

# A study of coral reef resilience and implications of adaptive management and rehabilitation in Khanh Hoa Province, Vietnam

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## Abstract

The Province of Khanh Hoa, Vietnam, is located in the western South China Sea and boasts a shoreline of 385 km and many islands. Previous studies have indicated the extreme diversity and abundance of coral reefs in its waters as compared with other coastal provinces of Vietnam. A study on the resilience of coral reefs against increased surface water temperature and anthropogenic impact is conducted at 19 reef sites in 2015. At each site, a series of parameters (e.g., coral covers, genus diversity, and coral recruitment, substratum heterogeneity, depth, water exchange level, and sediment deposit and water temperature) are measured quantitatively or semi-quantitatively. The measured data are rated based on the relationship between the parameter values and coral susceptibility; the consideration that reef health reflects the biological capability to adapt to environmental changes and the recruitment potential if bleached; and positive or negative influences of physical factors in the mitigation of thermal stress and protecting corals from bleaching. A cumulative analysis enables researchers to divide the studied reefs into four categories based on varying levels of reef health to support resilience, recovery, and vulnerability in the case of increased water temperature. Relevant management interventions for each category and other supporting activities are suggested to enhance management effectiveness and to plan the rehabilitation of coral reefs for biodiversity conservation and touristic development, taking into account the involvement of related stakeholders.

**Key words:** coral reefs, resilience, reef health, thermal stress, bleaching, recruitment, rehabilitation

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## 1 Introduction

The southern Vietnam province of Khanh Hoa occupies a special seaward position, located at the easternmost area of Vietnam Mainland with a bathymetric contour of 50 m along the shoreline. The coastal waters have good exchanges with the open sea through seasonal circulations and the heterogeneous shoreline, which stretches 385 km in length and features many bays and lagoons. The analysis of secondary materials from previous scientific studies indicated the extraordinary biodiversity of the waters, which contain numerous habitats, such as coral reefs, mangroves, seagrass beds, islands, and beaches, and include a high species richness of marine features. Among them, coral reefs were considered the target habitats in the shallow waters, mainly in the Nha Trang Bay and Van Phong Bay, as well as outside the Cam Ranh Bay, with records of more than 3 000 hm<sup>2</sup>. In terms of reef coral diversity, recent studies (Huang et al., 2015; Vo, 2014) have indicated that Khanh Hoa coastal waters make up the most diverse region in the western South China Sea.

Recent economic development has resulted in a number of environmental concerns in coral reef management, including habitat loss and degradation, overfishing, and pollution and land/seascape degradation. In addition, coral bleaching has become more popular in recent years, with records of bleached cor-

als at the Nha Trang Bay as well as other areas of South Vietnam in 1998, 2010, 2013, and 2014 at different levels (Vo, 2002; Nguyen and Vo, 2014). Coral reefs in Khanh Hoa have degraded, and the effects will become more serious under the integrated impact of anthropogenic activities and increased water surface temperature.

Recognizing the need to improve the management effectiveness of coral reefs for not only biodiversity conservation but also the enhancement of the fisheries and tourist engagement, an idea involving the tourist sector and communities in the management and rehabilitation at the site level was suggested by scientists and approved by provincial authorities. A study on the resilience of coral reefs against increased water temperature and anthropogenic impacts was identified as a task to develop interventions appropriate for the sites.

## 2 Materials and methods

### 2.1 Approach to coral reef resilience and related factors

Resilience refers to the ability of a system to adapt to or recover from disturbance and change while maintaining its functions and services (Grimsditch and Salm, 2006). As discussed by Grimsditch and Salm (2006), coral reefs should ideally be able to either resist bleaching in the first place or quickly recover from it

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through the contribution of critical resilience factors. Bleaching avoidance refers to oceanographic and other environmental factors that create pockets of reduced or non-stressful conditions in which corals can avoid severe bleaching. These include areas of local upwelling, strong currents, or shading/screening. Mixing with deeper water or the proximity of the coral reefs to deeper water were also considered as reliable indicators of cooling that mitigate thermal stress and protect corals from bleaching. Regarding physical conditions, Salm and West (2003) also emphasized that some factors, such as reduction-of-temperature stress, the enhancement of water movement, decrease-in-light stress, and the provision of physical enhancements of recovery potential, may influence bleaching-related mortality and recovery among various coral reef communities. Examples of protection against bleaching by upwelling can be seen from coral reefs in the Ca Na Bay of Vietnam, as indicated in a survey on a bleaching event in 1998 (Vo, 2002).

On the other hand, coral reef resilience is related to coral reef health. Healthy reef ecosystems are better able to provide the conditions required for the recruitment, survival and growth of new corals to replace those killed by bleaching (Marshall and Schuttenberg, 2006). In addition, healthy coral reefs are more resilient and have a greater ability to recover from chronic and acute stress (Kaufman et al., 2011). Reviewing studies in areas that have suffered past bleaching events indicate that large corals and high coral cover are good indicators of resistant assemblages (Grimsditch and Salm, 2006). By reviewing many previous studies, Crabbe (2010) indicated many factors that can improve coral reef resilience, including species and functional diversity, connectivity to larval sources, appropriate substrates for larval settlements, and protection from other anthropogenic effects. Crabbe's study also revealed that rugosity—three-dimensional topography and complexity—has been linked to reef resilience.

Coral reef resilience is driven by not only physical and ecological factors but also anthropogenic threats. As coastal and marine environments become increasingly degraded due to anthropogenic activities, the natural resilience of coral reefs is weakened by the impact on their population structure, biodiversity, and functional diversity (Grimsditch and Salm, 2006). Sedimentation is a critical threat to coral reefs worldwide. Major land use alteration on steep, highly erodible, semi-arid islands accelerates the potential of soil erosion, runoff, and sedimentation stress at nearshore coral reefs. Furthermore, it is needed to address sedimentation stress in the context of the future climate to reduce land-based threats and strengthen coral reef resilience (Otaño-Cruz et al., 2017).

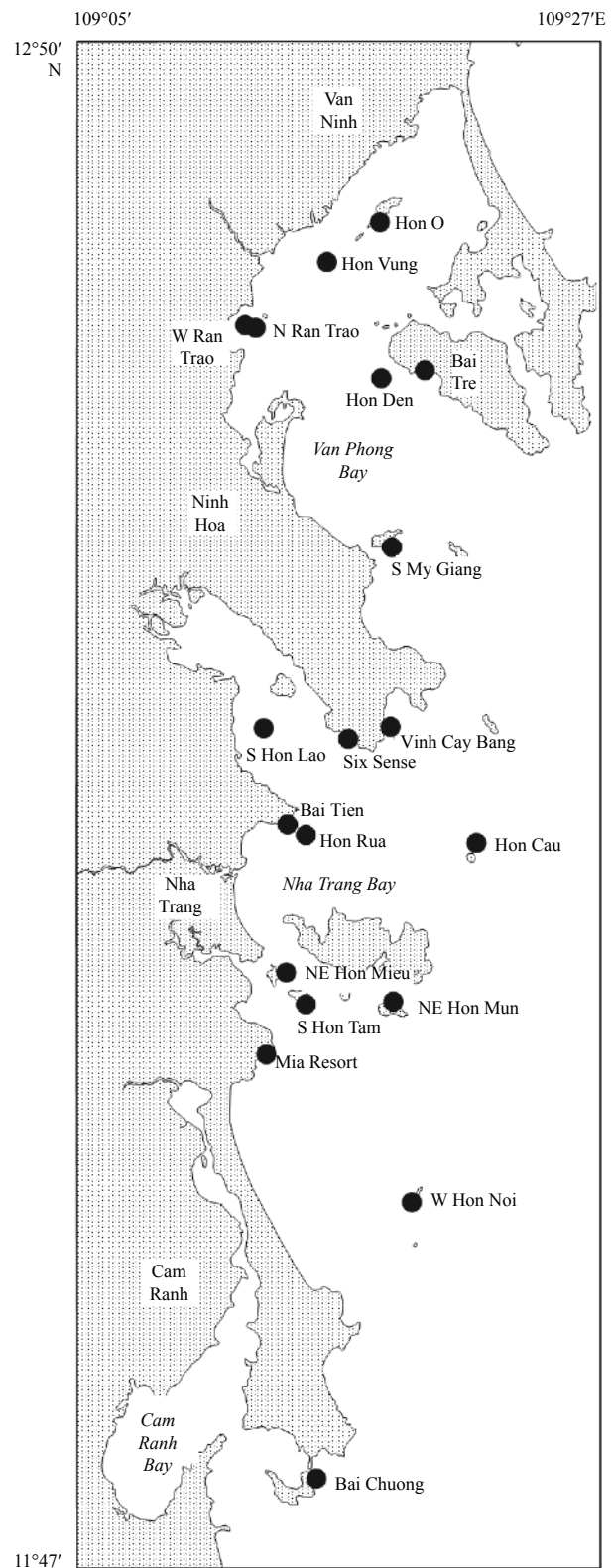
## 2.2 Parameter selection

Based on the above-described analysis of contribution factors to reef resilience as well as on the practical capacity and feasibility of this initial research, three biological parameters—coral cover (the total cover of hard and soft corals), the diverse levels of corals, and the number of young coral colonies—and four physical ones—the levels of water exchange, the maximum depth of the reefs, the substratum heterogeneity, and the water temperature—were selected. To consider the integrated impacts of anthropogenic activities, if any, sedimentation on the reefs was selected as an additional parameter.

## 2.3 Study site and time

Nineteen reef sites located either near tourist entities or in local communities were selected to implement the research, which aimed to involve them in the management of coral reefs in

the province (Fig. 1). A number of field trips were conducted in May and June 2015.



**Fig. 1.** The study sites.

## 2.4 Parameter measurements

The coral covers were measured using the reef check technology (Hodgson et al., 2006). At each site, two transects of 100 m were laid parallelly on two depth contours (2–5 and 6–10 m).

Each transect included four replicates of 20 m for each segment and an interval of 5 m between each segment. The calculation of the percentage of coverage of hard and soft corals was based on records of their presence on 80 points along the four segments, and a point-intercept transect method with an interval of 0.5 m was applied. The genus levels of the corals were identified and recorded on each point. The average number of coral genera in each replicate was used for the measurement of the diversity level of the sites. The number of young coral colonies (<5 cm) was counted in the areas of 20 m×1 m around the four above-mentioned replicates and was used in the assessment of recruitment potential. All parameters relating to reef health in the context of supporting coral reef resilience were rated on three scales: 1 represents being less than or equal to 15%, 2 represents 10%–30%, and 3 represents being greater than or equal to 30% for coral covers; 1 represents being less than or equal to 2, 2 represents 2–4, and 3 represents being greater than or equal to 4 genera per replicate for diverse levels; and 1 represents being less than or equal to 5, 2 represents 5–10, and 3 represents being greater than or equal to 10 young colonies per replicate for low, medium, and high recruitment potentials. The intervals of the values for the above scales are approximately equal to one-third of the maximum values of the parameters.

The levels of water exchange were semi-quantitatively assessed at three categories—(1) closed, (2) semi-closed, and (3) open—based on location, shoreline morphology, and wave exposure. The maximum depths of sites were measured using bathometers and classified into three categories: 1 represents being less than or equal to 3 m, 2 represents 3–6 m, and 3 represents being greater than or equal to 6 m. Substratum heterogeneity was divided into the following three categories: even and flat, uneven and flat, and steeping and uneven. The surface water temperature was measured using thermometers between 09:00 and 10:00 on the field trip days.

Inspired by [Fabricius and McCorry \(2006\)](#), sediment deposits (silt to fine resuspendable sand) on the substratum were rated on

a 4-point scale: 0 represents none; 1 represents thin layer of sediment; 2 represents thick layer, but the substratum can be cleaned by fanning off the sediment; and 3 represents high, thick layer of sediment, too deep to be completely removed by fanning.

### 3 Results and discussion

#### 3.1 Reef health

The data collected at the 19 sites ([Table 1](#)) indicate that most reefs had a coverage percentage of less than 50%, meaning that, according to the ranking of [English et al. \(1997\)](#), no reef reached categories of 4 (>50%–75%) and 5 (>75%–100%) in these coastal waters. Significantly, there were more than 31% reefs with coral covers of less than 10%, which reflects the degradation of a significant number of reefs. Rehabilitation and prevention of continuous degradation are, therefore, necessary for these reefs. The average number of genera per replicate recorded by the point-intercept transect method ranged from 1 to 6, indicating significant differences in the levels of diversity among sites. The number of young corals also varied significantly among sites, averaging between 2 and 15 colonies per replicate.

Looking at the ratings of reef health ([Table 2](#)) in terms of coral coverage and diversity, 10 of the 19 sites (53%) were considered as “good reefs” (scores of 2 or 3 for both parameters). Most of these 10 sites, with the exception of one (Bai Tre), had high or relatively high recruitment potential, with rating scores of 2 or 3. Among the six most degraded sites with low coral coverage and diversity (scores of 1 for both parameters), two sites had poor potential for recruitment (S My Giang and Bai Tien).

#### 3.2 Physical conditions

Most reefs in the study sites were located in shallow waters with a maximum depth of less than 7 m, and some reefs were even in waters of only 2–3 m in depth. In addition, the morphology of many reefs (nearly 50%) was flat and even. The rated scores ([Table 2](#)) show that many sites have unfavorable depth

**Table 1.** Parameters reflecting reef health status (abundance by coral cover, diversity by genera number and recruitment potential by young colony number recorded) of the study sites

No.	Site	Coral cover/%		Genera number		Young colony number	
		Average	SD	Average	SD	Average	SD
1	Hon O	23.75	16.01	2.25	0.50	14.25	5.85
2	Hon Vung	1.88	1.25	0.75	0.50	14.75	2.36
3	Bai Tre	28.93	14.06	3.29	1.11	4.50	3.54
4	Hon Den	22.19	22.18	3.00	1.93	11.88	7.24
5	N Ran Trao	63.44	30.28	4.00	3.34	6.14	2.79
6	W Ran Trao	39.38	12.07	2.50	0.58	5.00	2.94
7	S My Giang	4.06	3.26	1.13	0.76	2.83	1.33
8	Vinh Cay Bang	10.31	9.86	1.25	0.46	11.75	8.14
9	Six Sense	21.88	16.75	1.50	0.58	9.75	3.20
10	S Hon Lao	65.00	21.98	4.25	0.96	10.75	4.50
11	Bai Tien	2.50	2.04	0.75	0.50	3.25	2.75
12	Hon Rua	6.56	6.81	0.75	0.46	10.50	5.32
13	Hon Cau	37.19	14.32	4.50	2.00	12.86	7.15
14	NE Hon Mun	52.81	22.15	4.38	1.77	19.63	8.48
15	S Hon Tam	40.63	14.63	2.50	1.29	3.75	3.30
16	NE Hon Mieu	46.88	8.75	4.50	1.29	9.00	5.48
17	W Hon Noi	29.06	17.02	2.38	0.52	6.43	1.27
18	Mia Resort	4.38	4.27	1.25	1.26	6.00	5.48
19	Bai Chuong	41.25	21.19	3.38	2.00	12.83	3.66

Note: SD is short for standard deviation.

**Table 2.** Rating reef health status (1, 2 and 3 relevant to less, medium and good reef health, respectively) and favorability of physical conditions in reduction of thermal stress (1, 2 and 3 reflecting negative, medium and positive influences, respectively)

No.	Site	Reef health			Favorability of physical conditions against thermal stress		
		Coral cover	Diversity	Recruitment	Depth	Water exchange	Substratum heterogeneity
1	Hon O	2	2	3	1	1	1
2	Hon Vung	1	1	3	2	1	3
3	Bai Tre	2	2	1	2	1	1
4	Hon Den	2	2	3	1	2	1
5	N Ran Trao	3	2	2	2	1	2
6	W Ran Trao	3	2	2	1	1	1
7	S My Giang	1	1	1	2	2	2
8	Vinh Cay Bang	1	1	3	2	2	3
9	Six Sense	2	1	2	1	2	1
10	S Hon Lao	3	3	3	2	2	1
11	Bai Tien	1	1	1	2	2	1
12	Hon Rua	1	1	3	1	2	1
13	Hon Cau	3	3	3	3	3	3
14	NE Hon Mun	3	3	3	3	3	3
15	S Hon Tam	3	2	2	1	2	1
16	NE Hon Mieu	3	3	2	2	2	2
17	W Hon Noi	2	2	2	2	3	1
18	Mia Resort	1	1	2	2	2	1
19	Bai Chuong	3	2	3	1	2	1

and heterogeneity for reduction-of-temperature stress and decrease-in-light penetrability. Therefore, water exchange played an important role in mixing waters and reducing temperature. In the review on the physical conditions in central Vietnam (Bui, 2011), differences in water temperature were found along Khanh Hoa's coastal waters. With a low amount of water exchange, the northern section of the Van Phong Bay had high temperatures in the summer (perhaps 32°C at most), but the southern section experienced lower temperatures, with a maximum of 30°C. Meanwhile, the Nha Trang Bay was characterized by cooler temperatures, with maximum summer temperatures of 29.5°C in the northern part and 28.5°C in the southern part. Field measurements in the summer of 2015 (Table 3) reflected a trend of temperature reduction in the waters from the north (>30°C for most sites) to the south (generally around 28–29°C). The multi-year data show the fluctuation of average temperatures in the Nha Trang Bay as ranging between 24.0 and 29.5°C, with two minimums in January and June. The second one was due to the influence of upwelling, which occurs annually in the summer in the coastal waters southward of the Nha Trang Bay (Bui, 2011).

Overall, most reefs in the northern areas, especially those in nearshore waters in the Van Phong Bay, are more sensitive to increased water temperatures. Reefs in the Nha Trang Bay and southward, with their distribution around islands, are less vulnerable to temperature stress.

### 3.3 Possible anthropogenic impacts

The effects of human activity in the coastal waters of Khanh Hoa Province have been examined by a number of previous studies. It has been indicated that land-based inputs to the Van Phong and Cam Ranh Bays have come from a pond culture, sewage, and industry development (Pham et al., 2014; Phan et al., 2013). Meanwhile, the water quality in the Nha Trang Bay has mainly been impacted by river inputs and tourist development along the coast and on the islands, taking account into sedimentation from rivers during the rainy season and construction on the islands

(Vo, 2011).

Data on sediment deposits (Table 3) provided a figure on the possible impacts of land-based inputs, indicating that a number of reefs, mainly those in nearshore areas, may be affected by the human activity, such as coastal development or discharge from pond aquaculture. This includes the reefs in the inner Van Phong Bay (Hon O, Bai Tre, W Ran Trao) and the nearshore waters of the Nha Trang Bay (Bai Tien, NE Hon Mieu, Mia Resort). This would be an implicit factor that could increase the vulnerability of corals to increased water temperature.

**Table 3.** Rating sediment deposit and water temperature at the study sites, May–June 2015

No.	Site	Sediment deposit		Temperature/°C	
		Score	SD	Average	SD
1	Hon O	2.25	0.50	31.7	1.27
2	Hon Vung	1.00	0	30.5	0.57
3	Bai Tre	2.00	0	30.4	0.07
4	Hon Den	0.13	0.35	30.2	0.49
5	N Ran Trao	1.50	0.53	32.0	0.42
6	W Ran Trao	2.00	0	31.7	0.00
7	S My Giang	0.38	0.51	28.4	1.20
8	Vinh Cay Bang	1.00	1.06	NA	NA
9	Six Sense	1.25	0.50	28.4	0.69
10	S Hon Lao	0.50	0.57	29.3	0.23
11	Bai Tien	2.00	0.81	28.8	0.04
12	Hon Rua	1.88	0.64	29.1	0.01
13	Hon Cau	0.38	0.51	NA	NA
14	NE Hon Mun	0.63	0.51	28.8	0.18
15	S Hon Tam	0.25	0.50	29.1	0.63
16	NE Hon Mieu	3.75	0.50	29.2	0.14
17	W Hon Noi	0.25	0.46	29.2	0.20
18	Mia Resort	1.75	0.95	29.0	0.18
19	Bai Chuong	0.13	0.35	29.7	0.21

Note: NA represents no data available.

### 3.4 Management interventions

The reef at the study sites differed significantly in terms of supporting corals in adapting to environmental changes and favorability in the reduction of thermal stress in the case of increased water temperature as well as in terms of their recovery potential. Management interventions should, therefore, be developed appropriately to ensure management effectiveness. An analysis of collected data enabled the study sites to be classified into four categories (Table 4). The first two categories have favorable physical

conditions for the reduction of thermal stress and require mainly natural conservation to maintain a healthy state and sustainable use for the enhancement of fisheries and tourist activities. Should anything threaten to damage these reefs, they would recover naturally thanks to community recruitment. Bleaching and even mass mortality could occur on reefs of last two categories in the case of increased water temperature. For those reefs with low recovery potential (Category 4), reef communities should be artificially enhanced if mass mortality occurs after bleaching.

**Table 4.** Categorization for management interventions at the site level

Category	Site characteristics	Intervention	Site name
1	favorable physical conditions for reduction of thermal stress, healthy reefs and rapid or slow recovery if damaged	managed as a refugia for community enhancement at the sites and dispersal to others	S Hon Lao, Hon Cau, NE Hon Mun, S Hon Tam, NE Hon Mieu (5 sites)
2	favorable physical conditions for reduction of thermal stress, unhealthy reefs and rapid recovery if damaged	protected for natural rehabilitation and support to enhance reef communities	Vinh Cay Bang, W Hon Noi, Mia Resort (3 sites)
3	unfavorable physical conditions for reduction of thermal stress, healthy or unhealthy reefs and rapid recovery if damaged	support for natural restoration if mass mortality occurred after bleaching	Hon O, Hon Vung, Hon Den, Hon Rua, Bai Chuong (5 sites)
4	unfavorable physical conditions for reduction of thermal stress, healthy or unhealthy reefs, slow recovery if damaged	needs of artificial restoration if mass mortality occurred after bleaching	Bai Tre, N Ran Trao, W Ran Trao, S My Giang, Six Sense, Bai Tien (6 sites)

As mentioned previously, 6 of the 19 reefs had a status of severe degradation, with a coral coverage of less than 10%. Urgent restoration of these reefs is imperative to enable the enhancement of biodiversity and utilization for touristic purposes. It should also be noted that most of these reefs belonged to categories 3 and 4, with a high susceptibility to bleaching. The restoration of these sites should consider the vulnerability of restored corals to changes in physical conditions, including increased temperature. In addition, sedimentation would negatively impact the process of restoration at the two sites (Bai Tien and Mia Resort).

An analysis of the data on sediment deposits indicated that most of the reefs that had recently suffered sedimentation (Bai Tre, W Ran Trao, Bai Tien, Hon O) were categorized as highly susceptible to bleaching. The mitigation of land-based impacts should be considered in parallel with the management and restoration of these reefs because human activity increases coral damage via high temperatures through an integrated impact. Surveys in the Con Dao Islands (Hoang et al., 2008) provided evidence of the mass mortality (20%–90%) of corals and other reef invertebrates on the northwestern sides of the islands in October 2005. The combination of high water temperatures (>31°C) in a short period and the sudden decrease of salinity (<25.0) is considered the reason for the catastrophe.

Recently, the marine protected area of the Nha Trang Bay mainly focusing on biodiversity conservation in core zones, where the Hon Mun and Hon Cau Islands are located. The reefs around these islands with healthy statuses and favorable physical conditions in the reduction of thermal stress, as indicated, are very important for maintaining biodiversity and providing replenishment sources for other reef rehabilitation, if degraded, at least in the Nha Trang Bay and neighboring areas. Effective management of these reefs is critical for reef resilience in the Province of Khanh Hoa. The authorities should consider the issue of reef survivability when developing management plans for the entire marine protected area, including in issues of zoning and the implementation of management practices. As advised by Salm and West (2003), the planning should consider factors that promote water mixing and screen corals from damaging radiation, which

indicate potential preadaptation to temperature and other stresses, favor survival of at least some coral communities, indicate strong recovery potential, increase coral larval transport to the site, and prepare the substrate for successful coral larval recruitment.

Reefs around the Ran Trao Islands have been managed by local communities with limited capacities. Given that these reefs were revealed to be quite healthy but highly susceptible due to unfavorable physical conditions in the reduction of thermal stress, artificial restoration and support to mitigate stress from human activity are necessary. The remaining reefs at the study sites are not under any clarified management mechanism. Recently, a number of businesses have expressed their interest in restoring and managing the coral reefs for their use, mainly for tourist engagement. Recognizing the importance of the sustainable use of coastal habitats with stakeholders' participation, provincial authorities have encouraged this trend. A management and restoration policy based on reef health status and susceptible characteristics at the site level should be applied for those reefs located near tourist entities.

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