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Short Communication

First record of the invasive red alga *Heterosiphonia japonica* (Ceramiales, Rhodophyta) in Canada

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Abstract

Four specimens of the invasive red alga *Heterosiphonia japonica* were collected from Mahone Bay, Nova Scotia, Canada, in August 2012. The identity of these specimens was confirmed using molecular and anatomical evidence. To the best of our knowledge, this is the first report of *H. japonica* in Canada – an invasive red alga that has been advancing along the northeastern coast of North America since its recent introduction to Rhode Island circa 2007.

Key words: Asian Pacific; invasive species; Dasyaceae; COI-5P; Nova Scotia

Introduction

Heterosiphonia japonica Yendo (1920), an alga native to the Asian Pacific, was introduced to Brittany, France, in 1984 (Sjøtun et al. 2008) and spread rapidly along the coast of Europe reaching Norway and Spain by 1996 and the United Kingdom and Mediterranean by 1999. It is currently established along the coast from Norway to the Mediterranean (Sjøtun et al. 2008).

The first suggestion that *Heterosiphonia japonica* had reached North America was from the collection of an unidentified ceramialean alga from Fort Wetherill, Rhode Island, in 2007. It was collected again at the same site in 2009 and by 2010 there also were collections from just north of Cape Cod, Massachusetts (Table 1, Figure 1; unpublished data). Based on his collections of 2009, Schneider (2010) determined that this as yet unidentified species was the invasive alga *Heterosiphonia japonica*. Moreover, it was extremely abundant in the drift following Hurricane Bill, comprising 10 to 20% of the drift biomass at several sites along the New England coast. Since 2010, *H. japonica* has continued to spread north along the coast of New England. It was collected in April 2012 at Cape Ann, in northern Massachusetts, where it formed an extensive carpet over the usual turf-forming algae (Figure 1, inset). Also in 2012, colleagues collected this species from Cape Elizabeth in southern Maine (Idlebrook 2012).

It is clear that *H. japonica* has become well established in New England since it was first collected in Rhode Island in 2007. Previous to this study, the northernmost collections of *H. japonica* were those from Cape Elizabeth, Maine (Idlebrook 2012). This report documents the first records of *Heterosiphonia japonica* in Canada based on four specimens collected from Covey Head, Mahone Bay, Nova Scotia in 2012. Earlier reports of *H. japonica* from the west coast (British Columbia) were almost certainly *Heterosiphonia densiuscula* Kylin, 1925 (Sjøtun et al. 2008).

Table 1. Collections of *Heterosiphonia japonica* from the northeastern coast of North America between 2007 and 2012.

UNB voucher	Location	Prov/ State[1]	Date (dd.mm.yy)	Reproduction	COI-5P Genbank accession #
GWS005731	Fort Wetherill, Jamestown	RI	10.8.07	tetrasporangial	KC158580
GWS011810	Fort Wetherill, Jamestown	RI	17.4.09	none	HM917383
CWS09-42-32	Misquamicut St. Beach, Misquamicut	RI	24.8.09	tetrasporangial	HM542007
CWS09-43-42	Quonochontaug Central Beach, Charlestown	RI	24.8.09	no data	HM542008
GWS014706	White Horse Beach, Plymouth	MA	12.4.10	none	HM919011
GWS014721	White Horse Beach, Plymouth	MA	12.4.10	none	HM919024
GWS017837	Garbage Beach Breakwater, Woods Hole	MA	14.4.10	none	HM915097
GWS017912	Sandwich Town Beach, Sandwich	MA	14.4.10	none	HM915119
GWS017914	Sandwich Town Beach, Sandwich	MA	14.4.10	none	HM915120
GWS018007	Fort Wetherill, Jamestown	RI	16.4.10	none	HM915157
GWS027802	Corporation Beach, Dennis	MA	13.4.11	none	KC158576
GWS027819	Corporation Beach, Dennis	MA	13.4.11	none	ND[3]
GWS027836	White Horse Beach, Plymouth	MA	14.4.11	none	ND[3]
GWS027863	Garbage Beach Breakwater, Woods Hole	MA	15.4.11	none	ND[3]
GWS030121	Garbage Beach Breakwater, Woods Hole	MA	18.4.12	none	KC158582
GWS030144	Niles Beach, Gloucester	MA	19.4.12	none	KC158578
GWS030145	Niles Beach, Gloucester	MA	19.4.12	none	KC158577
GWS030148	Folly Cove, Gloucester	MA	19.4.12	none	KC158574
GWS030151	Folly Cove, Gloucester	MA	19.4.12	none	KC158581
GWS032028	Covey Head, Upper Blandford	NS	13.8.12	tetrasporangial	KC158579
GWS032029	Covey Head, Upper Blandford	NS	13.8.12	none	ND[3]
GWS032030	Covey Head, Upper Blandford	NS	13.8.12	tetrasporangial	KC158575
GWS032031	Covey Head, Upper Blandford	NS	13.8.12	tetrasporangial	ND[3]

[1]MA = Massachusetts; NS = Nova Scotia; RI = Rhode Island.
[2]Collections by C. Schneider and included in his earlier study (Schneider 2010).
[3]ND = No Data, molecular data was not available, specimens were identified using anatomical features.

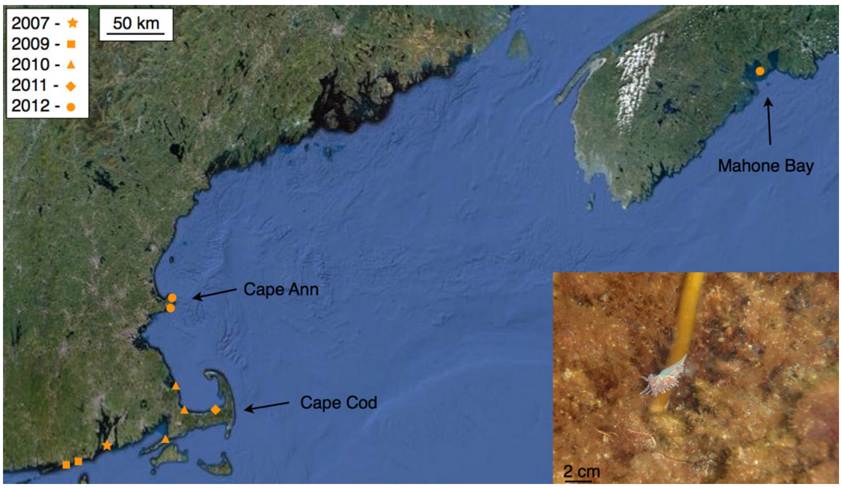

Figure 1. Map of the northeastern United States and Nova Scotia with locations where *Heterosiphonia japonica* was collected marked in orange and presented by year. Inset image displays *H. japonica* forming an extensive carpet over all other turf algae at Cape Ann. See Appendix 1 for primary geo-referenced species record data. Google Maps © 2012. Inset photograph by G. Saunders.

Methods

Specimens of *H. japonica* were collected from the intertidal and subtidal zone at several sites along the northeastern coast of North America (Appendix 1, Table 1 and Figure 1). Individuals were collected subtidally using SCUBA or were found in the drift. Specimens were dried in silica gel to serve as both a voucher and for subsequent DNA extraction; in some cases additional vouchers were pressed on herbarium paper.

DNA was extracted from dried material and 664 bp near the 5' end of the cytochrome c oxidase subunit 1 gene (COI-5P) were amplified

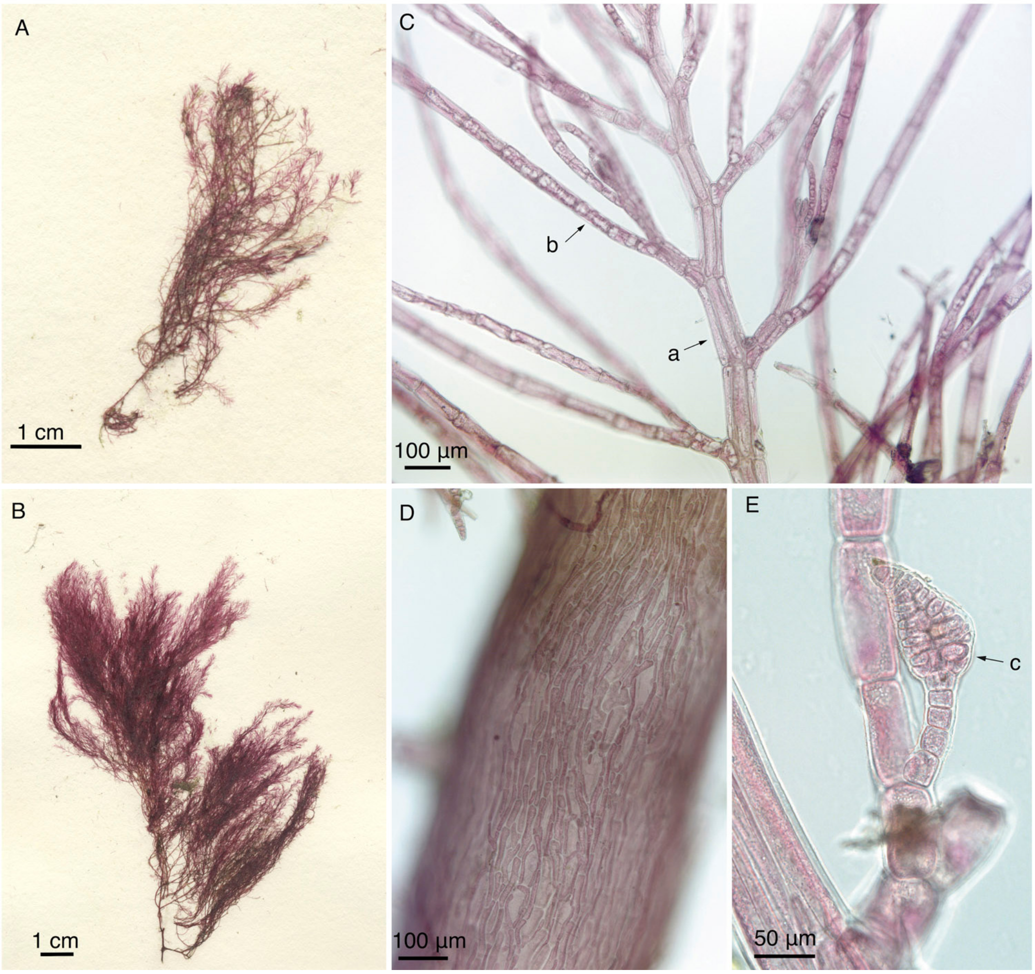

Figure 2. *Heterosiphonia japonica* from Nova Scotia. A. Brownish red, more sparsely branched plant (GWS032029), B. Darker red, highly branched plant (GWS032030), C. Upper portion of GWS032029 with uncorticated main axis displaying four periaxial cells (a) and monosiphonous pseudolaterals (b) arising from each segment in an alternate pattern, D. Heavy cortication at the base of the main axis of GWS032029, E. Tetrasporangial stichidium (c) in GWS032028. Photographs by A. Savoie.

following Saunders and McDevit (2012). The primer pair used for each specimen is recorded with their Genbank accession number (Table 1). Amplified product was sent to Génome Québec for sequencing and raw data were edited using Geneious version R6 (2012). Edited sequences were run through the BOLDSYSTEMS database (Ratnasingham and Hebert 2007) for identification.

Dried material was rehydrated in water and viewed using a Leica DM5000B light microscope. Slides were preserved using a 50% karo syrup, 4% formalin solution. Photomicrographs were recorded using a Leica DFC480 digital camera mounted onto the light microscope.

Results

Four specimens of *Heterosiphonia japonica* were collected on 13 August 2012 during a collecting trip to Nova Scotia as part of an ongoing barcode survey of red algae in Atlantic Canada (Appendix 1 and Table 1). All four plants were collected subtidally at a depth of approximately 3 meters, growing on rock at Covey Head, near the town of Upper Blandford, Mahone Bay. Mahone Bay, located in Lunenburg County on the south shore of Nova Scotia, is a large bay protected by several islands at its entrance, as well as Aspotogan Peninsula to the east and First Peninsula to the west. Covey Head is on the eastern side of Mahone Bay and is relatively sheltered due to its proximity to the Tancook Islands at the mouth of the bay.

The Nova Scotian specimens were a good morphological match to plants from New England (Schneider 2010) and Europe (Lein 1999). The plants ranged from 5.5 to 15 cm in height and were brownish to bright red-orange in colour (Figures 2a and 2b). The thalli consisted of relatively robust erect axes that were loosely subdichotomously branched, distichous and that tapered toward the apices (Figures 2a and 2b). Axes had four periaxial cells covered by rhizoidal cortication at the base of the plant, but became uncorticated toward the apices (Figures 2c and 2d). Monosiphonous pseudolaterals developed in an alternate pattern from distal segments of the axes and were often dichotomously branched (Figure 2c). Three of the four Nova Scotia plants were tetrasporangial (Figure 2e).

The identity of the Nova Scotian specimens was verified using COI-5P DNA barcode data for two specimens – the sequences were an exact match to those generated for *H. japonica* from New England (Appendix 1 and Table 1). In fact all 18 COI-5P sequences obtained from *H. japonica* in North America are identical (data not shown; Table 1) and match an isolate from Spain (Schneider 2010).

In Atlantic Canada, the only other species in the family Dasyaceae is *Dasya baillouviana* (S.G.Gmelin) Montagne (1841). However, this species is completely corticated obscuring the periaxial cells to the tips (Schneider and Searles 1991) removing any chance of confusion with *H. japonica*.

Discussion

It is difficult to determine when and how *H. japonica* was first introduced to Nova Scotia because there is no routine monitoring along the coast. While it is possible that this species has been overlooked in this area and that introduction may predate 2012, we visited this site or nearby sites in 2009, 2010 and 2011 and did not encounter this species despite targeting species of this morphology during sampling.

Schneider (2010) suggested that it is likely that *H. japonica* was introduced to New England though ballast water or hull fouling of ships traveling from Europe to Narragansett Bay, Rhode Island. At least one other introduced seaweed, the invasive red alga *Grateloupia turuturu* Yamada (1941), has spread along the coast of New England after being first recorded in Narragansett Bay (Mathieson et al. 2008). We cannot determine how *H. japonica* made it to Nova Scotia from the coast of New England, however, Mahone Bay was the first reported location for several other invasive marine organisms in Atlantic Canada. These include: the invasive green alga *Codium fragile* subsp. *fragile* (Suringar) Hariot (1889), which was discovered in Mahone Bay in 1989 (Bird et al. 1993); the Coffin box bryozoan *Membranipora membranecea* (Linnaeus, 1767), discovered in 1992 (Scheibling et al. 1999); and the Violet tunicate *Botrylloides violaceus* (Oka, 1927), discovered in 2001 (Carver et al. 2006). It is likely that these organisms, including *H. japonica*, were introduced though recreational boat traffic from the northeastern United States (Murray et al. 2011) or possibly transported by ocean currents.

Heterosiphonia japonica is tolerant of a wide range of environmental conditions including wave exposure, temperature, and salinity. This makes it particularly successful as an invasive species. It is more commonly collected at relatively protected sites, but is able to grow successfully in a variety of habitats, from sheltered sandy bays to moderately exposed rocky headlands, attached to rock or algae, or free-floating (Husa et al. 2004). It can survive being exposed to temperatures from 0 to 30ºC and salinities from 15 to 30 (Bjærke and Rueness 2004). The broad temperature tolerance of *H. japonica* means that it may be able to survive the winter in Nova Scotia, as the average water temperature in Mahone Bay in February is 0.5ºC. However, temperatures as low as -2.4ºC have been recorded (Coastal Shallow Water Climatology for Atlantic Canada 2007).

To date only sterile and tetrasporangial plants (diploid generation typically producing four haploid tetraspores in tetrasporangia) have been reported from North American populations (Table 1; Schneider 2010), and gametophytes are reportedly very rare in Europe (Sjøtun et al. 2008). In the absence of gametophytes, the importance of the presumably haploid tetraspores in the ongoing recruitment and possible spread of *H. japonica* in Nova Scotia remains equivocal and requires further study (see Bjærke and Rueness 2004). Regardless, *Heterosiphonia japonica* is able to reproduce by fragmentation by which pseudolateral branches produce rhizoids, detach and then reattach to the substrate, establishing new plants (Husa and

Sjøtun 2006). Additionally, it has been recently shown that *H. japonica* is more effective at nitrate uptake than morphologically similar native species and that it has a significant impact on the composition of seaweed assemblages at locations where it is present (Drouin et al. 2012).

Conclusion

The presence of *Heterosiphonia japonica* in Nova Scotia may present a serious threat to the health of this coastal ecosystem. It has proven to be a very successful invasive species in both New England and Europe and has the ability to spread quickly and become very abundant. Thorough monitoring of the coast of Nova Scotia will be essential in order to determine if *H. japonica* survives the winter and to document any further spread along the Nova Scotia coast.

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Appendix 1. Geo-referenced species record data with additional information on collectors and habitat for the samples recorded in Table 1.

UNB voucher	Collectors[1]	Habitat	Prov/State[2]	Latitude, Longitude
GWS005731	GWS & BC	Subtidal (6 m) on rock	RI	41.47910, -71.36066
GWS011810	GWS, BC & DM	Subtidal (6 m) on rock	RI	41.47910, -71.36066
CWS09-42-3	CS	Drift after Hurricane Bill	RI	41.32267, -71.80381
CWS09-43-4	CS	Drift after Hurricane Bill	RI	41.33683, -71.70225
GWS014706	BC, DM, MB, AS & CL	Subtidal (15ft) on rock	MA	41.93361, -70.56046
GWS014721	BC, DM, MB, AS & CL	Subtidal (15ft) on red algae	MA	41.93361, -70.56046
GWS017837	BC, DM, MB, AS & CL	Subtidal (10ft) on rock	MA	41.52518, -70.67256
GWS017912	BC, DM, MB, AS & CL	Drift	MA	41.76767, -70.48495
GWS017914	BC, DM, MB, AS & CL	Drift	MA	41.76767, -70.48495
GWS018007	BC, DM, MB, AS & CL	Subtidal (22ft) on rock	RI	41.47910, -71.36066
GWS027802	GWS, KD, AS, MB & DM	Drift on algae	MA	41.75184, -70.1874
GWS027819	KD & DM	Subtidal (3 m) on Fucus	MA	41.75184, -70.1874
GWS027836	GWS, KD, AS, MB & DM	Subtidal (3 m) on cobble	MA	41.93361, -70.56046
GWS027863	GWS, KD, AS, MB & DM	Subtidal (3 m) on algae	MA	41.52518, -70.67256
GWS030121	AS	Subtidal (6 m) on algae	MA	41.52518, -70.67256
GWS030144	GWS	Drift on algae	MA	42.59798, -70.65501
GWS030145	GWS	Drift	MA	42.59798, -70.65501
GWS030148	GWS	Subtidal (3 m) on rock	MA	42.68502, -70.64148
GWS030151	GWS	Subtidal (3 m) on rock	MA	42.68502, -70.64148
GWS032028	GWS & AS	Subtidal (3 m) on rock	NS	44.50839, -64.12634
GWS032029	GWS & AS	Subtidal (3 m) on rock	NS	44.50839, -64.12634
GWS032030	GWS & AS	Subtidal (3 m) on rock	NS	44.50839, -64.12634
GWS032031	GWS & AS	Subtidal (3 m) on rock	NS	44.50839, -64.12634

[1]AS = Amanda Savoie; BC = Bridgette Clarkston; CL = Caroline Longtin; CS = Craig Schneider; DM = Dan McDevit; GWS = Gary W. Saunders; KD = Kyatt Dixon; MB = Meghann Bruce.
[2]MA = Massachusetts; NS = Nova Scotia; RI = Rhode Island.