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Coral Reef Resilience in 17 Islands Marine Recreation Park, Riung – An Assessment of Functional Groups of Herbivorous Fish and Benthic Substrate

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Abstract

Coral reefs in Indonesia are threatened by destructive fishing including the use of bombs and cyanide. Reefs in eastern Indonesia are particularly affected including reefs within 17 Islands Marine Recreation Park (MRP), Riung, Flores. Coral reef ecosystems that have been damaged can recover when the threat is stopped but the ability to recover will depend on several factors including status of herbivorous fish stocks, availability of suitable substrate for coral larval settlement, larval source, water quality and local oceanography. This research focuses on assessing the recovery potential of coral reefs 17 Islands MRP by assessing these factors at 12 sites including [i.e coral emergence, herbivore fish biomass and abundance, oceanographic factors]. This research showed that South Tiga Island has the highest recovery potential, due to the high population of herbivorous fish that will assist in opening a new substrate for the settlement coral larvae and limit the growth of algae. This site also has good conditions for coral growth indicated by the highest cover of live hard coral, high available substrate and sheltered position. Furthermore this research really important to know site potential for reef recover. Also improve management prioritization of reef sites based on reef resilience factors.

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Keywords: Destructive fishing, , Herbivorous Fish, Available Substrate, Reef Resilience, Riung 17 Islands Marine Park

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1. Introduction

Indonesia is among the countries situated in an area of high marine biodiversity know as the 'Coral Triangle' that represents 18% of the global coral reef area and contains around 60% of the world's coral species[1]. However, the Indonesian coral reef ecosystems are among those that are persistently under the threat of destructive fishing practices, such as the use of bombs and cyanide, as well as overfishing, sedimentation, coastal pollution, coral mining, dredging and resort construction, industrial and agricultural effluents[2,3].

A coral reef assessment in 17 Riung Islands Marine Recreation Park (MRP) have documented signs of reef degradation in the area due to anchor damage, destructive fishing and sedimentation[4]. These human-induced disturbances might have occurred in a persistent manner in the past, which can make the process of coral recovery from natural disturbances (i.e. hurricane, predator outbreak) further reduced[5]. For the recovery of coral assemblages, the combination of human and natural disturbances may inhibit ecosystem recovery process such as by preventing coral larvae settlement and survival[6]. Evenif chronic stresses from anthropogenic activity has been reduced or put into cease, coral reef habitat may require a long-term (i.e. decadal) period to recover as recruitment rate, growth rate, and survivor-ability against predators and disease has been impaired[7]. Thus, a combination of biophysical and socio-economic factors contributes to coral recovery[4-8].

Part of the effort to understand coral reef ability to withstand disturbance is by understanding the current state of coral reef 'health' (i.e. coral-dominated, algae-dominated). The process of recovery can then be implicitly assumed, by reflecting current state with the former state of the reef. For coral reef managers, the answer to whether reef has or will recover may not be sufficient. They need to know factors that may facilitate, or enhance coral recovery in the future, given with the increasing pressure to coral reef from human activity both at local and global scale[5]. Among the factors that determine ecological resilience of the reef system are the availability of the substrate support, water quality, oceanographic conditions, larvae sources and abundance and biomass of herbivorous fish, which builds the reef's ecological resilience[8]. Here, 'reef resilience' is defined as "the [ecological] ability [of reef system] to resist, reorganize and re-establish from disturbance, as well as maintaining a diversity of options for development and evolution" [9].

This study assessed two of the 31 ecological resilience factors based on the work of, which are herbivorous reef fish abundance and distribution, and substrate availability[10]. Herbivorous fish play a critical role in the recovery of coral assemblages by limiting growth of algae communities that are competing with reef-building corals such as for space and light [11,12]. Based on their foraging behavior, herbivorous reef fish can be differentiated in four main groups; which are scrapers/small excavators, large excavators/borders, grazers/detritivores, and browsers[12]. Each category plays different and complementary roles in coral resilience in terms of how they feed benthic algae, what algae they consume, and their impact on the underlying substratum (i.e. hard corals)[12]. Moreover, the availability of stable substrate such as rock, dead coral, and coralline algae also plays an important role in providing surface for coral planula to settle and grow[13]. Correspondingly, mobile substrate such as rubble, sand, and silt are less stable and, therefore, give less opportunity for the survivorship of coral recruits in the development[14].The aim of this study was to assess the recovery potential of coral reefs at Riung 17 Islands MP through the measurement of available substrate, functional groups of herbivorous reef fishes, herbivore biomass, herbivore diversity, hard coral cover, physical human impacts, water quality, and local oceanography.

2. Materials and Methods

2.1 Site description

17 Riung Islands MRP is located at the northern coast of Flores islands, Indonesia. A zoning system was enacted in 2012 under the management of Natural Resources Agency of the East Nusa Tenggara province. There are five type of zones in MRP that mainly designated for both protection and different resource-use activities (Figure 1).

2.2 Surveys

In four survey days, from 11th to 14th November 2013, the coral reef assessment was carried out in twelve sites within 17 Islands Riung MPR boundary. Underwater surveys were conducted in sites representing different zonings in both sheltered and exposed coral reef habitats for each site (Fig. 1)

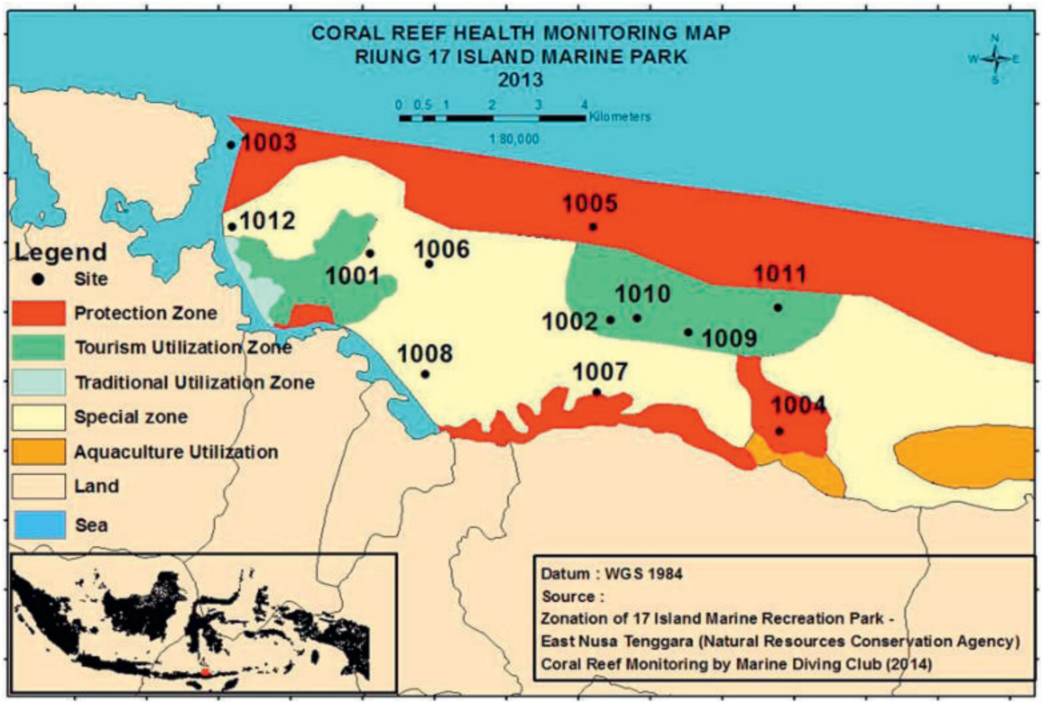

Fig. 1. Zoning map of the Riung 17 Islands Marine Park as per 2013

Reefs health was determined using the monitoring protocol of Wilson and Green[15] and Point Intercept Transect survey method[16]. Benthic surveys were carried out at the depth of ten meters using 3 replicates x 50-meter transect line laid parallel to the shoreline. For each transect line, benthic life form was visually identified at 0.5-meter point intervals and categorized based on the work of Wilson and Green[15. The percentage cover of each life form was calculated using formula (1).

$$\text{\% Cover emergence of life form} = \frac{\text{Number of point in that category}}{\text{Total number of point on the transect}} \quad (1)$$

'Substrate availability' was measured based on the presence of benthic life forms mainly of Rock, Coralline Algae, and Dead Coral substrate categories; whereas 'mobile substrate 'based on Rubble, Sand, and Silt. In the same depth and transect profile each site, herbivorous fish community composition was assessed using visual census based on the survey protocol developed by Green and Bellwood[12].The census involve observers visually estimated the total length of every fish encountered in the visual space of the belt transect[17]. Fish survey data was used as a surrogate for herbivorous fish community composition based on the average abundance and biomass at each location as well as the size structure of herbivores. For the analysis of each site, the fish average abundance was calculated using the following formula:

$$\text{Abudance ind/ha} = \frac{\text{Number of individuals per unit sampling}}{\text{Area of the sampling unit in m}^2} \text{ X } 10.000 \quad (2)$$

Fish biomass was gauged using size estimates as a proxy based on length-weight relationships for each species using the formulae $W = aL^{b18}$. Where: W = weight of the fish in grams (g); L = fork length (FL) of the fish in cm; and a and b are constants calculated for each species or genus[12]. Then the average fish biomass was calculated using the following formula:

$$\text{Biomass kg/ha} = \frac{W1+W2....+W:1000}{\text{Area of the sampling unit in } m^2} \text{ X } 10.000 \qquad (3)$$

[3]Where W1,W2,Wn is weight per 1 individual herbivore fish.

For each site, 'reef resilience' was determined by scoring key ecological factors (ie. Herbivore biomass, Herbivore diversity, Substrate suitability, Hard coral cover, Physical human impactsthat correspond to the aforementioned fish and benthic parameters of the survey. For the purpose of result presentation and discussion, reef resilience scores are converted in percentage scale (0 - 100 %)[10].

3. Results and Discussion

3.1 Percentage of live hard coral cover

Percentage of live hard coral cover (or, 'coral coverage') is among the primary indicator of coral reef health with higher hard coral cover indicating better coral health[8]. Table 2 lists coral coverage findings in each site.

Table 1. Percentage of live hard coral cover and results of physical-oceanographic parameters of the survey sites

SiteID	Site Name	HC (%)	Max. current (m/s)	Temperature (°C)	Salinity (°/₀₀)	Turbidity (m)	Type of location
1001	East Ontoloe Island	16	0.16	28	34	8.5	Exposed
1002	East Rutong Island	31	0.23	27.6	35	8.5	Sheltered
1003	East Torong Padang	19	0.07	28.3	35	11	Sheltered
1004	East Wire Island	8	0.36	28	34	7.5	Sheltered
1005	North Bakau Island	17	0.14	28.1	35	9	Exposed
1006	North Kolong Island	14	0.14	27	33.6	11	Exposed
1007	North Sui Island	17	0.25	27	35	9	Sheltered
1008	South Lain Jawa	26	0.16	27.8	34	6	Sheltered
1009	South Tiga Island	40	0.11	28.7	35	9	Sheltered
1010	West Bampa Island	24	0.38	28.4	33	9	Exposed
1011	West Touer Island	3	0.04	27.8	35	8.5	Exposed
1012	West Wongkoroe	17	0.17	28.6	35.5	11	Sheltered

The highest coral coverage was found in South Tiga, Rutong, and Lain Jawa Island sites. The survey locations in these reef sites are predominantly sheltered from wave force, which gives a more suitable habitat for coral growth[8]. Despite the one-time nature of this biophysical survey inconsistent to the method of previous coral reef assessments, there has been a number of past surveys in the island that can serve as a proxy for past condition. A survey by Manuputty[4] averaging the condition of 17 Riung Islands MRP using line intercept transect method showed that, 31,25 percent of the living hard coral cover was in 'excellent' condition, 43,75 percent was in 'good' condition, and 25 percent was in 'fair' condition. Moreover, low hard coral coverage was found in the East Wire and West Toer Island sites. During observation, this location is dominated by rubble that might have been the result of historical destructive fishing activity. Another recent impact survey result of in the same site using the Reef Check method[19]categorizes the coral damage as 'medium' (1.3-2).

3.2Availability of substrate for coral settlement

The survey identified locations with high availability of settlement providing substrate; which indicates higher opportunity for coral larvae to settle and grow, thus, a higher changes for coral to replenish. In the practice, to facilitate coral recovery in these locations, local management efforts may need to address social and environmental factors that can or are currently inhabiting coral settlement, survivorship and growth. Moreover, for sites with low substrate availability, rehabilitative management approach such as the deployment of artificial substrates may be feasible promoting coral recovery in the short term[20]. Fig. 2 shows the percentage of available substrate and mobile substrate cover of each survey site. Of the 12 sites surveyed, there are five sites that have substrate availability above 25 %, which are West Wongkoroe, North Bakau Island, East Torong Padang, South Tiga Island and West Bampa Island (see Tabel 1 and Fig. 2). Again, high substrate availability may indicate that there is more opportunity for recovery of these sites through coral planulae settlement and growth[8]. There are key ecological factors that can facilitate the success of early planulae settlement and survivorship, such as source of larva planulae, the suitability of local and regional oceanographic conditions, and healthy communities of herbivorous fish that prevents alga overgrowing coral recruits[8].

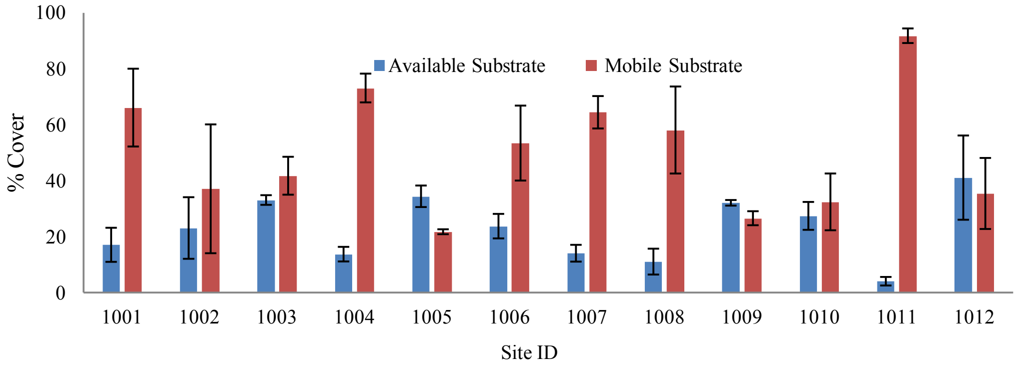

Fig. 2. Bar graph showing the percentage covers of available substrate percentage and mobile substrate of each survey sites. Horizontal axis showing site ID (Refer to Table 2), and cover in the vertical axis.

Thus, in the shorter term, this suggest some tractable management measures that may facilitate site recovery such as managing the extraction of herbivorous reef fish, such as the parrotfish[8,21,22], which is discussed at the end of this section. Five sites were found to have more than 50% mobile substrate coverage (Fig. 2). These include North Kolong Island, South Lain Jawa, North Sui Island, East Ontoloe Island and West Touer Island. These sites may be less likely to recover because there are fewer surfaces are available for coral planulae to settle. Although settlement in rubble surface or other mobile substrate can still occur, physical disturbance may prevent planula growth or survivorship due to instability of the substrate. For example, rubbles coexisting with sand and mud can increase the probability of juvenile coral mortality by partially covering, burying or braking them[14]. Accordingly, the rubbles dominating benthic composition of Touer Island sites (see Fig. 5) may still provide space planula settlement, but weak for coral to initiate growth. Coral reefs may take a long time to recover in these conditions, thus a shorter-term rehabilitation efforts may be necessary to assist coral recover yat these sites[8,12].

3.3Herbivorous reef fish role in facilitating recovery process of coral reef sites

Abundance and biomass each functional species of the herbivorous reef fish group was also used as an indicator of the potential for coral reef recovery. First, abundance and biomass of scrapers species group was found the highest in West Wongkoroe, which includes identified species of *Hiposcarus longiceps, Scarus forsteni, Scarus flavipectoralis, Scarus rivulatus*. This scrapers group plays a role in bio-erosion by consuming epilithic algae so helps to provide new settlement substrate[12]. The abundance and biomass of the excavators, the second group, was found the highest at South Tiga Island include species *Chlorous japanese*. Excavators are major agents of bio-erosion on coral reefs. For example, observations in the Great Barrier Reef found that smaller parrotfishes (i.e. *Scarus rivulatus*) able to scrape a greater substratum area per unit biomass relative to larger bodied parrot fishes that, instead, scrape greater volume of material per unit biomass[23]. The last group found, the grazers (i.e. *Achanturus blochii*), is very abundant and often seen schooling in North Sui Island (No. 1007, Fig. 3 and Fig. 4).

Grazers are different to scrapers and excavators in a way that they do not erode or dig substratum but play a role in controlling populations of epilithic algal turfsand macroalgae by limiting their growth thus helping to prevent the shift of coral to algae dominance[12].

The smaller parrotfishes usually only crop the algae surface and have little or no visible effect on the underlying coral substrate. Larger bodied parrotfishes, on the contrary, may be able to erode both algal and the underlying substratum and, thus, can more effectively removal of algae and open new colonization sites on reefs. The existence of fish species with their differences of anatomical and behavioral adaptation to different types of algae diets (i.e. turf algae, fleshy macroalgae), indicates that resilience building process is existed and ongoing in these reef sites. These 'reef lawnmower' fish species existed in all 12 sites indicates the importance of maintaining their foraging activity in controlling certain superior algae of out competing corals (i.e. for space and light) and thus allowing juvenile corals to survive[8,12].

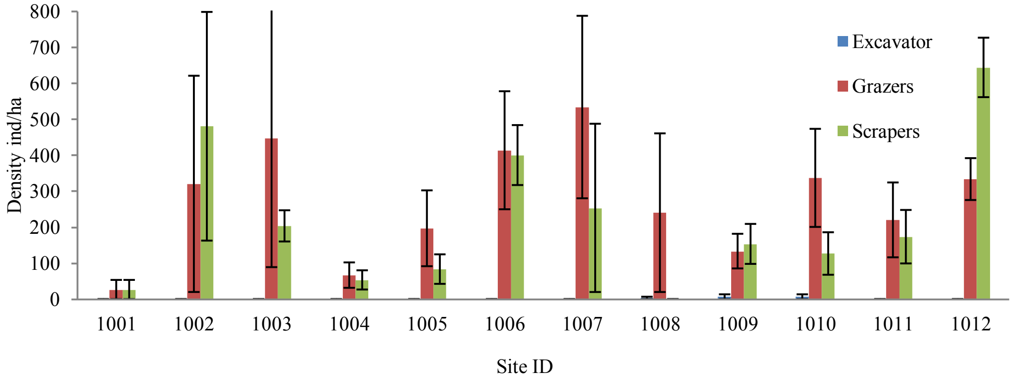

Fig. 3. Bar graph showing the abundance of herbivorous reef fish for each survey site. Vertical axis shows abundance in individuals/hectare unit. Error bars refers to Standard Error

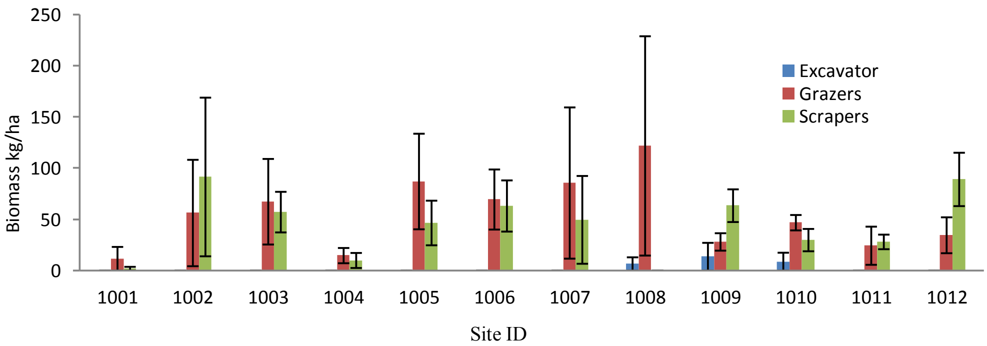

Fig. **4.** Bar graph showing the biomass of herbivorous reef fish for each survey site. Vertical axis shows biomass in kilograms/hectare unit.Error bars refers to Standard Error

The herbivorous reef fish abundance observed in this survey is, in general, are lower compared to result of reef fish in East Flores reef sitesusing same method[24]. The same report also suggested that the condition is partly resulted from local fishers who are also targeting herbivorous reef fish species. Similar findings were also reported in Karimunjawa National Park, Central Java; which found that historical over-extraction of economically valuable predatory reef fish species in the marine reserve, such as the grouper fish, have led to the harvesting herbivorous reef fish in the lower trophic level as it becomes a viable option to fulfill harvest target of local fishers or local subsistence demand[25]. Moreover, during the survey days, the main author of this paper discovered parrotfish dishes being served by local community members. At the time of writing, the harvest of herbivorous reef fish in Indonesia is yet uncontrolled. The survival of this functional reef fish species is critical to the continuation grazing process to facilitate the recovery of coral assemblages. The removal of this species also means lesser control of alga overgrowing coral and, thus, increasing the likelihood of reef habitat shifting to an undesirable state.

3.4 Assessing recovery potential

Coral reefs physically damaged by destructive fishing practices may require a long period of time to recover. Fish bombing, for example, which can instantly break living hard corals into fragments in just seconds, can leave traces of largely unstable substrate for coral larval settlements and, thus, lowering the chance of recovery. However, the combination of varied condition of substrate for settlement and herbivorous fish arrangement for controlling algae growth in each site can give different influence to the recoverability of damaged reef habitat in particular. Part of prioritizing management actions for these site, site recovery potential was scored based on the total abundance, biomass and diversity of herbivorous fish; substrate availability, live hard coral coverage, physical human impact and local oceanographic conditions (Table 1 and Tabel 2).

Fig. 5. Snapshots of different substrate conditions: 'Healthy' hard coral dominated reef site in South Tiga Island (Top),'Rock' dominated settlement substrate in South Tiga Island site (left bottom), and 'Rubble' dominated mobile substrate in Touer Island site (bottom right)(Photo: Caretta expedition team, Marine Diving Club, November 2013).

South Tiga Island (1009) scores the highest recovery potential relative to the rest of the sites based on the highest populations of herbivorous fish, 3 functional groups were recorded (scrapers, excavators, and grazers), substrate availability above 30 % and live hard coral cover of 40 %.The site could potentially be a good source of coral larva for the recovery of connected reef habitats (see table 2 and Fig. 5), however, conditional to the local dynamics of ocean current. Accordingly, it can be a candidate site for priority protection.

Table 2. Scoring of recovery potential of surveyed sites adapting indicators and scoring the work of McClanahan et al. [9]

Site	Herbivore biomass (0%-100%)			Herbivore diversity (0%-100%)	Substrate suitability (0%-100%)	Hard coral cover (0%-100%)	Physical human impacts (0%-100%)	Recovery potensial (0%-100%)
	Scrapers	Excavator	Grazers					
1009	15	27	8	8	12	17	7	13.45
1010	7	36	5	10	10	10	9	12.35
1012	16	9	3	10	15	7	14	10.68
1006	11	0	26	8	9	6	9	9.79
1005	9	10	9	8	13	7	11	9.55
1003	10	0	8	9	12	8	15	8.89

1008	0	15	18	7	4	11	4	8.40
1002	16	0	6	9	8	13	3	7.76
1007	9	0	11	10	5	7	6	6.87
1011	5	3	3	9	1	1	7	4.41
1001	1	0	2	3	6	7	10	4.18
1004	2	0	2	8	5	4	5	3.69

Furthermore, to recuperate sites with low scores of substrate availability and grazing fishes, such as (1011) West Touer Island, (1004) East Wire Island, and (1007) North Sui Island, an extensive management effort will be necessary to mitigate both local harvest of the herbivorous reef fish and future destructive activities. In particular to (1004) East Wire Island, land-based intervention, such as domestic waste management and treatment, is critical given by the proximity of the site to community dwellings where uncontrolled domestic waste and run-off resulting are triggering eutrophication resulting high algal populations in local coastal bed. Furthermore available substrate and live hard coral cover is lower at this location so it is expected that this location would need a long time to recover. In general, the range of salinity, temperature, and turbidity recorded from all sites indicate a feasible oceanographic condition to facilitate coral larvae settlement and coral growth[26] (see table 1). Current flow at the time of survey was low relative to the average current flow in northern part of Flores coast[27]. However, also mentions current dynamics where, in general, East Flores current flow fluctuating between east and wess monsoon west monsoon period[27]. Therefore, the oceanographic data obtained is still far from sufficient to explain coral larva distribution between the sites; which emphasize future research needs to examine current pattern for larval transport among the sites in a larger temporal and spatial scale[28].

4. Conclusion and Recommendations

The recoverability of damaged coral reef habitats will depend on the combination of biological, ecological, physical and socio-economic factors. This survey demonstrated that indicators of grazing process of the reef, such as herbivorous reef fish composition, and of larval recruitment potential, such as settlement substrate availability; can be used as a proxy for coral reef resilience to local anthropogenic disturbances. The survey identified South Tiga Island as the 'most healthy' site that can potentially be a good source of coral larvae for the recovery of connected reef habitats conditional to local dynamics of ocean current. West Touer, East Wire Island, and North Sui island was identified as 'critical' sites given the low score of its recovery potential. Enhancing the recovery of these sites will require a long-term intervention in herbivorous reef fish harvest control, limitation of destructive activities, and domestic waste discharge management. The survey has also demonstrated the use of two out of 31 indicators of reef resilience to facilitate prioritization of the management and protection of reef sites in 17 Riung Islands MRP. Incorporating more reef resilience indicators in the next surveys for these sites can be beneficial to improve the robustness of coral reef biophysical assessments in the region. A longer-term study of larval dispersal and connectivity between these sites is also necessary to improve management prioritization of reef sites based on larva source potential. Develop current modelling with larva dispersal including data [i.e coral recruitment, time spawning, current pattern, and coral DNA to know genetic relationship]

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