Improved timber harvest techniques maintain biodiversity in tropical forests

Jake E. Bicknell[1,*], Matthew J. Struebig[1], David P. Edwards[2], and Zoe G. Davies[1]

Tropical forests are selectively logged at 20 times the rate at which they are cleared, and at least a fifth have already been disturbed in this way [1]. In a recent pan-tropical assessment, Burivalova *et al*. [2] demonstrate the importance of logging intensity as a driver of biodiversity decline in timber estates. Their analyses reveal that species richness of some taxa could decline by 50% at harvest intensities of 38 m^3 ha^{-1}. However, they did not consider the extraction techniques that lead to these intensities. Here, we conduct a complementary meta-analysis of assemblage responses to differing logging practices: conventional logging and reduced-impact logging. We show that biodiversity impacts are markedly less severe in forests that utilise reduced-impact logging, compared to those using conventional methods. While supporting the initial findings of Burivalova *et al*. [2], we go on to demonstrate that best practice forestry techniques curtail the effects of timber extraction regardless of intensity. Therefore, harvest intensities are not always indicative of actual disturbance levels resulting from logging. Accordingly, forest managers and conservationists should advocate practices that offer reduced collateral damage through best practice extraction methods, such as those used in reduced-impact logging. Large-scale implementation of this approach would lead to improved conservation values in the 4 million km^2 of tropical forests that are earmarked for timber extraction [3].

Selective logging is the removal of specific timber trees from a forest stand, resulting in patchy canopy openings and extensive road networks, with associated negative impacts on biodiversity [4]. Forest damage can be minimised by employing techniques such as pre-harvest inventories, planned logging road networks, directional felling and winching, all of which are key components of reduced-impact logging (Supplemental information) [5]. Consequently, reduced-impact logging improves forest sustainability and ecosystem-service provision [6,7]. Indeed, the adoption of reduced-impact logging across production forests globally would cut carbon emissions by an estimated 160 million tonnes per year, equivalent to ca. 10 percent of carbon emissions from deforestation [8]. While reduced-impact logging has received growing attention (Supplemental information), few studies have directly compared the biodiversity impacts of this selective logging practice with those of conventional selective logging, making it difficult to build a strong evidence-base to inform conservation management and forestry policy.

Here, we address this knowledge gap via a pan-tropical meta-analysis that utilises species abundance information to examine the relative consequences of contrasting logging regimes. All available logging effect studies that compared primary tropical forest with conventional logging and/or reduced-impact logging forests were included in our analyses, amounting to 3474 comparisons from 41 studies (Supplemental Information). Tropical ecologists have reported both increases and decreases in diversity in response to selective logging at almost equal frequency [2], so we assess assemblage change to better account for shifts in the balance between generalist and specialist species that are expected following disturbance.

Our analyses reveal the effects of reduced-impact logging to be consistently lower than those of conventional logging, with smaller shifts in species abundance under reduced-impact logging (mean Hedge's g ± 95% CI: conventional logging = 0.476 ± 0.03; reduced-impact logging = 0.393 ± 0.05; Figure 1). This finding could be attributed to differences in harvest intensity, logging practices, or both. To control for intensity, we repeated effect size calculations to include only those conventional-logging studies with comparable harvest levels to those of reduced-impact logging (≤30 m^3 ha^{-1}), and the pattern remained the same (Figure 1). Considering different taxonomic groups separately, our dataset revealed smaller detrimental effects under reduced-impact logging for birds, arthropods and mammals (Figure 1), especially bats (Supplemental information). There were insufficient data to compare amphibians among logging techniques. Similarly, we could not examine the data grouped by geographic region, as no suitable reduced-impact logging studies exist outside of the Neotropics. However, within this region, reduced-impact logging still resulted in smaller effect sizes (Supplemental information).

Although, like Burivalova *et al*. [2], our meta-regression showed an association between logging intensity and effect sizes (conventional logging and reduced-impact logging combined: $Q_{model} = 4.75$, $p = 0.03$), when partitioned by extraction method, a further important result is evident. Restricted to conventional logging, there is no relationship ($Q_{model} = 0.44$, $p = 0.51$), even when considering only extraction intensities comparable with reduced-impact logging (conventional logging ≤30 m^3 ha^{-1}: $Q_{model} = 0.45$, $p = 0.500$; Figure 1 inset). Conversely, effect sizes under reduced-impact logging are positively related to harvest intensities ($Q_{model} = 27.6$, $p < 0.001$; Figure 1). Reported intensities under conventional logging are thus not closely related to levels of collateral damage, whereas they are under reduced-impact logging. This may be expected because harvest levels are recorded as the amount of commercial timber extracted, but this metric fails to account for the actual levels of stand disturbance associated with factors that are mitigated under reduced-impact logging (e.g., falling timber crushing non-harvest trees, indiscriminate use of bulldozers etc.). Meta-regressions of time since logging showed no effect under conventional logging ($Q_{model} = 1.18$, $p = 0.277$) or reduced-impact logging ($Q_{model} = 1.60$, $p = 0.206$), demonstrating that differences in forestry practices rather than time since disturbance are primarily driving biodiversity change. Consequently, solely considering harvest intensities puts the conservation value of production forests at risk of continued poor extraction practices.

Selective logging is the most widespread, but least detrimental disturbance faced by tropical forests [9], and logging estates are increasingly considered important to global conservation [4]. Although our study shows that best practice forestry

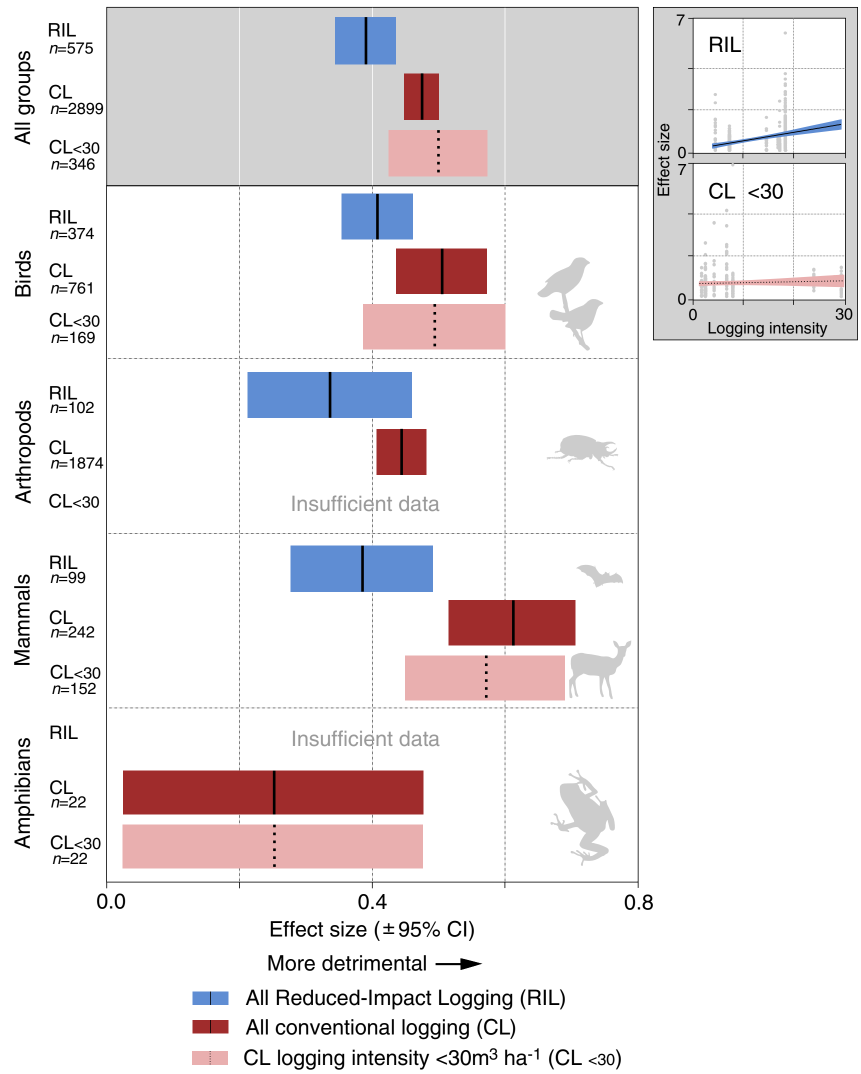

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Figure 1. Effect sizes and meta-regressions of reduced-impact logging and conventional logging.

Mean effect size (Hedge's g ± 95% CI) of reduced-impact logging (blue) and conventional logging (reds) impacts on tropical forest biodiversity. Black vertical lines indicate means, and box width shows the confidence intervals. Lighter reds with dashed mean include only conventional logging studies with timber harvest intensities comparable to reduced-impact logging (≤30 m^3 ha^{-1}). Top (dark grey section) comprises comparison across all taxonomic groups combined. Bottom (white) is partitioned by taxonomic group: birds, arthropods, mammals and amphibians. *n* gives the number of species-level comparisons used in the calculation of effect sizes. Inset: meta-regression (shaded area ± 95%CI) of reduced-impact logging and conventional logging effect sizes against logging intensity (m^3 ha^{-1}) at levels lower than 30 m^3 ha^{-1}.

estates should not be considered equal in conservation value to primary forests, our analyses suggest that implementing reduced-impact logging more widely would result in substantial gains for biodiversity compared to the status quo. Focusing on lower logging intensity alone could result in larger expanses of primary forest being logged to meet timber demand. This may be incompatible with forestry economics as it would likely reduce profits. Furthermore, expanding the logged area would be unfavourable for conservation, as more biodiversity is retained where high harvest intensities are combined with the sparing of primary forest reserves, rather than universally harvesting at lower intensities [10]. By contrast, our study suggests that even at high harvest intensities, reduced-impact logging will result in lower impacts than conventional logging, providing strong justification to improve logging practices. Unfortunately, uptake of reduced-impact logging has remained slow with conventional practices continuing to dominate the industry [3], so action is required among governments of tropical timber producer and consumer states to insist on best practice forestry.

Supplemental Information

Supplemental Information including experimental procedures and two figures can be found with this article online at http://dx.doi.org/10.1016/j.cub.2014.10.067.

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[1]Durrell Institute of Conservation and Ecology (DICE), School of Anthropology and Conservation, University of Kent, Canterbury CT2 7NR, UK. [2]Department of Animal and Plant Sciences, University of Sheffield, Sheffield S10 2TN, UK.
*E-mail: J.E.Bicknell-57@kent.ac.uk, jake.bicknell@gmail.com