

AQUATIC PLANT MANAGEMENT ON BIG CEDAR LAKE, ONTARIO

An Excerpt from: Report on Summer 2019 Activities

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Starry stonewort (*Nitellopsis obtusa*) in Big Cedar Lake



Figure 4. Approximate location of Starry stonewort (*Nitellopsis obtusa*) growth (blue shaded areas) as of October 2019 near the public boat launch in Big Cedar Lake.

1.1 Scientific Classification

Kingdom: Plantae
Division: Charophyta
Class: Charophyceae
Order: Charales
Family: Characeae
Genus: *Nitellopsis*
Species: *Obtusa*

Common Names: Starry stonewort, green algae, macroalgae

Similar Species: *N. obtusa* closely resembles and is easily confused with other species from its related genera *Chara* and *Nitella* such as: *Chara vulgaris* and *Nitella flexilis*. Positive identification of *N. obtusa* can be made through the presence of star shaped bulbils that are unique to this species.

1.2 Morphological Description



Shoot morphology



Root bulbil with typical "starry" formation



Typical "pillow" like growth form of large colony

Description: Despite its structure that resembles other "typical" aquatic plants, *N. obtusa* is actually a macroalgae. Its simple growth form consists of a main axis (comparable to a stem) with whorled branchlets (comparable to leaves) extending from the algal nodes. It has root-like rhizoids that can help to anchor the plant in the sediment and distinctive, star shaped bulbils that are produced for vegetative reproduction. The vegetative tissue of macroalgae, like *N. obtusa*, is referred to as a thallus or thalli. Below descriptions are compiled from: Bharathan, 1983,1987; Kipp et al, 2016; Naz et al, 2010; Sleith et al, 2015 and Wood, 1965.

Axis: This is the main stem of the macroalgae. It is smooth, thin, rounded and vibrant green in color. The main axis of *N. obtusa* can reach over two meters in length. Unlike many other species from the family Characeae, *N. obtusa* does not produce stipulodes (small spines) along its axis and nodes.

Branchlet: Nodes on the main axis of *N. obtusa* will produce whorls of 4-7 branchlets (leaves) that are thin, rounded and can be straight or slightly curved. Branchlets are typically 2-4cm in length. Individual branchlets will not furcate (fork) into additional whorls, although the production of small bracts along secondary branchlet nodes can give the appearance of furcation.

Bract: These are small, secondary leaf structures sometimes produced from branchlet nodes. They are approximately 1cm in length and can give *N. obtusa* branchlets a forked appearance.

Rhizoid: Rhizoids are thin, translucent filaments produced by *N. obtusa* to help anchor individuals into the sediment, if conditions permit. Rhizoids have been shown to produce higher densities of bulbils than other structural parts of this species.

Bulbil: Bulbils are flat, circular, white/cream colored propagules that have distinctive points (typically 4-7 points per bulbil) spaced around their circumference giving them the appearance of small stars. Bulbils are typically 2-4mm in size and can be produced from any node on the thallus, but are most commonly found on portions of the thallus closest to the sediment like rhizoids. These structures are responsible for this species adopting the common name of Starry stonewort. They are unique to this species of Characeae and are the most accurate way of differentiating *N. obtusa* from other species.

Reproductive Organs: *N.obtusa* is a dioecious species meaning that each individual in a population is sexually distinct and may be either male or female. Female reproductive organs are called oogonium and only form along upper branchlet nodes. They have a distinctive spiral appearance and are approximately 0.4mm in size. After their formation, two bracts form on either side of the oogonium. Male reproductive organs are called antheridium. They are round, orange/red in color, approximately 1mm in size and form along the branchlet nodes. Oogonium successfully fertilized by antheridium then form black to light brown, ellipsoid oospores, which will sprout rhizoids and eventually form another *N.obtusa* axis.

1.3 Distribution

Fossil records of *N.obtusa* date back to the Cretaceous-Tertiary period (Soulié-Märsche, 1979), 65 million years ago (Cooper and Penny, 1997). *N.obtusa* is native to parts of Europe and Asia and the historical distribution of this species covers a widespread area including: Mali, Mauritania, Sudan, Bashkiria, China, Georgia, Japan, India, Iraq, Turkmenistan, France, Germany, Great Britain and Romania (Naz et al, 2010; Soulié-Märsche et al, 2002).

The current (extent) distribution of *N.obtusa* still ranges across Europe and Asia, however, it is no longer found in any of its historical African distribution. Eurasian populations of *N.obtusa* can be found in: Iran, Myanmar, China, India, Japan, Uzbekistan, Bangladesh, Austria, Belgium, Czechoslovakian Republic, Denmark, Prussia, Estonia, France, Finland, Germany, Great Britain, Greece, Hungary, Italy, Montenegro, Poland, Portugal, Romania, Russia, Spain, Sweden, Switzerland, Ukraine and Yugoslavia (Kato et al, 2014; Naz et al, 2010; Soulié-Märsche et al, 2002).

Despite its occurrence in numerous countries, it appears that this species is in decline throughout parts of its native range. In the United Kingdom, >95% of the entire *N.obtusa* population has been reduced to a series of very small waterbodies (<1.5 km²) known as the Norfolk Broads in southeastern England (Hunter et al, 2010). The International Union for Conservation of Nature and Natural Resources (IUCN) Red List has designated *N.obtusa* as a vulnerable species in the United Kingdom (IUCN, 2016; Stewart, 2004).

Although native to Japan, this species had been considered fully extinct from the country since 1977, until its recent re-discovery in 2005 (Kato et al, 2005, 2014; Watanabe and Morita, 1977). Following its reappearance, the Government of Japan Ministry of Environment (GJME) was able to delist the species from extinct in the wild to critically endangered/threatened (GJME, 2012).

In 2002, Soulié-Märsche et al (2002) described Poland as having some of the densest and most expansive *N.obtusa* stands in Europe. Only eight years later, however, Gołdyn (2010) documented this species as being vulnerable and potentially endangered with a significant reduction in distribution across that country within the last 30 years.

N.obtusa was first observed in North America where it was found growing on a 72km section of the St. Lawrence River along the US shoreline of New York. At the time, its invasiveness or potential risk to North American ecosystems was not realized despite it being reported as a fast colonizing species (Geis et al, 1981). Since then, *N.obtusa* has spread to, and been documented in, a total of seven states within the US including: New York (c. 1978), Michigan (c. 1983), Indiana (c. 2008), Pennsylvania (c. 2009), Wisconsin (c. 2014), Minnesota (c. 2015) and Vermont (c. 2015) (Escobar et al, 2016; Kipp et al, 2016; Schloesser et al, 1986; Sleith et al, 2015).

Ontario: Although no formal surveys were conducted, its introduction into shared waters with the US in 1978 likely also meant that populations of this species were growing in Ontario. As of 2013, the presence of *N.obtusa* has been confirmed in the province. It was initially detected in a water quality surveillance program by the Ontario Ministry of the Environment (MOE) in Presqu'île Bay along the shores of Lake Ontario near Brighton, ON (Midwood et al, 2016). The Canadian Wildlife Service repeated the survey in 2015 and *N.obtusa* was found in 11 new sites along Lake Ontario and Bay of Quinte coastal wetlands, although the results were not published (Midwood et al, 2016). Practically no other published information exists regarding the confirmed distribution of *N.obtusa* in Ontario. Midwood et al (2016) suggested that given its similarities to other Chara sp. and Nitella sp., it is falsely identified in the field and its presence is not recorded. In 2015 and 2016, it was confirmed growing within several waterbodies in the Kawartha Lakes region in central Ontario (Sager, pers.obs.; Canning and Weissflog, pers.obs.), but no extensive surveys for the plant have been conducted on a province wide basis. Given its known distribution in shared waterbodies with the US (Lakes St. Clair, Ontario, Erie, Huron, Michigan and the St. Lawrence River), it seems inevitable that *N.obtusa* has and will have a much greater presence in Ontario than is currently acknowledged.

1.4 Life History

Growth: The growth habits of *N.obtusa* appear to differ somewhat between the North American and Eurasian populations, as well as regionally within North America. In its native range, *N.obtusa* is considered a summer annual. It begins growth between April-May and continues until it reaches its peak biomass in June. *N.obtusa* biomass then declines throughout late summer and fall and is known to die-back completely throughout the winter months, with some potential for overwintering as standing biomass if temperatures are unseasonably mild (Hargeby, 1990; Hutchinson, 1975; UK Biodiversity Action Plan, 1994).

In North America, growth of *N.obtusa* doesn't begin until July and August and continues until the macroalgae reaches peak biomass in September (~3 months later than Eurasian populations). Schloesser et al (1986) noted that *N.obtusa* emerged 1-2 months later than other macrophytes in the St.Lawrence River, but remained active in the water column 2-3 months longer. Biomass remains relatively stable at peak levels through the fall until November, when the species declines steadily, but remains in the water column until March (Nichols et al, 1988). Despite its late emergence, Geis et al (1981) observed that *N.obtusa* eventually dominated macrophyte communities and represented 35.4-72.1% of all macrophytes standing crop biomass over winter. **Table 1** shows seasonal changes to average *N.obtusa* dry-weight biomass values for populations sampled in the Detroit River.

Table 1: Seasonal changes in *N.obtusa* dry-weight biomass on the Detroit River. Peak biomass in North America is reached and maintained throughout the late fall-early winter and occurs ~3 months later than Eurasian populations. Data from Nichols et al (1988).

Month	<i>N.obtusa</i> Biomass (g/m²)
July/August	75
September	119
November	105
January	68-83
February	18
March-June	0

N.obtusa appears to exhibit some inconsistent growth trends on a yearly and regional basis in the US. In Michigan, Pullman and Crawford (2010) described significant differences in *N.obtusa* growth across different lakes in the state. In some areas, *N.obtusa* growth began much earlier than usual and produced nuisance-level biomass, where as in other bodies of water, this macroalgae appeared to be dormant, only to return the following year. After its initial discovery, *N.obtusa* distribution in Michigan was localized to Lake St.Clair and dispersal to other waterbodies was not observed for 30 years. As of 2016, however, Michigan has the highest number of *N.obtusa* colonized lakes out of any of the seven US states with this species (Kipp et al; 206; Pullman and Crawford, 2010; Schloesser et al, 1986).

Reproduction: *N.obtusa* can reproduce both sexually (using oospores) and vegetatively (through bulbils and tissue fragments). Since *N.obtusa* is dioecious, both male and female individuals must be present in the same waterbody for sexual reproduction to occur. Female oogonium and male antheridium develop independently and once mature, the antheridium cell wall becomes water-soluble and allows the antherozoids (sperm) to escape into the surrounding water. Antherozoids are chemically attracted to oogonium allowing for fertilization and oospore production to occur (Sharma, 2016). The production of an oospore is also referred to as fructification (Bharathan, 1987). Once fertilized, oospores remain dormant for a period of one to three months (Forsberg, 1965; Proctor, 1967), before developing rhizoid and axis tissue and eventually forming another mature individual (Bharathan, 1987). It is not clear for how long antherozoids remain viable once released into the water column or how far they can travel from their parent plant to fertilize mature oogonium. The process of fructification occurs between July and October, but appears to be highly sensitive to the abiotic conditions in the surrounding environment and does not always occur (Bharathan, 1987; Langangen, 2007; Naz et al, 2010).

N.obtusa propagates vegetatively through the formation of distinctive star-shaped bulbils and tissue fragments. Bulbils can be formed on any main axis or branchlet node, but are most readily found on thallus parts closest to the sediment, like the rhizoids (Bharathan, 1987; Geis et al, 1981; Pullman and Crawford, 2010). They can be produced throughout the entire growing season, but are most often observed during the spring and fall (Geis et al, 1981; Pullman and Crawford, 2010). *N.obtusa* creates bulbils by modifying the oldest branchlet whorls on the thallus creating compact, starch filled propagules (Bharathan, 1987). This gives bulbils their distinctive color and star-like shape. Unlike oospores, bulbils have no dormancy period and will produce new individuals within 3-5 days, once mature (Bharathan, 1987).

This species is often cited as spreading through vegetative fragments (Escobar et al, 2016; Hackett et al, 2014; MAISRC, 2015; Pullman and Crawford, 2010; Sleith et al, 2015). In these instances, however, it is not explicitly stated whether this refers to any sized *N.obtusa* fragment, or ones containing nodes and bulbils. Fragmentation is a common method of propagation in other members of the Characeae family, but is typically most successful when fragments consist of two or more nodes (Skurzyński and Bociąg, 2011). It is not clear whether a fragment of *N.obtusa* tissue comprised of only internodal thallus tissue would be able regenerate into an entire clonal member.

Dispersal: *N.obtusa* uses oospores and its vegetative propagules for dispersal, but appears to rely primarily on its bulbils and fragments as its most important dispersal units. Within its native range, the production of oospores is rarely, if ever observed (Escobar et al, 2016; Langangen, 2007; Naz et al, 2010; Olsen, 1944; Sleith et al, 2015; Willén, 1960). This is partly due to the dioecious nature of the species, as well as its sensitivity to environmental conditions.

In Eurasia, most bodies of water hold populations of *N.obtusa* that are comprised of only male or female individuals (Kasaki, 1962,1964,1994; Kato et al, 2014; Naz et al, 2010; Schubert and Blindow, 2003). Since the production of fertilized oospores requires both male and female individuals be present in the same waterbody, oospores are rarely if ever formed. Even in cases where both sexes of *N.obtusa* were in direct contact with one another, it has been shown that the production of oogonium/antheridium in this species only initiates when the macroalgae is exposed to eutrophic conditions (Bhatharan, 1987; Krause, 1985). *N.obtusa*, however, is considered to be a key indicator species for mesotrophic-oligotrophic lakes (Kasaki, 1962; Kato et al, 2014), suggesting that its exposure to eutrophic, oospore producing conditions is limited. Furthermore, Langangen (1974) observed that the frequency of fructification in *N.obtusa* increased with light intensity. This species, however, is commonly cited as growing in deeper waters under low-light conditions, below what is required for viable oospore formation (Bhatharan, 1987; Mulkerij, 1932; Schloesser et al, 1988).

When successfully produced, oospores have been shown to be transported long distances through endozoochoric (movement using vertebrate digestive tracts) and epizoochoric (“hitch-hiking” on the feathers, feet etc. of animals) dispersal mechanisms (Proctor, 1962, 1968; Pullman and Crawford, 2010; Sleith et al, 2015). Proctor (1962) observed that endozoochoric transport reduced the germination rates of oospores to around 30%, compared to germination rates in non-ingested oospores, which ranged from 40-60%. This could suggest epizoochoric dispersal as a more viable dispersal method for this species. The buoyancy of *N.obtusa* oospores has not been established and it is unclear whether they are also moved through hydrochory (dispersal through water current, wave action etc.). Oospores appear to have some degree of long term viability beyond their one to three month dormancy period (Bhatharan, 1987) and have been successfully germinated after seven months in storage (Proctor, 1962).

In North America, all *N.obtusa* populations appear to be comprised solely of male individuals and viable oospore production has not been documented in the US or Canada (Escobar et al, 2016; Mann et al, 1999; MIA SRC, 2015; Sleith et al, 2015). This means that tissue fragments (with or without bulbils) are the only means of dispersal for this species in North America. Bulbils, on their own, are not considered valuable, long-distance dispersal units (Bhatharan, 1987) and are thought to limit transmission of this species to endemic distributions only (Croy, 1982). This is because bulbils are typically produced on thallus parts closest to the sediment and when undisturbed, are not released by the rhizoids and germinate immediately in the sediment directly surrounding the parent plant (Bhatharan, 1987).

There is very strong evidence to suggest that transmission of *N.obtusa* through the US and Ontario is primarily driven by the human related movement of vegetative fragments (Escobar et al, 2016; Midwood et al, 2016; Pullman and Crawford, 2010; Sleith et al, 2015), not by transmission through animals. Sleith et al (2015) studied the distribution of *N.obtusa* in lakes in the state of New York. They found that every body of water colonized by this species had substantial human development including boat launches and marinas. Furthermore, they concluded that animal based transmission of *N.obtusa* was not prevalent because this species is only found within a limited area in the state and is not present in more naturalized, human excluded lakes, which would be more attractive to wildlife. In Ontario, Midwood et al (2016) showed that the three best predictors for determining the presence of *N.obtusa* in a waterbody were: dock density, conductivity and distance to a marina. Combined dock density and marina distance had the greatest contribution (42%) towards predicting the presence of *N.obtusa*.

1.5 Habitat Preferences

Temperature: This species can tolerate a wide range of water temperatures, from 0-30°C (Gies et al, 1981; Kipp et al, 2016; Marchyulene et al, 1982; Nichols et al, 1988). It has been shown to grow under ice thicknesses of up to 18cm (Nichols et al, 1988) and typically doesn't reach its peak biomass until after the warmest months of the growing season (Hutchinson, 1975; Nichols et al, 1988). Temperatures above 30°C inhibit growth of this species preventing the formation of apical cells and causing tissue death (Marchyulene et al, 1982).

Water chemistry: *N.obtusa* has shown similar water chemistry preferences in both its native and invasive distributions (Sleith et al, 2015). It is considered to be a key indicator species of mesotrophic to oligotrophic lakes (Kasaki, 1962; Kato et al, 2014). This species is more apt to colonize water with minimal nutrient loading, although healthy populations of this species have been observed in the nutrient rich (eutrophic) waters of the Trent-Severn Waterway in Ontario (Canning and Weissflog, pers.obs.). It has been found occupying waters with pH values ranging from 6.4-9.3 and conductivity values between 160-2250 $\mu\text{S}/\text{cm}$ (Geis et al, 1981; Simons and Nat, 1996; Sleith et al, 2014). It prefers an optimal alkalinity of between 110-190 mg/L (Pullman and Crawford, 2010). It is predominantly found in freshwaters, but can indefinitely inhabit brackish waters with maximum salinities of 5 PSU and can survive salinity exposure of 17 PSU for around one week (Winter et al, 1991).

Flow Rate: *N.obtusa* is known to colonize still to slow moving waters with up to 0.1 m/s flow rates (Mulkerij, 1932; Schloesser et al, 1988). It is also successfully growing in areas such as the St. Lawrence River, where current and flow rates are highly variable (Gies et al, 1981, Sleith et al, 2015). Large populations of *N.obtusa* are dense enough so that water flow rates are slowed by as much as 94% compared to adjacent open water areas (Nichols et al, 1988). Their preference for slow moving waters is also reflective of their weak, pseudo-rooting structures (rhizoids) and lack of hydrochoric dispersal mechanisms.

Depth: This species shows a preference for growing in deeper water compared to other competing macrophytes and has been observed growing at depths greater than 10m. The majority of populations in the US are located within 1-7m of water (Geis et al, 1981; Kipp et al, 2016; Krause, 1985; Nichols et al, 1988; Pullman and Crawford, 2010; Simons and Nat, 1996). Light requirements for this species have been measured at between 1-50% of surface PAR (photosynthetically active radiation) (Kipp et al, 2016; Nichols et al, 1988) and suggest a low light compensation point for this species.

Bottom Composition: *N.obtusa* will colonize a wide range of substrate types, but has a preference for soft organic sediments, silts, sands and gravel.

1.6 Ecosystem Interactions

Within its invasive range in the US and Canada, ecosystem interactions with *N.obtusa* are generally negative, however, limited positive outcomes have become apparent. Its recent introduction to Ontario means that the full impacts of this species to Canadian ecosystems are not fully understood (Crowder and Painter, 1991). Pullman and Crawford (2010) state that *N.obtusa* is the most aggressive aquatic plant ever observed in Michigan, which maintains the largest distribution of this macroalgae in the US.

Once introduced into a body of water, *N.obtusa* has been shown to outcompete all other local vegetation including prodigious invasive species such as: *Myriophyllum spicatum* (Eurasian watermilfoil), *Potamogeton crispus* (curly-leaf pondweed) and *Cabomba caroliniana* (fanwort) (Pullman and Crawford, 2010). It can create vast monoculture stands and can occupy the entire water column in water depths under 2m (Pullman and Crawford, 2010), lowering the species richness of local macrophyte communities (Brainard and Schulz, 2017). Free-floating and rooted floating macrophyte species such as: *Nymphaea odorata* (white water lily), *Lemna triscula* (star duckweed), *Ceratophyllum demersum* (coontail) and *Utricularia vulgaris* (common bladderwort), appear to grow well in communities with *N.obtusa* (Pullman and Crawford, 2010), which is a common occurrence in lakes where other densely growing, highly competitive invasive plants are present (Hofstra et al, 1999; Lacoul and Freedman, 2006; Lougheed et al, 2001).

Nichols et al (1988) initially suggested that this species could be an important source of food and shelter for animals during the winter, but the full collapse of *N.obtusa* colonies during the late winter/spring generally results in lower macroinvertebrate diversity than other macrophytes. Hargeby (1990) observed significantly lower populations of the isopoda *Asellus aquaticus* and amphipoda *Gammarus lacustris* on *N.obtusa* compared to the native charophyte *Chara tomentosa*, precisely due to the collapse phenomenon. This species has however been identified as supporting high densities of the invasive mydia, *Dreissena polymorpha* (zebra mussel) ranging up to 1000 individuals/m² (Lewandowski and Ozimek, 1997; Pullman and Crawford, 2010).

Established *N.obtusa* populations cause detrimental impacts to all stages of local fish development and survival. In Michigan, *N.obtusa* has been seen to inhibit the creation of nest sites and eventually led to the complete elimination of fish spawning activity in areas colonized by this species. The shift from a diverse plant community to monoculture *N.obtusa* stands can lead to an increase in mortality for young of the year and juvenile fish (Pullman and Crawford, 2010). Adult fish are also not able to easily penetrate *N.obtusa* stands, forcing them to expend more energy in the search for prey in the open pelagic zones of the lake (Pullman and Crawford, 2010; Sass et al, 2006). Local fish species susceptible to the introduction of *N.obtusa* include: *Micropterus salmoides* (largemouth bass), *Micropterus dolomieu* (smallmouth bass), *Ambloplites rupestris* (rock bass), *Lepomis macrochirus* (bluegill), *Lepomis gibbosus* (pumpkinseed), *Percina caprodes* (log darter), *Notropis anogenus* (pugnose shiner) and *Fundulus dispar* (starhead topminnow). Perhaps the only fish species whose spawning activity is not negatively impacted by *N.obtusa* is *Lepomis microlophus* (redeer sunfish), which has been observed building nests on top of benthic *N.obtusa* mats (Pullman and Crawford, 2010).

As this species starts to decline in the water column in the late winter, its detrital biomass can become layered on the bottom substrate, similar to a benthic mat, causing a reduction in dissolved oxygen and the accumulation of phytotoxins (Pullman and Crawford, 2010), severely reducing water quality. The presence of *N.obtusa* has however been linked to increases in water clarity through the uptake of phosphorous (Hilt et al, 2010), allelopathic suppression of cyanobacteria (Berger and Schagerl, 2004) and the water filtering capacity of dense *Dreissena polymorpha* colonies which grow on the axis and branchlets of this macroalgae (Pullman and Crawford, 2010).

Within its native range, *N.obtusa* is viewed in a much more positive manner and is considered an integral part of aquatic ecosystems. In Eurasia it is used primarily as an indicator of low nutrient loading, high water clarity and favored for its allelopathic suppression of cyanobacteria (Berger and Schagerl, 2004; Goldyn, 2010; Hilt et al, 2010; Kato et al, 2014; Kasaki, 1962). Given these properties, the potential of this species to act as a water quality restoration tool has been explored in Germany and Sweden (Berger and Schagerl, 2004; Blindow et al, 2002; Hilt et al, 2010).

1.7 Limitations to *N.obtusa* Growth

Despite the prodigious growth and range expansion of *N.obtusa* in North America, this species has undergone significant decline within its native distribution in Eurasia. Populations in countries like Poland, Germany, Sweden, Japan and the United Kingdom, where it once flourished, have been designated as threatened, endangered and even extinct (GJME, 2012; Goldyn, 2010; Hunter et al, 2010; IUCN, 2016; Kato et al, 2005, 2014; Watanabe and Morita, 1977). Conversely, in other areas where *N.obtusa* was considered locally extirpated, this species has begun to appear in new bodies of water with healthy populations (Golombek, 1998; Raabe, 2006; Trapp and Kirst, 1999).

This cycle of decline and then resurgence appears to be indicative of a series of limiting growth factors within its native range combined with human-related transmission to areas previously isolated from historical *N.obtusa* colonization (Escobar et al, 2016; IUCN, 2016; Stewart, 2004). The majority of *N.obtusa* decline has been attributed to: reduced water quality through eutrophication, the conversion of fen, marsh and peatland habitats into swamp and flooded woodland and the human-related channelization of waterways and artificial manipulation of water levels and flow rates (Stewart, 2004).

It is unclear if the invasive populations of *N.obtusa* in the US and Canada will be subject to the same growth limiting factors found in Eurasia or if the same cycle of population fluctuations will also establish itself in North America. Its presence in the eutrophic-mesotrophic lakes of the Trent-Severn Waterway could suggest that the Ontario population is better suited to growing in nutrient rich waters than populations throughout Eurasia. Given its limited natural long distance dispersal mechanisms, the most important step in stopping the spread of *N.obtusa* throughout the US and Canada is to eliminate the human related transmission of this species (Escobar et al, 2016; Midwood et al, 2016; Pullman and Crawford, 2010; Sleith et al, 2015).

1.8 Management of Invasive *N.obtusa*

Management programs are ongoing throughout the US in an effort to control and attempt to eradicate *N.obtusa*. The most successful treatments have occurred using chemical and physical techniques, but full control of this species has not been established. Treatment timing has become important for *N.obtusa* due to its impacts on fish spawning habitats. Early season treatments (April-May) have been shown to promote fish spawning habitat, but have also caused increased colonization by *M.spciatum*, *P.crispus* and *C.caroliniana*. Control treatments beginning later in the season (June-onwards) do not help to expose fish spawning areas, but have been seen to increase the biomass of native macrophyte species (Pullman and Crawford, 2010).

Chemical: *N.obtusa* has been shown to be sensitive to copper and endothall based chemical treatments in its early stages of colonization – none of which are licensed for application in Ontario (Pullman and Crawford, 2010; Sturtevant et al, 2016). Once this species becomes established, however, chemical controls have been observed to only affect the topmost portion of the axis, leaving healthy tissue growing throughout the rest of the water column. The addition of chelated amine salts to algaecide mixtures has been shown to increase the effective depth of chemical treatments, but still has not provided full control (Pullman and Crawford, 2010; Sturtevant et al, 2016). Further testing is required to explore new chemical control options and application techniques.

Physical: Physical control techniques for *N.obtusa* include mechanical harvesting and manual raking. These types of control techniques have demonstrated limited efficacy due to the high biomass of *N.obtusa* and the potential spreading of *N.obtusa* fragments and bulbils, which can become dislodged during management procedures. These types of control methods typically have only short-term impacts to *N.obtusa* populations because of the extremely aggressive recolonization of treated areas by this species (Pullman and Crawford, 2010; Sturtevant et al, 2016).

Biological: There are no known biological control agents for *N.obtusa*.

Other: Alternative control procedures for *N.obtusa* include: shade enclosures, benthic mats, suction dredging and water level drawdown. The growth of *N.obtusa* has even been encouraged in some waterbodies as a control technique for *M.spicatum* populations (Pullman and Crawford, 2010), although the use of an exotic invasive species to control another is not recommended as a sound management practice.