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Sustainability of commercial forest management in tropical rainforest

A report prepared for the
Rainforest Foundation Norway

October 9, 2018
Peter Wood, PhD

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SUSTAINABILITY OF COMMERCIAL FOREST MANAGEMENT IN TROPICAL RAINFOREST
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Editor’s Note

This report is the result of an assignment Rainforest Foundation Norway gave to Peter Wood in 2017.

We wanted Peter, as an expert in international forest policy, to write an up-to-date overview and analysis of recent research on the viability of socio-environmentally sustainable logging for commercial purposes in tropical rainforests.

Key questions we wanted to explore in this study included: What are the environmental effects of so-called “sustainable” industrial logging in intact rainforest areas, and to what extent is it possible to extract timber from primary rainforests without significantly disturbing and over time degrading the forest ecosystem regarding biodiversity, climate resilience and carbon storage?

While the report originally was intended for internal capacity building, we have now decided to make it publicly available. Our hope is that it will be as useful to others as it has been to us.

Solveig Firing Lunde
Rainforest Foundation Norway
September 2019

Peter Wood, PhD

Peter completed his PhD in Forestry at the University of Toronto, with a focus on international influences in domestic forest policy and management. He has worked on a variety of issues related to the sustainability of the forest sector over the past two decades, including for organizations such as the International Institute for Sustainable Development and Global Witness. He has consulted for intergovernmental organizations such as UNFF and FAO, and was a lead author in IUFRO’s Global Expert Panel on International Forest Governance. Currently he works for the David Suzuki Foundation as the National Campaign Manager for Environmental Rights in Vancouver, Canada.

Executive Summary

It is estimated that as much as half of the world's original primary tropical forest[1] area has been converted to other uses (Pimm and Raven, 2000), and that only 20% of the remaining half remains intact (Potapov et al, 2017). Logging has and will continue to have an extensive impact on tropical forests, having affected over 550 million hectares and with 400 million more designated as logging concessions. Home to the majority of the world's terrestrial biodiversity and millions of forest-dependent people located in the tropics, there is much at stake in ensuring the sustainability of forestry practices in this region.

The goal of this study was to provide an overview of current relevant research on the viability of sustainable logging for commercial purposes in tropical rainforests.

This report examines what is known regarding the impacts of "status quo" industrial logging, including on biodiversity, biomass/carbon, ecosystem resiliency, and timber yield. It then turns to examine whether reduced impact logging (RIL) and forest certification improve outcomes for these same values. Based on these findings, an overall determination is made regarding what constitutes "sustainable forest management" (SFM) in the tropics.

The report finds that industrial logging, even though it is done "selectively" due to the low density of commercially viable trees, results in a large impact to the remaining forest. While some of this occurs immediately during logging and construction of related infrastructure, there are also secondary impacts that can be even more significant. Decreased ecosystem resilience and removal of moisture-retaining canopy results in disruption of ecosystem processes and increased incidence of fire.

The literature indicates the existence of ecosystem thresholds in terms of logging intensity and frequency that, once exceeded, can make it difficult for a forest to recover. This may result in the forest being prone to desiccation and fire, and conversion to another ecosystem type. Logging results in increased access, often in areas with poor monitoring, providing a vector for hunters and illegal logging, and may enable conversion to agriculture. Biodiversity impacts of logging vary greatly, but in general, forest-dependent specialists tend to suffer the most, and the capacity for recovery is tightly linked with proximity to intact forest. Meanwhile, generalist and pioneer species may actually increase, taking advantage of the disturbed environment. Selective logging also results in a massive loss of carbon stocks, which may never be fully recovered.

Reduced impact logging (RIL) is a highly subjective concept, and the overall reduction of impact appears to be linked to logging intensity. Some studies claim to have found that RIL can reduce impact on non-target trees by 20-50%. However, the removal of the canopy favors rapid growth of pioneer species, and may prevent regeneration of commercially valuable trees. Regardless of how carefully the initial logging is done, RIL does not address the long-term risks associated with the introduction of road networks, particularly in areas of poor governance.

It is difficult to consistently assess the impacts that forest certification has had, due to a number of methodological issues. Impact studies remain largely inconclusive, with little evidence that certification results in statistically significant changes to loss of biodiversity and carbon, but may result in continued loss of intact forest, due to the introduction of roads and logging infrastructure.

There is a growing body of research that shows that the vast amount of tropical forest that has been degraded by logging has the capacity to be restored. However, this may

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[1] The term «tropical forest» includes all forest within the tropical region and should not be confused with «tropical rainforest» which is the geographical and thematical scope of this study. However, it has proven to be difficult to find accurate figures for the world's tropical rainforest.

require ongoing intensive intervention and management, which may be prohibitively costly.

What constitutes “sustainable forest management” (SFM) continues to be widely contested, with disagreement centered around the definition of both the terms “sustainable” and “forest”. Here we conclude that only management that sustains species-specific timber yields in perpetuity while maintaining the ecological integrity of the forest (“a forest’s full complement of ecosystem services and societal values”) should be defined as “sustainable forest management”. The strong likelihood of secondary impacts of logging suggests that these should be taken into consideration in any meaningful definition of SFM, including risks associated with increasing access to the forest. The precautionary principle should be exercised in ensuring that thresholds in logging intensity are not exceeded. SFM should not increase the vulnerability of the forest to unregulated access, and focus on restoration of the vast majority of tropical forests that have already been logged to some extent.

Given current knowledge, it is very difficult to justify logging of tropical IFL and primary forest as sustainable, let alone suggest that funds allocated to reduce deforestation and forest degradation should be supporting such activity or initiatives that facilitate it.

1: Introduction

This report provides an overview of the impact of industrial logging in tropical forests, including biodiversity, ecosystem resilience, and carbon/biomass. It will look at links between logging and deforestation and forest degradation and resilience. Second, it will look at the potential for reduced impact logging and forest certification to play a role in improving forest management. In light of the above, a working definition of “sustainable forest management” is proposed.

Given its large scope, the study focuses on meta-analyses with select examples for illustration.

2: Sustainability of conventional logging

Over 400 million hectares of tropical forest are currently designated as logging concessions (Martin et al 2015). Most tropical forest logging is largely done "selectively", in that only a small proportion of trees are harvested for a given hectare of forest (largely due to the low density of commercially viable species). However, the number of trees damaged and/or killed in the process but left behind can be indiscriminate and intensive. Furthermore, selective logging requires the construction of extensive infrastructure, providing access to previously remote areas.

Impacts from logging may become apparent at different time intervals and spatial scales. For example, the full impacts of activities resulting from increased access (such as hunting, illegal logging and agriculture) may not be apparent immediately after logging. Important forest ecosystem processes, such as seed dispersal and pollination, operate at very long time intervals, and thus the full impact of forest operations may only be known decades later. For example, damage to root structures might eventually lead to erosion, removal of canopy cover might lead to forest floor desiccation and increased susceptibility to fire, and introduction of invasive species may negatively impact local species. Depending on how soon after logging the observations are made, it may or may not capture all of the impacts.

Further complicating matters, while logging may deliver the first blow to the forest (most notably, the introduction of roads and other infrastructure), this may be followed by clearing for other uses (usually agriculture), either deliberately or due to increased susceptibility to fire, so it becomes difficult to distinguish and attribute impacts of logging. Depending on the circumstance, logging may be the primary driver for deforestation, it may facilitate or finance subsequent conversion to other land uses (most notably, agriculture), or it may be a way to establish ownership of the land (Pearce et al, 2003). Finally, the impact of logging can vary with the proportion of trees retained, and the time elapsed since the harvest (Chaudhary et al, 2016).

2.1 BIODIVERSITY IMPACTS

Biodiversity- the variation and variability of life on earth- can be measured at the ecosystem, species and genetic level[2] (CBD, 2017). Historically, the bulk of research on the impact of logging has largely focused on species-level impacts, and this will be the focus of this section. However, it should be noted that forest biodiversity is closely interrelated with ecosystem resilience (Thompson et al. 2009), discussed in the next section.

Tropical forests, despite covering only 10% of the earth's surface, are home to 50-80% of all terrestrial species. Less than half of the earth's original forests remain, and so it is not surprising that logging has had a major impact on biodiversity. Compounding this is that species are not evenly distributed, with 40% of all vascular plant, mammal, bird, amphibian and reptile species located in 25 areas identified as global biodiversity 'hotspots', which collectively cover <2% of Earth's land surface (Myers et al. 2000). Seventeen of these hotspots are in tropical forests. On average, only 12% of the original primary forest remains of these "hotspot" areas, compared to the tropical forest average of ≥50% (Lewis, 2006).

In broad terms, when it comes to biodiversity, selective logging creates winners and losers. The most vulnerable animal species in tropical forests are those that have both large area requirements and a low tolerance of the modified habitats surrounding fragments, while the most vulnerable plant species are those that respond poorly to edge effects or chronic forest disturbances, and that rely on vulnerable animal species for seed dispersal or pollination (Laurance et al, 2018). While logged forests may often have an equal or greater number of species than undisturbed forests, endemic, restricted-range or habitat-specialist species are most likely to decline or go extinct (Lewis, 2009).

An important meta-analysis of 48 studies across the tropics (Burivalova et al, 2014) of the impacts of selective logging found that mammal, amphibian, and invertebrate species richness decreases with an increase in logging intensity. Mammals and amphibians were particularly impacted, and suffered a halving of species richness at logging intensities of 38m^3 per ha and 63m^3 per ha, respectively. While bird species richness actually increased following logging, this was found to be due to an influx of generalist species, while birds that specialize in forests declined in heavily logged areas. It could be that birds are more easily detected in logged areas, and that their greater mobility could allow them to forage in logged sites while depending on unlogged areas for nesting.

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[2] This report focuses on species and ecosystem-level impacts of tropical forest logging. For consideration of genetic impacts, refer to Ratnam et al, 2014.

The analysis further suggests that the relationship between species richness, logging intensity, and taxonomic group also varies according to location: Neotropical fauna appears to be more sensitive to logging intensity than Afrotropical and Indomalayan fauna, apart from mammals, which decline even more steeply in richness in Africa than in the Neotropics (Burivalova et al, 2014). Mammals were found to be particularly sensitive to logging: every increase of 20m^3 ha−1 in logging intensity resulted in a 35% decrease in species richness. This was despite the fact that the meta-analysis excluded studies where additional pressures were present, such as hunting, mining, and burning. Since these activities are often a direct result of logging infrastructure providing access to the forest, it is likely that this analysis underestimates the total impact.

Other biodiversity studies have focused on specific taxa. Ewers et al (2015) found that the contribution of invertebrates to ecosystem processes (litter decomposition, seed predation and removal, and invertebrate predation) is reduced by up to one-half following logging, but that other taxa may step in to take their place in performing these services.

A meta-analysis of research done in the past 60 years by La Manna and Martin (2017) found that logging reduced tropical bird species richness by an average of 11% over 6 years with 50% basal-area retention, rising to 22% a year following low basal-area retention (around 5%) logging in the tropics. Even after 40 years of recovery, these areas still had 10.3% fewer bird species.

In Malaysian Borneo, Brodie (2014) found that hunting following logging led to a 31% decrease in mammals, especially species of ecological importance such as seed dispersers and herbivores, and led to complete “defaunation” of certain areas. In another study in the Republic of Congo, population density of several large mammals remained lower than in unlogged forests 2–3 decades after logging (Poulsen et al. 2011). The depletion of wildlife threatens the ability of forest dwellers to feed themselves, the survival of hunted species, and ultimately the sustainability of forestry (Robinson et al, 1999).

Other studies claim to show that selectively logged forests retain a high richness of forest taxa after the first cut. In fact, in one case (Edwards et al, 2011) it was found that over 75% of bird and dung beetle species found in unlogged forest persisted within forest that had been logged twice. Another study found that avian phylogenetic richness (the total evolutionary history across all species within a community) recovered to old-growth forest levels after about 30 years (Edwards et al, 2017). Dent and Wright (2009) found that after several decades species composition in secondary forests comes to resemble that of unlogged forests.

A study in the Peruvian Amazon found that biodiversity in an area recovering from logging contained 83% (±6.7) of species known to have occurred in the region before disturbance. Further, 88% of species of highest conservation importance predicted to exist in primary forest from the region remained (Whitworth et al, 2016).

However, it has been pointed out that the true impacts of selective logging could be masked by proximity to primary forests. This can lead to “spillover effects” into the logged forest, and may create “species extinction debts” only observable over periods of time longer than the timescale of most studies (in one review it was found that for 83.6% of cases, the research had been conducted within 12 years since logging)(Gibson et al, 2011). Furthermore, this doesn’t account for the ecosystem-level impact of repeated logging and the increase in fire and conversion that are associated with increased access to logged landscapes. It should be noted that the Whitworth et al study specifically sought to study a logged forest that had “effectively protected from confounding ongoing human disturbances”, and it is located in proximity to a large protected primary forest (Whitworth et al, 2016, p. 226). Another meta-analysis of 138 studies of the impact of anthropogenic land disturbances found that selective logging was relatively benign compared to conversion to agriculture, but ultimately concluded that “when it comes to maintaining tropical biodiversity, there is no substitute for primary forests” (Gibson et al, 2011).

Methodological challenges
It should be noted that assessing the impact of logging on biodiversity is inherently more complicated than doing so for timber yields or carbon stocks. Published studies can vary greatly in focus (e.g. species richness versus composition, or of particular taxonomic groups, such as birds or invertebrates), temporal scales (how soon after logging) and spatial scales (e.g. the inclusion of unharvested forest), making comparison of studies and meta-analysis more difficult (Putz et al, 2012). Time elapsed since logging may alter findings substantially, since many biodiversity impacts may not be visible in the near term. New access to previously impenetrable forests may put researchers into contact with species that were previously remote, temporarily boosting sightings, even though the overall population has declined.

The historic focus on species-level diversity as a measurement of impact has increasingly been called into question, as it does not capture several important aspects. For example, while the total number of species might remain the same or even increase following logging, disturbance-sensitive species might decline or go extinct, and be replaced by common, generalist species, or ones that thrive in a disturbed environment, a process that has been termed “biotic homogenization’: a reduction in ecosystem diversity (Phillips et al, 2017).

Researchers have identified other methodological challenges associated with assessing the true impact of logging on biodiversity. For example, inferences from biodiversity studies are constrained by differences in regional context as well as the context imposed by study-specific differences in research design and focus. (Gardner et al, 2009)

2.2 BIOMASS/CARBON IMPACTS

The loss of biomass and resulting carbon emissions related to logging is due to: (a) the loss from trees that are harvested ("extracted log emissions"); (b) the incidental damage caused to surrounding trees during harvesting ("logging damage factor"); and (c) the infrastructure built for removing the logs out of the forest ("logging infrastructure factor"). The latter includes skidding trails (caused by use of bulldozers or other equipment to transport the logs from the felling area to roads), logging decks or landings (areas where the logs skidded out from the forest are piled awaiting transport) and logging roads (Pearson et al, 2014). Based on these three forms of loss, it is possible to establish a "total emissions factor" for any given logging operation: the amount of carbon released for every cubic meter of wood harvested.

When this accounting method was applied in a study of logging in a selection of tropical countries, it was found that total carbon emissions per cubic meter of wood harvested is highly variable (ranging from .99 to 2.33 tons). However, in all cases, losses were mainly attributable to damage to surrounding vegetation and supporting infrastructure and not the logs that were harvested, with total emissions amounting to 3–15% of the original biomass (Pearson et al, 2014). It should be noted that this methodology did not account for changes in soil carbon.

A study using modeling and high-resolution remote sensing data in the Brazilian Amazon (Huang and Asner, 2010) found that selective logging was responsible for releasing an average of 0.04–0.05 Pg C per year (1999-2002). It also found that it took two to three decades for the forest to regain carbon lost due to selective logging, and up to a century to recover the original live biomass (if the forests are not subsequently cleared completely, as is highly likely, due to increased vulnerability).

In another study in Kigale National Park, Uganda, 18 years after logging and subsequent re-planting, the above-ground biomass was only 12% of that of the original forest. At this rate, it would take a total of 114 years to restore, with tree species diversity still much lower than before (Wheeler et al 2016). Another study in the same park found that even after 45 years, selectively logged forest exhibited higher light levels, lower stem density and total basal area, and 44% less above-ground biomass (Osazuwa-Peters et al, 2015).

Until recently, attempts to quantify forest carbon loss at a global scale focused on that related to deforestation, which is easier to detect and measure than forest degradation using satellite data. However, recent technological and methodological innovations have rapidly improved the ability to detect forest degradation. This has been helpful in revealing the true extent and impact of selective logging, and it is significant.

Pearson at al (2017) applied a combination of methodologies in assessing 2.2 billion hectares of tropical forest across 74 countries, for the period 2005 to 2010, and found that an estimated 2.1 Gt of CO^2 had been released due to forest degradation: 53% linked to timber harvest, 30% from woodfuel collection, and 17% from fire. This study likely underestimates the impact of timber harvesting, since it did not include impacts from illegal logging.

A recent analysis by Wood's Hole Research Centre (Baccini et al, 2017) used a different approach, measuring gains and losses in carbon *density* (tons of carbon per hectare) to arrive at a net value for tropical forests worldwide (the change in the amount of carbon stored). Gains are a result of forest regrowth, while losses are from deforestation, degradation and disturbance. This analysis concluded that between 2003 and 2014, tropical forests were a net source of carbon emissions, in the order of 425.2 ± 92.0 teragrams[3] of carbon per year (Tg C year–1), with losses of 861.7 ± 80.2 Tg C year–1 and gains of 436.5 ± 31.0 Tg C year–1. It is notable that this study found that degradation and disturbance was responsible for 68.9% of all losses.

As per the evaluation of biodiversity impacts, the impacts of logging on forest biomass continue long after the initial harvest period, as debris breaks down, resilience decreases, and factors such as drought and fire take hold.

2.3 ECOSYSTEM IMPACTS: FRAGMENTATION, DEGRADATION, RESILIENCE AND THRESHOLDS

Logging impacts tropical forest ecosystems in a number of ways, including degradation and fragmentation. A recent study found that over half of all forest degradation is caused by commercial logging, not including illegal logging (Pearson et al, 2017). Forest degradation may result in loss of ecosystem function with major consequences for biomass and species-level diversity. Importantly, these impacts are not captured by deforestation statistics, though severe degradation may be a precursor to loss of forest cover altogether. Large areas of degraded tropical forest exist, covering around 550 million ha by some estimates (Pan et al., 2011), though there is an ongoing debate as to how degradation is defined and measured.

One study in the Amazon estimated that logging severely damaged between 10-15,000 km^2 of forest annually (Nepstad et al, 1999). Another demonstrates how fragmentation and associated edge effects result in rapid biomass collapse (Numata et al 2011).

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3) 1000 teragrams = 1 Gt

Logging may also be only one of many activities on the landscape with biodiversity implications, and may interact with these to have disproportionate impacts, or collectively surpass disturbance thresholds, and thus a cumulative impacts approach is recommended (Stork et al, 2009). However, very few studies take this approach.

Furthermore, impacts of fragmentation on biodiversity and ecosystem processes are not only a consequence of local site features but also of broader changes occurring at landscape, regional, and even global scales (e.g. invasive species, climate change)(Laurance et al, 2018). The impact from these anthropogenic stressors on unlogged control sites may mask the impact of logging, as the true biodiversity baseline would likely have been higher in the absence of these (Alroy, 2017).

2.3.1 Intact forest landscapes and primary forests

Only 20% of the world's remaining tropical forests meet the criteria of "intact forest landscape" (IFL), defined as "a seamless mosaic of forest and naturally treeless ecosystems with no remotely detected signs of human activity and a minimum area of 500 km^2" (Potapov et al, 2017). These forests are associated with extremely high values for biodiversity and carbon storage, yet only 12% are protected worldwide, and their extent has been reduced by 7.2% between 2000 to 2013 (Potapov et al, 2017). A recent study found that even minimal deforestation within IFLs resulted in a disproportionately high rate of vertebrate biodiversity loss (Betts et al, 2017).

The term "IFL" should not be conflated with "primary forest." Primary forests form part of IFLs, but also exist outside of IFLs, in blocks smaller than the 500 km^2 threshold (Potapov et al, 2017). In fact, recent research has revealed these areas to be significant: 38.6% of the primary forest area in the Democratic Republic of the Congo is located outside of IFLs (Zhuravleva, et al, 2013), and 73.2% of that found in Sumatra, Indonesia (Margono et al, 2012). It should also be noted that IFLs may also include areas that are intact but naturally non-forested (bogs, lakes, etc), or have experienced some form of natural disturbance (e.g. forest fire), but are normally forested. IFLs do also include areas affected by low-intensity and historic human activities.

2.3.2 Resilience and Fire

Ecosystem resilience has been defined as "functional resistance to disturbance" (Ewers et al, 2015), and "an emergent property of ecosystems that is conferred at multiple scales by genes, species, functional groups of species, and the processes within an ecosystem" (ITTO, 2013, p.7). It is closely interrelated with biodiversity, and has become of increasing importance due to climate change (Thomson et al, 2009). Logging in tropical forests is linked with a decrease in resiliency to various disturbances, further exacerbating immediate impacts, and creating vulnerability to ecosystem change.

Tropical rainforests, in an undisturbed state, are practically fireproof, with the forest canopy and dense vegetation layers acting to retain moisture and keep the sun out (Tacconi et al, 2007). Once the forest is opened up via logging infrastructure, previously sheltered biomass is exposed to the sun and quickly desiccates. Logging infrastructure can also alter the forest's hydrology and water table, which can have the same effect, leading to fire. Regrowth following a fire often involves grasses and other biomass that dries out easily and perpetuates the fire cycle. If this is not interrupted, the forest may be replaced by grasslands or other ecosystem.

In an examination of the Brazilian Amazon, almost all forest fires were found to have originated in logged forest (Asner, 2006). An earlier study by Nepstad et al (1999) found that logging severely damaged 10,000 to 15,000 km^2 of forest per year, and that both logging and fire make the remaining forest more vulnerable to burning in the future.

Similar results were found in a study of Borneo between 2002 and 2005; nearly all deforestation occurred within 5 km of the forest edge, fire was highly correlated with land cover changes, and most fires were detected in degraded forests (Langner et al, 2007). Another study of the massive fires that Borneo experienced during the El Niño drought of 1997-1998 found that these mostly affected recently logged forests, while primary forests were less affected (Siegert et al, 2001).

2.3.3 Thresholds

While all logging is bound to have some form of impact (Chaudhary, 2016), some studies have pointed to thresholds in logging intensity (normally measured in cubic meters harvested per year, but may also refer to frequency of harvesting), above which there is a marked increase in impact, including higher levels of biodiversity loss and degradation of the forest ecosystem and its resilience. At the extreme "point of no return" this degradation can limit the ability of the forest (especially commercial, non-pioneer tree species) to recover on its own, and it may transform into a different ecosystem type altogether (e.g. savannah). There are three main reasons for this, namely: future crop and seed trees are killed during harvest; large gaps in the canopy favor growth by fast growing, low-value pioneer species; and logged stands are more fire prone, since they are dried out and full of woody debris.

To a certain degree, degraded forests have the potential to recover back to higher carbon and biodiversity value forest if left to regenerate naturally. However, lands that have been heavily degraded may become dominated by pioneer species and permanently "arrested" in an earlier successional state (Lawes and Chapman, 2006; Paul et al., 2004), especially if fire frequency increases (Cochrane, 2003). Other processes related to logging that may limit recovery include: topsoil erosion, reduction of seed bank, and changes in microclimate and local rainfall patterns, and limited dispersal potential. Forest landscape restoration, including planting of seedlings and clearing of competing pioneer species, can play a role in reversing this vicious cycle (Wheeler et al, 2016; Chazdon et al, 2016).

There is also reason to believe, based on our very limited knowledge of tropical tree pollination, genetic exchange, and reproductive success, that every tree species will face local extinction below a certain density threshold, but that the precise value for this remains a mystery (Sist et al. 2003a, Schulze et al. 2008, in Zimmerman and Kormos, 2012).

In a study of 35 mammal and bird species in Brazilian Amazon, Ochoa-Quintero et al (2015) found that landscapes reduced to less than 30–40% forest cover hosted markedly fewer species. Initially, every 10% of forest lost resulted in the elimination of one or two major species, and this continued until the forest cover fell below a threshold of 43%, at which point the rate of biodiversity loss escalated and anywhere between two and eight major species disappeared per 10% forest loss. The researchers believe that fragmentation (and loss of connectivity between fragments) may play a key role in creating this tipping point, causing species to hunt and mate in ever-decreasing circles (Mongabay, 2015). The authors conclude that this suggests that reforestation and restoration efforts be focused in areas that are on the edge of this threshold.

Similarly, a study of Brazilian Atlantic forest found that forest specialist species decline rapidly below 30% forest cover (Estavillo et al, 2013). Another study suggests that logging should only occur at intervals greater than 40 years in order to maintain sustainability (Huth and Ditzer, 2001).

A study in Malaysia, based on simulated growth modeling, suggests that a 40 year cycle, extracting 8 trees (60 m^3) per hectare and an annual volume of 1.5 m^3 per hectare, per year, is the best option to preserve ecological integrity, ensure the sustainability of timber yield, while maintaining economic profitability (Sist et al 2003b).

In a review, Zimmerman and Kormos (2012) arrived at several “rules of thumb” to avoid passing this threshold:

- harvest intensity should not exceed 5 stems per hectare (they note that conventional logging is currently 2-3 times that, especially in Asia, where commercially viable trees occur in greater density);
- single canopy gaps should measure less than 500 square meters;
- the gap’s area should not exceed 10% of the canopy’s area; and
- 85% of a stand’s basal area should be preserved (Struhsaker 1997, Sist et al. 2003a)[4].

Martin et al (2015) determined that using RIL techniques could help stay within this threshold: RIL can be carried out at intensities below 60 m^3 per hectare, while conventional logging must be limited to intensities below 40 m^3 per hectare.

Thresholds, Climate, and Forest Collapse
One review (Lewis, 2006) suggests that much of the world’s tropical forest area may be approaching climatic thresholds beyond which widespread ecosystem collapse is expected, resulting in this biome becoming a large net source of carbon. This includes water availability falling below 1200–1500 mm rainfall per annum, whereby forests are replaced by savanna systems (Salzmann & Hoelzmann 2005), and increased incidence of fire. “As the world warms and periodically dries, more forest is likely to be susceptible to burning more frequently, increasing the number, size and severity of forest fires. As such fires increase carbon fluxes to the atmosphere, this would further increase air temperatures, hence increasing the likelihood that forests may burn, creating a potentially dangerous positive feedback” (Lewis 2006, p. 205-6). While not directly attributable to logging, it is the context in which tropical forest management occurs.

3: Reduced Impact Logging

Given conventional logging’s large impact, it is not surprising that there is much room for improvement. While the impact of logging can be reduced in many ways, such as decreasing intensity, logging frequency, or by logging in secondary forests, “reduced impact logging” (RIL) typically refers to practices designed to minimize the amount of incidental damage done to the remaining forest in the course of harvesting target trees.

Historically, most conventional selective-logging operations in the tropics have been poorly planned and associated with excessive road-building activities, making it easy to identify ways to reduce the impact (Putz et al, 2000). This can range from the planning level (e.g. minimizing road networks) down to site/operations level (e.g. cutting vines and directional felling to minimize collateral damage). However, since there is no one definition of

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[4] Basal area is a metric used to calculate the total area (in square metres) of the cross section at breast height of all trees per hectare of land (NRCAN, 2018).

what qualifies as RIL, it is difficult to broadly evaluate its merits or impact.

One of the main points of debate here concerns logging intensity: that is, how many cubic meters of timber per hectare are extracted. Recent studies have emphasized that this needs to be taken into consideration (i.e. the evaluation of the merits of RIL must go beyond “how much damage per hectare” to “how much damage per cubic meter of wood harvested”).

In a review by Putz et al. (2008), RIL was shown to reduce collateral damage by 20%–50%. However, a) advance regeneration of high-value timber species is often not present in residual stands to begin with and (b) regardless of whether RIL was implemented and whether advance regeneration was present, high logging intensities and low minimum cutting diameters usually left such a high percentage of the canopy in open gap (20%–50%) that the residual stand became colonized by fast-growing, light-loving vines and pioneer species.

Zimmerman and Kormos (2012), in an examination of several long-term plot, timber-yield, and modeling studies, principally in Southeast Asia and Amazonia, found that these studies “unanimously conclude that even with RIL, virtually all of today’s national forestry codes guarantee commercial depletion, if not extirpation, of most timber species within three cutting cycles.”

Some believe that studies concerning the impacts of logging risk being biased towards better run logging operations, given that they depend on the allowed presence of researchers (Putz et al, 2012).

3.1 RIL AND BIODIVERSITY

In a recent meta-analysis of 287 published studies containing 1008 comparisons of species richness in managed and unmanaged forests, Chaudhary et al (2016) found that RIL did reduce the impact of logging on species richness (compared to conventional selective logging, which reduced richness by 13%). However, in the case of trees, this may be due to the lower logging intensities typically associated with RIL (Martin et al, 2015).

A study conducted in Guyana, claiming to be “the most comprehensive study to date to investigate the biodiversity impacts of RIL across multiple taxonomic groups,” found that RIL had a “relatively benign” effect on birds, bats and large mammals, based on observations made five years after logging (Bicknell, 2015).

One study in the Brazilian Amazon examined the short-term impact of RIL on bird species, and found that the presence of bamboo provided refuge and aided species otherwise affected by logging (Chaves et al, 2017).

3.2 RIL AND CARBON/BIOMASS

Because of the recent interest in forest carbon generated by REDD+, much of the research on RIL relates to the change in the amount of collateral damage produced per unit of merchantable timber following its introduction. In Putz et al (2012), RIL best practices are shown to be capable of reducing the carbon footprint of logging by 24%. However, critics counter that this will take decades to recover (Kormos and Zimmerman, 2014).

A recent meta-analysis of 62 studies (mostly located in Asia and the Americas, with relatively few in Africa) claiming to be “the most precise meta-analysis of the impacts of tropical selective logging on carbon and tree biodiversity to date” found that RIL did reduce collateral damage, but did little to improve post-logging biomass or species richness once logging intensity was accounted for (Martin et al 2015).

A recent study in the Brazilian Amazon found that one year after logging, biomass was reduced 14% by RIL and 24% by conventional logging, with corresponding merchantable species volume reductions of 21% and 31%; the findings also support the claim that use of RIL techniques accelerates rates of biomass and timber stock recovery after selective logging (Vidal et al 2016).

A study in East Kalimantan found that RIL (including FSC-certified operations) did not substantially reduce carbon impacts compared to conventional logging. The authors believe it is because key RIL techniques were not implemented consistently, including: cutting only usable trees; leaving ecologically valuable trees standing; using cables rather than bulldozers to haul logs; and using directional felling to minimize incidental damage and biomass loss to residual trees (Griscom et al, 2014).

A study of RIL in Gabon found that logging did not affect species richness, and that above-ground biomass was only reduced by 8.1%. However, this was based on very low intensity logging (0.82 trees/ 8.11 m^3 per hectare), and for each tree logged another 11 were damaged (Medjibe et al, 2011).

4: Forest certification in tropical forests

Since the early 1990s, forest certification has been used as a tool to encourage sustainable management of forests, but in practice has produced mixed results. Evaluation of its effectiveness is complicated by the paucity of impact studies that are free of potential bias, as many of these are conducted by certification schemes and supporting organizations. In addition, many impact studies are focused on the ability of certification to stop deforestation, often evaluated at the country level using remote sensing technology, and may not reflect changes in forest management that this may not capture. Overall, it is difficult to isolate certification amongst many possible influences and attribute specific outcomes to it.

In light of these and other limitations of existing efforts, a recent paper by Romero et al (2017) proposes a roadmap for more comprehensive and systematic evaluation of the impacts of FSC certification. Hopefully future efforts will become more methodologically rigorous.

Below, certification impact studies from a selection of tropical countries are presented.

INDONESIA

A study in Kalimantan compared outcomes in certified and non-certified operations between 2000 and 2008 (Miteva et al, 2015). It was found that although certified operations reduced aggregate deforestation by 5%, there were no statistically significant impacts on fire incidence or core areas, and actually increased forest fragmentation (perforation, an important proxie for disturbance and species diversity and richness, increased by 4 km^2 on average).

Another study in Kalimantan showed that seedling stem densities were higher in the certified forest site logged 10 years previously than in primary forest, and came to the conclusion that this could indicate that “biodiversity values may be conserved by following certification procedures” (Arbainsyah et al, 2014). However, it does not indicate if the saplings are pioneer or generalist species (as opposed to commercial or rare species).

Griscom et al, (2014) found that FSC-certified concessions in East Kalimantan did not have lower overall CO^2 emissions from logging activity (felling, skidding, and hauling).

The bigger picture for Kalimantan is that an estimated 25% of lands allocated for timber harvesting in 2000 had their status changed to industrial plantation concessions in 2010 (no indication of whether these are certified areas or not)(Gaveau et al, 2013).

GABON

A study in Gabon found that although certified operations resulted in less damage to surrounding trees (9.1 and 20.9 trees damaged per tree harvest, in FSC and conventional plots, respectively), when expressed as the impacts per timber volume extracted, the values did not differ between the two treatments (Medjibe et al, 2013).

MEXICO

A study in Mexico found that the impact of certification on deforestation levels has been limited (Blackman et al. 2015).

PERU

In a study of certification in the Peruvian rainforest, Brotto et al (2010) claim that forest certification was the precursor to the establishment of a biodiversity conservation system in the forest. However, this study does not indicate what the actual impacts of certification were.

PERU AND CAMEROON

Panlasigui et al. (2015) evaluated the impact of forest certification in Peru and Cameroon on deforestation levels, but did not find any statistically significant differences between certified and non-certified areas. However, the authors note that this was based on an early evaluation, and that baseline levels of deforestation were already low to begin with.

CONGO BASIN: INTACT FOREST LANDSCAPES

Efforts to restrict FSC certification of logging operations within IFLs have met with strong resistance from logging companies that operate in these areas. A recent report on IFL in the Congo Basin found that between 2000 and 2013, IFL loss was twice as high in certified operations as in non-certified operations, and ten times as high as in forest outside logging concessions (Greenpeace 2017; Potapov et al, 2017). The report notes that over half of the IFL area was lost from the FSC-certified concessions, amounting to 1.3 million hectares[5]. This is not surprising, given that selective logging is the dominant cause of intact forest loss in Africa, as it relies on an extensive road network to reach low densities of commercially valuable trees.

CONGO BASIN: SOCIAL IMPACTS

A 2014 study by CIFOR on the social impacts of certification in the Congo Basin, found several benefits including: consistently associated with better working and living conditions; better governance conditions and benefit-sharing arrangements. The authors suggest that the positive social outcomes were the result of companies being required to set and respect a calendar of implementation of their commitments, which were then regularly checked in annual evaluations (Cerutti et al, 2014).

5: Long term fate of a logged forest

Any consideration of the sustainability of forest management must take into consideration the long-term fate of the forest following logging, regardless of whether it was RIL or certified operation, and the vulnerability created by logging infrastructure. Most arguments in favor of RIL do not claim that RIL has no impact, rather that it is preferable to RIL than to have the forest cleared entirely, and replaced with agriculture or other uses. This comparative baseline is also often extended to protected areas: the claim is that since protected areas face illegal logging and encroachment due to poor monitoring and enforcement, active management and logging in a concession, if properly conducted, can result in a comparatively better outcome. But this fails to consider the problem that once these areas have been logged, access may no longer be controlled.

Part of the problem is due to socioeconomic effects of temporary logging booms, which act as population magnets (Brandt et al, 2016). Much of the problem is related to the integrity of governance, monitoring and enforcement capacity, and the likelihood that an area will succumb to additional pressures once it is made accessible.

Industrial logging, present in 28% of tropical forests worldwide, are likely the greatest single driver of road expansion in forest frontiers (Laurance et al, 2009), a vector for new pressures on the forest. Controlling road access is the most effective determinant of deforestation, as improving access to a forest area often creates strong pressures to deforest it (World Bank 2007, in ITTO, 2014). Stronger governance in high forest cover countries has been shown to moderate these pressures and reduce deforestation rates (Bare, Kauffman, Miller, 2015).

A study in the Brazilian Amazon found that 16% of selectively logged forests were clear-cut within one year,

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5) Note that IFL figures reflects the amount of forest that qualifies as “intact” (i.e. large blocks of roadless area), and not the area of forest in general.

and 32% were cleared within four years, with 95% of all deforestation and fires occur within 50 km of highways or roads (Asner et al, 2006).

A study in Southeast Asia showed that logging reduces harvestable yields of timber to uneconomical levels, leading to their abandonment and conversion to more profitable land uses, such as palm oil plantations (Edwards et al, 2011). Another study in this region revealed that roads built by loggers to access high densities of valuable trees in lowland forests led to deforestation in sparsely populated protected areas (Curran et al, 2004).

An Indonesian study concluded that improving governance offers the best hope of addressing the risk of forest fire and to have real and lasting impacts (Tacconi et al, 2007).

6: Defining SFM

There are many different interpretations of what constitutes "sustainable forest management," and it has become a controversial concept. Soon after the term was coined, it was adopted by industrial logging companies facing pressure from market campaigns, and a lack of an agreed definition has made it difficult to disprove these claims. Debate over what constitutes SFM can be traced to differing opinions over the fundamental question of what constitutes a "forest," what values are to be "sustained," and over what period of time.

Definition of "forest":

The most frequently cited definition is that of the FAO, which defines forest as an area greater than 0.5 hectare in size, with tree cover greater than 10%, capable of growing to over 5 meters high. There are several problematic elements with this definition, including its conflation of natural and plantation forests; the arbitrary tree cover threshold, and its failure to reflect forest degradation. The FAO's explanatory note specifically states that forests that are "temporarily unstocked due to clear-cutting" are still to be considered forest (FAO, 2015). This lack of a common understanding on what constitutes a forest has major repercussions. It may prevent agreement on the extent of deforestation and forest degradation, and how to address the problem. It may also allow for claims of "zero net deforestation" to be made, even while plantations replace primary forest (Brown and Zarin, 2013). It also does not reflect the unique attributes and values associated with primary and intact forests.

Definition of "sustainable":

Interpretations of what is to be sustained under SFM, and for how long, are wide-ranging. The ITTO's definition of SFM is one of the most often cited:

"Sustainable forest management is the process of managing permanent forest land to achieve one or more clearly specified objectives of management with regard to the production of a continuous flow of desired forest products and services without any undue reduction of its inherent values and future productivity and without undue undesirable effects on the physical and social environment."

The above contains several terms that allow for significant variation in interpretation. What objectives are sought? "Desired forest products and services" could mean just about anything. And what qualifies as "undue" and "undesirable" effects? Finally, logging has often been linked to facilitating conversion of land designated as "permanent forest" to other uses, despite the presence of a forest management plan.

At one extreme, one could opt to manage for the "specific objective" of maintaining intactness of the forest, and associated ecosystem services. At the other, one could narrowly select to manage for the continuous production of timber volume. Intergovernmental organizations such as FAO and UNFCCC have opted for narrow definitions of what is to be sustained, primarily focused on timber yield and carbon stocks. The UN Forum on Forests defines

SFM holistically, requiring SFM operations to maintain the full complement of a forest's ecological integrity (Kormos and Zimmerman, 2012).

One example of how this ambiguity is playing out in the literature is the debate over whether it is enough for SFM to sustain the yield of timber in general (with management based on subsequent depletion of increasingly less desirable species), or based on maintaining commercial species over time (Putz et al 2012, versus Kormos and Zimmerman 2012).

SFM remains an aspirational goal, but as nebulous a concept as "sustainable development." The true sustainability of operations currently claiming to be "SFM" will not be known for decades, as many forest processes affected by logging operate on very long-term time scales.

Pre-conditions to SFM:

Duncan Poore, in his book Changing Landscapes (2003), identifies a number of pre-conditions without which the achievement of SFM would be very difficult.

They included:
- Appropriate national policies and supporting legislation, and public support for these;
- An appropriate government structure to ensure the effective implementation of these policies, including the necessary connections between relevant sectors;
- Prescriptions for action based on best practices;
- Guidelines for all important forestry operations in both natural and planted tropical forests;
- High implementation standards;
- Adequate capacity in terms of institutions, staff numbers, qualifications, commitment and conditions of service.

While this may not contribute directly defining what constitutes SFM, many of these pre-conditions clearly speak to the importance of governance in achieving desired outcomes.

A proposed definition for SFM:

Based on the discussion above, the following definition of SFM is proposed:

Sustainable forest management: Forest management that sustains species-specific timber yields in perpetuity while maintaining the ecological integrity of the forest (a forest's full complement of ecosystem services and societal values).

The following questions should be taken into consideration in determining whether forest management is sustainable or not:

WHO manages the forest:

Management prioritizes local control of forests and broader land use decision making processes, based on the recognition of traditional rights and establishment of tenure and commercial rights where necessary.

WHERE does forest management occur:

Management is limited to forests that have already been subject to logging or other forms of human disturbance to the ecological forest function, apart from non-industrial traditional uses. Management should not increase the vulnerability of the forest to unregulated access.

Given what we now know about the disproportionate impact on both biodiversity and carbon storage that occurs with the introduction of logging into intact forest landscapes (both initially and through increased vulnerability), and given that there are less than 20% of the world's tropical forests that qualify as "intact," it is very difficult to justify IFL logging as sustainable, let alone suggest that funds designed to reduce deforestation and forest degradation should be supporting such activity.

The 80% of tropical forests that no longer qualify as "intact" due to introduction of roads and other infrastructure, remain available for forest management, including restoration and rehabilitation work. This part of management is currently underfunded, due to it being costly and because the rewards are public (carbon sequestration, biodiversity, reducing vulnerability to fire) and long term. In contrast, logging within IFLs generates short-term private wealth but has a high level of impact, drawing down forest biodiversity and carbon. This 80% also includes areas of primary forest that are too small to qualify as "intact" but still contain high values for biodiversity and carbon intensity, and these should be managed sustainably and in a way that does not compromise those values or increase vulnerability.

WHAT is to be maintained, and for how long?:

Management should seek to maintain species-specific timber yields in perpetuity, along with a full range of ecosystem services and non-timber forest products.

HOW is the forest managed:

Management is conducted in a way that restores and maintains ecological function and reduces vulnerability to natural disturbances, illegal access and conversion to other uses. Harvesting intensity and frequency is limited to that which avoids surpassing critical thresholds.

The strong likelihood of secondary impacts of logging suggests that these should be taken into consideration in any meaningful definition of SFM, including risks associated with increasing access to the forest. The precautionary principle should be exercised in ensuring that thresholds in logging intensity are not exceeded.

References

Karsenty et al. (2017). Deforestation and timber production in Congo after implementation of sustainable management policy: A reaction to the article by J.S. Brandt, C. Nolte and A. Agrawal. Land Use Policy 65.

Alroy, J. (2017). Effects of habitat disturbance on tropical forest biodiversity. Proceedings of the National Academy of Sciences, 114(23), pp.6056-6061.

Arbainsyah, de Iongh HH, Kustiawan W, de Snoo GR. Structure, composition and diversity of plant communities in FSC-certified, selectively logged forests of different ages compared to primary rain forest. Biodivers Conserv. 2014; 23: 2445–2472.

Asner, G.P. et al. (2005). Selective logging in the Brazilian Amazon. Science, 310, 480–482.

Asner, G.P. et al. (2006). Condition and fate of logged forests in the Brazilian Amazon. Proceedings of the National Academic Society of the USA, 103, 12947–12950.

Baccini, A. et al. (2017). Tropical forests are a net carbon source based on aboveground measurements of gain and loss. Science. http://science.sciencemag.org/content/early/2017/09/27/science.aam5962

Bare, M., Kauffman, C. and Miller, D.C. (2015). Assessing the impact of international conservation aid on deforestation in sub-Saharan Africa. Environmental Research Letters, 10(12), p.125010.

Barlow et al. (2007). Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. PNAS Vol. 104, no. 47,18555–18560.

Betts, M.G., Wolf, C., Ripple, W.J., Phalan, B., Millers, K.A., Duarte, A., Butchart, S.H. and Levi, T. (2017). Global forest loss disproportionately erodes biodiversity in intact landscapes. Nature, 547(7664), p.441.

Bicknell, J.E., Struebig, M.J. and Davies, Z.G. (2015). Reconciling timber extraction with biodiversity conservation in tropical forests using reduced-impact logging. Journal of Applied Ecology, 52(2), pp.379-388.

Blackman, A., Raimondi, A., & Cubbage, F. (2017). Does forest certification in developing countries have environmental benefits? Insights from Mexican corrective action requests. International Forestry Review, 19(3), 247-264.

Blake et al. (2008) Roadless wilderness area determines forest elephant movements in the Congo Basin. PLoS One vol. 3 (10) pp. 3546

Boucher, D., Elias, P., Faires, J. & Smith, S. Deforestation Success Stories: Tropical Nations Where Forest Protection and Reforestation Policies Have Worked. Union of Concerned Scientists June 2014 Report (2014).

Brancalion, P. H. S. and Chazdon, R. L. (2017), Beyond hectares: four principles to guide reforestation in the context of tropical forest and landscape restoration. Restor Ecol, 25: 491–496. doi:10.1111/rec.12519

Brandt, J.S., Nolte, C., Agrawal, A. (2016). Deforestation and timber production in Congo after implementation of sustainable management policy. Land Use Policy 52, 15–22.

Brodie, J.F., Giordano, A.J., Zipkin, E.F., Bernard, H., Mohd-Azlan, J. and Ambu, L. (2015). Correlation and persistence of hunting and logging impacts on tropical rainforest mammals. Conservation Biology, 29(1), pp.110-121.

Brotto L, Murray J, Pettenella D, Secco L, Masiero M. Biodiversity in the Peruvian Amazon. In: Sheil D, Putz FE, Zagt RJ, editors. Biodiversity conservation in certified forests. Wageningen, the Netherlands: Tropenbos International. (2010). Available: http://beahrselp.berkeley.edu/wp-content/uploads/2010/06/Biodiversity-conservation-in-certified-forests.pdf

Brown and Zarin (2013). What Does Zero Deforestation Mean? Science Vol 342 15.

Burivalova, Z., Şekercioğlu, Ç.H. and Koh, L.P. (2014). Thresholds of logging intensity to maintain tropical forest biodiversity. Current Biology, 24(16), pp.1893-1898.

Cannon CH, Peart DR, Leighton M. Tree species diversity in commercially logged Bornean rainforest. Science. 1998; 281(5381): 1366–1368. pmid:9721105

Cazzolla Gatti, R., Castaldi, S., Lindsell, J.A. et al. Ecol Res (2015) 30: 119. The impact of selective logging and clearcutting on forest structure, tree diversity and above-ground biomass of African tropical forests. https://doi.org/10.1007/s11284-014-1217-3.

CBD, 2017. The Centre for Biological Diversity. Definition of Biodiversity. Available: http://www.biologicaldiversity.org/programs/biodiversity/elements_of_biodiversity/

Cerutti P.O. et al. (2014). Social impacts of the Forest Stewardship Council certification: an assessment in the Congo basin. CIFOR.

Cerutti, P.O. et al. (2017). Social impacts of the Forest Stewardship Council certification in the Congo Basin. Int. Forest. Rev. 19 (S2), 1–14.

Charlotte E. Wheeler et al., Carbon sequestration and biodiversity following 18 years of active tropical forest restoration.

Chaves, W.A., Sieving, K.E. and Fletcher Jr, R.J. (2017). Avian responses to reduced-impact logging in the southwestern Brazilian Amazon. Forest Ecology and Management, 384, pp.147-156.

Chaudhary, A., Burivalova, Z., Koh, L.P. and Hellweg, S. (2016). Impact of forest management on species richness: global meta-analysis and economic trade-offs. Scientific reports, 6, p.23954.

Chaves et al. (2017). Avian responses to reduced-impact logging in the southwestern Brazilian Amazon. Forest Ecology and Management, Volume 384.

Chazdon R. (2014) Second growth: The promise of tropical forest regeneration in an age of deforestation. Chicago: The University of Chicago Press.

Chazdon, R.L., Broadbent, E.N., Rozendaal, D.M., Bongers, F., Zambrano, A.M.A., Aide, T.M., Balvanera, P., Becknell, J.M., Boukili, V., Brancalion, P.H. and Craven, D. (2016). Carbon sequestration potential of second-growth forest regeneration in the Latin American tropics. Science advances, 2(5), p.e1501639.

Curran, L.M., Trigg, S.N., McDonald, A.K., Astiani, D., Hardiono, Y.M., Siregar, P., Caniago, I. and Kasischke, E. (2004). Lowland forest loss in protected areas of Indonesian Borneo. Science, 303(5660), pp.1000-1003.

Dent, D.H. and Wright, S.J. (2009). The future of tropical species in secondary forests: a quantitative review. Biological conservation, 142(12), pp.2833-2843.

Edwards DP, Ansell FA, Ahmad AH, Nilus R, Hamer KC. The value of rehabilitating logged rainforest for birds. Conserv Biol. 2009; 23: 1628–1633. pmid:19775274

Edwards DP, Larsen TH, Docherty TDS, Ansell FA, Hsu WW, Derhé MA, et al. Degraded lands worth protecting: the biological importance of Southeast Asia's repeatedly logged forests. Proc R Soc B Biol Sci. 2011; 278: 82–90. pmid:20685713.

Edwards, D.P., Massam, M.R., Haugaasen, T. and Gilroy, J.J. (2017). Tropical secondary forest regeneration conserves high levels of avian phylogenetic diversity. Biological Conservation, 209, pp.432-439.

Estavillo, C., Pardini, R. and da Rocha, P.L.B. (2013). Forest loss and the biodiversity threshold: an evaluation considering species habitat requirements and the use of matrix habitats. PloS one, 8(12), p.e82369.

Ewers, R.M., Boyle, M.J., Gleave, R.A., Plowman, N.S., Benedick, S., Bernard, H., Bishop, T.R., Bakhtiar, E.Y., Chey, V.K., Chung, A.Y. and Davies, R.G. (2015). Logging cuts the functional importance of invertebrates in tropical rainforest. Nature communications, 6, p.ncomms7836.

Fahrig L (2002) Effect of habitat fragmentation on the extinction threshold: a synthesis. Ecol Appl 12: 346–353. doi:10.2307/3060946.

Fahrig L. (2003). Effects of Habitat Fragmentation on Biodiversity. Annu Rev Ecol Evol Syst; 34: 487–515.

FAO (2015). Forest Resources Assessment 2015 – Terms and Definitions. Available at: http://www.fao.org/docrep/017/ap862e/ap862e00.pdf

Fimbel, R. et al., eds (2001) The Cutting Edge: Conserving Wildlife in Logged Tropical Forests, Columbia University Press.

Gardner, T.A., Barlow, J., Chazdon, R., Ewers, R.M., Harvey, C.A., Peres, C.A. and Sodhi, N.S. (2009). Prospects for tropical forest biodiversity in a human-modified world. Ecology letters, 12(6), pp.561-582.

Gaveau DLA, Kshatriya M, Sheil D, Sloan S, Molidena E, Wijaya A, et al. Reconciling forest conservation and logging in Indonesian Borneo. PLoS One. 2013; 8: e69887–e69887. pmid:23967062

Gibson, L., Lee, T.M., Koh, L.P., Brook, B.W., Gardner, T.A., Barlow, J., Peres, C.A., Bradshaw, C.J., Laurance, W.F., Lovejoy, T.E. and Sodhi, N.S. (2011). Primary forests are irreplaceable for sustaining tropical biodiversity. Nature, 478(7369), p.378.

Goldsmith et al. (2011) Evidence for arrested succession within a tropical forest fragment in Singapore. J Trop Ecol 27: 323–326. Available: http://www.journals.cambridge.org/abstract_S0266467411000010.

Gourlet-Fleury, S., Mortier, F., Fayolle, A., Baya, F., Ouédraogo, D., Bénédet, F., & Picard, N. (2013). Tropical forest recovery from logging: a 24 year silvicultural experiment from Central Africa. Phil. Trans. R. Soc. B, 368(1625), 20120302.

Greenpeace (2017). Cut from Congo. Industrial logging and the loss of intact forest landscapes in the Congo Basin. Available at: https://www.greenpeace.org/africa/en/publications/2050/cut-from-congo/

Griscom et al. (2014): Carbon emissions performance of commercial logging in East Kalimantan, Indonesia. First published: 20 January 2014Full publication history. DOI: 10.1111/gcb.12386

Grogan, James, et al. "How sustainable is mahogany management?." ITTO Trop. For. Updat 25 (2016): 5-9.

Gullison RE. Does forest certification conserve biodiversity? Oryx. 2003; 37: 153–165.

Hall, J. S., Harris, D. J., Medjibe, V., & Ashton, P. M. S. (2003). The effects of selective logging on forest structure and tree species composition in a Central African forest: implications for management of conservation areas. Forest Ecology and Management, 183(1), 249-264.

Huang, M. and Asner, G.P. (2010). Long-term carbon loss and recovery following selective logging in Amazon forests. Global Biogeochemical Cycles, 24(3).

Huth and Ditzer (2001). Long-term impacts of logging in a tropical rain forest — a simulation study. Forest Ecology and Management Volume 142, Issues 1–3.

ITTO (2013). ITTO Principles and Guidelines for the Sustainable Management of Natural Tropical Forests. Available at: https://www.itto.int/direct/topics/topics_pdf_download/topics_id=3032&no=0

Kormos, C.F. and Zimmerman, B.L. (2014). Response to: Putz et al., Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conservation Letters, 7(2), pp.143-144.

Kraxner et al. (2017): Mapping certified forests for sustainable management http://www.sciencedirect.com/science/article/pii/S1389934116302246

La Manna and Martin (2017). Logging impacts on avian species richness and composition differ across latitudes and foraging and breeding habitat preferences. Biological Reviews. Volume 92, Issue 3, pages 1657–1674, August 2017

Langner, A., Miettinen, J. and Siegert, F. (2007), Land cover change 2002–2005 in Borneo and the role of fire derived from MODIS imagery. Global Change Biology, 13: 2329–2340. doi:10.1111/j.1365-2486.2007.01442.x

Laurance, W.F., Goosem, M. and Laurance, S.G. (2009). Impacts of roads and linear clearings on tropical forests. Trends in Ecology & Evolution, 24(12), pp.659-669.

Laurance, W.F., Camargo, J.L., Fearnside, P.M., Lovejoy, T.E., Williamson, G.B., Mesquita, R.C., Meyer, C.F., Bobrowiec, P.E. and Laurance, S.G (2018). An Amazonian rainforest and its fragments as a laboratory of global change. Biological Reviews, 93(1), pp.223-247.

Lawes, M.J. and Chapman, C.A. (2006). Does the herb Acanthus pubescens and/or elephants suppress tree regeneration in disturbed Afrotropical forest?. Forest ecology and management, 221(1-3), pp.278-284.

Lewis, S.L. (2006). Tropical forests and the changing earth system. Philosophical Transactions of the Royal Society B: Biological Sciences, 361(1465), pp.195-210.

Lewis, 2009. Biodiversity change and ecosystem function in tropical forests.

Lindenmayer D, Luck G. (2005) Synthesis: thresholds in conservation and management. Biol Conserv 124: 351–354. doi:10.1016/j.biocon.2005.01.041.

Lindenmayer, D & Laurance, W. (2012), 'A history of hubris - Cautionary lessons in ecologically sustainable forest management', Biological Conservation, vol. 151, no. 1, pp. 11-16.

Lindner, A., & Sattler, D. (2012). Biomass estimations in forests of different disturbance history in the Atlantic Forest of Rio de Janeiro, Brazil. New Forests, 43(3), 287-301.

Louzada et al. (2016), Do space-for-time assessments underestimate the impacts of logging on tropical biodiversity? An Amazonian case study using dung beetles. J Appl Ecol, 53: 1098–1105. doi:10.1111/1365-2664.12657

Margono et al. (2012). Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. Environ. Res. Lett. 7, 34010.

Martin, P.A., Newton, A.C., Pfeifer, M., Khoo, M. and Bullock, J.M. (2015). Impacts of tropical selective logging on carbon storage and tree species richness: A meta-analysis. Forest Ecology and Management, 356, pp.224-233.

Medjibe VP, Putz FE, Starkey MP, Ndouna AA, Memiaghe HR (2011) Impacts of selective logging on above-ground forest biomass in the Monts de Cristal in Gabon. For Ecol Manage 262:1799–1806

Medjibe, V.P., Putz, F.E. & Romero, C. Environmental Management (2013) 51: 524. https://doi.org/10.1007/s00267-012-0006-4

Miteva, D.A., Loucks, C.J. and Pattanayak, S.K. (2015). Social and environmental impacts of forest management certification in Indonesia. PloS one, 10(7), p.e0129675.

Mongabay (2015). Brazilian Amazon nears deforestation threshold past which wildlife may crash, says study. Available at: https://news.mongabay.com/2015/05/brazilian-amazon-nears-deforestation-threshold-past-which-wildlife-may-crash-says-study/

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A. and Kent, J. (2000). Biodiversity hotspots for conservation priorities. Nature, 403(6772), p.853.

Nasi and Frost (2009). Sustainable Forest Management in the Tropics: Is Everything in Order but the Patient Still Dying? Ecology and Society 14(2): 40.

NRCAN (Natural Resources Canada) (2018). Definition of basal area. Available at: http://cfs.nrcan.gc.ca/terms/330

Nepstad et al. (1999). Large–scale impoverishment of Amazonian forests by logging and fire. Nature, 398, 505–508.

Numata et al. (2011). Carbon emissions from deforestation and forest fragmentation in the Brazilian Amazon Environ. Res. Lett. 6.

Ochoa-Quintero, J.M., Gardner, T.A., Rosa, I., Barros Ferraz, S.F. and Sutherland, W.J. (2015). Thresholds of species loss in Amazonian deforestation frontier landscapes. Conservation Biology, 29(2), pp.440-451.

Osazuwa-Peters, O. L., Chapman, C. A., & Zanne, A. E. (2015). Selective logging: does the imprint remain on tree structure and composition after 45 years?. Conservation physiology, 3(1), cov012.

Pan, Y., Birdsey, R.A., Fang, J., Houghton, R., Kauppi, P.E., Kurz, W.A., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G. and Ciais, P. (2011). A large and persistent carbon sink in the world's forests. Science, p.1201609.

Panlasigui, S., Rico-Straffon, J., Swenson, J., Loucks, C.J. and Pfaff, A. (2015). Early Days in the Certification of Logging Concessions: Estimating FSC's Deforestation Impact in Peru and Cameroon.

Pardini et al. (2010) Beyond the Fragmentation Threshold Hypothesis: Regime Shifts in Biodiversity Across Fragmented Landscapes. PLOS ONE 5(10): e13666.

Paul et al. (2004) Arrested succession in logging gaps: Is tree seedling growth and survival limiting. Afr J Ecol 42: 245–251. Available: http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2028.2004.00435.x/abstract

Pearce, D., Putz, F.E. and Vanclay, J.K. (2003). Sustainable forestry in the tropics: panacea or folly?. Forest Ecology and Management, 172(2-3), pp.229-247.

Pearson, T.R., Brown, S. and Casarim, F.M. (2014). Carbon emissions from tropical forest degradation caused by logging. Environmental Research Letters, 9(3), p.034017.

Pearson, T.R., Brown, S., Murray, L. and Sidman, G. (2017). Greenhouse gas emissions from tropical forest degradation: an underestimated source. Carbon balance and management, 12(1), p.3.

Phillips, H.R., Newbold, T. and Purvis, A. (2017). Land-use effects on local biodiversity in tropical forests vary between continents. Biodiversity and Conservation, 26(9), pp.2251-2270.

Pimm, S.L. and Raven, P. (2000). Biodiversity Extinction by Numbers. Nature, 403, 843-845.

Poore (1993). Changing Landscapes: The Development of the International Tropical Timber Organization and its Influence on Tropical Forest Management. Earthscan Publications, London.

Potapov, P., Hansen, C., Laestadius, L., Turubanova, S., Yaroshenko, A., Thies, C., Smith, W., Zhuravleva, I., Komarova, A., Minnemeyer, S., Espinova, E. (2017). The last frontiers of wilderness: Tracking loss of intact forest landscapes from 2000 to 2013. Science Advances 3 (1): 2375-2548, doi: 10.1126/sciadv.1600821.

Poulsen, J.R., Clark, C.J. and Bolker, B.M. (2011). Decoupling the effects of logging and hunting on an Afrotropical animal community. Ecological Applications, 21(5), pp.1819-1836.

Putz et al. (2008). Reduced-impact logging: Challenges and opportunities. Forest Ecology and Management 256: 1427–1433.

Putz FE, Zuidema PA, Synnott T, Peña-Claros M, Pinard MA, et al. (2012) Sustaining conservation values in selectively logged tropical forests: the attained and the attainable. Conservation Letters 5: 296–303.

Putz, F. E., and R. Nasi. (2009). Carbon benefits from avoiding and repairing forest degradation. In A. Angelsen, editor. Realising REDD: national strategies and policy options. CIFOR, Bogor, Indonesia.

Putz, F.E. et al. (2000) Why poor logging practices persist in the tropics, Conserv. Biol. 14, 951-956

Putz, F.E., Zuidema P.A., Pinard M.A., Boot R.G.A., Sayer J.A., et al. (2008). Improved Tropical Forest Management for Carbon Retention. PLoS Biol 6(7): e166. doi:10.1371/journal.pbio.0060166

Rana, Pushpendra and E. Sills (2017). Does Certification Change the Trajectory of Tree Cover in Working Forests in the Tropics? An Application of the Synthetic Control Method of Impact Evaluation (CEnREP Working Paper No. 17-018). Raleigh, NC: Center for Environmental and Resource Economic Policy.

Ratnam, W., Rajora, O.P., Finkeldey, R., Aravanopoulos, F., Bouvet, J.M., Vaillancourt, R.E., Kanashiro, M., Fady, B., Tomita, M. and Vinson, C. (2014). Genetic effects of forest management practices: global synthesis and perspectives. Forest Ecology and Management, 333, pp.52-65.

Robinson, et al. (1999). Wildlife harvest in logged tropical forests Science, 284, pp. 595-596.

Romero, C., Sills, E.O., Guariguata, M.R., Cerutti, P.O., Lescuyer, G. and Putz, F.E. (2017). Evaluation of the impacts of Forest Stewardship Council (FSC) certification of natural forest management in the tropics: a rigorous approach to assessment of a complex conservation intervention. International Forestry Review, 19(S2), p.1.

Rudel TK. (2013) The national determinants of deforestation in sub-Saharan Africa. Phil Trans R Soc B 368: 20120405. http://dx.doi.org/10.1098/rstb.2012.0405

Salzmann, U. & Hoelzmann, P. (2005). The Dahomey gap: an abrupt climatically induced rain forest fragmentation in West Africa during the late Holocene. Holocene 15, 190–199.

Schulze M, Grogan J, Landis MR, Vidal E. (2008a). How rare is too rare to harvest? Management challenges posed by timber species occurring at low densities in the Brazilian Amazon. Forest Ecology Management 256: 1443–1457.

Siegert, G. Ruecker, A. Hinrichs & A. A. Hoffmann, (2001). Increased damage from fires in logged forests during droughts caused by El Niño. Nature 414, 437–440.

Sist, P., Fimbel, R., Sheil, D., Nasi, R., Chevallier, M.-H. (2003)a. Towards sustainable management of mixed dipterocarp forests of South-east Asia: moving beyond minimum diameter cutting limits. Environ. Conserv. 30, 364–374.

Sist, P., Picard, N., Gourlet-Fleury, S. (2003)b. Sustainable cutting cycle and yields in a lowland mixed dipterocarp forest of Borneo. Ann. For. Sci. 60, 803–814.

Slik JWF, Verburg RW, Keßler PJA. Effects of fire and selective logging on the tree species composition of lowland dipterocarp forest in East Kalimantan, Indonesia. Biodivers Conserv. 2002; 11: 85–98.

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in Indonesia (Daniela A. Miteva ,Colby J. Loucks, Subhrendu K. Pattanayak) Published: July 1, 2015 https://doi.org/10.1371/journal.pone.0129675
Stork et al. (2009). Vulnerability and Resilience of Tropical Forest Species to Land-Use Change. Conservation Biology, 23: 1438–1447. doi:10.1111/j.1523-1739.2009.01335.x
Struhsaker, T.T. (1998). A biologist's perspective on the role of sustainable harvest in conservation.
Swift TL, Hannon SJ. (2010) Critical thresholds associated with habitat loss: a review of the concepts, evidence, and applications. Biol Rev Camb Philos Soc 85: 35–53. doi:10.1111/j.1469-185X.2009.00093.x. PubMed: 19930172.
Tacconi, L., Moore, P.F. & Kaimowitz, D. Mitig Adapt Strat Glob Change (2007) 12: 55. https://doi.org/10.1007/s11027-006-9040-y
Thompson, I.; Mackey, B.; McNulty, S,; and Mosseler, A. (2009). Forest Resilience, Biodiversity, and Climate Change. A synthesis of the biodiversity/resilience/ stability relationship in forest ecosystems. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 43.
UNFF (2009). United Nations Forum on Forests. 2007. Non-legally Binding Instrument on All Types of Forests. UNFF Secretariat. http://www.un.org/esa/forests/pdf/session_documents/unff7/UNFF7_NLBI_draft.pdf
Vidal, E., West, T.A. and Putz, F.E. (2016). Recovery of biomass and merchantable timber volumes twenty years after conventional and reduced-impact logging in amazonian Brazil. Forest Ecology and Management, 376, pp.1-8.
Wheeler, C.E., Omeja, P.A., Chapman, C.A., Glipin, M., Tumwesigye, C. and Lewis, S.L. (2016). Carbon sequestration and biodiversity following 18 years of active tropical forest restoration. Forest Ecology and Management, 373, pp.44-55.
Whitworth et al. (2016). How much potential biodiversity and conservation value can a regenerating rainforest provide? A 'best-case scenario' approach from the Peruvian Amazon. Tropical Conservation Science Vol. 9 (1): 224-245, 2016
Wilcove DS, Giam X, Edwards DP, Fisher B, Koh LP. Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia. Trends Ecol Evol. 2013; 28: 531–540. pmid:23764258
Wilcove et al. (2013). Navjot's nightmare revisited: logging, agriculture, and biodiversity in Southeast Asia.
World Bank. (2008). Forests Sourcebook. Practical Guidance for Sustaining Forests in Development Cooperation. Washington D.C.
Pan et al. (2011). A large and persistent carbon sink in the world's forests. Science, 333, pp. 988-993
Zimmerman, B.L. and Kormos, C.F. (2012). Prospects for sustainable logging in tropical forests. BioScience, 62(5), pp.479-487.
Zhuravleva, et al. (2013). Satellite-based primary forest degradation assessment in the Democratic Republic of the Congo, 2000–2010. Environ. Res. Lett. 8, 024034.

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