Supplemental Information

Improved timber harvest techniques maintain biodiversity in tropical forests

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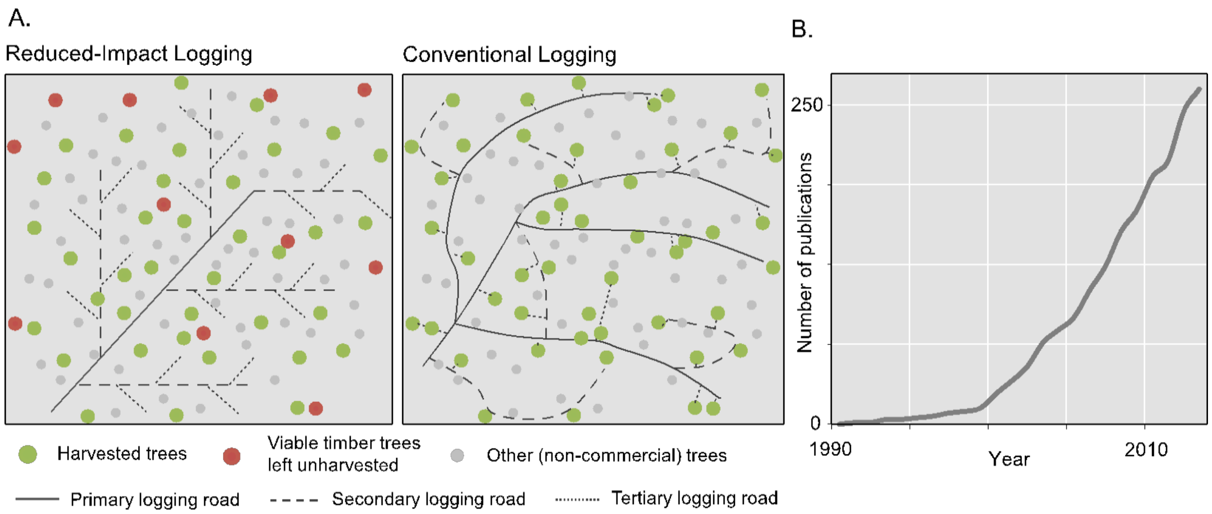

Figure S1. A. Example aerial view of logging road layout for Reduced-Impact Logging (RIL) and conventional logging (CL) in tropical forests. Logging roads under RIL are planned after a forestry inventory, and typically result in 20% less total logging road area. Minimum felling diameters and distances between extracted trees are used. Trees felled under RIL are winched to logging roads (reducing the overall road lengths), and directional felling and vine cutting are used to minimise damage to adjacent trees (vine cutting prevents connected trees from being dragged down during felling). RIL guidelines vary by context and country, and include many other treatments and technologies (e.g. reducing soil compaction, mitigating impacts to watercourses, setting of maximum operational slopes, use of specialised tree hauling equipment). RIL is economically viable and can result in greater profits than CL over the long-term [S1]. There is freely available financial modelling software to enable a rapid assessment of the economic viability of RIL under specific contexts (RILSIM: http://blueoxforestry.com). B. RIL has received increasing interest in recent years, as evidenced by the cumulative number of studies published with “Reduced-Impact Logging” in the title, keywords, or abstract from 1990 – 2013 (ISI Web of Science).

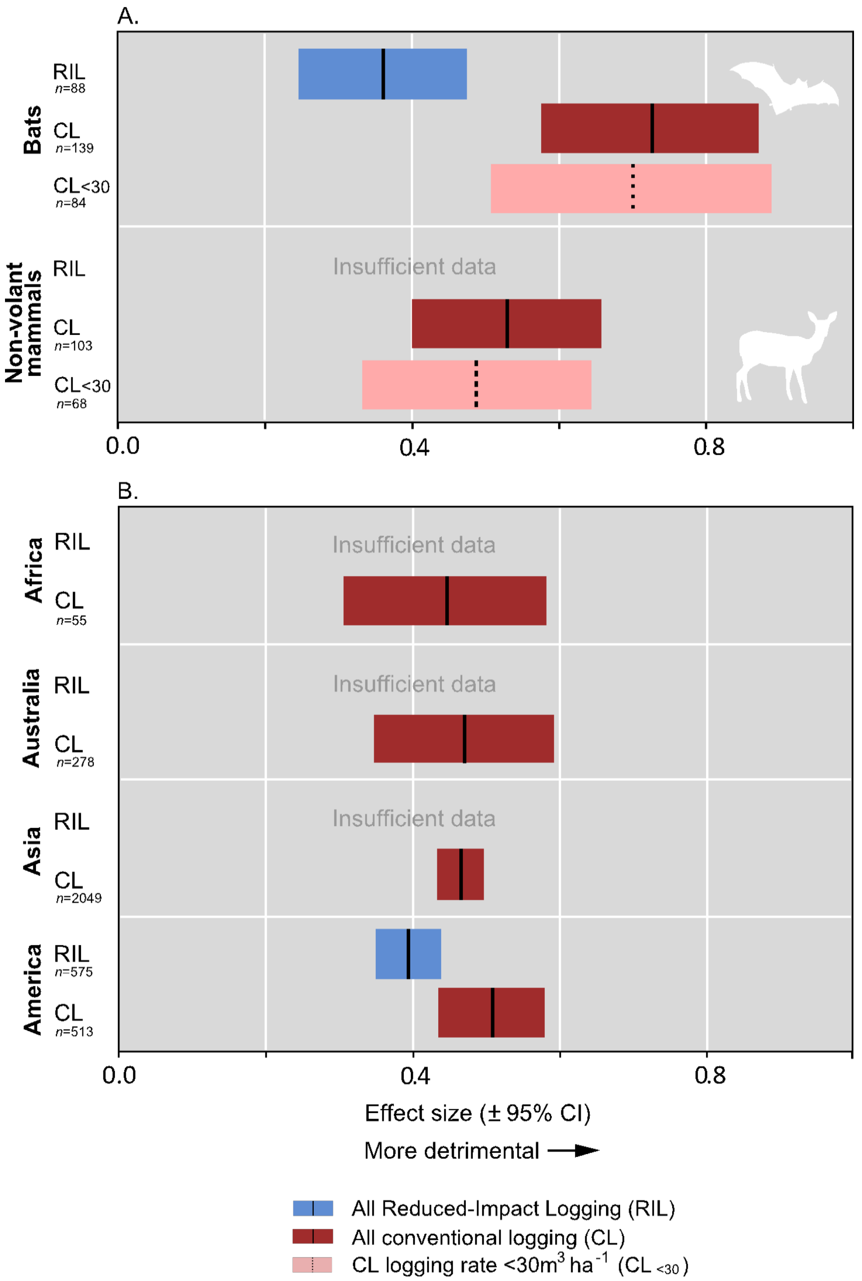

Figure S2. Mean effect size (Hedge's g ± 95%CI) of Reduced-Impact Logging (RIL: blue) and Conventional Logging (CL: reds) impacts on tropical forest biodiversity. Black vertical line shows the mean, and the box width indicates the confidence intervals. Lighter reds with dashed mean include CL studies where the logged sites were harvested at levels comparable to RIL (≤30 m^3 ha^{-1}). *n* gives the number of comparisons used in the calculation of effect sizes. A. Partitioned by bats and non-volant mammals. B. Partitioned by continent; America includes tropical South and Central America.

Experimental procedures

Inclusion criteria for studies used in the meta-analysis

Using ISI Web of Science and Scopus, we searched for all logging effect studies published between 1975 and May 2014. We used the terms “logging” OR “forestry” OR “timber” combined with “tropic*” AND “fauna” OR “wildlife” OR “biodiversity” OR “bird*” OR “bat*” OR “mammal*” OR “frog*” OR “amphibian*” OR “invertebrate*”. We also checked for further studies in the reference lists of papers identified by the search. In total, 1053 studies were located, which we filtered and retained if they met the following inclusion criteria: (i) reported the effects of industrial logging uncoupled from other anthropogenic disturbance in tropical forests (e.g. fragmentation, hunting, etc.); (ii) included measures of biodiversity abundance at sites in both primary and logged forests to allow calculation of effect sizes; and, (iii) indicated that the primary forests had not been subject to human disturbance. We also added data from our own study in Guyana (Bicknell et al. in review) which met these criteria. Where studies did not report the raw data or the variability of abundance estimates, we contacted the authors for this information. In some cases the authors had misplaced the data, and in others we received no response, so these studies were excluded. Where the same data were published in more than one study, we used them only once, utilizing the data from the most recent publication. To account for the spatial heterogeneity of logging impacts across production landscapes, all studies included in the analysis had a minimum of two independent samples across the study area. In most cases, these were randomly distributed. A small set of studies targeted specific interventions (e.g., gaps, logging roads/skid trails, etc.), and were only included if they also sampled the wider logged landscape.

Data extraction

To ensure that each effect size calculation was produced from a properly replicated sample, where a study sampled multiple sites from one forest patch, we took the mean of these, rather than drawing comparisons from potentially non-independent samples [S2]. We excluded measures of richness, as under low impact disturbance such as selective logging, the number of species does not sufficiently represent changes in species composition, as logged forests regularly hold similar richness to neighbouring undisturbed forests for most taxonomic groups [S3]. Additionally, richness metrics do not take account for the community becoming dominated by generalist species, alongside the loss of some specialists. Indeed, similar numbers of selective logging studies have reported decreases in biodiversity as have reported increases [S4], thus obscuring the signal. We therefore included all pairwise effect size comparisons of abundance for every species in each study to represent changes in community composition. Each comparison was classified by logging type, logging intensity, time since logging, taxonomic group, and geographic region. For studies that had been logged over more than one cutting cycle, we used the cumulative logging intensity from all cutting cycles. To directly compare CL with RIL at equal logging intensities we took the subset of CL studies that were logged at intensities ≤ 30 m^3 ha^{-1} as this was the maximum logging intensity under the RIL studies included. We also categorised region into continents (tropical Asia, Africa, South and Central America, Australia); and taxonomic group into birds, mammals, arthropods and amphibians. We further separated bats from non-volant mammals as these taxa use forest resources in different ways (Fig. S2). Our final dataset included studies from across the tropics, among multiple logging intensities and timeframes. Likewise, it comprised of data on bats, birds, terrestrial large and small mammals, primates, frogs and several groups of arthropods (e.g. butterflies, ants, bees, beetles, termites, spiders and flies).

Meta-analysis

For each pairwise measure of species abundance, we calculated the bias-corrected Hedges' g of the difference between primary and logged means, standardised by the pooled standard deviation following [S5]. We used the random-effects model to calculate the mean effect size, where each study was weighted by the inverse of its variance, plus the inter-study variance. We calculated the effect size for RIL and CL separately, and for each categorical subgroup (logging intensity, taxonomic group and region). We tested the dataset for possible publication bias by visually examining a funnel plot of the effect size plotted against the standard error of the effect size. The symmetry of the points either side of zero, and the fact that small effect sizes were not published at a lower frequency, indicated that publication bias did not affect the dataset.

Data extracted from studies which did not report logging intensity were only used in the overall calculation of effect size for the entire dataset. Furthermore, because logging intensities in all of the RIL studies that met the inclusion criteria were ≤30 m^3 ha^{-1}, we repeated effect size calculations under comparable intensities of CL. All of the RIL suitable studies were from South and Central America and, therefore, we conducted a separate analysis partitioned by region. Where studies reported logging intensities as trees ha^{-1}, we converted this to m^3 ha^{-1} based on the mean conversion from other studies in the same geographic region that reported both tree and volume extraction intensities, as done by [S4] and only affected <3% of the sample. Finally, we conducted meta-regressions of the effect sizes against logging intensities and time since logging for the entire dataset and separately for RIL and CL. Effect sizes and meta-regression were calculated in the programme Comprehensive Meta-analysis [S6].

Studies included in the meta-analysis

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