Marine Environmental Research 112 (2015) 9–20

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Phytoplankton biomass and composition in a well-flushed, sub-tropical estuary: The contrasting effects of hydrology, nutrient loads and allochthonous influences

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ARTICLE INFO

Article history:
Received 10 March 2015
Received in revised form
28 July 2015
Accepted 31 August 2015
Available online 4 September 2015

Keywords:
Guana Tolomato Matanzas estuary
Red tides
Karenia brevis
Water residence time
Eutrophication
Climate change

ABSTRACT

The primary objective of this study was to examine trends in phytoplankton biomass and species composition under varying nutrient load and hydrologic regimes in the Guana Tolomato Matanzas estuary (GTM), a well-flushed sub-tropical estuary located on the northeast coast of Florida. The GTM contains both regions of significant human influence and pristine areas with only modest development, providing a test case for comparing and contrasting phytoplankton community dynamics under varying degrees of nutrient load. Water temperature, salinity, Secchi disk depth, nutrient concentrations and chlorophyll concentrations were determined on a monthly basis from 2002 to 2012 at three representative sampling sites in the GTM. In addition, microscopic analyses of phytoplankton assemblages were carried out monthly for a five year period from 2005 through 2009 at all three sites. Results of this study indicate that phytoplankton biomass and composition in the GTM are strongly influenced by hydrologic factors, such as water residence times and tidal exchanges of coastal waters, which in turn are affected by shifts in climatic conditions, most prominently rainfall levels. These influences are exemplified by the observation that the region of the GTM with the longest water residence times but lowest nutrient loads exhibited the highest phytoplankton peaks of autochthonous origin. The incursion of a coastal bloom of the toxic dinoflagellate *Karenia brevis* into the GTM in 2007 demonstrates the potential importance of allochthonous influences on the ecosystem.

1. Introduction

Increased cultural eutrophication throughout the world has raised concerns about the future integrity of many coastal ecosystems (Nixon, 1995). Among the major components of aquatic ecosystems, phytoplankton are often the most directly and rapidly affected by nutrient enrichment, therefore, phytoplankton are widely used indicators of eutrophication and trophic status (Carlson, 1977; Cloern, 2001; Gupta, 2014). Anthropogenically-driven increases in nutrient loads have been linked to increased occurrences and intensities of algal blooms in many water bodies throughout the world (Hallegraeff, 2003; Glibert and Burkholder, 2006; Anderson et al., 2008; Heisler et al., 2008; O'Neil et al., 2012), however, predicting the responses of phytoplankton communities in coastal ecosystems to changes in nutrient load can be challenging due to the influences of mitigating physical, chemical and biological conditions (Mallin et al., 1999; Howarth et al., 2000; Cloern, 2001; Smayda, 2008; Paerl et al., 2014; Harding et al., 2015; Phlips et al., 2015). Classic 'single signal, single response' conceptual models, inspired by studies of eutrophication in lakes (Vollenweider, 1976), are often poor predictors of phytoplankton biomass in dynamic estuarine environments. For example, annual nutrient loads are higher in San Francisco Bay than in Chesapeake Bay, yet average primary production in San Francisco Bay is 20 times lower than in Chesapeake Bay (Cloern, 2001). In San Francisco Bay mitigating factors contribute to the resistance of

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http://dx.doi.org/10.1016/j.marenvres.2015.08.010
0141-1136/

phytoplankton production and biomass to increases in nutrient load, including short water residence times, top-down pressure from benthic grazer communities and shifts in the character of nutrient elements, particularly nitrogen (Alpine and Cloern, 1992; Cloern and Dufford, 2005; Glibert et al., 2014). Understanding the nature of such mitigating factors is of central importance in defining the responses of phytoplankton to differences in nutrient load (Cloern, 2001; Lucas et al., 2009).

The Guana Tolomato Matanzas (GTM) estuary is an example of a subtropical well-flushed ecosystem where regional differences in nutrient loads are not fully reflected in spatial patterns of phytoplankton biomass and composition (Phlips et al., 2004; Dix et al., 2013). Such flushed ecosystems are widespread throughout the world, but they have not been as extensively studied as those in temperate environments (Cloern et al., 2014). The GTM contains regions of significant human influence, such as the watersheds associated with St. Augustine, the oldest city in the United States (i.e. founded in 1565). Other regions of the GTM are characterized by relatively pristine watersheds with minimal human development. The GTM also contains regions of differing levels of tidal flushing. Regions near inlets to the Atlantic Ocean have water residence times on the order of days, while areas more distant from inlets have water residence times on the order of weeks (Sheng et al., 2008). The spatially diverse characteristics of the GTM provide an opportunity to examine the contrasting effects of nutrient load and water residence times on phytoplankton biomass and composition. In general, well-flushed estuaries, which experience relatively short water residence times, are often characterized by lower phytoplankton biomass and different community structure than more restricted ecosystems with similar nutrient loads (Knoppers et al., 1991; Monbet, 1992; Phlips et al., 2004; Badylak et al., 2007; Harrison et al., 2008; Lucas et al., 2009; Phlips et al., 2010). On the other hand, strong exchange of water with the coastal environment can also subject well-flushed ecosystems to incursions of coastal harmful algal blooms (HAB), including toxic red tide species (Steidinger, 1983; Heil et al., 2014).

In this study, the relationships between the phytoplankton community, hydrologic conditions (e.g. water residence times) and nutrient loads in the GTM were examined over a 10-year period, which included both drought and flood years, providing some insights into the effects of climatic variability. The GTM was incorporated into the National Estuarine Research Reserve System (NERRS) of the U.S. National Oceanographic and Atmospheric Administration (NOAA) in 1999, highlighting the importance of the ecosystem as a coastal marine resource, in part because of its location in the southeastern coast of North America and the diversity of habitat types within the system, including keystone oyster and salt marsh communities (Frazel, 2009). Over the past few decades some of the watersheds associated with the GTM have begun to experience significant human development, accentuating the need for water quality information that can assist in the design of management plans aimed at protecting this valuable aquatic resource. This paper examines one key aspect of this need for information, namely the sensitivity of phytoplankton communities within the GTM to temporal and spatial differences in nutrient load.

2. Methodology

2.1. Site description and sampling sites

The study area included the Guana River, Tolomato River and Matanzas River estuaries located on the northeast coast Florida, together designated as the GTM (Fig. 1). The Guana and Tolomato River estuaries lie north of the St. Augustine Inlet and the Matanzas estuary lies south of the St. Augustine Inlet in the vicinity of the Matanzas Inlet. The GTM is an inner shelf lagoon that forms part of the Intracoastal Waterway along the east coast of the United States. The GTM is characterized by a May through October warm wet season and November through April cool dry season. The GTM is also subject to tropical storm activity which can affect water quality conditions (Dix et al., 2008).

Water samples were collected at three NERRS System-wide Monitoring Program sites within the GTM from 2002 through 2012. The northern most sampling site was located at Pine Island in the Tolomato River, 16 km north of the St. Augustine Inlet, and designated PI (Fig. 1). Mean depth at PI was 3.1 m. Land use in the associated watershed includes 81% upland forests, wetlands, and surface waters; 13% urban/residential, and 5% agriculture/rangeland (FDEP, 2008). Water residence times in the Pine Island region are several fold longer than in the St. Augustine and Matanzas regions of the GTM. A hydrologic study in the spring of 2004 showed that water residence times (i.e. 50% water turnover time) in the Pine Island region averaged 15 days, compared to 2 days in the Matanzas region and 3 days in the St. Augustine region (Sheng et al., 2008).

The second sampling site was located near the outflow of the San Sebastian River, and designated SS (Fig. 1). The San Sebastian River receives drainage from the city of St. Augustine (FDEP, 2008). Mean depth at SS was 3.7 m. Land use in the associated watershed includes 68% upland forests, wetlands, and surface waters; 28% urban/residential, and 4% agriculture/rangeland (FDEP, 2008). Site SS is tidally influenced by the St. Augustine Inlet, which is located approximately 5 km north of the sampling site.

The third sampling site was located approximately 4 km north of the Matanzas Inlet and designated FM (Fig. 1). Mean depth at FM was 2.5 m. The region of the GTM where FM is located is characterized by relatively undeveloped watershed. Land use in the associated watershed includes 83% upland forests, wetlands, and surface waters; 15% urban, and 2% agriculture/rangeland (FDEP, 2008).

2.2. Field collections

YSI 6600 and YSI 6600 EDS multi-parameter data sondes were deployed at the three sampling sites at approximately mid-water column. Temperature and salinity were recorded at 30-min intervals from January 2002 to December 2006 and at 15-min intervals from January 2007 to December 2012. Water quality data, including total nitrogen (TN), total phosphorus (TP), silica (Si), colored dissolved organic matter (CDOM), Secchi disk depth (SD), and chlorophyll *a* (CHL), were downloaded from the NERRS Centralized Data Management Office website (http://www.nerrsdata.org/).

Water samples were collected monthly from 2003 through 2012 with an integrating sampling tube which captures water from the surface to within 0.1 m from the bottom. Water samples were used for subsequent analysis of colored dissolved organic matter (CDOM), total phosphorus (TP), total nitrogen (TN), silica (Si), chlorophyll *a* and phytoplankton composition. Samples withdrawn for water chemistry analysis were maintained on ice for return to the laboratory. Aliquots of water for chlorophyll *a* analysis were filtered onto 0.7 μm filters (i.e. Whatman GF/F) on site and stored frozen until analysis. Aliquots of water for CDOM analyses were filtered through 0.7 μm filters (i.e. Whatman GF/F) on site and stored on ice.

Water samples for phytoplankton analysis were collected from 2005 through 2009. Samples were preserved with Lugols solution. Aliquots of water for picophytoplankton analysis were kept frozen (i.e. −20 °C) until analysis within 48 h of collection using autofluorescence microscopy (Phlips et al., 1999).