Mangrove health index distribution on the restored post-tsunami mangrove area in Biak Island, Indonesia

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Abstract. Research Centre for Oceanography has launched and published a single metric for assessing mangrove health based on stand structure variables since October 2020. A spatial analysis study was conducted to implement the MHI formula in a post-tsunami area in a Pacific-edge island in Biak-Papua which has been rehabilitated since 2017, especially in Tanjung Barari lagoon. The study was aimed to analyze the recent MHI value based on field data collection and to interpolate the value in the entire mangrove area. We compared the MHI distribution along the study area in 2015 and 2020. Sentinel 2 imageries were used as primary data which were preprocessed for extracting the mangrove area in the lagoon area. A multiple vegetation indices relationship which was consisted of NBR, GCI, SIPI, and ARVI, was applied on each observation period for MHI distribution estimation. The interpretation of mangrove health was divided into three categories such as poor, moderate, and excellent. This study found that the mangroves area in the lagoon was declining at 33.53 ha during periods. Based on MHI value, mangrove was dominantly at the moderate level. In addition, moderate and excellent mangrove areas were increasing during observation. The poor mangrove area was decreased due to loss of the dieback mangrove, seedling natural settlement, and rehabilitation activities. We identified as many as 144.39 ha of the lagoon area in 2020’s imagery which was potential for the future rehabilitation area. Even though, the area needed to be confirmed related to environmental setting and land tenure issue.

1. Introduction
Indonesia is an archipelagic country occupied by the most proportion of mangrove forest area in the world by approximately 22.4% [1]. It is considered a significant global blue carbon contributor in terms of climate change issues [2]. However, Indonesia’s mangrove also releases the largest concentration of greenhouse gases since it has faced massive deforestation due to land-uses land cover change [3]. Aquaculture has driven a significant loss of mangroves in Indonesia in the last two decades [4]. On the other hand, natural disasters could destruct mangrove areas even though the impact is not as significant as human-driven threats [5].

Biak islands severed earthquake and tsunami in February 1996 and caused massive destruction on the city. An 8,2-Richter magnitude scale of the earthquake has been suspected as the main cause of damage to the mangrove forest in a specific area, namely Tanjung Barari village. It changed the hydrology system in
the forest by increasing water salinity significantly. Consequently, low saline and larger size species, *Brugueira gymnorrhiza* was facing dieback along this area. On the other hand, *Rhizophora stylosa* and *Sonneratia alba* have a better adaptation and domination recently. The local government in collaboration with NGOs and local communities has restored the degraded area since 2017 to improve and recover mangrove ecosystem services.

Mangrove health index (MHI) is a functional formula for estimating forest conditions and status in a certain area [6]. The index had a significant relationship to multivariable remote sensing-based vegetation indices which were running using Sentinel 2 imagery [7]. This study was aimed to analyze MHI distribution along the restored mangrove forest and compare its distribution between 2015 (before the rehabilitation program) and 2020. The potential rehabilitation area also was identified based on the MHI value. Hopefully, this study could deliver specific information for future restoration activity.

2. Material & Methods

2.1. Site Description

Mangrove in Tanjung Barari was mostly distributed in the wide lagoon which was dominated by *Rhizophora* (inner lagoon) and *Sonneratia* species (outer lagoon). A monitoring site located inner lagoon had a high canopy coverage and stand density (Figure 1). While the outer was low-canopy covered and fewer stands distributed [8].

2.2. MHI Distribution Analysis

Sentinel 2 imageries were selected and downloaded based on the clarity of cloud coverage in Tanjung Barari mangrove and lagoon. We used S2A_OPER_MSI_L1C_TL_EPA__20151020T012800_20161210T155750_A001701_T53MPU_N02_04_01 and L1C_T53MPU_A025582_20200516T012721 to compare the MHI distribution in 2015 and 2020, respectively. A free and open-source application, Quantum GIS (QGIS), was used as the main tool for image processing in this study. Each imagery was pre-processed by radiometric correction by the SCP plugin on QGIS. Mangrove area was
separated to adjacent objects which were guided by the interpretation of the false color of each image, applied manual digitization, and masked.

MHI was closely related to four vegetation indices of remote sensing analysis, such as Normalized Burn Ratio (NBR), Green Chlorophyll Index (GCI), Structure Insensitive Pigment Index (SIPI), and Atmospherically Resistant Vegetation Index (ARVI) [7].

\[ \text{MHI} = 102.12 \times \text{NBR} - 4.64 \times \text{GCI} + 178.15 \times \text{SIPI} + 159.53 \times \text{ARVI} - 252.39 \]

\[ \text{NBR} = \frac{\text{NIR} - \text{SWIR}}{\text{NIR} + \text{SWIR}} \]

\[ \text{GCI} = \frac{\text{NIR}}{\text{Green}} - 1 \]

\[ \text{SIPI} = \frac{\text{NIR} - \text{Blue}}{\text{NIR} - \text{Red}} \]

\[ \text{ARVI} = \frac{\text{NIR} - 2 \times \text{Red} + \text{Blue}}{\text{NIR} + 2 \times \text{Red} + \text{Blue}} \]

Where:

- NIR = Near Infrared band (B8)
- SWIR = Shortwave Infrared band (B11)
- Red = B4
- Green = B3
- Blue = B2

The MHI distribution was divided into three categories, i.e. poor (MHI <33.33%), moderate (MHI = 33.33 – 66.67%) and excellent (MHI >66.67%). The minimum value of MHI was found at 18% using its original formula since a lower number has no more vegetation [8]. On the other hand, the negative value of MHI was interpreted as a deeper water column. Rehabilitation potential area was categorized into 0 to 18% of MHI value as a shallow habitat for mangrove seedling or a post-dieback area. Area of each MHI category (18% – 100%) and potential rehabilitation area (0-18%) in hectares were calculated using the \( \text{area} \) formula in its attribute table.

3. Result and Discussion

3.1. Mangrove Area Changes 2015-2020

Mangrove existing area in Tanjung Barari was about 383.56 ha in 2020, which declined by 33.53 ha during 6 years [Figure 2 and 3]. The previous area was reduced due to the dying-back of mangrove stands. Dieback mangrove in this area was impacted by the natural event and has changed its species domination. In this area, human activities and coastal development including land use and land cover changes were minimum, hence the reduction of mangrove area was potentially caused naturally. Earthquake is the main factor delivering localized subsidence and then changes of its habitat salinity. The case was also identified along in Solomon Islands coastal area which was found land-rising until 70 cm [9].

Changes in salinity are the main factor driving mangrove dieback since it controls cellular osmotic pressure. Each species has its own adaptation range of salinity which forms a forest zonation. Bruguiera gymnorrhiza was categorized into mesohaline species, meanwhile, Rhizophora stylosa had a higher salinity tolerance. Facing a higher salinity could reduce mangrove biomass growth especially in B. gymnorrhiza, increase osmotic pressure and reduce leaf area [10,11]. Hyper-salinity was proven in the destruction of mangrove forests in Senegal [12].
3.2. Mangrove Health Index (MHI) Distribution

Reduction of total mangrove area in Tanjung Barari was only found in the poor MHI category. This area was declined from 215.49 ha in 2015 to be 115.63 ha in 2020 (Figure 4 and 5). It strengthened the indication that the dieback mangrove area was going to be changed. The poor category of mangrove in this area was also maintained by the natural settlement of mangrove seedlings and growth of seedlings as a result of rehabilitation programs since 2017. Maintained habitat drives degraded mangrove forests to be restored naturally [13,14]. Even though natural regeneration was enough for restoring mangrove areas, human contribution through rehabilitation programs would accelerate the mangrove restoration process [15].
Mangrove areas with moderate and excellent categories of MHI increased during two-period observations. Moderate status area improved from 175.71 ha to 202.78 ha or +27.07 ha from 2015 to 2020. In addition, the area of the excellent mangrove category experienced a significant improvement from 24.53 ha to 64.16 ha during observation. Mangrove growth was supported by less anthropogenic activities along the lagoon area. It was a chance for mangrove seedling and sapling to grow optimally. Moreover, the seedling was spreading easily the internal waters of the lagoon with less of threat. The location was protective from high waves and strong water current, even though the outer lagoon faced directly to the Pacific Ocean. Failure of mangrove planting could be delivered by a strong wave [16]. The lagoon also experienced less plastic waste pollution from a nearby city which made it a suitable habitat for mangrove recruits. Increasing the entire level of mangrove growth in the lagoon stimulated mangrove health.

**Figure 4.** Distribution of MHI comparison between 2015 (left) and 2020 (right).

**Figure 5.** Area changes of each MHI category in Tanjung Barari mangroves.
3.3. Potential Rehabilitation Area
Along this area, as many as 144.39 ha of the lagoon area was identified as a potential rehabilitation area (Figure 6). However, this area needs to be checked its environmental condition and tenure since the oceanographic and anthropogenic threats were not influenced in seedling’s survival rate. Suitable temperature, salinity, light, nutrient, flood, and sea-level rise were highly influenced on recruit’s settlement and development [17]. Salinity and light were related to leaf and whole plants physiology [18]. Land tenure is another important factor for the success of a rehabilitation program [19]. Involvement of local communities during a future restoration would improve the program achievement [20].

Figure 6. Potential rehabilitation area inside Tanjung Babari mangrove’s lagoon in 2020.

4. Conclusion
The total area of existing mangroves in Tanjung Barari lagoon decreased significantly from 2015 to 2020. However, its health status had increased by less of poor mangrove and more moderate-excellent categories due to seedling-sapling development, rehabilitation programs, and a lack of anthropogenic threats. We also identify that approximately 144 ha lagoon area could be potential for future mangrove restoration activities.

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