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Ecological effects of artificial reefs in Daya Bay of China observed from satellite and *in situ* measurements

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Abstract

Fishery resources along China's coasts have been declining. Could those decline be alleviated by deploying artificial reefs (ARs) in suitable areas? This study investigates effects of a big project conducted in December 2007 that deployed ARs in the southwestern part of Daya Bay. The ARs cover a total dimension of $966.10 \times 2850.60\ m^2$ and surface area of 91,500 m^2. This study analyzed the spatial and temporal variations of ecological factors, including Chlorophyll a concentrations (Chl-a), nutrients, attaching organisms and nekton resources, on and around the ARs using both satellite (Moderate Resolution Imaging Spectroradiometer, MODIS) and *in situ* data. Results showed that the potential affected area of ARs in Daya Bay reached a distance of 4.9 km in the water depth of 12.0–15.2 m. In the study area, Chl-a level reached 2.93 mg m^{-2} during the post-AR period (2008–2012), that was higher than the pre-AR period (2002–2007) (2.37 mg m^{-2}). Nekton biomass increased by 4.66–16.22 times compared with that in the pre-AR survey, and the species diversity increased by 15%–23%. This parallel trend suggested that ARs might have contribution to the increase in nekton biomass. Long-term observations shall be conducted to understand the response of phytoplankton to ARs.
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Keywords: Ecological effects; Artificial reefs; Remote sensing; Daya Bay, China

1. Introduction

Daya Bay is located at the northern part of South China Sea (SCS; Fig. 1A). The bay is shallow and semi-enclosed between 22°30′–22°50′N and 114°30′–114°50′E. It encompasses an area of approximately 600 km^2 with an irregular coastline, and the bay area has more than 50 islands (Xu, 1989). Daya Bay was one of the major aquaculture areas in Guangdong province because of the excellent water quality and rich biological resources. However, economic developments around the area has expanded rapidly in the past decades; the local permanent population doubled, and industries and establishments, such as nuclear power plants (with thermal discharge), petrochemical, printing, harbor, and tourism, expanded (Yu et al., 2007b, 2010). Along with such economic expansions, the water quality of Daya Bay has deteriorated, and the occurrence of harmful algal bloom has become more frequent (Hao and Tang,

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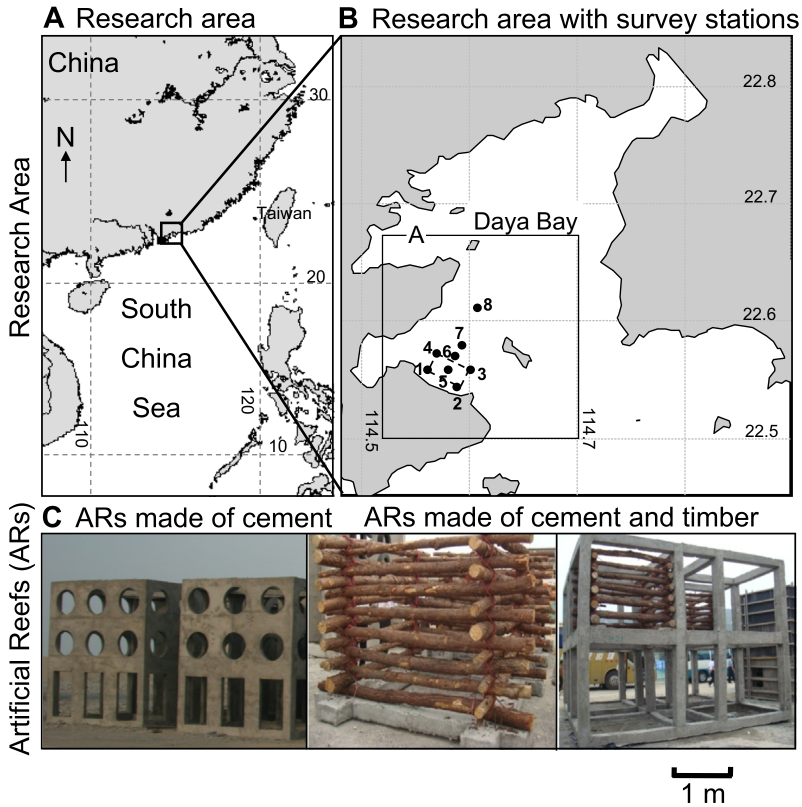

Fig. 1. Research area. (A) Location of Daya Bay. (B) Daya Bay map with the location of the ARs. The small box with dashed lines indicates the area of AR deployment. Box A shows the sample area of the satellite remote sensing data source. Black dots represent the eight survey stations. (C) Pictures of ARs deployed in Daya Bay.

2010; Hao et al., 2012; Song et al., 2009; Yu et al., 2007a). Overfishing aggravates the decrease in fish stock, and increasing bottom trawling operations accelerates seabed desertification and destroys the natural habitats of marine organisms in Daya Bay (Jia and Zhuang, 2009; Wang et al., 2010). The number of fish species declined significantly, and the dominant species shifted from high-value fishes such as hairtail and pomfret in the 1980s, to low-value fishes such as sardine, anchovy, and juvenile porgy at present times (Wang et al., 2010).

Therefore, immediate measures must be implemented to protect the environment and increase the fishery resources in Daya Bay. Artificial reefs (ARs) have been utilized for different purposes in coastal management, including increasing fish abundance and diversity (Tsumura et al., 1999), recreational diving (Ditton et al., 1999), and trawling prevention (Relini, 2000). The entire AR program in the Gulf of Mexico is driven by fisheries (Addis et al., 2013), and the increase in fish around the ARs placed in the Gulf of Mexico has been well recognized and documented. Similarly, Fish Aggregating Devices (FAD) are an ancestral fishing practice that are known to locally increase local fish biomass through the attraction of fish. However, the potential benefits of ARs are recognized. Generally, ARs are poorly understood in terms of the extent to which they change the ecological environment, increase fishery resources, and whether they have a net ecological effect.

Daya Bay provides an ideal case study for the assessment of the ecological influence of ARs in bay waters, because of its shallow water depth and semi-enclosed shape. The government of Guangdong Province designated Daya Bay as an ecological demonstration zone for ARs in 2007. Since 2000, local government agencies have invested 80 million RMB to establish 100 AR areas in Guangdong coastal waters (Wang et al., 2008, 2009a). By December 2007, 2202 AR units of cement concrete and timber with a dimension of $3 \times 3\ m^2$ have been deployed in Yangmei Cove, which is located in the southwestern part of Daya Bay (Figs. 1B and C).

Marine phytoplankton is a critical indicator of ecological conditions, due to its ecological function in primary production (Chen, 2000). Chlorophyll a concentration (Chl-a) has been evaluated as a useful indicator of phytoplankton biomass (Hao et al., 2012; Yu et al., 2007a). Satellite data have likewise been utilized for Daya Bay ecological studies (Chen et al., 2003; Tang et al., 2003; Yu et al., 2007a, 2007b, 2010). The products of Moderate Resolution Imaging Spectroradiometer (MODIS) onboard aqua satellites can provide information about Chl-a on spatial and seasonal variations, which the limited number of ship stations and surveys cannot provide (Tang et al.,

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