UN-REDD PROGRAMME

Expert meeting on assessment of forest inventory approaches for REDD+

Meeting Report

UN-REDD PROGRAMME

Rome, 31 May and 1 June 2011

UN-REDD Programme
MRV Report 8
2010

MEETING BACKGROUND

In February 2011, twelve prominent experts in forest inventory wrote to FAO and suggested holding a scientific meeting on forest inventory in relation to the requirements of REDD+. The concern expressed is that current approaches to REDD+ monitoring of forest carbon do not appear to take statistical analysis aspects sufficiently into consideration. Given the long experience of the developments in the science and application of national forest inventories, it may be valuable to the UNFCCC process to review this knowledge and its application for REDD+ monitoring.

On 31 May and 1 June 2011, **the Expert meeting on assessment of forest inventory approaches for REDD+** was held at FAO headquarters in Rome, Italy. The meeting objectives were to develop preliminary criteria for evaluating the design of national forest inventory systems with respect to C and delta-C estimates; assess the needs and opportunities to contribute to the methodological guidance to be prepared by UNFCCC and IPCC; define how a science forum, facilitated by FAO, can be organized to advise countries on national forest inventories/monitoring for REDD+ and prepare key preliminary messages for the above. We involved IPCC in this meeting, noting that the 2006 IPCC guidance on preparing greenhouse gas inventories promote the use of national forest inventories[1], and will continue the discussion as to what is the appropriate ways to work together to serve our member countries with knowledge, advise and technical assistance.

While the focus of the meeting was on C and delta-C estimates, it is also acknowledged that national forest inventories provide a wider range of information, related e.g. to REDD+ safeguards. National forest inventories therefore have a potential to support broader reporting requirements, as well as policy analyses in relation to REDD+ and broader forest/natural resources management.

16 visiting specialists and 17 FAO staff members attended (see the ***List of Participants*** in Annex 1).

[1] Note that the word ”inventory” is used is different ways. In the case of “greenhouse gas inventory”, it refers to a report (tabulated data) of emission fluxes (sources and removals). In the case of “national forest inventory”, it refers also to the process of data collection and analysis, in addition to the resulting tabulated data (see also Annex 4 on the definition of a national forest inventory).

MEETING PROCESS AND RESULTS

The meeting was conducted in three parts, following the ***Agenda*** in Annex 2.

The first part was an exchange of experiences and knowledge between the visiting specialists and FAO staff. Presentations are available through the FAO Climate Change website, under past events: http://www.fao.org/climatechange/53685/en/.

The discussion revolved around the following topics:

General

- Does the IPCC GPG model of activity emission factor work In a forest/REDD+ context, eg what is an activity?) (esp. valid when following all carbon) (are the tier1+2 requirements good enough?)
- What are the actual accuracy requirements?
    - what is good enough?
- How to achieve practical, believable and credible/trusted results?
    - trusted without additional costly reviews (this may be as important as error levels)
    - how to communicate error estimates and how use this information
    - what is simple enough?
- Wider objectives of nfi (definition of nfi)
    - Is C-MRV a subset of nfi (with necessary modifications to meet needs of REDD+ and GHG inventory)?
        - similarly, nfi data used for GHG inventory development
    - nfi includes field measurements and remote sensing approaches?
- How to develop systems over time, from scratch, phased improvements? (as seen in Annex-1 country reports)
- Capacity (international and national)
- Legal and institutional investments
- Replicability between countries (efficiency and capacity gains)
- Countries need to start developing nfi's now, for future performance-based payments

Specific for C and delta-C estimations

- Statistical design, sampling, stratification
    - how incorporate GHG inventory requirements?
- How to avoid basic bias?
    - for example how can we extrapolate emission factors?
- Estimates and error estimate methods, especially with respect to change
- Role of remote sensing
    - use beyond stratification?
- Cost-effectiveness
    - including plot design, which needs to be part of the overall design, pilots (but don't spend too much efforts on this, "optimal" design does not exist)
    - does small plot size require better info on forest/non-forest/land uses?
- Allometric functions
    - how to get funding in a trendy research finance situation (approach finance institutions that want to invest in REDD+)

In part two of the meeting, the visiting specialists discussed internally and formulated a set of guidelines, which are presented in Annex 4. These guidelines constitute the main and direct result of the meeting.

Part three of the meeting included both visiting specialists and FAO staff and considered optional ways forward. It was concluded that:

- Formalization of national forest monitoring (or national forest inventory) guidelines that include considerations for REDD+ monitoring and reporting requirements should be a priority for FAO;
- The recommendations of this meeting should be made available to the UNFCCC process through side events and/or submissions before COP-17 in Durban;
- Possibilities to include an expert meeting in the IPCC work plan for 2012 that addresses national forest inventories;
- The visiting specialists expressed their willingness to continue to contribute to this important work area.

ANNEX 1. PARTICIPANTS

Visiting Specialists

Ms/Mr	First name	Last name	Affiliation	Email
Mr	Piermaria	Corona	University of Tuscia, Italy	piermaria.corona@unitus.it
Mr	Simon	Eggleston	IPCC	eggleston@iges.or.jp
Mr	Lorenzo	Fattorini	University of Siena, Italy	fattorini@unisi.it
Mr	Lutz	Fehrmann	Georg-August-University, Germany	lfehrma@gwdg.de
Mr	Timothy	G.Gregoire	Yale University, USA	timothy.gregoire@yale.edu
Mr	Terje	Gobakken	Norwegian University of Life Sciences	terje.gobakken@umb.no
Mr	Christoph	Kleinn	Georg-August-University, Germany	Ckleinn@gwdg.de
Mr	Steffen	Lackmann	Coalition for Rainforest Nations	steffen.lackmann@gmx.de
Mr	Aleksi	Lehtonen	Finnish Forest Research Institute	aleksi.lehtonen@metla.fi
Mr	Erik	Naesset	Norwegian University of Life Sciences	erik.naesset@umb.no
Mr	Ross	Nelson	NASA, USA	Ross.F.Nelson@nasa.gov
Mr	Goran	Stahl	Swedish University of Agricultural Sciences	goran.stahl@srh.slu.se
Mr	Stephen	Stehman	State University of New York, USA	svstehma@syr.edu
Mr	Tomas	Thuresson	Norskog	Tomas.Thuresson@norskog.no
Mr	Erkki	Tomppo	METLA, Finland	erkki.tomppo@metla.fi
Mr	Andreas	Tveteraas	Norwegian Climate and Forest Initiative (by phone)	andreas.tveteraas@md.dep.no

FAO participants

Ms/Mr	First name	Last name	Affiliation	Country
Mr	Peter	Holmgren	FAO, Director, Climate, Energy and Tenure Division (NRC)	Peter.Holmgren@fao.org
Mr	Jose Antonio	Prado	FAO, Director, Forest Assessment, Management and Conservation Division (FOM)	JoseAntonio.Prado@fao.org
Mr	Jim	Carle	FAO, Chief, Forest Resources Development Service (FOMR)	Jim.Carle@fao.org
Mr	Alberto	Sandoval	FAO, UN-REDD Programme Coordinator (NRC)	Alberto.Sandoval@fao.org
Mr	Dan	Altrell	FAO, FOM	Dan.Altrell@fao.org
Ms	Anne	Branthomme	FAO, FOM	Anne.Branthomme@fao.org
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Ms	Inge	Jonckheere	FAO, FOM	Inge.Jonckheere@fao.org
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Mr	Danilo	Mollicone	FAO, FOM	Danilo.Mollicone@fao.org
Mr	David	Morales	FAO, FOM	David.Morales@fao.org
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Mr	Marco	Piazza	FAO, FOM	Marco.Piazza@fao.org
Ms	Rebecca	Tavani	FAO, FOM	Rebecca.Tavani@fao.org

ANNEX 2: AGENDA

31 May		
8.30 – 9.00	Registration, Coffee	
9.00 – 9.30	Opening Introductions Objectives	**Peter Holmgren** **Jose Antonio Prado**
9.30 – 12.30	**Framing the issue – What is the problem?**	
	Recap of REDD+ status and key activities to help prepare countries for REDD+	**Peter Holmgren**
	Issues raised in the scientist's letter	**Tim Gregoire**
	Real-world example – Guyana (after 11.00)	**Andreas Tveteraas** **Erik Naesset**
	What does IPCC say? Specifically about estimation errors?	**Simon Eggleston**
	Examples of design experiences of national forest inventories in REDD+ countries (eg Tanzania, Ecuador, Vietnam, DRC, Indonesia, PNG, Zambia) One-pagers to be prepared by presenters before meeting	**Erkki Tomppo,** **Danilo Mollicone** **Anssi Pekkarinen** **Danae Maniatis**
	Comparison of issues between REDD+ and Lulucf	**Lead discussant tbd**
	Discussion Expected outcome: Clarification of concerns	
12.30 – 14.00	Lunch	
14.00 – 15.30	**Progress report on the Systematic review on "Comparison of methods for the measurement and assessment of carbon stocks and carbon stock changes in terrestrial carbon pools"** Discussion **Expected outcome: Possible implications of findings of the systematic review for nfi research and implementation**	**Hideki Kanamaru**

15.30 – 17.00	**Preliminary identification of key issues/properties of a nfi to serve needs of national (large scale) estimates of carbon and delta-carbon including error estimates** **First part of discussion to focus on C and delta-C estimates, including sampling, use of remote sensing, allometry, change estimations**	**facilitator tbd**
1 June		
9.00 – 12.30	**Continued identification of key issues/properties** **Second part of discussion to include wider information needs/synergies and institutional considerations** **Expected outcome: "Checklist" of key considerations for nfi design/approach including carbon and delta-carbon estimates, and also broader concerns (wider information needs, institutional issues)**	**facilitator tbd**
12.30 – 13.30	Lunch	
13.30 – 15.00	**Opportunities for continued engagement** Opportunities for contributing to IPCC Opportunities for on-request scientific advise to countries Science (or science publication) gaps that could be filled Relevance and practicalities of a science forum on nfi design (for REDD+) Reporting from this meeting Next steps **Expected outcome: Recommendations on actions**	**facilitated by Holmgren**
15.00	**Closing**	

ANNEX 3. BIOGRAPHICAL SKETCHES OF VISITING SPECIALISTS

Biographical Sketches of Visiting Specialists

Piermaria Corona CV: http://www.disafri.unitus.it/staff.asp?azione=paginaUte&idPag=84
University of Tuscia (Italy) - mobile: 0039.3204304138 - email: piermaria.corona@unitus.it

For the past 20 years I have taught & conducted research in the areas of forest inventory and management. Since 2005, I have collaborated with Fattorini on coupling remotely sensed and field data for forest inventory and mapping purposes, and on the assessment of trees outside forests. I have been involved in the activities of the Italian Ministry of Environment concerning the reporting for Kyoto protocol.

Lorenzo Fattorini
Research interest: design-based inference; sampling strategies for environmental surveys

Professor of Statistics at the Faculty of Economics "R.Goodwin", University of Siena. From 2000 to 2003 and from November 2009 to April 2010 he has been Head of the Department of Quantitative Methods of the University of Siena.

He is currently working on sampling strategies for environmental surveys, with a special emphasis on the problems associated with estimating abundance and ecological diversity in plant and animal communities. He also has planned the sampling strategy adopted in the last Italian National Forest Inventory. At the moment he is Associate Editor of Environmetrics. From 2006 to 2009 he has been Coordinator of the National Permanent Working Group of the Italian Statistical Society on "Sample Survey Methodology".

Lutz Fehrmann, Georg-August-Universität Göttingen, lfehrma@gwdg.de
Research Assistant at the Chair of Forest Inventory and Remote Sensing

Research interest is in large area forest inventory, monitoring and assessment, comprising research, academic teaching, training and implementation. Special emphasis is on the optimization of sampling- and field plot designs in context of large area inventories. A further research topic is on non-parametric nearest neighbor techniques and the integration of remote sensing and field observations.

FAO expert consultations in context of planning for national forest inventories in the REDD context (Ecuador) and modeling of forest biomass and carbon sequestration.

Terje Gobakken (terje.gobakken@umb.no)
Associate professor at the Department of Ecology and Natural Resource Management at the Norwegian University of Life Sciences since 2006.

From 2004 to 2006 he was working at the Norwegian National Forest Inventory and was responsible for developing the calculations routines for the first Norwegian Reporting of Emissions and Removals from Land use, Land-use Change and Forestry (LULUCF) and reporting according to the Kyoto Protocol. He was participating in the European COST Action E43, 2004-2006.

His first peer-reviewed paper about airborne laser scanning was published back in 2004 and he has since 2006 been involved in sampling issues related to laser-assisted surveys (in collaboration with Gregoire,

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Nelson, Næsset, and Ståhl). He has to some extent also maintained his initial competence by some studies related to growth/yield, GIS, and long-term scenario models.

Timothy G. Gregoire CV: http://environment.yale.edu/uploads/profiles/docs/gregoire-cv.pdf
Yale University mobile: 1.203.508.4014 email: timothy.gregoire@yale.edu

For the past 30 years he has taught & conducted research in the areas of sampling and modelling correlated data with special emphasis on forestry applications. Fellow of the American Association for the Advancement of Science; Fellow of the American Statistical Association; Elected member International Statistical Institute

Since 2004, he has collaborated with Næsset and Nelson on application of LiDAR for aboveground forest biomass estimation.

Currently, he is helping the Ministry of Agriculture and Forests of Bhutan in the design and implementation of its NFI.

His 2008 text entitled *Sampling Strategies for Natural Resources and the Environment* can be browsed at http://crcpress.com/product/isbn/9781584883708

Christoph Kleinn, Georg-August-Universität Göttingen, ckleinn@gwdg.de
Head, Chair of Forest Inventory and Remote Sensing
Dean, Faculty of Forest Sciences and Forest Ecology (2010-2012)

Interest and experience in large area forest inventory, monitoring and assessment, comprising research, academic teaching, training and implementation.

Comprehensive practical experiences in large area forest inventory implementation in Nepal, Thailand, Mozambique, Costa Rica, Colombia, FYROM et al.

Collaborating with FAO on inventory issues since 1988. Member of the technical advisory group to the FAO Programme NFMA. Honorary member of the scientific advisory group to the Forest Survey of India, Member of the team of experts to the German NFI.

Ronald E. McRoberts email: rmcroberts@fs.fed.us
Mathematical Statistician, Forest Inventory and Analysis, U.S. Forest Service

Fellow American Statistical Association, Elected member International Statistical Institute, Elected member Italian Academy of Forest Science, Research Fellow Finnish Forest Research Institute

Member of U.S. SilvaCarbon initiative
Primary technical advisor to Guyana Forestry Commission in development of MRV
Co-editor of Springer book: *National Forest Inventories: Pathways for Common Reporting*

Research interests: statistical aspects of remote sensing, model-based inference, uncertainty assessment, nonlinear modeling, nearest neighbors techniques

Erik Næsset (erik.naesset@umb.no)
Norwegian University of Life Sciences, Department of Ecology and Natural Resource Management

My primary interest over the last 15 years has been development and implementation of operational methods for forest management inventories based on airborne laser scanning. This research also involves systematic studies of the influence of all sorts of technical parameters (sensor parameters, flight parameters) on the data and consequently on the forest variables produced at stand and plot level. Assessment of precise positioning techniques (GPS, GLONASS) for field observations (e.g. sample plots) is also part of the overall effort to use lasers for forest inventory.

Over the last 8-9 years the application of airborne lasers have been extended to include monitoring of effects of climate change (e.g alpine tree lines), changes in biomass and carbon stocks in marginal forests, detection and assessment of forest damage (insect attacks), sampling issues related to laser-assisted surveys (in collaboration with Gregoire, Gobakken, Nelson, Ståhl). I have to some extent also maintained my initial competence by some scattered studies over the years about stereo photogrammetry, growth/yield, decay of dead wood, allometry, long-term scenario models etc.

Ross Nelson (ross.f.nelson@nasa.gov),
bio: http://neptune.gsfc.nasa.gov/bsb/personnel/index.php?id=118
Biospheric Sciences Branch, Code 614.4, NASA-Goddard Space Flight Center, Greenbelt, MD, USA

His research interests center around (1) the use of airborne and space lidars as sampling tools for large-area forest inventory and regional/subcontinental carbon estimation, (2) the development and validation of sampling frameworks that incorporate these airborne and space lidar assets, and (3) the use of ancillary remotely sensed data sets, e.g., Landsat ETM+, MODIS, ASTER, PALSAR, to facilitate the large-area surveys. He's worked in the Biospheric Sciences Branch at Goddard for 30 years.

Göran Ståhl, Professor of Forest Inventory and half-time Vice Rector of SLU, responsible for environmental and resource monitoring issues.

My research involve forest inventory methodology ranging from practical fieldwork aspects to sampling theory. Lately the studies have involved harmonisation of estimates from large-scale inventories, using LiDAR techniques for sampling applications, and development of designs for the survey of sparse populations. Besides research I have, among other things, participated in the development of the Good Practice Guidance for GHG reporting for the LULUCF sector and developed a reporting system for Sweden. Between 1997 and 2008 I was the Head of the Swedish National Forest Inventory.

Steve Stehman (svstehma@syr.edu)
State University of New York, College of Environmental Science & Forestry (Syracuse, NY, USA)

My primary work relates to using sampling methods to estimate land-cover change from remotely sensed data. I have collaborated with Matt Hansen (South Dakota State, USA) on a project to estimate gross global forest cover loss for 2000-2005 based on Landsat imagery and with Tom Loveland (United States Geological Survey, USGS) on a project to estimate change in US land-cover (1973-2000) based on sampling and interpreting Landsat and MSS imagery. I have also worked with USGS to develop sampling methods for assessing accuracy of land-cover and land-cover change maps and investigated methods for estimating area (and accompanying standard errors) based on these map validation samples.

E. Tomppo has done research in the areas of forest remote sensing, forest inventory, biodiversity and biomass estimation for almost the past 30 years. Email: Erkki.Tomppo@metla.fi

Since 1990 until 2004, he was responsible for the Finnish National forest inventory, and after that, has been responsible for the project developing sampling and estimation methods for the Finnish NFI, including the entire multi-source NFI.

He was the chairman of the Management committee of the European COST Action E43, 2004-2008.

He constructed the sampling design for Tanzanian forest Inventory (NAFORMA) in a collaboration with FAO and the local experts, is on temporary leave from Metla working for FAO for establishing inventories in NFMA countries (Zambia, Vietnam) and estimation methods for Tanzania.

Authored or edited books:

Tomppo, E., Haakana, M., Katila, M. & Peräsaari, J. 2008. *Multi-source national forest inventory - Methods and applications*. Managing Forest Ecosystems 18. Springer. 374 p. ISBN 978-1-4020-8712-7

Tomppo, E., Gschwantner, Th., Lawrence, M. & McRoberts, R.E. (eds.) 2010. *National Forest Inventories - Pathways for common reporting*. Springer, 612 p. ISBN 978-90-481-3232-4

Tomppo, E., J. Heikkinen, H. Henttonen, A. Ihalainen, M. Katila, H. Mäkelä, T. Tuomainen, and N. Vainikainen. 20110b. Designing and conducting a forest inventory - case: 9th National Forest Inventory of Finland. *The 9th National Forest Inventory of Finland - methods and results*. To appear in Springer monograph series Managing Forest Ecosystems. Manuscript.

ANNEX 4. GUIDELINES FOR MULTI-OBJECTIVE NATIONAL FOREST INVENTORY TO SUPPORT REDD+ MRV

Background

The purpose of this document is to present general and good practice principles (guidelines) for planning and implementing a multi-objective national forest inventory as one of the crucial objectives to provide forest and land use and land use change information for REDD+ MRV. Note that IPCC guidelines give only recommendations, not binding instructions. The document has been written by a group of forest inventory and forest biometrics experts with the support of FAO. The goal is to help decision makers and inventory experts to establish long-term forest inventory systems which are grounded in sound practice and defensible scientific rigor.

The term NFI is used repeatedly in this document as an abbreviation for National Forest Inventory. A working definition of forest inventory has been provided in (2010) *National Forest Inventories* (DOI 10.1007/978-90481-3233-1_1): "forest inventory refers to both the tabulated forest information and to the process of measuring and analyzing the data on which the tabulated information is based." The adjective National in NFI implicitly defines the geographic and political scope of the inventory. By the "design" of an NFI we mean the entire suite of functions needed to implement the inventory and to assess the results it yield. These include the data collection methods, data processing methods, the inferential methods to draw scientifically credible results from the data. The NFI design is a function of the available resources and given accuracy requirements. As the term implies, a multi-objective NFI is designed to provide quantitative information to multiple stakeholder groups who depend on the resources of the forest.

Information/reporting requirements for REDD+ are currently defined in the Cancún agreement under the two categories mitigation activities and safeguards.

The REDD+ mitigation activities are specified in para 70 of the long-term cooperative action (LCA) text as follows:

> "70. Encourages developing country Parties to contribute to mitigation actions in the forest sector by undertaking the following activities, as deemed appropriate by each Party and in accordance with their respective capabilities and national circumstances:
>
> (a) Reducing emissions from deforestation;
>
> (b) Reducing emissions from forest degradation;
>
> (c) Conservation of forest carbon stocks;
>
> (d) Sustainable management of forest;
>
> (e) Enhancement of forest carbon stocks;"

Potentially, these mitigation activities extend to all forest areas, and they include both positive and negative changes of the carbon stock. They also include rapid as well as gradual changes of the carbon stock. Para 71 of the same document identifies the requirements of a robust and transparent forest monitoring system for the monitoring and reporting of the mitigation activities. Clearly, the monitoring of forest carbon and hence

the result of mitigation activities have many commonalities with general forest inventory and monitoring, and the long experiences of conducting national forest inventories should be used to find cost-effective solutions.

Para 71d in the LCA text further specifies that there should be a system for providing information of how safeguards are being addressed. These safeguards are listed in an annex to the text as follows:

(a) Actions complement or are consistent with the objectives of national forest programmes and relevant international conventions and agreements;
(b) Transparent and effective national forest governance structures, taking into account national legislation and sovereignty;
(c) Respect for the knowledge and rights of indigenous peoples and members of local communities, by taking into account relevant international obligations, national circumstances and laws, and noting that the United Nations General Assembly has adopted the United Nations Declaration on the Rights of Indigenous Peoples;
(d) The full and effective participation of relevant stakeholders, in particular, indigenous peoples and local communities, in actions referred to in paragraphs 70 and 72 of this decision;
(e) Actions are consistent with the conservation of natural forests and biological diversity, ensuring that actions referred to in paragraph 70 of this decision are not used for the conversion of natural forests, but are instead used to incentivize the protection and conservation of natural forests and their ecosystem services, and to enhance other social and environmental benefits;
(f) Actions to address the risks of reversals;
(g) Actions to reduce displacement of emissions.

The safeguards indicate that REDD+ mitigation activities are to be performed within the context or broader forest management objectives, and also stipulates stakeholder engagement. They also consider the risk of reversals or displacements of emissions. Taken together, the information requirements for addressing safeguards are consistent with information requirements for other/wider forest management objectives, and, consequently, and again, the experiences from national forest inventories should be well considered.

From this background and the discussions at the meeting on 31 May – 1 June in Rome, the following draft guidelines have been formulated, for using multi-objective national forest inventories for REDD+ monitoring. While national forest inventories can provide a wider range of information, e.g. related also to the REDD+ safeguards, these guidelines focus primarily on the requirements to monitor forest carbon.

General Guidelines

Inventory must reflect institutional capacity

- Create a vision and establish objectives for a long-term inventory
- Create a permanent institutional setting for a long-term inventory requires
- Build in-country forest inventory capacity and infrastructure

Inventory must satisfy information needs

- National and local level forestry and land use planning needs, and therefore the inventory should cover all land classes
- International monitoring and reporting needs including REDD+ MRV, both strategic and operational needs as much as possible
- Varying spatial and temporal resolution needs

- Accuracy requirements have to be determined for the most relevant attributes to be assessed when designing the inventory

Inventory should exploit remote sensing (RS) data as auxiliary to field data.

Design should be pre-evaluated by experts, including forest statisticians, to assure that it is feasible and will yield credible results.

Analysis should consider how to produce annual estimates of C and ΔC, possibly as early as the first year following implementation.

Inventory should be able to assess biomass ΔC from fellings.

Inventory must be designed to achieve the desired allowable error estimates for the current state and change estimates, including change estimates for each carbon pool (aboveground biomass, belowground biomass, litter, soil, deadwood) at the national level.

Analysis must permit statistically defensible assessment of uncertainty including all sources of variability, see section Recommendations (details follow).

Inventory must permit assessment of quality assurance and control (verification).

Recommendations

Design should target repeated inventories, e.g., including permanent field plots from the start.

Design should encompass a systematic layout of plot clusters (aligned or unaligned).

Stratification is recommended to increase the efficiency of an inventory and to capture the estimates for the rare events. Two options for stratification are suggested, notably:

- uniform systematic grid across the landscape followed by post-stratification, or
- pre-stratification with varying systematic intensity

There are trade-offs between these two options. Both pre- and post-strata boundaries will change over time. The statistical implications for analysis and inference differ between the two approaches, and at the planning stage it is crucial that these implications be understood so that inventory objectives with respect to ΔC can be satisfied.

The criteria that may be used for stratification (examples: accessibility; biogeographic region; landscape variability, etc.) will vary in importance by country and therefore it is expected that the selection of criteria will also vary by country.

Inventory should appropriately consider the plot size & shape & geolocation

- Geolocation is of utmost importance, mainly if linked to RS data for estimation
- Single plot cluster can be measured in one day, on average (some difficult to access plot clusters may require more time)

- The choice of plot size and shape should take into account all practicality, statistical validity and efficiency
- Empirical pilot study is recommended for the definition of size and shape also as training and capacity building

Estimation of uncertainty in estimates of *C* and *ΔC* should take into account all the sources of variability.

In this regard is the crucial matter of the basis for statistical inference, because the basis for inference may fundamentally affect how variance is assessed. The two most widely appreciated inferential bases are known as Design-based and Model-based. For purposes of REDD+ MRV we do NOT recommend a Bayesian framework for inference. Between the two choices – one based on the probability design of the inventory, the other based on a presumed model for the collected data – there lay substantial differences

The assessment of the uncertainty of estimates resulting from the NFI may be further complicated because estimation may be model-based, or model-assisted, and estimation may encompass a combination of model- and design-based approaches.

Nonetheless, estimation should take into account all the sources of variability, an abbreviated list of which include:

- Design
- Models, e.g.
    - Biomass models
    - Volume models
    - Link to RS data (see description of example, below)
    - Measurement and assessment error
    - Nonresponse (accessibility)

- RS for area estimation when applying the IPCC tier 1 and 2 approach.

Example

In general, all kinds of RS data providing auxiliary information could be used, i.e. optical satellite data, RADAR or LiDAR data. Suitable RS will vary over time and that is no problem as long as the accuracy of the final estimate can be calculated. Several examples linking inventory field data and optical satellite data exist. Also airborne LiDAR has been employed when linking LiDAR to field data, and accounting for sampling model variation in the process. Norwegian NFI plots were overflown to obtain height profiles of forest canopy on the plots as well the canopy between plots. Regression relationships using functions of the laser height data as the covariates were established for the various land cover categories. In Gregoire *et al* (2011, Model-assisted estimation of biomass in a LiDAR sample survey in Hedmark county, Norway. *Canadian Journal of Forest Research* 41:83-95) a model-assisted design-based approach to estimate the variance of aboveground forest biomass was developed. In contrast, in Ståhl *et al* (2011, Model-based inference for biomass estimation in a LiDAR sample survey in Hedmark County, Norway. *Canadian Journal of Forest Research* 41:96-107.) a model-based approach was developed. In a different setting, Baffetta *et al* (2011, *Canadian Journal of Forest Research* 41: 59-72) have used digital numbers from multispectral imagery for k-NN nonparametric design-based framework. The methods described in these articles illustrate the potential for lining RS data to NFI data for purposes of achieving REDD+ MRV mandates.

CONTRIBUTORS

Piermaria Corona, University of Tuscia, Italy

Lorenzo Fattorini, University of Siena, Italy

Lutz Fehrmann, Georg-August-Universität Göttingen, Germany

Terje Gobakken, Norwegian University of Life Sciences

Timothy G. Gregoire, Yale University, USA

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Steve Stehman, State University of New York, College of Environ'l Science & Forestry, USA

Erkki Tomppo, METLA, Finland