Starry Stonewort:
An Aggressive Invasive Freshwater Macroalga

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Introduction

Starry stonewort (*Nitellopsis obtusa*) is a Eurasian macroalga that was first recorded in the 1970s in the St. Lawrence River near Montreal, Quebec, Canada. This aggressive invasive species has since become widespread in the Laurentian Great Lakes Region, particularly in many inland lakes that are used for recreational activities. Rapidly growing during summer, starry stonewort can outcompete most native macrophyte species, and even other aggressive invaders such as Eurasian watermilfoil (*Myriophyllum spicatum*). Because of its ecological and morphological similarities to native charophytes, such as muskgrass (*Chara* spp.), and other stonewort / brittleworts (e.g., *Nitella* spp., *Tolypella* spp.), starry stonewort is difficult to identify and is poorly reported, which has likely enabled it to spread through the Great Lakes Region.

Starry stonewort was featured in a previous *LakeLine* article by Pullman and Crawford (2010); however, much has changed in the years since. Research has been undertaken into the ecology and management of this invasive species, and there are now targeted efforts toward reporting, tracking, and preventing the spread of starry stonewort. Here we present our experiences with understanding the ecology and predicting the spread of this invasive species in south-central Ontario, Canada, which are no doubt similar to other experiences and management efforts across the invaded range.

Experiences in Ontario

Currently, in south-central Ontario, Canada, starry stonewort has been mostly found along the Trent-Severn Waterway (TSW) (Figure 1a), a canal system connecting Lake Ontario to Georgian Bay in Lake Huron. Completed in the 1920s as a transportation corridor, but now mainly used by recreational boaters, this canal system has enabled the spread of many invasive species between lakes including zebra and quagga mussels (*Dreissena* spp.), Eurasian watermilfoil, round goby (*Neogobius melanostomus*), and spiny waterflea (*Bythotrephes longimanus*).

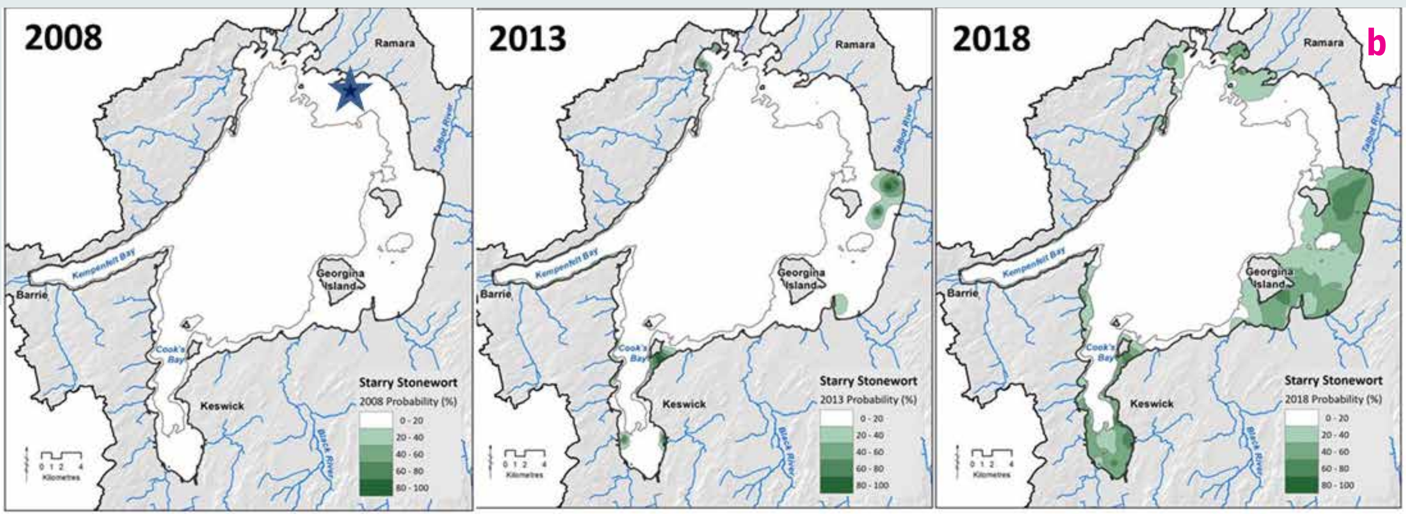
The first reports of starry stonewort in Ontario were a "weedy chara" reported in 2009 at a Presqu'ile Bay marina near Brighton, on Lake Ontario, at the eastern terminus of the TSW. In Lake Simcoe, bulbils were recovered in a benthos sample in 2009 and in 2010 a marina experienced a large increase of a "tangled weedy plant" following application of the herbicide diquat, used to control Eurasian watermilfoil. In the years since, the Lake Simcoe Region Conservation Authority's aquatic plant monitoring program tracked the expansion of starry stonewort across Lake Simcoe (Figure 1b, Ginn et al. 2021). From our initial record in 2009, starry stonewort increased to 33 percent of total lakewide aquatic plant biomass in 2013 and 67 percent in 2018.

In 2015, starry stonewort was identified by the Scugog Lake Stewards in Lake Scugog, a large, but shallow reservoir that is a major headwater of the TSW. For decades, the aquatic plant community was dominated by Eurasian watermilfoil for most of the growing season, however, a severe population collapse of Eurasian watermilfoil was documented (Harrow-Lyle and Kirkwood 2022) following starry stonewort establishment. The rapid increase in the amount of starry stonewort in these and other locations highlights the aggressive nature of this invader, particularly at the expense of Eurasian watermilfoil, another invasive considered to be equally aggressive in some locations.

Similar to other aquatic macrophytes, starry stonewort populations have proven to be dynamic over the monitoring period. In 2019, starry stonewort was 68 percent of the aquatic plant biomass (Figure 2) in Cook's Bay, a shallow (maximum depth 15 m) nutrient-enriched embayment at the south end of Lake Simcoe where it was first recorded in 2011. During the 2020 aquatic plant survey in Lake Simcoe, a large (~79 percent) decrease in starry stonewort was recorded, with similar phenomena anecdotally reported in Lake Scugog and in some smaller adjacent lakes along the TSW.

The cause of this population decrease, which continued into 2021, is currently being investigated. Harrow-Lyle and Kirkwood (2022) have previously determined that lake depth and cation (calcium, potassium, sodium, and magnesium) concentrations are important drivers of starry stonewort distribution. However, since there were no significant differences in environmental variables in either Lake Scugog or Lake Simcoe in 2020-21 relative to previous years, the cause of the recent declines are likely related to unique regional conditions that occurred during this time period. In 2022, the amount of starry stonewort increased in Lake Simcoe, an increase that occurred alongside the existing aquatic plant biomass, instead of outcompeting other species as in the past (Figure 3). Similarly, the biomass of starry stonewort increased in the shallow (average depth of 1.4 m) western basin of Lake Scugog. In contrast, the eastern basin of Lake Scugog (average depth of 7.6 m), had very little starry stonewort biomass in comparison to other years, and was almost exclusively composed of native stoneworts.

Figure 1. (a, at left) map of south-central Ontario showing the location of the Trent-Severn Waterway (blue line), (b, below) map of Lake Simcoe showing expansion of starry stonewort from 2008-2018, star denotes site of first bulbil recovery (b is re-drawn and modified from Ginn et al. 2021).



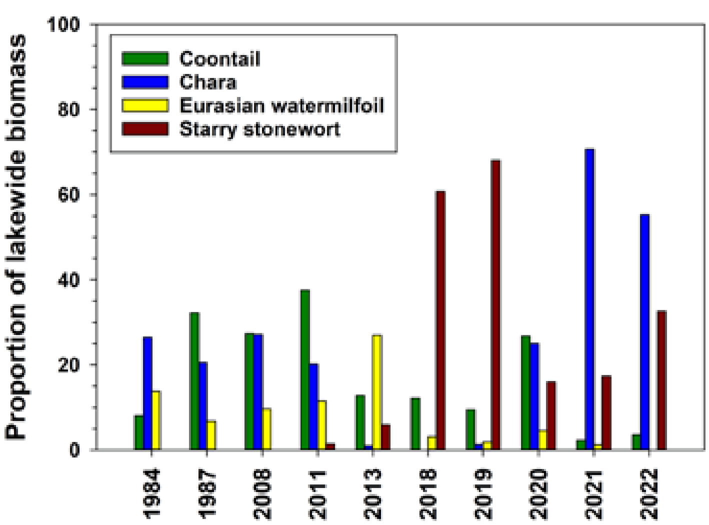


Figure 2. Proportion total aquatic plants that was starry stonewort in Cook's Bay, Lake Simcoe, 1984-2022.

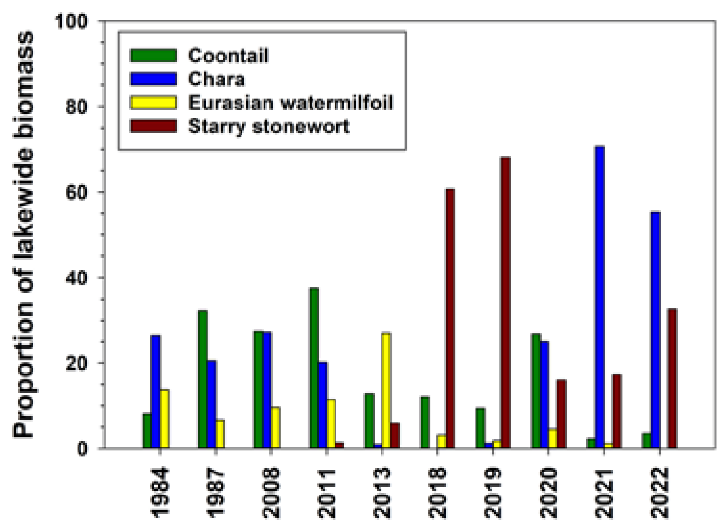


Figure 3. Proportion of aquatic plant community in the four most common species in Cook's Bay, Lake Simcoe 1984-2022.

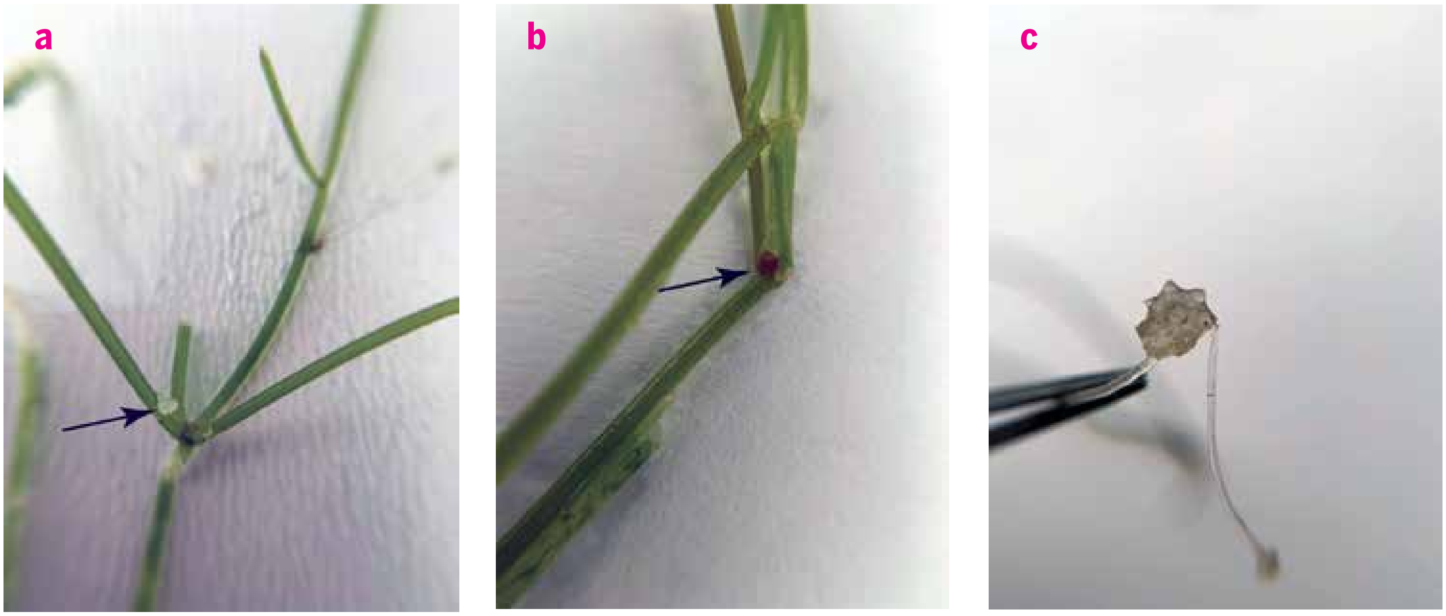


Figure 4. Reproduction structures recorded from starry stonewort in Lake Simcoe and Lake Scugog: (a) female oogonia, (b) male antheridia, and (c) bulbil attached to rhizoid.

In addition to the rebound of starry stonewort in 2022, we recorded the first instances of female reproductive structures (oogonia; Figure 4a) on starry stonewort in Lake Simcoe and Lake Scugog (Harrow-Lyle et al. 2023). Up until then, only male individuals of starry stonewort, identified by the presence of orange spherical gametangia (Figure 4b) had been reported in North America, and reproduction was thought to be through vegetative means, such as fragmentation and bulbils (Figure 4c). The explanation for this sudden occurrence of female individuals is interesting and more research is required. Likely scenarios include an environmental trigger such as changing climate conditions and longer growing seasons, or possibly as a response to the population decline during the two previous years.

Future expansion in Ontario

Although there have been many reports by the public that starry stonewort has invaded numerous lakes across south-central Ontario, the actual range distribution has not been fully established partly due to the prevalence of misidentification. Furthermore, in Ontario, there is a geological transition zone known as "The Land Between," representing a transition between limestone and granite-dominated parent bedrock (Figure 5, Harrow-Lyle and Kirkwood [in review]. The geology of the landscape is the main driver for a gradient of water hardness, most commonly measured as calcium carbonate ($CaCO_3$), which is important to starry stonewort and other stoneworts that benefit from bicarbonate as a carbon source for growth. Widespread monitoring for all components of aquatic habitat that could be conducive to starry stonewort invasion is not routinely undertaken in Ontario; however, essential parameters such as water hardness and calcium concentration are collected for a subset of lakes.

To date, starry stonewort appears to be relegated to shallow lake environments across south-central Ontario. Even so, Pullman and Crawford (2010) have documented that when all available habitat is colonized, starry stonewort will move to deeper habitats. Starry stonewort, and stoneworts in general, have been documented to grow at depths of 75 m, thus it is plausible that using depth as a habitat-defining characteristic may not be appropriate. Furthermore, stoneworts have a low light compensation point, therefore identifying conducive habitats based on water clarity may also not be appropriate. Until the full extent of chemical, physical, and biotic factors involved in starry stonewort invasion are elucidated, we think water hardness ($CaCO_3$) or calcium concentrations remain an important habitat constraint that should be considered.

By evaluating calcium concentrations available from the Ontario Lake Partner Program, we identified 170 lakes across Ontario with calcium concentrations that are conducive for present and future starry stonewort colonization (Figure 5; Harrow-Lyle and Kirkwood [in review]). Ultimately, the invasion of starry stonewort across Ontario lakes appears to be much more constrained than in bordering US states in the Great Lakes Basin, where the underlying parent material is dominated by limestone. Conducting further research is necessary to generate refined invasion risk assessments, which incorporate additional habitat characteristics (e.g., manganese and potassium concentrations, and site hydrodynamics) that support starry stonewort invasion across North America.

Management

Starry stonewort has the reputation in the Great Lakes Region for being very difficult to manage or eradicate. In Ontario, we have noticed that herbicides, such as diquat, seemingly have no effect on this invader and may actually increase starry stonewort biomass by killing competing species (such as Eurasian watermilfoil). In a canal estates community and several private marinas on Lake Simcoe, diquat has been applied annually to control Eurasian watermilfoil for aesthetic reasons and to allow boat traffic. Although Eurasian watermilfoil has been mostly eliminated at these sites, there has been a large increase in the

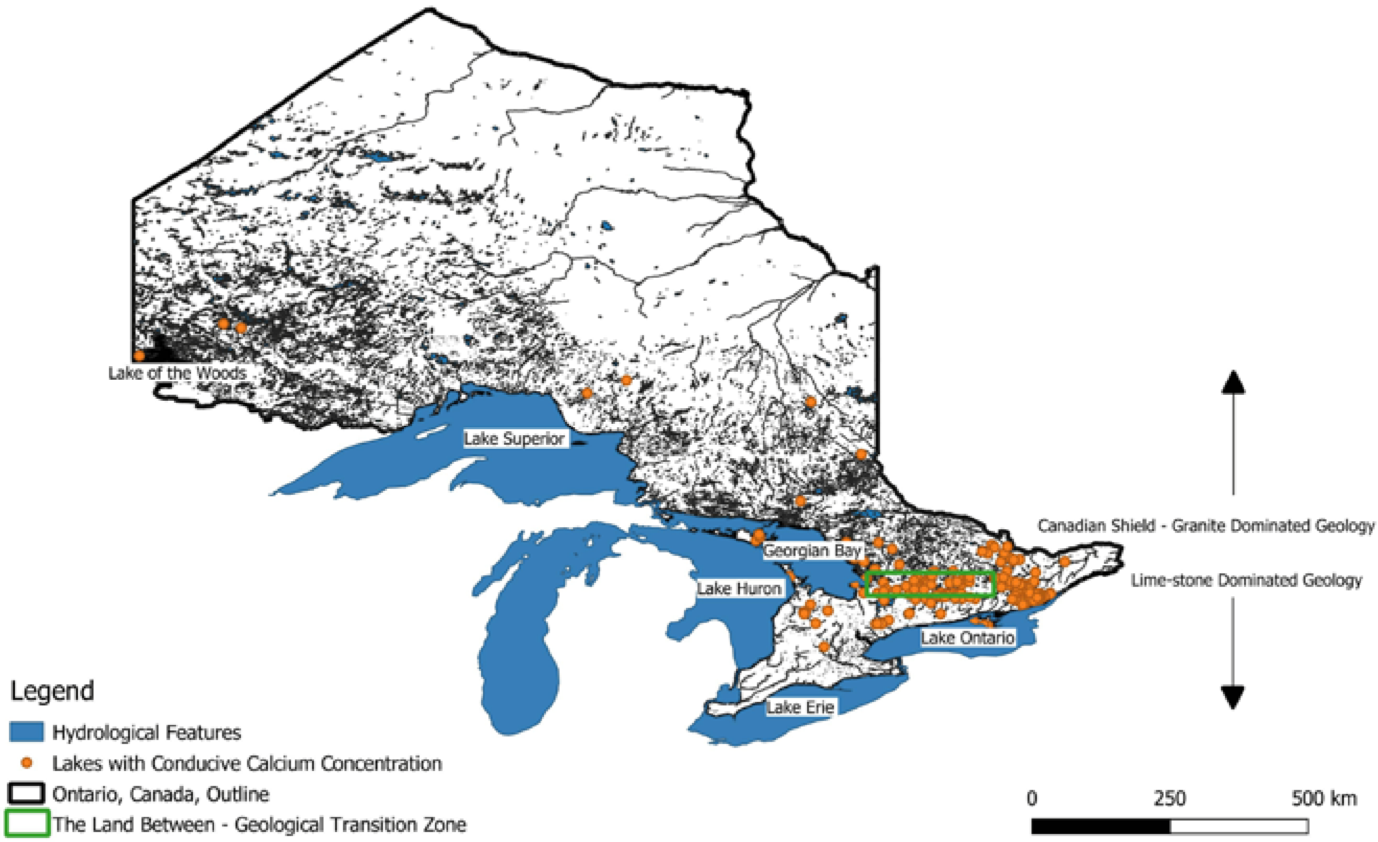


Figure 5. Ontario lakes with calcium concentrations conducive for starry stonewort survival and future invasion.

amount of starry stonewort to the point where backhoes and digging equipment are required to remove truckloads of biomass to keep waterways open.

Not widely used in Ontario, copper-based herbicides / algaecides have been tested in the USA with limited success. These algaecides seem to be effective at killing the top portion of a starry stonewort mass, but the lower part can often survive and overgrow the dead area above it. Copper algaecides offer some reduction in biomass when combined with mechanical harvesting. However, they seem to be ineffective at inhibiting bulbil viability in the sediments and thus treatments need to be repeated for several growing seasons (Glisson et al. 2018; Pokrzywinski et al. 2020). There has been some success with hand removal or hand pulling and diver-assisted suction harvesting (i.e., DASH) of starry stonewort, although these methods seem most effective in the early stages of the invasion where patches are small and relatively easy to access (Figure 6a). Mechanical harvesting of aquatic plants has been carried out in a limited capacity on Lake Simcoe, usually in response to aesthetic complaints from shoreline property owners, and has almost exclusively targeted Eurasian watermilfoil.

Strategic use of mechanical harvesters and hand tools (rakes and gas-powered pole saws) has been used at Friday Harbour, a marina condominium community on Lake Simcoe, in order to control Eurasian watermilfoil and starry stonewort. A mechanical harvester (Figure 6b) is used to trim Eurasian watermilfoil to a depth of one meter below the water surface. The remaining plant material attached to the bottom, and shorter growing native pondweeds, then serves as a shade to limit light reaching the substrate and prevent growth by starry stonewort. Hand tools are used along docks and piers to reach areas that cannot be accessed by the mechanical harvester. All harvested plant material is removed from the marina to reduce regeneration from cuttings. Although starry stonewort has been reported in this marina community, it has so far remained at a very low biomass compared to other locations on Lake Simcoe and other marinas that rely solely on diquat applications as a control strategy. The disadvantages of this harvester and hand tool method are the capital cost of the mechanical harvester and the amount of labour involved, particularly during the peak summer growing season for aquatic plants.

Despite these management efforts, fragmentation and the persistence of bulbils make any management option a multi-year initiative. Additionally, even though hand removal as a treatment seems like a gentle alternative to mechanical harvesting or herbicide application, Ontario legislation limits the cropping of aquatic plant beds in order to protect this vital fish habitat. However, the quality of fish habitat comes into question when starry stonewort is the dominant macrophyte. By outcompeting and overgrowing native aquatic plant species (Figure 6c), starry stonewort also alters the structure of shallow water habitats. In an aquatic plant community dominated by native species, and to some degree even Eurasian watermilfoil, the underwater habitat resembles a forest (Figure 7a) with many shelter spaces and nursery areas for warmwater species (e.g., perch and bass,

Figure 6. Aquatic plants management strategies for starry stonewort: (a) hand-pulling at boat slip, (b) mechanical harvester in marina, (c) starry stonewort overgrowing native muskgrass.

bait fish, and ambush predators such as northern pike, walleye, and muskellunge). Starry stonewort restructures this habitat space into a tangled mass of macroalgae (Figure 7b) that greatly limits available habitat space, displaces small fish into open water, and can force ambush predators to alter their hunting behavior to a more energetically costly pursuit strategy. In addition, our research on Lake Simcoe and Lake Scugog has shown that masses of starry stonewort reduce dissolved oxygen, which may further decrease fish habitat quality. In a native plant community, dissolved oxygen values average 9 mg/L, compared to hypoxic conditions (2 mg/L) within starry stonewort masses. Furthermore, these low dissolved oxygen values can facilitate internal loading of dissolved phosphorus from sediments, which can stimulate more algal and macroalgal growth as well as impede nutrient reduction strategies.

Conclusions

Starry stonewort is an aggressive invasive species that is widespread in the Great Lakes Region and continues to spread to new areas each year. Lakes with sufficient nutrient and cation concentrations, as well as boat traffic, seem to be most at risk for colonization and establishment. Currently, management and eradication options for this species are limited, however research is on-going to find a sustainable method for biomass control. Difficulty in identifying starry stonewort, and its similarity to native species makes tracking the spread challenging, however concerted identification training and reporting events are making the public more aware and involved. Our experiences in Ontario are similar to other areas, particularly Upstate New York, Michigan, and Minnesota. Using a coordinated effort, sharing information and research, and educating recreational lake users will, hopefully, lead to solutions in managing starry stonewort and other invasive species.

Acknowledgements

We wish to acknowledge with gratitude the Williams Treaties First Nations, including the Chippewas of Georgina Island, Rama, Beausoleil; the Mississaugas of Alderville, Curve Lake, Hiawatha, the Credit, and Scugog Island;

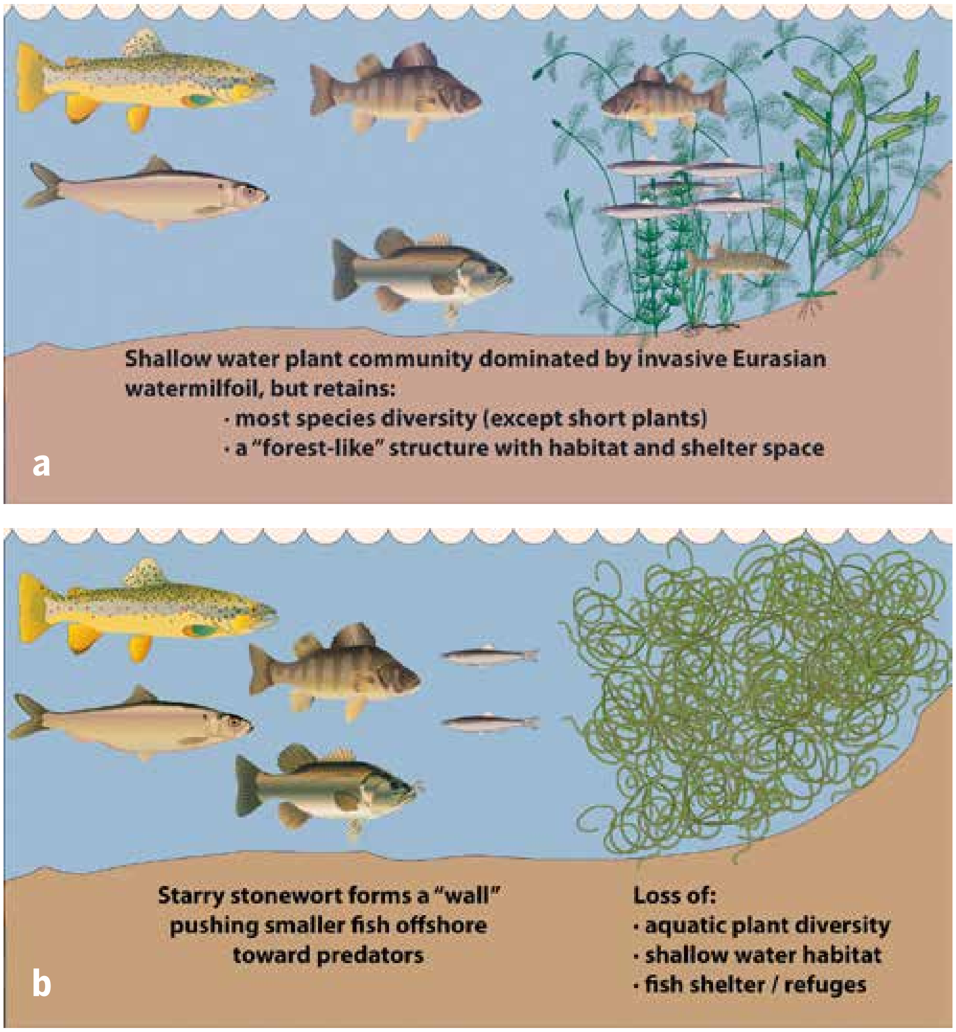


Figure 7. Structure of shallow water fish habitat: (a) dominance by native plants and / or Eurasian watermilfoil, and (b) dominance by starry stonewort.

as well as the Huron Wendat and Metis Nation of Ontario – Region 7, whose lands and waters we traversed in our research and monitoring. We thank D. Leeder of Hutchinson Environmental Services Ltd. and Friday Harbour Resorts for sharing insights into their aquatic plant management program; A. Kirkwood, M. Moos, and P. Strong for their thoughtful suggestions; and D. Campbell for Figure 1.

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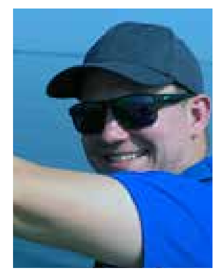

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