UN environment programme

CBD

Convention on Biological Diversity

Distr.
GENERAL

CBD/SBI/3/INF/36
16 May 2021

ENGLISH ONLY

SUBSIDIARY BODY ONIMPLEMENTATION
Third meeting
Online, 16 May – 13 June 2021
Item 8 of the provisional agenda*

A REVIEW OF DEFINITIONS, DATA, AND METHODS FOR COUNTRY-LEVEL ASSESSMENT AND REPORTING OF PRIMARY FOREST - A DISCUSSION PAPER FOR THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Note by the Executive Secretary

1. The Food and Agriculture Organization of the United Nations (FAO) Global Forest Resources Assessment (FRA) provides essential information for understanding the extent of the world's forest resources, their condition, management and uses. Data collected through the FRA reporting process are used to assess progress towards globally agreed targets and inform policy and decisions by governments, civil society and the private sector. Accurate and consistent global reporting on the extent of primary forests is crucial to assess progress towards global objectives such as the Aichi Biodiversity Target 5 forest-related goals and targets proposed in the zero draft of the post-2020 global biodiversity framework, Sustainable Development Goal 15 and the Global Forest Goals of the United Nations Strategic Plan for Forests 2017-2030.

2. As noted in document CBD/SBI/3/10 concerning cooperation with other conventions, international organizations and initiatives, cooperation with the Global Forest Resource Assessment team at FAO led to the compilation of a background report which summarizes past, current and emerging assessment methods for assessing the extent and trend in primary forests. FAO has undertaken to bring together FRA National Correspondents and other experts through a series of workshops to improve the operational methods for data collection and reporting on the extent of primary forests. The goal of these workshops is to increase the consistency of data collection methods and enhance the comparability among countries of estimates of the extent of primary forests. The workshops will be conducted in different regions based on ecological, geographical, language and forest management differences in primary forests. A first workshop for boreal forest countries was conducted in November 2020,[1] and another one for Latin American and Caribbean countries in April 2021.[2]

3. This information document presents the background report for the workshops series. The report is presented in the form and language in which it was received by the Secretariat. Any views expressed in the report are those of the authors or the sources cited and do not necessarily reflect the views of the Secretariat.

* CBD/SBI/3/1.

[1] http://www.fao.org/forest-resources-assessment/boreal-primary-forests/en/

[2] http://www.fao.org/forest-resources-assessment/primary-forests-in-latin-america-and-the-caribbean/en/

A Review of Definitions, Data, and Methods for Country-level Assessment and Reporting of Primary Forest

A Discussion Paper for the Food and Agriculture Organisation of the United Nations

March 2021

Prof Brendan Mackey, Dr Eloise Skinner and Dr Patrick Norman
Griffith Climate Action Beacon, Griffith University, Queensland, Australia
www.griffith.edu.au/research/climate-action

Contents

Acknowledgements

Funding for this report was provided by Natural Resources Canada.

1. Introduction

1.1 Purpose of this report

The Food and Agriculture Organization of the United Nations (FAO) Global Forest Resources Assessment (FRA) provides essential information for understanding the extent of the world's forest resources, their condition, management and uses. Data collected through the FRA reporting process are used to assess progress towards globally agreed targets and inform policy and decisions by governments, civil society and the private sector. Therefore, concepts, definitions and methods developed for the FRA have broad influence beyond the FRA and must be carefully developed to ensure they can be implemented consistently by as many countries as possible, to provide comparable global information.

One such concept is the area of 'primary forest'. The FRA requires countries and territories to report on the extent of their forests and defines several different types of forests for countries to report on. "Primary forest" is defined as "Naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed". Accurate and consistent global reporting on the extent of primary forests is crucial. The FAO's definition for primary forest has appeared in trade-related instruments, such as procurement policies and wood fuel regulations, and inconsistent reporting could lead to non-tariff trade barriers. In addition, accurate and consistent reporting is essential to assess progress towards global objectives such as the Aichi Biodiversity Target 5 forest-related goals and target proposed in the zero draft of the post-2020 Global Biodiversity Framework, Sustainable Development Goal 15 and the Global Forest Goals of the United Nations Strategic Plan for Forests 2017-2030.

While the definition of primary forest may be broadly accepted, consistently measuring the actual area of primary forest among countries has proven to be challenging. Studies have shown considerable variation in how countries apply the definition in their own circumstances, which raises questions about the comparability of the data among countries and its applicability for informing policy and decisions. In addition, other recent studies have suggested new methods to assess the area of primary forest, might be broadly applicable among many countries.

Although data collection efforts for the FRA 2020 have already been completed, the FAO's newly established online data collection and reporting system will enable countries to update their data more frequently. As the FAO moves towards more frequent reporting to better meet the demands of other global reporting commitments, there is a pressing need to increase consistency in data collection requirements and schedules for primary forest in order to enhance comparability of forest statistics among countries.

Therefore, the FAO has aims to bring together national correspondents and other experts through a series of workshops to improve the operational methods for data collection and reporting on the extent of primary forests. The goal of these workshops is to increase the consistency of data collection requirements and schedules as well as enhancing the comparability among countries for estimates of the extent of primary forests.

This report has been prepared by independent experts as a discussion paper for the workshop series with the following three objectives:

1. Review and assess definitions relating to primary forests;
2. Collate and evaluate datasets and methods currently available for measuring the extent of primary forests; and
3. Provide options for defining, assessing and reporting on primary forests.

1.2 About forest definitions

Globally forests are typically assessed as covering 31% of the Earths' land surface and are recognized as having significant values and benefits, including being critical for meeting Paris agreement commitments on mitigation and adaptation and many of the Sustainable Development Goals, including those related to halting deforestation and loss of biodiversity, fresh water and sustainable livelihoods for Indigenous Peoples and local communities.

Not all forests are the same in terms of their values and qualities, due to: natural variation in their structure and composition, their ecological condition as the result of prior and current land use impacts and the degree to which they are dependent on natural processes versus human intervention and management. At the most general level, a gradient in forest ecological condition can be recognized with primary forests on one end, dominated by natural processes and plantation forests at the other end, which are dependent on human management for regeneration, fertilisation and pest control, among other things. The values and benefits vary with forest type and condition, with plantation forests, for example, providing fast growing source of timber, and primary forests providing the highest quality freshwater flows.

Distinguishing between and tracking changes in the extent and condition of forests is critical in order to help ensure that the data and information needed to best conserve, benefit, manage and grow forests are being collected and reported. Meeting this need however, is complicated in no small part because there is no simple and universally accepted approach to defining, inventorying and mapping forests and their ecological condition. The varied origins, context and purposes for forest related definitions diverge largely within and between nations, stakeholders, and international conventions. Many forest related definitions exist, and in some cases overlap (Table 1).

In considering how to best describe, measure and map primary forests, it is necessary to first consider the question 'what is a forest' as many definitions exists (Table 1).

The current FAO 2020 (FAO, 2018) definition of forest is:

'Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use'. The FAO definition has remand unchanged since FRA 2000 following a series of expert consultations.

With the current FAO definition, no distinction is made between the different forest types found in tropical, boreal and temperate biomes, nor between natural and planted forests. Neither does this definition recognize the gradient in the ecological condition of forests as a function of land use impacts. In fact, under this definition, a forest can be cleared and remain a 'forest' so long as the intention is for it to be reforested and not converted to a different land use or land cover.

A similar definition is provided by the UNFCCC (2001) (UNFCCC, 2001):

'Forest is a minimum area of land of 0.05-1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10-30 per cent with trees with the potential to reach a minimum height of 2-5 meters at maturity in situ. A forest may consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest. Young natural stands and all plantations which have yet to reach a crown density of 10-30 per cent or tree height of 2-5 meters are included under forest, as are areas normally forming part of the forest area which are temporarily un-stocked as a result of human intervention such as harvesting or natural causes but which are expected to revert to forest.'

These definitions based on forest canopy structure and area extent are useful in that they serve the purpose of accommodating the full scope of national situations where 'forest' is recognized to occur. UNFCCC reporting furthermore distinguishes between managed and un-managed forest, where only the managed forest area is included in the emissions reporting. For the purpose of understanding primary forests, however, such definitions are necessary but insufficient as the characteristic height and canopy cover of a natural forest varies with biome and ecozone. Tropical moist forests, for example, naturally are characterised by canopies >20m in height and >60% canopy cover. Boreal forests, in contrast, especially in the higher latitudes, can be only 2-3m height and have 6-10% canopy cover. Forests with similarly short and sparse structural characteristics also occur in tropical and subtropical biomes where water availability is a limiting factor. Within the three broad biomes (tropical, temperate and boreal), varying environmental conditions (including, regional climatic gradients, topographic effects and substrate influences) result in ecozones within which further variation in canopy height and cover can be found.

Vegetation structural types can be recognised based on canopy height and cover thresholds that reflect environmental determinants on plant life forms. Figure 1 maps the current distribution of tree-dominated vegetation structural types defined by Carnahan (1990) (Carnahan, 1990) that encompass the FRA definitions of forest (Table 1). The Carnahan vegetation structural classes that correspond to the FRA (2018) definition of 'forest' are: tall, medium and low closed and open forest; and tall, medium and low woodland. Using this approach, the total global area of FRA forest is estimated to be 4 114 million ha (41,135,600 km^2) which can be compared to the FRA 2015 estimate of 3 999 million ha. Furthermore, including the far north boreal forest with >6% tree canopy, consistent with the Carnahan definition, gives a total global forest area of 4 358 million ha (43,584,206 km^2) (Figures 1 and 2).

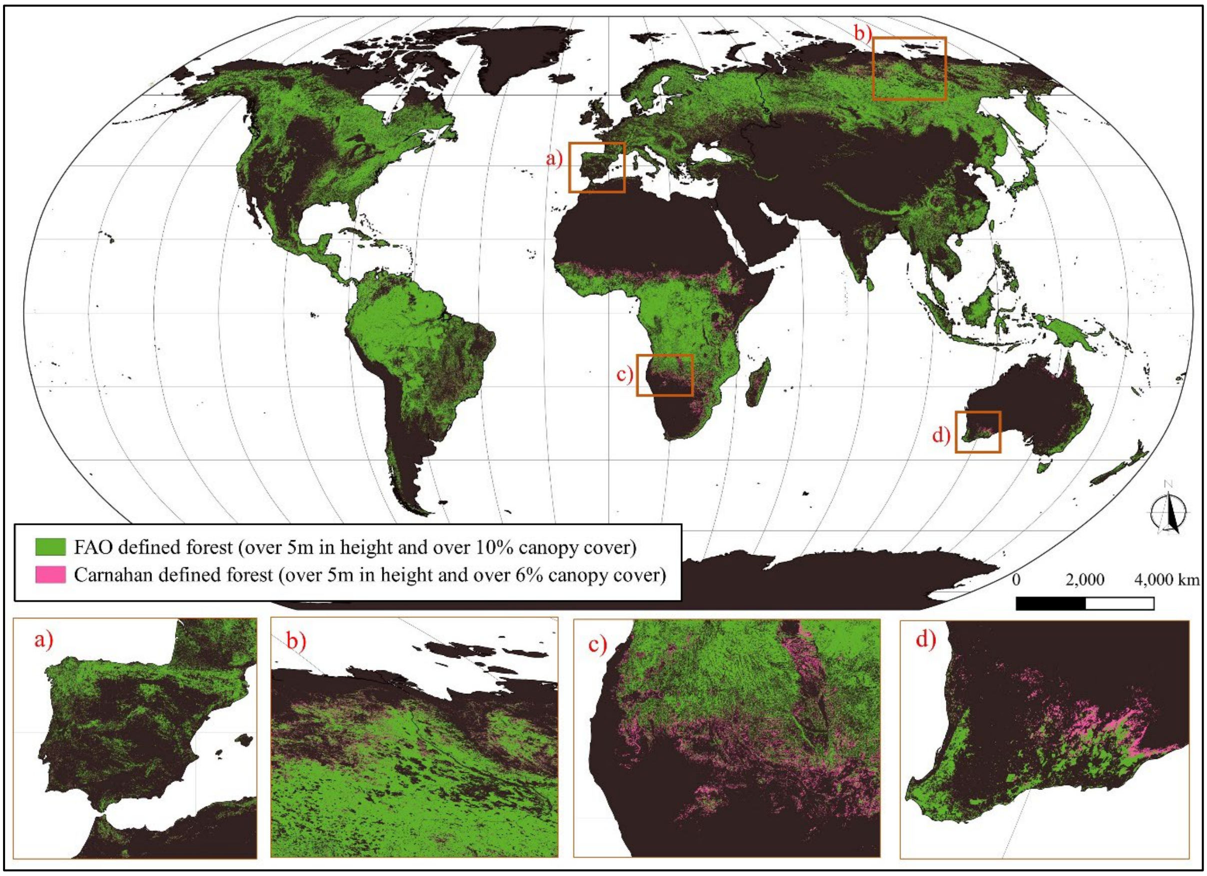


Figure 1 The comparison between the FAO defined forest (green) and Carnahan (Carnahan, 1990) defined forest (pink). Inset maps show the Iberian peninsula (a), northern Russia (b), Angola and Namibia (c) and south western Australia (d) in greater detail.

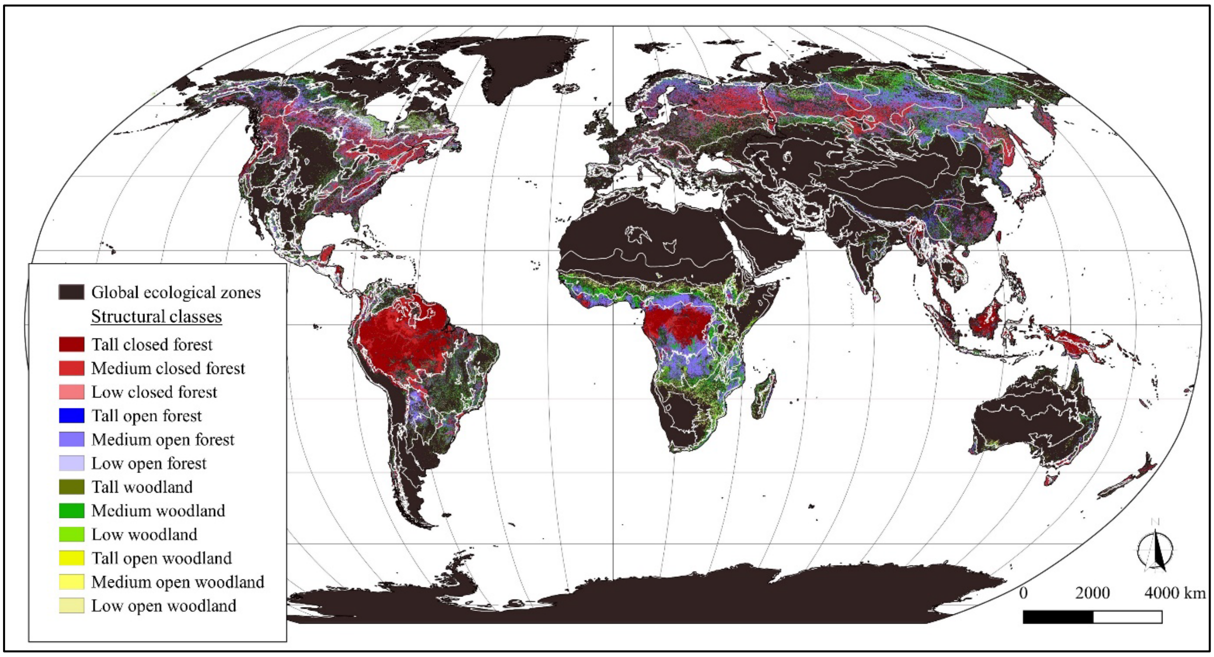


Figure 2 Forest Structural formations based on tree canopy height and cover classes after Carnahan 1990 (Carnahan, 1990). The current FAO definition of forests encompass all classes except tall, medium and low open woodland. Reproduced with permission of Shestakova et al. (in prep.). Also shown are boundaries of FAO global ecological zones (FAO, 2012).

When reporting on the current extent of primary forest and how this has changed, context is helpful. Knowing what the natural characteristic structural formation for a forest is, provides a benchmark for monitoring change. For example, take the hypothetical case of what is naturally a 'tall closed forest' which is subject to conventional forest management for commodity production, resulting in the canopy tree height and cover being reduced so that structurally it has become a 'low closed forest'. No deforestation has occurred, but the structural change is indicative of a shift from a primary forest condition.

Biomes and ecozones also provide important context on how the characteristic biodiversity of forests naturally vary, reflecting their distinctive evolutionary pathways, local adaptations and ecological relationships. Figure 2 shows the forest structural formations overlayed with the global ecological zones (FAO, 2012). Each of these ecological zones represent a region that has a distinctive and characteristic biodiversity. Thus, while African and South American tropical forests share similar vegetation structural attributes and ecological processes (such as nutrient cycling), their composite species and resultant ecological relationships differ. As with the structural formations, information on the natural characteristic biodiversity of a forest in a given biome and ecological zone, provides an important benchmark for monitoring changes in forest condition and reporting on primary forest.

Another fundamental distinction is between natural and planted forests. The 2020 FRA (FAO, 2018) defines planted forests as 'forest predominantly composed of trees established through planting and/or deliberate seeding', with the additional refinements that the planted/seeded trees are expected to constitute more than 50 percent of the growing stock at maturity and includes coppice from trees that were originally planted or seeded, along with rubberwood, cork oak and Christmas tree plantations, but excludes self-sown trees of introduced species. Forest typologies typically distinguish between natural formed and regenerating forests and planted forests (Harris et al., 2020, Gibson et al., 2011, Thompson et al., 2009).

One approach therefore, for reporting on primary forests, is to establish structural and biodiversity benchmarks for monitoring and reporting purposes. Another approach, and one that is more commonly used is to infer the presence of primary forest from the absence of certain land uses, such as conventional forest management for commodity production (Puettmann et al., 2015) whose impacts have been established to shift a forest out of a primary condition. While in theory a gradient exists, in practice it is more feasible to recognize relative categories ranked by their degree of naturalness with the more natural end being labelled primary forest or synonymous terms such as 'primeval', 'virgin', 'frontier', 'long untouched , 'intact' and 'stable' forest. (Buchwald, 2005, Watson et al., 2018, Funk et al., 2019).

Two further definitional issues also warrant raising.

(a) ***Narrow ecological meaning*** - in addition to the broad meaning of primary forest as defined by the FAO, it also has a narrower ecological meaning. In many forest ecosystems, species with specialized life history traits occupy different successional stages in the development of a stand following disturbance or the death of canopy trees, with a forest sequence dominated by pioneer, secondary and then primary trees which represent the forest's ecologically mature state. Typically, fast growing and shorter-lived tree species dominate disturbed sites, followed by slower growing longer-lived ones (Chazdon et al., 2010). While this is widely understood in scientific circles, this ecological meaning of the term 'primary' can be a source of confusion in the current context. For example, a forest stand might be in an early succession stage as the result of a natural disturbance. It would still therefore be a primary forest under the FAO definition but from the narrow ecological definition it could be defined as being in a secondary growth phase.

(b) ***Old-growth*** - in some countries, 'old-growth' is a commonly used term and used synonymously with primary forest. While definitions vary, it is typically defined as a forest with trees older than 120 years, noting that trees with a lifespan of <120 years old can dominate some older forests. It is also possible for disturbed/secondary forests to retain old-growth structural and functional characteristics as biological legacies. The structural characteristics of old growth can vary between locality and forest type but typically include mature trees (some very old), standing dead trees and downed logs, abundant coarse woody debris, and vertical and horizontal complexity in vegetation layering (Mackey et al., 2015). A forest in an early re-growth phase following a natural stand-killing disturbance may contain no living old growth trees but is still a primary forest according to the FAO definition.

Table 1. Forest and forest subcategory definitions widely adopted at national and global scales.

Term	Definition	Authors and reference
Forest	**FRA** – "Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use." **UNFCCC** – ""Forest" is a minimum area of land of 0.05-1.0 hectares with tree crown cover (or equivalent stocking level) of more than 10-30 per cent with trees with the potential to reach a minimum height of 2-5 metres at maturity in situ."	FAO, 2018 UNFCCC, 2001
Naturally regenerated forest	Forest predominantly composed of trees established through natural regeneration. Explanatory notes 1. Includes forests for which it is not possible to distinguish whether planted or naturally regenerated. 2.Includes forests with a mix of naturally regenerated native tree species and planted/seeded trees, and where the naturally regenerated trees are expected to constitute the major part of the growing stock at stand maturity. 3.Includes coppice from trees originally established through natural regeneration. 4.Includes naturally regenerated trees of introduced species.	FAO, 2018
Planted forest	Forest predominantly composed of trees established through planting and/or deliberate seeding. Explanatory notes • In this context, predominantly means that the planted/seeded trees are expected to constitute more than 50 percent of the growing stock at maturity.	FAO, 2018

	• Includes coppice from trees that were originally planted or seeded.	
Plantation forest	Planted Forest that is intensively managed and meet ALL the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing. Explanatory notes • 1.Specifically includes: short rotation plantation for wood, fibre and energy. • 2.Specifically excludes: forest planted for protection or ecosystem restoration. • 3.Specifically excludes: Forest established through planting or seeding which at stand maturity resembles or will resemble naturally regenerating forest	FAO, 2018
Primary forest	**FRA** - Naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. *Explanatory notes* • they show natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure and natural regeneration processes; • the area is large enough to maintain its natural characteristics; • there has been 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.	FAO, 2018
	Convention on Biological Diversity – "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. It is referred to "direct human disturbance" as the intentional clearing of forest by any means (including fire) to manage or alter them for human use. Also included as primary, are forests that are used inconsequentially by indigenous and local communities living traditional lifestyles relevant for the conservation and sustainable use of biological diversity."	Convention on Biological Diversity, 2006
	IUCN -"Primary forests are naturally regenerated forests of native tree species, including mangroves and peat forests, whose structure and dynamics are dominated by ecological and evolutionary processes, including natural disturbance regimes, and where if there has been significant prior human intervention it was long enough ago to have enabled an ecologically mature forest ecosystem to be naturally re-established. Many primary forests are also home to Indigenous Peoples and local communities and are the basis of their identity, culture, belief system, traditional knowledge, and livelihoods; a forest that meets the definition above would not be excluded due to the presence of these communities. As used here, primary forest is a broad term which encompasses related terms including: stable forest, 7 intact forest, 8 old-growth, frontier, long-untouched and virgin forest9 and is consistent with the ways 'primary forests' are defined by other authorities such as the CBD and the United Nations Food and Agriculture Organization (FAO)."	IUCN, 2020
Secondary forest	**Corlett** - Those formed as a consequence of human impact on forest lands, excluding plantations.	Corlett, 1994
	Convention on Biological Diversity – "A secondary forest is a forest that has been logged and has recovered naturally or artificially. Not all secondary forests provide the same value to sustaining biological diversity, or goods and services, as did primary forest in the same location."	Convention on Biological Diversity, 2006

Intact forest landscapes	An unbroken expanse of natural ecosystems within the zone of current forest extent, showing no signs of significant human activity, and large enough that all native biodiversity, including viable populations of wide-ranging species, could be maintained. A minimum patch size of 500 km^2.	Potapov et al., 2008
Hinterland forest	Forest patches without and removed from disturbance in near-term history, with a minimum patch size of 100km^2.	Tyukavina et al., 2016
Old growth forest	**White and Lloyd** - Old-growth forests are ecosystems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically differ from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function.	White and Lloyd, 1994
	Convention on Biological Diversity – "Old growth forest stands are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class."	Convention on Biological Diversity, 2006
Frontier forest	Intact natural forest ecosystems large enough to maintain biodiversity and viable population within each forest type.	Bryant et al., 1997
Intact forest	Forest that is free of significant anthropogenic degradation.	Watson et al., 2018
Stable forest	"Stable forests are those that are not already significantly disturbed nor facing predictable near-term risks of anthropogenic disturbance, and they represent a major global resource for carbon management, in addition to the value they provide through other ecosystem services."	Funk et al., 2019

1.3. Defining primary forests

As detailed in Table 1, definitions of primary forests have been provided by not only the FAO but also the Convention on Biological Diversity and the International Union for Conservation of Nature. The term is also widely used and reported in various publications, including scholar articles, where its definition draws upon on various criteria that can be broadly grouped into three categories relating to:

(a) ***Anthropogenic influences*** – with a focus on direct and indirect human impacts from human land use;

(b) ***Vegetation structure*** – where the emphasises is on canopy height and density, as well as vertical layering;

(c) ***Biodiversity and other ecological attributes*** – this category includes the framework tree species that dominate the canopy and other native species that are characteristically found in the forest including forest-dependent and interior-forest micro-climate dependent species.

Reference can also be made to physical and environmental factors providing further biome, ecozone or ecosystem context. Figure 3 summarises the number of publications that have used one or more of 19 variables found between these three broad categories.

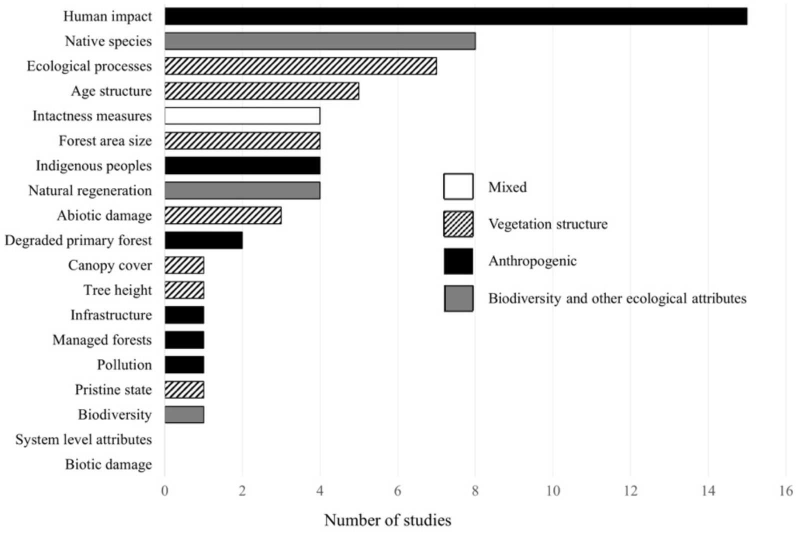


Figure 3: Key term count for articles using a definition of 'primary forest'.

Anthropogenic activity

All definitions of primary forests included mentions of human impacts including forest management for commodity production. Generally, a primary forest is recognized as not having been impacted by logging for commodity production, other industrial land uses, or significantly affected by large scale infrastructure and capital works such as transportation and utility corridors. The logic being, that such activities will significantly change the forest structure, taxonomic composition and ecological processes and therefore their absence can be used as a proxy for where primary forest occurs.

This approach of using the presence or absence of certain categories of land use can be complicated in forests with a long history of logging and intensive land use. Where these have occurred long ago and no further human impact has followed, the current forest condition can reflect natural ecological processes to be labelled as primary forest or synonymous terms such as 'long-untouched' (Buchwald 2005). Important breaking points therefore can be recognized in the continuum of forest condition that reflect major step changes in naturalness including (i) the presence of customary forest-dwelling Peoples and their traditional stewardship, (ii) logging for commodity production and (iii) plantation-orientated management (Buchwald, 2005).

Vegetation structure and related ecological processes

Attributes of vegetation structure commonly used in the definition of primary forests include (i) canopy height and density, (ii) the age structure of forest stands, (iii) the inclusion of mature trees and other old growth characteristics, and (iv) the full range of successional stages from pioneer to ecologically mature.

Some definitions also make reference to the minimum forested area necessary to maintain ecological processes that impact or are related to vegetation structure including (i) disturbance regimes especially fire and flooding regimes, (ii) ecological processes such seed dispersal, (iii) interior-forest micro climates, and (iv) the minimum area that can be reliably detected and mapped (Margono et al., 2012, Frey et al., 2016, Briant et al., 2010).

Fire regimes are the pattern of fire events in terms of the intensity, frequency, type, seasonality and extent, and are an important natural disturbance in temperate and boreal biomes (Mackey et al., 2002). Wildfire events per se are more generally considered part of the natural disturbance regime and therefore part of the natural dynamics that characterise primary forests. This is certainly the case for temperate and boreal forests where fire regimes have been a major selecting force on the evolution of species life history strategies and plant traits. Tropical closed forests, on the other hand, rarely if ever burn under natural conditions. However, where fire has been deliberately introduced by humans for the purpose of clearing the forest for another land use (such as ranching or cropping), most definitions of primary forest would consider the forest to be degraded (FAO, 2002). The situation however is becoming compounded as human-forced climate change in some bioregions is leading to drought conditions and onset of fire events, which either previously did not occur or now have changes in their intensity, frequency or seasonality.

Biodiversity and other ecological attributes

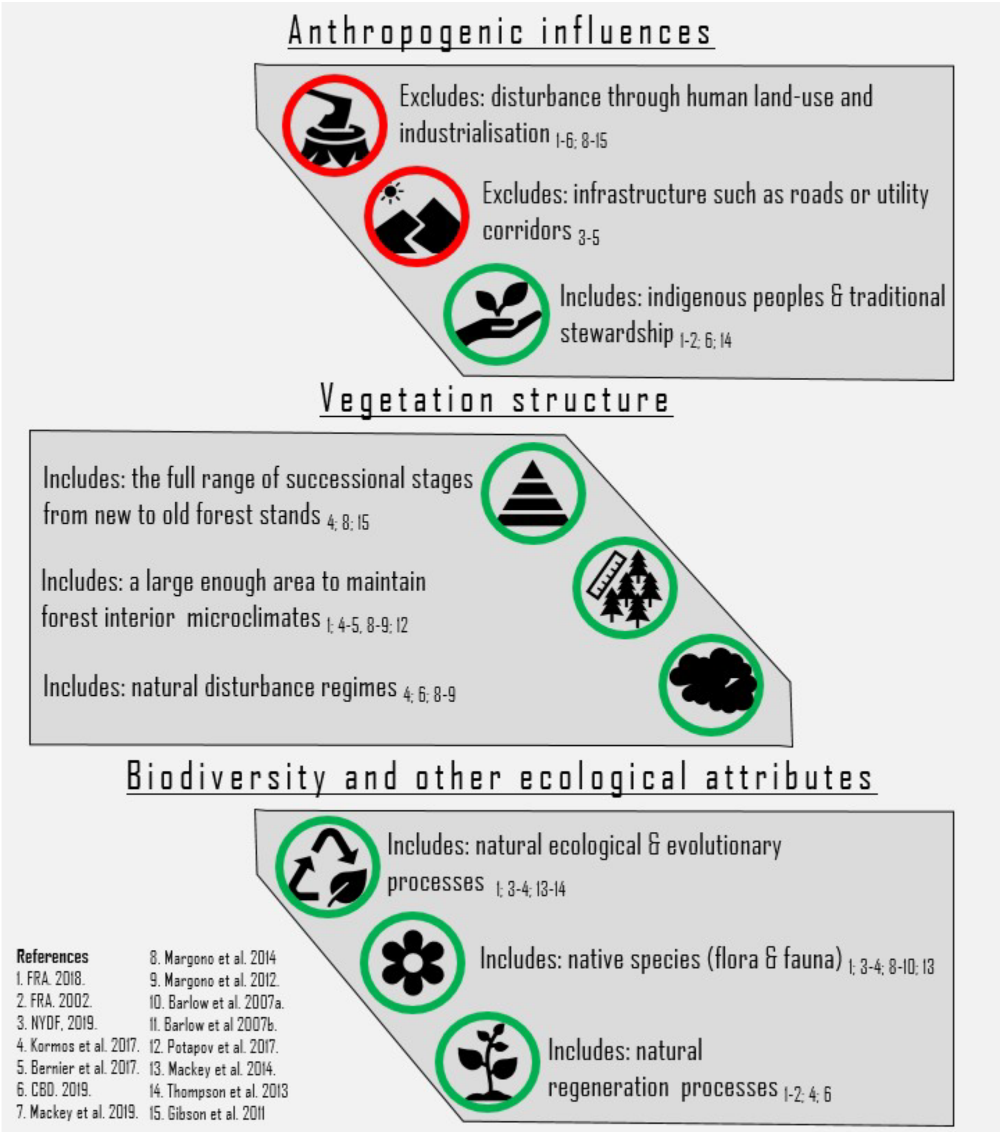
The main biodiversity attributes cited in primary forest definitions include having a native species composition and natural levels of biodiversity, along with the dominance of natural regeneration and other ecological and evolutionary process. These kinds of characteristics were cited less frequently than anthropogenic change but were still considered important in 30% of all primary forest definitions. Of particular importance are foundation (also called framework) species that dominate forest structure and ecosystem dynamics (Ellison et al., 2005, Fauset et al., 2015), which can also be sensitive to land use impacts (Gatti et al., 2015).

Box 1 is an infographic that summaries the categories of attributes that have been used to define primary forests.

Geographic area

As noted, definitions of forests typically prescribe a minimum geographic area of ~0.5-1.0 ha^{-1} while those for primary forest sometimes have a minimum area requirement orders of magnitude larger in extent. 'Intact Forest Landscapes' (IFL) (Potapov et al. 2008), for example, are the equivalent of primary forest dominated landscapes with a minimum area of 500 km^2. 'Hinterland forest' was coined by Tyukavina et al. (2016) as both primary and mature secondary tropical forest if no disturbance is documented within a defined interval and with a minimum area of 100 km^2 (Tyukavina et al. 2016). The IFL minimum area requirement was justified in part on the basis that this is large enough to include the full suite of natural processes including disturbance regimes. The minimum area for Hinterland forest however, largely reflects technical reasons related to limitations of the Earth observation data used for the mapping.

In tropical closed forests, edge effects on forest interior climates have been found to cease after ~1-2 km, depending on the extent of fragmentation, suggesting a minimum patch size of ~ 4km^2 (Briant et al., 2010). In temperate and boreal forests, natural fire regimes produce a more complex mosaic of age classes and successional vegetation associations, suggesting that a landscape rather than stand level is the more appropriate scale for defining primary forests in these biomes. However, it is worth noting that even relatively small patches of primary forest assume greater value in degraded landscapes as wildlife refuges, sources of propagules for landscape restoration, and anchors for connectivity conservation initiatives (Lamb et al., 2005, Castillo-Campos et al., 2008, Jacquemyn et al., 2001).



Box 1. Publications and articles that provide definitions of primary forests tend to draw upon multiple criteria which can broadly be grouped into three categories: (i) anthropogenic activity; (ii) vegetation structure and related ecological characteristics; and (iii) biodiversity and other ecological attributes.

2. Current reporting of primary forests

2.1 Global assessment overview

The FAO have coordinated the Global Forest Resources Assessment (FRA) approximately every 5 to 10 years since 1948. Derived from an agricultural interest, early assessments of global forests focussed on economic forest products, such as timber supply. In more recent years, however, this assessment of forests has evolved to address a growing interest in a broader suite of forest benefits and functions. The FRA provides essential information for understanding the extent of forest resources, their condition, management and uses. Data are now collected through a global network of national correspondents, undertaken every 5 years.

A range of different forest types are reported in the FRA including primary, planted, other planted, mangroves and naturally regenerated forest (FAO, 2018).

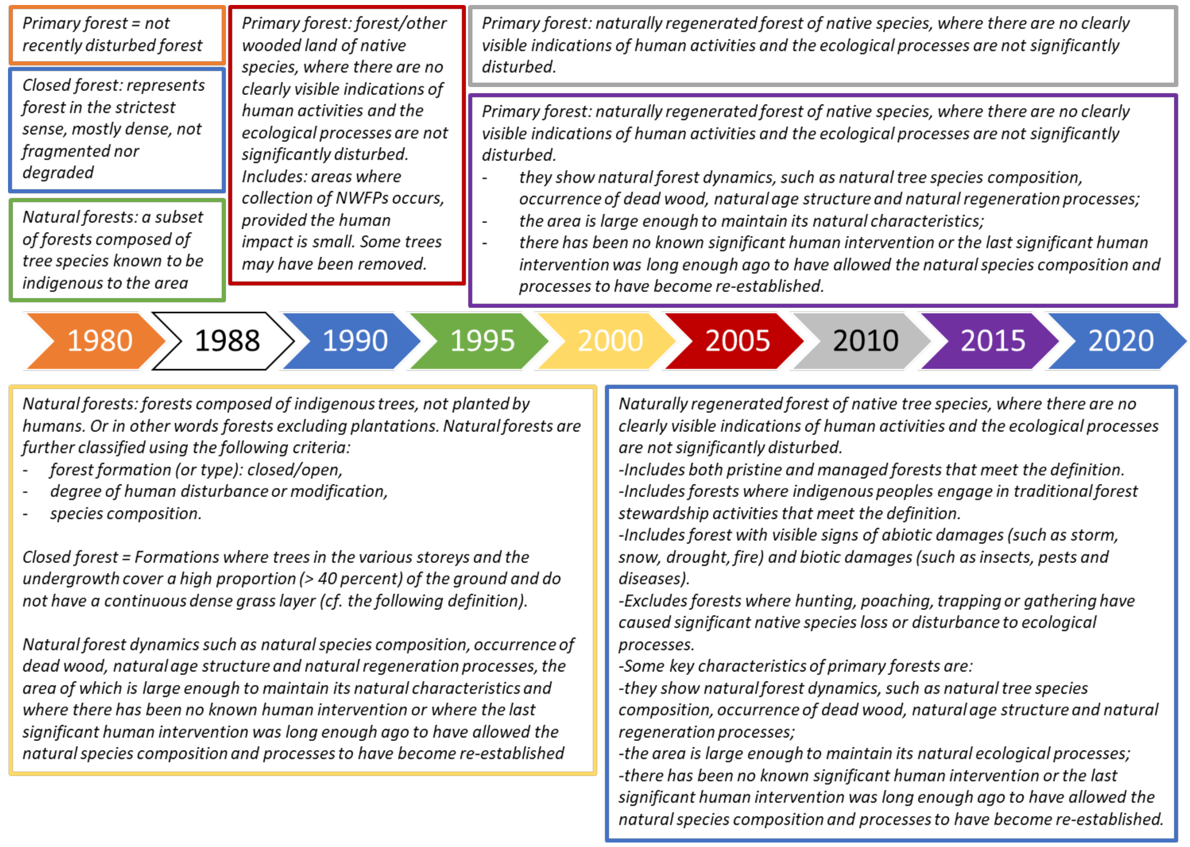
2.2 Primary forest definitions through FRA history

Primary forest reporting and definitions have changed through the FRA history. Box 2 summarises and illustrates the way primary forest related terminology has been used by the FRA from 1980-2020. In the 1980s, primary forests were defined simply as forests with no recent disturbance. In 1980/90s, the term' undisturbed closed forests' was used to represent forests in the strictest sense, mostly dense, not fragmented or degraded. The current definition of primary forest as outlined in FRA 2020 (FAO, 2018), includes components from the 'primary forest' definitions used in the 2005, 2010 and 2015 FRA reports:

- **Naturally regenerated forest of native tree species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed:**
- Includes both pristine and managed forests that meet the definition.
- Includes forests where indigenous peoples engage in traditional forest stewardship activities that meet the definition.
- Includes forest with visible signs of abiotic damages (such as storm, snow, drought, fire) and biotic damages (such as insects, pests and diseases).
- Excludes forests where hunting, poaching, trapping or gathering have caused significant native species loss or disturbance to ecological processes.
- ***Some key characteristics of primary forests are:***
- They show natural forest dynamics, such as natural tree species composition, occurrence of dead wood, natural age structure and natural regeneration processes;
- The area is large enough to maintain its natural ecological processes;
- There has been 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.

2.3 How global reporting is used

The data reported in the FRA are used for forest and land use assessments and economic evaluations at both national and global levels. They are also drawn upon for research, for example, following FRA 2015 a special issue of Forest Ecology and Management was published comprising of 13 articles focussed on the data and trends reported in the FRA (2015) (FAO, 2015). A literature search revealed that collectively there have been more than 1100 citations across these articles which covered a range of social, economic, conservation and climate related topics relating to the reported data.



Box 2. How the term primary forests changed over time within FAO Global Forest Resources Assessments (FRA).

2.4 Differences among country reporting methods

There are a wide range of methodologies used by countries to report on primary forest which warrant further examination as they are likely have an impact on the area of primary forest reported by each country. We reviewed the country reports from FRA 2015 for the 20 countries with the highest reported areas of primary forest (Table 2) and noted the following key points:

- A number of countries report all natural forests as primary forests which could result in an over estimation;
- Some countries calculated primary forest area based on land tenure, e.g. by including all forest that occurred within formal protected areas;
- One country identified primary forest as natural forest within formally surveyed logging estates that have not yet been subject to commercial harvesting;
- Primary forests are sometimes defined as climax or mature forest. Depending on the biome, only including late age class forest may result in an underestimation of primary forest area as patches of early successional stage forest stands, resulting from natural disturbances are excluded;
- While providing useful information, plot based inventories do not provide all of information required to characterise primary forest extent.

Given that the FAO definition of primary forest is not an operational one, it is not surprising to find that it has not been explicitly used by most countries for their reports. The differences apparent in the methodologies used by countries when calculating primary forest areas for FRA reports would likely result in variation in the area of forest reported.

3. Measuring, monitoring and mapping primary forest

3.1 In situ data

Many countries now have some national system of forest mensuration plots in place that measure key attributes including tree heights and canopy cover, tree diameters and framework tree species (Dengler et al., 2011, Crowther et al., 2015). Typically, these were established for informing policy and strategic decision making, rather than for wood production, rather than for ecological purposes including the identification of forest condition as it relates to primary forest. Many national forest inventories however are now multi-purpose and do include assessment of forest biodiversity in terms of species composition and measures of forest health. Some countries also do draw upon field survey data on species composition, vegetation structure and anthropogenic disturbances to classify land cover including primary forest. These more comprehensive data sets are needed in order to reliably distinguish primary forest from other forests (Brearley et al., 2004). While much progress has been made, there has yet to be an established global standardised system of forest survey plots comparable to that established for weather and climate monitoring. Whatever the attribute data recorded, in situ data represent only a sample of a forest's structure, composition and condition and therefore must be complemented by approaches that enable the characteristics of a forest to be mapped across its entire extent (Sandmann and Lertzman, 2003). Thus, remotely sensed sources are used to upscale site data to obtain landscape wide estimates of forest attributes.

3.2 Remotely sensed data

As is widely understood, in situ observations represent only a sample, at plot or stand scale and must be complemented with remotely sensed data in order to obtain spatially explicit maps of forest type and condition. A range of methods have been used for remote sensing primary forests including from satellites, unmanned aerial vehicles (UAV) and aeroplane/helicopter-based detection. Each range in the cost of data acquisition as well as spatial extent and resolution, with satellite-based detection being the most viable method at large spatial scales. Satellite based remote sensing include both (1) passive sensors which record multispectral and hyperspectral imagery and (2) active sensors such as lidar and radar. Satellite based passive detection methods allow for long term monitoring, have been operating for almost 50 years and have become an integral part of remote sensing.

Satellite-based Earth observation data provides a range of data on forests including canopy cover, canopy height and vegetation greenness (Hansen et al., 2013, Simard et al., 2011, Sadeghi et al., 2016, Xue and Su, 2017), along with human impacts such as the construction of roads and other infrastructure, settlements and intensive land use such as commercial cropping. Vegetation structure is the most amenable to remote sensing especially over large areas, though it is possible to also gather - albeit more limited - information on tree species composition. Relevant satellite-based vegetation related prducts including those derived from the Landsat-8 and Sentinel-2 satellites. Due to differences in resolution, frequency of images and length of time in operation, choosing which satellite data to use for a primary forest assessment depends on the size and human impacts of the study areas. Active satellite sensor data used for mapping forest canopy height include the Geoscience Laser Altimeter System (GLAS) on the Ice, Cloud, and Land Elevation Satellite (ICESat) satellite and GEDI.

3.4 Open data and cloud computing

Rapid progress is being made in the accessibility and application of remotely sensed Earth observation time series data, with global coverage at a range of spatial resolutions. Global datasets – including modelled data - relevant to primary forest mapping are detailed in Table 3. A number of these datasets provide information about forest cover that is related to condition and the mapping of primary forests. Some of the modelled datasets continue to be updated on an annual basis, which are valuable for assessing extent changes through time, e.g., the forest loss, drivers of forest loss and fire detection datasets.

Table 3. Examples of available global spatial datasets which can be used or assist when measuring the extents of primary forest. Modified from Hansen et al. (2019).

Authors/Creators	Region	Available spatial dataset	Dataset year	Link to dataset
Hansen et al., 2013	Global	Forest loss/gain	2000-2018	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.6.html
Hansen et al., 2013	Global	Percent tree cover	2000 and 2010	https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.6.html
Potapov et al., 2008	Global	Large intact forest landscapes	2000, 2013 and 2016	http://intactforests.org/data.ifl.html
Tyukavina et al., 2016	Pan-tropical	Hinterland forest extent	2013	https://glad.umd.edu/dataset/hinterland-forests-2013
Turubanova et al., 2018	Pan-tropical	Primary forest extent	2001	https://glad.umd.edu/dataset/primary-forest-humid-tropics
Simard et al., 2011	Global	Canopy height	2005	https://webmap.ornl.gov/wcsdown/dataset.jsp?ds_id=10023
Curtis et al., 2018	Global	Drivers of forest loss	2001-2015	https://data.globalforestwatch.org/datasets/tree-cover-loss-by-dominant-driver
Bunting et al., 2018	Global	Mangrove forest extent	1996-2016	https://data.unep-wcmc.org/datasets/45
Harris et al., 2020	82 counties	Plantation forests	2015	https://data.globalforestwatch.org/datasets/planted-forests
Newbold et al., 2016	Global	Impacts of forest change on local biodiversity intactness	2005	https://data.nhm.ac.uk/dataset/global-map-of-the-biodiversity-intactness-index-from-newbold-et-al-2016-science
UNEP-WCMC and IUCN, 2020	Global	Protected areas	2020	https://www.protectedplanet.net/
Bontemps et al., 2013	Global	Land cover classes	1992-2015	http://maps.elie.ucl.ac.be/CCI/viewer/download.php
Kennedy et al., 2019	Global	Human modification intensity	2016	https://developers.google.com/earth-engine/datasets/catalog/CSP_HM_GlobalHumanModification
Venter et al., 2016	Global	Terrestrial human footprint	2009	https://www.nature.com/articles/ncomms12558
Schroeder et al., 2014	Global	Fire detections	2012-2020	https://earthdata.nasa.gov/earth-observation-data/near-real-time/firms/active-fire-data

Furthermore, with the emergence of remote cloud-based computing it is now possible to map forest extents – and to an increasing degree forest condition -at a global scale on most computers with access to the internet. Google Earth Engine (Gorelick et al., 2017) and similar tools from the European Space Agency are providing hitherto unprecedented access to these data and a computational capacity enabling new modelling approaches to be developed for forest assessment. Google Earth engine for example allows users access to over 7 petabytes of remotely sensed data, including the entire Landsat image catalogue and provides the means to process these data using Google servers. With the vast number of datasets available directly through the platform, users of the software do not have to store large datasets on their personal devices. It also provides direct access to the 8 billion-pixel global forest extent dataset (Hansen et al., 2013), which can be used to calculate forest cover metrics, allowing for canopy cover thresholds to be readily changed depending on the forest type and ecoregion being assessed.

The Global Forest Watch web portal (Global Forest Watch, 2020) was initiated by the World Resources Institute (World Resources Institute, 2020) to provide public access to spatial data on forest cover change metrics generated by researchers from Earth observation data using Google Earth Engine (Gorelick et al., 2017). Through the web portal, a range of forest area estimations are directly available for countries, including the total tree cover extents and canopy cover 'losses' and 'gain' (Hansen et al., 2013) as well as information on the drivers of deforestation (Curtis et al., 2018).

3.5 Species distribution modelling

Major advances have also been made in making available data on species distributions include primary forest dependent species. Cloud based repositories such as *the Global Biodiversity Information Facility* (https://www.gbif.org/) are aggregating from reliable sources – such as national herbaria – and making available species location data. While modelling platforms such as the *Biodiversity & Climate Change Virtual Laboratory* (http://bccvl.org.au/) are providing the means to generate maps of their spatial distribution. These web based data and modelling portals provide new tools that can assist national governments in accounting for the biodiversity characteristics of their forests and helping to better distinguish and describe primary forests.

3.6 Landscape level metrics

Various landscape-level metrics have been developed that provide relevant information for the purpose of mapping primary forest (Table 4). These can draw upon both in situ and ex situ data. The value of conventional forest inventory data can be greatly enhanced by using them to estimate landscape level metrics such as characteristic stand age-class frequency distributions. These landscape-level metrics can provide a direct empirical basis for distinguishing primary forests from other forests based on a set of baseline conditions.

Table 4. Landscape-level metrics for identifying and mapping primary forests.

Methods of defining primary forest	References
• Stand age-class frequency distributions	Turner et al., 2009
• Biomass carbon frequency distributions	Keith et al., 2010
• Patch spatial statistics regarding the forest patch size and shape	McRae et al., 2001
• Frequency distribution of the area covered by forest ecosystem types	Mackey et al., 2002
• Fine and coarse woody debris including snags and large diameter dead biomass	Freedman et al., 1996 and Thorn et al., 2018
• Foundation/framework canopy tree species	Esquivel-Muelbert et al., 2019 and Ter Steege et al., 2013
• Characteristic biodiversity including interior forest micro-environment dependent plant, animal and fungi species.	Barlow et al., 2007 and Schmiegelow et al. 2006

4. Mapping primary forest

There are three basic approaches to mapping primary forest all of which can draw upon both in situ and ex situ data sources.

The first, as deployed by some countries (Table 2) is to identify those forests that have been formally surveyed but not yet subject to industrial logging including conventional forest management for commodity production. With this approach, the absence of specified land uses and associated infrastructure such as roads is used as a proxy for where primary forests occur. Information is needed therefore about where there is natural forest cover and timber survey maps or other such GIS-based information about historic, current or proposed extractive land use activities.

A second approach is to use a combination of data sources to generate landscape level metrics that can be compared against baselines values. However, to date no country has used this approach in the FRA reporting on primary forest, and their use to date has been largely restricted to and reported in the research literature.

A third approach is to use time series of remotely sensed data to monitor changes in forest canopy structure and draw upon in situ data, to calibrate when changes represent forest loss or degradation. This approach draws upon various remotely sensed data to estimate forest extent and canopy cover and height over large areas. The maps of global forest cover in Figure 1 and of forest structural formations in Figure 2 were generated from the such remotely sensed sources.

The third approach has been mostly applied to humid tropical forests which naturally support a closed forest canopy (e.g. tree canopy cover >60%) as major changes in canopy foliage cover are readily detected with greenness indices. Over the last decade a number of studies have used this approach to map forest cover at a range of scales from country level to global, including attempts to distinguish between all forests, natural forests and forests that are equivalent to primary forest, including IFL and Hinterland forest (Turubanova et al., 2018, Zhuravleva et al., 2013, Tyukavina et al., 2016, Mikoláš et al., 2019, Hansen et al., 2019, Margono et al., 2014, Potapov et al., 2008). IFL mapping is undertaken globally and by definition those areas include primary forest but also naturally occurring non-forested ecosystems. The 500 km^2 (50,000 ha^{-1}) minimum area threshold also results in small but obviously still significant primary forest areas being unmapped. The Hinterland forest by definition may include some degraded forest and again there are substantial areas of primary forest less than its 100 km^2 (10,000 ha^{-1}) threshold. Furthermore, it has only been mapped for the tropical biome.

Interpreting changes in forest canopy cover from remotely sensed data in terms of what this means for primary forests requires some information on the forest's ecological context. For a given forest type, a secondary or degraded forest will usually have a lower and more open tree canopy compared to a primary forest. However, as illustrated in Figure 2, the natural canopy cover varies with biome and ecological zone, along with smaller scale variations as the result of differences in tree species traits and the physical determinants of plant growth. Therefore, establishing baseline information about the characteristic vegetation structure for the types of forest being assessed is critical.

Baseline canopy cover and height thresholds have been used in several studies assessing primary forests particularly in tropical areas. For example, canopy cover values of greater than 60% have been used to define primary forest for tropical humid regions (Zhuravleva et al., 2013). However, even within the tropical biome different percentage cover thresholds have been found to be valid (Hansen et al., 2013, Ter Steege et al., 2013, Turubanova et al., 2018). Defining primary forests in temperate and boreal biomes based on canopy cover may be even more equivocal. Bioregional analysis of the available global forest data (Hansen et al., 2013) for eastern Russian forest has revealed that primary forest tree cover and heights, varies with ecological zone and is as low as 6% canopy cover and down to 2-3m in height in northern regions (Montesano et al., 2016). A single tree canopy percentage and height threshold to define 'forest', let along primary forest, is therefore not advisable for the boreal biome and is unlikely to be for the temperate biome, given the range of forest types it encompasses (Keith et al., 2009). These results suggest there is a benefit in primary forest evaluation and reporting to be undertaken on an ecological zone basis (FAO, 2012).

As noted earlier, the impact of fire is an important consideration when assessing primary forest extents. Where fires are part of the natural disturbance regime, even severely burnt and 'stand-replacing' fire events do not constitute a 'conversion' of the forest from a 'primary' to a 'degraded' state. Care must be taken therefore in interpreting remotely sensed stand replacement forest loss datasets (Hansen et al., 2013) particularly in boreal forests (Krylov et al., 2014) as well as canopy loss and gain data (e.g. World Resources Institute, 2020). Canopy impacts from fire events should not be automatically excluded from primary forest calculations. More nuanced analysis is now needed however, given the increasing influence of human-caused fires, along with climate change influences on fire weather.

4.1 Case study comparisons

To illustrate the utility and limitations of the available remotely sensed data sources and methods used for mapping primary forests, proxies for primary forests and natural forests more generally, we calculated forest cover statistics for seven countries that have the largest extents of forest cover as well as being examples of tropical, temperate and boreal biomes – Australia, Brazil, Canada, Democratic Republic of the Congo (DRC), Indonesia, Russian Federation and the United States of America.

Using Google Earth Engine (Gorelick et al., 2017) we estimate national level forest statistics using five available datasets: (a) tropical mature & partially degraded forest (Turubanova et al., 2018); (b) Intact Forest Landscapes (IFL) (Potapov et al., 2008); (c) Hinterland forests (Tyukavina et al., 2016); and global forest cover and loss from Hansen et al. (2013) for (d) canopy cover >10% and (e) >60%. We excluded from these data sets forest loss between 2000-2015 (Hansen et al., 2013, University of Maryland, 2020). For each country, we then compared estimates of forest cover from the five sets with FRA 2015 reported values for primary forests and all forests (Table 5).

Table 5. Global forest and primary forest calculations (thousand ha) for seven countries after forest loss between 2000-2015 have been removed, along with the country reported values from FRA 2015. For each of the primary forest estimates (a, b and c) the percent differences compared to the FRA 2015 primary forest calculations are also included. (*Hawaii only; **Torres Strait Islands only). (a) Turubanova et al., 2018); (b) Intact Forest Landscapes (Potapov et al., 2008); (c) Hinterland Forests (humid tropics) (Tyukavina et al., 2016); (d) Tree cover 2000 (>10% canopy cover) (Hansen et al., 2013); (e) Tree Cover 2000 (>60% canopy cover) (Hansen et al., 2013).

	Country reported values		*Forest extents (thousand ha) with areas of forest loss during 2000-2015 being removed.*				
Country	Primary forest (FAO, 2015)	All forest (FAO, 2015)	*(a)*	*(b)*	*(c)*	*(d)*	*(e)*
Australia	5,039	124,751	1** (NA)	5,446 (+8.1%)	622 (-87.7%)	71,095	19,143
Brazil	202,691	493,538	338,103 (+66.8%)	231,983 (+14.4%)	235,088 (+16.0%)	572,333	387,420
Canada	205,924	347,069	NA	245,357 (+19.1%)	NA	485,596	231,726
DRC	102,686	152,578	108,531 (+5.6%)	63,319 (-38.3%)	67,742 (-34.0%)	214,910	122,725
Indonesia	46,024	91,010	90,511 (+96.7)	32,413 (-29.6%)	35,810 (-22.2%)	146,297	120,223
Russian Federation	272,718	814,931	NA	232,194 (-14.9%)	NA	930,402	416,192
USA	75,300	310,095	277* (NA)	41,195 (-45.3%)	13*(NA)	346,114	166,643

The differences apparent in Table 5 reflect, among other things, the tree canopy threshold used to define 'forest' (columns "d" and "e"). The FRA reported estimates of primary forest most closely matched the Intact Forest Landscape values, except in the case of DRC which best matches the estimates of Turubanova et al. (2018) (column 'a'). Values for IFL (column "b") are generally smaller which simply reflects the 500 km^2 minimum threshold. Overall, the results suggest that modelled global estimates based largely on remotely sensed sources validate FRA reported primary forest statistics and therefore are a potentially source of independent information that can complement national level assessments.

5. Options for improved primary forest reporting

Providing specific guidelines for describing, measuring, mapping and reporting on primary forests is challenging because, among other things, natural forests differ in their physical environmental conditions, evolutionary histories and taxonomic compositions, structures and ecosystem processes and natural disturbance regimes, in addition to their land use histories, tenures, and governance systems.

Nonetheless, there is general agreement that primary forests represent the more natural 'bandwidth' of the forest condition gradient and we conclude that the FRA 2015 definition of primary forest is sufficiently consistent with how the term is used in the scientific and applied literature. There remains a need however for further guidance and assistance to facilitate more reliable and consistent FRA reporting at the country level. To this end, following are some options for consideration based upon the materials reviewed and the data analysed in this report.

1. ***Landscape forest metrics*** – The use of field-based observation, including forestry inventory and monitoring field data, in calculating landscape level forest metrics hold great promise for characterising primary forests and enabling them to be empirically compared to and distinguished from other forests. Such metrics can provide complementary information to other approaches and an empirical basis for identifying primary forest based on ecosystem-level and other ecological characteristics. Candidate metrics include: *Stand age-class frequency distributions*; *Biomass carbon frequency distributions*; *Patch spatial statistics regarding the forest patch size and shape; Frequency distribution of the area covered by forest ecosystem types*; *Fine and coarse woody debris including snags and large diameter dead biomass*; *Foundation/framework canopy tree species*; *Characteristic biodiversity including* i*nterior forest micro-environment dependent plant, animal and fungi species.* However, for such metrics to be useful, the underlying field-based data must be representative of ecological zones, forest types and forest condition. Conventional forest inventories, for example, were often designed to gather data on tree growth rates in regenerating forest stands (McKenney et al., 1996) and may under sample primary forest.

2. ***Primary forest categories***– Review of FRA reporting reveals that some countries may be underestimating the extent of primary forest by assuming it correlates with particular land tenures such as protected areas. Conversely, some countries may be overestimating by equating primary forest with all natural forest cover, some of which may be in a degraded condition. Greater comparability across country reporting could be facilitated by agreement on a set of categories that illustrate the range of forest conditions that warrant being labelled 'primary forest' and that help identify where forests lie on the forest condition gradient. This would also serve to help identify relevant forests in countries where other cognate terms are more commonly used such as old growth forest, primeval forest, frontier forest and long-untouched forest. The cognate primary forest categories could also be described in terms of the three main categories of variables used to define primary forest (Box 1 – anthropogenic influences, vegetation structure and related ecological processes, biodiversity and other ecological attributes).

3. Technical issues warranting further consideration

There are three technical issues that warrant further expert consideration which if clarified could significantly help improve guidance to countries and improve the reliability of primary forest reporting, including:

a. Forest vegetation structure – Assessment of primary forest is in part dependent on how natural forests are defined and in particular, the percentage tree canopy cover and height thresholds used to delineate forest from non-forest vegetation. This is particularly important if assessments are reliant upon remotely sensed data on forest canopy cover. Furthermore, in order to interpret a mapped percentage canopy cover as primary forest or not, it is necessary to have some ecological insight into the natural canopy structure. In the humid tropics, for example, primary forest is typically considered to have a canopy cover of >60% whereas in the Russian boreal a primary forest may have canopy cover of only 6-10%.

b. *Changing fire regimes* – Further analysis is needed on how the assessment of forest condition, and the delineation of primary forest, is impacted by changing fire regimes as the result of both intentional burning and climate change, given that wildfires are part of the natural disturbance regimes for many primary forests, particularly in temperate and boreal biomes.

c. *Spatial scale* – Further consideration is also needed regarding questions of spatial scale in assessing primary forests. The international definitions of forest have minimum area thresholds that relate to the stand or plot level (0.05-0.5 ha^{-1}). This makes sense from a wood production perspective, but part of the definition of primary forests requires consideration of ecological and evolutionary processes, along with fire regimes, and the multiple scales at which they operate. Complicating this issue is the fact that as important as larger areas of primary forest are for many processes and ecosystem services, even small patches of forest provide refuge for wildlife, a source of propagules for landscape restoration, and serve as anchors for connectivity conservation initiatives.

4. *National level forest data & information management* – Field-based observations, including forestry inventory data, long-term ecological monitoring sites, and other kinds of systematic and ad hoc scientific surveys, provide critical data that are unavailable through remotely sensed sources. Furthermore, all remotely sensed data – whether from active (e.g. Lidar) or passive (e.g. Landsat) sensors require field data for calibration and validation. In addition, there are many important forest characteristics that can only be measured and assessed in situ. Therefore, primary forest assessment is greatly facilitate when forest-related national field based data, biodiversity archives, remotely sensed and other relevant GIS data related to land use and tenure, are securely stored, discoverable and available in formats that enable them to be readily accessed and assimilated.

5. *Global forest data platform* – Spatial estimates of key forest structural characteristics and how these are changing over time based on remotely sensed satellite data (also called 'Earth observation data') are now available and more improved data and models are in the pipeline. These data products can be complemented by web-based data and modelling portals for biodiversity including primary forest dependent species distributions. The FAO could consider developing a global forest data platform – i.e. a web portal – that provides countries with access to a curated set of the most reliable and up to date global forest-related data sets. These data could be used by governments to cross validate their national assessments and provide the FAO with a standard set of metrics for global comparisons.

6. References

BARLOW, J., GARDNER, T. A., ARAUJO, I. S., ÁVILA-PIRES, T. C., BONALDO, A. B., COSTA, J. E., ESPOSITO, M. C., FERREIRA, L. V., HAWES, J. & HERNANDEZ, M. I. 2007. Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. *Proceedings of the National Academy of Sciences,* 104**,** 18555-18560.

BONTEMPS, S., DEFOURNY, P., RADOUX, J., VAN BOGAERT, E., LAMARCHE, C., ACHARD, F., MAYAUX, P., BOETTCHER, M., BROCKMANN, C. & KIRCHES, G. Consistent global land cover maps for climate modelling communities: current achievements of the ESA's land cover CCI. Proceedings of the ESA Living Planet Symposium, Edimburgh, 2013. 9-13.

BREARLEY, F. Q., PRAJADINATA, S., KIDD, P. S. & PROCTOR, J. 2004. Structure and floristics of an old secondary rain forest in Central Kalimantan, Indonesia, and a comparison with adjacent primary forest. *Forest Ecology and Management,* 195**,** 385-397.

BRIANT, G., GOND, V. & LAURANCE, S. G. 2010. Habitat fragmentation and the desiccation of forest canopies: a case study from eastern Amazonia. *Biological Conservation,* 143**,** 2763-2769.

BRYANT, D., NIELSON, D. & TANGLEY, L. 1997. The last frontier forests. *Issues in Science and Technology,* 14**,** 85.

BUCHWALD, E. A hierarchical terminology for more or less natural forests in relation to sustainable management and biodiversity conservation. Third expert meeting on harmonizing forest-related definitions for use by various stakeholders. Proceedings. Food and Agriculture Organization of the United Nations. Rome, 2005. 17-19.

BUNTING, P., ROSENQVIST, A., LUCAS, R. M., REBELO, L.-M., HILARIDES, L., THOMAS, N., HARDY, A., ITOH, T., SHIMADA, M. & FINLAYSON, C. M. 2018. The global mangrove watch—a new 2010 global baseline of mangrove extent. *Remote Sensing,* 10**,** 1669.

CARNAHAN, J. 1990. *Atlas of Australian Resources, Third Series, Volume 6: Vegetation,* Canberra, Australian Surveying and Land Information Group.

CASTILLO-CAMPOS, G., HALFFTER, G. & MORENO, C. E. 2008. Primary and secondary vegetation patches as contributors to floristic diversity in a tropical deciduous forest landscape. *Biodiversity and Conservation,* 17**,** 1701-1714.

CHAZDON, R. L., FINEGAN, B., CAPERS, R. S., SALGADO-NEGRET, B., CASANOVES, F., BOUKILI, V. & NORDEN, N. 2010. Composition and dynamics of functional groups of trees during tropical forest succession in northeastern Costa Rica. *Biotropica,* 42**,** 31-40.

CONVENTION ON BIOLOGICAL DIVERSITY. 2006. *Definitions* [Online]. Available: https://www.cbd.int/forest/definitions.shtml [Accessed [07/02/2020].

CORLETT, R. T. 1994. What is secondary forest? *Journal of Tropical Ecology,* 10**,** 445-447.

CROWTHER, T. W., GLICK, H. B., COVEY, K. R., BETTIGOLE, C., MAYNARD, D. S., THOMAS, S. M., SMITH, J. R., HINTLER, G., DUGUID, M. C. & AMATULLI, G. 2015. Mapping tree density at a global scale. *Nature,* 525**,** 201-205.

CURTIS, P. G., SLAY, C. M., HARRIS, N. L., TYUKAVINA, A. & HANSEN, M. C. 2018. Classifying drivers of global forest loss. *Science,* 361**,** 1108-1111.

DENGLER, J., JANSEN, F., GLÖCKLER, F., PEET, R. K., DE CÁCERES, M., CHYTRÝ, M., EWALD, J., OLDELAND, J., LOPEZ-GONZALEZ, G. & FINCKH, M. 2011. The Global Index of Vegetation-Plot Databases (GIVD): a new resource for vegetation science. *Journal of Vegetation Science,* 22**,** 582-597.

ELLISON, A. M., BANK, M. S., CLINTON, B. D., COLBURN, E. A., ELLIOTT, K., FORD, C. R., FOSTER, D. R., KLOEPPEL, B. D., KNOEPP, J. D. & LOVETT, G. M. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment,* 3**,** 479-486.

ESQUIVEL-MUELBERT, A., BAKER, T. R., DEXTER, K. G., LEWIS, S. L., BRIENEN, R. J., FELDPAUSCH, T. R., LLOYD, J., MONTEAGUDO-MENDOZA, A., ARROYO, L. & ÁLVAREZ-DÁVILA, E. 2019. Compositional response of Amazon forests to climate change. *Global Change Biology,* 25**,** 39-56.

FAO 2002. Expert Meeting on Harmonizing forest-related definitions for use by various stakeholders. Rome.

FAO 2012. Global ecological zones for FAO forest reporting: 2010 Update. Rome.

FAO 2015. Global Forest Resources Assessment 2015: How have the world's forests changed? . Rome, Italy.

FAO 2018. Terms and definitions FRA 2020.

FAUSET, S., JOHNSON, M. O., GLOOR, M., BAKER, T. R., MONTEAGUDO, A., BRIENEN, R. J., FELDPAUSCH, T. R., LOPEZ-GONZALEZ, G., MALHI, Y. & TER STEEGE, H. 2015. Hyperdominance in Amazonian forest carbon cycling. *Nature Communications,* 6**,** 1-9.

FREEDMAN, B., ZELAZNY, V., BEAUDETTE, D., FLEMING, T., JOHNSON, G., FLEMMING, S., GERROW, J., FORBES, G. & WOODLEY, S. 1996. Biodiversity implications of changes in the quantity of dead organic matter in managed forests. *Environmental Reviews,* 4**,** 238-265.

FREY, S. J., HADLEY, A. S., JOHNSON, S. L., SCHULZE, M., JONES, J. A. & BETTS, M. G. 2016. Spatial models reveal the microclimatic buffering capacity of old-growth forests. *Science Advances,* 2**,** e1501392.

FUNK, J. M., AGUILAR-AMUCHASTEGUI, N., BALDWIN-CANTELLO, W., BUSCH, J., CHUVASOV, E., EVANS, T., GRIFFIN, B., HARRIS, N., FERREIRA, M. N. & PETERSEN, K. 2019. Securing the climate benefits of stable forests. *Climate Policy,* 19**,** 845-860.

GATTI, R. C., CASTALDI, S., LINDSELL, J. A., COOMES, D. A., MARCHETTI, M., MAESANO, M., DI PAOLA, A., PAPARELLA, F. & VALENTINI, R. 2015. The impact of selective logging and clearcutting on forest structure, tree diversity and above-ground biomass of African tropical forests. *Ecological Research,* 30**,** 119-132.

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. 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. *Nature,* 478**,** 378-381.

GLOBAL FOREST WATCH. 2020. *Forest Monitoring Designed for Action* [Online]. Available: https://www.globalforestwatch.org/ [Accessed 07/02/2020].

GORELICK, N., HANCHER, M., DIXON, M., ILYUSHCHENKO, S., THAU, D. & MOORE, R. 2017. Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment,* 202**,** 18-27.

HANSEN, A., BARNETT, K., JANTZ, P., PHILLIPS, L., GOETZ, S. J., HANSEN, M., VENTER, O., WATSON, J. E., BURNS, P. & ATKINSON, S. 2019. Global humid tropics forest structural condition and forest structural integrity maps. *Scientific Data,* 6**,** 1-12.

HANSEN, M. C., POTAPOV, P. V., MOORE, R., HANCHER, M., TURUBANOVA, S., TYUKAVINA, A., THAU, D., STEHMAN, S., GOETZ, S. & LOVELAND, T. R. 2013. High-resolution global maps of 21st-century forest cover change. *Science,* 342**,** 850-853.

HARRIS, N. L., GOLDMAN, E. & GIBBES, S. 2020. Spatial Database of Planted Trees (SDPT) Version 1.0. www.globalforestwatch.org.

IUCN 2020. Approval of a policy statement on the importance of the conservation of primary forests. *98th Meeting of the IUCN Council, Gland (CH), 8-11 February 2020.*

JACQUEMYN, H., BUTAYE, J. & HERMY, M. 2001. Forest plant species richness in small, fragmented mixed deciduous forest patches: the role of area, time and dispersal limitation. *Journal of Biogeography,* 28**,** 801-812.

KEITH, H., MACKEY, B., BERRY, S., LINDENMAYER, D. & GIBBONS, P. 2010. Estimating carbon carrying capacity in natural forest ecosystems across heterogeneous landscapes: addressing sources of error. *Global Change Biology,* 16**,** 2971-2989.

KEITH, H., MACKEY, B. G. & LINDENMAYER, D. B. 2009. Re-evaluation of forest biomass carbon stocks and lessons from the world's most carbon-dense forests. *Proceedings of the National Academy of Sciences,* 106**,** 11635-11640.

KENNEDY, C. M., OAKLEAF, J. R., THEOBALD, D. M., BARUCH‐MORDO, S. & KIESECKER, J. 2019. Managing the middle: A shift in conservation priorities based on the global human modification gradient. *Global Change Biology,* 25**,** 811-826.

KRYLOV, A., MCCARTY, J. L., POTAPOV, P., LOBODA, T., TYUKAVINA, A., TURUBANOVA, S. & HANSEN, M. C. 2014. Remote sensing estimates of stand-replacement fires in Russia, 2002–2011. *Environmental Research Letters,* 9**,** 105007.

LAMB, D., ERSKINE, P. D. & PARROTTA, J. A. 2005. Restoration of degraded tropical forest landscapes. *Science,* 310**,** 1628-1632.

MACKEY, B., DELLASALA, D. A., KORMOS, C., LINDENMAYER, D., KUMPEL, N., ZIMMERMAN, B., HUGH, S., YOUNG, V., FOLEY, S. & ARSENIS, K. 2015. Policy options for the world's primary forests in multilateral environmental agreements. *Conservation Letters,* 8**,** 139-147.

MACKEY, B., LINDENMAYER, D., GILL, M. & LINDESAY, J. 2002. *Wildlife, fire & future climate: a forest ecosystem analysis*, CSIRO Publishing.

MARGONO, B. A., POTAPOV, P. V., TURUBANOVA, S., STOLLE, F. & HANSEN, M. C. 2014. Primary forest cover loss in Indonesia over 2000–2012. *Nature Climate Change,* 4**,** 730.

MARGONO, B. A., TURUBANOVA, S., ZHURAVLEVA, I., POTAPOV, P., TYUKAVINA, A., BACCINI, A., GOETZ, S. & HANSEN, M. C. 2012. Mapping and monitoring deforestation and forest degradation in Sumatra (Indonesia) using Landsat time series data sets from 1990 to 2010. *Environmental Research Letters,* 7**,** 034010.

MCRAE, D., DUCHESNE, L., FREEDMAN, B., LYNHAM, T. & WOODLEY, S. 2001. Comparisons between wildfire and forest harvesting and their implications in forest management. *Environmental Reviews,* 9**,** 223-260.

MIKOLÁŠ, M., UJHÁZY, K., JASÍK, M., WIEZIK, M., GALLAY, I., POLÁK, P., VYSOKÝ, J., ČILIAK, M., MEIGS, G. W. & SVOBODA, M. 2019. Primary forest distribution and representation in a Central European landscape: Results of a large-scale field-based census. *Forest Ecology and Management,* 449**,** 117466.

MONTESANO, P. M., NEIGH, C. S., SEXTON, J., FENG, M., CHANNAN, S., RANSON, K. J. & TOWNSHEND, J. R. 2016. Calibration and validation of Landsat tree cover in the taiga− tundra ecotone. *Remote Sensing,* 8**,** 551.

NEWBOLD, T., HUDSON, L. N., ARNELL, A. P., CONTU, S., DE PALMA, A., FERRIER, S., HILL, S. L., HOSKINS, A. J., LYSENKO, I. & PHILLIPS, H. R. 2016. Has land use pushed terrestrial biodiversity beyond the planetary boundary? A global assessment. *Science,* 353**,** 288-291.

POTAPOV, P., YAROSHENKO, A., TURUBANOVA, S., DUBININ, M., LAESTADIUS, L., THIES, C., AKSENOV, D., EGOROV, A., YESIPOVA, Y. & GLUSHKOV, I. 2008. Mapping the world's intact forest landscapes by remote sensing. *Ecology and Society,* 13.

PUETTMANN, K. J., WILSON, S. M., BAKER, S. C., DONOSO, P. J., DRÖSSLER, L., AMENTE, G., HARVEY, B. D., KNOKE, T., LU, Y. & NOCENTINI, S. 2015. Silvicultural alternatives to conventional even-aged forest management-what limits global adoption? *Forest Ecosystems,* 2**,** 1-16.

SADEGHI, Y., ST-ONGE, B., LEBLON, B. & SIMARD, M. 2016. Canopy height model (CHM) derived from a TanDEM-X InSAR DSM and an airborne lidar DTM in boreal forest. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing,* 9**,** 381-397.

SANDMANN, H. & LERTZMAN, K. P. 2003. Combining high-resolution aerial photography with gradient-directed transects to guide field sampling and forest mapping in mountainous terrain. *Forest Science,* 49**,** 429-443.

SHESTAKOVA ET AL. (in prep) Mapping forest ecosystem integrity.

SCHMIEGELOW, F. K., STEPNISKY, D. P., STAMBAUGH, C. A. & KOIVULA, M. 2006. Reconciling salvage logging of boreal forests with a natural-disturbance management model. *Conservation Biology,* 20**,** 971-983.

SCHROEDER, W., OLIVA, P., GIGLIO, L. & CSISZAR, I. A. 2014. The New VIIRS 375 m active fire detection data product: Algorithm description and initial assessment. *Remote Sensing of Environment,* 143**,** 85-96.

SIMARD, M., PINTO, N., FISHER, J. B. & BACCINI, A. 2011. Mapping forest canopy height globally with spaceborne lidar. *Journal of Geophysical Research: Biogeosciences,* 116.

TER STEEGE, H., PITMAN, N. C., SABATIER, D., BARALOTO, C., SALOMÃO, R. P., GUEVARA, J. E., PHILLIPS, O. L., CASTILHO, C. V., MAGNUSSON, W. E. & MOLINO, J.-F. 2013. Hyperdominance in the Amazonian tree flora. *Science,* 342**,** 1243092.

THOMPSON, I., MACKEY, B., MCNULTY, S. & MOSSELER, A. Forest resilience, biodiversity, and climate change. Secretariat of the Convention on Biological Diversity, Montreal. Technical Series no. 43. 1-67., 2009. 1-67.

THORN, S., BÄSSLER, C., BRANDL, R., BURTON, P. J., CAHALL, R., CAMPBELL, J. L., CASTRO, J., CHOI, C. Y., COBB, T. & DONATO, D. C. 2018. Impacts of salvage logging on biodiversity: A meta-analysis. *Journal of Applied Ecology,* 55**,** 279-289.

TURNER, P. A., BALMER, J. & KIRKPATRICK, J. 2009. Stand-replacing wildfires?: The incidence of multi-cohort and single-cohort Eucalyptus regnans and E. obliqua forests in southern Tasmania. *Forest Ecology and Management,* 258**,** 366-375.

TURUBANOVA, S., POTAPOV, P. V., TYUKAVINA, A. & HANSEN, M. C. 2018. Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia. *Environmental Research Letters,* 13**,** 074028.

TYUKAVINA, A., HANSEN, M., POTAPOV, P., KRYLOV, A. & GOETZ, S. 2016. Pan-tropical hinterland forests: mapping minimally disturbed forests. *Global Ecology and Biogeography,* 25**,** 151-163.

UNEP-WCMC & IUCN 2020. Protected Planet: The World Database on Protected Areas (WDPA), Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net.

UNFCCC 2001. The Marrakesh Accords and The Marrakesh Declaration. The Advance Versionof the Decisions and Other Action Adopted by the Conference of the Parties at Its Seventh Session, 29 October – 9 November 2001.

UNIVERSITY OF MARYLAND 2020. Global Forest Change 2000–2018 Data Download,. Available at: https://earthenginepartners.appspot.com/science-2013-global-forest/download_v1.6.html

WATSON, J. E., EVANS, T., VENTER, O., WILLIAMS, B., TULLOCH, A., STEWART, C., THOMPSON, I., RAY, J. C., MURRAY, K. & SALAZAR, A. 2018. The exceptional value of intact forest ecosystems. *Nature Ecology & Evolution,* 2**,** 599.

WHITE, D. L. & LLOYD, F. T. 1994. Defining old growth: Implications for management.

WORLD RESOURCES INSTITUTE. 2020. Global Forest Watch World Resources Institute [Online]. Available: https://www.wri.org/our-work/project/global-forest-watch

XUE, J. & SU, B. 2017. Significant remote sensing vegetation indices: A review of developments and applications. *Journal of Sensors,* 2017.

ZHURAVLEVA, I., TURUBANOVA, S., POTAPOV, P., HANSEN, M., TYUKAVINA, A., MINNEMEYER, S., LAPORTE, N., GOETZ, S., VERBELEN, F. & THIES, C. 2013. Satellite-based primary forest degradation assessment in the Democratic Republic of the Congo, 2000–2010. *Environmental Research Letters,* 8**,** 024034.

Table 2. The 20 countries with the largest areas of reported primary forest from FRA 2015, along with their entire forest extents (thousand ha), Intact Forest Landscape and Hinterland forest areas (thousand ha), FRA primary forest definition used in each country's report, the country's national primary forest definition as reported in the FRA 2015 and comments related to data definitions around primary forest. All countries reported using the FRA definition of "Naturally regenerated forest of native species where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed."

Country	Primary forest area (1,000 ha^{-1})	Total forest area (1,000 ha^{-1})	Intact Forest Landscape area (1,000 ha^{-1})	Hinterland Forest area (1,000 ha^{-1})	National primary forest definition	Comments in reports related to their data definitions about primary forest
Russian Federation	272,717.6	814,930.5	232,193.9	621.7	Undisturbed by man forest is climax forest (boreal climax of succession) where there are ecological processes are not significantly disturbed. Climax forests are mature and over mature stands of coniferous tree species. All Reserve forests and the mature forest in protected areas are considered as a primary forest (expert data).	Assessment based on expert knowledge. The area of primary forests is not taken into account in the forest management, therefore these data is not present in the State account of forest resources (SAFR). We assumed that all mature and over-mature coniferous stands of trees as primary, as they are a climatic climax in terrain of Russia. The sharp increase of the area of Primary forests is connected with the increase of Total forest area in 2010.
Canada	205,924	347,069	245,357.4	235,088.0	N/A	Tier 1 is indicated for status because the primary forest concept does not apply well in Canada and it is not tracked by Canada's NFI. It is estimated for this report using proxy indicators
Brazil	202,691	493538	231,983.2	NA	Naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.	The percentage of forest area within protected areas considered in each biome as primary forest was chosen based on the use and occupation of the soil.
Democratic Republic of the Congo	102,686	152,578	63,318.8	67,742.4	N/A	N/A
United States of America	75,300	31,0095	41,195.2	35809.6	N/A	Includes all Conservation of Biological diversity forest.
Peru	65,790	73,973	53,799.3	NA	Forested ecosystem with original vegetation, characterized by the abundance of mature trees of species of the upper dominant canopy, which has evolved naturally and has not been disturbed by human activities or natural causes (Translated to English using Google Translate).	It is the equivalent to the Primary Forest Category according to the FRA 2005 classification. For table 2 to 2010 and 2015, the same base information used in table 1 was considered. For the years 2005, 2000 and 1990, the figures reported in those years are maintained, although these figures may not be updated with more real information as a result of subsequent studies (Translated to English using Google Translate).
Indonesia	46,024	91,010	32,413.2	13.1	Forest with no ocular evidence of disturbance. This is indicated by the occurrence of logging roads.	The extent of primary forest from 1990 until 2010 has been reduced. This caused by the land cover change from forest to other land (deforestation)

						and reducing of forest quality (degradation).
Venezuela (Bolivarian Republic of)	45,746	46,683	31,377.0	46,723.0	N/A	ea was considered primary forest by subtracting forest plantations and the area of compartments used by private forest concessionary companies (380,000 ha.), Which are considered primary forest that has been intervened and is regenerating. • The 2010 forest area is 47 505 (1000 ha) and 2015 is 46 683 (1000 ha). • Primary forest is the entire forest subtracting forest plantations and compartment surfaces used by concessionaires. Regarding naturally regenerated forests, the areas with OFS and management plan are 2 852 063 ha, of which 380 000ha are the primary forest compartments that have been intervened and are being regenerated. The area of forest plantations is 557 323 ha. It is assumed that only 6% of the forest planted with native species, represented by the contributions of the MPPA, through Mission Tree and CONARE, about 32 202ha. Therefore, more than 94% of planted forest results with introduced species: pine, teak, eucalyptus, melina, others. It is assumed that the average annual area of deforestation (164,600 ha per year-1) primary forest converted to other lands • With the forest area data for the year 2000 and the forest area for the year 2010 according to the vegetation cover map (2011), the average annual surface area deforested 2000-2010 is 164 600ha year-1 (0.33%) and the projected average annual deforested area 2000-2015 is 164 400 ha year-1 (0.35%) (Translated to English using Google Translate).
Bolivia	36,164	54,764	18,303.7	29,937.0	N/A	In FRA 2005, natural forests were classified as 50% primary forests. However, it is estimated that 65% is closer to reality (Translated to English using Google Translate).
Mexico	33,056	66,040	1,495.0	21,608.5	N/A	It corresponds to forests of primary vegetation type according to what could be classified in the satellite images. It is possible that part of these forests has been affected by minor human interventions (Translated to English using Google Translate).

Papua New Guinea	17,599	33,559	14,069.0	2,359.9	All Potential Forest Areas designated in the National Forest Plan for timber production, but not yet logged. Also designated for REDD Pilot projects and conservation projects.	This includes all the forest that are either currently under timber permits and operational and those other areas that have been identified as potential timber areas and also those in the "reserve forest" areas where their status is yet to be determined. REDD pilot project areas also included.
India	15,701	70,682	3,252.5	11,240.6	N/A	N/A
Suriname	14,019	15,332	10,027.3	1,643.4	N/A	This might be an overestimation because areas logged before 1990 were not included. On the other hand, there might be an overlapping between the different types of other naturally regenerating forests.
Gabon	12,804	23,000	8,388.3	11,097.3	N/A	The concept of primary forest is currently the subject of debate among specialists in the field, because remote sensing work alone does not allow these ecosystems to be identified exactly. It therefore seems better to speak of mature forest while waiting to carry out inventory work on the ground (Translated to English using Google Translate).
Mongolia	12,551.6	12,552.8	940.3	12,184.6	N/A	N/A
Ecuador	12,467.3	12,547.8	5,272.6	NA	N/A	The IDH data were used for the years 1990, 2000, 2008. It is equivalent to level 2 that corresponds to native forest of the cover and land use map (Translated to English using Google Translate).
China	11,632.4	208,321.3	2,460.6	5,924.7	N/A	N/A
French Guiana	7,812.8	8130	6,283.4	620.9	Definition identical to that of FAO (Translated to English using Google Translate).	N/A
Congo	7,407	22,334	11,035.3	6,034.9	In the absence of national classes, the classification and definitions are the same as those of the FRA (Translated to English using Google Translate).	This area takes into account: the areas still intact of natural forests (dense forest on dry land, dense flooded forest, open forest and mangrove) (Translated to English using Google Translate).
Thailand	6,726	16,399	1872.0	13,677.3	Areas of national parks and wildlife sanctuaries	N/A