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Effects of silvicultural intensification on timber yields, carbon dynamics, and tree species composition in a dipterocarp forest in Kalimantan, Indonesia: An individual-tree-based model simulation

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ABSTRACT

Nature conservation through sustainable forest management is challenged in the tropics by unnecessarily destructive but selective logging and diminishing timber yields. Silvicultural treatments beyond reduced-impact logging are often recommended to increase timber stocking, tree growth, and profits. Despite lack of large-scale and long-term scientific support, Indonesia has embarked on large-scale silvicultural intensification. To fill this information gap, we assessed the timber, carbon, and tree species composition consequences of different silvicultural practices in dipterocarp forests in Kalimantan, Indonesia.

With data from 30 1-ha sample plots monitored for up to 20 years after silvicultural intervention coupled with a new forest growth and yield model simulation (SILFOR), we evaluated the long–term consequences of the following silvicultural practices: once logged with a minimum cutting diameter (MCD) of 60 cm (L60); once logged followed by under-planting with seedlings of commercial timber species (L60UP); twice logged with MCDs of 60 cm and then 40 cm (L60L40); and, twice logged followed by strip planting along cleared lines (L60L40SP).

The results indicate that timber yields will not be sustained by L60 or L60L40 even if cutting cycles are extended from the current minimum of 30 years to 60 years. In contrast, yields from enrichment planted logged-over forests will recover to levels higher than the first cut if cutting cycles are extended to 50 years for L60UP and to 40 years for L60L40SP. Under these intensive silvicultural regimes, biomass carbon stocks also recover to primary forests levels, but with increased representation of commercial species. Although silviculturally successful, the financial consequences of these approaches to management intensification remain to be scrutinized.

1. Introduction

Conservation in many of the 403 million ha of tropical forests designated for timber production (Blaser et al., 2011) will involve silvicultural intensification particularly where regeneration of commercial species requires large canopy openings or where the opportunity costs of forest retention are very high (Fredericksen and Putz, 2003; Putz and Ruslandi, 2015). Theoretically, intensification of natural forest management can promote conservation to the extent that it increases the financial value of the forest and thus decreases the attractiveness of conversion to plantations and other non-forest land uses. Common approaches to silvicultural intensification in the tropics, which all vary in their ecological and financial consequences, include increased logging intensity, liberation of future crop trees from competition, and enrichment planting with native commercial species.

Despite the many data from many experimental plots that demonstrate the benefits of improved tropical forest management practices (e.g., de Graaf et al., 1999; Finegan and Camacho, 1999; Peña-Claros et al., 2008; Villegas et al., 2009; Wadsworth and Zweede, 2006), few recommended silvicultural treatments are applied at large scales. Indonesia may become an exception to this pattern if forest managers follow a 2009 regulation from the Ministry of Forestry (MoF, 2009) that allows silvicultural intensification in some 65 million ha of natural forest. The new rules lower the minimum cutting diameter (MCD) from 50 to 40 cm and shorten the cutting cycle from 35 to 30 years (MoF, 2009). These changes are directly counter to the recommendation

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from many researchers to lower logging intensities to promote sustainability (e.g., Sist et al., 1998, 2003b; Van Gardingen et al., 2003). Also permitted in these new rules is strip planting of nursery-raised dipterocarp seedlings along cleared lines (*Tebang Pilih Tanam Jalur – TPTJ*); where enrichment planting is carried out, the minimum cutting cycle is further reduced from 30 to 25 years, which increases the area open for harvests each year (MoF, 2009). In 2010, 25 forest concessions were approved to implement TPTJ at varying scales from a couple hundred hectares to entire annual harvest areas (MoF, 2010). To help fill the information gap about the long-term consequences of these approaches to large-scale intensification of natural forest management, we used permanent sample plot data and a growth-and-yield simulation model to assess the timber, biomass, and tree species composition effects of different silvicultural treatments involving selective logging or logging followed by enrichment planting.

The growth-and-yield models available for natural forests in Borneo, such as DIPSIM (Ong and Kleine, 1996), SYMFOR (Phillips et al., 2003), and several matrix transition models (e.g., Boscolo et al., 1997; Ingram and Buongiorno, 1996; Mendoza and Setyarso, 1986; Sist et al., 2003a), were all developed to assess the effects of selective logging of primary forests and were not calibrated with data from twice-logged forests or areas subjected to other silvicultural interventions. Given that many forests in Borneo and elsewhere in the tropics are now being logged for at least the second time, and in response to the frequent calls for silvicultural interventions beyond reduced-impact logging (RIL; e.g., Peña-Claros et al., 2008; Putz et al., 2008; Sist et al., 2008; Wadsworth and Zweede, 2006), we extend this research to what we believe to be the new trajectory for many tropical forests (Putz and Romero, 2015). For this purpose we developed an individual-tree-based simulation model (SILFOR, which stands for silvicultural intensification in natural forest) calibrated with data from 30 1-ha permanent sample plots (PSPs) monitored for up to 20 years in Kalimantan. Specifically, we address the following:

1. How much timber will be available at the end of government-specified minimum cutting cycles of 30 years after intensified logging or 25 years after intensified logging and enrichment planting?
2. How long do cutting cycles need to be to sustain timber yields with and without enrichment planting?
3. How do forest biomass stocks vary over time after different silvicultural treatments and how long does it take them to recover to primary forest levels?
4. How does the representation of different tree species groups vary in response to different silvicultural treatments and in comparison with primary forests?

To the best of our knowledge, this study will provide some of the first data and analyses on the long-term effects of different silvicultural interventions applied at large scales in Southeast Asian forests. We hope the results of our analyses are used to inform forest policies in the region and beyond.

2. Methods

2.1. Study area

The study was conducted in the logging concession of PT Sari Bumi Kusuma (SBK) in Central Kalimantan, Indonesia (0° 56′N,111°68′E; Fig. 1). The concession covers 147,600 ha of lowland forest dominated by Dipterocarpaceae and Euphorbiaceae at 356–425 m elevation on undulating topography. SBK hosts some endemic species and is part of the Heart of Borneo Initiative, a cross-border conservation program managed by the Worldwide Nature for Fund (WWF, 2014). Company records for 2001–2012 indicate a mean annual precipitation of 3631 mm year^{-1} (3024–4762 mm year^{-1}), no months averaged <200 mm, and temperatures averaged 30–33 °C at midday and 22–28 °C at night (Suryatmojo et al., 2013). Soils are deep red-yellow clay loams (oxisols) with good internal drainage.

SBK started selective logging in 1978 with a minimum cutting diameter (MCD) of 60 cm and a cutting cycle of 35 years, as specified by the Indonesian Ministry of Forestry's system called *Tebang Pilih Tanam Indonesia (*TPTI; "Indonesian Selective Logging with Planting"; MoF, 1989). Starting in 1994 under the auspices of the USAID-funded Natural Resource Management Project and later by the Tropical Forest Foundation, SBK staff received regular training in RIL. In recognition of their good logging practices and

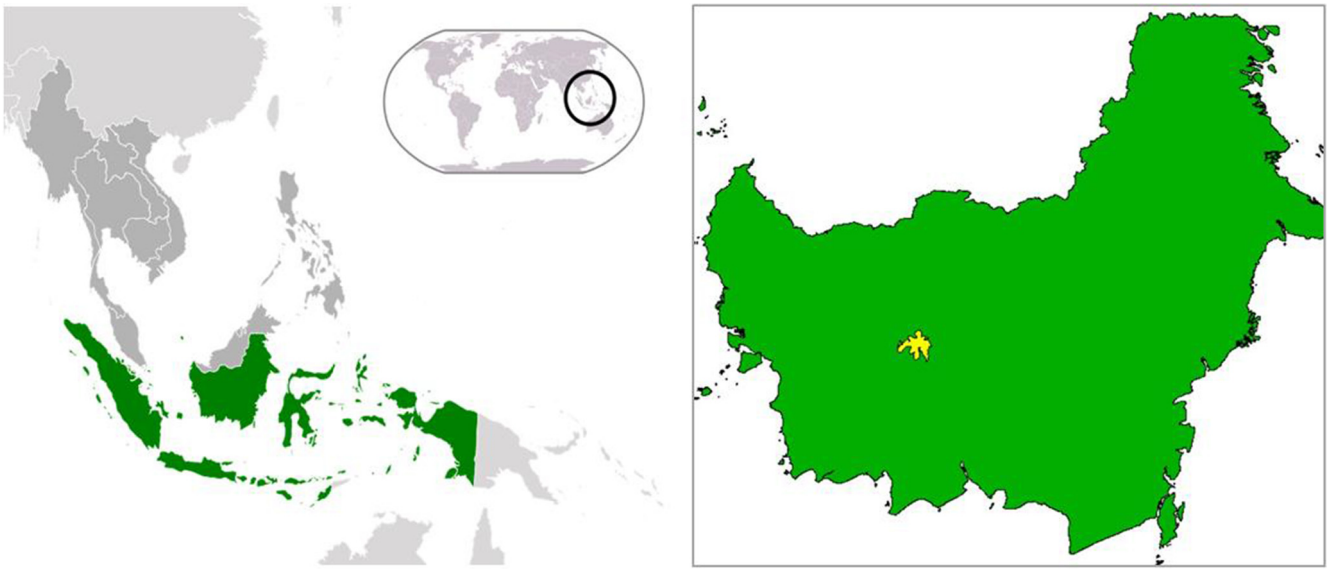

Fig. 1. Study site in the Sari Bumi Kusuma (SBK) concession (yellow) in Kalimantan, Indonesia. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)