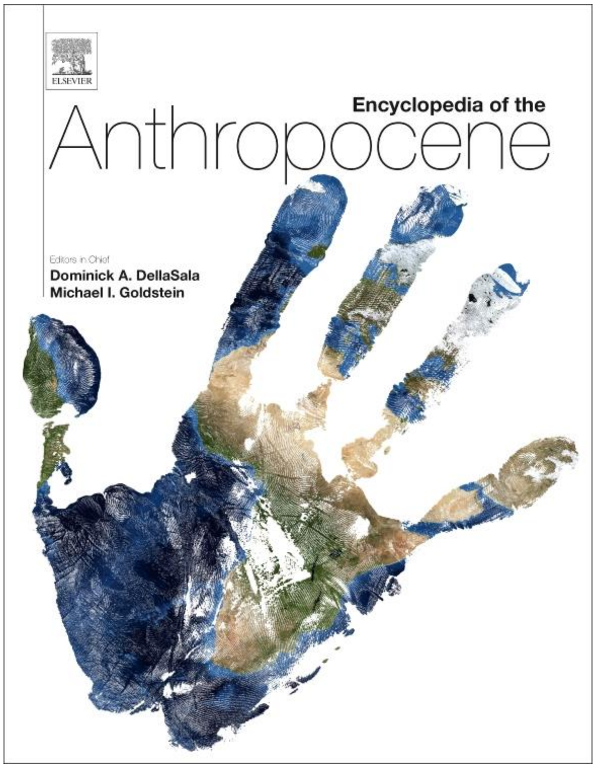

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Primary Forests: Definition, Status and Future Prospects for Global Conservation

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What Is a Primary Forest?

Earth has lost about 35% of its preagricultural forest over centuries. Earth's remaining forests cover some 4 billion hectares, widely distributed in tropical, temperate, and boreal regions (Mackey et al., 2014). Only about 32% (~1.3 billion hectares) of the planet's current forest cover is primary forest (FRA, 2012; Morales-Hidalgo et al. 2015). Most forests (57%) have been degraded to some degree by development, logging, and road building (FAO, 2012).

Primary forests therefore are a priority for conservation given they tend to support high concentrations of biological diversity, sequester and store substantial amounts of carbon, and play a vital role in hydrological cycles among myriad other ecosystem services (Mackey et al., 2014). They are also critically important for cultural and spiritual reasons, as a source of livelihoods, and for the Indigenous Peoples and local communities around the world who call these forests home. Thus, understanding and conserving primary forests is a global conservation goal and is increasingly a focus of large conservation organizations (e.g., the International Union for Conservation of Nature is developing a policy on primary forests) as well as coalitions of nongovernmental organizations (http://primaryforest.org).

Forests whose composition and structure largely reflect natural processes are known by various analogous terms including "primary," "frontier," "virgin," and "old growth." Here we use the term "primary forest" as it is the terminology of choice at the intergovernmental level. The most widely used definition of primary forest is the United Nations Food and Agriculture Organization's (FAO) definition from its 2015 Forest Resource Assessment (FAO, 2012):

[redacted]

According to FAO (2012) primary forests have the following unique characteristics:

- Natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure, and natural regeneration processes;
- sufficient geographic extent to maintain "natural characteristics"; and
- no known significant human intervention or the last significant human intervention was long enough ago to have allowed the natural species composition and processes to have become re-established.

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The Secretariat of the Convention on Biological Diversity (SCBD, 2001) uses a similar, but broader definition, stating that a "primary forest is a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age." SCBD further notes "direct human disturbance" refers to "the intentional clearing of forest by any means (including fire) to manage or alter them for human use." Finally, SCBD adds that primary forests are "forests that are used inconsequentially by indigenous and local communities living traditional lifestyles relevant for the conservation and sustainable use of biological diversity." The reference to Indigenous People is important as it highlights that it is the intensity of human activity rather than the presence of people per se that matters most to the conservation of a primary forest.

Building on the definitions provided by the FAO and Secretariat of the Convention on Biological Diversity, we suggest that the term "primary forest" describes natural forests that are:

- Largely undisturbed by industrial-scale land uses such as logging, mining, human-caused fires, dam, and road construction;
- the result of ecological and evolutionary processes including the full range of successional stages from new to old forest and with natural disturbance processes operating within historic bounds;
- more likely to possess the full complement of their evolved, characteristic plant and animal species with few if any exotics;
- dominated by a largely continuous tree canopy cover; and
- have unpolluted soil and water.

Some of the key attributes of primary forest are discussed further herein.

Intactness

The defining characteristics of primary forest are often discussed in terms of intactness. At the bioregional and landscape levels, intactness generally refers to the extent to which industrial land use, industrial extractive activity, roads, hydropower, and other capital-intensive works have fragmented a primary forest. The term "intact forest landscape (IFL)" is used to describe an unbroken expanse of natural ecosystems within a zone of current forest extent that has not been degraded and fragmented by modern human land use and industrial activity (Potapov et al., 2008). In general, an IFL will be dominated by primary forests and retain the full complement of its characteristic native biodiversity. The vegetation structure and composition in these forests is largely the product of natural processes, including natural disturbance events like wildfire, storms, insect outbreaks, and floods that result in resetting forest succession to early seral stages.

As with a primary forest generally, there is no single size threshold for delineating intact from fragmented forested landscapes. The ecological and conservation significance of a given intactness threshold varies with the purpose of the study, climatic zone where the study is being undertaken, and landscape context in terms of natural gradients and land use history. A 50,000-hectare threshold has been used for global reconnaissance assessments (Potapov et al., 2008). Contiguous areas meeting this threshold are called IFLs (Potapov et al., 2008). Most IFLs are found in boreal and tropical forests. Within the temperate forest zone only about 3% of the world's primary forest is in blocks >50,000 hectares, reflecting the extent to which these forests have been cleared (Strittholt et al., 2006; Mackey et al., 2014; Lindenmayer et al., 2012; Mackey et al., 2014). Here, as in other highly fragmented and degraded forests globally, remnant patches of primary forest play a vital role as wildlife habitats, restoration benchmarks, potential climate refugia, and core areas in protected area networks. Landscape context is critical as an area of heavily disturbed forest embedded in a matrix of structurally and compositionally intact forest has significantly improved options for restoration (Chazdon, 2003).

The meaning of intactness also encompasses a number of ecological characteristics.

Structurally intact

At the stand level, structural intactness refers to the vertical vegetation structure measured in terms of canopy height, overstory tree cover, and canopy layering. Degraded forests typically have a simplified structure and are dominated by younger and smaller trees. At larger spatial scales, a primary forest will be mostly continuous across the landscape, though encompassing a mosaic of successional stages depending on the natural disturbance regime along with other ecosystem types associated, for example, with localized substrate or ground water conditions. Therefore, at this scale, structural intactness describes the extent to which the forest extent has been geographically fragmented into small blocks by land use impacts, including roads and development, cleared and degraded lands.

Biologically intact

While structural intactness refers to the integrity of a forest's dominant vegetation vertically and horizontally, biological intactness refers to the extent the forest ecosystems are populated by native species that have evolved in and are characteristic of the ecosystem, including forest-dependent species and large apex predators. Various human impacts can result in the loss of native species and a decrease in biological intactness. Degradation at the stand and landscapes scales results in a loss of habitat conditions for dependent species, especially those that require interior forest conditions. Extraction of forest resources can result in local extirpation of dependent species, especially large mammalian predators, but also a wide range of seed dispersers from birds to small mammals. The absence of native species has profound implications for the adaptive capacity of a forest ecosystem due to the functional roles played by species in the ecosystem such as regulation of prey populations, pollination, and seed dispersal (Harrison et al., 2013; Peres et al., 2016).

Ecologically intact

The term "ecological" refers to dynamic ecological processes operating at the landscape scale. A key example is long distance movement of animals such as seasonal migrations of birds and butterflies. Other less appreciated examples are hydro-ecological processes including the role played by primary forests in maintaining water quality and recharging aquifers that are vital for groundwater-dependent ecosystems (Soulé et al., 2004). Further, wildland fire, particularly of mixed intensities, is important in maintaining the full suite of seral conditions at large spatio-temporal scales (DellaSala and Hanson, 2015a).

Bio-Culturally intact

Given the long association of Indigenous Peoples with primary forests, we can also recognize a "bio-culturally intact" forest landscape where the traditional custodial communities still reside along with their cosmology and sacred knowledge, beliefs and taboos that inform an ethical system, knowledge of natural history, including ecological relations of plants, animals, habitats, ecosystem dynamics, land and water resources, phytomedicinal compounds, climate, weather, natural resource use and management, cultural heritage such as oral histories, and practices such as rituals and ceremonies (Mackey and Claudie, 2015).

It follows that intactness is not a single binary variable but rather represents a multidimensional gradient of increasing infrastructure and industrial land use on the biodiversity, structure, and functions of natural forests. Various metrics of intactness have been developed, such as indices of wilderness quality based on measures of remoteness from urban settlements and modern infrastructure and the degree of ecological impacts from industrial activity (Leslie et al., 1988).

There is convergence in the literature that wilderness areas are relatively large and intact landscapes (Kormos, 2008; Watson et al., 2009). Wilderness areas that are forested, whatever the thresholds of delineation, would therefore constitute IFLs. However, it should be noted that intact areas this large are no longer possible in many regions such as the contiguous United States and Europe (Heilman et al., 2002). In the U.S. forest roadless areas >2000 ha have been recognized in forest policies for their relatively unique values.

Stand Age and Seral Stage

In the scientific literature, the term "primary" refers to both (i) natural forests largely undisturbed by industrial-scale land use and (ii) a stand of natural forest that has passed through seral stages and has reached late successional stages (this can be defined as when forest growth begins to level off—the culmination of mean annual increment of tree growth—along with older forest structures such as snags, vertical layering, and coarse woody debris). In forest ecosystems, species with specialized life history traits occupy different successional stages in development following natural disturbance such as the death of canopy trees that create gaps in the dominant overstory. Typically, fast growing plants and shorter-lived tree species dominate gaps, followed by slowly growing longer-lived ones that tolerate shaded environments (Chazdon et al., 2009; 2010). IFLs are usually dominated by late successional, primary forest patches with a scattering of patches representing younger seral stages created by natural disturbance events overtime.

While old-growth is a commonly used term for primary forest, there is no generally agreed definition of old growth or age of trees because age varies with site, regional, and biome specific factors. While many primary forest trees are long lived (300–1000 years; Vieira et al., 2005), old growth is generally defined according to the presence of specific forest structures including large, older trees, snags, coarse woody debris, and canopy layering that take decades to centuries to acquire (Lindenmayer et al., 2014).

Given sufficient time (i.e., centuries) and depending on the scale and intensity of disturbance, forests that are disturbed by human activities in the past may naturally regain many of the features that characterize primary forests while others will require restoration. It is also possible for logged and naturally disturbed forest to contain some mature (legacy) trees and other structures that if present could speed up succession to older forests.

Geographic Extent

There is no simple answer to the question of what is the minimum size for a forest, let alone that of a primary forest. We tend to define "large" and "small" by reference to human dimensions. Natural processes operate at different spatio-temporal scales—sometimes very slowly over centuries and requiring very large areas—hundreds of thousands of hectares or more. Furthermore, certain natural features are only apparent at specific scales. Thanks in no small part to satellite imagery, we have an increasing appreciation of the range of geographic and temporal scales at which species, ecological communities, and ecosystem processes operate, the emergence of different ecosystem properties at different scales, and the complex myriad ecological connections that promote resilience (Levin, 1992).

Most field surveys undertaken by ecologists and foresters occur at the stand-level that is typically sampled in a quadrant $\leq 1\ ha^{-1}$(100×100 m). Conventional, stand level perspectives of forest management have influenced international definitions of forest in terms of a minimum area, canopy height, and canopy density that range from 0.01–5 hectares minimum area, 2.5–10 m minimum height, and 10%–30% minimum canopy cover (FAO, 2010a; FAO, 2012; UNFCCC, 2005). At this fine spatial scale, intactness can be appropriately considered in terms of the vegetation structure—canopy height, cover, number of vertical layers, and richness of plant growth forms.

From a conservation perspective, and while the stand level is important for foresters, it does not entail ecological and evolutionary features that become apparent at larger geographic extents. Under natural conditions, primary forest at the landscape scale will encompass a diversity of forest ecosystems in a mix of successional stages reflecting natural heterogeneity in the physical conditions such a soil type along with stands influenced by natural disturbance events such as storms and wildfire. The bioregional scale (~1 million ha) is needed to consider the larger influences such as migrations, apex predators, and large-scale natural disturbances (e.g., wildfire, hydrology). The larger the extent of a forested landscape, the more likely we are to find heterogeneity due to edaphic and topographic conditions and a history of natural disturbance.

Benefits of Conserving Primary Forests

The scientific evidence that primary forests are unique and provide a myriad of ecosystem benefits and biodiversity has strengthened in recent years (Mackey et al., 2014). Combined with their increasing losses and ongoing threats, there is new impetus to prioritize the conservation of remaining primary forests. In this section we review some of the key benefits of primary forests.

Biodiversity

Primary forests are the most biodiverse terrestrial ecosystems on the planet, harboring many species new to science and not yet described, and are repositories for species that cannot persist in secondary and degraded forests (Barlow et al., 2007; Gibson et al., 2011). The full complement of primary forest fauna is also critical to maintaining the structure and composition of these forests as animals—especially pollinators and seed dispersers—and plants interact to provide key ecosystem functions. Many large mammals and birds play an essential role in eating fruit and dispersing the seeds elsewhere in the forest. Other trees and plants require pollination by a particular species—bird, butterfly, bee, nectar-feeding bat, or even a monkey—to reproduce. If these seed dispersers or pollinators are no longer present, for example, because they have been hunted to extinction or locally extirpated through human actions, it may not be possible for some tree species to regenerate, resulting in a significantly altered forest (Abernethy et al., 2013; Harrison et al., 2013; Muller-Landau, 2007; Peres et al., 2016).

Ecosystem Services

The superior ecological integrity and biodiversity of primary forests compared to secondary and degraded forests underpins the quality of the ecosystem services they provide. For example, Earth's terrestrial ecosystems maintain significant stock stores of carbon that in total (2500 Gt C) store more carbon then found in known fossil fuel reserves (1472 Gt C) or in the atmosphere (589 Gt C) (IPCC, 2013). Most terrestrial carbon is in forests, and, primary forests in particular contain 30%–70% more carbon than logged or otherwise degraded forests (Mackey et al., 2014). This is because most of the biomass carbon in a forest is stored in large, old trees, which are usually the first to be removed by logging operations. Contrary to earlier assumptions, forests in late successional stages (>200 years) and old-growth forests aged up to 800 years can continue to function as sinks for carbon (Luyssaert et al., 2008; Pan et al., 2011). Old-growth tropical forests, for example, accumulate around five tonnes of carbon per square kilometre a year in living biomass, yielding a global carbon sink of 1.3 billion tonnes of carbon per year (Lewis et al., 2009; Luyssaert et al., 2008).

It is the rich biodiversity of primary forests—many tropical forests have several hundred tree species per hectare (Condit et al., 2005)—that makes them more resilient to disturbance and environmental change, which in turn makes the carbon in a primary forest more securely stored than in a degraded or planted forest (Thompson et al., 2009). Researchers have found that in the tropical forests of Amazonia only 1.4% of forest tree species account for 50% of the carbon capture value of these forests (Fauset et al., 2016). What is more, if one looks at the species making up that 1%, most are dispersed by forest frugivores, such as monkeys, large frugivorous birds, forest-floor tortoises, bats, or pigs (Peres et al., 2016).

The role of forests in general, and in particular primary forests, in mitigating CO_2 emissions is of increasing importance as the world community seeks to meet emission reductions under the 2016 ratified Paris Agreement of the United Nations Framework Convention on Climate Change. Currently, estimate of emissions from deforestation and degradation account for at least a tenth of annual greenhouse gas emissions, that is to say >1 billion tonnes of carbon (or 3.67 billion tonnes of CO_2) each year (Le Quéré et al., 2015). Limiting global warming to <2°C requires anthropogenic emissions to drop to zero between 2050 and 2080. Clearly, the key mitigation action needed is to phase out fossil fuel as quickly as possible. However, given their current and potential emissions, avoiding emissions from deforestation and degradation in the tropics, and optimizing the sequestration potential of degraded tropical forests through restoration is a necessary part of a comprehensive approach to solving the climate change mitigation problem (Houghton et al., 2015). Climate benefits will be greater if boreal and temperate primary forests are also protected and degraded forests in these biomes are restored as these forests are known to be globally carbon-dense (Krankina et al., 2014).

It is important to emphasize that primary forests have a special contribution to make to climate mitigation given their denser carbon stocks and higher degree of resilience to disturbance events compared to logged and degraded forests. Crucially, this contribution has now been acknowledged in the Paris Agreement, which recognizes the importance of forest carbon "sinks" and "reservoirs" as well as the need for "ecological integrity" in meeting the challenges of climate change and identifies forests and ecosystems as fundamental to the world's climate change response. Thus, for the first time, governments view forests as essential for achieving global climate mitigation goals, and recognize that biodiversity and human rights must be protected when taking climate action.

Forests are also an important component of the global and local water cycles and depend on receiving sufficient water to support the growth and maintenance of the canopy cover that is one of their defining features. The process of photosynthesis by which trees absorb CO_2 from the atmosphere and grow new biomass requires significant volumes of water. Forests, therefore, are generally found in places with annual rainfall >500 mm, depending on potential evaporation rates (Holdridge, 1967). For every kilogram of CO_2 sequestered, plants pump about 120 L of water from the soil up into the atmosphere. The amount and rate of water evaporated into the atmosphere and the quantity and quality of water discharged from a watershed therefore changes with the type, density, and age of the vegetation cover.

The water transpired from large expanses of forest serves to recycle precipitation, resulting in a wetter regional climate than would otherwise occur. This phenomenon is a well-documented positive feedback between forests and regional climate, for example, about half the precipitation in the Amazon originates from evapotranspiration (Salati et al., 1979). Conversely, deforestation reduces precipitation recycling and contributes to climatic drying. Replacing old forests with young plantings can result in reduced water flow due to greater transpiration; disturbance can reduce the mean annual runoff by up to 50% compared to that of a mature forest, and can take 150 years to recover (Jayasuriya et al., 1993).

Forested watersheds reduce storm runoff, stabilize streambanks, shade surface water, cycle nutrients, filter pollutants, and their waters are often cooler with less sediment, nutrients, and chemicals than water from other lands (Furniss et al., 2010). Primary forest with intact canopy, understory, leaf litter, and organically enriched soil is the best watershed land cover for minimizing erosion by water and any land-use activity that removes this protection increases erosion (Dudley and Stolton, 2003). Intact forest watersheds therefore generally result in higher quality water than other land covers and alternative land uses such as logging that have been shown to increase sediment (DellaSala et al., 2011). This is also why primary forests are indispensable for maintaining much of the world's freshwater biodiversity, which is often found in streams, wetlands, and lakes within primary forests. By some estimates, Canada's boreal forests include a quarter of the world's wetlands and almost 80 million hectares of surface freshwater, most of which is low in pollutants (Pew, 2011).

Primary forest canopies, especially in the tropics, dramatically modify microclimatic conditions. The dense forest canopy reflects and absorbs sunlight during the day, reducing the amount of energy reaching the understory and the ground. Less energy reaching the ground lowers surface evaporation and raises humidity levels compared to degraded forests. The microclimate of primary forests therefore buffers the understory plants and animals from temperate highs and lows and local droughts. The dampened micro-conditions also make primary forests less vulnerable to wildfire (Cochrane and Barber, 2009; Taylor et al., 2014). Major ecological processes, including photosynthesis, decomposition, and the spread of diseases, are all regulated by the special microclimate created by these forests.

Sociocultural and Socioeconomic Benefits

Primary forests also provide critical services and benefits in support of local people and biocultural values. Approximately 400 million people depend directly on forests for their livelihoods, and many more benefit indirectly (FAO, 2010). Even where forests do not play a central role in livelihoods on a day-to-day basis, they may provide a crucial safety net, for example, during times of civil conflict (Bhaskar et al., 2015). The cultures as well as the livelihoods of Indigenous Peoples are inextricable linked with the forests they inhabit. The forest is not viewed simply as a resource to be exploited but rather as their ancestral home, central to their cosmologies, and to which they are personally linked and have traditional obligations (Mackey and Claudie, 2015).

Indigenous Peoples make an enormous contribution to primary forest conservation globally. Recent examples include from the recent, First Nations–led World Heritage nomination of Pimachiowin Aki, a 3.34 million hectare area of highly intact boreal forest, the strong indigenous support of the Sierra del Divisor National Park in Peru, and the vast Kaa-Iya National Park in the dry forests of Bolivia's Gran Chaco. The Kayapó in Brazil are known the world over for their impassioned defense of their 11.5 million hectare territory in the Rio Xingu region from logging and mining pressures. Members of the Prey Lang Community Network in Cambodia are working to protect roughly 360,000 hectares of forest, with a core of about 90,000 hectares of some of the last primary forests in the country. Similarly, the Tenkile Conservation Alliance, a network of 50 communities in Papua New Guinea, is working to protect the Torricelli Mountain Range, which spans 200,000 hectares, and have it officially designated as a conservation area. Similarly, numerous community organizations in the Democratic Republic of the Congo are working to protect Virunga National Park from extractive activities.

Status and Extent of Primary Forests

Primary forests are found in all climates—tropical, boreal, and temperate—wherever there is sufficient rainfall to support a canopy of trees. Almost all (98%) of the world's primary forests occur in just 25 countries (Mackey et al., 2014; Morales-Hidalgo et al., 2015), 75% in seven countries, the Russian Federation, Canada, Brazil, the Democratic Republic of the Congo, United States, Peru, and Indonesia, (Morales-Hidalgo et al., 2015).

Primary forests are in decline globally, although the extent of forest losses, in part, varies with the definition of forest used, data quality and reporting, and mapping approaches. FAO (2010b) noted that primary forests were being degraded or cleared at the rate of at least four million hectares per year. This was most likely a significant underestimate as country FRAs are based on self-reporting, and neither the Democratic Republic of Congo nor Indonesia reported data on primary forests for the 2010 period (DellaSala et al., 2012).

The 2015 FAO Forest Resource Assessment (FRA) found that the total primary forest area reported by 234 countries had decreased by 31 million hectares from 1990 levels, a decline of 2.5% or 1% per decade (Morales-Hidalgo et al., 2015). However, in the tropics, country assessments noted a much higher decline of 62 million hectares of primary forest since 1990; a statistic that understates loss of tropical primary forest as Indonesia and Venezuela did not report in the 2015 FRA (Morales-Hidalgo et al., 2015). The subtropics actually experienced an estimated loss of five million hectares of primary forest (Morales-Hidalgo et al., 2015). The FRA also reported some notable gains, including five million hectares of primary temperate forests (largely in the United States) and 30 million hectares in the boreal forest (largely in the Russian Federation). However, these reported gains were most likely due to two factors: (1) more countries reported on primary forests in 2015 compared with 2010; and (2) certain countries had reclassified some of their forests and were now reporting them as primary forests (e.g., Costa Rica, Japan, Malaysia, Russian Federation, and United States). Additionally, gains in forest cover are not necessarily associated with recovery of late-successional forests or forests of high biological diversity (DellaSala et al., 2012).

We note that while FAO assessments require countries to report on primary forests, countries define "primary forests" differently and some do not report on this category at all, or do not report consistently for succeeding five-year assessments, which creates inconsistencies in reporting and leads to data quality issues (DellaSala et al., 2012). FRA statistics are also contested in the literature. For example, a recent analysis based on satellite imagery suggests that net forest loss in the tropics in 34 countries from 1990 to 2010 accelerated by 62% rather than decreasing by 25% as claimed by the recent FRA (Kim et al., 2015). A number of studies also indicate primary forests are under greater threat than ever before. Haddad et al. (2015) suggest 70% of the world's forests are now within 1 km of a forest edge and therefore subject to the degrading effects of fragmentation. Similarly, Ritters et al. (2015) reported that we are losing the core or interior areas of forests and estimates the loss between 2000 and 2012 at 376 million hectares.

Notably, only about one fifth of the world's primary forest is found in IUCN Protected Areas Categories I–VI, which represents approximately 5% of preagriculture natural forest cover (Mackey et al., 2014). Therefore, primary forests remain vulnerable to additional development and logging as pressures increase to harvest natural resources globally.

Why Are Primary Forests in Decline?

Broadly speaking, over the past decade industrial activity has become the principal threat to primary forests (Laurance et al., 2015; Butler and Laurance, 2008). Industrial agriculture, mining, oil and gas extraction, industrial logging, conversion of forests for palm oil production, woody biomass for energy, and infrastructure development from roads to hydroelectric projects are proliferating in all forest biomes. Industrial agriculture, and in particular so-called forest risk commodities including palm oil, soy, sugar cane, cocoa, cattle, and raw materials for bioenergy are expanding rapidly and are responsible for the majority of global deforestation over the past several decades (Fearnside, 2005). Industrial logging and road building are the principal initial causes of primary forest degradation and fragmentation, often followed by additional threats caused by increased accessibility. Indeed, in many places, logging often provides the infrastructure and financing for subsequent industrial agriculture, or opens doors to other extractive activities, such as mining (Laurance et al., 2009).

Beyond direct forest degradation, fragmentation, and deforestation from road building, significant indirect impacts, are associated with the spread of roads through intact primary forest landscapes. For example, in Amazonia, 95% of tropical deforestation occurs within 50 km of a road or a river, because roads generate new developments, facilitate illegal logging, mining, or other activities, and encourage colonization of remote areas (Barber et al., 2014; Laurance et al., 2009). Road building in temperate regions has impacted nearly every forest ecosystem: even boreal forests of the far north are not immune to road building for logging, mining, and energy development (DellaSala, 2011; Haddad et al., 2015). The herringbone pattern of colonization and deforestation immediately following road building is prevalent around the world, with perhaps the best examples being the construction of the Trans-Amazonian Highway and other Amazonian highways beginning in the early 1970s, which resulted in devastation and the annihilation of many previously uncontacted indigenous tribes (Fearnside, 2007). Roads also facilitate hunting, not the least to supply demand from logging and mining operations (Laurance et al., 2006). Indeed, many logging and mining companies that claim their activities are "sustainable" never take hunting into account. In some regions, most notably Central Africa, hunting associated with logging roads has been so extensive that most large mammals have been extirpated from the forest. The term "empty forest syndrome" was coined to describe this phenomenon (Redford, 1992). Additionally, roads provide a vector for weed invasions, a source of stream sedimentation and water quality problems, and increase the risk of human-cause fire ignitions among other problems (DellaSala and Frost, 2001).

Is Industrial Logging of Primary Forests Sustainable?

The intent of many conservation groups and others over the past several decades was that carefully defined best practices might reduce impacts of industrial logging and make the industry sustainable, while certification schemes would help companies applying best practices by creating consumer demand for their "greener" timber products. In this way, sustainable industrial logging might provide an economic incentive to keep forests standing while maintaining primary forest values (Sheil et al., 2010). However, even when implementing best practices, industrial logging causes extensive damage resulting in depletion of forest carbon stocks and significant carbon dioxide emissions, loss of biodiversity, reduction in ecosystem resilience, degradation of water quality, and changed fire regimes (Mackey et al., 2014; DellaSala et al., 2011; DellaSala and Hanson, 2015b; Moen et al., 2014). In addition, logging road networks brings with them additional development and cumulative impacts (Asner et al., 2006; Laurance et al., 2009; Trombulak and Frissell, 2000) leading to additional deforestation, fragmentation, and degradation. In many countries governance in the forest sector remains very weak, corruption is common, and high levels of illegal logging often accompanies legal logging operations (Finer et al., 2014; Zimmerman and Kormos, 2012; Lawson and MacFaul, 2010) compounding the impacts of legal logging.

Hopes that certification would help compensate for governance problems and maintain primary forest values have not materialized. Uptake of certification in the tropics has been weak because best practices are expensive and certified wood products do not sell at a significant premium (Blaser et al., 2011). The process of certification has also been criticized around the world for being flawed, with numerous examples of highly damaging logging operations that have not followed best practices receiving a stamp of approval from some of the most respected certifiers (Elbein, 2016) or certification providing negligible benefits (Blackman et al., 2015; Nordén et al., 2016). Certification in the tropics almost never takes into account the impacts of hunting, which can be devastating even in areas where large tracts of forest are left standing (Wilkie et al., 2011). Several studies have found that certification in the tropics has either demonstrated limited success at reducing deforestation, (Miteva et al., 2015) or has had no impact at all (Blackman et al., 2015; Nordén et al., 2016). Recent evidence also suggests that certification in the tropics can lead to a very perverse impact of increasing deforestation and degradation because certified operators often have increased access to capital, technology, and foreign markets, leading to larger concessions and more intensive operations (Brandt et al., 2016).

One of the greatest limitations to credible certification in the tropics is that recent research demonstrates that industrial logging in primary tropical forests is not only currently unsustainable, but that achieving sustainability using with certified best practices is likely not possible. This is largely because primary tropical forests are so sensitive to disturbance, and tropical timber species grow so slowly, sometimes over hundreds of years, that logged species do not regenerate unless logging occurs at such low intensities and over such long intervals (at least 60 years), that logging no longer makes economic sense (Zimmerman and Kormos, 2012; Shearman et al., 2012). While logging with best practices may be preferable to conventional logging (Brandt et al., 2016 suggests we can no longer say this categorically), industrial logging simply has not proven to be a viable conservation strategy for primary tropical forests.

As underscored by the findings of World Bank's Independent Evaluations Group (WB IEG, 2012), industrial logging in primary tropical forests seems to have provided few local economic benefits, with most of the profits accruing to small number of people, despite the industry's heavy subsidization, and often in boom-bust cycles. We also know that a much larger proportion of global timber demand can be met through agroforestry, plantations on previously cleared lands or on degraded lands (at all times with the free prior and informed consent of communities including traditional land custodians), by using alternative fibers, and by reducing wasteful consumption (Boucher and Elias, 2014). Industrial logging of primary forests in developing countries often targets niche luxury markets for products that are largely status symbols, or markets for products that could be substituted from plantations, such as decking or plywood (Boucher and Elias, 2014).

While less publicized, primary forests in developed countries, dominated by temperate and boreal forests, continue to be cleared and degraded. Forest clearing can be the result of a lack of protection afforded forests on private lands while forest degradation results from industrial logging regimes unable to sustain forest carbon stocks or replicate natural disturbance regimes. The result is a shift to young regenerating and greatly simplified (structure, composition) stands with subsequent loss of biodiversity (DellaSala, 2011). Furthermore, in order to log a forest, even under a less intensive forestry approach, road building is most often needed for access. In temperate and boreal areas, certification schemes often fall short of including representative set-asides as required, especially of intact primary forests. Although these can qualify for protections under FSC's high conservation value forest category, large areas are seldom included (Slosser et al., 2005).

The Need to Prioritize Primary Forest Conservation

The world's primary forests are at a critical juncture. We have better information than ever on their many essential and irreplaceable values, many of which we are only starting to fully grasp. We have much greater clarity on the range of threats, from the expansion and intensification of industrial land use to road building, that lead to forest loss and degradation. The Paris Agreement under the UNFCCC on climate change provides a new opportunity for favorable global policy environment that recognizes the mitigation value of protecting primary forests. Focused international attention on the need to achieve the UN Sustainable Development Goals also provide additional incentive given the quality of the ecosystems services provided by primary forests. Nonetheless, primary forest loss continues at alarming rates and this trend will continue in the absence of prioritizing investments in the conservation.

Fortunately, we have a good understanding of how to keep primary forests intact. Properly managed and well-funded government protected areas, Indigenous Peoples' and community-conserved territories, private protected areas, new protected area designations, and other conservation mechanisms, such as payments for ecosystem services, have the capacity to maintain primary forests and their values. These mechanisms ensure maintenance of biodiversity, continuity of ecosystem services, and respect for rights and long-standing social and cultural relationships with primary forests. This last element is critical as there is frequently significant overlap between indigenous or community-owned lands and primary forests that are rich in biodiversity, carbon stores, and other critical ecosystem services. The challenge, therefore, is to find ways to prioritize the conservation of primary forests in domestic and international policy to help direct the funds and investments needed to change the current trajectory.

Mobilizing the financial resources needed to conserve primary forests globally is a feasible proposition. Large areas of primary forests are publicly owned and their land use subject to government policy. Extensive areas are recognized as customary land whose indigenous or traditional owners seek more ecologically sustainable development pathways. In developing, regions such as South America and Africa, the per hectare cost for protecting land is not high compared to the investments needed to meet many other societal needs. Reducing or eliminating harmful subsidies for activities that destroy or degrade primary forests, including fossil fuel energy subsidies as proposed in a recent International Monetary Fund analysis, could free up tens or even hundreds of billions of dollars. This policy could rapidly provide much greater financial flexibility to support increased funding for protected areas, Indigenous Peoples, and communities, as well as better enforcement to prevent illegal logging, mining, and other activities encroaching on forests. In the final analysis, protection of forests is by far the most cost-effective way of addressing many of our global problems, from climate change to freshwater availability.

Photo: Tilman Jaeger

Photo: Russ Mittermeier

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