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Environmental Dynamics and Anthropogenic Impacts in the Seomjin River Estuary and Gwangyang Bay: A Comprehensive Review of Hydrology, Nutrient Fluxes, and Benthic Ecosystems

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Abstract
This study reviews academic research on the lower Seomjin River and the northern part of Gwangyang Bay to assess the environmental conditions of the Seomjin River estuary and propose directions for improvement. A density front forms where freshwater from the Seomjin River meets seawater from Gwangyang Bay; however, the hydrological estuary does not align precisely with its geographical counterpart. Phytoplankton production plays a critical role in regulating particulate organic matter (POM), with nitrate and silicate primarily supplied by the river and phosphate by the bay. Nutrient distribution is largely governed by biological processes, while primary production significantly alters nutrient fluxes entering Gwangyang Bay. These fluxes are influenced by freshwater discharge and the concentration of dissolved inorganic nutrients. Sediment distribution, previously dominated by fine particles west of the river delta, shifted following industrial development, including delta degradation. High concentrations of di-butyl phthalate (DBP) and di-2-ethylhexyl phthalate (DEHP) were detected in seawater and surface sediments, suggesting riverine transport of these pollutants into the bay. Salinity was found to be a major factor shaping the spatial distribution of zooplankton, fish, and polychaete communities. To restore and protect the estuarine environment, it is essential to improve the upstream water quality, install monitoring stations with water quality management systems in the estuary, and implement a comprehensive pollutant discharge monitoring system in Gwangyang Bay.

Keywords: Estuarine Dynamics, Salinity Gradient, Primary Production, Nutrient Flux, Pollutant Accumulation, Benthic Community Structure.

Introduction

The Seomjin River basin, located in the southwestern part of the Korean Peninsula, is one of the five major river basins in South Korea. It is bordered by the Nakdong River basin to the east, the Yeongsan and Dongjin River basins to the west, and the Geum and Mangyeong River basins to the north [1]. The Seomjin River flows into the South Sea through Gwangyang Bay, with a basin area of approximately 4,911.89 km^2 and a main stream length of 223.86 km (total river length of approximately 300 km). The annual freshwater discharge ranges between 1.0 and 4.0×10^9 m$^3 \cdot s^{-1}$, and about 80% of this discharge occurs during the summer, flowing directly into Gwangyang Bay [2-4]. This seasonal influx of freshwater creates a quasi-estuarine environment during the flood season [5].

Gwangyang Bay is a semi-enclosed bay located at the river's mouth, approximately 27 km wide (east-west) and 15 km long (north-south) [6, 7]. It is connected to the South Sea via Yeosu Bay and to Jinju Bay through the Noryang Strait. The bay receives $5.8–8.7 \times 10^8$ m$^3 \cdot s^{-1}$ of freshwater and 0.8×10^6 m$^3 \cdot s^{-1}$ of suspended matter annually from the Seomjin River (Park et al., 1984). Fig. 1 indicates a study area, illustrating the main stream of the Seomjin River flowing into the South Sea, key geographical features of the estuarine and bay regions, and major industrial and reclamation developments around Gwangyang Bay.

Tidal circulation is bidirectional, with seawater entering through Yeosu Bay during high tide and exiting during low tide (KHOA). The tidal range reaches up to 4 m, and the maximum current velocities are 56.1 $cm \cdot s^{-1}$ at the surface and 9.8 $cm \cdot s^{-1}$ at the bottom layer [8]. Map showing the study area, including the Seomjin River estuary and the northern part of Gwangyang Bay, South Korea. Historically, the estuarine area supported extensive seaweed and shellfish cultivation [9]. However, large-scale reclamation and dredging projects—associated with the development of the Yeocheon Chemical Complex, Pohang Iron & Steel Company (POSCO), Yulchon Industrial Complex, Gwangyang Container Terminal, and the Myodo dredged soil disposal site—have reduced the bay's surface area by more than 40% since the 1970s [10, 11]. This development has led to water stagnation and degradation in water quality, sediment conditions, and ecological function, resulting in the bay becoming unsuitable for many aquatic organisms [12, 13].

The estuarine region, where freshwater from the Seomjin River meets saline water from Gwangyang Bay, forms a two-layered density stratification [14, 15]. This brackish zone plays a critical ecological role, serving as a transitional habitat where freshwater and marine organisms coexist. The interaction between river discharge and tidal inflow regulates water quality, sediment transport, and biological communities such as phytoplankton, zooplankton, fish, and benthic organisms [16-18]. Additionally, saline intrusion into the river varies with river discharge and tidal prism volume, extending 11–25 km upstream [19, 20]. These physical dynamics influence not only hydrological conditions but also biological productivity and ecosystem structure [21, 22].

Given its ecological and environmental significance, the Seomjin River estuary is a critical area for studying land–sea interactions. This study aims to examine the environmental characteristics of the Seomjin River estuary and the adjacent northern part of Gwangyang Bay. By synthesizing academic research conducted between 1974 and 2023, we assess the current state of the physical, chemical, and ecological environment and explore strategies for environmental restoration and sustainable management.

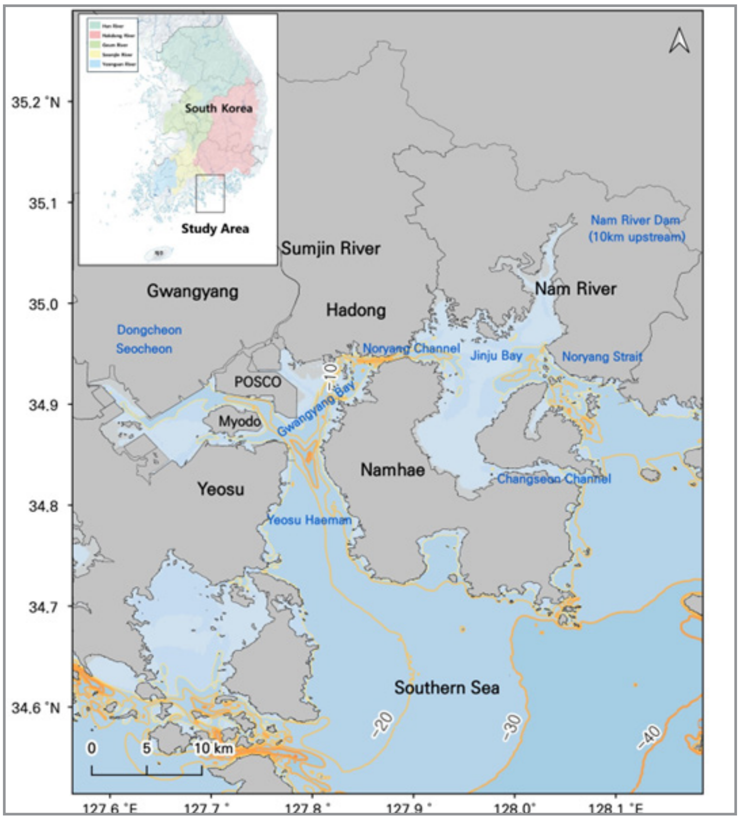

Figure 1: Location of study area including Seomjin River estuary and the northern part of Gwangyang Bay.

Materials and Methods

This study conducted a comprehensive review of 125 academic papers published between 1974 and 2023 on the environmental conditions of the Seomjin River basin. The scope included the main river and its major tributaries—Boseong River, Yocheon, Osoocheon, and Churyeongcheon—as well as the estuarine zone and the northern waters of Gwangyang Bay.

Relevant literature was identified through systematic searches of the Korea Citation Index (KCI) and the Science Citation Index (SCI). Korean-language papers were retrieved using the keywords "Seomjin River" and "Gwangyang Bay" via the KISS (Korean Studies Information Service System) platform, while English-language papers were searched in the ScienceDirect database. The year 1974 marks the earliest indexed publication related to the study topic in either KCI or SCI.

To maintain a focused and manageable scope, studies related to the upper watershed of the Seomjin River were excluded. This exclusion allowed the analysis to concentrate on aquatic and estuarine environments, particularly the lower Seomjin River and its interaction with the northern part of Gwangyang Bay.

The primary objective was to evaluate the current environmental status of the estuary and propose feasible strategies for improving its ecological health and water quality.

Results and Discussions

Overview of Research on the Seomjin River Basin and Estuary

Prior to focusing on the estuarine area of the lower Seomjin River, it is essential to understand the overall environmental research conducted within the entire Seomjin River basin. Table 1 summarizes research topics and the number of published studies related to both the Seomjin River basin and its estuary, including the northern waters of Gwangyang Bay, since 1974.

Fish ecology is the most extensively studied subject within the Seomjin River basin, followed by investigations into hydrology and runoff, water quality, benthic fauna (e.g., clams and river oysters), and mammals such as otters. In contrast, research in the estuarine region primarily focuses on the physical environment—such as tides, currents, and saltwater intrusion—followed by studies on water quality, phytoplankton and zooplankton communities, sedimentary environments, and aquatic flora including seagrasses.

Temporal analysis reveals increased research activity from 2000 onwards in both the basin and estuary regions, with a peak in the diversity and volume of studies observed in 2014, followed by notable research outputs in 2012, 2015, and 2020. These trends reflect heightened scientific interest, especially in the basin during these years.

Overall, while fish ecology, hydrology, and water quality dominate basin-level research, studies in the estuarine zone emphasize seawater dynamics, water quality, and planktonic communities. This indicates that water quality is a central concern throughout the Seomjin River basin's environmental research. However, given that many basin-focused studies are less directly relevant to the estuarine brackish water environment, this review will concentrate on research pertinent to the estuary and its immediate surroundings.

Table 1: Topics of the research related to Seomjin River watershed and its estuary

	Seomjin River Watershed (inside river)									Seomjin River Estuary (outside river							Total
Year	Hydrological Environ.	Geographical Environ.	Water Quality	Sediment	Plankton	Fish	Benthos	Mammal/ Aquatic Bacteria	Flora	Physical Environ.	Water Quality	Sediment	Plankton	Fish	Benthos	Flora	
1974										1							1
1975											1						1
1976																	-
1977																	-
1978																	-
1979																	-
1980																	-
1981																	-
1982																	-
1983									1								1
1984	1																1
1985																	-
1986											1						1
1987																	-
1988																	-
1989						1											1
1990										1					1		2
1991																	-
1992										1							1
1993																	-
1994	1																1
1995																	-
1996																	-
1997																1	1

1998																	-
1999																	-
2000	2			1			1	1	1			1					7
2001								1					2				3
2002	1										1		2				4
2003			2		1							1					4
2004		1									1	2					4
2005			3								1		2				6
2006						1	1			1							3
2007										1							1
2008			1				1			1							3
2009		1	2			1				1							5
2010										1			1			1	3
2011	1					1				1	1	1					5
2012					1	3	1				1		1			1	8
2013						2	1							1			4
2014	1	1	1							3	1		1		1		9
2015	1		1	1			2	1		1						1	8
2016				1							1						2
2017	1		1								1				1		4
2018	2						1	1			1						5
2019				1	1	1											3
2020		1	2			2	1	1	1	1							8
2021	2				3	3		1		1							7
2022						2	1			2	1						5
2023	1						1				1			1			3
Total	14	4	13	4	3	17	11	6	2	17	11	5	9	2	3	4	125

Physical Environment

Numerous studies have characterized the physical environment of the Seomjin River estuary and Gwangyang Bay, emphasizing the combined influence of tidal dynamics, freshwater discharge, and anthropogenic changes. Early observations by Chang et al. revealed that seawater circulation is primarily driven by tidal currents, with freshwater inflow from the Seomjin River forming a low-salinity zone and enhancing outflow from the bay [23]. Using two-dimensional hydraulic modeling, Lee and Lee (1990) identified a distinct density front and variability in the Froude number based on upper layer depth. Choi et al. found that a 100-year flood during spring tide could significantly raise water levels, particularly at the estuary [24].

Subsequent studies employed advanced numerical models to refine understanding of estuarine hydrodynamics. Kim et al. (2006) and Kim et al. used 3D models (POM, EFDC) to show that salinity fronts fluctuate seasonally, contracting in winter and expanding in summer due to increased river discharge [25]. demonstrated that dredging and land reclamation altered tidal range and flow velocities by modifying flow resistance [26, 27]. Sediment dynamics also changed, with concentrations increasing at the estuary [28]. showed that regulated dam discharges reduce saline intrusion during low flow periods, improving water quality [29].

Hydrodynamic stratification varies with discharge: Kwak et al. observed baroclinic two-layer flows during high flow and barotropic flows during low flow [30]. Kim et al. reported that over 80% of freshwater flows into Yeosu Bay [31]. Salinity intrusion distances, estimated at 11–25 km upstream (Kang et al., 2015), varied with tidal and discharge conditions, with refined measurements showing 22.2–24.1 km during neap and spring tides, respectively (Lee et al., 2022). Year-round observations and particle tracking simulations revealed spatial–temporal trends in seawater exchange, with residence times of 7.1–15.4 days and dominant flow toward Jinju Bay via the Noryang Channel [32, 33].

Collectively, these studies highlight the estuary's dynamic physical environment, shaped by interactions among tidal forces, river inflows, and human activities.

Water Quality Environment

The water quality of the Seomjin River estuary and adjacent Gwangyang Bay is shaped by freshwater inflow, nutrient dynamics, and biological processes. Jhoo and Sheo (1975) observed that freshwater input from the Seomjin River diluted seawater, enhanced dissolved oxygen (DO) levels, and reduced pollutant concentrations, forming a brackish zone favorable for fisheries. Lee et al. found low overall concentrations of heavy metals (Cu, Pb, Zn), though levels were elevated near river mouths, with significant correlations among metals and COD, suggesting common sources or transport mechanisms [34].

Studies on particulate and nutrient dynamics highlighted the dominant role of biological processes. Kwon et al. reported low suspended particulate matter (SPM) despite large river discharge, with phytoplankton identified as the primary contributor to particulate organic matter (POM), especially in intermediate salinity zones [35]. Kwon et al. showed that nitrate and silicate originated mainly from river inflow, while phosphate was sourced from the bay [36]. Nutrient fluxes peaked during the rainy season, and nutrient uptake by phytoplankton during dry periods explained mid-salinity nutrient depletion.

Kim et al. quantified nutrient loads from 33 rivers and industrial sources, showing the Seomjin River contributed over half the freshwater input and substantial proportions of DIN, TN, and DIP [37]. The elevated DIN/DIP ratio (>16) during the rainy season indicated potential phosphorus limitation for phytoplankton growth. Min et al. found that turbidity after rainfall reduced primary productivity in the Sunchon River estuary by limiting light penetration [38].

Park et al. (2012) demonstrated that salinity and nutrient concentrations in the estuary varied seasonally, with nutrient levels higher in the rainy season and Chl_a levels higher in the dry season—suggesting that freshwater discharge, rather than nutrient availability alone, drives phytoplankton biomass. Park et al. confirmed that nutrient export is primarily governed by discharge volume and nutrient concentration, with freshwater discharge increasing tenfold in the rainy season [39].

CDOM patterns also reflected riverine influence. Lee and Park found higher CDOM levels upstream and during the rainy season, negatively correlated with salinity and affected by temperature [40]. Lim and Baek (2017) reported that freshwater inputs in winter led to nutrient dilution and salinity shock-induced diatom mortality, promoting bacterial decomposition, CO_2 production, and pH decline.

Kim et al. identified salinity and organic matter—particularly from phytoplankton and sediment—as key factors influencing COD in estuaries, including the Seomjin River [41].

Collectively, these studies demonstrate that water quality in the Seomjin River estuary is governed by seasonal freshwater inflows, nutrient sources, phytoplankton dynamics, and organic matter decomposition, with clear spatial and temporal variability across the estuary-bay system.

Benthic and Sedimentary Environment

The benthic and sedimentary environments of the Seomjin River estuary and Gwangyang Bay are shaped by hydrodynamic conditions and anthropogenic influences. Cho et al. analyzed surface sediments from 91 sites in February and April 1997 and found that concentrations of Fe, Mn, Cr, Ni, and Zn were strongly correlated with sediment grain size, whereas Mn, Co, Cu, and Pb showed weak or no such correlation [42]. R-mode factor analysis revealed that Factor 1, associated with grain size and organic carbon, accounted for approximately 61% of total variance. Spatial patterns showed Zn and Pb enrichment along the northwestern coast of the Yeosu Peninsula, while Mn, Co, and Cu were concentrated near the southern Myodo channel.

Ryu (2003) examined sediment distribution at 82 sites in May 2001 and reported a shift from the original east-west pattern around the Seomjin River delta to a north-south orientation following extensive coastal development, including the Gwangyang Steelworks and Container Terminal. This development reduced tidal energy, especially in the southwestern bay, promoting finer sediment deposition and indicating a transition to a deposition-dominated environment.

Kim et al. detected phthalate esters—DBP and DEHP, both endocrine disruptors—in surface sediments of Gwangyang Bay (mean concentrations of 33.8 $ng \cdot g^{-1}$ and 67.4 $ng \cdot g^{-1}$, respectively) and in water and sediments from the Seomjin River estuary [43]. Elevated concentrations near industrial zones and river mouths suggested these compounds enter the bay primarily via riverine input, with concentrations decreasing toward the open sea.

Cho et al. assessed bisphenol A (BPA) levels in surface sediments from Gwangyang and Yeosu Bays collected seasonally in 1999–2000 [44]. BPA concentrations ranged from 0.46 to 24.59 $ng \cdot g^{-1}$, with generally higher levels in Gwangyang Bay, though seasonal variations were observed.

Heo et al. measured sediment oxygen demand (SOD) and denitrification rates in four estuaries, including the Seomjin River, and three tidal flats [45]. While Masan Bay exhibited the highest SOD and denitrification rates, the Seomjin River estuary also showed elevated activity, especially in summer. Denitrification in this region was enhanced by benthic microalgal photosynthesis, which facilitated nitrification-denitrification coupling rather than inhibiting it. Seasonal patterns of denitrification were linked to nitrate sources—either riverine input or in-situ nitrification—with summer maxima in the Seomjin estuary attributed to high water-column nitrate availability and favorable oxygen conditions.

Together, these studies highlight the dynamic and evolving nature of the benthic environment in the Seomjin River estuary, influenced by sediment composition, contaminant input, biological activity, and anthropogenic modifications to hydrodynamic conditions.

Biological Community

Phytoplankton and Zooplankton

The plankton communities in the Seomjin River estuary exhibit distinct seasonal and spatial variations shaped by salinity gradients and nutrient dynamics. Kwon et al. identified 96 phytoplankton species—predominantly diatoms (60 species)—with green algae prevailing in low-salinity zones and dinoflagellates increasing toward higher salinities [46]. A Skeletonema spp. bloom occurred in November at intermediate salinities (5–15 psu). Zooplankton surveys recorded 83 taxa, mainly marine copepods (34 taxa), with community composition shifting seasonally along salinity gradients. Freshwater taxa appeared below 8.1 psu in July, 4.7 psu in September, and 0.2 psu in November.

Lee et al. conducted field sampling and nutrient bioassays during dry (November 1999) and wet (September 2000) seasons, revealing nitrogen limitation across both periods [47]. Nitrogen originated primarily from riverine and industrial sources, while phosphorus was attributed to local point sources. Park et al. found that zooplankton biomass peaked in spring (>3,000 ind·m^{-3}), declined in summer and autumn, and increased in winter [48]. Seasonal dominance of taxa varied with salinity, with copepods prevalent across zones in winter and dinoflagellates dominating high-salinity areas in spring.

Kwon et al. reported that DIN/DIP ratios frequently exceeded 16 in low-salinity and high-Chl_a areas, indicating phosphate limitation. In contrast, higher salinity zones showed nitrogen limitation (DIN/DIP <16). Skeletonema costatum, capable of rapid salinity adaptation, was the main bloom-forming species, especially sensitive to phosphate availability [49].

Youn et al. observed that zooplankton, especially copepods, were abundant year-round, with community composition influenced by seasonal changes in salinity and temperature [50]. Acartia spp. and Paracalanus parvus s.l. growth was regulated by these factors. Annual copepod productivity was estimated at 3.49 gC·m^{-2}·yr^{-1}, supported by high phytoplankton biomass and the wide salinity tolerance of dominant species.

Cho and Lee demonstrated that freshwater inflow stresses Cochlodinium polykrikoides, leading to increased mortality during vertical migration, as evidenced by elevated DNA/RNA content during diel cycles in stratified tank experiments [51].

Yang et al. found that primary productivity in 2001 ranged widely (50.7–14,203.3 mgC·m^{-3}·d^{-1}), influenced primarily by nutrient availability rather than light [52]. Nitrogen and phosphorus were supplied by industrial discharges and river inflows, respectively, with salinity modulating nutrient dynamics.

Min et al. used tracer and pigment analyses (2009–2010) to show peak productivity in August, highest in upstream areas [53]. Fucoxanthin dominance indicated that Skeletonema costatum played a key role in primary production.

Bae et al. (2014) reported diatom dominance, particularly Eucampia zodiacus and Skeletonema costatum-like species, driven by increased light and nutrient input in summer. Bioassays showed similar growth rates in both inner and outer bay regions, but lower phosphate half-saturation constants offshore. Nitrogen addition enhanced summer growth, indicating nitrogen limitation despite continuous input. Silicate was non-limiting due to recycling from diatom decomposition and freshwater input, maintaining a stable diatom-based phytoplankton community.

Fish Communities

Seo et al. conducted a seasonal fishery survey using shrimp nets from February to November 2009 in the Seomjin River estuary and adjacent coastal waters of Namhae Island. A total of 113 species were identified, including 16 algal (3 phyla) and 97 animal species (68 families) [54]. Species richness peaked in winter (63 species) and declined in summer (44 species); however, diversity and evenness indices were highest in summer and lowest in winter, showing an inverse trend to species count. The ten most abundant species—such as maru shrimp, mullet, Amur starfish, blue mullet, and dottyback—accounted for 81.4% of total individuals and 49% of total biomass. Seasonal and spatial variations in species composition were evident, with larger individuals generally found in the southern coastal waters compared to the estuary.

Kim et al. assessed spatiotemporal variation in fish communities using gill and trammel nets at eight sites across the Seomjin River estuary and Gwangyang Bay from 2020 to 2021 [55]. A total of 5,111 individuals representing 78 species, 68 genera, 42 families, and 14 orders were recorded. Pennahia argentata and Nuchequula nuchalis were dominant. Cluster analysis (Bray–Curti's similarity) classified communities into three distinct groups—brackish, inner coastal, and outer coastal. ANOSIM revealed significant differences between inner and outer coastal groups, driven primarily by the distribution of sand eel and mud eel.

Benthic Animals

Shin and Koh surveyed polychaete communities seasonally at 10 sites in Gwangyang Bay from July 1987 to April 1988 using a van Veen grab. By comparing with 1982 data (pre-reclamation), they documented significant anthropogenic impacts [56]. A total of 79 polychaete species were identified, with an average density of 520 ind.·m^{-2}. Lumbrineris longifolia, Nephtys polybranchia, and Sternaspis scutata were dominant. Formerly abundant species such as Lagis bocki and Chone teres had nearly disappeared, while L. longifolia and S. scutata increased. In the western inner bay, L. longifolia was replaced by Tharyx sp., reflecting habitat changes due to reclamation and dredging.

Kang et al. analyzed spatiotemporal variation in polychaete communities across 24 sites from 2012 to 2013 in relation to environmental factors [57]. Correlation and principal component analyses identified salinity, sediment type, organic matter, and dissolved oxygen as key drivers. Based on these gradients, three ecological zones were delineated: Saline Water Zone (SWZ), Brackish Water Zone (BWZ), and Fresh Water Zone (FWZ), each with distinct dominant species. Seasonal changes were also observed, with L. longifolia, Prionospio cirrifera, and Tharyx sp. showing spatially segregated patterns.

Seo et al. surveyed macrobenthic communities at seven sites in the Seomjin River estuary from May 2015 to May 2016 [58]. A total of 163 species were identified, with an average density of 1,865 individuals·m^{-2} and biomass of 204 g·wet m^{-2}. Polychaetes exhibited the highest species richness and density, while Corbicula japonica dominated biomass year-round. Community composition varied with bottom salinity: Praxillella praetermissa dominated in high salinity (>30 psu), C. japonica and Hediste diadroma in low salinity (<10 psu), and Heteromastus filiformis was broadly distributed except in the most upstream site. Salinity and total organic carbon were the primary factors shaping community structure, consistently segmenting the estuary into three zones regardless of season [59].

Conclusion

This study reviewed 125 academic papers published between 1974 and 2023 on the environmental conditions of the lower Seomjin River and northern Gwangyang Bay, with a particular focus on the Seomjin River estuary. The findings were synthesized to evaluate the current status of the estuarine environment and to identify key management tasks for its improvement.

A density front forms at the Seomjin River estuary where freshwater meets seawater from Gwangyang Bay; however, the location of the hydrological estuary—defined by a density Froude number of 1.0—does not always coincide with the geographical estuary. Dredging of the estuarine sandbar has increased the tidal range in Gwangyang Bay, thereby altering its hydrodynamic regime. Approximately 81% (97.4 $m^3 \cdot s^{-1}$) of the river's annual average freshwater discharge (120 $m^3 \cdot s^{-1}$) flows into southern Yeosu Bay, while around 21.1 $m^3 \cdot s^{-1}$ flows into eastern Jinju Bay.

Phytoplankton production is the primary factor controlling the distribution of particulate organic matter (POM) in the estuary. While nitrate and silicate are mainly supplied via riverine input, phosphate originates largely from Gwangyang Bay, likely introduced through industrial point sources. Thus, nitrogen inputs are predominantly fluvial, whereas phosphorus is of marine or anthropogenic origin. The abundant silicate supply supports the maintenance of a diatom-dominated ecosystem in Gwangyang Bay.

Although biological processes largely regulate nutrient distribution, primary production in the estuary significantly modifies nutrient flux into the bay. Phosphorus, rather than nitrogen, appears to be the limiting nutrient for phytoplankton growth in Gwangyang Bay. Primary productivity in the estuary exhibits strong seasonal variability, ranging from 12 to 1,169 $mgC \cdot m^{-2} \cdot d^{-1}$, with peaks typically occurring after the rainy season. Nutrient fluxes are governed primarily by the concentrations of dissolved inorganic nutrients in freshwater and by discharge volume, both of which are strongly influenced by salinity. Salinity and Chl_a concentrations are the major factors affecting chemical oxygen demand (COD) in both the estuary and bay, although sedimentary organic matter also contributes.

Before the development of the POSCO industrial complex, fine sediments were concentrated west of the Seomjin River delta. However, dredging and land reclamation have since altered sediment distribution to an east–west orientation and have weakened seawater exchange. Suspended sediments, primarily composed of clay from external sources, have increased sediment fineness throughout the estuary and bay. Pollutants such as di-butyl phthalate (DBP), di-2-ethylhexyl phthalate (DEHP), and bisphenol A (BPA) have been frequently detected in both seawater and sediments, indicating ongoing pollutant transport via Seomjin River inflow.

Phytoplankton abundance ranged from 183 to 833 $cells \cdot ml^{-1}$. Zooplankton species composition and distribution varied according to salinity, which could be classified into low (<5 psu), medium (5–18 psu), and high (>18 psu) zones, or grouped by taxonomic categories such as copepods, crustaceans, and luminous species. Dominant fish species included Pennahia argentata and Nuchequula nuchalis. Fish communities were categorized into brackish, inner coastal, and outer coastal zones, reflecting patterns similar to those observed in zooplankton distribution.

The benthic polychaete community also underwent significant changes following POSCO development. Dominant species in 1982, such as Lagis bocki and Chone teres, were nearly replaced by Lumbrineris longifolia, Nephtys polybranchia, Terebellides horikoshii, and Sternaspis scutata by 1987. Polychaete communities were delineated into marine, brackish, and freshwater zones, with salinity, sediment type, and organic matter content identified as key environmental drivers. These spatial patterns closely matched those observed for zooplankton and fish communities.

In summary, salinity emerged as the dominant factor influencing biological communities in the Seomjin River estuary. Estuarine primary production alters nutrient fluxes into Gwangyang Bay, which are further regulated by freshwater nutrient concentrations and discharge volume. During flood events, Seomjin River freshwater can influence the entire Gwangyang Bay area, extending its impact to Yeosu Bay and effectively transforming the system into a sub-estuarine environment.

Given the high concentrations of harmful substances detected in both the estuary and Gwangyang Bay, improving upstream water quality is critical for enhancing the bay's ecological health. Establishing a continuous water quality monitoring system equipped with real-time sensors is strongly recommended for the estuary. Furthermore, due to historical dredging and land reclamation activities, weakened seawater circulation has hindered pollutant dispersion and contributed to the alteration of benthic ecosystems. Therefore, a comprehensive pollutant discharge monitoring and management system is urgently needed for Gwangyang Bay.

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