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Dynamics of Macroalgal Blooms along the Cape Cod National Seashore

Technical Report NPS/NER/NRTR—2008/115



ON THE COVER

Drift macroalgae (mostly *Ulva* and *Polysiphonia*) washed up on the Atlantic beach of Cape Cod National Seashore.
Photograph by: Patrick Lyons (August 10, 2006)

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Abstract

Accumulations of nuisance drift macroalgae along the open-coast Atlantic beaches of the Cape Cod National Seashore have been observed on an anecdotal basis for over 50 years. This entire stretch of coastline is sandy, with no solid substrata for algal attachment. During the summer of 2006, we collected data on drift macroalgal accumulations repeatedly throughout this National Seashore. Peak biomass (primarily consisting of filamentous red algae and *Ulva lactuca*) was found in early August, primarily at the northernmost site. Our data, together with current patterns and anecdotal evidence suggest that macroalgae may originate in rocky shorelines of northern New England and are transported south by Gulf of Maine currents. Algae are most likely caught along the Cape Cod National Seashore shoreline by sand bars, particularly in the northern part of the shoreline.

Introduction

Macroalgal blooms have received increasing attention in the scientific community throughout the last few decades. Although less well studied than toxic phytoplankton (Townsend et al. 2001), macroalgal blooms also have important ecosystem functions such as providing habitat for invertebrates (Hull 1987, Norkko et al. 2000) or fish (Kingsford 1995), and food for herbivorous grazers (Salovius and Bonsdorf 2004). In addition, blooms may indirectly cause hypoxic or anoxic conditions upon decomposition (Raffaelli et al. 1998); they also have been associated with decline of corals (Bell 1992) and seagrasses (Peckol et al. 1994) due to competition for nutrients and/or shading. Bloom forming species are typically characterized by thalli with large surface area to volume ratios (either thin and blade-like or filamentous and repeatedly branched), allowing for fast uptake of nutrients (Litter and Litter 1980, Lotze and Schramm 2000, Wallentinus 1984). Blooms most commonly consist of green algae (Raffaelli et al. 1998, Valiela et al. 1997), but both red and brown species of macroalgae can be present as well (Gross, 1994). Common explanations for the occurrence of macroalgal blooms include increased availability of nitrogen and/or phosphorus, as well as changes in water circulation (Raffaelli et al. 1998). Wind driven upwelling events, which replenish nutrients, have also been linked to occurrences of blooms (Kiirikki and Blomster 1996). In the Northeastern United States, several estuaries with frequent macroalgal blooms exist. Wilce et al. (1982) and Gross (1994) both described seasonal blooms of *Pilayella littoralis* (L.) Kjellm. in Nahant Bay, Massachusetts, which have occurred for at least fifty years. The Waquoit Bay Natural Research Reserve on the south shore of Cape Cod, Massachusetts has seasonal blooms of green algae such as *Ulva* and *Cladophora* (Valiela et al. 1997). In Narragansett Bay, Rhode Island, green and red macroalgal blooms have been observed, particularly in Greenwich Bay (Granger et al 2000, C. Thornber, unpubl. data).

The Cape Cod National Seashore (CCNS) is known for its extensive and continuous Atlantic beaches, attracting swimmers, surfers, fisherman, and sunbathers by the thousands. These sandy beaches are frequently fouled by filamentous drift macroalgae during the summer. While Collins (1914) noted only scattered remnants of drift algae on these shores, casual observations over recent decades (Graham Giese, Provincetown Center for Coastal Research, Provincetown, MA., pers. comm.) imply that although drift algae amounts vary from year, they are becoming more abundant. In the late 1980s, macroalgae accumulated at Head of the Meadow Beach (Fig. 1) during late August and caused repeated beach closures (Gross 1994). In addition, in June of 1993,

large amounts of *P. littoralis* were positively identified throughout the CCNS, particularly at Head of the Meadow Beach (Gross 1994; Fig. 1).

This occurrence is particularly interesting in that macroalgal blooms are typically found in eutrophic estuaries, in which water residence times are long enough for macroalgae to absorb large pulses of nutrients and form blooms (Valiela et al. 1997). The blooms at the CCNS, by contrast, occur along well-flushed, open coastlines. Furthermore, the entire stretch of shore is sandy, with no hard substrate for algal attachment. Thus, it is likely that these algae originate elsewhere and are transported to beaches at the CCNS via physical processes, e.g. by coastal currents and/or by upwelling. Where, when, and at what rate algae are transported to the shore will have a large effect on their spatial and temporal abundance. Local proliferation and deterioration rates also are likely to be important and may be determined by algal density, nutrient availability (Lotze and Schramm 2000), and herbivory (Salovius and Bonsdorff 2004).

With this background, we identified three main objectives for our study: 1) establish a quantitative base line of seasonal and spatial variation in the density and species composition of drift macroalgae throughout the summer; 2) assess the relationship between algal density and water column nutrient concentrations, and 3) examine the hypothesis that drift macroalgae are transported shoreward by upwelling events.

Field-site Description

The entire outer shore of Cape Cod is characterized by shifting sand bars. The southern stretch of the shore (sites 1 - 22, Fig. 1) have sand bars extending perpendicularly from shore forming a hook (referred to as “J bars” hereafter, which accurately describes their appearance as viewed from a boat offshore). Going northwards (sites 22 – 26), a sandbar runs parallel to the shoreline, almost acting as a barrier island. At the northern end of the cape (sites 27 – 40), J bars once again dominate (Fig. 2). In the three months in which this study was conducted, considerable sandbar movement was observed, particularly of J bars, throughout this region.

Methods

Qualitative Surveys

Shore-wide surveys were conducted biweekly from Coast Guard Beach, Eastham, MA (Site 1) to Race Point Beach, Provincetown, MA (Site 40), at 1 km intervals (Fig. 1), to assess macroalgal abundance throughout the entire CCNS region during the summer of 2006. To allow for monitoring of the entire shoreline, surveys were conducted qualitatively, using a scale from 0 to 5 (Tables 1 and 2). Surveys were conducted at low tide so that the macroalgal abundance could be assessed both on shore (intertidal) and in the water (subtidal); typically, algae would occur on the beach most often at low tide, having been cast during the ebb tide (P. Lyons, pers. obs.). At each site, the two levels were assessed separately and then summed together. We used a Kruskal-Wallis test to determine differences in relative algal abundance among sites.

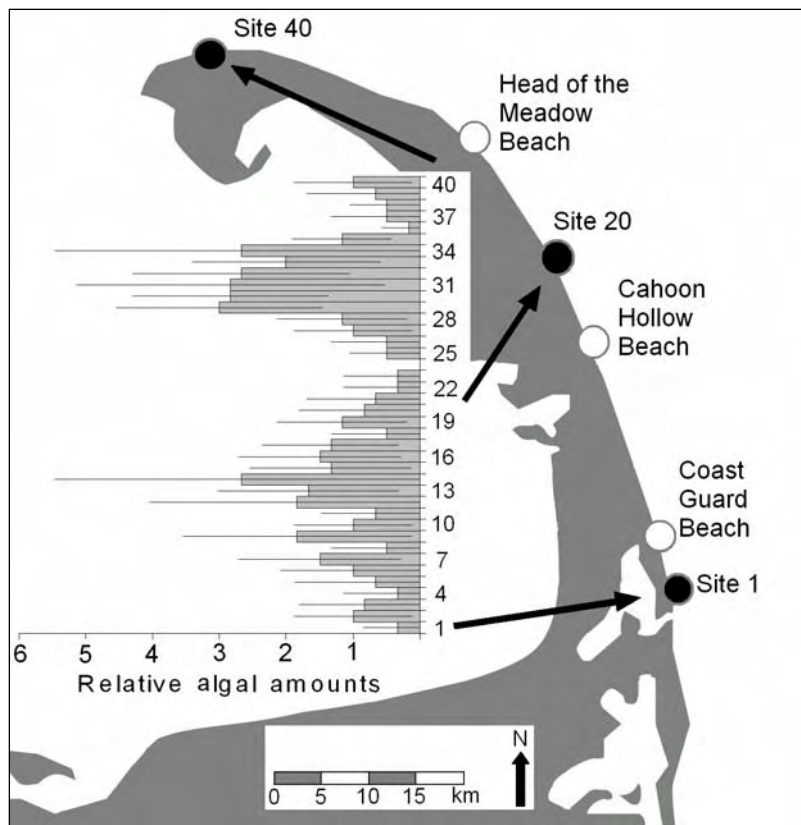


Figure 1. Field sampling sites along the CCNS and qualitative survey means and standard deviations. The three sites where quantitative surveys were done have clear dots; the forty sites (spaced equally at 1km apart) where qualitative surveys were done have black dots; only three of the forty sites are shown for clarity. Shore-wide summer means reflect the sum of qualitative subtidal and intertidal score (0-10) for algal abundance, ± 1 standard error.



Figure 2. Northern stretch of shoreline with J bars. Photo by J. Portnoy 8 May 2004.

Table 1. Intertidal survey scale assessed for area between mean tide level and mean low tide level.

0. <u>Absent</u>	No macroalgae present on the beach
1. <u>Sparse</u>	Some cover by macroalgae (0-10% of any given area). Odor unlikely. Thin accumulations present (<1 cm thick), mostly individuals occurring separately.
2. <u>Mediocre</u>	Cover by macroalgae roughly 10-40%. thin accumulations present but thicker areas (2-4 cm thick) may occur. Odor possible in proximity to macroalgae.
3. <u>Masses</u>	Much cover by macroalgae (40-75% of any given area). Thickness from 0-4 cm with extremes up to 6 cm. Odor likely in proximity and even several meters from macroalgae.
4. <u>Complete coverage</u>	Generally, the whole area is covered with very little areas of exposed sand. Depth ranges to 20 cm. Odor present throughout most of beach dependent on wind.
5. <u>Severe</u>	Complete coverage. Depth of 20 cm or more. Odor powerful and present well away from algae, dependent on wind.

Table 2. Subtidal surveys assessed for water extended from shore out 10 m.

0. <u>Absent</u>	No macroalgae present throughout the water column.
1. <u>Sparse</u>	Some individual macroalgae scattered in water column on surface or bottom. No large clumps.
2. <u>Mediocre</u>	Some clumps present on bottom, in water column, or on surface. Macroalgae mostly scattered.
3. <u>Masses</u>	Large clumps present. Macroalgae may blanket the bottom or surface. Difficulty in distinguishing clumps. Roughly half of the entire water column contains macroalgae.
4. <u>Saturated</u>	Large clumps present. Very little algal free water. Some difficulty in swimming would result.
5. <u>Severe</u>	Large scale clumping. Entire water column full of macroalgae. Clumps can't be distinguished from water or other clumps. Wind induced ripples absent, and wave dynamics appear altered. Much difficulty swimming or just moving through the water.

Quantitative Surveys

During the summer of 2006, we conducted biweekly quantitative surveys of macroalgal abundance at three beaches on the Atlantic shoreline of CCNS (Head of the Meadow Beach, Truro; Cahoon Hollow Beach, Wellfleet; Coast Guard Beach, Eastham; Fig. 1), spaced approximately 12 km apart. All three beaches contained J Bars. Each time, at each beach, three random locations were selected within a 1 km stretch using GIS software, and for each location, algal biomass was measured at low tide in both 1.5 m water depth (subtidal) and in the lower intertidal zone. Three subtidal samples for each location were collected directly offshore; thus, 9 collections were made per sampling day per beach. We used a 40 cm long by 15 cm diameter cylinder to collect approximately 10.5 L of ocean water for each sample, from a depth of 0 - 40 cm. The seawater and drift algae were brought to shore and filtered through a 1 mm sieve to remove all drift macroalgae. The collected algae were later identified to species or genus (using Villalard-Bohnsack 2003), and voucher specimens were preserved on herbarium paper and on permanent slides. The total wet biomass of all algal material of each sample was determined by first spinning all algae 20 times in a salad spinner to remove excess water and then weighing the algae to the nearest 0.1 g.

For intertidal surveys, on each sampling date, a 10 m transect running parallel to the shore in the lower intertidal was used for each location (thus three times per beach). We used a 0.25 m² quadrat (subdivided into 100 squares), placed at 1 m intervals, to determine algal percent cover in each quadrat for each of three groups: 1. *Ulva* spp, which consisted mostly of *U. lactuca* (L.) but also included *Ulva intestinalis* (L.), 2. filamentous red/brown, which consisted of mostly the genera *Polysiphonia*, and 3. other, which included all other species including green, red, and brown algae. Group 3 species had larger thalli but were typically rare (less than 2 % cover in individual quadrats); the Appendix contains a complete list of all macroalgal species encountered. Algae in quadrats 1, 5, and 9 along each 10 m transect were collected and brought to the lab to determine wet mass. Two-way repeated measure ANOVAs were used to assess the effects of site and sampling date, on both intertidal and subtidal algal densities, using JMP 5.1 (SAS Institute, Carry, NC).

Nutrient Assays

We collected water samples to determine dissolved inorganic nitrogen (DIN) concentrations in the form of nitrate (NO₃⁻) and ammonium (NH₄⁺), from the middle of dense macroalgal accumulations as well as areas free of macroalgae. Water samples were collected at both Head of the Meadow Beach and Cahoon Hollow Beach. At each beach, one sample was taken in a dense patch and another in an algal-free patch during low tide on each sampling date. Macroalgal densities were measured as above (see Quantitative Surveys). All water samples were analyzed by flow-injection analysis using a Lachat Quik-Chem™ system. Correlations among nutrients (NO₃⁻ and NH₄⁺, and total DIN) and subtidal macroalgal densities were analyzed with logistic regression analysis using JMP 5.1 (SAS Institute, Carry, NC).

Upwelling Events

Temperature was recorded using HOBO® data loggers (Onset Computer Corporation, Pocasset, MA) attached to buoys anchored by cinder blocks in approximately 1.5 m of water (at low tide) at Head of the Meadow Beach, Cahoon Hollow Beach, and Coast Guard Beach (Fig. 1). Data were recorded at half hour intervals from May 31, 2006 to August 28, 2006, and daily

temperatures were averaged for each site. Wind data and daily air temperature averages were collected for Chatham, MA from www.wunderground.com. The occurrence of an upwelling event was based on the satisfaction of three criteria: 1) the wind was consistently from the southwest for at least 16 hours during the given day, 2) daily water temperature was at least 1.5 °C lower than the previous day, and 3) daily air temperature was at most 2.0 °C lower than the previous day. With the orientation of the shore, a southwest wind would be needed to generate an upwelling event, which would be marked by a decrease in water temperature due to influx of cold bottom water. The third criterion was put in place to avoid anomalous identification of upwelling events. Changes in subtidal and intertidal macroalgal densities since the last sampling date were calculated from the quantitative survey data, as well as the time since the last upwelling event. A one-way ANOVA was used to assess the effects of upwelling events on the changes in intertidal and subtidal algal densities, using JMP 5.1 (SAS Institute, Carry, NC).

Results

Qualitative Surveys

Significant differences in relative algal abundance were found among the 40 sites ($P < 0.001$). Sites 29 through 34 had the highest mean abundances (1.4 – 2.3 relative summer mean, Fig. 1). The week of 9 August had the highest overall algal densities throughout the CCNS, matching our quantitative survey data.

Quantitative Surveys

Drift macroalgal densities were the highest during August, for both the intertidal and subtidal zones, and varied significantly among sampling dates ($P = 0.005$ and $P = 0.013$, respectively; Tables 3 and 4; Figs. 3 and 4). Intertidal densities were typically 1-2 orders of magnitude greater in August than in June or July. Head of the Meadow and Cahoon Hollow beaches had higher densities of macroalgae ($2911.5 \text{ g} \cdot \text{m}^{-2}$ and $243.9 \text{ g} \cdot \text{m}^{-2}$ in the intertidal during the week of August 9) than Coast Guard Beach; this among-site variation was significant for intertidal sites ($P = 0.028$) but not subtidal sites ($P = 0.153$, Tables 3 and 4). The week of August 9 was the only sampling date with measurable amounts of algae at Coast Guard Beach ($36.97 \text{ g} \cdot \text{m}^{-2}$ intertidal and $0.08252 \text{ g} \cdot \text{L}^{-1}$ subtidal). The most abundant species were *Ulva lactuca* and *Polysiphonia/Neosiphonia* spp.; all species encountered are listed in the Appendix.

Nutrient Assay and Upwelling Events

Water-column DIN varied inversely with subtidal macroalgal density ($R^2 = 0.543$, $P = 0.037$; Fig. 5). NO_3^- was significantly negatively correlated ($R^2 = 0.472$, $P = 0.013$) with algal density, while NH_4^+ was not ($R^2 = 0.055$, $P = 0.575$). Although several upwelling events were recorded, their occurrence had no significant effect on either intertidal or subtidal algal density ($F_1 = 2.6202$, $P = 0.1664$; $F_1 = 2.2466$, $P = 0.1942$, respectively).

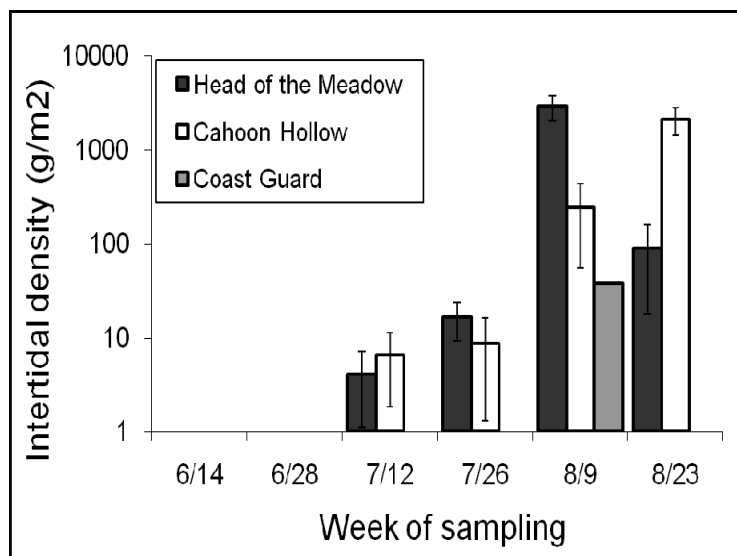


Figure 3. Intertidal algal densities (wet mass * m⁻²) for the three quantitative survey sites in summer 2006; the Y axis is in log scale. Data are means $\pm$ 1 standard error.

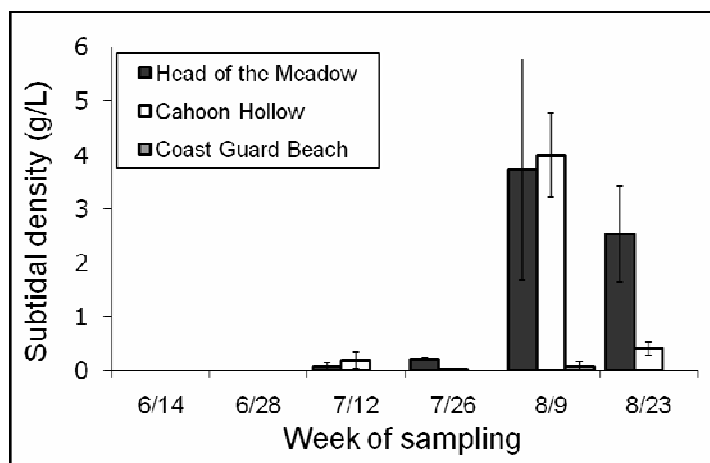


Figure 4. Subtidal algal densities (wet mass * L⁻¹) at the three quantitative survey sites in summer 2006. Data are means $\pm$ 1 standard error.

Table 3. Results of a repeated measures two-way AVOVA on intertidal macroalgal density ($\text{g}\cdot\text{m}^{-2}$) among sites and sampling dates. P values in bold are significant ($P < 0.05$).

Source	df (num, den)	F	P
Site	2, 22	4.232	0.028
Sample Week	1, 38	6.572	0.005
Site*Week	3, 38	7.198	0.004

Table 4. Results of a repeated measures two-way AVOVA on subtidal density ($\text{g}\cdot\text{L}^{-1}$) among sites and sampling dates. P values in bold are significant ($P < 0.05$).

Source	df (num, den)	F	P
Site	2, 23	2.039	0.153
Sample Week	1, 28	6.471	0.013
Site*Week	2, 28	2.142	0.128

Discussion

A peak of algal density occurred during the second week of August in the subtidal and intertidal sites for two of three beaches and in the last week of August for the third beach. This closely matched our prediction based on previous findings (Gross 1994). However, unlike previous studies (Wilce et al. 1982), we found very little *P. littoralis* in either the ball form described by (Wilce et al. 1982) or in the linear form; our blooms were mainly composed of *Ulva* spp. and *Polysiphonia* spp. We found the highest densities of macroalgae at Head of the Meadow Beach, in both the intertidal and subtidal. These results were substantiated by our shore-wide qualitative surveys, which revealed a peak just north of Head of the Meadow Beach (Fig. 1).

Temporal Abundance Patterns

Drift macroalgal blooms have typically been described in the literature as following broadly consistent temporal trends in abundance. Blooms typically peak in late summer (e.g. Berglund et al. 2003), due to light levels, nutrient levels, water temperature, and other factors associated with seasonality. We found that algal abundance along the CCNS did peak in August. However, on smaller temporal and spatial scales, drift macroalgal biomass was quite patchy. We found a significant negative relationship between algal density and DIN concentration (Fig. 5), implying that algae are likely using nutrients to proliferate while drifting, and their growth may be nutrient-limited in dense aggregations. However, subtidal drift macroalgae did not only occur in dense aggregations, and these aggregations only occurred occasionally. Along the CCNS, waves break closer to shore at high tide, potentially acting to disperse aggregations every 12 hours. We found no significant relationship between algal abundance and upwelling events, which are typically nutrient-rich (Kiirikki and Blomster 1996). This indicates that algae may not be limited by nutrients on a larger scale, possibly because the entire CCNS shoreline is exposed to open ocean and water exchange is presumably adequate.

Sources of Macroalgae

The large abundance of drifting macroalgae and lack of hard substrate found along the CCNS imply that macroalgae are most likely transported from other locations. While some macroalgae may originate from local areas, this is likely a minor fraction of the total. Much of the offshore bottom has been mapped and consists of sandy sediment, with little habitat suitable for macroalgal attachment (Poppe et al. 2005). Upwelling events could provide a means of transportation from offshore locations to beaches, but no correlation between upwelling events and algal abundance was found. Instead, we suggest that macroalgae drift from more distant locations; the most likely mechanism is that drift algae originate within the Gulf of Maine and are transported by the Western Maine Coastal Current (WMCC) toward Cape Cod (Churchill et al. 2005; Pettigrew et al. 2005; Fig. 6). Gulf of Maine circulation and mixing of the WMCC and the Eastern Maine Coastal Current (EMCC) has been linked to the spread of the toxic red tide dinoflagellate, *Alexandrium fundyense* (Balech), throughout the Gulf of Maine (Townsend et al. 2001). The EMCC typically contains higher levels of nutrients and *A. fundyense* cells (Townsend et al. 1987). It is possible that some of the same mechanisms affecting *A. fundyense* spread may contribute to drift macroalgal accumulations along the Atlantic shore of Cape Cod.

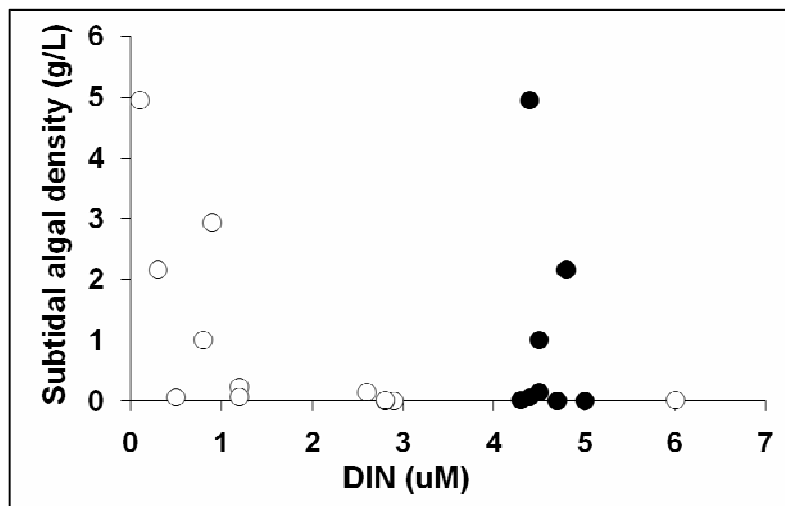


Figure 5. Correlation between DIN and subtidal algal density from both sites (Head of the Meadow Beach and Cahoon Hollow Beach). Solid circles denote NH_4^+ ($R^2 = 0.055$, $P = 0.575$) and open circles denote NO_3^- ($R^2 = 0.472$, $P = 0.013$).

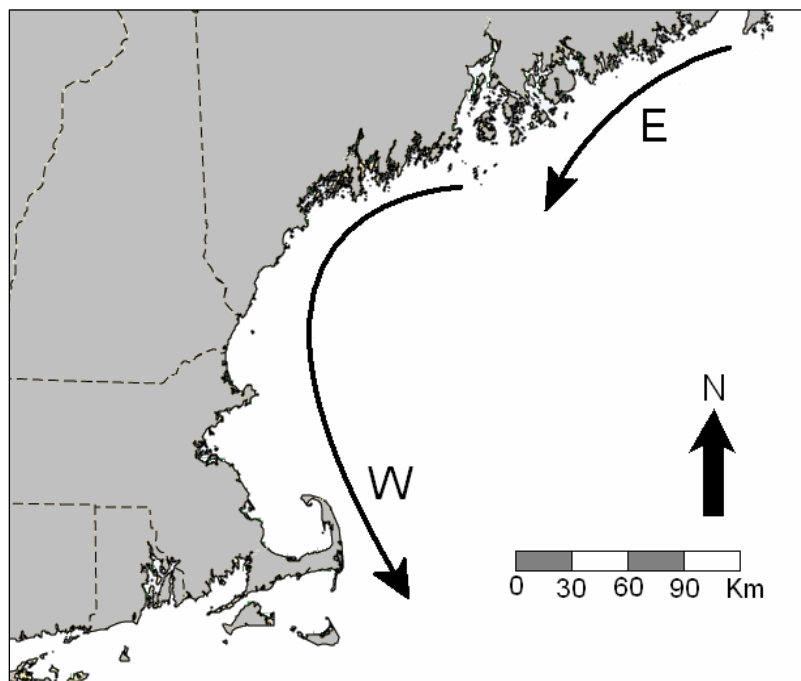


Figure 6. Gulf of Maine coastal circulation. W denotes Western Maine Coastal Current and E denotes Eastern Maine Coastal Current. Modified from:
<http://www.bakerlite.co.uk/pics/North%20America/New%20England/Map.jpg>

Spatial Patterns

Significant spatial variability occurred throughout the summer in macroalgae density. Both quantitative and qualitative surveys indicate that the shoreline just north of Head of the Meadow beach has greatest algal biomass. This pattern is consistent with our hypothesis that algae are drifting from northern New England. This northern stretch of shoreline would be first to receive drift macroalgae via the southward flowing WMCC (Fig. 6). In addition, drogue studies (J. Manning, National Marine Fisheries Service, Wood's Hole, MA., pers. comm.) indicate that the extensive bar and shoal system just east of the tip of Cape Cod acts to increase water residence times and thus capture southward-drifting debris.

Drift macroalgae were not limited to the northern part of the shore. Accumulations in the southern part of the shoreline occurred near J bars which could retain algae as they drift south, while macroalgae along the more northern shoreline accumulated even in areas without J bars. It is probable the stretch of beach between sites 22 and 26 (Fig. 1) had relatively little algae due to lack of J bars to concentrate southward drifting macroalgae (Paalme et al. 2004).

The most southern part of the shore received very little algae throughout the summer, except for the first week in August, even though this stretch of shore does contain J bars that could locally retain algae. During early August, large amounts of macroalgae did occur at the southern stretch of shoreline, following a period of strong Northwest winds. Thus, the general occurrence of drift macroalgae, as well as site to site differences in accumulations along CCNS's Atlantic shoreline, appear to result from seasonal production in waters north of Cape Cod, southward transport via New England coastal currents, and capture of drift algae by the outer Cape shoal and bar system. This study provides a repeatable protocol and quantitative data base for future assessments of trends in the timing, spatial distribution, species composition, and abundance of drift macroalgae along the Atlantic shore of Cape Cod.

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Appendix

Species Present

Most Common

- | | |
|--|---|
| - <i>Neosiphonia harveyi</i> (Bailey) ^R | - <i>Polysiphonia nigra</i> (Huds.) Batters ^R |
| - <i>Polysiphonia flexicaulis</i> (Harv.) Collins ^R | - <i>Polysiphonia stricta</i> (Dillw.) Grev. ^R |
| - <i>Polysiphonia fucoidea</i> (Huds.) Grev. ^R | - <i>Ulva lactuca</i> (L.) ^C |

Less Common

- | | |
|--|---|
| - <i>Callithamnion corymbosum</i> (Smith)
Lyngb. ^R | - <i>Ectocarpus siliculosus</i> (Dillw.) Lyngb. ^P |
| - <i>Ceramium virgatum</i> (Roth) ^R | - <i>Palmaria palmata</i> (L.) Kuntze ^R |
| - <i>Chondrus crispus</i> Stackhouse ^R | - <i>Pilayella littoralis</i> (L.) Kjellm. ^P |
| - <i>Cladophora albida</i> (Huds.) Kützinger ^C | - <i>Rhodomela confervoides</i> (Huds.) P.C.Silva ^R |
| - <i>Codium fragile</i> subsp. <i>tomentosoides</i> (Goor)
P. C. Silva ^C | - <i>Ulva intestinalis</i> (L.) ^C |
| | - <i>Vertebrata lanosa</i> (L.) T.A. Christensen ^R |
| | -several <i>Fucus</i> and <i>Laminaria</i> species ^P |

Superscripts refer to algal taxonomy: R- Rhodophyta (red), C- Chlorophyta (green), P- Phaeophyceae (brown).

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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