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Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015 ☆

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ABSTRACT

The global community has recognized the importance of forests for biodiversity, and has prioritized the preservation of forest biodiversity and ecosystem functions through multiple multilateral agreements and processes such as the Convention on Biodiversity's Aichi Targets and the Millennium Development Goals. The Global Forest Resources Assessment (FRA) provides one mechanism for tracking progress toward such goals in three particular areas: primary forest area, protected forest areas, and areas designated for the conservation of biodiversity. In this paper, we quantify current area and trends in forest areas designated for the conservation of biodiversity, protected forest areas, and primary forests by country and biome; and examine the association between total forest area and measures of protection, per-capita income, and population. The overall findings suggest that countries are increasingly protecting forests of ecological significance at the global scale (7.7% of forests were protected in 1990 rising to 16.3% in 2015), with a strong upward trend in protected areas in the tropical domain (from 12% in 1990 to 26.3% in 2015). However, primary forest area has declined by 2.5% globally and by 10% in the tropics over the period 1990–2015 (using data for countries that reported in all years). Given that many species in the tropics are endemic to primary forests, losses in that climatic domain continue to be of concern, although the rate of decline appears to be slowing.

Using multiple regression analysis, we find that a 1% increase in protected area or area designated for biodiversity conservation within a country is associated with an increase in total forest area in that country of about 0.03% ($p < 0.05$). A 1% within-country increase in population density and per capita GDP are associated with a decrease in forest area of about 0.2% ($p < 0.01$) and an increase in forest area of about 0.08% ($p < 0.05$) respectively. Our findings also indicate that, since FRA is used as one mechanism for tracking progress toward goals like the AICHI Biodiversity Targets, country correspondents may require additional assistance toward reporting on primary forest, protected forest, and biodiversity conservation statistics.

1. Introduction

Forests provide critical ecosystem goods and services such as food, water, shelter, and nutrient cycling among others, and play a fundamental role in conservation of biodiversity. According with recent studies, forests cover nearly 30 percent of the Earth's land area (Keenan et al., 2015), containing 80 percent of terrestrial biomass and providing habitat for over half of the world's known terrestrial plant and animal species (Shvidenko et al., 2005; Aerts and Honnay, 2011).

The global community has recognized the importance of forests for biodiversity, and has prioritized the preservation of forest biodiversity and ecosystem functions through multiple multilateral agreements and processes. For example, the Aichi Biodiversity Targets established by the Convention on Biological Diversity (CBD) in its strategic plan include halving the rate of loss of natural habitats including forests (target 5) and conserving 17% of terrestrial areas through effectively and equitably managed, ecologically representative and well connected systems of protected areas (target 11) (SCBD, 2006). Despite global acknowledgement of the

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importance of forests, recent data show that forest area has continued to shrink (Keenan et al., 2015) as agricultural land continues to expand in 70% of countries (FAO, 2003). Deforestation is declining, globally from 16 million ha annually in the 1990s to 13 million ha annually between 2000 and 2010 (FAO, 2010), but the current 0.08% rate of loss reported by Keenan et al. (2015) for the years 2010–2015 is still a matter of concern because the loss is occurring in areas with particularly high ecological value.

Given that a majority of known terrestrial species live in forests, and 9 percent of tree species alone are currently threatened with extinction, it is clear that achieving success in meeting the Aichi Biodiversity Targets and Millennium Development Goals is linked to slowing or reversing deforestation (JLG, 2008). While the global community appears to agree on the importance of biological diversity and forest cover, quantifying progress toward meeting biodiversity and forest degradation targets proves challenging.

Currently, designating protected areas is one of the primary strategies for conserving biodiversity. Watson et al. (2014) discuss the increase in protected areas over the past century; however, they find that many key biodiversity areas are not adequately covered by protected area status. Joppa and Pfaff (2009) reached similar conclusions.

Beyond forests that are specifically protected, countries may recognize certain forest areas as important for the conservation of biodiversity. The Global Forest Resource Assessment (FRA) asks countries to report on forests that are designated for conservation of biodiversity with the understanding that these forests may include those in protected areas, but may also encompass other areas. That additional forest area may contribute to meeting Aichi Biodiversity Target 11, which calls for including 17% of terrestrial area in protected areas and other effective area-based conservation measures (SCBD, 2006).

While forests are recognized as important for biodiversity and protected areas are doubtless important for biodiversity conservation, not all forests are equal in terms of the diversity they support and the quality of the ecological functions they provide. Primary forests are globally irreplaceable with unique qualities that make significant contributions to biodiversity conservation, climate change mitigation, and sustainable livelihoods (Foley et al., 2007; Gibson et al., 2011), and with particular importance in tropical areas. Barlow et al. (2007) found that 25% of species in Amazonian Brazil were unique to primary forests, and almost 60 percent of tree and liana genera were recorded only in primary forests. In North America, primary forest (sometimes referred to as "old growth" or "mature forest") is characterized by high structural heterogeneity as well as biodiversity. Biodiversity in North American primary forests often includes a wide range of lichens, fungi, insects, bats, spiders, and other organisms found only in structurally complex mature forests (Spies, 2003).

Given the global recognition of the importance of biodiversity, the link between biodiversity and forests, the need for protected areas to preserve biodiversity, and the contribution of primary forests (or structurally complex mature forests) to biodiversity within countries, tracking those resources through time is integral to maintaining target goals. To this end, the Food and Agriculture Organization of the United Nations (FAO) includes in the FRA instrument questions requesting countries to report forest area within formally established protected areas independent of the purpose for which the protected areas were established; forest area designated primarily for conservation of biological diversity, including but not limited to areas within protected forests; and 'primary forest' – naturally regenerated forests of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Countries are asked to review their national definitions for the relevant metrics in light of the definitions specified in the FRA, and to adjust their estimates as needed to bring them in line with the FAO definitions [see more details about the definitions and reporting process in MacDicken (2015)].

The global FRA offers one of the few, if not only, opportunities to collate and analyze data on the above metrics across a long time period at a global scale. When analyzed in relation to other metrics (e.g., socioeconomic data), trends in these measures of forest area may provide insights into the factors that influence conservation of forests at a broad scale and offer possibilities for improvement both in forest conservation and in tracking the status of forests believed to be particularly important for conservation. This exploration of FRA data should reveal strengths and weaknesses in the metrics currently reported in the global assessment.

2. Methods

2.1. Sources

FAO has been monitoring the world's forests since 1946, initially at 10-year intervals, and every 5 years since 2000. Since its inception, FAO has produced eleven Global Forest Assessments. This paper is intended to serve as one component of the 12th global FRA, dated 2015.

The FRA provides a consistent approach to describing the world's forests and how they are changing. The assessment is based on two primary sources of data: (a) Country and territory reports prepared by national correspondents and (in some cases) desk studies by the FRA team and (b) remote sensing analysis conducted by FAO together with national focal points and regional partners. This paper excludes the remote-sensing analyses and is based only on the data collected for the country and territory reports and contained within the FRA database (available online).

The FRA report compiles information from 234 countries and territories around the world. Since 2000, each participating country has designated an official national correspondent who is charged with providing the official national statistics for their country. For FRA 2015, in addition to the national reports, ancillary data such as gross domestic product (GDP), per capita income level, and population were incorporated using information from World Bank (World Bank, 2013). For more detail regarding the methods, classifications and definitions used in FRA 2015 please refer to MacDicken (2015).

In this paper, whenever trends and changes in areas are described, the figures include only countries and territories that reported in all years, so as not to bias trends by including a changing set of countries. The numbers thus presented may, therefore, not match the corresponding area reported in a given year.

For data analysis, descriptive statistics per country, sub-region or climatic domain were used. In addition, multiple regression analysis was used to investigate the relationship between socioeconomic variables such as population density, per-capita GDP, and the impacts of conservation efforts on forest cover.

A descriptive analysis of data reliability was performance using the tier system introduced by MacDicken (2015), in order to have a better understanding of the information provided.

2.2. Examining the effects of protected area and biodiversity conservation area on forest area

While primary forest area is assumed to relate to biodiversity at the global scale, protected area and biodiversity conservation area can be thought of as measures of conservation effort. Below we report the results of multiple regression analysis directed at examining the impacts of these two measures of conservation effort as well as other variables (population density and per capita GDP) on total forest area. The main question of interest is whether an increase in protected and biodiversity conservation area are associated with an increase in forest area, all else remaining the same. We do not attempt to explain most variation in forest area, an undertaking that is beyond the scope of this article.

We wish to avoid estimating spurious correlations that are likely to arise in such cross-country data. For example, there may be a negative correlation between protected area and forest area across countries because countries with small remaining forest areas may expand protected areas. To deal with this, we specify our first regression model as

$$y_{it} = \alpha_i + \beta_1 p_{it} + \beta_2 g_{it} + \beta_3 a_{it} + u_{it}$$

where $i \in \{1, \ldots, N\}$ denotes a country and $t \in \{1990, 2000, 2005, 2010, 2015\}$ denotes a year. y, p and g are the natural logs of forest area, population density, and GDP per capita at purchasing power parity in constant dollars respectively, a is the natural log of either Protected Area or Biodiversity Conservation Area, and u is a random error term. α_i is a "country fixed effect", an unknown quantity that represents all country-specific effects on forest area that do not change over time. We now eliminate the country fixed effects as follows. For each country, i sum this equation over t and divide by the number of years to get

$$\bar{y}_i = \alpha_i + \beta_1 \bar{p}_i + \beta_2 \bar{g}_i + \beta_3 \bar{a}_i + \bar{u}_i$$

where $\bar{x}_i$ denotes the average or mean of x in country i over all years. Subtracting the second equation from the first, we get

$$\hat{y}_{it} = \beta_1 \hat{p}_{it} + \beta_2 \hat{g}_{it} + \beta_3 \hat{a}_{it} + \hat{u}_{it}$$

where $\hat{x}_{it}$ denotes the deviation of x in year t from its mean in country i. Differentiating this equation with respect to, $\hat{p}$ we find that

$$\frac{\partial \hat{y}}{\partial \hat{p}} = \beta_1$$

so that the slope coefficient β_1 is the effect of a unit change in the log of population density within a country on the log of forest area in that country. This formulation makes it transparent that only within-country variations over time in the logs of forest area, population density, per capita income, and Protected Area or Biodiversity Conservation Area are used to estimate the slope coefficients, β_1, β_2 and β_3. Possible spurious correlations arising from between-country comparisons have been removed along with the country-fixed effects. The estimated coefficients are reported in the columns labeled 'Model 1' in Tables 6 and 7.

Model 2 accounts for the possibility that a coincidence in trends over time in forest area and an explanatory variable may give rise to a spurious correlation even in the de-meaned variables. For example, if forest area is decreasing and protected area increasing over time, Model 1 will tend to produce a negative estimate of the effect of protected area on forest area. Model 2 adds a term γt to the first equation above so that the passage of time can have a (linear) effect on (the log of) forest area. This allows us to de-trend the variables in addition to the de-meaning procedure carried out above, and eliminates the possibility of a spurious correlation arising from coincidental global trends in forest area and the explanatory variables. The coefficients from this model are reported in the columns headed 'Model 2' in Tables 6 and 7.

Finally, Model 3 eliminates the possibility that different trends in each domain – tropical, subtropical, temperate and boreal – rather than simply a common global trend, could bias the slope coefficients. The results are in Tables 6 and 7 in the column headed 'Model 3'.

The de-meaned data were checked for outliers using the BACON algorithm (Billor et al., 2000) and none were found.

3. Results

3.1. Global forest area

The total global forest area reported by country in year 2015 was 4000 million ha, a decrease of 3% from 4128 million ha reported in 1990. This decrease was due to a decline of 200 million ha in the tropical domain, partly offset by an increase of 65 million ha in the temperate domain, with smaller changes in boreal and sub-tropical domains. The tropical domain reported the highest percentage of forest area in 2015 (44% of the total), followed by the Temperate domain (26%). In terms of regions, Europe (including the Russian Federation), has the highest reported forest area at 25% of the total, followed by South America (21%) and North America (16%). For more information regarding forest area statistics and trends, see Keenan et al. (2015).

3.2. Forest designated as protected areas or for conservation of biodiversity

Protected areas in FRA 2015 were defined in accordance with the IUCN definition (excluding categories V and VI) as "areas especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means". All figures reported in this paper include only forests in protected areas. Areas designated for conservation of biodiversity were defined as "forest area designated primarily for conservation of biological diversity that includes but is not limited to areas designated for biodiversity conservation within the protected areas".

Data on both forest included in protected areas and forest in areas designated for biodiversity conservation was incomplete (Fig. 1), though increasing; data on these variables are not available for all countries in all years, with a maximum of 86% reporting on forest designated for biodiversity conservation in 2010 and fewer reporting on formally protected forest (Fig. 1, left panel). However, the percentage of global forest area in countries reporting biodiversity conservation area was 99.6% in 2010 (right panel). Even in 1990, the year with the least reporting, more than 80% of the global forest area was in countries that reported forest area protected, and more than 88% of the global forest area was in countries that reported biodiversity conservation area. Countries with large forest areas that did not report on forest in protected areas in all years, included the Democratic Republic of Congo, Australia, Peru, Mexico, Bolivia, and Venezuela.

Variable and incomplete reporting made it difficult to compare between years, so we examined trends by including only data for countries that reported in all periods (Fig. 2; these account for 507 million ha of the total 651 million ha of protected forest reported for 2015). The area of forest included in protected areas increased considerably in all climatic domains over the 25-year period with most of the increase taking place prior to 2010.[1] Forest in protected areas, as a percentage of total forest area in the consistently reporting countries, rose from 16% to 29% in the tropics and from 10% to 16% globally over the period. The largest reported percentage of forest area in protected status was in the Tropics domain (Table 1).

There was considerable variability between sub-regions in reported forest area protected in relation to total forest area (Fig. 3). While forest in protected areas increased over time in all sub-regions, Central and South America showed the greatest increases in protection since 1990, and South America had the

[1] In fact, protected areas increased in every FRA subregion as well. Only 15 countries reported a decrease in protected area between 1990 and 2015, mostly of small magnitude. The decline exceeded a million hectares in only one country, Botswana, although it was just under a million hectares in Mongolia and Mali.

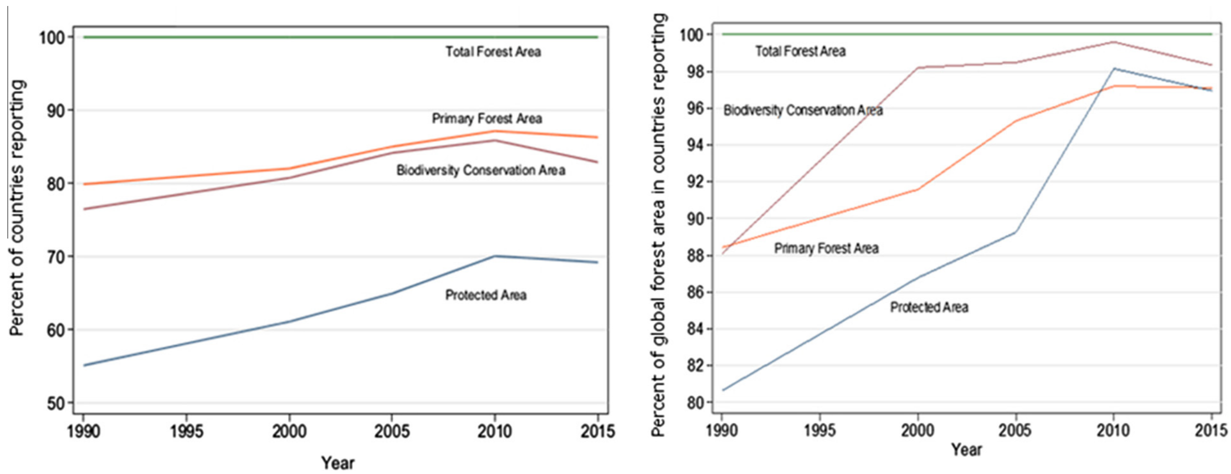


Fig. 1. Extent of country reporting to the FRA by year on total forest area, forest area in protected areas or designated for biodiversity conservation and primary forest area. Left panel: Percent of 234 countries or territories with data on the relevant variables. Right Panel: Percent of global forest area in countries or territories with data.

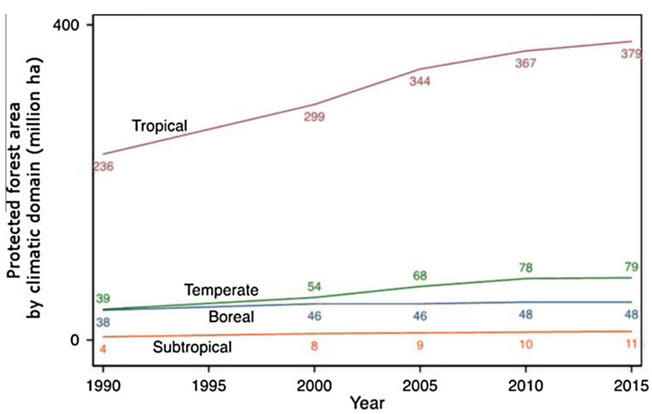


Fig. 2. Trends in forest area included in protected areas for each climatic domain. Countries that did not report in all years were excluded from the domain totals. The consistently reporting countries included in the domain totals accounted for about 80–81% of the global forest area in each year.

greatest proportion of formally protected forests of all the sub-regions (34%). Oceania reported a large increase in forest protection during the past 10 years, as well, from almost zero protection in 1990 to 15% of forest area included in protected areas in 2015. Other sub-regions such as North America, Caribbean, East and Southern Africa, showed a more modest growth in forest protection. The sub-regions with proportionally least protected forests in 2015 (Fig. 3) were Europe (including the Russian Federation) with 4.6% protected forest, followed by West and Central Asia (5.6%) and North America (8.6%). The countries that reported the largest designated protected forest area in 2015 (Table 2) included several countries excluded from the temporal trend analysis because they did not report in all years.

Table 1
Percentage of forest included in protected areas in each domain, as reported to FRA 2015 by countries.

Climatic Domain	Protected area as percent of forest area		
	1990 (%)	2005 (%)	2015 (%)
Tropical	12.0	19.6	26.6
Sub-tropical	1.3	11.0	13.5
Temperate	6.5	10.1	11.0
Boreal	1.6	2.6	2.8
Total	7.7	12.8	16.3

The increasing trends for forests in protected areas also held true for forest in areas designated for biodiversity conservation (Fig. 4). The consistently reporting countries included in Fig. 4 accounted for 427 million ha of the total 524 million ha forest area reported as designated for biodiversity conservation area for all countries in 2015. The countries reporting the greatest area designated for biodiversity conservation in 2015 (Table 3) were largely the same as those reporting the greatest protected area (Table 2), with the exceptions of Mexico and Colombia.

3.3. Primary forest area

While 234 countries reported (including countries and territories reports and desk studies) total forest area for all report years, the number of countries reporting primary forest area increased from 187 in 1990 to 202 in 2015 (Fig. 1). The total primary forest area reported by these 202 countries in 2015 was 1,277 million ha, 32% of the total forest area of all 234 reporting countries.[2] The Russian Federation, Canada, Brazil, the Democratic Republic of the Congo, United States, Peru and Indonesia together accounted for 75% of the global reported primary forest area in 2015 (Table 4).

Tropical countries that reported on their primary forest area in all reporting periods from1990 to 2015, showed an overall decline of 62 million ha (10%; Fig. 5) between 1990 and 2015, and subtropical countries reported a similar proportional reduction in primary forest area of 5 million ha and at global scale, primary forest area, experienced a net decrease of 31 million hectares (2.5%) over the period 1990–2015 – about 1% per decade. These declines were roughly in line with the rates of overall forest area loss for these domains (Keenan et al., 2015). The reported increases of 6 and 30 million ha in temperate and boreal countries, respectively, are accounted for almost entirely by Russia (boreal) and the United States (temperate) (Table 4), with the annual percent rates of increase in these countries 0.4% and 0.3%, respectively. A few countries reported large percentage increases in primary forest, the largest being Bulgaria with an annual average growth rate of over 7%, however most of this increment is related to a change in the methods to assess primary forest area and change in the definitions.

Some countries with large areas of primary forest that did not report in all years include Venezuela and Indonesia, which reported over 45 million ha of primary forest each in some years (Table 4), as well as Australia, the Republic of Korea, and New

[2] And 32% of the total forest area of the 202 reporting countries since these countries accounted for more than 97% of the global forest area (Fig. 1, right panel).

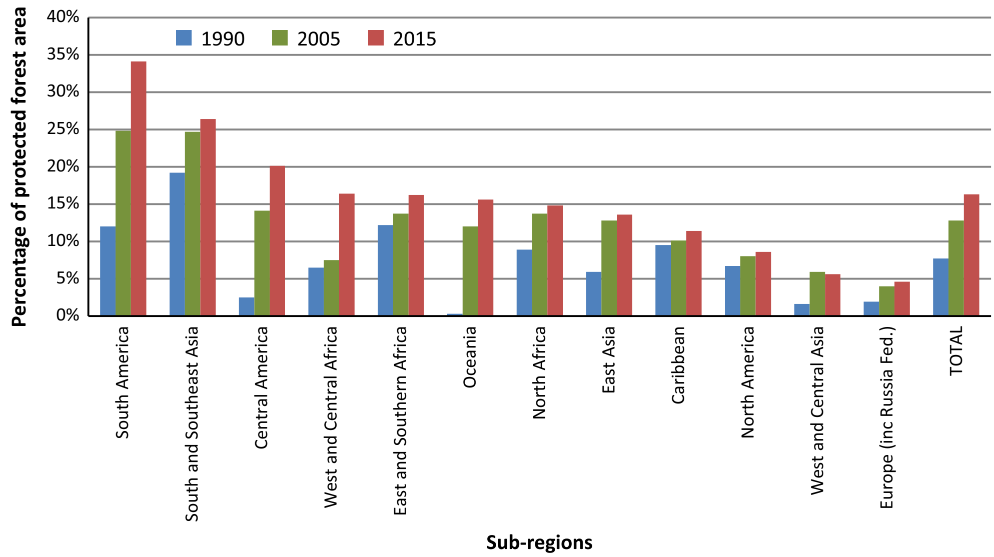


Fig. 3. Change in forest area in protected areas by sub-region and over time according country data reported to FRA 2015.

Table 2
Top 15 countries reporting the largest amounts of forest included in protected areas (ordered by area in year 2015).

Country	1990		2000		2015	
	Area ('000 ha)	% of forest area	Area ('000 ha)	% of forest area	Area ('000 ha)	% of forest area
Brazil	95,263	17.4	185,564	36.6	206,227	41.8
United States	19,826	6.6	28,189	9.2	32,863	10.6
Indonesia	29,862	25.2	29,855	30.5	32,211	35.4
China	4640	3.0	23,831	12.3	28,097	13.5
Congo, the Democratic Republic	–	0.0	–	0.0	24,297	15.9
Venezuela, Bolivarian Republic of	–	0.0	–	0.0	24,046	51.5
Canada	23,924	6.9	23,924	6.9	23,924	6.9
Australia	–	0.0	17,012	13.3	21,422	17.2
Peru	–	0.0	–	0.0	18,844	25.5
Russian Federation	11,815	1.5	16,488	2.0	17,667	2.2
India	12,740	19.9	15,600	23.0	16,122	22.8
Botswana	13,718	100.0	11,943	100.0	10,840	100.0
Bolivia, Plurinational State of	–	20.2	10,680	21.2	10,680	22.0
Zambia	10,680	0.0	10,680	18.2	10,680	19.5
Thailand	7134	50.9	9,394	58.3	10,624	64.8

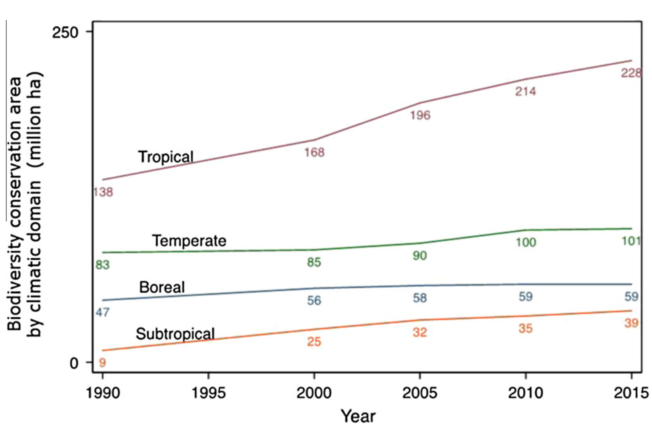


Fig. 4. Trends in forest area designated for biodiversity conservation by climatic domain (countries that did not report in all years are excluded from the domain totals in this figure). The consistently reporting countries included in the domain totals accounted for about 88% of the global forest area in each year.

Zealand, which collectively accounted for over 10 million ha of primary forest in 2010. Fig. 5 therefore, understates the *total* primary forest area in each domain (in fact, by more than 90 million ha in the tropical domain in 2010).

Table 3
Top 15 countries reporting area for conservation of biodiversity to the FRA report 2015 by year (ordered by year 2015).

Country	FRA reporting years (area '000 ha)				
	1990	2000	2005	2010	2015
United States	60,561	60,715	60,846	65,050	64,763
Brazil	18,952	21,491	33,536	46,841	46,969
Mexico	3998	16,520	22,887	25,468	28,049
Russian Federation	21,170	25,281	25,840	26,603	26,511
Australia		16,430	18,902	21,909	26,397
Congo, the Democratic Republic of the		19,600	19,600	26,314	26,314
Venezuela, Bolivarian Republic of		15,755	15,755	15,755	24,742
Canada	23,924	23,924	23,924	23,924	23,924
Indonesia	19,672	19,649	19,696	21,233	21,233
Peru	4777	13,321	18,505	16,977	19,674
India	12,740	13,029	15,600	16,122	16,122
Bolivia, Plurinational State of	0	10,680	10,680	10,680	10,680
Zambia		10,680	10,680	10,680	10,680
Colombia	7199	7270	8426	9910	10,523
Thailand	6726	8707	8853	8853	10,500

Table 4
The 15 countries reporting largest primary forest area (in 1000 ha) to FRA 2015 (representing 90% of the global primary forest area reported in FRA 2015).

Country	Primary forest area (area '000 ha)						
	1990	2000	2005	2010	2015	% of total (2015)	Cumulative,%
Russian Federation	241,726	258,131	255,470	273,343	272,718	21.4	21.4
Canada	206,638	206,359	206,225	206,062	205,924	16.1	37.5
Brazil	218,240	210,466	206,578	202,691	202,691	15.9	53.4
Congo, the Democratic Republic of the	105,189	104,455	104,088	103,387	102,686	8.0	61.4
United States	70,012	72,305	75,709	75,294	75,300	5.9	67.3
Peru	69,632	67,684	67,148	66,524	65,790	5.2	72.5
Indonesia		49,453	48,310	47,167	46,024	3.6	76.1
Venezuela, Bolivarian Republic of				46,568	45,746	3.6	79.7
Bolivia, Plurinational State of	40,804	39,046	38,164	37,164	36,164	2.8	82.5
Mexico	39,443	35,303	33,826	33,168	33,056	2.6	85.1
Papua New Guinea	31,329	25,837	23,091	20,345	17,599	1.4	86.5
India	15,701	15,701	15,701	15,701	15,701	1.2	87.7
Suriname	14,986	14,742	14,590	14,422	14,019	1.1	88.8
Gabon	20,934	17,634	15,984	14,334	12,804	1.0	89.8
Mongolia	12,534	11,714	11,305	13,038	12,552	1.0	90.8

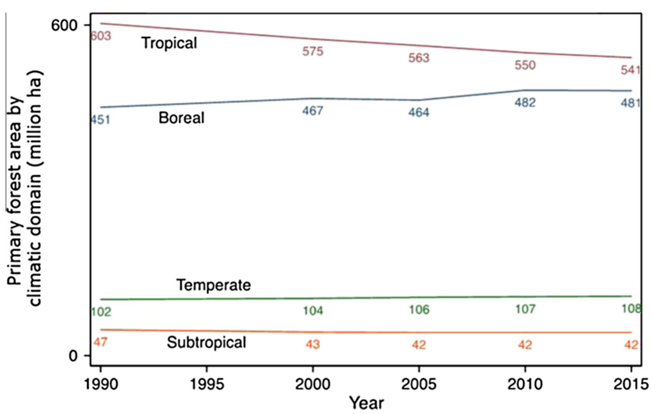


Fig. 5. Trends in primary forest area by climatic domain (Countries that did not report in all years are excluded from the domain totals in this figure). The consistently reporting countries included in the domain totals accounted for about 88–89% of the global forest area in each year.

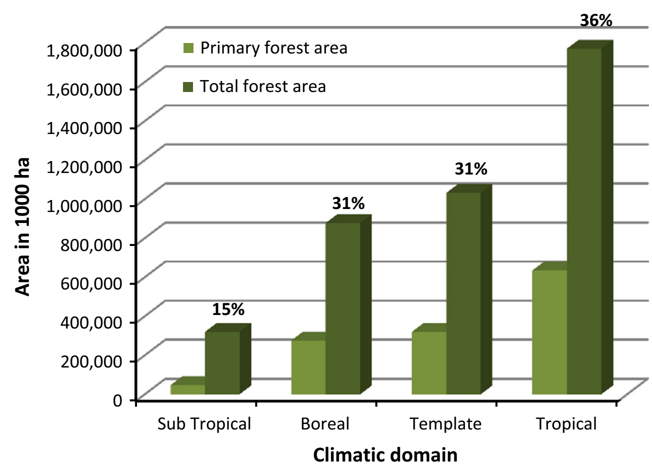


Fig. 6. Total and primary forest area and percentage of primary forest by climatic domain reported for all countries in year 2015 to FRA.

Fig. 6 shows the total and the primary forest area per climatic domain in the year 2015. The tropical domain had the highest total area and with the highest percentage of primary forest area, followed by the template domain. The subtropic domain had the lowest percentage of primary forest area (15%).

Table 5 shows the countries that reported the largest losses of primary forest area over the 25-year reporting period. This table excludes Indonesia because 1990 data were not reported for that country. Indonesia reported a loss of primary forest of about 3.4 million hectares in the period 2000–2015, the fourth-largest after Papua New Guinea, Brazil and Gabon. There was considerable variability in the rate of loss of primary forest reported across countries, with Nigeria reporting that nearly all its primary forest was lost.

Eighty-two countries also reported zero primary forest area in all reporting years. Most of these countries and territories have only small forest areas, but some have substantial forest areas. The latter include several European countries – for example Spain (16 million ha), Germany (11 million ha), Greece, and the UK. There were also several African countries with forest area in the millions of hectares that reported zero primary forest in all years. These included Angola with 59 million ha of forest (averaged over all years), Mozambique (40 million ha), Tanzania (50 million ha), Zambia (50 million ha), and several others. In most of these countries primary forest data were reported as Tier 1, the least reliable level according with the Tier definitions for FRA 2015 (MacDicken, 2015).

Table 5
The 15 countries reporting to FRA 2015 with the greatest loss of primary forest area between 1990 and 2015 (area '000 ha).

Country	Primary forest area Change 1990–2015	% of the change at country level (1990 baseline year)	% of Global primary forest area (1990 baseline year)
Brazil	−15,549	−7.1	−1.3
Papua New Guinea	−13,730	−43.8	−1.1
Gabon	−8130	−38.8	−0.7
Mexico	−6387	−16.2	−0.5
Bolivia, Plurinational State of	−4640	−11.4	−0.4
Peru	−3842	−5.5	−0.3
Guyana	−3000	−31.7	−0.2
Congo, the Democratic Republic of the	−2503	−2.4	−0.2
Ecuador	−2119	−14.5	−0.2
Central African Republic	−1912	−49.0	−0.2
Guatemala	−1617	−54.8	−0.1
Nigeria	−1536	−98.7	−0.1
Suriname	−967	−6.5	−0.1
Malawi	−882	−51.1	−0.1
Canada	−444	−58.0	0.0

3.4. Impacts of protection, demographics, and income on forest area

We now examine to what extent an increase in protected and biodiversity conservation area are associated with an increase in forest area, all else remaining the same.

The first column of Tables 6 and 7 show the estimated slope coefficients for Model 1 (described in Section 2.2 above) using Protected Area in Table 6 and Biodiversity Conservation Area in Table 7.[3] Since the variables are in logs, a slope coefficient is an elasticity – the percentage change in forest area induced by a 1% change in an explanatory variable. We see from Table 6, Model 1, that if population density were to increase by 1% in a country and the other variables (GDP and Protected Area) were held constant, then the model implies a 0.18% decrease in forest area in that country. The effect of an increase in GDP on forest area is positive – a 1% increase in GDP is associated with a 0.08% increase in forest area. The effect of an increase in Protected Area is also positive, but quite small, a 1% increase in Protected Area is associated with a 0.037% increase in forest area. In Table 7, Model 1, in which Protected Area is replaced by Biodiversity Conservation Area, the results are quite similar.

The results reported in the columns headed 'Model 2' in Tables 6 and 7 pertain to de-trended as well as de-meaned data. The coefficients on population density, GDP per capita, and Protected Area and Biodiversity Conservation Area are not very different from those in Model 1.

As noted earlier, Model 3 eliminates the possibility that different trends in each domain – tropical, subtropical, temperate and boreal – rather than simply a common global trend, could bias the slope coefficients. Once again, the elasticity of forest area with respect to the different variables are quite similar to those in the previous two models. Only in Model 3 of Table 6 does the coefficient of population density become distinctly smaller and not statistically significant at even the 10% level. However, the estimated effect of population density on forest area remains quite similar and statistically significant even in Model 3 in Table 7 where Biodiversity Conservation Area is used instead of Protected Area.

When these models are run after excluding boreal and temperate countries, very similar coefficients are obtained (not reported to save space), although the smaller sample results in their being less statistically significant for the most part.

This evidence is suggestive of a positive effect of an increase in protection on total forest area, although the effect is not very large – a slope coefficient of 0.03 implies that a doubling of protected area leads to an increase in forest area of about 2%.

A similar regression analysis was attempted to examine the effects of these variables on primary forest area using 99 countries for which data on all variables are available. However, variation in primary forest area over time is very limited – 82 countries reported consistently zero primary forest area. Many countries also reported no or small changes in primary forest area. Unsurprisingly, then, the results of the econometric analysis were inconclusive. The estimated effects of the independent variables on primary forest area are not statistically different from zero. Therefore, the tables of results were not included.

3.5. Data reliability

The FRA uses a tier rating system for countries to self-report data quality, ranging from tier 3 (data collected less than 10 years ago using National Forest Inventory or remote sensing with ground truthing (highest quality data) to tier 2 (full cover mapping/remote sensing or National Forest Inventory >10 years old) and finally to tier 1, which is designated only as "other" and could represent a respected professional opinion (MacDicken, 2015). Tiers are reported for both current status and for trends. Fig. 7 shows the percentage of area by tiers and categories.

While 45% of countries reported using the lowest tier for forest area, those countries represent only 11% of total forest area. Only 28% reported using tier 3 data, but those countries represent 59%

[3] Some countries are missing in Tables 6 and 7 because they showed no variation in Protected Area or Biodiversity Conservation Area between FRA years, so they cannot be used in the estimation that uses only within-country variation.

Table 6
Effects of protected area on forest area.

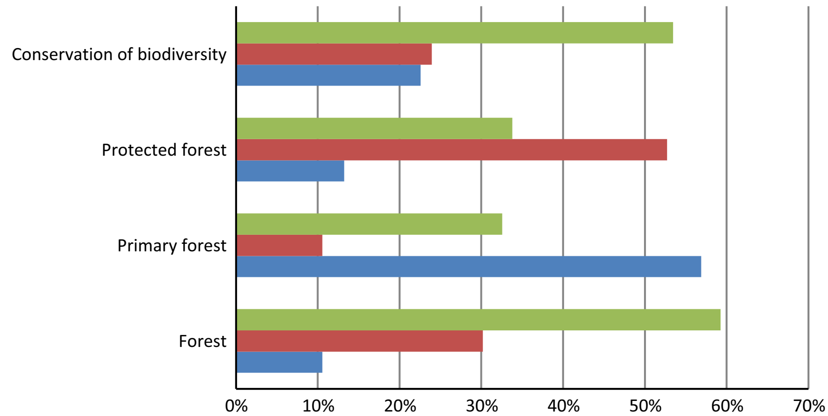
	Model 1	Model 2	Model 3
Dependent variable: Log(forest area)			
Log(Population density)	−0.180***	−0.203**	−0.118
	(0.0557)	(0.0939)	(0.0920)
Log(real GDP per capita)	0.0792**	0.0669*	0.0666*
	(0.0312)	(0.0377)	(0.0368)
Log(Protected Area)	0.0372**	0.0338*	0.0240*
	(0.0173)	(0.0175)	(0.0136)
Boreal domain trend (5-year unit)			0.0333
			(0.0354)
Subtropical trend (5-year unit)			0.0219*
			(0.0113)
Temperate trend (5-year unit)			0.00401
			(0.00732)
Tropical trend (5-year unit)			−0.0111
			(0.0109)
Global trend (Unit = 5 years)		0.00427	
		(0.00973)	
Constant	6.562***	6.751***	6.875***
	(0.482)	(0.561)	(0.570)
Observations	586	586	586
R-squared	0.114	0.116	0.174
Number of countries	137	137	137

Note: All models include country fixed effects. Reported coefficients are the percentage change in forest area associated with a 1% change in population density, per capita GDP, and protected area, and with a five-year change in the others. Robust standard errors, clustered by country, in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Table 7
Effects of biodiversity conservation area on forest area.

	Model 1	Model 2	Model 3
Dependent Variable: Log(Forest Area)			
Log(Population density)	−0.242***	−0.256**	−0.223*
	(0.0593)	(0.0996)	(0.122)
Log(real GDP per capita)	0.0817**	0.0751**	0.0740**
	(0.0329)	(0.0339)	(0.0336)
Log(Biodiversity Conservation area)	0.0292**	0.0269*	0.0232*
	(0.0119)	(0.0144)	(0.0126)
Boreal domain trend (5-year unit)			−0.00317
			(0.00547)
Subtropical trend (5-year unit)			0.0182
			(0.0154)
Temperate trend (5-year unit)			0.00472
			(0.00650)
Tropical trend (5-year unit)			−0.00442
			(0.0138)
Global trend (Unit = 5 years)		0.00252	
		(0.00944)	
Constant	6.490***	6.592***	6.656***
	(0.528)	(0.528)	(0.532)
Observations	664	664	664
R-squared	0.171	0.172	0.192
Number of countries	146	146	146

Note: All models include country fixed effects. Reported coefficients are the percentage change in forest area associated with a 1% change in population density, per capita GDP, and biodiversity conservation area, and with a five-year change in the others. Robust standard errors, clustered by country, in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.



	Forest	Primary forest	Protected forest	Conservation of biodiversity
Tier 3	59%	33%	34%	53%
Tier 2	30%	11%	53%	24%
Tier 1	11%	57%	13%	23%

% Area in each category by tier

Fig. 7. Percentage of countries reporting by tier and category and percentage of area in each category by tier.

of forest area. Fifty-five percent of countries representing 57% of forest area reported using tier 1 data for primary forest, while only 33% of area was represented by tier 3 data, suggesting that primary forest may be a less accurate variable. The largest percent of protected forest area was represented by tier 2 and 3 data, at almost 87% of reported area in those two tiers. Finally, 51% of countries reported using tier 2 and 3 data for conservation of biodiversity, which accounted for 77% of area in that category.

4. Discussion

The designation of areas specifically meant to protect forests and for the conservation of biodiversity is one of the primary mechanisms currently used to help meet biodiversity targets outlined in such strategic programs as the Aichi Biodiversity Targets. Similarly, tracking primary forest area is one method of capturing change in forests that are assumed to be particularly important ecologically. The global FRA serves as a unique instrument for tracking changes in areas that countries self-report as primary forest, protected forest, or forests set aside for the conservation of biodiversity.

Our study showed a loss of 128 M ha of total global forest area from 1990 to 2015, with the majority of that occurring in the tropics. Both FRA and Hansen et al. (2013) show that global forest loss is highest in the tropical domain, an area with high biological biodiversity and increasing concern over forest protection. Global forest area change and further comparisons with other datasets is further explored in this special issue by Keenan et al. (2015).

In FRA 2015, primary forest area was defined as: "naturally regenerated forest of native species where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed. Key characteristics include: 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". However, there appeared to be some variability in how countries interpreted the definition as it applied to their specific forests, and/or how countries arrived at their estimates. For example, some increases in primary forest area over the years analyzed in this paper appeared to result from new definitions of forest area or primary forest; other increases appeared to be due to the use of new technologies (e.g.: high resolution and multispectral imagery, UAV, others) and approaches for analysis.

Continuing loss of primary forests in both the tropics (62 M ha) and the subtropics (5 M ha) mirrors patterns of total forest area loss in those biomes. Global primary forest loss of 1 percent per decade (and 4 times that in the tropics) is potential cause for concern. While ecologists debate the conservation value of "secondary" versus "primary" forest, and differing ideas about what constitutes a primary forest make it difficult to assess the true impact of these changes, some authors have attempted to assess impacts of primary forest loss. Gibson et al. (2011) reviewed 138 studies of primary forests to determine impacts of primary forest loss and/or disturbance on overall biodiversity in the tropics and found that secondary forests have demonstrably lower overall biodiversity and that disturbance effects were "essentially universal," leading the authors to conclude that primary forests are irreplaceable reserves of tropical biodiversity. In many cases, the persistence of threatened and endangered species appears to be dependent upon the availability of intact primary forest. For example, Gregory et al. (2012) found that orangutan population size was heavily influenced by the degradation of primary forests, and estimated a reduction in orangutan populations of 40–80 percent without measures toward protection of these forests. There is some hope, as tropical primary forest loss appears to be slowing over time. Additionally, the lack of complete country reporting may underestimate the total amount of global primary forest, and may impact overall global trends.

Our results were similar to those reported by Mackey et al. (2014) in that almost 98% of primary forest was found within 25 countries, where half of this percentage belong to developed countries (Russian Federation, Canada, USA, Australia, Japan, Republic of Korea). We also found that a large proportion of primary forest (75%) reported by countries was contained within 7 countries, including Indonesia. Indonesia alone reported a 3.4 M ha loss of primary forest from 2000 to 2015, which is half the 6 M ha Landsat-derived primary forest loss estimate for Indonesia reported by Margono et al. (2014). In this particular case, Indonesia reports that their primary forest variable for FRA 2015 was derived using the highest FRA tier rating, implying that the variable was determined from a national forest inventory sample or remotely sensed data coupled with ground truthing. While some of the discrepancy between the 3.4 M ha reported to FRA and the 6 M ha derived from landsat is certainly methodological or definitional and hinders direct correlation between the two, it's clear from both that Indonesia is losing primary forest at an alarming rate. Kessler et al. (2005) reported distinct declines in species richness of both vegetation and wildlife when Indonesian forests were converted from primary states to other forested states, suggesting that biologically, even if the loss of primary forest is not a loss of forest cover in general, in Indonesia it represents a distinct loss of biodiversity.

Protected area establishment and setting forest area aside for biological diversity conservation are two ways in which both global forest area losses and loss of primary forest can be slowed or reversed and/or important functions and resources within forests can be maintained. Interestingly, though primary forest area is declining we found that, in countries that report regularly, forests in protected areas have increased. The increase in protected areas was highest in the tropics, where – as noted above – primary forest area loss is highest. Inconsistent reporting rates across years severely limit the ability to report on and draw meaningful conclusions from trends in protected forests and forest set aside for biological conservation. For example, only 77 percent of the forest area reported as protected in FRA 2015 could be examined in this paper in terms of trends.

Forest area set aside to conserve biodiversity also grew in all domains with the highest increases in the tropics. This begs the question of whether high-productivity primary forests are being protected at the same rate as secondary forests.

Our analysis found that increases in protected area and in biodiversity conservation area within countries are associated with increases in forest area but the effect is not large. These relations persist in the smaller sample of tropical and sub-tropical countries, more strongly in the case of biodiversity conservation area which is reported by more countries. It is possible that the beneficial effect of protection could to some extent be masked in the data by spurts of deforestation leading to an increase in protected area. It could also be true that countries that increased protection simultaneously adopted other policies to reduce deforestation, so that the estimated effect of protection could also be overstated. Andam et al. (2008) found that from the 1960s to the 1990s, deforestation in Costa Rica was decreased as a result of protected areas, but that the impact of protected areas on deforestation had previously been overestimated (by as much as 65 percent). Wendland et al. (2015) found that protected areas in European Russia had little impact on rates of forest disturbance. This may be somewhat unsurprising, given that the Millennium Ecosystem Assessment (2005) reported that many protected forest areas are specifically situated because they are unsuitable for other use by humans. Despite the aforementioned limitations in their effectiveness, the increase in protected forest area and forests designated for biodiversity conservation is encouraging, particularly given that the largest increase in protected areas was in the tropical domain where total global forest loss is highest.

In the Democratic Republic of the Congo, forest cover loss within protected areas was more than two times lower than the national average, but forest cover loss still increased by 64% between 2000–2005 and 2005–2010 in protected areas (Potapov et al., 2012). In a meta-analysis of published case studies assessing tropical forest cover change, Porter-Bolland et al. (2012) found that community managed forests resulted in lower deforestation rates in the tropics than the declaration of protected forests. Their study showed that protected areas experienced deforestation due to agricultural expansion, human population growth, and infrastructure development, along with economic activities outside of forests, and that reforestation was more common in community forests (Porter-Bolland et al., 2012). Other studies similarly report that protected areas may not be successful at preventing deforestation (Andam et al., 2008; Nagendra, 2008; DeFries et al., 2005). Tittensor et al. (2014) project based on current trends that protected areas will increase significantly by 2020, meeting terrestrial Aichi Targets (which includes forests). However, they also note that declared protection does not always mean adequate protection.

Human population pressure has long been understood as one of many drivers in the conversion of natural habitats to other land uses. We found that increases in population density within countries are negatively associated with increases in forest area while per capita income shows a positive association. This is the case globally and also in the subsample of tropical and sub-tropical countries. This is broadly consistent with DeFries et al. (2010)'s finding that urban population density and agricultural exports were correlated with deforestation measured using satellite data between 2000 and 2005 in a sample of tropical countries (although this study uses between, rather than within-country comparisons). Mills Busa (2013) notes that high-income countries import more wood than do countries with lower GDP, suggesting that "rich countries practice preservation within borders but appropriate resources from poorer countries to sustain consumption" leading her to the conclusion that consumption reduction is as important a strategy as forest protection. Meyfroidt et al. (2010) also note that countries that experience increased forest cover have often redistributed their resource use to other countries; i.e., exploitation of resources elsewhere is facilitating reforestation locally. Indeed, Indonesia – the country with the largest primary forest loss as mentioned earlier – is among the countries absorbing the displaced agricultural demand from countries experiencing reforestation (Meyfroidt et al., 2010).

Among studies that used only within-country variation, Scrieciu (2007) and Culas (2007) failed to find statistically significant effects of income and population density on deforestation, but were limited by having data on fewer countries over a shorter time span in the late 20th century. In the Democratic Republic of the Congo, forest loss intensity was associated with areas of high population density (Potapov et al., 2012).

Drawing meaningful conclusions from the FRA data requires an assessment of the quality and credibility of data at such a large scale. While many countries used tier 1 data in reporting, most of the area represented in each category was covered by tier 2 and 3 data, suggesting that data quality comes from fairly reliable sources, overall. The exception seems to be primary forest, which may be a reflection of the difficulty in applying the definition of primary forests in each country. Assessment of the impact of tier 1 data on the overall quality of the results of our study is infeasible given that there is little or nothing with which to compare the data reported for countries using tier 1 information.

Additional challenges exist in analyzing trends in primary forest, protected area, and area set aside for conservation of biodiversity. First, country response rates are variable, both among years and among countries, limiting the types of analyses that we were able to conduct as well as the sensitivity of our analyses. Second, we noted that challenges exist in the harmonization of country data to FRA definitions, suggesting that additional conversations may be necessary amongst national correspondents to FRA as regards some variables, particularly primary forest. The overall findings of our study suggest that, while some progress has been made in the protection of forests at the global scale in that last 25 years, and while tropical countries are increasingly protecting forests, primary forests of ecological significance in the tropical domain are still declining. The decline is decreasing, however, which allows for some optimism as global conversations and awareness continue. Our findings also indicate that, if FRA is to be used as one mechanism for tracking progress toward goals like the AICHI Biodiversity Targets, country correspondents may require additional assistance toward reporting on primary forest, protected forest, and biodiversity conservation statistics.

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