

Catch organism assemblages along artificial reefs area and adjacent waters in Haizhou Bay

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Abstract

To better understand the community patterns mediated by connectivity in artificial reefs of coastal areas, it is necessary to understand the distribution and coexistence of organisms with artificial reefs area and adjacent waters. This study was conducted to examine main catches assemblages collected by trawls in Haizhou Bay, which included five habitats: the artificial reef area (AR), aquaculture area (AA), natural area (NA), estuary area (EA) and comprehensive effect area (CEA). The result shows that the total abundances of species in the five habitats were highly different (univariate PERMANOVA: $P = 0.001$, $n = 24$), but some species were also unique in their habitat (e.g. *Scapharca subcrenata* and *Glossaulax didyma* in AA). The body size distribution of specific species between habitats are different. For *Collichthys lucidus*, their body size in AR ($14.63 \text{ cm} \pm 1.64 \text{ cm}$) and EA ($14.3 \text{ cm} \pm 0.85 \text{ cm}$) is higher than that in NA ($10.65 \text{ cm} \pm 1.64 \text{ cm}$), CEA ($11.28 \text{ cm} \pm 1.85 \text{ cm}$) and AA ($12.1 \text{ cm} \pm 0.43 \text{ cm}$), which indicates the potential connection from AR to EA mediated by their adult population. We concluded that artificial reefs in AR can be considered key components that have the ability to support species assemblages in adjacent habitats. This study has implications for the conservation and monitoring of species assemblages in coastal areas in terms of that artificial reefs can be applied in different stages of habitat protection implementation and in different combinations of scenarios.

Key words: assemblage, artificial reefs, adjacent water, Haizhou Bay

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1 Introduction

The global trends of continuous processes associated with human activities and coastal development, such as overfishing, habitat destruction and marine environmental pollution, have led to general degradation of the entire coastal ecosystem, which has imposed tremendous pressure on estuaries, harbors, gulfs and nearshore regions (Walker and Schlacher, 2014; Dance and Rooker, 2015; Reis-Filho et al., 2019). Over the years, many artificial reefs have been constructed as human-made structures to increase environmental quality and species abundance in marine ecosystems for coastal ecological restoration (Seaman and Sprague, 1991; Ammar, 2009; Mclean et al., 2015; Komyakova et al., 2019) by creating suitable habitats and places for many marine organisms to grow, reproduce, forage and hide (Sherman et al., 2002). At present, ecological principles combining the planning, design and operation of artificial reefs have been extensively investigated in many coastal areas (Whitmarsh et al., 2008; Walker and Schlacher, 2014; Tessier et al., 2015; Folpp et al.,

2020). Given that artificial reefs aim to retard marine habitat degradation, protect endangered species and restore biodiversity, artificial reefs are regarded as conservation and enhancement tools for marine environments and habitat recovery (Dafforn et al., 2015; Becker et al., 2017).

Haizhou Bay, which is located in Lianyungang City, Jiangsu Province, is one of the important fishing grounds in the Yellow Sea. Because of numerous human activities (e.g. overfishing, port construction and waterway transportation), since the 1980s, the habitat environment and fishery resources in Haizhou Bay have been vastly and adversely affected, suffering habitat fragmentation and destruction of the ecosystem structure (Zhang et al., 2006; Zhang et al., 2013). Since 2002, the local government has begun to build marine protected areas (MPAs) dominated by artificial reefs for ecological restoration and resource conservation in Haizhou Bay (Zhang et al., 2006). The construction of artificial reefs affects aquatic biodiversity and food web ecology by affecting the flow of water, sediments and organisms (Clark and Ed-

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wards, 1999; Sherman et al., 2002). These processes in turn affect the community structures and ecological patterns in adjacent waters (Keller et al., 2017; Reeds et al., 2018). However, the impacts of artificial reefs on marine ecosystems and communities in adjacent waters, as well as the ontogenetic shifts and utilization patterns of reef species, are largely unknown, especially in temperate seas. To support the sustainable socioeconomic development of MPAs, as well as the ecosystem approaches in fishery management and spatial planning in coastal areas (Olds et al., 2016; Liao et al., 2017), it is necessary to thoroughly explore the biodiversity in artificial reefs and adjacent waters.

In this study, we used a multi-habitat approach, focusing on species-habitat associations in five habitats along artificial reefs and adjacent waters in Haizhou Bay. We aimed to (1) compare and analyze species abundance in artificial reefs and adjacent waters to determine whether there are spatial differences in assemblages between habitats, and (2) identify single species based on their body sizes to determine whether there is potential connection between habitats. Our research helps provide a more scientific basis and better improve specific planning for improving the strategy, fishery management and construction of MPA networks in temperate coastal habitats in China.

2 Material and methods

2.1 Study area

Haizhou Bay, which is located in the westernmost part of the Southern Yellow Sea, is mainly composed of sandy and muddy habitats and is an open bay with an area of approximately 877 km² (Xie et al., 2007). The climate and hydrology of Haizhou Bay are greatly influenced by the mainland, and most fishing areas are controlled by coastal currents (Luo and Li, 2009). The

tidal in this region is mainly rotating flow, with a velocity of 0.4–0.65 m/s and a direction from northeast to southwest, and the tidal range is between 2.69–5.05 m (Xie et al., 2007).

2.2 Definition of habitat types

The site design refers to the satellite image and current direction. According to the available geographical coordinate data sets in the study area (34°49.20′–34°55.00′N, 119°16.167′–119°59.50′E) and the direction of Yellow Sea Warm Current (YSWC) and Yellow Sea Coastal Current (YSCC) described in Fig. 1 (Sun et al., 2003; Zhang et al., 2017), five major investigation areas with 24 sampling sites ranging from the Linhong Estuary to the artificial reef area were set. In the real sea area, there are clear dividing area between habitats (e.g. AA/AR and EA/AA). NA and CEA can also be clearly divided according to the current direction (northeast to southwest). The brief description of each habitat were listed in Table 1.

2.3 Sample collection

The environmental and fishery resource surveys presented in this study were conducted in the coastal waters of Haizhou Bay in October 2020, corresponding to autumn in the study area, when the fishery resources were at their best (Sun et al., 2010; Su et al., 2015). Environmental data were recorded by a conductivity, temperature, and depth (CTD) measuring system, and fish and invertebrate were sampled by a single ship with a wing single capsule bottom trawl (15 m × 4 m × 8 m, mesh size: 1 cm × 1 cm) at each site. The fishery investigation was conducted for approximately 30 mins at each site, and the speed of the ship was 2.4 kn to maintain a relatively consistent distance of each tow as much as possible. A large number of reefs were commonly present at the bottom of AR and in culture nets and cages in AA, and we could only

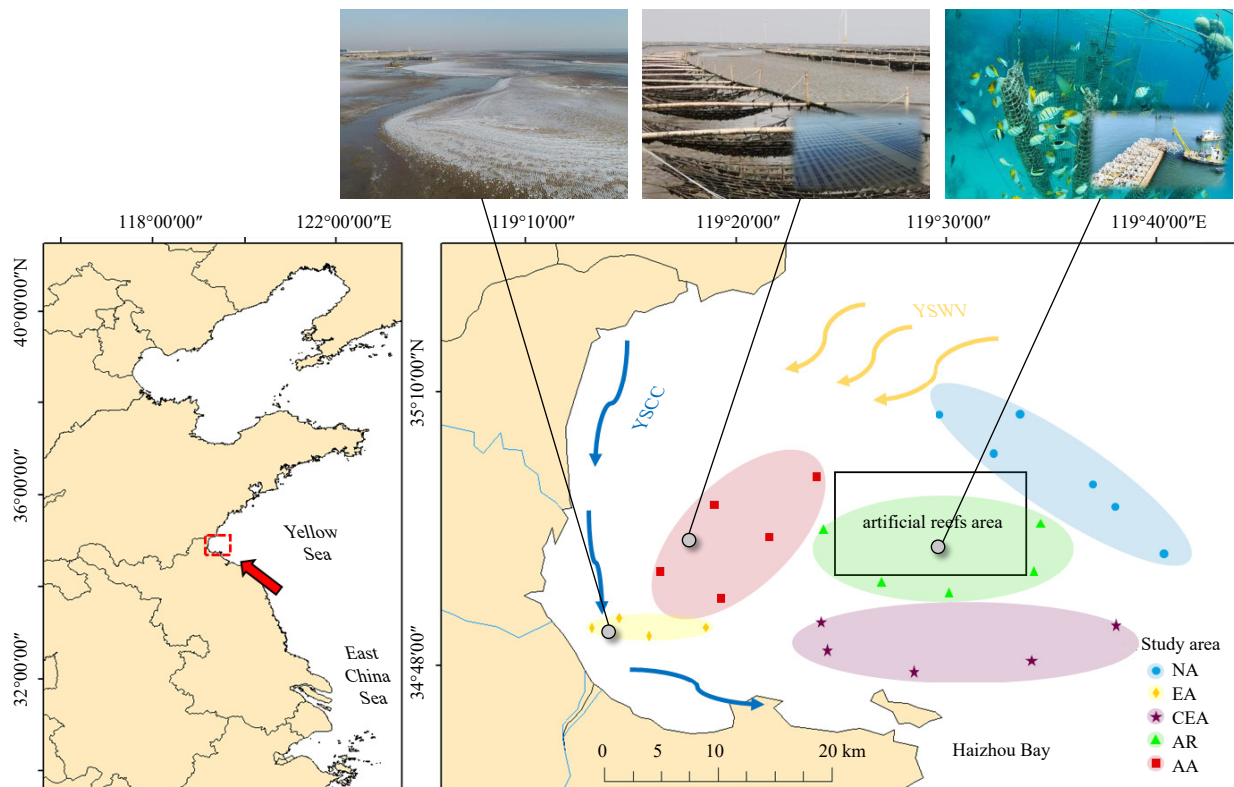


Fig. 1. Study area and sampling sites AR, CEA, AA, EA and NA represent the artificial reef area, comprehensive effect area, aquaculture area, estuary area and natural area, respectively. YSWC is the Yellow Sea Warm Current, YSCC is the Yellow Sea Coastal Current.

Table 1. Brief description of habitats

Habitats	Acronym	Brief description	Salinity	Depth/m	Temperature/ °C
Estuary area	EA	the most polluted area and features a coarse sand substrate	13.09–17.06	4.40–10.21	18.46–19.29
Aquaculture area	AA	an area mainly used for culturing shellfish and algae (e.g. nori, kelp)	17.22–30.72	3.89–9.53	18.54–19.45
Artificial reefs area	AR	a protected area consisting of a series of artificial reefs (e.g. concrete cubic reef, iron cone reef) on the sea bottom, with survey area of 40.231 3 km ²	14.10–30.87	7.22–15.85	19.61–19.80
Natural area	NA	an area that has not been overly impacted by humans	18.61–31.00	5.95–16.21	19.74–19.92
Comprehensive effect area	CEA	an area with several habitats co-occurring, mainly affected by AR and AA	16.94–30.83	5.06–15.97	19.73–20.04

sample around these habitats. To obtain the specific pelagic species in the center of AR and AA, the gill nets (30 m × 1.5 m, mesh size: 2.5 cm × 2.5 cm) were used in these habitats under a depth of 2 m for 2 days, which was fixed by the ship dropping anchor at the fore and after target sites. The gill nets were also used in other habitats with same condition for sampling balance. After a rough identification for fishes, crabs, shrimps or other taxa, the samples were packed into 100 cm × 150 cm PVC bags with fresh ice for preservation. The collection, treatment and analysis of samples were in accordance with the relevant provisions of the Specifications for Oceanographic Survey-Part 6: Marine Biological Survey (GB/T 12763.6–2007). The basic biological indicators (weight and length) and numbers of all samples were recorded at the onshore laboratory (the total length of each sample was measured accurate to 0.1 cm). All species were identified to the lowest possible classification level (<http://www.fishbase.org>).

2.4 Species community analysis in different habitats

The species abundance in each habitat was calculated to evaluate the relationship between the use of different habitat types and species size. All species were identified at the species level, and the species numbers were counted.

2.4.1 Community difference and similarity

The distribution of species abundance among different habitats was calculated using the habitat as a fixed factor. The differences in species abundance between habitats were analysed by permutational univariate analysis of variance (PERMANOVA) based on a Bray–Curtis distance, and post hoc pairwise comparisons were evaluated using the PERMANOVA *t* statistic, with a $P \leq 0.05$ significance level. Then nonmetric multidimensional scale analysis (NMDS) was used for visualization, with the data of species abundance in five habitats. To assess the similarity of species abundance among habitats, a heatmap was produced by clustering the samples on the *x*-axis with Bray–Curtis similarity (based on Whittaker's index of association: [Clarke and Gorley, 2015](#)) on the *y*-axis.

2.4.2 Species–habitat associations based on sizes

The three fishes with the highest abundance (*Amblychaeturichthys hexanema* ($n = 84$), *Chaeturichthys stigmatias* ($n = 55$), and *Collichthys lucidus* ($n = 120$) and the top three most abundant shrimp and crabs (*Oratosquilla oratoria* ($n = 143$), *Trachypena curvirostris* ($n = 65$), and *Portunus trituberculatus* ($n = 141$)) were selected to verify species–habitat associations based on their body sizes. Boxplots were produced using body size frequency data from each habitat type, and a generalized linear model (GLM) was used to test the differences of body size between habitats.

2.5 Tool for data analyses

The survey map were made in ArcGIS (v. 10.3). The PERMANOVA and PERMDISP analyses, as well as the visualization of NMDS and clustering heatmap were performed in R software (v. 4.0.3), using the R package “vegan”, and GLM were performed using the R package “mgcv” ([Anderson–Cook, 2007](#)).

3 Results

3.1 Species community characteristics

A total of 10 234 individuals were collected from five habitats, including 68 species belonging to 42 families (Table S1). In total, 2 867 individuals belonging to 21 families and 35 species were collected in AR, 3 213 individuals from 29 families and 39 species were collected in AA, and 2 664 individuals belonging to 22 families and 39 species were collected in CEA. In contrast, fewer species were found in EA (1 263 individuals belonging to 13 species in 8 families) and NA (227 individuals belonging to 20 species in 15 families) ([Fig. 2](#)).

The predominant family in AR was Gobiidae (4 species, 12.1%, represented by *C. stigmatias*), followed by Penaeidae (5 species, 15.1%, represented by *T. curvirostris*). The most dominant family in AA was Clupeidae (2 species, 5.1%), represented by the species *Sardinella zunas*. The families in NA were mainly composed of Gobiidae (2 species, 10%), Portunidae (1 specy, 5%) and Penaeidae (2 species, 15%), and those in EA were composed of Portunidae (2 species, 16.7%), *P. trituberculatus* and *Charybdis japonica*. The dominant family in CEA was Penaeidae (1 specy, 2.6%). In terms of the number of individuals, Gobiidae was the dominant family of AR, accounting for 26.6% of all species, followed by Penaeidae, which accounted for 21.8% of all species. Clupeidae was the main family in AA, accounting for approximately 41.6%, and Gobiidae was the main family in NA, accounting for 25.6%. The most dominant family in EA was Portunidae, accounting for 77.6%. *Oratosquilla oratoria* of Squillidae was the dominant species in CEA, accounting for approximately 30% ([Fig. 3](#)).

3.2 Species assemblages and utilization of different habitats

Nearly all species were widely distributed in the five habitats, with the majority using two, three, or four habitats at the same time, but only Gobiidae, Squillidae, Cynoglossidae, Sciaenidae, Penaeidae and Portunidae were found living in all five habitats, among which *C. stigmatias*, *O. oratoria* and *P. trituberculatus* had the largest numbers (Table S1). There were 18 specific species that appeared to use a single habitat, including 10 species of Platycephalidae and Pholidae in AR, Apogonidae in NA and Mugilidae and Paguridae in AA (S1).

The total abundances of species in the five habitats were highly different (univariate PERMANOVA: $P = 0.001$, $n = 24$) (Ta-

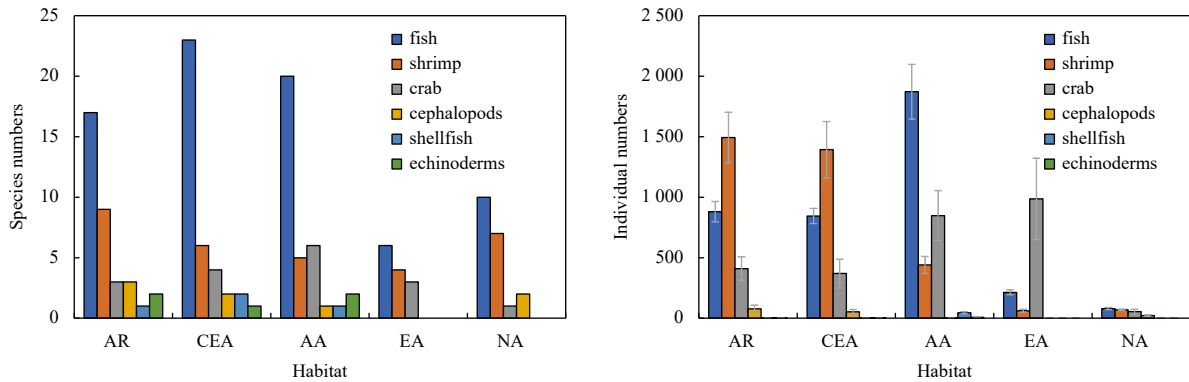


Fig. 2. Species and mean numbers of individual fish, shrimp, crab, shellfish, and cephalopods in the five habitats. The error bars represent the standard error of individual numbers in each group. The same applies below in Fig. 3.

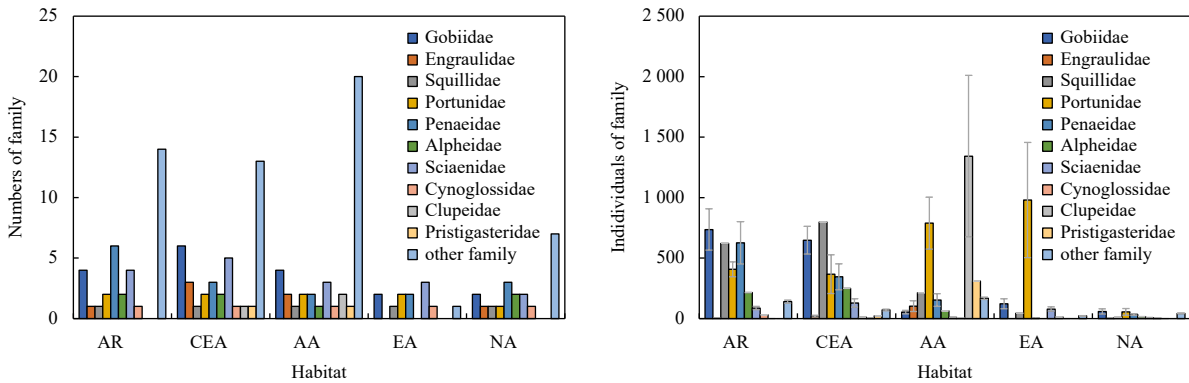


Fig. 3. Species and mean numbers of individuals of different families in the five habitats

ble S2). The pairwise PERMANOVAs indicated that all the habitats (e.g. AR/NA: $P = 0.008$, $n = 5$) accounted for the main variations in species abundance (Table S3). According to non-metric multidimensional scale (NMDS), the species assemblages recorded over five habitats were relatively well defined, with very little overlapping. The points in EA had a close distance, which means a weak species similarity compared to other habitats. Even though the points of CEA and AR do not overlap, the layout formed by the points of two habitats intersects, which indicates a potential relationship between species composition among these two habitats (Fig. 4).

The heatmap that combines the two cluster analyses of the assemblage data identified four separate groups of habitat types (top dendrogram) and five principal groups (left dendrogram) of taxa with similar habitat associations (Fig. 5). NA formed an isolated profile. A second group was formed by AR and CEA, while the third group included AA and EA. Upon cross-referencing these clusters with species recorded during the study, two groups of 12 species (Fig. 5-II and Fig. 5-VI) from a number of different families were strongly associated with AR. This group included *O. oratoria*, *Johnius belangerii* and *Pennahia argentata*, which was also recorded extensively in CEA. Two groups of 4 species (Fig. 5-II) and 10 (Fig. 5-V) species were strongly associated with CEA, while two groups of 2 (Fig. 5-I) and 19 (Fig. 5-III) species were mainly detected in AA. Only 3 species were strongly associated with NA, and some unique species including *Penaeus semisulcatus* (Fig. 5-I), *Alpheus distinguendus* (Fig. 5-II) and *Heikea japonica* (Fig. 5-III), dispersed in each group were found in EA.

Different species, even within the same family, presented varying degrees of habitat partitioning (Fig. 5). In the case of the

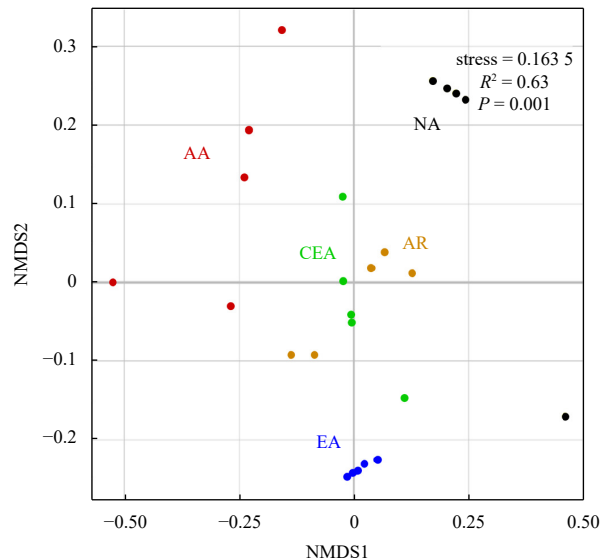


Fig. 4. Visualization of the nonmetric multidimensional scale (NMDS) results for the composition of organism assemblages in the different marine habitat types of Haizhou Bay. The stress function value ($0.1635 < 0.2$) shows the rationality of the ranking model. Different colored points represent the different habitat types, and each point indicates a sampling site.

family Gobiidae, for example, *C. stigmatias* and *Tridentiger barbatus* were most often associated with AR, and *Amblychaeturich-*

thys hexanema and *Odontamblyopus rubicundus* were associated predominantly with CEA, while *Cryptocentrus filifer* were most common in EA.

3.3 Length and size classes of species

A total of 608 species were used to describe their body size distribution in different habitats (Fig. 6). The body size of *A. hexanema* in AA was higher than that in CEA ($P = 0.0001$, $n = 65$) and AR ($P = 0.001$, $n = 12$), and that in EA was higher than that in CEA ($P = 0.0001$, $n = 65$) and AR ($P = 0.008$, $n = 12$). The body size of *C. lucidus* in AR was higher than that in AA ($P = 0.018$, $n = 3$), CEA ($P = 0.0001$, $n = 86$) and NA ($P = 0.0001$, $n = 6$), and that in EA was higher than that in CEA ($P = 0.0001$, $n = 86$) and NA ($P = 0.0001$, $n = 6$). The body size of *O. oratoria* in EA was higher than that in AA ($P = 0.019$, $n = 18$), AR ($P = 0.0001$, $n = 47$), CEA ($P = 0.003$, $n = 62$) and NA ($P = 0.0001$, $n = 10$), and that in CEA was higher than that in AR ($P = 0.001$, $n = 86$) and NA ($P = 0.031$, $n = 6$), and that in AA was higher than that in AR ($P = 0.004$, $n = 86$) and NA ($P = 0.026$, $n = 6$). While there is no difference of body size of *C. stigmatias*, *T. curvirostris* and *P. trituberculatus* between habitats.

ats.

4 Discussion

In this study, we conduct a multi-habitat survey on the catch organisms in the artificial reef area and adjacent waters of Haizhou Bay. In the past, the study of fishery resources in Haizhou Bay focused only on artificial reef areas and contrasting areas (Zhang et al., 2006; Su et al., 2015), and contrasting areas include CEA, AA (e.g. shellfish culturing area, algae culturing area), NA and other habitats. Therefore, the contrasting areas consisting of multiple habitats may affect the effect assessments on artificial reefs and the results of fishery resource analysis, which is not scientific or reasonable. In addition, comparing the distributions of fishery resources in a single habitat cannot explain the intrinsic connections of habitats (Perry et al., 2018). Therefore, the study area of Haizhou Bay was clearly divided into five habitats, which was conducive to the study of the potential relationship between the characteristics of fishery resources and the interaction of population structures in artificial reefs and adjacent waters.

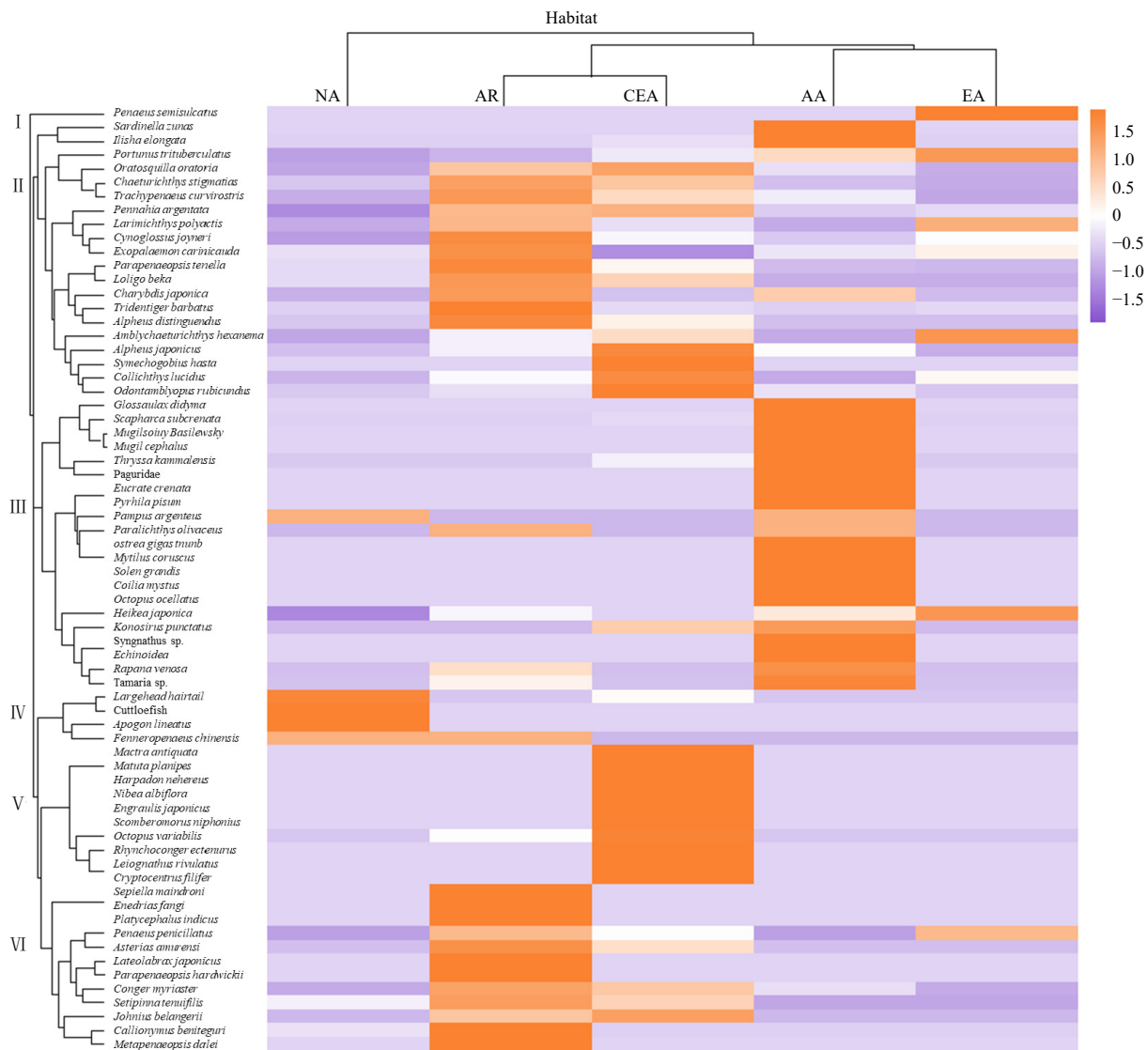


Fig. 5. Heatmap of the distribution of species among the five habitat types (top dendrogram), showing the six groups (left cluster) of species and their habitat associations. The color gradient from orange (strong correlation) to purple (weak correlation) indicates the strength of the species–habitat association.

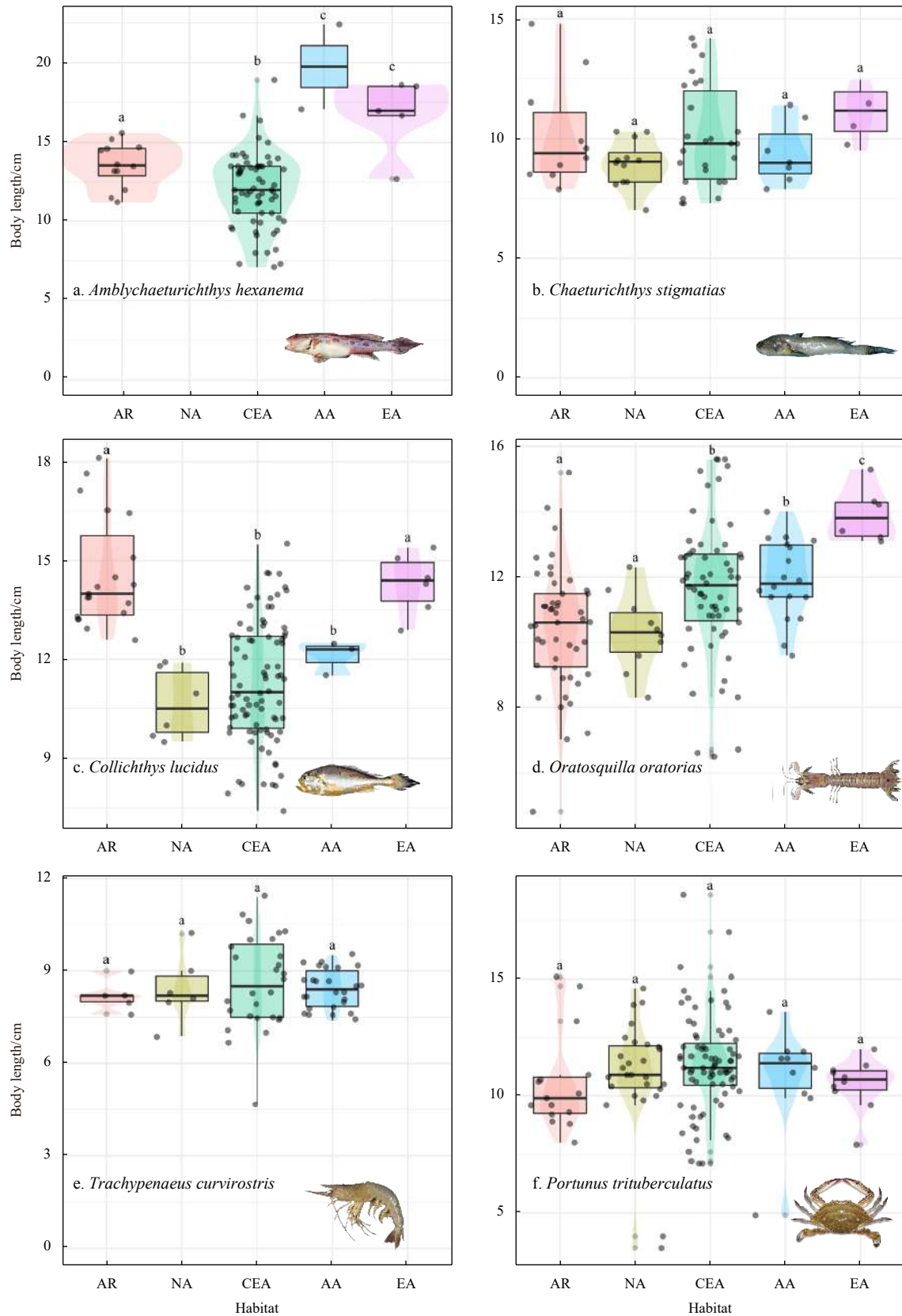


Fig. 6. The different size classes of six abundant species with multihabitat associations in Haizhou Bay. The upper and lower limits of the box indicate the 1st and 3rd quantiles, respectively, and the inner line of the box indicates the average of the data distribution. (a. *Amblychaeturichthys hexanema*, b. *Chaeturichthys stigmatias*, c. *Collichthys lucidus*, d. *Oratosquilla oratorias*, e. *Trachypenaeus curvirostris*, f. *Portunus trituberculatus*). Notes: The letters on top of the box are significance test from generalized linear model (GLM). The same letter indicates significant difference, and vice versa.

Estuary area is a major source of nutrient transport to the ocean and represents an important transition region in which energy from land and sea mixes, and this area is dominated by a variety of communities (Pasquaud et al., 2008; Howe et al., 2017). However, we did not observe a high level of species abundance in EA, which may be related to EA being subjected to the strongest interference by humans and large variation of salinity (13.09 to 17.06) (Li et al., 2011; Zhang et al., 2020; Deng et al., 2022). Furthermore, the water level (4.40 to 10.21 m) of EA fluctuates due to the intermittent influence of tides (tidal range: 2.69 m–5.05 m), which may lead to different assemblages (Gao et al., 2009; Yang et al., 2014; Zhang et al., 2017). Aquaculture area presents species assemblage with a variety of benthic shellfish and snails that other habitats do not include, which could explain the remarkably high benthic abundance in AA. The current in Haizhou Bay includes a branch of the YSWC and the YSCC, which flows from northeast to southwest (Sun et al., 2003). The research of Zhang (2013) showed that the spatial pattern of macroinvertebrate communities in Haizhou Bay under the influence of seasonal variations in different water masses, currents and other factors. Therefore, the high species abundance in CEA is expected, as it is the gathering place of the AA, AR and NA habitats under that influence of currents. As for NA, some samples are small.

Artificial reefs are an effective way to increase habitats and populations of fish species (Folpp et al., 2020); thus, we assume that AR is a mosaic that connects other habitats. Since artificial reefs were placed in local habitats, the abundance of species has shown an increasing trend over time (Wang et al., 2017), which is similar to results from most temperate seas (Lowry et al., 2014; Smith et al., 2016; Folpp et al., 2020). In this study, AR included almost all species (mostly fish, shrimps and crabs) present in the other habitats except for species specific to EA, AA, and NA, especially benthic mollusks in AA (Figs 2 and 3). According to the results of cluster analysis, most species utilized multiple habitats (Fig. 5), however, the composition of community structures were totally different between habitats (Fig. 4). This could be attributed to each habitat having a relatively unique assemblage, especially in AR, AA and CEA, among which AR had the largest number of species, at up to 24 (Fig. 5). Given that AA and CEA were not originally adjacent to each other, mediation by artificial reefs in AR as artificial habitats may increase the abundance of species among these habitats. This conclusion has been confirmed in most previous studies (Ammar, 2009; Lowry et al., 2014; Mclean et al., 2015; Smith et al., 2016; Wang et al., 2017; Komyakova et al., 2019; Folpp et al., 2020). Therefore, we believe that the similarity and uniqueness of the assemblages between habitats can indicate the ability of artificial reefs in AR to support assemblages comparable to those identified in adjacent habitats.

In the present study, strong links were also identified between the size-related assemblages and the distribution of habitats in artificial reefs and adjacent waters. There is significantly different body size of *A. hexanema* between some habitats, and no difference in the body size of *C. stigmatias* was found, which may be related to the weak swimming ability and settlement behavior of Gobiidae after reaching adulthood, resulting in uneven distribution of individual size between habitats (Han et al., 2013). The body size of *P. trituberculatus*, with strong swimming ability, also showed no difference between habitats in this study (Fig. 6). The reason is that *P. trituberculatus* is active in coastal waters (e.g. EA, AR and NA in this study) (Yue et al., 2020). Moreover, EA is also the discharge area of *P. trituberculatus* in Haizhou Bay, which also indicates that the effect of stock enhancement to this species is positive. In total, the regularity of body size variations in each

species in different habitats is not strong, which was related to many factors. On the one hand, differences in body size may be caused by differences in the growth rates of species in different habitats (Sogard, 1997). Longer, faster-growing fish are more likely to survive to maturity (Moss et al., 2005). On the other hand, differences may also be due to size-based selective mortality resulting in differences in body size. Density-dependent settlement, growth and mortality are often the major factors controlling recruitment success (Juanes, 2007). In addition, the observed variations in the body size gradients of *C. lucidus* and *O. oratoria* in different habitats reflect potential species-habitat associations of some marine species in different habitats. For example, similar body sizes of *C. lucidus* appeared in both AR and EA, which were higher than those in other habitats (Fig. 6). First, changes in habitat are often accompanied by diet shifts (Yang et al., 2018), indicating that the feeding environments created by AR and EA for *C. lucidus* may be relatively similar and implying that artificial reefs in AR could increase fish abundance by attracting fish (Lowry et al., 2014). Second, it should be noted that *C. Lucidus* is a migratory fish, and their appearance in AR may be due to migration of the mobile species from other sea areas (Jiang et al., 2016). Therefore, we consider that for some mobile species like *C. Lucidus*, there is variation in the size of individuals in different habitats, and their migration is an important media for potential connections between habitats, but more empirical studies are needed before a convincing conclusion can be drawn.

Finally, there are some places need to be improved in this study. The sample size of species in some areas (e.g. NA) is relatively small, which may lead to representative results. Therefore, more investigations should be conducted in the future. According to the characteristics of the species and environment in temperate seas, it is worth considering selecting the appropriate netting gear during the survey. The coastal waters of the Yellow Sea where Haizhou Bay is located are mainly dominated by muddy and sandy habitats, in which the underwater visibility is low, making it difficult to study communities by diving or snorkeling (Dorenbosch et al., 2007; Wang et al., 2011). Moreover, the current velocity is relatively high, and the methods used for underwater visual surveys, such as baited remote underwater video systems (BRUVs), are very limited (Reis-Filho et al., 2019). Therefore, trawl and gill nets are more commonly used for sampling in this region. However, trawling is the fishing method that caused the greatest harm to fisheries and marine environments (Trenkel et al., 2019). In the future, fishery resources and its community differences could be assessed by combining acoustic telemetry methods. In addition, whether some migratory species use a variety of habitats to complete their life cycle at different stages in their life histories or simply exhibit cross-habitat behavior remains unclear. It may be necessary to combine otolith microelement (Maciel et al., 2020) or environmental DNA (eDNA) (Yamanaka and Minamoto, 2016) techniques for further in-depth analysis.

5 Conclusions

In this study, a mesoscale survey of trawling catch communities associated with artificial reefs and adjacent waters was conducted for the first time to describe the characteristics of the rich diversity of species in the coastal water of Haizhou Bay. Our results show that each habitat exhibited species similarity, and some species were also unique in their habitat. We believed that there is a potential species-habitat associations among habitats within artificial reef areas and adjacent waters, and some mobile species can be served as an important media for potential connec-

tions between habitats. We concluded that artificial reefs in AR can be considered key components that have the ability to support species assemblages comparable to those identified in adjacent habitats, and can be applied in different stages of habitat protection implementation and in different combinations of scenarios.

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Supplementary information

Table S1. The number of individuals in the artificial reef area (AR), comprehensive effect area (CEA), aquaculture area (AA), estuary area (EA) and natural area (NA) in Haizhou Bay.

Table S2. Univariate PERMANOVA results for the overall interaction of species abundance in the five habitats.

Table S3. Univariate PERMANOVA results of pound-by-pair interactions of species abundance in the five habitats.

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