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EVALUATION OF THE EFFECT OF A MARINE PROTECTED AREA ON ROCKY INTERTIDAL MOLLUSCS IN WEH ISLAND, INDONESIA

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Abstract

A partial marine protected area (MPA) has been established in Weh Island, Indonesia since 2010 to ptotect marine biodiversity. However, the influence of this MPA on rocky intertidal assemblages is currently not evaluated. The present study analysed differences in molluscan assemblages (species density, abundance, and species composition) inside and outside the protected area using permutational multivariate analysis of variance to evaluate the effectiveness of this MPA. Twenty-five species of molluscs were identified. Tenguilla musiva was the most frequent and the most abundant species. Species composition was significantly different between inside and outside the MPA (p perm<0.05), but species density and abundance showed insignificant differences (p perm>0.05). The abundance of a non-targeting species, Cerithium litteratum, was significantly higher inside the MPA (p perm<0.05), but that of other species including some targeting species was not significantly different between inside and outside the MPA (p perm>0.05). These results indicate that the newly established and partial MPA in Weh Island is currently not effective enough for protecting molluscan assemblages on rocky intertidal shores.

***Keywords**: Marine protected area; Partial protection, Molluscan assemblages; Tenguilla musiva; Cerithium litteratum; Rocky intertidal shores; Weh Island*

Introduction

Marine protected areas (MPAs) are an effective management tool for protecting marine biodiversity [1]. The establishment of MPAs is more important in small islands (less than 10,000km^2) as these islands often have high biodiversity and endemicity levels [2, 3] but are vulnerable to human activities, including overfishing [4, 5] and tourism [6]. Meanwhile, the population of marine species in small islands mainly relies on self-recruitment [7] as the larvae from the mainland need travelling long distances (up to thousands of kilometers in several months) to settle in the islands [8]. Therefore, the development of MPAs is one of the high priorities in conservation and natural resource management in small islands [9].

The effectiveness of MPAs to preserve biodiversity depends on the level and age of protection. Full protection or no-take zone is the most effective MPA in protecting biodiversity and increasing ecosystem resilience [10]. Nevertheless, 94% of MPAs in the world implement

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partial protection that allows limited extractive activities (e.g., fishing) [11] to gain both conservation and socio-economic benefits [12]. The effectiveness of MPAs in preserving biodiversity also increases with the age of protection [13, 14]. Conservation benefits of MPAs can be received after 5 to 10 years of establishment depending upon the level of protection [14-20].

Rocky intertidal shores are often more accessible to visitors making marine organisms on these habitats more vulnerable to human activities, including collecting [21] and trampling [22]. MPAs in rocky intertidal shores are important to protect marine flora and fauna diversity and density. MPAs provide positive impacts on rocky intertidal assemblages in many places [15-17, 20, 23-28] but not in some locations, such as California Marine Managed Areas [29], Parque Litoral Norte, Portugal [30], Bouddi Marine Extension, Australia [31], and Biophysical Interest Zone of Avencas, Portugal [32]. However, those previous studies are limited to the evaluation of fully protected and/or old MPAs (>10 years protection). So far, the effect of newly established (<10 years protection) and partial MPAs on rocky intertidal assemblages remains unknown.

The Indonesian government has established a partial MPA in the eastern part of Weh Island, a small tropical island in the Indian Ocean since 2010 [33]. This island has high marine biodiversity [34-36] and some of them are endemic species [37]. Therefore, the establishment of MPA in Weh Island is important to protect marine biodiversity around the island. However, evaluating the effect of the MPA in this island is limited to subtidal assemblages (corals and reef fishes) [38]. Up to the present, the effectiveness of new and partial MPA on rocky intertidal assemblages in Weh Island is not evaluated, yet almost 200,000 tourists annually visit the island [39] for beach and water activities [40, 41] that probably disturb rocky intertidal assemblages. Physical disturbances in Weh Island are expected to increase in the next years after the Indonesian government prioritises this island for an ecotourism destination in 2020-2024 [42].

Previous studies evaluated effects of MPAs in rocky intertidal shores by analysing distribution patterns of molluscan assemblages [15, 20, 23-26, 28, 29, 31, 43]. These assemblages are selected because they are diverse [44], important in many ecological processes (e.g., herbivory) [45], valuable food and ornamental sources [46-48], and show different responses to anthropogenic activities, including collecting [21, 49], trampling [22], and coastal pollution [50]. The effectiveness of MPAs can be evaluated by comparing marine assemblages before and after the establishment of MPAs or between inside and outside the protected areas depending on the availability of baseline data [51].

Here, we aim to evaluate the effectiveness of a new and partial MPA in rocky intertidal shores of Weh Island. The evaluation was done by analysing differences in species diversity, abundance, and species composition of molluscan assemblages between inside and outside the protected area because baseline data before the establishment of MPA are not available. Our study can be used as a scientific consideration for the Indonesian government in designing the MPA in Weh Island to achieve marine conservation goals.

Materials and methods

Study area

Weh Island is a small (120.7km^2), tropical, the westernmost island of Indonesia located in the Indian Ocean with the distance to the mainland (Sumatra Island) of about 16km (Fig. 1). The coastline of this island is dynamic; eroded from 2002 to 2009 and accreted between 2009 and 2015 [52]. The island has two seasons that are influenced by the southward and northward movement of the inter-tropical convergence zone: dry season occurs from February to August and wet season occurs between September and January [53]. Sea surface current velocity ranges from 0.19 to 0.38m/s with the directions toward northwest and southeast [54] depending upon bathymetry profiles and seasons [55]. Sea surface temperature ranges from 29.40 to 29.90°C, and surface salinity is between 30.8 and 31.4ppt [54]. Weh Island has a mixed semidiurnal tidal cycle with a height of about 1.9m [54] and the velocity of up to 0.85m/s [56].

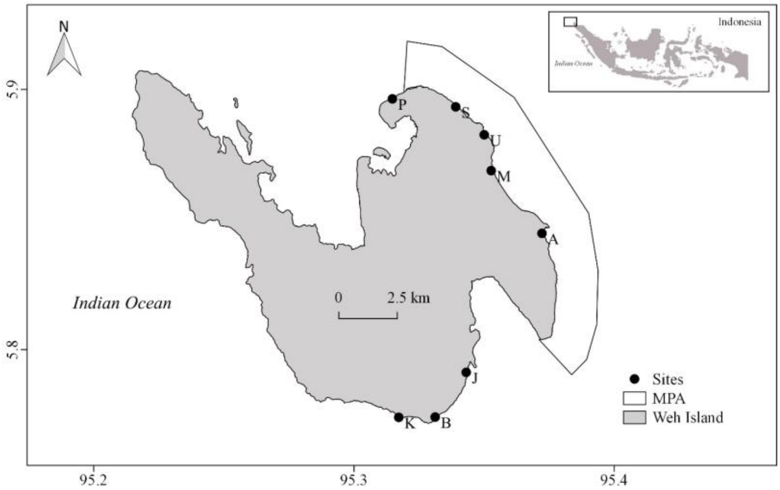

Fig. 1. Sampling sites for the observation of molluscan assemblages in Weh Island, Indonesia. Sites inside marine protected area (MPA) were Sumur Tiga (S), Ujong Kareung (U), Mata Ie (M), and Anoi Itam (A). Sites outside the MPA were Pantai Kasih (P), Jaboi (J), Beurawang (B), and Keneuikai (K)

Local government regulates spatial planning in Weh Island for the period of 2012-2032. The northern part of the island is mainly used for housing development, the western and eastern part are developed for tourism, and the southern part is for industrial area, including national and fish landing port [57]. The Indonesian government has also established an MPA ($32.07km^2$) in the eastern part of Weh Island since 2010 to sustain marine resources. The MPA is managed by national government, local government, and local leaders (Panglima Laot, "sea commander" in Acehnese dialect). Recreational activities and fishing with limited gears are permitted inside the MPA, except for harvesting ornamental and reef fishes [33, 58].

Observation design

The observation design consisted of three factors. The first factor was location, fixed, with two levels: inside and outside the MPA. The second factor was site, random, nested within the location, with four sites inside the MPA (Anoi Itam, Mata Ie, Sumur Tiga, and Ujong Kareung) and four sites outside the MPA (Pantai Kasih, Jaboi, Beurawang, and Keneukai). All those sites are distributed around the eastern part of Weh Island with the linear distance between adjacent sites is around 1 to 7km (Fig. 1). The third factor was transect, random, nested within the site, with three transects at each site.

Sampling technique

Molluscan assemblages (the size of >2cm) were observed in the dry season (March 2018) at low tide. Three belt transects of 4x50m separated by 100m were placed perpendicularly to the shoreline at each site. Molluscan assemblages inside the transects were identified *in situ* up to the lowest taxon possible and counted individually. Unidentified species were collected and preserved in 96% ethanol for further identification in the laboratory. Species names were validated based on World Register of Marine Species (www.marinespecies.org).

Data analysis

Differences in species density, abundance, and species composition of molluscan assemblages inside and outside the MPA were analysed using permutational multivariate analysis of variance (PERMANOVA) with two nested factors (site and transect) and 999 permutations. The PERMANOVA test for differences in species density and abundance was conducted on the basis of Euclidean distance dissimilarity measure on untransformed data, and the test for species composition was carried out based on Bray-Curtis's dissimilarities on Hellinger-transformed species abundance data [59].

The overall dissimilarity of species composition between inside and outside the MPA and the contribution of each species to that difference was determined using similarity percentage (SIMPER) with 999 permutations [60]. The difference in the abundance of each species inside and outside the MPA was then analysed using PERMANOVA based on the Euclidean distance dissimilarity measure on untransformed data with two nested factors (site and transect) and 999 permutations.

Principal Coordination Analysis (PCOA) was used to ordinate species composition inside and outside the MPA [61]. Data analysis and visualisation were performed using a free software R (https://www.r-project.org/) with the following packages: 'vegan' [62] and 'ggplot2' [63].

Results

A total of 506 individuals belonging to 25 species (Gastropoda: 22 species, Bivalvia: 3 species) was identified. We found 20 species inside the MPA and 19 species outside the MPA. Six species (*Conus coronatus*, *Conus litteratus*, *Naria erosa*, *Nassarius* sp., *Tridacna squamosa*, and *Turbo bruneus*) were only found inside the MPA, and five species (*Bursa bufonia*, *Drupa morum*, *Pinna* sp., and two species of nudibranch) were only detected outside the MPA. *Tenguella musiva* was the most frequent (75% of total transects) and the most abundant species (50.40% of total individuals) (Table 1).

Table 1. Molluscan species found in the easten part of Weh Island, Indonesia, with their occurrences over transects (F) and relative abundance (N)

Species	F (%)	N (%)	Species	F (%)	N (%)
Bursa bufonia (G)	4.17	0.40	*Naria erosa* (G)	4.17	0.20
Cerithium litteratum (G)	16.67	8.50	*Nassarius* sp. (G)	4.17	0.59
Conus coronatus (G)	4.17	0.20	*Nerita albicilla* (G)	16.67	1.58
Conus ebraeus (G)	25.00	1.38	Nudibranch 1 (G)	4.17	0.20
Conus frigidus (G)	8.33	0.59	Nudibranch 2 (G)	4.17	0.20
Conus litteratus (G)	8.33	0.40	*Strigatella retusa* (G)	25.00	6.72
Cypraea caputserpentis (G)	20.83	1.58	*Tenguella musiva* (G)	75.00	50.40
Drupa morum (G)	8.33	1.58	*Tridacna crocea* (B)	58.33	7.11
Engina mendicaria (G)	12.50	0.59	*Tridacna squamosa* (B)	8.33	0.59
Harpago chiragra (G)	8.33	0.40	*Trochus histrio* (G)	12.50	0.99
Latirolagena smaragdulus (G)	50.00	11.66	*Turbo bruneus* (G)	4.17	0.20
Pictocolumbella ocellata (G)	12.50	1.19	*Vasum turbinellus* (G)	33.33	2.57
Pinna sp. (B)	4.17	0.20			

Note: G is Gastropoda, and B is Bivalvia

PERMANOVA tests showed that species density and abundance not significantly differed between inside and outside MPA (p perm > 0.05) (Table 2), around 4 – 4.5 species/transect and 20 – 22 individuals/transect, respectively (Fig. 2). In contrast, species composition was significantly different between inside and outside the MPA (p perm < 0.05) (Table 2), with the overall dissimilarity of 74.21% based on SIMPER analysis.

The difference in species composition between inside and outside the MPA was visualised in the PCOA plot with 35.13% of total variation (PCOA1 = 21.07% and PCOA = 14.06%). Species composition was clearly separated between inside and outside the MPA based on this ordination, especially between molluscan assemblages in the Mata Ie (inside the MPA) and those in other sites (Fig. 3).

Table 2. Permutational multivariate analysis of variance results for differences in species density, abundance, and species composition of molluscan assemblages between inside and outside marine protected area (MPA) in Weh Island, Indonesia

Source of variation	DF	Species Density		Abundance		Species Composition	
		Pseudo-F	**p-perm**	**Pseudo-F**	**p-perm**	**Pseudo-F**	**p-perm**
MPA	2	1.128	0.383	1.327	0.332	2.674	0.004
MPA/Site	5	3.801	0.058	3.724	0.076	3.049	0.001
MPA/Site/Transect	8	0.745	0.676	2.517	0.283	1.379	0.092
Residuals	8						

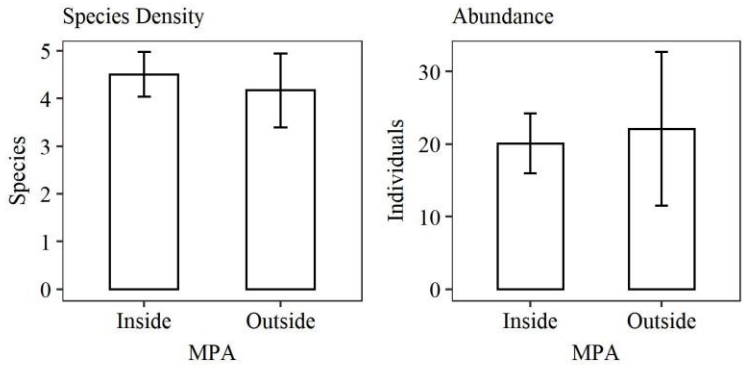

Fig. 2. Species density (species/200m^2) and abundance (individuals/200m^2) of molluscan assemblages inside and outside of marine protected area (MPA) of Weh Island, Indonesia

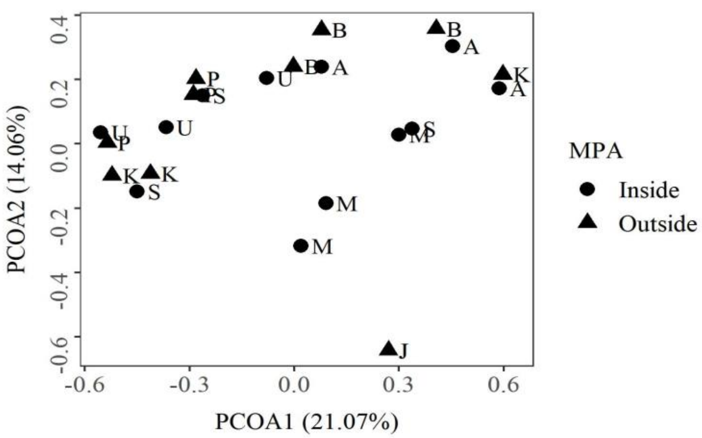

Fig. 3. Principal Coordination Analysis (PCOA) plot of mollusca assemblages inside and outside marine protected area (MPA) in Weh Island, Indonesia. Sites inside the MPA were Sumur Tiga (S), Ujong Kareung (U), Mata Ie (M), and Anoi Itam (A). Sites outside the MPA were Pantai Kasih (P), Jaboi (J), Beurawang (B), and Keneuikai (K).

SIMPER analysis showed that ten species (*Tenguella musiva*, *Tridacna crocea*, *Latirolagena smaragdulus*, *Strigatella retusa*, *Vasum turbinellus*, *Cerithium litteratum*, *Nerita albicilla*, *Conus ebraeus*, *Pinna* sp., and Nudibranch 1) contributed to 75% cut-off difference in species composition between inside and outside the MPA. The abundance of *Cerithium litteratum* was significantly higher inside the MPA (p perm < 0.05) with a difference of over 3 individuals/transect, while that of *Strigatella retusa* was twice higher outside the MPA (p perm < 0.05). The abundance of other species not significantly differed between inside and outside the MPA (p perm > 0.05) (Table 3).

Table 3. Similarity percetage results for differences in the species composition of molluscan assemblages between inside and outside marine protected area (MPA) in Weh Island, Indonesia: average abundance of each species (individuals/200 m^2), their contribution (%) to the dissimilarity between inside and outside MPA, and the cummulative of the contribution

Species	**Abundance**		**Contribution**	**Cummulative**
	Inside	**Outside**		
Tenguella musiva	5.67	15.58	12.66	17.07
Tridacna crocea	1.50	1.50	9.40	29.74
Latirolagena smaragdula	1.33	3.58	7.51	39.87
*Strigatella retusa**	0.92	1.92	6.58	48.78
Vasum turbinellus	0.58	0.50	4.81	55.22
*Cerithium litteratum**	3.50	0.08	4.52	61.31
Nerita albicilla	0.58	0.08	3.62	66.19
Conus ebraeus	0.25	0.33	2.95	70.16
Pinna sp.	0.00	0.08	2.94	74.13
Nudibranch 1	0.00	0.08	2.94	78.09
Trochus histrio	0.08	0.33	2.68	81.70
Cypraea caputserpentis	0.25	0.42	2.44	84.99
Pictocolumbella ocellata	0.08	0.42	1.60	87.15
Conus litteratus	0.17	0.00	1.13	88.67
Drupa morum	0.00	0.67	1.12	90.19
Tridacna squamosa	0.25	0.00	1.06	91.62
Engina mendicaria	0.08	0.17	1.05	93.04
Harpago chiragra	0.08	0.08	0.94	94.30
Conus frigidus	0.08	0.17	0.88	95.48
Conus coronatus	0.08	0.00	0.76	96.50
Nassarius sp.	0.25	0.00	0.66	97.39
Naria erosa	0.08	0.00	0.61	98.21
Turbo bruneus	0.08	0.00	0.55	98.95
Nudibranch 2	0.00	0.08	0.50	99.63
Bursa bufonia	0.00	0.17	0.27	100.00

Note: The symbol of asterisk at species names shows a significant difference in the abundance of those species between inside and outside the MPA (p perm<0.05)

Discussion

Our study found that species diversity, species density, and abundance were not much different between inside and outside the MPA. These results indicate that the current MPA is not effective enough to protect molluscan assemblages in rocky intertidal shores of Weh Island.

The medium-sized MPA (~32km^2) should be sufficient to protect molluscan assemblages in Weh Island as this size still accommodates the home range of most gastropods (<1km^2) [64, 65] and protects marine biodiversity [18, 19]. However, the MPA gives partial protection since it allows sustainable fisheries and tourism. In Weh Island, tourism operators and fishermen seemingly show high participation in rules enforcement [58]. However, visitors may still negatively impact molluscan assemblages inside the MPA through collecting [21] or trampling [22]. In fact, five species (*Bursa bufonia*, *Drupa morum*, *Pinna* sp., and two species of nudibranch) were absent from inside the MPA. Underperforming partial MPA in protecting intertidal molluscs is also reported in the Parque Litoral Norte, Portugal [30].

The MPA of Weh Island is still young, about eight years old when data were collected. Eight-year protection should be enough for tropical molluscs to increase their population as they often spawn throughout the year and become sexually mature in a short period [66].

However, collecting and human trampling may suppress the recruitment of most species inside the MPA of Weh Island as occurred in other places, such as Central Chile [67], northern Port Philip Bay, Australia [49], and Patagonia, Argentina [68]. Conservation benefits of the MPA for the protection of molluscan assemblages in Weh Island maybe not yet gained. In rocky intertidal shores, conservation benefits of partial MPAs for the protection of macroalgal assemblages are obtained after 12 years of establishment [27]. However, this length is still not enough for protecting two invertebrate species: the sea urchin *Paracentrotus lividus* and the mussel *Mytilus galloprovincialis* [30]. Conservation benefits of newly established MPAs (<10 years old) in rocky intertidal shores are only obtained when any extraction activity is not permitted [15-17, 20].

Species composition of molluscan assemblages was significantly dissimilar between inside and outside the MPA. The MPA may differently influence the relative abundance of molluscan species in Weh Island. Individual numbers of *T. musiva*, *T. crocea*, *L. smaragdulus*, *S. retusa*, *V. turbinellus*, *C. litteratum*, *N. albicilla*, *C. ebraeus*, *Pinna* sp., and Nudibranch 1 changed differently from inside to outside the MPA. The MPA also allows species turnover between inside and outside the protected area. *C. coronatus*, *C. litteratus*, *N. erosa*, *Nassarius* sp., *T. squamosa*, and *T. bruneus* were restricted to occupy outside the MPA and replaced by more adaptive species, such as *B. bufonia*, *D. morum*, *Pinna* sp., and nudibranch. The number of species restriction and replacement seems to be equal, thus species density and abundance not significantly differed between inside and outside the MPA. It suggests that molluscan assemblages inside and outside the MPA have similar species density and total abundance, but those are composed of different species and relative abundance. Previous studies also found different responses of rocky intertidal species to the establishment of MPAs that are showed by changes in species distribution or relative abundance [16, 17, 20].

The MPA may support few molluscan species in Weh Island, such as *C. litteratum* indicated by more individuals inside the protected area. Fisheries and tourism may not affect the abundance of this species as they are non-targeting species for fisheries or souvenirs. Nevertheless, the MPA provides a limited contribution to targeting species, such as *C. coronatus*, *C. litteratus*, *N. erosa*, *Nassarius* sp., *T. squamosa*, and *T. bruneus*. The abundance of these species inside the MPA was extremely low (less than 0.2 individuals/transect). Visitors may collect these species for ornaments and trade as found in Bali and Pangandaran [47].

The MPA may be less beneficial for well-adapted molluscan species in Weh Island, such as *T. musiva*. This species was widely distributed around the study area, including inside and outside the MPA, with high individual numbers. Morphological and physiological performances of this species as well as of another aquatic animals [69, 70] may deal with environmental and anthropogenic pressures in the island. This species has a mechanically strong shell with the proportion of shell weight of about 73.6% [71] that may provide full protection from physical disturbances. In addition, this species has a minimum lifespan of about nine years and mature rapidly within 1.5 years after hatching [72]. Thus, they can produce new individuals within a short period. *T. musiva* also tends to be tolerant of trace metal pollution as they can uptake 14.6μg/g Cd, 143 14.6μg/g Cu, and 2050 14.6μg/g Zn [73].

Overall, the present study supports that the level and age of protection are important factors in designing MPAs to achieve marine conservation goals. Partial MPAs seem to be successful for the conservation of subtidal assemblages [38, 74-76], but these MPAs are ineffective for the conservation of rocky intertidal assemblages as shown in the present and a previous study in Portugal [30]. Additionally, eight-year protection is not adequate to gain conservation benefits of partial MPAs. The conservation benefits of MPAs are often obtained after ten years of establishment [14, 18, 19]. However, it may take longer to gain benefits of partial MPAs for the protection of rocky intertidal assemblages [27, 30]. Newly established MPAs (<10 years old) are only beneficial for marine conservation when no-take and limited visitation are implemented [15-17, 20, 77-79].

The present study has two limitations. First, molluscan assemblages were only examined in the dry season. It remains unclear whether the influence of MPA on molluscan assemblages will show similar results in the wet season as molluscan assemblages often show seasonal variations [80-82]. Some studies show that effects of MPAs on the diversity and abundance of protected biota are independent to season [77, 83, 84]. Nevertheless, future studies should emphasise the influence of seasonal variations on the effectiveness of MPA in Weh Island. Second, there is no baseline data of molluscan assemblages in the study area. Thus, we cannot compare distribution patterns of those assemblages before and after the establishment of MPA. Alternatively, the present study analysed differences in molluscan assemblages inside and outside the protected area to evaluate the effectiveness of MPA. Such approach is also used in many previous studies to evaluate the effectiveness of MPAs in rocky intertidal shores [15-17, 20, 23, 24, 27-32]. Data collected in the present study can be used as baseline data for evaluating the effectiveness of MPA in Weh Island in the future, particularly after the MPA is old enough (>10 years).

Regardless of limitations, the present study exhibits that the current MPA is not effective enough for protecting molluscan assemblages on rocky intertidal habitats in Weh Island, although this MPA seems to be successful for conserving corals and reef fishes in subtidal habitats [38]. Our study can be used as scientific consideration in designing MPA in Weh Island, especially related to the level and age of protection. Changing partial to full protection can be considered to gain conservation benefits of the MPA within less than ten years as also suggested in previous studies [15-17, 20]. Alternatively, the current MPA should be implemented in Weh Island for more than ten years since the establishment with limited extraction and visitation as also recommended in previous studies [14, 18, 19, 27, 30].

Conclusions

Species density and abundance of molluscan assemblages were not significantly different between inside and outside the MPA although species composition showed a significant difference. The abundance of a non-targeting species, *Cerithium litteratum*, was significantly higher inside the MPA, but that of other species including some targeting species (i.e., *Conus coronatus*, *Conus litteratus*, *Naria erosa*, *Nassarius* sp., *Tridacna squamosa*, and *Tridacna bruneus*) was not significantly different between inside and outside the protected area. In addition, the individual number of *Strigatella retusa* was even twice higher outside the MPA. These results indicate that the current MPA is not effective enough for protecting molluscan assemblages on rocky intertidal shores of Weh Island.

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