Spatial and temporal analysis for mangrove community healthiness in Liki Island, Papua-Indonesia

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Abstract. Indonesian mangrove declined significantly in the last two decades which has been considered to deliver a negative impact for adjacent communities in small islands. Mangrove quality monitoring was conducted during Nusa Manggala Expedition in 2018, which was aimed to analyze forest structure and healthiness using spatial-temporal investigation in Liki island, Papua. Field data were collected from 10m x 10m quadratic plots which were distributed following stratified purposive sampling method. Spatial and temporal was implemented using Sentinel 2 imagery on this area from 2016 to 2021. The result of this field study had considered that mangrove in Liki island was in moderate healthiness since the MHI value was between 33.33% - 66.67%. It was supported by remote sensing analysis in 2018 which showed that the moderate MHI area was dominant by approximately 42% compared to the excellent area in about 33%. Liki’s mangrove had experienced a declining trend of excellent category from 2016 and reached the lowest area of its category in 2018. In the last four-year observation, excellent areas gradually increased which was covering 57.68% of forest MHI. The dynamic of mangrove healthiness on this island tended to be delivered by natural events.

Keywords: mangrove, mangrove health index, spatial-temporal analysis

1. Introduction
Indonesia has the most extensive mangrove area in the world with approximately 22.6% of global mangrove [1]. According to Indonesian National One Map data, as many as 3.31 million ha mangroves has existed in this country whereas about 0.6 million ha was in a critical state [2]. Papua, mainland and its archipelago, has the largest mangrove area among Indonesian mangrove and most of them are in a pristine condition due to lack of anthropogenic threats [3]. On the other hands, Indonesian mangrove has decreased massively since it was converted to be several major lands uses such as aquaculture, coastal development and oil palm cultivation [4]. Indonesia had been responsible to the most atmospheric carbon emission due to a massive deforestation [5]. Mangrove stands degradation has been considered to affect mangrove ecosystem functions and services to the coastal communities [6].

Mangrove has important roles on small island coastal area since it delivers ecological, protection and economic benefits for adjacent ecosystems. Mangrove existence supports nurseries and feeding ground for fauna diversity who has an economical value for alternative livelihood [7-9]. A healthy forest protects the coastline from abrasion [10], maintains saltwater intrusion [11] and reduces coastal residence damages caused by typhoons and tsunami [12-13]. Mangrove forests have been considered to mitigate climate change impact, sea-level rise, which risks islands existence [14]. The function and
services of mangroves to the surrounding communities could be optimum since mangrove forest quality is maintained.

There are several ways for estimating the quality of the mangrove ecosystem. Assessing community structure on field measurement is the most common and simple method which has been frequently applied in recent studies [15-17]. Ecological indices and species diversity of mangroves were also involved in compiling criteria of the forest quality [18]. Remote sensing approaches have been familiar for spatial and temporal studies with some field assessments for validation [19-21]. Vegetation indices have been common to be related to forest healthiness, density, canopy density and species distribution [22-24]. Satellite imagery analysis would be valuable for initial recognition and sampling distribution for field measurement [25].

Mangrove health index (MHI) has been developed to propose a single metric for estimating forest community healthiness based on three main stand structure parameters, i.e. diameter, canopy coverage and density. Those parameters were selected from various community structure variables using a principle component analysis (PCA) [25]. The index was considered for representing mangrove on the ecosystem scale since mangrove plant communities have an important role in ecosystem productivity and stabilized food chain. The value of MHI was significantly correlated to several vegetation indices based on remote sensing analysis. MHI could be estimated from multiple indices such as GCI, SIPI, NBR and ARVI [26]. The model is the potential to be applied in other areas and various temporal settings. This study was aimed to analyze mangrove community structure and the MHI value in a small island. We had also calculated the temporal and spatial dynamic of MHI on the entire area during a six-year observation.

2. Materials and methods

2.1. Site description
Field data were collected during Nusa Manggala Expedition 2018 investigating Indonesia’s outmost islands in northern Papua and Moluccas archipelago. Liki Island was one of the sampling sites of the expedition in December 2018 which was located in Sarmi Regency, Papua. Liki is categorized into a small island since its land area has covered approximately 1,318,54 ha. Mangrove forest area in this island has been localized inner a small bay in the south-eastern part of this island (Figure 1). The forest had only occupied around 10 ha dominated by Rhizophoraceae members. Study sites were mostly distributed inside the bay.
2.2. Forest assessment

Stratified purposive sampling was applied for distributing sampling sites on this study based on species composition and abundance. The forest was divided into three zones i.e. landward (LW), middle zone (MZ) and seaward (SW) perpendicularly from land to seaside. Each zone was accommodated with six 10m-x-10m quadratic plots as a measurement unit. Diameter at breast height (DBH) was measured on each stand which was categorized into two growth’s levels, i.e. sapling (DBH<5cm) and tree (DBH ≥ 5 cm). In addition, seedlings, a growth level with less than 1.5 m height, were counted in the same area [25]. Measured stands were also identified for their species nomenclature [27]. Species density, dominancy and frequency was calculated using DBH size and number, then those parameters were used to calculate the important value index (IVI) [25].

The hemispherical photography method was applied for assessing mangrove canopy coverage by collecting nine hemisphere photographs from each plot [28]. The photographs were further analyzed using ImageJ software for calculating forest canopy coverage. Forest height (h) was also estimated using a protractor by involving the angle of forest tip (θ), measuring distance (d) and observer eye height (h₀), following Equation 1. Mangrove health index (MHI) involving a score of canopy coverage (Sc), sapling density (Snp) and diameter (Sdbh) was calculated following Equation 2-5 [25].

\[
ht = h₀ + (\tan \theta \times d) \tag{1}
\]

\[
Sc = 0.25 \times C - 13.06 \tag{2}
\]

\[
Snp = 0.13 \times Nsp + 4.1 \tag{3}
\]

\[
Sdbh = 0.45 \times DBH + 1.42 \tag{4}
\]

\[
MHI = \frac{(Sc + Snp + Sdbh)}{3} \times 10 \tag{5}
\]

2.3. Mangrove Health Index (MHI) distribution

Spatial distribution of MHI on Sentinel 02_SR imagery had been estimated by a multivariable vegetation indices equation [26]. Each pixel’s value of MHI had a significant correlation (R²-adjusted: 0.831) to a combination of several vegetation indices, i.e. NBR (Normalized Burn Ratio), GCI (Green Chlorophyll Index), SIPI (Structure Insensitive Pigment Index) and ARVI (Atmospherically Resistant Vegetation Index) following Equation 6. The result of MHI values were categorized into five classes, such as wet substrate (negative value), poor (0-33.33%), moderate (33.33-66.67%), excellent (66.67-100%), and dry substrate/built area/land (>100%).

\[
MHI = 102.12 \times NBR - 4.64 \times GCI + 178.15 \times SIPI + 159.53 \times ARVI - 252.39 \tag{6}
\]

For conducting temporal changes of MHI on Liki Islands, annual Sentinel 2 data were used during 2016 to 2021. Data acquisition, preprocessing and MHI estimation were conducted on Google Earth Engine, while annual visualization of MHI was laid out on QGIS.

2.4. Data analysis

Univariate data such as canopy coverage, tree, sapling and seedling density, morphometric size (DBH and height), important value index (IVI) and mangrove health index (MHI), were descriptively analyzed for their mean and standard deviation. Each parameter was visualized into a bar chart. The data was normally distributed so that, the parametric variance analysis, ANOVA followed by Tukey test were applied to identify the differences of each parameter among sites. Data analysis was conducted on R studio. Spatial and temporal changes of MHI were visualized into a thematic map annually using QGIS.
3. Results & discussion

3.1. Mangrove community structure

As many as three species were found in the landward (LW) zone which was dominated by *Rhizophora apiculata* (IVI=156.59%) followed by *Bruguiera gymnorrhiza* (IVI=93.41%) and *R. stylosa* (IVI=50.00%). The middle zone was dominated by *B. gymnorrhiza* (IVI=152.59%) and co-dominated by *R. apiculata*. On the other hand, two different species, *Xylocarpus molucensis* and *Ceriops tagal*, were found in the seaward zone, though *B. gymnorrhiza* occupied the major part of IVI 166.65% (Figure 2). Rhizophoraceae group had a preferred habitat on muddy substrates [29]. In some Papuan Small Islands, *R. apiculata* and *B. gymnorrhiza* were found dominating species distribution on the muddy habitats [30]. Rhizophora complexity roots were influenced by soil conditions [31].

Mangrove forest in Liki Island was covered by a dense canopy which had no significant difference among zones. Overall, the mean value of canopy coverage was higher than 75%, ranging from 76.69±2.57% on middle zone mangrove to 80.42±3.53% (Figure 2). Canopy coverage percentage showed that Liki’s mangrove had less anthropogenic pressure. In mangrove forest nearby residences, mangrove canopy coverage was reaching less than 50% due to illegal logging. Some pristine areas in Papua also found the higher mangrove canopy coverage such as in Wondama (82.46%) [32], Rajaampat (84.73%) [33] and Meos Mangguandi-Biak (93.88%) [30]. Another outermost small island in Papua, Miossu Island had a distinctive canopy coverage among zones, where its value in Rhizophoraceae zone reached the highest value at 85.04% [26]. Mangrove forest in Ayau Islands was covered by 76,57-86.49% by their canopy [34].

![Figure 2. Mangrove canopy coverage (a) and its important value index (IVI) (b) on each zones.](image)

Less canopy coverage on the middle zone was coincidentally followed by less tree density, though there have no significant differences among zones (ANOVA, p<0.05). The distribution of trees on those sites was ranged from 783 to 1167 stands per ha, and the overall mean value of tree density was less than 1000 stand/ha (Figure 3). Tree density trend had a negative relationship to stand diameter which was found at the largest values in the middle zone. Value of density and diameter tended to have a contrast value, which the denser mangrove stand was distributed, the smaller of mangrove morphometric size [30, 35-36]. This study was similar to the mangrove community in Miossu Island, Papua, which had a low tree density (800-1300 stands/ha) and large mangrove stand size by reaching 24.67±4.96 cm in diameter and 17.60±0.57 m of stand height [26]. On the other hand, mangrove forest height in this study was ranged from 12.02 m to 13.20 m which had no significant difference among zones (ANOVA, p<0.05).

Mangrove regeneration in this area was in good condition since it was found a lot of seedlings on among the sites. On average, 1300 seedling/ha were found, which was ranged from 600 seedlings/ha in the landward zone to 1600 seedling/ha in the seaward zone. The number of seedlings in this area was greater than other studies in a threatened protected forest in South Sumatra ranged from 100-800 seedling/ha [37]. The high number of recruitments in mangrove forests has indicated that the forest was
in stable condition, while it was still limited to harvest mangrove wood [38]. Sapling stand-level had a gradually increasing trend from landward to seaward zone, at 200 to 400 sapling/ha, respectively. In more anthropogenic threaten islands, mangrove forest has a denser sapling stand density, such as Kaledupa, Wakatobi 2300 stands/ha [36] and Bintan 3200 stand/ha [39]. In the newly grown mangrove habitat after affecting tsunami, mangrove in Nias Island had dominated by sapling stands which were distributed at 3100 stand/ha [35].

![Figure 3. Mangrove stands density (a) and its morphometric size (b) in Liki Island.](image)

Overall, the mangrove health index on the field sites was categorized into moderate conditions since the mean MHI value was at 60.03±8.34% or between 33.33% to 66.67%. The largest MHI was found in SW at 63.69 ±6.01%, while LW had the lowest MHI value at 54.54±9.52% (Figure 4). The domination of the moderate class was also represented by the spatial distribution of MHI value in 2018 (Figure 4). Moderate MHI had a higher area than excellent class in 2018 at 3.63 ha (41.92% of total mangrove forest) compared with 2.86 ha (34.56%), respectively.

![Figure 4. Measured (a) and projected distribution (b) of mangrove health index (MHI) in 2018.](image)

3.2. Spatial and temporal changes of MHI
Based on the temporal and spatial observation, mangroves in Liki Island experienced a decreasing area of mangrove healthiness in the middle of periods and turned up later until 2021 (Figure 5). It was represented by a reduction area of excellent category from 4.53 ha in 2016 to 2.87 ha in 2018. These changes were contributed to the increasing area of poor and moderate MHI categories during the same
periods about 0.59 ha dan 0.72 ha, respectively. There were observed a gradual increase of excellent category area in the next periods from 2.87 ha in 2018 to 4.97 ha in 2021 (Figure 6). Based on the result, the moderate category was considered to be transformed to excellent areas since it had experienced a slightly decreasing trend on the last four-year observation. During this period, mangrove healthiness was in a better condition since the poor mangrove was also declining.

**Figure 5.** A six-year observation for MHI distribution dynamic in Liki’s mangrove forest.

**Figure 6.** Area dynamic of mangrove health index (MHI) during a six-year observation on Liki Island Papua, Indonesia.

Several factors have influenced the healthiness of mangrove forests during spatial and temporal observations driven by natural events and anthropogenic activities. The large morphometric size of the mangrove stand was more vulnerable to be fallen due to lightning and strong wind [40]. Stand diameter was sensitive in forest vulnerability on facing cyclones [41]. The storm has also been considered to
deliver massive damage to the mangrove forest [42-43]. Indonesian small island’s mangrove in the Pacific had faced a natural threat due to earthquakes and tsunami [44]. Mangrove area in Papua archipelago was rather to decline due to natural event than anthropogenic land use change such as aquaculture, reclamation and oil palm cultures [3]. Oil spill had also driven a massive damage of mangrove forest [45], but it was not found in this area.

4. Conclusion
Mangrove community in Liki Island was in pristine condition, since it had a dense canopy coverage, large morphometric size and promising natural regeneration. Mangrove health index shown that in 2018, the forest was in moderate healthiness, it was the minimum slope of MHI value along 2016-2021 observation periods. Since 2019, MHI in Liki Island self-recovered to reach a similar value in 2016.

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