XV WORLD FORESTRY CONGRESS
Building a Green, Healthy and Resilient Future with Forests
2–6 May 2022 | Coex, Seoul, Republic of Korea

Forest monitoring: issues and good practices in sample-based area estimation

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Abstract

REDD+ and greenhouse gas reporting for the agriculture, forestry and other land use (AFOLU) sector requires land use changes to be characterized to estimate the associated greenhouse gas emissions or absorptions. It is becoming increasingly common for countries to track these changes using visually interpreted, sample-based approaches. Known as sample-based area estimation, the technique has been widely used in recent years in the generation of activity data for REDD+ Monitoring Reporting and Verification (MRV). However, implementing countries and agencies have repeatedly highlighted the lack of guidance on certain frequently encountered issues with this approach. This paper responds to this need for guidance by trying to address the most urgent technical issues faced by countries relating to sample based area estimation. Among others, it tackles issues such as how to best monitor beyond deforestation or for multiple purposes, how to account for variability between interpreters looking at the same satellite image, what type of sample unit to use and how many measurements are needed per sample unit. Existing good practices are consolidated, and new good practices are proposed as solutions where appropriate. The paper also indicates areas of future research, which should be pursued to answer the remaining questions surrounding area estimation. This paper will enable donors, academia, and countries that currently use or that want to use sample based area estimation for generating activity data for REDD+ or for other purposes. This paper is conceived to gain an overview of the most pressing research needs in the area and to delve into current good practice and existing literature. It will give non-experts an overview of area estimation, its applications and limitations.

Keywords: area estimation, REDD+, statistics, remote sensing, forest monitoring

Introduction, scope and main objectives

Reducing emissions from deforestation and forest degradation and enhancing forest carbon stocks by way of forest restoration and afforestation are essential to limiting global temperature rise to 1.5°C, which countries committed to under the Paris Agreement (IPCC 2019, Roe et al 2019).

REDD+ and greenhouse gas reporting for the agriculture, forestry and other land use (AFOLU) sector requires land use changes to be characterized to estimate the associated greenhouse gas emissions or absorptions. It is becoming increasingly common to generate these estimates using sample-based area estimation. The technique has been widely used by countries in recent years in the generation of activity data – particularly for estimating areas of deforestation for REDD+ MRV. However, implementing countries and agencies have repeatedly highlighted the lack of guidance on how to address certain frequently encountered issues with this approach.

The objective of this paper is to bring to light to the most urgent technical issues faced by countries relating to sample-based area estimation, as identified and ranked by experts in 2020. The issues are addressed in full in the white paper "Issues and good practices in sample-based area estimation" (FAO, 2022 (in press)).

Methodology/approach

Beginning in March 2020, FAO conducted a series of online consultations using teleconferencing software and online

surveys targeting identified experts including representatives from more than 15 national governments and from academia in order to gain a list of the most urgent issues to address in sample-based area estimation. FAO compiled the issues highlighting priority areas and grouping them into four technical areas: general design of monitoring system; sampling design; response design; and QA/QC. The compilation was shared and discussed with experts in a series of three webinars to gain a final expert ranking of priority areas to address in sample- based area estimation. Experts collaborated on a white paper "Issues and good practices in sample-based area estimation" (FAO, 2022, in press) and this conference paper is a distillation of the key lessons from that white paper. For a deeper analysis, readers are invited to read the relevant section(s) of the white paper once it becomes available in 2022.

Results

The results of the ranking of the top issues to be addressed concerning the technique sample based area estimation (SBAE) can be seen in Table 1. Experts narrowed the original list of 81 issues down to the 13 most pressing. Note that the 13 issues in the table are of equal ranking and that the remaining 68 lower ranked issues are not shown here. The numbers 1-13 are for reference to the text that follows the table, rather than indicating order.

Table 1: The expert ranking of the top issues per technical area relating to sample based area estimation

Technical area	Issue
General design of monitoring system	1. Sample-based area estimation in monitoring degradation, reforestation and afforestation
	2. Issues related to varying dates and qualities of imagery in sample-based area estimation
	3. Maintaining consistency as imagery improves
Sampling design	4. Omission errors in large strata in stratified area estimation
	5. Sampling designs for multi-purpose monitoring
	6. Temporal tracking of land use in the context of temporary vs. permanent sample units
	7. New stratification vs. updating a base map for stratified area estimation
	8. Estimators for sample-based area estimation in finite and infinite populations including effects on sample units spanning strata boundaries
Response design	9. Point, pixel or multi-point area-based sample units: practical considerations
	10. Area-based sample unit design – number of points and sample unit size
	11. Labelling protocols and sample unit data summarization
	12. Interpretation paradigms: interpretation without or with context
QA/QC	13. Assessing and reporting quality of reference data

Summary of issues relating to the general design of a monitoring system

1. In forest monitoring SBAE has been mostly used for estimating area of deforestation, but is being increasingly used for estimating areas of degradation, afforestation etc. This requires additional considerations. The REDD Sourcebook (Achard et al, 2016) and the GFOI MGD (2020) provide good overviews of the methods for monitoring REDD+ activities including degradation. Examples can be found in Shimabakuro et al (2014), Lima et al (2019), Maniatis and Mollicone (2010), Bullock et al (2020) and in the Forest Reference Emission Levels (FRELs) of Liberia (2019) and Equatorial Guinea (2020). A sampling design based on a combination of systematic and stratified can provide the flexibility to assess a range of parameters beyond deforestation. It is essential to have a robust interpretation (response) protocol to assess degradation transitions and more guidance needs to be made available on response design for degradation.

2. Low quality and availability of temporally and spatially consistent images are common obstacles when estimating land cover/land use changes over time. Differences between pixels (e.g. size, acquisition date, season, cloud cover) need to be accounted for to minimize the effect on interpretation and subsequent area estimation. Using cloud-free composites, using the same spatial resolution for Time 1 and Time 2 and using imagery for stratification and for reference data from the same season are good practices to address radiometric anomalies such as clouds, spatial inconsistencies and spectral inconsistencies, respectively. Tracking the date of each pixel used and using reference data the date of which is as close as possible to the target date are very important and one of the simplest ways to reduce errors induced by temporal inconsistencies. It is good practice to use all available data (i.e. all available sensors and time series) to facilitate the best possible interpretation of the sample units.

3. In order to track emissions and mitigation actions, it is essential to use consistent methodology. For REDD+, countries need to compare activity data from a reference period with their FRL/FREL. However, satellite imagery as well as the software used to analyse it are continually evolving. While improvements can mean increased accuracy, it can also mean that estimates are not comparable with the FRL/FREL. Maintaining consistency can be a challenge that needs to be adequately addressed. When using improved satellite imagery with SBAE, four good practices were identified: maintain minimum mapping unit and imagery sources used in reference period throughout the reporting periods; use the improved data not necessarily to report but rather to ensure that estimates based on interpretation of original imagery are consistent and conservative; in the case that better imagery is available for the entire time series it is possible to switch to this data; and use the better imagery to prepare land use/land cover change maps to stratify the area of estimation for the reporting periods.

Summary of issues relating to sampling design

4. When a stratum is large, it is possible to miss categories of interest such as deforestation. These omission errors (i.e. deforestation occurred but was not identified in the stratification map) in SBAE, especially those occurring in large strata, may have a strong impact in uncertainty assessment (Olofsson et al. 2020). There are two options for practitioners to decrease the impact of omission error: a) increase sample size or decrease the size of the stratum; or b) define an additional “buffer” stratum that is intended to capture omission errors. Further research is required on creating maps that effectively identify the “buffer” stratum, and on the statistical question of how the trade-off between area of omission captured by the buffer stratum and total area assigned to the buffer stratum impact precision.
5. Defining the sampling design of a monitoring system that is intended to be multi-purpose (beyond forest) can pose challenges. Different sampling designs can be selected depending on the specific needs of each country (GFOI 2018, 2020). Stratified random sampling can be useful when rare classes are present (such as change classes). Having a minimum sample size in all strata then allocating the remaining sample units proportionately to the rest of the strata is recommended (Olofsson et al 2014). Systematic or simple random sampling do not require a map for stratification and are easy to implement but require large sample sizes to capture rare classes with low uncertainty. Another option is to intensify sampling in areas where the rare classes occur. The sampling design of multipurpose should be designed to be integrated with other monitoring systems such as field observations from NFI. This can generate synergistic information that is of greater value than that produced

independently by each system. Common land use and or land cover classification systems should be used for both/all systems to be integrated, and consideration should be given e.g. to plot size. 6. As mentioned above, stratified random sampling is frequently used to estimate change area. However, it is usually implemented successively in the form of independent surveys. This precludes tracking of land use through

time, which can severely impede the ability to detect real change and/or lead to double counting through time. Three approaches are recommended in order to overcome this challenge: assess the history of each temporary sample unit in the years preceding the monitoring period; use permanent sample units rather than temporary with systematic or random sampling; use a combined approach of systematically sampling permanent sample units and stratified sampling with temporary sample units.

7. Closely related to point six, some countries opt to create new stratification maps for each reporting interval while others create a base-map that is updated over time. More research is needed to determine the pros and cons of each. The 2018 FREL of Suriname is a good example of the update of a base-map, as well as of the third approach mentioned in point 6 above (Suriname, 2018).
8. There are three theoretically different sampling strategies: two-stage, two-step and cluster (refer to Patterson (2012) for more detail). The choice of sampling strategy depends on the practitioner's preference, yet the theoretical differences between the three have some practical implications that should be considered. Clear articulation of the sampling strategy selected is important for international reporting. Use of a two-step sampling strategy avoids the issues of sample units crossing strata boundaries and of imperfect tessellation to the population. However, unlike the other two strategies (two-stage and cluster) it can require familiarity with infinite population theory.

Summary of issues relating to response design

9. Different types of sample units have been used for SBAE, with a review of the main types in GFOI (2018). It can be shown that for the same number of sample units, area-based multi-point units yield higher precision estimates than those calculated using pixels or points. The number of additional point or pixel sample units needed to achieve the same precision depends on the distribution of classes across a landscape. The tradeoff between cost, evaluation time and precision needs to be considered.
10. If opting to use the above-mentioned (point 9) larger area-based sample units, the following questions arise: how many plots are needed, how large should they be, how many points should be placed within each one and how should those points be distributed? Endeavoring to lower the standard error to an acceptable level can be one reason for deciding how many plots, how many points per plot and how large plots should be. Deciding on these parameters should be based on needs (e.g. of users in terms of standard error, reporting requirements, costs and of the practicality of implementation).
11. Three different labeling protocols are commonly used to assign a class to a sample unit: 1) assigning a single dominance class to the sample unit, 2) recording the land use proportions for each sample unit, and 3) recording and maintaining the point-level LULC labels. 1) may be easier to analyze, but it should be considered that even small changes in the land classes in the plot can lead to a) a complete change in the dominance class of the plot from one class to another which may lead to false detection (commission error) of land use change, or b) could lead to errors of omission as land use change which does not reach the threshold for dominance remains undetected/unreported. 2) increases the amount of detail captured about landscape composition but it may be hard to assess the LU transitions within the plot: only net population-level changes can be accurately calculated from these data. 3) provides the most exact information and allows tracking of land use changes within the plot.
12. Interpretation rules are core to response design. When assigning a label to a sample unit or the elements within, interpreters usually take into consideration the forest definition and minimum map unit. Two basic types of interpretation rules have been implemented referred to as interpreting the land use without or with context. Interpreting without context is determining whether the sample unit is forested by assessing whether the amount of tree cover within the sample unit meets or exceeds the forest canopy cover definition without looking at the landscape around the unit. Instead, in interpretation with context the interpreter examines land use patterns both within and without the

sample unit. These two approaches may lead to different results. Generally, interpretation with context will provide a more exact estimate of the areas of the different land uses than interpretation without.

Summary of issues relating to QA/QC

13. Visual interpretation is susceptible to error and inconsistencies between interpreters. Some good practices to improve consistency include using 5-7 interpreters, developing labeling protocols and/or SOPs, common training regimes, consistency checks discussing problematic cases. Differing interpretations can be resolved by expert decision, consensus decision or majority interpretation but more guidance is needed. There are currently two approaches to estimating interpreter variability: using multiple interpreters for all sample units (McRoberts et al. 2018) and the random subsample selected for duplicate

interpretation (Pengra et al. 2020). Templates for reporting interpreter error and further guidance on disagreement resolution, training and estimating variability are needed.

Discussion

More and more countries are using sample based area estimation as part of their national forest monitoring systems (most of them for deforestation). This approach is able to provide information in line with IPCC guidelines at relatively low cost and within the period needed for UNFCCC reporting. There are free tools and guidance available and many countries have developed capacities to implement it by themselves. As it is increasingly, implemented, technical issues have emerged relating to each step of the process (general design, sample design, response design and QA/QC).

Of the many issues identified only 13 were prioritized and addressed here. Those remaining issues still need to be described and analysed to identify good practice. For each of the 13 priority issues covered here, there are several areas of further research required.

As the SBAE process is quite flexible it is adaptable for each country to satisfy their needs, and there are several options to choose at each step of the process (different sampling design, plot size and shape, number of classes etc.), some of which were briefly described here. Most of those options have so far been implemented without deep analysis on quantifying the implications of using one versus the other. Further research that attempts to quantify those implications will better inform national decision-making, forest management and planning, and reporting on international commitments, notably the Paris Agreement. It is hoped that this paper and the more detailed white paper (FAO, 2022) is a start.

Conclusions

The summary of issues and good practices described here is a brief compendium of the prioritized issues identified by expert consultation conducted in 2020 concerning the approach sample based area estimation. The paper should be of interest to anyone planning or currently implementing SBAE as an aide in identifying and avoiding possible issues and good practices to improve the process. Some areas of further research were identified, and donors, capacity building practitioners and experts should consider these in the near future.

Acknowledgements

The present paper is a brief summary of the FAO white paper “Issues and good practices in sample-based area estimation” (expected publication 2022). The present work is therefore entirely based on the contributions of the many expert authors who contributed to that publication: the authors wish to thank Frédéric Achard, Remi D’Annunzio, Andres Espejo, Erik Lindquist, Andrew Lister, German Obando, Pontus Olofsson, Paul Patterson, Ron McRoberts, Christophe Sannier, Charles Scott and Steve Stehman for their work.

The authors also wish to thank the World Bank Forest Carbon Partnership Facility for funding this study.

The views expressed in this information product are those of the author(s) and do not necessarily reflect the views or policies of FAO.

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