Narragansett Bay
Research Reserve

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A protocol for rapidly monitoring macroalgae in the Narragansett Bay Research Reserve

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Introduction

Macroalgae (i.e., seaweed) is an important source of primary production in shallow estuarine systems, and at low to moderate biomass levels it serves as important refuge and forage habitat for nekton (Sogard and Able 1991; Kingsford 1995; Raposa and Oviatt 2000). Macroalgae is typically nitrogen limited in estuaries and it can therefore respond rapidly when anthropogenic nutrient inputs increase (Nelson et al. 2003). Under eutrophic conditions, macroalgae can shade and outcompete eelgrass and other submerged aquatic vegetation (SAV) species and lead to hypoxic and anoxic conditions that can alter estuarine ecosystem function (Peckol et al. 1994; Raffaelli et al. 1998). Macroalgae is therefore an excellent indicator of current estuarine condition and of how these systems respond to changes in the amount of anthropogenic nitrogen inputs.

Narragansett Bay is an urban estuary in Rhode Island, USA that receives high levels of nitrogen inputs from waste-water treatment facilities (WWTFs), mostly into the Providence River at the head of the Bay (Pruell et al. 2006). As a result, excessive summertime macroalgal blooms dominated by green algae (e.g., *Ulva* spp.) are a conspicuous and problematic occurrence in many parts of the upper Bay and in constricted, shallow coves and embayments (Granger et al. 2000). Many of these same areas also experience periods of bottom hypoxia during summer, but the degree to which this is caused by macroalgae has not been quantified. In fact, even though macroalgae is an excellent indicator of estuarine eutrophication, long-term quantitative macroalgal monitoring does not currently occur in Narragansett Bay. This is even more surprising given that expensive public efforts to reduce nitrogen inputs into the Bay from major WWTFs are ongoing; 30% of these inputs have already been reduced, and a total reduction of 50% from peak levels is slated to occur by 2014. It is imperative, therefore, to collect as much high-quality pre-reduction data on macroalgae composition, distribution, and cover as possible, and then to continue the same monitoring over time after the nitrogen reductions to evaluate change.

The purpose of this project is to collect pilot data that will be used to develop a quantitative rapid assessment macroalgal monitoring protocol at the Narragansett Bay National Estuarine Research Reserve (NBNERR or Reserve) on Prudence Island, RI. The resultant protocol will then be used to monitor macroalgae in the Reserve annually over time in order to quantify the extent to which algal demographics change in response to the large-scale WWTF nitrogen reductions. Since nuisance macroalgal blooms are not generally widespread around Prudence Island (Raposa personal observation), this protocol will also be distributed to appropriate scientists in the Narragansett Bay research community in an effort to expand its use to other areas of the Bay where macroalgal blooms are more problematic.

This project is based on a novel method for conducting rapid visual macroalgal surveys that was first used on Cape Cod, MA (Lyons et al. 2009). Briefly, this method involves defining the survey area, breaking up the shoreline of that area into equal intervals, and then conducting multiple intertidal and subtidal macroalgal surveys each year using a simple visual cover scale. These methods were essentially replicated at NBNERR in 2009 and 2010 in order to provide pilot data for developing an efficient yet quantitative long-term monitoring protocol for use in the Reserve and other parts of Narragansett Bay.

Methods

This project was conducted on Prudence Island, which is in the geographic center of Narragansett Bay (Fig. 1). Over 85% of the land on Prudence Island is protected as open space by the Reserve (which is based on Prudence), the Audubon Society of Rhode Island, and the Prudence Conservancy. The shoreline of Prudence Island extends for approximately 31 km and is largely comprised of unconsolidated beaches that are often intermixed with patches of fringing *Spartina alterniflora* salt marsh. The southern half of Prudence Island largely consists of long stretches of beach, while meadow salt marshes and shallow coves are found along much of the northern section of the Island. In general, the eastern shore of Prudence Island receives a northerly flow of bottom water from Rhode Island Sound, while the western shore receives southerly flowing water from the upper reaches of the Bay. Due to its location in the middle of Narragansett Bay and its extensive network of undeveloped and protected lands, nutrient concentrations around Prudence Island are relatively low compared to more urban areas further up in the Bay (Heffner 2009). As a result, macroalgae is generally not a problem around much of Prudence Island, although small pockets of relatively dense algae can form in the shallow coves at the northern end of the Island (Raposa personal observation).

Following the methods used in Lyons et al. (2009), the entire 31-km shoreline of Prudence Island was broken up into contiguous 1-km sections (Fig. 1). A single location within each of these segments was then randomly identified using geographic information systems (GIS). These 31 locations were then used as the fixed stations for conducting the rapid macroalgae assessments (RMAs) in 2009 and 2010.

The original goal was to conduct RMAs around Prudence Island monthly from June-October in both 2009 and 2010 (i.e., five surveys per year). However, the amount of time required to train seasonal staff and to have them conduct surveys in conjunction with other ongoing duties was underestimated. Therefore, only four surveys were conducted each year (one each in June, mid July-August, September, and October).

During each RMA, all 31 stations were visited over 2-4 days and surveyed for macroalgal composition and cover. Each station was located using a global positioning system (GPS) and a record of each station's geographic coordinates (Table 1). All surveys were conducted within a four-hour window centered around the predicted low tide. Multiple days were required for each RMA in part due to the logistical difficulties getting to some of the stations, which included the use of kayaks (Table 2). At each station, overall macroalgal cover was visually estimated using a simple scale from 0 (no algae) to 5 (very high amounts of algae) (Table 3 and Figs. 2-5). Separate estimates were made for intertidal and shallow subtidal portions of each station. In 2009, general notes were taken on the types or species of macroalgae present at each station, although this was not a comprehensive list. In 2010, all macroalgae present in each zone at every station was identified to the lowest possible taxonomic level and recorded, although visual cover scores were still only determined for algae as a whole. To facilitate identifications, a field guide to the common macroalgal species around Prudence Island was also developed in 2010 (Appendix A).

A series of three-way ANOVAs was used to compare macroalgae cover between years, across months and among tidal zones and geographic sections of Prudence Island (i.e., north v south and east v west). The first ANOVA used year, month, and tidal zone as main factors. The second test used year, month, and longitudinal section of Prudence Island (i.e., east v west) as main factors. The third test used year, month, and latitudinal section of Prudence Island (i.e., northern half v southern half) as main factors. The latter two models used cover score data that were summed from intertidal and subtidal portions of each station, following Lyons et al. (2009). Year and month were included in each model to ensure that variability associated with both temporal scales was accounted for and to determine if any statistically significant spatial differences depended on the month or year of sampling (i.e., to test for interaction effects). For each test, any significant differences for any factor were followed up with Holm-Sidak multiple comparison tests to identify specific differences between treatment groups.

Simple sample size estimators were used to quantify the number of macroalgal survey samples that would be necessary to reach a desired level of precision. These were calculated using the formula: $N=(t^2CV^2)/L^2$ (Snedecor and Cochran 1980), where N is the required number of samples, t is a constant that varies with the desired confidence interval, CV is the coefficient of variation, and L is the desired level of precision. In this case, t=1.96, and the desired level of precision around the mean was selected as 20% (i.e., L=0.2). Sample size estimators were calculated for the intertidal zone, subtidal zone, and for both zones added together within each individual RMA over both years. Sample size estimates were also calculated for these three tidal categories after averaging all monthly scores within each year.

For the remainder of the report, ‘scores’ and ‘cover scores’ refer to individual scores from a particular tidal zone that range from 0-5. ‘Station scores’ refers to summed scores from both tidal zones within each station (i.e., ranging from 0-10).

Results and Discussion

Spatial and Temporal Patterns in Cover

Macroalgae cover scores spanned the entire 0-5 range across the two-year sampling period. Most scores (90%) ranged from 0-2, indicating that Prudence Island as a whole does not generally have an issue with excessive macroalgae. However, scores of 4-5 were observed 4% of the time, indicating that small-scale macroalgal blooms do occur, generally in the shallow coves located at the Island's northern end (see *Macroalgae Distribution* section below). Qualitatively, station scores were slightly higher in 2009 than in 2010 (means of 2.52 and 2.27, respectively), while cover scores were higher in the subtidal zone than in the intertidal zone every month each year (intertidal mean of 1.04; subtidal mean of 1.36). Macroalgal station scores were comparable across months, although they peaked in July-August and were lowest in June and October (mean station scores averaged between years and across all stations are as follows: June=1.77; July-August=2.92; September=2.55; October=2.35). This is consistent with results from Cape Cod, MA where the peak in macroalgal cover was observed in the second week of August (Lyons et al. 2009).

Based on the first three-way ANOVA, statistically significant differences in macroalgal cover scores were found among months ($F=7.82$; $p<0.001$) but not between years ($F=2.14$; $p=0.14$). There was also a statistically significant interaction effect between year and month ($F=2.98$; $p=0.03$). Based on Holm-Sidak multiple comparison tests, macroalgal cover scores in 2009 were significantly lower in June than in all other months, and in 2010 they were significantly lower in June and October compared to July-August. It was also found that macroalgal cover scores were significantly higher in the subtidal zone than in the intertidal zone ($F=14.61$; $p<0.001$).

Macroalgal station scores varied among geographic sections of Prudence Island. Mean station scores were higher in the East Passage than in the West Passage (2.73 and 2.40, respectively in 2009; 2.62 and 1.98, respectively in 2010). Based on three-way ANOVA, there was a statistically significant difference in station scores between the West and East Passage sides of Prudence Island ($F=3.94$; $p=0.048$) and this was consistent between years and across all months (i.e., there were no statistically significant interaction effects). However, this pattern is clearly driven by high macroalgal cover within Potter Cove; when stations in the Cove were separated from the others on the East Passage side, mean station scores between the western and eastern halves of Prudence Island are more similar (2.40 v 2.17, respectively in 2009; 1.98 v 2.06, respectively in 2010). Thus, the relatively eutrophic Potter Cove is driving the higher mean station scores on the East Passage side of Prudence Island.

A more striking difference was seen when comparing the southern and northern halves of Prudence Island. In both years, mean station scores along the northern half of Prudence Island were higher than in the southern half (2.97 v 1.81, respectively in 2009; 2.68 v 1.63, respectively in 2010). Based on three-way ANOVA with year, month and island section (north v south) as factors, there was a statistically significant difference in macroalgal station scores between the northern and southern halves of Prudence Island ($F=25.50$; $p<0.001$) and this was consistent between years and across all months. Again, much of this difference appears to be due to high macroalgal station scores in the coves on the northern half of the Island (see *Macroalgae Distribution* section below).

The overarching spatial pattern in macroalgal cover observed here is one of higher station scores in the northern coves on Prudence Island. This is probably a direct result of summertime inputs of recreational boater wastes (i.e., nitrogen) into Potter and Coggeshall Coves (King et al. 2008; Raposa unpublished data). The residence time of these excess nutrients is probably high due to reduced flushing between these semi-enclosed embayments and the Bay proper. This scenario provides an excellent opportunity for bloom-forming macroalgal species to grow and this is indicated by the high station scores seen in these areas.

Patterns in Species Composition and Richness

Only 10 macroalgal taxonomic groups were recorded in 2009; these included 5 species (*Chondrus crispus*, *Codium fragile*, *Gracilaria tikvahiae*, *Grateloupia turuturu*, and *Porphyra umbilicalis*,), 2 genera (*Fucus* spp. and *Ulva* spp.), and 3 generic groups (red and green filamentous and red laminar) (Table 4). In 2010, 21 individual algal species were identified. This compares favorably with results from an earlier survey at nearby Dyer Island that recorded 25 species during summer (Villalard-Bohnsack and Harlin 1992). Based on relative abundance data, it was found that three macroalgal species each contributed over 10% of the total number of observations in 2010 (*G. turuturu* 20%, *Polysiphona lanosa* 15%, and *G. tikvahiae* 14%). These three species combined comprised approximately 50% of all observations. An additional 4 species each contributed at least 5% of the observations and, when combined with the three dominant species, comprised over 75% of the cumulative total (*Agardhiella subulata* 9%, *Ulva lactuca* 9%, *Cladophora sericea* 5%, and *Polysiphonia stricta* 5%). The remaining 14 species each contributed 3% or less of the total number of algal observations in 2010.

The same macroalgal species that were dominant overall were present in the same general proportions when considering intertidal and subtidal zones separately in 2010 (Table 5). Seventeen species were found in the intertidal zone in 2010, while 20 were found subtidally. This is in direct contrast to an earlier study that found a higher number of species in the intertidal zone compared to the subtidal at every station that was sampled (Villalard-Bohnsack and Harlin 1992). The reasons for this discrepancy are unclear, although it must be kept in mind that only one year of species-level data is available in this study. More elaborate tidal zone comparisons of algal species richness and composition will be possible as more data are collected over subsequent years.

When considering species occurrences across months in 2010, few patterns are evident. Two of the dominant species, *G. tikvahiae* and *G. turuturu*, were common during every month of the survey (Table 6). Species such as *P. stricta*, *C. crispus*, and *Fucus distchus* were more common in early summer, while *P. lanosa* was much more common in mid-summer. All but two species were present from July-September when macroalgal cover peaked around Prudence Island; *Chaetomorpha linum* and *Palmaria palmata* were both only observed once in June. Beginning in 2011, more quantitative spatial analyses of species-level data will be possible once the cover of individual species is recorded at each site (see *Recommendations for Future Monitoring* section below).

Villilard-Bohnsack and Harlin (1992) found that more macroalgal species were found in lower Narragansett Bay and in areas that receive abundant flows of incoming oceanic water (e.g., in the East Passage and Sakonnet Rivers). Areas in the Upper Bay and West Passage sections of the Bay supported fewer species, likely due to higher nutrient levels and less flushing. In this current study, a similar number of species was found between the East and West Passage sides of Prudence Island (17 and 18 species, respectively) and between the northern and southern halves of the Island (19 species in both cases). Thus, the broader patterns observed earlier by Villalard-Bohnsack and Harlin (1992) have either been subdued due to overall increases in nutrient levels, which can impact algal composition and richness (Harlin 1995), or to the fact that Prudence Island alone is too small of a sampling area to notice such differences. Either way, in terms of macroalgal species richness, there do not appear to be any broad spatial patterns when considering Prudence Island as a whole.

Macroalgae Distribution

Spatial patterns in macroalgal distribution and cover are clearly visible when examining GIS maps based on the 2009 and 2010 station scores. Similar patterns were observed during every month in 2009 and 2010 (Figs. 6 and 7) and when averaged across all months within years and across all available data (Fig. 8). Macroalgae was observed around virtually all of Prudence Island, but generally at low cover classes. The exceptions were the shallow coves at the northern end of the Island. Both Coggeshall and Potter Coves, on the western and eastern sides of north Prudence Island respectively, consistently supported the highest macroalgal station scores during all RMAs. Again, this is surely a function of reduced tidal circulation in these semi-enclosed embayments and enhanced nitrogen levels from recreational boater wastes (at least in Potter Cove; King et al. 2008).

Sample Size

The number of samples required to achieve the desired level of precision (hereafter referred to as estimated sample sizes) varied by month and tidal zone (Table 7). In many cases, it exceeded the 31 samples that were collected during each RMA in 2009 and 2010. However, estimated sample sizes were typically lower from July through September compared to June and October. They were also lower and in the subtidal zone compared to the intertidal zone during every RMA. Estimated sample sizes were generally reduced when averaging across months within a year. Even so, estimated sample sizes using these pooled data still approximated 30 samples (except for the intertidal zone in 2009, which was much higher). It was hoped that this analysis would indicate that a smaller number of samples could be collected in the future to ease logistical pressures; this is clearly not the case. Since the estimated sample sizes using data averaged across months approximated 30 samples, it seems logical to retain the 31 samples that have already been collected during all RMAs. Although the number of samples should not be reduced during individual RMAs, it may be possible to conduct fewer RMAs each year. For example, estimated sample sizes did not change appreciably when considering only the data during the time of peak macroalgal cover (mid July-September). In fact, when using all data, the estimated sample size using data summed across tidal zones and averaged across months ranged from 30-32 with a mean of 31; when considering only the July-September data, estimated sample size ranged from 27-33 with a mean of 30. Based on this sample size analysis alone, it may be possible therefore to only conduct two RMAs between mid July and September.

Recommendations for Future Monitoring

A streamlined yet statistically robust RMA protocol can be developed from these two years of pilot sampling data. For example, species composition patterns and sample size analyses indicate that 31 samples need to be collected during each RMA, but the number of RMAs conducted each year can be reduced from four to two. Based on the timing of peak cover and species composition patterns, it is therefore recommended that one RMA be conducted in July and the second in September. To minimize potential differences in identification skills moving forward, the NBNERR-specific algal identification key should be used in the field during all future surveys. Any new species subsequently encountered should be added to this field guide. In addition, beginning in 2011, cover scores should be determined for every individual species present at each site, as well as overall scores for green, red, and brown algal groups, and for all algae combined, thus facilitating analyses at three hierarchical levels. By applying the revised monitoring protocol described above, the NBNERR will be able to collect quantitative data on macroalgal species composition, cover (of species, groups, and all algae combined), and distribution with approximately 24 hours (across 6 days) of field work from one seasonal staff member each year. This will facilitate statistical analyses of community metrics (e.g., richness, diversity, composition) and cover among different areas of Prudence Island and across years as the monitoring dataset grows. This will be particularly useful for determining if upcoming reductions in WWTF nitrogen levels affect macroalgal communities around Prudence Island.

In summary, the final NBNERR RMA protocol will include the following primary elements:

1. 31 samples will be collected around Prudence Island during each RMA;
2. Two RMAs will be conducted each year; one in July and one in September;

3. All algae present will be identified to species or the lowest possible taxonomic group using the NBNERR macroalgal field guide; new species encountered will be added to the guide;
4. Cover scores will be recorded for individual algal species, algal groups, and for all algae combined.

Potential additions to this basic monitoring protocol could include:

1. Replicating previous sampling on Dyer Island conducted by Villalard-Bohnsack and Harlin (1992) to quantify any changes at that site since 1989-90;
2. Adding further quantitative sampling at a small number of stations to determine macroalgal biomass (g dry wt m^{-2}) following methods in Lyons et al. (2009);
3. Determining the relative sources of summer nitrogen inputs into Potter Cove;
4. Exploring how to link RMA sampling with larger-scale aerial photographs collected by the Narragansett Bay Estuary Program (Deacutis unpublished data) and how to conduct these RMAs over a broader region of the Bay by involving additional groups or volunteers.

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Table 1. Geographic coordinates for each of the 31 RMA sampling stations.

Site #	Latitude	Longitude
1	41.63155	-71.34779
2	41.63827	-71.35241
3	41.64782	-71.35375
4	41.65172	-71.34817
5	41.65025	-71.34374
6	41.65238	-71.34464
7	41.65763	-71.35057
8	41.66452	-71.34747
9	41.65686	-71.33786
10	41.65061	-71.33783
11	41.64825	-71.33585
12	41.64241	-71.33572
13	41.64832	-71.33573
14	41.63931	-71.34034
15	41.63474	-71.33467
16	41.63127	-71.32235
17	41.62930	-71.31466
18	41.62080	-71.30515
19	41.61029	-71.30364
20	41.60522	-71.30421
21	41.59802	-71.30766
22	41.58768	-71.31412
23	41.58583	-71.31526
24	41.57880	-71.32681
25	41.58068	-71.33092
26	41.58792	-71.33639
27	41.59632	-71.33623
28	41.60502	-71.33353
29	41.61505	-71.32749
30	41.62744	-71.32910
31	41.63143	-71.33976

Table 2. General descriptions of substrate and notes on access for each RMA sampling station. Descriptions compiled by B. Russell in 2009.

Site #	Substrate	Access Notes
1	Boulder, cobble	Kayak from #31
2	Boulder, cobble	Kayak from #31
3	Intertidal rock shelf; subtidal sand, boulders	Kayak from #4
4	Intertidal sand with some boulders, cobble; subtidal silt	Drop in at end of Long Trail Rd. (first left past North End gate)
5	Intertidal mud (salt marsh); subtidal silt	Kayak from #4
6	Intertidal mud (salt marsh); subtidal silt	Kayak from #4
7	Intertidal cobble; subtidal cobble, silt	Kayak from #4
8	Intertidal gravel; subtidal gravel	Kayak from #4
9	Cobble, gravel	Kayak from #10 or walk from Bear Pt.
10	Gravel	Kayak or walk from #11
11	Gravel	Kayak from Potter Cove dock
12	Gravel	Kayak from Potter Cove dock
13	Gravel	Kayak from Potter Cove dock
14	Gravel	No notes
15	Cobble, gravel	No notes
16	Gravel, sand	Access by Rafael Ln.
17	Cobble, gravel	Access by Rafael Ln.
18	Cobble, gravel	Park at ferry and walk north
19	Cobble, gravel	Park on Narragansett Ave. near Wells Ln.
20	Gravel, pebble, sand	No notes
21	Intertidal rock shelf; subtidal sand	Drive down Broadway, take last right to a small park
22	Cobble, gravel	Access from East Shore Dr.
23	Cobble, gravel	Walk from #22 or along beach from southern end
24	Cobble, gravel, sand, adjacent fringe marsh	Access from path along Levesque Memorial Dr.
25	Cobble, gravel, sand	Access from path along Levesque Memorial Dr.

Table 2, continued.

Site #	Substrate	Access Notes
26	Cobble, gravel	Access from path along Levesque Memorial Dr., Albro Farm Rd.
27	Intertidal rock ledge; Subtidal sand, boulder	Kayak from #26
28	Boulder, cobble, gravel	Stone pier
29	Intertidal cliff, boulders; subtidal gravel, sand	Take trail from picnic table at Division Rock
30	Sand	Kayak or walk along beach from Picnic Tree area
31	Cobble, gravel	Access where Pine Hill Trail hits Jenny Marsh

Table 3. Descriptions of the macroalgal visual cover class scores (taken from Lyons et al. 2009).

Intertidal

Number	Class	Description
0	Absent	No macroalgae present on beach.
1	Sparse	Some macroalgal cover (0-10%). Sulfur odor unlikely. Thin accumulations present (<1 cm thick). Mostly individuals occurring separately.
2	Mediocre	Cover by macroalgae 10-40%. Thin accumulations present but thicker areas (0-2 cm) may occur. Odor possible in proximity to algae.
3	Masses	Much cover by macroalgae (40-75% of a given area). Thickness 0-4 cm, with extremes up to 6 cm. Odor likely in proximity and several meters from algae.
4	Complete coverage	Generally whole area is covered with few areas of exposed substrate. Depth ranges to 20 cm. Odor present through much of vicinity dependant on wind.
5	Severe	Complete coverage, depth of 20 cm or more. Odor powerful and present well away from algae, dependant on wind.

Subtidal

Number	Class	Description
0	Absent	No macroalgae present throughout water column.
1	Sparse	Some individuals scattered in water column, on surface, or bottom. No large clumps.
2	Mediocre	Some clumps present in water column, on surface, or bottom. Macroalgae mostly scattered.
3	Masses	Large clumps present. Macroalgae may blanket bottom or surface. Difficulty in distinguishing clumps. Roughly half entire water column contains macroalgae.
4	Complete coverage	Large clumps present. Very little algae-free water. Some difficulty in swimming could result.
5	Severe	Large scale clumping. Entire water column full of macroalgae. Clumps can’t be distinguished from water or other clumps. Wind induced ripples absent, wave dynamics appear altered. Much difficulty swimming or just moving through water would result.

Table 4. Composition of macroalgal communities in 2009 and 2010. “# of Obs.” refers to the number of times each species or algal group was observed each year. “Rel. Abun. (%)” is the relative contribution of each species to the overall community each year based on the number of observations. “Cumulative %” refers to the cumulative contribution of sequential algal species while moving down the table.

2009

Species	# of Obs.	Rel. Abun. (%)	Cumulative (%)
Gracilaria tikvahiae	127	30.83	30.83
Grateloupia turuturu	102	24.76	55.58
Ulva spp.	75	18.20	73.79
Green filamentous	30	7.28	81.07
Chondrus crispus	22	5.34	86.41
Codium fragile	22	5.34	91.75
Red filamentous	13	3.16	94.90
Fucus spp.	12	2.91	97.82
Red laminar	6	1.46	99.27
Porphyra umbilicalis	3	0.73	100.00

2010

Species	# of Obs.	Rel. Abun. (%)	Cumulative (%)
Grateloupia turuturu	121	19.58	19.58
Polysiphonia lanosa	92	14.89	34.47
Gracilaria tikvahiae	85	13.75	48.22
Agardhiella subulata	57	9.22	57.44
Ulva lactuca	54	8.74	66.18
Cladophora sericea	32	5.18	71.36
Polysiphonia stricta	32	5.18	76.54
Mastocarpus stellatus	21	3.40	79.94
Gloiosiphonia capillaris	20	3.24	83.17
Ulva intestinalis	19	3.07	86.25
Chondrus crispus	17	2.75	89.00
Fucus distichus	17	2.75	91.75
Porphyra umbilicalis	14	2.27	94.01
Codium fragile	10	1.62	95.63
Ulva linza	10	1.62	97.25
Chondria dasyphylla	7	1.13	98.38
Ascophyllum nodosum	4	0.65	99.03
Cladostephus spongiosus	2	0.32	99.35
Fucus vesiculosus	2	0.32	99.68
Chaetomorpha linum	1	0.16	99.84
Palmaria palmata	1	0.16	100.00

Table 5. Macroalgae species present in both tidal zones in 2010. Column descriptions are the same as in Table 4.

	Intertidal		Subtidal	
Species	# of Obs.	Rel. Abun. (%)	# of Obs.	Rel. Abun. (%)
Grateloupia turuturu	56	19.38	65	19.76
Polysiphonia lanosa	43	14.88	49	14.89
Gracilaria tikvahiae	45	15.57	40	12.16
Agardhiella subulata	28	9.69	29	8.81
Ulva lactuca	29	10.03	25	7.60
Cladophora sericea	15	5.19	17	5.17
Polysiphonia stricta	8	2.77	24	7.29
Mastocarpus stellatus	10	3.46	11	3.34
Gloiosiphonia capillaris	6	2.08	14	4.26
Ulva intestinalis	12	4.15	7	2.13
Chondrus crispus	9	3.11	8	2.43
Fucus distichus	8	2.77	9	2.74
Porphyra umbilicalis	6	2.08	8	2.43
Ulva linza	6	2.08	4	1.22
Codium fragile	4	1.38	6	1.82
Chondria dasyphylla	3	1.04	4	1.22
Ascophyllum nodosum	0	0	4	1.22
Cladostephus spongiosus	0	0	2	0.61
Fucus vesiculosus	0	0	2	0.61
Palmaria palmata	1	0.35	0	0
Chaetomorpha linum	0	0	1	0.30

Table 6. Macroalgae species present during each month in 2010. Column descriptions are the same as in Table 4.

	June		July/August		September		October	
Species	# of Obs.	Rel. Abun. (%)	# of Obs.	Rel. Abun. (%)	# of Obs.	Rel. Abun. (%)	# of Obs.	Rel. Abun. (%)
Grateloupia turuturu	15	13.89	41	17.52	35	20.47	30	28.57
Gracilaria tikvahiae	19	17.59	26	11.11	22	12.87	18	17.14
Polysiphonia lanosa	0	0	41	17.52	44	25.73	7	6.67
Agardhiella subulata	1	0.93	18	7.69	25	14.62	13	12.38
Ulva lactuca	12	11.11	20	8.55	14	8.19	8	7.62
Cladophora sericea	8	7.41	9	3.85	7	4.09	8	7.62
Polysiphonia stricta	18	16.67	13	5.56	1	0.58	0	0
Mastocarpus stellatus	0	0	8	3.42	2	1.17	11	10.48
Gloiosiphonia capillaris	4	3.70	6	2.56	8	4.68	2	1.90
Chondrus crispus	11	10.19	6	2.56	0	0	0	0
Porphyra umbilicalis	12	11.11	0	0	2	1.17	0	0
Ulva intestinalis	1	0.93	16	6.84	0	0	2	1.90
Fucus distichus	4	3.70	12	5.13	1	0.58	0	0
Codium fragile	1	0.93	3	1.28	2	1.17	4	3.81
Ulva linza	0	0	3	1.28	7	4.09	0	0
Chondria dasyphylla	0	0	4	1.71	1	0.58	2	1.90
Ascophyllum nodosum	0	0	4	1.71	0	0	0	0
Chaetomorpha linum	1	0.93	0	0	0	0	0	0
Palmaria palmata	1	0.93	0	0	0	0	0	0
Cladostephus spongiosus	0	0	2	0.85	0	0	0	0
Fucus vesiculosus	0	0	2	0.85	0	0	0	0

Table 7. Summary of results from sample size estimations conducted in three tidal zones (intertidal, subtidal, and both summed together at each station) during each month in both years. Bold estimates on the far right were calculated from station scores that were averaged across all months prior to conducting the sample size estimates.

2009	Estimated sample size				
	Jun	Jul/Aug	Sep	Oct	All months
Intertidal	162	52	81	48	**53**
Subtidal	139	24	43	19	**22**
Intertidal+subitdal	135	30	50	22	**32**

2010	Estimated sample size				
	Jun	Jul/Aug	Sep	Oct	All months
Intertidal	174	47	44	136	**35**
Subtidal	73	46	37	93	**30**
Intertidal+subitdal	103	39	30	101	**30**

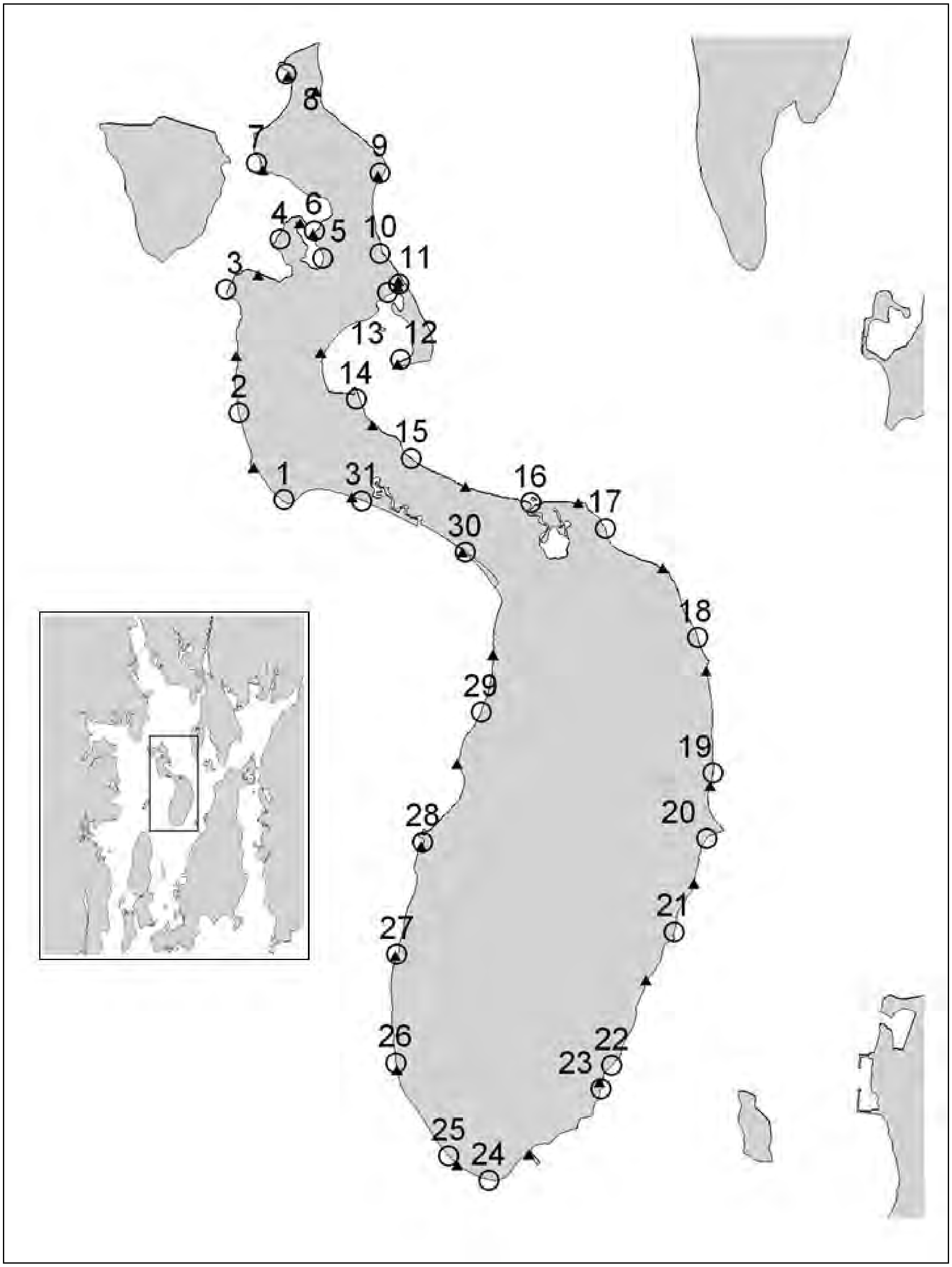


Figure 1. Locations of the original 31 macroalgal survey sites around Prudence Island. Closed triangles indicate the borders of each 1-km section of shoreline and open circles indicate the location of each sampling station.

Figure 2. Macroalgae cover classes in the intertidal zone; class 1 (top) and class 2 (bottom).

Figure 3. Macroalgae cover classes in the intertidal zone; class 3 (top) and class 4 (bottom). A picture of cover class 5 was not available for this report.

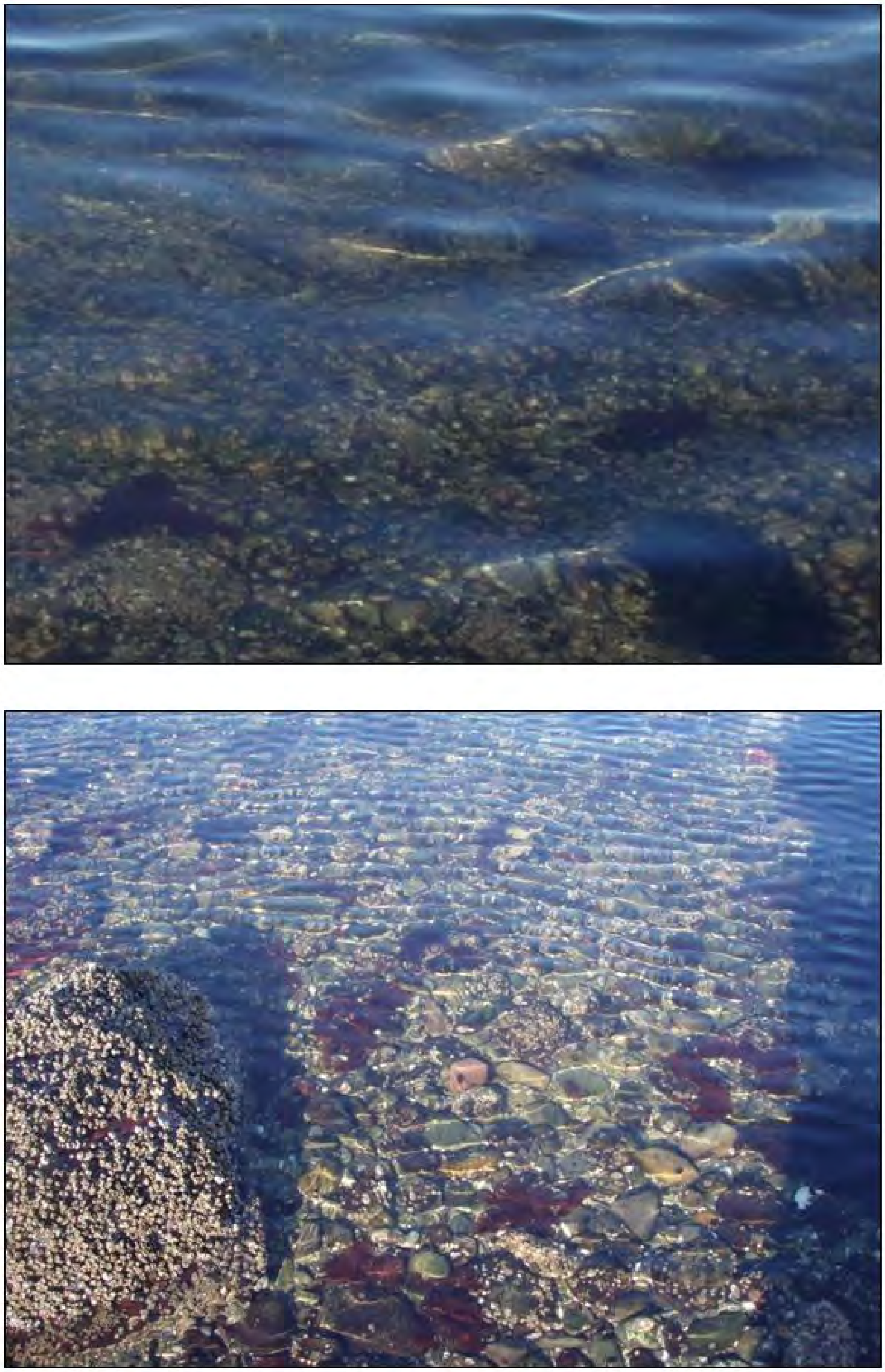


Figure 4. Macroalgae cover classes in the subtidal zone; class 1 (top) and class 2 (bottom).

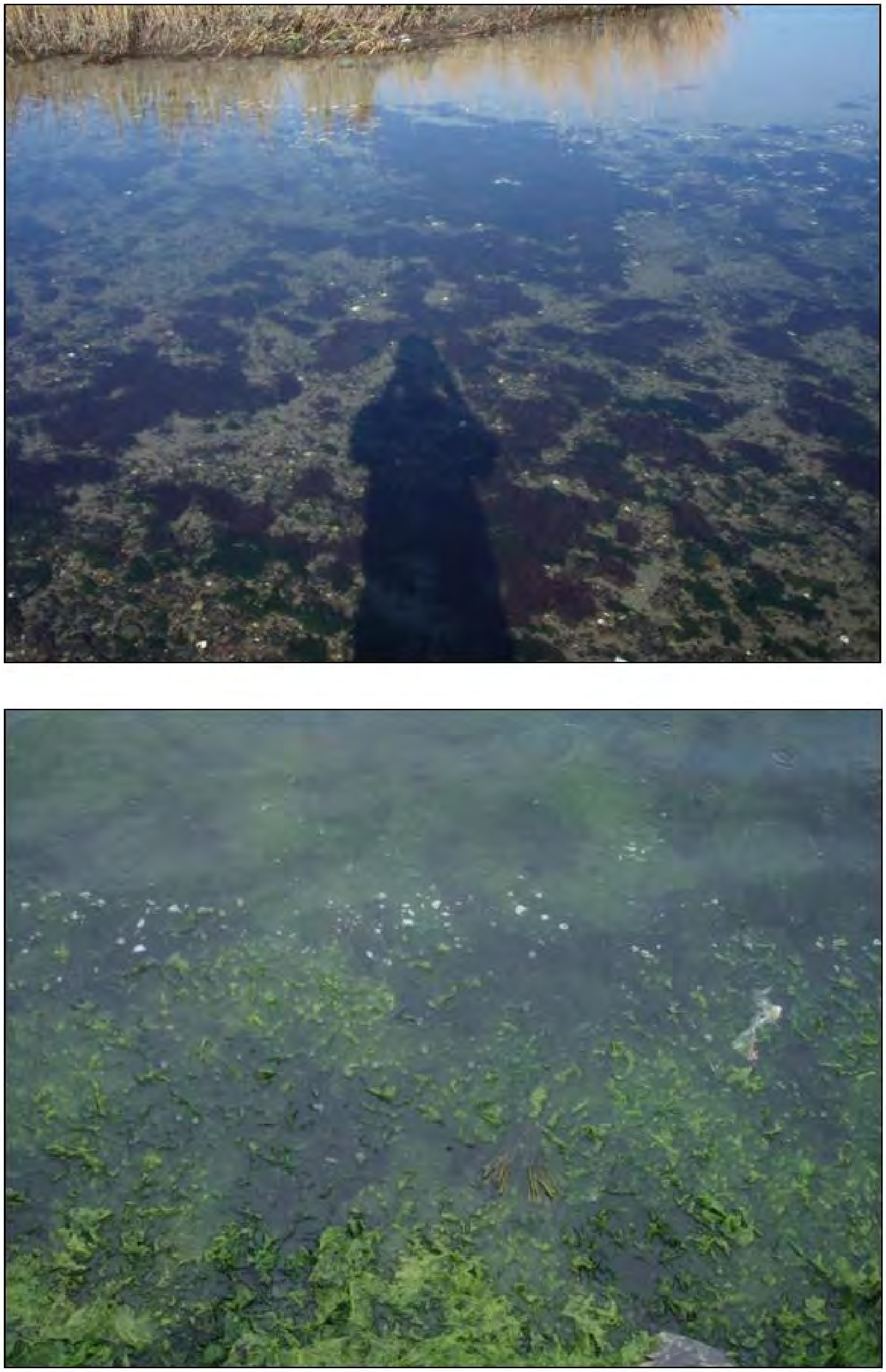


Figure 5. Macroalgae cover classes in the subtidal zone; class 3 (top) and class 4 (bottom). A picture of cover class 5 was not available for this report.

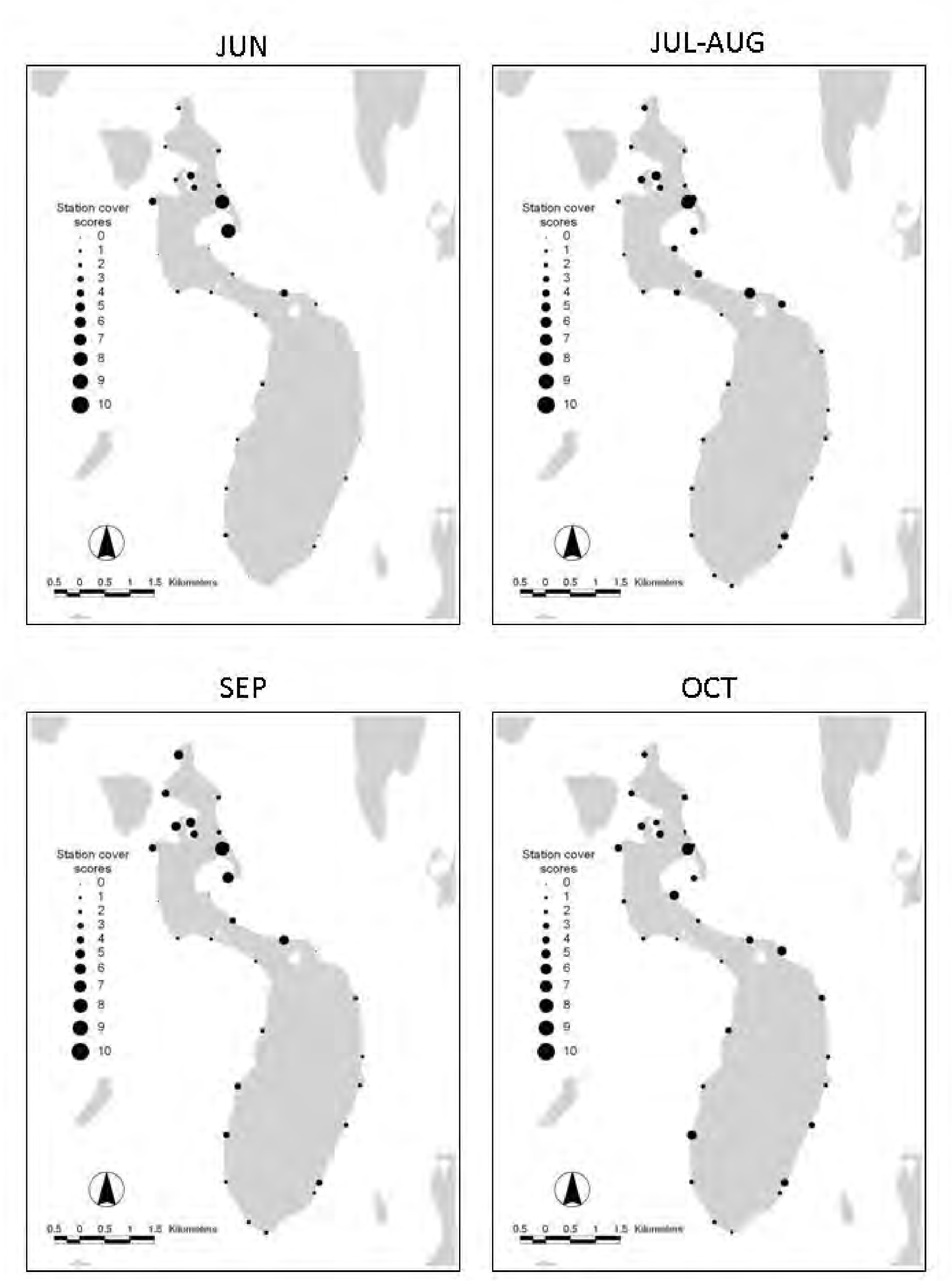


Figure 6. The distribution and cover of macroalgae around Prudence Island each month in 2009 from RMA sampling.

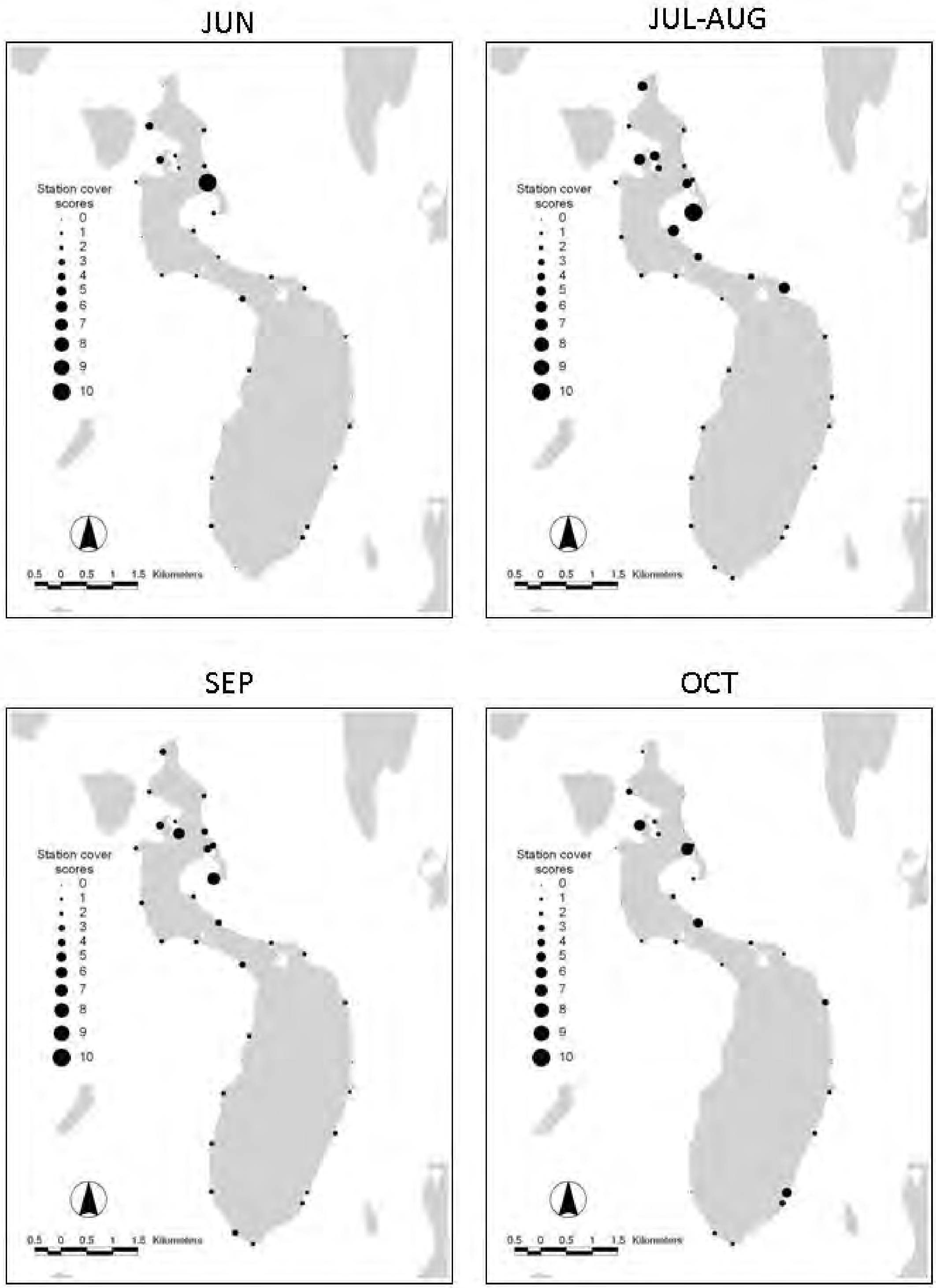


Figure 7. The distribution and cover of macroalgae around Prudence Island each month in 2010 from RMA sampling.

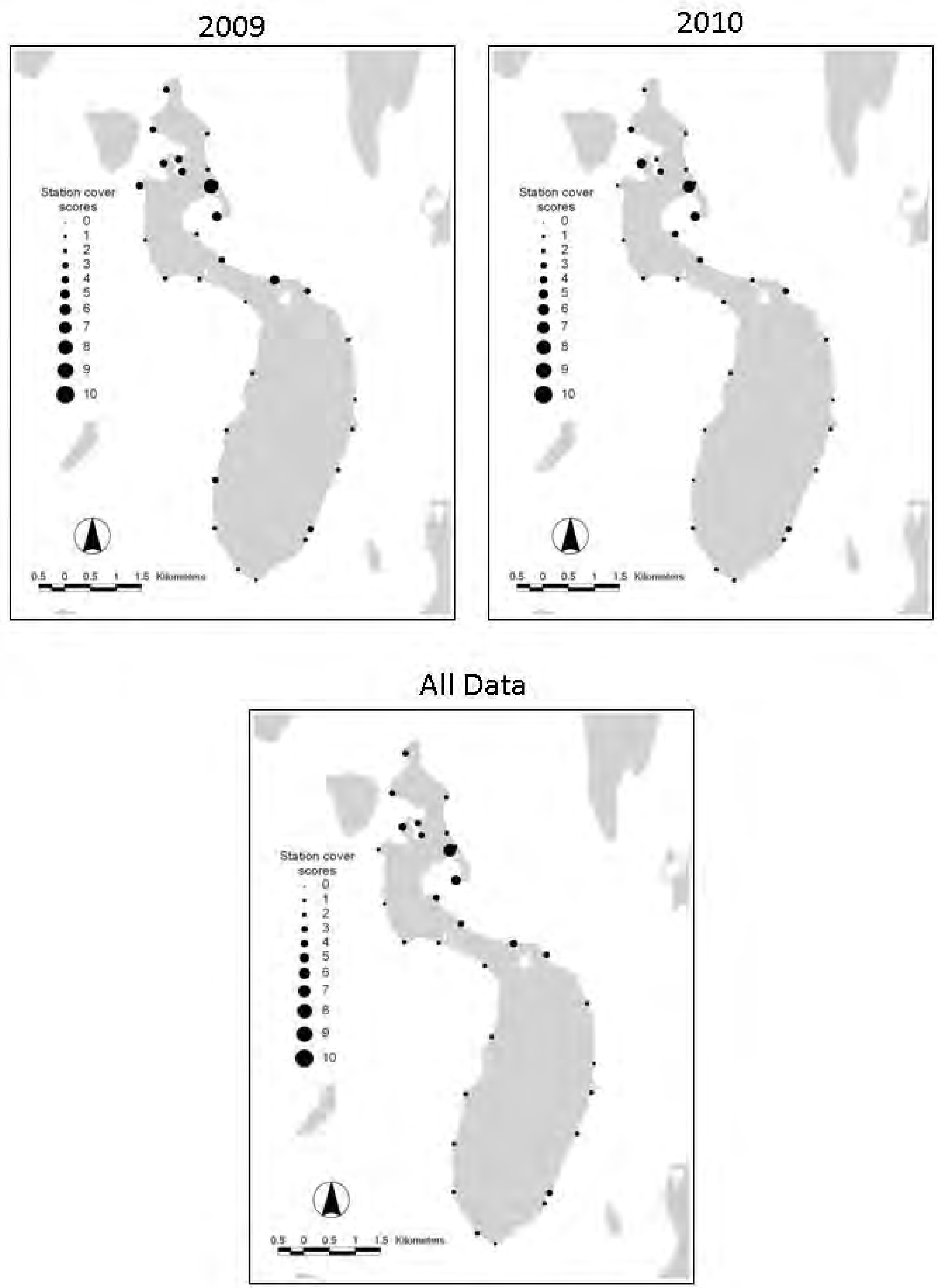


Figure 8. The distribution and cover of macroalgae around Prudence Island from RMA sampling averaged across all months in 2009 and 2010 and then averaged across all data from both years.

Appendix A.

A Field Guide to Common Macroalgae Found around Prudence Island, RI

Chlorophyta
(Green Algae)

General description: Thallus is usually grass-green, but can range from yellow-green to dark-olive green, and sometimes even brownish or black.

Chaetomorpha linum

Class Ulvophyceae

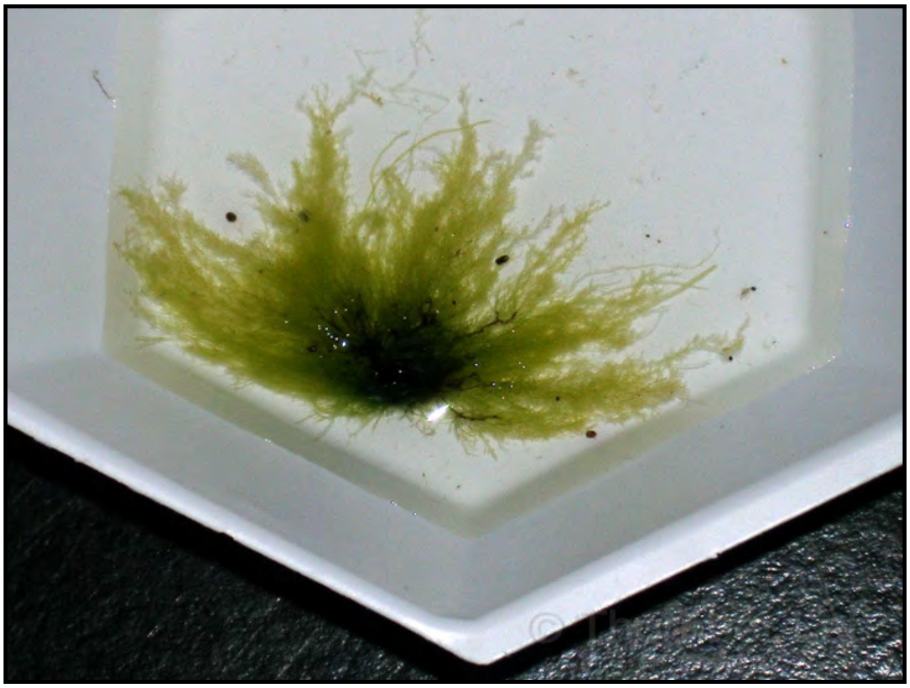
Common name: "Spaghetti algae."

Description: Course, stiff, entangled filaments that are light green in color, sometimes appearing white at the ends. They are unbranched and unattached and can range from 5-10 cm in length. Filaments are often found in dense, free-floating masses that provide habitats for many small invertebrates.

Habitat: Can be found year-round on open coasts, in estuaries and in the intertidal and subtidal zones of New England. Of the 5 local *Chaetomorpha* species (including *C. aerea, C. melagonium, C. brachygona, C. picquotiana), C. linum* is the most common.

Cladophora albida

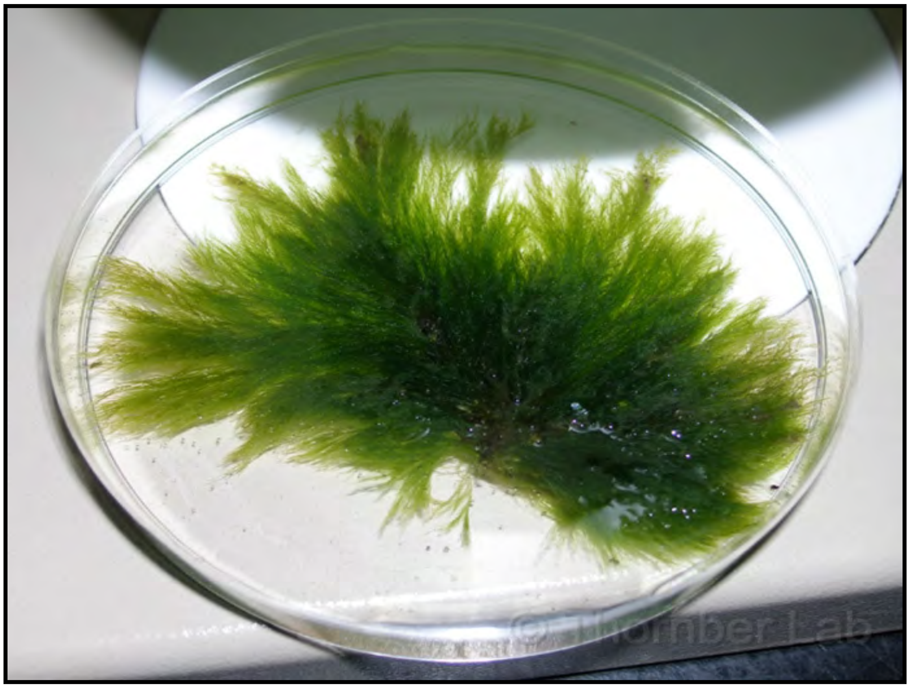
Class Ulvophyceae



Common name: None.
Description: Green to yellowish-green in color. Soft in texture, grows up to 25 cm in length. Branches usually distinctly curved.
Habitat: Common species found year-round in New England. Generally found on open coasts, estuaries, tide pools in the subtidal, and attached to rocks down to 3 m.

Cladophora sericea

Class Ulvophyceae



Common name: None.
Description: Green to yellowish-green in color. Rough in texture, grows up to 40 cm in length. Branches often in comb-like series.
Habitat: Common species found year-round in New England. Generally found on open coasts, estuaries, tide pools in the intertidal and subtidal, and attached to rocks down to 6 m.

Codium fragile

Class Bryopsidophyceae

Common name: “Dead man’s fingers”, “Green fleece alga” and “Felty fingers”.
Description: Spongy, finger-like, cylindrical tubes that exist in large clumps with dichotomous branching (even, Y-shaped branches) up to 70 cm in length and 1 cm wide. Dark green in color.
Habitat: Common species found year-round in New England that was originally introduced from Asia. Generally found on open coasts, in estuaries and in the intertidal and subtidal zones. Can be found attached to rocks and shells as deep as 12 m, and occasionally found as an epiphyte on other species of algae. Occasionally found in tide pools covered in epiphytic algae.

Ulva spp. (blade forming)

Class Ulvophyceae

Common name: Variable (e.g., *U. lactuca* is known as "Sea lettuce").
Description: Three common and similar blade-forming species are found in Narragansett Bay (*U. rigida*, *U. compressa*, and *U. lactuca*; the latter is shown and specifically described here). Bright green in color and sheath-like in appearance (white when dead and dried out). Rounded, oval or elongated blade (up to 50 cm in length) that is often perforated with holes. Species is often undulated at edges and lobed or jagged at tip.
Habitat: Very common species found year-round in New England. Can be found on open coasts, in estuaries, and in the intertidal and subtidal zones. Also found attached to rocks, shells and wood as deep as 24 m, can be found drifting in large masses and in some cases it is epiphytic.

Ulva spp. (tube forming)

Class Ulvophyceae

Common name: Variable (e.g., *U. linza* is known as “slender sea lettuce”).
Description: There are approximately seven similar tube-forming species found in Narragansett Bay; *U. linza* is shown above and described specifically here. Grass-green in color, sometimes yellow-green. Unbranched tube, flattened in center, with hollow undulated edges. Can be up to 40 cm in length and 5 cm wide.
Habitat: Very common year-round in New England. Found on open coasts, in estuaries and in the intertidal and subtidal zones. Can be found growing singly, in tufts or in large patches attached to rocks, wood and shells down to 12 m. Occasionally found as an epiphyte.

Phaeophyta

(Brown Algae)

General description: Thallus generally light to dark brown, but can sometimes be black, greenish-brown or yellowish.

Ascophyllum nodosum

Class Phaeophyceae

Common name: "Knotted wrack."
Description: Irregular branching with short side branches. Vesicles present along main axis and swollen receptacles are present when reproductive. Dark brown and sometimes yellow or greenish in color. Can grow up to 1 m in length or more. Modified morphology in tidal flats and salt marshes, branching is irregular and entangled and vesicles are few or absent.
Habitat: Very common year-round in New England. Found in semi-exposed and sheltered areas along the open coast, in estuaries, in mid or low intertidal areas (attached to rocks), but can also be found free-floating in salt marshes and tidal flats.

Cladostephus spongiosus

Class Phaeophyceae

Common name: None.
Description: Brown to dark brown in color. Branches often stiff and wiry, growing up to 30 cm in height. Axes and branches are covered with densely packed sheath of short whorled tufts.
Habitat: Species found year-round in New England. Generally found attached to rocks in the subtidal and on open coasts and in estuaries. Sometimes found in the drift after storms.

Fucus distichus

Class Phaeophyceae

Common name: "Rockweed"
Description: Long, pointed receptacles (sometimes forked) up to 15 cm long, 4-10 times the width. Dichotomously branched. Large thallus, 75 cm or more in length. Olive-green to yellowish-green in color. Tips of receptacles are generally yellowish in color.
Habitat: Found year-round in New England. Usually found attached to rocks on the open coast in exposed areas or in the intertidal zone.

Fucus spiralis

Class Phaeophyceae

Common name: None.
Description: Round or oval receptacles (swollen) with rigid edge. Thallus can be up to 25 cm long. Brownish to yellowish-green in color.
Habitat: Very common year-round in New England. Found attached to rocks in the upper intertidal zone. Forms band along with barnacles.

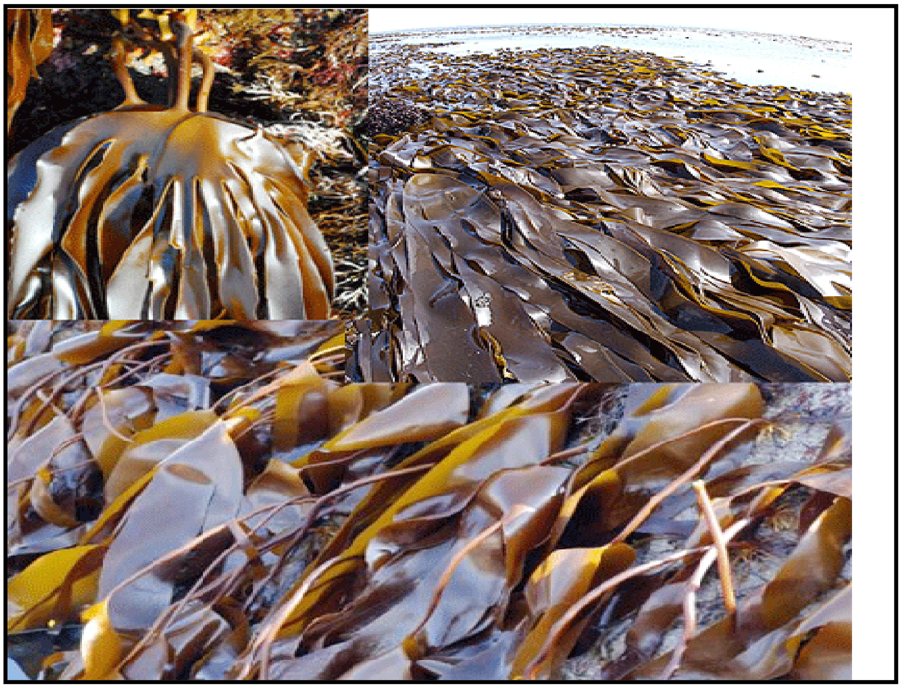
Fucus vesiculosus

Class Phaeophyceae

Common name: “Bladderwrack.”
Description: Strap-shaped branches, irregularly twisted with pairs of vesicles present. Thallus is golden to dark brown in color and can get up to 70 cm in length and up to 1.5 cm wide. Vesicles may be absent in certain exposed conditions.
Habitat: One of the most common species in New England, can be found year-round. Usually attached to rocks on the open coast, in estuaries, and in the mid to low intertidal zone.

Laminaria digitata

Class Phaeophyceae



Common name: "Oarweed."
Description: Conspicuous kelp with a broad blade that is divided longitudinally into strap-like segments. Thallus is leathery. Grows up to 15 m in length. Dark brown and glossy in color, no midrib. A similar, but non-branched subtidal species – *Saccarina latissima* (not shown) - can also be found in the drift.
Habitat: Common species found year-round in New England. Generally found in very exposed areas, on the open coast and in the subtidal zone. Flourishes in strong currents. Can be found as low as 18 m deep attached to rocks and shells. Commonly found after a storm in the drift.

Rhodophyta
(Red Algae)

General Description: Thallus usually pale to rosy pink, light to dark red, or purplish, but sometimes straw-colored, greenish or black.

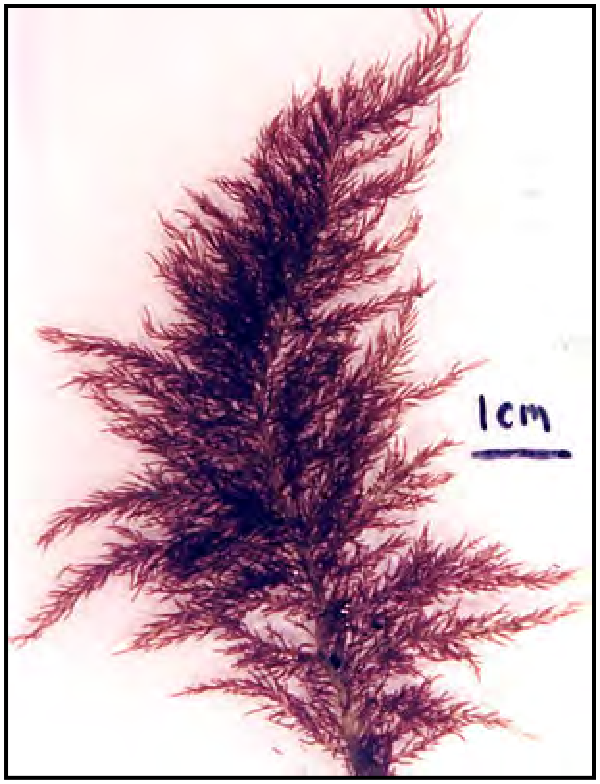
Agardhiella subulata

Class Florideophyceae

Common name: None.
Description: Firm, fleshy thallus, bright red to burgundy red in color. Alternatively branched, with tapering at ends of branches.
Habitat: Common year-round in New England. Found mostly in estuaries, but also found in the intertidal and subtidal zones attached to stones and shells.

Chondria dasyphylla

Class Florideophyceae



Common name: None.
Description: Dark brownish or purplish-red to rosy red in color, sometimes even straw colored. Thick, fleshy, Christmas tree-shaped thallus with club-shaped branchlets. Can be up to 2.5 mm wide and 100 mm long.
Habitat: Commonly found south of New Hampshire on open coasts, and sometimes as epiphytes on other algae.

Chondrus crispus

Class Florideophyceae

Common name: “Irish moss” and “Carrageen moss.”
Description: Flat stipe and branches, dichotomously branched. Blunt or rounded tips. Medulla loose and filamentous. Bushy, leathery, upright thallus. Grows 5-10 cm tall, sometimes longer, with 3-5 mm round mounts near tip when reproductive. Dark purplish-red to yellowish-green.
Habitat: One of the most common species in New England year-round. Generally found on open coasts, in estuaries, in the low intertidal and subtidal zones. Found as low as 10 m deep attached to rocks and shells. Often grows in large clumps or populations.

Corallina officinalis
Class Florideophyceae

Common name: “Coral moss.”
Description: Fan shaped, cylindrical, flattened segments up to 5 cm tall. Calcified and whitish-pink to lilac in color. Opposite and sometimes irregular branching.
Habitat: Found year-round in New England. Generally found on open coasts, in estuaries, in the low intertidal and upper subtidal zones, and in tide pools attached to rocks. Also commonly found in the drift and in drainage runnels. Found as deep as 18 m. It is occasionally found on mollusk shells and on other algae.

Gloiosiphonia capillaris

Class Florideophyceae

Common name: None.
Description: Pale brownish red to deep rosy red in color, sometimes yellowish. Bushy thallus with numerous small, bushy branchlets. Can grow to 40 cm in length.
Habitat: Generally found on open coasts and exposed areas. Can be found in the subtidal, in tide pools and down to 3 m.

Gracilaria spp.

Class Florideophyceae

Common name: *G. tikvahiae* is known as "graceful red weed."
Description: Two species are commonly found in mid-Narragansett Bay; a native species (*G. tikvahiae*; shown above and described here), and an invasive species (*G. vermiculophylla*; branches tend to be longer than the native; not shown). The invasive species is generally more abundant than the native species in the Bay at present. Irregular, often flattened branches brownish red to dull purple in color. Can sometimes be yellowish green or straw color. Has short, thin, pointed projections and is firm and fleshy to the touch. Can grow up to 40 cm in length.
Habitat: Common year-round in New England. Generally found in the subtidal and is often detached. Can be found in both protected bay and high energy coastlines.

Grateloupia turuturu

Class Florideophyceae

Common name: None.
Description: Large, slippery, silky foliose thallus. Pinkish to brownish-red, and sometimes even yellowish in color. Branches can vary in morphology, being long and narrow or short and heart shaped at the base. Can sometimes be found singly, but often found in clumps.
Habitat: Common species in New England regularly confused with *Palmaria palmata.* Generally found in the lower intertidal and subtidal zones attached to rocks and mussels. Can be found in both protected and exposed areas.

Mastocarpus stellatus

Class Florideophyceae

Common name: "False Irish Moss."
Description: Firm, thick, fleshy thallus. Small (17 cm in length). Branching dichotomous, sometimes irregular. Dark reddish-brown to purple in color. Often confused with *Chondrus crispus*. Reproductive structures aid to distinguish the two species. *M. stellatus* can be distinguished from *C. crispus* by the presence of papillae (proliferations at tip of blade).
Habitat: Found year-round in New England. Common on rocky shores and exposed areas in the mid to lower intertidal; also found in tide pools. Occasionally inhabits deep waters. Not commonly found in the mid-Narragansett Bay region.

Palmaria palmata

Class Florideophyceae

Common name: "Dulse", "Dilisk", "Sea parsley" and "Sea lettuce flakes."
Description: Large, leathery thallus, pinkish-red to red in color, sometimes greenish, yellowish or even reddish-purple. Lobes are broad, blades are dichotomous (Y-shaped) or palmate (finger-like). Can be 20-50 cm in length, sometimes reaching 1 m.
Habitat: Very common species year-round in New England. Commonly an epiphyte on *Laminaria*, but also found attached to rocks. Found in the drift, the lower intertidal and subtidal zones as deep as 20 m in both sheltered and exposed areas.

Polysiphonia stricta

Class Florideophyceae

Common name: None.
Description: Soft bushy tufts, bright pink to burgundy in color. Can be up to 30 cm in length. Branching abundant at tips. Two similar invasive species (*Heterosiphonia japonica* and *Neosiphonia harveyi*) are present in Narragansett Bay but are not feasibly differentiated from *P. stricta* during rapid field surveys; by necessity, these three species will be folded up into one broad 'Siphonia' group.
Habitat: Very common species year-round in New England. Found in both open coasts and estuaries, in the mid-intertidal and subtidal zones, and as deep as 25 m. Can be attached to rocks, shells and mud. Occasionally found as an epiphyte on other algae.

Porphyra spp.
Class Bangiophyceae

Common name: *P. umlibicalis* is known as “laver-bread”.
Description: Soft, slippery and sometimes rubbery thallus. Morphology variable, can be oblong and rounded or elongated with scalloped or shredded edges. Brownish, greenish, purple or reddish in color. Sometimes can have yellowish tips. Can be 50 cm or more in length.
Habitat: Commonly found in the spring or summer in New England. Found in the intertidal or just below, on the open coasts and in estuaries, attached to rocks or even epiphytic on other algae. *P. umlibicalis* (shown above) is the most common local *Porphyra* species.

Vertebrata lanosa

Class Florideophyceae

Common name: None.
Description: Short stiff tufts. Filamentous. Thin, dense dichotomous branches. Can be 2-5 cm tall. Dark red or black in color. Looks like “pom poms” on *Ascophyllum nodosum.*
Habitat: Common species found year-round in New England. Found as an epiphyte on *Ascophyllum nodosum.* Found in the mid littoral of rocky shores.

Glossary

Alternative branching: A branching style in which branches arising from different levels are on opposite sides of the axis.
Calcified: Encrusted with lime, including calcium and magnesium carbonates; stone-like.
Dichotomous branching: Y-shaped, even, and regular branching or forking.
Epiphytic: Growing on a plant or an alga (not parasitic).
Filamentous: A chain of cells joined end to end and forming a hair-like strand.
Foliose: Leafy. Of, relating to, or resembling a leaf.
Intertidal: The area of the coastline located between the highest high tide and the lowest low tide.
Irregular branching: Branching in no consistent pattern; cells not of the same type throughout; cells of varying shapes and dimensions.
Medulla: Rounded or elongated cells, usually colorless, located on the inside of the cortex, either loosely or compactly organized.
Morphology: The study of the form, structure and configuration of an organism. This includes aspects of the outward appearance (shape, structure, color, pattern) as well as the form and structure of the internal parts like bones and organs.
Opposite branching: A type of branching in which two branches originating from one node are at a 180 degree angle from each other.
Palmate branching: Leaf that is divided like the fingers of a hand.
Papillae: A tiny outgrowth on the surface of a petal or leaf.
Receptacle: A raised or inflated portion of a thallus, branch, or branch tip bearing reproductive cavities (conceptacles), as in the Fucale.
Stipe: A stem-like portion of thallus; cylindrical or flattened.

Subtidal: The area of the coastline located below the lowest low-tide level and always submerged.
Thallus: A simple plant-like body, without differentiation into organs (roots, stems, leaves) or complex tissues.
Vesicles: Air bladders. A rounded bladder-like structure, usually filled with gases and/or polysacchari.

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Field Guide Photo Credits

Chlorophyta	Chaetomorpha linum	http://www.phishybusiness.com/caribbean/images/Spaghetti%20algae%20Chaetomorpha%20linum.jpg
	Cladophora albida	http://www.uri.edu/cels/bio/thornber/galleries/algae_chlorophyta/images/Cladophora_albida.jpg
	Cladophora sericea	http://www.uri.edu/cels/bio/thornber/galleries/algae_chlorophyta/images/Cladophora_sericea3.jpg
	Codium fragile	http://www.massbay.mit.edu/exoticspecies/exoticmaps/images/codium_big.jpg
	Ulva lactuca	http://www.jonolavsakvarium.com/blog/200708/ulva.jpg
	Ulva linza	http://www.seaweedsofalaska.com/photos/seaweed/Ulva_linza_2.JPG
Phaeophyta	Ascophyllum nodosum	http://www.fisherycrisis.com/chondrus/fig33.jpg
	Cladostephus spongiosus	http://www.seaweed.ie/_images/DSC_1553.png
	Fucus distichus	http://www.uri.edu/cels/bio/thornber/galleries/algae_phaeophyceae/index.htm
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	Laminaria digitata	http://www.celtnet.org.uk/images/kelp.gif
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	Corallina officinalis	http://www.carolscornwall.com/On%20the%20Beach/Seaweed-Corallina%20officinalis11-02-09.jpg
	Gloiosiphonia capillaris	http://images.marinespecies.org/resized/14832_gloiosiphonia-capillaris.jpg
	Gracilaria tikvahiae	http://media.photobucket.com/image/Gracilaria%20tikvahiae/Basilesim/Herbier%20algae/Gracilariatikvahiae.jpg
	Grateloupia turuturu	http://farm2.static.flickr.com/1429/1460276523_21814e091b.jpg
	Mastocarpus stellatus	http://natureinfocus.files.wordpress.com/2009/06/p1090083a1.jpg
	Palmaria palmata	http://www.jonolavsakvarium.com/blog/200708/algae01.jpg
	Polysiphonia stricta	http://www.uri.edu/cels/bio/thornber/galleries/algae_rhodophyta_polysiphonia/images/P_stricta.jpg
	Porphyra umbilicalis	http://www.jgi.doe.gov/sequencing/why/ppurpurea.jpg
	Vertebrata lanosa	http://www.carolscornwall.com/On%20the%20Beach/Seaweed-Polysiphonia%20lanosa-cu-11-03-09.jpg