

THE MARINE MACROALGAE OF BRIER ISLAND, NOVA SCOTIA, CANADA*

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ABSTRACT

From May to October 2017 seaweeds were identified in the field and laboratory from 20 sites around Brier Island, Nova Scotia. While most sites were intertidal rocky shores, there were one small salt marsh and one eelgrass bed included in the study, and some subtidal sampling was conducted utilizing SCUBA and snorkeling. The Brier Island seaweeds comprised 152 species and varieties of which 62 were Rhodophyta, 44 were Chlorophyta, 44 were Phaeophyceae, and two species were Xanthophyceae. Three species were new records for eastern Canada: *Colaconema bonnemaisoniae*, *C. endophyticum*, and *Elachista stellaris*, all were previously recorded from New England. The flora included eight non-native species of which *Colpomenia peregrina* and *Bonnemaisonia hamifera* (both gametophytic and tetrasporophytic stages) were abundant at two or more sites, and the invasive *Codium fragile* subsp. *fragile* was recorded based on a single drift specimen. With 150 species and varieties of seaweeds, Brier Island has the highest species richness of a limited area of eastern Canada. The Cheney floristic index at 2.4 is higher than comparable areas, and suggests that many additional brown algae remain to be found.

Keywords: Chlorophyta, *Colaconema*, Bay of Fundy, Brier Island, Phaeophyceae, Rhodophyta, seaweeds

INTRODUCTION

Brier Island, Nova Scotia (44°15'N, 66°22'W) is the most westerly point in Nova Scotia, at the end of Digby Neck and Long Island, in

* We dedicate this paper to three pioneers of the seaweed flora of the Maritime Provinces: Tikvah Edelstein, Constance MacFarlane, Jack McLachlan

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the outer Bay of Fundy. A portion is under management by the Nature Conservancy of Canada as part of an effort to preserve native habitat of the globally endangered *Geum peckii* Pursh¹ (Rosaceae). With its highly exposed location in the Bay of Fundy, a largely undisturbed shoreline, and a diversity of habitats, a baseline study of Brier Island provides a baseline for long-term monitoring of impacts of sea level rise, climate change and invasive organisms. Here we provide a floristic study of the marine macroalgae carried out in 2017.

The marine macroalgal flora of Brier Island was initially investigated by Edelstein *et al.* (1970) as part of a detailed floristic and seasonal study of Digby Neck and adjacent Long and Brier Islands. While the Brier Island flora was not treated separately, the subsequent review of seaweed distributions for the Bay of Fundy by Wilson *et al.* (1979) included 66 species on Brier Island including 30 Rhodophyta, 9 Chlorophyta and 27 Phaeophyceae. No comprehensive account of the algae followed, although more focused observations of individual species and single sites were undertaken as part of more geographically wide-ranging studies. For example, Novaczek and McLachlan (1989) carried out a single transect on Brier Island at North Point as part of transects on rocky intertidal shores of the Maritime provinces, although the results for Brier Island were merged with those of other sites in the outer Bay of Fundy. Further physiological and ecological studies were carried out on *Palmaria palmata* (e.g. Garbary *et al.* 2012), *Prasiola stipitata* (Kang *et al.* 2014); *Ascophyllum nodosum* and *Vertebrata lanosa* (Garbary 2017a); and *Prasiola crispa* (Garbary and Hill 2017). There are complementary floristic studies from the western side of the Bay of Fundy in both Canada and USA. These include South *et al.* (1986) for Passamaquoddy Bay, Bates *et al.* (2009) for coastal New Brunswick, Mathieson *et al.* (2009) for Cobscook Bay, Maine, and Mathieson (2018) for northeastern ('downeast') Maine. Here we present a list of the seaweeds of Brier Island based on sampling from May to October 2017, and discuss our findings in the context of seaweed distributions in the Maritime Provinces and adjacent northeastern United States. This new species list provides a detailed account for an area that has received little attention for about 50 years.

¹ Authorities for species are provided in the text only when they are not included in Appendix 1.

MATERIALS AND METHODS

Brier Island has a circumference of about 24 km (Fig 1). It has a boreal climate, and as a consequence of being surrounded by the cold waters and large tides of the Bay of Fundy, its maritime climate tends to have cooler summers and milder winters than the rest of Nova Scotia. The island is sparsely settled with a single community of Westport (population *ca.* 220), where economic activity focuses on fishing and ecotourism. Much of the terrestrial landscape consists of secondary growth of boreal forest (mostly black spruce) undergoing secondary succession from abandoned agricultural and logging activity. There are extensive peatlands, some of which are inhabited by *Geum peckii*. The western side of the island has a fringe of coastal heaths in which the invasive *Rosa rugosa* Thunberg has become dominant and is outcompeting both herbaceous and shrubby vegetation on the coastal fringe (Garbary *et al.* 2013).

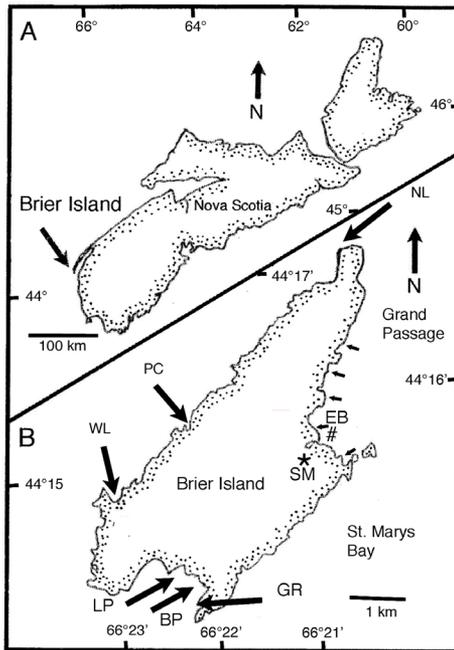


Fig 1 Map of Nova Scotia (A) and Brier Island (B) indicating primary collection sites. Abbreviations and symbols: NL, Northern Light; PC, Pero Jack Cove; WL, Western Light; LP, Little Pond Cove; BP, Big Pond Beach; GR, Gull Rock Point; SM, salt marsh*; EB, eelgrass bed#; small arrows, Westport Village.

Table 1 Primary sites on Brier Island sampled for seaweed biodiversity and sampling dates. Primary sites were visited multiple times on low tides. Secondary sites were visited once on poor tide, or by SCUBA. Coordinates indicate approximate midpoint on the shore, taken from Google Earth. Primary sites listed counter-clockwise from Northern Light. See Fig 1 for locations. All sampling times are from 2017.

Site	Latitude (°N)	Longitude (°W)	Dates sampled (day/month)
Primary sites			
Northern Light	44°19.19'	66°20.64'	13/5, 2/6, 23/6, 27/7, 2/9, 6/10
Pero Jack Cove	44°15.97'	66°22.07'	24/6
Western Light	44°14.94'	66°23.46'	1/6, 22/6, 25/7, 7/10
Little Pond Cove	44°14.35'	66°22.71'	11/5, 25/6, 26/7, 28/8, 8/10
Big Pond Cove	44°14.35'	66° 22.28'	12/5, 24/6, 6/10
Gull Rock Point (east side Big Pond Cove)	44°14.15'	66°22.22'	29/7
Grand Passage (Westport)	44°15.90'	66°20.95'	10/5, 21/6, 22/6, 26/6, 23/7, 28/7, 31/8, 8/10
Westport eelgrass*	44°15.62'	66°20.94'	23/7, 27/8 [#] , 29/8 [#] , 7/10
Westport salt marsh*	44°15.56'	66°21.15'	4/6, 22/7, 6/10
Secondary sites			
North of Pero Jack Cove	44°16.30'	66°21.99'	13/5
Westport, floating dock ¹	44°15.50'	66°20.84'	21/6
Hog Cove	44°13.92'	66°22.23'	21/6
Peters Island [#]	44°15.52'	66°20.19'	27/8
Gull Rock [#]	44°11.28'	66°25.21'	28/8
Whipple Point [#]	44°14.38'	66°22.96'	28/8
Gull Rock [#]	44°12.29'	66°23.90'	28/8
Northwest ledges [#]	44°21.09'	66°21.77'	29/8
Seal Cove [#]	44°17.26'	66°20.75'	29/8
Gull Rock (east side) [#]	44°12.80'	66°23.10'	30/8
Gull Rock (west side) [#]	44°12.84'	66°23.32'	30/8
North Point (east side)	44°16.90'	66°20.46'	3/9

* Coordinates from centre of habitat/site

DFO SCUBA sampling

¹ floating dock pulled ashore – unknown provenance

The bedrock is the endpoint of a basalt ridge that extends 200 km along much of the southern shore of the Bay of Fundy (Roland 1982). The intertidal zones (Tables 1, 2) are mostly exposed basalt bedrock and boulder fields (Fig 2) with numerous rock pools (Fig 3). The shores include steep cliffs rising about 10 m above the intertidal zone, gently sloping shores comprising boulder fields, a single sandy beach, and some muddy-gravel shores associated with the village of Westport. A salt marsh (*ca.* 2 ha) on the landward side of the main road at Westport is part of the drainage from the eutrophic Big Meadow

Table 2 Summary of primary physical features of sampling sites. Width of site refers to portion of shore explored. Site length refers to length of intertidal zone.

Site	Width of site (m)	Site length (m)	Primary substrata	Comments
Northern Light	180	140	Boulder fields, bedrock, tidal pools	Most wave-exposed site
Pero Jack Cove	80	100	Boulder field, bedrock, freshwater inflow	
Western Light	50	75	Boulder field, bedrock	Extensive platform at low water, protected by islets and headlands
Little Pond Cove	100	500	Boulder field, bedrock, numerous shallow pools	Protected by ridges of basalt bedrock
Big Pond Cove	400	NA	Sandy gravel beach with some cobble	Visited for wrack collection
Gull Rock point	200	60	Boulder field with low pools	
Grand Passage (Westport)	1500	50-100 m	Boulder fields, mud, wood pilings, concrete walls, floating dock	Low wave-exposure
Westport eelgrass bed	> 100	NA	Eelgrass in muddy sand	Requires spring tides
Westport salt marsh	100	150	Marsh mud/peat, sides of drainage channel, high pools with floating mats	Limited tidalmarsh exchange via culvert

Bog into the ocean. In addition, two tiny remnants of salt marsh (each *ca.* 20 x 10 m) of *Spartina alterniflora* Loisel. remain on the seaward side where Big Meadow Bog drains into Grand Passage via a culvert. A single bed of *Zostera marina* occurs in the low intertidal and shallow subtidal zone at Westport (Fig 1) and is bounded on the seaward side by an active salmon aquaculture facility. Artificial substrata of concrete at the government wharf and ferry terminal, a floating dock in the main harbour, and numerous pilings associated with the fishing industry wharfs and fish shacks provide extensive wood substrata. Remnant pilings from the destruction caused by the



2



3



4

Figs 2-4 Selected intertidal habitats for macroalgal collections. (2) Shore at Little Pond Cove at low tide with numerous shallow pools. (3) Mid-shore rock pool at Northern Light with diversity of algae including: *Alaria esculenta* (with midrib), *Chaetomorpha melagonium* (green hair), and *Corallina officinalis* (calcified pink alga). (4) Low intertidal rock pool at Northern Light with *Laminaria digitata* and diverse algae in background.

February 2, 1976 Groundhog Day gale are also scattered along the shorefront of Westport.

Marine algae were collected between May and October 2017 around Brier Island (Fig 1, Table 1). The primary sites (i.e., Western Light, Little Pond Cove, Big Pond Cove, Northern Light, Westport shore and eelgrass bed) were visited multiple times. One to three people visited a site on a tide and attempted to collect all of the species present. Field work was carried out such that collections were undertaken during periods that overlapped with spring tides. Many conspicuous algae were simply noted in the field at each site, and general collections were returned to a field laboratory on Brier Island to identify species requiring microscopic evaluation, and to examine large plants for epiphytic and endophytic taxa. Algae were typically processed while fresh, with voucher specimens prepared for deposit in regional herbaria at ACAD and STFX. Microscopic species were prepared as semi-permanent slides in 40% clear corn syrup. Subtidal collections were carried out by snorkeling at low water in July, and some additional collections were made in late August-early September by SCUBA divers from the Department of Fisheries and Oceans collecting at *ca.* 10 m depth (Table 1). We use the floristic index of Cheney [1977; = (#green algae + # red algae) / # brown algae] to compare other regional floras.

Mathieson and Dawes (2017) was the primary resource for keys and descriptions, although Brodie *et al.* (2007) was especially useful for green algae, Bird and McLachlan (1992) for red algae, and Fletcher (1987) for brown algae. Keys in Sears (1998) and Villalard-Bohnsack (2003) were also useful. Authorities for all algal species identified are given Appendix 1.

RESULTS

Over 1,100 identifications of 152 species and varieties of marine and brackish water macroalgae were recorded from Brier Island (Appendix 1). These species included 62 Rhodophyta, 44 Chlorophyta and 44 Phaeophyceae and two species of *Vaucheria* (Xanthophyceae). Of these species, over 35 were new for Digby Neck, 12 were new for the Bay of Fundy, one was new for Nova Scotia, and three were new records for Canada (Table 3).

Table 3 New distribution records for Brier Island and associated geographic areas.

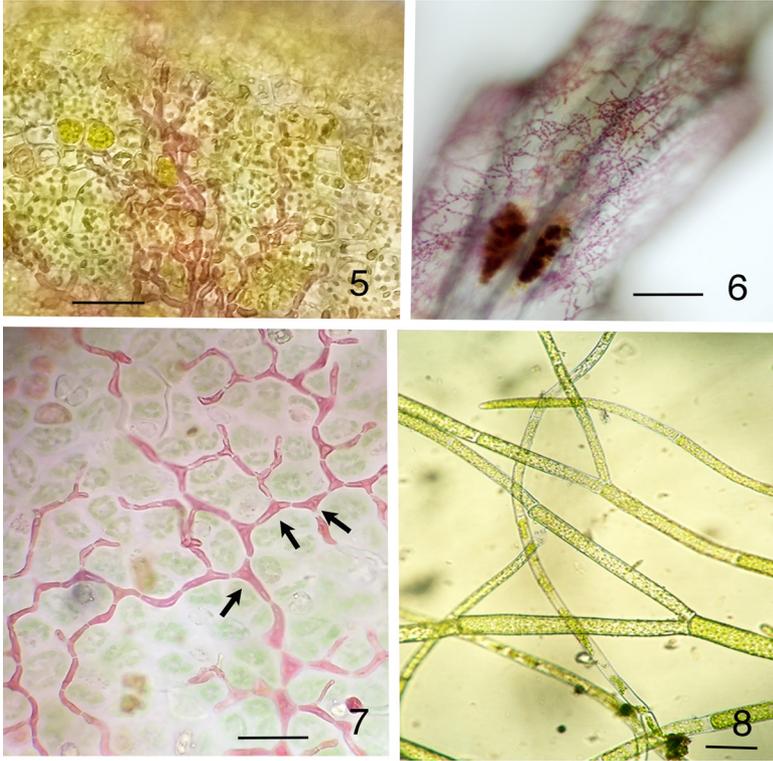
Species	Eastern Canada	Bay of Fundy	Digby Neck	Comment
Chlorophyta				
<i>Blidingia subsalsa?</i>			+	Requires culturing to distinguish from <i>B. ramifera</i> (Garbary and Barkhouse 1987)
<i>Capsosiphon fulvescens</i>			+	
<i>Chaetomorpha picquotiana</i>			+	
<i>Chlorochytrium cohnii</i>			+	
<i>Cladophora liniformis</i>		+	+	High marsh pool; new record for Nova Scotia
<i>Codium fragile subsp. fragile</i>		+	+	Single drift specimen
<i>Derbesia marina</i>			+	
<i>Eugomontia sacculata</i>		+	+	
<i>Percursaria percursa</i>			+	
<i>Prasiola crispa</i>		+	+	See Garbary and Hill (2017)
<i>Pseudoclonium dynamenae</i>			+	
<i>Pseudothrix borealis</i>			+	
<i>Tellamia contorta</i>			+	
<i>Ulothrix laetevirens</i>			+	
<i>Ulothrix subflaccida</i>		+	+	
<i>Ulva torta</i>			+	
<i>Ulvella repens?</i>			+	Endophyte in <i>Elachista</i>
<i>Jucicola</i>				
Rhodophyta				
<i>Acrochaetium endozoicum</i>		+	+	Endozoic in bryozoan
<i>Acrochaetium humile</i>		+	+	
<i>Acrochaetium luxurians</i>		+	+	
<i>Acrochaetium minimum</i>		+	+	
<i>Acrochaetium parvulum</i>		+	+	
<i>Bonnemaisonia hamifera</i>			+	Abundant gametophytes and tetrasporophytes
<i>Coccotylus hartzii</i>			+	
<i>Colaconema bonnemaisoniae</i>	+	+	+	Common endophyte in <i>Bonnemaisonia hamifera</i>
<i>Colaconema endophyticum</i>	+	+	+	Rare endophyte in <i>Dictyosiphon</i>
<i>Colaconema daviesii</i>			+	
<i>Erythrotrichia carnea</i>			+	
<i>Lithothamnion glaciale</i>			+	
<i>Pneophyllum fragile</i>			+	
<i>Rhodomela lycopodioides</i>			+	
<i>Rhodophysema georgii</i>			+	
<i>Scagelia pylaisaei</i>			+	

Table 3 Cont'd

Species	Eastern Canada	Bay of Fundy	Digby Neck	Comment
Phaeophyceae				
<i>Colpomenia peregrina</i>			+	Abundant at several sites
<i>Dictyosiphon eckmannii?</i>			+	
<i>Ectocarpus siliculosus</i> var. <i>pygmaeus</i>			+	
<i>Elachista stellaris?</i>	+	+	+	Epiphyte on <i>Vertebrata lanosa</i>
<i>Sphacelaria rigidula?</i>			+	
<i>Spongonema tomentosum</i>			+	
Xanthophyceae				
<i>Vaucheria intermedia</i>		+	+	
<i>Vaucheria</i> sp.	?	?	+	Non-reproductive

Three distinct intertidal habitats were explored: 1) the rocky intertidal zone of the west side of the island, 2) the bed of *Zostera* in Grand Passage, and 3) the salt marsh at Westport. The majority of species occurred on the rocky intertidal of the west side (121 species with 69 exclusive species), 38 species (8 exclusive) were found in the eelgrass bed, and 15 species (7 exclusive) were found in the salt marsh (Appendix 1). Two species, *Melanosiphon intestinalis* and *Peyssonnelia rosenvingei* were found only on artificial structures in Westport village; the former was associated with an old piling north of the ferry terminal, and the latter grew on concrete at the ferry terminal.

Following the species concepts in Garbary *et al.* (1982) and Mathieson and Dawes (2017) we identified two endophytic algae for the first time in eastern Canada: *Colaconema endophyticum* and *C. bonnemaisoniae* (Figs 5, 7). Both species were previously recorded in the northwestern Atlantic Ocean only south of Cape Cod (Mathieson and Dawes 2017). The former species had very small cells (< 10 μm long) and the single parietal chloroplasts were devoid of pyrenoids. The latter species had much larger cells (15-30 μm), each with a single parietal chloroplast and pyrenoid. *C. endophyticum* was found once in *Dictyosiphon foeniculaceus* in the subtidal zone south of Northern Light on the Fundy shore. *C. bonnemaisoniae* was more common and observed ten times in the gametophytic phase of *Bonnemaisonia hamifera*, and was particularly conspicuous in the cell walls of the hooked branches of its host when host tissue was



Figs 5-8 Photomicrographs of selected endophytic red algae (Figs 5-7) and a free-living green alga. (5) *Colaiconema endophytica* in outer cell wall of *Dictyosiphon foeniculaceus*. Scale bar = 20 μm . (6) *Acrochaetium endozoicum* in bryozoan. Scale bar = 100 μm . (7) *Colaiconema bonnemaisoniae* endophytic in outer wall of *Bonnemaisonia hamifera*; arrows indicate single pyrenoid in each cell. Scale bar = 25 μm . (8) *Cladophora liniformis* in high salt marsh pool. Scale bar = 100 μm ,

bleached or senescent. While no attempt was made to quantify the occurrence of *C. bonnemaisoniae*, only a few specimens of the host gametophytes were required to find the endophyte. Accordingly, it probably is fairly common. Another endobiotic species is the rare *Acrochaetium endozoicum* (Fig 6). It occurred in a bryozoan epiphytic on *Chaetomorpha melagonium* in a low shore rock pool. This was only the second record of this species in Canada. The single previous Canadian record is from the sublittoral of Halifax County (Edelstein *et al.* 1969).

The identification of *Elachista stellaris* was somewhat problematic as the identification keys are based primarily on host identity.

Our material was a common epiphyte on *Vertebrata lanosa* and was identified seven times in the collections. The thalli were very small relative to *E. fucicola*, and only 1-2 mm high. A single clump of the host sometimes had five or six thalli. In both Europe and North America, *E. stellaris* is reported from a variety of hosts but neither *Ascophyllum* nor *Fucus* which are regarded as the only hosts for *E. fucicola* (Fletcher 1987, Mathieson and Dawes 2017). Host switching of *E. fucicola* onto *V. lanosa* remains a possibility.

Two species of *Vaucheria* were present in the salt marsh: *V. intermedia* and *Vaucheria* sp., which, in the absence of gametangia, could not be identified to species. Its narrow filaments (*ca.* 20 μm) and the absence of reproduction suggest *V. minuta* Blum & Conover, but further collections are needed to confirm this identification (see Mathieson and Dawes 2017).

Cladophora liniformis (Fig 8) formed an extensive floating mat in a high pool in the salt marsh at Westport, where it was the dominant species and mixed with *Ulva torta* (new for Digby Neck). *C. liniformis* was not previously recorded from Nova Scotia, and previous records from eastern Canada were questioned by South (1984).

DISCUSSION

Species richness in the Maritime Provinces and Gulf of Maine

The 152 species and varieties of seaweeds identified on Brier Island in 2017 indicate a relatively diverse flora in a limited geographic area. The Brier Island flora thus represents 60% the 254 species of red, brown and green seaweeds for the Bay of Fundy reported by Wilson *et al.* (1979) for New Brunswick and Nova Scotian shores to Cape Sable Island (Table 4). This difference in species richness is explained by the much larger area and greater diversity of habitats in the Bay of Fundy as a whole. In addition, the Wilson *et al.* inventory included historical collections made over more than 50 years; thus, the greater likelihood of including rare taxa.

A primary objective of this work was to compare the current flora of Brier Island to that detailed by Edelman *et al.* (1970) based largely on collections from Digby Neck, with only limited sampling undertaken on Brier Island. The species identified in that study and other incidental collections on Brier Island in the ensuing years were mapped by Wilson *et al.* (1979). While the algal distributions

Table 4 Comparison of the seaweed flora of Brier Island with other localized floristic lists in Nova Scotia, New Brunswick and Maine indicating numbers of Chlorophyta (G), Phaeophyceae (P), Rhodophyta (R), and Xanthophyceae. The Cheney (1977) floristic index, (#R + #G) / #P is provided for each flora (see text for discussion).

Flora	Chlorophyta	Phaeophyceae	Rhodophyta	Xanthophyceae	Total	Index
Brier Island	44	44	62	2	152	2.4
Digby Neck ¹	33	61	52		146	1.4
Bay of Fundy ²	62	93	99		254	1.7
Passamaquoddy Bay ³	45	58	68		171	1.9
Cobscook Bay ⁴	38	46	64		148	2.2
New Brunswick (coast) ⁵	16	25	31		72	1.9
Bras d'Or Lake ⁶	23	31	31		85	1.7
Pomquet Harbour ⁷	39	44	32	5	120	1.6
Prince Edward Island (north shore ⁸)	19	50	52		131	1.6

¹ Edelstein *et al.* 1970 (duplicate records based on life history phase removed)

² Wilson *et al.* 1979

³ South *et al.* 1988 (numbers based on only summer collections)

⁴ Mathieson *et al.* 2010

⁵ Bates *et al.* 2009 (numbers based on strictly intertidal observations)

⁶ McLachlan and Edelstein 1970

⁷ Bird *et al.* 1976

⁸ Bird *et al.* 1983

reported by Edelstein *et al.* (1970) for Brier Island (as given in Wilson *et al.* 1979) were clearly limited because of collection intensity, many of those species can reasonably be expected to occur on Brier Island today. This list includes five brown algae: *Punctaria tenuissima* (C.Agardh) Greville [as *Desmotrichum undulatum* (J.Agardh) Reinke], *Entonema polycladum* (Jaasund) Jaasund, *Eudesme virescens* (Carmichael ex Berkeley) J.Agardh, *Microspongium globosum* Reinke, and *Myriotrichia claviformis* Harvey (as *M. filiformis* Harvey). A sixth species *Stragularia clavata* (Harvey) Hamel (as *Ralfsia bornetii* Kuckuck) is now considered the sporophytic phase of Scytosiphonaceae (see Mathieson and Dawes 2017). In addition, one green alga, *Ulva rigida* C.Agardh, and three red algae, *Harveyella mirabilis* (Reinsch) F.Schmitz & Reinke, *Hydrolithon farinosum* (J.V.Lamouroux) Penrose and Y.M.Chambelain, and *Leptophytum leave* Adey were listed. Most of these algae could reasonably be expected to occur on Brier Island. Of these, *Hydrolithon farinosum* is typically found as an epiphyte on *Zostera marina* Linnaeus during fall and winter (Mathieson and Dawes 2017), for which we had only limited collections.

South *et al.* (1988) reported 176 species from Passamaquoddy Bay. While this was more than the 150 species we found on Brier Island, theirs was over a collection area at least several orders of magnitude greater, and encompassing habitats (e.g., estuaries) not found on Brier Island. Their study was also based on extensive subtidal sampling via SCUBA with experienced phycologist-divers including a specialist on crustose coralline algae. Moreover, the total for that list included many species that were not found specifically in the study area but were assumed to be present based on reports from the outer Bay of Fundy. While more species might be found on Brier Island with winter collections and more extensive subtidal sampling, our number of summer species is unlikely to be significantly increased.

The bed of *Z. marina* has endured two major environmental impacts since the 1970s that could well have limited species richness. The first was storm damage from the Groundhog Day gale (2/2/1976) that destroyed the waterfront of Westport and sent seawater across 3 km of the island through the low-lying Big Meadow Bog. This would have severely impacted the eelgrass bed. Subsequently, a salmon aquaculture facility was installed adjacent to the *Z. marina* bed, with possible effects on trophic levels. The extensive diatom growth we observed on leaf blades may have limited colonisation of

epiphytic macroalgae. Even in its current state, *Z. marina* provided a habitat for 38 species, mostly as leaf epiphytes. The single collection of *Derbesia marina* was an unattached mat from within the eelgrass bed. Should storm action or sea-level rise cause a major breach in the barrier beach at Big Pond Cove, this would create a large area suitable for colonisation by *Z. marina* and its epiphytes.

Some species not recorded for Brier Island relative to the Edelstein *et al.* (1970) inventory may result from algal seasonality. Hence *Porphyra linearis* Greville, *Ulvella parasitica* (Oltmanns) R.Nielsen, C.J.O'Kelly & B.Wysor (as *Acrochaete*), and *Chlorochytrium dermatocolax* Reinke were found only in the winter, and probably explains why these species were not found in the current study.

In Nova Scotia and the southern Gulf of St. Lawrence, three additional species lists of marine algae have been compiled for limited geographic areas: Bras d'Or Lake, Pomquet Harbour, and the north shore of Prince Edward Island (Table 4). All have lower diversity (85 to 131 species) even though Bras d'Or Lake and Prince Edward Island have much greater coastal areas. Only Cobscook Bay in Maine, with a much larger shoreline, has an equivalent species richness to Brier Island (148 vs 152).

The Cheney (1977) index for the floras in Table 4 ranges from 1.6 to 2.4, suggesting that these floras are all boreal, with cold-water affinities. It is of note that Brier Island has the highest value (2.4) with Cobscook Bay close at 2.2. This suggests that the Brier Island flora is underrepresented in brown algae. The inventories of species in Edelstein *et al.* (1970) and Wilson *et al.* (1979) recorded from Digby Neck that were not found in the current study include ten green algae, 24 brown algae, and nine red algae. Should all of these species occur as well on Brier Island it would raise the species number to 184, more than the 176 species from Passamaquoddy Bay on the opposite side of the Bay of Fundy. In addition, it would lower the Cheney index to 1.8, consistent with other regional floras.

Introduced seaweeds

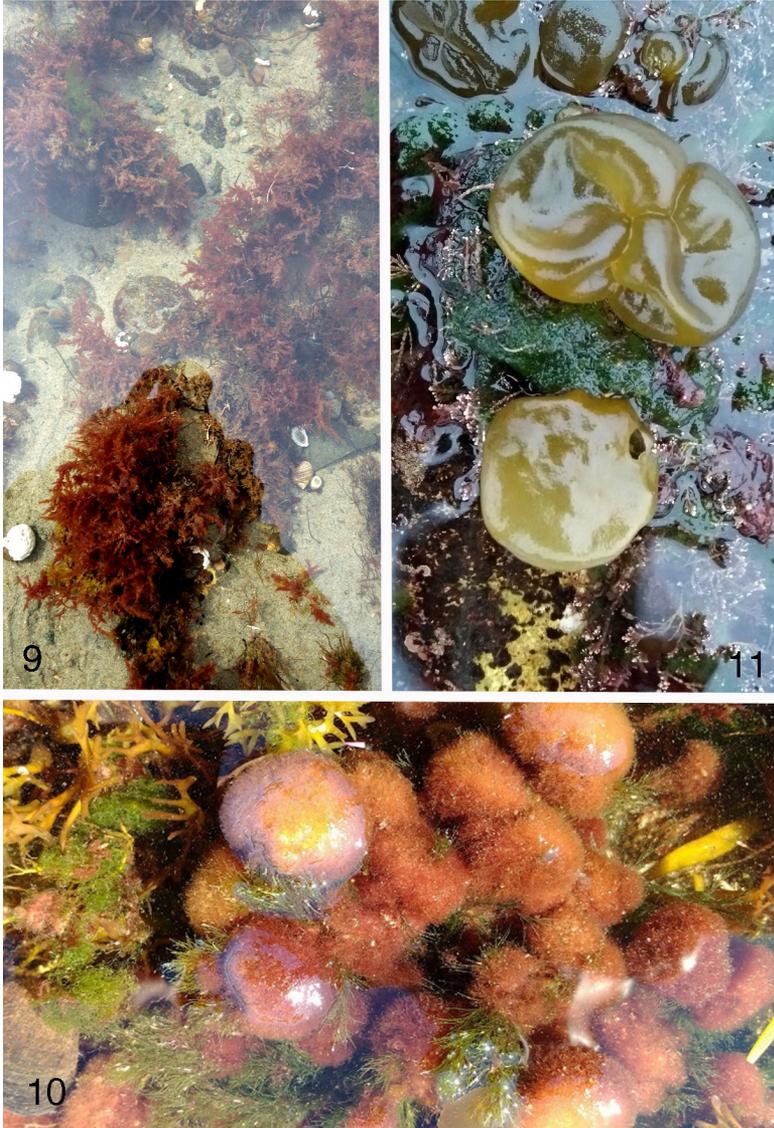
Mathieson and Dawes (2017) provided a list of 32 introduced species for the northwest Atlantic Ocean. Seven of these were found on Brier Island: *Codium fragile* subsp. *fragile*, *Colpomenia peregrina*, *Melanosiphon intestinalis*, *Ulonea rhizophorum*, *Bonnemaisonia hamifera*, *Ceramium secundatum*, and *Dumontia contorta*. Several of these species appear to be naturalized (e.g., *M. intestinalis*,

U. rhizophorum, *Ceramium secundatum*, and *D. contorta*) without invasive properties. The non-native, Nova Scotian invasive species, *Fucus serratus* Linnaeus, was not observed. The introduction and spread of *F. serratus* in Nova Scotia were discussed by Edelman *et al.* (1971-1973), and the closest reported populations are in southwestern Nova Scotia, about 50 km south from Brier Island (Wilson *et al.* 1979).

Bonnemaisonia hamifera

There was an abundance of both the tetrasporophytic and gametophytic phases of the introduced species *Bonnemaisonia hamifera* (Figs 9, 10). Neither life-history stage of this species was recorded by Edelman *et al.* (1970) or Wilson *et al.* (1979) for Digby Neck, and the nearest recorded populations were in the Yarmouth area, about 75 km south from Brier Island. In 2017, it would have been difficult to avoid these tetrasporophytic plants (i.e., the *Trilliella*-phase) in a general collection from any rocky shore on the island where it formed distinct epiphytic tufts up to several cm wide or occurred as scattered filaments in most rock pools. In subtidal collections, it was associated with kelp holdfasts and diverse red algae. Similarly, the gametophytic stage occurred at every site, and fragments were common in the drift or attached via their hooked branches to other macrophytes. In mid- to low-intertidal rock pools it was abundant and seemingly replaced the expected populations of *Ceramium virgatum*.

Chen *et al.* (1970) described the vegetative development of gametophytic plants directly from the *Trilliella*-phase, and this might account for the abundance of gametophytes on Brier Island. Alternatively, the abundance of the gametophytic phase of *B. hamifera* might also reflect warming of the Bay of Fundy (Hebert *et al.* 2018). Breeman *et al.* (1988) showed that the life history of *B. hamifera* in Europe was regulated by both temperature and daylength. Tetrasporangia formed when water temperatures were over about 11°C and daylength was less than 12 h of light. We suggest that appropriate conditions for tetrasporangial production had been reached in late summer and fall of 2016, and that the resulting tetraspores produced the gametophytes that we observed in 2017. Whereas tetrasporophytes were present in our mid-May collections, the larger gametophytic phase was not noted until late June. That is, the gametophytes that we observed appeared not to have overwintered as large plants, but must have developed in late spring to early summer. This seems inconsistent with the finding of gametophytes in winter along the Atlantic coast of Nova Scotia



Figs 9-11 *In situ* photographs of two non-native species common on Brier Island. (9) Dense population of gametophytic stage of *Bonnemaisonia hamifera* in low intertidal rock pool (figure courtesy of Roy Gjelstad). (10) Dense population of tetrasporophytic stage (*Trailiella*-phase) of *Bonnemaisonia hamifera* in rock pool; each 'pom-pom' about 2 cm in diameter. (11) Two thalli of *Colpomenia peregrina* with larger thallus about 10 cm diameter.

(Chen *et al.* 1969). We saw no thalli with male or female gametangia, or cystocarps, although spermatangia, carpogonia and rudimentary pericarps have been recorded from Nova Scotia (Chen *et al.* 1969, 1970; Bird 1980). In addition, none of the tetrasporophytic thalli we observed had produced tetrasporangia by early October. In view of this, it will be interesting to see if *B. hamifera* gametophytes are as abundant in the future.

Colpomenia peregrina

Colpomenia peregrina (Fig 11) was abundant at two sites on the west side of Brier Island, at Little Pond Cove and Pero Jack Cove. It has been considered rare on the Atlantic coast of Nova Scotia (Bird and Edelstein 1978) where it was found only at a few widely separated locations, in the sublittoral zone down to 3-5 m. It has since then become a regularly occurring species in Halifax County, where it is collected by SCUBA divers (B. Hymes pers. comm.). On Brier Island the species was found in July-August at low water on spring tides, attached to *Mastocarpus stellatus* and *Corallina officinalis*, with many thalli exposed. Thalli were up to 20 cm in diameter. Despite considerable wave exposure on the west side of the island, the two locations were protected from waves by offshore rock outcrops and nearby headlands. Green *et al.* (2012) described the southward extension of *C. peregrina* in the northwest Atlantic Ocean, and it now occurs as far south as Cape Cod. The findings on Brier Island represent an almost 100 km extension of the distribution from previous records in southwestern Nova Scotia. The abundance of *C. peregrina* may suggest aggressive colonization, as the species is considered a potential oyster-thief in Maine (Green *et al.* 2012) and the Mediterranean Sea (Verlaque *et al.* 2015). However, with its general lack of robustness in thallus structure, it is unlikely to become an aggressive invasive species on the exposed shores of Brier Island.

Melanosiphon intestinalis

Melanosiphon intestinalis, first reported by Edelstein *et al.* (1970a, b) as a new record for eastern North America from Digby Neck, is now known from Long Island (New York) to Labrador (Mathieson *et al.* 2008; Mathieson and Dawes 2017). On Brier Island, it was found on a single exposed piling in Westport village, and thalli were 1-2 cm long. One of us (CJB) recalls that this species was previously abundant on the wall of the local ferry terminal (*ca.* 1970).

Extensive searches there and elsewhere on Brier Island failed to locate additional populations. In addition, thalli were mostly less than 1.5 cm long and about 1 mm wide, suggesting that the species may be on the verge of extirpation from environmental or competitive interactions.

Codium fragile* subsp. *fragile

Codium fragile subsp. *fragile* has an extensive distribution along the Atlantic coast of Nova Scotia from Yarmouth to Canso and in the southern Gulf of St. Lawrence (Watanabe *et al.* 2010). These distributions were likely based on independent introductions in Mahone Bay (Bird *et al.* 1993) and Prince Edward Island (Garbary *et al.* 1997, Hubbard and Garbary 2001). We found a single thallus (*ca.* 12 cm high) on the last collecting period in October amongst extensive mounds of seaweed wrack at Big Pond Cove, and none was found in four visits to Big Pond Cove in 2018. This suggests either that it had been transported a long distance as drift, or that a population on Brier Island had only recently been established. The SCUBA diving by DFO in late August/early September at eight locations found no *C. fragile*; if any populations are present, they are likely to be limited. The nearest known populations are in southwestern Nova Scotia (*ca.* 100 km from Brier Island; Watanabe *et al.* 2010). The species is well established in the Gulf of Maine (Mathieson *et al.* 2003), and the thallus on Brier Island may also have arrived via drift from northern Maine where it has been found in Cobscook Bay (Mathieson *et al.* 2010).

CONCLUSIONS

For its size, Brier Island possesses relatively species-rich communities of marine macroalgae in a limited geographic space. The three main community types of rocky intertidal zone, salt marsh and eelgrass beds all contribute unique species to the overall diversity of over 150 species of seaweeds. Given the relative isolation of the western shoreline of the island, and the already protected nature of key adjacent terrestrial habitats, Brier Island warrants consideration for protection of its coastal marine habitats.

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Appendix 1 List of species of macroalgae and their local distribution on Brier Island in 2017. Note: Eelgrass bed and salt marsh are specific habitats found within Westport which covers the shores along Grand Passage with various natural and built substrates. P = Present.

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Chlorophyta					
<i>Acrosiphonia arcta</i> (Dillwyn) Gain	P	P			
<i>Acrosiphonia sonderi</i> (Kützing) Kornmann	P				
<i>Acrosiphonia spinescens</i> (Kützing) Kjellman	P	P			
<i>Blidingia marginata</i> (J.Agardh) J.P.L. Dangeard ex Bliding			P		P
<i>Blidingia minima</i> (Nägeli ex Kützing) Kylin	P	P	P		P
<i>Blidingia subsalsa</i> (Kjellman) Kornmann & Sahling ex Scagel			P		
<i>Bolbocoleon piliferum</i> Pringsheim	P				
<i>Caposiphonia fulvescens</i> (C. Agardh) Setchell & N.L. Gardner					P
<i>Chaetomorpha brachygonia</i> Harvey	P			P	
<i>Chaetomorpha ligustica</i> (Kützing) Kützing	P	P	P	P	
<i>Chaetomorpha linum</i> (O.F. Müller) Kützing					
<i>Chaetomorpha melagonium</i> (F. Weber & D. Mohr) Kützing	P	P	P	P	P
<i>Chaetomorpha picquotiana</i> Montagne ex Kützing			P	P	
<i>Chlorochytrium cohnii</i> E. P. Wright			P		
<i>Cladophora liniformis</i> Kützing					P
<i>Cladophora rupestris</i> (Linnaeus) Kützing	P	P			
<i>Cladophora sericea</i> (Hudson) Kützing	P	P			
<i>Codium fragile</i> (Suringar) Hartot subsp. <i>fragile</i>		P			
<i>Derbesia marina</i> (Lyngbye) Solier					P
<i>Eugomontia sacculata</i> Kornmann		P	P		
<i>Gayralia oxysperma</i> (Kützing) K. L. Vinogradova ex Scagel <i>et al.</i>		P	P		

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
<i>Gomontia polyrhiza</i> (Lagerheim) Bornet & Flahault			P	P	
<i>Monostroma grevillei</i> (Thuret) Wittrock	P	P			P
<i>Percursaria percursa</i> (C.Agardh) Rosenvinge	P				
<i>Prasiola crispa</i> (Lightfoot) Kützing	P	P	P		
<i>Prasiola stipitata</i> Suhr ex Jessen	P				
<i>Pseudoclonium dynamenae</i> R. Nielsen	P				
<i>Pseudolithrix groenlandica</i> (J.Agardh) Hanic & S.C.Lindstrom	P				
<i>Rhizoclonium riparium</i> (Roth) Harvey	P		P		P
<i>Spongomorpha aeruginosa</i> (Linnaeus) Hoek		P			
<i>Tellamia contorta</i> Batters	P				
<i>Ullothrix flacca</i> (Dillwyn) Thuret	P		P		
<i>Ullothrix speciosa</i> (Carmichael) Kützing	P				
<i>Ullothrix subflaccida</i> Wille			P		
<i>Ulva compressa</i> Linnaeus			P		
<i>Ulva intestinalis</i> Linnaeus	P	P	P	P	P
<i>Ulva lactuca</i> Linnaeus	P	P	P	P	P
<i>Ulva linza</i> Linnaeus	P	P			
<i>Ulva prolifera</i> O.F.Müller			P		
<i>Ulva toria</i> (Mertens) Trevisan					P
<i>Ulvaria obscura</i> (Kützing) Gayral ex Blieding	P		P	P	
<i>Ulvella repens</i> (Pringsheim) R.Nielsen, C.J.O'Kelley & B.Wysox		P			
<i>Urospora penicilliformis</i> (Roth) Areschoug	P				

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
Rhodophyta					
<i>Acrochaetium endozoicum</i> (Darbshire) Batters	P				
<i>Acrochaetium humile</i> (Rosenvinge) Borgesen		P		P	
<i>Acrochaetium luxurians</i> (J.Agardh ex Kützing) Nägeli				P	
<i>Acrochaetium parvulum</i> (Kyllin) Hoyt				P	
<i>Acrochaetium secundatum</i> (Lyngbye) Nägeli	P	P			
<i>Acrochaetium</i> sp.	P				
<i>Ahnfeltia plicata</i> (Hudson) Fries	P	P			
<i>Antithamionella floccosa</i> (O.F.Müller) Whittick	P	P	P		
<i>Bangia atropurpurea</i> (Mertens ex Roth) C.Agardh	P				
<i>Bonnemaisonia hamifera</i> Hariot	P	P	P		
<i>Ceramium deslongchampsii</i> Chauvin ex Duby	P	P	P		
<i>Ceramium secundatum</i> Lyngbye	P	P			
<i>Ceramium virgatum</i> Roth	P	P	P		
<i>Chondrus crispus</i> Stackhouse	P	P	P		
<i>Choreocolax polysiphoniae</i> Reinsch	P	P			
<i>Choreocolax rabenhorstii</i> Reinsch	P	P			
<i>Clathromorphum circumscriptum</i> (Strömfelt) Foslie					
<i>Coccolytus hartzii</i> (Rosenvinge) LeGall & G.W.Saunders	P	P			
<i>Coccolytus truncatus</i> (Pallas) M.J.Wynne & J.N. Heine	P				
<i>Colaconema bonnemaisoniae</i> Batters	P	P			
<i>Colaconema daviesii</i> (Dillwyn) Stegenga	P				
<i>Colaconema endophyticum</i> (Batters) J.T.Harper & G.W.Saunders	P ¹				
<i>Colaconema minimum</i> (Collins) Woelkerling	P				
<i>Coralina officinalis</i> Linnaeus	P	P			

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
<i>Cystoclonium purpureum</i> (Hudson) Batters	P	P			
<i>Devaleraca ramentacea</i> (Linnaeus) Guiry	P	P			
<i>Dumontia contorta</i> (S.G.Gmelin) Ruprecht	P	P	P	P	
<i>Erythrotrichia carnea</i> (Dillwyn) J.Agardh	P	P	P		
<i>Euthora cristata</i> (C. Agardh) J. Agardh	P	P	P		
<i>Fimbrifolium dichotomum</i> (Lepechm) G.I.Hansen	P	P	P		
<i>Hildenbrandia rubra</i> (Sommerfelt) Meneghini					
<i>Lithothamnion glaciale</i> Kjellman	P	P			
<i>Mastocarpus stellatus</i> (Stackhouse) Guiry	P	P	P	P	
<i>Meiodiscus spetsbergensis</i> (Kjellman) G.W.Saunders & McLachlan			P		
<i>Membranoptera fabriciana</i> (Lyngbye) M.J.Wynne & G.W.Saunders	P	P			
<i>Palmaria palmata</i> (Linnaeus) F.Weber & D.Mohr	P	P	P	P	
<i>Peyssonnelia rosenvingei</i> F.Schmitz					
<i>Phycodryx rubens</i> (Linnaeus) Batters	P	P	P		
<i>Phyllophora pseudoceranoides</i> (S.G.Gmelin) Newroth & A.R.A.Taylor ex P.S.Dixon & L.M.Irvine	P	P			
<i>Phymatolithon laevigatum</i> (Foslie) Foslie	P	P			
<i>Phymatolithon lenormanatii</i> (Areschoug) Adey	P	P			
<i>Plumaria plumosa</i> (Hudson) Kuntze	P	P			
<i>Pneophyllum confervicola</i> (Kützting) Y.M.Chamberlain					
<i>Pneophyllum fragile</i> Kützting					
<i>Polyides rotundus</i> (Hudson) Gaillon	P	P		P	
<i>Polysiphonia elongata</i> (Hudson) Sprengel			P		
<i>Polysiphonia flexicaulis</i> (Harvey) Collins			P	P	

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
<i>Polysiphonia stricta</i> (Mertens ex Dillwyn) Greville	P	P		P	
<i>Porphyra umbilicalis</i> Kützting	P	P	P	P	
<i>Ptilota serrata</i> Kützting	P	P			
<i>Pyropia leucosticta</i> (Thuret) Neefus & J.Brodie	P		P		
<i>Rhodochorton purpureum</i> (Lightfoot) Rosenvinge	P		P		
<i>Rhodomela confervoides</i> (Hudson) P.C.Silva	P				
<i>Rhodomela lycopodioides</i> (Linnaeus) C.Agardh		P			
<i>Rhodomela virgata</i> Kjellman	P			P	
<i>Rhodophysema elegans</i> (P.Crouan & H.Crouan ex J.Agardh) P.S.Dixon		P			
<i>Rhodophysema georgei</i> Batters			P	P	
<i>Rubrointrusa membranacea</i> (Magnus) S.L.Clayden & G.W.Saunders	P		P	P	
<i>Scagelia pylaisaei</i> (Montagne) M.J.Wynne	P	P	P	P	
<i>Titanoderma pustulatum</i> (J.V.Lamouroux) Nägeli	P	P			
<i>Verrebrata lanosa</i> (Linnaeus) T.A.Christensen	P	P	P		
<i>Wildemanita miniata</i> (C.Agardh) Foslie	P	P			
Unidentified red crust (non calcified)	P ²				
Phacophyceae					
<i>Agarum clathratum</i> Dumortier					
<i>Alaria esculenta</i> (Linnaeus) Greville	P				
<i>Ascophyllum nodosum</i> (Linnaeus) LeJolis	P		P		
<i>Asperococeus fistulosus</i> (Hudson) W.J.Hooker		P			
<i>Chordaria flagelliformis</i> (O.F.Müller) C.Agardh	P	P	P		
<i>Colpomenia peregrina</i> Sauvageau	P	P			

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
<i>Desmarestia aculeata</i> (Linnaeus) J.V.Lamouroux	P	P		P	
<i>Desmarestia viridis</i> (O.F.Müller) J.V.Lamouroux	P	P			
<i>Dictyosiphon chordaria</i> Areschoug	P				
<i>Dictyosiphon ekmanii</i> Areschoug				P	
<i>Dictyosiphon foeniculaceus</i> (Hudson) Greville	P	P		P	
<i>Ectocarpus fasciculatus</i> Harvey	P	P		P	P
<i>Ectocarpus siliculosus</i> (Dillwyn) Lyngbye	P				P?
<i>Ectocarpus siliculosus</i> var. <i>pygmaeus</i> (Areschoug) Gallardo	P	P	P		
<i>Elachista fucicola</i> (Velley) Areschoug	P	P	P		
<i>Elachista stellaris</i> Areschoug	P	P			
<i>Etonema polycladum</i> (Jaasund) Jaasund	P	P			
<i>Fucus distichus</i> Linnaeus subsp. <i>distichus</i>	P	P			
<i>Fucus distichus</i> subsp. <i>edentatus</i> (Bachelot de la Pylaie) H.T.Powell	P	P			
<i>Fucus distichus</i> subsp. <i>evanescens</i> (C.Agardh) H.T.Powell	P	P	P		
<i>Fucus spiralis</i> Linnaeus	P	P	P		
<i>Fucus vesiculosus</i> Linnaeus	P	P	P		P
<i>Halosiphon tomentosum</i> (Lyngbye) Jaasund		P			
<i>Isthmoplea sphaerophora</i> (Carmichael) Gobi	P				
<i>Laminaria digitata</i> (Hudson) J.V.Lamouroux	P	P	P		
<i>Leathesia marina</i> (Lyngbye) Decaisne	P	P			
<i>Melanosiphon intestinalis</i> (D. A. Saunders) M.J.Wynne			P		
<i>Microsporgium stilophorae</i> (P.Crouan & H.Crouan) Cormaci & G.Furnari		P			
<i>Mikrosyphar polyisiphoniae</i> Kuckuck	P				
<i>Myrionema corunnae</i> Sauvageau		P			

Appendix 1 cont'd

Appendix 1 Cont'd

Species	Northern Light to Western Light	Little Pond Cove to Gull Rock Point	Westport	Eelgrass bed	Salt marsh
<i>Myrionema magnusii</i> (Sauvageau) Loiseaux <i>nom. inval.</i>				P	
<i>Myrionema strangulans</i> Greville		P			
<i>Petalonia fasciata</i> (O.F.Müller) Kuntze	P		P	P	
<i>Planosiphon complanatus</i> (Rosenvinge) McDevit & G.W.Saunders				P	
<i>Planosiphon zosterifolius</i> (Reinke) McDevit & G.W.Saunders				P	
<i>Protolalopteris radicans</i> (Dillwyn) Draisma, Prud'homme & H.Kawai			P		
<i>Punctaria latifolia</i> Greville		P			
<i>Pylaiella littoralis</i> (Linnaeus) Kjellman	P	P	P	P	
<i>Ralfsia fungiformis</i> (Gunnerus) Setchell & N.L.Gardner	P	P			
<i>Ralfsia verrucosa</i> (Areschoug) Areschoug	P	P	P		
<i>Saccharina latissima</i> (Linnaeus) C.E.Lane, C.Mayes, Druehl & G.W.Saunders	P	P	P		
<i>Sacchoriza dermatodea</i> (Bachelot de la Pylaie) J.Agardh	P	P			
<i>Scytosiphon dotyi</i> M.J.Wynne			P		
<i>Scytosiphon lomentaria</i> (Lyngbye) Link	P	P	P		
<i>Sphacelaria rigidula</i> Kützting		P			
<i>Sphacelaria</i> spp.	P	P			
<i>Spongonema tomentosum</i> (Hudson) Kützting	P		P		
Xanthophyceae					
<i>Vaucheria intermedia</i> Nordsted					P
<i>Vaucheria</i> sp.					P

1 Northwest Ledges

2 Gull Rock – DFO diving

