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# APPLICATIONS OF FOREST MONITORING TOOLS FOR DEVELOPMENT PROJECTS

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# Table of Contents

# Executive Summary

Designing and implementing successful policies for sustainable development requires accurate measures of policy outcomes, specifically, the impacts on forests. Forest monitoring tools are multifaceted; able to measure forest condition and extent, detect sudden changes, and analyze longer-term trends. The objective of this report is to summarize and characterize the current suite of forest monitoring tools and review how they are being used by World Bank Group (WBG) funded projects to monitor or reduce deforestation, direct or indirect, resulting from those projects.

Methods to gather the report information included a literature review of forest monitoring tools; a desktop study of WBG projects in the online database in seven focal countries (Brazil, Colombia, Democratic Republic of Congo, Indonesia, Liberia, Mozambique, and Peru); and interviews with WBG staff. The results of the study show there exist dozens of “top-down”, or satellite-based, forest monitoring tools that operate at multiple scales. Although most global tools are operated by the US and EU, national tools operated by developing countries are emerging more recently with the focus on capacity building for national forest monitoring systems. There are also a handful of free and open source mobile applications available specifically for “bottom-up” monitoring for patrolling and community-based monitoring. The diverse set of existing forest monitoring tools are used for a range of applications and audiences. In fact, fitting the tool to the application is key for choosing a forest monitoring tool. There are two general applications of forest monitoring tools with tradeoffs between accuracy and timeliness of information. These are 1) informing policy and practice; and 2) enabling rapid response.

A search of the 161 active, closed, or pipeline projects in the focal countries from Fiscal Year 2015 to present found 38 WBG-funded projects potentially impacting forests. Of those projects, 27 projects were flagged to affect forests (26 triggered WB OP/BP 4.36 on forests). Of these projects, 17 were forestry projects and 10 were non-forestry projects. Only one of the 10 non-forestry projects mentioned using forest monitoring tools—in this case, to monitor forest impacts of sustainable agriculture development. Almost three-quarters of the forestry sector projects specifically mention a forest monitoring tool. The monitoring tools approaches were split 50-50 between “top-down” monitoring and “bottom-up” monitoring.

While forest monitoring tools are applied to about three-quarters of the forestry sector WBG projects in this study, these tools seem to be underutilized to monitor and mitigate forest impacts from other development projects. A few reasons may be that developing project-specific tools is expensive, navigating the suite of current tools is daunting, and training stakeholders to use tools is time-consuming and sometimes costly. Improving the networks of knowledge sharing for forest monitoring tools is recommended for projects to capitalize on the wealth of free tools that do exist and build upon lessons learned from other system developers when building new tools. Better guidance on fitting the tool to the application is also key for choosing or designing the right forest monitoring tool. Overall, to reduce the forest impacts of WBG development projects, task team leaders and their staff could benefit from integrating rapid response applications with bottom-up approaches to increase community engagement.

# Introduction

Forests are vital for biodiversity conservation and provide people with critical ecosystem services. Forest store 45% of the world's terrestrial carbon (Bonan, 2014) and are thus key for mitigating climate change while also enhancing both ecological and social resilience to climate change. Globally, 1.6 billion people depend on forests as sources for fuel, building materials, medicine, and food (Waisq & Ahmad, 2004) and forests influence the availability and quality of freshwater (Perlis, 2007). However, over a 25 year period from 1990-2015, 6% (240 M hectares) of natural forest were lost to deforestation (Keenan et al., 2015)[1]. Deforestation rates continue unabated with 40% of deforestation directly driven by expanding commodities (i.e. soy, palm, timber, and beef), 33% by local subsistence agriculture, and 17% development from mining and infrastructure (Hosonuma et al., 2012). In addition, infrastructure development increased access to forests for subsistence agriculture and fuelwood collection (Curtis et al. 2018; NYDF Assessment Partners 2018).

Policy makers and conservation practitioners do recognize the need for countries to develop for improving livelihoods and economies. In the early 2000s there was broader recognition by policy makers that community-managed conservation was both more effective and more ethical practice than exclusionary protected areas to achieve biodiversity conservation goals (Lele, Wilshusen, Brockington, Seidler, & Bawa, 2010). Policy makers recognized that communities live within critical natural ecosystems, particularly in the tropics, and therefore have shifted to mixed-use conservation planning in attempt for a "win-win" for both biodiversity conservation and improving livelihoods (DeFries, Hansen, Turner, Reid, & Liu, 2007). For example, the UNFCCC's original carbon mitigation initiative, REDD, was expanded from climate mitigation by reducing deforestation and degradation to "REDD+", the "+" signifying the enhancement of forest carbon stocks, sustainable management of forests, and conservation of forest carbon stocks. Thus the "+" expanded REDD's focus to include multiple benefits of sustainably managing forest for climate change mitigation, poverty alleviation, biodiversity conservation, and preserving ecosystem services (Arild Angelsen, 2009).

Multilaterals are currently focused on designing pathways to sustainable development. The United Nations' Sustainable Development Goals (SDGs) outlined 17 ambitious global goals and 169 targets to guide what and how nations need to do to develop and prosper sustainably. SDG 15 is to "Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation and halt biodiversity loss." Meanwhile, Goal 8 is focused on sustainable economic growth that, "…create[s] the conditions that allow people to have quality jobs that stimulate the economy while not harming the environment" (UN News Centre, 2015).

One of the targets of SDG 8 is to "decouple economic growth from environmental degradation". Consistent with these goals and targets, the World Bank Group's (WBG) Forest Action Plan ("FAP," April 2016) set out two pillars to heighten the Bank's support for forests. The first was an increase in direct support for forest programs and the second was to "mainstream" forests so that they are taken fully into account in other sectors. Overall, the FAP "aims to integrate the sustainable management of forests more fully into development decisions and define priorities for WBG interventions" during Fiscal Years (FY) 2016-2020.

Implementing development practices that effectively minimize deforestation remains challenging due to the complex relationship between development and deforestation. Even successful policies may not be successful when replicated in a different geographic, social, political context. Yet, understanding this relationship and the potential tradeoffs of development and forest cover change is important to designing and implementing successful policies for sustainable development (Cuaresma & Heger, 2019). A key component to understanding this relationship is the ability to accurately monitor forest changes. Forest monitoring includes methods to measure landscape condition and extent, detect sudden changes, and analyze longer-term trends.

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[1] net rate of loss of natural forest halved, from 11.5 M ha y-1 to 5.8 M ha y-1, between the 1990s and 2010–15 (Keenan & Keenan, 2015)

# Objective

The objective of this report is to compile and characterize the current suite of forest monitoring tools and review how these tools are being used to monitor or reduce deforestation, direct or indirect, resulting from WBG funded development projects. The report aims to highlight opportunities for the WBG and other development finance institutions to improve applications of tools and methods for monitoring, reporting, and verification of forest status and impacts of projects they finance, particularly in sectors that drive deforestation (agro-commodities, infrastructure, extractive industries).

# Background

Forest monitoring tools designed to monitor forest dynamics are used for a range of applications and audiences. For example, some tool applications are better fit for accurately quantifying forest change over a historical time period, while others are designed to alert to change happening in near real-time.

## FOREST MONITORING APPLICATIONS

Generalizing by application, there are two main applications for forest monitoring tools: 1) informing policy and practice; and 2) enabling rapid response. The correct tool for the application is influenced by the accuracy of the monitoring data, the latency of data (e.g., how quickly data is available to make a decision), and the resources available to the users (i.e., internet connectivity, mobile devices, human capacity, computing capacity, etc..) (Tabor & Holland, in prep). Near real-time monitoring tools, often coarser in spatial resolution and less accurate for quantifying forest change, are more appropriate tools for monitoring and responding to emerging environmental degradation. Whereas annual forest cover and change tools are more accurate but are often produced six months to two years after the forest change occurred. These two applications highlight a trade-off between accuracy and timeliness of forest monitoring tools and how tool selection is important to ensure the tool fits the application. Tools can be designed to overcome this latency/accuracy trade-off; however, other trade-offs emerge such as increased costs for high resolution satellite imagery and reduced automation.

## FOREST MONITORING APPROACHES

Forest monitoring tools also have diverse approaches to monitoring. This study characterizes four main “system” approaches to forest monitoring based on where the monitoring technology is collecting data (i.e. from space, air, or ground). The various approaches can be described as “top-down”, “bottom-up”, “integrated”, and “interactive” (Pratihast et al., 2016; Tabor & Hewson, 2018; Wright et al., 2018) (Figure 1). Reduced technology costs for portable sensors, drones, and cloud services; combined with open-development of open applications for smart phones enabled the recent emergence of the two latter approaches.

The different approaches for forest monitoring aim to meet the needs of different applications by trade-offs in system design (Figure 2). A top-down approach for a rapid response application will capture information with low-latency, low costs, but also lower accuracy. A bottom-up system may aim to increase community engagement with higher accuracy monitoring information, but also requires more training for sustained use. The descriptions of each approach and the trade-offs are discussed below.

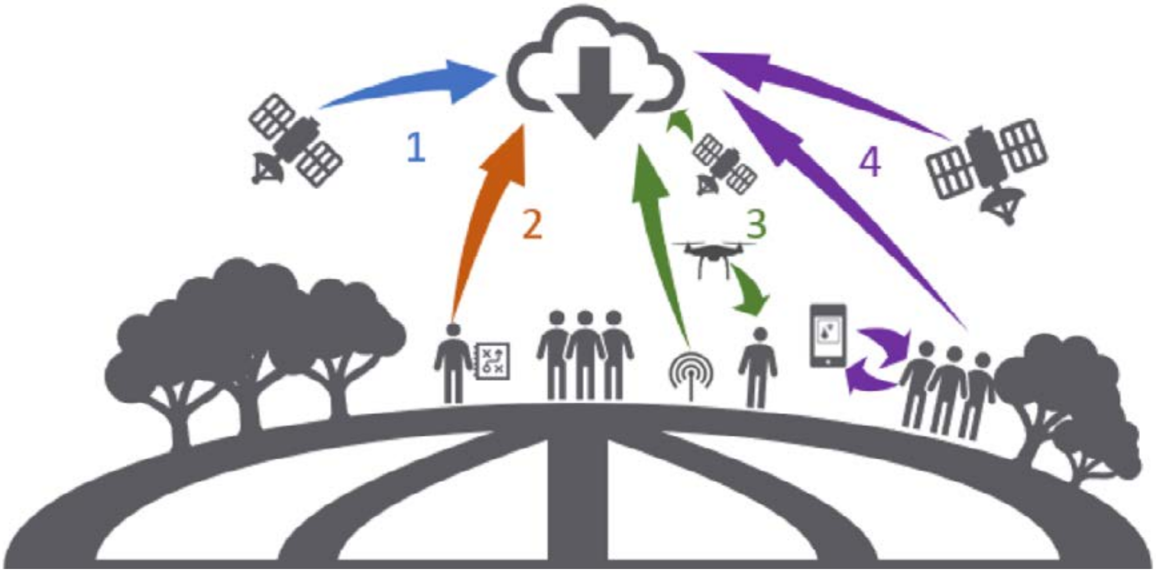

**FIGURE 1:**

Different approaches to forest monitoring. 1) top-down monitoring uses satellite data; 2) bottom-up monitoring is monitoring from the ground by people; 3) integrated monitoring combines difference data collection devices, for example, in-situ sensors, satellites, and drones; 4) interactive monitoring combines satellite monitoring with monitoring on the ground by people and a social network to ground-truth satellite data. Drone by Patrick McDonnell and Sensor by Tami Nova from the Noun Project.

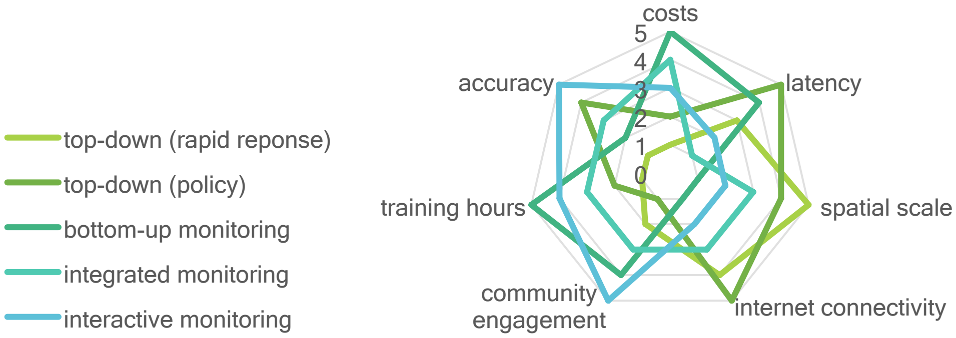

**FIGURE 2:**

Trade-offs of approaches to forest monitoring by system design. The different approaches are ranked from 1-5 (1 is low and 5 is high) in categories that help inform application needs. The top-down approach was divided into two distinct applications, enabling rapid response and informing policy and practices because the design of the system is very different for each application.

### Top-Down Approach to Forest Monitoring

The consistency and reliability of repeated forest monitoring from satellites is attractive for forest monitoring. Satellite-based forest monitoring is considered a “top-down” approach that can provide a long historical record of forest cover dynamics and also alert to forest changes in near real-time. Fortunately, with advances in computing capacity and open-source data policies from the United States and European Union, satellite monitoring of forest cover and change are more readily accessible (Tabor & Hewson, 2018). These datasets, which are primarily free and open-source, can provide global transparency to forest cover change and regeneration in response to development or conservation interventions. These data have been critical for countries developing National Forest Monitoring Systems and that support measuring, reporting, and verification (MRV) for REDD+ and for reporting on Nationally Determined Contributions (NDCs) to emissions reductions under the Paris Accord. These data also enable evaluations of conservation and development interventions by analyzing deforestation rates before and after the intervention while controlling for factors that may influence deforestation rates not directly linked to the intervention outcomes (Blackman, 2013).

Satellite remote sensing has emerged as not only a valuable tool for monitoring and reporting forest cover and change, it is also a valuable land management tool to respond to emerging forest threats (Musinsky et al., 2018; Tabor & Hewson, 2018). In recent years, conservation and development actors have produced a proliferation of web-based early warning and alerts systems (EWS) for improving policy and land management decisions (Palomino, Muellerklein, & Kelly, 2017). These conservation EWS predominantly rely on the near real-time capabilities of satellites to detect and monitor fires, deforestation, and forest degradation. The routine and timely monitoring information is used by a range of stakeholders (i.e., communities, fire managers, local conservationists, local and national government officials, policy makers, and private sector companies) to increase public awareness of ecosystem threats, enhance strategic land management decisions, and enforce land use policies (Musinsky et al., 2018).

### Bottom-up Approach to Forest Monitoring

While tools that use satellite remote sensing are considered a top-down approach to monitoring, other methods focus on a “bottom-up” approach reporting forest cover and change from field observations. Previously, ground observations were collected by paid technicians and were expensive, collected infrequently, and rarely sustainable in the long term (Pratihast et al., 2016). Local monitoring by communities emerged as a method to reduce the costs of forest monitoring while strengthening the engagement between communities living near or in forests with the institutions requesting the monitoring (Fry, 2011). For example, community-based monitoring in the context of REDD MRV engages local communities and indigenous groups to monitor, measure, and report on forest changes (Torres, 2014). One benefit to this approach is enhancing the ownership role of communities in forest management (Fry, 2011). There do, however, remain challenges to community-based monitoring including the lack of rigor and consistency of data collection and limited spatial coverage (Pratihast et al., 2016).

### Integrated Monitoring Approach to Forest Monitoring

Integrated monitoring combines different monitoring platforms to create a more holistic monitoring system. Integrated systems can combine different satellites to use the strengths of each satellite’s products. For example, a system can use a coarse spatial resolution satellite that frequently overpasses an area to flag forest change, then use a high resolution satellite to accurately validate and measure the deforestation, and even identify the cause of the deforestation, whether from small-scale agriculture, cattle grazing, or palm oil plantations (e.g., Finer et al. 2018).

Integrated monitoring also can combine sensors from space and on the ground. Optical satellites commonly used to alert to deforestation are not able to see below the forest canopy for understory clearing or selective logging. Therefore, a system can integrate satellite monitoring with routine monitoring from in-situ field observations, acoustic sensors, and camera trap data (Bustamante, Roitman, & Aide, 2016; Tabor & Hewson, 2018; Wright et al., 2018).

### Interactive Approach to Forest Monitoring

Interactive monitoring integrates the advantages of both top-down and bottom-up approaches combining the consistency and reliability of satellite monitoring with accurate, on-the-ground monitoring by communities engaged with forest management (Pratihast et al., 2016). An interactive monitoring system can capture satellite monitoring information and send alerts of suspected changes to communities and individuals who can investigate the alerts or send alerts of forest changes seen from the ground in the same system. Pratihast et al. (2016) argue that interactive monitoring systems can be more effective than a single approach (only top-down or bottom-up) because they can provide timely information, are cost-effective, transparent, and engage stakeholders in forest monitoring and management.

# Methods

I gathered information for this report through a literature review, web search, desktop study of WB projects, and interviews with WBG staff familiar with the discovered projects that use forest monitoring tools.

First, I researched the current state of forest monitoring tools through a review of peer-reviewed literature and web-searches based on previous knowledge of tools. I assessed existing tools on a suite of characteristics (e.g., spatial resolution, geographic coverage, country of origin, data latency, alert dissemination…) and classified each tool by approach. The characteristics considered here were as follows: spatial coverage, spatial resolution, information latency, technical requirements, open-source, country of origin.

Next, I searched project documents looking for WBG funded projects that used forest monitoring tools to enhance forest conservation/sustainable forest management or to reduce deforestation resulting from development. I accessed the documents through the WBG database (www.projects.worldbank.org). I focused this report's geographic scope to Brazil, Colombia, Democratic Republic of Congo, Indonesia, Liberia, Mozambique, and Peru to capture practices in significant tropical forest countries where the WBG has active engagement in both forest and development programs.

I performed an advanced search for each country using the following selection criteria to filter project results:

**Project status:** **active, closed, or pipeline.**
**Project approval date:** **"After January 2015"**
**Major Sector:** **"Agriculture, Fishing, and Forestry" or "Energy and Extractives" or "Transportation"**
**Environmental category:** **A or B**

Finally, I used the text search option for all WB projects in the 7 countries mentioned above with the search terms, "forest", "monitoring", "tools", "community-based monitoring", "satellite", and "forest monitoring" to provide an additional check for any forest monitoring projects that may have been excluded from the initial search. For all discovered projects that triggered Forest OP/BP-4.36, I thoroughly examined the safeguard documents to discover the plan for how deforestation would be mitigated.

Next, I conducted phone and in-person interviews and sent email communications with staff at the WBG and other MDBs familiar with funded development projects that used forest monitoring tools. The interviews were necessary to gather additional information on the projects and document project objectives, methods, costs, outcomes, and lessons learned not available through online documents.

# Results

## CURRENT STATE OF FOREST MONITORING TOOLS

The following section highlights the current suite of forest monitoring tools categorized by their application and approach. Each section describes how the tools are used for forest management.

## FOREST MONITORING TOOLS FOR RAPID RESPONSE

### *Top-down fire monitoring & forecasting for rapid response*

Fire disasters in the tropics are increasing in both quantity and extent due to longer and more intense dry seasons, and contribute 6%-17% to global carbon emissions (G. R. van der Werf et al., 2009). Fire early warning systems are effective at detecting fires and forecasting fire weather to prevent and mitigate tropical forest fires. In the early 2000s, the University of Maryland (UMD) and partners developed one of the earliest operational forest monitoring tools using active fire information detected by satellites (Davies, Ilavajhala, Wong, & Justice, 2009). The Fire Information for Resource Management System (FIRMS) processed and delivered near real-time alert information of active fires targeted for forest and fire management applications. FIRMS was promoted by Conservation International (CI) for use in the global tropics, where fire is the main tool used for deforestation (Cochrane, 2003). The use of satellite-derived active fire products for forest monitoring continued to grow in popularity as key tools for tropical forest management. Popular applications for fire alert systems for forest management are management of protected areas (in terms of response, monitoring, and planning), to facilitate forest surveillance, and to enforce and inform land use policies (Musinsky et al., 2018). In addition to active fire detections, early warning systems also disseminate information on fire danger forecasting, and post-fire assessment of burned area estimates. These fire early warning applications are vital for informing the main fire management activities (Figure 3):

**FIGURE 3:**

This shows the continuum fire management activities enabled by fire early warning systems that are essential for sustainable forest management. Image source (GAO, 2003)

- Fire Danger Prediction to inform pre-fire activities such as public awareness of when agricultural or other types of fire may burn out of control and damage forests or infrastructure. These data are used to allocate resources in advance of severe fire seasons or conduct prescribed burns to reduce fuels. They are also effective tools in outreach and engagement with the public and land managers (Figure 4).
- Active Fire Detection to inform during-fire activities, for example active fire management activities, which include controlling and extinguishing a fire. Conservation practitioners rely on active fire detections to alert managers to protected area encroachment and dispatch patrols to investigate (Musinsky et al., 2018).
- Burned Areas Assessment to inform post-fire activities, for example quantifying forest loss, carbon emissions (i.e., van der Werf et al. 2017), and informing post-fire recovery activities to prevent further ecosystem degradation (i.e., erosion management (Elliot, Miller, & Enstice, 2016)).

There are several global and national monitoring systems that disseminate active fire data, burned area data, and fire danger forecasting information for the purpose of forest monitoring and sustainable forest management (Table 1).

**FIGURE 4.**

An illustration from a graphic brochure produced by Fundación Amigos de la Naturaleza to educate rural farming communities of the dangers of fire spread (FAN 2011).

### *Top-down forest disturbance monitoring for rapid response*

Operational forest disturbance monitoring emerged after active fire monitoring. System developers utilized the same satellite sensors (e.g. MODIS and VIIRS) to rapidly detect anomalous changes in vegetation greenness. The current suite of operational forest disturbance alert systems include Sistema de Detecção do Desmatamento em Tempo Real na Amazônia (DETER); FORest Monitoring for Action (FORMA), QUICC, Terra-i (Musinsky, 2014; Potter, 2014; Shimabukuro, dos Santos, Formaggio, Duarte, & Rudorff, 2013; Wheeler, Hammer, Kraft, & Steele, 2014). Recent advances in computing capacity have enabled system developers to produce moderate resolution forest disturbance alerts (~60-30m). These systems include Brazil's DETER-B (60 m) (Diniz et al., 2015) available for Brazil; and UMD's Global Land Analysis & Discovery (GLAD) (30 m) (Hansen et al. 2016), available for the global tropics and sub-tropics. Forest disturbance data are used by land managers who need to know emerging threats to forests in order to inform and enforce land use policies and rapidly respond to mitigate further ecosystem degradation (Hansen et al. 2016).

### *Interactive Monitoring for rapid response*

Engaging the local decision makers in forest monitoring can hasten the response time from the detection of a threat to an intervention to prevent further degradation or forest loss (Danielsen et al. 2010). One example of interactive monitoring for rapid response in the literature is a REDD+ monitoring project funded by the International Climate Initiative (IKI) of the German Federal Ministry for the Environment, Nature Conservation, Building, and Nuclear Safety (BMU). Pratihast et al. (2016) demonstrated an interactive monitoring system to improve forest monitoring and increase engagement of communities with conservation in the Kafa Bio-Sphere Reserve in Southwestern Ethiopia. The project was able to monitor small-scale deforestation using changes in Normalized Differential Vegetation Index (NDVI) from Landsat; but was unable to detect forest degradation from the Landsat imagery. It was able to monitor degradation from the ground with local experts; however, ground-based monitoring is often expensive and the data records are sparse, both temporally and spatially. By combining both approaches, the project generated near-real time information on forest change with a cost-effective approach. Engaging stakeholders from the start of the project with the design of the monitoring system, the implementation, and the responsibility of forest management activities enhanced community participation. The results were improved forest management and increased conservation awareness within the community. Pratihast et al. (2016) attributed the success of interactive monitoring for increasing system transparency and community ownership of the application.

### *Integrated forest monitoring for rapid response*

Cloud computing and the reduced costs of sensor technology aided the recent emergence of integrated forest monitoring tools. Integrated monitoring projects are currently operational only at local to regional scales due to the challenges and costs of scaling. One example is a pilot study for Conservation International in the Alto Mayo Reserve that integrates near real-time monitoring from sensors in space, in the air, and on the ground. Threats of fires are detected by satellites and active fire alerts are disseminated through CI's Firecast system. An acoustic sensor network on the ground listens for the distinct sound waves generated from chainsaws. When the sounds waves are recognized, Firecast sends an email alert to the park managers. Drones are dispatched by the rangers to investigate a detected threat (Wright et al., 2018).

Another example of an operational integrated monitoring system is the Monitoring of the Andean Amazon Project (MAAP). MAAP's unique approach helps resolve the trade-off between data latency and accuracy by leveraging the near real-time monitoring capability of coarse resolution satellites and then acquiring moderate and high resolution satellite imagery to accurately map, measure and identify post-deforestation land use. First, MAAP uses coarse resolution disturbance alerts from Terra-i and FORMA and moderate resolution disturbance alerts from GLAD to locate potential deforestation events. Second, MAAP uses moderate resolution imagery from Landsat and Perusat to confirm the deforestation detection. Third, MAAP tasks high-resolution commercial imagery at sub 3 m spatial resolution to determine the cause of the deforestation (I.e. logging, mining, migrant settlements). The imagery and assessment of the deforestation is posted online on the MAAP blog to raise public awareness of illegal deforestation in the Andean Amazon (Finer et al., 2018). MAAP's approach to overcome the latency/accuracy trade-off does introduce other tradeoffs including increased costs for high resolution satellite imagery and increased person hours required for manual analyses.

This past decade there was an explosion of rapid response forest monitoring tools enabled by advances in webmap services, cloud computing services, and mobile applications. Although most global tools are operated by government agencies and others in the United States and European Union, more national tools operated by developing countries are emerging.

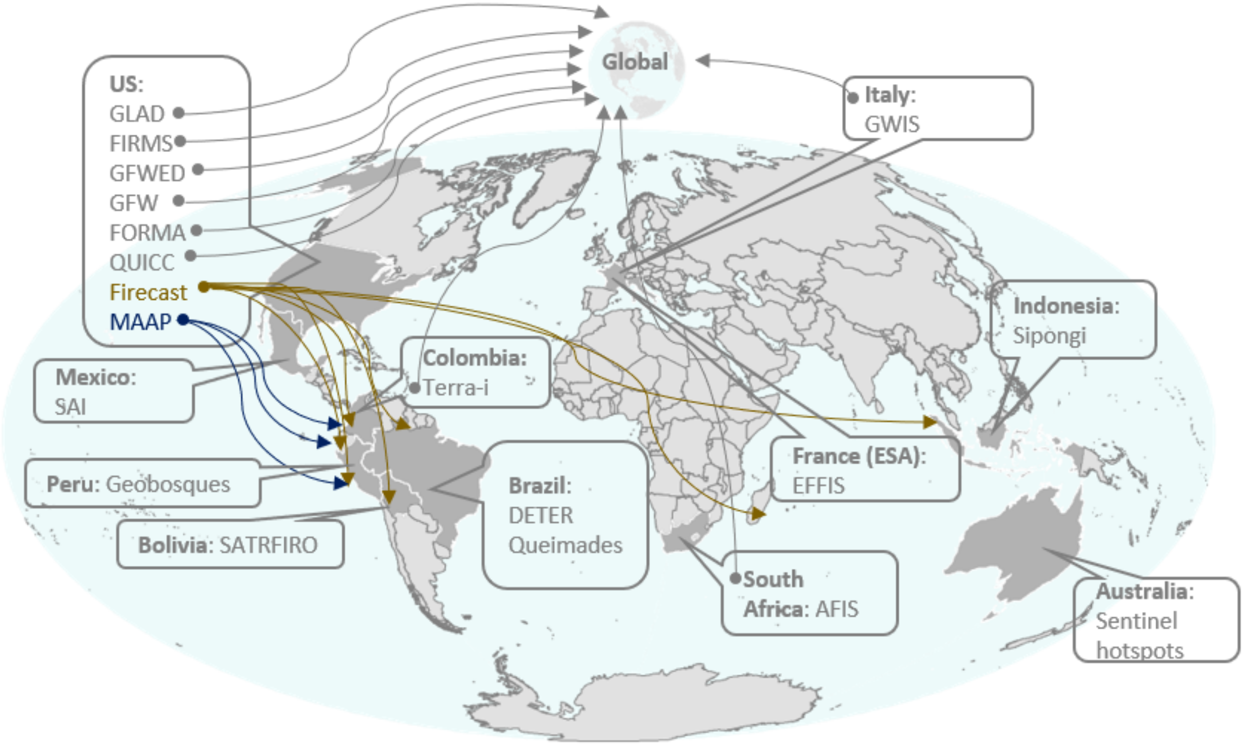

**FIGURE 5:**

The current suite of top-down and integrated forest monitoring tools for rapid response. Figure from (Tabor & Holland, in prep). This is not a definitive list of tools, but an illustration to demonstrate the number of tools and their country of origin.

## INFORMING POLICY AND PRACTICE

### *Deforestation monitoring tools to inform policy and practice*

Forest cover and change monitoring leverage moderate resolution satellite data (e.g., Landsat, Sentinel) to accurately quantify forest change annually or every 5 to 10 years, depending on the purpose of the monitoring. As part of Brazil's Federal Action Plan for Prevention and Control of Deforestation in the Legal Amazon, Brazil developed a suite of monitoring systems to keep tabs on deforestation rates while also enabling rapid response to emerging threats (Diniz et al., 2015). Brazil's PRODES (Projeto de Monitoramento do Desmatamento na Amazônia Legal por Satélite) generates annual forest cover and change information to inform public policies (Shimabukuro et al., 2013). Brazil's top-down monitoring systems, in combination with  forest management policies, contributed to a 75% decline in deforestation between 2004 and 2014 (Laurance, Achard, Peedell, & Schmitt, 2016).

UMD produced the first operation global 30-m forest cover and change product ( Hansen et al., 2013) hosted in the World Resources Institute (WRI)'s Global Forest Watch (GFW) platform (globalforestwatch.org). WRI launched GFW in 2011 as a platform for consistent and uniform global forest monitoring  (Musinsky, 2014). The GFW platform hosts a variety of tools for forest monitoring and to assist countries, communities and corporations alike with meeting global sustainability and land management goals (De Sy et al., 2016).

WRI most recently launched GFW PRO (pro.globalforestwatch.org), specifically designed as a tool companies can use to monitor deforestation in their supply chains. The tool allows subscribers to track progress over time, analyze data, and produce graphs and reports to share with management, clients, customers, and shareholders. In fact, there is an acute need for routine identification of post-deforestation land use to increase supply chain transparency and sustainability. These analyses are currently focused at the national or sub-national level. MAPBIOMAS is a national tool for Brazil that produces annual land use beginning in1985 and attributes the commodity expansion to deforestation. These associations not only help understand the spatial drivers of deforestation, but also attributes the deforestation to a specific commodity or even company that can be held responsible for the deforestation (Gardner et al., 2018).

### *Forest degradation monitoring to inform policy and practice*

Developments in science and technology have enabled operational forest cover change monitoring. Operational forest monitoring tools provide rigorously validated, methodically consistent, and routine monitoring products that are relied upon for by end users. This is opposed to a forest monitoring tools that may in applied for a single project or a tool in the research and development phase. The next frontier for forest monitoring tools is operational forest degradation monitoring, which is still in the research and development phase due to the complexity of quantifying changes to canopy density and structure (Mitchell, Rosenqvist, & Mora, 2017). With advances in computing capacity, and variety of sensors and satellite agencies providing free data, analysis techniques such as optical/SAR fusion which greatly enhance our ability to characterize canopy change, are promising for operational degradation monitoring (Reiche, Hamunyela, Verbesselt, Hoekman, & Herold, 2018; Tabor & Hewson, 2018; Zorrilla-miras et al., 2017). Current operational forest change and forest degradation monitoring tools are listed in (Table 2).

### *Bottom-up forest monitoring tools to inform policy and practice*

While satellite monitoring systems for degradation are only just emerging, degradation can be monitored from the ground through field-based monitoring. Participatory monitoring is one method to monitor forest degradation and loss (Fry, 2011). Engaging local communities and indigenous groups in MRV activities to monitor, measure, and report on forest changes for REDD is termed "Community-based monitoring" (Fry, 2011; Torres, 2014). UNFCCC MRV methods require field-based monitoring to complement remote sensing observations for the "Measurement" for REDD+ that is often performed by researchers or technicians external to the monitoring site. Community-based monitoring can have lower costs while also engaging the community to take ownership of forest management, which can be advantageous for sustained management (Fry, 2011). Community-based monitoring can be achieved with low-tech solutions, i.e., field notes with pen and paper. There is a growing number of mobile applications available to facilitate data collection capable of collecting a diversity of data types, from photos, videos, field notes, to audio recordings (Table 3). Some applications have graphic menus for users who may be illiterate or non-literate. Digital data collection can be useful to standardize data collection and share data, but it can also be intimidating to use and introduces data privacy concerns, especially with traditional ecological knowledge (Brammer et al., 2016).

## DESCRIPTION OF TOOLS USED BY WBG OR MDBS FOR DEVELOPMENT PROJECTS

The advanced search of the WBG database resulted in a total of 38 development projects with expected forest impacts (Figure 6). Twenty-six of these projects triggered the Forests OP/BP 4.36 safeguard, and one more had a specific forest monitoring focus. Of these, 17 of the projects were forestry sector projects and 10 were non-forestry projects (agriculture, mining, road development). In total, only half (13) of development projects documented forest monitoring tools to mitigate deforestation (Figure 7). The documentation in the WBG database was often lacked details on the approaches to forest monitoring. Supplemental information from web searches and literature searches was required to gather more detailed information on the monitoring approach for the projects. From the 13 projects that mentioned applying forest monitoring tools, the split between top-down and bottom-up approaches was about 50-50 (Table 4). Seven projects used a top-down approach and these were all in Brazil, Colombia, and Mexico; countries that have advanced national forest monitoring systems and high technical capacities. Six projects used a bottom-up approach to forest monitoring, and these were in DRC, Indonesia, Liberia, Mexico, Mozambique, and Peru.

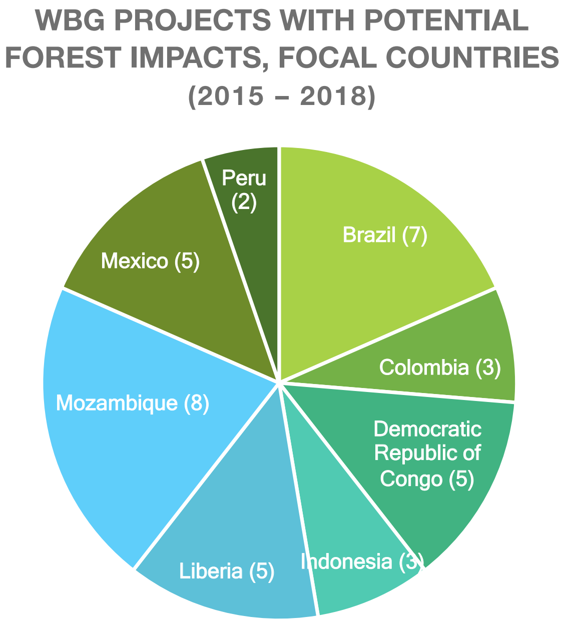

**FIGURE 6.**

Number of WBG projects in study, distributed by country.

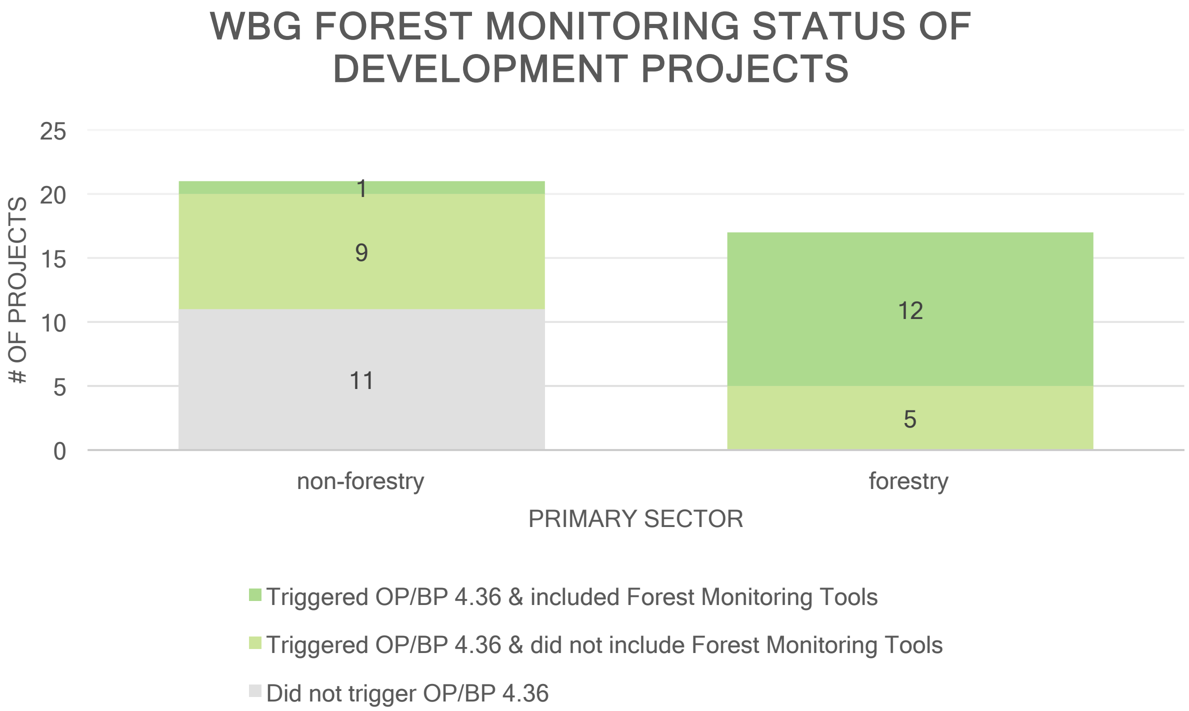

**FIGURE 7.**

Breakdown of forestry and non-forestry projects that triggered OP/BP 4.36 and described forest monitoring tools.

The next section highlights projects discovered in the desktop study that specifically mentioned using forest monitoring tools.

## BRAZIL

### *Platform of Monitoring and Warning of Forest Fires in the Cerrado (2014-2017)*

Only 55% of the Cerrado Biome remains due to conversion to agriculture and pasture. Therefore, the objective of this project was to mitigate climate change in the Cerrado Biome by improving natural resources management with policies and practices. The project consisted of several activities: 1) promoting environmental regularization of landholdings; 2) preventing, combating, monitoring and early detection of forest fires with an early detection of fires with TERRA-MA-Queimadas; and 3) enhancing integrated forest-fire management. The Brazilian Space Agency (INPE) was responsible for expanding the Queimades fire early warning system from operational in the Amazon biome to operational in the Cerrado biome. Queimades (http://www.inpe.br/queimadas/bdqueimadas/) is an online early warning system delivering alerts of fires, fire danger, and burned area. This project ended in 2017 and reported successful results for reduced fires and improved forest management. The project estimates contributing to carbon stored 1.40-1.74 tCO2/ha/year during the life of the project with a potential reduction over 20 years for the Cerrado of 8.15–9.97 million tCO2/hectare (World Bank, 2013). This appears to provide an excellent model for adaptation of an existing top-down monitoring system for a specific need, in this case, detecting fire in the Cerrado. Instead of funding a new system to monitor fire in the Cerrado, the WBG invested in enhancing an existing system.

## COLOMBIA

### *Additional Financing Forest Conservation and Sustainability in the Heart of the Colombian Amazon Project (2017-2022)*

This project supports additional funding to the original grant approved in 2014 to the Government of Colombia to help fund their low-carbon development strategy for the Amazon called Visión Amazonía. One significant outcome of the original project was expanding the national protected areas system to 1.3 million ha. The additional funding covers new activities, outcomes, and indicators of the original project components that included improving protected area management; establishing conservation agreements in RAMSAR sites; establishing conservation agreements with traditional indigenous authority associations and smallholder farmers; developing a funding mechanism for the national protected areas systems; developing of an early warning system for deforestation; and engaging with commodity sectors for sustainable development.

The Colombian Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) is leading the forest monitoring tool development. The rapid response approach uses top-down satellite monitoring to alert for forest disturbance on a quarterly basis. The forest monitoring system, also their national forest monitoring system for REDD MRV, monitors forest change and carbon stocks on an annual basis to inform climate policy ( World Bank, 2017a). IDEAM uses the forest cover mapping methods from (Hansen et al., 2013), however, the maps are informed and validated with local field data. This produces a more locally relevant and accurate forest cover map compared to the global map by Hansen et al. (2013). In addition to developing the top-down monitoring system, IDEAM invested in training staff to utilize deforestation alerts to respond to emerging threats. IDEAM prioritized engagement with staff from the national parks with the highest rates of deforestation (G. Galindo, personal communication, May 19, 2016) This example stressed the importance of training and engaging the end-users or decision makers to facilitate the use of forest monitoring tools.

## DR CONGO

### *DRC Mai-Ndombe Final Emissions Reduction (2018- )*

The Mai Ndombe province contains 9.8 million ha. of forests; however, fuelwood, logging, and subsistence agriculture pose major risks of deforestation. This Forest Carbon Partnership Facility (FCPF) funded project supports the development of a forest carbon measurement, monitoring, and reporting system for the province. The system will be nested in the country's national REDD+ strategy, aligned with the Forest Investment Program (FIP), to avoid double counting of emissions reductions in NDC reporting. The project supports bottom-up forest monitoring implemented through a collaborative mapping platform, MOABI (http://rdc.moabi.org/en/). The aim of this independent monitoring approach to REDD is to improve forest governance by increasing transparency and accountability, while also engaging community participation in REDD+ monitoring and more generally, natural resource monitoring. (FCPF Carbon Fund, 2016). The project is also aligned with the top-down approach to monitoring forest cover with satellite data through the DRC's national forest monitoring system (http://www.rdc-snsf.org/). Many countries are currently grappling with how to nest REDD+ site activities into a national program and report on NDCs. While this project is still in the early phase, it will be worth watching to see if it emerges as a model to be replicated.

## INDONESIA

### *Promoting Sustainable CBNRM and Institutional Development (2016-2021)*

This project supports community-based natural resource management (CBNRM) of Forest Management Units (FMUs) in alignment with the Indonesia Forest Investment Program (FIP) to reduce GHG emission and enhance carbon stocks with the additional benefits of improved livelihoods. CBNRM is a natural resources management approach designed to both increase communities' capacities to sustainably manage their natural resources and empower communities to protect their resources against threats such illegal and commercial resource extraction. The CBNRM is criticized for implementing a formalized management structure that can lead to social inequities and corruption within the communities. However, when designed to fit within the current management structure of the communities, positive outcomes of CBNRM can revive traditional ecological knowledge, increase political and economic autonomy from the national government, and improve welfare (Muhammad, Possumah, Abu Talib, Shah, & Padli, 2018; Villamayor-Tomas & García-López, 2018). The WBG-funded CBNRM activities in Indonesia include capacity building training for forestry staff in forest inventory and participatory mapping; capacity trainings for communities in community-organized fire management; and sustainable forest management training for patrol operators and field technicians, including conflict mediation. The project also includes the development of a knowledge management system to collect monitoring information (World Bank, 2016b). The project is still in early implementation and therefore the success of CBNRM as applied in Indonesia is yet to be determined.

## LIBERIA

### *Liberia Forest Sector Project (2016-2020)*

Liberia has abundant natural resources and low deforestation rates; however, Liberia also has low human development, high poverty, and social inequity. Liberia looks towards the forestry sector as a potential avenue for sustainable economic development coupled with improved livelihoods. The Liberia Forest Sector Project builds off a decade of investment in REDD+ readiness from the WBG (World Bank, 2016a). The bottom-up monitoring is conducted by forestry officials who inventory forest cover and change with the Open Foris Collect mobile data collection app (Table 3). This new method of data collection will replace inventories with paper forms, thus enabling a streamlined data collection process that promotes data standardization and ensures data is centralized and stored digitally for preservation of site-based monitoring records. Liberia's national forest inventory will inform the Forest Reference Emissions Level (FREL) required for REDD+ MRV (FAO, 2018).

## MOZAMBIQUE

### *Mozambique Forest Investment Project (MozFIP) (2017-2022)*

The MozFIP project builds off the investment of the World Bank's Forest Carbon Partnership Facility in REDD MRV and improving performance of national monitoring in partnership with JICA (Japanese International Cooperation Agency). The project supports a bottom-up approach to forest monitoring with community-based forest management to enhance community-land delineation and community-based natural resources management (World Bank, 2018b). One World Bank assessment of community-based management in Mozambique was optimistic of the potential for the activity to engage communities in natural resource management; however, the programs established to date were challenged by the lack of a coherent implementation strategy without the sufficient funds required for long-term success (Aquino, Fonseca, & Mwehe, 2016).

An Africa-regional GEF-funded project executed by the WBG and aligned with the MozFIP and Terra Segura (see Table 4) is Satellite Monitoring for Forest Management (SMFM) (smfm-project.com). The objective of the SMFM project is to develop satellite-based methods for monitoring biomass changes in dry forests annually because the current suite of forest monitoring methods and biomass estimates are less accurate for dry forest (Ryan, Williams, & Grace, 2011). SMFM is a compilation complementary top-down forest monitoring tools. Three tools are aimed at informing policy and practice: semi-automated process for Land Cover/Use Mapping; annual above-ground biomass estimation; and mapping drivers of degradation and deforestation. The fourth tool is a rapid response application to alert to forest disturbance and forest degradation in near real-time (every 5 days). The current project covers Mozambique and Zambia, with a third country to be determined. The project outputs include research and development of novel methods for monitoring dry forests and free and open-source code for the tools listed above. This project highlights that investment in developing new tools is appropriate when the current suite of tools does not fit the application needs.

## MEXICO

### *Mexico: Sustainable Productive Landscapes Project (2018 - ?)*

The Mexico Sustainable Productive Landscapes project is the only non-forestry sector development project that specifically mentions forest monitoring tools implemented by the country's REDD+ MRV methodologies (World Bank, 2017b). The Mexico National Forest Monitoring system operated by the National Forestry Commission (CONAFOR) combines satellite remote sensing with field-based estimates for carbon inventory. However, Mexico's REDD+ strategy has been criticized for being too top-down as implemented at the national-level, but not well-nested in sub-national implementation (Deschamps & Larson, 2017). National Forest Monitoring Systems can provide routine estimates of forest cover or change on an annual to interannual bases. A high level of accuracy is required for these datasets and therefore they often have a 12-18 month latency which hinders adaptive land management to prevent further land degradation from the intervention.

### PERU

#### *Integrated Forest Landscape Management Project in Atalaya, Ucayali (2019-2024)*

Nearly half of Peru's deforestation (45%) is occurring on land with no legal status. The causes of deforestation are migrants, unsustainable small agriculture practices, and mining, oil, and gas extraction. In response, Peru's Forest Investment Plan sets an ambitious goal for net-zero emissions from agriculture, forestry, and other land-use (AFOLU) by 2021. The objective of the Integrated Forest Landscape Management Project led by Ministry of Environment and Natural Resources (MINAM) is to strengthen sustainable management and use of forest landscapes in the Raimondi, Sepahua and Tahuanía districts of the Atalaya province. The project activities include a strong focus on equality, with the goals of 80% of beneficiaries being indigenous peoples and 30% being women. The projects aims to promote land use rights in forest landscapes and community-level forest management. The forest monitoring will be bottom-up and model a successful USAID-funded community-based monitoring system implemented in Peru called Veedurias Forestales Communitarias (VFCs) towards improving monitoring and reporting of illegal activities. Technical support will be provided to Regional Environmental Authority personnel, responsible for law enforcement within forest areas, to improve the prevention, inspection, and detection of illegal activities in forested areas (World Bank, 2019).

# Discussion

There exists an abundance for forest monitoring tools for diverse applications, from fire management and reporting emissions contributions, to emerging applications monitoring drivers of deforestation detected in near real-time. The expansion of tool development by developing countries or co-developed by in-country institutions is encouraging to decentralize the ownership of monitoring tools and technologies from US and European countries. There is also a rapidly expanding suite of mobile field data collection applications from a range of developers including commercial, NGOs, governments, and academic institutions. Multiple forest monitoring tools and approaches are useful, as tool design should be targeted to the end-user's needs and applications. There exists a diverse set of stakeholders for forest monitoring applications. One challenge the large and diverse suite of tools poses for practitioners is how to discover and discern the appropriate application that meets their needs.

Of the projects discovered in the WBG database, most projects that use forest monitoring tools are from the forestry sector, specifically to support the development forest monitoring tools and platforms for national-level REDD MRV. This result is expected given the WBG's investment in the Forest Carbon Partnership Facility and its goals under the Forest Action Plan to support 50 countries in developing national capacities for REDD+.

While forest monitoring tools are applied to about three quarters of the forestry sector WBG projects in this study, these tools seem to be underutilized for other WBG projects. There is little evidence from this study that forest monitoring tools are used to directly prevent deforestation from non-forestry projects, e.g. for infrastructure, agriculture, and extractives. The one non-forestry project that mentioned forest monitoring tools, the Sustainable Productive Landscapes Project in Mexico, indicated improved monitoring of sustainable agriculture in forested landscapes by investment in further development of CONAFOR's national forest monitoring systems for monitoring forest cover with satellite remote sensing. This tool is optimized for informing policy and practice in retrospect of the deforestation.

The current suite of forest monitoring tools provides near real-time monitoring tools designed for rapid response applications to inform adaptive management and timely response to threats as they emerge. For this reason, forest monitoring tools designed for rapid response may be the best fit for reducing the impacts of development projects. These tools should be preferred to relying on tools designed to inform policies and practices such as REDD MRV forest monitoring tools that are designed to accurately measure deforestation on an annual to inter-annual time scale. Emerging tools that monitor forest degradation and identify drivers of deforestation and degradation provide even more valuable and timely information on forest intactness and can attribute the forest degradation to a specific driver-- for instance, when it is the development project or other factors unrelated to the development project. New approaches to monitoring will continue to evolve with advances in sensor technology, social networking, crowd sourcing, and artificial intelligence that can analyze the voluminous, complex, and heterogeneous monitoring data (Laurance et al., 2016). These approaches will combine top-down and bottom-up monitoring in novel ways that engage local communities and stakeholders in forest monitoring and management while providing timely, accurate, and cost-effective forest monitoring information optimized for the application.

# Recommendations

Recommendations from this report are summarized here based on the review of the current suite of forest monitoring tools, the recent application of forest monitoring tools for WBG-funded development projects, and the lessons learned from WBG staff overseeing such projects.

The WBG is committed to reducing impacts on forest from development projects and the WBG does require implementing agencies to recognize if the project will have an adverse impact on forests and devise plans to monitor or mitigate the impact. In this light, it is surprising to find only one of ten non-forestry projects, and only three-fourths of forest projects, report use of forest monitoring tools.

Development projects do not need to invest money to create new tools given the suite of free and open source tools currently available. Often grants for national programs sub-grant to expensive private consultants to develop new systems instead of checking if there is an existing system (free) that meets the need of the project (Petersen, Davis, Herold, & De Sy, 2018). However, the challenge is not knowing what tools are already available. **WBG-funded projects need guidance to navigate the tools options** available to help reduce the negative impacts of development projects on forests. We hope that this report serves as a step in that direction, and specifically, recommendations for the WBG include:

- Provide a Guidance Note or Good Practice Note (for OP4.36, ESS6, and PS6) to advise staff and borrowers of the expectation that forest impacts be monitored, to outline the approaches and tools available for this purpose, and the costs and benefits of each.
- Ensure references to forest monitoring tools (and the relevant guidance) are included in project planning documents, wherever needed/helpful.
- Train WBG project monitoring staff and government counterparts in planning for the choice and use of forest monitoring tools, including plans for community use, where appropriate.
- Require borrowers to allocate sufficient project resources for capacity building and stakeholder engagement to promote the use of the appropriate tool by key decision makers
- Provide guidance to ensure the monitoring system meets the need of the applications. For example, development projects may be best monitored with tools for rapid response applications that enable adaptive management to prevent impacts.

Investment in tool development should continue, although strategically, when no existing tool meets the project's needs. One example of this is the SMFM project where a tool was developed specifically for dry forest monitoring because existing forest monitoring tools were optimized for detecting deforestation in humid forest biomes. There still may be inefficiencies when building new tools without coordination with system developers and building upon lessons learned from developers of previous systems (T. Castren, personnel communication, January 30th, 2019). Tool developers could benefit immensely from lessons learned by other developers. However, such knowledge sharing is not happening in any consistent way.

The Group on Earth Observations (GEO) provides one opportunity for knowledge sharing. GEO is a global initiative to coordinate the development, collection, and use of Earth observations data for the benefit of society (earthobservations.org). GEO also supports regional and thematic initiatives to promote the use of Earth Observation tools and data for the benefit of society. One emerging initiative from the GEO Global Forest Observation Initiative (GFOI) is a Forest Monitoring Tool Registry. Therefore, further recommendations for the WBG are as follows:

- Collaborate with other development finance institutions and governments on development and applications of forest monitoring tools and systems.
- Share lessons learned from the development of monitoring systems in coordination with other forest monitoring system developers, via regular channels such as meetings of the International Association for Impact Assessment or the Multilateral Finance Institutions' Working Group on Environment.
- Participate in GEO, if it is not already, to share knowledge on the projects developing and using forest monitoring systems.
- Require projects register forest monitoring tools with the GFOI Forest Monitoring Tool Registry

While these recommendations are directed toward the World Bank, given the scope of our study and the WB's leading role in financing both forests and development, it seems likely that other forest and development actors (financial intermediaries, governments), could similarly benefit by more systematically considering forest monitoring and tools suited to their contexts.

# Conclusion

Enabled by recent advances in technology and cloud computing, private, public, and non-governmental organizations have produced a variety of forest monitoring tools used for a range of applications and audiences. Routine monitoring of fires and forest cover is fully operational; and emerging monitoring capabilities will soon enable routine monitoring of forest degradation and identify drivers of deforestation and degradation. New approaches to forest monitoring, enabled by reduced costs of technology, artificial intelligence, and social networking, will continue to evolve meet the diverse needs for monitoring applications.

Despite the abundance of tools readily available, forest monitoring tools are currently underutilized to monitor and mitigate forest impacts from development projects. Projects are not documenting details about monitoring tool selection aimed to reduce forest impacts. The sparse use of forest monitoring tools may reflect practical issues too:  developing project-specific tools is expensive, navigating the suite of current tools is daunting, and training stakeholders to use tools is time-consuming and sometimes costly. **Improving the networks of knowledge sharing for forest monitoring tools is recommended** for projects to capitalize on the wealth of free tools that do exist and build upon lessons learned of other system developers when building new tools for niche applications. **Better guidance on fitting the tool to the application is also key for choosing the right forest monitoring tool.** Overall, to reduce the impact of WBG non-forestry projects, task team leaders and their staff could **benefit from integrating rapid response applications with bottom-up approaches to increase community engagement.**

Promoting the use of the forest monitoring tools as a matter of policy and practice across its portfolio represents a substantial opportunity for the Bank to demonstrate its leadership on forests and natural resource management more broadly.  Doing so will empower WBG clients to reduce projects' impact on forests and make progress towards the ultimate goal of decoupling development from environmental degradation and making development truly sustainable.

# Tables

## TABLE 1. FOREST MONITORING TOOLS FOR RAPID RESPONSE

| SYSTEM | FULL NAME | OPERATOR | COUNTRY OF ORIGIN | SPATIAL COVERAGE | PRODUCTS | SPATIAL RESOLUTION | SENSORS | LATENCY | ALERT DELIVERY |
|---|---|---|---|---|---|---|---|---|---|
| Sentinel Hotspots | Sentinel Hotspots | Australian Government | Australia | Oceania | active fire | 375m, 1km | AVHRR, MODIS, VIIRS | 2 hr | none |
| SATRIFO | DEGRAD | Fundación Amigos de la Naturaleza (FAN) | | | active fire<br>fire weather | 375m, 1km<br>500m | MODIS, VIIRS | 3 hr<br>24 hr | report<br>report |
| Firecast | Fire and Forest monitoring and Alert system | Conservation International | USA | Bolivia, Colombia, Ecuador, Indonesia, Madagascar, Peru, Suriname | active fire | 375m, 1km | MODIS, VIIRS | 3 hr | email |
| Queimades | Queimades | National Institute of Space Research (INPE) | Brazil | Brazil | active fire<br>fire weather | 375m, 1km | MODIS, VIIRS | <1 hr | unknown |
| Terra-i | Terra-i | International Center for Tropical Agriculture (CIAT) | Colombia | Latin America + global tropics | forest disturbance | 250 -m | MODIS | 16 days | unknown |
| EFFIS | European Forest Fire Information System | ESA | European Union | European Union | active fire<br>burned area<br>fire weather | 375m, 1km<br>250m, 375m<br>10-36km | MODIS, VIIRS<br>MODIS, VIIRS<br>ECMWF | 3 hr<br>32 day<br>24 hr | none<br>none<br>none |
| FIRMS | Fire Information for Resource Management System | NASA | USA | Global | active fire | 375m, 750m, 1km | MODIS, VIIRS | 3 hr | email |
| AFIS | Advances Fire Information System (AFIS) | Council for Scientific and Industrial Research's (CSIR) | South Africa | Global | active fire<br>burned area<br>fire weather | 375m, 1km, 4km<br>500 m<br>? | MODIS, VIIRS, GOES<br>MODIS<br>? | <1<br>32 day | SMS, mobile app |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| GWIS | Global Wildfire Information System | Europeans Unions' Joint Research Centre | European Union | Global | active fire<br>burned area<br>fire danger | 375m, 1km<br>500 m<br>16 km | MODIS, VIIRS<br>MODIS<br>ECMWF | 3 hr<br>32 day<br>24 hr | none<br>none<br>none |
| GWF Fires | Global Forest Watch Fires | The World Resource Institute | USA | Global | active fire<br>fire weather | 375m, 1km<br>5 km | MODIS, VIIRS, NOAA 18 | 3 hr<br>24 hr | email, SMS, mobile app<br>none |
| Vulcain | Vulcain | Gouvernement de la Nouvelle-Calédonie | New Caledonia | New Caledonia | active fire<br>fire danger<br>burned area | 375m, 1km, 2km | MODIS, GPM, HIMAWARI | ? | webmap |
| SiPongi | Land and Forest Fire Monitoring System | Indonesia | Indonesia | Indonesia | active fire | 375m, 1km | MODIS, VIIRS | 3 hr | unknown |
| SAI | Sistema de Alerta de Incendios | National Commission for the Knowledge and Use of Biodiversity (CONABIO) | Mexico | Mexico | active fire | 375m, 750m, 1km | MODIS, VIIRS | <1-hour | email |
| Geobosques | Geobosques | Ministry of Environment (MINAM) | Peru | | Forest disturbance | 30-m | Landsat Perusat | 8 days | mobile |
| GFW | Global Forest Watch | World Resources Institute | USA | Global<br>select tropical countries | forest disturbance<br>GLAD** | 250m<br>30m | MODIS<br>Landsat | 16 days<br>16 days | webmap<br>email<br>mobile |
| GFWED | Global Fire Weather Database | NASA Goddard | USA | Global | fire weather | 25-km | GOES-5 | <12 | none |
| GLAD | Global Land Analysis & Discover** | University of Maryland | USA | select tropical countries | Tree Cover loss Alerts | annual from 2011 | 30m | Landsat | 16-day |
| MAAP | Monitoring the Andean Amazon | Amazon Conservation | USA | Peru, Ecuador, Colombia | deforestation + associated drivers | <3 m -30 m | Landsat, Planet, Digital-globe, Sentinel, Perusat. | 16-day | blog |
| Mighty Earth | Mighty Earth Rapid Response Monitoring System | Mighty Earth | USA | select oil palm plantations in Indonesia & Malaysia | forest disturbance, post-deforestation land use | 5-30m | GLAD alerts, Planet | 16-day | files grievances with trader + reports |

## TABLE 2. FOREST MONITORING TOOLS TO INFORM POLICY AND PRACTICE

| SYSTEM | FULL NAME | OPERATOR | COUNTRY OF ORIGIN | SPATIAL COVERAGE | PRODUCTS | FREQUENCY | SPATIAL RESOLUTION | SENSORS |
|---|---|---|---|---|---|---|---|---|
| PRODES | Projeto de Monitoramento do Desmatamento na Amazônia Legal por Satélite | INPE | Brazil | Brazil | Deforestation |  | 30m | Landsat |
| DEGRAD | DEGRAD | INPE | Brazil | Brazil | Degradation |  | 60 m | Sentinel |
| SAD | Sistema de Alerta de Desmatamento | Imazon | Brazil | Brazil | Deforestation |  |  |  |
| Deforestation and Forest Degradation in the Amazon Biome | Deforestation and Forest Degradation in the Amazon Biome | Imazon | Brazil | Brazil | Degradation | annual from 2007 | 30 m | Landsat, CBERS |
| MAPBIOMAS | MAPBIOMAS | Imazon, UEFS, APNE, IPAM, UFRGS, and partners | Brazil | Brazil | Land Cover | annual from 1985 | 30m | Landsat |
| Geobosques | Geobosques | Ministry of Environment (MINAM) | Peru |  | Annual forest cover |  | 30-m | Landsat Perusat |
| GFW | Global Forest Watch | World Resources Institute | USA | Global | Global Forest Change* | 2000-present | 30m | Landsat |
| GLAD | Global Land Analysis & Discover** | University of Maryland | USA | select tropical countries | Tree Cover loss Alerts | annual from 2011 | 30m | Landsat |
| Global Forest Change | Global Forest Change* | University of Maryland | USA | Global | Forest Cover loss & gain | annual from 2000 | 30m | Landsat |

## TABLE 3. MOBILE APPLICATIONS FOR COMMUNITY-BASED FOREST MONITORING

| MOBILE APP NAME | FULL NAME | OPERATOR | COUNTRY OF ORIGIN | OS |
|---|---|---|---|---|
| Forest Watcher | Forest Watcher | WRI | USA | iOS, Andriod |
| CyberTracker | Cybertracker | CyberTracker Conservation | South Africa | desktop install required |
| ODK Collect | Open Data Kit Collect | Google | US | Andriod |
| GEO-wiki pictures | GEO-wiki pictures | International Institute for Applied Anlaysis | Austria | Andriod |
| Sapelli | Sapelli | University College London | UK | Android |
| Open Foris Collect | Collect | Forestry Department of the Food and Agriculture Organization of the United Nations | Italy | Android |
| Survey 123 | Survey 123 | Ersi | US | iOS, Android |

## TABLE 4. WBG PROJECTS BY COUNTRY

| COUNTRY | PROJECT NAME (SHORTENED) | WB ID | APPROVAL DATE | BANK FINANCING | PRIMARY SECTOR | FORESTS OP/BP 4.36 | FOREST MONITORING |
|---|---|---|---|---|---|---|---|
| Brazil | Platform of Monitoring and Warning, Forest Fires in Cerrado | 149189 | 2014-12-15 | 14 M | forestry | NA | top-down |
| | Bahia road rehabilitation and maintenance project | 147272 | 2016-01-29 | 200 M | non-forestry | no | none |
| | Amazon Sustainable Landscapes Project | 158000 | 2017-05-03 | 0 M | forestry | yes | top-down |
| | Paraiba Sustainable Rural Development | 147158 | 2017-10-20 | 50 M | non-forestry | yes | none |
| | FIP: Environmental regularization of rural lands Cerrado | 143334 | 2015-07-21 | 0 M | forestry | yes | top-down |
| | Piaui: Pillars of Growth and Social Inclusion Project | 129342 | 2015-12-21 | 120 M | non-forestry | yes | none |
| | Integrated Landscape Management in the Cerrado Biome | 164602 | 2018-10-29 | 21 M | forestry | yes | top-down |
| Colombia | Forest Conservation and Sustainability Colombian Amazon | 158003 | 2017-10-31 | 12 M | forestry | yes | top-down |
| | Connectivity & Water Service Provision Plan Pazcifico | 156880 | 2017-12-14 | 41.9 M | non-forestry | yes | none |
| | Sustainable Low-Carbon Development in Orinoquia region | 160680 | 2018-02-16 | 20 M | forestry | yes | top-down |
| DRC | Purchase / Sale of Emission Reductions (ER) Mai Ndombe | 160320 | 2018-10-25 | 50 M | forestry | yes | bottom-up |
| | DRC Electricity Access & Services Expansion (EASE) | 156208 | 2017-05-04 | 0 M | non-forestry | yes | TBD |
| | DRC Agriculture Rehabilitation and Recovery AF | 159037 | 2017-03-22 | 75 M | non-forestry | yes | none |
| | Strengthening Hydro-Meteorological and Climate Services | 159217 | 2017-03-08 | 8 M | non-forestry | no | - |
| | Forest Dependent Communities Support Project | 149049 | 2016-04-08 | 6 M | forestry | yes | none |
| Indonesia | Promoting sustainable CBNRM and inst development | 144269 | 2016-10-03 | 22 M | forestry | yes | bottom-up |
| | Strategic Irrigation Modernization and Urgent Rehabilitation | 157585 | 2018-06-21 | 250 M | non-forestry | no | - |
| | Strengthening Rights and Economies of Adat and LC | 156473 | 2017-03-06 | 6 M | forestry | yes | none |
| Liberia | Southeastern Corridor Road Asset Management Project | 149279 | 2018-12-18 | 29 M | non-forestry | no | |
| | Liberia Forest Sector Project | 154114 | 2016-04-19 | 0 M | forestry | yes | bottom-up |
| | Liberia - Emergency Monrovia Urban Sanitation Project 3AF | 158315 | 2016-02-18 | 0 M | non-forestry | no | |
| | Liberia Renewable Energy Access Project | 149683 | 2016-01-11 | 2 M | non-forestry | no | |
| Mozambique | Rural roads emergency maintenance project | 156236 | 2015-08-21 | o M | non-forestry | no | |
| | Mozambique Conservation Areas for Biodiversity & Devel | 166802 | 2018-09-20 | 45 M | forestry | yes | none |
| | Mozambique Land Administration Project (Terra Segura) | 164551 | 2018-12-04 | 100 M | non-forestry | yes | none |
| | Smallholder Irrigated Agriculture and Market Access Project | 164431 | 2018-06-29 | 55 M | non-forestry | no | - |
| | Integrated Feeder Road Development Project | 158231 | 2018-05-08 | 150 M | non-forestry | no | - |
| | Dedicated Grant Mechanism for Local Communities | 161241 | 2017-12-05 | 0 m | forestry | yes | none |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mining and Gas Technical Assistance Additional Financing | 161683 | 2017-11-01 | 28 M | non-forestry | no | - |
| | Moz Agriculture and Natural Resources Landscape Mgmt | 149620 | 2016-06-30 | 40 M | non-forestry | yes | none |
| | Mozambique Forest Investment Project | 160033 | 2017-03-07 | 15 M | forestry | yes | bottom-up |
| Mexico | Mexico: Sustainable Productive Landscapes Project | 159835 | 2018-03-30 | 0 M | non-forestry | yes | top-down |
| | Entrepreneurship in Productive Forest Landscapes | 164661 | 2018-01-29 | 56 M | forestry | yes | bottom-up |
| | Mexico Dedicated Grant Mechanism for IP and LC | 151604 | 2017-09-15 | 0 M | forestry | yes | none |
| | Grain Storage and info for Agricultural Competitiveness | 160570 | 2017-03-24 | 120 M | non-forestry | yes | none |
| | Energy Efficiency in Public Facilities Project (PRESEMEH) | 149872 | 2021-10-31 | 100 M | non-forestry | no | - |
| Peru | Integrated Forest Landscape Management Atalaya, | 163023 | 2019-01-04 | 0 M | forestry | yes | bottom-up |
| | National Program for Innovation in Fisheries & Aquacul- | 155902 | 2017-01-27 | 40 M | non-forestry | yes | none |

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