



## COLLABORATION FOR ENVIRONMENTAL EVIDENCE

**Working Title: Comparison of methods for the measurement and assessment of carbon stocks and carbon stock changes in terrestrial carbon pools.**

### **Draft Review Protocol**

Lead contact: Gillian Petrokofsky

Address: University of Oxford

Email: [gillian.petrokofsky@plants.ox.ac.uk](mailto:gillian.petrokofsky@plants.ox.ac.uk)

FAO contacts: Hideki Kanamaru, Claudia Hiepe, Peter Holmgren, Food and Agriculture Organization of the United Nations (FAO)

Email: [hideki.kanamaru@fao.org](mailto:hideki.kanamaru@fao.org); [Claudia.Hiepe@fao.org](mailto:Claudia.Hiepe@fao.org); [peter.holmgren@fao.org](mailto:peter.holmgren@fao.org)

Protocol collaborators: Frederic Achard, Ralph Ashton, Alessandro Baccini, Barney Dickson, Holly Gibbs, Terje Gobakken Scott Goetz, Matt Hansen, Martin Herold, Ole Hofstad, Christoph Klein, Werner Kurtz, Danae Maniatis, Danilo Mollicone, Christine Negra, Andrew Pullin, Florian Siegert, Stephen Twomlow, Jerry Vanclay

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## COVER SHEET

Title	Comparison of methods for the measurement and assessment of carbon stocks and carbon stock changes in terrestrial carbon pools.
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Systematic review website	<a href="http://www.fao.org/climatechange/55337/en">http://www.fao.org/climatechange/55337/en</a>
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## 1. Background

The complex, inter-related issues of land use, land cover change, deforestation, logging and illegal logging are well documented as amongst the most important factors which contribute to the social and environmental challenges facing mankind in the 21st century. Deforestation alone is probably responsible for 18% of the world's greenhouse gas emissions (Stern, 2006). If current trends continue, tropical deforestation will contribute 3 billion tonnes of carbon each year (Chomitz et al., 2006), with emissions from deforestation throughout the world expected to reach 40 billion tonnes of carbon between 2008 and 2012. The combined effects of logging, clear-cutting and forest regrowth on abandoned land are estimated to have released 10-25 % of global human-induced emissions (Achard et al., 2002; Gullison et al., 2007). Current rates of deforestation in Indonesia and Brazil would equal four-fifths of the annual reduction target for Annex I countries of the Kyoto Protocol (Santilli et al., 2005).

Under the Kyoto Protocol, reducing emissions from tropical deforestation cannot be credited in the first commitment period. However, reduced emissions from deforestation and degradation (REDD) could alter this situation. The focus would be on reducing emissions by slowing deforestation and preserving forested areas that can be used as carbon sinks. For developing countries, REDD could include the implementation of policies and measures for reducing deforestation rates such as, for example, sustainable forest management (SFM) and reduced impact logging (RIL). The countries or projects in question would be compensated in terms of carbon credits. In the light of the REDD debate, it is crucial to investigate the spatio-temporal variation of carbon stocks stored as vegetation biomass. Obtaining sufficient ground-data to do so is an expensive and time-consuming task.

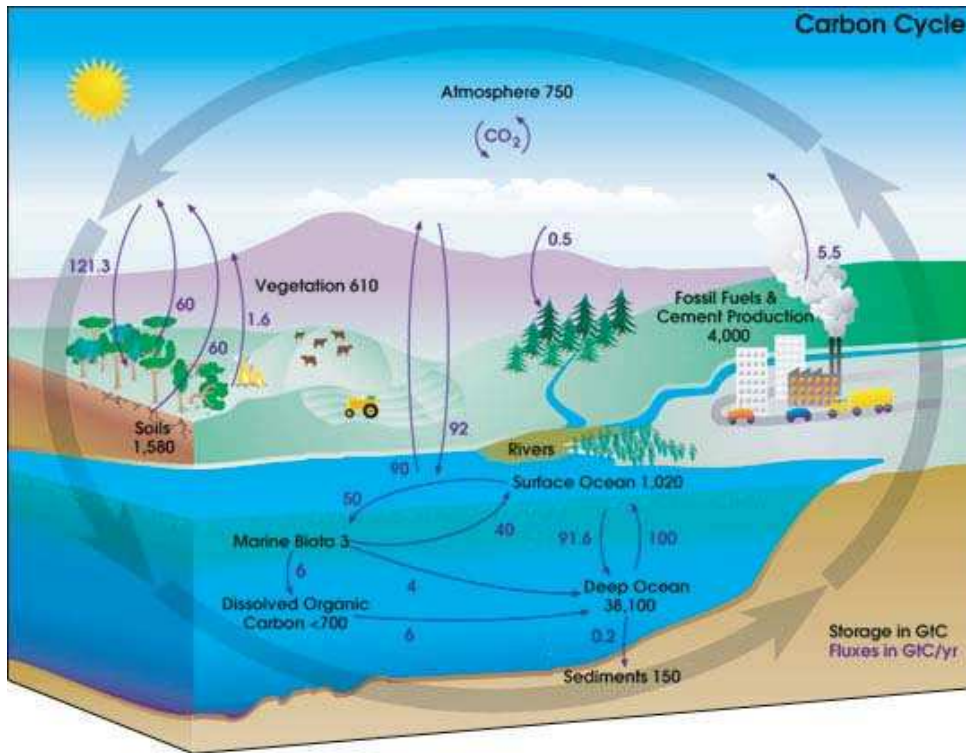


Figure 1 Major carbon pools and fluxes of the global carbon balance (Food and Agriculture Organization, 2004)

### 1.1. Tropical forests and biomass

Estimates of the total above-ground biomass (AGB) biomass in forest ecosystems are critical for carbon dynamics studies at multiple scales (Drake et al., 2003). Many studies have been published on AGB estimates in tropical forests around the world (e.g. Brown et al., 1999; Chave et al., 2001; Gaveau et al., 2003; DeWalt and Chave, 2004; Segura and Kanninen, 2005; Saatchi et al., 2007; Sales et al., 2007). However, both the biomass stocks and their distribution for tropical forests remain poorly determined at the regional scale (Fearnside, 1996; Houghton et al., 2001; Houghton, 2005; Saatchi et al., 2007). Uncertainties in biomass could contribute as much to the inconsistent estimates of carbon emissions as uncertainties in deforestation rates (Houghton, 2005). Moreover, owing to a number of factors, including difficulties of access, a limited number of forest inventories, the spatial extent of tropical forests (Baker et al., 2004a; Malhi et al., 2004) and the large number of published biomass equations (Baker et al., 2004b), there is a substantial amount of variation in estimates and calculations for tropical forest biomass (Ramankutty et al., 2007). Consensus is yet to be reached in the scientific literature on how much carbon is being emitted by tropical land use changes (Malhi and Grace, 2000; Achard et al., 2002; Malhi et al., 2002; Fearnside and Laurance, 2003; Ramankutty et al., 2007).

Most studies on tropical forest AGB have been conducted in the Brazilian Amazon and in South-East Asia. Few studies in the literature have reported AGB for forests in Africa. A very recent paper by Goetz et al. (2009), however, has addressed this issue by providing a map of AGB for Africa. There is an urgent need for improved, and more accurate, methods of determining tropical forest biomass and its spatial distribution in general.

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### 1.1.1. Reliable tropical forest biomass measurements

A key technical challenge for successful implementation of mechanisms such as REDD is the reliable estimation of AGB and carbon stocks in tropical forest biomass. Biomass consists of approximately 50% carbon ((Brown and Lugo, 1982; Malhi et al., 2004). Reliable estimation of AGB depends on a number of sampling factors, including sampling of spatial variability, determination of forest structural allometry and knowledge or determination of tree wood density (referred to in the literature also as ‘wood specific gravity’ (WSG)).

Sampling a sufficient number of trees to represent the species and size distribution in a forest (particularly in a highly diverse tropical forest) to generate information on local or regional WSG is a time consuming and costly exercise. Guidelines for WSG measurements in the field have been in existence for some years. For tropical regions, however, published data on WSG are frequently limited to a relatively small number of commercial timber species that often only represent a fraction of the forest biomass. WSG data on other species are very scarce or completely lacking.

Biomass calculations are based on allometric equations. Allometric models or equations relate one measurement of an organism to another. These commonly include easily measured parameters such as diameter and height which are related to measurements such as volume, leaf area, and biomass, which are more difficult to make. The purpose of the allometric function, in this context, is to simplify and make feasible large scale sampling and estimation of these complex parameters (Zianis, 2008). Height and diameter are the most common dependant variables. However, height is relatively difficult to measure for individual trees in tropical forests, and the most practical allometric models for tropical forestry are generally based on tree diameter alone (Williams and Schreuder, 2000; Alder and van Kuijk, 2009). This is not without problems.

Vieira et al. (2008) demonstrated the difference in accuracy where height was imperfectly measured. A stem with a DBH of 20 cm and 13 m height assessed using models developed by Chave et al. (2005) and Scatena et al. (1993) gave estimated AGB of 153.0 and 127.0 Kg, respectively. Keeping the same DBH but increasing the estimated height by one meter, AGB estimates become 164.1 and 136.6 Kg, respectively, an increase of around 7% and 5% in the estimated AGB.

Chave et al. (2004) provide an overview of error propagation for tropical forest biomass estimates. They identify four types of uncertainty associated with AGB estimates:

- error due to tree measurements
- error due to the choice of an allometric model relating AGB to other tree dimensions
- sampling uncertainty
- representativeness of small plot networks across the vast forest landscape

They find that the most important source of error is related to the choice of allometric model. Currently, allometric data are almost entirely based on Southeast Asian and South American measurements. Chave et al. (2005) reported that there are no destructively sampled trees to develop allometries for Central African forests.

There is a clear need to carry out country- and region-specific case studies to address some of these shortcomings. Ideally, such studies would utilise good ecological plot data. However, these are often of poor quality or lacking completely. Commercial inventory data are therefore an alternative source of site-specific data. These are not normally available in the published literature, but they are a necessary and rich resource for improving methods for estimation of forest carbon.

For accurate assessment, a grid of ground sample plots with very precise location would normally be needed, together with a classification of areas according to vegetation types, and/or cover classes. This can be made on the basis of state of the art satellite imagery or aerial photography. Estimates of above ground biomass or carbon stock for large areas can then be calculated. More precise vegetation classification and a denser network of sample plots will give more precise estimates at higher costs. The validity and reliability of allometric functions are of utmost importance. Allometric functions for some African tree species or forest vegetation types are available (Hofstad, 2005), but are by no means comprehensive.

Sampling can be improved by a third (or fourth) set of data: radar and laser assessments. Radar assessments of biomass density can be made from satellites. Similarly, airborne laser can be used to assess biomass density, either fully covering certain areas, or sampling along transects. Both these techniques can improve accuracy of estimates based on ground plots, or can be used to reduce the cost of accurate estimates. Radar can penetrate clouds, laser cannot. Radar measurements probably get saturated at lower biomass densities than laser (see figure 1).

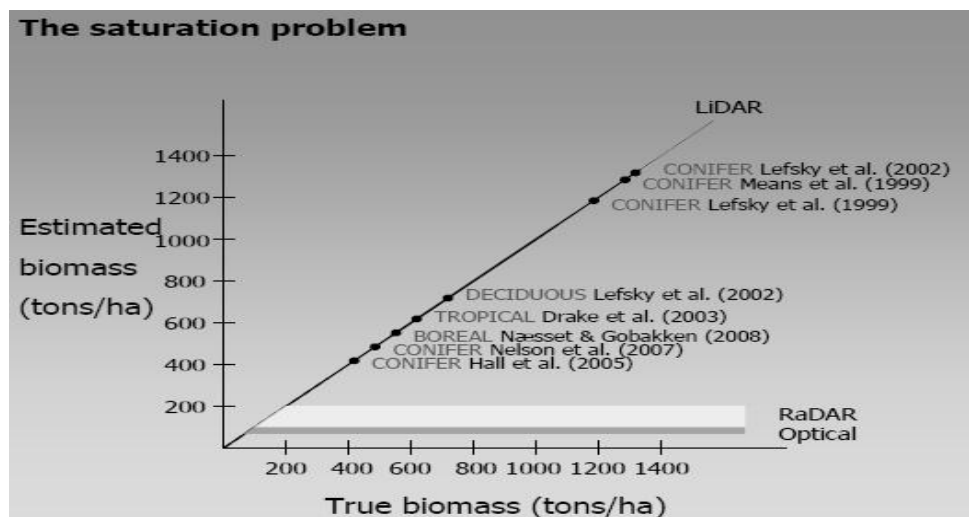


Figure 2. The saturation problem (after Hofstad)

## 1.2. Remote sensing

Remote sensing has considerable potential as a source of biomass data (Foody and Cutler, 2003; Goetz et al., 2009). Direct measurements of AGB are limited to small areas of forest inventories and site-specific allometric equations that cannot be generalised for a forest basin or region. As of yet, no space-borne instrument exists that can measure tropical forest biomass directly. The use of space-

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borne radar backscatter data is becoming increasingly accepted as a method for measuring woody biomass over much larger areas in the tropics because of their capability of penetrating through the forest canopy and all-weather acquisition.

Published studies very often use national forest inventory data to verify results of remote sensing estimates of carbon. Many claim to show strong correlation. However, there are limitations reported in the literature. In particular, weak (or absent) relationship between radar backscatter and AGB often due to geo-location error, for example old GPS instruments being used by those constructing the inventories, uncertainty in establishing the ‘centre of plot’ point, uncertainty in compass directions, etc. (Alder and van Kuijk, 2009).

Remote sensing is potentially useful for covering larger areas of spatial variability than can be achieved using field inventory. There are a number of approaches to estimate AGB from remote sensing data. Most of them fall under multiple regression analysis, nonparametric k-nearest neighbour technique (k-NN), neural networks, or through indirect relationships between forest attributes (remotely sensed) and biomass. An increasing number of studies use fine resolution imagery such as Quickbird, aerial photographs, IKONOS for modelling tree parameters or forest canopy structures, though they may not be applied to large areas owing to cost and technical demand. Medium spatial resolution imagery such as Landsat is widely in use. Where optical sensors have limitation, radar and light detection and ranging (LiDAR) data are being used. The majority of past studies on AGB estimates have not provided accuracy assessments with respect to ground data (Lu, 2006). Rosenqvist et al. (2003) undertook a qualitative review of remote sensing techniques for use under the Kyoto Protocol but have not provided an assessment of their operational status for use at national scales. Patenaude et al. (2005) made quantitative assessments of the accuracy and comparative costs of optical, radar and LiDAR techniques for reporting deforestation activities through land-cover classification analyses and quantification of forest above ground carbon stocks for the UK and countries with similar reporting requirements.

There is clearly a need to critically review the accuracy, precision and cost of various remote sensing techniques against ground observation and among methods, and their applicability in geographically varied regions.

### 1.3. Carbon stocks in peat and soil

Soils are the largest carbon reservoir of the terrestrial carbon cycle. The quantity of C stored in soils is highly significant; soils contain about three times more C than vegetation and twice as much as that which is present in the atmosphere (Batjes and Sombroek, 1997). On average, soils contain three times more organic carbon than vegetation (1500 Pg of C to 1 m depth and 2500 Pg of C to 2 m, where 1 Pg = 1 Gt) than is contained in vegetation (610 Pg of C) and twice as much C as the atmosphere (750 Pg of C) (see Figure 1). Carbon storage in soils is the balance between the input of dead plant material (leaf and root litter) and losses from decomposition and mineralization processes (heterotrophic respiration). Under aerobic conditions, most of the C entering the soil is labile, and therefore respired back to the atmosphere through the process known as soil respiration or soil CO<sub>2</sub> efflux (the result of root respiration – ‘autotrophic respiration’ - and decomposition of organic matter – ‘heterotrophic respiration’).

### 1.3.1. Forest soils

Estimates of the mass of forest soil organic carbon (SOC) are applied to determine long-term carbon fluxes, to manage natural resources and to design carbon sequestration strategies. Several approaches to estimating these forest SOC stocks are currently in use and may provide conflicting results. One method for estimating forest SOC stocks is a regression approach in which regional SOC densities (mass SOC/area) are a function of temperature, precipitation, age class, and land-use history for different ecosystems. An updated methodology for estimating SOC stocks applies a geographic information system (GIS) to calculate SOC densities for each forest type within a region soil databases and satellite-derived land cover images. Preliminary comparative studies in the USA showed large differences in the methods (Elliott Campbell et al., 2008). The authors identified a need to determine absolute errors in both approaches by using direct measurements of SOC in future studies. The fact that the methods have been used interchangeably in the past indicates the existence of errors perpetuated in the literature. There is a clear need to identify the uncertainty associated with current understanding of SOC stocks and changes in stocks.

### 1.3.2. Peat

Only recently has science recognized the importance of tropical peat soils for GHG emissions and climate change. Compared with the aboveground emissions that result from clearing or burning forest vegetation, emissions from peat are significantly larger in cases of fire and continue through time because drainage allows biological oxidation of the peat. Both processes cause significant emissions of GHG gases. During the 1997-1998 El Niño drought peat fires emitted 2.0-3.5 Gt CO<sub>2</sub>, which was equivalent to some 10% of global fossil fuel emissions for the same year (Page et al., 2002; Van Der Werf et al., 2004).

Many variables linked to peat oxidation are not well understood and few reliable measurements exist for many of them. Uncertainty begins with the extent of tropical peatlands in Southeast Asia and worldwide as well as the carbon stored in the peat layer. The peat humification process has strong influence on the mass of peat per volume, the hydraulic conductivity and moisture retention capacity. Knowledge on the 3D topology of the peat dome is important for hydrology and modelling, however peat depth and dome shape have been measured only in few locations. Sampling a sufficient number of locations to allow for spatial modelling is a time consuming and costly exercise. New technologies may be capable of reducing time and effort.

Even less is known about emissions factors, which are essential for reliably estimating GHG emissions. Emission estimates from peat fires have great uncertainties, because a highly variable mass of peat may be combusted and various gases and compounds are emitted depending on fire severity, water table, peat moisture and previous fire history. Data on most of these processes is very scarce or completely lacking. Over time GHG emissions by biological oxidation of peat are also significant. Very few suitable long term measurements of at least a year required to assess emission rates under differing water management regimes exist today. A recent review shows that cleared and

drained peatlands emit in the range of 9 CO<sub>2</sub> t/ha/yr for each 10 cm of additional drainage depth (Couwenberg et al., 2009). The role of tropical peat is crucial not only in terms of GHG emissions but also for REDD, as the carbon stock of peat considerably outweighs that of the biomass above ground and significant amounts of carbon are released by fire and bacterial decomposition. Peat is currently not considered in REDD, though peat swamp forest ecosystems may be considered.

#### 1.4. Land use change

Guo and Gifford (2002) conducted a meta analysis of 74 publications reporting on the influence of land use changes on soil C stocks. They point out that the world database available for their meta analysis was quite small, necessitating a 'relaxed' approach to the criteria for data inclusion in their meta analysis. Results may therefore be subject to bias because of the predominance of studies from certain regions or even authors. They point to the need for a more comprehensive analysis of some of the hypotheses generated in their study: soil C stocks decline after land use changes from pasture to plantation (-10%), native forest to plantation (-13%), native forest to crop (-42%), and pasture to crop (-59%). Soil C stocks increase after land use changes from native forest to pasture (+ 8%), crop to pasture (+ 19%), crop to plantation (+ 18%), and crop to secondary forest (+ 53%).

#### 1.5. Need to synthesise studies from different disciplines

In summary, it is clear that a wide range of efforts are currently being undertaken in public and corporate research to provide for optional methods and data sources for carbon stock assessments. There has been a proliferation of scientific and technical papers and there is a huge body of knowledge reaching back several decades on measurement systems and strategies for determining carbon in different pools. Current monitoring of forests have been called 'insufficiently accurate or precise for an international protocol that would administer finances based on monitoring results of forest area or forest carbon storage' (Holmgren and Marklund, 2007). There is no reason to suppose that the literature on systems of carbon assessment for other pools have been better analysed and synthesized. The adequacy of current or potential systems for reliable carbon stock assessment at national, regional or local levels (under the REDD framework or elsewhere) has not been systematically evaluated. Nor has the scientific underpinning of these approaches been properly examined. It has been argued that a REDD system must be flexible to allow and account for variability in methodologies and accuracy. Variability in methodology and accuracy is inevitable when there are such wide differences between countries and between assessment methods. But flexibility must come with knowledge of the limits of confidence in these variable approaches if REDD is to be credible, transparent and fair. It is timely to undertake a systematic review of methods and approaches to carbon stock assessments

## 2. Object of the review

### 2.1. Primary question

How do current systems and methods compare in their ability to measure and assess terrestrial carbon stocks and changes in carbon stocks with accuracy, precision and reliability?

### 2.2. Sub-questions

1. How accurate and precise are direct measurements of variables used for estimating carbon stock?

2. How accurate, precise and geographically valid are approaches used for the conversion of direct measurements into carbon stock estimates?
3. How accurate and precise are sampling approaches for generating carbon stock estimates for larger geographical areas (particularly regions, countries)?
4. How accurate, precise and sensitive are remote sensing approaches to estimating carbon stocks?

### 2.3. Components of the questions

The subject for all sub-questions will be the 5 terrestrial carbon pools identified by the IPCC:

- Above-ground biomass
- Below-ground biomass
- Deadwood
- Litter
- Soil

### 2.4. Outcomes

Outcomes will assess accuracy and precision against gold standard methods and systems which are generally agreed to have the highest accuracy and precision. Comparative costs will be assessed by proxy factors, such as technology and personnel requirements. Consideration will be taken of frequency requirements built into the methods and systems (e.g. necessity for annual measurements, etc.)

## 3. Methods

### 3.1. Search strategy

It is known that a large volume of work on systems and methods of measurement and assessment has not been published formally. Recognised experts, authors and people who have worked in the field using these techniques as practitioners will be contacted to contribute further ideas on resource identification and invited to share relevant publications or data. A large database of potential contacts has already been established for this purpose in the scoping phase of this project and will be made available to the reviewers for the sole purpose of this systematic review.

#### 3.1.1. Resources to search

##### 3.1.1.1. Published material

The following computerised information resources will be searched for published studies and resources in organisational libraries

1. Forestscience.info <http://www.forestscience.info/>
2. CAB Abstracts <http://www.cabi.org>
3. Google Scholar <http://scholar.google.com>
4. ISI Web of Knowledge (including Web of Knowledge with Conference Proceedings, BIOSIS Previews <http://apps.isiknowledge.com>
5. Scopus [www.info.scopus.com](http://www.info.scopus.com)
6. SCIRUS <http://www.elsevier.nl/>
7. AGRICOLA <http://agricola.nal.usda.gov>
8. Scielo <http://www.scielo.org>
9. GeoRef database <http://www.ovid.com/>
10. ScienceDirect [www.sciencedirect.com](http://www.sciencedirect.com)
11. ProQuest Dissertations and Theses <http://www.il.proquest.com/>
12. Science.gov [www.science.gov](http://www.science.gov)
13. US Department of Agriculture Forest Service Treearch <http://www.treearch.fs.fed.us/>
14. Australian Government Department of Climate Change website <http://www.climatechange.gov.au/index.html>
15. Tropical forest conservation and development database <http://forestry.lib.umn.edu/bib/trps.html>
16. EuroForest portal <http://forestportal.efi.int/>
17. EDIS (Electronic Data Information Source) <http://edis.ifas.ufl.edu/>
18. Forests in flux <http://www.unep-wcmc.org/forest/flux/index.htm>
19. ATROFI-UK ; Archive of Tropical Forestry Inventory <http://www.rdg.ac.uk/ssc/atrofi/>
20. NRCAN Library Catalogue <http://catalogue.nrcan.gc.ca>
21. World Environment Library <http://www.nzdl.org/fast-cgi-bin/library?a=p&p=about&c=envl>
22. CGVlibrary <http://vlibrary.cgiar.org>
23. UN-REDD Web Platform [http://unfccc.int/methods\\_science/redd/items/4531.php](http://unfccc.int/methods_science/redd/items/4531.php)
24. FAO Online Catalogues <http://www4.fao.org/faobib>
25. CIFOR Publications <http://www.cifor.cgiar.org/Publications>
26. ISRIC <http://www.isric.org/>
27. UNEP Publications <http://www.unep.org/publications>
28. World Agroforestry Centre Publications <http://www.worldagroforestry.org>
29. Columbia Earth Institute – International Research Institute for Climate and Society - <http://portal.iri.columbia.edu/portal/server.pt>
30. European Space Agency Earth Observation Projects Department –[www.esa.int](http://www.esa.int)
31. Tropical Soil Biology and Fertility Institute of CIAT (TSBF-CIAT): Conservation and Sustainable Management of Below-Ground Biomass project <http://www.bgbd.net>

### 3.1.1.2. Unpublished and grey literature

Owing to the necessity of hand searching through organisational resources, which will include a high proportion of print material that has not been digitised, the search strategy and list of searchable resources will be further developed iteratively during the early phases of the review. The review will utilise the expertise of members of the International Directory of Forest Information Services: Libraries, Documentation Centres, and Subject Specialists, launched by IUFRO in 2002 and hosted by Forintek in Canada, which contains details of 152 forestry libraries and information centres in 49 countries (<http://iufro.forintek.ca>).

Collaboration with agricultural information professionals and librarians will be canvassed through the International Association of Agricultural Information Specialists (<http://www.iaald.org>), whose members are drawn from research and development institutes, international agencies, universities and colleges, government departments, information providers, non-governmental organisations and the private sector.

Logging companies with significant inventory resources will be pursued during the early stages of the review for information resources of relevance to the review questions.

#### 3.1.2. Search Terms

1. (Carbon near/2 stock\*) AND (aboveground OR 'above ground' OR above-ground OR belowground OR 'below ground' OR below-ground OR forest OR forests OR terrestrial OR land OR soil OR peat)
2. Carbon AND (forest near/2 inventor\*)
3. Biomass AND(aboveground OR 'above ground' OR above-ground OR belowground OR 'below ground' OR below-ground OR forest OR forests OR terrestrial OR land)
4. Carbon and (deadwood OR dead wood OR litter OR humus OR soil\* OR peat OR peatland\*)
5. estimate\* OR asses\* OR measure\* OR monitor\* OR method\*)
6. Carbon and (Remote near/2 sens\* OR Aerial near photo\* OR lidar OR AVHRR OR MODIS OR MERIS OR VGT OR Landsat- OR ASTER, OR LISS OR AwiFs OR CBERS OR PALSAR OR IKONOS OR QuickBird)

((1 OR 2 OR 3 OR 4) AND 5) OR 6

Searches using the terms listed below will be carried out in French, Spanish, and Portuguese. Language experts familiar with the subject will be used to advise on the extent to which it will be practical to retrieve in documents in other languages.

### 3.2. Knowledge management strategy

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The bibliographic details of all studies retrieved by this search strategy will be captured in a RefWorks bibliographic library. Studies will be coded to indicate which of the sub questions they have been retrieved for. Many studies will be relevant to more than one sub question. In order to reduce replication of effort retrieved studies will be are coded for all sub questions before being entered in the bibliographic library. Full texts will be retained on a secure site and will be coded with the unique ID taken from the RefWorks bibliography.

### 3.3. Study inclusion criteria

Studies will first be assessed for inclusion on the basis of title only; followed by assessment on the basis of abstract, and finally, full-text. Preliminary studies during the scoping phase have revealed the difficulty of assessing relevant studies on the basis of either title or abstract alone; studies will therefore be included unless there is clear information to justify exclusion.

To reduce the effects of between-reviewer bias, two reviewers will apply the inclusion criteria for a random sample of 20% of the studies retrieved (up to a maximum of 200 studies) to assess repeatability of the selection criteria. Kappa analysis will be performed, with a rating of substantial (0.6 or above) being required to pass the assessment. Disagreement regarding inclusion or exclusion of studies will be resolved by consensus, or following assessment by a third reviewer. If the Kappa value is low, the reference list will be reassessed against adjusted inclusion and exclusion criteria. The same subset of references will be re-assessed by a second reviewer with Kappa analysis. Reviewers will then consider articles viewed at full text for relevance, either excluding them from, or admitting them to, the review.

#### 3.3.1. Relevant subjects

All land uses  
Above--ground biomass  
Below-ground biomass  
Deadwood  
Litter  
Soil

#### 3.3.2. Comparators

Studies comparing either one method of carbon stock/carbon stock change measurement or assessment compared over time or space or one method compared against another method.

#### 3.3.3. Types of outcome

Ability to assess carbon stocks or carbon stock changes accurately and precisely.

Repeatability (over time and space).

#### 3.3.4. Types of studies

Any comparative primary study which compares methods of assessment or estimation or attempts to assesses the effectiveness of the method against clear criteria.

### 3.3.5. Potential for heterogeneity in outcomes

Differences in terrain/vegetation, spatial scale, temporal scale, technical and/or personnel limitations

### 3.4. Study quality assessment

To assess the extent to which each the research methodology is likely to have been subject to systematic errors or bias each study will be assessed at full-text using a simple list of desirable study characteristics based on a hierarchy of evidence developed for other systematic reviews in medicine and conservation.

### 3.5 Data extraction strategy

The volume and quality of information available to address the review sub-questions are not known at this stage. Methods for data extraction and synthesis will be refined during the early phases of the review. The protocol will be amended as this process is undertaken. If information is too limited to perform meta-analysis of methodology comparisons, studies will be categorised according to subject, comparator and outcome, and a detailed qualitative summary will be produced. Where information is sufficient meta-analysis or other quantitative analysis will be used to provide a summary of quantified differences in methods.

## 4. Potential conflicts of interest and sources of support

[to be completed by review team]

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*This is a draft protocol. Additional work is in progress. Please do not quote any part of this work without the prior consent of Peter Holmgren, [peter.holmgren@fao.org](mailto:peter.holmgren@fao.org)*

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