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Factors influencing tree diversity and compositional change across logged forests in the Solomon Islands

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ABSTRACT

Tropical forests in the Solomon Islands have been heavily logged in the last century. However, little is known about forest recovery dynamics across this region. Extrapolating findings from logged forests in tropical mainlands or large continental landbridge islands to isolated archipelagos such as the Solomons is inappropriate because succession and diversification patterns and processes differ between the former and latter. We compared the taxonomic diversity and composition of trees between unlogged forest and sites that were logged 10, 30 and 50 years previously to provide an indication of the potential dynamics of these forests following timber harvesting. The distance to logging roads and to unlogged forest influenced post-logging recovery, emphasising the importance of edge effects in previously logged forests. At least in the first 50 years after logging, tree-community composition did not appear to converge toward that in unlogged forests over time. Although species assemblages in logged forests generally tend to shift from light demanding-pioneers to old-growth species over time, a long-lived pioneer *Campnosperma brevipetiolata* dominated the forest even 50 years after logging. We suggest that recovery of the tree community in logged forests has been hindered by the persistence of *C. brevipetiolata*, and suggest that it could be thinned via careful silviculture techniques to enhance growth of mature-phase forest species. Removal of such persistent, long-lived pioneer trees could potentially help to accelerate recovery of heavily logged forests.

1. Introduction

Industrial logging is a major driver of the decline of old-growth forests in the tropics (Putz et al., 2012; Edwards et al., 2014; Katovai et al., 2015a). Nonetheless, logging is often the economic lifeline for many developing tropical countries, generating substantial revenue through wood exports (Katovai et al., 2012; Shearman et al., 2012; Zimmerman and Kormos, 2012). Some countries have exhausted timber stocks as a result of unsustainable harvesting (see Shearman et al., 2012 for examples). However there has been an increase in logging activities in many parts of the tropics over the recent past (FAO, 2015). For example, the Eastern Melanesian islands in the northwest Pacific have recently become a logging hotspot as a result of timber depletion in neighbouring Southeast Asia (Shearman et al., 2012; Katovai et al., 2015a). Logging operations in Eastern Melanesia have increased dramatically over the past several years, and have contributed significantly to economies in the region (Katovai et al., 2015a).

In the Solomon Islands, logging exports have generated over half of the country's annual export revenue for the past two decades (Solomon Islands National Forest Resources Assessment (SINFRA), 2011; Shearman et al., 2012; Katovai et al., 2015a). However, unregulated harvesting, exacerbated by poorly conceptualised and implemented state policies, corruption, and illegal harvesting has driven accessible timber stocks to near depletion (Kabutaulaka, 2000; Shearman et al., 2012; Katovai et al., 2015a). A collapse of the timber industry would have serious consequences for the country's economy. Furthermore, increased logging can possibly trigger a widespread loss of biodiversity and ecological functions via the disruption of species interactions (Zimmerman and Kormos, 2012).

The effects of industrial logging on tropical forest biodiversity in the mainland tropics and continental landbridge islands such as those of Southeast Asia are well documented (see review in

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Wilcove et al., 2013). These studies propose that logged forests retain much of their pre-logged biodiversity, even when intensively logged (Edwards and Laurance, 2013). This might not hold true for tropical oceanic islands, because the regional and nearby species pools that influence their local diversity differ from those in mainland regions Gillespie et al., 2008).

Tropical oceanic islands are currently ‘hot-spots’ for industrial logging, but their responses to logging are relatively poorly studied to date (Katovai et al., 2012, 2015a, 2015b). The Solomon Islands, for example, currently has large tracts of forests that have been logged over the last several decades, yet little is known about biodiversity within them (Bennett, 1995, 2000; SINFRA, 2011; Katovai et al., 2012) or their temporal and spatial patterns of post-logging recovery. Such forests are highly vulnerable to further degradation by re-entry logging and subsequent land-use activities.

In an effort to inform forest-management policies, we examined tree species communities across an array of logged forests on Kolombangara Island in the Solomon Islands. We assessed the factors influencing recovery of tree diversity and species composition in previously logged forests, with a particularly focus on determining whether a half century was sufficient to allow forests to recover to pre-logging conditions.

2. Materials and methods

2.1. Study area

Forests in the Solomon Islands are rich in biodiversity and contain exceptionally high endemism (Whitmore, 1969; Olson and Dinerstein, 1998; Gillespie et al., 2008; Walter and Hamilton, 2014). For example, over half of all palm, orchid and climbing pandanus (*Freycinetia* spp.) species are endemic to the region, with some endemic to a single island or forest type (Hancock and Henderson, 1988). Such high insular biodiversity is thought to have originated via very rare dispersal events from mainland tropical locations (Gillespie et al., 2008; Keppel et al., 2009). A decline of species diversity and ecological complexity of forests as one moves eastward across Melanesia, further away from New Guinea and Southeast Asia, supports this model (Gillespie et al., 2008; Keppel et al., 2010). For instance, a 30-year census of tree dynamics in naturally disturbed forests on Kolombangara, Solomon Islands revealed a simple pattern of species replacement involving the re-establishment of particular species at various stages of succession (Burslem and Whitmore, 1999). In contrast, forests on the tropical mainland and large continental landbridge islands undergo more complex successional patterns involving a larger array of successional species, resulting in naturally disturbed forests becoming floristically divergent with time (Keppel et al., 2010).

This study was conducted on Kolombangara Island (157°E and 5°S) in the New Georgia group of the Solomon Islands. The geomorphology and floristics of large islands in New Georgia are very similar to one another and also broadly comparable to other large islands across the region (Whitmore, 1967; Hancock and Henderson, 1988). Kolombangara is an extinct Pleistocene volcano that is ~32 km in diameter and circular in shape (Fig. 1). Topography increases from the relatively flat coastal plains to the base of the central volcanic cone at ~700 m elevation and progressively steepens to the crater rim at ~1700 m elevation. The central crater, at ~600 m elevation, is ~6.5 km in diameter and topographically uneven. Rainfall is relatively uniform across the island, exceeding 3000 mm/yr, with bi-annual wet seasons from November to March and July to August (Aldrick, 1993; Katovai et al., 2012).

Kolombangara was once covered with dense wet-tropical forests, but with fewer families, genera and species compared to the neighbouring Islands of New Guinea (Whitmore, 1969; Hancock and Henderson, 1988). However, much of Kolombangara’s lowland forests have been cleared or degraded since the early 1900s (Katovai et al., 2012). For example, since 1964, heavy logging has degraded >90% of accessible lowland forests from the coastline to 400 m elevation (Bennett, 2000; Katovai et al., 2012). Logging has been more limited from 400 to 700 m elevation because of unstable soils and steep slopes.

Initial logging on Kolombangara was exclusively implemented by a single U.K. company, Lever Brothers (Katovai et al., 2012, 2015a). For this reason, harvesting strategies and extraction patterns were highly systematic and consistent among sites (Bennett, 2000). Operations began on the southeast of the island and progressed anticlockwise (Bennett, 2000). Some patches of traditionally owned land in the southwest were logged later, beginning in the 1980s, by various other foreign companies. Nonetheless, these later logging practises were relatively similar to those used by the Lever Brothers.

In the past three decades, much of Kolombangara’s logged forests in the SE, NE and NW quadrants of the island have been converted into commercial wood plantations (Bennett, 2000). However, patches of both logged and unlogged forests remain scattered across these quadrants (Fig. 1). The absence of commercial plantations in the SW quadrant has allowed natural regeneration in large areas. Unlogged patches of lowland forests on the island are typically restricted to traditionally owned and church-leased lands (Whitmore, 1989; Katovai et al., 2012). However, most of these forests have already been included in logging-concession areas and are open to logging over the next few years.

2.2. Study design

From January to November 2013, we sampled 144 0.1-ha (50 m × 20 m) vegetation plots in six logged and six unlogged coupes spanning an elevation gradient from 20 to 422 m. During this process we used oral traditional information and published information to avoid establishing plots in old human settlements (e.g. Burslem et al., 2000; Bayliss-Smith et al., 2003), to exclude effects of past land use in our study.

We sampled a post-logging chronosequence, with two coupes each sampled from areas that had been logged 10, 30, and 50 years previously. Unlogged (control) coupes were largely intertwined with logged coupes to ensure they were matched topographically and elevationally (Fig. 1). In each coupe, 12 plots were established using stratified random sampling to determine plot locations, with plots stratified on the distance to the nearest logging road (e.g. Laurance et al., 2001). Distances to the nearest logging road and to unlogged forest were determined using GPS (Garmin 76cx GPS; Garmin International, Inc., Kansas City, USA).

Basal area of cut stumps was used as a proxy for harvest intensity in logged forests. We first measured the diameter and height of all cut stumps in a 50 m × 70 m quadrat centred on the plot. For each partially decomposed stump, we estimated stump diameter by visually reconstructing the cut-level circumference using available information on the buttressing and bole profile from stump base to cut level. A stem profile model developed for tropical forests was then used to generate DBH estimates for stumps that were either cut below or above the conventional DBH [~1.3 m] (see protocol details in Ito et al., 2010). Finally we estimated the basal area of harvested trees using these values for each quadrat.

In each plot, we measured elevation and soil nitrogen (N) as these variables may strongly affect floristic communities (e.g. Hardwick et al., 2004; Sundqvist et al., 2013; Asase et al., 2014). Elevation was determined using GPS. To determine N in each plot, we extracted soil samples to 30 cm depth from four randomly selected points using a cylindrical soil extractor. Samples from