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Distribution characteristics of the fish assemblages to varying environmental conditions in artificial reefs of the Jeju Island, Korea

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ABSTRACT

Artificial reefs (ARs) have long been practiced to manage and enhance fisheries resources worldwide. Here, we aimed to identify relevant indicator species for the specific environmental conditions of ARs by comparing fish diversity against control sites (Conts). We used a combination of non-metric multidimensional scaling and indicator value analysis to identify the indicator species of the specific AR environments. More individuals and species of fish were present in ARs compared to Conts. Water temperature over the seasons was the most important environmental factor associated with the trophic group composition of fish. In particular, macrocarnivores and benthic invertivores/cleaners closely reflected habitat conditions in a consistent manner. Some dominant fish species were detected at all sites, while the indicator species were more predominant under certain environmental conditions. Altogether, ARs should be monitored at regular intervals to optimize management of their health by detecting the community representativeness via indicator species.

Globally, coastal ecosystems are being destroyed by various natural and anthropogenic threats, and these issues are causing the loss of economically important fisheries resources (Lundin and Linden, 1993; Jackson et al., 2001; Goudie, 2006; Worm et al., 2006; Lebata-Ramos and Doyola-Solis, 2016). As part of efforts to restore fishery resources and recover damaged coastal ecosystems, artificial reefs are often deployed on the seafloor to provide new habitats for marine organisms (Collins et al., 1990; Jensen et al., 1994; Steimle et al., 2002; Fang et al., 2013; Leitão, 2013; Lowry et al., 2014). Since 1972, artificial reefs have been gradually deployed along the coastal area of Korea, with the areas covered by such reefs expanding in the 1990s (Fig. 1). In 2004, an annual monitoring program was officially launched to manage these reefs effectively by the Korean government (Fig. 1).

The positive effects of artificial reefs on the fish community are well documented in coastal areas, and a number of studies have conducted post-deployment observations of the marine ecosystem surrounding artificial reefs. The distribution of fish assemblages surrounding artificial reefs were influenced by varying environmental conditions including seasonal variation, artificial reef effect (with or without), reef age, reef structure, bottom habitat type, reef material, and hydrological features (Bohnsack and Sutherland, 1985; Bombace et al., 1994; Fabi and Fiorentini, 1994; Godoy et al., 2002; dos Santos et al., 2010; Hackradt et al., 2011; Scott et al., 2015). However, the artificial reef effects on certain fish groups and/or species, and science-based studies in policy on the management of such reefs are also limited (Pratt, 1994; Jensen, 2002; Claudet and Pelletier, 2004). Artificial reefs do not warrant the direct enhancement of fish community at all times, and thus it is necessary to delve into finding the specific responses of fish species to artificial reefs deployment.

Many statistical techniques have been proposed and applied to interpret the relationship between environments and organisms. For example, several earlier studies have successfully applied simple and intuitive statistical methods such as non-metric multidimensional scaling (NMDS) and indicator value (IndVal) analysis proposed by Dufrêne and Legendre (1997). These methods are often utilized to address representative fish species and groups as an indicator of habitat preference, environmental change, and anthropogenic impact (Mueter and Norcross, 2002; Nobriga et al., 2005; Habit et al., 2007; Lasne et al., 2007; Penczak, 2009; Bennett and Kozak, 2016; Sirot et al., 2015).

In the present study, we collected meta-data on environmental parameters and the fish community at control sites and artificial reefs along the coastal area of the Jeju Island, Korea. Among the varying environmental variables, we specifically selected three general significant environmental conditions based on the previous findings (refer to mini-review of Table S4): water temperature as the most influential factor, artificial reef material as the vertical habitat structure, and bottom habitat type as the horizontal/base structure for inhabitants. And then,

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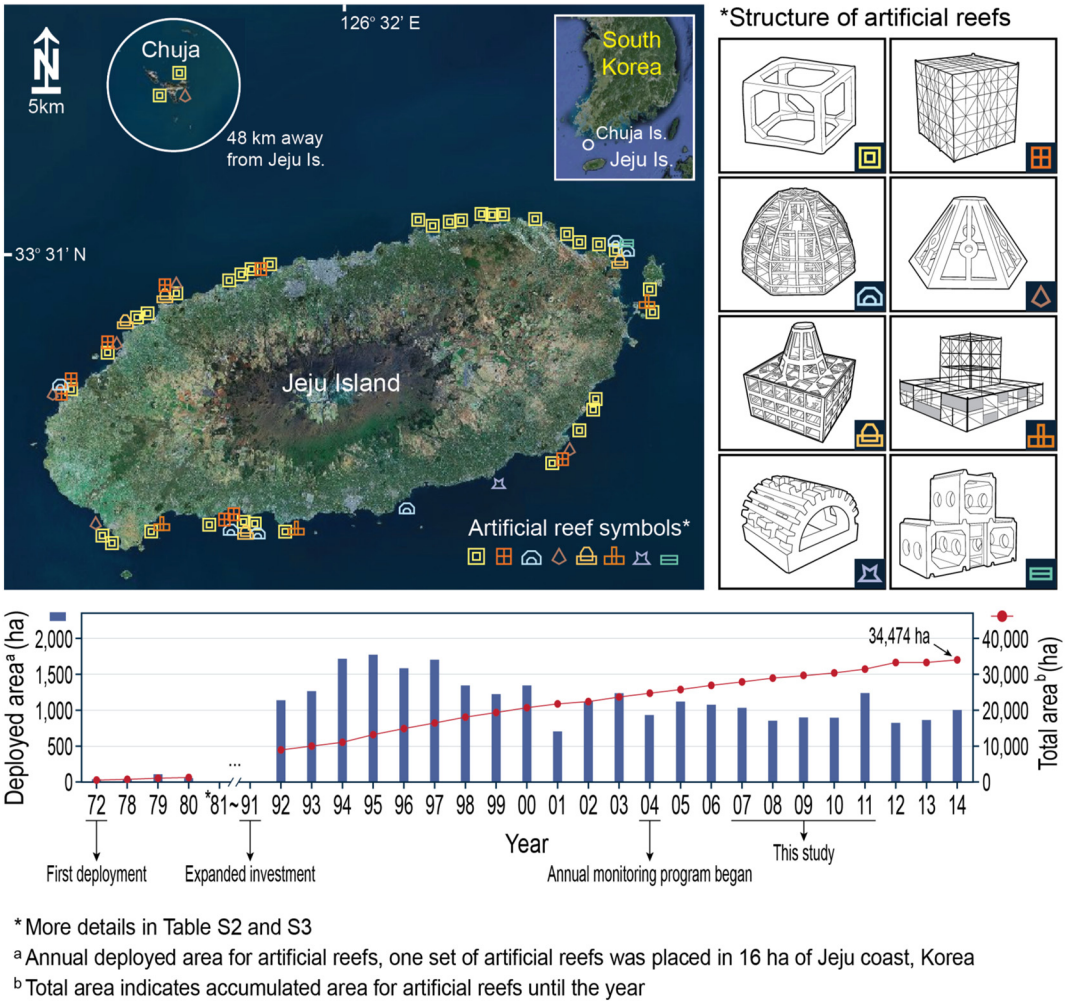

Fig. 1. Map of the study area around Jeju Island, Korea showing the sampling sites, artificial reef structure, and a brief history and of artificial reef deployment, since 1972. The meta-data analyzed in this study were collected from 5 years of monitoring surveys extending from 2007 to 2011.

the NMDS and IndVal analysis were used to characterize the relationship between artificial reef environments and fish community responses. We also used these methods to identify fish species as the indicator reflecting habitat preference to the artificial in a fairly wide geographical region along the coastal area, Jeju Island. In brief, we 1) evaluated the effect of artificial reef through the comparison of fish community between artificial reefs and their control sites in the three environmental parameters (water temperature, artificial reef materials, and bottom habitat) that contribute to establishing the fish community in artificial reefs, 2) intensively analyzed the responses of fish trophic groups under the 11 environmental conditions given in artificial reefs, 3) identified indicator fish species prevailing under certain environmental conditions in the artificial reefs, and 4) suggested how to improve ecosystem based management with respect to artificial reef fisheries.

Jeju Island is located about 100 km off the southwest of the Korean peninsula (126° 08′ ~ 58′ E; 33° 06′ ~ 34° 00′ N), while Chuja Island is located about 48 km north of Jeju Island (126° 19′ E; 33° 56′ N) (Fig. 1). A total of 231,000 modules of ARs, mostly made of concrete and steel, have been deployed along 34,474 ha coastal area around the Jeju and Chuja islands from 1972 to 2014 (Korea Fisheries Resources Agency, 2014). These reefs were deployed at seafloor depth ranges of 10 to 50 m at Jeju Island and 5 to 48 m at Chuja Island (averaging 25 m). Several reef blocks were deployed at once to form a community set. Various shapes, size, inner volume, and arrangement of modules were used for AR deployment. There were eight types of AR in the present study, such as quadrilateral, box (3 types), hemisphere, hexagon, cylinder, and tunnel types (details in Table S2 and S3). The number of quadrilateral and box types was predominant. This study used a set of environmental and fish sampling data collected from annual surveys (2007–2011) around the Jeju Island, which formed part of the AR management program (Fig. 1).

Since the mid-2000s, annual monitoring surveys have been conducted in the ARs along the coasts of Jeju and Chuja islands by the Korea Fisheries Resources Agency. Collectively, a total of 110 ARs and 81 Conts were analyzed between 2007 and 2011 (5 annual reports) in this study; 16 reefs in March of 2007, 11 reefs from March to August of 2008, eight reefs in October of 2009, 13 reefs from May to September of 2010, and 14 ARs from July to October of 2011 (details in Table S2). The Cont are situated approximately 1–2 km from the artificial reefs deployed in the study area. Of note, the geometry and hydrographic variations for the water temperature, depth, pH, DO, and bottom sediment type were comparable between control and artificial reef sites. One control site could be corresponded for 2–3 artificial reefs. The locations of the ARs and their Conts were recorded using a global positioning system with a WGS84 of coordinate system.

Dissolved oxygen, pH, salinity, and water temperature, were measured in situ using a YSI 650 multi-Parameter Display System (YSI Inc., Yellow Springs, OH, USA) at each site (Table S2). Fish sampling was conducted using four trammel nets that were 25 m in length and 3 m in