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Impacts of oyster cultures on nitrogen budgets in Hiroshima Bay, the Seto Inland Sea of Japan

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Abstract The impact of oyster culture on the nitrogen budget was demonstrated for the northern Hiroshima Bay. The output from a simple two-layer box model and nitrogen measurements in the bay over a 1 year period were used to estimate the nitrogen budget in the northern Hiroshima Bay (NH). The annual dissolved inorganic nitrogen (DIN) budgets indicated that all input terms to the northern Hiroshima Bay were equivalent to 22±7.8 ton N d^{-1}, whereas DIN export to the central part of the bay was equivalent to 14±13 ton N d^{-1}. These results suggest that a significant part of DIN input is consumed by phytoplankton and converted into the particulate form in the NH region. Estimated filtration rates of cultured oysters (7.3 ton N d^{-1}) suggested that oyster cultures play a significant role for removing the particulate N from the water column in Hiroshima Bay. In addition, the amount of nitrogen harvested as oyster products was about 0.66 ton N d^{-1}, which is about 6% of daily terrestrial DIN input into the NH region. The removal rate through oyster harvesting is five times higher than that by fishing activities, suggesting that oyster culture plays a significant role on the recycling of nitrogen from Hiroshima Bay to the land.

Key words: environmental impacts, Hiroshima Bay, nitrogen budgets, oyster cultures

Bivalve aquaculture has some additional function other than food production, and can have a variety of effects on coastal and estuarine ecosystems. For example, bivalves filter suspended particle matter, both living and detrital, in the water column. It has been suggested that the grazing activity of bivalve populations controls phytoplankton dynamics on the scale of entire embayments (Cloern 1982). High rates of organic biodeposition near aquaculture sites have been shown to result in anaerobic benthic environments (e.g. Hatcher *et al.* 1994), and change the benthos community (e.g. Crawford *et al.* 2003). Harvesting activities can remove nutrients such as nitrogen and phosphorus from coastal and estuarine areas (e.g. Songsangjinda *et al.* 2000). As such, bivalve aquaculture can significantly alter material and energy flows in coastal and estuarine ecosystems.

Hiroshima Bay is located in the western part of the Seto Inland Sea of Japan, having a surface area of ca. 1,000km^2 and a mean depth of ca. 25m (Fig. 1). The annual oyster production in the bay is 15,000-30,000 tons, which accounts for about 60-70% of oyster production in Japan. A method of hanging oysters under a floating raft with a size of 20×10m has been used for oyster culture in the bay. A large number of floating rafts can lead us into a belief that oyster cultures have some impact on the ecosystem of Hiroshima Bay.

The objectives of this study were twofold. First, I wished to construct a nitrogen budget for Hiroshima Bay, based on the field observations and a simple box model analysis. My second objective was to examine filtering activity of phytoplankton particulate nitrogen by cultured oysters and removal efficiency of nitrogen from the bay by oyster harvesting. The results and discussions of this study will be elaborated in detail elsewhere, and briefly

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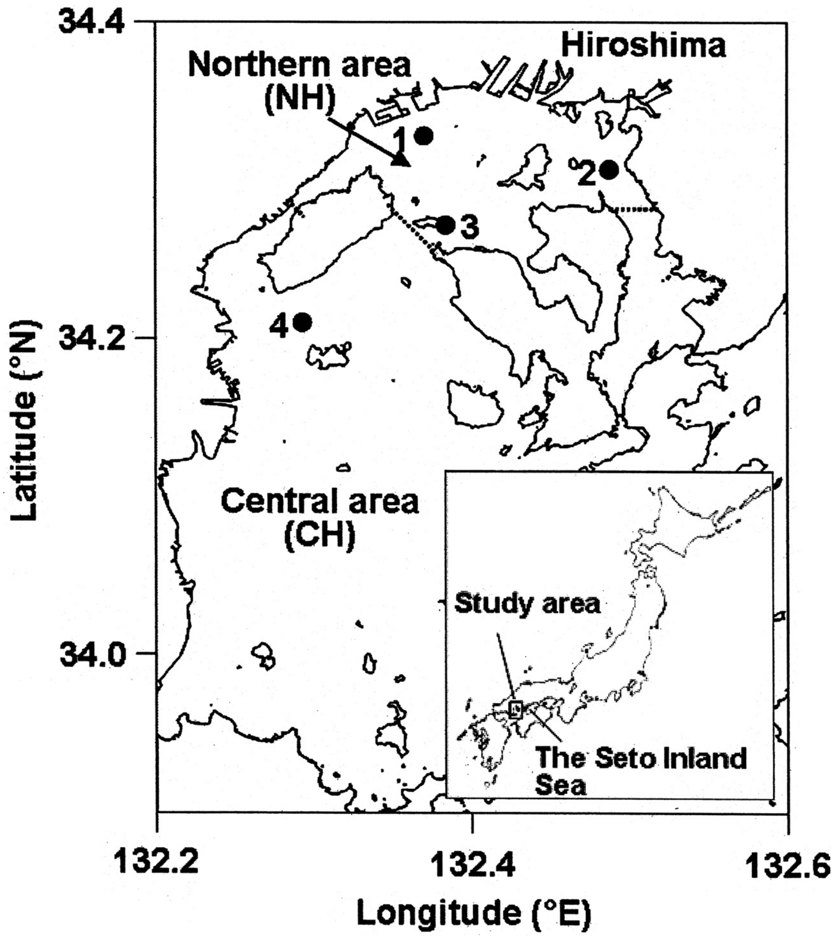

Fig. 1. Study area and sampling stations in Hiroshima Bay. Box dimensions for the model analysis are also given.

outlined here.

Nitrogen budgets in the northern part of Hiroshima Bay

A simple box model was used to characterize the residual circulation in the bay and then to estimate the nitrogen budgets in the northern part of Hiroshima Bay. Hiroshima Bay was divided into two adjacent boxes, northern Hiroshima Bay (NH) and central Hiroshima Bay (CH), depending on the hydrological characteristics (Fig. 1). On the basis of a two layered circulation pattern, each box was segmented into two layers separated by a zero-velocity level which was fixed at 5m depth (Fig. 2). Assuming that the volume of each box remains constant over time scales greater than 1 tidal cycle, the following relationships can be described for the budget of salinity in each box

$$Q_f + Q_{21} - Q_{13} = 0$$

$$V_1 \frac{dS_1}{dt} = S_2 Q_{21} + D_{12} (S_2 - S_1) - S_1 Q_{13}$$

$$Q_{42} - Q_{21} = 0$$

$$V_2 \frac{dS_2}{dt} = -S_2 Q_{21} + D_{12} (S_1 - S_2) - S_4 Q_{42}$$

where Q_f is the freshwater inflow, Q_{ij} is the transfer coefficient from Box-i to Box-j, D_{12} is the vertical mixing between Box-1 and Box-2, V_1 and V_2 are the volume of Box-1 and Box-2, respectively, and S_i are

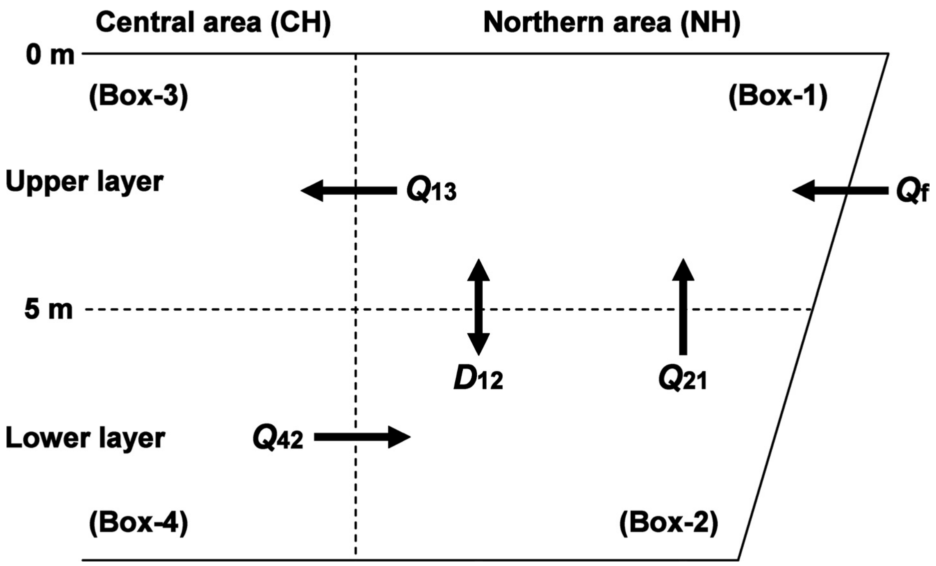

Fig. 2. Schematic diagram for the box model used in this study. Q_f, Q_{ij} and D_{12} represent the freshwater inflow, the transfer coefficient from Box-i to Box-j and the vertical mixing between Box-1 and Box-2, respectively.

the averaged salinity in Box-i. Q_f was calculated as the sum of the discharge from the Ohta River and sewage treatment plants, precipitation and evaporation. Dissolved inorganic nitrogen (DIN) fluxes in the NH region of Hiroshima Bay were estimated from the output of the box model combined with measurements of DIN in the river, the sewages and the bay.

Monthly measurements of water temperature, salinity and DIN concentration were made from Apr 2001 through March 2002 at 3 stations in NH region and one station in CH region (Fig. 1). The Ohta River discharge and DIN concentration in the river were obtained from the River Bureau, Ministry of Land, Infrastructure and Transport, Japan and the Hiroshima Prefecture Environmental Bureau, respectively. The sewage discharge and DIN concentration data were provided by the Hiroshima City Sewage Bureau. Rainfall data was obtained from the Hiroshima Meteorological Local Observatory. Evaporation was calculated from an empirical relationship based on wind velocity and vapor pressure.

During the stratified season (April to August), the Ohta River and sewage treatment plants supplied 4.2 ± 2.5 and 6.3 ± 1.3 ton N d^{-1} of DIN, respectively, to the NH region (Fig. 3A). DIN export to the CH region was 3.7 ± 1.3 ton N d^{-1}, significantly lower than a sum of DIN input from the river, sewage and the CH regions (5.2 ± 2.0 ton N d^{-1}). River and sewage DIN inputs to the NH region were 3.7 ± 1.7 and 6.4 ± 0.8 ton N d^{-1}, respectively, during the vertically mixed season (September to March), similar to those during the stratified season (Fig. 3B). On the other hand, DIN export to the CH region (22 ± 12 ton N d^{-1}) was significantly greater than that during the stratified season.

The average terrestrial DIN input during the study period was 10 ± 2.6 ton N d^{-1}. Based on the data during April 1996 to March 1997, Lee and Hoshika (2000) estimated the combined river and sewage DIN inputs to the NH region to be 327 ton N $month^{-1}$ (11 ton N d^{-1}) which was similar to the estimate made by the present study. The annual DIN budget (Fig. 3C) indicated that all input terms combined river, sewage and the CH region, to the NH region were equivalent to 22 ± 7.8 ton N d^{-1}. On the other hand, DIN export to the CH region was equivalent to 14 ± 13 ton N d^{-1}. These results suggest that a significant part of DIN input is consumed by phytoplankton and converted into the particulate form in the NH region, especially in

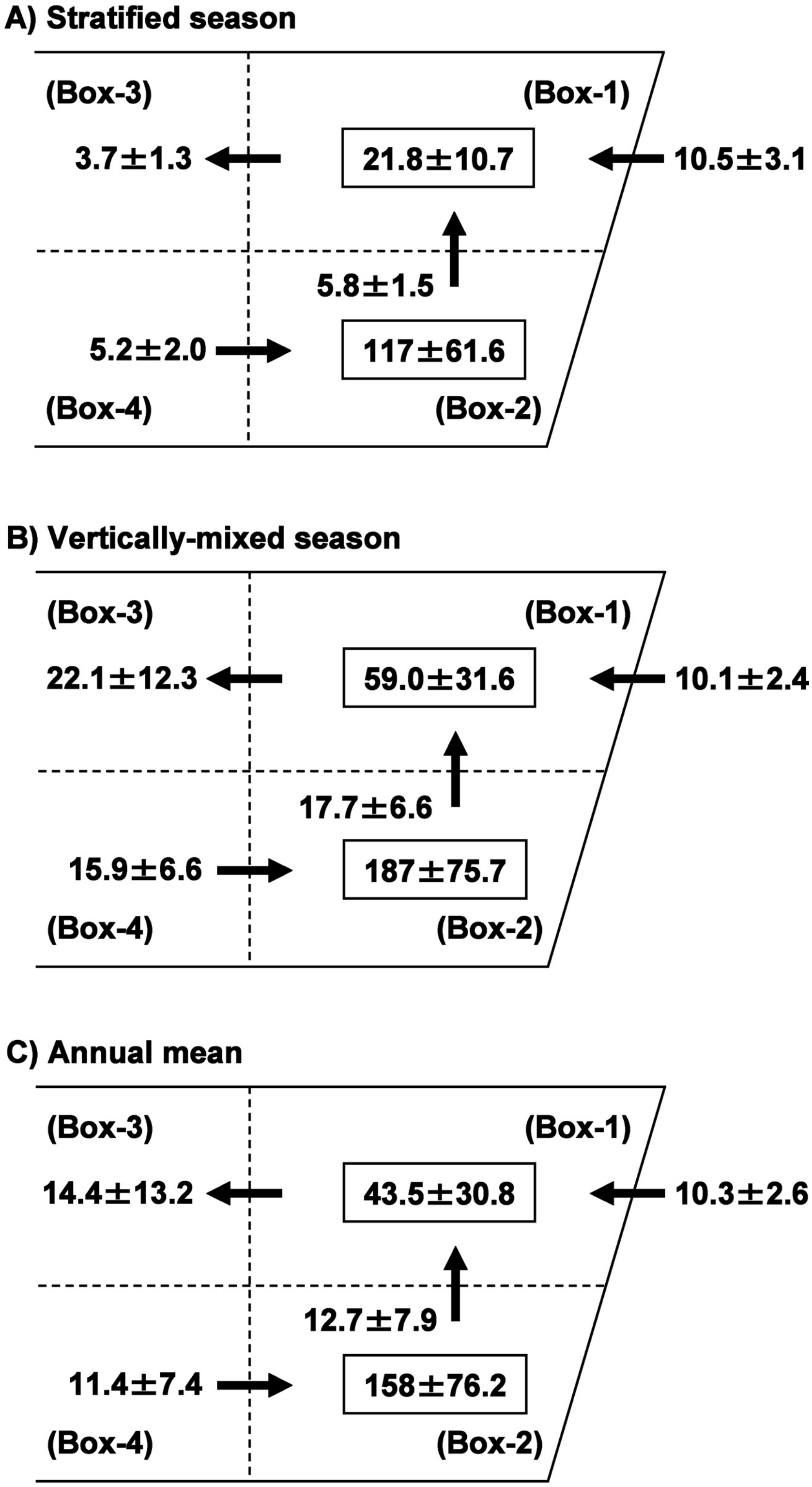

Fig. 3. DIN budget in the northern Hiroshima Bay. A) stratified season (April to August 2001), B) vertically mixed season (September 2001 to March 2002), and C) annual mean during April 2001 to March 2002. Arrows represent mean fluxes (±1 SE) in ton N d^{-1}. Values within square represent mean standing stocks (±1 SE) in ton N.

the upper layer. Phytoplankton productivity in the NH region of Hiroshima Bay was measured at the same time as nutrient samples were collected for this analysis. High phytoplankton nitrogen demand (228 mg N $m^{-2} d^{-1}$), which estimated from annual carbon productivity with the Redfield ratio (Redfield 1958), strongly supports the suggestion driven from the box model analysis.

Filtering activity of phytoplankton particulate nitrogen by oyster cultures

The grazing activity of oyster cultures was determined from the filtration rate and the ambient phytoplankton biomass. In the present study, oyster filtration rate was estimated as a function of total oyster biomass and water temperature (Chapelle et al. 2000). The monthly cultured oyster biomass was estimated by working backward from the harvest with first-order approximation for two year of cultivation period.

On an annual basis, Chl. *a* loss through oyster grazing was estimated to be 0.83 ton Chl. *a* d^{-1}, corresponding to be 7.3 ton N d^{-1} with a phytoplankton C: N ratio of 5.7 and a C: Chl. *a* ratio of 50: 1. This result suggests that an average 20% of the phytoplankton production (36 ton N d^{-1}) is consumed by cultured oysters in the NH region of Hiroshima Bay.

Micro- and macro-zooplankton are generally principle consumers for phytoplankton community. Extrapolating from the biomass data measured during the same study period in accordance with Uye et al. (1996) and Uye and Shimazu (1997), annual grazing rates of micro- and macro-zooplankton were estimated to be 2.4 and 4.0 ton N d^{-1}, respectively in the NH region (unpublished data). Therefore, oyster grazing accounts for 53% of daily phytoplankton nitrogen loss, suggesting that oyster cultures play a significant role for removing the particulate N from the water column in Hiroshima Bay.

Removal efficiency of nitrogen from Hiroshima Bay by oyster cultures

Annual oyster production in Hiroshima Bay was about 19,500 ton during April 2001 to March 2002. Given that the nitrogen content of cultured oyster was account for 1.24% of fresh meat wet weight production (Whyte and Englar 1982), the nitrogen removal rate through oyster harvesting was estimated to be 0.66 ton N d^{-1}. On an annual basis, this rate is account for 6.4% of daily terrestrial DIN input into the NH region. On the other hand, the nitrogen removal rate through fisheries was estimated to be 0.15 ton N d^{-1}, from annual catches of 5,030 ton with fish nitrogen composition of, indicating that oyster cultures recycled nitrogen to terrestrial areas in quantities approximately 5-fold greater than fisheries in Hiroshima Bay.

Conclusion

In summary, the present study has shown that oyster cultures have a significant impact on the nitrogen cycles in Hiroshima Bay in terms of removing the particulate matter and nitrogen from the water column. These results suggest that oyster cultures could be used as a possible tool for suppressing eutrophication in addition to their primary function of food production. However, large oyster populations can lead to a variety of negative effects on the benthic ecosystems. Therefore, appropriate management of oyster cultures is necessary for beneficially operating their removal efficiency of nitrogen.

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