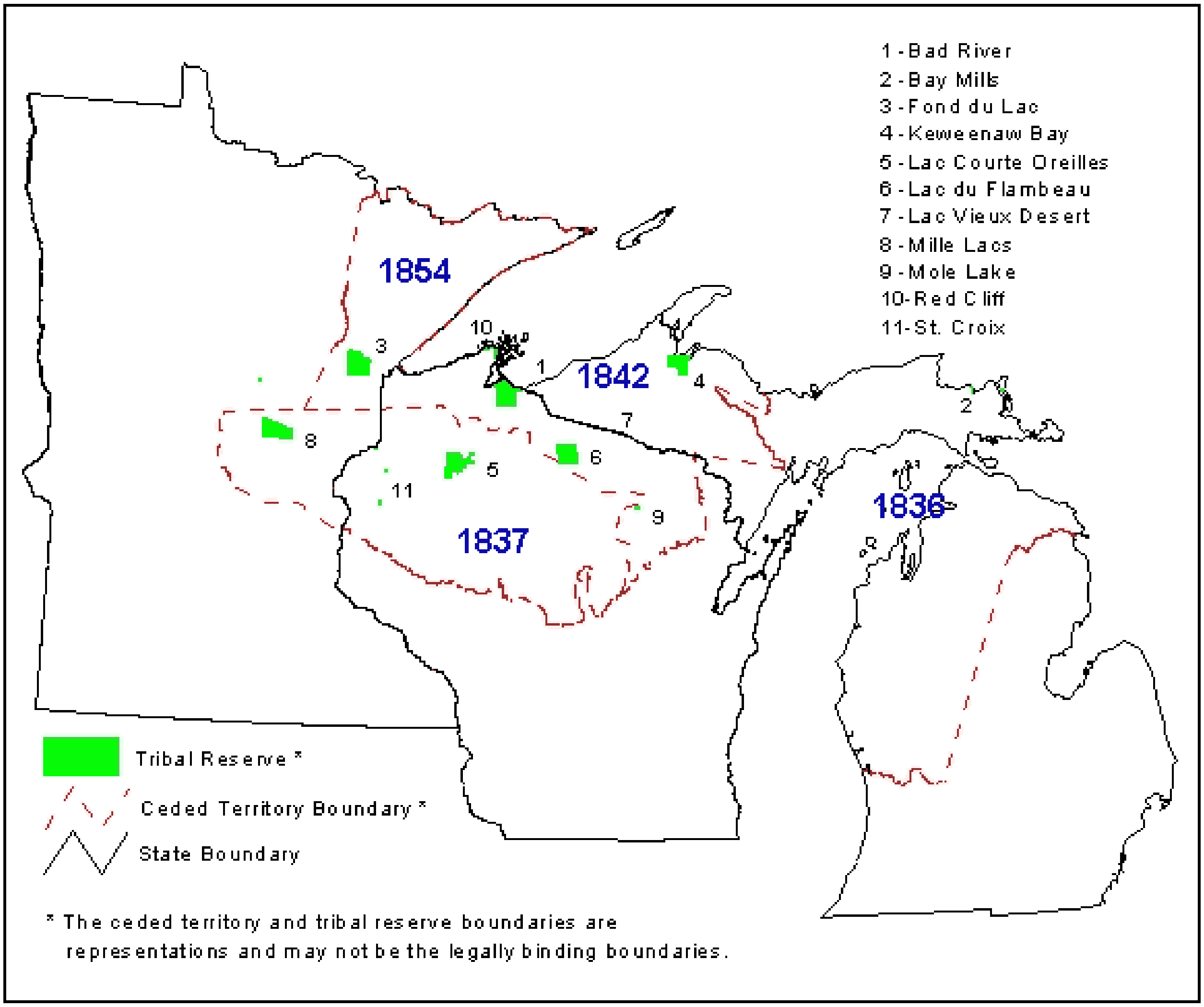

Figure 1. GLIFWC member tribes and ceded territory boundaries.

Healthy aquatic plant and animal communities provide a foundation for the exercise of treaty rights by providing food and habitat for culturally important game species, as well as subsistence foods and medicines for tribal members. Non-native invasive aquatic plants and animals threaten the health of native ecosystems and the resources harvested and utilized by tribal members, by altering aquatic ecosystems and adversely affecting native species.

Since the early 1800s, at least 162 species of fish, plants, invertebrates, algae, and pathogens have been introduced into the riparian and aquatic habitats of the Great Lakes (Ricciardi 2001, from various sources). Many of these organisms have since invaded inland lakes and rivers in the ceded territory, and others are now poised to do so. The more destructive of these invasives have caused major environmental and economic impacts; for example, the economic cost of zebra mussels alone has been estimated at $100 million since its introduction (Pimentel et al. 2000).

The objectives of the 2004 GLIFWC aquatic invasive species surveys were: 1) to develop a rapid assessment protocol, 2) to assess and document the scope of the problem, 3) to detect small populations of the worst invasives before they become large, environmentally damaging populations, and 4) to prioritize education and management efforts.

Unless otherwise indicated, vascular plant nomenclature and geographic origin follow Gleason and Cronquist (1991).

OVERVIEW OF INTRODUCED AQUATIC SPECIES

Target and Nontarget Species

These surveys were designed to detect certain "target" invasive plants and animals that are listed as aquatic invasive species in the 1837 Treaty Conservation Code for the Minnesota Ceded Territory (the Model Code). These original target plants were flowering rush (*Butomus umbellatus*), European frog-bit (*Hydrocharis morsus-ranae*), hydrilla (*Hydrilla verticillata*), purple loosestrife (*Lythrum salicaria*), Eurasian water-milfoil (*Myriophyllum spicatum*), and water chestnut (*Trapa natans*). Several additional plants were also considered target plants for this survey: yellow iris (*Iris pseudacorus*), brittle naiad (*Najas minor*), yellow floating-heart (*Nymphoides peltata*), Eurasian forms of common reed (*Phragmites communis*), and curly-leaf pondweed (*Potamogeton crispus*). Two more plants, water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes* L.) were also added to this list based on information in WDNR (2003). A phenology of key attributes for detecting the "original" target plants was developed to guide survey efforts (Table 1).

The target animal was the zebra mussel (*Dreissena polymorpha*), with quagga mussel (*Dreissena bugensis*), spiny water flea (*Bythotrephes longimanus*), and fishhook water flea (*Cercopagis pengoi*) also added to the list. Brief information on these species is presented below.

Other invasive plants and animals are also established in the ceded territory. Most of these are considered generally less invasive, or so common as to be impractical to delineate patches on lakes where they occurred. These were simply recorded as "present" or "absent" on each lake.

Table 1. Optimal phenology of key plant attributes used for detecting target invasive plants (May - October).

<table>
<tr><th rowspan="2">Plant</th><th colspan="2">May</th><th colspan="2">June</th><th colspan="2">July</th><th colspan="2">August</th><th colspan="2">September</th><th colspan="2">October</th></tr>
<tr><th>Early</th><th>Late</th><th>Early</th><th>Late</th><th>Early</th><th>Late</th><th>Early</th><th>Late</th><th>Early</th><th>Late</th><th>Early</th><th>Late</th></tr>
<tr><td>Brittle Naiad
Najas minor</td><td></td><td></td><td></td><td colspan="9">Near-surface vegetation</td></tr>
<tr><td>Common Reed (Eurasian haplotype)</td><td></td><td></td><td colspan="10">Stems</td></tr>
<tr><td>*Phragmites australis*</td><td></td><td></td><td></td><td></td><td></td><td colspan="7">Flower or seed heads</td></tr>
<tr><td>Curly Pondweed</td><td></td><td></td><td colspan="4">Near-surface vegetation</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>*Potamogeton crispus*</td><td></td><td></td><td></td><td></td><td colspan="8">Turions</td></tr>
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<tr><td>Eurasian Water Milfoil</td><td></td><td></td><td></td><td></td><td colspan="5">Near-surface vegetation</td><td></td><td></td><td></td></tr>
<tr><td>*Myriophyllum spicatum*</td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Flowering</td><td></td><td></td><td></td><td></td></tr>
<tr><td>European Frog-bit</td><td></td><td colspan="9">Floating vegetation</td><td></td><td></td></tr>
<tr><td>*Hydrocharis morsus-ranae*</td><td></td><td></td><td></td><td colspan="6">Flowering</td><td></td><td></td><td></td></tr>
<tr><td>Flowering Rush</td><td></td><td></td><td colspan="8">Emergent vegetation</td><td></td><td></td></tr>
<tr><td>*Butomus umbellatus*</td><td></td><td></td><td></td><td></td><td colspan="4">Flowering</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Hydrilla</td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Seedheads</td><td></td></tr>
<tr><td>*Hydrilla verticillata*</td><td></td><td></td><td></td><td></td><td colspan="6">Near-surface vegetation</td><td></td><td></td></tr>
<tr><td>Purple Loosestrife</td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Flowering</td><td></td><td></td></tr>
<tr><td>*Lythrum salicaria*</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">Seedheads</td></tr>
<tr><td>Water Chestnut</td><td></td><td></td><td></td><td colspan="7">Floating vegetation</td><td></td><td></td></tr>
<tr><td>*Trapa natans*</td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Flowering</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="5">Seeds</td></tr>
<tr><td>Yellow Floating Heart</td><td></td><td></td><td></td><td colspan="7">Floating vegetation</td><td></td><td></td></tr>
<tr><td>*Nymphoides peltata*</td><td></td><td></td><td></td><td></td><td colspan="6">Flowering</td><td></td><td></td></tr>
<tr><td>Yellow Iris</td><td></td><td></td><td></td><td colspan="6">Emergent vegetation</td><td></td><td></td><td></td></tr>
<tr><td>*Iris pseudacorus*</td><td colspan="5">Flowering</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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Nontarget plants included Eurasian marsh thistle (*Cirsium palustre*), Eurasian mints (generally *Mentha* x *gentilis*), water forget-me-not (*Myosotis scorpioides*), reed canary grass (*Phalaris arundinacea*), white and crack willow (*Salix fragilis* and *S. alba*, along with their hybrid, *S*. x *rubens*), bittersweet nightshade (*Solanum dulcamara*), and narrow-leaf and hybrid cattails (*Typha angustifolia* and *T*. x *glauca*). Nontarget animals were Asian mysterysnails (*Cipangopaludina chinensis* subsp. *malleata*), Georgia mysterysnails (*Viviparus georgianus*), and rusty crayfish (*Orconectes rusticus*). Except for rusty crayfish, the spread and impact of these species have not been systematically monitored or researched.

Because they are such aggressive and notorious invasives, several terrestrial plants that sometimes occur along lakeshores, in wet woods, etc. were also recorded as present/absent. These included Eurasian bush honeysuckles (*Lonicera tatarica*, *L. morrowii*, and their hybrid, *L*. x *bella*), common buckthorn (*Rhamnus cathartica*), glossy buckthorn ®*. frangula*), and Japanese barberry (*Berberis thunbergii*).

While these surveys focused primarily on populations of the above plants and animals on the survey lakes, it was intended to be flexible, and occasionally other introduced plants were recorded as well.

Target Plants

Emergent and shoreline plants

Purple loosestrife is native to Eurasia. It is now widespread and locally common throughout the upper Great Lakes region. Flowering usually begins in July. GLIFWC, the Wisconsin Department of Natural Resources (WDNR) and Minnesota Department of Natural Resources (MNDNR), and citizen volunteers have been distributing *Galerucella* beetles [*G. calmariensis* L. and *G. pusillus* Duft., (Coleoptera: Chrysomelidae), both USDA-approved biological control agents] at various loosestrife-infested sites throughout the ceded territory.

Flowering rush is also native to Eurasia. It is the lone member of the plant family Butomaceae. It is a relative newcomer to the upper Great Lakes region, and is still quite localized here. Flowering rush typically grows as an emergent or wet-ground species, but can also form persistent, entirely submersed patches in deeper water (Hroudova et al. 1996). For sampling purposes it was assumed that if deepwater colonies were present, emergent plants would also be present. Flowering rush begins flowering around late June or early July.

Common reed is both native and introduced to North America. Prior surveys conducted by GLIFWC staff suggest that nearly all common reed colonies in northern Wisconsin and the western Upper Michigan are of the native genotype. The non-native type is somewhat different than the native type in appearance and habitat requirements (though there is some overlap), and is generally much more aggressive in natural habitats (Blossey 2002). For these surveys only colonies of the introduced type were recorded as an invasive.

Yellow iris is native to Europe. Scattered populations of yellow iris now occur across the upper Great Lakes region. This plant can be aggressive in wetland and shoreline habitats, forming dense colonies several meters or more in diameter. Mature plants are easy to spot in May and June, when they produce large, bright yellow flowers. Small, non-blooming patches can be very difficult to separate from the native blue flag iris (*Iris versicolor*).

Free-floating plants

Free-floating species typically inhabit quiet waters such as marshes, ponds, backwaters of rivers and streams, sloughs, and sheltered bays of larger lakes, though they can conceivably be found adrift anywhere in a lake.

European frog-bit was the only target free-floating plant. As its name indicates, it is native to Europe. While not yet known from the upper Great Lakes region, European frogbit has become abundant along portions of the upper St. Lawrence Seaway and its tributaries from Vermont as far west as Detroit, and is also established at a site in Washington State (Jacono 2002). It begins flowering around mid- to late June, but is distinctive enough to be easily recognized from early June onward. Unless European frog-bit is newly introduced to a lake, it would probably form large floating patches unlikely to be missed.

Two additional floating aquatic invasive plants, water hyacinth (native to the Amazon region of South America) and water lettuce (native to tropical America), have recently been found in Wisconsin inland waters (WDNR 2003). Water hyacinth was discovered in a “lagoon” in northern Wisconsin, where eradication efforts are underway (WDNR 2003). Although these plants are generally not thought to be cold-hardy enough to become established in the upper Midwest (see Jacono and Richerson 2003 for water hyacinth, and Ramey 2001a and USGS 2003 for water lettuce) the discovery of at least transient populations in the upper Great Lakes region is cause for concern.

Rooted, floating-leaved plants

Water chestnut (native of Eurasia) was the only target rooted, floating-leaved plant. Although this plant would probably not begin to flower here until July onward, its floating rosette of leaves is unlike anything in our flora, so this plant is likely detectable from June onward. The large, four-spined seeds might well be obvious on the shoreline. As with European frogbit, established colonies of water chestnut are likely to be dense and extensive.

Another floating-leaved plant likely to show up in the upper Great Lakes region at some point is yellow floating-heart. Native to Europe, yellow floating-heart is now locally established across much of the central US, from Vermont to Illinois and Texas, and in several western states (USDA-NRCS 2004), and is attaining pest status in some areas. Though it superficially resembles the true water lilies (e.g., *Nymphaea* and *Nuphar* spp), yellow floating-heart belongs to an entirely different plant family. It flowers from June through September.

Submersed plants

Target submersed plants included Eurasian water-milfoil and hydrilla. Native to Eurasia, Eurasian water-milfoil (or just Eurasian milfoil) can reach the surface from as deep as 5 m, and grow as deep as 10 m (Aiken et al. 1979). It typically branches only sparsely until is nears the surface, where it then branches profusely, forming a “canopy” that shades out the vegetation below. Eurasian milfoil is now fairly common across the upper Great Lakes region, and is probably the region’s most problematic introduced aquatic plant.

Hydrilla is native to Asia. It can live in water only a few cm deep, and has been found rooted in water as deep as 15 m, with 3 m roughly optimal (Langeland 1996). Its stems can reach 7.6 m long, allowing the plants to reach the surface from deep water (Ramey 2001b). Hydrilla possesses some rather unique physiological adaptations, allowing it to survive and grow at less than 1% of full sunlight, and to colonize deeper water than almost any other aquatic plant (Van et al. 1976, Langeland 1996). Both monecious and dioecious strains of hydrilla exist; the monoecious form (thought to be native to Korea) appears to be more cold-tolerant and is the form now established in the eastern US and in Washington State. While it has not yet been found in the region, the monoecious type may be cold-tolerant enough to invade upper Great Lakes waters. The US-ACE (2001) considers hydrilla to be the worst submersed invasive plant in North America.

Curly-leaf pondweed (or curly pondweed) is native to Eurasia, Africa and Australia (Catling and Dobson 1985). It is the only introduced pondweed *(Potamogeton* spp.) in the Great Lakes region (FNA 1993+). It is now apparently common in lakes of northwest Wisconsin and northeast Minnesota, but uncommon or even absent from large areas in northeast Wisconsin and western Upper Michigan (WIS 2005, D. Blumer, *pers. comm*.). Its optimal depth is 1 to 3 m, though it is known to occur in water as deep as 7 m (Bolduan et al. 1994). After living through the winter as an immature rosette, curly pondweed grows rapidly in the spring, producing turions in early summer and disintegrating in July (but see *Results*). These turions (often with attached shoots) may be seen floating just below the surface as late as August (*pers. obs.*).

Brittle naiad is native to the Old World. It has been reported as colonizing water as deep as 3.7 m, and reaching the surface from 2.7 m (VT-DEC 1998). Brittle naiad is now found in the eastern US as far north as Vermont and southeastern lower Michigan, and as far west as Illinois and Oklahoma (USDA-NRCS 2004), and could soon begin to show up in lakes and rivers of the ceded territory.

Nontarget Plants

Although many of these plants are usually not considered to be serious invasives (reed canarygrass being a major exception), all of them are very likely increasing in abundance across the region, and may eventually be viewed as serious pests. Most of these invaders (e.g., nightshade, reed canarygrass) are already common across the ceded territory (WIS 2005). Others are still uncommon, but have become abundant elsewhere in the Great Lakes region. One of these (white willow) has already become abundant along lakeshores and other suitable habitat in southern Michigan (A. Reznicek, *pers. comm.*), with unknown but probably significant effects (e.g., on native willows). Another, Eurasian marsh thistle, is well on its way to becoming a serious pest throughout the upper Great Lakes region. Voss (1996, p. 519) related how this aggressive invasive spread from Marquette, Michigan, where it was first discovered in the midwest in 1934, across the Upper Peninsula to northern lower Michigan and northeast Wisconsin.

Reed canarygrass is native to Eurasia and to western North America (Gleason and Cronquist 1991, Merigliano and Lesica 1998). It appears to have been widely established in the "Inland Northwest" (Montana, Idaho, and Wyoming) well before widespread European settlement (Merigliano and Lesica 1998). Collections made in the early through late-1800s indicate that it was abundant in the floodplains of the major rivers, and occasionally present (but apparently uncommon) in isolated meadows, lakeshores, and other wet areas in the region (Merigliano and Lesica 1998). Whether reed canarygrass is native to central and eastern North America is questionable. It seems likely, though, that all or nearly all midwestern populations are Eurasian strains or hybrids with these strains (Maurer et al. 2002).

WIS (2004) describes nonnative plants according to their invasiveness, with “ecologically invasive” being its highest ranking, followed by “potentially invasive” and then several lesser ratings. Except for yellow iris, which is listed as “potentially invasive”, all of the target plants that are known from Wisconsin are described as “ecologically invasive”. Of the nontarget aquatic and wetland plants recorded during these surveys, reed canarygrass and water forget-me-not are described as “ecologically invasive”, with narrow-leaved and hybrid cattails and nightshade listed as “potentially invasive”. The terrestrial species (along with Oriental bittersweet, *Celastrus orbiculatus*) are all listed as “ecologically invasive” by WIS (2004).

Target Animals

Zebra and quagga mussels

Zebra mussels originate from the Caspian Sea basin of eastern Europe (US-ACE 2004). Zebra mussels were spread by boat traffic throughout Europe in the 1800s, finally reaching North America in the mid-1980s, presumably as hitchhikers in the ballast water of a transatlantic ship. Since their discovery in Lake Champlain in 1988, they have spread throughout the Great Lakes, including a number of inland lakes in lower Michigan and eastern Wisconsin (see GLIFWC 2005). They have also colonized the Mississippi River system, as far north as the lower St. Croix River (WDNR 2003). So far only a handful of inland sites are known across upper Michigan, northern Wisconsin, and central and southeastern Minnesota (see GLIFWC 2005).

Zebra mussels are associated with a number of significant impacts on aquatic ecosystems, including alteration of habitats, decline or elimination of native species, and changes in water quality. They filter large amounts of water and have high population growth rates. Their shells accumulate in windrows along beaches and shorelines. They are notorious for fouling water intakes, boat hulls and engines, docks and navigational buoys (US-ACE 2004). Recently they have been implicated in blooms of toxic blue-green bacteria, by feeding selectively on competing green algae (Vanderploeg et al 2001).

The susceptibility of a lake (or other water body) to colonization by zebra mussels can vary not only from lake to lake, but also within a lake. The US-ACE (2004) has developed a calculator that allows the susceptibility of a lake to zebra mussel infestation to be estimated based on five factors: pH, calcium concentration, dissolved oxygen, salinity, and temperature (number of months above 12° C). US-ACE (2004) strongly recommends one year of reliable data collection for these parameters before attempting to predict the sensitivity of a water body to zebra mussel colonization. They also recommend estimating the risk of infestation of a lake before implementing a monitoring program.

One of the best single indicators of susceptibility to invasion is pH (US-ACE 2004). Lakes with pH of about 8.0 and above are susceptible to massive infestation. Veligers cannot survive below about pH 6.9, and adults cannot survive indefinitely below 6.5.

Another key parameter influencing zebra mussel veliger presence or absence in the water column is temperature (US-ACE 2004). Female zebra mussels begin to release eggs when the water temperature reaches 10-12° C, while the slightly more cold-adapted quagga mussels start releasing eggs at around 8-10° C. Spring sampling for veligers is generally not worthwhile before water temperatures reach these levels.

Quagga mussels are native to an estuary of the Black Sea. They were first discovered in North America in 1992 (May and Marsden 1992), and are now established in the St. Lawrence River and Lakes Erie, Ontario, and Michigan. They are somewhat more cold-adapted than zebra mussels, colonizing depths to 100 m or more in the Great Lakes (Spidle et al. 1995).

Water fleas

Spiny and fishhook water fleas are native to the Baltic Sea and Caspian Lake/Sea regions of Eurasia, respectively (MacIsaac and Grigorovich 1999). The spiny waterflea first appeared in North America in the 1980s, and has since colonized all the Great Lakes and scattered inland lakes (Caceres and Lehman 2002). Adults can reach slightly over 1 cm long, including the long, thin “tail” spine. Nearly all the summer adults are females that produce viable eggs parthenogenically (without fertilization). Females typically produce only females until fall, when stressful conditions (reduced food supplies, dropping temperatures, etc.) cause them to produce eggs that hatch into males. These males then mate with the females, resulting in “resting” eggs that pass the winter on the bottom, hatching in the spring to start the cycle over.

Spiny water fleas typically are active in the water column throughout the summer (Berg 1991). Adults of this cool-water species are sensitive to warm waters. Adult spiny water fleas disappear from shallow western Lake Erie in late summer, when the temperature throughout the water column reaches roughly 25° C (Berg 1991). In other areas of the Great Lakes, spiny waterfleas are able to escape to deeper, cooler waters in late summer. Research into the spread of the spiny waterflea involving Michaelis-Menton type assessments of vector outflows from invaded lakes to other invaded lakes or to other, uninvaded lakes is ongoing in Ontario (Anonymous 2004).

The fishhook water flea has been found at scattered locations in Lakes Michigan, Ontario, and Erie, and in the Finger Lakes region of New York. Large adults can reach nearly 2 mm in body length, with a caudal process (“tail spine”) of up to 10 mm (Anonymous 2004). In Lake Ontario, predation by the fishhook waterflea has significantly decreased populations of three dominant native zooplankton species (Laxson et al. 2003).

Nontarget Animals

Mystery snails

During GLIFWC’s 2003 St. Croix headwater lakes survey (Milroy 2004), two species of non-native snails were observed to inhabit some of these lakes. The striped or Georgia mysterysnail is native to the southeastern United States, including the Ohio River drainage. It is apparently not native to Michigan (Pace and Szuch 1985, Myers and Burch 2001) or the upper Great Lakes region, though there is some disagreement about this (D. Heath, pers. comm.). To complicate matters further, Clarke (1981, cited in Mills et al. 1993) points out that the Georgia mysterysnail is nearly indistinguishable from the closely-related European mysterysnail *Viviparus viviparus*, and that some apparent Georgia mysterysnail populations in North America might really be this species.

The Chinese mysterysnail is native to east Asia. This snail first reached Wisconsin roughly 50 years ago, and is now well established in northern Wisconsin (D. Heath, pers. comm.). A third snail, the Japanese mysterysnail C. japonica) is not yet known to occur in Wisconsin (D. Heath, pers. comm.). It is very closely related to the Chinese mysterysnail, and some authors consider it a subspecies or variety of that species (Jokinen 1982).

Asian and Georgia snails often become common to abundant in the lakes where they have been introduced, even forming windrows of shells on the beaches and leaving shell fragments scattered across the bottoms.

Rusty crayfish

The rusty crayfish is native to the Ohio River Basin and certain adjacent drainages, in the states of Ohio, Kentucky, Tennessee, Indiana, and Illinois (Gunderson 2004). They have since been introduced to much of the northeastern and midwestern US, primarily by anglers using them as bait. Once introduced, rusty crayfish often become abundant, destroying plant beds and leading to reduced productivity and loss of habitat for a wide variety of organisms, including native crayfish (Lodge and Lorman 1987, Olsen et al. 1991).

In a 2003 GLIFWC surveys of northwest Wisconsin lakes, scuba diving proved an effective way of finding rusty crayfish, at least where they were abundant. At lower infestation levels, rusty crayfish can be difficult to detect without setting out crayfish traps for them.

Other potential regional invaders

Another invertebrate introduced into the upper Great Lakes region is the amphipod *Echinogammarus ischnus*. It appeared in Lake Erie in the early 1990s, and has since been found in Lake Superior. In Lake Erie it appears to strongly prefer rocks covered by zebra mussels (with which it evolved) to mussel-free rocks, where it is replacing the native amphipod *Gammarus fasciatus* (Dermott et al. 1998). The subtropical African waterflea *Daphnia lumholtzi* has become established in scattered locations in the southeast US. It was discovered in Lake Pepin, on the Minnesota / Wisconsin border in 1999, and in 2003 evidence of a reproducing population was found there (MNDNR 2004). It is also established in Lake Erie (Muzinic 2000). The Asian clam (*Corbicula fluminea*) is locally established across much of the US, as far north as the Mississippi River in western Wisconsin and in northeast Minnesota (USGS 2001). This significant invader can reach very high densities of 1000 or more per m^2 (Stites et al. 1995). It is likely to show up in the ceded territory in coming years. Because of increasing global trade and overall lax federal standards for limiting new introductions, the list of invaders (both plant and animal) to the Great Lakes region will undoubtedly continue to grow.

METHODS

Survey Lakes

Thirteen long-term study lakes and 14 of the top wild rice and walleye harvest lakes were chosen for survey (Figure 2). Two of these lakes were visited more than once. Based on reports of infestation by spiny water fleas, a lake which had not originally been scheduled for survey (Sand Lake in Sawyer County) was added to the list. Lakes sampled, along with acreage, dates surveyed, and other information appear in Table 2.

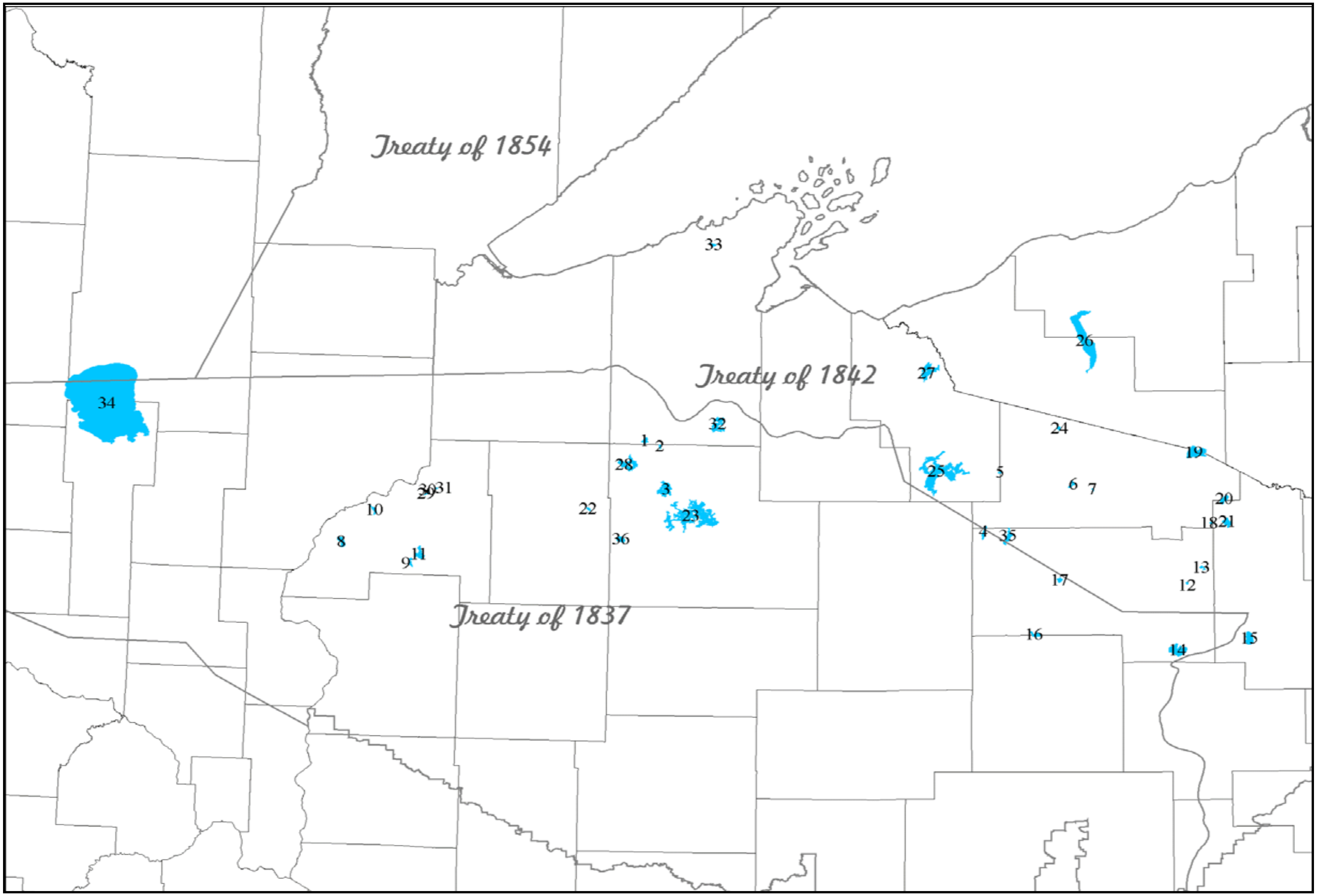

Figure 2. Lakes surveyed for invasive species in 2004 (numbers refer to Table 2).

Table 2. Lakes surveyed for invasive plants and animals during the summer of 2004. Maps of these lakes are included in the Appendix.

Waterbody	County	State	Acres	Dates Surveyed	Map
Totagatic	Bayfield	WI	538.1	6/15	1
Pacwawong	Sawyer	WI	147.9	6/16	2
Round	Sawyer	WI	3324	6/17, 6/21, 8/22, 9/13-9/14, 9/30	3
Squaw	Oneida - Vilas	WI	735.5	6/22, 9/9	4
Sherman	Iron	WI	126.3	6/23	5
Allequash	Vilas	WI	405.5	6/24	6
Aurora	Vilas	WI	82.8	6/24	7
Phantom	Burnett	WI	932.1	6/29	8
Long	Burnett	WI	329.2	6/30	9
Clam River Flowage	Burnett	WI	411.9	7/1	10
Clam Lake	Burnett	WI	1337.6	7/7-7/8	11
Spur Lake	Oneida	WI	112.6	7/12	12
Thoroughfare	Oneida	WI	174.9	7/13	13
Pelican	Oneida	WI	3544.8	7/14-7/15	14
Metonga	Forest	WI	2038.5	7/16	15
Rice River Flowage	Lincoln / Oneida	WI	559.6	7/20	16
Bearskin	Oneida	WI	402.7	7/21	17
Upper Nine Mile	Vilas/Forest	WI	107.7	7/22	18
Lac Vieux Desert	Vilas / Gogebic	WI / MI	4017.3	7/26-7/27	19
Kentuck	Vilas / Forest	WI	1001.1	7/28	20
Butternut	Forest	WI	1246.3	7/29	21
Bass	Washburn	WI	187.4	8/2	22
Chippewa Flowage	Sawyer	WI	14377.9	8/3-8/5	23
Annabelle	Vilas	WI	194.5	8/9	24
Turtle Flambeau Flowage	Iron	WI	12942.3	8/10-8/12	25
Gogebic	Ontonagon / Gogebic	MI	13120.3	8/16-8/17	26
Gile Flowage	Iron	WI	3137.6	8/18-8/19	27
Nelson	Sawyer	WI	2715.9	8/23-8/24	28
Gull	Burnett	WI	178.3	8/24	29
Loon	Burnett	WI	56.5	8/24	30
Briggs	Burnett	WI	53.6	8/24	31
Namekagon	Bayfield	WI	2607.1	8/25-8/26	32
Siskiwit	Bayfield	WI	284.8	8/30	33
Mille Lacs	Aitkin/Crow Wing/Mille Lacs	MN	127221.9	8/31-9/2	34
Squirrel	Oneida	WI	1309.5	9/7-9/8	35
Sand	Sawyer	WI	928	9/15	36

* *Acreages obtained from a 1:24,000 map coverage, using ArcView 3.1 (ESRI Corp., Redlands, California)*

Data Collection

Data were recorded directly into a GIS spatial database using a handheld Trimble GeoXM GPS receiver/data recorder (Trimble Navigation Ltd., Sunnyvale, CA) running ArcPad GIS software (ESRI Corp., Redlands, CA)(Figure 3). Customized data entry applications were developed for each data category (invasive species, boat landings, and water quality) using ArcPad Application Builder (ESRI Corp., Redlands, CA)(Figure 4). The customized data entry applications speeded data entry in the field and reduced the potential for error during data entry by providing standardized nomenclature, required fields, and an integrated environment to display the real-time GPS location overlain on existing GIS layers such as lakes, local roads, and invasive species locations.

Figure 3. GPS receiver running ArcPad.

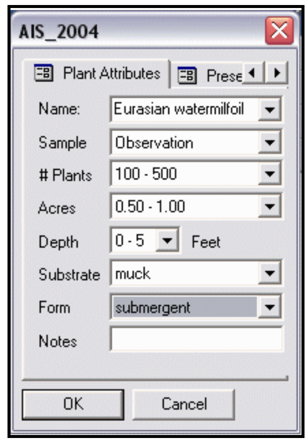

Figure 4. Custom data entry form.

Potential "Hotspot" Areas

Boat landings

Because nonnative aquatic species are often transported on boats, trailers, and associated equipment, boat landings are high-probability locations for introduction and establishment of many invasive plants and animals (Skogerboe et al. 2003). The likelihood of invasives being introduced to each lake is probably directly proportional to user intensity (the number of boats entering per unit time) as well as the proximity to already-infested lakes. All public and some private boat landings on each lake were surveyed for invasives.

Boat landing names and locations were recorded using the hand-held GPS receiver. The presence and types of informational signs (if any) posted at each landing warning boaters about invasive species were also recorded. This data will be combined with similar information collected by GLIFWC electroshocking crews and the WDNR, to identify any landings lacking signs.

At each landing, submersed plants were sampled using two garden rake heads clamped together back-to-back, and attached to a rope (e.g., Skogerboe et al. 2003, see also Bednarz and Wandell 2002, p. 16 for illustration). The area out from and on each side of the boat landing was sampled by choosing a point in about 1 to 2 m of water. At each point the landing name and water depth was recorded. The rake was thrown 6 to 9 m from the boat and dragged back along the lake bottom. Two throws were made at each point, one towards shore and the other away from shore, in order to sample the greatest depth gradient from that point. The material retrieved by each throw was dumped into a pan and searched for introduced plants and animals.

Inlets

Though not as high-priority as boat landings, tributaries are another possible entryway for invasives into lakes, especially if these tributaries pass through developed areas or are fed directly by other lakes and ponds. The inlets of these streams and rivers, and any associated wetlands, were searched for invasive plants. At least one source (VT- DEC, no date) also recommends paying special attention to outlets.

Other "hotspots"

Lakeshores in close proximity to roads seemed to be higher-probability spots for finding purple loosestrife and perhaps Eurasian marsh thistle. These areas also were a search priority, at least for emergent and shoreline plants. Developed shorelines were also considered "hotspots", especially for invasive plants.

Invasive Plant Surveys

Because of their need for light and corresponding affinity for relatively shallow water, invasive vascular plants are most likely to become established along shorelines and in near-shore areas (the littoral zone). Shorelines (including island shorelines) were surveyed from the outer edge of or occasionally within the littoral zone from a slow-moving boat, checking any suspicious-looking patches of vegetation. Small, shallow rice lakes were sampled from a canoe, while the larger lakes were sampled from a small motorboat. Adjacent wetland areas, including inlets and outlets of streams and rivers, were also surveyed. Locations of target invasive plant patches were recorded at about the center of the patch, along with basic information on patch size and habitat. Nontarget aquatic and terrestrial invasives were recorded as present or absent for each lake. Only the location of the first patch was recorded for these nontarget species, however.

Whenever purple loosestrife patches were discovered, evidence of damage (if any) by loosestrife beetles (*Galerucella* spp.) was recorded. Similarly, whenever Eurasian milfoil was discovered an attempt was made to find milfoil weevils [*Euhrychiopsis lecontei* Dietz (Coleoptera: Curculionidae)]. While this native weevil's natural host is northern milfoil (Creed and Sheldon 1993), it performs as well or even better on Eurasian milfoil (Newman et al. 1997). Typically the terminal 0.25-0.50 m of the branches were collected and later examined for weevil larvae, by looking for damage on the plants and slicing stems lengthwise with a razor blade.

Specimens of invasive plants were collected whenever a target plant was found in a new lake, or when the species was a "county record", or thought to be regionally uncommon. These specimens were pressed and sent to public herbaria, along with a label giving the location and appropriate notes. Duplicates of several collections were deposited in the GLIFWC herbarium. Finally, an informal list of native emergent and aquatic plants observed on each lake was kept, for future reference.

Zebra Mussels

Sampling for veligers

Sampling for veligers is probably the most efficient and sensitive method for detecting zebra mussel infestation, particularly if the settled population is small and/or localized in a lake (US-ACE 2004). An attempt was made to obtain at least three samples per lake, in representative habitats and locations. Typically at least one sample was taken near a busy boat landing, and one or two additional samples in other areas of the lake, with the number of samples based on lake size. More than three samples were taken in the large lakes and flowages, while several of the smaller "rice lakes" only had one spot that was deep enough for a tow. The very shallow lakes were not sampled for veligers.

Sampling was accomplished using a 64 µm (size 25, or 200 meshes per inch) mesh plankton net with a 30 cm opening and a plankton collection cup with 64 µm mesh over the holes. [The water volume sampled then equals $r^2(h)$, where r is the radius of the net opening and h is the distance through which the net traveled.] The net was lowered cup-down into the water, allowed to sink to the appropriate depth (typically 5 m), and then slowly pulled vertically back to the top (WDNR 2004a). When the sampling point was too shallow for a 5-m tow, two 2.5-m tows were taken instead. In the more oligotrophic lakes, two 5-m tows were taken for each sample. After removing the net from the water, all net contents were flushed into the cup. The samples were then transferred to plastic sample bottles, labeled, and preserved with 4 parts 95% ethanol.

Zebra mussel plankton tow samples were kept refrigerated until they could be taken to the WDNR Service Center in Plymouth, Wisconsin for analysis. Cross-polarized light was used to aid in veliger detection.

Surveys for juveniles and adults

Because of time and resource limitations, systematic surveys for settled individuals (juveniles and adults) were not possible. However, beach debris, boat pier supports, rocks, and shorelines at each public boat landing were checked for evidence of zebra mussels (live animals or shells). Shoreline debris and aquatic macrophytes were occasionally examined visually for small zebra mussels, as the lakeshore and littoral zones were being surveyed for invasive plants.

Waterfleas

Horizontal plankton tows were used to sample for spiny and fishhook water fleas, following the protocol of Johnson (2004). A 0.5 m-opening, 253 µm mesh net with a 64 µm mesh cup was used for waterfleas. A suitably deep portion of the lake was chosen to sample (typically 5 m or more), and the net was towed through the water at low speed for approximately 100 m. This distance was measured using a hand-held GPS receiver, aided later on with 2 small, anchored plastic floats. Just before the starting point, the net was dropped into the water cup-first (to allow air to escape), immediately followed by the mouth of the net. Typically the net was allowed to sink to a depth of 3-5 m during the first part of the tow and then raised slowly, removing it from the water at the end point. The net contents were then washed into the cup, transferred to a plastic bottle, and preserved with 95% ethanol.

As with the veliger tows, one sample from each lake was typically taken in the vicinity of a busy boat landing, and 1-2 additional samples in other areas of the lake. Shallow “rice” lakes were not sampled for waterfleas. Waterflea tow samples were kept refrigerated until they could be analyzed by personnel at the WDNR Plymouth Service Center.

Rusty Crayfish

While rusty crayfish were not systematically sampled or searched for, (usually dead) crayfish in shallow water were examined, and “rusties” were recorded as present when found. Recently-dead rusty crayfish in reasonably good condition were preserved in alcohol for future reference. Because they are of major concern, data on these animals is included with the target species below.

Nonnative Snails

In conjunction with the plant surveys, shorelines and shallow-water areas were searched for evidence of Georgia and Asian mysterysnails, and these animals recorded as present if found. A few shells of each target species were collected from each lake where they were found. Occasionally shells of other snails were also collected. Live individuals were occasionally collected also - these were either preserved in 95% EtOH or kept alive in aquaria. Shells were keyed using the keys in Strayer (1990) and Brown (2001). Specimens of the Asian mysterysnails were examined to verify that they were indeed *C. chinensis*, and not the closely related *C. japonica*. These shells and samples were retained for future reference.

Water Quality

Water Clarity

Secchi disk readings were taken in all but the shallowest lakes, following the protocol of WDNR-LMP (2002). As is common practice, these readings were generally taken at the deepest part of the lake. In several very large lakes more than one reading was taken, typically at the deepest point in different bays. Readings were taken between 10 AM and 2 PM, on the downwind, shaded side of the boat. Calm, sunny days were chosen whenever possible. The disc was lowered until it just disappeared from sight, then raised until it reappeared. The average of these two depths was then recorded.

Unfortunately weather conditions were sometimes not optimal for secchi disk readings, so readings were only recorded to the nearest 0.25 m. During visits to a few lakes it was overcast the entire time, and readings were not taken. Water color was estimated by viewing the white part of the disk when held under 30 cm of water.

Secchi disk readings were used as a rough estimate of the maximum rooting depth (MRD) of submersed plants in each lake, using the equation MRD = 0.832104 + 1.22(MSD) meters, with MRD = maximum rooting depth and MSD = mean secchi disk depth (Nichols 1999).

Water temperature and pH

At each veliger sampling point, pH and temperature were measured in order to obtain some idea of the likelihood of zebra mussels establishing and spreading in each lake. Except for the first few lakes, where a thermometer was used, pH and temperature were measured with a YSI pH 100 pH/ORP/temperature meter. Readings were taken at a depth of 1 m and 4 m (or about 30 cm above the bottom, if the point was less than 4 m deep) at each zebra mussel sampling point.

Whenever sample size allowed, basic statistical parameters were calculated using Statistix version 4.1 (Analytical Software, Tallahassee, FL). For each lake, pH values were converted to H^+ concentrations, the mean and 90% confidence interval (not reported) was calculated using the *t*-distribution, and then these values were converted back to pH values. Mean temperatures and 95% confidence intervals (also not reported) were calculated using the normal distribution.

Decontamination

After leaving each lake, the boat and all equipment were disinfected thoroughly. All equipment was removed from the boat, and plant fragments and other debris were removed by hand. The boat, trailer and equipment were then treated with vinegar or chlorine bleach solution. Plankton nets were soaked in vinegar for 20-30 minutes. Everything was then rinsed off with a power sprayer. Lakes known to be infested with zebra mussels (Metonga), heterosporis (*Heterosporis* spp., an introduced fish pathogen), and other hard-to-detect and easily-carried invasives were surveyed at the end of the week, so the boat could dry over the weekend. The two lakes known to have spiny water fleas (Gogebic and Gile) were surveyed the same week.

RESULTS

Invasives Found by Lake

Target nonnative plants and animals (along with rusty crayfish) found in or bordering each lake are listed in Table 3. Nontarget plants and animals found at each lake appear in Table 4.

Plants

Target plants

Curly pondweed was abundant in both Clam River Flowage and Clam Lake, where it was previously known, and on Long Lake, where it had not officially been recorded. On Mille Lacs, this plant appeared to be restricted primarily to sheltered inlets and bays on the south side of the lake.

Eurasian milfoil was found only in lakes where it had previously been reported. It appeared to be common in the Chippewa Flowage, especially in the more eutrophic bays. It was also sporadically established in Round Lake, where it is being treated with herbicides. Only one Eurasian milfoil fragment was found in Mille Lacs, washed up on the west shore. No Eurasian milfoil was found during our survey of Kentuck Lake. In early fall of 2004, however, GLIFWC fisheries technician Henry Mieloszyk informed us that he had found Eurasian milfoil there.

Purple loosestrife was found on eight lakes, and reported by a WDNR warden from another (Turtle Flambeau Flowage). On one of these lakes (Namekagon) only a single flowering plant was found, next to a boat landing. This plant was dug up and removed.

Flowering rush was only observed in Round Lake. This invasive emergent has apparently been established in the lake for about 30 years, according to local residents, but was first brought to the attention of the WDNR personnel in 1998 (Herman 2004). It is now one of the dominant emergents around this bay, with several smaller colonies established outside the bay as well.

Yellow iris was found in three lakes: Pacwawong, Pelican, and Squirrel. All three sites represent new records for this plant, according to WIS (2004). The plant is well-established along the shoreline and in wetlands surrounding Pacwawong (a shallow rice lake contiguous with the St. Croix National Scenic Riverway) and Squirrel lakes. Three small patches were also found on Pelican Lake, by which time the flowers of this early-flowering plant had nearly all shriveled and fallen. Squirrel Lake yellow iris patches were distinguishable from patches of blue flag iris by both their greater average height (yellow iris plants can grow to 1 m or more tall) and their much greater density and size. The Squirrel Lake population was also confirmed by a local resident, who told us that the lake had “both blue and yellow irises”. It is quite possible that smaller patches of this species on other lakes were missed, though, as after flowering they would appear vegetatively quite similar to blue flag iris, as well as cattails and other emergent vegetation.

Table 3. Target plants and animals (along with rusty crayfish) observed in survey lakes during the summer of 2004. An "N" denotes "new" sites found during these surveys, an "O" indicates "overlooked" sites previously documented by other sources, but not found by these surveys, and a "C" indicates "confirmed" or previously known sites also found by these surveys. A * indicates that signs giving specific information for these species were posted at the landings. (The presence of signs for a particular invasive does not necessarily indicate that that species is present in the lake - see text.)

	Plants					Animals		
Waterbody	Curly Pondweed	Eurasian Milfoil	Purple Loosestrife	Flowering Rush	Yellow Iris	Zebra Mussel	Spiny Waterflea	Rusty Crayfish
Totagatic								
Pacwawong					N			
Round		C*	N	C		N^		O
Squaw								O*
Sherman								
Allequash								
Aurora								
Phantom								
Long	N							
Clam River Flowage	C							
Clam Lake	C	*						
Spur Lake								
Thoroughfare								O*
Pelican			C*		N			O*
Metonga		C*	*			C*		C*
Rice River Flowage			*					
Bearskin								C*
Upper Nine Mile								N
Lac Vieux Desert								N
Kentuck	O*	*	O*					C*
Butternut								C
Bass								

Waterbody	Plants					Animals		
	Curly Pondweed	Eurasian Milfoil	Purple Loosestrife	Flowering Rush	Yellow Iris	Zebra Mussel	Spiny Waterflea	Rusty Crayfish
Chippewa Flowage		C*	C					
Annabelle								
Turtle Flambeau Flowage			O					
Gogebic			N				C*	
Gile Flowage			N				C*	
Nelson								
Gull								
Loon								
Briggs								
Namekagon			N					
Siskiwit								
Mille Lacs	C	C*	C					
Squirrel		*	C*		N			C*
Sand								O
Total	5	4	10	1	3	2	2	12
Percent (n = 36)	14	11	28	< 1	1	1	1	48

^ Round Lake sighting consists of one positive plankton tow sample, with low numbers of veligers (<1/m^3). No other evidence of zebra mussels have been found in this lake, and it is not on the WDNR "Zebra Mussel Infested Waters" list at this time.

Table 4. Nontarget plants and animals recorded as present (X) in survey lakes or shorelines during the summer of 2004. A (?) indicates uncertainty in identification.

Waterbody	Plants									Animals		Other
	Japanese Barberry	Narrow-leaf Cattail	Crack Willow	Eurasian Mints	Eurasian Honeysuckles	Eurasian Marsh Thistle	Reed Canary grass	Night-shade	Water forget-me-not	Asian Mysterysnail	Georgia Mysterysnail	
Totagatic			X		X							
Pacwawong					X		X	X	X			
Round	X	X	X	X			X	X	X			
Squaw										X		
Sherman												
Allequash		X								X		
Aurora							X					
Phantom		X					X					
Long		X					X			X		
Clam River Flowage							X					
Clam Lake		X	X				X					
Spur Lake												
Thoroughfare						X	X			X		
Pelican		X	X			X	X	X	X	X	X	A
Metonga			X	X	X	X	X	X				B, C
Rice River Flowage		X					X			X		
Bearskin			X	X						X		
Upper Nine Mile											X	
Lac Vieux Desert	X	X	X				X		X	X	X	
Kentuck	X	X				X	X		X	X	X	
Butternut	X	X				X	X		X			
Bass					X		X					
Chippewa Flowage		X	X		X		X			X		
Annabelle	X		X				X					
Turtle Flambeau Flowage		X	X				X		X			
Gogebic	X		X	X	X		X	X	X		X	D
Gile Flowage		X	X		X		X			X		E
Nelson		X		X	X(?)		X		X	X	X	

Waterbody	Plants									Animals		Other
	Japanese Barberry	Narrow-leaf Cattail	Crack Willow	Eurasian Mints	Eurasian Honeysuckles	Eurasian Marsh Thistle	Reed Canary grass	Night-shade	Water forget-me-not	Asian Mysterysnail	Georgia Mysterysnail	
Gull		X										
Loon		X										
Briggs												
Namekagon	X	X	X		X		X	X	X			B
Siskiwit				X			X					
Mille Lacs		X	X		X		X	X		X	X	E
Squirrel	X	X	X				X		X	X		
Sand					X		X			X	X	
Total lakes (n = 36)	8	19	15	6	11	5	26	7	11	15	8	
Percent of lakes	22%	53%	42%	17%	31%	14%	72%	19%	31%	42%	22%	

A = European mountain-ash (*Sorbus aucuparia*), B = Oriental bittersweet (*Celastrus orbiculata*), C = Amur silvergrass (*Miscanthus sacchariflorus*), D = common buckthorn, E = glossy buckthorn.

None of the remaining target plants (Eurasian forms of common reed, brittle naiad, European frogbit, hydrilla, water chestnut, and yellow floating-heart) were found on any of the lakes.

"Present/absent" plants

As expected, several of the "present/absent" plants were widespread and sometimes common. Reed canary grass had the highest frequency of all the riparian and aquatic species, bordering 69% of the 36 lakes surveyed. Next in frequency were the narrow-leaved and hybrid cattails, which were collectively found in 53% of the lakes surveyed. These were followed by white and crack willows (39%), water forget-me-not (25%), Eurasian mints and bittersweet nightshade (both 17%), and Eurasian marsh thistle (14%).

Eurasian marsh thistle was only found bordering lakes in northeast Wisconsin. This is consistent with the known distribution of this plant in Wisconsin (WIS 2005).

The most frequent terrestrial plant taxa was the Eurasian bush honeysuckles, which were detected on or near the shorelines of 31% of the lakes surveyed. Common and glossy buckthorn were only found along the shorelines of two lakes and one lake, respectively. These low totals may simply be due to the fact that these species blend in well with other forest vegetation during the summer.

During the summer, populations of two uncommon native plants were discovered. A population of *Potamogeton vaseyi* was found in Phantom Lake, and fragments of *Callitriche hermaphroditica* were found in Namekagon Lake. Both of these species are listed as "special concern" in Wisconsin. For both plants, collections were made for herbaria, and rare plant reporting forms were completed and sent to the WDNR Bureau of Endangered Resources. A substantial population of *P. vaseyi* was also observed in the Chippewa Flowage [this may be a known population (Laatsch 2004)] and a fragment that appeared to be *P. vaseyi* (but lacking floating leaves) was found in a sample bag from Nelson Lake, but due to time constraints these two populations were not formally documented.

Animals

Zebra mussels

Plankton tow samples for veligers gave positive results for only two lakes: Metonga, from which zebra mussels have been know for about four years, and which is now heavily infested, and Round Lake, where zebra mussels were previously unknown. Levels in the one positive Round Lake sample were very low (<1 veliger/m^2).

Several follow-up visits were made to Round Lake. During these visits seven more veliger tow samples were obtained, several from the vicinity of the previous positive sample and the rest from previously-unsampled bays. GLIFWC staff also searched the shore and shallow water areas for shells, and scuba dove near the site. All of these efforts failed to find additional evidence of zebra mussels in this lake.

Water fleas
The spiny water flea was detected only from the two waterbodies where it was previously known: Lake Gogebic and Gile Flowage. Individuals were easily seen swimming in the single sample taken from each lake. Spiny waterflea individuals were also captured in at least one zebra mussel veliger tow from each lake. Fishhook water fleas were not found in any of the survey lakes.

"Present/absent" animals
Asian mysterysnails were found in 42% of the survey lakes, while Georgia mysterysnails were found in 22% of these lakes. Six (17%) of the lakes had both snails. With a few exceptions these snails were common to abundant in the lakes where they were found.

Rusty crayfish were observed in 19% of the lakes surveyed. All of these were "known" lakes, except for Upper Nine Mile Lake and Lac Vieux Desert. They were not seen in an additional 5 lakes where they occur.

Water Quality

Water temperature, pH, and secchi disk data for selected sample lakes appears in Table 5. The lowest pH values at both 1 m and 4 m were recorded in Annabelle and Siskiwit lakes, followed by Thoroughfare. Annabelle and Siskiwit both had 1 m pH values below 6.9, as did all three lakes at 4 m. Five lakes had 1 m values between 6.9 and 7.4, six had values between 7.4 and 8.0, and 13 had values above 8.0. At 4 m, three lakes had pH values between 6.9 and 7.4, eight had values between 7.4 and 8.0, and ten had values > 8.0. Lakes in northeastern Wisconsin (along with Lake Gogebic in western Upper Michigan) appeared to have somewhat lower mean pH than lakes in northwestern Wisconsin. With few exceptions, pH values at 4 m were lower than values at 1 m.

Mean temperatures were fairly consistent between lakes and throughout the season, ranging from 18.3 to 25.4° C at a depth of 1 m, and 18.4 to 23.8° C at 4 m (or just above the bottom). As expected, temperature readings were usually lower at 4 m than 1 m.

In the four lakes where replicate secchi disk readings were taken, readings were relatively consistent, with Lake Gogebic's two samples (2.25 and 2.75 m) showing the most within-lake variation. Butternut Lake had the highest water clarity, followed closely by Lake Metonga, which
is heavily infested with zebra mussels.

While these data are not adequate to measure conditions in each lake over time, they do give an indication of conditions in these lake around the time they were sampled.

Table 5. Mean pH, water temperature, and secchi disk readings for the 36 survey lakes. MRD indicates the maximum rooting depth, calculated from the corresponding secchi disk reading (Nichols 1999).

Waterbody	Mean pH			Mean Temp (°C)			Secchi (m)		MRD
	n	1 m	4 m	n	1 m	4 m	n	Mean	
Totagatic	0	na	na	0	na	na	1	1.00	2.05
Pacwawong	0	na	na	0	na	na	1	1.50	2.66
Round (Visit 1)	3	na	na	1	19	na	1	4.75	6.63
Squaw (Visit 1)	3	na	na	1	19	na	1	1.00	2.05
Sherman	0	na	na	0	na	na	1	2.50	3.88
Allequash	0	na	na	0	na	na	1	2.25	3.58
Aurora	0	na	na	0	na	na	1	>1	> 2.05
Phantom	0	na	na	0	na	na	0	na	na
Long	1	8.90	7.72	1	21.0	18.4	1	2.00	3.27
Clam River Flowage	1	8.62	8.16	1	23.9	20.1	1	1.50	2.66
Clam Lake	2	8.67	8.37	2	20.4	19.9	1	1.00	2.05
Spur Lake	0	na	na	0	na	na	0	na	na
Thoroughfare	1	6.99	6.33	1	24.2	14.5	1	1.00	2.05
Pelican	3	7.98	7.92	3	21.0	20.4	1	2.00	3.27
Metonga	1	8.35	8.33	1	21.8	19.7	1	5.50	7.54
Rice River Flowage	1	7.06	na	0	na	na	1	1.00	2.05
Bearskin	1	8.72	8.67	0	na	na	1	3.00	4.49
Upper Nine Mile	0	na	na	0	na	na	0	na	na
Lac Vieux Desert	3	8.66	7.70	3	23.2	21.7	1	2.25	3.58
Kentuck	2	8.66	8.63	2	23.6	23.4	1	2.75	4.19
Butternut	3	8.34	8.37	3	22.2	21.9	1	5.75	7.85
Bass	2	8.39	8.57	2	25.4	23.8	1	4.75	6.63
Chippewa Flowage	6	7.73	7.49	6	24.2	23.2	3	1.83	2.97
Annabelle	1	6.66	6.38	0	na	na	1	3.00	4.49
Turtle Flambeau Flowage	2	7.73	7.69	0	na	na	1	1.50	2.66
Gogebic	3	7.84	7.72	3	19.2	18.9	2	2.50	3.88
Gile Flowage	3	7.26	7.27	3	19.3	19.5	1	1.00	2.05
Round (Visit 2)	1	na	na	1	18.3	na	0	na	na
Nelson	2	8.63	7.75	0	na	na	1	0.75	1.75
Gull	1	7.80	6.89	0	na	na	0	na	na
Loon	0	na	na	0	na	na	0	na	na
Briggs	0	na	na	0	na	na	0	na	na
Namekagon	3	8.40	8.02	0	na	na	1	2.00	3.27
Siskiwit	1	6.78	6.73	1	19.2	19.1	1	1.50	2.66
Mille Lacs	7	8.87	8.88	7	19.3	18.9	2	1.75	2.97
Squirrel	3	8.31	8.11	3	19.7	19.6	2	2.37	3.88
Squaw (Visit 2)	2	7.21	6.88	2	19.8	19.0	1	0.75	1.75
Round (Visit 3)	6	7.83	7.59	6	19.8	19.7	0	na	na
Sand	2	7.40	7.28	2	20.0	19.8	1	2.25	3.58

Sampling Effectiveness

These surveys found several undocumented sites for curly pondweed, purple loosestrife, and yellow iris. One “known” occurrence of curly pondweed and two of purple loosestrife were missed. Of the 27 occurrences known after these surveys, 33% were newly discovered by GLIFWC, 11% were missed by GLIFWC, and 56% were confirmed by GLIFWC. (Table 6). Only 17% (3 of 18) of “known” populations were missed.

Table 6. Effectiveness in finding target plants and animals in the 36 survey lakes during the summer of 2004. “New” sites are previously unknown sites found during these surveys, “Overlooked” sites are those previously documented by other sources, but which these surveys did not find, and “Confirmed” indicates previously known sites that were also found by these surveys.

Target Species	Sampling Effectiveness							
	New		Overlooked		Confirmed		Total	
Curly Pondweed	1	17%	1	17%	3	50%	5	100%
Eurasian Milfoil	0	0%	0	0%	4	100%	4	100%
Purple Loosestrife	4	40%	2	20%	4	40%	10	100%
Flowering Rush	0	0%	0	0%	1	17%	1	100%
Yellow Iris	3	100%	0	0%	0	0%	3	100%
Zebra mussel	1	50%	0	0%	1	50%	2	100%
Spiny water flea	0	0%	0	0%	2	100%	2	100%
Total	9	33%	3	11%	15	56%	27	----

The WDNR has recently begun to track yellow iris in their “northern” region, though they do not actively search for it (L. Herman, *pers. comm.*). If this plant were excluded from the tabulation, our surveys would have found 25%, missed 13%, and confirmed 63% of the sites (error due to rounding). Also, curly pondweed is common in northwest Wisconsin and west into Minnesota (including the Mille Lacs area), and some within the WDNR may have decided that reporting this plant is no longer worthwhile.

DISCUSSION

Invasive Plants

Prospects for Control

While the 2004 lakes surveys led to occasional detection of new infestations of target plants, many observations were of populations that were already known. Most of these “known” populations appeared to have already formed extensive patches in their respective lakes. The substantial extent of these populations probably precludes the possibility of eradication at this time. Many of the smaller populations are probably still quite treatable, though.

A large amount of literature has accumulated on the control of aquatic plants (Madsen 1997). These methods include manual, chemical, and habitat manipulation techniques. Small, nascent populations can often be treated manually. These small populations should be aggressively attacked with eradication as the goal. To effectively control large populations, an integrated pest management approach using a variety of control techniques is often necessary. Control of large populations usually requires a long-term commitment as well. Regardless of the method(s) chosen, care should be taken to minimize adverse ecological impacts to nontarget species. State permits are generally required before implementing mechanical and chemical control methods for aquatic plants. Nichols (1991), Madsen (1997, 2000), and Getsinger et al. (2002) give excellent overviews of treatment methods available for invasive aquatic plants.

Some of the most innovative work on aquatic plant control has been done by the US Army Corps of Engineers, using low levels of herbicides (US-ACE 2001, see also http://el.erdc.usace.army.mil/aqua/ and links). Their techniques take advantage of the selectivity of various herbicides and the differences in sensitivity of various aquatic plants to these herbicides, to reduce or eliminate certain invasive species (e.g., Eurasian milfoil) while leaving the native plant community more-or-less intact. Low levels of herbicides are introduced to portions of lakes or even entire lakes ("whole-lake treatment"). Herbicide concentrations are monitored and carefully maintained for as long as 60 days or more.

By far the best control method for controlling aquatic invasive species is to prevent their spread to new waterbodies and watersheds. Public education and awareness is invaluable in stemming the tide of invasive species. The Stop Aquatic Hitchhikers program, developed by the Aquatic Nuisance Species (ANS) Task Force and sponsored by the US Fish & Wildlife Service and the US Coast Guard, is an example of a highly successful program of public outreach and education (see http://www.protectyourwaters.net/ for more information).

Biological Control

Biological control methods may provide the greatest hope of controlling invasive plant infestations in lakes. Most biocontrol efforts to date have focused on finding an invader's natural pests and predators from its native land, and (after careful testing to make sure these agents are host-specific and likely to be effective) releasing them in the invader's new range. Introduced biological control insects have proven effective in controlling purple loosestrife and a number of other aquatic and terrestrial plants.

Biocontrol has advantages and disadvantages (US-ACE 2001, Madsen 1997). Advantages include longer term, species-specific control of invasives at relatively low overall cost, in a way that is often the least disruptive to the environment. Disadvantages include the possibility that, despite the careful testing and evaluation done before approval and release, an introduced organism may prove ineffective in controlling its target invasive, at least in some habitats. Another, more serious problem is the possibility that an introduced biocontrol agent might feed on closely related native species and cause significant damage to that species. Even if one or more biocontrol agents successfully establish, effective control may take years, as the agents increase in numbers and adjust to their new environment.

Before potential biocontrol agents are approved for release in North America, they are carefully tested. Preliminary research for potential biocontrol agents is generally conducted overseas, in the native range of the invasive plant. Potential biocontrol agents are also searched for domestically, to see whether nonnative organisms may have already been accidentally introduced here, and whether native organisms might be attacking the plant as well.

Once promising (nonnative) biocontrol agents are discovered, they are carefully tested in a quarantine facility. Much of this testing is conducted by the Center for Applied Bioscience International (CABI) in Switzerland (see http://www.cabi-bioscience.org/html/Biocontrol.htm for more information). The USDA Agricultural Research Service also maintains biological control laboratories overseas, in Argentina, Australia, and France (Pemberton 2002). Insects or other agents are tested for their ability to use and suppress the target species, as well as their ability to use nontarget species (generally closely-related native species). Potential biocontrol agents which are not host-specific to the target species are dropped from consideration. Agents which are host-specific and appear to be suitable as biocontrols are then bred for several generations in order to increase their numbers and rid them of any diseases or parasites of their own, that may reduce their effectiveness after release. These agents are then shipped to quarantine facilities in the US or Canada for further testing. The entire process of discovering, raising, testing, and releasing biocontrol agents may take as long as 20 years (Pemberton 2002).

Recently more effort has gone into searching for native organisms that can control certain invasives. One of these, the native milfoil weevil, has shown some promise for controlling Eurasian milfoil. In its broadest sense biological control includes the maintenance or restoration of the native plant community, in order to inhibit the reinvasion and/or spread of invasives, and to restore ecosystem function (Madsen 1997). As applicable, the status of biocontrol research for each invasive species is summarized below.

Curly pondweed

With the exception of the very large and windswept Lake Mille Lacs, curly pondweed was common to abundant where found. This plant is now widespread and locally common across the upper Great Lakes region, including northwestern Wisconsin and much of Minnesota (WIS 2005, MINN 2005).

Curly pondweed’s morphology and life history is unique among pondweeds (FNA 1993+), suggesting that it is taxonomically distinct from these other species. Therefore it seems quite possible that insects or other organisms specific to curly pondweed and potentially useful as biocontrol agents await discovery. A review of relevant literature revealed little if any research into possible biocontrol organisms for this plant. As a monocot, “broad-leaf” herbicides would be relatively ineffective. A study by Skogerboe and Getsinger (2002) found that low concentrations of an endothall-based herbicide were highly effective against both curly pondweed and Eurasian milfoil, while causing little or no apparent damage to most of the native aquatic plants tested.

Eurasian milfoil

Eurasian milfoil also seemed to be well-established when observed. This dicot can sometimes be treated with relatively little disruption to the native plant community, using broadleaf herbicides such as 2,4-D and triclopyr. These herbicides have relatively little effect on the native pondweeds and other aquatic monocots which generally comprise most of the native aquatic plant community.

The only way yet devised to rid lakes and other waterways of large, established Eurasian milfoil populations involves whole-lake treatment with herbicides (US-ACE 2001). These types of treatments are generally best undertaken by state natural resource departments or other agencies or groups with the necessary resources and expertise.

For several years the Lac Courte Oreilles Conservation Department (LCO) has been inventorying and treating the Round Lake Eurasian milfoil population (D. Tyrolt, *pers. comm.*). For the first few years of the program LCO staff surveyed the entire shoreline and treated Eurasian milfoil patches themselves. Then last year they set up a volunteer monitoring program in coordination with the Round Lake Lake Association. Volunteers monitor sections of the shoreline, and report any Eurasian milfoil patches to LCO. LCO staff verify and map the patches, and then either remove them manually (small patches) or treat them with a 2,4-D based formulation (larger patches). The number of treated acres has gone from roughly 10 acres/year several years ago to approximately 0.25 acres in 2004. While this program is not likely to eliminate Eurasian milfoil from the lake, LCO staff believe that it will keep the plant at acceptable levels. This program has been funded with a combination of LCO, WDNR, and lake association funds.

The Lac Courte Oreilles College Extension Program recently initiated a project to monitor and control Eurasian milfoil and purple loosestrife infestations on the Chippewa Flowage (E. Olson, *pers. comm.*). Monitoring efforts for this initiative will also be primarily volunteer-based.

Because our 2004 surveys for milfoil weevils were rather informal, more systematic and thorough surveys for these insects should be conducted prior to initiating any new treatment programs for Eurasian milfoil on these lakes. Jester et al. (1997) surveyed 27 lakes across Wisconsin, and found weevils in 25 of them. They found adult milfoil weevils visually by snorkeling. They found all life stages (eggs, larvae, pupae, and adults) by collecting the upper 0.5 m portions of stems and later examining them for damage under a dissecting scope, and slicing open stems that showed signs of damage. Milfoil weevils are fairly easy to raise in 20-gallon aquaria (see Cofrancesco and Crosson 1999 for step-by-step instructions) and may be a viable option for controlling Eurasian milfoil on some waterbodies.

Purple loosestrife
Most if not all the purple loosestrife populations on the survey lakes are probably worth treating. The only lake that appeared to have a very large population of this plant was Squirrel Lake. Even on this lake there appeared to be minor *Galerucella* damage in some locations. The extent and effectiveness of this beetle population should be assessed in early summer, and additional *Galerucella* beetles introduced. Where *Galerucella* appears to be ineffective, other biocontrol insects [e.g., the stem- and root-boring weevil *Hylobius transversovittatus* Goeze (Coleoptera: Circulionidae)] might be considered for release.

Though the Chippewa Flowage loosestrife populations appear to be fairly numerous and widely scattered, the majority of the patches were small. Due to time constraints, it was not possible to map all the populations on this flowage in 2004. Data for the eastern portion of the flowage was collected by LCO Community College in 1997 and 1998, though, and new efforts are underway by Lac Courte Oreilles College Extension to update this data, beginning in 2005 (E. Olson, *pers. comm.*).

The site of the single loosestrife plant (which was dug up and removed) on Namekagon should be monitored for several years, and any new seedlings eradicated. As purple loosestrife is probably present elsewhere on this lake as well, a survey of the entire shoreline should be done in 2005, and any additional colonies treated.

The Gile Flowage loosestrife population appears to be relatively small, consisting of one modest-sized patch and a few isolated individuals. Whether this is due to the severe drawdown regime on this flowage, or to a relatively recent introduction (or both) is unclear. This population should be treated with herbicides, with the goal of eliminating it. The Lake Gogebic population is also small and localized, and could be eliminated with a modest effort. The purple loosestrife populations in Turtle Flambeau Flowage are currently being treated by the local lake association, according to a WDNR ranger there.

Loosestrife populations on many of the other lakes are also relatively small, and might be treated through more aggressive means. If not already present, *Galerucella* beetles, *Hylobius* beetles, or other biocontrol insects could be introduced to larger populations. Any new control efforts on these lakes should be coordinated with existing control efforts.

Flowering rush
Some 30 years after its introduction, the Round Lake flowering rush population has become quite extensive. Large populations of this plant are very difficult to treat: digging tends to free underground parts from the substrate, which can then be transported by wind and waves to reroot elsewhere, and the narrow leaves tend to shed herbicides, greatly reducing their effectiveness against this plant (MNDNR 1999). Also, flowering rush is attractive when in bloom, and this population may be important to lake residents, especially those with property along the shoreline where it occurs.

Judging from our surveys and from WIS (2004) and other sources, it appears that flowering rush is still rare on northern lakes. In order to keep it that way, some sort of control program should be implemented on Round Lake, to keep this significant invasive from spreading further.

A review of relevant literature revealed little if any research into possible biocontrol organisms for flowering rush. It would seem to be an excellent candidate for biocontrol, as it is taxonomically unique, with no close relatives.

Yellow iris

The Pelican Lake yellow iris population consists of several rather small colonies (of roughly a few square meters each) and is still quite treatable. Beginning next spring, any new patches should be marked with a GPS and then dug up, removing any seeds or underground parts. Follow-up visits should be made yearly for several years to eliminate any new shoots or seedlings.

Ideally an effort should be made to contain or eliminate the large, well-established yellow iris infestation on Pacwawong Lake. This population should be reported to the St. Croix National Scenic Riverway, National Park Service (St. Croix Falls, WI). The downstream and upstream extent of this population should be delineated, and plans should be made to eliminate it if possible.

The Squirrel Lake population appears to be very extensive, and judging from the comments of two lake residents, probably has a popular following. Public education and cooperation will need to be a part of any significant control efforts against yellow iris on this lake.

The fact that well-established yellow iris populations were found on two of the survey lakes and several colonies found on a third, suggests that this plant is more common than current records would indicate. A review of relevant literature revealed no significant research into possible biocontrol organisms for yellow iris.

Eurasian marsh thistle

Populations of Eurasian marsh thistle were found on or near the shorelines of several northeast Wisconsin lakes. The WDNR has recently included this species on its list of “target species” that are now gaining a foothold in the state or are poised to do so in the near future (WDNR 2004b). Unfortunately marsh thistle is one of the most abundant and well-established of these target species in the state, being reported from 9 counties in northeastern and north central Wisconsin (WIS 2005). It is also locally common across Upper Michigan and northern Lower Michigan (Voss 1996; *pers. obs.*). The fact that marsh thistle is a monocarpic perennial that must reproduce by seed (Falinska 1997) may render it more susceptible than some other species to persistent control efforts. On the other hand, its very light, windblown seeds and persistent seed and seedling-bank (Grime et al. 1988, Falinska 1997) will make it more difficult to control.

Eurasian marsh thistle will undoubtedly continue to spread into Wisconsin and beyond, invading roadsides, marshes, bogs, shores and wet woods along the way. Smaller, “leading edge” populations should be aggressively attacked, to try and slow the spread of this invasive plant.

Though much less aggressive than the Eurasian marsh thistle, the native swamp thistle (*Cirsium muticum*) appears superficially similar to marsh thistle, and often occurs in the same habitats. As part of any control efforts for Eurasian marsh thistle, care should be taken to properly identify target plants, to avoid impacting swamp thistle or other native species.

Nontarget invasives

Useful information was gathered on the degree to which "minor" invasive plants have invaded these lakes as well. Though often overlooked, water forget-me-not is a significant invasive of shorelines, wetlands, and similar habitats. Narrow-leaf and hybrid cattails have established colonies on the isolated, virtually undisturbed shorelines of several lakes. These and other invasives are likely to continue to increase in abundance and impact throughout the region for the foreseeable future.

Reed canarygrass is almost ubiquitous in the upper Great Lakes region, and effective control options for large populations of this very aggressive and tenacious plant are basically nonexistent. The best way to prevent canarygrass invasion of natural areas is to avoid disturbance, including the influx of silt- or nutrient-laden runoff into these areas (Maurer et al. 2002).

The Oriental bittersweet patches found near the shorelines of lakes Metonga and Namekagon are cause for concern, as this species is becoming a major forest pest in eastern North America (Dreyer 1994). The Metonga patch had apparently been planted by a cabin owner as a ground cover - it completely carpets the slope above the shoreline and has spread to an adjacent woodlot.

The terrestrial invasive plant occurrences found during these surveys will be added to GLIFWC's invasive plant database. These may be helpful at some future date, should means and methods for effective control of these serious and widespread invasives become available.

Invasive Animals

Because of their greater mobility and general lack of effective, environmentally sound control methods, invasive animal populations are often difficult to impossible to control. Probably the best that can be done at present is to attempt to limit their spread through public education.

Zebra mussels and lake parameters

The US-ACE (2004) gives a list of 5 risk factors for zebra mussel infestation, of which pH is a key factor:

Threshold value for adult survival:	6.5
Threshold value for veliger survival:	6.9
Incipient lethal level for veligers:	7.4
Value for massive infestation:	8.0

According to this scale, it would appear that Annabelle, Siskiwit, and perhaps Thoroughfare might be resistant to invasion by zebra mussels, with Rice River Flowage, Squaw, and Sand resistant also. The rest of the survey lakes are presumably susceptible to invasion. Twelve of the lakes had pH values above 8.0 (at least at a depth of 1 m) and may be susceptible to massive infestation, including Metonga (which is already heavily infested). With a pH just below 8, Round Lake would also appear to be susceptible to invasion by zebra mussels. All 5 of the US-ACE (2004) risk factors undoubtedly interact to some degree, though, and as these pH data are quite limited in their spatial and temporal applicability, they are of limited predictive value.

Even though the summer of 2004 was generally cool, water temperatures encountered throughout the surveys were all well above the 12° C threshold needed for zebra mussel reproduction (US-ACE 2004). This indicates that the absence of veligers in nearly all our samples was not due to sampling too early in the spring. It also illustrates the fact that temperatures of inland lakes in the ceded territory remain above this threshold throughout the summer months, indicating that temperature is not a limiting factor for zebra mussel infestation of these lakes.

The status of Round Lake

The presence of very low levels of zebra mussel veligers in a single sample from Round Lake, and the subsequent failure to find more evidence of zebra mussels there, leaves the status of this lake with regard to zebra mussels in question. As this positive sample was the first one taken in 2004, contamination from sampling equipment seems impossible. Probably the most likely explanation is that a small population of zebra mussels is established in the lake, but was not detected on subsequent visits. Of course other explanations, such as the detection of veligers from a passing contaminated boat, cannot be ruled out.

Given this uncertainty, it is strongly recommended that Round Lake be closely monitored in the future. Visual surveys of pier supports, the undersides of watercraft, floating docks, and other submerged objects by lakeshore residents can be quite effective and efficient in detecting adult zebra mussels, and are highly recommended ®. Martin, *pers. comm.*). Additional veliger samples should also be taken in various locations around the lake, especially in the vicinity of the positive sample. Veliger sampling of other heavily-used lakes in the area may also be warranted.

Possible control methods

Research into possible biological and other methods for controlling zebra mussels is ongoing (US-ACE 2004). A literature study of the known natural enemies of *Dreissena* spp. found 176 species involved in predation, 34 in parasitism, and 10 in competitive exclusion of these mussels worldwide (Molloy 1997, cited in US-ACE 2004). Much of this research has focused on host-specific parasites and pathogens of *Dreissena* spp., with the hope that these organisms can someday be economically mass-produced, and used to induce artificially high, intense infections lethal to *Dreissena* mussels (US-ACE 2004).

The discovery of effective biocontrol agents for zebra and quagga mussels, and the development of effective techniques for their use, is still years away at best. The fact that these mussels are generally common in their native range indicates that their natural enemies are having only a relatively small effect on their populations there, and suggests that these natural enemies may not be effective in significantly controlling mussel populations in North America either.

Spiny waterfleas

So far spiny waterfleas are only sparingly established in inland lakes in the ceded territory. Inexplicably these crustaceans appear to have disappeared from a reservoir (Fish Lake) in northeast Minnesota where they had previously been established (Exotic Species Program 2004). In general, though, spiny waterfleas can be expected to continue to spread in the region.

Mysterysnails

Asian and Georgia mysterysnails are now established in a significant number of the survey lakes. In lakes where they were observed it was not uncommon to find live individuals floating just below the surface, well away from shore. This suggests that once these snails become established in a lake, they probably are able to disperse throughout the lake in a relatively short period of time.

Little if any research has been done into the effects of these introduced snails on lake environments in North America. Yet their high abundance in many northern lakes strongly suggests that they are having an effect on the ecology of these lakes.

Rusty crayfish

Rusty crayfish often have major impacts on the ecology of northern lakes (Lodge and Lorman 1987, Olsen et al. 1991). These impacts stem primarily from their tendency to destroy aquatic plant beds (Lodge and Lorman 1987), which in turn reduces habitat for a wide variety of invertebrates, fish, and other organisms. Primary production is also reduced, leading to disruption of the food chain. Rusty crayfish are also highly aggressive towards native crayfish, often to the point of eliminating them from the lake. Their larger size also renders them less susceptible to predation by fish (Lodge and Lorman 1987). It seems likely that rusty crayfish in Lac Vieux Desert and Upper Nine Mile will increase in numbers until they reach their carrying capacity, and begin to exert similar disruptive effects on these lakes as they have in many other lakes in the region.

Water Quality

Light is the single most important factor limiting plant distribution and abundance in lakes. The amount of light available to submersed aquatic plants depends primarily on both water transparency and depth (US-ACE 2001). The algal population (both green algae and blue-green bacteria) is usually the largest and most variable component of water clarity (Shaw et al. 1996). These algae are a ubiquitous and necessary component of the planktonic community. In eutrophic lakes they tend to become very abundant, though, leading to low dissolved oxygen levels, which in turn can lead to fish kills and numerous other adverse ecological effects.

It is important to not read too much into water clarity comparisons between these lakes, because readings were generally only taken once in one location on each lake, and at different times and under different conditions throughout the summer. Weekly or biweekly recordings throughout the season and over a period of several years are needed to closely monitor water clarity (Shaw et al. 1996).

The decrease in pH often seen at 4 m versus 1 m depths is typical of freshwater lakes - photosynthesis in the upper layer reduces CO_2 concentration (and therefore concentration of the weak acid HCO_3^-) and raises pH, while greater decomposition in the lower levels produces CO_2, lowering pH (Wetzel 1983, p. 211). Again, more measurements would need to be taken over a longer period of time, in order to get a more accurate picture of pH conditions in these lakes.

Sampling Effectiveness

The fact that plants and animals were usually observed in the lakes where they had already been reported provides confidence in the methods used in 2004. That more populations of invasives were not found probably reflects the absence of these species in most of these lakes. Some of the target plants, including Eurasian milfoil and purple loosestrife, are difficult to detect from a boat early in the season, and the very cool summer may have amplified that effect. Others, such as water chestnut, European frogbit, and hydrilla were probably not detected because they have not yet arrived in the upper Great Lakes region.

These surveys also provided a better understanding of the distribution and abundance of a number of introduced plant species that are not officially “tracked”. Plants such as narrow-leaved cattail, crack and white willows, reed canary grass, and water forget-me-not appear to be widespread in and around the region’s lakes.

Problems Encountered in 2004

Suboptimum phenology was at times a significant problem in detecting invasive plants. Some lakes were surveyed too early to reliably find later-blooming plants including purple loosestrife, flowering rush, and Eurasian marsh thistle, while others were surveyed too late to reliably detect early-bloomers such as yellow iris and water forget-me-not. Some of the submersed aquatics such as Eurasian milfoil and hydrilla may not reach the surface until July.

Although curly pondweed is reputed to disintegrate by mid- to late-July, rooted, intact plants were observed in and collected from sheltered bays of Mille Lacs on September 1. The degree to which the persistence of these plants can be attributed to the unusually cool summer is unknown.

The available qualitative survey protocols for aquatic invasive plants [e.g., VT-DEC (no date), NH-DES 1999] generally recommend surveying shorelines from the outer edge of the littoral zone by boat, and checking any suspicious patches of vegetation. It should be noted, however, that Madsen and Bloomfield (1992) consider these methods both qualitatively and quantitatively inadequate for submersed species. At a minimum they recommend diver swimovers of representative habitats and locations of a lake, by snorkeling or preferably SCUBA diving.

Viewscopes constructed in fall of 2004, after these surveys were completed, may aid in detection and delineation of submersed species populations in future surveys.

During our shoreline surveys there was a tendency to drift too far from the littoral zone, so that some plants (especially submersed plants) could have been missed. Of course frequent and prolonged motorboat travel through plant beds should also be avoided, as this can cause significant damage to these beds.

Rake sampling appeared to be of inadequate intensity to be effective in finding invasives. When invasives were brought up with the rake, they were generally also found visually elsewhere in the lake. Rake throws were probably as likely to find mollusks as plants, with Asian and Georgia mysterysnails and (in Lake Metonga) clumps of zebra mussels brought up on the rake.

It seems reasonable to assume that the majority of introductions occur at landings, and that invasives (plants and animals) are most likely to get started there. The fact that these surveys did not detect any early infestations in the vicinity of boat landings may be due to insufficient sampling in those areas. During their surveys of 16 western Upper Michigan lakes, Skogerboe et al. (2003) found two isolated Eurasian milfoil infestations in two different lakes, both near public boat landings.

Finally, while the survey schedule generally allowed sufficient time (1-2 days per lake) to adequately survey the smaller lakes, even 3 days was inadequate to completely survey the shorelines of the Chippewa Flowage, Turtle Flambeau Flowage, and several other very large lakes.

Recommendations for Future Surveys

A number of factors contribute to the risk of a lake being inoculated with invasive species. Foremost among these are the amount of boat traffic a lake receives and the proximity of other infested waters. Large lakes that receive a lot of traffic and are near other infested lakes are at greatest risk for invasion. Such lakes also tend to be closer to more populated areas. For greatest efficiency in finding invasives, surveys should target these lakes.

During future surveys, each lake could be surveyed once between early June and mid-July, and again between early August and mid-September. On each visit the shoreline should be surveyed at low speed, from the outer edge of the littoral zone. (Binoculars can be quite helpful in identifying plants that are just out of range.) Suspicious-looking plant patches should be inspected closely. The shoreline and shallow-water areas should be searched for mysterysnails and other nonnative animals. Future surveys should continue to concentrate on boat landings and perhaps other high-use areas. Finally, Eurasian marsh thistle should be considered a major invasive and should be added to the target list.

Secchi disc readings are problematic as the weather does not always cooperate. However it would be advantageous for at least three of these to be taken in each lake as well. Adequate secchi disc readings might allow a more accurate estimate of the maximum rooting depth (MRD), which in turn might facilitate more targeted and efficient plant surveys in each lake. Using a bathymetric map and a GPS, Skogerboe et al. (2003) set up a grid of sampling points for each lake, with points 100 m apart, and then sampled each point having a depth ≤ the MRD with four rake throws. This type of systematic sampling could be considered for future surveys, at least on the smaller lakes.

Probably the most environmentally damaging invasive moving into the northern lakes at present is the zebra mussel. Unless a lake is quite small, a minimum of three veliger tows should be done in each lake. Sampling for pH, temperature, and either alkalinity or (preferably) calcium should be taken with each veliger tow. One pH and temperature reading at a depth of 2 m (instead of one at 1 m and one at 4 m) would probably be adequate. (On the other hand, sampling at 1 or 2 m and again just above the bottom would be ideal.) On larger lakes, temperature, pH, and calcium could also be measured at several locations, at spring and fall turnover. As veliger presence in infested waters can be erratic (D. Sachs, *pers. comm.*), sampling for veligers (along with pH and temperature measurements) should be done on both visits to each lake.

Adequate water quality data (particularly pH and calcium) would be particularly useful in getting a handle on which lakes are susceptible to zebra (and quagga) mussel infestation and which are unlikely to be infested. Smaller, more acidic lakes might even be able to be dropped from future monitoring for zebra mussels based on these data.

The UW-Stevens Point Lake Water Quality Program (see http://www.uwsp.edu/cnr/etf/Lake.htm) recommends measuring water quality parameters twice per year, during spring and fall turnover, in order to ensure the greatest uniformity of these parameters throughout the lake. They would supply clean bottles and analyze samples for calcium content for approximately $13/sample. In softwater lakes, calcium is fairly stable over varying depths and throughout the season (Wetzel 1983), so samples taken in summer might be acceptable. Given the fact that zebra mussels have successfully invaded the lower Great Lakes, with their relatively low salinity and temperatures, it can probably be assumed that these factors are not limiting in the region's northern inland lakes.

Sampling for spiny and fishhook waterfleas should continue as well. As with the veliger sampling, at least three samples should be taken per lake. As these animals seem to inhabit the water column throughout the summer, sampling at various times during the survey season should not be a serious problem.

While specific methods for surveying for some of the up-and-coming invasive animals (Asian clam, African waterflea, and others) poised to invade the region are outside the scope of this report, some consideration should be given to sampling or at least searching for these animals in the future. Setting a few traps out for one or a few days to more carefully sample for rusty crayfish would be relatively simple to do, and might also be an option.

Collections

Collections of target plants are indispensable for verifying the accuracy of surveys (US-ACE 2001). Time constraints prevented the collection of voucher specimens from each individual population in 2004. Future surveys should make this aspect a priority. Accurate information on any “known” populations occurring in the lakes scheduled to be surveyed is of great help in making plant (and animal) collection as efficient as possible.

Samples of mysterysnails (at least shells), rusty crayfish (males are best), zebra mussels, and other invasive animals should also continue to be collected from each lake where they are found. Because crayfish identification can be problematic (see Gunderson 2004), samples should be preserved in 95% ethanol, and kept for future reference.

Decontamination

Chlorine combines with naturally-occurring organic substances to form organochlorines, which are known to be hazardous to living organisms, including humans. Therefore the use of chlorine bleach for disinfecting boats, motors, and other equipment should be discouraged. Household vinegar, which was used for disinfecting nets and occasionally other equipment during these surveys, is as effective as bleach for killing zebra mussel veligers and other invasive animals (M. Beall, *pers. comm.*), and is much safer to humans and the environment than bleach. For these reasons, vinegar (along with careful removal of plant fragments, power washing, etc.) should be used instead of bleach to decontaminate equipment.

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