A Decade of Starry Stonewort in Michigan:

Observations and Operational Management Considerations

1999 to 2009

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Abstract

The recent invasion of starry stonewort (*Nitellopsis obtusa*, (Desv.) J.Grove) may easily represent the greatest challenge to lake management professionals, regulators, recreation, and the biological integrity of inland lakes in the history of lake management in Michigan. The impact on plant communities and critical fishery habitats is profound. Observations from 20 lakes were compiled to offer a warning to lake managers and regulators and provide a point of discussion and future inquiry to lake managers in North America. Starry stonewort was reported in Lake St. Clair in 1974 and was probably present in Michigan inland lakes in the lake 1990's. Anecdotal evidence suggests that starry stonewort has been present in some Michigan inland lakes since the late 1990's; however, it was not positively identified until 2006. It appears that vegetative parts and oocytes can be easily moved by boat ore waterfowl and this has contributed to the rapid spread of starry stonewort to lakes throughout the Michigan lower peninsula in the past decade.

Starry stonewort appears to be easy to suppress. It does appear to be possible that selective control can be achieved and that endemic *Chara* populations can be protected.

Introduction

Starry stonewort (*Nitellopsis obtusa*, (Desv.) J.Grove) is considered to be exotic charoid species in North America. It has reportedly been present in Lake St. Clair since 1986 (Schloesser, 1986). In stark contrast to other invasive species such as the zebra mussel, starry stonewort has apparently taken nearly 30 years for it to become conspicuous in Michigan inland lakes,. Anecdotal observations suggest that it may have been present in several southeastern Michigan lakes as early as 1999, but was thought to be a “super weedy chara”. Reflection also suggests that it may have been present in some lakes where fluridone had been used to manage milfoil populations and where successful milfoil control resulted in a “chara” bloom. Unfortunately, samples were not preserved from any of these lakes. Starry stonewort was first positively identified on February 06, 2006 by G. Douglas Pullman in Lobdell Lake, Genesee County, Michigan. Since that time it has been found in Michigan lakes in the lower peninsula, ranging from Mason County to Wayne County. It is probably present in nearly every county in the Michigan lower peninsula, although this is still conjecture. The invasion and growth of stonewort has been observed in the Michigan lakes listed in Table 1.

Identification

The starry rhizoids are definitive for identification of starry stonewort. They have been observed to be present on all parts of the plant at all times of the year in Michigan Lakes, but are particularly common on the plant parts that are closest to the sediments in the late fall and early spring. It also produces conspicuous, orange colored oocytes that are easily detected by the naked eye. Starry stonewort is a light green color compared to other charoid species in Michigan when it is actively growing. It is like Nitella where the stem-like thallus is comprised of a single cell. If the thallus is broken the cellular contents can be easily expressed from the cell and leave a translucent “tube-like” cell wall. Compared to to other charoid algae in Michigan, the branching pattern of starry stonewort is more irregular giving the plant a characteristic “disheveled” look. Unlike other Michigan charoid algae, starry stonewort can grow to remarkable heights and depths. This characteristic can also aid in identification. It has been observed growing 2 meters (7’) tall at 9 m (27’) water depth in Williams Lake, Oakland County. And, it is probably capable of taller growth at even greater depths. Starry stonewort forms dense mats of vegetation that completely cover the lake bottom. When it becomes dense and overcomes most of the other vegetation in an area, it is said to “pillow” or form irregularly spaced “pillows” of dense vegetation of various heights rather than a mat of uniform height. When the growth slows or the plants decline (usually in the summer) circular openings may appear in the dense pillowed mats imparting a “swiss cheese” pattern in the pillowed mats.

Most charoid algae have a musky or garlic odor. This odor is not nearly as pronounced in starry stonewort. However, caution must be taken here because some chara species appear to be capable of co-mingling in the dense starry stonewort mats and may contribute more odor to samples that contain both plants.

Starry Stonewort Terminology

A new terminology has been developed and used by investigators and herbicide applicators in Michigan to describe the growth and development of starry stonewort communities. These terms have been useful to facilitate better communications between observers and aquatic plant control practitioners and may be found useful by others. “Pillowed” is a term used to describe the stage where starry stonewort covers nearly all of the sediments in an area and forms irregular, undulating “pillows” of biomass. This stage forms and persists into ultimate stage of starry stonewort invasion which is referred to as “packing”. The term “packing” is used to refer to a starry stonewort population that has filled all available habitat and has moved upslope and downslope into areas that do not appear to be ideal but still adequate for its growth. The term “cheesy” is used to describe starry stonewort when it appears to be dormant or is in decline. Holes open in the starry stonewort mats that resemble the hole patter in swiss cheese. “Hair Cut Treatments” is a term used to refer to algaecide treatments that reduce the height of the starry stonewort mats without eliminating all starry stonewort biomass in a treatment area. The reasons that this is used are described below.

Biology

Starry stonewort is thought to be native to Europe and is classified as endangered in the U.K. The U.K. biodiversity Action Plan www.ukbap.org.uk/UKPlans.aspx?ID=474 describes starry stonewort as a plant that prefers deeper, less turbulent water, and as becoming increasingly rare. The starry stonewort observed in Michigan Lakes also appears to thrive in deeper water, but will also thrive in shallow water where it will grow at the water surface. It does not appear to grow well in boat lanes and high energy shorelines which is consistent withe the European description of being relatively intolerant of mechanical disturbance or turbulence. It will; however, grow in boat lanes when it has colonized or filled virtually all of the habitable area of the lake. It appears grow well in a wide range of Michigan Lake types including clearwater and dark water systems. It will colonize highly organic, unconsolidated sediments and sands and gravel. It seemingly shows no preference for shade or full sun. The lakes from which these observations were made are not routinely monitored for water hardness, but are typical hard-water Michigan lakes where calcium carbonate alkalinity ranges from 110 to 190 mg/L as CaCo3. Total phosphorus concentrations in infested lakes run from below 10 ppb to 80 ppb (Tipsico Lake, Oakland County).

The U.K. biodiversity Action Plan www.ukbap.org.uk/UKPlans.aspx?ID=474 describes starry stonewort as an annual plant that that may overwinter mild winters. Contrastingly, the starry stonewort in Michigan appears to thrive in the cooler waters of fall, winter, and spring and become dormant or less active during the hottest part of the summer. However, extremely active, nuisance level production and growth has been observed in Indianwood (2007 and 2008), Lower Straits (2008), Sears (2008) and Williams (2006, 2007, and 2008) Lakes during the hot summer months which required management attention.

It is common to observe the collapse or regression of opportunistic, non-endemic aquatic macrophyte species in Michigan Lakes. Collapse and regression also appear to be part of the production patterns observed in starry stonewort. For unknown reasons, starry stonewort was observed to be growing aggressively in many Michigan inland lakes in the early summer of 2009 (ex. Indianwood, parts of Lobdell Lake); however, it appeared to be dormant in others (ex. Whitmore). Conditions were cool all summer in 2009 and rapid growth was anticipated; but, highly invasive growth did not occur in many lakes until October. It appears that growth patterns Starry stonewort appears to be so sensitive to aquatic pesticides that some of the lower production levels observed in 2009 may have related to plant control efforts that were specifically focus on herbicide tolerant nuisance plant populations.

Starry stonewort appears to spread rapidly from lake to lake. It produces oocytes, as do other charoid algae, and these structures would appear to be easily transported on bird feathers or the fur of aquatic animals. They could also be easily transported in aquatic plant debris that may be caught on boat trailers. Often, the presence of public launch sites are associated with the early invasion of alien aquatic plants; however, starry stonewort has quickly become established in many lakes that have not public access. The role of water fowl in the dissemination of starry stonewort could be very significant.

Starry stonewort is also easily fragmented and these fragments could seemingly act as disseminules that could be important in the spread of the plant within a lake and from lake to lake. Boat traffic can cause significant fragmentation of starry stonewort which can float on the water surface and create nuisance conditions on leeward shorelines. This type of fragmentation has been implicated in the dissemination of other alien species in Michigan such as the invasive milfoils (Eurasian and hybrids).

Plant Community Interactions

Starry stonewort has been observed to invade the nearshore areas of Michigan Lakes at water depths ranging from approximately 0.5m to 1.5m (2' to 4') deep and then spread downslope and upslope from that point in the lake. This seems to be the typical invasion patter, but it may have colonized deeper areas of lakes and not have been observed. It is the most aggressive aquatic plant ever observed in Michigan and is able to outcompete all other Michigan plant species, including all invasive species and current alien species such as watermilfoil, fanwort, and curly leaf pondweed. A precipitous decline in biodiversity index values was expected in LakeScan Monitored Lakes, but this has not always been observed. Individual competing plants, such as milfoil or pondweed plant may still be found within the Bio-Assessment Site (BAS). It is not uncommon to see a single errant plant, growing in the depressions between the pillowed patches of starry stonewort biomass. Biodiversity values would be expected to decline if BASs were smaller and provided greater resolution; however, these resolutions are impractical and too costly for the administrative bodies that fund these studies. Even though there may not be a numerical decline in biodiversity values in an infested lake, there is a shift to lower lake wide mean density and distribution pattern values from high density to lower ("d and c" to "c or b") densities and from patch distributions to scattered single plant distributions. It is extremely obvious in all of the infested lakes that the biomass of competing species has declined significantly in every lake where starry stonewort has spread and come to dominate the lake flora. This would certainly have been reflected in biomass estimates however these values were not compiled for any of the lakes upon which these observations have been made.

An interesting observation is made when starry stonewort has been eliminated from an area where the plant covered the bottom sediments for more than a year. The dark sediments appeared to have become phytotoxic and were not recolonized as quickly as might be expected. It appears that starry stonewort can act like a commercial benthic barrier that contributes to the accumulation of phytotoxins, such as volatile fatty acids (VFA's), and render the sediments inhospitable for plant growth until the conditions change, redox potentials increase, and VFA's are oxidized or diffuse from the sediments. There would be certain obvious benefits to the rootless starry stonewort when redox potentials are suppressed and nutrients are released from the sediments. Interestingly, certain plant species seem to thrive in the presence of starry stonewort. The apparent impact benthic barrier impacts on sediment chemistry may be the reason that the rootless bladderworts and coontail can thrive in starry stonewort infested lakes. These plants would not have to cope with low redox concentrations and associated bio-geochemical factors that would sour the rhizosphere; but they may still benefit from the release of nutrients from the sediments. Common bladderwort (Utricularia vulgaris), reached near nuisance levels in Indianwood Lake in 2008 and 2009. Water lilies seem to be able to compete effectively or are not apparently diminished by starry stonewort until the starry stonewort occupies the water surface and this is believed to be attributable to the efficiency of the internal ventilation system (Dacy, 1981). Once starry stonewort begins to grow at the water surface, water lilies appear to be excluded from the infested area but the impact appears to be as much a physical/space competition factor as anything else.

The impact of starry stonewort visual impact and the influence on the submersed flora of Michigan lakes cannot be underestimated. But, these impacts are not confined to the macroflora. Starry stonewort also appears to have a dramatic direct and indirect impact on water clarity. The water clarity in lakes infested with starry stonewort appears to increases dramatically with increasing domination of the benthic community. Indirectly, starry stonewort appears to be a favored substrate for zebra mussel and the filtering impact of zebra mussel and affect on water clarity is well known (Macisaac et al, 1995). It is also possible that the upper parts of the dense plant mats compete effectively with phytoplankton for nutrient resources. And, there is speculation that charoid algae are capable of producing allelopathic compounds (Forsberg, et al, 1990; Berger and Schagerl, 2003; Mulderij, et al, 2003; Mulderij, et al, 2007).

Critical Fish Habitat Impacts

The impact on critical fish habitats which include spawning, nursery and refuge habitat is profound. Black basses and sunfish species are the most targeted gamefish species in the majority of Michigan inland lakes. LakeScan surveys and analysis in numerous lakes several years in succession confirm (Stevenson et.al, 1969) that bottom substrate consisting of some combination of clean sand and gravel are the preferred for nest creation and spawning activity. These surveys also revealed that these "nesting sites" are highly conserved much like the spawning grounds of anadromous and potadromous fish species. The fact that bass and sunfish species preferentially select traditional spawning sites within a lake, irrespective of the availability of suitable habitat at other locations (often near by), has heightened the importance of these areas to with respect to sustainability of resident fish populations. It also sets the framework for a discussion of the impacts to fisheries by starry stonewort.

Starry stonewort directly impacts spawning habitat by the formation of a thick mat that serves as a physical barrier effectively impeding access to substrates for nest creation resulting in 1) reduction in nesting area and density of nests and 2) complete elimination of spawning activity in the area of infestation. In lakes supporting a mature and / or expanding infestation of starry stonewort spawning fish must compete for remaining spawning habitat in areas that are suboptimal for spawning. This increased competition may increase stress related to reproductive activities resulting in spring fish kills in a small lake with excessive growth of starry stonewort (Softwater Lake, Oakland County, Michigan). It is also likely that increased mortality through predation on eggs and fry by young bluegill may also occur (Smith and Crumpton 1977). Encroachment on traditional spawning habitat can occur very rapidly and typically requires ice scour or mechanical removal to provide access to bottom substrates. In areas where these mechanisms are not in operation traditional spawning areas are lost. An attempt was made to clear known traditional nesting sites with chemical controls during the spawning season in Big Lake, Oakland County, Michigan in 2008. The chosen area was successfully cleared and spawning activities began; however, starry stonewort re-colonization of the cleared area occurred so rapidly that a successful spawn was not completed. It appeared that a much larger area needed to be cleared to provide adequate protection of the spawning substrate, but the total area that would be necessary for improvement was not determined. Michigan riparians inadvertently maintained a traditional nesting sites, free of starry stonewort, in both Williams Lake and Lake Waumegah, Oakland County, using labor intensive mechanical methods or weed rollers. Although the removal of starry stonewort was done to support swimming and boating activities, a high degree of utilization by spawning sunfish was observed. Spawning was minimal or absent in areas immediately adjacent to the clearings. Both bass and sunfish will spawn readily in areas containing dense growths of native chara, in comparison, areas in close proximity but dominated by starry stonewort of relatively equal density did not exhibit spawning activity. We are unsure why this occurs.

Observations of spawning bass and large sunfish indicate a tendency to segregate reproduction activity away from small sunfish, nesting in deeper water or offshore areas when large numbers of small sunfish are present. This may be in response to high levels of predation related mortality one year old bluegill can inflict on eggs and fry of both bluegill and bass (Gray, Breck and Webb 1998; Barwick and Holcomb 1976; Smith and Crumpton 1977). Unfortunately, this behavior may make bass and large sunfish more susceptible to starry stonewort impacts as mats tend to be uniformly thicker in deep water. In many lakes these habitats are the first to be lost.

Though concern for gamefish is has been voiced by riparians on infested lakes there is also concern for biodiversity of lake fauna such as native fish species including logperch, darters and various minnow species, native clams and invertebrates whose intimate association with the lake bottom is absolutely necessary for survival.

In 2009, LakeScan critical fishery habitat survey was conducted in Whitmore Lake, Washtenaw County, Michigan. During the survey, redear sunfish (*Lepomis microlophus*) were observed nesting on a newly developing mat of starry stonewort that had covered a traditional nesting site. This species is not native to Michigan but has become naturalized through public and private stocking efforts. A closer inspection revealed that the nests were absent of sand and gravel and starry stonewort had been pressed down within the spawning depressions. The sunfish demonstrated the territoriality and nest guarding behavior associated with active reproduction. Redear sunfish were observed utilizing both sand gravel habitats in other traditional spawning sites within the lake. Rock bass, smallmouth bass, largemouth bass, bluegill and pumpkinseed sunfish nests were observed during the survey but these species completely avoided starry stonewort preferring sand gravel complexes as spawning substrate. It appears that redear sunfish will not be greatly impacted in by starry stonewort during early stages of infestation.

Critical nursery habitat consists of areas that provide optimum conditions for growth and safety for fry and juveniles of a myriad of fish species. These areas exhibit a high degree of vertical structural complexity in the form of vegetation and/or drowned timber that provide niche habitat for feeding and refuge from larger predators. In temperate lakes shallow areas provide warmer temperatures for increased metabolic rates and rapid growth. Starry stoneworts' mat forming growth habit reduces structural complexity by physically and possibly chemically preventing the growth of aquatic macrophytes. Observations in nursery habitat areas overtime show a gradual decrease in stem density and number of plants as starry stonewort prohibits growth of pondweeds, milfoils and water lilies. Elimination and reduction of niche habitat may result in increased mortality of young-of-the-year and juvenile fish species of both native and non native species. Rare and imperiled fish species such as the pugnose shiner (*Notropis anogenus*) and starhead topminnow (*Fundulus dispar*) are at particular risk due to the fact that robust stands of aquatic vegetation are critical to its survival (Becker, G. C., 1983).

Anecdotal reports of a decrease in quality of the angling experience have increased among resident anglers of lakes exhibiting mature and extensive infestations of starry stonewort. Experienced resident anglers can have an intimate knowledge of structure supporting certain fish species and the distribution of fish within a lake during a specific time of year. Physical structure including weed beds, shoals and stumps are what experienced anglers target because they are known to attract or "hold fish". Reports of angler frustration such as an inability being able to locate black crappies because the stumps have disappeared beneath the mat of starry stonewort or that bass are more difficult to catch because of the disappearance of certain weed beds are becoming more commonplace in our lake management practice. Loss of woody habitat complexity results in a change in distribution and decrease in condition of largemouth bass as a result of a change in predatory strategy from the more efficient sit and ambush strategy to the less chase strategy within the pelagic zone (Sass et al. 2006)). Bass also shift from a prey base dominated by aquatic organisms to a prey base dominated by terrestrial organisms which may result in a decrease physical condition (Sass et al. 2006). Critical woody habitat is often rare in developed lakes and primarily consists of sunken snags or stumps. The rate of natural addition of new woody structure is also low because of fewer trees along the shoreline of a developed lake. Loss of this critical habitat to starry stonewort encroachment represents a serious threat to a valuable form habitat already in short supply.

Indirect impacts to fish populations that occur as a result of changes to lake ecology are not yet understood and remain viable opportunities for study. A fully developed starry stonewort infestation can result in a tremendous increase to the total of vegetal biomass present in a lake. It is not unreasonable to conclude that such a massive increase in vegetative biomass by a single species likely to impact the nutrient and carbon pathways associated with phytoplankton production. The potential shift of primary productivity from the water column to the starry stonewort dominated benthos could have a significant impact on zooplankton and fish populations and total secondary production. It is thought that zebra mussels may have a similar impact as they decrease the availability phytoplankton to zooplankton, however, findings of impact on zooplankton communities and fish have been mixed (MacIsaac et al. 1995, Pace, M.L., S.E.G. Findlay, and D. Fischer, 1998, Idrisi et al. 2001). Potential differences between starry stonewort and zebra mussel impact on lake primary productivity is that while zebra mussels physically filter and concentrate phytoplankton production and resources in the benthic community, starry stonewort appears to compete directly with phytoplankton for the nutrients and carbon necessary for phytoplankton production. The association between starry stonewort and zebra mussels has be positively correlated and profound in all lakes where they have been observed. More than 2000 individual zebra mussels $^{m\,-2}$ were found on Chara spp. and 1000 $^{m\,-2}$ on starry stonewort in a Polish Lake(Lewandowski and Ozimek 1997). The combined effect of zebra mussels and starry stonewort on primary and, secondary production should not be underestimated and warrants research.

Starry Stonewort Management

Starry stonewort appears to be highly sensitive to common copper and endothall based algaecides and appears to be even more susceptible than most common Michigan charoid species. The application rates recommended for chara control on the US EPA Approved Pesticide labels appear to be sufficient to control low-growing starry stonewort. Problems can arise when starry stonewort mats become tall. The algaecide application rates that are normally used in chara control operations usually cause impacts on only the upper surface of the starry stonewort mats. It seems logical that the higher levels of biomass found in dense starry stonewort communities require higher concentrations of active ingredients, and it appears that the active ingredients are sequestered in the upper portions of the starry stonewort mats and the lower portions of the mats are not injured. Injury can be caused at greater depths in the starry stonewort mat when chelated agents are used, the amine salt of endothall (Hydrothol 191, United Phosphorus, Inc., King of Prussia, PA) is added as an adjuvant or other adjuvants are added to the algaecide mixture. Challenge testing is being performed in laboratory studies at Clemson University as of this writing, and operational results are being analyzed to develop more effective control strategies.

Field data collected in 2009 also suggests that starry stonewort may be susceptible to a broader range of aquatic herbicides than was considered in previous years. There was a significant decline in the percent occurrence of starry stonewort as observed in biological observation sites in any lakes in 2009 as an apparent result of nuisance plant control efforts that were focused on herbicide tolerant aquatic angiosperms (Bass, Cedar, Lobdell, Sanford, White, Whitmore). These management efforts included mixtures of herbicides that included a product known as Cutrine Ultra (Applied Biochemists, Germantown, WI). Cutrine Ultra, combined with other herbicides appeared to be the factor that has resulted in the consistent suppression of starry stonewort. The total area covered by starry stonewort did not increase in Stony Lake where no herbicides or harvesting have been used; however, other plant species appeared to have reached the surface of the water before starry stonewort began to enter it’s exponential growth phase. Consequently, it appears that starry stonewort may have succumbed to shading in that singular lake.

Mechanical harvesting was used for the control of starry stonewort in Indianwood Lake and has been used for the control of other nuisance plant growth in some of the other lakes that are inhabited by starry stonewort. The amount of biomass produced by starry stonewort in a relatively small area can very quickly fill a mechanical harvesting machine to capacity and cause harvesting operations to be very slow relative to the harvesting of other nuisance vascular plant species. The "sponge" like mats of starry stonewort are also prone to roll down the forward conveyor of some harvesting machines making it difficult to pick the cut plants off of the surface of the water. Starry stonewort appeared to grow faster than and and all competing plants in the harvested areas of Indianwood Lake and shifted the plant community to a mono-culture of starry stonewort in 2007. The resulting outcome was inconsistent with the lake management goals for that lake and harvesting operations were suspended in 2008. The use of algaecides provided far better control, more quickly, and with less ecosystem disturbance. Depending upon the timing of the treatment, milfoil, a pondweed hybrid, naiad, and sago pondweed seemed to be able to colonize areas where the starry stonewort had been removed with algaecides.

The ability to control only the upper biomass of starry stonewort mats presents some interesting aquatic plant management opportunities. Many of the lakes where starry stonewort has been found have historically been challenged by the spread, proliferation, and domination of milfoil species and hybrids. Starry stonewort is a superior competitor and will eliminate nuisance milfoil growth from the deeper parts of some lakes. And, if the water is clear starry stonewort will not grow as tall in the water column. Riparian property owners, recreational water users, and some lake managers have been very pleased with this outcome. If starry stonewort grows taller, the height of the starry stonewort can be reduced with low level algaecide treatments. This is referred to as a "hair cut treatment" and is used to suppress plants like milfoil and still keep boat lanes open. The wisdom of such a treatment strategy may be debatable, but the utility of the approach has been very effective.

The timing of starry stonewort treatment is also worthy of consideration. Early treatment may be necessary, as stated above [see Gary's discussion] to open spawning habitats. However, early treatment may open large areas of the lake bottom to colonization by early growing season species such as milfoil, milfoil hybrids, curly leaf pondweed, fanwort, or other highly undesirable invasive species in Michigan. If treatment is delayed to late June, the adverse impacts on these early growing invasive species may be exaggerated. Presumably, some of the more desirable pondweed species may benefit from the suppression of these vascular invasive species and then creation of habitat when the starry stonewort is removed late in June. This strategy is only one of several that is being considered and evaluated in Michigan.

Concerns and Questions

Starry stonewort may be the greatest challenge that has ever faced lake management professionals and lake user groups in Michigan. The impact on Michigan fisheries could be profound. Although it is relatively easy to control, management strategies need to be fine tuned to be more effective and useful.

There are may questions that need to be answered or investigated to gain a better understanding of the biology and threat to midwestern and North American Lakes that is posed by the spread of the starry stonewort in Michigan. The following points are offered for discussion and to possibly guide researchers.

1. BASIC BIOLOGY: The biology of starry stonewort is very different in Michigan, where it is a hardy and aggressive opportunist, and Europe, where it is a threatened species. It also seems peculiar that starry stonewort inhabited Lake St. Clair for nearly 30 years before it became conspicuous in inland lakes and then to have spread so rapidly throughout the lower peninsula of Michigan. This suggests that the starry stonewort that is now found commonly in Michigan inland lakes is a particular genotype or even a hybrid that is distinct from the starry stonewort found in Europe and perhaps other parts of North America. Starry stonewort genotyping may be very useful to understand why starry stonewort suddenly became so invasive in Michigan and to determine if the invasive genotypes are common in other parts of North America. These data are critical to develop risk statements.

2. EPIPHYTE AND AWFUCH COMMUNITY INTERACTIONS: A strong association has been found between starry stonewort and zebra mussel. It appears that starry stonewort is a

preferred substrate for the attachment of these filter feeders. There is evidence from the great lakes that cladophorales algae benefit from being in close proximity to the pseudofeces of zebra mussels which are able to supply necessary plant nutrients. It is very possible that zebra mussels provide these same benefits to starry stonewort and help to support the growth of cells in the upper part of the starry stonewort pillows that may be several feet above the nutrient reserves contained in the sediments. The interaction between starry stonewort and mussels should be investigated.

The awfuchs community that colonizes the surface of starry stonewort has not been investigated. This community could also be key to the successful upward growth of starry stonewort, as it is known that epiphytic cyanobacteria are known to fix nitrogen on charoid algae in rice paddies (Ariosa, et al., 2004). Manipulation of these communities may help to regulate upward growth of starry stonewort pillows and mats.

3. BASIC WATER QUALITY: Starry stonewort appears to have a profound impact on water clarity in Michigan Lakes. The dense mats of starry stonewort stabilize lake sediments and may contribute to lower concentrations of suspended solids when the mats of vegetation become tall and cause water to become more quiescent. Direct and indirect competition with phytoplankton is certainly sigificicant. The impact of starry stonewort on the inorganic and nutrient chemistry of lakes has not been directly addressed. It is likely that starry stonewort is having a profound impact on the limitation of plant nutrients necessary to support beneficial or desirable phytoplankton communities. Phosphorus may limit essential and desirable plankton community production is starry stonewort lakes. This may have a similarly profound impact on watershed management plans.

4. PLANT COMMUNITY DIVERSITY: The impact of starry stonewort on plant community richness and biodiversity has been obvious. Some plants, such as bladderworts and coontail appear to be benefited by starry stonewort infestations. Other rooted species are suppressed. However, long-term information is not available to determine how other benthic maacrophytes will compete with starry stonewort. Sediment impacts will probably be a key factor in these determinations.

5. SEDIMENT IMPACTS: It appears that starry stonewort can have a dramatic impact on sediment bio-geochemistry. However, these observations are still anecdotal and sediment testing, below starry stonewort mats may reveal impacts that would be useful to resource managers, especially in regard to the timing of control efforts and predicting the recovery of areas formerly inhabited by the plant. The impact on redox potentials, the availability of suitable electron acceptors for the terminal stages of sediment diagenesis (breakdown), and the accumulation of phytotoxic volatile fatty acids that certainly accumulate below dense starry stonewort mats would be another area of keen investigation in regard to understanding the recolonization of areas by rooted vascular plants that may have previously been dominated by starry stonewort.

6. IMPACTS ON PRIMARY PRODUCTION: Resource competition and allelopathy have both been implicated as ways that charoid algae may have an impact on phytoplankton populations (Forsberg, et al., 1990; Mulderij, et al., 2003; and Mulderij, et al., 2007). There is evidence that charoid algae can serve as a nutrient sink, by a wide variety of mechanisms, and thereby limit primary production though resource deprivation (Kufel and Kufel, 2002, Bindlow, et al., 2004). Frequent testing for total phosphorus, total nitrogen, and free carbon dioxide at different times of the day may reveal why the water is so clear in starry stonewort dominated systems. The production, presence, and function of starry stonewort allelopathic compounds would be difficult to investigate, but needs to be considered because of the implications for fishery production.

   It appears that starry stonewort has a negative impact on planktonic primary productivity based on water clarity; however, the impacts on the richness and diversity of phytoplankton communities may be even more profound. Blue green algae blooms have been observed in some lakes that are dominated by starry stonewort (Williams Lake, Lobdell Lake, Indianwood Lake) and this needs to be investigated in greater detail to determine if starry stonewort can be a controlling factor in the specific composition of phytoplankton communities. The association of starry stonewort with zebra mussel may also be a determining factor.

7. IMPACTS ON SECONDARY PRODUCTION: The changes observed in the phytoplankton communities in lakes that have been recently dominated by starry stonewort have been obvious. Less obvious is the impact on the invertebrate communities. It is reasonable to expect a shift in zooplankton species from those associated with pelagial habitats to species associated with littoral habitats. It appears that zebra mussel populations may be positively correlated with increasing starry stonewort biomass. And, the expected impact on benthic invertebrates must be profound. These factors need to be investigated to better understand the impact of starry stonewort infestations on public health (production of blue green algae phytotoxins) and fisheries production.

8. IMPACTS ON FISHERIES: The impact of starry stonewort on bottom spawning fish and those that depend on diverse plant communities is intuitively obvious in starry stonewort dominated lakes. Some of the questions that we have considered are: Are temperate lakes that support extensive and mature infestations of starry stonewort more vulnerable to winter kill if large amounts of biomass are carried over into times of the year where there is ice cover? How do increases in water clarity and possible reductions in dissolved organic carbon effect the selection of spawning habitat by yellow perch in lakes? Do redear sunfish nests yield the same number of swim up fry in starry stonewort and sand gravel complexes? How much critical spawning and nursery habitat is enough to support viable fish populations in inland lakes? Is angler dissatisfaction in starry stonewort lakes linked to density, condition or distribution of fish? These answers to these question is critical to reveal better ways to manage starry stonewort populations and protect fishery production and quality.

9. STARRY STONEWORT MANAGEMENT: Although there seem to be a myriad of ways to control starry stonewort, better ways could be developed to control its growth with lower concentrations of active ingredients. The timing of control operations is likely to have a significant impact on the subsequent decolonization of areas where where starry stonewort was once the dominant macrophyte due to the impact of dense starry stonewort mats on sediment biogeochemistry. Better estimates of the rate of starry stonewort encroachment

on areas that have been cleared for restoration of spawning habitats need to be made to calculate how large an area must be managed to protect these resources.

10. STARRY STONEWORT PRODUCTION: The biology of starry stonewort has at times been confusing. The populations in some lakes seem to exhibit slow growth or may even decline in the hot summer months while continued growth has continued in other lakes. This greatly complicates management programs and plans. The differences in the populations may be genetic or may be determined by other factors. Does the appearance of open pockets (cheesey effect) suggest that starry stonewort mats may collapse soon? When with the exponential growth phase of starry stonewort begin so that management efforts can be better timed? These considerations and the differences observed in different lakes need to be investigated to improve management practices.

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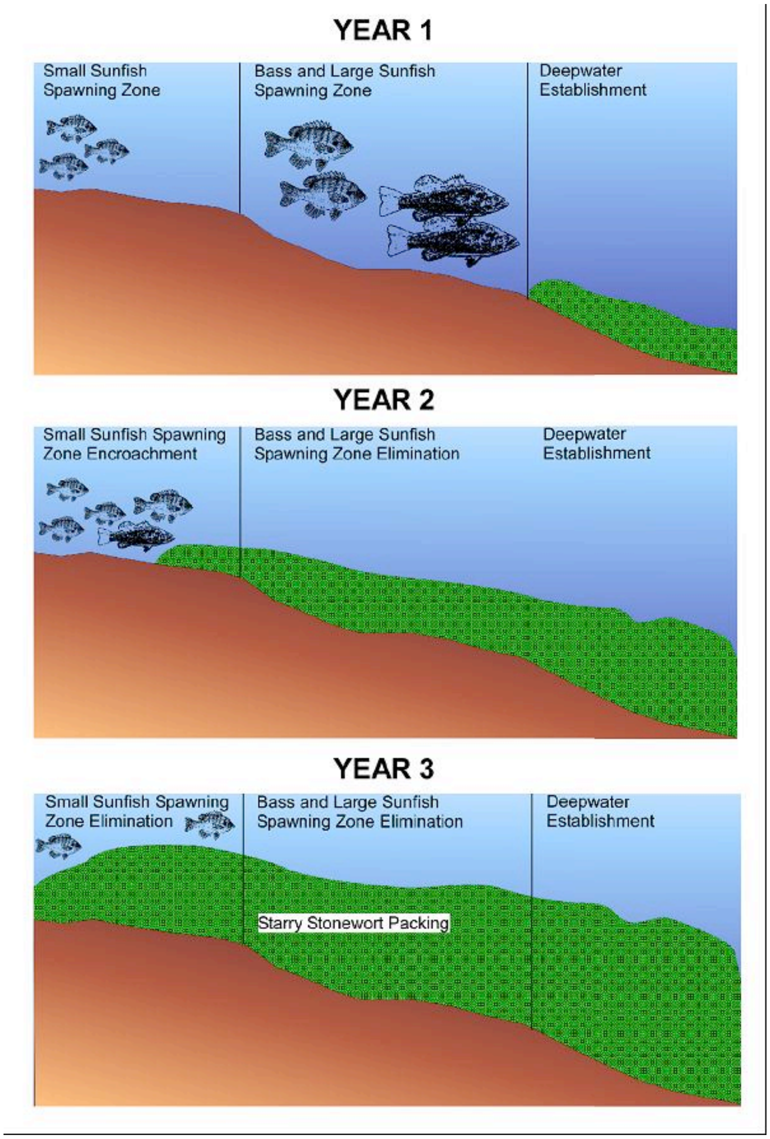
			Occurrence as Observed in the Maximum Number of BOS			
Lake Name	**County**	**Date of First Observation**	**2006**	**2007**	**2008**	**2009**
Lobdell Lake	Genesee and Livingston	February, 2006	88%	97%	92%	
Indianwood	Oakland	July, 2006		93%	100%	100%
Sears	Oakland	July, 2006	n/a	n/a	n/a	n/a
Softwater	Oakland	July, 2006	n/a	n/a	n/a	n/a
Lower Straits	Oakland	June, 2006	n/d	n/d	11%	
Pleiness	Mason	June, 2006	n/a	n/a	n/a	n/a
Sears	Oakland	June, 2006	n/a	n/a	n/a	n/a
Whitmore	Livingston and Washtenaw	June, 2006	7%	40%	26%	18%
Williams	Oakland	June, 2006	70%	68%	78%	
Cedar	Alcona and Oscoda	June, 2007	n/d	65%	33%	0%
Iron	Washtenaw	June, 2007	n/a	n/a	n/a	n/a
Joslin	Washtenaw	June, 2007		n/a	n/a	27%
Kent	Oakland	June, 2007	n/d	4%	35%	50%
North	Washtenaw	June, 2007	n/a	n/a	n/a	n/a
Ogemaw	Ogemaw	June, 2007	n/d	74%	10%	3%
Sanford	Midland	June, 2007	n/a	n/a	11%	0%
Waumegah	Oakland	June, 2007	n/a	n/a	n/a	n/a
Millecoquin	Mackinac	August, 2007	n/a	n/a	n/a	n/a
Bass	Mason	June, 2008	n/d	n/d	6%	0%
Stony	Macomb	June, 2008	n/d	n/d	23%	5%
Tipsico	Oakland	June, 2008	n/d	n/d	53%	
Wamplers	Lenawee	June, 2008	n/a	n/a	n/a	n/a
Big	Oakland	May, 2006	n/d	n/d	47%	
Tamarack	Montcalm	October, 2006	n/a	65%	72%	1%
Townline	Montcalm	October, 2007	n/d	n/d	87%	
White	Oakland	September, 2007		n/a	75%	67%


YEAR 1
Small Sunfish Spawning Zone
Bass and Large Sunfish Spawning Zone
Deepwater Establishment
YEAR 2
Small Sunfish Spawning Zone Encroachment
Bass and Large Sunfish Spawning Zone Elimination
Deepwater Establishment
YEAR 3
Small Sunfish Spawning Zone Elimination
Bass and Large Sunfish Spawning Zone Elimination
Deepwater Establishment
Starry Stonewort Packing

Starry Stonewort - *Nitellopsis Obtusa*