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Vegetation regeneration in a sustainably harvested mangrove forest in West Papua, Indonesia

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ABSTRACT

Bintuni Bay, located in the south of the Bird's Head Peninsula of West Papua, Indonesia, contains one of the largest mangrove forests in the world, growing in a variety of environmental conditions and geomorphologies. In the southern area of the bay, 82,120 ha of mangrove forest are actively undergoing a management regime conducted by PT. Bintuni Utama Murni Wood Industries (PT. BUMWI). Operations are focused upon woodchip production; however, sustainable forest management is also a priority as the area is Forest Stewardship Council® (FSC®) certified. Currently, PT BUMWI is approaching the completion of a 25-year rotation (with stands ranging from 0 to 25 years) which presents a good time to examine and evaluate current management practices and their effects on the forest concession. Part of a successful regeneration of a forest stand is attaining the range of ecological integrity and ecosystem functions similar to baseline forests. Forest structure and complexity, along with biodiversity at the stand level could function as regeneration criteria to evaluate the success of a sustainable forest management program. The objective of the study was to observe if the forest structure and biodiversity in secondary stands, considered as proxies for ecological integrity, would regenerate to similar levels within the 25 years as baseline forests. Post-harvest forest regeneration was evaluated in different aged secondary forest stands by measuring biomass, species composition and forest structure in circular plots along transects. Nonlinear regression was used to determine and predict different forest structure dynamics (sapling and stem densities, tree height, DBH), diversity and volumes throughout and beyond the 25-year rotation period. Dynamics in species composition and diversity of tree species was observed. Results suggest that the forest structure in secondary stands follows a natural regeneration dynamic over the rotation period but had not yet attained the same structure and composition as baseline forests at 25 years. Furthermore, growth models suggest that the harvest rotation may need to be extended to 30–40 years for secondary stands to attain similar ranges of forest structure, compositions and volumes to that of baseline forests. These observations will help future forest management of the concession as the company strives to manage secondary forests to keep the same ecosystem functions and high volumes observed in baseline forests.

1. Introduction

Mangrove forests in South East Asia are experiencing rapid decline, either through land conversion for commodity production (aquaculture, rice, oil palm), unsustainable harvesting for timber and charcoal, or poor management (Macintosh et al., 2002; Richards and Friess, 2016). To counter this trend, there is an attempt to determine what criteria and observations are required to ensure the successful regeneration of mangrove forests (Lewis, 2009; Andradi-Brown et al., 2013), particularly one that is regularly harvested. A successfully regenerated forest is often defined as a forest that has fully replaced structural or functional characteristics that were previously altered or lost (Field, 1998).

Successful regeneration of mangrove vegetation is a key component contributing to sustainable harvesting because forest productivity, yield, biodiversity and ecosystem services would be restored and maintained for future management. Such processes require intensive and long-term monitoring in order to understand process thresholds such as forest compositions, maximum volumes and stem density dynamics; however, few studies in mangroves exist that have been monitored intensively and over the long term. Furthermore, most of these studies do not incorporate all components of regeneration; observers either interpret it in context of silviculture and not ecological functionality or vice versa (Datta et al.,

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2012; Goessens et al., 2014). Thus, the regeneration of mangrove areas and the sustainability of forestry practices are often only partially observed.

Goessens et al. (2014) observed a long-term rotational forest in Matang (Malaysia), and found that forest structure and diversity in the oldest secondary forests were rarely similar to baseline forests. Observing the overall forestry history of the area, there had been a constant decrease in harvest production, which was attributed to a lower level of tree diversity (Goessens et al., 2014). Furthermore, Bosire et al. (2008) suggested in their study that natural ecological function and forest resilience were restored with increased stand structural complexity and biodiversity, with a biodiverse baseline stand having more diverse niches than monoculture stands (Bosire et al., 2008). Thus, regeneration is less likely to be successful under a monoculture stand rather than a mixed species stands.

These publications compare stands at a specific age to the original forest condition to observe whether regeneration is successful or not (Bosire et al., 2008). However, a set of regeneration criteria that incorporate both silvicultural and ecological components has not yet been developed. Implementation of such criteria in sustainable forest management schemes is rare in mangrove harvesting practices, particularly in South East Asia (Lewis, 2009). Such criteria would help forest managers observe and predict when harvested secondary forests would reach a similar ecological and structural stage to their baseline counterparts. In the context of this work, the criteria for regeneration in a sustainably managed forest would be:

(1) Forest Structure & Complexity; which can be used as a metric for forest productivity (Kairo et al., 2002) as well as a proxy of certain ecosystem services such as coastal protection, carbon storage, and erosion control (Bosire et al., 2008; Andradi-Brown et al., 2013).
(2) Tree Diversity; representing the variety of forest environments supporting various niches for fauna and flora found in baseline forests (Bosire et al., 2008) and the enhancement of ecosystem stability (Tilman and Downing, 1994; Wardle and Zackrisson, 2005; Bosire et al., 2006).

This study investigated the development of a secondary mangrove forest in Bintuni Bay, West Papua that is experiencing commercial rotational harvesting, taking into account the different conditions it grows in (species composition, stem density, volumes). In particular, this study (1) observes if and at what rate secondary stands are developing a forest structure, complexity and volumes similar to observed baseline forests; and (2) compares tree diversity of secondary and baseline mangrove forests. During regrowth, it is predicted that the forest stand will experience self-thinning (Goessens et al., 2014), significantly reducing stem density as the vegetation get older. Under the current harvest regime, it is estimated that secondary stands would not be able to produce the same volumes after 25 years as baseline forests. Undisturbed forests would have a more diverse species composition and volumes than older (>20 years) secondary stands. Thus, it can be assessed whether the current management ensures regeneration under the previously mentioned criteria. Such information is vital for forest managers to ensure a sustainable harvest and maintenance of ecosystem services.

2. Materials and methods

2.1. Study area

Bintuni Bay (E133°35′73″ S2°31′25″), located in the southern coast of the Bird's Head Peninsula of West Papua, Indonesia, is primarily composed of a large mangrove forest that covers islands, peninsulas, and estuaries divided by a network of rivers, channels and creeks (up to 4 km wide and 21 m deep) (Fig. 1) (Erftemeijer et al., 1989; Pribadi, 1998). At approximately 260,000 ha, mangrove forests within the bay comprise 8.4% of Indonesia's total mangrove resource, and 1.9% of the world's mangrove cover (Pribadi, 1998; Giri et al., 2011). Mangroves in Bintuni Bay transition landward into sago and lowland tropical rainforest as elevation increases, with hills reaching above 500 m.

This study was conducted in an 82,120 ha concession (2.6% of Indonesia's mangrove forest area) licensed to a private forestry company until the year 2053 (Wahyudi et al., 2013; Friess et al., 2016). The concession is located within four districts of Bintuni (Babo, Aroba, Kaitaro, Kuri), which comprise a total population of 8233 (IDEAS, 2015). Approximately 63.5% of the concession is zoned for mangrove wood extraction (Grady, 2015), inclusive of buffer zones. Baseline forest surveys report that the dominant species are *Rhizophora* spp. (69%), mostly consisting of *Rhizophora apiculata* and *Rhizophora mucronata* (Wahyudi et al., 2013). Other common mangrove species include *Bruguiera gymnorrhiza*, *Bruguiera parviflora* and *Ceriops tagal* (Wahyudi et al., 2013).

Mangroves are harvested along estuaries and rivers using the keyhole and seed tree method. For one harvest stand, a log pond (15 m × 50 m) is established along the mangrove fringe, where logs are gathered to load onto the pontoons for transportation to the chip mill. The harvested area (diameter: 150–200 m) is located beyond the log pond, respecting a 50 m buffer from the mangrove fringe. All trees that are not marked as seed trees and that are larger than 10 cm diameter at breast height (DBH) are harvested within the harvest block. Seed trees - healthy trees ⩾20 cm DBH are left in the harvest block to produce propagules for natural regeneration. Currently, the seed tree density has been maintained to ⩾40 trees ha^{-1} in compliance to regulation *No.60/Kpts/DJ/I/1978* (Ministry of Agriculture, 1978). Since 2016, the regulation on seed tree densities has been revised to ⩾25 trees ha^{-1} (*P.8/PHPL/SET/3/2016*, Ministry of Environment and Forestry, 2016), which the company would refer to at the end of the current 10-year plan in 2020. Furthermore, *Rhizophora apiculata* saplings are planted, when necessary in the log pond and harvest area within 3 years after harvest to ensure forest regrowth and compliance with Indonesian government regulations on regenerated sapling density (2500 saplings ha^{-1}). About 200–300 keyhole harvest areas are cut per year making an average 800 ha of forest harvested per year (target harvest area: 1000 ha) within an allocated 2200 ha block. The concession currently has reached the end of its 25-year harvest period, with stands aged 1–25 years old and some exploratory harvests aged up to 28 years.

2.2. Field vegetation surveys

Field surveys were conducted from June to August 2015. A total of 28 transects were established (4 transects per stand age) in regenerating stands of ages 1, 5, 10, 15, 20, 25 years post-harvest (24 transects) and baseline natural mangrove forest stands (4 transects) (Fig. 1). All transects were selected at random harvest plots in the intertidal zone along rivers of relatively the same size. This is representative of areas where most forestry operations are carried out. The intertidal zone is defined as an area frequently inundated and located between the lowest tide and the highest tide of the day.

Following a modified version of the methodology described by Kauffman and Donato (2012), measurements were taken in plots along linear transects extending perpendicularly from the mangrove fringe through the log pond and harvested area. Each transect was 165 m in length and contained 6 circular plots (radius = 7 m, 168 plots in total), with the first plot located 15 m