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WORKING PAPER

ENDING TROPICAL DEFORESTATION: A STOCK-TAKE OF PROGRESS AND CHALLENGES

TROPICAL FOREST MONITORING: EXPLORING THE GAPS BETWEEN WHAT IS REQUIRED AND WHAT IS POSSIBLE FOR REDD+ AND OTHER INITIATIVES

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KEY POINTS

- The past ten years have ushered in a "golden age" of forest monitoring. Advances in satellite-based remote sensing and other technologies now provide low-cost, frequently updated, and consistent information on the extent, characteristics, and changes in forest cover.
- International investments in REDD+ readiness have provided a catalyst for strengthening national systems for forest monitoring and reporting in tropical forest countries, but there remains a wide gap between what is possible and what is practiced.
- Proliferating data and methods to meet diverse stakeholder needs have generated confusion and, in some cases, redundant investments.

THE ISSUE

Never has there been so much demand for data and information about the world's forests. Achieving international goals and national commitments related to forest conservation and management, climate change, and sustainable development requires credible, accurate, and reliable monitoring of changes in forest extent and carbon stocks. Rapid developments in forest monitoring technologies—notably the use of satellite data and other remote sensing methods—now enable efficient monitoring of forest extent, characteristics, and changes over large areas consistently through time. However, there is a widening gap between what is demonstrated in a research

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context and what is developed, maintained, and applied in tropical forest countries. At the same time, proliferating demands for forest-related information and the diversity of forest monitoring systems developed to meet those demands risk creating confusion and redundancy.

WHY MONITORING IS IMPORTANT TO FORESTS, CLIMATE CHANGE, AND DEVELOPMENT

International commitments related to climate change and sustainable development have grown in number and ambition over the last ten years. While reporting structures vary between commitments, each requires credible and consistent monitoring to assess progress toward forest- and climate-related targets. These commitments include:

- The **Paris Agreement,** which is likely to require improvements in the quality and transparency of national greenhouse gas (GHG) inventories, including clarifying how countries account for forests. Global stock-takes will regularly assess progress toward the agreement's 1.5–2.0°C target.
- **REDD+** efforts,[1] which are moving into a performance-based phase that requires a robust, credible system for measuring, reporting, and verification (MRV).
- Goal 15 of the **Sustainable Development Goals (SDGs),** which includes the ambition to halt deforestation by 2020. All goals have defined indicators that require annual reporting from 2015–30 (Mora et al. 2016).
- **Aichi Target 5** of the Convention on Biological Diversity, which by 2020 aims to at least halve the rate at which natural habitats, including forests, are being lost.
- The **New York Declaration on Forests**, which aims to halve deforestation by 2020, end it completely by 2030, and restore hundreds of millions of acres of degraded land (a global effort together with the **Bonn Challenge**).
- Pledges by more than 400 **Consumer Goods Forum** members to achieve zero net deforestation in their commodity supply chains by 2020.

In addition to supporting better reporting on commitments, data on forest area, carbon, and biodiversity values are critical for designing and implementing domestic policies to meet these goals. For example, forest monitoring data can support land use planning, including identifying areas critical for the establishment or enforcement of protected areas, or areas suitable for logging, mining, agriculture, or other productive purposes.

In summary, there has never been greater demand for systematic, dependable forest monitoring at national-to-global scales. These demands have arisen alongside unprecedented advances in the technology of forest monitoring—notably, the use of satellite data and other remote sensing tools.

RECENT PROGRESS IN FOREST MONITORING TECHNOLOGIES

Traditionally, many countries have monitored forest area, health, and change through a selection of site-based plots as part of a national forest inventory. However, inventories are cost- and resource-intensive and are thus updated infrequently—at best every five years. The lack of timely and reliable information can undermine policy efforts to address deforestation. For example, a key challenge to realizing REDD+ initiatives was a perception that tropical forest data was insufficient to support credible monitoring necessary to enable results-based payments (Harris et al. 2018).

Subsequent years ushered in a "golden age" of forest monitoring. Advances in remote sensing and cloud computing have developed as complements to traditional field-based approaches and made it possible to monitor forest extent, key forest changes, and forest characteristics faster and more cost-effectively. While there have also been advances in the use of drones and mobile technology to monitor forests at local scales, this brief focuses on satellite-based remote sensing, which remains the most cost-effective method for understanding forest dynamics consistently through time and across large areas.

Key advancements in forest monitoring over the last ten years include:

Increased satellite imagery diversity and resolution. The single most significant advancement in remote sensing occurred in 2008, when the U.S. Geological Survey opened all data from its Landsat satellite to the public for free (Wulder et al. 2012), permitting large-scale analyses through time back to the program's start in 1972. Many previous mapping efforts utilized freely available coarse resolution MODIS satellite data. Suddenly, Landsat offered 30-meter resolution data—almost 70 times better than MODIS—permitting much finer-scale monitoring of forest changes, such as roads and shifting cultivation. Landsat became the "go-to" source of imagery for mapping forest extent and change.

Satellite imagery spatial resolution and availability continue to improve. In 2013, the European Commission and European Space Agency (ESA) decided to openly license data from the Sentinel satellites (ESA 2013), complementing Landsat with freely available, 10-meter data, as well as radar satellites that can see through cloud cover, smoke, and haze (Reiche et al. 2016). An increasing number of commercial satellite companies (e.g., Planet, TerraSar) offer high spatial resolution data that—while costly for large-scale systematic analyses—can be valuable for validation, calibration, and verification.

Enhanced machine learning and processing capabilities. In the past, experts visually interpreted satellite imagery and delineated forest extent and deforestation by hand. For example, the annual deforestation monitoring system in Brazil (known as PRODES) still heavily relies on expert interpreters to manually inspect imagery for forest changes. However, improvements in machine-learning algorithms facilitated automatic mapping of forest extent, changes, and values using methods that are faster and more consistent than human interpreters. Cloud computing platforms enable these algorithms to interpret increasing volumes of imagery cheaply, and at scale (e.g., FAO SEPAL, Google Earth Engine, Amazon Web Services).

Data visualization and online mapping. As forest monitoring technology has evolved, so too has the demand to make the resulting information public. Once accessible only through paper maps (or not at all), forest monitoring data has become widely available through online geoportals and databases that are simple for non-experts to use. The launch of the Global Forest Watch (GFW) platform in 2014 was notable in making global spatial forest monitoring data accessible to the public for free and in easy-to-understand and dynamic maps, charts, and graphs.

The advancements underpinned two major breakthroughs in forest monitoring research: the ability to characterize forests over large geographic areas—i.e., the global, high resolution maps of annual forest cover change from Hansen et al. (2013) and pantropical maps of aboveground live woody biomass density from Saatchi et al. (2011) and Baccini et al. (2012) (see Figure 1)—and the ability to detect forest changes as soon as imagery is available—e.g., rapid forest disturbance alerts from Hansen et al. (2016) and Reiche et al. (2018a, 2018b).

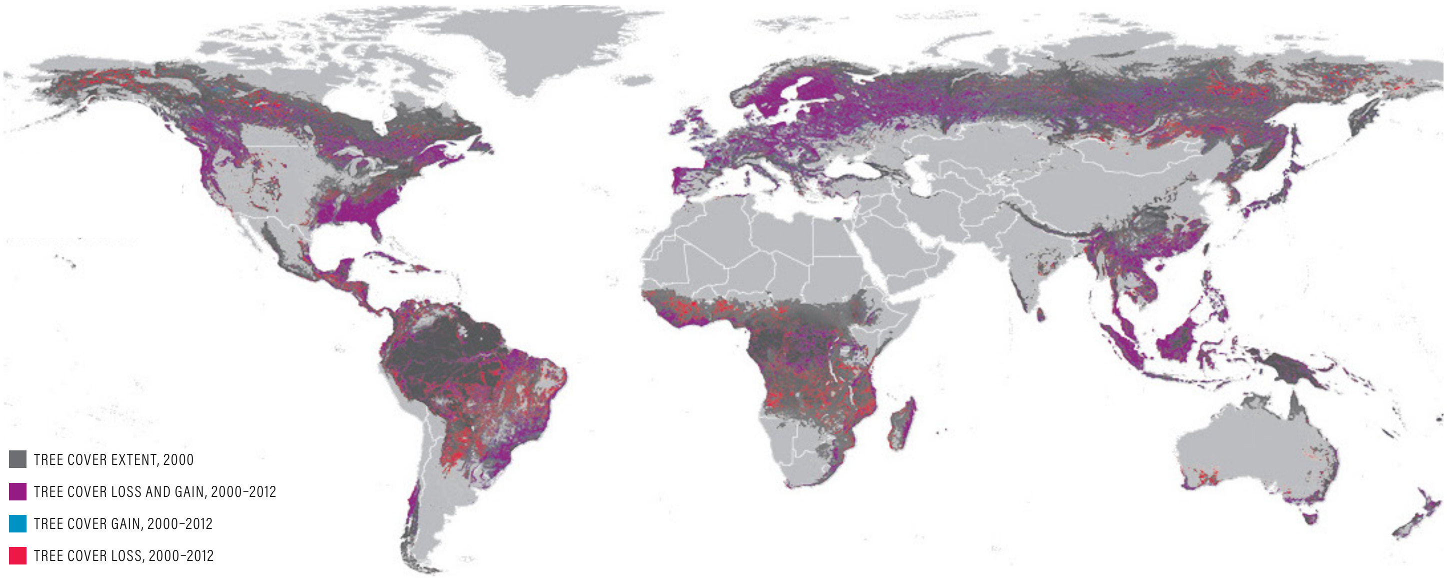
More important than technological advances is how forest monitoring data have been applied to support improved forest management by a range of stakeholders.

Estimation and reporting for REDD+

REDD+ performance is determined by MRV forest-related emission reductions benchmarked against preset reference levels. Monitoring plays the critical role of ensuring the credibility of the "payment-for-performance" mechanism.[2] REDD+ readiness efforts have triggered significant investments—at least $1.65 billion in public funds—aimed at improving developing countries' technical and institutional capacity for forest monitoring, including the use of satellite remote sensing technologies (Lujan and Silva-Chávez 2018). For example, in a recent analysis of 38 Forest Reference Emissions Levels (FRELs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC), all relied on satellite data to estimate deforestation rates, although methods and resulting accuracies varied (see Box 2) (Harris et al. 2018).

These investments and interests have spurred the research community to develop new data sources,[3] methods, space missions,[4] and guidance[5] to support applications of forest monitoring for REDD+ reporting. As a result, tropical countries' forest monitoring capacities have improved considerably in the past decade, as evidenced by the increasing number of national land cover and forest change maps. Because of these efforts, since 2005, the number of countries with good or very good forest area change monitoring capabilities increased from 37 to 54 (Romijn et al. 2015).

Figure 1 | **First Detailed Map of Global Tree Cover Extent, Loss, and Gain**



Notes: The first-ever global tree cover extent, loss, and gain dataset produced by the University of Maryland processed over 650,000 Landsat images. It offered the first consistent characterization of global forest change at locally relevant scales. The data capture a range of forest dynamics, including fires, disease, logging, and agriculture.
Source: Hansen et al. 2013.

Technology advances have made it possible to monitor several key components required under REDD+, including forest cover change and forest carbon stocks. However, the objective of REDD+ forest monitoring is not only to monitor forest carbon change, but also to support policy formulation and implementation. Incorporating information on the socioeconomic and other processes that drive or are impacted by forest change—such as land use, rural and urban population growth—will likely see countries gain a deeper understanding of what activities drive deforestation and how they are linked to other (non-forest) sectors. More comprehensive monitoring allows countries to ensure compliance with REDD+ safeguards, define and prioritize REDD+ strategies, and link them with broader land use sector objectives, such as is envisioned in the SDGs and the Paris Agreement.

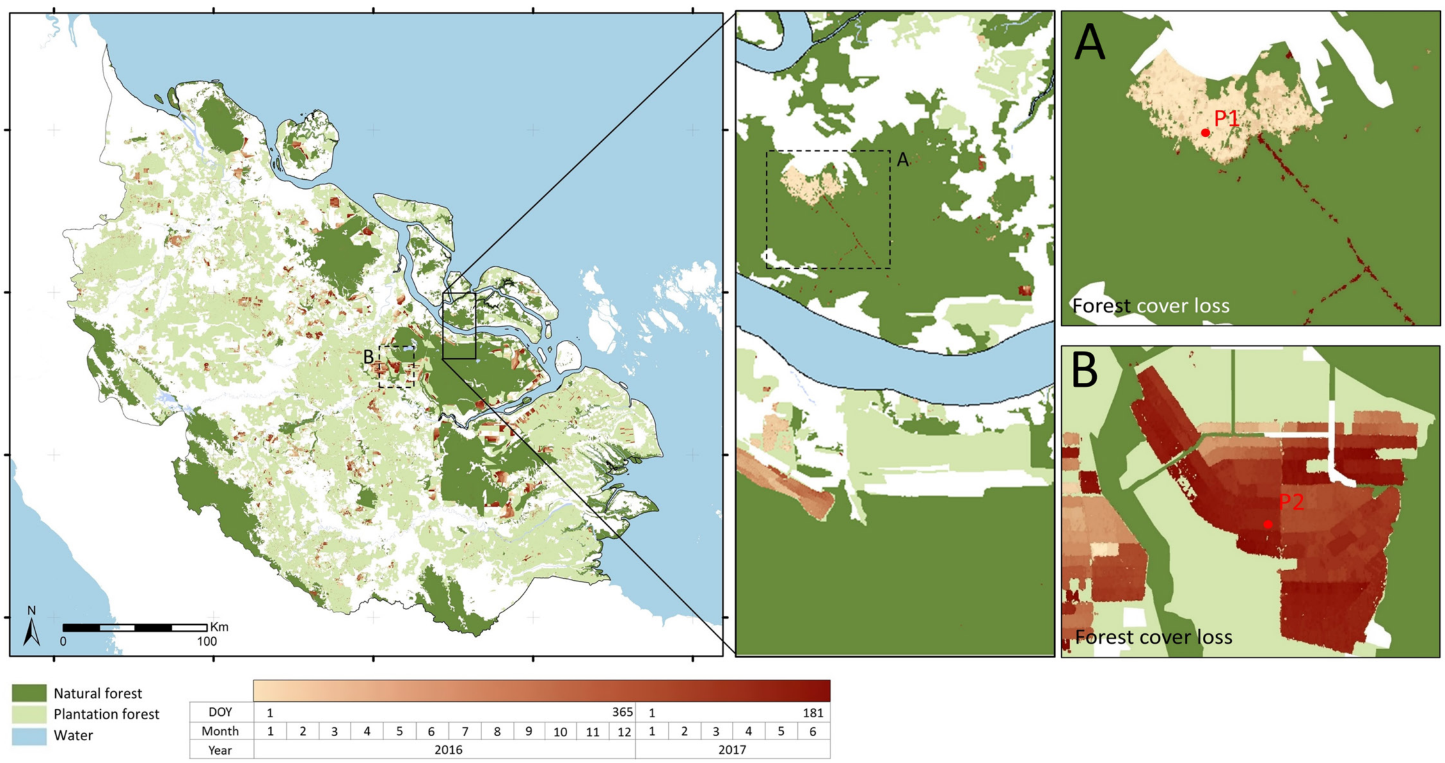
Law enforcement

Several multilateral forestry platforms, trade agreements (e.g., the Convention on International Trade in Endangered Species of Wild Fauna and Flora, CITES), and voluntary partnerships (e.g., the European Union Forest Law Enforcement, Governance and Trade initiative, EU FLEGT) aim to tackle illegal logging and mining and ensure that producer countries enact credible measures to assure the legality of timber and mineral exports.[6]

Illegal activities are difficult and often dangerous to investigate through traditional means, such as foot patrols. Near real-time, remotely sensed forest disturbance detection ("early warning") can support law enforcement to quickly identify areas of potential illegal activity, act against such activities, and deter future unplanned land conversion.

In 2004, Brazil developed the first national early warning system to target illegal logging and land conversion, called DETER. The country's environmental enforcement agency (IBAMA) uses DETER to prioritize field investigations and implement national laws and policies. Some researchers attribute the application of this near real-time satellite data, along with increased enforcement efforts, to reduced deforestation rates in the Amazon (Assuncão et al. 2013). Government agencies in Peru and Colombia also currently operate early warning systems and have developed protocols (at various stages) for how law enforcement should interpret, analyze, and verify monitoring data.

Figure 2 | **Weekly Tree Cover Loss Alerts for Riau, Indonesia**



Notes: Weekly tree cover loss alerts for the province of Riau, Indonesia detected, for the period 1/01/2016–1/30/2017 from Sentinel-1 radar satellite time series. Panel A shows illegal forest encroachment, including road construction into natural forest; panel B shows large-scale plantation dynamics.
Source: Reiche et al. 2018b.

However, one cannot discern the legality of clearing from remotely sensed data alone. Satellite data must be combined with information about how land is allocated, permitted, or managed to discern possible legality. Efforts to compile land use, land tenure, and other spatial data, such as the Open Timber Portal Platform or Indonesia's One Map process, serve as critical complements for using satellite-based forest monitoring in law enforcement efforts.

Most early warning systems utilize optical imagery, which means that cloud cover often obscures forests from view. However, new freely available global radar data from the ESA Sentinel-1 satellite affords an opportunity to detect disturbances despite haze and clouds. With the availability of global radar data, truly "near real-time" monitoring to support law enforcement is more feasible than ever (see Figure 2) (Reiche et al. 2016).

Civil society and indigenous communities

The past ten years have seen growing demand for and application of transparent, timely, and accurate forest monitoring data by civil society. These users include environmental journalists who rely on maps to support stories, activists who cite data as evidence in public campaigns, and indigenous and local communities participating in community-based forest monitoring efforts at local to regional scales, as described in Box 1.

With Peru and Brazil being notable exceptions, few governments provide updated spatial forest monitoring data to the public in easy-to-use formats that meet these diverse needs. As a result, several freely available, independent forest monitoring initiatives have arisen for this purpose, including GFW and Imazon SAD. Indigenous communities are increasingly consumers of satellite-based forest monitoring information, contributing to community-based forest monitoring initiatives (Pratihast et al. 2016).

Box 1 | **How Civil Society Organizations, Law Enforcement Authorities, and Local Communities Are Using Early Warning Data to Improve Forest Management**

Uganda: The Jane Goodall Institute trained monitors at Uganda's National Forest Authority (NFA) and park rangers with the Uganda Wildlife Authority (UWA) how to use weekly forest disturbance alerts to monitor national parks and forests. NFA and UWA staff now use those alerts and other data to prioritize patrols and find and document illegal forest clearing. These data have led to prosecutions, fines, and investigations within several critical habitats, including Kibale National Park.[a]

Peru: The Peruvian Ministry of Environment (MINAM) distributes weekly forest disturbance alerts via their online portal Geobosques to over 800 subscribers from government, civil society, and the private sector. The alerts help Peruvian authorities to identify, halt, and prosecute cases of illegal logging and mining. The Peruvian government is now in the process of building a national system (Sistema Nacional de Control y Vigilancia) to share early warning data and coordinate law enforcement actions across agencies.

The Amazon Conservation Association's Monitoring of the Andean Amazon Project (MAAP) program and the environmental journalism site Mongabay used satellite data to identify and draw international attention to a rapid expansion of cacao plantations in Peru that had destroyed over 2,000 hectares of old growth rainforest. The company responsible for the destruction faced media outcry and a national lawsuit. "Because of pressure from civil and international society over its cacao and oil palm plantations, United Cacao was delisted from the London Alternative Market and its operations have halted in the Peruvian Amazon," Mongabay reported.[b]

The Amazon region: The Rainforest Foundation US has trained over 30 communities in the Amazon to use deforestation alerts and mobile phones to monitor active threats to their territory. Intelligence from indigenous patrols is shared with law enforcement to support investigations or used directly to support indigenous territorial planning.[c]

Sources: Weisse et al. forthcoming; MAAP 2016; and a. Palminteri 2017; b. Tarabochia 2017; c. Rainforest Foundation US 2017.

Zero-deforestation supply chain commitments

Growing public concern about the environmental impacts of agricultural products such as palm oil and soybeans has created reputational risk for companies trading or financing these commodities. Notably, over 400 companies have pledged to achieve net zero deforestation from their agricultural commodity supply chains.[7] To implement these pledges, companies seek information about where their direct operations or third-party suppliers may be responsible for deforestation.

Satellite-based forest monitoring data are being paired with supply chain traceability initiatives to link locations of deforestation (e.g., a farm, supply shed, or jurisdiction) to the producers responsible for that area, as well as downstream traders, processors, retailers, consumers of global commodities, and financial institutions. Tools such as GFW Pro, Global Risk Assessment Services (GRAS), Starling, and The Sustainability Consortium's Commodity Mapping Tool support companies to identify and monitor deforestation risk within their supply chains and inform strategies to avoid future deforestation.

Some of the greatest progress can be seen in the palm oil sector, where several multinational companies and nongovernmental organizations (NGOs) have collaborated to create a publicly available database of palm oil mill locations (Dowell et al. 2015). Particularly notable was the decision in November 2013, at the 10th General Assembly of the Roundtable on Sustainable Palm Oil (RSPO), that required all members to submit concession maps, whether certified or not, which were then published via an online map (RSPO 2013). By combining concession boundaries and mill locations with relevant forest monitoring data, companies such as Unilever and Mondelez have been able to identify and engage "high-risk" processing facilities in their supply chains.

REMAINING FOREST MONITORING CHALLENGES

Despite major advances in forest monitoring, several challenges remain.

"Closing the gap" between what is possible and what is practiced

Despite improvements in forest monitoring and investments in capacity building, a gap remains between what is demonstrated in a research or academic

environment and what can be developed and maintained in an operational environment, such as a national forest monitoring system.

The reasons for this gap include unclear arrangements between government agencies regarding who should fund and operate monitoring systems, and high turnover of technical staff trained under specific projects in tropical forest country governments. High turnover threatens the sustainability of monitoring efforts, including governments' ability to respond to new requirements and technical opportunities. Similarly, reliance on external consultants (e.g., in the context of developing REDD+ monitoring systems) may result in failure to develop and embed knowledge within the country's institutions.

The consistency and sustainability of forest monitoring is critical, because monitoring systems become more valuable the longer they function. Long-term monitoring can show trends in forest dynamics and underpin the permanence of forest-related policies and management practices (Federici et al. 2017). The lack of long-term operational monitoring systems is particularly evident from recent experience with early warning applications. While researchers have improved operational early warning systems from monthly detections at 500 meters (Hammer et al. 2014) to weekly 30-meter disturbance detection (Hansen et al. 2016), only two countries maintain similarly regular, low latency systems (Brazil's DETER system and Peru's Geobosques platform). In this context, major investments in developing new monitoring technologies require prior consideration of the institutional and financial requirements to scale, operationalize, and reliably maintain the new technology over time.

There have been promising efforts to bring the private and academic sectors together to accelerate forest monitoring methods and transfer lessons learned to government institutions. For example, the MapBiomas effort in Brazil convenes leading researchers and technology companies with the goal of producing annual land use and land cover maps. These maps address key gaps and limitations of official government data produced via the TerraClass program of the Brazilian Space Agency and Agricultural Ministry. TerraClass only publishes data for the Legal Amazon, while MapBiomas produces data for the entire country. In addition, TerraClass has only released data for 2004, 2008, 2010, 2012, and 2014. Because it uses an automated algorithm processed in the cloud, MapBiomas can more quickly process satellite imagery and publish land cover maps each year, from 2000 to the present. The MapBiomas team includes members of the Brazilian government as expert reviewers and strives to transfer lessons learned to government institutions. MapBiomas hopes this monitoring data will create possibilities for more robust estimations of GHG emissions from land cover and land use changes in Brazil.

Proliferation of methods

Increasingly diverse demands for forest monitoring data, uncoordinated capacity building efforts, and rapid research and development have resulted in a proliferation of methods with which to monitor forests. The diversity of methods can create confusion for end users about which data is more accurate and appropriate for their needs. Data produced using different methods—e.g., national-level deforestation estimates vs. global estimates of tree cover loss—can cause confusion over which data are "correct" and which methods are "best." For example, among FRELs submitted to the UNFCCC, a wide variability of definitions, time periods, methods, and application of methods across countries resulted in a wide range of accuracy and results that are not comparable across countries or over time, or with global independent estimates (see Box 2).

While diversity of data and approaches can facilitate transparency and accountability—e.g., global estimates of forest change can hold countries accountable for publishing and justifying official statistics while methods and forest definitions can be tailored to reflect national circumstances—lack of comparability prevents comprehensive, transparent monitoring of progress toward global goals. The high cost of creating national forest monitoring systems raises the question of whether there is more scope to tailor freely available global data to meet national-level reporting needs for REDD+, and/or to seek some consolidation or alignment among the many overlapping initiatives while supporting national "ownership" of forest monitoring efforts.

Not only does the proliferation of forest monitoring efforts risk confusion, it also represents a redundancy in investment. For example, many early warning monitoring systems—including DETER, Amazon SAD, Terra-i, FORMA, GLAD alerts, JJ-FAST and MapBiomas Alerts—are currently emerging with similar technical specifications, albeit for different geographies. The rise

Box 2 | Comparing Approaches for Estimating Deforestation Across 38 Forest Reference Emission Levels

A recent analysis[a] found that among the 38 Forest Reference Emissions Levels (FRELs) submitted to the United Nations Framework Convention on Climate Change (UNFCCC) by tropical forest countries, dozens of different definitions of forest and deforestation, as well as varying reference periods, are used. At least four different methods are used to detect deforestation, implemented to varying degrees of quality, resulting in high variability with respect to both precision and accuracy. Considering this variability, country-reported statistics and independent global data on forest loss[b] often diverge, causing confusion and controversy over which deforestation figures are "correct" for a given country or region, and explains why estimates sometimes differ so much. The Harris et al. (2018) study provides clarity on the definition and methodological differences that account for these divergences.

Sources: a. Harris et al. 2018; b. Hansen et al. 2013.

of private, for-profit imagery and artificial intelligence analysis companies increases the risk that donor agencies and/or tropical forest countries will invest in costly systems in cases where freely available imagery or cheaper methods would adequately suit user needs.

EVIDENCE GAPS AND AREAS OF CONTROVERSY

Limitations of satellite remote sensing

While monitoring and reporting of tropical forest cover loss has reached an operational stage, certain types of land cover and land use dynamics remain difficult to discern from space. These include detecting changes in tropical dry forests, the extent and timing of forest regrowth, land use characteristics and impacts (e.g., shifting cultivation cycles), and estimating forest variables such as height, biomass, and structure. Several technologies exist to map these values, such as drones or airborne Light Detection and Ranging (LiDAR) instruments, but they are not yet cost-effective enough to deploy over large areas.

Fortunately, many exciting remote sensing prospects are on the horizon. Operational radar data from Sentinel-1 will help overcome cloud cover limitations, and missions planned to map biomass and forest structure from space (e.g., NASA's GEDI mission) will enable more sophisticated approaches for quantifying forest carbon.

Increased investment and collaboration in research and development is needed if emerging technologies are to transition from viable prototypes to operational systems within a time frame consistent with ambitious targets to halt deforestation set by global policy frameworks.

Little guidance or research on forest monitoring outside of the REDD+ context

In the developed world, advances in forest monitoring technology often occur in labs, companies, or institutions, without appropriate guidance and best practices for how tropical nations can adopt and use them. Further research is required to provide streamlined guidance on how monitoring technology can be leveraged through the processes and institutions of land use planning, enforcement, and policymaking to achieve forest and climate goals. For example, while Brazil and Peru have made progress incorporating forest monitoring data into law enforcement protocols, guidance and best practices could help accelerate uptake of early warning systems in additional tropical forested countries.

CONCLUSIONS AND NEXT STEPS

Forest monitoring capabilities have dramatically improved over the past decade, thanks to technological advancements as well as major capacity-building investments by donors in tropical forest countries as part of the REDD+ "readiness" agenda.

While key gaps in the technology exist, increasing imagery availability and analytical sophistication suggest that forest monitoring data will continue to improve. At the same time, demand for high-quality, timely, and comprehensive forest monitoring data is growing, driven by an expanding list of policy applications outside REDD+ monitoring, including law enforcement, civil society, and implementation of private sector commitments to zero-deforestation supply chains.

A bigger challenge relates to the institutional, financial, and political barriers that prevent cost-effective application and maintenance of currently available technologies within tropical forested countries. Key challenges remain in transferring knowledge from international experts and researchers to national practitioners and ensuring that forest monitoring systems are operationalized to meet the demands of multiple stakeholders.

Box 3 | Forest Monitoring in Ghana

Ghana provides an illuminating microcosm of current challenges and opportunities presented by new forest monitoring needs, technologies, and applications. The persistence of cloud coverage over the country limits the availability of cloud-free optical satellite images. Meanwhile, the pervasiveness of mixed agroforestry systems, where trees are interspersed with crops, makes it difficult to distinguish between different land uses. Some crops, notably cocoa, are underplanted within forest reserves; this form of degradation is impossible to detect with current satellite-based approaches.

Despite these challenges, for much of the last five years, the Forestry Commission of Ghana has invested in strengthening its national forest monitoring system to meet the needs of REDD+. To develop a Forest Reference Emission Level (FREL), the Forestry Commission started with maps of forest cover for 2000 and 2010 based on national inventories, prepared under a project supported by Japan. The Forestry Commission supplemented those maps with Landsat-based maps for 2013 and 2015 prepared with assistance from Winrock International. The fact that the various maps were produced by different teams using different sources of data introduces potential inconsistencies between different map products and forest statistics.[a] The Forestry Commission and the Ministry of Lands and Natural Resources are working toward better understanding of the sources of error and uncertainty within various historic products.

In early 2018, in the context of negotiating an Emission Reduction Payment Agreement with the Forest Carbon Partnership Facility, the Forestry Commission found itself in need of a better estimate of emissions from forest degradation for the FREL. Due to the limitations of satellite-based approaches to detect cocoa trees under the forest canopy, the Forestry Commission is considering a proposal to test if Light Detection and Ranging (LiDAR) surveys can fill this data gap in a repeatable and cost-effective way. The proposal is part of a larger project agreed to by UK and Ghanaian institutions, supported by the UK Space Agency, but with co-investment from Ghana and selected companies.

In the meantime, Ghana's cocoa industry had come under international scrutiny as a driver of illegal deforestation in the country's forest reserves. In 2017, the government of Ghana joined neighbor Côte d'Ivoire and a coalition of 35 cocoa supply chain companies (including Hershey, Mars, Mondelez, Nestle, Touton, and others) in the new Cocoa and Forest Initiative, with a declaration to "end deforestation and forest degradation in the global cocoa supply chain, with an initial focus on Côte d'Ivoire and Ghana."[b] This declaration introduced a new set of forest monitoring needs, since signatories need to understand how much of current supply was coming from illegal sources, and to monitor progress toward the declaration's stated goal. Many supply chain companies had already invested in various approaches to mapping their supply sheds and would prefer to build on those systems rather than create new ones.

As of mid-2018, the Forestry Commission was faced with a wide range of options for moving forward on incorporating two challenges: the need for improved land cover data, and the need for a platform to transparently share data as part of its national forest monitoring system. Prospective partners from international donor agencies, nonprofit organizations, and for-profit companies are actively marketing their preferred sources of data, analysis methods, and platforms to meet these needs.

Source: Forestry Commission 2017; a. Harris et al. 2018 and b. World Cocoa Foundation 2017.

The future of forest monitoring should focus on improving the capabilities of current systems, but not at the expense of ensuring that available technologies are effectively applied to support improved policy implementation and are maintained over the long term. The international community can support these goals by addressing the following needs:

- **Provide better guidance and best practices for the use of forest monitoring data outside REDD+ applications.** While there is significant guidance on the use of forest monitoring data for REDD+ applications (e.g., from the Global Forest Observation Initiative's Methods and Guidance document), guidance is also needed so users can select the most appropriate forest monitoring solutions for other applications, such as law enforcement and land use planning. Notably, the recent proliferation of early warning systems requires better guidance and lesson sharing to ensure effective uptake by civil society and law enforcement and to reduce duplicative efforts. A recently formed global working group on early warning, convened by the World Resources Institute, the Global Forest Observation Initiative, the U.S. Forest Service, the Norwegian International Climate and Forests Initiative, and others, is a step in the right direction.

- **To make effective use of limited resources, decisions about how to prioritize future investments in forest monitoring technologies must be underpinned by an understanding of evolving user requirements.** A cost-benefit approach to investment will help avoid wasting resources on redundant systems (i.e., in cases where user needs could be met by existing systems) or on systems that have been over-engineered relative to more modest operational needs.

- **Deepen investments in institutional capacities in tropical forest countries** to operate, maintain, and improve forest monitoring systems over the long term. Investments in new satellite data sources and analysis methods must be followed by additional and sometimes more significant investments in institutional capacities. For example, building expertise in remote sensing and geographic information systems, and establishing modern computing infrastructure in tropical forested countries, could help support technology adoption and sustainability.
- **Promote greater transparency and alignment of forest monitoring data and methods** on the part of national governments and independent researchers to support the above needs, and to ensure accountability for and a shared understanding of progress toward international commitments related to forests.

ABBREVIATIONS

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
ESA	European Space Agency
EU FLEGT	European Union Forest Law Enforcement, Governance and Trade initiative
GFW	Global Forest Watch
GHG	greenhouse gas
GRAS	Global Risk Assessment Services
LiDAR	Light Detection and Ranging
MAAP	Monitoring of the Andean Amazon Project
MINAM	Peruvian Ministry of Environment
MRV	measuring, reporting, and verification
NFA	National Forest Authority
NGO	nongovernmental organization
RSPO	Roundtable on Sustainable Palm Oil
SDG	Sustainable Development Goal
UNFCCC	United Nations Framework Convention on Climate Change
UWA	Uganda Wildlife Authority

ENDNOTES

1. REDD+ stands for reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks in developing countries.
2. For more on REDD+, see the companion paper in this series, "REDD+: Lessons from National and Subnational Implementation" (Duchelle et al. 2018).
3. Such as the annual global forest change (Hansen et al. 2013) product available via Global Forest Watch, www.globalforestwatch.org.
4. European Commission/European Space Agency Sentinel missions.
5. For example, the Global Forest Observation Initiative's Methods and Guidance, www.gfoi.org/methods-guidance/.
6. For more on forest legality initiatives, see the companion paper in this series, "Assessing the Timber Legality Strategy in Tackling Deforestation: Accomplishments and Remaining Challenges in Addressing Illegal Logging and Associated Trade" (Barber and Canby 2018).
7. For more on commodity supply chain commitments, see the companion paper in this series, "The Elusive Impact of the Deforestation-Free Supply Chain Movement" (Taylor and Streck 2018); for more on corporate finance and governance, see "Mining Global Financial Data to Increase Transparency and Reduce Drivers of Deforestation" (Graham et al. 2018).

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Our Challenge
Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision
We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach
COUNT IT
We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT
We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT
We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.