E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.549
IJFAS 2019; 7(3): 128-133

www.fisheriesjournal.com
Received: 17-03-2019
Accepted: 21-04-2019

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Artificial coral reefs restore coastal natural resources

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Abstract
Fisheries play an important role in the local economic development of the province of Quang Nam, Vietnam. Recently, however, coastal resources have declined dramatically due to the pressure from the large numbers of inshore fishing vessels and other industrial operations in the inshore area. Artificial coral reefs have been used worldwide to mitigate human impacts in coastal ecosystems, and enhance resource reproduction and fisheries. This study constructed 500 artificial coral reef units and deployed them over 1,424,500 m^2 in the waters of Quang Nam to provide an alternative habitat to restore natural resources. Results indicated that both fish frequency of appearance (FA) and relative abundance (RA) were higher in an artificial coral reef, relative to the deployment. Only 44 marine species were found in the absence of artificial coral reefs, while this increased to 78 species after 12 months of deployment. This study suggests that artificial coral reefs are able to restore natural resources overtime.

Keywords: Artificial reef, resource restoration, coastal management, effectiveness, Quang Nam fisheries

1. Introduction

Artificial coral reefs, including submerged structures placed on the substrate, in mid-water, or floating on the surface, have been used worldwide during the past several decades as an effort to restore marine resources, improve the catch rate of a variety of fish species, protect natural ecosystems, provide new habitat, and control beach erosion [1–5]. In addition, artificial coral reefs have been used to mitigate the negative effects from human activity in the marine environment [6]. A variety of artificial coral reefs have been constructed, consisting of concrete block, formed concrete modules, polyvinyl chloride pipe, used vehicle tires, damaged ships, discarded scrap, and waste materials [3, 4]. Performance of natural resource restoration of the artificial coral reefs depend on the marine environment (i.e. depth, substrate, and current), construction scope, reef structure, materials, and deployment [1, 4, 7, 8].

Quang Nam province is located in central Vietnam, and has 125 km coastline. Quang Nam Sea, home to the marine protected area Cu Lao Cham situated in the upwelling region, is recognized as a high biodiversity region, with 174 phytoplanton, 178 zooplanton, 106 seaweed, 130 coral reef, 48 invertebrate, and 500 vertebrate species [9 - 12]. Fisheries represent a major contribution to the local economy and employment of the province, particularly in coastal communities [13]. There are 4,161 fishing vessels operating in Quang Nam, but 91.5% are inshore fishing vessels, i.e. less than 90 hp [13]. Landings in 2018 were approximately 67,000 metric tons accounting for $ 250 million USD in landed value [13]. Multiple fishing methods, i.e. purse seining, trawling, longlining, gill netting, trapping and set-net, are used in the province. Inshore fisheries in Quang Nam province have been recognized as over exploitative due to the rapid small scale fishing expansion that occurred during the 2000s [14].

As a coastal province, marine ecosystems have provided food, ecological services, and livelihoods for the local communities for centuries. However, pressure to protect the coastal habitats have increased due to population growth, economic development requirements, (i.e. aquaculture, marine transportation), and tourist activities, (i.e. diving). Illegal fishing, the use of unfriendly fishing gears, i.e. trawling, and marine pollution have also contributed to the damage of natural ecosystems and the environment [9, 14]. Additionally, local people have exploited the dead coral reefs to trap juvenile lobsters because of high demand for lobster aquaculture [14]. Regarding global climate change, ocean water temperature in the South China Sea, including Quang Nam Sea, has been increasing an average of 0.014^{0}C annually [15]. The increasing sea surface temperature poses potential risks to the hatching, growing, maturation, distribution, and migration of marine species and fisheries, particularly inshore fisheries [16]. Evidence suggests that there was a significant negative correlation between the fish landings and ocean temperature [16]. Therefore, restoring the coastal natural resources in Quang Nam province is important and has the potential to improve the livelihoods of local people.

The overall purpose of this study was to design and install artificial coral reefs in order to restore coastal natural resources in the province of Quang Nam, Vietnam. We investigated the effectiveness of artificial coral reefs on fish species occurrences and abundances over time.

2. Materials and Methods

2.1. Study site

The study was deployed at approximately 1 km from the east of Ban Than Cove (Latitude between 15°31'00"N and 15°31'30"N, Longitude between 108°40'30"E and 108°41'30"E), off Tam Hai, Nui Thanh, Quang Nam province, with a total area of 1,424,500 (1,850m x 770m) m^2 (Fig. 1). This site was selected based on several criteria: (1) natural coral reef used to be present there; (2) sand, rocky and dead coral substrates occur; (3) sufficient depth (15-25 m); (4) high plankton production area; (5) undisturbed fishing operations; and (6) large distance from shipping lanes.

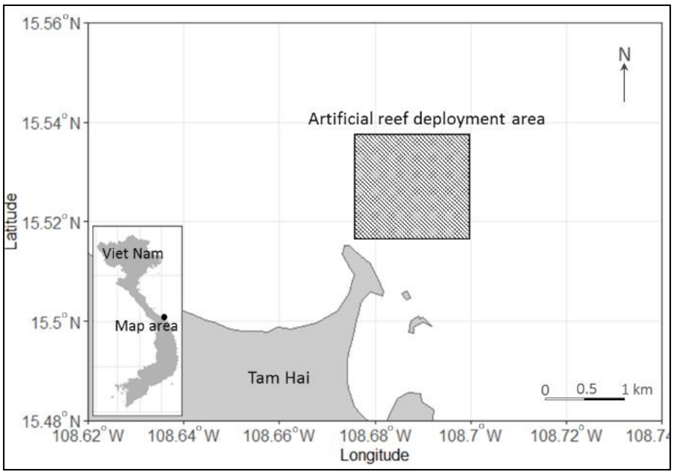

Fig 1: Map of study site located in the Tam Hai commune, Nui Thanh district, Quang Nam province, Vietnam

2.2. Artificial coral reef structure and installation

The artificial coral reef was cylindrical in shape and 1.2 m x 1.5 m high, with holes of 20 cm in diameter in the wall to create caves and corners (Fig. 2). A total of 500 units of artificial coral reef were built using reinforced concrete, with a weight of each reef of approximately 2,500 kg. In addition, 25 stations were constructed across the study site, of which there were 20 artificial coral reef units at each location. The distance between stations was approximately 160 m. Fig. 3 indicates the deployment processes.

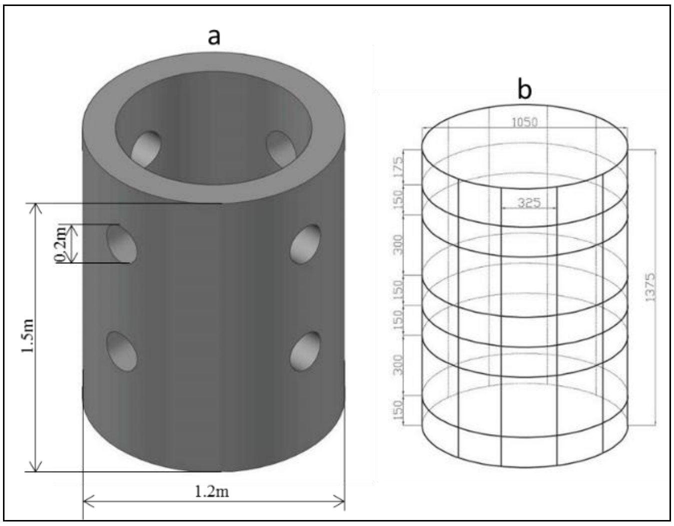

Fig 2: Artificial coral reef structure (a), and reinforcement structure (b)

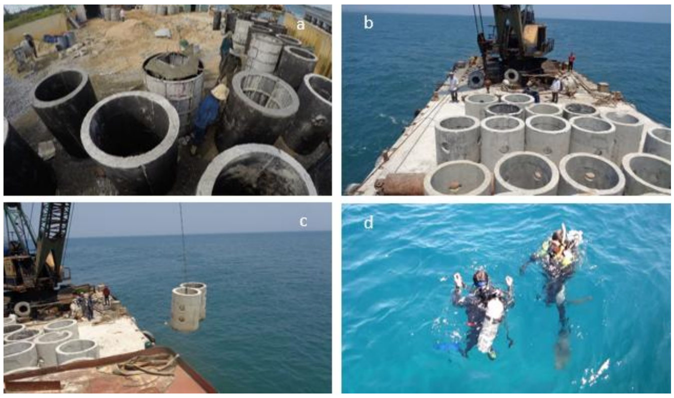

Fig 3: Deployment process a) concrete is poured in the shape; b) artificial coral reefs are carried to the study site; c) place reefs onto the seabed; d) scientists check deployment

2.3. Census techniques

Censusing was conducted on linear transects by pair divers to count and record visual fish in the artificial coral reef during the period of April 2017 to December 2018 [1, 2, 17, 18]. This technique is safe and sufficient for most fish species and natural habitat, despite a certain underestimation of both the cryptic and most abundant species [2]. There were 5 fish censuses during that period including monitoring before reef installation and 4 censuses after placement. In order to record and have exact assessments, GoPro HERO6 cameras were also used and reviewed after diving. At each reef location, we conducted fish counts in two transects that were parallel and perpendicular to the shoreline, with an area of 3 m wide x 3 m high x 40 m long for each transect using nylon lines stretched by lead weights at both ends [i.e. (3 x 3 x 40) m x 2 = 720 m^3 at each sampling point]. Fish censuses were conducted during the sunny daytime to avoid using flashlights that may affect fish schooling, aggregation, and behaviour.

2.4. Species composition and statistic

The abundance of each species observed in this study was determined by two indices: frequency of appearance (FA) and relative abundance (RA) in all censuses [2, 17]. The FA was determined by number of censuses in which the *i* species was observed divided by the total number of censuses x 100. The RA was determined by the pooled number of individuals of the *i* species from all censuses divided the total number of all individuals in all censuses x 100. A census was defined as a single count of fish around a pillar or along a transect at a given date. The resulting values were then transformed into abundance or frequency categories.

A Chi-square test (χ^2) was used to assess the relation between species and deployment time using RStudio. Analyses were calculated at a confidence level of $p\text{-value} < 0.05$.

3. Results

Overall, a total of 78 marine species were recorded during all censuses, which consisted of 48, 13, 12, and 5 species of vertebrates, crustacean, mollusks, and cephalopods, respectively (Table 1). Demersal fish were the majority (RA = 87%) of fish observed in all censuses (FA= 92%). *Ambassis kopsii*, *Siganus canaliculatus*, *Siganus fuscescens*, *Upeneus japonicus*, *Epinephelus areolatus*, *Strombus canarium*, and *Ovula ovum* species were the top seven most popular with over 80% found across the censuses and found in almost all censuses (FA = 75%), followed by *Sargocentron rubrum*, *Apogon quadrisquamatus*, *Lutjanus fulviflamma*, *Leiognathus splendens*, *Gerres filamentosus*, *Rachycentron canadum*, and *Diadema setosum* ranging between 60% and 80%, finally *Ambassis gymnocephalus*, *Archamia fucata*, *Brachirus annularis*, *Hypoatherina temminckii*, *Carangoides caeruleopinnatus*, *Pterois miles*, and *Thenus orientalis* with less than 10% observed. *Epinephelus areolatus*, *Naucrates ductor*, *Thenus orientalis*, *Branchiostegus japonicus*, and *Pseudorhombus arsius* appeared to aggregate in the center of the reef (FA > 90% in the center).In contrast, *Hyporhamphus quoyi*, *Strongylura strongylura*, *Ambassis gymnocephalus*, and *Upeneus tragula* were distributed mostly in the edge rather than the center (FA > 80% in the boundary). Juvenile fish dominated all censuses, accounting for over 84% individuals observed for all species.

Table 1: Relative abundance (RA) and frequency of appearance (FA) of all species that were observed in the censuses. Asterisks (*) indicate the level of abundance and frequency: * represents <1%, ** represent 1 - 20%, *** represent >20 - 40%, **** represent >40 - 60%, ***** represent >60 - 80%, ****** represent >80%.

Species	RA	FA	Species	RA	FA
Acanthaster planci	**	****	*Meretrix lyrata*	**	***
Acetes japonicus	******	**	*Metapenaeus affinis*	***	**
Ambassis buruensis	***	****	*Metapenaeus joyneri*	*	**
Ambassis gymnocephalus	****	*	*Naucrates ductor*	***	**
Ambassis kopsii	***	******	*Octopus spp*	*	**
Amusium pleuronectes	**	**	*Ovula ovum*	****	******
Anadara subcrenata	**	****	*Panulirus homarus*	*****	***
Apogon poecilopterus	**	***	*Panulirus longipes*	****	***
Apogon quadrisquamatus	***	*****	*Panulirus ornatus*	*	**
Apogon semilineatus	*	****	*Panulirus penicillatus*	***	**
Archamia fucata	*	*	*Paphia undulata*	***	****
Babylonia areolata	*	**	*Parupeneus spilurus*	***	**
Bothus myriaster	*	**	*Penaeus merguiensis*	**	****
Brachirus annularis	*	*	*Perapenaeopsis sculptilis*	*	***
Branchiostegus japonicus	*	**	*Platax teira*	***	****
Carangoides caeruleopinnatus	***	*	*Platycephalus indicus*	***	**
Caranx ignobilis	*	**	*Plectorhynchus lineatus*	*	**
Charybdis cruciata	**	**	*Plectorhynchus pictus*	***	**
Cheilinus fasciatus	**	****	*Plectropomus leopardus*	***	**
Chlamys nobilis	**	****	*Plotosus lineatus*	*	**
Diadema setosum	****	*****	*Portunus pelagicus*	***	**
Drepane punctata	*	**	*Portunus sanguinolentus*	**	***
Epinephelus areolatus	*****	******	*Pseudorhombus arsius*	**	****
Epinephelus epistictus	*****	**	*Pterois miles*	**	*
Gazza minuta	***	***	*Rachycentron canadum*	******	*****
Gerres filamentosus	***	*****	*Sargocentron rubrum*	*	*****
Halichoeres nigrescens	**	**	*Saurida tumbil*	*****	****
Haliotis ovina	*	**	*Siganus canaliculatus*	****	******
Holothuria vagabunda	*	**	*Siganus fuscescens*	******	******
Hypoatherina temminckii	**	*	*Siganus guttatus*	**	****
Hyporhamphus quoyi	***	**	*Strombus canarium*	***	******
Leiognathus bindus	**	**	*Strongylura strongylura*	*	**
Leiognathus equulus	*****	**	*Takifugu oblongus*	*	***
Leiognathus splendens	****	*****	*Terapon jarbua*	**	***
Loligo chinensis	***	**	*Thenus orientalis*	*	*
Loligo edulis	***	**	*Toxopneustes pileolus*	****	****
Lutjanus fulviflamma	**	*****	*Turbo bruneuus*	***	***
Lutjanus russellii	**	****	*Upeneus japonicus*	***	******
Lutjanus sanguineus	***	**	*Upeneus tragula*	******	***

Result indicated that a number of species was associated with the time since the artificial coral reef was installed (χ^2 = 12.29, p = 0.02). Only 44 species were found before installation. This increased to 75 species after 3 months, and 77 species after 6 and 9 months, and 78 species after 12 months since deployment (Fig. 4). The time since the artificial coral reef was installed significantly affected total biomass (χ^2 = 32.86, p < 0.001). Average fish density varied between 1110 and 1128 individuals per 100 m^2 at each census of which most of individuals were juvenile and negligible adult fish were observed. Fig. 5 shows fish abundance around the artificial coral reef.

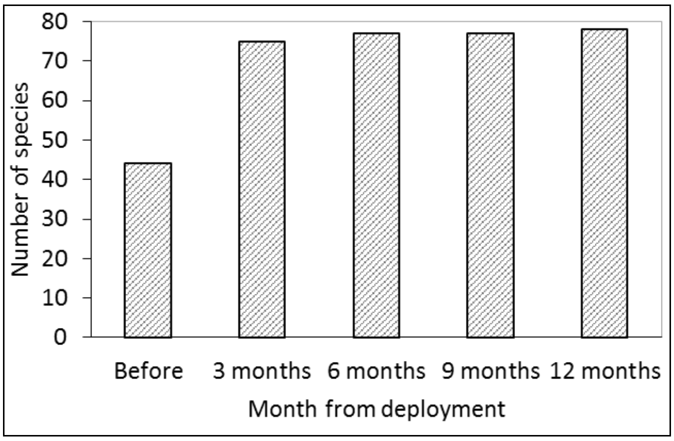

Fig 4: Number of species observed

Fig 5: Restoration of natural resources. a-c) fish and other species aggregate around the reef; d) natural coral reef grows on artificial coral reef after 12 months deployment.

Additionally, five natural coral reefs were recruited in the new artificial coral reef areas after 12 months post-installation (Fig. 5), including coral species *Astreopora myriophthalma, Montipora tuberculosa, Turbinaria peltata, Euphylia ancora, Plerogyra sinuosa, Caulatrea tumida, Goniastrea, Leptastrea, Montastrea, Oulophyllia, Platygyra, Lobophyllia, Symphyllia, Pectinia, Goniopora, Porites, Pachyseris, Diploria labyrinthiformis, Scleractinia, Acropora palmata, Acropora cervicornis, Acropora aculeus*, and *Sargassum*. The artificial coral reef units provided stable bases upon which natural coral reefs were able to attach and develop. Fig. 5 shows fish concentrated around the artificial coral reef.

4. Discussion

In this study we found that fish species richness, biomass, and fish numbers have been restored after 12 months of deployment. The results of this study found higher frequency of appearance and relative abundance on artificial reefs compared to before construction. This suggests that artificial coral reefs can be deployed in appropriate conditions in inshore areas for altering the damaged landscapes to restore marine natural environmental functions (i.e. providing nursery area, nesting habitat of adult fishes, and recruitment). The new habitat that was provided by the artificial coral reef supported a diverse ichthyofaunal assemblage comprised of both mobile pelagic and demersal species, but reef fish were dominant. Constructing artificial coral reefs does not destroy the traditional fishing ground, instead it concentrates economically valuable species. Moreover, artificial coral reef structures are better to natural habitat in their ability to support a good base and environment for restoring natural coral reef.

More fish being found in artificial coral reefs in this study was consistent with previous findings. For instance, fishes present on a shallow temperate artificial reef and feeding on or immediately near a reef had produced tissue through both growth and reproduction, increasing the standing stock biomass by up to 78% [19]. A significant increase of both species richness and fish abundance were recorded in the artificial structures compared to natural sites before deployment [2]. Neighboring artificial coral reefs and natural coral reefs would achieve a similar fish population given sufficient time [20].

To date, there have been over 40 countries that have built the artificial coral reefs for a variety purposes [4, 21]. For instance, large scale artificial coral reef deployment in the offshore areas in the open water has been conducted in Hong Kong as a technical measure to bring back natural resources by limiting offshore trawling operation [22]. Artificial coral reefs have been constructed in Japan and United Arab Emirates to improve the spawning, recruitment, and survival of juvenile and larvae fish, while in the United States fisheries improvement reefs have been built to improve commercial harvests [4, 6]. For other countries, like Maldives, building coral reefs was not only for ecological rehabilitation, but it also protected the beach from erosion [7].

Although regulatory measures to preserve and protect natural resources and coral reefs already exist in Vietnam in general and Quang Nam province in particular, lack of enforcement, surveillance, and support from the local community have led to policy failure and ineffective management [23]. We suggest close cooperation among fishermen, scientists, management, agencies, and other stakeholders to maintain healthy natural resources and provide other strategies for sustainable fisheries development. For example, the implementation of fisheries laws in Vietnam to protect inshore fisheries will need effort and commitment from state government, local government, and the broader fishing industry. Educating and improving the awareness of environmentally safe and friendly use of fishing methods by fishermen will be an important measure to retain ecosystem sustainability and reduce negative environmental impacts. Such marine fisheries form an important source of income for local communities. Any changes in fishing practices can significantly affect their livelihoods. When adopting new technical or management measures, especially if restrictive, governments should wisely consider providing alternative sources of income support to manage the transition [24]. Additionally, developing an environmentally friendly fishing method, such as setnet, pot, and line and hook, is necessary to conserve the coastal fishery resources for the long-term benefit, and maintain a source of income, for future generations. In order to avoid conflict between the interest groups in the inshore space, collaboration amongst stakeholders (i.e. fishers and tourist companies) is encouraged in order to improve the income of fishers by making the recreation fishery available as a new tourist product for the tourism industry.

Attractive performance is known to vary across different locations and factors, as constructing an artificial coral reef not only provides benefits, it also produces problems for ecology. For instance, [6] showed that restoration ability could be low for many artificial structures, instead they simply attracted fish from the surrounding natural area. Attraction and aggregation of fish on artificial reefs can be problematic, as concentrated fishing efforts near artificial reefs could ultimately lead to declines in local populations. However, other research has indicated that artificial coral reefs attracted fish from natural reefs at first, but fish soon develop in the new habitat [21]. Moreover, artificial reefs could potentially attract the predators that have the potential to create unnatural top–down regulation of fish populations. As there is a short distance between the study site and marine protected area Cu Lao Cham (i.e. about 50 km), the interaction in fish movement from natural reefs to artificial coral reefs precluded our ability to get as detailed measurements and assessments as possible. Further research on the comprehensive evaluation of real value of artificial reef is recommended, especially whether new structures affect neighboring ecosystems and fish stocks.

5. Conclusion

The study found that species numbers, biomass, species riches, frequency of appearance, and relative abundance have been increased within one year of deployment. This suggests the effectiveness of artificial coral reefs as being an alternative solution to restore coastal resources. In order to maintain artificial coral reef operating a long term, collaborating amongst stakeholders, i.e. fisheries managers, fishers, and tourist companies, is encouraged.

6. Acknowledgement

This study is funded by Quang Nam Department of Science and Technology. We are grateful to the People's Committee of Nui Thanh District and the People's Committee of Tam Hai Commune for organizing the conferences and artificial coral reef management. We also thank the Institute of Marine Science and Fishing Technology for providing the effort to deploy this study.

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