Ecological Informatics 34 (2016) 1–12

Contents lists available at ScienceDirect

Ecological Informatics

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

Spatial variability of estuarine environmental drivers and response by phytoplankton: A multivariate modeling approach

Bhanu Paudel [a,*], David Velinsky [a], Tom Belton [b], Helen Pang [b]

[a] Academy of Natural Sciences of Drexel University, Patrick Center for Environmental Research, Department of Biodiversity, Earth and Environmental Science, Drexel University, 1900 Benjamin Franklin Parkway, Philadelphia, PA 19103, United States
[b] New Jersey Department of Environment Protection, 401 East State Street, Trenton, NJ 08608, United States

ARTICLE INFO

Article history:
Received 7 December 2015
Received in revised form 25 April 2016
Accepted 26 April 2016
Available online 27 April 2016

Keywords:
Structural equation modeling
Bayesian linear regression
Nutrients
Inflow
Phytoplankton

ABSTRACT

Environmental variables such as river inflow, dissolved chemicals, temperature, total suspended solids, dissolved oxygen, and pH are the environmental drivers that maintain phytoplankton growth in estuaries. Spatial variability of environmental drivers in Barnegat Bay, New Jersey, and their roles in the distribution of phytoplankton were investigated in order to identify spatial variability in phytoplankton production in the bay. The water quality data collected and analyzed by New Jersey Department of Environmental Protection from 14 different stations in Barnegat Bay were divided into two different data sets, i.e. Northern Barnegat Bay (NB) and Southern Barnegat Bay (SB) data. Structural equation modeling, Bayesian linear regression, and kriging interpolation were used for the modeling study. The study identified higher dissolved N:P(88:1) in NB as compared to SB (19:1). The NB phytoplankton growth was maintained by the dissolved chemicals transported by inflow, whereas, the SB phytoplankton growth was maintained by sediment–water processes and regeneration. The lower ratio of regression coefficients of dissolved N to P throughout SB, as compared to that of NB, indicates low dissolved nitrogen concentrations in SB. In addition, higher inflow induced transport of dissolved nutrients and carbon may explain the significant north–south chlorophyll-α concentration gradient. The findings identified indirect effects of inflow and direct effects of nutrients on NB phytoplankton growth. Within SB, there were direct effects of nutrients, carbon dynamics, dissolved oxygen, pH, and turbidity on phytoplankton growth. Therefore, the results of this study are useful to state and federal water quality agencies in developing management strategies for northern and southern Barnegat Bay.

Published by Elsevier B.V.

1. Introduction

Phytoplankton composition is the indicator of the state of estuaries ecosystem. Fluctuations in phytoplankton composition due to the change in environmental variables are the primary focus when developing a management plan for sustainable estuarine ecosystem health (Cloern, 1999). Distribution of autotrophs in estuaries depends on light intensity, water temperature, and riverine discharge of dissolved or particulate material (Cloern, 1999; Odum, 1996). These environmental variables vary spatially in estuaries and are the environmental drivers for the change in autotroph communities. For instance, phytoplankton growth is low in estuary turbidity maximum zone, especially, at the riverine sources because of high disturbance and low light intensity (Cloern, 1987). Similarly, change in wind direction can shift suspended sediment transport and vary its concentration, thus affecting light penetration in the water column. In addition, peak inflow events bring more dissolved materials to estuaries, which, when transported to less turbid zones promotes phytoplankton growth. Estuarine water quality variables, such as levels of organic matter, DO, and pH fluctuate along the river inflow-to-tidal inlet salinity gradients. These spatial gradients in environmental drivers and their interactions can cause variation in phytoplankton growth. Hence, phytoplankton growth relies not on one single environmental parameter but is rather the result of an interaction of different environmental variables. Discerning the individual and cumulative effects of environmental variables is a key to prediction and management of eutrophication in estuaries (Paerl, 2006). Prediction of the spatial distribution of environmental drivers and their direct and indirect effects in autotrophic distribution can assist scientists and managers in developing estuarine management plans.

Sustainable estuaries management practices rely on identifying environmental drivers and their spatial distribution for the change in phytoplankton populations. Nutrients maintain phytoplankton growth and distribution, and excess nutrient inputs are the major cause of eutrophication. Nutrients in coastal water fluctuate with changes in variables such as: river inflow, suspended sediments, and physico-chemical parameters. For instances, freshwater inflow and increased nutrients loading were concomitant in Texas lagoons (Montagna and Li, 2010). The Guadalupe Estuary, with higher inflow, has higher nutrient concentrations compared to the Nueces Estuary, with lower inflow

* Corresponding author.
E-mail address: bhanu.paudel@drexel.edu (B. Paudel).

http://dx.doi.org/10.1016/j.ecoinf.2016.04.013
1574-9541/Published by Elsevier B.V.

(Paudel and Montagna, 2014). At the local and regional scale, river inflow, waste water effluent, and upwelling were identified as a source of N in the coastal water of the Southern California Bight (Howard et al., 2014). A recent study identified that high and low flow conditions can alter the quality of chromophoric dissolved organic carbon transported down to an estuary (Dixon et al., 2014), which has role in primary production. Recent studies have identified interrelationship between different environmental drivers and their direct and indirect effects on phytoplankton, as well as direct and indirect effects on environmental drivers that can alter primary production. Changes in these drivers have a potential effect on phytoplankton growth and distribution.

In developing an estuarine management strategy, it is vital to understand the relationships of phytoplankton with nutrients and other environmental drivers. Freshwater inflow was identified to be the significant predictor variable, using structural equation modeling (SEM), for the distribution of inorganic nutrients in estuaries (Arhonditsis et al., 2007; Paudel and Montagna, 2014), and consequently affect phytoplankton populations. Freshwater inflow predominates in the northern part of Barnegat Bay (BB) as compared to the southern part (Hunchuk-Kariouk and Nicholson, 2001; Chizmadia et al., 1984; Kennish, 2001b). Developmental activities in the watershed of Barnegat bay increased nutrients and toxic substances, the decrease in DO resulted to that affect shellfish population (Kennish et al., 2007; Kennish and Fertig, 2012). Loadings from rivers in the Barnegat Bay are higher in the north bay versus the south. A recent modeling study revealed that flushing is greater in the southern half of Barnegat Bay compared to the northern half, resulting in a high probability of particle retention in the northern half of the Bay (Defne and Ganju, 2014). Furthermore, due to the complete turnover of Barnegat Bay water every 96 tidal cycles (with one tidal cycle in 12.7 h), and with short residence time, nutrients might escape sea-ward through tidal inlets (Chizmadia et al., 1984; Defne and Ganju, 2014). This high flushing rate in BB could lower nutrients levels in southern Barnegat Bay resulting in lower phytoplankton biomass, as was found in a study of the Bertioga Channel, Sao Paulo, Brazil (Gianesella et al., 2000). However, water column phosphorus, collected during July and October 2014, was higher in the southern half of the Bay versus the northern half (Velinsky unpublished data). It was still not clear which environmental variables explain the change in nutrients and chlorophyll, and why there are higher P concentrations in southern bay while higher loadings in the northern part. Therefore, a modeling tool that identifies spatial variability of phytoplankton growth with the inclusion of direct and indirect effects of environmental drivers would help to imply best management practice in the bay. The main purpose of this study is to identify and predict the direct and indirect effects of water quality parameters on the spatial distribution of phytoplankton growth as a function of environmental drivers in the northern and southern parts of Barnegat Bay. SEM modeling techniques can identify direct and indirect effects of environmental drivers for the change in chlorophyll-α (Arhonditsis et al., 2007), while regression model can only identify direct effects of predictors. Further, regression model are appropriate to develop predictive equation, i.e. suitable for exploratory analysis, while SEM model are suitable for confirmatory test thus appropriate to evaluate multivariate hypotheses (Grace, 2006). Here, our main focus is to predict direct and indirect effects of environmental drivers on phytoplankton growth over the spatial extent of Barnegat bay ecosystem using two different modeling techniques. Following is the study hypotheses: there are no significant differences in the spatial distribution of phytoplankton population, measured as the proxy of chlorophyll-α concentration, in the northern and southern Barnegat Bay, due to the effects of environmental drivers.

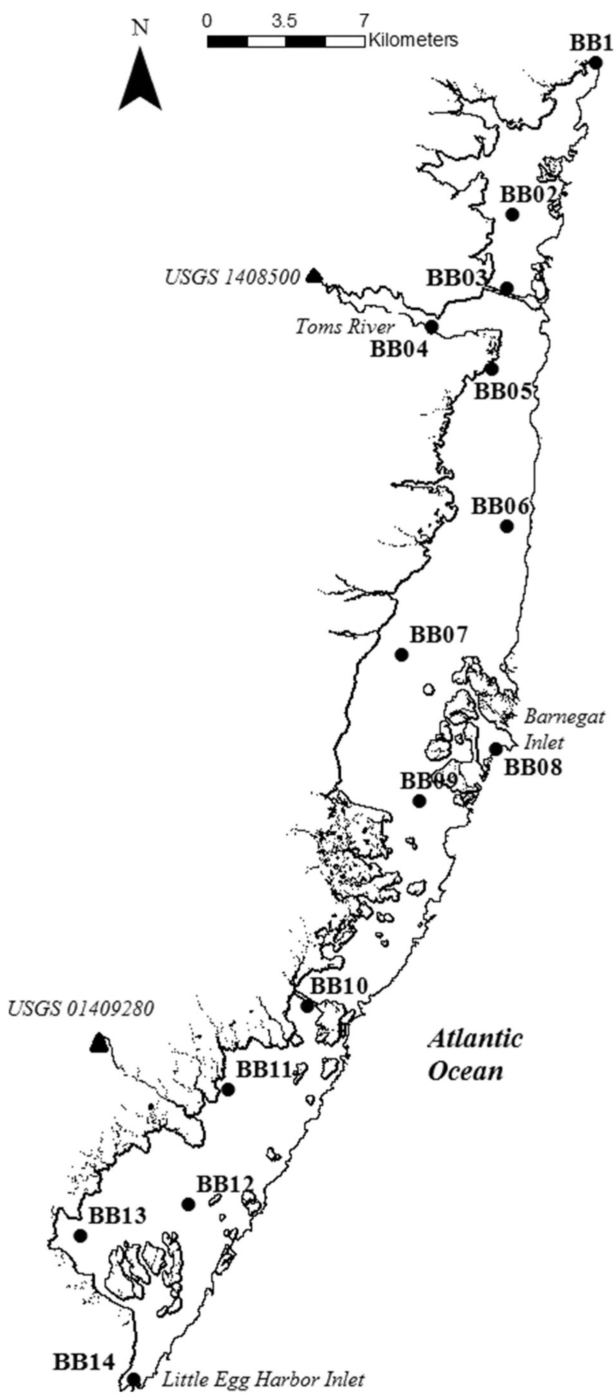

Fig. 1. Map of the study sites with sampling stations.

2. Method

2.1. Site description

Barnegat Bay (BB) is a back-barrier lagoon-type estuary, located along the central New Jersey coastline in the Atlantic Coastal Plain (Fig. 1). The variety of highly productive shallow water and adjacent upland habitats found in this system include barrier beach and dune, submerged aquatic vegetation (SAV) beds, intertidal sand and mudflats, salt marsh islands, fringing tidal salt marshes, freshwater tidal marshes, and palustrine swamps. The Bay watershed covers an area of approximately 1700 km^2 and has been extensively urbanized over the past 70 years (Velinsky et al., 2011). The tidal waters cover approximately 280 km^2 with a ratio of watershed area to water area of 6:1. Importantly, watershed development (urban area) has increased over time. From 1986 to 2006, the area of urban land cover increased from 15 to 21%, while forested land cover has decreased (Lathrop, 2004a, 2004b; Kauffman and Cruz-Ortiz, 2012).