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Original paper

ASSESSING ECOLOGICAL RESILIENCE OF INDONESIAN CORAL REEFS

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ABSTRACT

Ecological resilience is an important property of natural ecosystem to be understood in coral reef management. Resilience of Indonesian coral reefs was assessed using 2009 COREMAP data. The assessment used 698 data of line intercept transects collected from 15 districts and 4 marine physiographies. Resilience index used in the assessment was developed by the authors but will be published elsewhere. The results showed that coral reefs at western region had higher average resilience indices than eastern region, and Sunda Shelf reefs had higher resilience indices than coral reefs at Indian Ocean, Sulawesi-Flores, or Sahul Shelf. Four districts were found to have coral reefs with highest resilience indices, i.e. Bintan and Natuna (western region), and Wakatobi and Buton (eastern region). Raja Ampat had coral reefs with lower average resilience indices than that of Wakatobi. Uses of resilience index in coral reef management should be coupled with other information such as maximum depth of coral communities.

Keywords: Resilience index ; coral reef ; Indonesia ; management

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INTRODUCTION

Knowing ecosystem state is the first step in ecosystem-based management. Global climate change has been predicted to expose coral reef ecosystem not only to disturbances but also to 'surprises' (Hoegh-Guldberg, 1999; Hoegh-Guldberg *et al.*, 2007), i.e. disturbances which are beyond ecosystem experience in magnitude, intensity, and frequency. Annual mass coral bleaching has been predicted to occur in Phuket and the Great Barrier Reef in 2030 (Hoegh-Guldberg, 1999), if carbon emission proceeds as usual. Threat of ocean acidification is waiting for surviving corals in the annual bleaching events (Kleypas *et al.*, 1999; Hoegh-Guldberg *et al.*, 2007). Disturbances have been part of the external factors establishing the present coral reef ecosystem (Connell, 1997), but human presence in the last two centuries has changed natural capability of coral reef ecosystem to recover from disturbances (Jackson, 1997; Jackson *et al.*, 2001). Ecosystem resilience is therefore increasingly important factor in planning an ecosystem-based management on coral reefs (Nystrom *et al.*, 2008).

Assessment of ecosystem resilience should be used as an important tool in coral reef management. At present, many studies conducted resilience assessment after disturbance (Berumen and Pratchett, 2006; Ledlie *et al.*, 2007; Smith *et al.*, 2008). Such assessment method might not be very useful in management planning. Resilience assessment should be carried out before disturbance that managers can prioritize efforts to save more valuable and more resilience coral reefs. Method for assessing coral reef resilience before disturbance is under development. Therefore, there is no single study yet to assess coral reef resilience before disturbance.

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Recently, there are three available methods for assessing pre-disturbance coral reef resilience. Obura and Grimsditch (2009) provided a comprehensive method in resilience assessment involving about 35 variables collected using 5 protocols. This complex assessment method is doubtfully applicable in developing countries, as it needs large financial support and high expertise. The absence of data analysis protocol in the method would make it more difficult to make resilience comparison among reefs. Maynard *et al.*, (2010) provided a more practical method in resilience assessment. The assessment that merely relied on personal judgment would be carried out in a focus discussion group involving coral reef researchers, managers, and other important stakeholders. Bachtiar *et al.*, (2011) provided a resilience assessment method using line intercept transect (LIT). Since LIT is the most popular coral reef monitoring method, resilience assessment can be used directly on readily available collected data. The latest method will produce a single value called resilience index of each transect.

The index was designed to measure ecological resilience, and to predict coral reef recovery after disturbances. This method still needs, however, to be verified, that its usefulness will be validated in coral reef management. The index should be applicable to carry out a general assessment on coral reef resilience in order to make management priority in the whole Indonesian country.

Indonesia has the largest coral reef area in the world (Tomascik *et al.*, 1997), and the epicenter of coral reef biodiversity (Veron, 2002), that general assessment is a very important step in planning national coral reef management. Its complex geological history provides the archipelago with very diverse marine habitats, flora, and fauna (Tomascik *et al.*, 1997). The aims of this study were to determine resilience level of Indonesian coral reefs and to look at spatial distribution of coral reef resilience among marine physiographies, regions, and districts (*kabupaten*).

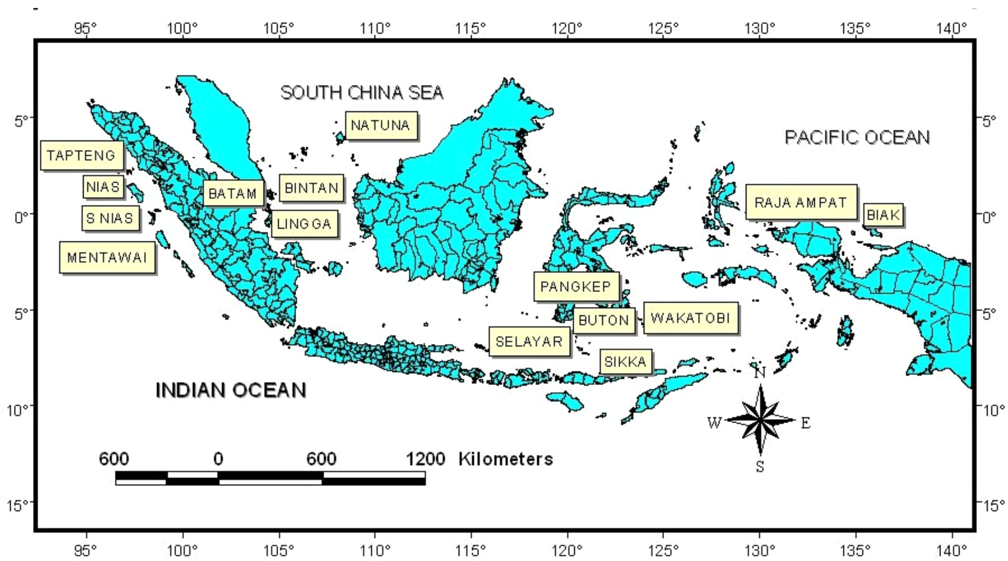

Fig. 1. Locations of the study that included 15 districts, and 4 marine physiographies regions.

MATERIALS AND METHODS

Data collection

Data used in the present study were collected-data from P2O-LIPI (Research Center for Oceanography, Indonesian Institute of Sciences) on the COREMAP (Coral Reef Rehabilitation and Management Program) in 2009. The data were collected from permanent transect, 10 m length, on 15 districts in 7 provinces of Indonesia, which included: Biak and Raja Ampat (West Papua), Sikka (East Nusa Tenggara), Pangkep and Selayar (South Sulawesi), Buton and Wakatobi (South East Sulawesi), Natuna, Bintan, Batam, and Lingga (Riau islands), Center Tapanuli, Nias, and South Nias (North Sumatera), Mentawai (West Sumatra) (**Fig. 1**). These districts are

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unintentionally also represented four marine physiographic features, i.e. northern Sahul Shelf (West Papua), Sunda Self (Riau Island), Indian Ocean (North Sumatra and West Sumatra), and transition zone (Sulawesi and Flores).

Assessment of coral reef resilience

Assessment of coral reef resilience has jus at the beginning of development. There are three available assessment methods that were developed by Obura and Grimsditch (2009), Maynard *et al.*, (2010), and Bachtiar *et al.*, (2011). Among the three methods, the last method is likely the most suitable method to the condition of Indonesian reefs. The method requires ordinary data from line intercept transects. It does not need many variables as required in Obura and Grimsditch (2009) or high expertise as required in Maynard *et al.*, (2010).

Coral reef resilience was assessed using the resilience index developed in the same study but will be published elsewhere (Bachtiar *et al.*, 2011). The resilience index was calculated using the following formula:

$$RI = \left[0.56\left(\frac{2(13-0)}{(13-0)+(13-CFG)}-1\right)+0.42\left(\frac{2(50-0)}{(50-0)+(50 \ldots}\right.\right.$$

RI= resilience index. CFG= coral functional group, the number of coral life form as described in *English et al.*, 1994). CHQ= coral habitat quality, square-root of Acroporiid coral cover times massive and sub-massive corals. CSN= coral small-size number, number of coral colonies ≤10 cm transect length. COC= coral cover. USS= unsuitable settlement substrate, sum of sand and silt covers. AOF= algae and other fauna cover, sum of total algal cover and other fauna covers.

Table 1. Classification of coral reef resilience index (Bachtiar *et al.*, 2011)

Resilience category	Class interval
• Excellent	≥ 0.806
• Good)	0.581 – 0.805
• Fair	0.356– 0.580
• Poor	0.131 – 0.355
• Bad	≤ 0.130

The resilience index may be classified into five classes, based on the mean and standard deviation of a normal distribution. The classification and its category are summarized in **Table 1.**

Data analysis

Comparison of resilience indices was carried out using ANOVA (analysis of variances). Data collection was not designed for spatial comparison, rather than temporal comparison, that number of districts was not the same between regions (eastern and western Indonesia) and among marine physiographic, nor the number of stations among districts. This imbalance proportion for each factor did not fit with factorial ANOVA design. Data analysis was therefore carried out using a one-way ANOVA to compare means of resilience index among marine physiographic, and among district of each region. A Tukey test, α=0.05, was applied when significant differences were detected on ANOVA.

Results And Discussion

In general, coral reefs of Indonesian waters had a fair resilience index in 2009. The mean (±SE) of resilience indices was 0.542±0.008. Between regions, coral reef resilience index was higher on western than on eastern Indonesia. In the western Indonesia, mean resilience indices was 0.494±0.011, while in eastern Indonesia it was 0.577±0.010. The difference between the two regions was significant (t test, t=5.519, P<0.001). This finding was very interesting as the center of marine mega-biodiversity was believed to be located on eastern region of Indonesia, while high coral reef resilience was found on western Indonesia.

Among four marine physiographies, there were significant differences on means of

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resilience indices (F=72.078, P<0.001). Sunda Shelf was found to have a significantly higher resilience index than the others (**Fig. 2**). Coral reefs at Sulawesi-Flores had similar resilience indices to reefs at the Sahul Shelf. These findings are very interesting since Sunda Shelf has the youngest reef in Indonesia.

Sunda Shelf was flooded and become an ocean about 8000 BP (before present) (Tomascik *et al.*, 1997). It is very much younger than Indian Ocean (N-W Sumatra) which had already have reef formation since the Jurassic Era, 216-144 million BP, when it was part of the Tethys Sea (Veron, 2000). Indian Ocean should also have better water quality, as it is located very far from run-off of large Sumatran rivers. Since reef corals are sensitive to water quality, Indian Ocean should have had better coral reef and higher resilience. This paradox could only be explained from the disturbance history of the reefs.

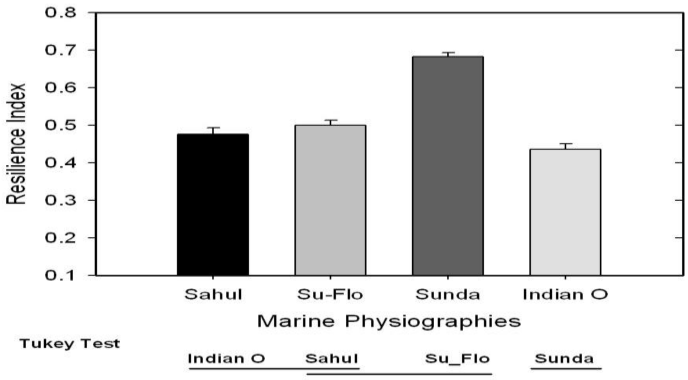

Fig. 2. Comparison of resilience indices means (+1SE) among four marine physiographies in Indonesia. Tukey Test was done at α=0.05. Indian O=Indian Ocean, Su-Flo=Sulawesi-Flores.

In eastern Indonesia, coral reef resilience indices were significantly different among districts (F=13.391, P<0.01). Sikka had the lowest resilience index, while Wakatobi and Buton had the highest resilience indices (**Fig. 3**). Raja Ampat which is well-known for its high reef fish diversity had lower coral reef resilience index than Wakatobi. It has been a debate on which coral reefs is better between Raja Ampat and Wakatobi districts. Both districts are located in Marine National Park (MNP), and its spatial jurisdiction is exactly the same as the size of the MNP. This study showed the superiority of Wakatobi to Raja Ampat. Results of Tukey test showed that coral reefs of Raja Ampat had about the same average of resilience indices as those of Selayar, Pangkep, and Biak.

Comparisons of index category also confirmed that coral reef at Wakatobi and Buton had a better resilience index (**Fig. 4**). Proportion of transects with excellent resilience category were 14.28-15.56%, but this category was absence in Raja Ampat and Biak. Pangkep and Selayar had even better resilience category than Raja Ampat and Biak. These results are apparently not supported by previous publications regarding the superiority of coral reef at Raja Ampat (McKenna *et al.*, 2002a) and its surrounding areas, including Biak.

It has been a number of publications showed the superiority of Raja Ampat on reef coral and fish diversity (Allen and Erdman, 2009; Veron, 2002). Many of them suggested that Raja Ampat is at the central of coral reef biodiversity. High coral reef fish diversity found by Allen and Erdman at Raja Ampat was some part based on cumulative data from early publications, down to 1920s. Since coral reef publications are spatially very patchy in Indonesia, comparisons among districts or locations are not in balance. Coral cover of Raja Ampat coral reefs was also low, with a range of 5.3-53.3% and 10% transects had coral cover ≥50% (McKenna *et al.*, 2002b). Since coral cover has large contribution to resilience index, it is not surprising that Raja Ampat had considerably low index than expected.

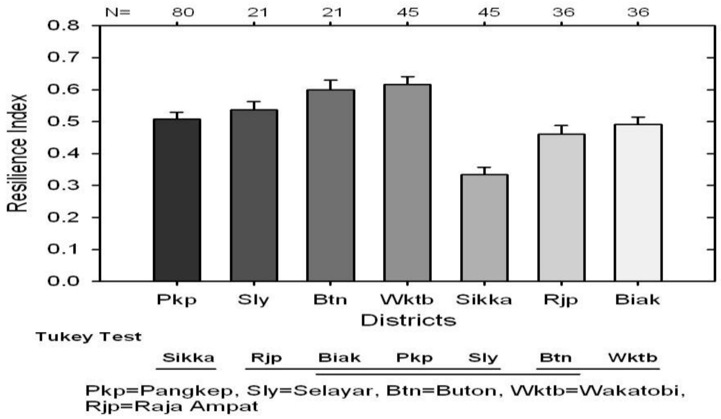

Fig. 3. Comparison of resilience indices means (+1SE) among districts in Eastern Indonesia region. Tukey Test was done at α=0.05. Numbers above the graph are sample sizes (numbers of transects).

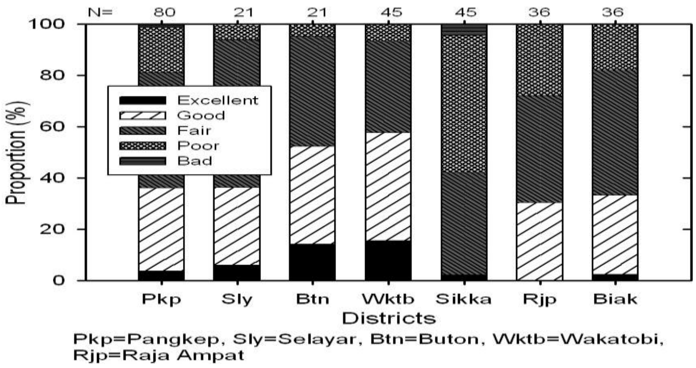

Fig 4. Comparison of proportion of resilience indices category among marine districts in Eastern Indonesia region. Numbers on top are sample sizes.

Several other studies also showed that Raja Ampat superiority in reef fish diversity was not linearly followed by reef coral diversity. Suharsono (2008) produced a map of coral generic diversity of Indonesia that showed Raja Ampat had a lower number of coral genera compared to Wakatobi, Buton, and Pangkep. Average age of coral genera in Indonesia is about 37 millions (Veron, 2000), it is about the same time when northern Sahul Shelf, and south- and southeast- Sulawesi moved across equator to the present locations. Reef formation on Raja Ampat should be about the same time as Wakatobi and Buton that are located at southeast of Sulawesi. It could be inferred therefore that coral reef at Wakatobi had a better condition than that of Raja Ampat; regardless both reefs have about the same geological ages.

In western Indonesia, coral reefs at Sunda Shelf were generally had better resilience indices than at Indian Ocean (F=42.578, P<0.01). Multiple comparisons using Tukey Test showed that differences in resilience indices between reefs of Sunda Shelf and Indian Ocean were not very obvious. At Central Tapanuli (Indian Ocean), coral reefs had average resilience indices similar to Lingga and Batam (Sunda Shelf). South Nias had the lowest resilience index, while Bintan and Natuna had the highest resilience indices (**Fig. 5**).

Comparison of index category showed that Bintan and Natuna had larger proportion of transects in excellent category, about 28% (**Fig. 6**). In contrast, coral reefs at Nias, South Nias, and Mentawai did not have any transects with excellent resilience category. Between the two poles, Batam, Lingga and Central Tapanuli had moderately proportion of excellent resilience category.

This finding needs explanation as old reefs had less resilience indices than younger reefs. One of the explanations is that the trasects were not laid at the same depth. As Sunda Shelf reefs are relatively young, reef

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development was not prominent. Maximum depth of coral colonization was very shallow. Many reefs did not have coral communities at 5 m depths (CRITC 2007; Cappenberg and Djuwariah, 2008; Cappenberg and Salatalohi, 2008). Many reefs only had coral communities in the range of 3-4 m depths. Although they showed high resilience indices, this did not necessary mean that they have high conservation value. At Indian Ocean, maximum depth of coral communities was also relatively shallow, around 7-20 m depths (Makatipu and Leatemia, 2009). The best maximum depth of coral communities was found at Wakatobi, about 25-40 m depths (Budiyanto *et al.,* 2009). Maximum depth of coral communities could indicate good water clarity and low sedimentation. The use of the resilience index in management planning should therefore be coupled with other observation, e.g. maximum depth of coral communities.

The second explanation is that abundant of target reef fishes was very low at Sunda Shelf reefs that destructive fishing practices was economically not suitable. Coral reefs with low anthropogenic pressures may have high resilience index. At present, there is no available fish abundant data that support this hypothesis. Data on fish species diversity, however, showed that maximum depth of coral communities on a reef was correlated with fish species diversity (P2O unpublished data). It could be speculated that depth of coral communities also related to reef fish abundance, and therefore indirectly supported the hypothesis.

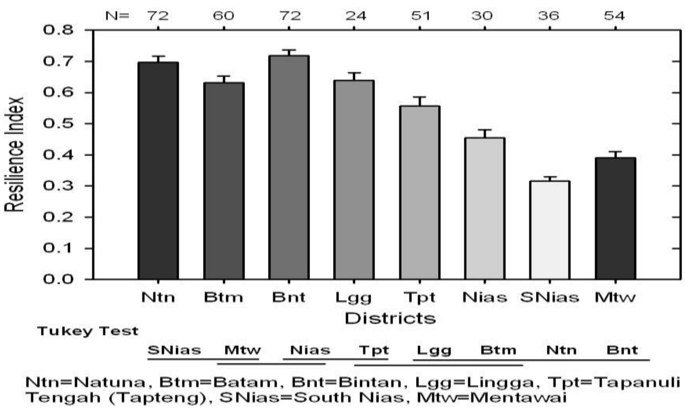

Fig. 5. Comparison of resilience indices means (+1SE) among districts in Eastern Indonesia region. Tukey Test was done at α=0.05. Numbers on top are sample sizes.

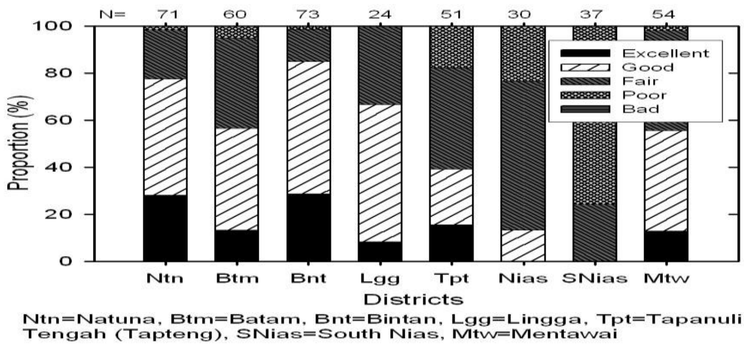

Fig. 6. Comparison of proportion of resilience indices category among marine districts in Eastern Indonesia region. Numbers on top are sample sizes.

Resilience assessment should be described specifically to particular disturbance, resilience of what to what (Carpenter *et al.,* 2001). An ecosystem may be resilience to disturbance A but not resilience to disturbance B. Resilience index on this study is a general assessment of resilience level on coral reefs. The value of the index was then available for further interpretation regarding specific disturbances. At present, the interpretation is not yet available.

Lack of index interpretation method is

not the monopoly of this resilience index. Other coral reef resilience assessments developed by Obura and Grimsditch (2009) and Maynard *et al.,* (2010) also do not provide ecological interpretation of the index. Further studies are required for interpreting the index and comparing quality of the three indices. Index with more variables does not necessarily provide a better quality since not all theoretically important variables have significant contribution to total variances.

CONCLUSION

Comparing resilience indices on the scale of hundreds or thousands kilometers needs very careful interpretation. Magnitude, intensity, and frequency of disturbances are very likely to be different among regions, physiographic, and districts. Interpretation of resilience index should be done with regard to history of the reefs, disturbances that had happened and is happening on the coral reefs. All disturbances may have impacted coral reefs and reduce its resilience index.

The resilience index developed by Bachtiar *et al.,* (2011) could show resilience levels of coral reefs, but it did not necessarily showed the whole conservation value of the reef. In determining conservation value of a coral reef, the index should be used in parallel with maximum depth of growing corals at the sites.

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