Marine Pollution Bulletin 90 (2015) 304–311

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Baseline

Edited by Bruce J. Richardson

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Human and riverine impacts on the dynamics of biogeochemical parameters in Kwangyang Bay, South Korea revealed by time-series data and multivariate statistics

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ARTICLE INFO

Article history:
Available online 4 December 2014

Keywords:
Nutrient cycles
Riverine nutrient transport
Atmospheric nitrogen deposition
Cluster analysis
Factor analysis
Kwangyang Bay

ABSTRACT

The successful management of sustainable coastal environments that are beneficial to both humans and marine ecosystems requires knowledge about factors that are harmful to such environments. Here, we investigated seawater nutrient and carbon parameters between 2010 and 2012 in Kwangyang Bay, Korea, a coastal environment that has been exposed to intensive anthropogenic activities. The data were analyzed using cluster and factor analysis. We found that the biogeochemical cycles of nutrients and carbon were determined by river discharge into the bay and biological activity. However, the impacts of these factors varied both spatially and seasonally. During the past 10 years, nutrient loads from the river and industrial complexes to the bay have decreased. The impacts of this decrease are visible in the phosphate concentration, which has fallen to a third of its initial value. We also examined the potential role of atmospheric nitrogen deposition in nitrogen cycling in the study area.

Coastal seas, which connect continental margins and open oceans, are the most dynamic and productive aquatic environments, and are thus habitats for diverse marine organisms and ecosystems. Humans also use coastal areas for residential areas, recreation, aquaculture and industrial infrastructure, such as harbors, power plants, and factories. During recent decades, these human activities have increased rapidly with economic and population growth, and coastal waters have been exposed to increasing contamination. As a result, many coastal environments have become extremely vulnerable habitats (Lotze et al., 2006; Diaz and Rosenberg, 2008). Despite continuing efforts to prevent and manage the contamination introduced to coastal waters, many coastal regions remain exposed to significant human influences, and there is growing concern for their future in many parts of the world (Wang, 2006; Todd et al., 2010). Major impacts on coastal environments arising from the introduction of anthropogenic pollutants include eutrophication by reactive nitrogen (all inorganic nitrogen species other than N_2) and phosphate, which often provoke harmful algal blooms and deplete oxygen (Smith, 2003). Reactive nitrogen has been released into the environment by the use of agricultural fertilizers and fossil fuels (Galloway et al., 2008; Ciais et al., 2013). Atmospheric deposition and submarine groundwater efflux can transport significant amounts of nitrogen pollutants into coastal waters adjacent to heavily populated regions (Paerl, 1997; Kim et al., 2013, 2014), although a large portion of anthropogenic nitrogen ultimately reaches coastal waters via riverine discharge.

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http://dx.doi.org/10.1016/j.marpolbul.2014.08.044
0025-326X/

To properly manage these environmental threats and thus sustain coastal regions as habitable places for marine organisms, it is necessary to understand the factors governing the levels of biogeochemical parameters in coastal waters, and their spatial and temporal variation. An area where such efforts are much needed is Kwangyang Bay, located on the central southern coast of Korea. The bay is subjected to a variety of anthropogenic activities, including reclamation of tidal flats, steel and petrochemical industrial complexes, cargo ship navigation, and a harbor. In addition, Seomjin River, the fifth largest river in South Korea, discharges $\sim 2–4 \times 10^9\ m^3\ yr^{-1}$ of freshwater into the bay (Kim et al., 2013). Because of these multiple pollution sources and the resulting degradation of water quality, in 1982, the Korean government designated the bay area as a special management area, and the dynamics of nutrients and phytoplankton have been investigated in several studies (Kwon et al., 2001; Jang et al., 2005; Lee et al., 2005; Baek et al., 2011). However, we are aware of only one study covering multiple years (2001–2003) (Jang et al., 2005). Moreover, to the best of our knowledge, none of the previous studies utilized seawater carbon parameters to elucidate biogeochemical cycles in the bay. In this study, we determined the major factors controlling the levels of biogeochemical variables such as nutrient and carbon parameters in Kwangyang Bay, using multivariate analysis of data collected seasonally between 2010 and 2012 across the entire bay. In addition, we compared our results to past data, and suggested possible causes for the differences identified.

Kwangyang Bay covers an area of $\sim 230\ km^2$, with an extension of ~ 17 km from east to west and ~ 14 km from north to south. The bay area consists of three geographical zones: the western area, the northeastern area, and a southern channel. In two of these zones, the bay waters are exchanged with riverine and offshore waters. The Seomjin River, with a watershed area of $4900\ km^2$, discharges into the northernmost part of the bay (Fig. 1). To the south, the bay is connected to the offshore waters of the South Sea of Korea (a northern extension of the East China Sea) via a 3 km-wide waterway between Yeosu and Namhae (the southern channel). Thus, the north–south waterway connecting the Seomjin River and the southern channel provide a major channel for water flow. The western part of the bay is a shallow inner bay surrounded to the north by steel and to the south by petrochemical industrial complexes, and housing Kwangyang harbor in the west. The northeastern part of the bay is directly influenced by the Seomjin River. However, saline water also intrudes from the neighboring Jinhae Bay via a narrow (0.5 km wide) channel between Hadong and Namhae. The bay area exhibits a semi-diurnal tide with a range of ~ 1 and ~ 3 m during neap and spring tide, respectively (Korea Hydrography and Oceanographic Administration, www.khoa.go.kr). The

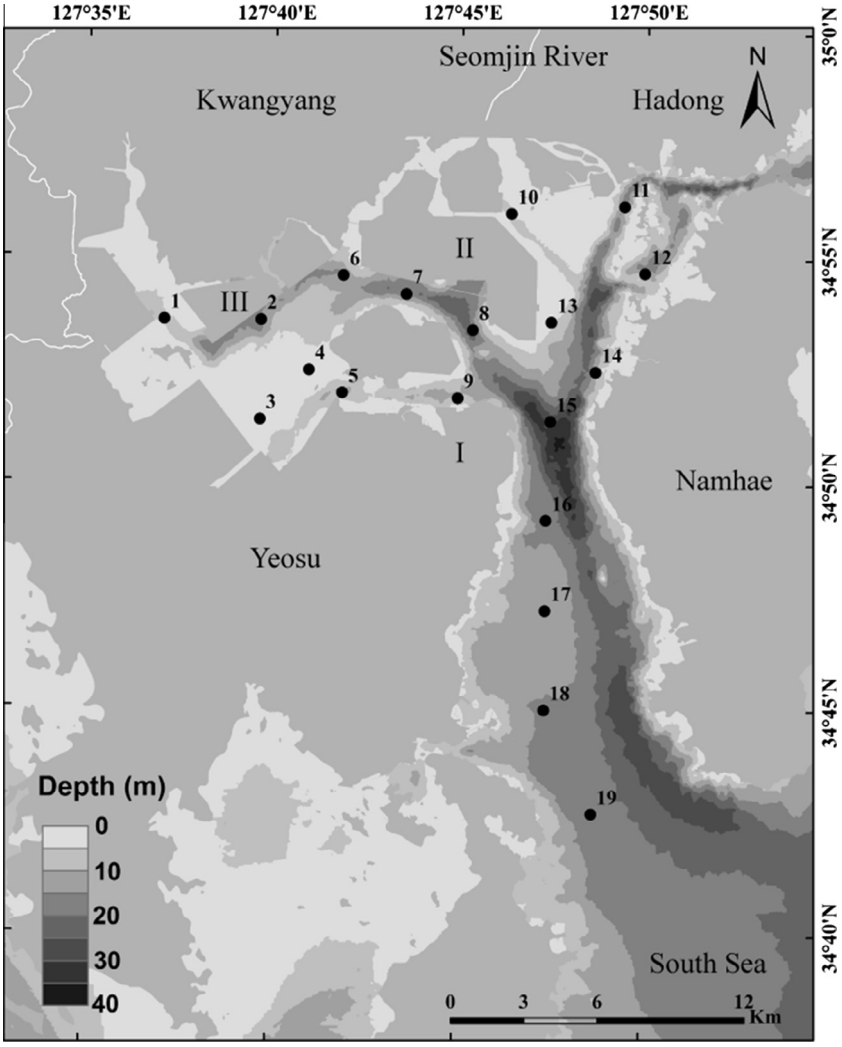

Fig. 1. Map of Kwangyang Bay showing sampling stations (circles) with corresponding station numbers, the Seomjin River, and industrial complexes. Gray shadings indicate water depths (m). Symbols of I, II and III indicate the petrochemical, steel industrial complexes, and the Kwangyang Harbor, respectively.