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Empirical relationship between eelgrass extent and predicted watershed-derived nitrogen loading for shallow New England estuaries

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ABSTRACT

Seagrasses provide important ecological services that directly or indirectly benefit human well-being and the environment. Excess nitrogen inputs are a major cause of eelgrass loss in the marine environment. Here we describe the results of a study aimed at quantifying the extent of eelgrass as a function of predicted watershed-derived nitrogen loading for small-to-medium-sized shallow estuaries in New England. Findings confirm that reduced extent of eelgrass corresponds to increased loading of nitrogen to this class of estuary. At lower levels of nitrogen loading ($\leq$50 Kg ha^{-1} yr^{-1}), eelgrass extent is variable and is likely controlled by other ecosystem factors unrelated to water quality. At higher loading rates, eelgrass coverage decreases markedly, with essentially no eelgrass at loading levels $\geq$100 Kg ha^{-1} yr^{-1}.

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1. Introduction

1.1. Excess nutrients as ecosystem Pressures

Human activities have dramatically changed the amounts, distributions, and movement of major nutrient elements (nitrogen and phosphorus) and have increased nutrient loading to receiving waters (Howarth et al., 2002). Some of these changes affect use of the nation's aquatic resources and pose risks to human health and the environment (NRC, 2000). EPA is in the process of developing guidelines that the states and tribes can use to set nutrient criteria for our nation's waters. For waters assessed as impaired, nutrient loading target plans, called total maximum daily loads (TMDLs), are needed to eliminate the cause(s) of the impairment. However, our current understanding of marine ecosystems is inadequate to extrapolate from nutrient load-ecological effects models developed for estuaries with extensive data (e.g., Chesapeake Bay and Long Island Sound) to those estuaries or, classes of estuaries, across regions with more limited data. To fill the gap in understanding this paper describes how seagrass extent varies with predicted nitrogen load for small-shallow estuaries in New England.

1.2. Ecological effects of excess nutrients

Ecological responses to excess nutrients generally fall into two categories: primary and secondary (Cloern, 2001). The primary response is an increase in algal production or carbon supply as defined by Nixon, (1995) and/or shifts in the algal community composition at the base of the food web. Secondary responses include an increase in extent and duration of hypoxia, loss of submerged aquatic vegetation (SAV) including eelgrass, and change and loss of biodiversity, including change in fish abundance and species composition (Cloern, 2001). There is a consensus among estuarine ecologists that excess nitrogen, not excess phosphorus, is the main cause of eutrophication in most estuaries (Howarth and Marino, 2006).

Seagrasses provide important ecological services including fish and shellfish habitat, and shore-bird feeding habitats, nutrient and carbon cycling, sediment stabilization, and biodiversity in tropical and temperate regions throughout the world (Orth et al., 2006; Duarte et al., 2008). Excess nitrogen loading has long been implicated in the loss of eelgrass (Short et al., 1995). The major mechanism of decline is considered to be nitrogen-fueled eutrophication through light limitation via planktonic, macro-algal, or epiphytic shading (Neckles et al., 1993; Duarte, 1995; Hauxwell et al., 2001, 2003). Vegetation in the shallow water marine environment compete with each other for nutrients and light in such as way that some forms thrive while others languish (Sand-Jensen and Borum, 1991; Havens et al., 2001). Also factors such as waves, currents, and

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tides affect the distribution of seagrasses (Koch, 2001). High organic loading derived from excess nitrogen may cause water column hypoxia and sediment sulfide production which also has been shown to affect seagrass health (Sand-Jensen and Borum, 1991; Koch, 2001; Eldridge et al., 2004; Vaudrey, 2008a). Thus, while light limitation is considered the major proximate cause of eelgrass decline, the ultimate cause is generally considered to be excess nutrient loading (Hauxwell et al., 2001; Leschen et al., 2010).

SAV abundance in subestuaries of the Chesapeake Bay has been shown to exhibit a strong threshold response to point source nitrogen inputs (Li et al., 2007). Moreover, using data from a limited number of estuaries ($n \leq 10$), others have described a threshold relationship between watershed-derived nitrogen loading and seagrass coverage in the northeast US (Short and Burdick, 1996; Bowen and Valiela, 2001; Hauxwell et al., 2003). The present study of over sixty (60) estuaries in New England is tailored to confirm and further define eelgrass coverage threshold behavior with respect to watershed-derived nitrogen loading.

2. Methods

The development of relationships between predicted nitrogen load and ecosystem response is based on a comparative systems approach in which loading and ecological responses are determined for a number of study embayments along a nitrogen load gradient. The research is divided into two components: 1) determination of nitrogen loading rates to coastal embayments from the watershed and atmosphere (Latimer and Charpentier, 2010); and 2) assessment of eelgrass extent, using aerially-derived digital images. As noted above, there is considerable science that describes the causal mechanisms between excess nitrogen, eutrophication, and seagrass effects (Conley et al., 2009; Waycott et al., 2009) typically following the paradigm: nitrogen loading => nitrogen concentration => chlorophyll-a concentration (or epiphyte magnitude) => light attenuation => seagrass light requirements => seagrass coverage. However, in this study we use a simplified approach that involves nitrogen loading => seagrass coverage using a comparative systems approach.

2.1. Study systems

Sixty-two (62) estuarine embayments, reflecting a gradient of watershed-derived + atmospheric nitrogen loading in southern New England, were evaluated in this study (Fig. 1). The study estuaries were classified as semi-enclosed coastal water bodies that are influenced by fresh water input that reduces salinity to below 30 psu during at least two months of the year (Madden et al., 2005).

Table 1 contains the descriptors and the range of values applicable for the study systems in this research summary. Table 2 provides summary statistics for some of the physical characteristics of the study embayments as well as loading estimates and eelgrass extent. To compare the results of this study to an estuary beyond those evaluated, one should keep in mind the components of the study systems noted in Tables 1 and 2. The closer the match

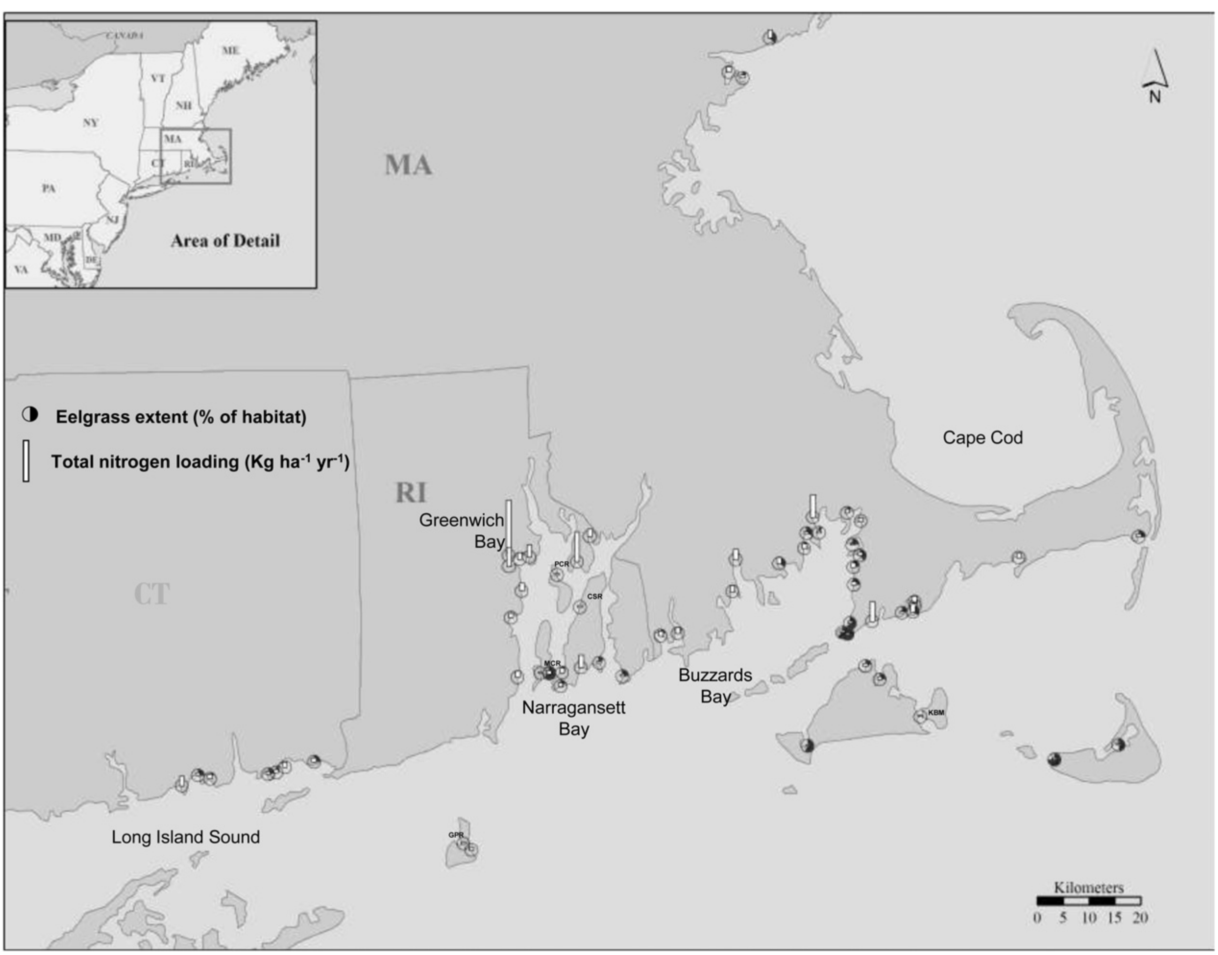

Fig. 1. Map of abundance of eelgrass in (percent of available habitat), and nitrogen loading to (Kg N ha^{-1} yr^{-1}), the study embayments.