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# Green Algal Ropes: A Novel Estuarine Phenomenon in the Gulf of Maine<sup>1</sup>

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**ABSTRACT:** During late summer and early autumn of both 1984 and 1985 we observed and photographed the development of a green algal bloom on intertidal mudflats in eastern Maine. The bloom culminated in the formation of thick (8–10 cm) mats and long (> 50 m) serpentine rope-like structures. The algal mat was polytypic but composed primarily of *Enteromorpha intestinalis* L. We describe the probable sequence of events which led to the formation of algal ropes. The processes involved appear to parallel the development of ball-like masses in other algae. Algal ropes developed after mat formation, as prevailing winds and tidal currents rolled individual and entwined strands across the mudflat. The great mass of algae eventually became embedded into the sediment surface producing anoxic conditions in the substrate up to several cm deep. The ecological significance and possible negative effects of this altered environment on a commercially important bivalve species are discussed.

## Introduction

Dense blooms of benthic macroalgae are common phenomena along the shores of many temperate oceans. In particular, mats of green algae on intertidal mudflats are well-documented phenomena in Europe (Kautsky 1982; Soulsby et al. 1982; Owens and Stewart 1983), Asia (Ho 1981), North America (Sawyer 1965; Shellem and Joselyn 1982; Pregnall and Rudy 1985) and Australia (Gordon et al. 1980). Green algal blooms can also develop on rocky shores following eutrophication (Sawyer 1965) or on pristine intertidal shores where herbivores have been excluded or removed (Jones 1948; Vadas 1982; personal observation in Maine and Washington, U.S.A. and Chile; Bertness 1984), thereby allowing these algae to approach the "presumed" carrying capacities of their immediate environments. Blooms of opportunistic species regularly occur during spring at temperate or boreal latitudes. Such natural algal blooms are common in tide pools (Lubchenco 1978; Sze 1980) and on emergent substrata (Vadas et al. 1977) in the Gulf of Maine.

Published accounts of macroalgal blooms on

mudflats are rare for both the Gulf of Maine and the northwest Atlantic ocean (Sawyer 1965). However, in 1984 and 1985 we observed massive blooms of green algae during late summer and autumn on several intertidal mudflats in eastern Maine (Washington Co.). These blooms have occurred with increasing frequency during the last decade (personal communication, W. Murray, clam harvester; Edmunds, Maine). We describe the development of these algal blooms, their significance and potential impact on commercially important shellfish.

## Observations

Periodic observations and photographs of the mudflat were made from 1 April 1984 to 30 December 1984 to assess the population dynamics of the soft-shell clam *Mya arenaria* L. Regular observations during 1984 and 1985 provided information on the sequence of algal development and rope formation. In addition, surveys of six shellfish committees in Washington Co. were conducted, and a series of aerial (color and infra-red) photographs was taken of the Cobscook Bay Region in September 1984. Qualitative ground assessments were also made from 1984 to 1986 on several mudflats in eastern Maine.

The blooms that we report here developed in

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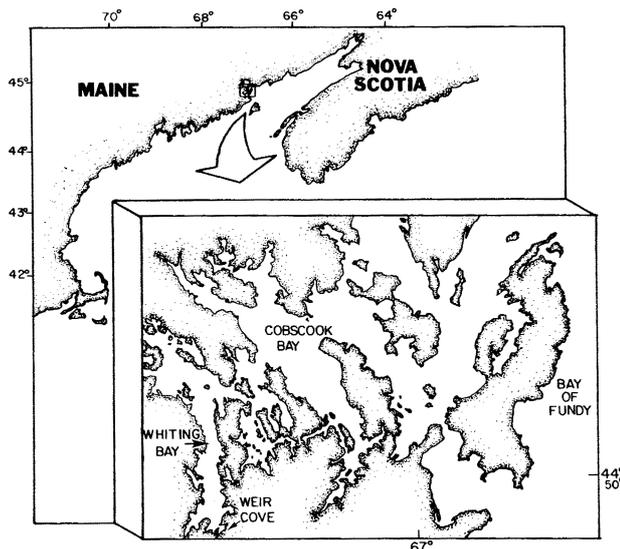


Fig. 1. Map of Maine including the Cobscook Bay region.

Weir Cove, upper Whiting Bay (Fig. 1), which purportedly had experienced massive annual blooms for several years. These mudflats consist of poorly sorted fine-to-medium size sand sediments (*sensu* Folk 1974) and are part of the Passamaquoddy and Cobscook Bay system (44°48'45"N, 67°09'52"W). Whiting Bay is subject to tidal ranges of 4–6 m and currents approaching 20 cm s<sup>-1</sup>. During late summer of 1984 and 1985, we observed thick algal mats and extremely long and massive networks of green, rope-like structures covering much of the intertidal region (Fig. 2). These serpentine complexes (Fig. 3) consisted primarily of *Enteromorpha intestinalis* but also contained other taxa, including green algae and seagrasses (Table 1). In addition, floating debris, especially dead *Zostera marina* L., was often entwined in the matrix (Fig. 4).

The algal covering was absent or undetectable in July but apparent by August. During August, but prior to the development of any rope-like structures, a thick interconnected network of algae had formed. Thick algal mats (8–10 cm) and long ropes (>50 m × ca. 0.2 m) were present by late August; both forms remained relatively intact through November. These late season developments may have been aided by unseasonably mild autumns (Anonymous 1984, 1985).

Development of the algal ropes appears to be related to several physical factors, including tidal height and currents, intertidal slope and wind direction. The early stages of rope formation consisted of a series of small strands growing and twisting together under the combined influence of tides and winds. These strands developed into short, complex entwined networks in an accumulative



Fig. 2. Overview of the upper and mid intertidal zone in Weir Cove showing numerous serpentine rope-like structures (scale bar = 1 m).

(snowball effect) manner (Fig. 5). Eventually these networks developed into large serpentine, rope-like structures.

Subsequently, the lower portions of both the algal ropes and mats became embedded into the surface of the mud, probably as a result of the weight of the algae. The embedding of the lower portions

TABLE 1. Macrophytes associated with *Enteromorpha* blooms on mudflats in Weir Cove, Trescott, Maine between August and December 1984.

Taxa	Location*
Chlorophyta	
<i>Cladophora sericea</i> (Hudson) Kutzing	UI
<i>Chaetomorpha linum</i> (Müller) Kutzing	UI, LI
<i>Enteromorpha intestinalis</i> (L.)	UI, LI
<i>Enteromorpha prolifera</i> (Müller) J. Agardh	UI
<i>Rhizoclonium riparium</i> (Roth) Harvey	UI, LI
<i>Ulva lactuca</i> L.	UI, LI
Angiosperms	
<i>Ruppia maritima</i> L.	SF
<i>Zostera marina</i> L.	LI, SF

\* Key UI = upper intertidal, LI = lower intertidal, SF = sublittoral fringe.



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Fig. 3. Isolated view of massive algal ropes forming a serpentine structure (large scale bar = 1 m, small scale bar = 0.15 m).

Fig. 4. Surface view of a mature algal rope showing individual thalli of *Enteromorpha* sp. and dead blades of *Zostera marina* (scale bar = 0.15 m).

Fig. 5. Terminal portion of an algal rope showing the early formation and entwining of strands in mid and upper intertidal region (approximate distance from foreground to shore is 150 m).

Fig. 6. Experimental soft-shell clam (*Mya arenaria*) plot (0.25 m<sup>2</sup>, for scale, wooden stakes are 0.5 m apart) in September 1984 showing typical algal coverage and position of dead *Mya* (arrow).

of the ropes and mats reduced or prevented further algal movement at the sediment interface. The algal mass gradually became anaerobic and produced a black, hydrogen sulfide-enriched mud up to several cm thick similar to that reported by Nicholls et al. (1981) and Soulsby et al. (1982).

### Discussion

The development and growth of dense, green, benthic, algal mats composed primarily of *Enteromorpha* spp. and *Ulva* spp. have been reported elsewhere in North America (Price and Hylleberg 1982; Shellem and Josselyn 1982; Pregnall and Rudy 1985) and Europe (Lowthion et al. 1985). We observed the formation of similar algal mats in Whiting Bay and the novel phenomenon of algal ropes (A. M. Pregnall, personal communication 1986, indicated that rope-like algal structures also formed in the Coos Bay estuary, Oregon). Although our direct observation of mat and rope development was restricted to Wier Cove, aerial overflights and ground inspections of mudflats confirm similar algal development elsewhere in the Cobscook Bay region. Our surveys of shellfish committees reveal that between 10 and 35% of most mudflats in Washington County are now periodically covered by these algal blooms. Aerial observations revealed not only the widespread nature of these algal blooms but also the presence of a sharp lower boundary or zonation in several areas. These algal-free areas appear to be similar to the halos created by fish and sea urchins in other environments (Randall 1965; Ogden et al. 1973). Whether these patterns are the result of biotic or abiotic interactions remains to be determined.

The facility with which algae develop or secondarily become associated into ball- or rope-like forms appears to be related to both genetic and environmental factors. These forms occur in a number of unrelated environments and at various depths (Abbott 1986). *Cladophora* spp., for example, commonly form monotypic ball-like morphologies (Brand 1902, 1909; Ganong 1905, 1909; Smith 1950; Sakai 1964; Chapman 1968). *Cladophora* "balls," long known from Japan, Europe, and North America, result from a rolling motion along shallow bottoms, where they continue to enlarge. Recently, massive developments of aegagropiloid (ball-like) forms of *Cladophora montagneana* Kütz were described from Australia (Gordon et al. 1985). These spheres are associated with a lack of acropetal organization, heavy eutrophication and a gentle rolling motion. Similarly, a ball-like form of *Valoniopsis pachynema* (Martens) Borgesen is thought to result from the mechanical action of rolling waves on shallow shores (Abbott 1986). In the Azores and Mediterranean, *Codium bursa* (L.) C. Ag. nor-

mally develops into a ball-like form (Silva 1962; K. Luning, personal communication 1985), which presumably is genetically determined. An environmentally induced ball-form of a brown alga, *Pilayella littoralis* (L.) Kjellm, with novel methods of population increase, including an association with an holocarpic fungus, was recently described from Massachusetts (Wilce et al. 1982). Nonliving monotypic ball-like morphologies have also been described for the rhizomes of the seagrass, *Posidonia oceanica* (L.) Delile (Cannon 1979). Cannon (1979) experimentally demonstrated that the physical effects of oscillating water movement over a substratum produced a form similar to that found in nature. Polytypic ball forms have also been described for marine algae from the coast of Nova Scotia (MacKay 1908, in Ganong 1909). The novel algal ropes described here are also polytypic (but dominated by *Enteromorpha intestinalis*) and also appear to be environmentally induced.

Blooms of *Enteromorpha* are ecologically important and potentially may be economically significant if they directly or indirectly influence recruitment, growth or survival of soft-shell clams. Occlusion of the sediment-water interface, for example, might interfere with filtering. Further, anoxic sediments may alter the behavior and depth positioning of clams and live juvenile clams may become entangled in the mats of algae (Fig. 6 and personal observations), both of which may increase their susceptibility to predation.

The algal mats in eastern Maine may play an important role in the productivity of these areas. Most of the algal biomass occurred in the mid and upper intertidal regions, similar to that observed in Oregon (Pregnall and Rudy 1985). The large quantities of floating algal debris suggest that the productivity of these waters is being substantially enhanced. In other regions *Enteromorpha* blooms contribute to the production of estuarine areas through the release of dissolved organic carbon, burial of algae in sediments, fragmentation by herbivores and the loss of entire plants (Nicholls et al. 1981; Pregnall and Rudy 1985). These algae may also serve as food sources for amphipods and other mudflat invertebrates (Shellem and Josselyn 1982). The formation of thick mats is also relevant to the depletion of oxygen in the mudflats. The totally anaerobic muds support much-reduced biomass and, where high concentrations of H<sub>2</sub>S penetrate to lower layers, these conditions can persist throughout the year (Nicholls et al. 1981).

The presence of intertidal algal mats can also play a significant role in structuring benthic communities (Nicholls et al. 1981; Soulsby et al. 1982). Both studies demonstrated that mudflat epifaunal densities (especially of the gastropod *Hydrobia ul-*

*vae*) increased due to the interaction of increased habitat heterogeneity and food. Conversely, algal mats have also been shown to have negative effects on polychaete and bivalve species. For example, the population densities of two filter-feeding bivalves, *Abra tenuis* (Montagu) and the commercially important *Cerastoderma edule* L., decreased by an order of magnitude when covered by algal mats (Nicholls et al. 1981). Similarly, heavy blooms of *Ulva rigida* (C. Agardh.) LeJolis and *Gracilaria* sp. have been reported to smother *Tapes decussatus* (L.), a highly valued Italian clam (Breber 1985). However, in neither case were the actual mechanisms causing mortality identified.

Research is needed to address several interesting questions, such as what mechanisms naturally control the growth and productivity of these algae and what allows such massive blooms to develop in this relatively undeveloped and unpolluted region of eastern Maine; what is the physiological condition of algae at different layers in the mat; how many and what kinds of animals have taken up residence in these mats and have these animals contributed to the secondary production of these waters; do these algal ropes die and decompose or are they buried and then decompose; what is the fate of these potentially significant sources of carbon to adjacent coastal waters; how do these algae affect the physical and chemical properties of clamflats; and what are the specific mechanisms that reduce the survivorship of commercially important bivalves on these mudflats?

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