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# Seasonal distribution of phytoplankton assemblages and nutrient-enriched bioassays as indicators of nutrient limitation of phytoplankton growth in Gwangyang Bay, Korea

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ABSTRACT

To assess the effect of nutrient limitation on phytoplankton growth, and its influence on seasonal variation in phytoplankton community structure, we investigated abiotic and biotic factors in surface and bottom waters at 20 stations in inner and offshore areas of Gwangyang Bay, Korea. Algal bioassay experiments were also conducted using surface water, to assess the effects of nutrient addition on the phytoplankton assemblages. The fate of major nutrients in the bay was strongly dependent on the discharge of freshwater from the Seomjin River. River flow during the rainy season provides a high nitrogen (N) influx, pushing the system toward stoichiometric phosphorus (P) limitation. However, at some times during the rainy season there was insufficient N to maintain phytoplankton growth because it was rapidly consumed through nutrient uptake by phytoplankton under stratified environmental conditions. Diatoms made a relatively large contribution to total phytoplankton biomass. The dominant diatoms, particularly in winter and summer, were *Skeletonema marinoi-dohrnii* complex and *Skeletonema tropicum*, respectively, while *Eucampia zodiacus* and the cryptophyte *Cryptomonas* spp. dominated in spring and autumn, respectively, comprising more than 75% of the community at most stations. In the bioassay experiments the phytoplankton biomass increased by 30–600% in the +N (added nitrogen) and +NP (added nitrogen and phosphorus) treatments relative to the control and the +P (added phosphorus) treatments, indicating that phytoplankton growth can respond rapidly to pulsed nitrate loading events. Based on the algal bioassay and the field survey, the abrupt input of high nutrient levels following rainfall stimulated the growth of diatom assemblages including the *Skeletonema* genus. Our results demonstrate that the growth of centric diatoms was enhanced by inputs of N and Si, and that the concentrations of these nutrients may be among the most important factors controlling phytoplankton growth in Gwangyang Bay.



## 1. Introduction

Several strong seasonal cycles of bottom-up factors, including temperature, light, nutrient loading in rainfall and river runoff, water mixing and stratification can drive changes in the phytoplankton community composition (Thompson et al., 2008). Changes in water circulation and tidal currents are also reflected in the dynamics of coastal phytoplankton populations. In temperate seas the typical annual phytoplankton succession is characterized by low winter and summer biomass. This is because of the low light levels, absence of water stability, and low temperatures in winter, and the depletion of inorganic nutrients in the euphotic zone in summer. Conversely, phytoplankton blooms in spring and autumn are characteristic of the annual phytoplankton cycle. Spring blooms develop in response to increased insolation and water column stability, and autumn blooms are associated with the breakdown of summer stratification, which allows nutrient-rich deep waters to mix into the euphotic zone (Townsend et al., 1992).

A common feature in coastal ecosystems is the onset of high productivity periods, driven by physical factors including

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freshwater discharge (Del Amo et al., 1997). Freshwater inputs to coastal waters are an important source of nutrients that directly support phytoplankton growth. However, the growth of phytoplankton can be limited by the relative absence of one or more essential nutrients. Nutrient limitation is largely determined by the mass balance among the elements silicon (Si, as silicate), nitrogen (N) and phosphorus (P), because of their relationship to phytoplankton growth requirements (Redfield et al., 1963; Dortch and Whitledge, 1992; Justić et al., 1995). Nutrient ratios in water samples can be used to indicate the nutrient loading status and predict productivity (De-Pauw and Naessens, 1991). Different phytoplankton species can respond differently to the same nutrient conditions because of differing nutrient requirements and half saturation constants among species. Therefore, nutrient addition bioassays are useful in assessing the effects of nutrients on variations in phytoplankton communities, and in identifying nutrient limitations (Holmboe et al., 1999).

Gwangyang Bay is located in the southern coastal area of Korea, which is one of the most industrially polluted coastal areas of Korea. It is connected to the open sea by the 4-km wide Yeosu Channel to the south and the Seomjin River to the north; the latter annually discharges 10.7–39.3 × $10^8$ tons of freshwater. The water depth in the bay is generally <5 m, except in two tidal channels that each exceed 20 m depth (Korea Hydrographic Office, 1983). The bay includes the main estuarine delta and tidal flats; commencing in the 1970s, these were extensively reclaimed to establish diverse industrial facilities. As a consequence, various aquatic habitats in the Seomjin River estuary and the shallow water embayment of the bay have been severely damaged by industrial pollutants, and are becoming notorious for their levels of eutrophication and frequent occurrences of red tides associated with discharges of industrial and sewage effluents (Lee and Kim 2008; Lee et al., 2005; Baek et al., 2014).

The objectives of the present study were to: (1) evaluate the major nutrient inputs in the Seomjin River runoff; (2) determine the nutrients limiting phytoplankton growth, based on relative element ratios and the absolute concentrations of N, P and Si; (3) use bioassays to study the response of phytoplankton from each station to nutrient addition; and (4) assess the spatial and temporal variations in biotic and abiotic factors, and the effects of N and P on the phytoplankton community structure in Gwangyang Bay.

## 2. Materials and methods

### 2.1. Field survey

Water samples were collected at 20 stations (Fig. 1) located throughout the bay over four seasons: winter (5–6 February 2010), spring (1–2 May 2010), summer (26–27 August 2010) and autumn (25–26 November 2010). Vertical profiles of temperature and salinity were measured using a conductivity–temperature–depth sensor (CTD; Ocean Seven 319; Idronaut Co., Brugherio, Italy). Water samples were collected at the surface (1 m below the surface) and bottom (1 m above the bottom) using a 5 L PVC Niskin sampler (General Oceanics, Miami, FL, USA). Water samples for nutrient analysis were filtered (GF/F; 25 mm, pore size 0.45 μm; Whatman, Middlesex, U.K.), placed in acid-cleaned polyethylene bottles, and poisoned with $HgCl_2$. Ammonia, nitrate, nitrite, phosphate and silicate concentrations were determined in the laboratory using a flow injection autoanalyzer (QuikChem 8000; Lachat Instruments, Loveland, CO, USA). The nutrient concentrations were calibrated using standard brine solutions (CSK Standard Solutions; Wako Pure Chemical Industries, Osaka, Japan). For chlorophyll-*a* (Chl-*a*) measurements, 0.3–1.0 L (depending on the season) of seawater was immediately filtered through a 47-mm diameter GF/F filter (pore size 0.45 μm, Whatman) on board the research vessel, and the filters were stored at −20 °C until further laboratory analysis. Chl-*a* was measured using a Turner-designed fluorometer (Turner BioSystems, Sunnyvale, CA, USA) following extraction of the filtered material with 90% acetone for 24 h in the dark. To identify and enumerate phytoplankton, 0.5-L subsamples were stored in polyethylene bottles and fixed with 0.5% Lugol's solution.

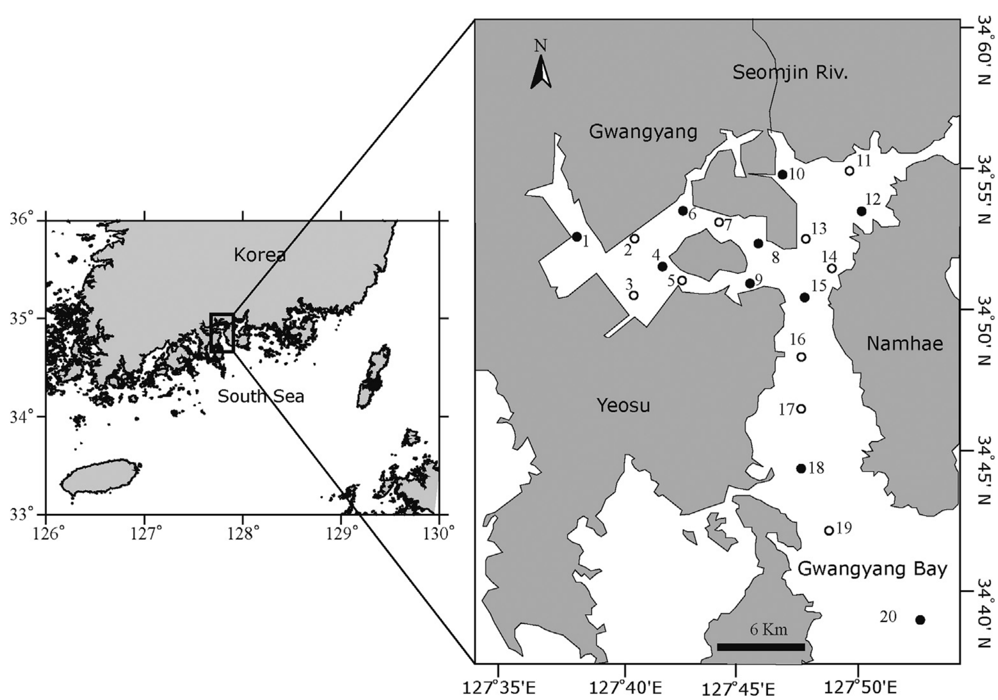


**Fig. 1.** Location of sampling stations in Gwangyang Bay, South Sea, Korea. Algal bioassay experiments were conducted for stations marked by black circles.