Potency, status and carrying capacity of coral reef ecosystem for sustainable marine ecotourism development; a case study of small islands in Kepulauan Riau-Indonesia

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Abstract. This study aims to provide reliable information to mapping the potential of coral reef ecosystems for development of sustainable marine ecotourism in Benan Island and surrounding areas. The mapping was done by considering the carrying capacity of the environment which includes the limits of the island's ability to receive several tourists with the intensity of optimum use of natural resources. Approach to the assessment of the potential and status of coral reef ecosystems was carried out to evaluate reef fish and benthic conditions using the LIT transect method and presented spatially using ArGis 10.3. The results showed the status of the coral reefs ecosystem in Benan Island waters and the surrounding areas were categorized as moderate conditions with average live coral coverage were 37.76%. The highest live coral cover reached was 55% in Katang Island. The carrying capacity of the utilization of diving tourism in Benan Island was reached 444 people/day, 69 people/day at Selada Island, 66 people/day at Segenting Island, 234 people/day at Sunda Air Island and 76 people/day at Nopong Island. The carrying capacity of small islands was different from one region to another. Hopefully, this will be able to minimize the vulnerability of small islands to ecosystem degradation. Keywords: Benan Island, carrying capacity, coral reef, marine ecotourism, small islands.

1. Introduction

Indonesian coral reef ecosystem is part of the world coral triangle which highest coral diversity in the world [1]. Coral reef ecosystem have important roles such as: marine tourism development, coastline protection and protein source for coastal community [2] [3] [4].

Riau Islands Province has a strategic location, adjacent directly to some country in ASEAN region like Singapore and Malaysia [5]. The small islands in this region are equipped with coastal ecosystem such as, mangrove ecosystem, seagrass ecosystem and coral reef ecosystem. These ecosystems can be utilized in the development of marine tourism [6]. The development of marine tourism can provide economic benefits for improving the welfare of the community [7] [8] [9].
Utilization of small island resources has limitations, such as isolation, small size, limited natural and human resources [10]. In addition, the development of marine tourism activities on small islands can have an sustainable impact on ecosystem [11]. One of the impacts of the development of marine tourism on ecosystems is the degradation of coral reefs [12] [13] [14] [15].

The development of marine tourism must refer to the principle of sustainability in order to minimize negative impacts on ecosystems, give economic benefit and socially and culturally acceptable to local communities [16] [17] [18]. Sustainable tourism development is a solution to optimize the use of environmental resources, respect the socio-cultural perspective of local communities, and ensure long-term economic benefits [19]. The principle of sustainability can be supported by limiting activities based on carrying capacity which includes physical, social and ecological carrying capacity [20] [21]. Specifically the carrying capacity for marine tourism activities has been developed referring to the calculation of the physical carrying capacity of the area for small islands [22].

This study aims to assess the status, potential of coral reef ecosystems and the carrying capacity of diving ecotourism in the Benan Island cluster and its surroundings based on biological and non-biological resources such as the physical condition of the waters. The results of this research can be the basis for the management of marine biological resources in the development of responsible and sustainable marine ecotourism.

2. Methodology

2.1 Study location

This study was conducted in the coastal waters of Benan Island and arround, Riau Islands, Indonesia in September 2016, in eleven station. The coordinates of the sampling sites are presented in Table 1 and survey location of reef fish data collection presented in Figure 1.

2.2 Coral reef

The coral survey was carried out using SCUBA diving. Line Intercept Transect (LIT) method was used following [23] of a fifty-meterlong transect line layed parallel to the coastline at 5-10 m of depth. Parameters observed include bentic community cover. The interpretation of the criteria for percentage of coral community cover is based on [24], with categories, 0.0–24.9% (Poor), 25.0–49.9% (Fair), 50.0–74.9% (Good), and 75.0–100.0% (Excellent).

2.3 Reef fish

Observation of reef fishes were collected by using Underwater Visual Census [23] at 250 m2 transect area (50 m length and 5 m width). Reef fishes found inside the transect area were identified to the species level following [25] [26]. Identified species was then categorized into target species, major species and indicator species according [23] Retrieval of reef fish data is divided into groups of herbivorous fish (Siganidae, Scaridae and Acanthuridae), target fish (Lutjanidae, Serranidae, Haemulidae, Caesionidae, Lethrinidae, and Nemipteridae), indicator fish groups (Chaetodontidae) and groups of major fish (Pomacentridae, Pomacentridae, Pomacentridae, Bleniidae, and Apogonidae).

2.4 Water quality parameter

Tide measurements using Wave and Tide Recorder type SBE-26, current speed is measured using Digital Current Meter CM2X Dentan, temperature profile and salinity from surface to near the bottom of the waters are measured using CTD profiler type SBE-19. Measurement of pH, DO, clarity using a multiparameter instrument.
Table 1. Survey sites of coral reef and fish reef

| Station Numbers | Location sites       | Geographical Positioning |
|-----------------|----------------------|--------------------------|
|                 |                      | Latitude     | Longitude |
| ST 1            | Benan Island         | 00°28'41.6"  | 104°27'50.2" |
| ST 2            | Benan Island         | 00°27'38.5"  | 104°27'05.5" |
| ST 3            | Bakau Island         | 00°27'48.0"  | 104°26'17.0" |
| ST 4            | Air Kulah Island     | 00°28'11.8"  | 104°23'50.5" |
| ST 5            | Air Kulah Island     | 00°06'12.1"  | 104°23'21.4" |
| ST 6            | Katang Island        | 00°29'25.8"  | 104°25'10.2" |
| ST 7            | Air Sunda Island     | 00°28'28.8"  | 104°24'32.1" |
| ST 8            | Air Sunda Island     | 00°28'35.1"  | 104°24'20.1" |
| ST 9            | Nopong Island        | 00°29'39.0"  | 104°23'30.2" |
| ST 10           | Katang Island        | 00°30'10.0"  | 104°25'04.9" |
| ST 11           | Benan Island         | 00°29'22.7"  | 104°26'14.5" |

Figure 1. Map of study location. A - location of sampling sites; B - location of Kepulauan Riau Province, Indonesia; C - location of Benan Island.

2.5 Suitability for marine ecotourism diving
Suitability analysis conducted in this study focused on the designation of marine ecotourism areas (diving activities). The suitability of diving tourism considers six parameters including the clarity of the waters, coral community cover, type of life form, type of reef fish, current velocity, and depth of coral reefs [22]. The matrix for calculating the suitability of diving ecotourism is presented in Table 2.
Table 2. The Suitability matrix of marine ecotourism diving

| No | Parameter               | Weight | Very Suitable | Score | Suitable | Score | Not Suitable | Score |
|----|-------------------------|--------|---------------|-------|----------|-------|--------------|-------|
| 1  | Water clarity (%)       | 5      | >65           | 3     | 20-65    | 2     | <20          | 1     |
| 2  | Coral cover (%)         | 4      | >65           | 3     | 25-65    | 2     | <25          | 1     |
| 3  | Type of coral lifeform  | 4      | >10           | 3     | 4-10     | 2     | <4           | 1     |
| 4  | Type of reef fish       | 3      | >75           | 3     | 20-75    | 2     | <20          | 1     |
| 5  | Current (cm/s)          | 5      | 0-25          | 3     | 26-50    | 2     | >50          | 1     |
| 6  | Depth of coral reef     | 3      | 3-20          | 3     | 21-30    | 2     | >30          | 1     |

The formula used to calculate the suitability value of marine ecotourism: 

\[ SI = \sum \left( \frac{Ni}{N_{max}} \right) \times 100\% \]

where, \( SI = \) Suitability index; \( Ni = \) Parameter value (weight x Score); \( N_{max} = \) Max value from diving tourism. Marine ecotourism suitability classification is divided into three classes: Very suitable (SI) with \( SI > 75\% \), Suitable (S2) SI 50-75\%, and Not suitable (TS) with \( SI < 50\% \).

2.6 Carrying capacity for diving tourism

This study examines only the physical carrying capacity of the environment relating to the number of tourists that can be accommodated by considering the ecological impact of its natural resources. The carrying capacity calculation uses the following [27]. Based on the area of potential development, the optimum utilization of the carrying capacity of the conservation area is 10% of the area of the utilization zone [28].

3. Result and discussion

3.1 Coral reef cover

Based on percent coral cover, the health condition of coral reefs in Benan and surrounding area is categorized as fair with an average percent coral reef cover level of 41.48%. The highest level of live percent coral reef cover was at Station ST 10 in Katang Island which was 55% and the lowest present coral cover was at ST 7 in Air Sunda Island at 29.9% (Figure 2 and 3). The high present coral cover of living in the waters of Katang Island is inseparable from the local wisdom of the people who make the waters of the island their marine protected area, not allowing any activity in these waters except for research purposes. While in ST 7 in Air Sunda Island which has the lowest live percent coral cover is more due to the main traditional fishing activities of the local community and is a game dominated by muddy sand substrate. Sloping island land makes mangrove vegetation grow well on Sunda Air Island so that the mud catch is high. In addition there is an input of water from the mainland (run-off) into waters marked by a fairly low salinity reaching 25 %.

The condition of coral reefs has various form such as acropora branching (Acropora sp.), Foliose (Montipora sp.), Fungi (Fungia sp.), Encrusting (Lithoppylon sp.) and several types of massive corals such as Goniastrea sp., Favia sp., Platygyra sp., And Lobophyllia sp. (Figure 5).

Coral reef clusters are generally of fringing reef type. These coral type formations generally have reef flat and reef crest sections. The reef flat is characterized by a small stretch of coral mixed with seagrass and seaweed, especially Sargassum sp. Observations of coral cover in this study were mostly done on the edge.

Between the reef flat and the edge, many stretches of Sargassum sp. The existence of this seaweed expanse is estimated to be part of the process of shifting the balance of habitat succession (phase shift) that is the location that was originally in the form of a stretch of coral reefs and then changed into seagrass beds. The shift that occurred was closely related to the presence of abundance of Herbivorous fish. Herbivorous fish can control the growth of seaweed and algae [29] [30]. The resulting correlation value is \( r = - 0.56 \) (Figure 4). This negative value means that if the abundance of herbivorous fish is getting smaller then the level of algae cover will be higher. Herbivorous fish found in coral waters in the Benan Islands are generally of the Siganidae and Scaridae classes.
Figure 2. Coral reef coverage based on station

Figure 3. Coral reef percentage coverage based on island

Figure 4. Correlation of herbivorous fish abundance with algae cover
3.2 Reef fish abundance
Observations found at least 13 families and 53 species of reef fish that were scattered in the waters of the island's coral reefs in the Benan Islands (Table 3). An average of 28 fish / m² were found in each island. The waters of the reefs which are found by many types of fish are found in Bakau Island, Tokong (Nopong), and Katang. Based on the group, the largest composition of fish presence is in the other groups, followed by the target fish group, herbivore fish, indicator fish and major fish groups.
This type of fish group variation can be an interesting diving tourist attraction because this type of water fish has beautiful colors and is very diverse such as butterfly fish (Chaetodon sp.), Batew fish (Platax sp.), three striped fish (Diplorion bifasciatum), and red fat fish (Cheilinus fasciatum). Fish with schooling behavior are also often found to be attractive underwater objects. This behavior is mainly found in yellow tail fish species (Caesio teres), cardinal fish (Apogon sp.). This fish has a unique character, docile and not easily run when approached.

Abundance of reef fish ranged from 13.8 to 35 fish/m². The highest presence of reef fish is found in Nopong Island reaching 35%, and the lowest in Benan Island is 13.8%. This condition is more due to the abundance of different types of fish, on Nopong Island (ST 9) and Bakau Island (ST 3) the presence of fish with clustered behavior from the Caesonidae and Apogonid families is higher than other islands (Figure 7). Based on the main fish group, the target fish group is the fish that is most often found. In general, target fish that are found are of medium size, especially in the type of snapper (Lutjanus sp.) and grouper fish (Epinephelus sp.) from the Scaridae family. The target fish is the main catch of local fishermen in the waters of Benan Island and its surroundings.

Table 3. The presence of reef fish family in Benan waters.

| Family      | Survey Station |
|-------------|----------------|
| Siganidae   | ST 1 ST 2 ST 3 |
| Scaridae    | ST 4 ST 5 ST 6 |
| Acanthuridae| ST 7 ST 8 ST 9 |
| Lutjanidae  | ST 10 ST 11   |
| Nemipteridae|               |
| Lethrinidae |               |
| Serranidae  |               |
| Caesionidae |               |
| Haemulidae  |               |
| Chaetodon   |               |
| Pomacentrid|               |
| Apogonid    |               |
| Bleniidae   |               |
| Others      |               |

Figure 6. Composition of fish group
3.3 Water quality parameter

The level of clarity of sea water on the island of Benan and its surroundings is quite high reaching 10 meters from the depth of the water an average of 12 meters. The high clarity of waters are supported by the dominant substrate of rocky sand and a little mud. Mangrove Island area is dominated by mangrove forests so that the waters around the island are dominated by muddy sand substrate. The results of water quality measurements at the study site are presented in Table 4.

| No | Type of Data              | Sampling location          |
|----|---------------------------|-----------------------------|
|    |                          | Bakau Island                | Air Sunda Island            | Air Kulah Island            |
|    |                           | N 00°27’57,3”               | N 00°27’49,7”               | N 00°26’55,7”               |
|    |                           | E 104°26’35,6”              | E 104°25’31,8”              | E 104°24’16,9”              |
| 1  | Water Clarity (meter)     | 10                          | 8                           | 10                          |
| 2  | Substrat type             | Sand, mud with rubble       | Sand with Mud               | Sand with rubble            |
| 3  | Current Velocity(cm/s)    | 15                          | 500                         | 100                         |
| 4  | Height of Wave (meter)    | 20-50                       | 20-40                       | 20-30                       |
| 5  | Tide (meter)              | 2.1                         | 2.1                         | 2.1                         |
| 6  | pH (pH)                   | 8.2                         | 8.1                         | 8.9                         |
| 7  | Dissolved oxygen (mg/L O₂)| 8.22                        | 8.59                        | 8.31                        |
| 8  | Salinity (%)              | 33                          | 25                          | 35                          |

Table 4. Result of water quality parameter

Based on physical interactions the current velocity on Air Kulah Island is faster than Bakau Island and Air Sunda which is 500 centimeters / second, with an average wave height of about 30 cm. At high tide, the water depth reaches 3 to 5.5 meters and the lowest ebb ranges from 1 to 2.5 meters from the average water level. The pH concentration found around the waters of Benan ranges from 8.1 to 8.9. Dissolved oxygen content in Benan waters ranges from 8.22 to 8.59 mg / L. Salinity (salinity) in these waters ranges from 25 to 35 ‰ (Table 4).

3.4 Suitability of the marine area for ecotourism diving

The results of the analysis of the suitability of waters matrix for the development of marine ecotourism for diving in the waters of Benan Island and its surroundings as a whole location are eligible for ecotourism diving, with an average SI of 78% or very appropriate. There are four islands with very suitable classes, namely; Island of Benan, Bakau, Katang and Nopong. Three other islands namely; Island of Air Kulah and Air Sunda have appropriate class categories (Table 5).
Table 5. Results of the analysis of suitability for ecotourism diving

| Names of Island | IKW (%) | Suitable classes  |
|-----------------|---------|-------------------|
| Benan           | 84,7    | Very Suitable     |
| Bakau           | 84,7    | Very Suitable     |
| Air Kulah       | 70,8    | Suitable          |
| Katang          | 77,8    | Very Suitable     |
| Air Sunda       | 70,8    | Suitable          |
| Nopong          | 77,8    | Very Suitable     |

3.5 Number of visitors allowed per time period per location

Determining the number of tourists allowed per period of time per location is carried out using a carrying capacity of biophysics approach, namely, the optimum number of visitors that can be physically accommodated in the area provided at a certain time without causing disturbance to nature and humans or the ability area to receive a number of optimal visitors continuously without damaging the environment.

The carrying capacity of the area will determine the sustainability of a marine tourism activity itself. The carrying capacity of each region differs from region to region and is related to the type of tourism activities to be developed. Therefore, the carrying capacity of the area needs to be considered in developing a dive tourism area. Based on the specified quality standards, the area developed based on the carrying capacity of the area is 10% of the area of the existing utilization zone. So for the calculation of the carrying capacity of the area in one day is the potential available width x 10% for diving tourism, considering this activity is very sensitive to external factors because tourists are dealing directly with the ecosystem.

The carrying capacity of the area for diving tourism in Benan Island is 444 people / day for the southern reefs of P. Benan, 69 people / day in Karang Selada, 66 people / day in Karang Segenting, 220 people / day for Karang Tajur, 234 people / day for the utilization of Sunda Air Corals and 76 people / day in Karang Nopong (Table 6).

| Location         | Area(M²)       | AreaUtilization (10%) | Carrying Capacity(Visitor / Location/day) |
|------------------|----------------|-----------------------|------------------------------------------|
| Benan Island     | 1,110,956.26  | 111,095.63            | 444                                      |
| Air Kulah Island | 172,067.86    | 17,206.79             | 69                                       |
| Katang Island    | 165,966.10    | 16,596.61             | 66                                       |
| Bakau            | 549,562.54    | 54,956.25             | 220                                      |
| Air Sunda        | 585,717.49    | 58,571.75             | 234                                      |
| Nopong           | 189,511.12    | 18,951.11             | 76                                       |

3.6 Study implication

The results of the study of the potential, coral health status and the suitability level of the natural resources of the waters, the type of diving tourism activities (diving) can be recommended to be developed in Benan Island, Bakau Island, Air Kulah Island and Nopong Island with consideration being; percentage of coral community cover level 30-50%, reef fish species that have high diversity, one hundred percent water clarity and adequate current velocity, and relatively shallow coral reef depth. All of these attributes or parameters are very supportive for diving activities. Although Katang Island has a 77.8% tourism suitability index with a very suitable class but we don't recommend it for the development of ecotourism diving because some of the waters of Katang Island are marine protect areas of the local community. The local wisdom of the community in protecting the coral reef...
ecosystem on Katang Island has succeeded in maintaining live coral cover by 55%, the highest cover in this group of islands. Map of recommendations for developing marine ecotourism for diving shown in figure 8.

![Figure 8. Map of ecotourism diving development](image)

4. Conclusion
Potential and status of coral reef ecosystems in the waters of Benan and surrounding areas are in the moderate category with an average live coral cover of 41.48%. In this study, 13 types of reef fish families were identified with an average abundance of 28 islands per m². The condition of the waters and biological resources in the waters of Benan Island and its surroundings are still in the good category with an average tourism suitability index reaching 78% which is very suitable to be developed for ecotourism diving. The development of the waters of Benan Island and its surroundings for ecotourism diving must pay attention to the carrying capacity of the region. Benan Island and its surroundings are able to accommodate tourists for diving reaching 76-444 people/day.

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