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Assessing coral reef resilience for sustainable resource management (case study in Hon La island, Quang Binh province, Vietnam)

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Abstract
Coral reefs play a crucial role in providing ecosystem services for the coastal communities. However, the resilience of coral reefs is quickly degraded due to both global and local stressors, including climate change and marine pollution. Hon La island in Quang Binh province, Vietnam is one of the most important coral reef ecosystems. However, this area was heavily influenced by human activities and marine pollution. Therefore, the present study is implemented in order to evaluate the resilience of coral reefs in Hon La island for proposing sustainable development solutions. The proposed indicator framework consisted of three dimensions (coral diversity, biodiversity and environment), containing 26 indicators that potentially provided the quantified methods for decision makers to inform a range of management strategies in protecting coral reefs and using natural resources effectively. Results showed that coral reefs in Hon La island had a low resilient index, about 0.369 because of a degradation of diversity, seawater contaminated by oils and the high turbidity. Several solutions were proposed to enhance the resilience of coral reefs, including the establishment of marine protected areas; integrated management of the coastal zone; rehabilitation of coral reefs and application of co-management models. The theoretical framework from the present study could be potentially applied to evaluate the coral reef resilience in other marine areas in Vietnam with appropriate modification.

Keywords: Coral reefs, resilience, indicators, sustainable resource management, Hon La island.

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INTRODUCTION

Climate change and anthropogenic activities are main factors threatening the natural resilience of coral reef ecosystems. Reef resilience is the capacity of an ecosystem to resist and recover from disturbances while maintaining the same services, function and structure [1]. Resilience is a vital factor to maintain biodiversity and tolerance to negative impacts from external factors such as increasing pollution and sediment concentrations in the marine ecosystem. The coral resilience depends on many factors, including biodiversity, coral recruitment, human activities and habitat characteristics [2]. When the disturbances exceed the resilient threshold, coral reefs will be degraded, causing degradation of biodiversity in either coral reef ecosystem or other coastal ecosystems. As a result, policymakers, conservationists, scientists and communities have called for action to restore and sustain the resilience of coral reefs to minimize impacts of climate change and environmental pollution. Research on the resilience of coral reefs to climate change and human activity began to take place after the outbreak of coral bleaching in 1988/1999. The International Union for Conservation of Nature (IUCN) has developed a procedure for determining the resilience and recovery of coral reefs. There are two main resilient factors: Ecological factor (species and functional diversity); spatial factors (reproduction and connectivity; shifting geographic ranges) [1]. Therefore, the protocol (IUCN 2009) implemented the measurement or estimation of 61 'resilience factors' with rankings (based on high to low scores) to inform management and identified plan for refining resilience assessments [3]. This has created a scientific basis for determining the level of resilience, identifying the causes of ecosystem degradation and contributing to decisions on management strategies, conservation. Thus, the coral reef resilience assessment researches have been extensively carried out in the south of the Great Barrier Reef, Australia; Nosy Hara Marine Reserve, Northwest Madagascar; the Pemba, Tanzania and Indonesian islands [3–6]. A total of 11 resilience indicators: Coral diversity, recruitment, bleaching resistance, temperature variability, herbivore biomass, macroalgal cover, nutrient input, sedimentation, fishing pressure, coral disease and anthropogenic physical impacts have been developed for assessing coral reefs [2]. The case study in Saipan applying the McClanahan's indicators has provided a general rating scale for resilience, thereby proposing management solutions for each specific area with the respective level resilience [7].

In Vietnam, coral reef degradation is occurring from the north to the south. Human activities and climate change are major factors that cause such degradation. According to the World Resources Institute, about 80% of coral reefs are facing the serious bleaching, in which 50% are at high levels [8]. Vietnam coastal zone is one of the most vulnerable areas by climate change, especially in Hon La island in Quang Binh province. According to the climate change and sea level rise scenarios for Vietnam, the average temperature of the country increases by over 0.5^{o}C in the past 50 years; the trend of storm development has become more severe with frequency and complexity causing bleaching and degradation of coral biodiversity [9]. In addition, coastal socio-economic development is contributing to the degradation of the seawater quality, which extremely affected coral reefs and marine life. For example, as the consequence of marine pollution from Formosa Ha Tinh Steel Company (FHS) in April 2016, coral reefs in Hon La were severely degraded. It would take many years for the ecosystem to recover as before [10]. The deterioration of coral reef ecosystems is detrimental to marine biodiversity and livelihoods in coastal areas and damage from natural disasters increases. Therefore, the resilience, maintenance and conservation of this ecosystem are indispensable. Based on available research database and additional investigations, the assessment of the resilience of the coral reef ecosystem will help managers determine the factors that mainly influence the recovery and resilience in order to propose solutions to mitigate negative impacts and to maintain ecosystem functions and services.

On the other hand, although many studies have focused on policies, strategies, and climate change related to coral reefs, virtually no study on coral reef ecosystem resilience has been performed in Vietnam. Therefore, the objective of this paper is to assess coral reef resilience to climate change and pollution for proposing solutions of sustainable resource management in Hon La island, Quang Binh province, Vietnam.

STUDY AREA

Hon La island is about 1 km^2 in area, has narrow terrain with the slope from West-East located in the Tonkin Gulf, in Quang Dong commune, Quang Trach district, Quang Binh province (fig. 1). In particular, Hon La island has the largest area of 0.47 km^2, more than 0.5 km away from land [11]. The study area has two typical seasons: Rainy season and dry season with an annual average temperature of 24–25^oC. Total rainfall is 1,500–2,000 mm per year, unevenly distributed between the seasons [12].

Marine circulation in the area is dominated by two typical winds in the northeast and southwest. During the winter, the area is affected by northeast monsoon along with cold flow West - South China. During the summer, the sea flows south-west through central Vietnam [13].

According to the Quang Trach Statistical Yearbook 2014, there are about 4,277 people in Quang Dong. The commune includes five villages: Vinh Son, Minh Son, Tho Son, Dong Hung and 19-5 villages. The study area has Hon La port with a total area of 194.37 ha, adjacent to the coral area in the northwest and the tidal area of the southwest of this island. In the Hon La port, fishing activities around the island are quite hectic with about 673 fishing boats.

At water depths of 30 m, coral reefs around the island are very narrow in size, with a total area of 50 ha, in which the main island is 40 ha (fig. 1). Coral reefs are mainly concentrated in the west of the island. Coral reef morphologic type is fringing reef, usually concentrated in shallow waters, no more than 7–10 m depth [11]. Reef structures are abundant in the area such as reef flat, fore-reef slope and reef crest.

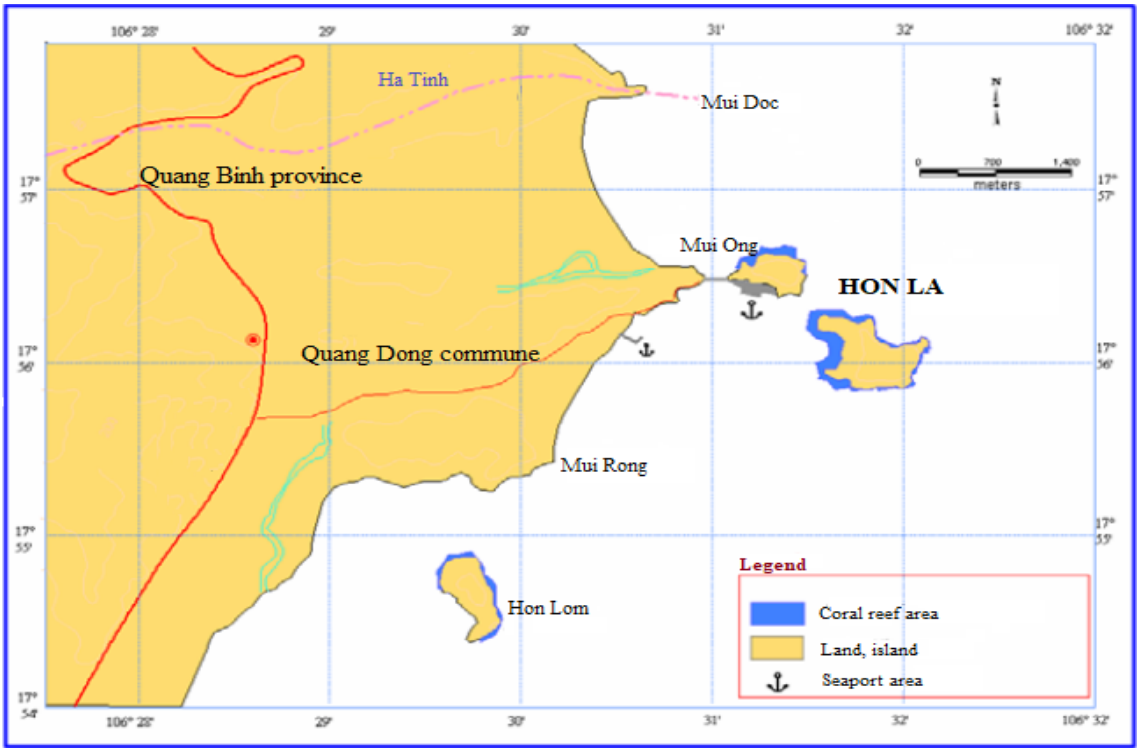

Fig. 1. Coral reef distribution in Hon La island, Quang Binh province [11]

THEORETICAL FRAMEWORK AND METHODOLOGY

Theoretical framework

The present study proposed an assessment framework with five steps to give an overview of the research plan; the mode of implementation through scientific and practical basis; study objectives and effective management methods (fig. 2). The framework is developed to be easy to approach and implement and to engage the local community in the management of coral reefs.

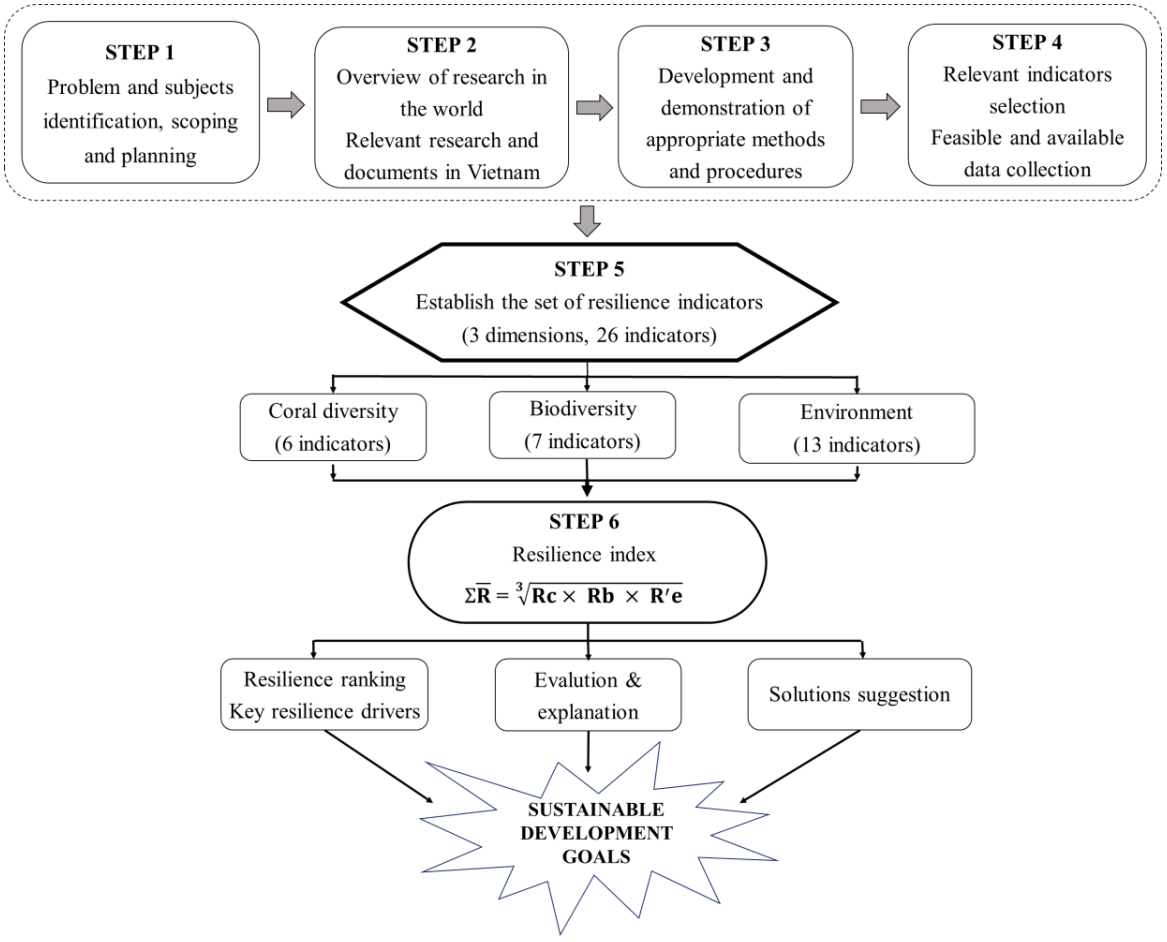

Fig. 2. A framework to assess the coral reef resilience. See text for detailed description

After identifying the objectives, subjects and tasks, the study conducted collection of relevant research materials, methods of study, the resilience index of the coral reefs in the world and Vietnam. Therefore, by developing scientific and legal basis, the study proposed three main dimensions that inherit the contents and pillars of the some case studies in the world, such as the south of the Great Barrier Reef, Australia; Nosy Hara Marine Reserve, Northwest Madagascar; the Pemba, Tanzania and Indonesian islands [3–6]. Three dimensions of coral diversity, biodiversity, and environment with 26 indicators are identified based on three criteria: Feasible and available data; easy to understand and apply; suitability of the area (table 1). Then, by collecting data, using appropriate calculation methods to quantify and assess the coral reef resilience in Hon La, the research will create a scientific basis for applying research in other areas, contributing recommendations for decision makers in strategies, sustainable management.

Table 1. Set of coral reef resilience indicators

Dimension	Sub-Dimension	Indicators	Unit	Scoring methods
Coral diversity	Coral reef abundance	Number of hard coral species (+)	Individual	Eq. (1)
		Number of soft coral species (+)	Individual	Eq. (1)
	Benthic cover	Proportion of soft coral cover (+)	%	Eq. (1)
		Proportion of hard coral cover (+)	%	Eq. (1)
		Proportion of dead coral cover (-)	%	Eq. (2)
		Proportion of algae cover (-)	%	Eq. (2)
	Herbivore fish abundance	Coral fish biomass (+)	g/m^2	Eq. (1)
Biodiversity	Benthic animal abundance	Mollusca density (+)	individuals/ m^2	Eq. (1)
		Crustacea density (+)	individuals/ m^2	Eq. (1)
		Echinodermata density (+)	individuals/ m^2	Eq. (1)
	Plankton diversity	Polychaeta Species (+)	individual	Eq. (1)
		Zooplankton density (-)	mg/m^3	Eq. (2)
		Phytoplankton density (-)	$cell/m^3$	Eq. (2)
Environment	Environmental parameters	Temperature (-)	^oC	-
		pH (-)	-	-
		Salinity (-)	‰	-
		Dissolved oxygen (DO) (+)	mg/l	-
		Turbidity (-)	NTU	-
	Nutrients	NH_4^+ (-)	mg/l	Eq. (2)
		PO_4^{3-} (-)	mg/l	Eq. (2)
	Pollutants	Pb (-)	mg/l	Eq. (2)
		Cd (-)	mg/l	Eq. (2)
		Hg (-)	mg/l	Eq. (2)
		Phenol (-)	mg/l	Eq. (2)
		CN^- (-)	mg/l	Eq. (2)
		Dispersed oil (-)	mg/l	Eq. (2)

Note: (+): Positive resilience indicator; (-): Negative resilience indicator.

Scoring methods

Resilient indicators have different characteristics and units, so in order to compute and compare indicators, the study converted them into a unique identifier type using Min/Max calculation. The research used the highest and lowest values of each indicator in synthesis report of project results of Directorate of Fisheries in 2015 [14] and specific threshold values as environmental parameters to define Min/Max value.

The real value result of the indicators was normalized to the range value between 0–1. Resilient scores were calculated as the average of resistance or recovery scores with a higher score indicating higher resilience [7].

There are two types of indicator: Positive and negative indicators. Each indicator type is applied in Min/Max equations as follows:

For positive resilience indicator:

$$Xi(+) = \frac{Xn - X\min}{X\max - X\min} \quad (1)$$

For negative resilience indicator:

$$Xi(-) = \frac{X\max - Xn}{X\max - X\min} \quad (2)$$

For Eq. (1) and Eq. (2), Xn is a value of indicator X; Xmax and Xmin indicate the maximum and minimum scaled values of indicator X respectively.

After that, the resilience dimensions and sub-dimensions will be calculated by the mean equations as follows:

Geometric mean:

$$R_i = \sqrt[m]{X1 \times X2 \times ... \times Xm} \quad (3)$$

Arithmetic mean:

$$R_i^{'} = \frac{\sum_{i=1}^{m} Xi}{m} \quad (4)$$

For Eq. (1), Eq. (3) and Eq. (4), *Xi* is a value of indicator *i*.

Then, the general resilience of Hon La reef ecosystem is calculated based on the value of the component resilience index as follows:

$$\sum \overline{R} = \sqrt[3]{Rc \times Rb \times R^{'}e} \quad (5)$$

For Eq. (5), *Rc* is a value of resilient index of coral diversity; *Rb* is a value of resilient index of biodiversity; *R'e* is a value of resilient index of environment.

Finally, based on Reef Assessment Scale by Jeffrey Maynard, the study will identify the level of aggregate resilience of coral reef ecosystem [7]:

0.8–1: High resilience;
0.6–0.79: Medium resilience;
< 0.6: Low resilience.

The aggregate indicator index ($\sum \overline{R}$) is closer to 1, meaning coral reef ecosystem more resilience and vice versa.

Data collection

This study needs many types of datasets for calculating resilient index. Therefore, the data collection was performed by reviewing the scientific reports and documents that showed the characteristics of the coral reef ecosystem and marine environment in Vietnam coastal area [11, 14]. Another dataset of natural features, socio-economic characteristics of the study area was collected from Quang Binh Web portal. The data is statistically analyzed using Microsoft Excel software.

RESULTS AND DISCUSSION

Coral reef resilience dimension indices

Based on the criteria, there are 13 indicators representing biodiversity and 13 indicators of environmental condition. The study has balanced the number of indicators in two main sides for assessing the coral reef resilience accurately.

Coral diversity

The diversity of coral species enhances the function of the ecosystem, as the loss of one or more species can lead to decreased tolerance and recovery [15]. Corals are divided into two main groups: Hard and soft corals. The characteristics of each species in the ecosystem will determine their resilience to external impacts [16]. There are many indicators as dominant size class, recruitment, largest corals, shading and screening,... to assess coral resilience but based on the criteria, in this coral diversity dimension, the study focused on the situation of coral health by algae, hard coral and soft coral.

In 50 ha area, there are 72 species of coral (in which 65 species of hard coral dominate) narrowly distributed, Hon La is less diverse than other reefs in Vietnam coastal area. Despite the highest hard coral cover (20.26%) of the Tonkin Sea area, coral reefs have developed poorly, 0.6–4.03% mortality of corals within 5 years. Compared to the reef areas of Vietnam, Hon La has lower coral cover. In addition, in the coral substrata, 0.68% of seaweeds with 28 species are distributed on corals or other species of seaweed [14]. Thus, the study evaluated the species composition and the low rate of coral cover at Hon La, the resilient value of the number of hard coral, soft coral, and cover of each coral species was less than 0.6 (fig. 3).

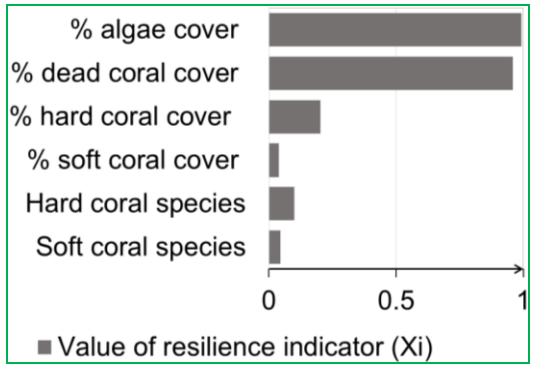

Fig 3. Resilience values of Hon La coral diversity index

Biodiversity

The diversity of species facilitates coral reef to develop and survive, maintaining

ecosystem functions and services. However, there still exist some harmful species, such as crown of thorns starfish, abundance of phytoplankton. Production organisms (such as algae, seaweeds), consuming organisms (crab, shrimp, fish) and decomposing organisms (microorganisms) have specific functions and roles in promoting the recovery process of coral reefs and retaining diversity and resistant ability against disturbances [15, 17, 18]. Besides assessing coral and algae situation, in this study, the biodiversity dimension evaluates the coral resilience through animal abundance and plankton diversity. Plankton plays an important role not only in the food chain but also in the quality of seawater affecting the development and rehabilitation of coral reef ecosystems. The diversity and abundance of phytoplankton, which cause algal blooms phenomena, will affect the DO (dissolved oxygen) and water transparency [17, 19]. The phytoplankton density in Hon La is 187.61 mg/m^3, being lower than other coral reefs in the north [14]. As the results, the average resilient values of plankton density ranged from 0.965–0.971 (fig. 4).

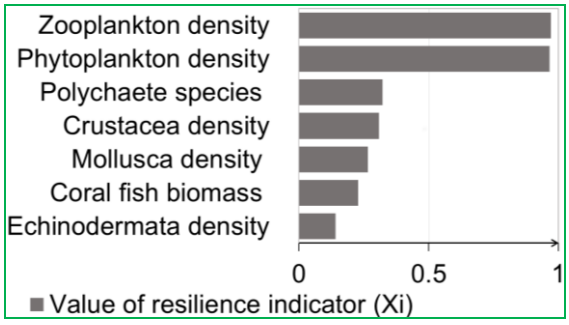

Fig 4. Resilience values of Hon La biodiversity index

However, benthic animals in Hon La island are less diverse than other islands in Vietnam, indicated by the density index of Mollusca, Crustacea, Echinodermata and Polychaeta species, about 7.5–26.8 individuals/m^2. In addition, Hon La island has 62 species of coral fish with small biomass, 34.28 g/m^2 [14]. These indicator indices have higher value meaning coral reef ecosystem resilience more enhanced. Consequently, animal species in Hon La reef ecosystem are less diverse, so the resilient values of 5/7 indicators in biodiversity dimension were < 0.5 (fig. 4).

Environment

In fact, corals only exist and grow in a specific and strict environment with a certain range of temperature, pH, salinity, turbidity and nutrient concentration. In the allowable range, the values of resilient indicators nearly approaching threshold are more susceptible to impacts but coral reef can still be thrived and recovered [17, 20]. Therefore, these indicators were normalized to the highest score 1 as the greatest resilient ability of coral reef. However, when the threshold is exceeded, coral reefs will be degraded so that the resilience value reaches the lowest threshold of 0. In general, the physical and chemical parameters of Hon La sea water environment are likely to be suitable for coral reef ecosystem development but there are signs of pollution because of oil and high turbidity, which restrict the resilience and recovery of coral reef to disturbances (table 2).

Specifically, the impacts of climate change on the marine environment are performed through the changes of temperature and pH [16, 21]. According to monitoring results of the study (table 2), if these parameters are in the allowable range for coral reef ecosystem development, thus resilience of coral reef is not affected. Coral survives in the strict conditions with the value of temperature, DO, pH, salinity, turbidity. Moreover, based on the specific features of area, there are many water quality standards for marine, including coral reef development. When marine animals can survive strongly showing the quality of the environment so coral reef can progress in that environment. In Vietnam and Hon La, in order to assess the current environmental condition, the study used national technical regulation on marine water quality for aquatic conservation.

Besides, the research indicated that other chemical characteristics such as salinity and DO of the Hon La area are favorable for coral reef ecosystems to sustain its services and functions. Temperature and pH indicators represent the effect of climate change, being in the acceptable threshold for marine animals and coral development. Nutrient concentrations

such as NH_4^+ and PO_4^{3-} are also lower than the threshold in national technical regulation on marine water quality [22]. Consequently, the resilient values of the temperature, pH, salinity, DO, NH_4^+ and PO_4^{3-}index reached a maximum of 1 (fig. 5). Nevertheless, turbidity is higher than the allowable threshold because of human activity; topography and climate characteristics, causing degradation of coral reef ecosystem with the minimum resilience value of 0 (fig. 5). Furthermore, the non-essential elements in water affecting the growth and development of corals as Pb, Cd, Hg, phenol, cyanide (CN^-) are in the permitted concentration for aquaculture [22]. Subsequently, the resilience value of these indicators Pb, Cd, Hg, phenol, and cyanide is quite high, ranging from 0.7 to 0.93 (fig. 5).

Meanwhile, dispersed oil concentration in water was 0.67 mg/l (table 2) beyond the allowable regulation as turbidity value so the resilience value of its parameter was adjusted to zero (fig. 5).

Table 2. Environmental parameters of seawater in Hon La

No.	Parameters	Unit	Result	Threshold value	Reference
1	Temperature	^oC	27.12	20–32^oC	[23]
2	pH	-	7.92	6.5–8.5	[22]
3	Salinity	‰	27.68	25–35‰	[24]
4	DO	mg/l	6.14	>= 5	[22]
5	Turbidity	NTU	6.15	0 - 2	[20]
6	NH_4^+	mg/l	0.07	0.1	[22]
7	PO_4^{3-}	mg/l	0.0062	0.2	[22]
8	Pb	mg/l	0.0035	0.05	[22]
9	Cd	mg/l	0.00019	0.005	[22]
10	Hg	mg/l	0.0014	0.001	[22]
11	Phenol	mg/l	0.0079	0.03	[22]
12	Cyanide (CN^-)	mg/l	0.001438	0.01	[22]
13	Dispersed oil	mg/l	0.67	0.5	[22]

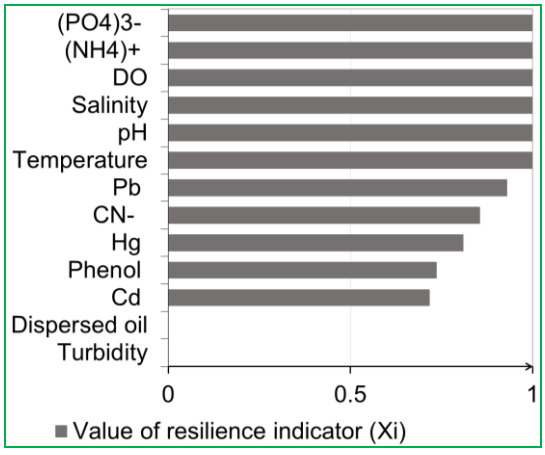

Fig 5. Resilience values of Hon La environment index

Coral reef resilient index in Hon La, Quang Binh

Based on the resilience scale, the results showed that the coral reef resilience degraded with a value about 0.369 (fig. 6). The biodiversity is the main driver with the lowest resilient value (0.181) affecting the resilience of coral reef ecosystem in Hon La. It represents enhancement and maintenance of the resilience as the main function in the ecosystem against negative impacts. Moreover, habitat characteristics are a critical condition that governs the survival, development, reproduction of coral reef. However, according to fig. 6, despite the highest resilient value of environment index (0.7731), Hon La reef is very sensitive and vulnerable to disturbances such as marine pollution. Oil pollution and high turbidity are one of the reasons for the degraded coral cover and species diversity in Hon La (fig. 5). Coral larvae are not grown under appropriate conditions to expand the reef area. As a result, proposing solutions is indispensable to improve the marine environment and minimize other negative impacts.

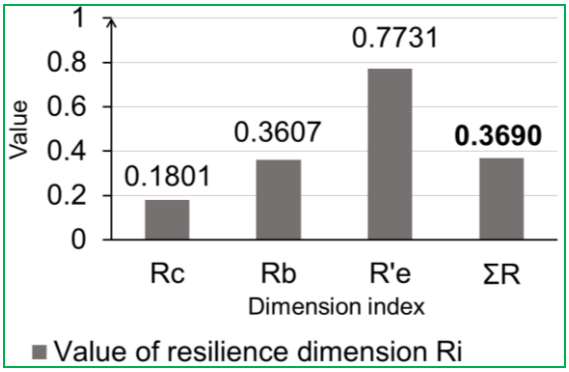

Fig. 6. Aggregate value of coral reef resilience index in Hon La

Solutions for sustainable resource management

Based on the scientific basis of the role, function, status of coral reefs and the basis for legal provisions, the system of legal documents relating to the sea and marine resources; some important sub-laws regulating the exploitation, management and conservation of marine resources, coral reefs and marine biodiversity, the study proposed several solutions for the sustainable management of coral reef ecosystems and natural resources as follows:

Establishment of marine protected areas aims to create favorable conditions for the preservation and restoration of coral reef ecosystem, ensuring ecological balance, regulating the environment, maintaining biodiversity and aquatic resources in a long term;

Integrated coastal zone management, environmental impact assessment, marine environmental pollution control to create a suitable and stable habitat for reef ecosystem recovery;

Rehabilitation of coral reefs to enhance the biodiversity and coral cover;

Conservation of coral reef ecosystems by co-management with the involvement of local communities, the state and other stakeholders in contributing to minimizing environmental conflicts in protection, preservation and exploitation.

CONCLUSIONS

The present study has developed a theoretical framework and a set of indicators, consisting of three dimensions (coral diversity, biodiversity and environment) and 26 indicators to evaluate the level of sensitivity, current status of the coral reef ecosystem in Hon La island, Quang Binh province. Results showed that the overall resilient index of the coral reefs was 0.369, not mainly influenced by climate change. The low resilience is due to strong influence from high concentration of oils and the high turbidity in seawater. The study has proposed some solutions to inform sustainable management, including the establishment of MPAs; integrated coastal management; restoration, and co-management method to manage and use sustainable resources, improve the resilience and resistance of coral reef ecosystems to the disturbance of human activities and climate change.

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