Evaluating the effectiveness of mangroves rehabilitation efforts by comparing the beta diversity of rehabilitated and natural mangroves

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Abstract. Indonesia has lost 30% of the area over the past two decades due to anthropogenic activities. To overcome this problem, mangrove rehabilitation—which is generally interpreted as mangrove planting program - become the most popular option. These efforts could enhance the quantitative function (increasing mangrove areas extent and number of trees planted), yet the quality functions (biodiversity and ecological function) remain unclear. This analysis was carried out simultaneously with medium to high-resolution satellite image analysis to differentiate mangrove canopy pattern of these sites. The results showed that beta diversity value of mangroves in rehabilitation sites was lower than mangroves in natural area, which was characterized in satellite imagery as more uniform canopy and finer texture. Rehabilitation efforts that are mostly done through monoculture, are unable to produce an equal mangrove ecosystem function as natural mangroves do. This paper aims to examine the effectiveness of rehabilitation efforts whether they can develop an equal ecological function as good as natural mangrove ecosystem, by comparing the difference of beta diversity in two study sites which representing the natural (north Sulawesi) and rehabilitated mangrove (West Bali).

Keywords: beta diversity, mangrove, rehabilitation

1. Introduction

Indonesia is the world’s largest archipelagic state that has more than 17,000 islands, with approximately 81,000 km of coastlines and more than 60% of its territory is covered by oceans. The national jurisdiction area is about 7.73 million square kilometers (km²), which is composed of 1.93 million km² of land (that stretches 5,120 km from east to west and 1,760 km from north to south), 2.8 million km² of archipelagic waters, 0.3 million km² of territorial sea, and 2.7 million km² of exclusive economic zone (Sukardjo 2002). Because of the geographical factor, Indonesia has the largest mangrove area and the highest mangrove diversity in the world (up to 53 species) (Huffard et al 2012). Mangrove ecosystem has many important functions, such as spawning, nursery and feeding grounds for fish in coastal area, wood production (for building materials, firewood, or medicines) (Aburto-Oropeza et al 2008, Walters et al 2008, Thatoi et al 2013), improving the quality of surrounding waters (e.g. Bouchez et al 2013), carbon sequestration and storage (Alongi 2011, Pendleton et al 2012), also for coastal protection (Barbier 2016). The threat due to the loss of mangrove ecosystems
including sea-level rise (Sasmito et al. 2016, Ellison 2015) and increasing intensity and frequency of storms (Ellison 2012, Primavera et al. 2016).

The extent of Indonesian mangroves has been verified in 2009 by The National Coordinating Agency for Survey and Mapping (BAKOSURTANAL, or now known as Badan Informasi Geospasial/BIG), where the total area of mangrove forest in Indonesia reached 3.24 million ha; about half of Indonesian mangroves can be found in West Papua, 20% in Kalimantan, 18% in Sumatra, 5% in Maluku, about 5% in Sulawesi, and 2% in Java and Nusa Tenggara/Lesser Sunda Islands (Saputro et al. 2009). Despite blessed with the vast mangrove area, Indonesia has actually lost 30% of the mangrove area over the past two decades (FAO 2007, Giri et al. 2011) due to multiple factors, largely because of extensive land-use conversion into aquaculture in 1980s (Ilman et al. 2016). Unfortunately, many of these ponds were abandoned due to low productivity only several years after the mangroves have been cut.

Efforts to rehabilitate mangroves in these abandoned ponds began since the 1990s (Stevenson 1997). There are many studies in rehabilitating mangrove area (Field 1999, Kamali and Hashim 2011, Kusmana 2017, Djamaluddin et al. 2018) however, replanting seedling using single mangroves species became the most popular option in Indonesia at that time. It is a reasonable choice because rehabilitation effort usually a time-constrained activity and required a large number of funds that can only be provided by donor.

Extensive mangrove conversion at an alarming rate combined with rehabilitation efforts using single genus or certain species (monoculture), have posed a new threat to Indonesian mangroves, i.e. potentially losing various useful mangrove ecological functions for human, and also declining mangrove species richness at the rehabilitation site. Furthermore, the beta diversity or differences in species composition that inhabit one area compared to other regions, will decline as an effect of decreasing diversity of mangrove species.

Therefore, evaluating the quality of mangrove rehabilitation efforts become important since most of these efforts were measured in short-term using modest quantity parameters, such as extent of rehabilitated area, number of seedlings that have been planted, survival rate, which intended as part of report to donor, without any advanced monitoring and evaluation in the longer term; whether the replanted mangroves able to rehabilitate the abandoned ponds or not; can it restore the ecosystem function to its original condition; can the mangrove forest be sustainable or not. The current period is the right time to start reviewing the "rehabilitation success" of mangrove areas because there are many replanted mangrove forests aged more than 10 years old. This paper aimed to examine the effectiveness of rehabilitation efforts whether they can develop an equal ecological function as good as natural mangrove ecosystem by comparing the difference of beta diversity in two study sites which representing the natural (North Sulawesi) and rehabilitated mangrove (west Bali).

2. Materials and methods

The data source for this study consisted of mangrove forests inventory, relevant publications and high-resolution satellite images to visualize the differences of mangrove canopy structures in selected sites. Ground measurement and sampling methods to obtain relevant forest parameters that describe mangrove forests physiognomy and species composition were refered to Bengen (2000), Kauffman and Donato (2012) and Sutaryo (2009).

2.1. Site description

There are four natural mangrove ecosystems in North Sulawesi that were observed from 2013 to 2015; where two of them are in small islands (Lembeh Island-Bitung City and Sangihe Island-Sangihe
Regency) and the rest of them are in mainland of Sulawesi (Ratotok-southeast Minahasa and Kema-north Minahasa) (figure 1a). The selected site for rehabilitated mangroves was located in Perancak estuary (S8.3916°; E114.628°), a 7 km² estuary in Bali Island that surrounded by several rivers (Air Kuning, Awen, Budeng, Loloan, Samblong, and Tibukleneng Rivers), flow from surrounding mountains (figure 1b). Massive expansion of shrimp ponds in the 1980s have reduced a large part of mangrove areas, but then many of ponds were abandoned in the ’90s. Afterward, there is a reforestation evidence over these abandoned ponds as a result of mangrove growth by plantation and self-generation. In this study site, we observed mangroves plantation inside ten closed ponds and six semi-closed abandoned ponds in May and November 2014.

![Figure 1](image1.jpg)

**Figure 1.** Study sites in north Sulawesi Province (Ratatok, Kema, Lembeh Island, and Sangihe Island) (a) and Perancak, Bali (b).

### 2.2. Methods

#### 2.2.1. Beta diversity analysis.
R.H. Whittaker (1960), introduced terms in diversity measurement as alpha (\(\alpha\)), beta (\(\beta\)) and gamma (\(\gamma\)) diversity; where alpha diversity is defined as local diversity (the number of species found in a particular area or ecosystem); gamma diversity as regional diversity, (the sum of all the species of all habitats within the region of interest), and beta diversity as “the extent of differentiation of communities along habitat gradients”. The essential relationship between \(\alpha\), \(\beta\) and \(\gamma\)-diversity in the most simple form is \(\beta = \gamma/\alpha\) (Whittaker 1972). In this study, beta diversity will be used to show variations in the composition of mangrove species that distinguish diversity between the two ecosystems, with the following equation:

\[
\beta_A = (S_1 - c) + (S_2 - c)
\]

where, \(S_1\) = total number of species recorded in the first ecosystem, \(S_2\) = the total number of species recorded in the second ecosystem, and \(c\) = the number of common species in both ecosystems.

#### 2.2.2. Visual observation using very high resolution satellite (VHRS) images.
General observation in mangroves rehabilitation sites were conducted using high spatial resolution of satellite images (IKONOS-2 acquired at October 12th 2001, GeoEye of October 23th 2010, and WorldView-2 of March 26th, 2014), where the pixel size ranged from 50 cm to 1 m for the panchromatic mode and from 1 m to 4 m for the multi-spectral mode. This type of satellite images contains extra and more relevant information that is useful for a better mangrove identification and distribution (Alexandris *et al* 2013).
3. Results and discussion

Based on field observations, 17 mangrove species were found in natural mangrove forest (in north Sulawesi), while in rehabilitated area, we identified eight species inside closed ponds, and 11 species in semi-closed ponds (Table 1). Common mangroves species that found in all study sites were *Bruguiera gymnorrhiza*, *Rhizophora apiculata*, *R. mucronata* and *Sonneratia alba*. Among all species found in north Sulawesi, *B. hainesii* is considered as critically endangered and *C. decandra* as near threatened in IUCN red list (Duke *et al* 2010a, Duke *et al* 2010b). In general, Indonesia has 43 species true mangrove out of 202 species mangrove plant including tree, liana, palm, herb, epiphytes and fern (Faridah-Hanum 2014). Moreover, mangrove species distribution in the main islands ranges from 25 to 29 species. The highest species distribution is in Papua (29 species) followed by Maluku, Java and Bali-Lesser Sunda Islands (28 species), Sumatra and Sulawesi (27 species) and Kalimantan (25 species).

Some mangroves grow dominant in north Sulawesi, which are *B. gymnorrhiza*, *R. mucronata*, *R. stylosa*, *S. Alba* and *A. alba* (Saputro 2009). As reported by Kepel *et al* (2017) *R. mucronata* has the largest number of stands at all locations in north Sulawesi. The important role of *R. mucronata* also reflected in its important value index (IVI), which are 61.7 in Lembeh, 94.23 in Kema, 118.94 in Ratatotok and 239.7 in Tahuna (RDCMCR 2013, 2014, 2015, Kepel *et al* 2017). Other species that has high IVI in north Sulawesi were *S. alba* (118.49 in Kema) and *B. gymnorrhiza* (62.24 in Ratatotok).

| No  | Species                      | Natural mangrove forest (Ratotok, Kema, Lembeh, Sangihe – north Sulawesi) | Rehabilitated mangrove (Bali) | Closed ponds | Semi-closed ponds |
|-----|------------------------------|---------------------------------------------------------------------------|--------------------------------|--------------|-------------------|
| 1   | *Avicennia alba*             | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 2   | *Avicennia eucalyptifolia*   | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 3   | *Avicennia marina*           | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 4   | *Avicennia officinalis*      | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 5   | *Bruguiera gymnorrhiza*      | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 6   | *Bruguiera hainesii*         | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 7   | *Bruguiera parviflora*       | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 8   | *Ceriops decandra*           | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 9   | *Ceriops tagal*              | ✓                                                                         | ✓                              | ✓            | ✓                 |
| 10  | *Exoecaria agallocha*        |                                                                          |                                | ✓            |                   |
| 11  | *Lumnitiera littorea*        | ✓                                                                         |                                | ✓            |                   |
| 12  | *Lumnitiera racemosa*        | ✓                                                                         |                                | ✓            |                   |
| 13  | *Rhizophora apiculata*       | ✓                                                                         |                                | ✓            |                   |
| 14  | *Rhizophora mucronata*       | ✓                                                                         |                                | ✓            |                   |
| 15  | *Rhizophora stylosa*         |                                                                           |                                | ✓            |                   |
| 16  | *Sonneratia alba*            | ✓                                                                         |                                | ✓            |                   |
| 17  | *Scyphiphora hydrophyllacea* | ✓                                                                         |                                | ✓            |                   |
| 18  | *Xylocarpus granatum*        |                                                                           |                                | ✓            |                   |
| 19  | *Xylocarpus mekongensis*     |                                                                           |                                | ✓            |                   |
| 20  | *Xylocarpus moluccensis*     |                                                                           |                                | ✓            |                   |

Beta diversity values can be generated by comparing species in these three types of habitats, where the highest value is the beta diversity between natural mangrove ecosystem compared to rehabilitated...
mangrove inside semi-closed ponds (equal to 12). This illustrates a higher variety of mangrove species composition between these two habitats and a more stable ecosystem rather than beta diversity between rehabilitated mangroves inside closed and semi-closed ponds (equal to 3) (table 2).

| **β-diversity** | Natural mangroves (in north Sulawesi) | Rehabilitated mangroves in closed ponds | Rehabilitated mangroves in semi-closed ponds |
|-----------------|--------------------------------------|----------------------------------------|--------------------------------------------|
| Natural mangroves (in north Sulawesi) | -                                   | 11                                     | 12                                        |
| Rehabilitated mangroves in closed ponds | 11                                  | -                                     | 3                                         |

The highest beta diversity between habitat can be observed in natural mangrove and rehabilitated mangrove in semi-closed ponds. There were 12 different species between these two habitats namely: *A. eucalyptifolia*, *B. hainesii*, *B. parviflora*, *C. decandra*, *C. tagal*, *E. agallocha*, *L. littorea*, *R. stylosa*, *S. hydrophyllacea*, *X. granatum*, *X. mekongensis*, and *X. moluccensis*. The high difference in species composition indicates low dominance of certain species. From field observation in natural mangrove sites, we observed that distance among trees were loose, enabling penetration of the sunlight which facilitates photosynthesis process so that the mangrove saplings can flourish (figure 2).

Meanwhile, the lowest beta diversity value is between mangrove rehabilitation area in closed and semi-closed ponds. Only 3 mangrove species differences, namely: *E. agallocha*, *L. racemosa* and *X. moluccensis*, where all of these species were found in semi-closed ponds. Rehabilitated mangrove in closed ponds is dominated by genus *Rhizophora* as shown in figure 2 below. There were few stands of *Avicennia* and *Bruguiera* spp that found on the edge of ponds (non-dominant species).

![Figure 2](https://via.placeholder.com/150)  
**Figure 2.** Natural mangrove condition in north Sulawesi Province. Top-left: mangrove in Ratotok (mainland of Sulawesi), 2013; and other pictures are natural mangroves in Lembeh Island (2015), showing many self-regenerate mangroves saplings surround adult trees (Photo by Blue Carbon Group, P3SDLP-MoMAF, 2013 -2015).

From field observation, we found that rehabilitation activities in Perancak area were mostly carried out with monoculture system using the genus *Rhizophora* or *Bruguiera* (figure 3). Tight spacing between trees (±0.5 m) in closed ponds have caused natural hydrology to become disturbed or modified, and also difficult to self-regenerate because their seedling unable to receive enough sunlight.
Figure 3. (a) Mangrove rehabilitation using *Rhizophora* spp. monoculture system, with half-meter distance between trees - in adult stages, (b) very high density of planted young mangroves inside closed ponds, (c) mangrove monoculture observed with Worldview-2 image, with distinctive characteristics as uniform and regular canopy row.

On the contrary, in semi-closed ponds (ponds with partially broken dikes) where surrounding rivers could flow into ponds and carries tidal that facilitate propagule entering the pond area, the diversity of mangrove species inside ponds have increased (figure 4). Increasing diversity in this mangrove area is considered good since different species of mangroves will fill different ecological niches and will provide different ecological roles and functions for the surrounding environment (Field *et al* 1998).

Therefore, we need to reconsider the rehabilitation activities inside closed pond areas using monoculture systems. In addition to the low threat of subsidence, also other impacts that may arise are not running the regeneration process because there is no seedling that can live and develop. For areas where mangroves were planted, thinning of mangrove stands can be done or by improving the hydrological canal so that the process of seedling recruitment can run naturally, as have been practiced by Lewis (2005) and Djamaluddin *et al* (2018) or using mangrove area with silvofishery system (Kusmana 2017).

Figure 4. (a) Young mangrove plantation inside semi-closed ponds observed with IKONOS-2 image that was acquired at October 12th, 2001; (b) Planted mangroves at adult stages inside semi-closed ponds that grew with other species of self-generated mangrove. Seeds of self-generated mangroves possibly carried by river currents (observed using GeoEye image that was acquired on October 23rd, 2010).
Based on field observations and visual analysis of satellite imagery, it can be concluded that rehabilitation efforts are not effective if carried out using single mangrove genus inside closed ponds that have very limited influence of natural hydrology. After a decade, the condition of mangrove species richness inside closed ponds and semi-closed ponds is not the same as the surrounding natural mangroves. For further rehabilitation activities it is best to prioritize natural hydrological improvements so that seedling from surroundings area can enter the pond and enrich the species diversity. For existing mangrove planted inside ponds, options of mangrove thinning and opening of water channels can be done to improve water quality and support mangrove regeneration.

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