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IMPLEMENTATION OF REEF BALL ARTIFICIAL STRUCTURES OFF SOUTH-CENTRAL VIETNAM FOR CORAL REEF RESTORATION: FIRST ACHIEVEMENTS

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Among methods of coral reef rehabilitation worldwide, the Reef Ball™ (RB) technology based on artificial concrete modules mimicking natural reef structures is well-known and has been used for three decades in more than 55 countries. These modules serve as habitat promoting an increase in fish diversity, as well as appropriate hard substrate for natural coral recruitment and artificial coral transplantation efforts. The project on implementation of RB method in south-central Vietnam was launched in 2023 using two sets of RB modules in two different coastal marine areas: protected one (MPA) and recreational one (RA). The present study aimed to estimate the efficiency of these structures in promoting coral recruitment and enhancing fish diversity and abundance. The 1-year exposition of RB modules revealed similar coral recruitment patterns between MPA and RA with the dominance of *Porites* and *Pocillopora*. The density of coral recruits was (9.5 ± 2.2) and (8 ± 2.1) recruits·module^{-1} in MPA and RA, respectively. In MPA, fish diversity reached 18 species, and abundance was (131 ± 6) fish·100 m^{-2}, whereas RA exhibited the values of 10 species and (110 ± 7) fish·100 m^{-2}. The longer, 3-year exposition of RB modules in MPA revealed 4-fold rise in density of recruits, up to (42.5 ± 6) recruits·module^{-1}, and overwhelming dominance of *Porites* in recruitment pool. During this period, fish abundance exhibited 2-fold increase, whereas fish diversity rose to 33 species. This study showed that RB modules can be effectively used for reef ecosystem rehabilitation in coastal areas with various exploitation statuses; however, protection from anthropogenic load may significantly enhance the outcome of this technology in marine environments.

Keywords: Reef Ball, Vietnam, coral recruitment, fish diversity, reef restoration

Over the past three decades, coral reefs have faced a complex negative effect determined by a number of natural and anthropogenic disturbances: climate change and related ocean warming, together with an increase in frequency and severity of seasonal anomalies of sea surface temperature (hereinafter SST), ocean acidification, pollution, coastal reclamation, overfishing, rise in outbreaks of corallivorous predators, coral bioerosion, and diseases [Burke et al., 2011; Hoegh-Guldberg et al., 2007; Hughes et al., 2018]. At present, more than half of all tropical coral reef structures are considered completely degraded [Bruno, Selig, 2007; Burke et al., 2011; Eddy et al., 2021]. With the widespread destruction of coral reefs, various methods of coral restoration and rehabilitation of reef habitats are becoming increasingly important worldwide. Deployment of artificial structures to assist the natural coral and fish recruitment processes is a common practice in many degraded reefs [Sherman et al., 2002].

Reef Ball^{TM} (hereinafter RB) technology has long been known as one of the effective methods of coral reef rehabilitation and enrichment of fish abundance and diversity [Barber, 2000]. This method has been implemented in over 4,000 projects in 56 countries [Barber et al., 2008]. The dome-shaped RB concrete structures designed by the Reef Ball Development Group Ltd., mimic large, massive coral heads, which provide a hard substrate for natural coral larval settlement and for artificial transplantation of coral fragments for further development. Moreover, these structures are important fish habitats promoting an increase in fish diversity. Being deployed on sandy sites where corals normally do not grow, RB modules serve as the first stepping stone to establish coral reef communities.

Coral reefs in South-East Asia account for 34% of the world total, with the highest coral diversity. However, almost 95% of the region reefs are at risk of destruction, with more than 50% at high or very high risk [Burke et al., 2011; Status of Coral Reefs, 2008], and with 11% of mean coral loss during the last two decades [Status of Coral Reefs, 2020]. The coral reefs of Vietnam, included in South-East Asia region, are estimated to be highly threatened, with only ~ 2% still being in a relatively healthy stage and coral cover ranging from 50% to 90% [Dung, 2020; Nguyen, Vo, 2013, 2014; Tkachenko et al., 2025]. Though the RB method is widely used in South-East Asia, especially in Indonesia [Bachtiar, 2000; Bachtiar, Prayogo, 2010; Kojansow et al., 2013], this technology did not receive much attention in Vietnam; the only attempt of utilization of RB structures for coral rehabilitation was made in Nha Trang Bay in 2013–2016 [Ben et al., 2020; Dan, Tuyen, 2017]. The recent project on the implementation of the RB method in Vietnam was launched by the Joint Vietnam–Russia Tropical Science and Technology Research Center in 2022. The aim of this study was to estimate the benefit of using Reef Ball modules in terms of efficiency in promoting coral recruitment, growth rates of transplanted coral fragments, and enhancement of reef fish abundance in the new environment.

MATERIAL AND METHODS

Study sites. RB modules were deployed in two coastal locations of south-central Vietnam, namely in Nha Trang Bay (Hon Tre Island, Dam Bay, 12°11′41″N, 109°17′26″E, location 1, Khanh Hoa Province) and in the southern part of a small Hon Nua Island situated 70 km north from the first site (12°49′36″N, 109°23′27″E, location 2, Dak Lak Province) (Fig. 1).

All the modules were deployed on sandy substrates within 3–5-m depth range. Totally, 34 modules were deployed in location 1 in July 2022, and 30 modules, in location 2 in July 2024. Location 1 represents a marine protected area (hereinafter MPA) where several coral culture experiments, including the present one, are ongoing since 2017. However, an extensive outbreak of a crown-of-thorns starfish *Acanthaster* cf. *solaris* in 2015–2020, typhoon Damrey in November 2017, and SST anomaly in June 2019 caused total degradation of the adjacent natural coral communities around MPA by 2020 [Tkachenko, 2023; Tkachenko et al., 2020, 2025]. In contrary, location 2 is situated in a tourist recreational area (hereinafter RA), and it was neighboring natural coral reef in a rather healthy state at the time of RB project launch in 2024. The mean stony coral cover on this reef was estimated to be 51%, with the dominance of massive and branching *Porites*, foliaceous *Montipora* and *Echinopora*, and solitary corals *Fungia* spp. (Tkachenko, unpublished data). Despite a better initial environment of location 2 in terms of water quality, it is a tourist area with heavy speedboat daily traffic across the zone of the modules' deployment.

Both sites are affected by seasonal upwelling driven by strong southwestern winds blowing parallel to the coastline of Central Vietnam. Every summer, May to August, an extremely narrow shelf of the Vietnamese coast of the South China Sea (the East Sea in Vietnam) between 11°N and 16°N becomes the center of the monsoon-induced Vietnamese upwelling. It causes the SST to drop by 3–5 °C in comparison to the temperature of surrounding waters [Kuo et al., 2000]. Thus, annual mean SST ± *SD* is (+27.73 ± 1.55) °C, with the variation range of 6 °C. Upwelling mitigates SST abnormal seasonal elevations and allows considering the waters of Khanh Hoa Province as a potential thermal refuge for reef-building corals in the western South China Sea [Tkachenko et al., 2016, 2025]. At the same time, south-central Vietnam is located in the path of tropical cyclones generated within the northwestern Pacific Ocean or in the South China Sea; most cyclones come to the coastline from the southeast. Cyclones and heavy rains during wet season (October to February) determine remarkably high annual discharge and sedimentation load from 21 rivers located on the province coastline [Tkachenko et al., 2025]. A seasonally increasing flow of two streams entering the water area of location 1 may cause temporary drop (up to several days) in sea surface salinity (within a 50-cm layer) from a mean of 32.4‰ to a mean of 27‰, and a rise in sedimentation load from a mean of 6 mg·cm^{-2}·day^{-1} in dry season (March to October) to a mean of 40 mg·cm^{-2}·day^{-1} in wet season (November to February) (Samoilov, Dung, unpublished data).

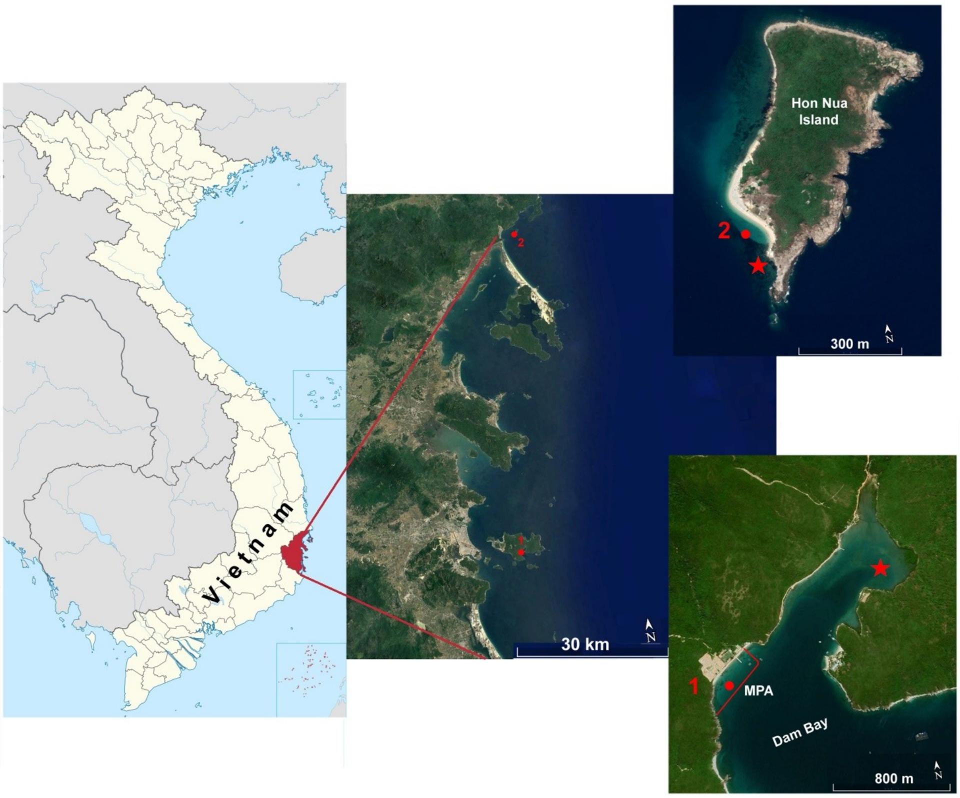

Fig. 1. Map showing locations of Reef Ball modules deployment off south-central Vietnam (Khanh Hoa and Dak Lak provinces). 1, marine protected area in location 1; 2, recreational area in location 2. Stars show the areas of the development of natural coral reef communities

Рис. 1. Карта двух локаций в прибрежной акватории южно-центрального Вьетнама (провинции Кхань Хоа и Дак Лак), где были размещены модули Reef Ball. 1 — охраняемая акватория в локации 1; 2 — рекреационная акватория в локации 2. Звёздочками показаны зоны развития естественных коралловых сообществ

Characteristics of Reef Ball modules. Concrete RB modules were designed in classic dome shape with sizes as follows: 120 cm in height; 180 and 50 cm in diameter of the lower and upper cross-sections, respectively; surface area 5.1 m^2; wall thickness 15 cm; and total weight 1,300 kg (Fig. 2). Each module was supplied with holes for screwing special pins assigned for fixing coral fragments directly or fixing the plastic grid with pre-fixed coral fragments. The design of RB modules in the present project differed from that in previous study [Dan, Tuyen, 2017] by larger sizes and weight, which made the modules a very stable and durable foundation at any hydrodynamic impacts. In location 1 (MPA), the exposition of RB modules reached three years (July 2022 – July 2025); in location 2 (RA), one year (July 2024 – July 2025).

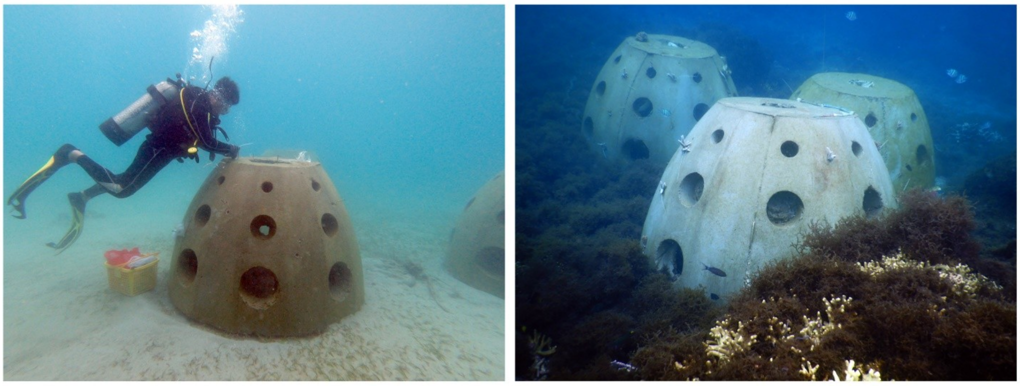

Fig. 2. Reef Ball modules deployed in two locations. Coral fragments fixed on pins are seen on the right photo

Рис. 2. Модули Reef Ball в двух локациях. На правом фото видны фрагменты кораллов, прикреплённые к специальным штырям

Sampling and data analysis. Surveys on coral recruitment rates, as well as on growth rates of coral recruits and transplants, were carried out using SCUBA and *in-situ* estimation and measurements with Vernier caliper (precision 0.1 mm). All coral recruits > 5 mm were counted. The largest dimension of a colony was accepted as the size of a recruit. Two fast-growing and common Indo-Pacific coral genera were used for transplantation experiments: *Acropora* (*A. muricata*, *A. intermedia*, *A. latistella*, and *A. hyacinthus*) and *Pocillopora* (*P. verrucosa*). Linear extension rate was determined based on change in the transplant length over one year. The distance between two longest branches was accepted as the length for the estimation of linear extension of branching *A. muricata*, *A. intermedia*, and *P. verrucosa*. For the same purposes, in planar *A. latistella* and *A. hyacinthus*, the largest diameter of a colony was accepted. In addition, the increment in the number of new branches for arborescent *A. muricata* and *A. intermedia* was estimated. The annual survival rates of coral transplants were accepted as the percentage of survived transplants of a single species over one year. A transplant was considered dead if it had no living tissue left and/or was covered by other organisms: algae, barnacles, or ascidians.

The fish abundance and diversity were assessed using fish video belt transect method [Pelletier et al., 2011; Tessier et al., 2005]. Three belt transects of 25 × 4 m in size were deployed haphazardly within the area of RB modules' placement after 1-year exposition of the latter and surveyed simultaneously by two divers.

Differences in recruitment rates, and growth rates of dominant coral recruits and coral transplants were tested using one-way analysis of variance (ANOVA). Data were tested for homogeneity of variance (Cochran's *C* test) and log-transformed when required [log (x) + 1]. Statistica 8.0 software for Windows (StatSoft Inc.) was used for calculations.

RESULTS AND DISCUSSION

Coral recruitment and growth rates. Deployed RB modules significantly contributed to the enhancement of coral recruitment in both locations. The total number of coral recruits in location 1 (MPA) after 1-year exposition compiled 319 recruits *per* 34 RB modules; variation and mean were 7–15 and (9.5 ± 2.2) recruits·module^{-1}, respectively. In location 2 (RA), totally 240 coral recruits settled within 1-year on 30 RB modules, with variation and mean of 4–14 and (8 ± 2.1) recruits·module^{-1}. Difference between locations in mean number of recruits *per* module was not statistically significant (ANOVA, $F = 3.736$, $P = 0.053$). The longer, 3-year exposition in MPA showed high coral recruitment rates [variation 33–60 recruits·module^{-1}, and mean (42.5 ± 6) recruits·module^{-1}] and a noticeable [14.7-fold] increase in proportion of *Porites* spp. in total number of recruits (Fig. 3).

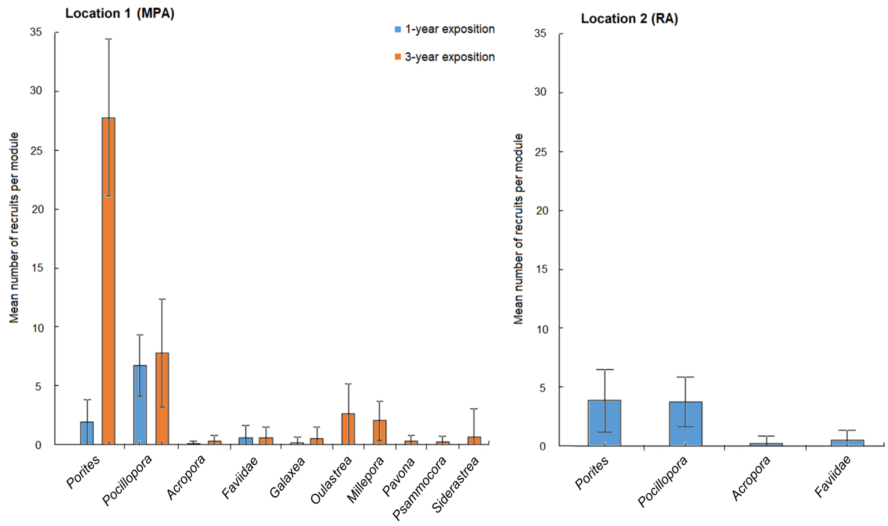

Fig. 3. Recruitment rates (mean ± *SD*) during 1-year and 3-year exposition of Reef Ball modules in location 1 (Dam Bay, marine protected area) and 1-year exposition in location 2 (Hon Nua Island, recreational area)

Рис. 3. Темпы рекрутинга (спата) кораллов (среднее ± стандартное отклонение) в течение 1-летней и 3-летней экспозиции модулей Reef Ball в локации 1 (Дам Бай, охраняемая акватория) и 1-летней экспозиции в локации 2 (остров Хон Ныа, рекреационная акватория)

The taxonomic compositions of coral recruits on RB modules in both locations were likely site-specific. In MPA, recruits of *Pocillopora* spp. contributed the most during the first year of exposition (Figs 3, 5A). It can be explained by the redundant surrounding resources of this coral genus in location 1, where *Pocillopora* dominates on shallow natural rocky and limestone boulders. Moreover, *Pocillopora* spp. (mostly *P. verrucosa*) are the main objects in coral culture experiments within MPA, where at least 300 polyvinyl chloride frames (1 × 2 m each) with ~700 cultured *Pocillopora* colonies have been deployed nearby RB modules (in 100-m radius) since 2017. However, 3-year exposition of RB modules in MPA resulted in an increase in both abundance and diversity of the recruits' pool and in a change of a recruitment pattern towards the overwhelming dominance of *Porites* recruits (Fig. 3). In spite of the lack of *Porites* spp. within MPA, the closest dense thickets of branching *Porites cylindrica* and large, massive heads of *Porites lobata* are located in the inner upstream part of Dam Bay in 1.2 km northeast from the area of deployment of RB modules (see Fig. 1). This neighborhood might cause such a contribution of *Porites* spp. to the recruitment pattern.

The 1-year recruitment pattern in location 2 (RA) was similar to that in location 1: *Porites* spp. and *Pocillopora* spp. were the major contributors to the recruitment pool. Nevertheless, the initial recruitment of *Pocillopora* spp. in MPA was 2.1-fold higher than that in RA (Fig. 3). The large proportion of *Porites* recruits in the recruitment pool of RA can be mediated by the closest proximity of RB modules to dense thickets of *P. cylindrica* at this location. *Pocillopora* spp., due to their mostly weedy (ruderal) life strategy [Darling et al., 2012; Kayal et al., 2015], are pioneers, which opportunistically occupy available hard surfaces in reef environments and tend to dominate coral assemblages at the earlier stages of disturbance due to high recruitment and growth rates, and also due to fast turnover among generations [Kayal et al., 2015; Lenihan, Edmunds, 2010].

Porites cylindrica is also known to have weedy life strategy [Darling et al., 2012], rapid growth, and high resistance to stress [Fitt et al., 2009; Visram, Douglas, 2007], which makes this coral a significant recruiter, with high relative abundance compared to that of other species. Thus, the predominance of these two species in the recruitment pool can be driven by both their redundancy in surrounding environment and by their life strategies. *Pocillopora* and *Porites* are considered resilient coral taxa due to sustained recruitment that promotes demographic elasticity through a constant replacement of individuals and resistance to perturbations [Kayal et al., 2015; Mumby et al., 2014].

Natural coral recruitment is affected by sedimentation [Fabricius, 2005; Hodgson, 1990; Rogers, 1990], type of substrate [Burt et al., 2009; Harriot, Fisk, 1987], competition with algae and other epifauna representatives [Chadwick, Morrow, 2011; McCook et al., 2001; Norström et al., 2009], and pollution [Markey et al., 2007]. Such environmental parameters, as geographic location, surrounding substrate, proximity to other natural habitats, water depth, and general hydrodynamic conditions in the area of deployment, must be conducive to coral recruitment [Sheng et al., 2000]. Natural coral recruitment has been widely acknowledged as an important process for the successful maintenance of coral reef systems, particularly in the recovery and replenishment stages following disturbances [Glassom et al., 2006; Raj, Patterson Edward, 2012].

Notably, the recruitment of Acroporidae (mostly *Acropora*) in 1-year period was very low in both locations, (0.05 ± 0.01) in location 1 and (0.23 ± 0.14) in location 2, despite proximity of location 1 (MPA) to a natural source of branching *Acropora* and *Montipora* in the inner part of the bay and availability of several sources of cultured *Acropora* within MPA. The natural reef near location 2 (RA) showed scarce occurrence of *Acropora*. The negligible proportion of *Acropora* in the recruitment pattern was similar to that in the Gulf of Mannar, where during almost 15-year exposition of ferro-cement artificial modules at 6-m depth, the recruitment pattern was determined mostly by massive coral taxa, Faviidae and Poritidae, together with *Turbinaria* in spite of the fact that surrounding natural substrata were dominated by *Acropora* and *Montipora* [Raj et al., 2020]. Recruitment of Acroporidae is highly dependent on sedimentation rates, presence of crustose coralline algae, and surface roughness [Baird, 2001; Ricardo et al., 2017]. Moreover, in contrast to *Pocillopora* and *Porites*, the established populations of adult acroporids have positive attractiveness for *Acropora* recruits [Kayal et al., 2015; Pisapia et al., 2019]; this feature may also be one of determinants of the recruitment patterns on RB modules within the first year of exposition.

Size ranges of coral recruits belonging to *Porites* and *Pocillopora*, two genera with the highest contribution to the recruitment pool during 1-year exposition, are shown in Fig. 4. The mean size of *Porites* recruits in MPA was significantly larger than in RA (ANOVA, $F = 8.536$, $p < 0.01$), whereas the larger size of *Pocillopora* recruits in location 1 was not confirmed statistically (ANOVA, $F = 3.874$, $p = 0.055$). The size range and spatial patterns of coral recruits are strongly related to time of settlement [Martinez, Abelson, 2013]. Larger sizes of dominant coral recruits in MPA can be stipulated by difference between MPA and RA in time of coral spawning peaks. However, other, unknown environmental factors in MPA may also contribute to the difference in size range of recruits.

Linear growth rates were estimated for transplants of five coral species (Table 1, Fig. 5B).

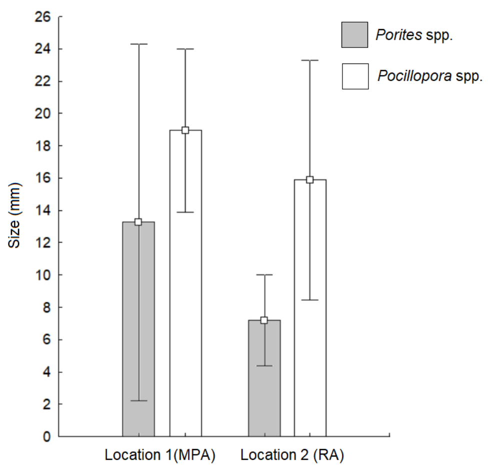

Fig. 4. Size variation (mean ± *SD*) of two main contributors to coral recruitment in two locations after 1-year exposition of Reef Ball modules

Рис. 4. Вариация размеров молоди (среднее ± стандартное отклонение) двух коралловых таксонов, характеризующихся наибольшим вкладом в коралловый рекрутинг (спат) в двух локациях размещения модулей Reef Ball, после первого года экспозиции

Table 1. Annual mean linear extension (mm·year^{-1}) and survival rate (%) of coral transplants on Reef Ball modules. Location 1 is Dam Bay (marine protected area); location 2 is Hon Nua Island (recreational area)

Таблица 1. Средний годовой линейный рост (мм·год$^{-1}$) и выживаемость (%) трансплантов кораллов на модулях Reef Ball. Локация 1 — Дам Бай (охраняемая акватория); локация 2 — остров Хон Ныа (рекреационная акватория)

Species	Location 1		Location 2	
	Mean extension	Survival rate	Mean extension	Survival rate
Pocillopora verrucosa	90.1 ± 11.3 (55)	79.4	67.7 ± 16 (28)	70.5
Acropora muricata	81.1 ± 7.7 (45) *4.5 ± 1.4	72.3	94.3 ± 19 (33) *6.1 ± 1.4	67
Acropora intermedia	92.6 ± 18 (46) *3.3 ± 1	66.1	–	–
Acropora latistella	122.5 ± 14.2 (46)	68.4	76.9 ± 11.2 (35)	71.5
Acropora hyacinthus	98.1 ± 14.3 (10)	70	–	–

Note: annual mean extension is given as mean ± *SD*; the number of coral transplants is provided in brackets; *, mean increment of branches.

Примечание: средний годовой рост указан как среднее значение ± стандартное отклонение; количество пересаженных кораллов приведено в скобках; средний прирост ветвей отмечен астериском.

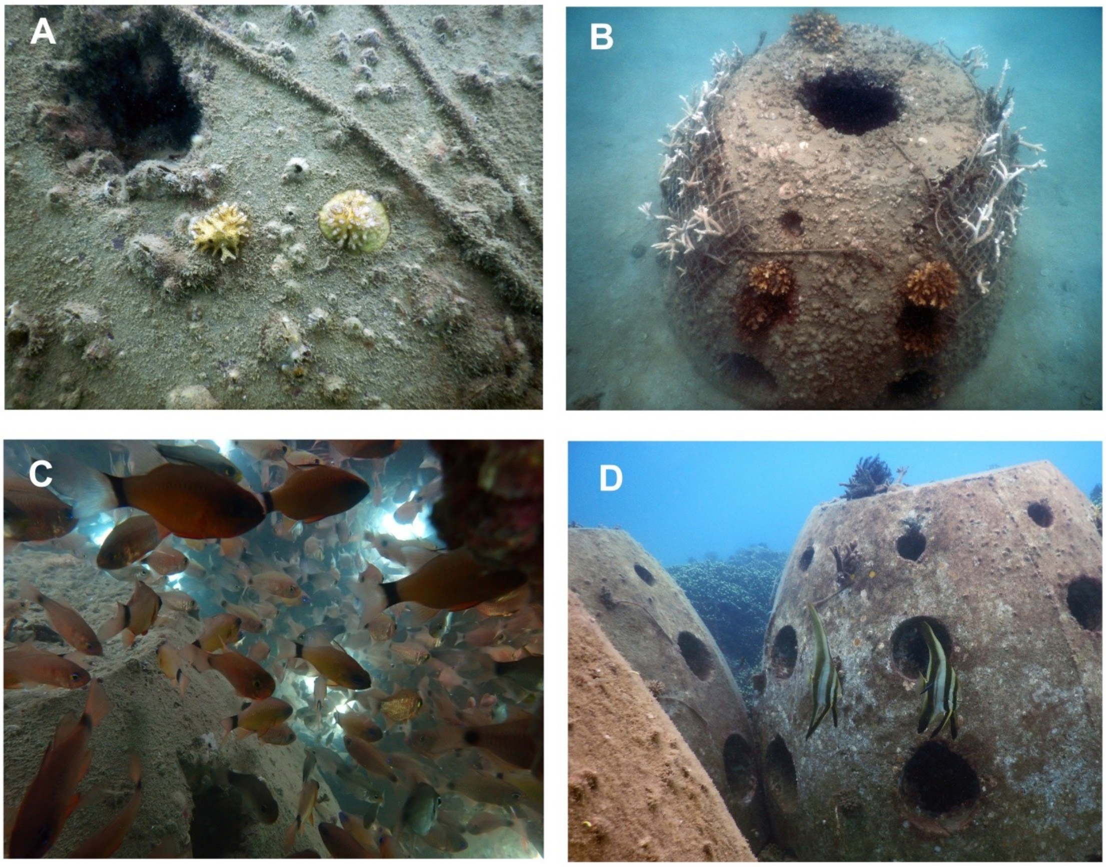

Fig. 5. A, recruits of *Pocillopora* sp. on the surface of Reef Ball (RB) module; B, growth of coral transplants of *Acropora* and *Pocillopora* on RB module; C, D, fish diversity at RB modules

Рис. 5. A — рекруты (молодые колонии) *Pocillopora* sp. на поверхности модуля Reef Ball (RB); B — рост трансплантов кораллов из родов *Acropora* и *Pocillopora* на RB-модуле; C, D — разнообразие рыб у RB-модулей

The transplants of *P. verrucosa*, one of the dominant coral taxa on natural substrate and in the recruitment pool in location 1 (MPA), had statistically significantly higher growth rates (ANOVA, $F = 70.513$, $p < 0.001$) and survival rates than those in location 2 (RA) (see Table 1). Among two planted in both locations *Acropora* species, the corymbose transplants of *A. latistella* showed noticeably higher growth rates in MPA (ANOVA, $F = 17.632$, $p < 0.001$), whereas arborescent transplants of *A. muricata* had better growth (ANOVA, $F = 12.456$, $p < 0.001$) and increment of branches in RA (Table 1).

According to Osinga *et al.* [2011], the primary requirements for coral growth are: light and inorganic nutrients (needed for photosynthesis); organic food (for organic tissue synthesis and organic matrix synthesis); and calcium and dissolved inorganic carbon (carbon dioxide, bicarbonate, and carbonate) (for skeleton formation). In addition to these basic requirements, water movement is an important factor facilitating coral metabolism. There are several factors inhibiting coral growth: increase in SST above coral bleaching threshold, UV radiation, pollution, sedimentation, decrease of dissolved oxygen, and biological stressors (predators or spatial competitors) [Fabricius, 2005; Osinga et al., 2011]. The phenomenon of higher growth rates of two test coral taxa within MPA may partly be stipulated by higher nutrient and organic natural influx during wet season in Dam Bay (location 1), which may contribute to coral growth, in comparison to the open sea site, Hon Nua Island (location 2). However, this hypothesis requires further investigation. It is known that slight nutrient enrichment (especially with nitrogen, like ammonium) may boost coral growth by feeding their symbiotic algae (Zooxanthellae) and improving photosynthesis [Dunn et al., 2012]. However, this benefit is a delicate balance; higher concentrations of phosphorus can become harmful, promoting algal overgrowth, bleaching, disease, and weaker skeletons, and also highlighting a crucial dose-dependent relationship [D'Angelo, Wiedenmann, 2014].

Fish population dynamics. An assessment of fish diversity and abundance revealed significant differences between two locations after 1-year exposition of RB modules (Table 2). Location 1 (MPA) exhibited an increase in fish diversity to 18 species, whereas location 2 (RA), to 10 species. Three-year exposition of RB modules within MPA resulted in a rise in fish diversity to 33 species and a 2-fold increase in fish abundance (see Table 2, Fig. 5C, D). Such differences in the development of reef fish community on RB modules demonstrated as follows: despite harsher hydrological conditions in location 1, protection from both artisanal fishing and disturbance related to regular boat-induced noise pollution within MPA resulted in higher fish abundance and diversity.

Underwater noise can affect both physiology and behavior of fish on a wide-ranging scale, from minor changes and adaptations to major injury and death. Noise from engine boats negatively affects coral fish by disrupting critical behaviors: feeding, anti-predator responses, and reproduction [Simpson et al., 2016; The Effects of Noise on Aquatic Life II, 2016]. It may cause stress, mask communication, reduce foraging efficiency, and hinder the development of embryos, ultimately affecting individual fitness and population health [Popper et al., 2004; Simpson et al., 2016]. Moreover, anthropogenic noise affects the way juvenile fish assess risk, which will reduce individual fitness and survival [McCormick et al., 2018]. Our data on fish settlement on RB modules showed that even the creation of appropriate artificial environment will not enhance fish diversity and abundance, if this environment is confined to areas of constant disturbance including noise pollution and fishing. In contrary, even the smallest no-take reserves (about 1–5 km^2), like MPA of location 1, are known to provide conservation benefits in terms of enhancing diversity and biomass of sedentary target species within their boundaries [Halpern, 2003; Tkachenko, Soong, 2010], and ensure some fish spillover into adjacent unprotected areas [Gell, Roberts, 2003; Halpern, 2003; Russ et al., 2004].

Table 2. Fish diversity and mean abundance (fish·100 m^{-2} ± SD; n = 3) in two locations of Reef Ball deployment after 1-year and 3-year exposition

Таблица 2. Разнообразие рыб и их среднее обилие (рыб·100 м$^{-2}$ ± SD; n = 3) в двух локациях, где были размещены модули Reef Ball, после 1-летней и 3-летней экспозиции

No.	Species	Location 1 (MPA)		Location 2 (RA), 1-year exposition
		1-year exposition	3-year exposition	
1	*Pritolepis fasciatus*	9 ± 1	6 ± 2	9 ± 2
2	*Sillago sihama*	10 ± 1	6 ± 2	7 ± 2
3	*Amphiprion polymnus*	1 ± 1	2 ± 2	
4	*Dascyllus trimaculatus*	36 ± 4	30 ± 6	25 ± 4
5	*Dascyllus reticulatus*	16 ± 4	21 ± 4	30 ± 3
6	*Canthigaster valentini*	3 ± 1	4 ± 1	
7	*Cheilinus chlorourus*	4 ± 1	3 ± 1	10 ± 2
8	*Pomacentrus* sp.	5 ± 1	9 ± 3	
9	Apogonidae	5 ± 1	12 ± 4	
10	*Chaetodon lunula*	4 ± 1	4 ± 1	
11	*Chaetodon auriga*	4 ± 1	4 ± 1	
12	*Chromis* sp.	4 ± 1	14 ± 3	
13	*Scarus ghobban*	2 ± 1	7 ± 3	
14	*Labroides dimidiatus*	3 ± 2	6 ± 2	5 ± 2
15	*Abudefduf vaigiensis*	14 ± 3	12 ± 6	
16	*Abudefduf bengalensis*			15 ± 2
17	*Heniochus diphreutes*	2 ± 1	2 ± 1	7 ± 1
18	*Pterois volitans*	1 ± 1	1 ± 1	1 ± 1
19	*Siganus guttatus*	8 ± 2	7 ± 3	
20	*Platax teira*			1 ± 1
21	*Arothron hispidus*		1 ± 1	
22	*Ostracion cubicus*		1 ± 1	
23	*Plotosus lineatus*		11 ± 10	
24	*Cheilodipterus quinquelineatus*		27 ± 4	
25	*Lutjanus fulviflamma*		15 ± 4	
26	*Lutjanus fulvus*		5 ± 2	
27	*Aeoliscus strigatus*		35 ± 10	
28	*Thalassoma lunare*		7 ± 3	
29	*Scolopsis ciliata*		6 ± 2	
30	*Monotaxis heterodon*		3 ± 2	
31	*Acanthurus xanthopterus*		3 ± 2	
32	*Cantherhines pardalis*		6 ± 2	
	Total mean abundance	131 ± 7	272 ± 20	110 ± 6

Conclusions. The deployment of Reef Ball (RB) modules in two coastal locations of south-central Vietnam has become a stepping stone for implementation of this method of reef restoration in Vietnamese waters. The first achievements were the development of coral communities in the new environment determined by artificial structures. Three-year exposition of RB modules in a marine protected area resulted in a 4-fold increase in density of coral recruits on the modules' surface and a 2-fold rise in fish diversity and abundance in the new environment. The boat-induced noise pollution in recreational area limits the development of reef fish community. The annual mean survival rate of coral transplants on RB modules in both locations was rather high (70.6%). From the preliminary results obtained in the study, it becomes clear that deployment of artificial reefs, such as RB modules, in a degraded reef environment is highly effective in promoting proto reef and boosting coral recruitment and reef ecosystem rehabilitation. However, protection from anthropogenic disturbances may significantly enhance the outcome of this technology in marine environments.

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ВНЕДРЕНИЕ ИСКУССТВЕННЫХ КОНСТРУКЦИЙ REEF BALL В МОРСКИХ АКВАТОРИЯХ ЮЖНО-ЦЕНТРАЛЬНОГО ВЬЕТНАМА ДЛЯ ВОССТАНОВЛЕНИЯ КОРАЛЛОВЫХ РИФОВ: ПЕРВЫЕ ДОСТИЖЕНИЯ

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В мировой практике среди методов восстановления коралловых рифов технология Reef Ball™ (RB), в которой предполагается применение искусственных бетонных модулей, имитирующих естественные рифовые структуры, хорошо известна и используется на протяжении трёх десятилетий в более чем 55 странах. Эти модули служат средой обитания и способствуют увеличению разнообразия рыб, а также являются подходящих твёрдым субстратом для естественного заселения и для искусственной трансплантации рифообразующих кораллов. Проект по внедрению технологии RB в южно-центральном Вьетнаме стартовал в 2023 г. Использованы два комплекта RB-модулей в двух морских акваториях — в охраняемой (ОА) и рекреационной (РА).

Целью настоящего исследования было оценить эффективность RB-модулей в стимулировании осаждения коралловых планул (рекрутинга) и в увеличении разнообразия и обилия рыб. Экспозиция первого года показала сходные паттерны кораллового рекрутинга для ОА и PA с доминированием кораллов из родов *Porites* и *Pocillopora*. Плотность коралловой молоди составила (9,5 ± 2,2) и (8 ± 2,1) рекрутов·модуль$^{-1}$ в ОА и PA соответственно. В ОА разнообразие и обилие рыб достигли значений 18 видов и (131 ± 6) рыб·100 м$^{-2}$ соответственно, в PA — 10 видов и (110 ± 7) рыб·100 м$^{-2}$. Более длительная, трёхлетняя экспозиция RB-модулей в ОА показала четырёхкратный рост плотности коралловой молоди, до (42,5 ± 6) рекрутов·модуль$^{-1}$, и абсолютное доминирование кораллов рода *Porites* в спате. Обилие рыб за этот период увеличилось вдвое, а разнообразие возросло до 33 видов. Настоящая работа показала, что применение RB-модулей может быть эффективным для восстановления рифовых экосистем в прибрежных акваториях с различным статусом эксплуатирования. Тем не менее защита от антропогенного воздействия может значительно улучшить результаты использования этой технологии в морской среде.

Ключевые слова: Reef Ball, Вьетнам, коралловый рекрутинг, разнообразие рыб, восстановление рифов