Assessing of coral reef resilience on Lembeh Island, North Sulawesi

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Abstract. Resilience is the ability of a system to reach equilibrium after a temporary disturbance. When an ecosystem is disturbed, then the recovery of the system is very dependent on the diversity of species that are still left. The remaining communities determine the direction of new successional communities formed after the disturbance has passed, including coral, fish, and other biota communities. This study aimed to determine the level of resilience of coral reef ecosystems on Lembeh Island. The observation was carried out from January 16-19, 2019, at a 7-meter depth. Determination of the coral reef index will refer to coral reef resilience index table.

It is found that the resilience of coral reefs on Lembeh Island currently has a high potential for recovery (resilience) from natural stressors based on the 16 parameters. Seven parameters have very high resilience values: the proportion of bleaching resistant species, community resistance to bleaching, taxonomic diversity, size/age distribution, the abundance of reef fish on live coral, and the abundance of coral benthos on live coral and coral disease levels.

Lembeh Island is dominated by hard corals measuring between 5.1 to 25 cm (size M) by ~46%, then sizes more than 25 cm (size L) by ~37% and juvenile size (size S) by 17%. The coral health index on Lembeh Island has the capacity to recover if the condition of coral cover is minimally maintained or improved and lower fleshy seaweed cover by increasing the abundance and biomass of herbivorous fish.

Keywords: coral reef; Lembeh Strait; potential recovery; resilience

1. Introduction
Indonesia’s coral reefs have the highest biodiversity in the world. There are more than 2000 fish species, 650 coral species; Therefore, Indonesia is declared the centre of the world’s marine biodiversity [1-3]. The Indonesian Institute of Sciences (LIPI) issued the status of the condition of Indonesia’s coral reefs in 2017, of which only 6.39% were in excellent condition. The distribution of Indonesian coral reef cover conditions for the western region with excellent conditions is around 8.97%; the middle is 4.91%, and the eastern is 4.05% [4].

Global climate change puts unavoidable pressure on coral reefs, coral bleaching due to rising sea temperatures is expected to shorten the cycle and become an annual event in the Phuket region and the Great Barrier Reef (GBR) by 2030 [5]. The faster the frequency of coral bleaching occurs the majority of coral populations will not have enough time to recovery. Several studies suggest that the ability of coral reef ecosystems to deal with disturbances and rebuild coral-dominated systems is the only way to manage coral reefs to deal with disturbances associated with global climate change [6-9].

Lembeh Strait was located in the world’s coral triangle with high marine biodiversity. Lembeh Strait has unique environmental conditions that play an essential role in distributing and sustaining marine life [10]. Environmental threats that impact coral reefs in the Lembeh Strait come from human disturbances and natural factors. There are concerns about the future of coral reefs health on Lembeh Island stemming...
from coastal development, port construction, and marine tourism development [10]. It will undoubtedly have a significant impact on the sustainability of coral reef ecosystems. So, there is a need for comprehensive research and studies that could provide input for the management of coral reef ecosystems. One of the studies that need to be addressed is the resilience of coral reefs on Lembeh Island. This study aims to assess the resilience of coral reef ecosystems on Lembeh Island to environmental pressures.

2. Materials and methods

2.1. Location and time of research
Observations were conducted for three days from 16-19 January 2019, around the waters of Lembeh Island from north to south. Observations were made during the day from 7 am till 4 pm at an average depth of 7 m and a maximum of 12 m on the reef flat of Lembeh Island. Observation locations are depicted on the map (figure 1).

2.2. Data collection technique for coral reef habitat
2.2.1. Observation of waterbed substrate condition. Observation of benthic substrate type was conducted using the Underwater Photo Transect protocol based on Giyanto et al. [11]. A 50 m long transect was stretched parallel to the shoreline, then photographed every 1 meter with 58 x 44 cm figure of quadrant transect. The observed photos were then analyzed using Coral Point Count with Excel extension (CPCe) software to produce the percentage of substrate cover [11].

2.2.2. Coral community structure, fish, benthic invertebrates and coral health. Observation of coral community structure, benthic invertebrates, and coral health using a belt transect length of 50 x 1 m. The fish community uses a belt transect with a length of 50 x 5 m. [12, 13]. Component of the coral reef health index value was measured using a method developed by LIPI, which was determined based on two main components. LIPI methods utilized the benthic biota component based on coral cover and the reef fish component based on the total biomass of the target fish. The resilience level factor or recovery
factor was calculated based on fleshy seaweed cover and rubble cover. The community structure is seen from the index of diversity and equality, which is used to see a community depressed or not.

2.2.3. Coral recruitment. Coral recruitment was observed using a belt transect of 50 meters with a 1-meter width observation installed parallel to the shoreline [12]. Identified recent coral colonies by counting and recording all coral species with a maximum diameter of 5 cm (d" 50 mm) on each transect [13]. The length of the diameter of the coral was a benchmark for the size of a recent coral colony (juvenile), or the coral is approximately three years old [14, 15]. All corals that fall into the juvenile category are recorded at the genus level.

2.3. Data analysis

2.3.1. Substrate's condition. Each transect's underwater photo data was analyzed using CPCe (coral point counted with excel extensions) [11]. The percentage analysis of biota cover referred to English et al. [12] by calculating the percentage of substrate cover categories obtained from the formula:

\[
\text{Percentage of cover category} = \frac{\text{Sum of cover category to} - i}{\text{The number of random points}} \times 100\% \quad (1)
\]

The assessment of coral reef conditions was using the criteria developed by Zamani and Madduppa [14]. This assessment consists of 4 parameters, that is live coral cover, algae cover, sand cover, and mortality cover. Mortality cover be composed by rubble, dead coral, and dead coral algae category. from the combined data the results will show what criteria the location belongs to table 1.

2.3.2. Community structure of coral, fish, and benthic invertebrates. The community structure is analyzed using the following equations:

a. Diversity is known using the Shannon-Wiener index, which takes into account species richness and evenness.

\[ H' = \sum Pi \ln Pi \quad (2) \]

Pi is the proportion of abundance of species i.

b. Evenness is calculated by the equation:

\[ Ei' = Hi' / H' \text{ max} \quad (3) \]

H' is the diversity index, and H' max = H/\ln S, and S is the species richness.

c. Dominance is calculated by the equation. Pi is the proportion of abundance of species i

\[ D = \sum Pi^2 \quad (4) \]

| Parameters                  | Very Good | Good | Fair | Bad  |
|-----------------------------|-----------|------|------|------|
| Live coral cover (%)        | 75-100    | 50-74.9 | 25-49.9 | 0-24.9 |
| Algae cover (%)             | 0-24.9 | 25-49.9 | 50-74.9 | 75-100 |
| Sand cover (%)              | 0-24.9 | 25-49.9 | 50-74.9 | 75-100 |
| Mortality index             | 0.75-1   | 0.50-0.749 | 0.25-0.499 | 0-0.249 |

Table 1. Criteria for coral reef health [14].
2.3.3. The level of coral reefs resilience. Determination of coral reef resilience index will refer to the table developed by Grimsditch and Salm [16], coral reef resilience could give information about the how the ecosystem could maintain from natural stressor. This data table consist of biodiversity from coral reef, invertebrates, and fishes. Furthermore, coral cover and disturbance, the disturbance is consisted of space competitor and predation [16].

3. Result and discussion

3.1. Conditions of substrate

The results showed that the percentage of live coral cover varied with a range of 5.2-58.9% with an average of 27.17% (moderate category) [17]. The highest percentage of live coral cover was found in Honey Bay. The lowest was in Batu Sandar. The complete average of bottom substrate cover was present in figure 2. The ecological role of each community member in the ecosystem can be group into several functional groups [18]. The life form indicates the functional groups of coral communities, grouped into 13 types [19]. Each life form provides the same habitat, but these reflect different levels of habitat complexity. So, it can be said that the Honey Bay has a relatively high level of functional complexity of the habitat, while the Batu Sandar of functional complexity is low figure 2.

3.2. Community structure of hard coral, coral reef fish, and benthic invertebrates

3.2.1. Hard coral community. This study is found 224 coral species that live in the Lembeh Strait figure 3, which belong to 15 families. Less than 40% of the coral species were spread along the Strait and mostly are in the north [10]. Observations found that the condition of hard coral communities varied with the range of 200-300 thousand colonies/ha, with an average of about 30 thousand colonies/ha. The Fungia genus was the most abundant hard coral figure 4, while the lowest was the Psammocora genus. Forty-eight hard coral genera were observed in this study. Based on the diversity index analysis, a value of 3.07 was obtained, grouped as high diversity. The evenness index used for the distribution of individuals in the community was 0.79, denoting a stable coral community.

An ecosystem could have high species diversity, but if one important functional group could be damaged by stressor, it will cause the ecosystem function to be disturbed. The positive impact of diversity in ecological functions on ecosystem functions is the possibility of a decrease in species diversity by a disturbance without being followed by a decrease in ecosystem function [20].

Coral predators prefer corals of the Acroporidae and Pocilloporidae species [21, 22]. In moderate disturbances, other members of the coral community are not disturbed by certain coral predators. Corals Acroporidae and Pocilloporidae have lower resistance to coral bleaching than corals from other families [23, 24]. High resilience of the coral community with high coverage of coral reefs will have a swift recovery. High diversity is needed to support ecological processes, but ecosystem resilience is determined by species diversity and functional diversity [25].
3.2.2. Benthic invertebrates community. Observations recorded 191 species of non-coral benthic invertebrates in this study. The species with the highest abundance are *Didemnum molle* (500 thousand individuals/ha), *Haliclona koremella* (3,333 individuals/ha), *Aglaophenia cupressina* (2,563 individuals/ha), *Capillaster centosus* (1,625 individuals/ha), and *Pseudoceratina* sp. (1,354 individuals/ha) figure 5. All angel window (>Window contains the most abundant invertebrates community with >200,000 individuals/ha). The lowest abundance is in the East of Pasir Panjang (<25,000 individuals/ha), with the total abundance found 2,472,600 individuals/ha. Seen in terms of the highest species richness is found in Tanjung Dula (>60 types) and the lowest in East Pasir Panjang (<20 types) with a total of 195 species. The highest diversity index found in California Dreaming with 3.08 means indicated that conditions of the invertebrates are still stable. The lowest in east Pasir Panjang with 1.91 showed that the community is in a depressed condition. Non-coral benthic invertebrates are also affected by the diverse conditions of coral reefs and hard coral cover [26].

Observations during the study found as many as 191 species of non-coral benthic invertebrates. The species with the highest abundance are *Didemnum molle* (500 thousand individuals/ha), *Haliclona koremella* (3,333 individuals/ha), *Aglaophenia cupressina* (2,563 individuals/ha), *Capillaster centosus* (1,625 individuals/ha), and *Pseudoceratina* sp. (1,354 individuals/ha).

3.2.3. Coral recruitment. The survival of coral reefs depends on the recruitment and attachment of coral juvenile filling, and blending of coral structures. The process of recruitment of corals is naturally through coral reproduction, both sexually and asexually [27]. They are artificially done by making artificial reefs that can stimulate the attachment of coral juvenile, as done by Bachtiar and Prayogo [28] in Lombok.
East Nusa Tenggara. Corals with a maximum of 5 cm in length become a benchmark of the size of corals that are on the juvenile phase, or approximately corals are three years old [14-15].

Lembeh Island is dominated by hard corals measuring between 5.1 to 25 cm (size M) by ~46%, then sizes more than 25 cm (size L) by ~37% and juvenile size (size S) by 17%. In some observation sites, groups of hard coral genera sometimes form an inseparable expanse between colonies. It is included in the size of L (expanse Euphyllia, Anacropora, Acropora, Goniopora, Porites, and Turbinaria). Hard coral genera measuring < 5 cm are mostly from Fungia and Acropora (~14%), Montipora (~12%), and other species (~0.2-7%). These three types are indeed the most dominating genus in the waters of Lembeh Island.

Coral recruitment in natural habitats is measured based on the number of juveniles defined as coral colonies measuring ≤ 5 cm [28,29]. According to Miller et al. [30] and McClanahan et al. [31] in Bachtiar [28], colony size 2 cm and 5 cm, as well as colony size 2-40 mm and stated that colony size 0.5-5.0 cm entered juvenile The proportion of the recent coral colonies with the largest is quite broad, indicating that the coral reef community on Lembeh Island has natural recruitment potential. A coral reef community will occur continuously if the structure of the coral community has many sizes of colonies, or the smallest colony size range with the largest is quite broad. The number of colonies in the

Figure 5. The abundance of ten types of non-coral benthic invertebrates found on Lembeh Island.

Figure 6. The abundance of non-coral benthic invertebrates was found on Lembeh Island at every observation site.
The smallest class of colony size can reflect recruitment on the coral reefs. This condition means that with the smallest and largest proportion of colony sizes having a reasonably extensive range and the discovery of a relatively large number of small colonies (< 5cm), it indicates that the natural recruitment process will be going well.

If the base substrate structure is stable, can made the colonization of corals, other benthos and new coral communities are formed faster. Mobile organisms can be distinguished as passive and active organisms, such as juvenile nekton, or other biotas which move passively on the water column [32]. This component provides a supply of juvenile that will colonize open space due to interference. The recolonization of coral reefs through spreading juvenile is very important to [33]. The recovery of a coral reef depends on the surrounding coral reef ecosystems as a support system. In an open ecosystem, the role of connecting organisms is enormous. Only slight coral juvenile produced on a coral reef will live settled in the last habitat. Coral juvenile has a lifespan of 23-244 days [33], so most of the juvenile is potentially washed away by ocean currents and lives settled on other coral reef ecosystems. Genetic research on Goniastrea coral exhibits that corals in the Okinawa Islands receive juvenile from the Kerama Islands, about 50 km away [34].

3.2.4. The resilience of coral reefs. The restoration of coral reef ecosystems after the passage of disturbance will depend on those ecosystems' ecological memory. Ecological memory is the composition and distribution of organisms and their interactions in space and time [32]. Ecological memory consists of three components: biological and structural inheritance that survives, active moving connective organisms, and supporting areas. The first component serves as internal memory, while the
second and third components serve as external memory in the ecosystem recovery process after a disruption.

Several studies reveal that ecosystem resilience is associated with biodiversity. High diversity indicates ecosystems are more resistant to disruption. Resilience refers to the capacity of the reef to recover after the occurrence of disturbances [35], species diversity and function is one of the factors coral reef health indicators, higher the diversity show more good condition of coral reef ecosystem [36], and monitoring is one of the mechanisms and strategies to improve the elasticity of coral reefs. Maynard et al. [37] gathered various evidence of reef recovery due to the curling, such as in the Chagos Islands [38], Palau [39], and Western Australia [40] because of good management. Biodiversity at the species level gives coral communities strength against coral bleaching and bleaching disturbances by Acanthaster plancii or Drupella. At present, there are two methods for assessing coral reef resilience. Obura and Grimsditch [40] have made a guide to coral reef resilience assessment, then Maynard et al. [41] also developed a method of assessing coral reef resilience.

Surviving biological and structural components can be the most critical components in the succession of coral reef ecosystems. The ability to recover the system from disruption phenomenon depends on the diversity of remaining species on the withstand ecosystem. The remaining communities determine the direction of a succession of recent communities formed after the disturbances have passed. The higher the diversity of the remaining communities, the more similar the structure and composition of the new community to the previous community. Hughes et al. [42] provide a specific definition for coral reef resilience, namely the ability of coral reefs to deal with (censor) disruption and rebuild coral-dominated systems.

Although there are many threats to the health of coral reefs on Lembeh Island. Large-scale ships are passing by because it is close to Bitung Port. However, the condition shows a potentially high level of resistance to its natural pressure. Water quality damage, destructive fishing, flooding, sediment transportation, solid waste disposal, mangrove deforestation, have been seen as anthropogenic factors that reduce coral reef conditions and sometimes even kill corals [43,44]. Among anthropogenic factors with the addition of some natural disorders (e.g., Climate change, extreme western seasons, predatory).

Previous studies of coral reefs in Jamaica show that the disappearance of turtle and mermaid populations did not cause a change of phase, as its ecological function could be replaced by herbivorous

Figure 9. The proportion of hard coral genus by size on Lembeh Island.
Ecological resilience is determined mainly by the inter-scale redundancy of species and the redundancy of ecological functions between scales [25]. Redundancy within the intra-scale is indicated by the number of species that perform the same ecological functions, such as massive-shaped corals. Massive coral colonies provide habitats that large Seranidae and Lutjanidae fish can inhabit. These massive corals can come from Faviidae, Poritidae, or another coral family. At the same time, each family of corals consists of many species. Inter-scale redundancy is indicated by several species of different colony sizes but performs almost the same functions. Small-bodied massive corals and large-bodied massive corals serve the same as hiding fish from predators of different scales.

The observations of the coral reef curling index in Lembeh Island (table 3) obtained a general assessment showing that the current condition of coral reefs in Lembeh Island has a high potential for recovery (resilience) from natural pressures. Seven parameters have a very high value in the proportion of bleaching resistant species, bleaching resistance of community, taxonomic diversity, size/age distribution, the abundance of juvenile recruits, abundance of herbivorous fish, the abundance of urchins, and the abundance of other herbivores. Although lives coral cover on Lembeh island into the low category, macroalgae cover and other faunas are high, and high sand and mud cover.

Coral reefs, as natural ecosystems get disturbance (disturbance, perturbation), make factors that form and increase the resilience of coral reefs, so coral reef management needs to understand the response of

| Resilience Factor | Resilience variable | very low | low | moderate | high | very high |
|-------------------|---------------------|----------|-----|----------|------|-----------|
| Hard coral cover  | the proportion of bleaching resistant species | 2        | 5   |          |      |           |
|                   | bleaching resistance of community |          |      |          |      |           |
|                   | taxonomic diversity           |          |      |          |      |           |
|                   | size/age distribution |          |      |          |      |           |
|                   | substrate suitability |          |      |          |      |           |
|                   | the abundance of juvenile recruits |          |      |          |      |           |
| Recruitment       | juvenile survival | 2        |      |          |      |           |
|                   | good juvenile supply         | 2        |      |          |      |           |
|                   | the abundance of herbivorous fish | 3        |      |          |      |           |
| Herbivory         | abundance of urchins | 1        |      |          |      |           |
|                   | the abundance of other herbivores | 1        |      |          |      |           |
|                   | overall herbivory            | 1        |      |          |      |           |
|                   | the abundance of corallivores fishes on live |      |      |          |      |           |
| Bioeroders,       | coral |                          |      |      |          |      |           |
| Corallivores,     | the abundance of corallivores benthos on live coral (0.11%) | 5        |      |          |      |           |
| Disease           | levels of coral disease |                          |      |      |          |      |           |

Table 2. Matrix of coral reef resilience analysis on Lembeh Island [16].

Fish [45].
coral reefs to disturbances. Naturally, coral reefs have high resilience to all existing disturbances [48,49], so they can survive for hundreds of millions of years [49]. Anthropogenic pressure reduction will increase coral reef resilience to deal with natural disturbances. Based on the analysis results of the resilience index in Lembeh Island has a high resistance to natural disturbances.

4. Conclusions
The percentage of coral cover living on Lembeh Island is quite varied, with a range of 5.2-58.9% with an average of 27.17% (in the category of sufficient). The wealth of hard coral clans that have been found is as many as 48 hard coral clans, with the diversity of hard corals on Lembeh Island being in the high category and the level index approaching one means that the hard coral community on Lembeh Island is in stable condition. The abundance and biomass of herbivorous fish still fall into the low category, but low fleshy seaweed cover makes the coral reef ecosystem on Lembeh Island have a good ability to recover. A total of 191 species of non-coral benthic invertebrates have been found on Lembeh Island, with the diversity of non-coral benthic invertebrates as a whole on Lembeh Island obtained a value of 3.71, meaning that its diversity is high, with an even index approaching 1, meaning that the community of non-coral benthic invertebrates is located in stable condition. The coral health index on Lembeh Island has the capacity to recover if the condition of coral cover is minimally maintained or improved and lower fleshy seaweed cover by increasing the abundance and biomass of herbivorous fish. The proportion of coral colonies on Lembeh Island has natural recruitment potential. The coral reefs in Lembeh Island currently have a high potential for recovery (resilience) from natural pressures, as seen from the 16 parameters used in the assessment, seven parameters have a very high value that is in the proportion of bleaching resistant species, bleaching resistance of community, taxonomic diversity, size/age distribution, an abundance of corallivores fishes on live coral, an abundance of corallivores benthos on live coral and levels of coral disease.

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