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Modeling inorganic nutrient distributions among hydrologic gradients using multivariate approaches

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ABSTRACT

River inflow can control the distribution of dissolved inorganic nutrients in an estuary. So, it is expected that estuaries with different inflow regimes will have a different nutrient transport and different structural and functional balance of nutrient dynamics. A long term (1987–2012) data set of nutrients in the three South Texas Estuaries (the Guadalupe (GE), Lavaca–Colorado (LC), and Nueces (NC) Estuaries) was used to test these hypotheses. The nutrient dynamics in the estuaries were compared using multivariate linear regression and structural equation modeling (SEM). The Nueces Estuary is relatively oligotrophic because the probabilities of detecting ammonia, nitrite + nitrate, and orthophosphate concentrations at ≤ 1 μmol/L were 0.63, 0.75, and 0.64 respectively. Although the GE and LC Estuaries have more river inflow than the NC Estuary, the probability of detecting dissolved inorganic nitrogen (DIN) (ammonia + nitrite + nitrate) concentrations of ≤ 1 μmol/L was greater than 0.5. In all the three estuaries, silicate was constantly available and was always at a high concentration, whereas inorganic nitrogen and phosphorus concentrations have decreased since 1987. The SEM identified that environmentalflow and phytoplankton were the most important predictor variables to predict DIN, silicate and orthophosphate, whereas TSS was important in predicting phosphorous and silica. The direct negative effect of latent variable phytoplankton to DIN implies that remineralization is likely maintaining the supply of DIN concentrations. The environmental flow was identified as the most important predictor variable in maintaining DIN. However, the low path coefficient of environment flow to nitrogen and other nutrients indicate that there is insufficient river inflow to maintain inorganic nitrogen and phosphorus concentrations into the estuaries. These findings imply future water diversions or a drier climate that could lead to oligotrophication.

1. Introduction

Knowledge of drivers of spatial and temporal inorganic nutrient distributions is needed to develop sustainable management practices to maintain healthy estuary ecosystems. River inflow can control the distribution of inorganic nutrients in an estuary. Fluctuation of inorganic nutrients transported to the estuary affects the structural and functional balance of the ecosystem because the biotic community responds to sudden changes in inorganic nutrients. Seasonal differences in the loading of dissolved nitrogen and dissolved orthophosphate affect the phytoplankton biomass in Chesapeake Bay (Malone et al., 1996). Other studies in Chesapeake Bay have found that change in the floristic composition was due to the change in dissolved silicate concentration as well (Adolf et al., 2006; Conley and Malone, 1992). Low inorganic nutrient concentrations in the Guadalupe, Nueces, and Lavaca–Colorado Estuaries during dry years were accompanied by low chlorophyll-a (chl-a) concentrations (Montagna and Palmer, 2012).

Freshwater diversions for human consumption and irrigation have reduced the amount of freshwater inflow to estuaries. Estuary conditions have become worse due to construction of dams, which not only curtail freshwater inflow but also reduce sediment and nutrient loading to an estuary (Alber, 2002; Jassby et al., 1995; Montagna et al., 2002, 2013). The amount of inflow to the estuaries is also affected by the frequency and severity of drought. A simulation study forecasting future precipitation has reported that in the 21st century South Texas will experience seasonal decreases in rainfall and increases in temperature (USGCRP, 2009). The frequency of drought and need of freshwater inflow for the management of nutrient and sediment loadings to the estuary require identification and prediction of the variables that can control inorganic nutrients in the estuaries.

Varying freshwater inflow alters the inorganic nutrient concentrations in the Lavaca–Colorado, Nueces, and Guadalupe Estuaries (Montagna and Li, 2010; Palmer et al., 2011; Pollack et al., 2009). However, a future management challenge lies in understanding direct, indirect, and interactive effects of environmental components for development of coastal management schemes (Cloern, 2001). For instance, the direct effect of inflow by altering flow volume and indirect effect of inflow resulted by altering water transparency that might have a different magnitude

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of impact on the inorganic nutrient concentrations. An increase in flow volume has increased inorganic nutrients, likewise an increase in fine suspended particles affects adsorption–desorption of inorganic nutrients. Identifying the roles of environmental components, thus, supports in developing management policies.

One method to identify the direct and indirect effects of different environment variables on the dynamics and patterns of biological components is using structural equation modeling (SEM) (Arhonditsis et al., 2007a, 2007b; Grace and Pugesek, 1997; Malaeb et al., 2000). Direct relationships between predictor and response variables can also be examined using multivariate linear regression (MLR) (Grace and Bollen, 2005). In the present study SEM and MLR were used to identify direct and indirect effects of environment variables on the distribution of inorganic nutrients. The nutrient studies in the estuaries have been biased towards temperate regions (Cloern, 2001). Therefore, the present study fills the gap by reporting on the long term dynamics of inorganic nutrients in the three South Texas Estuaries. The objectives of the present study are: 1) to identify temporal change in inorganic nutrient distribution in the Lavaca–Colorado, Guadalupe, and Nueces Estuaries, 2) to predict the inorganic nutrient concentration in the three estuaries by the application of structural equation modeling and multivariate regression, and 3) to identify the impact of different parameters on the change in the inorganic nutrient concentrations.

2. Materials and methods

2.1. Study area

The three South Texas Estuaries (Lavaca–Colorado, Guadalupe and Nueces Estuaries) are located in the Coastal Bend and have similar geomorphic structure and physiography (Fig. 1), but different hydrologic regimes (Table 1). The three estuaries consist of primary and secondary bays and are separated by a barrier island from the Gulf of Mexico. Inflow and precipitation decrease south of the Lavaca–Colorado Estuary with the Nueces Estuary getting the least amount of inflow. Due to the distinct climatic differences and lack of connection between watersheds each estuary is fed by different rivers. The Lavaca and Colorado Rivers drain into the Lavaca–Colorado Estuary. The San Antonio and Guadalupe Rivers confluence, and drain into the Guadalupe Estuary. The Nueces River drains into the Nueces Estuary. All three rivers have dams.

2.2. Data description

Quarterly sampling (four per year) was performed to collect water quality data. The water quality variables used for the present study were temperature (temp), pH, dissolved oxygen (DO), salinity (sal), secchi depth, total suspended solids (TSS), volatile particulate organic matter (VOM), chlorophyll-a (chl-a), ammonia (NH_3), nitrite + nitrate (NO_{2+3}), orthophosphate (o-PO_4) and silicate (SiO_4) concentrations. Details on sample collection, sampling stations, water quality parameters, and procedures to measure water quality parameters are in several papers (Kim and Montagna, 2012; Montagna and Kalke, 1992; Palmer et al., 2011; Pollack et al., 2009). For inorganic nutrient analysis the best applicable range of method detection limit (MDL) recommended by the manufacturer of an OIA segmented flow auto analyzer are 0.1–10 μmol/L for NH_3, 0.02–10 μmol/L for o-PO_4, 0.35–35 μmol/L for SiO_4, and 0.02–40 μmol/L for NO_{2+3}. The concentrations higher than detection limit were determined by sample dilution. During the data analysis concentrations lower than MDL were considered as 0 μmol/L.

Three statistical analyses were performed: a probability distribution analysis using a long term (1987–2012) data set, and MLR and SEM using a short term (2010–2012) data set. The short term data set

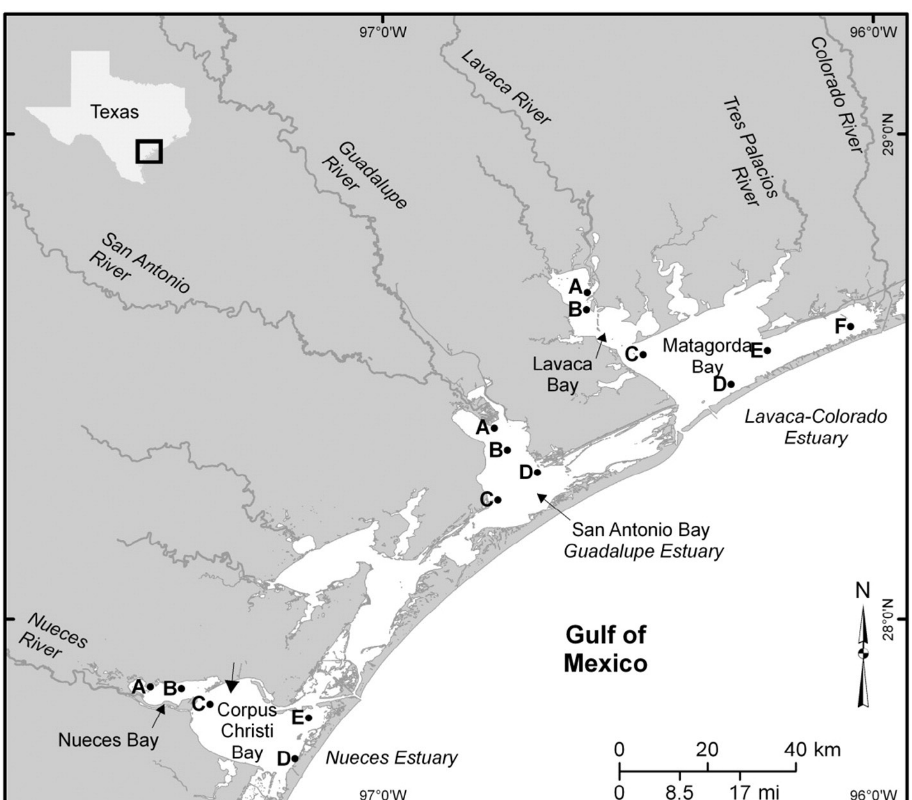

Fig. 1. Location of the three South Texas Estuaries with sampling stations.