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Environmental and biogeochemical changes following a decade's reclamation in the Dapeng (Tapong) Bay, southwestern Taiwan

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ABSTRACT

This study examines the environmental and biogeochemical changes in Dapeng (formerly spelled Tapong) Bay, a semi-enclosed coastal lagoon in southwestern Taiwan, after two major reclamation works performed between 1999 and 2010. The lagoon was largely occupied by oyster culture racks and fish farming cages before December, 2002. Substantial external inputs of nutrients and organic carbon and the fairly long water exchange time (τ) (10 ± 2 days) caused the lagoon to enter a eutrophic state, particularly at the inner lagoon, which directly received nutrient inputs. However, the entire lagoon showed autotrophic, and the estimated net ecosystem production (NEP) during the first stage was 5.8 mol C m^{-2} yr^{-1}. After January, 2003, the aquaculture structures were completely removed, and the τ decreased to 6 ± 2 days. The annual mean concentrations of dissolved oxygen increased, and nutrients decreased substantially, likely due to improved water exchange, absence of feeding and increased biological utilization. The NEP increased 37% to 7.7 mol C m^{-2} yr^{-1} after structure removal. The second reclamation work beginning from July, 2006, focused on establishing artificial wetlands for wastewater treatment and on dredging bottom sediment. Although the τ did not change significantly (8 ± 3 days), substantial decreases in nutrient concentrations and dissolved organic matter continued. The NEP (14.3 mol C m^{-2} yr^{-1}) increased 85% compared to that in the second stage. The data suggest that the reclamations substantially improved water quality, carbon and nutrient biogeochemical processes and budgets in this semi-enclosed ecosystem.

1. Introduction

Dapeng (formerly spelled Tapong) Bay is a tropical and choked-type lagoon located on the southwestern coast of Taiwan. During several decades of intensive aquaculture before 2003, the lagoon was occupied largely by oyster culture racks and caged fishery structures. The lagoon ecosystem has undergone eutrophication due to poor circulation and continuous inputs of nutrients and organic matter from internal and external sources, as the lagoon was also surrounded by watersheds that were intensively used for urban and aquaculture purposes (Hung and Hung, 2003; Hung et al., 2003a). Cultured oysters and fishes may have also released nutrients into the lagoon via recycling from excretion (Souchu et al., 2001) and remineralization of feces and pseudofeces (Reusch and Williams, 1998). In the past decade, the Taiwan government has begun planning the development of Dapeng Bay as a central part of the National Scenic and Recreational Park. Hence, governmental agents began taking action to clean up the lagoon-associated environments. The first step was the complete removal of aquaculture structures from the lagoon in January, 2003.

Although the lagoon remained in a eutrophic state after structure removal, the water exchange time decreased from about 10 days to about 6 days in the periods before and after removal, respectively (Hung et al., 2008). The mean salinity of the lagoon water therefore increased, and biogeochemical and ecological conditions changed substantially. The cultured oysters were totally removed, and rack-associated periphytons eventually vanished after the structure removal (Hung et al., 2008). However, the external inputs of nutrients and organic matter continued and improvement of water condition progressed slowly. For efficient improvement in water quality, the second step of environmental improvement beginning in 2006 focused on watershed reclamation and bottom sediment dredging. The second-stage improvement introduced external wastewater into multiple wetland sites constructed around the lagoon before discharging into the lagoon. Studies show that artificial wetlands can efficiently reduce nutrient levels in

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polluted waters (Jing et al., 2001; Lin et al., 2005). In addition to the dredging activity, the tidal inlet was also slightly modified in an attempt to improve water exchange conditions as well. Thus, this study aims at understanding the biogeochemical and ecosystem responses to two major environmental reclamations during a decade's experiment in a human influenced and semi-enclosed lagoon.

2. Materials and methods

2.1. Study site

The Dapeng Bay is a small and semi-enclosed coastal lagoon in southwestern Taiwan (22°27′N, 120°26′E) (Fig. 1) with a total area of 5.32 km^2 and a volume of approximately 11.6×10^6 m^3. The depth ranges from 1 m near the tidal inlet to 6 m in the inner bay with a mean depth of 2.2 m before dredging. Water exchange between Dapeng Bay and Taiwan Strait is driven primarily by a semi-diurnal dominated tide, which is somewhat restricted by exchanging water through a narrow tidal inlet. In addition to direct input of precipitation, the terrestrial water input via the Lipan Dike is derived mainly from urban and aquaculture wastewater with a moderate salinity ($S < 20$). The lagoon was farmed extensively with hanged oysters and caged fishes (Fig. 2a), but all aquaculture structures were completely removed around January 2003 (Fig. 2b). Since 2006, many individual wetland systems have been constructed for wastewater treatment before discharging into the lagoon (Fig. 2c).

2.2. Sampling and analytical methods

Water samples were collected from Dapeng Bay (Sta. 1 ~ Sta. 10, Fig. 1), Lipan Dike, and the adjacent coastal sea during three periods. The first period (from August 1999 to July 2002) and second period (from February 2003 to September 2004) were associated with before and after removal of the aquaculture structures, respectively. The third-period samplings after wetland construction were performed from August 2009 to June 2010. Samples were taken bi-monthly or quarterly throughout the study period. Water samples were collected from upper, middle and bottom layers using a peristaltic pump and a pre-cleaned silicone tube. Dissolved oxygen (DO) was measured *in situ* with a portable DO meter (YSI 52) calibrated by the method of direct spectrophotometry of total iodine (Pai et al., 1993). The reproducibility was better than 3%. Water column pH was measured *in situ* with a portable pH meter (Mettler MP-120) with reproducibility better than ±0.02. Salinity was determined with an Autosal salinometer (Guildine 8400B) in the laboratory to gain accuracy (±0.002) against the recognized standard seawater for deriving salt and water budgets. Chlorophyll *a* (Chl-a) samples were collected *in situ* by filtering 100 ml water through GF/F filters that were frozen in the dark condition as short as possible before analyses in the laboratory. Another four liters of each sample were stored in a polyethylene bottle and brought back to the laboratory immediately for further quantitative filtration and analyses.

A part of each water sample was filtered through pre-combusted GF/F filters (at 450 °C, 4 h). The filtered water was used to measure dissolved nutrients, dissolved organic carbon (DOC), nitrogen (DON) and phosphorus (DOP). Three replicate measurements were made for each chemical analysis. Dissolved inorganic nitrogen ($NO_3 + NO_2 + NH_4$, hereafter DIN), phosphate (PO_4^{3-}, hereafter DIP) and silicate (H_4SiO_4, hereafter Dsi) were determined colorimetrically (Grasshoff et al., 1983) equipped with a flow injection analysis. Recovery of spiked nutrients in oligotrophic Kuroshio surface water was better than 95%. DOC was measured by the high temperature catalytic oxidation method (Shimadzu TOC 5000) (Hung et al., 2003b, 2007) with accuracy better than 4% against reference materials (41–44 μM C) provided by Dr. D. A. Hansell from the University of Miami. DON was determined from the difference between total dissolved nitrogen (TDN) and dissolved inorganic nitrogen. TDN was measured with the high temperature oxidation and chemiluminescent detection (Antek N/S analyzer), and the relative error was <6% against Hansell's reference. DOP was determined from the difference between dissolved inorganic phosphate and total dissolved phosphorus (TDP) that was measured by the UV-persulfate oxidation and colorimetric method (Ridal and Moore, 1990). Reproducibility of TDP measurement in seawater ($n = 8$) was ±7%.

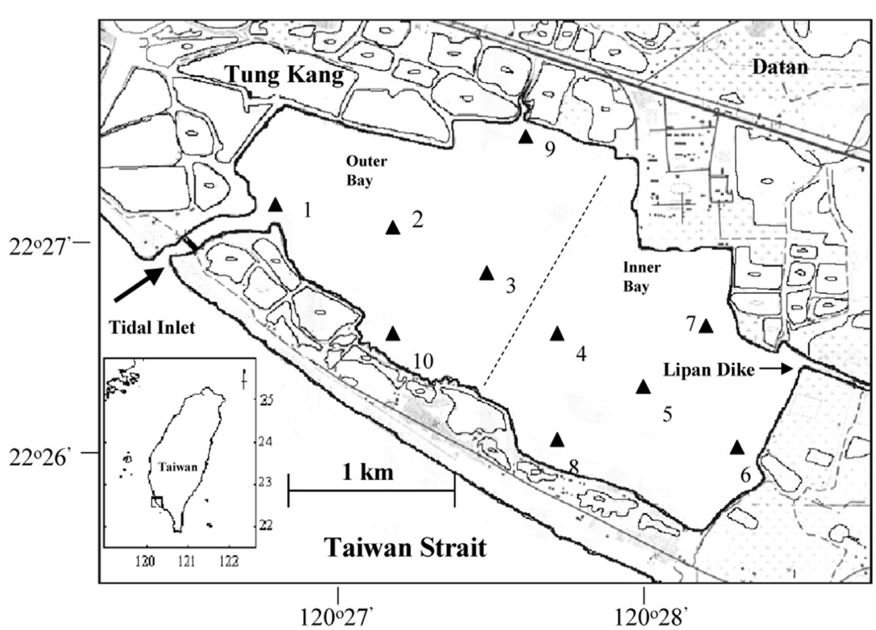

Fig. 1. Locations and sampling sites of Dapeng Bay. The dashed line indicates the boundary between the inner and outer lagoons.