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An assessment of data sources, data quality and changes in national forest monitoring capacities in the Global Forest Resources Assessment 2005-2020

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Abstract

Globally, countries report forest information to the Food and Agriculture Organization of the United Nations (FAO) Global Forest Resources Assessments (FRA) at regular intervals. While the status and trends of national forest monitoring capacities have been previously assessed for the tropics, this has not been systematically done worldwide. In this paper, we assess the use and quality of forest monitoring data sources for national reporting to the FRA in 236 countries and territories. More specifically, we (1) analyze the use of Remote Sensing (RS) for forest area monitoring and the use of National Forest Inventory (NFI) for monitoring forest area, growing stock, biomass, carbon stock, and other attributes in FRA 2005-2020, (2) assess data quality in FRA 2020 using FAO Tier-based indicators, and (3) zoom in to investigate changes in tropical forest monitoring capacities in FRA 2010 - 2020. Globally, the number of countries monitoring forest area using RS at good to very good capacities increased from 55 in FRA 2005 to 99 in FRA 2020. Likewise, the number of countries with good to very good NFI capacities increased from 48 in FRA 2005 to 102 in FRA 2020. This corresponds to ~85% of the global forest area monitored with one or more nationally-produced up-to-date RS products or NFI in FRA 2020. For large proportions of global forests, the highest quality data was used in FRA 2020 for reporting on forest area (93%), growing stock (85%), biomass (76%), and carbon pools (61%). Overall, capacity improvements are more widespread in the tropics, which can be linked to continued international investments for forest monitoring especially in the context of Reducing Emissions from Deforestation and Forest Degradation in tropical countries (REDD+). More than 50% of the tropical countries with targeted international support improved both RS and NFI capacities in the period 2010-2020 on top of those that already had persistent good to very good capabilities. There is also a link between improvements in national capacities and improved governance measured against Worldwide Governance Indicators (WGI). Our findings – the first global study – suggest an ever-improving data basis for national reporting on forest resources in the context of climate and development commitments, e.g. the Paris Agreement and Sustainable Development Goals.

Keywords: Forest resources assessment, national forest monitoring capacities, data sources, data quality, forest area and area change, national forest inventories, remote sensing, REDD+

1. Introduction

Being one of the most biologically rich ecosystems extending over almost one-third of the global land (FAO, 2020), forests provide crucial goods and services to the planet and human well-being. Forest resources such as food, fiber, timber, and medicines are the main sources of income and livelihoods for millions of people in many countries (Vedeld et al., 2007; Angelsen et al., 2014). Further, forests provide various essential services, e.g., water cycle regulation, soil formation and stabilization, erosion control, to name a few (Martínez Pastur et al., 2018). They are also important for aesthetic, spiritual, educational, and recreational purposes (Daniel et al., 2012; FAO, 2020). On top of these vital benefits, forests have a crucial role in global climate regulation being a source and sink of carbon (Pan et al., 2011). Globally, deforestation and forest degradation account for 12-20% of CO_2 emissions (van der Werf et al., 2009; Houghton et al., 2012; Friedlingstein et al., 2019).

At the same time, forests absorb a vast amount of carbon, and over the last decade, the forest carbon sink accounts for about 3.2 Gt CO_2 yr^{-1} (Friedlingstein et al., 2019). If managed sustainably, forests could contribute up to 30% of the Paris Climate Agreement goal towards limiting global warming below 2°C by 2030 (Griscom et al., 2017).

To support climate mitigation and other forest benefits, reliable and systematic monitoring of forests is essential. The Food and Agriculture Organization of the United Nations (FAO) performs global forest resources assessment (FRA) regularly at the request of and in collaboration with member countries since 1946 (FAO, 2020). The most recent assessment, FRA 2020, examines forest resources, their management, and use in 236 countries and territories (FAO, 2020). Forest area change and biomass/carbon stock are key variables in FRA, particularly to support countries reporting on 'Life on Land' indicators - 15.1.1 and 15.2.1 of Sustainable Development Goals (SDGs) (FAO, 2020) and the Nationally Determined Contributions (NDCs) to the Paris Agreement adopted at the Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 (IPCC, 2006; Herold & Skutsch, 2011; Joseph et al., 2013; GOFC-GOLD, 2016).

Historically, many countries have been producing information on forest area and carbon content using data from forest inventories (Tomppo et al., 2010; Goetz et al., 2015; GOFC-GOLD, 2016; FAO, 2018). With the development of satellite imaging and processing technologies, countries have begun to integrate satellite remote sensing (RS) data in their national forest monitoring systems since the early 1980s (FAO, 2018). RS data have been used effectively to obtain consistent information about changes in forest area over time (Pekkarinen et al., 2009; Saatchi et al., 2011, Hansen et al., 2009, 2013).

In the global context, variations in data sources and quality can reduce the consistency in forest information among countries. In FRA 2015, countries assessed data quality using Tiers developed by FAO (FAO, 2015), and ~60% of the global forest cover was reported with the highest quality data (Keenan et al., 2015). Two consecutive studies on tropical forest monitoring capacity assessment revealed that the number of tropical countries having good or very good capacities to use RS and NFI increased from 37 countries in FRA 2005 to 54 countries in FRA 2015 and from 29 countries in FRA 2005 to 40 countries in FRA 2015, respectively (Romijn et al., 2012; 2015).

As tropical forests have a critical role in climate mitigation and maintenance of other ecosystem services, substantial international investments have been channeled to tropical countries to support forest monitoring, particularly in the context of Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD+) (UN-REDD, 2013; Romijn et al, 2015; Kim et al., 2019). The Global Forest Observations Initiative (GFOI) provides an inventory of targeted international support to tropical countries for RS and NFI capacity building and helps coordinate activities for REDD+ and related forums (GFOI, 2020). Apart from the tropics, a significant share of international support has been provided for temperate forests, particularly in Eastern Europe (McAlpine & Church, 2018). Similarly, some countries have invested billions in assessing their forest resources, as notable in forest inventory and analysis in the USA since 1930 (Tinkham et al., 2018) and the development of Europe's 2013 'Forest Strategy' to strengthen sustainable forest management and reduce deforestation in Europe (EC, 2018). In this context, it is important to understand how such investments have shaped countries' forest monitoring capacities over time.

There is also an important connection between forest monitoring and forest governance. Transparency is the backbone of the Paris Agreement. There is a need for enhanced transparency and accountability in the forest and land-use sector through higher-quality, more accessible, and frequently updated information and attention to the institutions and accountability mechanisms that support its responsible use. National governance quality has also been linked to the management of forest resources (Gore et al., 2013; Norman et al., 2017), and worldwide governance indicators (WGI) influence the protection, restoration, and management of forests in tropical countries (Griscom et al., 2020). Forest governance has been central to REDD+ (Van Bodegom et al., 2012), and evidence from Brazil, Indonesia, and Guyana—the first recipients of results-based finance— suggests that REDD+ initiatives positively influenced forest governance through increased transparency and public participation (Duchelle et al., 2019). Certainly, national governance positively influences forest monitoring capacities or vice versa, but this relationship is still unclear and needs to be further explored.

Until now, national forest monitoring capacities have been studied in the tropics, and significant improvements have been observed (Romijn et al., 2012; 2015). However, there exists little understanding on how the status and trends in national use of different data sources and their quality (e.g. timeliness) compare globally and whether trends of improving capacities in tropics are persisting. The recent release of FRA 2020 allows updating of this knowledge and assessing the latest status and trends in data sources and quality across the globe. Filling these information gaps is crucial particularly in the context of FRA and also,

for evaluating the progress of global forest-based initiatives such as the Paris Agreement, New York Declaration on Forests, and SDGs, among others.

In this paper, we assess and analyze national forest monitoring capacities and capacity changes globally across 236 countries and territories from FRA 2005, 2010, 2015, and 2020. This is a global analysis that includes all countries and territories covered by FRAs for the first time. Additionally, we zoom into 99 tropical and non-annex 1 countries to the UNFCCC[i] - "mostly developing countries that are particularly vulnerable to the adverse effects of climate change and/or the implementation of measures to respond to it, because of their specific geographic, climatic, or economic conditions" - to provide a most recent picture on capacity changes in the tropics expanding on the previously published analysis by Romijn et al. (2012; 2015). More specifically, we:

1. analyze forest monitoring data sources used by all countries reporting for the consecutive FRAs in 2005, 2010, 2015, and 2020;
2. evaluate forest monitoring data quality globally in FRA 2020 using the FAO Tier system;
3. further, zoom in to investigate changes in forest monitoring capacities in 99 non-annex 1 tropical countries.

2. Data and Methods

2.1 Data Sources for Forest Monitoring

We assessed national forest monitoring data sources in 236 countries and territories from FRA 2005 to FRA 2020 using the approach developed in previous studies by Romijn et al. (2012; 2015). Forest monitoring data sources can be assessed using different criteria. In our study, we first analyzed whether countries derive forest information using RS and/or NFI data sources. After that, we assessed the origin (external/in-country), frequency, and timeliness of these data. To analyze the two main data sources separately, we used separate indicators for RS and NFI data sources, namely "Use of RS", and "Use of NFI". The "Use of RS" is deployed by a country for monitoring its forest area and area change while the "Use of NFI" for deriving forest area and area change, growing stock, biomass, carbon stock, and other forest parameters (FAO, 2020). Data sources used in FRA provide an indication of the country capacities to monitor the forests.

Five different criteria were used to rank the indicators between "low" and "very good" data sources for forest monitoring (Table 1). "Low" means that countries did not use RS/NFI to derive their forest estimates. Very good use of RS/NFI denotes that countries have their own abilities to monitor forests in a consistent and timely manner using RS/NFI. Limited or intermediate use of RS/NFI means that countries use either partial data or data produced by external sources for forest monitoring. The indicators were scored based on the rank values - from 0 for "low" to 4 for "very good" data sources. Underlying data sources were assessed for the consecutive FRAs in 2005, 2010, 2015, and 2020 and forest monitoring capacity changes were evaluated by comparing FRA 2005 to FRA 2020 data sources.

Table 1: Indicator criteria and scores for the data source assessment indicators: Use of RS for forest area monitoring and Use of NFI for forest monitoring in 236 countries and territories in FRA 2005, 2010, 2015, and 2020.

Indicators	Indicator Criteria	Indicator Value	Indicator Score	Data Source
Use of Remote Sensing for forest area monitoring	No forest cover map	Low	0	Section 1.2.1 in FRA 2005, FRA 2010 and FRA 2015 country reports, Section 1 in FRA 2020 country reports
	One forest cover map (external)	Limited	1	
	Multiple forest cover maps (external)	Intermediate	2	
	One or more forest cover map(s) (in-country); most recent produced before 2000 for 2005 assessment, before 2005 for 2010 assessment, before 2010 for 2015 assessment, before 2015 for 2020 assessment	Good	3	
	Multiple forest cover maps (in-country); most recent produced after 2000 for 2005 assessment, after 2005 for 2010 assessment, after 2010 for 2015 assessment, after 2015 for 2020 assessment	Very good	4	

[i]List of current non-annex 1 countries to the UNFCCC: https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states

Use of NFI for forest monitoring	No forest inventory	Low	0	Section 5.2.1 in FRA 2005, Section 6.2.1 in FRA 2010, Section 3.2.1 in FRA 2015, Section 2 in FRA 2020 country reports
	One forest inventory (external)	Limited	1	
	Multiple forest inventories (external); or in-country, but no full cover for all forests	Intermediate	2	
	One or more forest inventories (in-country); most recent before 2000 for 2005 assessment, before 2005 for 2010 Assessment, before 2010 for 2015 assessment, before 2015 for 2020 assessment	Good	3	
	Multiple forest inventories (in-country); most recent produced after 2000 for 2005 assessment, after 2005 for 2010 assessment, after 2010 for 2015 assessment, after 2015 for 2020 assessment	Very good	4	

2.2 Forest Monitoring Data Quality

We assessed forest monitoring data quality in FRA 2020 in 236 countries and territories using FAO's Tier system (Table 2). FAO Tiers represent data quality based on Tier 1, Tier 2, and Tier 3 on forest area, growing stock, biomass, and carbon pools (FAO, 2020). Tier 3 represents the highest data quality with the most recent and consistent data sources, Tier 2 older, or incomplete data, and Tier 1 the lowest data quality including expert estimates (FAO, 2020). The years reported for data quality assessment generally correspond to the years of data collection (as indicated in FRA 2020 guidelines and specifications). The data sources for forest area include either RS or NFI or both while the data are sourced from NFI for growing stock. The status tiers are based on the most recent data point (i.e. RS and/or NFI data in a particular year) while trend tiers look at the existence of multiple data points in time (FAO, 2020).

Table 2: FAO tier indicators used in the assessment of forest monitoring data quality.

Tier Indicators		**Indicator Criteria**	**Indicator Value**	**Data Source**
Forest area	**Status**	Data from 2013 or more recent from a good data source (NFIs, sample-based RS, wall-to-wall mapping)	Tier 3	Section 1 in FRA 2020 country reports
		Data older than 2013 and good data source	Tier 2	
		Other (incl. data from registers or questionnaires, expert assessments)	Tier 1	
	Trend	Multiple consistent data points (in terms of methods and classes), all from 2013 or more recent or Tier 3 Status, incl. recent forest area change estimates (i.e. from a REDD+ FREL)	Tier 3	
		Multiple data points but limited consistency (in terms of methods and classes), and/or older than 2013, incl. 1 data point and expanded trends from the external data source	Tier 2	
		Other	Tier 1	
Growing Stock	**Status**	Data from NFIs from 2009 or more recent, (incl. RS-based method calibrated by inventory plot data)	Tier 3	Section 2 in FRA 2020 country reports
		Data from NFIs older than 2009	Tier 2	
		Other	Tier 1	
	Trend	Data from multiple consistent NFIs, all from 2009 or more recent	Tier 3	
		Data from multiple NFIs or RS-based estimates but limited consistency, and/or older than 2009, incl. cases with one NFI and using detailed multi-date RS assessment of different forest types	Tier 2	
		Other	Tier 1	
Biomass *Only Tier 1 and Tier 3 are considered		Data derived from country-specific or targeted expansion factors, allometric models, etc.	Tier 3	Section 2c in FRA 2020 country reports
		Data derived from default factors or generic equations, i.e. all countries using the biomass calculator	Tier 1	
Carbon pools		Data provided for all five carbon pools (AGB, BGB, litter, deadwood, soil)	Tier 3	Section 2d in FRA 2020 country reports
		Data provided for at least 2 carbon pools	Tier 2	
		Other	Tier 1	

2.3 Analysis of Tropical Forest Monitoring Capacity Improvements

An additional analysis was conducted in 99 non-annex 1 tropical countries to examine if targeted international support in the tropics contributed to national forest monitoring capacity improvements. Our assessment of forest monitoring data sources was used as a proxy for forest monitoring capacities. Data on the international support for forest monitoring capacity building was compiled from the GFOI inventory of activities. Forty-nine of these tropical countries received targeted support to improve their RS and/or NFI capacities (GFOI, 2020). We classified support separately for countries receiving support for RS and those receiving support for NFI capacity building in order to align it with the capacity (i.e. forest monitoring data sources) indicators. Then, we analyzed capacity changes in countries that received targeted support in comparison to countries without support. As countries started to receive support through GFOI collaborative actions in the 2010s, capacity changes were analyzed over the period from 2010 to 2020. The capacity changes were analyzed in three groups: very good capacity throughout the period, capacity improvements, and no capacity improvements. Here, no capacity improvements do not necessarily mean low capacities. For example, a country can have good capacities but did not improve to very good capacities over the period examined.

The RS and NFI capacity changes in 99 countries were further investigated in the abovementioned three groups in relation to the quality of country governance from 2010 to 2020. We performed the Kruskal-Wallis test to explore if there is a difference in WGI trend between three groups for both RS and NFI capacity changes. This test was selected as the WGI trend was not normally distributed. We used the World Bank governance indicators (WGI) for this analysis since they are the most widely used indicators across the countries since 1996 (Kaufmann & Kraay, 2019). The WGI comprises six indicators summarizing the quality of governance: voice and accountability, political stability and absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, and control of corruption. WGI ranges from -2.5 (weak governance) to 2.5 (strong governance) (Kaufmann & Kraay, 2019).

3. Results

3.1 Data Sources for Forest Monitoring

Fig. 1 and Table 3 show that both the use of RS and NFI for forest monitoring improved significantly across the globe between FRA 2005 and FRA 2020 (see Appendix 1 for indicator values in all countries). Out of 236, 99 countries demonstrated good to very good use of RS in FRA 2020 (Table 3). This represented an 80% increase in the number of countries capable to produce in-country forest cover maps using RS compared to FRA 2005. Furthermore, countries with good to very good use of NFI more than doubled over the period from 48 countries in FRA 2005 to 102 countries in FRA 2020. The improvements were also reflected in the amount of forest cover monitored with improved data sources over the period (Fig. 2). The proportion of global forest cover monitored with good to very good use of RS increased from 69% (2848 million ha) in FRA 2005 to 84% (3406 million ha) in FRA 2020. The corresponding figure for use of NFI increased from 55% (2280 million ha) in FRA 2005 to 85% (3462 million ha) in FRA 2020.

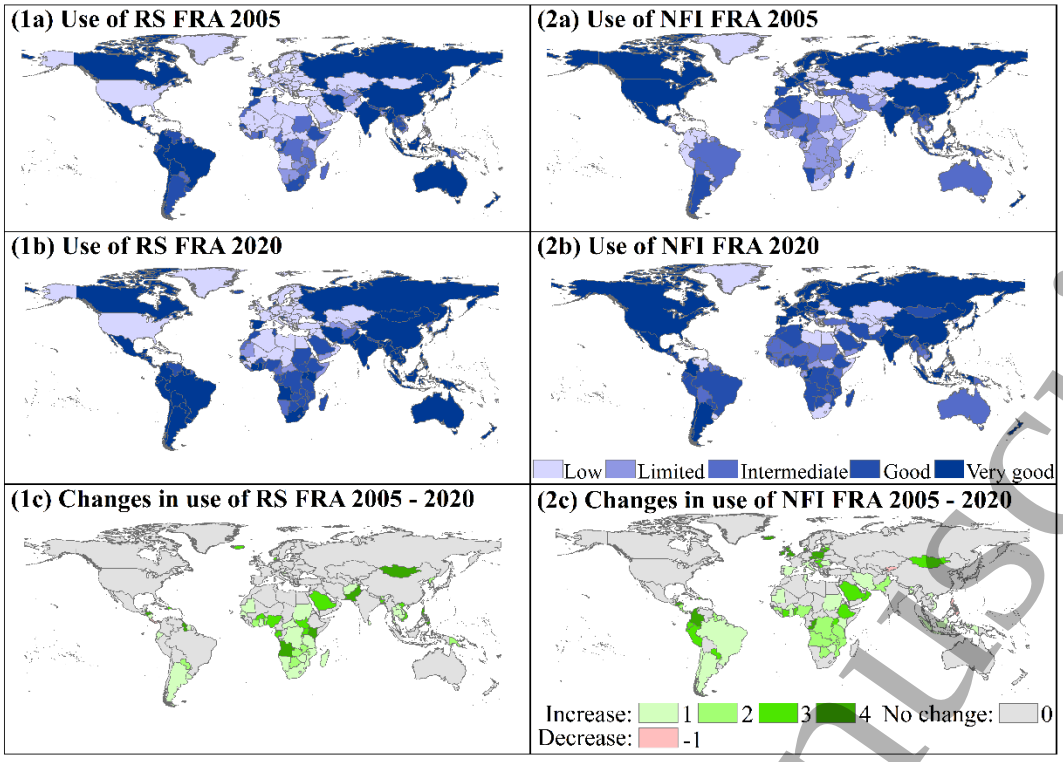

Fig. 1: Use of data sources for forest monitoring and changes in the use of data sources in 236 countries and territories from FRA 2005 to FRA 2020: use of RS for forest area monitoring in FRA 2005 (1a), FRA 2020 (1b), and changes in the use of RS (1c); use of NFI for forest monitoring in FRA 2005 (2a), FRA 2020 (2b), and changes in the use of NFI (2c).

Noticeably, the greatest improvements took place in tropical countries where the good to very good use of RS and NFI increased from 35 and 21 countries in FRA 2005 to 69 and 57 countries in FRA 2020, respectively (Fig. 1 and Table A2.1 in Appendix 2). Specifically, tropical countries significantly improved their use of NFI between FRA 2015 and FRA 2020 (see also Fig. 2). Further zooming in revealed that improvements are more pronounced in African countries where capacities to produce in-country RS maps and NFIs rose to 31 and 27 countries respectively in FRA 2020, from 8 countries in each case in FRA 2005 (Table A2.2). Similarly, capacities improved in South America where seven countries were able to produce in-country NFIs in 2020 compared to two countries in FRA 2005 (Table A2.7). Overall, most of the countries in Asia, Oceania, and South America had very good use of RS (Table A2.3, A2.6, A2.7) while the USA and Canada had very good use of NFIs throughout the period (Fig. 1). A substantial improvement also occurred in Europe where the number of countries with consistent time series of in-country NFIs more than doubled over the period (Table A2.4).

Table 3: The number of countries by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n = 236).

Data source indicator value	**Use of RS for forest area monitoring**				**Use of NFI for forest monitoring**			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very good	23	22	36	53	20	24	32	41
Good	32	44	44	46	28	40	45	61
Intermediate	25	26	23	24	21	29	34	34
Limited	22	24	23	22	39	36	24	14
Low	134	120	110	91	128	107	101	86

Between FRA 2005 and FRA 2020, the number of countries with low use of RS and NFI went down globally by 31% and 33% respectively (Table 3). The number of countries using partial or external RS data (limited and intermediate use) remained stable, while the number of countries with limited and intermediate use of NFI decreased by 20%. Overall, the decline in RS and NFI deployment only took place in very few countries. Specifically, the RS use in Costa Rica and Panama, and the NFI use in Kyrgyzstan and the Philippines fell from very good to good over the period (Fig. 1c and Fig. 2c). The reason for this

decline is that countries did not regularly update data which made the data sources too old to be labeled as very good in FRA 2020.

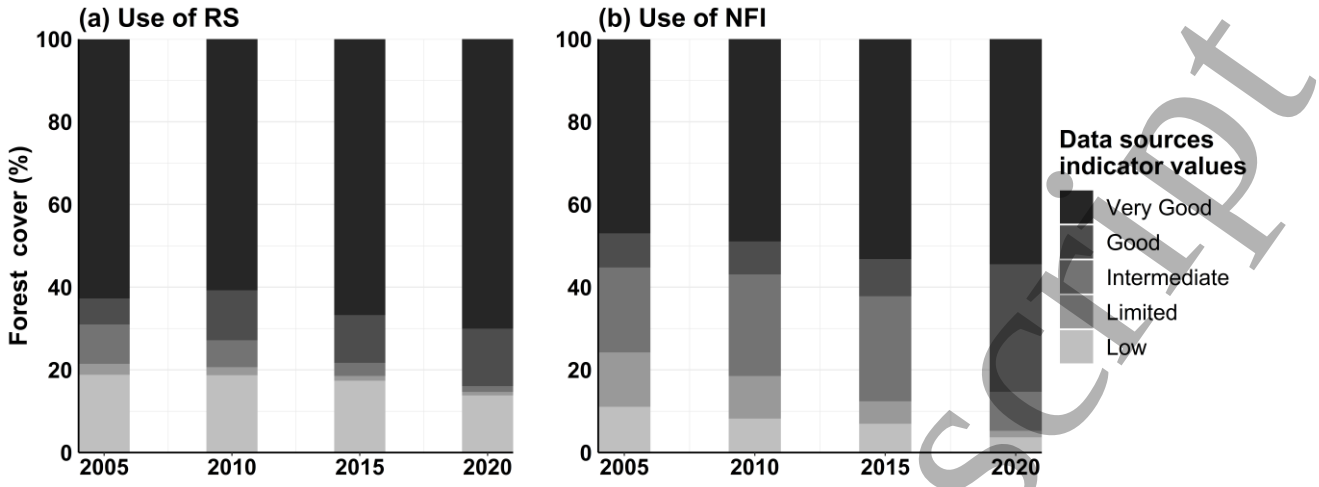

Fig. 2: The percentage of total forest cover monitored by data source indicator value for use of RS for forest area monitoring (a), and use of NFI for forest monitoring (b) in 236 countries and territories from FRA 2005 to FRA 2020.

Fig. 3 shows that most of the countries used recent data for forest monitoring. Out of 145, 104 countries used RS data produced in the 2010s including 70 countries using data produced since 2015. Regarding NFI, 94 countries used data produced in the 2010s and 62 countries from 2015. Notably, many countries in the (sub)tropics used recent data: 91 and 62 countries used the RS and NFI data respectively produced in the last ten years. Among them, 59 countries had RS data, and 40 countries NFI data, produced since 2015. Also, several temperate countries used recent NFI data - 26 countries using data from the 2010s and 20 countries from 2015 onwards. Comparing the two graphs in Fig. 3 demonstrates that RS-based data sources are more recent than those for NFIs. This reflects that countries are able to produce more frequent and recent RS-based estimations while NFIs take some time to complete and keep up to date for reporting. Although the use of recent data was notable, temporal frequency varied between 5 and 10 years in most of the countries with multi-date data.

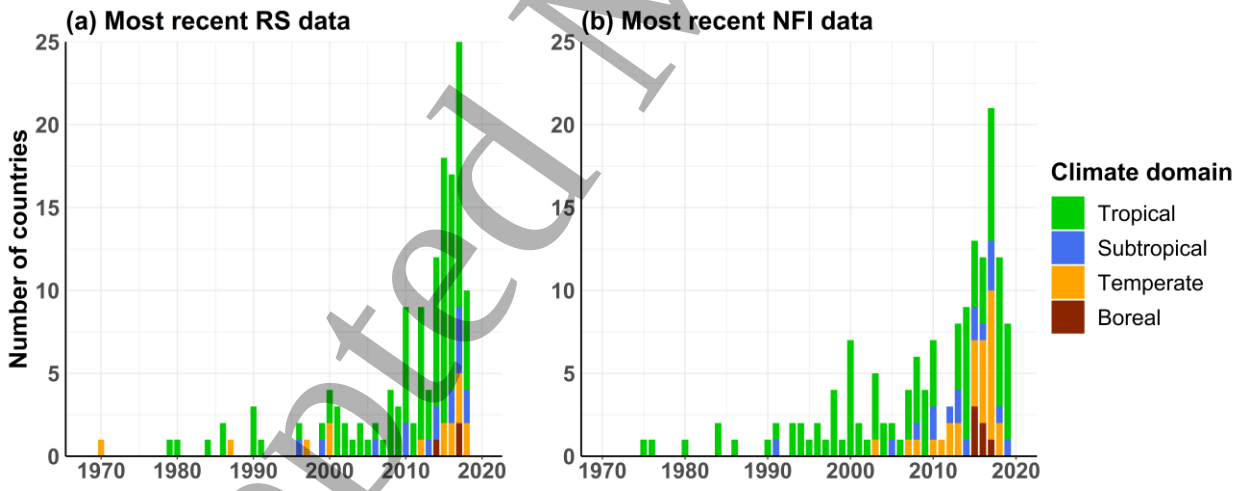

Fig. 3: Temporal distribution of the most recent RS and NFI data points aggregated by climate domain; the countries and territories totaled at 145 for RS and 150 for NFI data. Here, data points mean if countries have RS and/NFI data in a particular year. The years generally refer to years in which RS and NFI data were collected.

3.2 Data Quality Assessment in FRA 2020

The data quality results show that more than half of the countries (53%) used the highest quality data (i.e. Tier 3 data) for reporting forest area status in FRA 2020 covering ~93% of the global forest cover (Table 4). However, the number of countries using Tier 3 data is relatively smaller for growing stock status, followed by biomass and carbon pool. Furthermore,

comparatively fewer countries used the highest quality data for trend estimations. When it comes to biomass, just a quarter of the countries used Tier 3 data but covered about three-quarters of the global forests, and among them, six countries viz. Australia, Brazil, Canada, China, Russia, and the USA covered more than 57% of the forests (>2 billion ha). For reporting carbon pool, only ~19% of the countries used Tier 3 data, while it covered nearly 61% of the global forests and out of it, Australia, Brazil, Canada, Russia, and the USA covered around 52% of the forests.

Table 4: Data quality assessment across the countries with the corresponding forest coverage (%) using FAO Tier indicators in FRA 2020 (n=236). Tier 1 is the lowest and Tier 3 the highest data quality. Only Tier 1 and Tier 3 are considered in the case of biomass indicator.*

Tier Indicators		Number of countries in Tiers				Forest area % under Tiers			
		No data	Tier 1	Tier 2	Tier 3	No data	Tier 1	Tier 2	Tier 3
Forest area	Status	-	54	57	125	-	2	5	93
	Trend	-	71	62	103	-	2	12	86
Growing stock	Status	32	72	40	92	~4	5	7	85
	Trend	32	84	60	60	~4	8	27	61
Biomass*		30	146	-	60	<1	24		76
Carbon pool		30	22	139	45	<1	1	38	61

In general, most of the countries in Western Europe, and North and Central America used Tier 3 data for forest monitoring, followed by Asia and South America, whereas African countries mostly used Tier 1/Tier 2 data (Fig. 4). Especially for measuring trends, biomass, and carbon pool, most of the African countries used lower quality data. Many countries in Asia, Eastern Europe, and South America also used lower quality data for biomass and carbon pool measurements. On the other hand, some countries including Australia did not report growing stock; these countries cover ~4% of the global forests. The forest coverage with no data was <1% for both biomass and carbon pool.

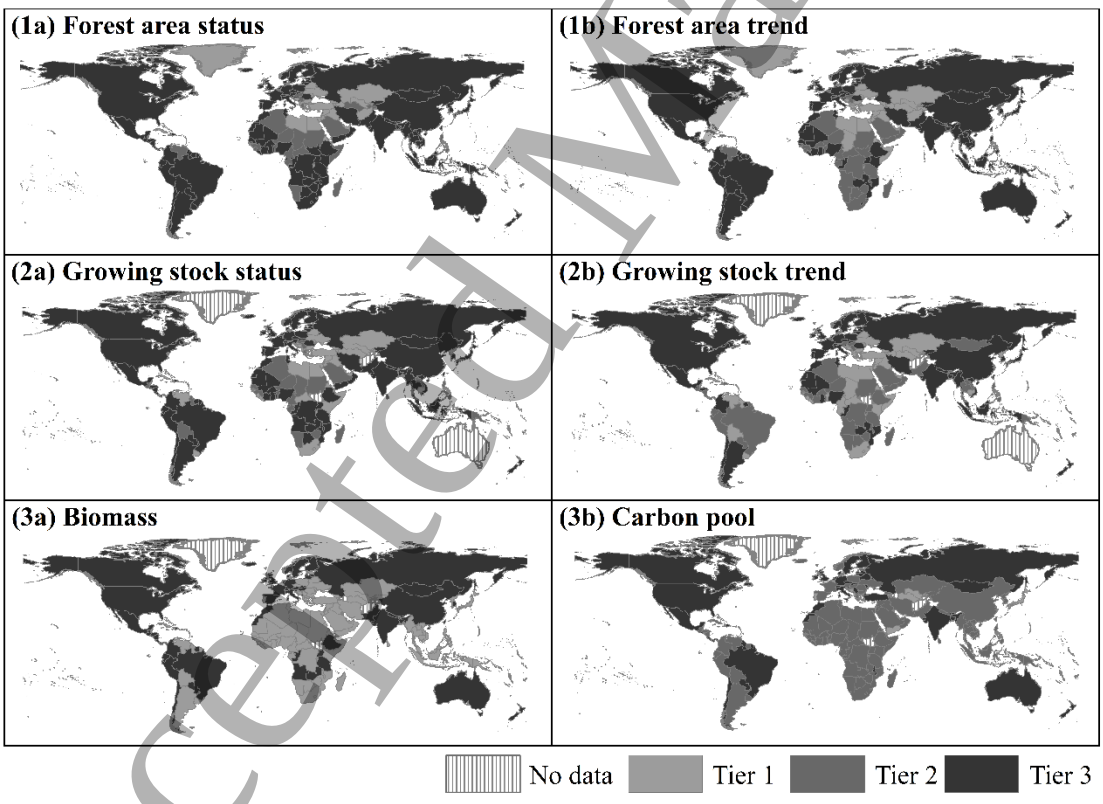

Fig. 4: Data quality assessment in 236 countries and territories in FRA 2020 using FAO Tier Indicators: forest area status (1a), forest area trend (1b), growing stock status (2a), growing stock trend (2b), biomass (3a), and carbon pool (3b).

3.3 Analysis of Tropical Forest Monitoring Capacity Improvements

Capacity improvements are higher in the tropical countries receiving direct, targeted support for forest monitoring compared to tropical countries without such support (Table 5). More than 50% of the countries with targeted support for both RS and NFI improved their capacities on top of those with good and very good capabilities over the period. In contrast, some 45% of the countries showed no capacity improvements both for RS and NFI in the absence of dedicated support. Still, 40% of the countries without support improved their RS capacities, and 34% improved NFI capacities. There is a small share of countries (16%) that received support but did not improve their RS capacities, and this figure was almost double for NFI. The reason could be that fieldwork, data analysis, and reporting on NFIs take longer, and some countries initiated NFIs with support, but they did not yet complete them and report on the estimations.

Table 5: Forest monitoring capacity improvements with and without targeted international support for RS and NFI in 99 non-annex 1 tropical countries from FRA 2010 to FRA 2020. The analysis was based on support reported in the GFOI inventory of activities. There might be more countries with support not reported in the GFOI inventory of activities.

Capacity improvement group	Forest area change monitoring and RS capacities		NFI capacities	
	Countries with support (n=49)	Countries without support (n=50)	Countries with support (n=43)	Countries without support(n=56)
"Good and very good" capacities throughout the period	29%	16%	19%	21%
Capacity improvements	55%	40%	51%	34%
No capacity improvements (including decline)	16%	44%	30%	45%

Our study further revealed a link between forest monitoring capacity improvements and improving governance trends (as defined by WGI) in tropical countries (Fig. 5). Regarding both RS and NFI, countries with very good capacities throughout the study period, and countries with capacity improvements, were found to have comparatively higher-quality governance trends than countries with no capacity improvements. In particular, very good NFI capacities were found in countries with much higher governance trends compared to very good RS capacities. About 75% of the countries with very good RS capacities had governance trends above zero whereas all countries with very good NFI capacities had positive governance trends. However, no significant differences between the groups were found.

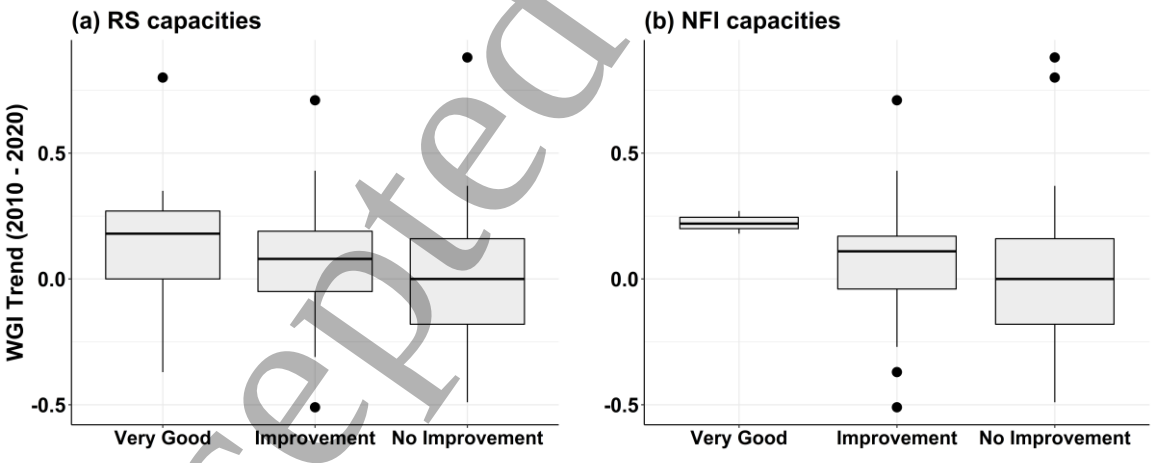

Fig. 5: Forest area monitoring and RS capacity improvements, H = 4.6, p = 0.10 (a), and NFI capacity improvements, H = 5.5, p = 0.06 (b) relating to WGI trend from 2010 to 2020. Capacities are grouped into very good capacities throughout the period, capacity improvement, and no improvement from FRA 2010 to 2020.

4. Discussion

Overall, our findings show a trajectory towards improvement in forest monitoring capacities worldwide. Improvements are especially promising in tropical countries where the use of RS at good to very good levels improved by ~49% between FRA 2005 and FRA 2015. The use of NFI improved even more (~71%) in the same period. From FRA 2015 onwards, the tropics have seen substantial improvements; the numbers of countries with good to very good use of RS and NFI increased by ~33% and ~58% respectively. These findings reassert a continuation in the trends of capacity improvements in the tropics observed by Romijn et al. (2015). Significant improvements have also been observed in monitoring temperate and boreal forests mostly using NFIs at good to very good levels.

Our results confirm the previous findings by Romijn et al. (2015) that capacity improvements in tropical countries can be linked to international investments, and show that these improvements persist. More specifically, the RS and NFI capacity improvements with international support in the majority of the tropical countries emphasize the positive effects of dedicated RS and NFI capacity development activities. This is further supported by the result that a large fraction of countries showed no capacity improvements in the absence of international support, emphasizing the need for continuation and amplification of such investments in the coming years. Nonetheless, the question warrants further research as the existence of tropical countries with dedicated support but no improvements indicating the possibility that other factors affect capacity developments in these countries. Capacity improvements in tropical countries with or without external support are in particular due to investments in forest monitoring motivated by national and international climate agendas such as results-based payments under the REDD+ mechanism. Other possible reasons could be an increase in technology transfer through online material and documentation, and experience sharing among countries.

The observation of a link between forest monitoring capacity improvements and improvements in governance trends in the tropics is not surprising, given that good governance has been linked to better forest management (Griscom et al., 2020). The results that persisting very good NFI capacities in countries with much higher governance trends compared to very good RS capacities indicate that increasing good governance in countries favor the implementation of fieldwork required for completing the field inventories for NFI and updating them regularly. We suggest international support for tropical forest monitoring should be linked to efforts for overall governance improvements to promote enhanced transparency and accountability among countries for continuing and maintaining capacity improvements, more prominently NFI capacities.

Despite significant capacity improvements in the tropics, a consistent time series of in-country RS data is still rare in Africa and parts of Asia. A consistent time series of in-country NFIs is even rarer in Africa, parts of Asia, and South America. In some countries, capacities have not improved in spite of receiving international support, and this share of countries is much higher for NFI. This may be due to the longer time that it takes for completing field inventories needed in NFI (Mcroberts & Tomppo, 2007; Wittke et al., 2019). In addition, forest monitoring in many tropical countries is currently based on either partial, external, or very old data and the amount of forest cover monitored with these data is comparatively higher for NFI (773 million ha). All these findings suggest that further efforts are needed to improve capacities in tropical countries, with emphasis on providing updated NFI-type information more frequently.

Globally, reporting on ~85% of the forest cover is now based on nationally derived RS or NFI data. A striking methodological difference is observed in forest monitoring between Northern and Southern countries. Tropical countries mainly use RS data, while Europe and the USA predominantly rely on NFI data. This tendency could be linked to the origin of forest inventories in Europe and the USA in timber resource assessments which later gave rise to their broader use for sustainable forest management (Lorenz & Fischer, 2013; Tkacz et al., 2013). This also reflects the availability of the resources in these countries to sustain the NFI system for forest monitoring and partially, the importance of the forest sectors in the national economy in some of these countries.

In terms of temporal frequency in forest monitoring, variations between 5 and 10 years were observed in most of the countries. Thus, current country reporting does not provide global data at annual/biannual time steps. Satellite RS data would allow more frequent reporting on some attributes because it provides observations at a higher temporal frequency which can be used for monitoring forest dynamics such as tree cover loss, deforestation, and forest fires (Setiawan et al., 2015; Tang et al., 2019). While NFIs take significant time to complete, integrating frequent RS observations with NFIs could help increase reporting frequency on tree cover, forest area, biomass, and their changes, anticipating more frequent reporting needs in the future under the Paris Agreement and the SDGs.

Globally, more than half of the countries now use Tier 3 data for reporting forest area status covering ~93% of the forests, which reveals a 33% increase from 2015 compared with the findings by Keenan et al. (2015). However, nearly two-thirds of the countries worldwide report biomass using Tier 1 data which is linked to the use of default biomass conversion factors due to lack of NFIs particularly in Africa, parts of Asia and South America, and Eastern Europe. However, some tropical countries use the default biomass conversion factors despite having NFIs, be it for convenience or because they have not started to use country-specific factors since NFIs are recent. Also, ~80% of the world countries report carbon pool using Tier 2 data, i.e. these countries are not producing deadwood, litter, and soil-related carbon data. This is because these parameters are not fully measurable without an NFI (Pearson et al., 2014). In some cases, tropical countries report biomass/carbon pool using lower quality data to international reporting, despite having the highest quality data available, such as in Indonesia. Such limits in reporting capacities suggest that international support should be provided not only to enhance forest monitoring capacities but to be continued until countries have built capacities for high-quality international reporting as well.

The quality of forest monitoring data in our study was measured in terms of age and nature of the data. We did not investigate if countries used temporary or permanent field plots in case of multiple NFIs nor do we explicitly differentiate between forest inventories and logging inventories as this information was not consistently available across all countries. As these variations in NFIs can influence data quality, they could be considered in a more detailed analysis. Furthermore, diversity in NFIs can lead to variations in data quality across countries (Vidal et al., 2016). Field sampling and analytical methods have been reported to result in varying estimates in European forests (Clarke et al., 2011). Such data variations across Europe led to the establishment of the European NFI Network in 2003 to enhance data harmonization for international comparisons, which could be a benchmark to start data harmonization in other countries (Vidal et al., 2016). Also, sources of variations could be integrated into the FRA data quality assessment to enhance data harmonization across the globe. Additionally, data latency can also affect data quality and timely reporting of forest information to national and international platforms. Therefore, reducing higher data latency particularly in NFI could be an important objective in future forest monitoring capacity building initiatives.

5. Conclusions

This study shows substantial improvements in national forest monitoring capacities around the globe. Forest area monitoring using RS at good to very good levels increased from 55 countries in FRA 2005 to 99 in FRA 2020. The number of countries with good to very good use of NFI rose from 48 in FRA 2005 to 102 in FRA 2020. These figures correspond to more than 3.4 billion ha (~85%) global forest cover monitored with good to very good use of RS or NFI data in FRA 2020. The use of RS is not expected to increase in the Northern countries including Europe and the USA since they mostly use NFIs as main data sources to report on forests. While the use of RS is more widespread in the Southern countries (tropics), the use of multi-date RS is rare, especially in Africa. In addition, there are still several tropical countries particularly in Africa, and Western and Central Asia where the use of RS is low. Tropical countries have recently started to implement NFIs, but multi-date NFIs remain rarer particularly in Africa and parts of Asia and South America. Globally, 53% of the countries now use the highest quality data for reporting forest area status covering ~93% of the forest cover. However, the use of the highest quality data is lower for monitoring growing stock, biomass, and carbon pools in Africa, parts of Asia and South America, and East Europe. Therefore, greater efforts should be made in these regions to enable countries to implement NFI which will also help to improve data quality especially biomass and carbon pool that depends on NFI data.

More than 50% of countries receiving dedicated external financial support improved both their RS and NFI capacities, apart from those with already very good capacities throughout the period. However, several countries that received support have not improved capacities, and this proportion is higher for NFI. Our study further reveals a positive link between improved forest monitoring capacities and improvement on indicators of good governance, and this link is more pronounced for NFI. These results suggest that it could be advantageous to combine international support for forest monitoring with governance improvements in tropical countries to better advance national forest monitoring capacities, more prominently NFI capacities. However, further investigation is needed to reveal how country governance or other factors affect forest monitoring capacities.

This study is the first investigation of the status and trends in global data sources and forest monitoring capacities between FRA 2005 and FRA 2020, and an analysis of forest monitoring data quality in FRA 2020. Thus, it offers the information required to evaluate the need for further efforts in improving national capacities in using RS and NFI data sources and data quality in the context of evaluating the progress of global forest-based climate change mitigation and development initiatives.

In addition, the findings are useful for donors and policymakers to decide where to direct further support for improving forest monitoring capacities.

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Disclaimer

The designations employed and the presentation of the material in the maps do not imply the expression of any opinion whatsoever on the part of the authors concerning the legal or constitutional status of any country, territory or sea area, or concerning the delimitation of frontiers.

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7. Appendices

Appendix 1: Data source assessment scores for all countries

This appendix contains the indicator scores for the data source assessment indicators: Use of RS for forest area monitoring and Use of NFI for forest monitoring for 236 countries and territories in FRA 2005-2020. The scores correspond to the indicator values (Table 1) where 0 represents low, 1 limited; 2 intermediate, 3 good, and 4 very good use of data sources.

Country	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	2010	2015	2020	2005	2010	2015	2020
Afghanistan	1	1	1	2	0	0	0	0
Albania	0	0	0	0	0	0	0	0
Algeria	0	0	0	0	3	3	3	3
American Samoa	2	2	2	2	1	1	1	1
Andorra	3	3	3	3	0	0	0	0
Angola	0	0	0	4	1	1	1	3
Anguilla	0	0	0	0	0	0	0	0
Antigua and Barbuda	0	0	0	0	0	0	0	0
Argentina	3	3	4	4	3	3	4	4
Armenia	0	0	0	0	0	0	0	0
Aruba	2	2	2	2	0	0	0	0
Australia	4	4	4	4	2	2	2	2
Austria	0	0	0	0	4	3	3	4
Azerbaijan	0	0	0	0	0	0	0	0
Bahamas	0	0	0	0	1	1	1	1
Bahrain	0	0	0	0	0	0	0	0
Bangladesh	1	3	4	4	3	3	3	4
Barbados	0	1	1	1	0	0	0	0
Belarus	0	0	0	0	0	0	0	0
Belgium	0	0	0	0	2	2	2	2
Belize	0	2	2	2	0	1	1	1
Benin	1	1	2	3	0	3	3	3
Bermuda	0	0	0	0	0	0	0	0
Bhutan	2	2	3	4	1	1	1	3
Bolivia (Plurinational State of)	4	4	4	4	2	2	2	2
Bonaire, Sint Eustatius and Saba	1	1	1	2	1	1	1	0
Bosnia and Herzegovina	0	0	0	0	0	0	0	0
Botswana	1	2	2	3	1	1	1	3
Brazil	4	4	4	4	2	2	2	3
British Virgin Islands	0	0	0	0	0	0	0	0

Country	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	2010	2015	2020	2005	2010	2015	2020
Brunei Darussalam	3	3	3	3	2	2	2	2
Bulgaria	0	0	0	0	0	0	0	0
Burkina Faso	0	0	1	3	2	2	2	3
Burundi	1	1	1	1	0	2	2	2
Cabo Verde	0	0	0	0	1	1	3	3
Cambodia	3	3	3	4	1	1	1	1
Cameroon	2	2	2	2	3	3	3	3
Canada	4	4	4	4	4	4	4	4
Cayman Islands	0	3	3	3	0	0	0	0
Central African Republic	0	0	1	1	1	1	1	1
Chad	0	0	0	0	2	2	2	2
Chile	4	4	4	4	3	3	3	4
China	4	4	4	4	4	4	4	4
Colombia	4	4	4	4	0	1	3	4
Comoros	0	0	0	0	0	0	3	3
Congo	3	3	3	3	0	0	3	4
Cook Islands	0	0	0	0	0	0	0	0
Costa Rica	4	3	3	3	1	1	3	3
Cote d'Ivoire	2	3	3	4	0	0	0	3
Croatia	3	4	4	4	0	0	0	0
Cuba	0	0	0	0	0	0	0	0
Curacao	1	1	1	1	1	1	1	1
Cyprus	3	3	3	3	0	0	0	0
Czechia	0	0	0	0	0	3	3	4
Democratic People's Republic of Korea	0	0	0	2	0	0	0	0
Democratic Republic of the Congo	2	3	3	3	1	2	2	3
Denmark	0	0	3	3	0	3	4	4
Djibouti	1	1	1	1	0	0	0	0
Dominica	2	2	2	2	0	0	0	0
Dominican Republic	0	3	3	3	0	0	0	3
Ecuador	3	3	4	4	0	0	3	3
Egypt	0	0	0	0	0	0	0	0
El Salvador	3	3	3	3	0	0	0	3
Equatorial Guinea	0	0	0	3	1	1	1	1
Eritrea	0	0	0	0	0	0	0	0
Estonia	0	0	0	0	3	4	4	4
Eswatini	3	3	3	3	3	3	3	3
Ethiopia	3	3	3	3	0	0	0	3
Falkland Islands (Malvinas)	0	0	0	0	0	0	0	0
Faroe Islands	0	0	0	0	0	0	0	0
Fiji	0	0	0	0	2	3	3	3
Finland	0	0	0	0	4	4	4	4
France	0	0	0	0	4	4	4	4
French Guyana	2	2	2	2	2	2	2	2
French Polynesia	0	0	0	2	0	0	0	0
Gabon	0	0	0	3	1	1	1	1
Gambia	1	1	1	3	1	1	3	3
Georgia	0	0	0	0	0	0	0	0
Germany	0	0	0	0	4	4	4	4
Ghana	3	3	3	4	1	2	2	2
Gibraltar	0	0	0	0	0	0	0	0
Greece	0	0	0	0	1	1	1	1
Greenland	0	0	0	0	0	0	0	0
Grenada	0	1	1	1	0	0	0	0
Guadeloupe	0	0	0	2	0	0	0	0
Guam	2	2	2	2	1	1	1	2
Guatemala	4	4	4	4	3	3	3	3

Country	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	2010	2015	2020	2005	2010	2015	2020
Guernsey	0	0	0	0	0	0	0	0
Guinea	0	0	0	0	0	2	2	2
Guinea-Bissau	2	2	2	2	0	0	0	0
Guyana	0	0	4	4	0	1	2	2
Haiti	0	0	0	4	0	0	0	0
Holy See	0	0	0	0	0	0	0	0
Honduras	0	0	0	4	0	3	3	4
Hungary	0	0	0	0	0	0	0	3
Iceland	0	0	4	3	0	3	3	4
India	4	4	4	4	4	4	4	4
Indonesia	4	4	4	4	3	3	4	4
Iran (Islamic Republic of)	4	3	4	4	2	3	3	3
Iraq	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	0	3	4	4
Isle of Man	0	0	0	0	0	0	0	0
Israel	0	0	0	0	0	2	2	2
Italy	0	0	0	0	3	4	4	4
Jamaica	3	3	3	3	1	1	2	2
Japan	4	4	4	4	4	4	4	4
Jersey	0	0	0	0	0	0	0	0
Jordan	0	0	0	0	0	0	0	0
Kazakhstan	0	0	0	0	0	0	0	0
Kenya	0	0	4	4	1	2	2	2
Kiribati	0	0	0	0	0	0	0	0
Kuwait	0	0	0	0	0	0	0	0
Kyrgyzstan	4	4	3	4	4	4	3	3
Lao People's Democratic Republic	3	3	3	4	3	3	3	3
Latvia	0	0	0	0	0	3	4	3
Lebanon	3	3	3	4	3	3	3	3
Lesotho	2	2	2	2	0	0	0	0
Liberia	2	2	2	2	0	0	0	0
Libya	0	0	0	0	0	0	0	0
Liechtenstein	0	0	0	0	0	0	0	3
Lithuania	0	0	0	0	0	3	4	4
Luxembourg	0	0	0	0	3	3	3	3
Madagascar	2	2	3	3	3	3	3	3
Malawi	1	1	2	3	1	1	1	3
Malaysia	4	4	4	4	3	4	4	3
Maldives	0	0	0	3	0	0	0	0
Mali	0	0	0	0	2	2	2	2
Malta	1	1	1	1	0	0	0	0
Marshall Islands	0	1	1	1	0	1	1	1
Martinique	0	0	0	2	0	0	0	0
Mauritania	0	0	0	1	1	1	1	2
Mauritius	0	0	0	0	0	0	0	0
Mayotte	0	3	3	4	0	0	0	0
Mexico	4	4	4	4	4	4	4	4
Micronesia (Federated States of)	0	1	1	1	1	2	2	2
Monaco	0	0	0	0	0	0	0	0
Mongolia	0	0	0	4	0	0	0	3
Montenegro	2	2	2	2	0	1	3	3
Montserrat	0	0	0	1	0	0	0	0
Morocco	3	3	4	3	3	3	4	3
Mozambique	2	2	2	3	1	1	1	3
Myanmar	4	4	4	4	3	3	3	3
Namibia	1	2	2	2	3	3	3	3
Nauru	0	0	0	0	0	0	0	0

Country	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	2010	2015	2020	2005	2010	2015	2020
Nepal	3	3	3	3	3	3	3	3
Netherlands	3	3	3	3	4	4	4	4
New Caledonia	0	3	3	3	1	1	1	1
New Zealand	4	4	4	4	4	4	4	4
Nicaragua	3	3	3	4	1	3	3	3
Niger	0	0	0	0	2	2	2	2
Nigeria	0	0	0	3	1	1	1	3
Niue	0	0	0	0	0	3	3	3
Norfolk Island	0	0	0	0	0	0	0	0
North Macedonia	0	0	0	0	0	0	0	0
Northern Mariana Islands	2	2	2	2	1	1	1	2
Norway	0	0	0	0	4	4	4	4
Oman	0	0	0	0	0	0	0	3
Pakistan	0	0	1	4	1	1	1	3
Palau	2	2	2	2	1	2	2	2
Palestine	0	0	0	0	0	0	0	0
Panama	4	4	4	3	2	2	2	3
Papua New Guinea	2	2	3	4	2	2	2	2
Paraguay	2	2	3	4	0	0	0	3
Peru	4	3	4	4	0	0	0	3
Philippines	0	3	4	4	4	3	3	3
Pitcairn	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	4	4
Portugal	0	0	0	0	4	4	4	4
Puerto Rico	0	0	0	0	2	2	2	2
Qatar	0	0	0	0	0	0	0	0
Republic of Korea	4	4	4	4	4	4	4	4
Republic of Moldova	0	0	0	0	0	0	0	0
Reunion	0	0	0	2	0	0	0	0
Romania	0	0	0	0	3	3	4	4
Russian Federation	4	4	4	4	4	4	4	4
Rwanda	0	0	3	3	0	3	3	3
Saint-Martin (French Part)	0	0	0	1	0	0	0	0
Saint Barthelemy	0	0	0	1	0	0	0	0
Saint Helena, Ascension and Tristan da Cunha	0	0	0	0	0	0	0	0
Saint Kitts and Nevis	0	1	1	1	0	0	0	0
Saint Lucia	2	2	2	3	2	2	2	2
Saint Pierre and Miquelon	1	1	2	2	0	0	0	2
Saint Vincent and the Grenadines	0	1	1	1	3	3	3	3
Samoa	3	3	3	3	0	0	0	3
San Marino	0	0	0	0	0	0	0	0
Sao Tome and Principe	0	0	0	0	1	1	2	2
Saudi Arabia	0	3	3	3	0	3	3	3
Senegal	3	3	3	4	3	3	3	3
Serbia	0	0	0	0	0	3	3	3
Seychelles	0	0	0	0	0	0	0	0
Sierra Leone	2	2	2	2	0	0	0	0
Singapore	0	0	1	4	0	0	0	4
Sint Maarten (Dutch part)	1	1	1	1	1	1	1	1
Slovakia	0	0	0	0	2	3	3	4
Slovenia	3	4	4	4	3	4	4	4
Solomon Islands	0	0	0	0	0	2	2	2
Somalia	1	1	1	1	0	0	0	0
South Africa	3	3	3	4	0	0	0	0
South Sudan	0	0	3	3	0	0	0	0
Spain	4	4	4	4	3	4	3	4
Sri Lanka	3	3	4	4	3	3	3	3

Country	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	2010	2015	2020	2005	2010	2015	2020
Sudan	2	2	3	3	1	2	2	2
Suriname	3	3	4	4	1	1	2	2
Svalbard and Jan Mayen Islands	0	0	0	0	0	0	0	0
Sweden	0	0	0	0	4	4	4	4
Switzerland	0	0	0	0	4	4	4	4
Syrian Arab Republic	0	0	0	0	0	0	0	0
Tajikistan	1	1	1	1	0	0	0	0
Thailand	3	3	3	4	2	2	2	2
Timor-Leste	3	3	3	3	0	0	3	3
Togo	0	0	0	3	0	0	0	3
Tokelau	0	0	0	0	0	0	0	0
Tonga	0	3	3	3	2	2	2	2
Trinidad and Tobago	3	3	3	3	3	3	3	3
Tunisia	3	3	4	3	3	3	4	4
Turkey	0	0	0	0	2	2	2	2
Turkmenistan	1	1	1	1	0	0	0	0
Turks and Caicos Islands	0	0	0	1	0	0	0	0
Tuvalu	0	0	0	0	0	0	0	0
Uganda	1	3	3	4	0	0	0	3
Ukraine	0	0	0	0	0	0	0	0
United Arab Emirates	0	0	0	0	0	0	0	0
United Kingdom	0	0	0	0	0	0	3	4
United Republic of Tanzania	2	2	3	3	1	1	3	3
United States of America	0	0	0	0	4	4	4	4
United States Virgin Islands	0	0	0	0	1	1	2	2
Uruguay	3	3	3	4	0	0	0	0
Uzbekistan	0	0	0	0	0	0	0	0
Vanuatu	1	1	1	1	0	0	0	1
Venezuela (Bolivarian Republic of)	3	3	4	3	0	0	0	0
Viet Nam	1	1	4	4	3	4	4	4
Wallis and Futuna Islands	3	3	3	3	0	0	0	0
Western Sahara	2	2	2	2	2	2	2	2
Yemen	1	1	1	1	1	1	1	1
Zambia	1	1	3	3	1	1	3	3
Zimbabwe	2	2	2	3	1	2	2	2

Appendix 2: Regional analysis of data sources

Table A2.1: The number of non-annex 1 tropical countries by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n = 99).

Data source indicator value	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very good	13	11	22	38	4	5	7	11
Good	22	30	30	31	17	21	29	46
Intermediate	18	19	15	09	11	20	24	21
Limited	12	10	10	07	29	24	14	07
Low	34	29	22	14	38	29	25	14

Table A2.2: The number of African countries by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n=58).

Data source indicator value	Use of RS for forest area monitoring				Use of NFI for forest monitoring			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very Good	0	0	03	08	00	00	02	02
Good	08	12	16	23	08	10	14	25
Intermediate	13	13	12	08	05	12	13	12

Limited	10	07	06	05	19	14	09	03
Low	27	26	21	14	26	22	20	16

Table A2.3: The number of Asian countries by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n=48).

Data source indicator value	**Use of RS for forest area monitoring**				**Use of NFI for forest monitoring**			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very Good	09	08	12	21	06	07	07	08
Good	09	13	11	06	09	10	11	15
Intermediate	01	01	00	02	04	04	04	04
Limited	06	05	06	03	04	04	04	02
Low	23	21	19	16	25	23	22	19

Table A2.4: The number of European countries by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n=50).

Data source indicator value	**Use of RS for forest area monitoring**				**Use of NFI for forest monitoring**			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very Good	02	04	05	04	10	13	18	23
Good	04	02	03	04	06	11	09	06
Intermediate	01	01	01	01	02	01	01	01
Limited	01	01	01	01	01	02	01	01
Low	44	42	40	40	31	23	21	19

Table A2.5: The number of countries in North and Central America by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n=41).

Data source indicator value	**Use of RS for forest area monitoring**				**Use of NFI for forest monitoring**			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very Good	05	04	04	06	03	03	03	04
Good	04	07	07	08	03	05	06	08
Intermediate	03	04	05	07	03	03	05	05
Limited	04	08	07	10	08	08	05	04
Low	25	18	18	10	24	22	22	20

Table A2.6: The number of countries in Oceania by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n=25).

Data source indicator value	**Use of RS for forest area monitoring**				**Use of NFI for forest monitoring**			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very Good	02	02	02	03	01	01	01	01
Good	02	04	05	04	00	02	02	03
Intermediate	05	05	04	05	04	06	06	08
Limited	01	03	03	03	06	05	05	04
Low	15	11	11	10	14	11	11	09

Table A2.7: The number of countries in South America by data source indicator value for 'Use of RS' and 'Use of NFI' in FRA 2005, 2010, 2015, and 2020 (n=14).

Data source indicator value	**Use of RS for forest area monitoring**				**Use of NFI for forest monitoring**			
	2005	**2010**	**2015**	**2020**	**2005**	**2010**	**2015**	**2020**
Very Good	05	04	10	11	00	00	01	03
Good	05	06	02	01	02	02	03	04
Intermediate	02	02	01	01	03	03	05	04
Limited	00	00	00	00	01	03	00	00
Low	02	02	01	01	08	06	05	03