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Multi-Regional

Satellite Monitoring for Forest Management

Use of Earth Observation Tools in the Monitoring of Tropical Dry Forests:
A Briefing Note for Forest Managers and Policymakers.

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ENB

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Acronyms

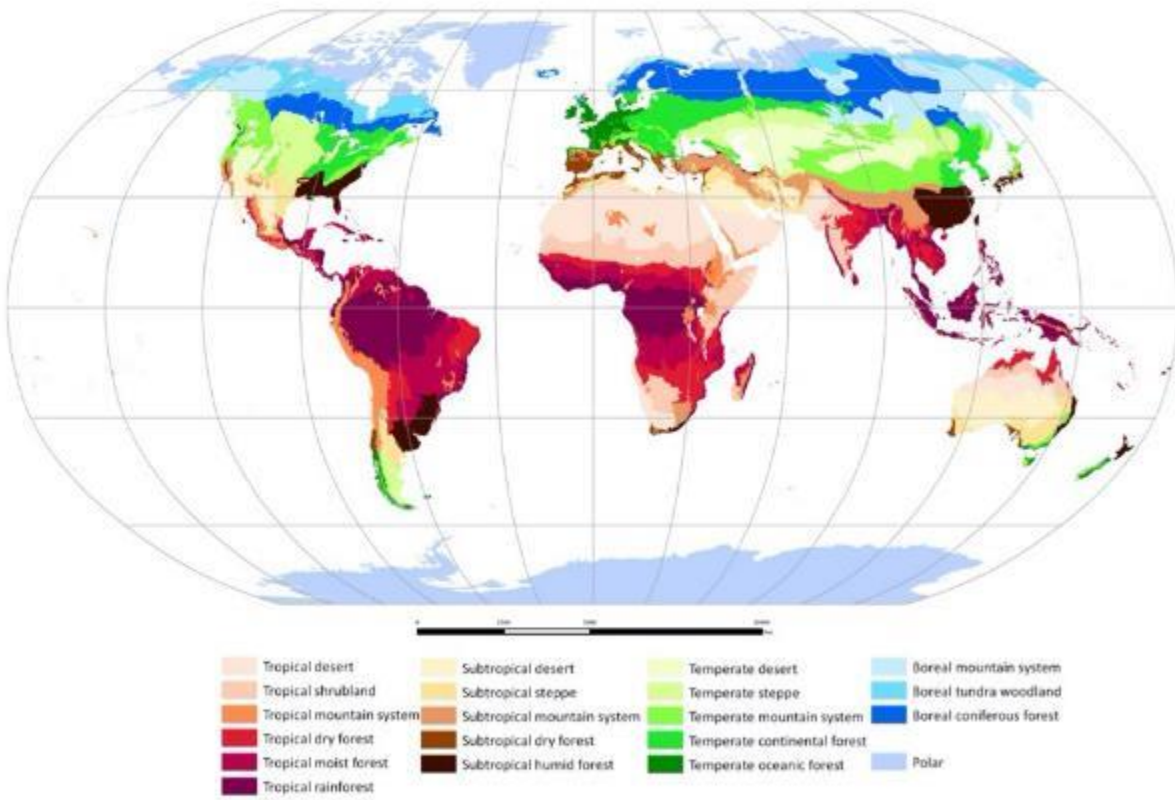
AI	Artificial Intelligence
ALOS	Advanced Land Observation Satellite
C	Carbon
EO	Earth Observation
ESA	European Space Agency
F-TEP	Forestry Thematic Exploitation Platform
FAO	United Nations Food and Agricultural Organization
FRA	Global Forest Resource Assessment
GEF	Global Environment Facility
GPG	Good Practice Guidance
IT	Information Technology
JAXA	Japan Aerospace Exploration Agency
PALSAR	Phased Array type L-band Synthetic Aperture Radar
RADAR	Radio Detection and Ranging
REDD	Reducing Emissions from Deforestation and Forest Degradation
SEPAL	System for Earth Observation Data Access, Processing and Analysis for Land Monitoring
SMFM	Satellite Monitoring for Forest Management

N.B. weblinks in the document are temporary and will be updated after SMFM tools have been transferred to the FAO SEPAL site

1. TROPICAL DRY FOREST AND TECHNOLOGICAL CHANGE

1. **Dry forests are estimated to comprise close to half of the world's subtropical and tropical forest area, and with 1.1 billion ha of dry forests, they make up about 27 percent of the global forest cover and represent an important carbon stock.** While no single global definition exists, tropical dry forests are broadly understood as land areas with woody vegetation covering at least 10 percent of the ground area in climates with five to eight months of dry season and annual rainfall between 500 and 1,500 mm. They include woodlands and savannas, both sides of the equator and across five continents, with the most extensive areas situated in Africa (Figure 1). Due to its relatively low growth rate, dry forest carbon stock takes long to build up and to recover from such disturbances as deforestation and degradation. Some estimates put the carbon sequestration potential of dry land ecosystems in Africa alone at around 0.5 billion tons of carbon (1.84 billion tons of CO_2e, i.e. 1.4-times the annual CO_2 emissions of all African countries) per year.

Figure 1 Global Forest Ecosystem Distribution

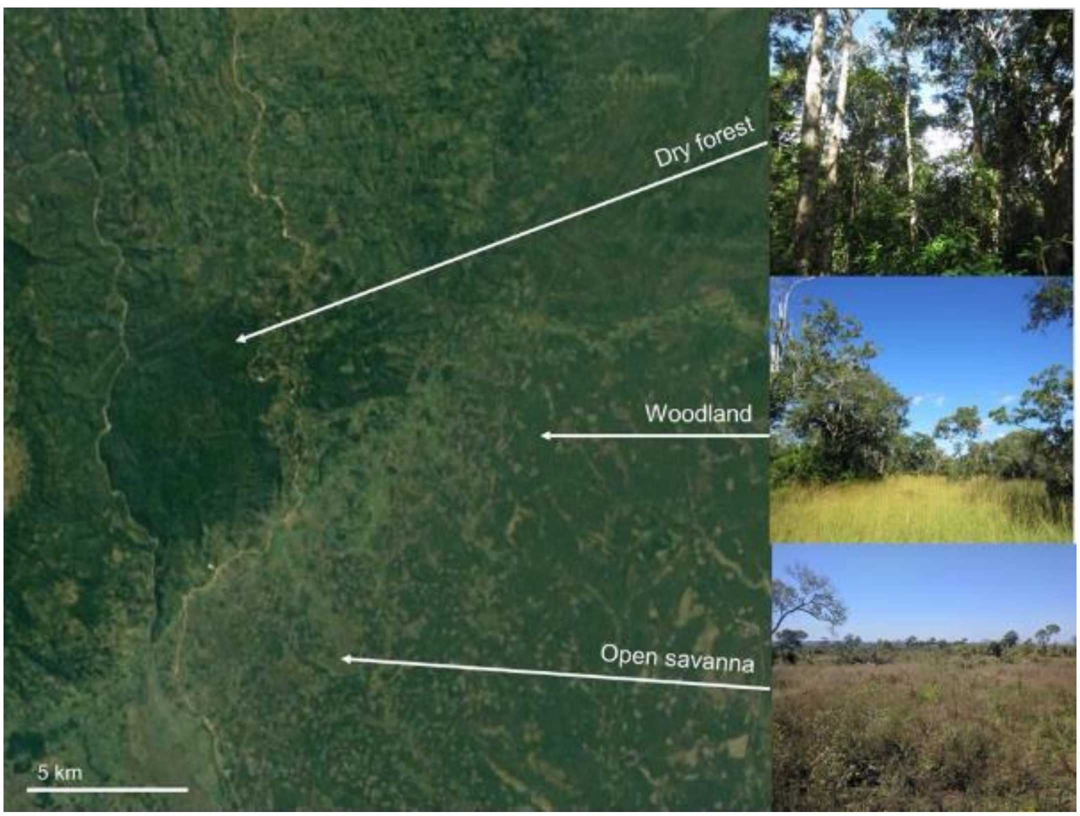


Tropical dry forest in red; FAO. 2012

2. **Tropical dry forests provide important benefits to local communities in the form of non-timber forest products, energy, construction material, soil and water conservation, pasture and agroforestry, but they also face increasing threats.** It is estimated that in sub-Saharan Africa alone some 60 percent of the population depend on dry forest for their livelihoods. Tropical dry forests face various threats, primarily from agricultural expansion and land conversion, but also from fires and grazing pressure resulting in either degradation or outright deforestation. Climate change is putting additional pressure through longer dry seasons and variation in rainfall patterns. A recent FAO[i] assessment revealed that tropical dry forests appear to be under-reported in national statistics and in reporting to the global Forest Resource Assessment (FRA). This is due to various reasons. Since dry forests are seen as less important from production perspective, traditional forest inventory methods are not adapted to tropical dry forests.

3. **Countries need reliable information on the extent and condition of dry forests to understand what drivers are causing changes, but traditional data collection methods are difficult to use in dry forest landscapes.** Presently forest managers have only limited possibilities to monitor loss and gain of forest cover effectively, or to analyze historic trends. One reason for the limited knowledge is the huge diversity within the dry forests. As can be seen in Figure 2 below, dry forests can differ greatly from site to site and this has an impact on remote sensing systems used. Consequently, there is a clear information and knowledge gap around tropical dry forests that needs to be addressed. In large dry forest areas field mission have had high unit costs making their costs not always worth the benefits achieved.

Figure 2 Different dry forest types: example from Manica Province, Mozambique



Source: *Google Earth (Landsat/Copernicus), Sam Bowers (The University of Edinburgh)*

4. **New innovative and affordable solutions in accessing and processing of satellite data have introduced options for using satellite-based remote sensing to improve monitoring and management of dry forests.** While using remote sensing data still requires particular expertise and knowledge, it is no longer limited to the scientific community and externally financed development projects. Two particular developments in the past years have improved access to data and lowered the threshold for using EO data in countries with notable tropical dry forests. The two main changes are:

(a) ***Improved access to relatively high-resolution satellite data free of charge*****:** Availability of free satellite imagery and radar data at short intervals and with comparatively high spatial resolution makes moving towards near real-time forest monitoring a reality.

(b) ***New opportunities for cloud computing enable processing satellite data even with relatively inexpensive and accessible IT and bandwidth infrastructure****:* While the high frequency of new satellite imagery constitutes a rich information potential, the sheer amount of data to access, download and process can present a serious obstacle. To overcome this challenge, recent development in cloud computing allows processing data remotely.[ii]

5. **This briefing note presents some recent developments in satellite-based earth observation (EO) and how new and disruptive technology can improve understanding on tropical dry forests.** In particular, it focuses on tools and algorithms developed by the Satellite Monitoring for Forest Management (SMFM) project financed by the Global Environment Facility (GEF) and implemented by the World Bank in 2017–2020[iii]. This note summarizes the key aspects on using satellite data in dry forest monitoring and its target audience is senior forest managers, policy makers and other users of forest data. For more technology focused audience, the SMFM project also prepared a series of other documents: i) Good Practice Guidance – A guidance document for dry forest assessment and monitoring; ii) Validation Compliance Report; iii) Project Implementation Summary; and iv) Working Practice document (manual) for each tool developed under the project. The documents are available at *[#final weblink]*.

2. EARTH OBSERVATION TECHNOLOGY - NEW OPPORTUNITIES FOR FOREST MEASURING AND MONITORING

2.1 Solutions and benefits

6. **Satellite-based EO technology has many benefits to forest monitoring: it allows for the covering of large areas at national or even global level; is easily repeatable at annual, or even shorter intervals; and is generally cost effective, when compared to traditional field-based approaches.** Some of the global satellite missions (e.g. NASA's Landsat and ESA's Sentinel-1 and-2) offer free and open access to their data. Combined with open source applications and cloud processing services, satellite data is becoming increasingly accessible for such institutional users as government agencies and forest departments. This provides unprecedented opportunities for forest and other natural resource monitoring. However, it needs to be recognized that even with advanced remote sensing methodologies, field measurements are needed to provide ground-truthing of remote sensing data. Secondly, if remote sensing data is used for monitoring for example encroachment or other illegal and unauthorized activities, enforcement still needs to be done on the ground. Technology helps to make field operations more efficient and targeted but does not replace them.

7. **EO data come in different forms: optical satellite images allow identifying and classifying land cover and forest types, whereas radar satellite data can be used to detect, measure and monitor above-ground biomass (AGB).** Optical data has been used more widely and requires less processing than radar data. However, as a major shortcoming, it does not provide information from below the tree canopy and is obstructed by clouds. In many tropical countries this means, that larger areas need to be covered by *mosaic images* that consist of separate cloud-free images taken at different points of time.[iv] Radar data does not have the same limitations but, on the other hand, their technical processing is more demanding than that of optical data.[v]

8. **Newly developed EO data processing tools allow forest managers and remote sensing specialists to access and exploit new data sources and improve the accuracy and timeliness of forest data**. Based on novel and innovative approaches, new EO tools offer ways to assess and monitor tropical dry forests. For instance, EO data allows monitoring large areas without expensive field missions. Some tools can be used to provide early warning information; this is information that is not necessarily very detailed but comes timely and helps directing management activities (e.g. law enforcement or protection). Using satellite radar data can help revealing forest degradation that previously remained undetected, and making use of frequently updated satellite data allows detecting early changes in forest cover or condition at very short intervals (i.e. near real-time), often related to degradation events as a precursor to deforestation. The key benefits of using satellite data for forest monitoring and in providing information for forest management decisions, include the following:

(a) ***Information becomes available from large, previously poorly covered or even inaccessible areas*****.** Satellite data collection cover all forests in all areas of the globe with no geographic limitations. This allows unprecedented access to collect information from all forests.

(b) ***Once systems have been established and tools calibrated, the unit cost of repeat assessments (*****e.g.** ***annual or more frequent monitoring) may be low.*** Building necessary information systems, calibrating the tools (e.g. collecting ground verification data) and training staff all have notable costs. However, once these initial investments have been made, updating the satellite data collection becomes relatively low cost.

(c) ***Information is easy to validate, distribute and it becomes tamperproof****.* Satellite data is received and processed in digitalized format making it easy to distribute electronically. It also easy to validate the analysis and its results by running the same scripts on the same data by separate teams. This mitigates the risk of, for example, field organizations or concessionaires providing falsified information. As a result, information on valuable forest resources become tamperproof, or at least falsified information is easier to identify.

9. **Satellite data systems do not solve all information challenges in forest monitoring: they require upfront investments and capacity building, and these can be costly and time-consuming. Additionally, tools often need to be localized before they can be used.** Some of the issues to be addressed when developing and using satellite-based remote sensing data in dry forest management include the following:

(a) ***Satellite monitoring is an indirect way of collecting information and not all variables can be monitored by satellites.*** Some examples: in dry forests it is difficult to differentiate very low levels of tree cover from grasses and other ground vegetation. This leads also to challenges in monitoring forest *regrowth* (as an example, replanting and landscape restoration cannot be easily monitored by satellites). Secondly, satellite data does not necessarily differentiate between species and even forest types (planted *vs.* natural forests) unless there are clear differences in their physical characteristics. Only radar data provides information on volume, optical data mainly measures only canopy and other vegetation cover.

(b) ***Systems require technical and human capacity that is not always available and can be costly to build.*** While satellite data processing software and tools have become more user-friendly and closer to "mainstream computing", they still require notable technical skills both in processing the data and interpreting the results. This could be achieved by establishing specialized units with the forest administrations or in collaboration with other agencies, e.g. universities or research centers.

Recent developments in cloud computing and processing platforms (see paragraph 4(b) above) have reduced the needed investments in in-house computing capacity and IT infrastructure. In most cases satellite data can be analyzed by using modern standard office computers with adequate internet connection. This requires that the actual computing is done in the cloud and only the required scripts and results, not raw satellite data, are downloaded. It is also important that forest administrations' local and decentralized units, not only headquarters in the capitals, have adequate access in the Internet. This allows their use of the available data and contribution of observations.

(c) ***Technical development is rapid and staying updated requires constant updating of systems.*** The global satellite missions develop constantly, and new types of data become available. Also processing tools develop and become more efficient and easier to use. This requires that officials in charge of developing forest administrations' information management stay on top of global development in this area. Particular concern is to avoid *technology lock-in* where the systems are not flexible enough to adjust and adapt to emerging new practices. Many earth observation tools (including those developed by the Satellite Monitoring for Forest Management project) are based on open source license[vi] that allow modifying the tools by the users. Technology lock-in can become a particular concern for proprietary software tools where adjustments are more difficult, and a given technology can become obsolete on the service provider chooses to discontinue their support or change their business model[vii].

2.2 Combining new and old technology

10. **In most cases using satellite data alone without ground-truthing gives a relatively superficial view of the forest resource and obtaining reliable information requires field observations.** Satellite data is as good as it is designed to be, and it does not analyze or explain the characteristics forests have. It only records what it sees and therefore it is essential that satellite data is combined with field observations made with human eye. Only then the satellite data can reveal more, and end-users are able to interpret what the images tell.

11. **Use of training datasets[1] – or *calibration* – is particularly important for optical data where data from other sources is used to understand better how the data from satellites correlates with actual conditions on the ground[viii]**. Calibration data can be (i) produced from field surveys, (ii) taken from existing data sets (e.g. forest inventory plots) or (iii) identified using higher resolution remote sensing data. Then, the algorithm can link all pixels with the given set of characteristics with a given forest type. Ideally, data collection for calibration can be linked to a network of permanent sample plot established for the national forest inventory. In some cases, also data from neighboring countries can be used if the forest characteristics are adequately similar. The decision on the adequacy of calibration data needs to be done on case-by-case -basis depending on how homogeneous the forests are, what is the required accuracy of measurement and what kind of time and financial resources are available. On example of using calibration data with earth observation can be found when comparing supervised classification with unsupervised classification (Box 1).

Box 1 Unsupervised and supervised classifications

Unsupervised classification is generally used when there is no prior knowledge on the expected classes or categories available. In an unsupervised classification, pixels in remote sensing image data are grouped into clusters on the basis of their properties, using clustering algorithms. It is left to the user to decide on the number of clusters or classes to retain and to apply labels to to these.

Supervised classification is used for extracting quantitative information from remotely sensed image data where classes are specified in advance. The user has prior knowledge of the area to classify and selects sample pixels in a remote sensing image, the "training data sites" that are representative of specific land cover classes. Classification algorithms determine the spectral signature of each training site and cluster, or classify the remaining image pixels into the spectrally closest cluster or category.

12. **Another area where field action is obviously needed is law enforcement, forest risk (e.g. fire) management, forest restoration and production forestry but these can be made more efficient by using information from satellite observations.** While remote sensing can provide invaluable information on where human intervention is needed, the actual interventions need to be conducted on the ground. Therefore, it essential that earth observation systems and information are closely integrated with information systems for operational planning and management.

13. **Different types of information are used in different places and often there is a trade-off between having recent and updated information on one hand, and on having detailed and precise information on the other.** For example, payments for REDD+ or other environmental services need to be based on accurate and detailed data on forest cover and biomass. However, this information does not need to be collected often and, for example, annual data is adequate and in can be based on measurements done earlier. On the other hand, information needed for active forest management (including enforcement) on the ground, can more less precise but it needs to be available frequently and it needs to be based on freshly obtained data (*i.e.* near real-time).

[1] "Training datasets" are data that have known characteristics (e.g. forest type) and can be used to verify the link between field observations and satellite data.

3. TOOLS USING SATELLITE DATA: EXAMPLES FROM THE SATELLITE MONITORING FOR FOREST MANAGEMENT PROJECT

14. **The suite of EO tools highlighted here were developed in collaboration between EO scientists and institutional users in tropical dry forest countries in Southern Africa under the SMFM project**. These tools are based on open source making them free to use, customize and develop further. The main resulting EO tools for assessing and monitoring tropical dry forest, named *Biota*, *Deforest* and *Acacia*, are briefly highlighted below and presented in more detail in Table 1 on page 10.

(a) The ***BIOTA*** **tool** uses radar data to generate annual wall-to-wall maps of above-ground biomass that can be calibrated to national dry forest definitions and parameters. Forest managers can use *Biota* to prepare maps of annual deforestation and degradation at national or sub-national scales[ix]. Key to this is an established relationship between above-ground biomass (or carbon content) and the reflection from the satellite's radar signal which allows the tool to extract AGB values at each image pixel.[x]

(b) With the ***DEFOREST*** **tool**, forest managers can use Sentinel-2 imagery to analyze change in dry forest cover, making use of dense time series of satellite images. With new Sentinel-2 imagery becoming available approximately every five days, the tool benefits from near real-time information of likely dry forest changes. Accessing and analyzing satellite imagery at very short intervals involves handing and processing large volumes of data and the *Deforest* tool is designed to be mainly operated on cloud-based platforms.

(c) The ***ACACIA*** **tool** analyses and classifies deforestation events into groups with similar characteristics that may be attributed to specific drivers or threats. This information provides valuable insights into the processes that lead to changes or loss of tropical dry forests. It helps analyzing concentrations or hotspots of threats in a landscape and thereby allows deploying targeted mitigation measures. While still experimental, this tool sets the direction of potential future developments using artificial intelligence to identify the drivers of deforestation automatically.

15. **Two more tools are available that can be used to pre-process Sentinel-1 and Sentinel-2 imagery for use in land cover mapping or as inputs to other EO processing steps.** For Sentinel-1 radar data, the ***Sen1mosaic*** **tool** corrects, improves and combines single scenes into a continuous mosaic. For Sentinel-2 optical imagery, the ***Sen2mosaic*** **tool** not only color-balances and assembles the tiled data, but also masks and removes clouds and cloud shadows by using a unique process that inserts cloud-free pixels from other scenes from of same period or season. See Text box 1 below for information on how to access the tools.

16. **Like all other EO-tools, also the SMFM-tools need to be calibrated to local ecosystems, conditions, and definitions.** By default, the tools work with a calibration model built around Southern African conditions and should therefore be applicable in similar dry forest environments. For their use in other regions, the calibration can be customized using locally available AGB values as reference data. The results produced with the tools require validation if used for official reporting, e.g. in the context of REDD+. Early warning information produced with *Deforest* may instead be used directly for targeted verification of presumed deforestation sites on the ground.

Text box 1 Hosting of SMFM tools

The SMFM tools and supporting documentation are hosted on FAO's System for Earth Observation Data Access, Processing and Analysis for Land Monitoring (SEPAL) site that provides an access to number of other EO tools as well. The tools can also be run also on ESA's Forestry Thematic Exploitation Platform (F-TEP) as well as on individual computers. The tools are also available for download on Github. The key weblinks are:

SEPAL: https://sepal.io/
F-TEP: https://f-tep.com/
Github: https://github.com/smfm-project/

17. **Selecting the right tools and technology is not always easy and requires considering a number of sometimes conflicting aspects: the underlying forest management challenge, how fast the information is needed, what existing data there is (both remote sensing and field data), human capacity, technical capacity, financial resources, etc.** They all need to be in balance and while lack of one resource can often be partially substituted by another, in most cases at least a minimal amount of technical readiness as well as forest management capacity and financial resources are needed. If any of them is entirely lacking, it may still be necessary to collaborate with an outside expert organization and focus on in-house capacity building.

18. **The choice of technology to support forest management needs to be based on the underlying forest management challenges and objectives; not availability of technology.** Remote sensing and earth observation are means to an end and technology choice needs to be based on the forest management objectives. Figure 3 presents a schematic decision tree that allows assessing which of the SMFM tools presented in Chapter 3 above could be used to provide the necessary information. The technical capacity requirements from each tool then presented Table 1 on page 10. The table also presents the products delivered by each tool. Figure 3 only shows the primarily intended uses; particularly national tools like Sen1Mosaic and Sen2Mosaic can also be used to produce local images. The tools that have been originally designed for local-level application – Deforest and Acacia – can also be used over larger areas. However, that may require extensive computational and field calibration resources.

Figure 3 **Selection of the right tool – a decision tree**

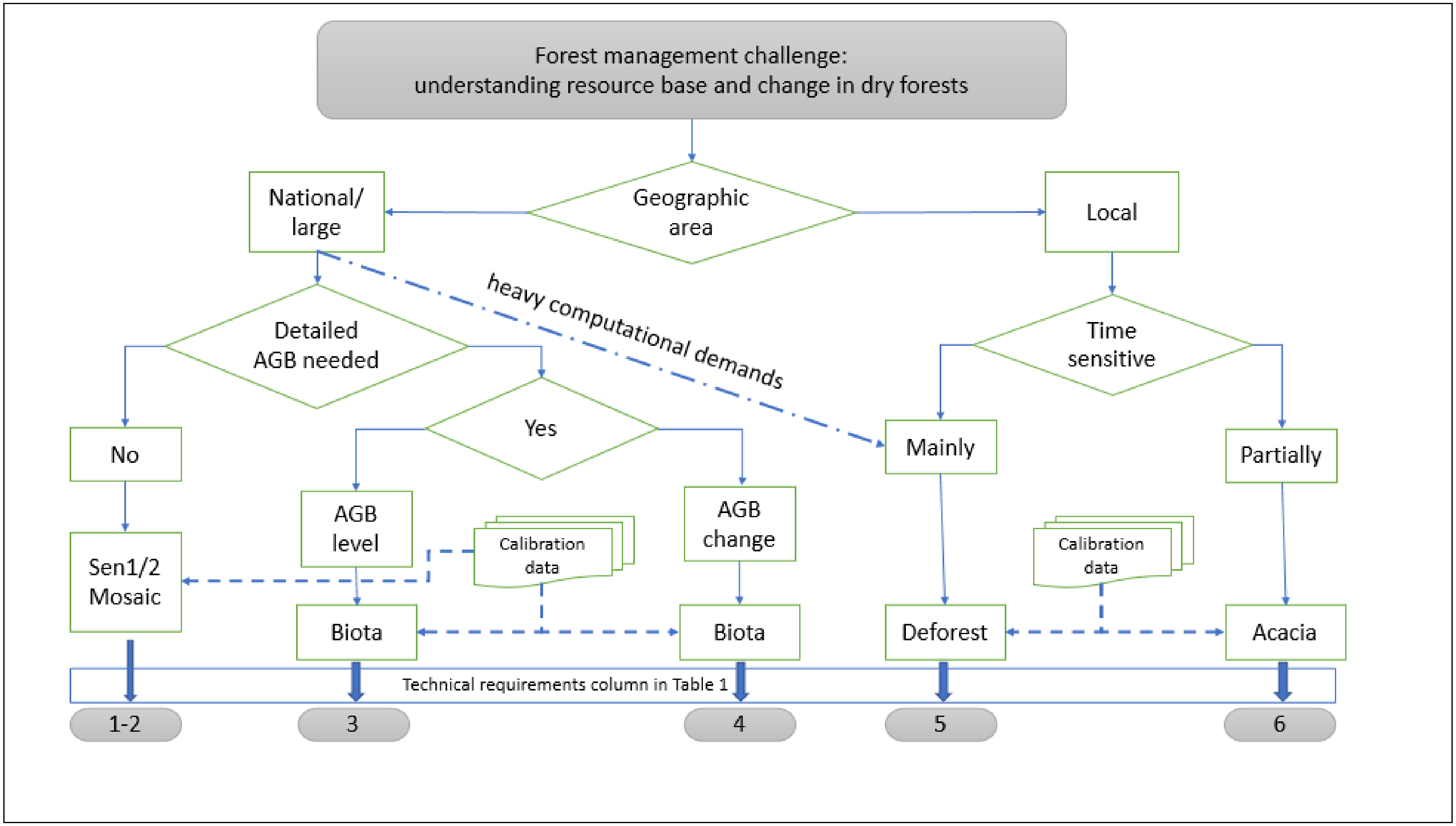


Table 1 Selection matrix for EO tools and technical requirements

	Information need / purpose					
	1) LU/LC mapping incl. TDF*	**2) LU/LC mapping incl. TDF**	**3) Assessment of TDF extent**	**4) Monitoring of TDF changes**	**5) Detection of TDF loss**	**6) Drivers of deforestation**
Interval / frequency	one off	one off	one off	annual	sub-annual, near real-time	annual
Scope / extent	national	national	national	national	sub-national	small / hot spots
Processing	local	local	local	local / EO cloud	EO cloud	local
Tool	**SEN1MOSAIC**	**SEN2MOSAIC**	**BIOTA**	**BIOTA** **BIOTA on SEPAL**	**DEFOREST on SEPAL**	**ACACIA**
EO Data	Sentinel-1 radar imagery	Sentinel-2 optical imagery	ALOS Palsar mosaic	ALOS Palsar mosaic	Sentinel-2	AGB change map from BIOTA
Calibration data	ground reference data	ground reference data	LU/LC map / ground reference data	ground reference data	LU/LC map	ground reference data
Calibration data collection	survey plots / Collect Earth	survey plots / Collect Earth	AGB model	survey plots / Collect Earth	AGB model	Collect Earth
Required IT capacity	medium	medium	medium	medium	high	medium
Required storage capacity	high	high	low	medium	low	low
Required skill capacity	▪ radar remote sensing ▪ Linux / Python	▪ image processing ▪ Linux / Python	▪ radar remote sensing ▪ Linux / Python	▪ radar remote sensing ▪ Linux / Python	▪ image processing ▪ SEPAL	▪ image processing ▪ Linux / Python
Validation requirements	▪ ground reference data ▪ visual inspection	▪ ground reference data ▪ visual inspection	▪ ground reference data	▪ ground reference data	▪ targeted verification	▪ ground reference data ▪ user input
Output data / type	enhanced mosaics	cloud-free, seamless mosaics	continuous AGB map	AGB change maps	sites of likely deforestation	clusters of deforestation types
Products	▪ input data for LU/LC mapping	▪ input data for LU/LC mapping ▪ input to DEFOREST	▪ AGB classes total AGB	▪ AGB change ▪ degradation - restoration	▪ early warning information	▪ type of deforestation ▪ distribution of drivers
Limitations	▪ n/a	▪ n/a	▪ Signal saturation at 150t/ha AGB	▪ Signal saturation at 150t/ha AGB	▪ Difficult in open forest types	▪ Still experimental

* TDF: tropical dry forests; LU: Land use; LC Land cover

4. MAINSTREAMING EO TOOLS IN FORESTRY OPERATIONS: OPPORTUNITIES AND OPTIONS

19. **High-quality forest management requires access to adequate and accurate information, and innovative, EO-based forest monitoring approaches open up new avenues for improved and information-based forest management**. New technology can enable approaches to forest management that were not available a few years ago. Easily accessible and exploitable satellite data can help reveal early deforestation that previously remained undetected. Being able to tap into the vast and constantly increasing volume of available earth observation data, provides a new dimension to forest management, and in particular to forest monitoring. A satellite-based early warning system for deforestation is just one example of a new technology that makes a previously impossible task an achievable reality.

20. **Continuous biomass maps: a new way of looking at an old problem.** Less dramatic, but still ground-breaking, is the possibility to generate nation-wide, wall-to-wall maps and digital datasets representing actual aboveground biomass levels, based on a systematic measurement using satellite radar data. Currently widely available conventional forest type maps simply show classes or categories of forest types. Changes only appear when there is a change from one forest type to another and change within a class is not detected or shown[xi]. By contrast, maps of continuous variables can also reveal low-level change, making them highly relevant for early detection of degradation and deforestation. This may also lead to new ways of reporting on actual changes in biomass instead of simply on forest/non-forest categories.

21. **With many EO tools and data being free of charge, testing becomes easier and new approaches can be developed to meet localized information needs.** Given that the monitoring tools are freely accessible and use open access EO data, there is little cost – other than staff time and other in-house costs –testing the tools in the operational context. Forest managers should enable and encourage technical staff and monitoring specialists to explore the tools and their documentation and run the tools on small, well-known areas. This will allow judging the tool's relevance and the assessing added value the tools could provide to existing forest monitoring processes. In addition, if these modern tools are used on EO platforms such as SEPAL, users can test and compare the tools and tool outputs to other methodologies offered on the platforms.

22. **To benefit from the potentials of modern EO approaches, relevant tools need to be integrated into existing forestry department operations and processes making these more efficient. This also requires that the importance of information management is recognized by senior management.** The new EO methodologies have been developed into open source software tools that are well documented, their implementation is relatively feasible in professional organizations. This requires local capacity to adjust and use the applications, and forest departments interested in making use of the tools need to have staff capacity and remote sensing and IT skills. Specialized remote sensing or forest monitoring units are probably best suited to operate and test the tools. If a forestry department does not have such units and there are no plans for setting them up, an institutional collaboration with a national remote sensing center could offer a solution. Irrespective of the institutional format, it is essential that information is recognized as an essential part of forest administration. If possible, agencies can nominate a *chief information officer* at senior management level. This would demonstrate that information management and use of appropriate data is recognized at the highest level.

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[i] Food and Agricultural Organization of the United Nations: Trees, forests and land use in drylands: the first global assessment, full report, Rome 2019

[ii] Emerging online cloud services for EO data processing – for example FAO's SEPAL or ESA's F-TEP platforms – have the advantage of having necessary processing algorithms already installed with significant processing power and storage capacity. Satellite data are not downloaded and stored for local processing but are instead processed in the cloud at the source, requiring only to download and store the analysis results. This allows using satellite data also in environments that have narrow bandwidth for internet access.

[iii] The project was implemented in close collaboration with the European Space Agency (ESA), University of Edinburgh, LTS International and forest and REDD+ authorities in Mozambique, Namibia and Zambia.

[iv] Examples for optical imagery include NASA's Landsat with archived data from 1972 and the European Space Agency's (ESA) Sentinel-2 data.

[v] Radar can have different wave lengths and generally, the longer the wavelength, the greater the penetration into the target (e.g. vegetation and soil). In EO, the commonly used wavelengths are C- and L-band, where L-band has longer wavelength and is thus able to collect more information. L-band is particularly suitable for measuring the woody biomass component of dry forest trees. Another widely use type of radar data, shorter wavelength C-band, is more common but it does not capture tree volume that well. Shorter wavelength data gets 'saturated' more easily, i.e. it stops to recognize changes after a given, relatively low level. Examples for radar imagery include ESA's Sentinel-1 (C-band) and the Japan Aerospace Exploration Agency's (JAXA) ALOS PALSAR (L-band) data.

[vi] "Open source" software (or technology) is software with source code that anyone can inspect, modify, and enhance. This is different from "proprietary software" that has source code that only the person, team, or organization who created it—and maintains exclusive control over it—can modify. In some cases proprietary software can be distributed free-of-charge but it still remains the developer's intellectual property.

[vii] This applies also to proprietary tools are currently provided free-of-charge or under preferential terms to developing countries.

[viii] Systems using radar backscatter models produce over time more consistent biomass maps compared to repeated land cover classifications from optical satellite imagery. The fact that radar methods are based on a "static" calibration model that defines the ratio between radar backscatter values and levels of woody biomass makes it more of a "measurement" of signal values rather than an "interpretation" of spectral information as in conventional satellite image classification.

[ix] The tool uses freely available annual mosaics of ALOS Palsar L-band data prepared by JAXA.

[x] This approach works reasonably well up to AGB values of 150t/ha (approx. 75 tC/ha). Generally, AGB values for tropical dry forest are in the range of 100-150 t/ha, with dry woodlands ranging at 20-100 t/ha and open savannas at 5-20 t/ha.

[xi] Change in class does not necessarily reflect how big the change has been. For example, if canopy cover is barely above the threshold in the local forest definition and it declines just below it, the change is classified as deforestation. As a comparison, as long as the canopy cover percentage remains above the threshold in the forest definition, even large canopy cover changes are not identified in deforestation maps.