Distribution of *Nitellopsis obtusa* (Characeae) in New York, U.S.A.

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Abstract. The charophytic green alga *Nitellopsis obtusa* was first reported in the New World in the St. Lawrence River in 1978. Since that time, *N. obtusa* has been reported from inland lakes throughout Michigan, northern Indiana, and western New York and has been listed as an aggressive invasive species by the United States Geological Survey. This study addresses the distribution of *N. obtusa* by surveying 390 waterbodies throughout New York. Previous reports are confirmed and new localities are presented, including new reports from five counties (Franklin, Ontario, Seneca, Wayne, and Yates). In total, *N. obtusa* was found in 17 counties at 31 sites, including 16 inland lakes, seven sites in the St. Lawrence River, and eight sites in Lake Ontario.

Key Words: Characeae, Charophyceae, Charophyta, invasive, New York, *Nitellopsis obtusa*, Starry Stonewort.

Nitellopsis obtusa (Desv. in Loisel.) J. Groves (Charophyta: Characeae) is the only extant species of the Early Quaternary genus *Nitellopsis* (Soulié-Märsche et al., 2002; Feist et al., 2005). *Nitellopsis obtusa* (Figs. 1, 2) is a dioecious, robust species, that is capable of growing more than 2 m tall in dense beds at depths to 10 m (Simons & Nat, 1996; John, 2002; Pullman & Crawford, 2010). Wood and Imahori (1965) placed *N. obtusa* in the tribe Chareae based on the 5-celled coronula and branchlets that do not furcate. *Nitellopsis obtusa* differs from other members in the Chareae by lacking stipulodes and possessing specialized star-shaped bulbils (Fig. 1B, C). These bulbils are unique among the Characeae in their complex morphology, role in vegetative reproduction, and star-like shape (Bharathan, 1987; John, 2002). This shape gives rise to the common name Starry Stonewort.

Nitellopsis obtusa has a widespread, yet rare distribution in its native range of Europe and Asia (Simons & Nat, 1996; Soulié-Märsche et al., 2002; Kato et al., 2014). Previously unknown in the New World, the first record of *N. obtusa* in North America was in the St. Lawrence River in 1978, where it was hypothesized to be introduced by ballast water from trans-oceanic shipping (Geis et al., 1981). In 1983, it was recorded in the St. Clair-Detroit River system in Michigan, and is currently distributed throughout Michigan's inland lakes, northern Indiana, and western New York (Schloesser et al., 1986; Eichler, 2010; Pullman & Crawford, 2010).

Initial studies in North America were cursory and suggested *Nitellopsis obtusa* outcompetes native aquatic vegetation and inhibits fish spawning (Pullman & Crawford, 2010; Kipp et al., 2014). This species is a major nuisance in lakes that hold recreational value: it fouls boat motors and impedes swimming and fishing. *Nitellopsis obtusa* fragments easily and may be spread as debris on boats and trailers. Control methods have been attempted, but the United States Geological Survey has stated that successful eradication is expensive (Kipp et al., 2014). Reports from lake associations and state agencies indicate that the range of *N. obtusa* is increasing in Michigan and New York (Pullman & Crawford, 2010; Eichler, 2010). Eichler (2010) reported the distribution of *N. obtusa* in New York, adding 13 sites to the 10 reported by Geis et al. (1981). Voucher specimens are important for the collection information they provide and to confirm determinations. Attempts were made to locate voucher specimens of

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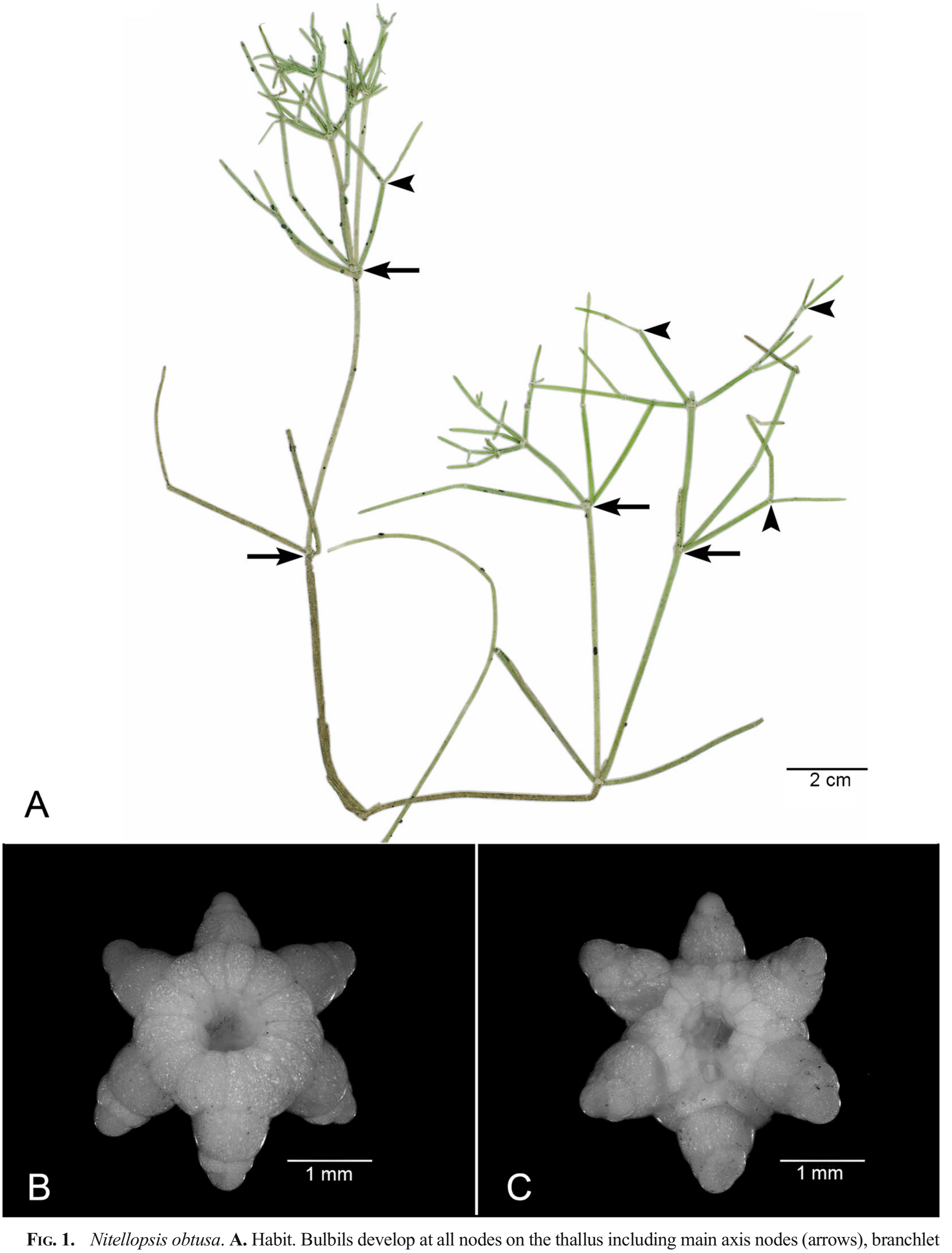

FIG. 1. *Nitellopsis obtusa*. **A.** Habit. Bulbils develop at all nodes on the thallus including main axis nodes (arrows), branchlet nodes (arrowheads) and rhizoid nodes (not shown). **B.** Ventral bulbil view **C.** Dorsal bulbil view.

N. obtusa summarized in Eichler (2010) without success. In this study we confirm, with voucher specimens, 13 of 23 previously reported localities (Geis et al., 1981; Eichler, 2010) and report 18 new records of *N. obtusa*, for a total of 31 sites in New York.

FIG. 2. Developing *Nitellopsis obtusa* antheridium (male reproductive structure) shown at branchlet node.

Materials and methods

Waterbodies (canals, lakes, ponds, rivers, streams, etc.) were selected using the Spatial Survey Design and Analysis package in R (Kincaid & Olsen, 2013) to place 400 points throughout New York. Satellite imagery was then used to locate the body of water with an area greater than 0.05 sq km closest to each point. Of these, 390 sites were accessible and were sampled from June to September 2014 (Fig. 3). Near shore regions were surveyed by wading and the use of a dredge fashioned after Allen (1887). The New York Department of Environmental Conservation's guidelines for preventing the spread of invasive species were followed by soaking all collecting materials in Formula 409® for at least 10 minutes after each use. Water conductivity and pH measurements were collected with an In Situ SmarTroll MP (Ft. Collins, CO, U.S.A). Living material was collected in triplicate in Whirl-Paks® (Nasco, Fort Atkinson, WI, U.S.A.) and returned to The New York Botanical Garden for identification and vouchering. Voucher specimens were deposited in The William and Lynda Steere Herbarium (NY) and when possible, duplicates were distributed to the Academy of Natural Sciences of Drexel University (PH) and the Norton-Brown Herbarium, University

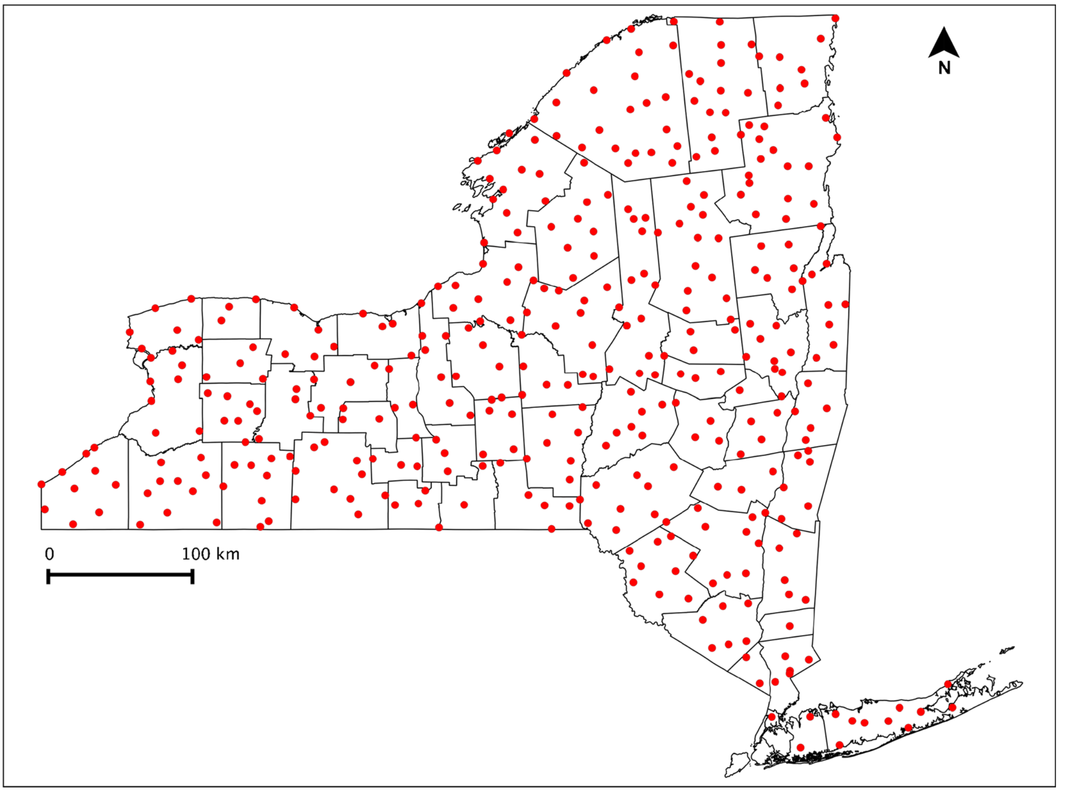

FIG. 3. Map of New York, U.S.A. showing county boundaries and the 390 sites sampled (dots).

TABLE I

LOCALITIES OF *NITELLOPSIS OBTUSA* IN NEW YORK. REPRESENTATIVE NY BARCODES ARE PROVIDED EXCEPT FOR THE TWO UNCONFIRMED LOCATIONS (WANETA LAKE AND LAKE ONTARIO AT WILSON TUSCARORA STATE PARK). NUMBERS IN THE LABEL COLUMN CORRESPOND TO FIG. 4. BOLD LABEL NUMBERS INDICATE NEARBY COLLECTIONS THAT WERE AGGREGATED FOR DISPLAY IN FIG. 4.

Label	Locality	Barcode (NY)	Latitude	Longitude	County	Year
1	Owasco Lake	02026406	42.90455	-76.53976	Cayuga	2013
1	Owasco Lake	02146770	42.90253	-76.53964	Cayuga	2013
1	Owasco Lake	02146787	42.90540	-76.53987	Cayuga	2014
1	Owasco Lake	02146788	42.75446	-76.47193	Cayuga	2014
2	Lake Ontario, Sterling Pond	02146785	43.34287	-76.69901	Cayuga	2014
2	Lake Ontario, Sterling Pond	02137428	43.34267	-76.69903	Cayuga	2012
3	Lake Como	02146789	42.68068	-76.30353	Cayuga	2014
4	Duck Lake	02146782	43.15025	-76.69116	Cayuga	2014
5	Chautauqua Lake	02146790	42.10118	-79.29687	Chautauqua	2014
6	Tully Lake	02023121	42.76461	-76.13810	Cortland	2007
6	Tully Lake	02023118	42.76461	-76.13810	Cortland	2007
6	Tully Lake	02146767	42.76435	-76.13708	Cortland	2012
6	Tully Lake	02146780	42.77263	-76.13326	Cortland	2014
6	Tully Lake	02145907	42.77267	-76.13335	Cortland	2014
6	Upper Little York Lake	02023120	42.70702	-76.14972	Cortland	2005
6	Upper Little York Lake	02023119	42.70119	-76.15628	Cortland	2009
6	Upper Little York Lake	02146766	42.70273	-76.15699	Cortland	2012
6	Upper Little York Lake	02146775	42.70868	-76.15120	Cortland	2013
6	Upper Little York Lake	02146779	42.70866	-76.15149	Cortland	2014
6	Upper Little York Lake	02145906	42.70873	-76.15110	Cortland	2014
7	St. Lawrence River, mouth of Raquette River	02146765	44.99302	-74.69757	Franklin	2011
8	St. Lawrence River, Grass Point State Park	02146764	44.28094	-76.00130	Jefferson	2011
8	St. Lawrence River, DeWolf Point State Park	02146799	44.33187	-75.99093	Jefferson	2014
9	St. Lawrence River, Millen Bay	02145901	44.17155	-76.24451	Jefferson	2014
10	Lake Ontario, Association Island Marina	02146762	43.89265	-76.21634	Jefferson	2011
10	Lake Ontario, Green Point Marina	02146761	43.67202	-76.18512	Oswego	2011
11	Lake Ontario, Chaumont Bay Public Beach	02146763	44.06994	-76.14594	Jefferson	2011
11	Lake Ontario, Chaumont Boat Launch	02146800	44.06823	-76.14854	Jefferson	2014
12	Lake Ontario, South Colwell Pond	02145904	43.69722	-76.19384	Jefferson	2014
13	Lake Bonaparte	02146796	44.14037	-75.37919	Lewis	2014
14	Lake Moraine	02146783	42.85920	-75.51329	Madison	2014
15	DeRuyter Reservoir	02146784	42.80099	-75.88734	Madison	2014
16	Cazenovia Lake	02146768	42.92713	-75.86420	Madison	2013
17	Lake Ontario, Braddock Bay	02146791	43.31776	-77.72276	Monroe	2014
18	Lake Ontario, Wilson Tuscarora State Park	unconfirmed	43.30730	-78.85680	Niagara	2006
19	Canandaigua Lake	02146781	42.87525	-77.27198	Ontario	2014
20	Oneida Lake, Oneida Shores Park	02146759	43.22847	-76.10880	Oswego	2011
20	Oneida Lake, Smith Ridge Boat Launch	02146760	43.16262	-75.92658	Oswego	2011
20	Oneida Lake, Muskrat Bay	02146773	43.22372	-76.10416	Onondaga	2013
20	Onieda Lake, Spruce Grove Marina	02145905	43.24400	-75.98115	Oswego	2014
20	Oneida Lake, Muskrat Bay	02146774	43.22844	-76.10877	Onondaga	2013
21	Otsego Lake	02146776	42.70298	-74.92248	Otsego	2014
22	Waneta Lake	unconfirmed	42.43243	-77.09955	Schyluer	2008
23	Yellow Lake	02146797	44.31679	-75.60972	St. Lawrence	2014
24	St. Lawrence River, Wilson Hill Boat Launch	02146794	44.92928	-75.01115	St. Lawrence	2014
25	St. Lawrence River	02146795	44.67611	-75.52959	St. Lawrence	2014
26	St. Lawrence River, Schermerhorn Harbor	02146798	44.41321	-75.79035	St. Lawrence	2014
27	Cayuga Lake, Myers Park	02146778	42.53577	-76.54974	Tompkins	2014
27	Cayuga Lake, northwest shore	02146771	42.90001	-76.74960	Seneca	2013
27	Cayuga Lake, Allen H. Treman Boat Launch	02146777	42.45647	-76.51218	Tompkins	2014
28	Lake Ontario, Sodus Bay	02146786	43.22348	-76.92986	Wayne	2014
29	Keuka Lake	02146772	42.65808	-77.05766	Yates	2013

of Maryland-College Park (MARY). Additionally, herbarium collections (NY) were examined for other New York *Nitellopsis obtusa* records.

Discussion

Nitellopsis obtusa localities are listed in Table I. By combining an herbarium survey with 2014 field work we were able to confirm *N. obtusa* in 13 of 23 previously reported sites (Geis et al., 1981; Eichler, 2010). Geis et al. (1981) reported 10 sites in close proximity in Jefferson and St. Lawrence counties. We confirmed sites in both counties but did not re-survey all (Geis et al., 1981) sites. The two previously reported sites we were unable to confirm were Waneta Lake and Lake Ontario at Wilson Tuscarora State Park (Eichler, 2010). Because both of these sites include large areas, it is possible that the exact location was missed by our sampling strategy. We found *N. obtusa* for the first time in seven inland lakes, five sites in the St. Lawrence River, and six sites in Lake Ontario (Fig. 4). These include new reports in five counties: Franklin, Ontario, Seneca, Wayne, and Yates. *Nitellopsis obtusa* is distributed throughout the St. Lawrence River corridor and across the central Finger Lakes region of New York (Fig. 4). Notably, *N. obtusa* was not found in other areas of New York (e.g., The Adirondack Park, The Catskill Park, Long Island).

Geis et al. (1981) reported water chemistry parameters including pH and conductivity for 19 sites in a 120 km stretch of the St. Lawrence River. Table II presents water chemistry measurements for the St. Lawrence River, as well as parameter ranges for all year 2014 sites where *Nitellopsis obtusa* was found in New York. The pH and conductivity values in the St. Lawrence River were similar between Geis et al. (1981) and our year 2014 measurements. However, the values across all *N. obtusa* year 2014 sites show a broader

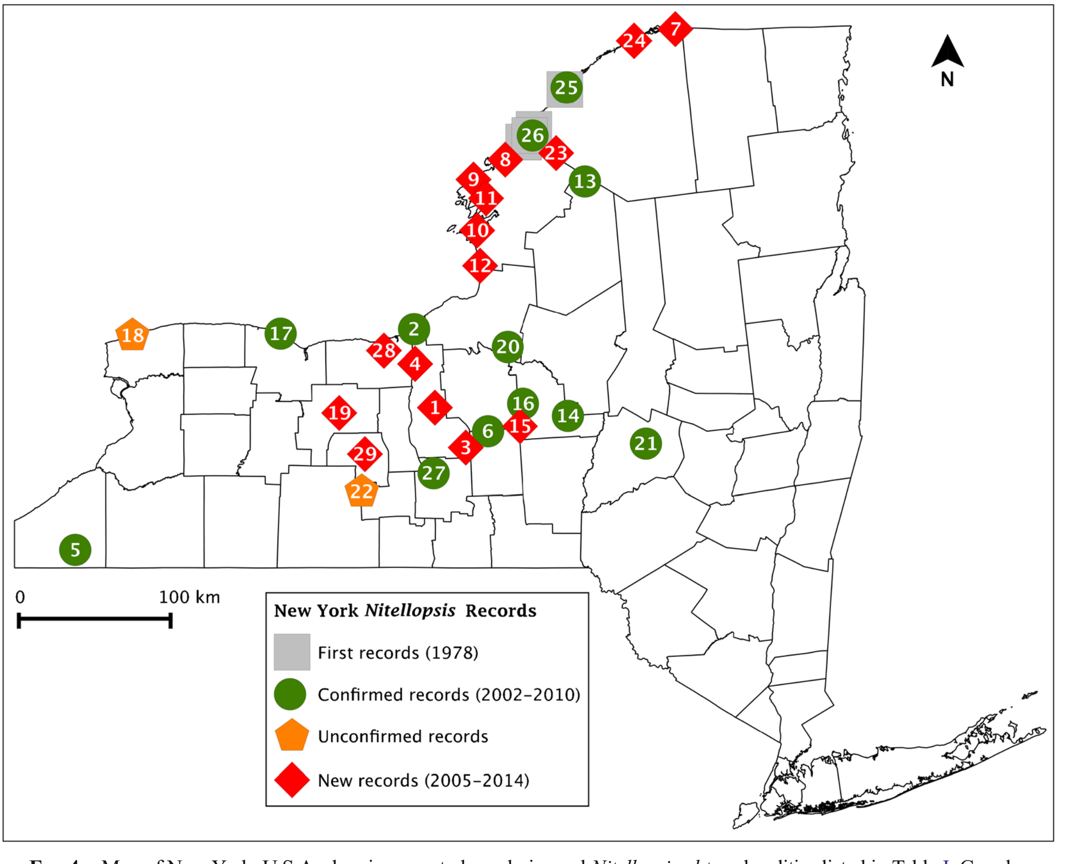

Fig. 4. Map of New York, U.S.A. showing county boundaries and *Nitellopsis obtusa* localities listed in Table I. Gray boxes indicate the initial reports by Geis et al. (1981). Green circles indicate records from Eichler (2010) that were confirmed in this study. Orange pentagons indicate records from Eichler (2010) that were not confirmed. Red diamonds indicate new records. For the purposes of display, nearby records were aggregated (see Table I).

TABLE II
CHEMICAL PARAMETERS FOR THE NETHERLANDS (NL 1996) FROM SIMONS AND NAT (1996), THE ST. LAWRENCE RIVER (SLR 1978) FROM GEIS ET AL. (1981) MEASURED IN 1978, AND FOR THE ST. LAWRENCE RIVER FROM THIS STUDY (SLR 2014). NEW YORK 2014 SHOWS PARAMETERS FROM ALL SITES WHERE *NITELLOPSIS OBTUSA* WAS FOUND.

Parameter	NL 1996	SLR 1978	SLR 2014	New York 2014
pH	6.4-9.0	8.47-8.70	8.30-8.90	7.28-9.30
Conductivity (μS/cm)	320-2250	306-319	283-298	160-499

range, indicating that *N. obtusa* inhabits a wider range of pH and conductivity than previously known in North America. Simons and Nat (1996) reported water chemistry parameters for *N. obtusa* habitats in The Netherlands. The geographic coverage (Simons & Nat, 1996) is small when compared to year 2014 sites, but there are differences that are worth noting. The minimum pH of The Netherlands habitats is lower than the measurements from year 2014 sites, while the maximum pH is similar (Table II). This indicates that native *N. obtusa* occupies a broader range of habitats than North American *N. obtusa*. The minimum conductivity recorded from year 2014 sites is 160 μS/cm lower than the conductivity measured from The Netherlands. It is unclear whether this difference is the result of a broader tolerance in North American *N. obtusa* or a lack of sampling lakes with low conductivity in The Netherlands. The maximum conductivity of 2250 μS/cm in its native range suggests that *N. obtusa* is able to inhabit slightly brackish water, which is consistent with the ballast water hypothesis of introduction. It remains unknown whether North American *N. obtusa* has a similar salinity tolerance to native populations, or if the introduced *N. obtusa* has a restricted physiological tolerance.

Mann et al. (1999) reported that only male sexually reproductive *Nitellopsis obtusa* plants occur in North America and that *N. obtusa* could be moved clonally from lake to lake by human activity. Our work supports these statements; of the specimens that were reproductive, only male specimens were found in New York (Fig. 2). Pullman and Crawford (2010) reported female *N. obtusa* plants in Michigan. However, Figure 3 of Pullman and Crawford (2010) describes "orange-colored oocytes," but antheridia are pictured. A relationship between latitude and gender has been suggested for *N. obtusa* in its native range, with only male plants observed at higher latitudes (Soulié-Märsche et al., 2002). It is possible that female plants exist in North America but have avoided detection.

Endozoochory, dispersal via vertebrate digestive tract (predominately waterfowl), has been proposed as the primary dispersal pathway for Characeae (Proctor, 1962, 1968; Charalambidou & Santamaría, 2002). This mechanism relies on mature oospores, which survive passing through the digestive tract of waterfowl. The apparent absence of reproductive female *Nitellopsis obtusa* in North America makes endozoochory an unlikely form of dispersal. Epizoochory, dispersal on feathers or feet of waterfowl, could disperse bulbils or vegetative propagules to new sites and has been discussed as a method of transport in Michigan (Pullman & Crawford, 2010). In New York, all lakes where *N. obtusa* was found had substantial human development, including boat launches. Our survey included many undeveloped lakes, and *N. obtusa* was not found in these low human impact areas. If waterfowl were indeed responsible for dispersing *N. obtusa* we would expect a higher frequency of *N. obtusa* statewide as well as occurrence in low human impact lakes. Consequently, in New York, *N. obtusa* is not likely transported by endozoochory or epizoochory and is most likely transported by humans.

The new county and site records we report indicate two patterns. The range of *Nitellopsis obtusa* in New York has not expanded beyond the boundary described by the localities reported in Eichler (2010). In areas where *N. obtusa* has been established, there is increasing density, with more local lakes becoming infested. This is particularly evident in Ontario and Yates counties in the Oswego River/Finger Lakes Watershed and in the Jefferson county region of the Lake Ontario Tributaries Watershed (Table I; Fig. 4). Further work is needed to understand how environmental variables and human activities contribute to the current distribution of *N. obtusa* in North America. Proactive management and public awareness will be necessary to limit and control the invasion of this enigmatic macroalgae.

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Literature cited

Allen, T. F. 1887. Dredge for *Chara*. Botanical Gazette 12: 297.

Bharathan, S. 1987. Bulbils of some charophytes. Proceedings: Plant Sciences 97: 257–263.

Charalambidou, I. & L. Santamaría. 2002. Waterbirds as endozoochorous dispersers of aquatic organisms: a review of experimental evidence. Acta Oecologica 23: 165-176.

Eichler, L. W. 2010. Annual Report–2010 Darrin Fresh Water Institute Aquatic Plant Identification Program. DFWI Technical Report 2010-11

Feist, M., N. Grambast-Fessard, M. Guerlesquin, K. Karol, L. Huinan, R. M. McCourt, W. Qifei & Z. Shenzen. 2005. Treatise on Invertebrate Paleontology. PartB. Volume 1: Charophyta. The Geological Society of America, Inc., Boulder CO

Geis, J. W., G. J. Schumacher, D. J. Raynal & N. P. Hyduke. 1981. Distribution of *Nitellopsis obtusa* (Charophyceae, Characeae) in the St Lawrence River: a new record for North America. Phycologia 20: 211–214.

John, D. M. 2002. The Freshwater Algal Flora of the British Isles: An Identification Guide to Freshwater and Terrestrial Algae. Cambridge University Press, Cambridge.

Kato, S., H. Kawai, M. Takimoto, H. Suga, K. Yohda, K. Horiya, S. Higuchi & H. Sakayama. 2014. Occurrence of the endangered species *Nitellopsis obtusa* (Charales, Charophyceae) in western Japan and the genetic differences within and among Japanese populations: *Nitellopsis obtusa* from Lake Biwa. Phycological Research 62: 222-227.

Kincaid, T. M. & A. R. Olsen. 2013. spsurvey: spatial survey design and analysis. R package version 2.6. URL: http://www.epa.gov/nheerl/arm/

Kipp, R. M., M. McCarthy & A. Fusaro. 2014. *Nitellopsis obtusa*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL.

Mann, H., V. W. Proctor & A. S. Taylor. 1999. Towards a Biogeography of North American Charophytes. Australian Journal of Botany 47: 445-458.

Pullman, G. D. & G. Crawford. 2010. A decade of starry stonewort in Michigan. LakeLine.

Proctor, V. W. 1962. Viability of *Chara* oospores taken from migratory water birds. Ecology 43: 528-529.

———. 1968. Long-distance dispersal of seeds by retention in digestive tract of birds. Science 160: 321-322.

Schloesser, D. W., P. L. Hudson & S. J. Nichols. 1986. Distribution and habitat of *Nitellopsis obtusa* (Characeae) in the Laurentian Great Lakes. Hydrobiologia 133: 91–96.

Simons, J. & E. Nat. 1996. Past and present distribution of stoneworts (Characeae) in The Netherlands. Hydrobiologia 340: 127–135.

Soulié-Märsche, I., M. Benammi & P. Gemayel. 2002. Biogeography of living and fossil *Nitellopsis* (Charophyta) in relationship to new finds from Morocco. Journal of Biogeography 29: 1703–1711.

Wood, R. D. & K. Imahori. 1965. A revision of the Characeae. Monograph of the Characeae. J. Cramer, Weinheim.