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Biodiversity of coral reefs and associated seagrass beds in Quy Nhon Bay, Binh Dinh Province

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ABSTRACT

The distribution of critical marine habitats in Quy Nhon Bay, Binh Dinh Province, was assessed with the combination of resolution of Google Earth images and local knowledge through local consultations and ground truthing using small boats to check the sites supporting coral reefs and seagrass beds with local involvement. Detailed surveys on species diversity and conditions of marine habitats were conducted at 24 sites of coral reefs and four sites of seagrass beds at three sites (Nhon Ly, Nhon Hai, Ghenh Rang, and Nhon Chau) in 2016–2017. More than 152 ha of coral reefs, 5 ha of seagrass beds, and 720 species belonging to 7 key groups (290 species of fishes; reef-building corals: 194, molluscs: 123, seaweeds: 47, echinoderms: 40, crustaceans: 20 and seagrasses: 6 species) associated with the above habitats were recorded in the Bay. Among them, 92 species were facing different threats, in which 3 species were endangered (EN), including branching corals (*Alveopora minuta*), flat pen shells (*Atrina vexillum*), and top shells (*Tectus pyramis*); 38 species at vulnerable (VU); and 51 species at near threatened (NT) following the IUCN Red List and Vietnam Red Book. In general, the coral reefs and seagrass beds at Bai Dua and Seo Island (Nhon Ly); Kho Nho Island, Bo Dap (Nhon Hai); S. Ngang Island, Bai Nam and Bai Nom of Dat Island (Ghenh Rang); Da Ban, Bai Lang, Bai Lang Ba and Ong Gia Island (Nhon Chau) supported higher diversity and better conditions than other sites. Establishing restricted zones at these sites is an urgent need, but it also holds the premise of sustainable utilization and conservation of resources in the future.

Keywords: Marine habitats, distribution, species diversity, status of habitats, Quy Nhon Bay.

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INTRODUCTION

Coral reefs provide millions of people with ecosystem services, including food [1] and economic benefits through fisheries and tourism [2]. The mean economic value of reefs with tourism is \$482,428 per square kilometer annually; remarkably, the most valuable reefs generate more than \$7 millions annually [2]. Reefs also protect coastal communities from large waves generated by storms or tsunamis [3, 4]. However, these services and the continued existence of countless species that inhabit reefs depend on stable populations of reef-building corals, many of which have been declining globally. Coral loss also leads to reduced fisheries production, tourism value, and coastal buffering [5].

As indicated in the previous studies, coral reefs were widely distributed in the coastal waters of Binh Dinh Province with a total area of some 100 ha, in which some 89 ha were recorded from Nhon Ly in the North to Nhon Hai, Ghenh Rang, and Nhon Chau in Quy Nhon Bay [6]. The total catch of reef-related target resources was some 637.43 tonnes/year. Some 936,450 juveniles of fish (orange-spotted grouper, six-bar grouper, and lobsters) have been caught in each year. Sixteen important grounds including three spawning grounds of cuttlefishes and murex snails, and 13 nursery grounds of swimming crabs, lobster 'seeds', sea cucumbers, rabbitfishes, and groupers were found in the Bay [7]. Using of coastal resources for socio-economic development, such as fishing, tourism, and marine aquaculture, has benefited the local communities in recent years. However, these activities have caused stresses on marine biodiversity and resources in Quy Nhon Bay and adjacent areas, contributing to the degradation of ecosystems and the decline of resources. Although some studies conducted on the marine biodiversity of Quy Nhon LMMA, the results of these studies were quite scattered due to having different goals and covering a variety of study areas. Therefore, there is a need for more focused and coordinated research efforts in the area to ensure that the results meet the requirements for resource management.

A comprehensive assessment of key marine biodiversity in the Quy Nhon LMMA was conducted from 2016 to 2017 within the framework of the sub-project on "Assessments and identification of areas of marine biodiversity in Quy Nhon Bay" (Code: CRSD/BD/3.d.4.1/2016). The aims of this study are: 1) to provide updated comprehensive data and information on the distribution of critical marine habitats (coral reefs and seagrass beds) and the diversity of associated species in the waters of the Quy Nhon Bay, and 2) to identify critical important locations for long-term conservation and sustainable uses of marine biodiversity in the future.

MATERIALS AND METHODS

Assessments of marine habitats

Rapid assessments of the distribution and extent of coral reefs and seagrass beds were implemented with a combination of resolution of Google Earth images and local knowledge through local consultations and ground truthing using small boats to check the sites supporting coral reefs and seagrass beds with local involvement. The number of surveyed sites at each location was 12 sites at Nhon Ly, 15 sites at Nhon Hai, and eight sites for each location at Ghenh Rang and Nhon Chau communes in November 2016. The coordination position of the sites of coral reefs and seagrass beds was recorded by using GPS.

Detailed assessments of marine biodiversity of critical habitats

Seagrass beds

Studies of seagrass beds were carried out at 3 sites representing 3 locations: Nhon Hai commune (TCB1), Ghenh Rang commune (TCB2), and Nhon Chau commune (TCB3) in April 2017 (Fig. 1). At each sampling site, a vertical transect was laid from the shoreline to the end of seagrass beds. At each of 5 m along the transect, total cover and dominant species of seagrasses were calculated using a quadrat

of 1/4 m² divided into 25 small squares from the start to the end of the transect. The seagrasses' density was calculated using three quadrats of 1/16 m² placed at the transect's 3 points (start, middle, and end). The cover was calculated following [8]. Calculating the density of seagrasses in each quadrat was conducted by collecting all of the quadrat's 1/16 m² (0.0625 m²) and placing them at 3 representing points. Samples of seagrasses were cleaned and counted in the field. Seagrasses were identified as follows [9–11].

Species composition of associated resources (fishes and macro-invertebrates) living in the seagrass beds were assessed by observers swimming along the same transect at each survey site in 5 m wide (2.5 m on each side of the transect).

Coral reefs

Detailed marine biodiversity studies were conducted at 39 transects of 24 sites in April 2017 at 4 locations (Fig. 1). These sites were widely distributed at different locations of Islands and represented all major coral reef communities. At each site, deep and shallow transects 100m long each were established at reef flat (2–4 m) and reef slope (5–8 m below low tide level) depending on the structure of the study reef because of strong depth-related gradients in species composition in some taxa.

Assessment of community structure: The survey method was a form of Rapid Ecological Assessment (REA). The various taxonomic groups' species composition and relative abundance were carefully assessed during 45-minute meandering SCUBA survey swims at each transect. At each site, two transects 50 m long in different depth ranges in deep and shallow slopes were surveyed independently by "zic zac" swimming across the reef flat and reef slope. Each swim covered an area of approximately 250 m² (5 m width and 50 m length). Although 'semi-quantitative', this method has proven far superior to more traditional quantitative methods (transects, quadrats) in terms of biodiversity assessment, allowing the specialist to actively search for new species records at each site rather than being

restricted to a defined quadrat area or transect line [12]. Detailed inventories of reef-building corals, macro-molluscs, macro-echinoderms, and fish were compiled during each swim.

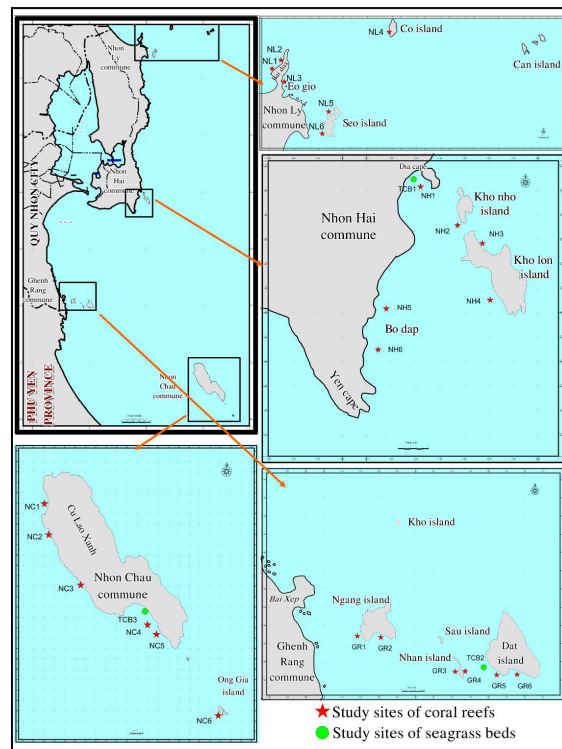


Figure 1. Study sites of coral reefs and seagrass beds at each location in Quy Nhon Bay

Taxa were identified in situ to the following levels: Stony (hard) corals - species wherever possible [13–16], otherwise genus and growth form (e.g., *Porites* spp. of massive growth-form). Reef fishes - to species wherever possible [17–20]. Macro-molluscs and echinoderms - to species or genus [21–24]. At the end of each swim, the inventories were reviewed, and each species was ranked in terms of its relative abundance in the community.

Status of coral reefs: Detailed assessments of the status of coral reefs were also conducted at 24 permanent sites as carried out with community assessments (Fig. 1). At each site, two transect tapes were laid along the selected depth contours from a randomly selected starting point on the reef slope and reef flat. The first segment of 20 m started at the

beginning of the tape. The second segment started after an interval of 5 m from the end of the first segment (i.e., at 25 m) and similarly for the third (50 m) and fourth segment (75 m) (Fig. 2). Quantitative assessments were made within the four 20 m line transects using SCUBA and these four segments are considered as replicate transects for each station at each site. To minimize the bias in data collection, the surveys were all carried out using the same observer and between 9:00 and 14:00 local time. Methodology and ecological indicators were assessed using the manual surveys for tropical marine ecosystems [25] and Reefcheck [26]. Additional indicators (local indicators) suitable to local conditions of coral reefs were also assessed during the surveys at each site. Ecological indicators for monitoring were as follows:

Types of coral reef components: Components were recorded at each 0.5 m interval of the four segments of each transect (20 m long of each segment). Parameters of coral reef components recorded include hard corals (HC), soft corals (SC), recently killed corals (RKC), dead coral with algae (DCA), fleshy seaweeds (FS), coralline algae (CA), turf algae (TA), sponges (SP), rock (RC), coral rubble (RB), sand (SD), silt/clay (SI) and others (OT). The total points recorded on each segment were 40 and 160 for the transect.

Coral reef fishes: The fish visual census was conducted at the four shallow and deep transect segments. The fish observer swam slowly along the transect line and counted the number of fishes and their fork length to species level within 100 m² (5 m wide, 5 m above, and 20 m long of each segment). Survey time completed at each station was about 50–60 minutes.

Macro-invertebrates: Methods surveyed for macro-invertebrates were conducted on the same segments as reef fish in the area of 100 m² (20 m long and 5 m wide of each segment). Major indicators are following the Indo-pacific indicators introduced by Reefcheck, including triton shell (*Charonia tritonis*), giant clams (*Tridacna* spp.), top shells (*Trochus* spp.), coral banded shrimp (*Stenopus hispidus*), lobsters

(*Panulirus* spp.), pencil urchins (*Heterocentrotus mammilatus*), long-spined sea urchins (*Diadema* spp.), sea cucumbers (except *Synapta* spp.).

Impacts on coral reefs: Indicators for assessments of impacts to coral reefs included crown of thorn seastar (*Acanthaster planci*), anchor damages, dynamite, fishing nets and garbage, the number of bleached coral colonies, and other scars.

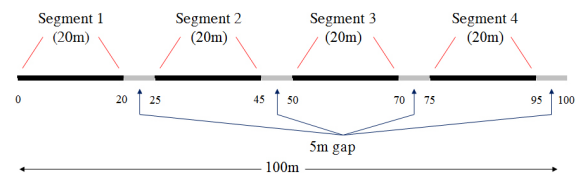


Figure 2. Benthic cover, fish and invertebrate belt transects [26]

Data storage and analysis

Cover and density of seagrasses: Data were analyzed and calculated by using Excel software for Windows. Cover and density used in the report are mean values of 3 quadrats and standardized to roots/m².

Status of coral reefs: Reef fishes were divided into four size classes and families. Some families belonging to target fishes included groupers (Serranidae), snappers (Lutjanidae), emperors (Lethrinidae), parrotfishes (Scaridae), rabbitfishes (Siganidae), fusiliers (Caesionidae) and ornamental fishes such as butterflyfishes (Chaetodontidae), damselfishes (Pomacentridae), wrasses (Labridae), surgeonfishes (Acanthuridae) and angelfishes (Pomacanthidae). The densities of reef fishes and macro-invertebrates at each site displayed in the report are mean values of 8 segments (mean ± standard deviation; s.d.) collected on reef flat and reef slope in an area of 100 m² (20 m long × 5 m wide).

RESULTS AND DISCUSSION

Distribution of critical marine habitats

Combination of GIS techniques and information from local consultations through interviews and field rapid assessment at the four crucial locations in Quy Nhon Bay, the results show that seagrass beds were found in three of the 4 locations (Nhon Hai, Ghenh

Rang, and Nhon Chau). The total area of seagrass beds was 5 ha, including Bai Nam (2.67 ha), Mui Dia (1.37 ha), and Bai Lang (0.98 ha) (Figs. 3 & 4). The dominant species in these seagrass beds were *Halophila ovalis* and

Thalassia hemprichii. Actual seagrass beds with mud-sandy bottoms were only recorded at Bai Nam, while seagrass beds in Mui Dia (Nhon Hai) and Bai Lang (Nhon Chau) were grown on dead corals with sands.

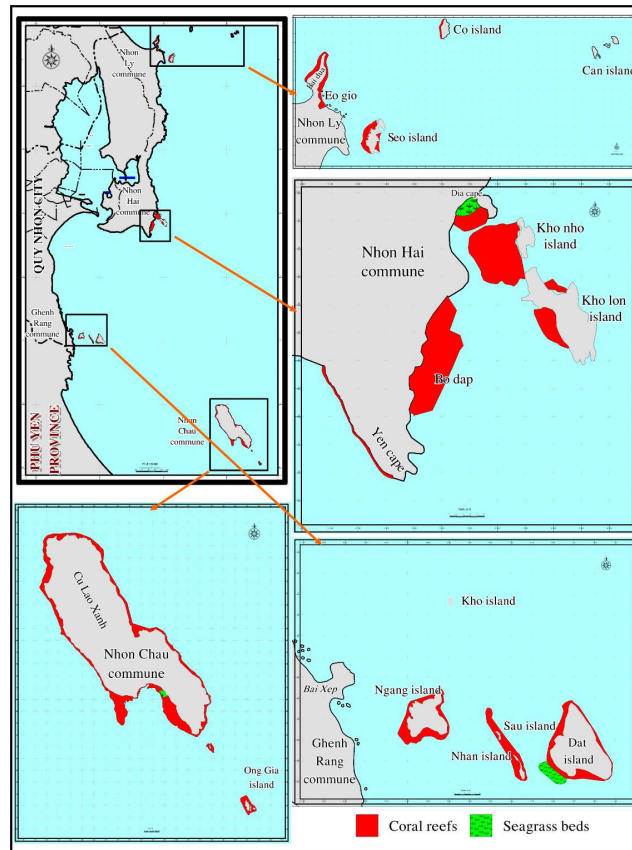


Figure 3. Maps showing the distribution of seagrass beds and coral reefs in LMMMA Quy Nhon

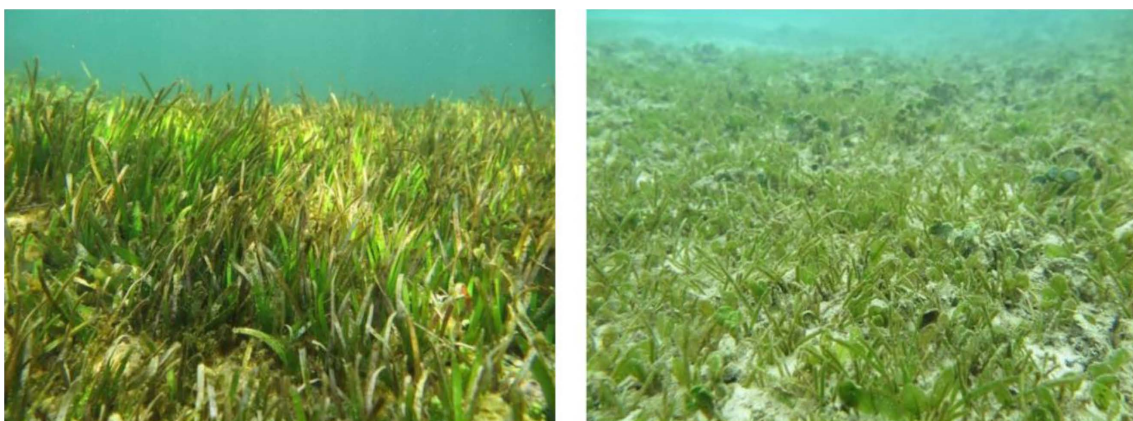


Figure 4. *Thalassia hemprichii* dominated at Mui Dia - Nhon Hai (left), *Halophila ovalis* and *Halodule uninervis* dominated at Bai Lang - Nhon Chau (right)

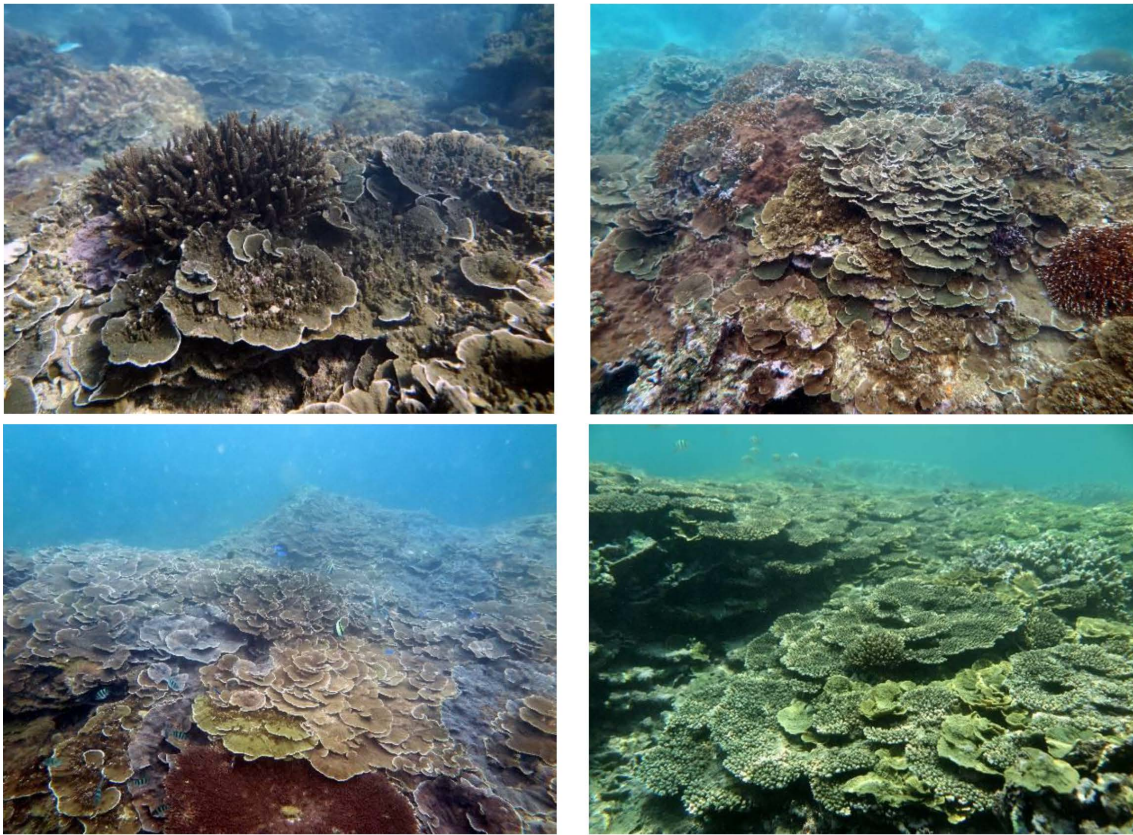


Figure 5. Coral reefs at Bai Dua - Nhon Ly (left above), Kho Nho Island - Nhon Hai (right above) and Dat Island - Ghenh Rang (left below), Bai Lang - Nhon Chau (right below)

The survey results show a total area of 152.35 ha of coral reefs in 4 locations of Quy Nhon Bay, including nearshore and offshore sites. The largest area of coral reefs was at Nhon Chau (69.03 ha), followed by Nhon Hai (39.38 ha), Nhon Ly (24.52 ha), and lowest at Ghenh Rang (19.42 ha) (Figs. 3–5).

Species diversity

A total of 720 species belonging to 353 genera and 161 families of 7 key groups of marine organisms were recorded from the surveys conducted in 2016–2017. Among them, fish was the most diverse group (290 species of 151 genera and 65 families; occupied 40.3% of total species), followed by reef-building corals (194 species of 55 genera and 16 families; 26.9%), molluscs (123 species of 66 genera and 31 families; 17.1%), seaweeds (47 species of 35 genera and 21 families; 6.5%),

echinoderms (40 species belonging to 26 genera and 17 families; 5.6%), crustaceans (20 species of 15 genera and nine families) and seagrasses (6 species of 5 genera and two families; 0.8%) (Table 1). Among 720 species identified, 3 of them were at endangered level (EN), including branching corals (*Alveopora minuta*), flat pen shells (*Atrina vexillum*), and top shells (*Tectus pyramis*); 38 species at vulnerable level (VU); and 51 species at near threatened (NT) following the IUCN Red List [27] and Vietnam Red Book [28].

In the seagrass beds, some 39 species belonging to 18 families, including 6 species of seagrasses (*Cymodocea rotundata*, *Halodule pinifolia*, *Halodule uninervis*, *Enhalus acoroides*, *Halophila ovalis* and *Thalassia hemprichii*), 9 species of fishes, 24 species of macro-invertebrates were preliminarily recorded, giving the numbers of species between study sites were similar with 19–24 species/site.

Table 1. Numbers of species of key groups of marine organisms recorded in different locations in Quy Nhon Bay

No.	Groups of organisms	Quy Nhon Bay			Nhon Ly	Nhon Hai	Ghenh Rang	Nhon Chau
		Family	Genera	Species				
1	Seagrasses	2	5	6	0	5	2	3
2	Seaweeds	21	35	47	30	22	27	6
3	Hard corals	16	55	194	167	155	144	153
4	Molluscs	31	66	123	50	61	58	49
5	Crustaceans	9	15	20	1	1	1	1
6	Echinoderms	17	26	40	14	25	14	33
7	Fishes	65	151	290	134	126	108	155
Total		161	353	720	396	395	354	400

In the coral reefs, 661 species belonging to 227 genera and 124 families of 6 groups of reef organisms were recorded in Quy Nhon Bay, including 210 species of fishes, 194 species of hard corals, 118 species of molluscs, 47 species of seaweeds, 40 species of echinoderms and 2 species of crustaceans.

Comparison in the number of species at key coastal areas in the south of Vietnam, which

support the high potential of marine biodiversity of coral reefs, shows that Quy Nhon Bay was much higher than that in Con Co Islands, Hai Van - Son Cha, the coast of Da Nang, Ly Son Islands, the coast of Phu Yen province, Tho Chu Islands. However, these were lower than that in Cu Lao Cham Islands, Van Phong Bay, Hon Cau marine protected area, Phu Quy Islands, Con Dao Islands, and Phu Quoc Islands (Table 2).

Table 2. The number of species of key groups of marine organisms of coral reefs recorded in Quy Nhon Bay are compared with that of different locations in Vietnam’s coastal waters

No.	Location	Seaweeds	Hard corals	Molluscs	Crustaceans	Echinoderms	Reef fishes	Total	References
1	Quy Nhon Bay	47	194	118	2	40	210	611	This study
2	Con Co	44	166	102	15	27	172	526	[29]
3	Hai Van - Son Cha	42	106	137	21	30	191	527	
4	Ly Son	99	74	122	31	36	90	452	
5	Da Nang	72	226	32	4	12	162	508	[29, 30]
6	Cu Lao Cham	122	227	129	32	37	200	747	
7	Van Phong	31	294	52	68	37	267	749	
8	Nha Trang	116	350	236	33	31	528	1294	
9	Hon Cau	163	184	110	23	29	306	815	
10	Phu Quy	95	239	146	46	45	169	740	
11	Con Dao	84	307	115	35	33	206	780	
12	Phu Quoc	85	275	123	33	39	152	707	
13	Tho Chu	49	198	144	32	49	99	571	

The numbers of species of the six key groups of organisms in the study sites ranged between 61–225 (mean: 160.6 ± 37.4 species/site) with the highest number being found in Nhon Chau (188.8 species/site), 1.1 times higher than Nhon Ly (174.3 species/site),

and 1.3 times higher than that in Nhon Hai (148.2 species/site) or 1.4 times higher than Ghenh Rang (131.2 species/site). Higher species richness was found in Nhon Ly and Nhon Chau (69.9–71.2 species/250 m²), followed by Nhon Hai (56.2 species/250 m²)

and Ghenh Rang (55.3 species/250 m²) (Nhon Hai); West Nhan Island, Bai Nam and Bai Nom of Dat Island (Ghenh Rang), Bai Nom, Da Ban, Bai Lang, and Ong Gia Island (Nhon Chau) (Table 3). The species richness was high in Hon Cao, Bai Dua, Bai Chai and Hang Lo (Nhon Ly), Kho Nho and SW Kho Lon Islands and N. Bo Dap

Table 3. Species richness (species/250 m²) of reef communities at study sites

No.	Site name	Total	Corals	Fishes	Molluscs	Echinoderms
<i>Nhon Ly</i>		71.2	26.1	32.3	7.2	5.6
NL1	Hon Cao	73.0	28.0	32.0	8.0	5.0
NL2	Bai Dua	80.0	30.5	34.0	9.0	6.5
NL3	Dong Nganh	61.5	29.5	22.5	5.5	4.0
NL4	Co Island	66.0	15.0	37.0	7.0	7.0
NL5	Bai Chai	70.5	23.5	32.5	7.5	7.0
NL6	Hang Lo	76.0	30.0	36.0	6.0	4.0
<i>Nhon Hai</i>		56.2	17.3	26.3	6.5	6.2
NH1	Mui Dia	43.0	13.0	11.0	11.0	8.0
NH2	Kho Nho Island	63.5	28.5	22.5	6.5	6.0
NH3	N. Kho Lon Island	64.0	16.0	36.0	7.0	5.0
NH4	SW. Kho Lon Island	62.0	24.5	25.5	5.5	6.5
NH5	N. Bo Dap	48.0	6.0	34.0	2.0	6.0
NH6	S. Bo Dap	56.5	15.5	28.5	7.0	5.5
<i>Ghenh Rang</i>		55.3	22.9	19.3	7.9	5.1
GR1	W. Ngang Island	27.0	4.0	20.0	3.0	0.0
GR2	S. Ngang Island	62.0	38.0	13.5	6.5	4.0
GR3	W. Nhan Island	45.0	13.5	17.5	7.5	6.5
GR4	E. Nhan Island	54.0	15.0	19.0	14.0	6.0
GR5	Bai Nam	78.0	39.0	22.0	8.0	9.0
GR6	Bai Nom	65.5	28.0	24.0	8.5	5.0
<i>Nhon Chau</i>		69.9	17.3	37.8	7.3	7.5
NC1	Bai Nom	76.5	26.5	36.0	7.5	6.5
NC2	Bai Da Hon	71.0	18.0	42.0	5.5	5.5
NC3	Da Ban	66.5	18.0	38.0	4.5	6.0
NC4	Bai Lang	65.0	15.5	38.5	5.0	6.0
NC5	Bai Lang Ba	59.5	15.5	31.5	7.5	5.0
NC6	Ong Gia Island	81.0	10.0	41.0	14.0	16.0
Overall mean		63.1	20.9	28.9	7.2	6.1
s.d.		12.9	9.4	8.9	2.8	2.7

Status of key habitats

Seagrass beds

Generally, the mean cover of seagrass beds in Quy Nhon Bay was medium, with 42.6 ± 17.3%. The highest cover was at Mui Dia - Nhon Hai (62.5%), while this value at the Southwestern side of Dat Island - Ghenh Rang

and Bai Lang - Nhon Hai averaged 32.0% to 33.2% respectively (Table 4). The density of seagrass in the Bay was about 56.3 ± 381.8 roots/m², highest in Bai Lang and lowest at the southwestern side of Dat Island. The dominant species in Mui Dia was *Thalassia hemprichii*, while *Halodule uninervis* and *Halophila ovalis* were dominant on the southwestern side of Dat Island and Bai Lang.

Table 4. Cover and densities of seagrasses at study sites

No.	Study site	Cover (%)	Density (roots/m ²)			
			Total	TH	HU	HO
TCB1	Mui Dia	62.5	720.3	378.7	247.2	94,4
TCB2	Dat Island	32.0	128.0	0	84.6	43,4
TCB3	Bai Lang	33.2	841.6	0	473.6	368,0
	Mean	42.6	563.3	126.2	268.5	168.6
	s.d.	17.3	381.8	218.6	195.4	174.6

Notes: TH: *Thalassia hemprichii*; HU: *Halodule uninervis*; HO: *Halophila ovalis*.

Coral reefs

Benthic cover: In general, the status of coral reefs at 24 study sites was not in good condition, with a mean cover of live corals being at medium level ($27.2 \pm 22.8\%$) following the categories of English et al., (1997), in which the cover of hard and soft corals was $23.5 \pm 18.1\%$ and $3.7 \pm 7.9\%$ respectively (Table 5). The cover of seaweeds, coralline algae, and turf algae were low (mean: 2.7–3.3%). The cover of recently killed and dead corals with algae averaged only 0.3% and 3.3%, respectively. However, it was noticed that the cover of coral rubble was high at Bai Dua, Hang Lo, SW. Kho Lon Island, Bo Dap, and most other sites in Ghenh Rang and Nhon Chau (mean: 4.1–22.8%).

Density of reef fishes: The overall mean density of reef fishes at 24 study site was low ($78,7 \pm 43.1$ inds./100 m², ranging: 16.8–176.3 inds./100 m²), in which the fishes at a small size (1–10 cm) was dominant in most of the study sites (occupied 72.3% of total density), followed by 11–20 cm (27.1%) and > 20 cm group with very low density (< 1%) (Table 6). In terms of locations, the density of reef fishes in Nhon Ly and Nhon Chau (averaged: 72.4–74.0 inds./100 m²) were 1.5 times higher than that in Nhon Hai (48.6 inds./100 m²) and about 2.2 times higher than that in Ghenh Rang (32.7 inds./100 m²). Sites with a high density of reef fishes were Bai Dua, Hon Co, Bai Chai, and Hang Lo (Nhon Ly); N. Bo Dap (Nhon Hai); S. Ngang Island (Ghenh Rang); Bai Nom, Bai Da Hon, Da Ban, Bai Lang and Ong Gia Island (Nhon Chau) (Table 6). The fishes at large sizes (> 30 cm) were found in Bai Dua, Hang Lo, Kho Nho Island, Da Ban, Bai Lang.

Regarding consumption value, the total density of target fishes averaged $20.1 \pm$

14.8 inds./100 m² (with 25.6% of total density), followed by predatory fishes (2.9%). Among them, some families such as surgeonfishes (Acanthuridae: 7.5 inds./100 m²), parrotfishes (Scaridae: 5.4 inds./100 m²), and rabbitfishes (Siganidae: 2.2 inds./100 m²) belonging to herbivorous fishes were occurred with high densities, while the families of target fishes such as groupers (Serranidae), snappers (Lutjanidae), sweetlips (Haemulidae) and emperors (Lethrinidae) were at low density (< 0.5 inds./100 m²) (Table 7). Regarding locations, the density of target fishes in Nhon Hai and Nhon Ly was 2 and 3 times higher than in Nhon Hai and Ghenh Rang, respectively. Sites supported higher densities of reef fishes included Hon Co, Bai Chai, Hang Lo (Nhon Ly); N. Kho Lon Island (Nhon Hai); Bai Nam of Dat Island (Ghenh Rang); Bai Nom, Da Ban, Bai Lang, Bai Lang Ba and Ong Gia Island (Nhon Chau) (Table 7).

The fishes with small sizes belonging to ornamental fishes dominated the reefs with an overall average density of 58.5 ± 33.6 inds./100 m² (ranging: 11.5–133.8 inds./100 m²), in which damselfishes (Pomacentridae: 43.1 inds./100 m²) and wrasses (Labridae: 9.2 inds./100 m²), while butterflyfishes (Chaetodontidae), angelfishes (Pomacanthidae) and moorish idol (Zanclidae) occurred in very low densities. In comparison between locations, the density of reef fishes in Nhon Ly and Nhon Chau was similar (75.1–76.2 inds./100 m²), but this was 1.5 times higher than that of Nhon Hai and about 2.3 times higher than that in Ghenh Rang. Sites with a high density of ornamental fishes were all sites in Nhon Ly (except Dong Nganh); N. Bo Dap (Nhon Hai); S. Ngang Island (Ghenh Rang); and most of the sites in Nhon Chau except Bai Lang Ba.

Table 5. Cover (%) of some major substrata of coral reefs at study sites

No.	Site name	HC	SC	RKC	DCA	CA	TA	FS	SP	RC	RB
<i>Nhon Ly</i>		31.9	2.7	0.4	1.6	0.5	1.4	0.7	0.3	48.8	2.4
NL1	Hon Cao	16.9	24.4	0.0	0.6	0.6	0.0	0.0	0.0	48.8	0.6
NL2	Bai Dua	26.9	0.3	0.6	1.6	0.6	1.9	1.3	0.0	56.6	4.1
NL3	Dong Nganh	39.1	0.0	0.0	2.5	0.6	2.5	0.0	0.3	50.9	0.0
NL4	Co Island	10.6	0.0	0.0	0.6	0.0	0.0	0.0	1.3	58.8	2.5
NL5	Bai Chai	29.7	0.3	0.3	0.9	0.3	2.2	1.3	0.0	58.1	0.0
NL6	Hang Lo	50.0	0.6	0.9	2.2	0.6	0.6	0.9	0.3	24.7	6.6
<i>Nhon Hai</i>		20.8	4.9	0.0	0.6	3.5	6.6	4.2	0.1	42.8	5.3
NH1	Mui Dia	16.3	0.0	0.0	0.0	8.8	21.9	7.5	0.6	32.5	0.6
NH2	Kho Nho Island	23.1	0.0	0.0	0.3	2.2	11.3	11.3	0.3	40.0	0.6
NH3	N. Kho Lon Island	10.6	0.0	0.0	0.0	1.3	0.6	0.0	0.0	78.8	0.0
NH4	SW. Kho Lon Island	10.9	0.0	0.0	2.2	5.3	1.3	3.1	0.0	49.7	9.4
NH5	N. Bo Dap	67.5	3.8	0.0	0.0	0.0	7.5	0.0	0.0	4.4	11.3
NH6	S. Bo Dap	12.5	20.3	0.0	0.0	3.4	2.2	0.9	0.0	45.0	7.8
<i>Ghenh Rang</i>		18.1	1.0	0.3	0.6	0.5	0.5	3.6	0.1	48.8	9.9
GR1	W. Ngang Island	0.6	0.0	0.0	1.3	1.3	3.1	18.1	0.0	45.6	1.9
GR2	S. Ngang Island	42.5	0.3	0.0	1.3	0.0	0.0	0.3	0.3	35.6	3.1
GR3	W. Nhan Island	5.0	0.0	0.0	0.0	0.6	0.3	2.8	0.0	52.2	22.8
GR4	E. Nhan Island	10.0	0.0	1.9	1.3	1.3	0.0	0.0	0.6	55.6	10.6
GR5	Bai Nam	16.9	2.5	1.3	0.6	0.0	0.0	0.0	0.0	51.9	6.9
GR6	Bai Nom	20.6	3.1	0.0	0.0	0.3	0.3	4.1	0.0	55.3	9.1
<i>Nhon Chau</i>		22.5	6.1	0.5	8.9	7.3	0.6	2.4	0.2	26.6	8.4
NC1	Bai Nom	29.7	0.0	0.3	1.3	3.8	0.6	0.0	0.0	50.3	7.8
NC2	Bai Da Hon	5.9	15.3	0.0	19.4	11.6	0.0	6.3	0.6	16.6	6.6
NC3	Da Ban	40.3	5.0	0.0	5.3	0.9	1.9	0.3	0.0	23.4	6.6
NC4	Bai Lang	24.7	0.0	2.5	12.2	10.0	1.3	0.3	0.0	17.5	21.3
NC5	Bai Lang Ba	17.9	3.4	0.3	15.0	17.8	0.0	7.2	0.0	20.6	8.4
NC6	Ong Gia Island	7.6	20.0	0.0	0.3	0.0	0.0	0.6	0.3	31.3	0.0
Overall mean		23.5	3.7	0.3	3.3	3.2	2.1	2.7	0.2	40.8	6.6
s.d.		18.1	7.9	1.3	7.9	7.3	4.8	5.1	0.7	22.0	11.0

Notes: HC: hard corals; SC: soft corals; RKC: recently killed corals; DCA: dead corals with algae; CA: coralline algae; TA: turf algae; FS: fleshy seaweeds; SP: sponges; RC: rock; RB: rubble corals.

Table 6. Density (inds./100 m²) at different size classes of reef fishes at study sites

Site name	1–10 cm	11–20 cm	21–30 cm	> 30 cm	Total
Nhon Ly	72.4	22.9	0.7	0.2	96.2
Nhon Hai	48.6	11.5	0.1	0.1	60.2
Ghenh Rang	32.7	11.5	0.1	0.0	44.3
Nhon Chau	74.0	39.5	0.5	0.1	114.0
Overall mean	56.9	21.3	0.3	0.1	78.7
s.d.	31.6	15.4	0.6	0.2	43.1

Table 7. Density (inds./100 m²) of the families of predatory, target and ornamental fishes at study sites of coral reefs

Location	Predatory	Target	Ornamental
Nhon Ly	1.6	21	75.1
Nhon Hai	2.9	9.9	50.3
Ghenh Rang	2.3	11.8	32.5
Nhon Chau	2.4	37.8	76.2
Overall mean	2.3	20.1	58.5
s.d.	3.0	14.8	33.6

Density of macro-invertebrates: In terms of molluscs, the overall density at 24 study sites was relatively low and averaged 9.4 ± 7.0 inds./100 m² (ranged: 1.3–32.3 inds./100 m²). Among them, the family Muricidae was dominated by 6.8 inds./100 m² (occupied with 72.3% of total density), coral-eaten snails

(*Drupella* spp.) and murex snails (*Chicoreus* spp.) were dominated. Other families such as top shells (Trochidae), cone shells (Conidae), conch shells (Strombidae), turbo shells (Turbinidae), pearl oysters (Pteriidae), and giant clams (Tridacnidae) occurred with very low density (0.1–0.5 ind./100 m²) (Table 8).

Table 8. Density (inds./100 m²) of the families of molluscs at study sites of coral reefs

Location	Total	Snails	Top shells	Cone shells	Conch shells	Turbo shells	Pearl oysters	Giant clams
Nhon Ly	15	12.8	0.3	0.4	0.4	0.2	0.2	0.2
Nhon Hai	8.4	4.9	0.8	0.9	0.1	0.3	0.1	0.1
Ghenh Rang	8.1	5.4	0.9	0.2	0.4	0.2	0.2	0.1
Nhon Chau	6.1	4.0	0.3	0.5	0.5	0.4	0.1	0.1
Overall mean	9.4	6.8	0.5	0.5	0.4	0.3	0.1	0.1
s.d.	7	7.2	0.7	0.7	0.6	0.3	0.2	0.2

For crustaceans, the 2 indicators including spiny lobster (*Panulirus* spp.) and coral-banded shrimp (*Stenopus hispidus*) were rarely found. Spiny lobsters were detected in only 1/24 study sites (Bai Dua - Nhon Ly with 0.3 ind./100 m²), and coral-banded shrimp occurred in 2/24 sites (N. Kho Lon Island - Nhon Hai with 0.5 ind./100 m² and Bai Lang - Nhon Chau with the density of 0.3 ind./100 m²).

Among macro-invertebrates, echinoderms were dominated in density in the reefs with a mean density of 22.9 ± 35.2 inds./100 m² (ranging: 0.0–107.3 inds./100 m²). The highest density was found at Ghenh Rang with 48.4 inds./100 m², which was about 1.3 times higher than that in Nhon Ly (37.0 inds./100 m²), and about 11 times higher than that in Nhon

Chau (4.3 inds./100 m²) or about 26 times higher than that in Nhon Hai (1.8 inds./100 m²) (Table 9). However, most of them were long-spined sea urchins (*Diadema* spp.) with a density of 16.4 ± 28.8 inds./100 m², or short-spined sea urchins (*Echinothrix* spp: 5.8 inds./100 m²), collector urchin (*Tripneustes gratilla*) and sea cucumbers (*Stichopus* & *Holothuria* spp.) were recorded with very low density (< 0.5 ind./100 m²) (Table 9). In general, sites that supported a higher density of echinoderms were Hon Cao, Bai Dua, Co Island, Bai Chai, and Hang Lo (Nhon Ly); W. and E. Nhan Island, Bai Nam and Bai Nom of Dat Island (Ghenh Rang), while other sites in Nhon Hai and Nhon Chau were recorded with much lower density.

Table 9. Density (inds./100 m²) of the families of echinoderms at study sites

Location	Total	Long-spined sea urchins	Short-spined sea urchins	Collector urchin	Sea cucumbers
Nhon Ly	37.0	25.8	10.5	0.7	0.1
Nhon Hai	1.8	1.0	0.7	0.1	0.1
Ghenh Rang	48.4	34.6	12.0	0.7	1.1
Nhon Chau	4.3	4.0	0.0	0.2	0.0
Overall mean	22.9	16.4	5.8	0.4	0.3
s.d.	35.2	28.8	7.5	0.6	0.9

Solutions for sustainable utilization

The status of coral reefs and seagrass beds was generally not in good condition, with mean cover of live corals assessed by rapid and transect methods ranging between 23.5–24.8% and 42.6% for seagrass beds. Associated reef fishes and macro-invertebrates with high values were over-exploited. Among them, 92 species were facing high levels of impact and needed to be conserved, of which 3 species were endangered (EN), including branching coral (*Alveopora minuta*), pen shells (*Atrina vexillum*), and top shells (*Tectus pyramis*); 38 species in vulnerable (VU); and 51 species in near threatened (NT) following IUCN Red List and Vietnam Red List. There were 16 spawning and nursery grounds of 9 target species (murex snails, squids, spiny lobsters, swimming crabs, rabbitfishes, groupers, and sea cucumbers) found, of which they are primarily concentrated in Nhon Hai and Ghenh Rang communes [7]. Results from the present study showed that Bai Dua and Seo Island (Nhon Ly); Kho Nho Island, Bo Dap (Nhon Hai); South of Ngang Island, Bai Nam and Bai Nom of Dat Island (Ghenh Rang); Da Ban, Bai Lang, Bai Lang Ba, and Ong Gia Island (Nhon Chau) are important in terms of supporting higher diversity, representatives of reef communities, higher replenishment index and high cover of live corals and target fishes and macro-invertebrates.

Up to the present, the zoning plan approved under Decision 3740/QĐ-UBND dated 24/10/2016 of Binh Dinh PPC is considered an important baseline for implementing management at site levels in the LMMA Quy Nhon. However, the existing zoning plan developed was mainly based on data from

different projects from previous studies, so data were comprehensive and updated in space and time. In addition, baseline data used for this zoning plan were mainly based on the distribution of key habitats, species diversity, and some socio-economic factors. In contrast, the distribution and characteristics of representative communities, distribution and seasonal occurrence of spawning and nursery grounds of target species, and sites supported high replenishment potential were not considered. Results from this study provided more comprehensive and updated data and information related to marine biodiversity and resources. The study has pointed several vital sites supporting high diversity value, spawning, and nursery ground, and high replenishment potential. So, it is necessary to find suitable solutions to protect and conserve these important sites for long-term sustainable uses. Besides, the area of the core zone in the approved zoning plan is too large and complex to manage in the field due to weak management capacity. Therefore, revision of the existing zoning plan is necessary to conserve important sites supporting representatives of communities, high replenishment potential, spawning and nursery grounds to meet the requirements in new conditions to enhance conservation effectiveness and sustainable uses of marine resources.

Based on the analysis of advantages and difficulties as mentioned above, the outlook of the proposal of revision of the zoning plan of the LMMA Quy Nhon is the same area as those approved at Decision No. 3740/QĐ-UBND of Binh Dinh PPC dated 24/10/2016. To enhance resilience and management effectiveness in the present situation, revising the zoning plan by

adding an area of restricted zone in the core zone as approved is necessary (Fig. 6), while the buffer zone is the same as those approved. The restricted zone, with a total area of 215 ha, occupying 2.2% of the core zone and 0.6% of the buffer zone of the LMMA as approved, supports higher areas of coral reefs and seagrass beds and species diversity located at

different locations such as Bai Dua - Cong Coc cape - Eo Gio and Seo Island (Nhon Ly); Kho Nho Island and Bo Dap (Nhon Hai); South of Ngang Island and Dat Island (Ghenh Rang); Da Ban - Kho Island in the north, Bai Lang - Lang Ba cape and Ong Gia Island (Nhon Chau) should be considered as essential sites for future management.

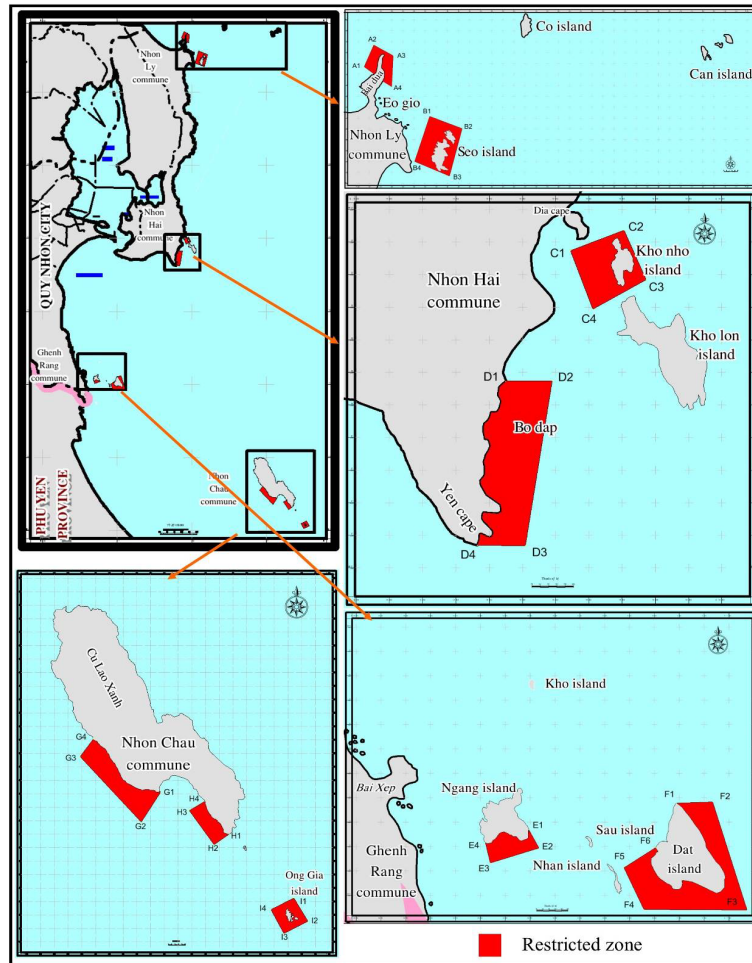


Figure 6. Key sites recommended for establishment of restricted zone in LMMA Quy Nhon

CONCLUSIONS

The total area of coral reefs at the 4 locations, including Nhon Ly, Nhon Hai, Ghenh Rang, and Nhon Chau was some 152 ha. Among them, Nhon Chau had the highest area (69.03 ha), compared to Nhon Hai (39.38 ha), Nhon Ly (24.52 ha) and the lowest in Ghenh Rang (19.42 ha). The total area of seagrass

beds was 5 ha, mainly found at Mui Dia - Nhon Hai (1.37 ha), S. Dat Island (2.67 ha), and 1 ha at Bai Lang of Cu Lao Xanh Island - Nhon Chau.

With more than 720 species belonging to 353 genera and 161 families of 7 key groups of marine organisms, coral reefs support a higher species diversity (611 species, 15.6 times higher) than that in seagrass beds (39 species), indicating that Quy Nhon Bay supports a

relatively high diversity compared to that in some areas in the North of Binh Dinh but less diversity than that in several areas in the south of Binh Dinh. Nhon Ly, Nhon Hai, and Nhon Chau supported a higher species diversity than Ghenh Rang. Among them, 92 species were facing different levels of threats, in which 3 species were endangered (EN), including branching corals (*Alveopora minuta*), flat pen shells (*Atrina vexillum*), and top shells (*Tectus pyramis*); 38 species at vulnerable (VU); and 51 species at near threatened (NT) following the IUCN Red List and Vietnam Red Book.

Coral reefs and seagrass beds were not in good condition, with the mean cover being $27.2 \pm 22.8\%$ for live corals and $42.6 \pm 17.3\%$ for seagrass beds, equivalent to medium level following world standards. Resources of coral reefs were over-exploited, of which ornamental fishes with small size and low value were the major group (occupied with > 72%), macro-invertebrates including murex snails and sea urchins were dominant, but they have been continuously over-harvested. Coral reefs and seagrass beds at Bai Dua and Seo Island (Nhon Ly); Kho Nho Island, Bo Dap (Nhon Hai); S. Ngang Island, Bai Nam and Bai Nom of Dat Island (Ghenh Rang); Da Ban, Bai Lang, Bai Lang Ba and Ong Gia Island (Nhon Chau) are important sites in maintenance and development of marine biodiversity and fisheries resources need to protect in the restricted zone in the future entirely.

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