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Impacts of tropical selective logging on carbon storage and tree species richness: A meta-analysis

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ABSTRACT

Over 400 million hectares of tropical forest are currently designated as logging concessions. This practice is an important source of timber, but there are concerns about its long-term sustainability and impacts on biodiversity and carbon storage. However, logging impacts vary widely, making generalisation and, consequently, policy implementation, difficult. Recent syntheses of animal biodiversity have indicated that differences in logging intensity – the volume of wood removed ha^{-1} – might help to explain some of these disparities. In addition, it has widely been assumed that reduced impact logging (RIL) might minimise some of the negative effects of logging; though in practice, this has rarely been tested. To test the hypothesis that RIL reduces negative impacts of selective logging once intensity is controlled for, we used meta-analyses of selective logging impact studies, focusing specifically on (1) residual tree damage, (2) aboveground biomass and (3) tree species richness. Our results indicate that RIL appears to reduce residual tree damage when compared to conventional methods. However, changes in aboveground biomass were negatively related to logging intensity. Any effect of RIL, independent of logging intensity, was difficult to discern since it was carried out at relatively low intensities. Tree richness appeared to increase at low intensities but decreased at higher intensities and any effect of RIL was difficult to detect. Our results tentatively support the hypothesis that RIL reduces the negative impacts of logging on tree damage, but do not support suggestions that RIL reduces loss of aboveground biomass or tree species richness. However, this lack of support may be a result of the relative paucity of data on the topic. Based on our results, we suggest that better evidence is needed to assess the differences between the impacts of RIL and conventional logging. Studies that consider plot-level differences in logging intensity are required to fill this knowledge gap. In addition, there must be clarification of whether RIL is an inherently low intensity practice so that this can be factored into management.

1. Introduction

Over 400 million hectares of tropical forest are designated as timber concessions, making selective logging – the removal of selected trees from a stand – one of the most widespread human disturbances in tropical forests (Asner et al., 2009). Tropical logging produces approximately one eighth of global timber (Blaser et al., 2011), and is an important contributor to many local and national economies. However, logging can have negative impacts on biodiversity (Berry et al., 2010) and leads to increased carbon emissions (Bryan et al., 2010; Nepstad et al., 1999). Poor management of logging concessions can endanger the long-term sustainability of timber production and there have been suggestions that we might be approaching peak timber production in the tropics (Shearman et al., 2012).

Given the large global demand for tropical timber, researchers have proposed modifications to logging techniques to reduce their negative environmental effects, particularly regarding carbon emissions (Putz et al., 2008b) and their impacts on biodiversity (Bicknell et al., 2015). The direct impacts of selective logging are largely the result of the effects of harvesting, skidding of logs, and construction of infrastructure, such as roads, on the mortality and recruitment of trees. The major source of carbon losses is the felling of large trees. However, damage and subsequent death of smaller trees as a result of crushing by felled trees or damage during removal of logs can also be a major contributor of carbon

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emissions (Putz et al., 2008b). Damage and mortality of non-target trees can also limit forest recovery (Gourlet-Fleury et al., 2013b; Sist et al., 2014) and, if recruitment fails to keep pace with mortality, this can result in altered tree community composition (Ouédraogo et al., 2011). Some of the negative effects of logging on carbon emissions and biodiversity could potentially be minimised by reducing large tree mortality, reducing residual damage to trees that are not felled, or increasing the recruitment of priority species.

One of the most widely accepted means of reducing large tree mortality is to limit the minimum diameter at breast height (DBH) at which trees can be cut (Sist et al., 2003a). Placing such limits decreases logging intensity (volume of trees extracted ha^{-1}). In addition to reducing the number of large trees felled, limiting logging intensity can also reduce residual damage to unfelled trees (Mazzei et al., 2010; Picard et al., 2012). In terms of biodiversity, recent work has shown that increases in logging intensity leads to a linear reduction in animal species richness for most vertebrates while a slight increase in bird species richness is observed at low intensities (Burivalova et al., 2014). Similarly, it is likely that species richness of trees might be enhanced at low intensities owing to an influx of shade intolerant species as suggested by the intermediate disturbance hypothesis (Bongers et al., 2009; but see Fox, 2013 for a full discussion of the intermediate disturbance hypothesis).

In recent years reduced impact logging (RIL) techniques have been considered to reduce the negative environmental impacts of selective logging (Putz et al., 2008a). Though application of RIL is not uniform, it tends to involve one or more of the following activities: cutting lianas prior to logging, felling trees in predetermined directions to minimise the impact to the surrounding forest, limiting road construction, identification and mapping of trees to be cut prior to logging, and planning of roads and skid trails (Pinard and Putz, 1996). Individual studies have suggested that RIL might reduce carbon emissions (Pinard and Putz, 1996), residual tree damage (Sist et al., 2003c), and result in more favourable biodiversity outcomes (Bicknell et al., 2014) when compared to conventional logging. It has also been suggested that RIL could be carried out at similar intensities to conventional logging while causing less damage to residual trees (Pinard and Putz, 1996; Putz et al., 2001; but see Sist et al., 2003a,b,c). Furthermore, it has been proposed that its wide implementation could reduce global carbon emissions from selective logging by 30% (Putz et al., 2008b). If true, these minimisations in the negative consequences of selective logging could be vital in securing long-term sustainability of timber producing tropical forests.

Despite claims made about the benefits of RIL, evidence is conflicting. Studies that investigate the effectiveness of RIL in reducing the negative impacts of conventional logging generally do so by comparing between areas logged using RIL techniques at relatively low intensities. For example, in one of the few studies comparing the effects of RIL and conventional logging on carbon stocks, any treatment effect was confounded by an approximately 50% higher logging intensity in conventionally logged plots (Pinard and Putz, 1996). Moreover, in the studies where differences in the logging intensity have been controlled for, there appears to be little difference in the impacts of RIL on the damage to residual trees (Sist et al., 2003c) and carbon stocks (Griscom et al., 2014). Taken together, these observations bring the value of RIL into question, given that a major aim of RIL is to reduce impact whilst maintaining timber yields (Keller et al., 2003).

Though RIL is widely cited as a method for limiting the negative effects of tropical selective logging there is little information regarding its general impact once logging intensities are controlled for. Though Putz et al. (2012) provided a valuable overview of the impacts of tropical selective logging on biomass and tree species richness, no attempt was made to explain differences in these impacts between sites. The recent meta-analysis by Bicknell et al. (2014) indicated that RIL reduced impacts on animal populations, but there are no equivalent syntheses of effects on trees. Given that REDD+ aims to provide economic incentives to reduce loss of carbon and biodiversity from forests (Harvey et al., 2010) and RIL has been suggested as means of attaining these reductions (Putz et al., 2008b), understanding variation in logging impacts is vital to inform management. In this study, we aim to address this knowledge gap by conducting a meta-analysis to determine which factors relating to logging method and intensity might explain differences in (1) residual stand damage, (2) aboveground biomass loss, and (3) tree species richness.

2. Methods

2.1. Systematic review

We defined selectively logged tropical forests as native forests between the latitudes of 40′N and 40′S subjected to selective tree removal for timber. We undertook a standard systematic review as described by Pullin and Stewart (2006) and used the terms (“biomass” OR “carbon” OR “basal area” OR “damage” OR “snag” OR “non-target” OR “tree” OR “species richness” OR biodiversity) AND (selective logg* OR felling OR timber extraction OR reduced-impact logging OR degradation) AND “tropical forest” to search Web of Knowledge, Wiley Blackwell and Science Direct databases. We also used the appendices of Clark and Covey (2012), Gibson et al. (2011), Picard et al. (2012) and Putz et al. (2012) to identify potentially relevant literature. The final literature search was undertaken on 20/06/2014. In addition, we contacted researchers working on the subject to identify any unpublished datasets.

In order to be included in our analysis, studies had to:

(i) Present data on residual stand damage following logging or aboveground tree biomass and/or species richness of trees from at least one undisturbed forest and one logged forest site.
(ii) Include sites with spatially replicated measures of tree species richness or aboveground biomass of trees in both logged and unlogged sites with at least three plots present in each. This rule was relaxed for the studies of residual stand damage since very few were replicated or provided comparisons with unlogged sites.
(iii) Include logged sites that were unaffected by multiple disturbance types such as fire or drought.
(iv) Be carried out in terrestrial forests, excluding mangroves.

First, articles were excluded if titles were deemed irrelevant. Following this, abstracts were examined to filter out irrelevant articles. The remaining articles were read and retained only if they met the inclusion criteria described above. The search produced 6422 potentially relevant references and, following exclusion of irrelevant papers, we extracted data from 62. If there was evidence that relevant data had been collected but were not presented in the publications, data were requested from authors. If data were presented in tables, they were directly transferred to our database, whereas if data were presented as graphs, we used the program datathief (vIII) (Tummers, 2006) for data extraction. For details of the studies used see Table 1 and Tables S1–S3.

In articles that measured changes in biomass or species richness, we extracted the mean, standard deviation, and sample size for sites in logged and unlogged forests. Where multiple sites were measured per study we extracted data for each site separately. In