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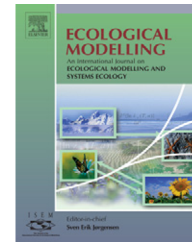

An estimation of net ecosystem metabolism and net denitrification of the Seto Inland Sea, Japan

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ABSTRACT

Net ecosystem metabolism (NEM) and net denitrification (ND) of the Seto Inland Sea were estimated from monthly budgets of dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) according to the method proposed by the Land Ocean Interaction in the Coastal Zones (LOICZ) Working Group. In the model, the Seto Inland Sea was separated into 16 boxes in terms of geographic features (eight regions) and was vertically stratified into two layers. Monthly computation of the DIP budget revealed that the regional characteristics of each strait and basin reflected the hydrography, geography and vegetation of each box. The amount of particulate phosphorus (PP) formed from DIP was estimated to be 12.2 t P year^{-1}, which accounted for 99.6% of the total DIP load. This indicates that the Seto Inland Sea is a very efficient system in terms of the transfer efficiency of material. By converting the amount of formed PP to carbon, the NEM of the Seto Inland Sea was estimated to be 0.08 g C m^{-2} day^{-1} (0.47 Mt C year^{-1} for the whole area), which accounted for about 12% of the reported primary production. The net denitrification of the Seto Inland Sea was estimated from the difference between the DIP budget and the DIN budget. Particulate nitrogen formed from DIN was ca. 50% (88×10^3 t N year^{-1}), and the remaining 50% was estimated to be released to the air by the denitrification process.

1. Introduction

There are several conventional methods that have been used for the in situ direct measurement of primary production and denitrification. However, these methods are highly subjected to weather conditions, particularly light intensity (Platt, 1975a,b; Yamamoto et al., 1994), and thus the time of day at measurement. Since the fluctuation in environmental conditions is severe, particularly in estuaries, the reliability of the monthly average or annual average estimated from these discrete measurement values would be low. The frequency of measurements therefore has to be increased to obtain reliable values both spatially and temporally.

An alternative sophisticated method is recommended for the simultaneous estimation of net ecosystem metabolism (NEM) and net denitrification (ND) from budgets of phosphorus and nitrogen by the Land Ocean Interaction in the Coastal Zone (LOICZ) Working Group (Gordon et al., 1996). In the method, the increase/decrease in phosphorus and/or nitrogen in the targeted area (box) is assumed to be governed by both physical transportation processes in the targeted area (box) and the neighboring area (box), and biological transforming processes such as primary production and respiration/decomposition. Finally, carbon-based NEM and ND are estimated stoichiometrically from the phosphorus/nitrogen-based budgets assuming the Redfield ratio (mean C/N/P ratio of plankton; Redfield, 1934). The Seto Inland Sea is the largest

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semi-enclosed coastal sea (ca. 23 000 km^2) in Japan, connected to the Pacific Ocean through two main channels (Environment Agency of Japan, 1993). The inner inland sea is divided by narrow straits into several regions such as bays and nadas. A nada is a stagnant small basin with both ends of the basin connected to the neighboring regions through tidally mixed straits. Therefore, the Seto Inland Sea is an inlet which basically forms a strait–basin system (Fujiwara and Nakata, 1991). In addition to the straits, numerous islands (ca. 1000) make water exchange in the inner area difficult. Furthermore, the loads of eutrophic substances such as nitrogen and phosphorus from the land are high due to industrialization and urbanization along the coast. However, the social and economic factors that have been in play in this area along with the natural characteristics of the Seto Inland Sea mentioned above have resulted in the Seto Inland Sea being highly productive (Hashimoto et al., 1997b).

In this regard, the Seto Inland Sea is the most challenging estuary in Japan in terms of applying a budget approach because of its spatial size. In this area, administrative-guided routine monitorings have been made for the water body and tributary areas. The objectives of the present study are to estimate the NEM and ND of the Seto Inland Sea by the LOICZ recommended method using the available data sets.

2. Materials and methods

The net ecosystem metabolism and net denitrification of the Seto Inland Sea were estimated from monthly budgets of dissolved inorganic phosphorus (DIP) and dissolved inorganic nitrogen (DIN) according to the method proposed by the Land Ocean Interaction in the Coastal Zone Working Group (Gordon et al., 1996). According to geographical configurations (Fig. 1; Table 1), the Seto Inland Sea was separated into eight regions; from east to west, Osaka Bay, Harima Nada, Bisan Seto, Hiuchi Nada, Hiroshima Bay, Aki Nada, Suo Nada, and Iyo Nada. Naruto Strait, which connects Harima Nada and the Kii Channel, was included because of the significant effect on the residence time of materials in the Seto Inland Sea (Takeoka, 1991). However, Kanmon Strait, which is located at the western end of Suo Nada, was not included in our model because it has a negligible water exchange due to its narrow waterway (Murakami et al., 1985). Kii and Bungo Channels were considered boundary regions. Computations were carried out for a year, from April 1991 to March 1992. Judging from the vertical profiles with thermocline around a 10 m depth in both Harima Nada and Hiuchi Nada, where the water column is typically stratified in summer (Yanagi et al., 1985), a two-layer box model (upper layer was the surface to 10 m) was applied for the entire year.

2.1. Estimation of water exchange

Assuming that the physical transportation process was represented by diffusion, horizontal and vertical dispersion coefficients were estimated by calculating salt budgets using the published data on precipitation, riverine freshwater discharge and salinity in the area. For the stratified season, the

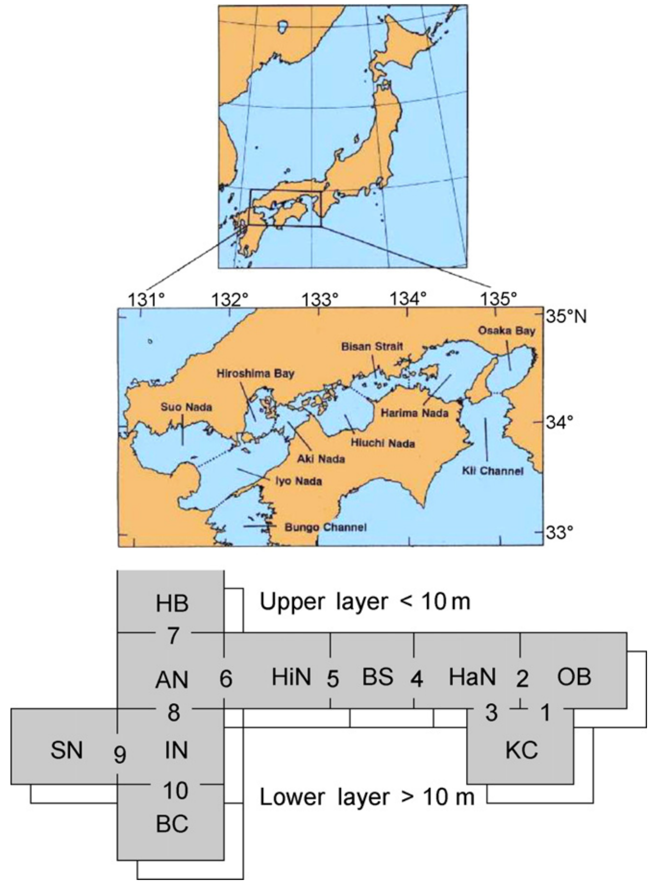

Fig. 1 – Map showing the location of the Seto Inland Sea, Japan (upper panel), geographical demarcation of regions (middle), and their arrangement image for the model of the present study (lower).

change in salinity in the upper layer box and that in the lower layer box of a given region are expressed by the following equation,

$$V\left(\frac{\partial S}{\partial t}\right) = \sum k\left(\frac{\partial S}{\partial x}\right)A - (Q_R + Q_P - Q_E)S \quad (1)$$

where, V: volume of the box (m^3), S: the average salinity in the box (psu), t: time (s), x: distance from the center of the box to that of the neighboring box (m), K: horizontal dispersion coefficient (Kx) or vertical dispersion coefficient (Kz) (m^2 s^{-1}), A: cross-sectional area of the interface between boxes (m^2), Q_R: riverine freshwater inflow (m^3 s^{-1}), Q_P: precipitation (m^3 s^{-1}), Q_E: evaporation (m^3 s^{-1}).

The salinity of the following month was calculated by changing Kz from 0.01 to 5.0×10^3 m^2 s^{-1}, and Kz from 0.01 to 1.0×10^{-3} m^2 s^{-1} with a time step of 600 s. Then, Kx and Kz were determined by iteration so that the salinity difference between the calculated value and measured value became minimum for all boxes. The calculation was carried out for every month using the measured value as the initial value.

From unpublished data records on shallow sea conditions observed at 77 stations distributed in the entire area, data