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Short-term variations of phytoplankton communities in response to anthropogenic stressors in a highly altered temperate estuary

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ABSTRACT

Data for phytoplankton size classes, taxonomy, and water properties were collected through an episodic freshwater discharge event (4 days) in the temperate Youngsan River estuary, which is highly disturbed by manually regulated inputs of freshwater from a sea dike, to investigate the effects of an acute change in anthropogenic stressors on the short-term dynamics of phytoplankton and their surrounding environments. The salinity of the well-mixed saline water (33.2–33.5) decreased to as low as 4.0 and water temperature increased to 24.0 °C during the freshwater discharge, resulting in a stratified water column in the upper region of the estuary. During the discharge, chlorophyll *a* (chl *a*) concentrations increased to as much as 15.66 μg L^{-1} with micro-sized phytoplankton being dominant due to the presence of micro-sized freshwater phytoplankton, mostly *Aulacoseira ambigua* (98% in cell abundance), transported from the reservoir. Primary production decreased to as little as 87.9 mg C m^{-2} d^{-1}, although nutrients such as NO_2^- + NO_3^- were supplied by the freshwater inputs of the discharge. Following the discharge, dinoflagellate blooms, dominated by *Heterocapsa* sp. (>88%), a nano-sized red tide species, developed in the upper regions of the estuary with peaks in chl *a* concentrations reaching as high as 30.33 μg L^{-1}. Another red tide species, *Prorocentrum micans*, was also dominant in the estuary, suggesting that harmful algal blooms (HABs) are associated with anthropogenic stressors related to the freshwater inputs. The Shannon diversity index decreased to 0.18 while the Simpson dominance index increased to 0.94 during the discharge, but the diversity increased again following the discharge. The phytoplankton communities and diversity changed along the salinity gradient, corresponding to an "ecocline" pattern. The results of multivariate statistical analysis suggested that phytoplankton species and size structure were controlled mainly by salinity, water temperature, turbidity, and PO_4^{3-}, which were affected by the regulated freshwater discharge. This study indicates that rapid changes in anthropogenic stressors related to the operation of an engineered structure may impact the eutrophication and biotic integrity of an estuarine system by generating short-term variations in phytoplankton biomass, size, and species composition, especially of harmful algae.

1. Introduction

Changes in salinity can directly influence the physiological and ecological activities of marine organisms by changing the water density, viscosity, and osmosis of marine systems (Gasiūnaitė et al., 2005; Quinlan and Phlips, 2007; Thurman and Trujillo, 2007; Carić et al., 2011; Ganguly et al., 2013). The stress resulting from drastic changes in salinity may present a challenge, especially for organisms living in estuaries, because estuaries are transition zones where freshwater and saltwater interact and salinity gradients form along the estuary axis (Pritchard, 1967). Biological assemblages generally display gradual compositional shifts along salinity gradients in the river–estuary continuum, which indicate the importance of salinity change to estuarine ecology (Bulger et al., 1993; Attrill and Rundle, 2002). Brackish and marine phytoplankton, for instance, are influenced negatively by a decrease in salinity in estuaries (Lionard et al., 2005; Quinlan and Phlips, 2007; Telesh et al., 2011). However, phytoplankton dynamics are much more complex in estuaries because other abiotic properties, aside from salinity, such as water temperature, light, nutrient availability, flushing related to river flow and tidal forcing, as well as biotic factors, also affect phytoplankton (Lehman, 2007; Murrell et al., 2007; Saeck et al., 2013).

Engineered structures within estuarine systems, such as sea dikes and dams, have been constructed over the past few decades to supply drinking or agricultural water (Tockner and Stanford,

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2002). Phytoplankton may experience anthropogenic pressures such as rapid salinity and other environmental changes due to large volumes of freshwater being discharged directly from sluice gates of engineered structures to saline zones. However, the responses of marine phytoplankton communities to acute changes in anthropogenic stressors have been rarely documented, despite their importance in understanding the ecology of estuarine phytoplankton and improving the management of estuarine ecosystems. The size and taxonomic composition of phytoplankton are useful parameters for evaluating the ecological effects of environmental perturbation on estuarine ecosystems because the perturbation can induce changes in phytoplankton size and species that affect primary production, the food web, and biogeochemistry in marine systems (Rousseau et al., 2000; Finkel et al., 2009).

The Youngsan River estuary is located in a temperate region (34°40′–34°54′ N, 126°17′–126°35′ E) affected by the Asian monsoon. It is experiencing anthropogenic stress from a sea dike constructed in its coastal area that physically transects the water body into freshwater and marine ecosystems. The saltwater area is a semi-enclosed water body when freshwater is not being discharged from the reservoir and is dominated by ebb tides with mean neap and spring tidal ranges of 3 and 6 m, respectively (Kang and Jun, 2003; Byun et al., 2004). Eutrophic freshwater from the reservoir inside the sea dike (Lee et al., 2009) is discharged throughout the year at rates as high as 7.39×10^8 m^3 mo^{-1}, which occurred during the summer monsoon of 2012. The effects of freshwater discharge on phytoplankton size structure and nutrients have been investigated over an annual cycle (Sin et al., 2013). However, short-term variations in phytoplankton size and taxonomic structure have not been examined, although phytoplankton responses to anthropogenic freshwater discharges can depend on cell size and the species present in the estuary. Additionally, the *in situ* short-term dynamics of phytoplankton communities over a few days in coastal estuaries with engineered structures are poorly understood. Thus, in this study, we investigated water properties and phytoplankton size/taxonomic structure over a short period (days) before, during, and following freshwater discharge to elucidate the variations in phytoplankton communities and environmental parameters that result from anthropogenic freshwater inputs, and identify the major environmental drivers that govern the short-term dynamics of phytoplankton communities.

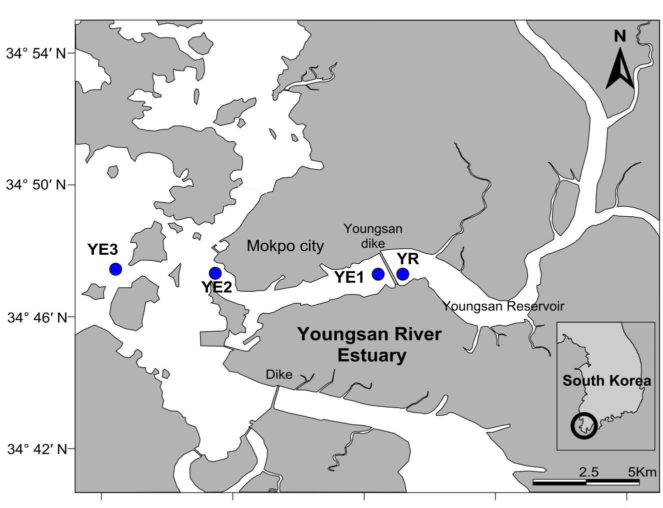

Fig. 1. Sampling stations along the axis of the Youngsan River estuary, which is transected by an engineered structure.

2. Materials and methods

2.1. Study site and sampling design

A sea dike was constructed ~7 km from the mouth of the estuary of the Youngsan River in 1981 (Fig. 1) to reclaim tidal flats and supply agricultural water to the extensive rice fields in the basin of the freshwater reservoir. The Youngsan River watershed spans 3467.8 km^2, and the main channel of the river has a length of 136.7 km. The freshwater reservoir begins approximately 24 km upstream from the sea dike, and has a surface area of 34.6 km^2 and a storage capacity 2.54×10^8 m^3. When the water level of the reservoir peaks, the sluice gates in the sea dike are opened at low tide and freshwater intrudes into the estuary. Hypoxia often develops in the bottom water of the reservoir, at water depths greater than 10 m, especially during the warm season (Yi et al., 2006). Phytoplankton (chlorophytes) and fish diversity and the ecological health of the estuary have declined since the sea dike was constructed (Lee et al., 2009; Shin and Yoon, 2011). The tides in the estuary are typically semidiurnal, with a macro-tidal range of 3–6 m.

Three stations along the channel of the estuary (Fig. 1) were sampled daily from 29 June to 2 July, 2012. The sluice gates in the dike were opened and freshwater (6.74×10^6 m^3) was discharged on 30 June (Fig. 2). Only Station YR, in the reservoir, and Station YE1 were sampled on 30 June because the freshwater plume did not extend to Station YE2 during the sampling on this date. Freshwater (13.6×10^6 m^3) was also discharged on 2 July, and water samples were collected before the gate was opened. No freshwater was discharged during other sampling dates. The sampling dates from 29 June to 2 July are hereafter designated in this paper as D − 1, D, D + 1, and D + 2, respectively. During this period, water samples were collected during an ebbing tide at 0.5 m below the surface and from the bottom using a Niskin water sampler. The water depths at the sampling stations ranged from 8.0 to 25.3 m, and the tidal range was 1.2–4.7 m during the sampling period.

2.2. Measurement of meteorological and water properties

Precipitation data are collected by the Korean Meteorological Administration, and data for the freshwater discharge from the sea

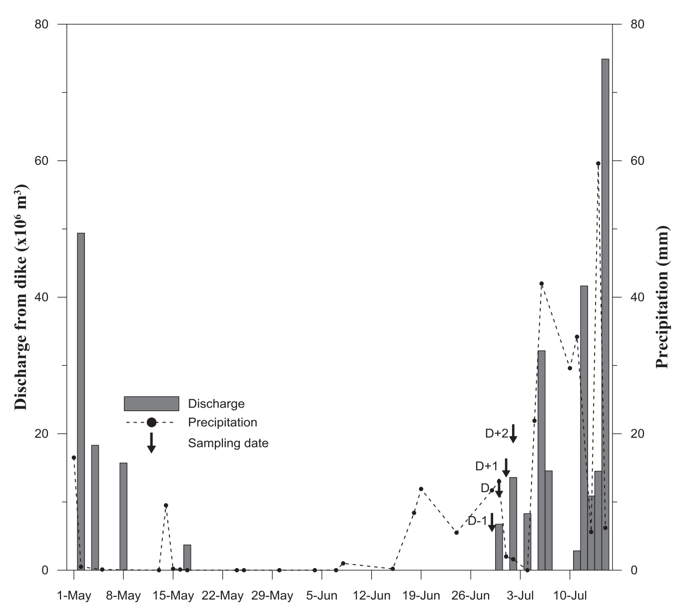

Fig. 2. Daily precipitation records for the Youngsan River estuary area and daily freshwater discharge (m^3 d^{-1}) from the Youngsan dike from May to July 2012.