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Impacts of eutrophic freshwater inputs on water quality and phytoplankton size structure in a temperate estuary altered by a sea dike

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ABSTRACT

Phytoplankton size structure and water properties in the Youngsan River estuary, which has been altered by a sea dike, were monitored over an annual cycle (2003–2004) to investigate the effects of freshwater inputs on their spatial and temporal variation. Trophic status was also evaluated using the trophic status index (TRIX). Freshwater was discharged from an artificial reservoir throughout the year, supplying nutrients (except for NH_4^+) and low levels of dissolved oxygen to the estuary, which resulted in eutrophication ("greatest trophic level"). Turbidity increased, and density stratification developed in the water column. The density stratification in turn affected the reduction of dissolved oxygen concentration in the bottom water during the freshwater discharge. Chlorophyll *a* concentrations, dominated by nano-sized (<20 μm) particles, were generally much lower when the water column was stratified by freshwater discharge (.90–5.03 μg chl L^{-1}) than when the water column was well-mixed with no freshwater inputs from the dike (3.42–47.0 μg chl L^{-1}). The net-scale (>20 μm) decrease in phytoplankton biomass differed from that in tropical estuaries affected by monsoons and in other temperate estuaries. Temporal variations in water quality and phytoplankton size structure were more strongly influenced by artificial regulation of the freshwater discharge than by monsoon meteorological events. This study implies that a different paradigm than that for natural estuaries or larger estuaries with dams is required for the better understanding and management of ecosystems in estuaries altered by anthropogenic activities, such as the construction of sea dikes.

1. Introduction

Estuaries are highly productive ecosystems in marine environments and serve as important nursery and recruitment habitats for various living resources (Dauvin, 2008; McLusky and Elliott, 2004). River discharges are important sources of the nutrients that support productive ecosystems by supplying primary producers, especially phytoplankton (Adolf et al., 2006; Smith, 2006). However, eutrophication resulting from excessive inputs of nutrients causes water-quality problems such as hypoxia (Diaz and Rosenberg, 2008; NRC, 2000) by driving phytoplankton blooms, which are major sources of organic matter and result in oxygen depletion in estuaries through microbial processes (Smith et al., 1992).

The response of phytoplankton to riverine nutrient inputs is dependent on changes in other properties of the water column related to river discharge, such as turbidity and flushing time (Lehrter, 2008). In estuaries, phytoplankton growth is affected by bottom-up mechanisms such as nutrient fluxes, light availability, and temperature, whereas biomass is regulated by grazing rates, viral lyses, and rates of dilution and advection of phytoplankton (Murrell et al., 2007; Örnólfsdóttir et al., 2004; Ortmann et al., 2011). On the other hand, the phytoplankton response to environmental changes, including nutrient pulses, is size-dependent, especially for inputs of anthropogenic origin (Lassen et al., 2004; Nayar et al., 2005). An increase in the abundance of larger cells that respond to enrichment has been reported for estuaries (Cermeño et al., 2006; Sin et al., 2000). Variations in the size composition of phytoplankton have important effects on the structure of the food web in marine systems (Froneman et al., 2004; Vargas and Gonzalez, 2004). In this context, it is important to understand the linkages between size-fractionated phytoplankton and nutrient inputs related to environmental changes caused by river discharges for better management of eutrophication and biotic integrity in estuarine systems.

The Youngsan River estuary is located in a temperate region (34°40′–34°54′ N, 126°17′–126°35′ E). It receives freshwater input

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from a sea dike, which is regulated by sluice gates, located 7 km upstream from the mouth of the estuary. Freshwater from the reservoir inside the sea dike remains eutrophic (Yi et al., 2006), and discharge occurs throughout the year, reaching as much as 3.81×10^8 m^3 per month during the summer monsoon (Sin et al., 2005). When freshwater is not being discharged from the reservoir, the estuary remains a semi-enclosed bay dominated by ebb tides with a tidal range of 3–6 m (Byun et al., 2004; Kang and Jun, 2003). The well-mixed hypersaline bay can experience rapid changes in environmental properties when a large volume of eutrophic freshwater is discharged into the ecosystem. Sea-level rises and changes in tidal characteristics have been predicted by modeling studies since the construction of the sea dike (Byun et al., 2004; Kang, 2009), but no records are available for changes in the biological and chemical properties of the estuary. Many estuarine systems on the coast of South Korea have experienced similar perturbations due to the construction of sea dikes (*e.g.*, Sin et al., 2012).

Human activities such as the construction of dams have changed the biogeochemistry and ecosystem structures of coastal systems on long-term timescales (Domingues et al., 2012; Humborg et al., 1997; Li et al., 2007). However, the direct effects of freshwater introduced from sea dikes on hypersaline water column processes have rarely been documented, and the dynamics of water quality and size-fractionated phytoplankton linked to the freshwater inputs are poorly understood for altered estuarine systems. Therefore, the objectives of this study were to investigate the impacts of freshwater discharge on water column processes by monitoring spatiotemporal variation in water properties and phytoplankton size structure in relation to freshwater inputs and to evaluate the contribution of the freshwater inputs to eutrophication in the estuary.

2. Materials and methods

2.1. Study site and sample collection

A sea dike was constructed in the estuary of the Youngsan River in 1981 (Fig. 1) to reclaim tidal flats and to supply agricultural water for the extensive rice fields in the basin of the freshwater reservoir. This dike is about 7 km from the mouth of the river. The Youngam and Geumho seawalls were constructed in coastal regions south of the estuary. When the reservoir water level peaks, freshwater is discharged into the estuary at low tide through the sluice gates in the sea dike. The tides in the estuary are generally semidiurnal, with mean neap and spring tidal ranges of 3 and 6 m, respectively.

Eight stations along the channel of the estuary were sampled monthly over an annual cycle, from October 2003 to October 2004 (except in December 2003, and January and March 2004). The sluice gates of the dike were open and freshwater was being discharged during the sampling in October and November 2003 and June, August, and September 2004. Water samples were collected during a low neap tide .5 m below the surface and from the bottom using a Niskin water sampler. The water depth at the sampling stations ranged from 9.1 to 17.7 m, and the tidal range was 1.2–4.7 m during the sampling period.

2.2. Measurement of physical and chemical properties

Water temperature (°C), salinity (psu), and dissolved oxygen (DO, mg L^{-1}) were measured using a YSI® Model 85 S-C-T. Irradiance was determined using a spherical underwater quantum sensor connected to a spherical LiCor® photosynthetically active radiation (PAR) quantum radiometer at depths of .1, .35, .60, .85, and 1.10 m. The light attenuation coefficient K_d, an index of water transparency, was calculated using Beer's Law $I_z = I_o e^{-Kdz}$, where I_z is the light intensity at depth z, and I_o is the light intensity at the surface. Water transparency was estimated using a Secchi disk. Water depth was measured using a Hondex PS-7 digital sounder.

Water samples (100 ml) for nutrient analysis were filtered through Whatman® 25-mm GF/F glass microfiber filters (.7 μm) immediately after sampling to minimize microbial transformation. Samples for ammonium (NH_4^+), nitrite + nitrate ($NO_2^- + NO_3^-$), dissolved silica (DSi), and orthophosphate (PO_4^{3-}) analyses were stored frozen (<−20 °C). Nutrients were measured using a Bran Luebbe® autoanalyzer (Parsons et al., 1984).

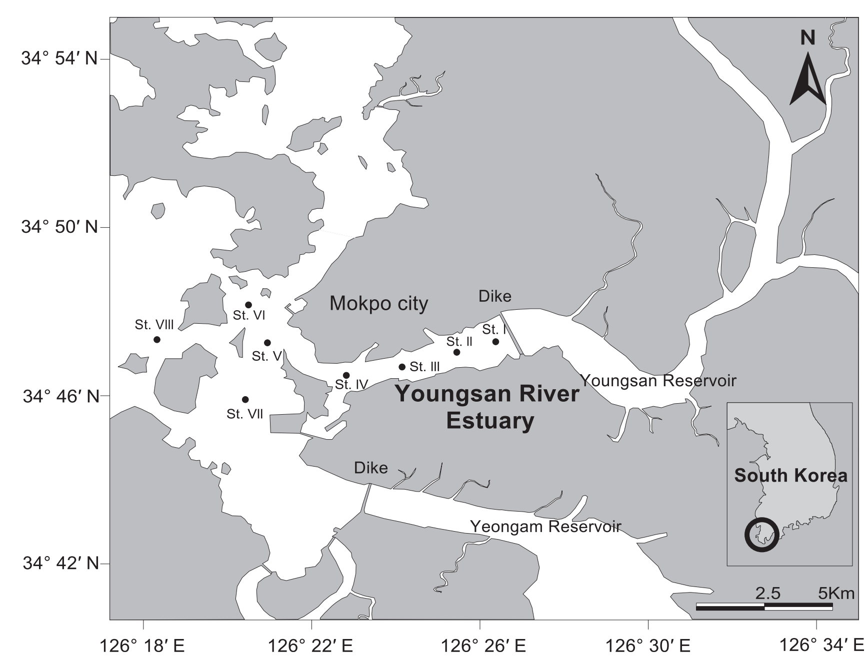

Fig. 1. Sampling stations located along the axis of the Youngsan River estuary. Freshwater is discharged from the gates of the sea dike to regulate the water level in the Youngsan Reservoir.