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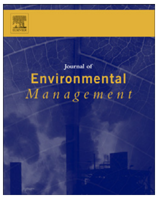

Research article

Macroalgal composition and accumulation in New England estuaries

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ABSTRACT

New England estuaries provide essential feeding grounds and nursery habitat for important recreational and commercial species. However, these functions are being altered by a recent shift in estuarine plant dominance from rooted plants to opportunistic drift macroalgae that can form dense accumulations. We hypothesize that formation of these macroalgal accumulations is controlled by the level of nutrient enrichment and the low hydrodynamic energy regime present in many estuarine basins. To test this hypothesis, we conducted temporal macroalgae surveys in eight s.e. Massachusetts estuaries to quantify the level of accumulation within basins with varying levels of nitrogen enrichment and bottom currents. Our results indicate that opportunistic *Ulva* spp. dominated the macroalgal community in both estuaries with temporal surveys, Green and Great Ponds. Measurements of tidal transport revealed a net import of macrophyte material but with no import or export of *Ulva*. Within each estuary, occurrence of opportunistic macroalgae was positively related to levels of water column total nitrogen ($R^2 = 0.76$) and growth rate of *Ulva* spp. directly related to total nitrogen + light level ($R^2 = 0.92$), while bottom coverage was >20% at TN levels >0.48 mgL^{-1}. We conclude that opportunistic species accumulate in response to nutrient enrichment with *in situ* processes controlling growth and decay, while import and tidal transport play relatively minor roles in the distribution of opportunistic drift macroalgae in these shallow estuaries.

1. Introduction

Opportunistic drift macroalgae are capable of rapid growth, thick accumulations and are increasingly suspected to cause loss of eelgrass and benthic animal habitat in New England estuaries (Valiela et al., 2002; Scanlan et al., 2007). As a result, numerous studies have been conducted on the primary environmental variables driving macroalgal growth and accumulation (Pederson and Borum, 1996; Lotze et al., 2001; Martins et al., 2008; Krause-Jensen et al., 2007). Relationships between water depth, light attenuation, water velocity, nutrient supply, light penetration, bed stability, turbidity, temperature, hydrography and suitable substratum have been related to increased opportunistic macroalgae concentrations (Chambers et al., 1999; Lanari et al., 2017; Scanlan et al., 2007).

Nitrogen enrichment driven by rising coastal populations and increased watershed loads support a general trend toward accumulation of macroalgal species (Nixon et al., 2001; Menesguen and Piriou, 2012; Valiela et al., 2002). Measurements have revealed that macroalgal biomass on the shoreline of Narragansett Bay and in Waquoit Bay can reach or surpass densities of 300 $gWWm^{-2}$ and 335 $gWWm^{-2}$, respectively (Thornber et al., 2008; Valiela et al., 2002). In these estuaries, phosphorous is typically abundant due to the weathering of rocks and input from fresh water sources, while available inorganic nitrogen is rapidly utilized and tends to limit plant growth (Ryther and Dunstan, 1971). Low nutrient concentrations and sufficient bottom light support diverse assemblages of phytoplankton, macroalgae and seagrass. Increased nitrogen availability drives phytoplankton blooms which reduce light penetration. Macroalgal communities shift from slow growing, large perennial species, to low light tolerant, fast growing opportunistic species (Duarte, 1995; Krause-Jensen et al., 2007). Nutrient enrichment thereby initiates a cascade of negative effects for coastal habitats, eventually shifting from seagrass to macroalgae/phytoplankton dominated systems.

Under nutrient enriched conditions, habitat health declines and a cascade of negative effects occur; including declining seagrass coverage due to increased light attenuation, loss of diverse aquatic

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habitat, reduction of fish and shellfish populations, and oxygen depletion (D'Avanzo and Kremer, 1994; McGlathery, 2001; Smith, 2006). Nitrogen enrichment induced eelgrass loss is associated with shading due to the increase in magnitude and duration of phytoplankton blooms (Benson et al., 2013; Kemp et al., 1983), growth of epiphytes (Short et al., 1995), increased frequency of Spring macroalgae blooms (Sundbäck et al., 2003) and smothering/shading by accumulated macroalgae (Bell et al., 1995; Kennish et al., 2011). Opportunistic macroalgae have high surface area to volume ratios, absorb nutrients over their entire surface and are able to grow in low light (Hein et al., 1995; Martins et al., 2008), which provides a competitive advantage relative to rooted macrophytes (Mann, 1973; Martins et al., 2008; Pederson and Borum, 1996). Given the availability of suitable substrate, shorelines can be both a source of drift macroalgae (Bell and Hall, 1997) and a region of deposition.

The most common genera of opportunistic drift macroalgae in New England estuaries include *Ulva, Gracilaria, Codium, Polysiphonia* and *Cladophora* (McGlathery, 2001). Dense accumulations of these genera are frequently associated with losses of benthic animal communities and eelgrass (Green et al., 2014; Hauxwell et al., 2001; McGlathery, 2001). Drift macroalgae can originate on hard substratum or seagrass, then break off and grow unattached, resulting in drifting mats (Bell and Hall, 1997). The passive transport of macroalgae allows hydrodynamic processes to control retention and accumulation. Significant quantities (0.5–1.0 tons) of macroalgae were found to enter Biscayne Bay, FL during flood tides, however it was unclear whether net import occurred as ebb tide export was not quantified (Biber, 2007).

Efforts to quantifying the density of macroalgal blooms (Thornber et al., 2008) and the total amount (mass and coverage) in an estuary has been hampered by need for spatial and temporal coverage over large areas and the potential movement of the macroalgae itself. Previous studies investigating macroalgal coverage have utilized SCUBA diver monitoring of fixed sites, aerial surveys (Berglund and Mattila, 2003), and acoustic methods (Riegl et al., 2005). Since drift macroalgae can be transported within systems, fixed site methods may not provide true estimates of spatial coverage. Aerial and acoustic methods can provide spatial and temporal information, but are not capable of identifying macroalgal types and require expensive equipment.

Given the growing number of nitrogen enriched estuaries and associated loss of seagrass habitat, we sought to assess spatial and temporal variability in coverage and the relative importance of *in situ* growth versus transport for developing accumulations and to derive both intra- and inter-estuarine comparisons with key environmental variables. A continuous georeferenced video survey approach was implemented which allowed large areas to be surveyed within single tidal cycles. Transport of macrophyte materials through a tidal inlet was quantified to clarify source populations and import dynamics. In addition, *in situ* growth rates relative to bottom light levels and rate of decay of senescing macroalgae were measured to evaluate *in situ* production and “loss” within regions of accumulation. The resulting relationships between spatiotemporal macroalgae distribution, macrophyte transport, growth, decay and environmental variables provide useful metrics for resource managers concerned with dense nuisance macroalgae accumulations.

2. Materials and methods

2.1. Area of study

Eight estuaries distributed throughout southeastern Massachusetts were surveyed from 2011-2013 for macroalgal species coverage and abundance in parallel with key eutrophication related water quality parameters. The estuaries were shallow (depth ≤4 m), semi-enclosed basins, with tide ranges from 0.5 to 3 meters and direct tidal exchange with Buzzards Bay, Cape Cod Bay, Nantucket Sound, Vineyard Sound, or the Atlantic Ocean (Fig. 1). Two of the eight estuaries were surveyed three times in 2011, seven times in 2012 and once in 2013. Macroalgal growth and decay and macrophyte transport in tidal flows through the inlet were also investigated. The systems were selected to represent estuaries with different source waters and tidal ranges.

2.2. Vegetation surveys

Macrophyte surveys were conducted using continuous video footage similar to previous studies (Vaudrey et al., 2009), with down-sampling to obtain still frames paired with location data (±0.9 m). The surveys were conducted in eight estuaries of varying levels of nitrogen enrichment and tidal flushing from 2011 to 2013 (Fig. 1). In 2011, a black and white underwater video camera (Explorer Underwater Black & White Camera System SWJ-2110) was used for the surveys, while in 2012 and 2013 a color video camera (Deep Blue Pro Splashcam) was used. A DVD recorder captured video in 2011 (Sony DVDirect MC6), DVD's were converted to VOB files using MPEG Streamclip 1.2. In 2012 and 2013, a DVR recorder was used to capture video, which provided VOB files for further processing. The video in VOB format was then down-sampled (Avidemux video processing software) to provide a still photo every 8–14 meters along the survey line, depending on the vessel speed. During surveys the video camera was mounted on a pole to allow the camera to be positioned about 0.5 m above the bottom, to capture a known area. Survey position was recorded at 8 s intervals with a Garmin 76 GPS linked to a GPS enabled mapping program (Terrain Navigator). Time and coordinates were recorded with each frame of video. Type of vegetation and percent cover was recorded and binned using a modified Braun-Blanquet estimate; none: 0, very sparse: 0 > 10%, sparse: 10 > 40%, moderate: 40 > 70%, and dense: 70 > 100% (Braun-Blanquet, 1964).

Macroalgae coverage was evaluated in three ways. First, “frame coverage” was determined by estimating percent coverage from photos associated with a distinct location along the video transect (latitude/longitude coordinate). Second, “estuarine coverage” allowed for inter-estuarine comparisons and was calculated from the number of times macroalgae was present in all survey photos divided by the number of frames processed in the whole estuarine system. Third, “sub-section coverage” allowed intra-estuarine comparisons and was calculated as the number of times

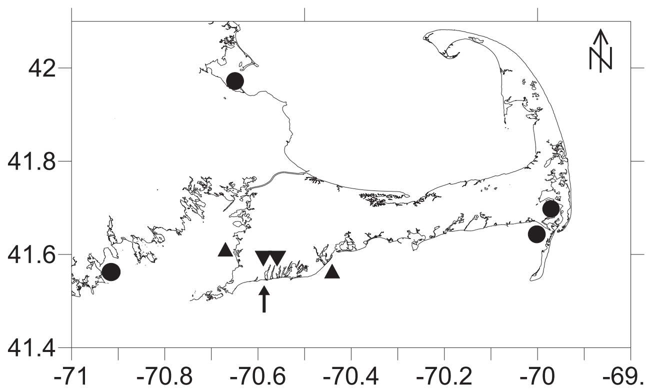

Fig. 1. Location of eight estuaries surveyed from 2011-2013. Circles indicate systems surveyed once in 2012, triangles: three times in 2011 and once in 2012 and inverted triangles: three times in 2011, seven times in 2012 and once in 2013 and had growth and decay studies. Great Pond (arrow) was the site of tidal exchange studies.