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Environmental factors associated with the distribution of non-native starry stonewort (*Nitellopsis obtusa*) in a Lake Ontario coastal wetland

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ABSTRACT

Starry stonewort (*Nitellopsis obtusa*) was likely introduced to the Laurentian Great Lakes via ballast water in the late 1970s. Since its introduction, little research has been conducted to determine the extent of its spread throughout the Great Lakes basin or to explore the environmental variables associated with its distribution. This is partly because, outside of its native range, *N. obtusa* is not often differentiated from other native Characeae. Here, we document the spatial distribution of *N. obtusa* in Presqu'ile Bay, Lake Ontario and identify physical and chemical environmental factors that predict the presence of *N. obtusa*. In Presqu'ile Bay, *N. obtusa* was primarily clustered along the north-shore and tended to be at locations with higher conductivity, water hardness, and nitrate–nitrite and lower exposure to wind and wave action. The best predictors of *N. obtusa* presence, based on a boosted regression tree model, included high density of docks within a 1 km radius, high conductivity, short distance to the nearest marina, and low fetch. These results support the notion that *N. obtusa* can be transported via boating activity, and the findings can be used by management agencies to focus search efforts when attempting to determine *N. obtusa* presence. Given the paucity of knowledge regarding both the distribution of *N. obtusa* in the Great Lakes and how its introduction has influenced native flora and fauna, it is hoped that this study will spur future research.

Introduction

There is a history of introduction of non-native species into the Laurentian Great Lakes and, to date, over 180 aquatic invasive species have been documented (Riccardi, 2006; Rothlisberger and Lodge, 2013). While the consequences of some of these introductions are well documented from both an economic (Rothlisberger et al., 2012) and an ecological perspective (e.g., round gobies [reviewed in Kornis et al., 2012] and zebra mussels [reviewed in Karatayev et al., 2015]), the effects of the majority of non-native species are still largely unknown (Mills et al., 1993). Because the effect of non-native plants on native species (extirpation in particular) may not become apparent for decades or centuries (Gilbert and Levine, 2013), assessing the consequences of their introduction can be challenging.

Starry stonewort (*Nitellopsis obtusa*; hereafter *Nitellopsis*) is a member of the Characeae family (green algae) and is native to Europe and Asia. In their natural range, these aquatic macroalgae provide important food and habitat for fish, waterfowl and invertebrates, enhance water clarity by preventing resuspension of sediments, and store carbon and other nutrients (Auderset Joye and Rey-Boissezon, 2015; Schneider et al., 2015). The ability of *Nitellopsis* to respond morphologically to changing environments (Rey-Boissezon and Auderset Joye, 2015) combined with a broad environmental tolerance relative to other Characeae (Rey-Boissezon and Auderset Joye, 2015) makes it a strong candidate for successful invasion of new habitat (Theoharides and Dukes, 2007). However, due to a restricted distribution in parts of its natural range, *Nitellopsis* has been listed as *near threatened* in the Baltic Sea (Baltic Marine Environment Protection Commission — Helsinki Commission; http://Helcom.fi/RedList Species Information Sheet/HELCOM Red List *Nitellopsis* obtusa.pdf; accessed 24 July, 2015) and *vulnerable* in Great Britain (Biodiversity Action Plan in Great Britain; http://jncc.defra.gov.uk/_speciespages/474.pdf; accessed 24 July, 2015).

Nitellopsis was first identified in 1978 in the St. Lawrence River and was presumably introduced into the Great Lakes via ballast-water (Geis et al., 1981). It has since been found in the Huron–Erie corridor (Schloesser et al., 1986) and Lake Ontario, where there is evidence of range-expansion (Sleith et al., 2015). It has also been identified as a target for control efforts in inland lakes in Michigan (Pullman and Crawford, 2010) and found in several inland lakes in New York State (Sleith et al., 2015). From an ecosystem perspective, *Nitellopsis* has the potential to out-compete native aquatic macrophytes which may negatively affect waterfowl that rely on these native submerged aquatic vegetation for nesting, shelter, and foraging (Kipp et al., 2014). Fish may

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experience loss of foraging, nursery, spawning habitat and changes in the invertebrate community may occur (Kipp et al., 2014; Pullman and Crawford, 2010). The spread of *Nitellopsis* within the Great Lakes and between inland systems is thought to be aided by epizoochory (dispersal on feathers or feet of waterfowl or fur of mammals) and hitch-hiking on boats or boat trailers; however, there is little known about how environmental variables and human activities influence the distribution of *Nitellopsis* (Pullman and Crawford, 2010; Sleith et al., 2015; Veraldi et al., 2011).

Given *Nitellopsis*' history of aggressive invasion in inland Michigan and New York lakes (Pullman and Crawford, 2010) and its expansion in Lake Ontario (Sleith et al., 2015), there is concern over its continued expansion throughout the Great Lakes and the potential effects on nearshore environments; especially coastal wetland habitat and dependent wildlife. The first goal of this paper was to determine the spatial distribution of *Nitellopsis* in a large Lake Ontario coastal wetland. The second goal was to identify environmental (chemical and physical) and anthropogenic factors that predict the presence of *Nitellopsis*. This study represents the first effort to document the spatial coverage of *Nitellopsis* within a Great Lakes coastal marsh and it is intended to encourage recognition of *Nitellopsis* by researchers and managers within the Great Lakes basin.

Methods

Study site

Presqu'ile Bay is located on the north shore of Lake Ontario near the town of Brighton, Ontario, Canada (latitude 44.02°, longitude −77.70°; Fig. 1). Large parts of the bay have natural shorelines, with Presqu'ile Provincial Park dominating the western shoreline. Throughout the bay, there are numerous boat launches; but the majority of marinas, docks, and boat launches are situated along the northern shore near the town of Brighton. *Nitellopsis* was incidentally identified in Presqu'ile Bay in September 2013 by Ontario Ministry of the Environment and Climate Change personnel as part of a nearshore water quality surveillance program (Nadine Benoit, pers. comm.); this appears to have been the first reported record of *Nitellopsis* in Presqu'ile Bay.

Field sampling

A sampling grid with 100-m spacing and 391 points (sampling stations) was overlaid on Presqu'ile Bay imagery in a GIS (ArcMap 10.1; ESRI 2012, Redlands, CA; ET Geowizards v11.1 extension; Tchoukanski, 2014) with the intent of including many of the small bays within the larger bay (Fig. 1). Although *Nitellopsis* can occupy depths of up to 9 m (Pullman and Crawford, 2010), the goal of this study was to sample depths of approximately 2 m or less, which represents the deep-water extent of coastal wetlands (Lee et al., 1998). The survey boat was held in place at a sampling station using a Danforth or Navy anchor and *Nitellopsis* presence was determined by two approximately 1-m long substrate drags with a rake modified to have a 3-m long handle. Vascular plants collected from the drags were identified to species following Crow and Hellquist (2000), but macroalgae from the family Characeae were only identified to genus (e.g., *Nitella* spp. and *Chara* spp.). All macrophytes resembling *Nitellopsis*, including those found on the anchors during retrieval, were examined for the presence of bulbils (starry rhizoids), which are a unique identifying

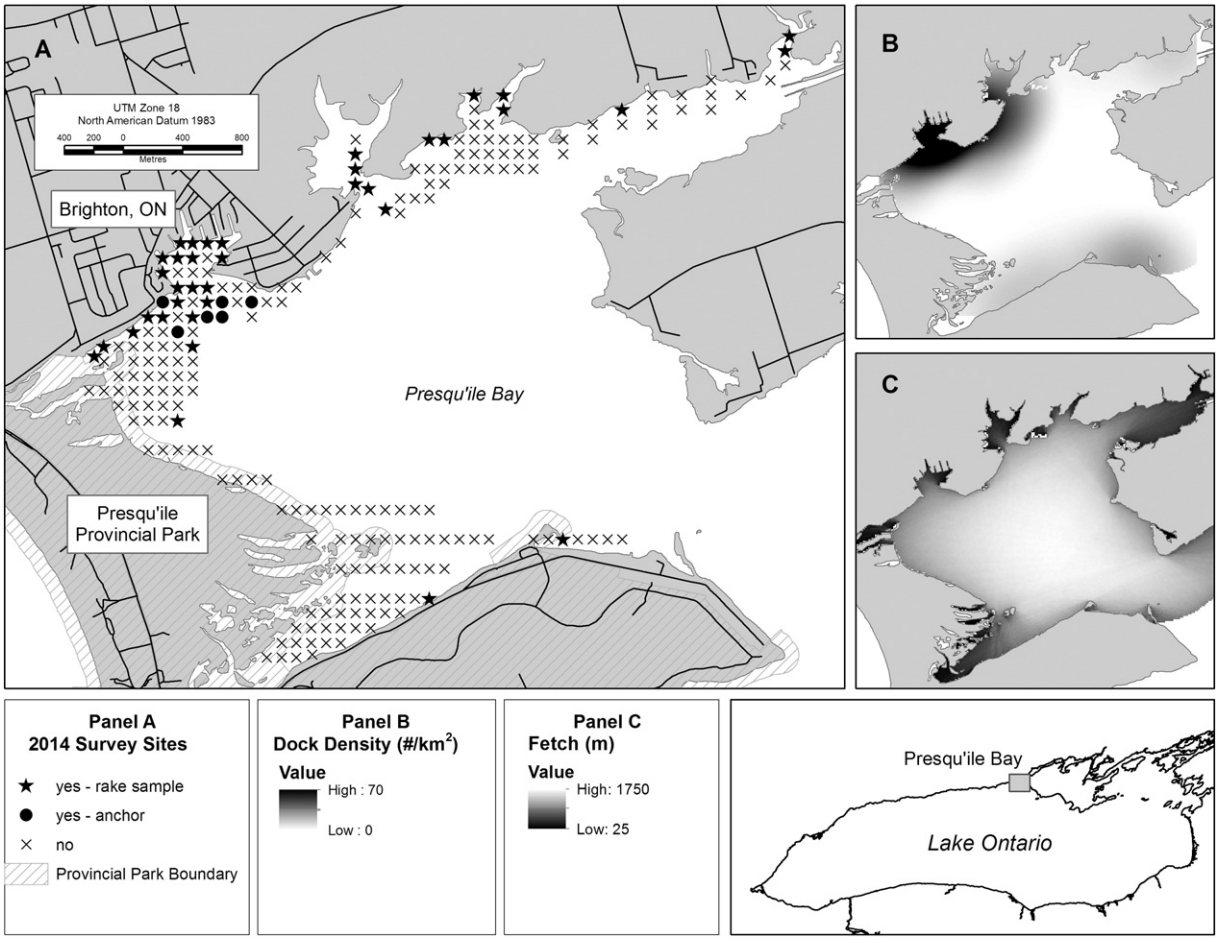

Fig. 1. Location of the study site, Presqu'ile Bay, along the northern shore of Lake Ontario (bottom right panel). The locations of the sampling stations and stations where *Nitellopsis* was discovered are shown in panel A. Panel B shows the density of docks within a 1-km search radius and panel C shows the mean fetch throughout the Bay.