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The mixing ratio of tree functional groups as a new index for biodiversity monitoring in Bornean production forests

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ABSTRACT

While tree community composition can be a robust index for biologically indicating impacts of forest managements on tropical rain forests, the need of taxonomic expertise and accompanying costs may become a burden for foresters. The mixing ratio of two distinct functional groups (*i.e.*, indicator genera for mature and disturbed forests) could be an alternative to the previous index that requires the identification of all species/genera. However, tree taxa indicative of logging intensity in a wide geographic range have not fully been determined. In this study, we conducted a large-scale vegetation survey in six forest management units (FMUs) spanning geographically distinct regions of Borneo (East Kalimantan in Indonesia, and Sarawak and Sabah in Malaysia) to detect a set of common indicator genera for logging intensity. A total of fifty 20-m radius plots were established in forests with a wide range of disturbance regimes in each FMU. A cluster analysis that was applied to all data combining the six FMUs identified two main vegetation types; one was the mature forest (with greater above-ground biomass, AGB) and the other was the disturbed forest (with lower AGB). Subsequently, 92 genera were derived as indicators for the mature forest by an indicator analysis, whereas 8 genera were derived for the disturbed forest. The mixing ratios of the two indicator groups per plot [(densities of mature-forest indicators – densities of disturbed-forest indicators)/densities of all trees] significantly correlated with another index of forest degradation (*i.e.*, remaining AGB). When the number of indicator genera was greatly reduced by removing all genera other than those of Dipterocapaceae for the mature-forest indicators and *Macaranga* and *Neolamarkia* for the disturbed-forest indicators, the mixing ratios of indicator groups still significantly correlated with the index of forest degradation (remaining AGB). Because the two indicator groups with a minimal number of genera can be easily identified by local foresters, we conclude that the mixing ratio is a robust and practical index for the responses of tree communities to logging disturbances in Bornean tropical production forests.

1. Introduction

Tropical forest ecosystems harbor rich biodiversity and provide significant ecosystem services (Gardner et al., 2009). Today, most areas of tropical forests suffer from deforestation and forest degradation caused by human activities such as land conversions and commercial timber productions (*e.g.*, Hansen et al., 2009; Margono et al., 2012). In Borneo, over one half of the total land area is designated as production forests (the area is compartmentalized into forest management units, FMUs) where commercial logging is legally conducted (Imai et al., 2009). Therefore, the sustainable use of forests in FMUs is a key target to conserve biodiversity in Borneo (Imai et al., 2009; Kitayama, 2013). Recently, two mechanisms have been proposed to produce financial incentives for forest managers to alleviate deforestation and forest degradation, which is also beneficial for biodiversity conservation in FMUs. The first mechanism is forest certification (*e.g.*, certification of the Forest Steward Council). By certifying the FMUs that comply with sustainability standards, timbers from the certified FMUs will have a better market access, which may result in a financial benefit for forest managers. The second mechanism is Reduced Emissions from Deforestation and forest Degradation plus (REDD+) proposed by

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the United Nations Framework Convention on Climate Change (UNFCCC). In this framework, tropical countries may receive financial supports through reducing the greenhouse gas emission due to deforestation and forest degradation. Forest certification requires biodiversity monitoring because conserving biodiversity is an important environmental standard. The REDD+ mechanism also requires a monitoring, reporting and verification (MRV) system for verifying biodiversity safeguard. Consequently, developing a cost effective MRV system with a robust index is urgently needed for both mechanisms.

Richness and community composition have been used to represent the response of biodiversity to forest management (logging and land conversion) in tropical forests. Although the former index has been commonly used (*e.g.*, Lawton et al., 1998; Schulze et al., 2004), community composition, including richness and abundance as attribute, is recently recognized as the more useful index for biodiversity monitoring because community composition more sensitively reflected the magnitude of forest disturbance than richness; community compositions of different taxa consistently changed in relation to forest disturbance while species richness showed the inconsistent responses to forest disturbance (Barlow et al., 2007; Basset et al., 2008; Uehara-prado et al., 2006).

In addition to this, determining taxa that efficiently represent the magnitude of forest disturbance is also important to develop a robust index for biodiversity monitoring. Many taxa such as birds, insects and trees have been proposed as the useful taxa in tropical forests based on both survey costs and the representativeness of forest disturbances (Favila and Halffter, 1997; Gardner et al., 2008; Imai et al., 2014). Among these taxa, Imai et al. (2014) suggested that tree species could be a good taxon for biodiversity monitoring not only because monitoring tree species was relatively cost-effective compared to the other taxa (Gardner et al., 2008), but also because changes in canopy tree community composition could be detected with remotely sensed data (Asner and Martin, 2011; Foody and Cutler, 2003; Fujiki et al., 2016; Thessler et al., 2005). Sensitivity to remotely sensed data is a critical advantage because monitoring biodiversity in FMUs in the tropics needs the employment of remote sensing techniques to cover such large target areas (Goetz et al., 2015).

While tree species composition can be the best index for verifying the biodiversity safeguard in tropical forests (Fujiki et al., 2016; Imai et al., 2014), the reduction of identification costs is another important issue for developing the biodiversity monitoring system applicable to tropical FMUs where limited resources in term of time, money and skills for identification are available. The identification at a genus level instead of at a species level will reduce the identification costs (Balmford et al., 1996; Imai et al., 2014). However, it is still a burden for forest managers because the identification of many tree genera other than common commercial tree genera requires taxonomic expertise. Therefore, a new index that has both simplicity and representativeness is required for improving the monitoring system of biodiversity in tropical FMUs.

An index using indicator tree genera that represent logging intensity can be useful to reduce time and financial costs (Caro and Doherty, 1999; Pearson, 1994). In general, densities of late-successional tree genera decrease with increasing logging intensity whereas densities of pioneer tree genera increase as demonstrated in Bornean tropical forests (Imai et al., 2014). This suggests that the mixing ratio of the two distinct functional groups continuously changes in relation to disturbance magnitude, and that the mixing ratio of mature-forest and disturbed-forest indicators, which might correspond to the late-successional and pioneer tree groups, can represent the shift of tree community composition. In Borneo, some genera have been considered as the indicators for forest disturbance, *e.g.*, *Macaranga, Mallotus*, *Neolamarkia* and *Trema* (Slik et al., 2003a; Swaine and Whitmore, 1988). However, their indicator values may vary with geographic locations (Franklin and Rey, 2007; Slik et al., 2003a). Thus, a study to identify genera that have high indicator values for logging intensity over an extended geographic area is needed to establish a new index for verifying biodiversity safeguard.

In this study, we developed a new simpler index of community composition for biodiversity monitoring (*i.e.*, the mixing ratio of tree indicator groups) as an alternative to the previous index based on all tree genera (*e.g.*, Imai et al., 2014). First, we conducted a field survey with the standardized method of Imai et al. (2014) in six FMUs located in Indonesia (East Kalimantan) and Malaysia (Sarawak and Sabah), and tested if the previous index of tree community composition could represent logging intensity in our dataset. We here defined remaining above-ground biomass (AGB) of logged-over forests as a surrogate of logging intensity because more intense logging removes a greater AGB (Imai et al., 2014) and because the Intergovernmental Panel on Climate Change defined it as a measure of the magnitude of forest degradation (Penman et al., 2003). Second, we listed the indicator genera that could be commonly used for a large geographic region (*i.e.*, Central to north Borneo) by calculating indicator values. Finally, using these genera, we calculated the mixing ratio of tree indicator groups for each plot, and tested if the mixing ratio could represent the responses of tree communities to logging intensity.

2. Materials and methods

2.1. Study sites

This study was conducted in six Bornean forest management units (FMUs) where legal commercial logging was being conducted with a selective logging system (Table 1). FMUs in Borneo typically ranged from 500 to 1000 km^2 in size and their areas were mainly covered by lowland mixed dipterocarp forests (Imai et al., 2009). The studied FMUs were Segaliud Lokan (5 °20′–27′N, 117 °23′–39′E, 576 km^2) and Sapulut (4 °40′–55′N, 116 °30′–117 °00′E, 956 km^2) in Sabah, Malaysia; Anap-Muput (2 °09′–38′N, 112 °38′–59′E, 1058 km^2) in Sarawak, Malaysia; and Roda Mas (0 °46′–1 °05′N, 114 °25′–115 °06′E, 703 km^2), Ratah (0 °7′S–0 °13′N, 114 °58′–115 °30′E, 982 km^2) and Seroja (0 °14′–0 °27′N, 115 °03′–115 °21′E, 365 km^2) in East Kalimantan, Indonesia (Fig. 1).

2.2. Plot sampling

We conducted a field survey for Segaliud Lokan, Sapulut, and Ratah (site 1, 2 and 6 in Fig. 1, respectively) in 2011–2012 (Imai et al., 2014), Anap-Muput in 2011–2013 (site 3 in Fig. 1), and Roda Mas, Seroja and Ratah in 2014–2015 (site 4, 5 and 6 in Fig. 1, respectively). Plots were established using a stratified random

Table 1
Logging history and forest certification of the studied forest management units (FMU). Information was cited from Fujiki et al. (2016).

Name of FMU	Nation	Silviculture and timber harvest	Forest Certification
Segaliud Lokan	Malaysia	1958–2002 CL, 2003-RIL	MTCC
Sapulut	Malaysia	1956–2000 CL, 2001- RIL	MTCC
Anap-Muput	Malaysia	1977–2004 CL, 2005- RIL	MTCC
RodaMas	Indonesia	At least 2008- RIL	FSC
Ratah	Indonesia	1972–2010 CL, 2010- RIL	FSC
Seroja	Indonesia	CL	–

CL, Conventional Logging; RIL, Reduced Impact Logging; MTCC, Malaysian Timber Certification Council; FSC, Forest Stewardship Council.