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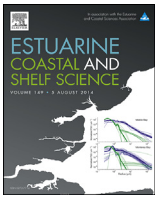

Modeling future scenarios of light attenuation and potential seagrass success in a eutrophic estuary

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ABSTRACT

Estuarine eutrophication has led to numerous ecological changes, including loss of seagrass beds. One potential cause of these losses is a reduction in light availability due to increased attenuation by phytoplankton. Future sea level rise will also tend to reduce light penetration and modify seagrass habitat. In the present study, we integrate a spectral irradiance model into a biogeochemical model coupled to the Regional Ocean Model System (ROMS). It is linked to a bio-optical seagrass model to assess potential seagrass habitat in a eutrophic estuary under future nitrate loading and sea-level rise scenarios. The model was applied to West Falmouth Harbor, a shallow estuary located on Cape Cod (Massachusetts) where nitrate from groundwater has led to eutrophication and seagrass loss in landward portions of the estuary. Measurements of chlorophyll, turbidity, light attenuation, and seagrass coverage were used to assess the model accuracy. Mean chlorophyll based on uncalibrated in-situ fluorometry varied from 28 $\mu g\ L^{-1}$ at the landward-most site to 6.5 $\mu g\ L^{-1}$ at the seaward site, while light attenuation ranged from 0.86 to 0.45 m^{-1}. The model reproduced the spatial variability in chlorophyll and light attenuation with RMS errors of 3.72 $\mu g\ L^{-1}$ and 0.07 m^{-1} respectively. Scenarios of future nitrate reduction and sea-level rise suggest an improvement in light climate in the landward basin with a 75% reduction in nitrate loading. This coupled model may be useful to assess habitat availability changes due to eutrophication and sediment resuspension and fully considers spatial variability on the tidal timescale.

1. Introduction

Seagrass meadows are found in many coastal areas around the world and are regarded as key indicators of ecosystem health (Dennison et al., 1993). They are among the most productive plant communities, and represent one of the major sources of primary production in shallow waters worldwide (Hemminga and Duarte, 2000). These plants serve as a nursery for many species, providing habitat and food for a variety of marine organisms (Orth et al., 2006). They also trap nutrients, thereby improving water transparency and filtering substantial quantities of both N and P from estuarine waters, serving as a buffer between land-based pollution sources and adjacent estuaries (Nixon et al., 2001; Short and Short, 2004; McGlathery et al., 2007; Hayn et al., 2014). Consequently, the increasing loss of seagrass beds raises concern because of a potential reduction in coastal ecosystem productivity, a decrease in water quality, and a decline in fishing resources. Additionally, in a report prepared for the European Union, Terrados and Borum (2004) estimate the value of ecosystem services provided by seagrasses as two orders of magnitude higher than productive agricultural lands.

Despite the ecological and economic value of seagrass meadows, their disappearance has accelerated in the last decades (Short and Wyllie-Echeverria, 1996; Waycotta et al., 2009). The causes of decline range from natural disturbances (e.g., storms) to anthropogenic pressures (e.g., nutrient loading). In temperate estuaries, one of the dominant factors for seagrass loss is eutrophication (Short and Neckles, 1999; Orth et al., 2006). In eutrophic waters, there is an overabundance of nutrients that leads to phytoplankton blooms, an increase in epiphytes growing on seagrass tissues, and subsequent light reduction (Burkholder et al., 2007). This reduction can impede seagrass growth and its ability to assimilate nitrogen, as they are vascular benthic autotrophs that require clear water and high levels of Photosynthetically Active Radiation (PAR). In fact,

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minimum light requirements of seagrasses (2–37% of surface irradiance, SI) are much higher than those of macroalgae and phytoplankton (about 1–3% of SI) (Dennison et al., 1993; Lee et al., 2007). Therefore, seagrass photosynthesis, and thereby their growth, survival, and depth distribution, are directly linked to PAR reaching the plant surface (Cabello-Pasini et al., 2003). The spatial variation in light availability of eutrophic estuaries can cause changes in the spatial distribution of seagrass on the order of meters. Another aspect that should be taken into account is that the allocation and abundance of seagrasses have changed over evolutionary time in response to sea-level rise (SLR) (Orth et al., 2006). In areas where the tidal range increases, plants at the lower edge of the bed will receive less light at high tide, which increases plant stress, reduces photosynthesis, and therefore decreases the growth and survival of the vegetation (Short and Neckles, 1999; Titus et al., 2009). The complexity and variability of eutrophic estuaries with seagrass meadows highlights the need for a spatially explicit model that can resolve spatial distributions of chlorophyll, turbidity, colored dissolved organic matter (CDOM), and ultimately light attenuation. There are relatively few coupled hydrodynamic-light models that calculate light attenuation as a function of different attenuating substances apart from chlorophyll and water (Everett et al., 2007; Hipsey and Hamilton, 2008), and even fewer take into account spectral underwater irradiance (Bissett et al., 1999a, 1999b).

In the present study, we develop a new tool to assess the evolution of seagrass communities under future nitrate loading and sea-level rise scenarios using a three-dimensional circulation model (Regional Ocean Model System, ROMS) coupled to a Nutrient Phytoplankton Zooplankton Detritus (NPZD) eutrophication model (Fennel et al., 2006), where we have integrated a spectral light attenuation formulation (Gallegos et al., 2011). We describe the model and the linkage of this tool with a benthic seagrass model (Zimmerman, 2003), which calculates seagrass distribution. We apply the model to West Falmouth Harbor, a temperate estuary where seagrass has considerably diminished in recent years in the more nitrogen-polluted inner reaches (Howarth et al., 2014). In the sections that follow we describe: 1) general features of West Falmouth Harbor, 2) the observational methods and results, 3) the numerical model and skill assessment, and 4) future scenarios of nitrate loading and sea-level rise. Finally, we discuss the utility and limitations of the approach and future directions.

2. Site description

West Falmouth Harbor is a eutrophic groundwater-fed estuary situated on the western shore of upper Cape Cod, Massachusetts, USA (Fig. 1). Tidal range at the harbor entrance is 1.9 m during spring tides and 0.7 m during neap tides (Ganju et al., 2012). The average depth is approximately 1 m, the surface area is 0.7 km^2 and the flushing rate is between 1 and 2 days. The harbor is connected to Buzzards Bay and ultimately the Atlantic Ocean through a 3 m deep, 150 m wide channel constrained by rock jetties on both sides (Ganju et al., 2012). The harbor is comprised of different subembayments (Outer Harbor, South Cove, and Snug Harbor). The presence of perennial eelgrass (*Zostera marina*), fish, and shellfish communities in the Harbor is particularly important from a habitat perspective. However, Costello and Kenworthy (2011) showed that there has been an ecologically significant alteration of eelgrass distribution in West Falmouth Harbor within the past decades. In 1979, eelgrass meadows were found throughout the harbor, with beds in the Outer Harbor, South Cove, and Snug Harbor (Costa, 1988). At present, these meadows have been lost from the landward basins, and eelgrass beds are only found in the Outer Harbor. In Snug Harbor, eelgrass beds died off as of mid summer of 2010, and grasses present during the previous several seasons had very high epiphyte loads on their blades and showed signs of considerable physiological stress (Howarth et al., 2014). The estimated

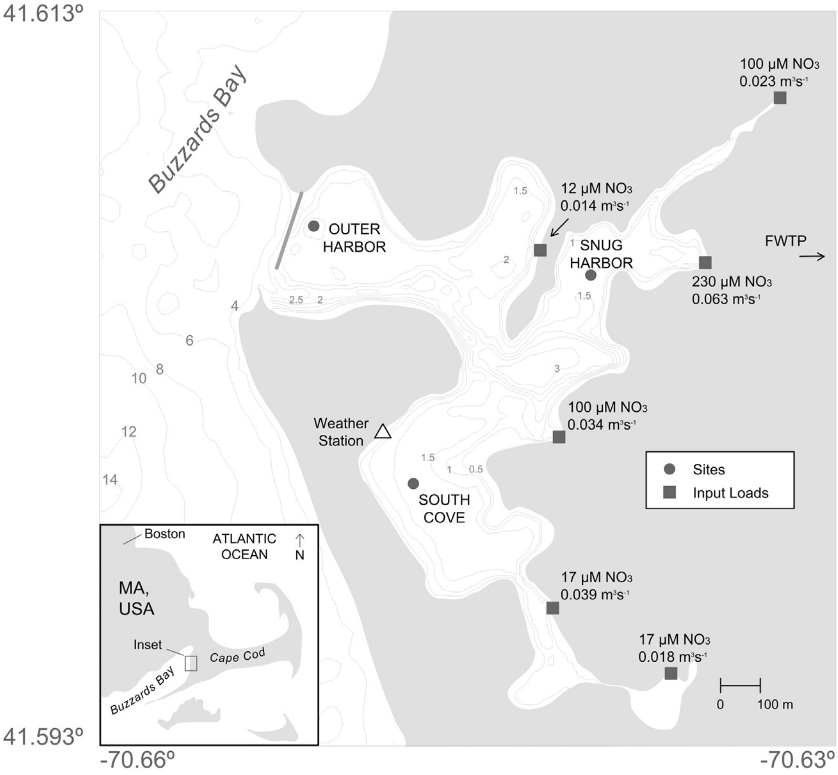

Fig. 1. West Falmouth Harbor, site locations and average summer input loads.