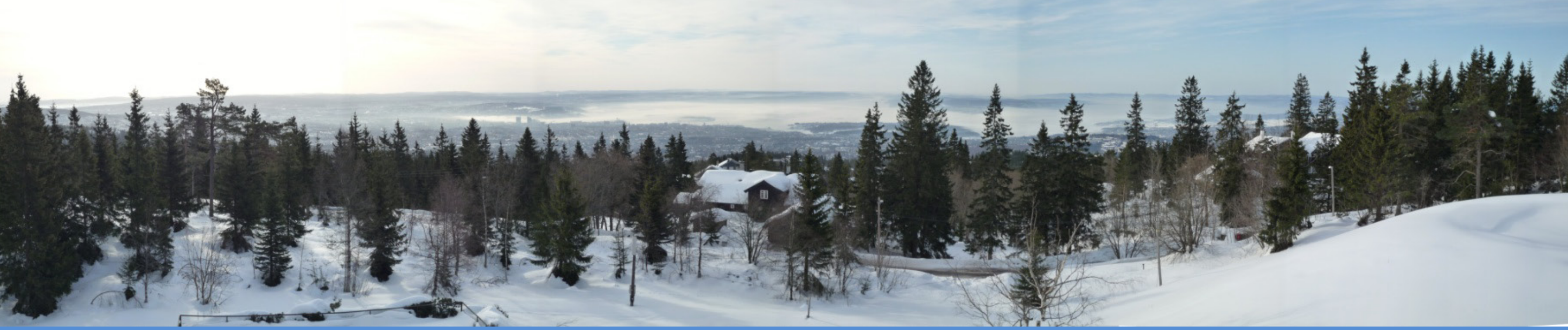

Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals

IPCC Expert Meeting Report

5 -7 May, 2009, INPE, São José dos Campos, BRAZIL

Task Force on National Greenhouse Gas Inventories

INTERGOVERNMENTAL PANEL ON
climate change

WMO UNEP

The IPCC would like to thank Brazil and INPE for their generous support in holding this meeting.

Published by the Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC

Please cite as:

IPCC 2010, Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals, eds: Eggleston H.S., Srivastava N., Tanabe K., Baasansuren J. Meeting Report, 5 -7 May, 2009, INPE, São José dos Campos, Brazil, Pub. IGES, Japan 2010

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Printed in Japan

ISBN 978-4-88788-061-0

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Contents

1. Executive Summary

The IPCC Guidelines for National Greenhouse Gas Inventories and the Good Practice Guidance are used by Parties to the UNFCCC to report their anthropogenic emissions by sources and removals by sinks as required by the UNFCCC and by Annex I Parties for accounting under the Kyoto Protocol.

In 2003 the IPCC reported that "The scientific community cannot currently provide a practicable methodology that would factor out direct human-induced effects from indirect human-induced and natural effects for any broad range of LULUCF activities and circumstances" (IPCC 2003b). Therefore the IPCC Guidelines have adopted the use of estimates of greenhouse gas emissions and removals on managed land as a proxy for the estimation of anthropogenic emissions and removals. Since 2003 the scientific understanding of the drivers of greenhouse gas fluxes from LULUCF sources has developed and so the IPCC decided to revisit the use of the managed land proxy.

While several concerns and deficiencies of the managed land proxy were identified, none of the alternatives considered at the meeting proved to be sufficiently well developed (for all Tier levels required) to justify an IPCC recommendation for change in the default estimation approach, thus the meeting concluded that the managed land proxy is currently the only widely applicable method to estimate the separation between anthropogenic and natural fluxes. Participants also recognised that with increasing impacts of climate change (an indirect human-induced cause) the managed land proxy could in the future include an increasing proportion of natural and indirect human contributions to the reported emissions and removals. Therefore work needs to continue to identify and test approaches to separating (factoring-out) anthropogenic impacts from others. The meeting briefly reviewed a number of proposed alternatives to the managed land proxy and considered they still needed further development before they can be assessed for use by the IPCC. These methods need to be reviewed with regard to their methodological implications, data requirements and compatibility with the inventory principles.

While the meeting agreed that annual emission inventories should estimate the actual emissions in the inventory year, it was also noted that there is a need to be able to identify the impact of mitigation and management efforts even where these are obscured by inter-annual variations in greenhouse gas fluxes for example by the impacts of natural processes (e.g. wildfire) or indirect human-induced processes (e.g. climate change impacts).

A clearer, common understanding of *anthropogenic* is needed particularly in relation to the distinction between direct, indirect and natural effects, and how to classify effects that have a range of natural and direct influences, for example where there is a natural origin (e.g. dry lightening strike) but the associated emission is mainly determined by direct anthropogenic factors (e.g. management of forest plantation) or vice versa for example, where there is an anthropogenic origin (e.g. accidental fire ignition) but the magnitude of emissions is determined by natural causes (e.g. prolonged drought causing severe fire conditions).

Guidance for wetlands will need development in the future but currently the scientific understanding of the factors determining these fluxes is still developing. One issue that will need to be addressed is how to deal with areas with significant natural fluxes, so that emissions estimated using the IPCC guidelines reflect the changes seen by the atmosphere. This situation occurs in other sectors but is particularly acute in the wetland sector. In addition, emissions and removals from wetlands are impacted by processes and activities on neighbouring lands as they are connected by significant lateral fluxes of water, carbon and nutrients.

2. Introduction

The IPCC Guidelines on National Greenhouse Gas Inventories and the Good Practice Guidance are used by Parties to the United Nations Framework Convention on Climate Change (UNFCCC) to report emissions and removals as required by the convention. The Revised 1996 Guidelines (IPCC 1997) and the subsequent Good Practice Guidance (IPCC 2000; IPCC 2003a), are currently adopted by the UNFCCC for reporting[1]. The IPCC has recently updated this guidance in the 2006 Guidelines (IPCC 2006) and these are currently being considered by the UNFCCC.

The UNFCCC requires the estimation and reporting of anthropogenic emissions and removals of greenhouse gases not covered by the Montreal Protocol. Generally the definition of anthropogenic emissions is clear. However, emissions and removals associated with land use activities (LULUCF[2] and/or AFOLU[3]) occur together with those of natural origin, and it is not always straightforward how only to estimate the anthropogenic components. In this situation the authors of the IPCC Guidelines have used emissions and removals from *managed land* as a proxy for anthropogenic emissions and removals (implicitly in the Revised 1996 Guidelines and explicitly in later documents). The São José dos Campos meeting was to review the use of managed land as a proxy for anthropogenic emissions in the context of improved understanding of the causal drivers of changes in carbon stocks in the various land carbon pools.

This report summarizes the discussions and outcome of the São José dos Campos meeting which assessed the appropriateness of the use of managed land as a proxy for anthropogenic effects in different contexts and considered methods being developed to apportion greenhouse gas emissions and removals to specific drivers.

[1] The use of Revised 1996 Guidelines and the subsequent Good Practice Guidance is mandatory for Annex I parties and encouraged for Non-Annex I Parties.

[2] LULUCF – Land Use, Land-Use Change and Forestry, a sector in the IPCC Good Practice

[3] AFOLU – Agriculture, Forestry and Other Land Use, a sector in the 2006 Guidelines.

The meeting in Brazil started with invited papers reviewing some of the background and current scientific causal understanding of these effects and practical approaches to estimating them (See Annex 1). The issues were discussed in smaller groups. The outline of the document was agreed by these groups, the draft report prepared by the core writing team, reviewed twice by all the participants, each time revised by the core writing team to address reviewer comments.

This report first describes the current managed land proxy and its rationale. It then reviews the use of this proxy, both globally and by sector and then briefly considers some potential alternatives. The report concludes that despite the increasing recognition of shortcomings, the managed land proxy remains the recommended default method for reporting anthropogenic GHG emissions and removals and that further research to separate direct human induced from indirect and natural effects is encouraged.

2.1. Previous Discussions in the IPCC

The IPCC has previously considered this issue twice. COP Decision 11/CP7 requested the IPCC, amongst other things, to consider how to separate (factor out) direct human-induced effects from indirect and natural effects on emissions and removals. The possible causes of indirect and natural effects included: age class structure, CO_2 and nitrogen fertilisation, disturbances, etc. The IPCC's first meeting on the issue in Geneva in 2002[4], developed a work plan for a possible IPCC report to provide a framework for factoring out, but questioned the feasibility of providing *...a definite methodology complete with facts and figures.* The second meeting in Geneva in 2003 concluded that *The scientific community cannot currently provide a practicable methodology [to] factor out direct human-induced effects from indirect human-induced and natural effects for any broad range of LULUCF activities and circumstances.* (IPCC 2003b) .

[4] The IPCC's meetings were held as a result of a request from the UNFCCC (Decision 11/CP7)

3. Rationale and assumptions underlying the managed land proxy

The distinction between anthropogenic and natural emissions is clear in most sectors apart from LULUCF / AFOLU. It is clear, that estimating all carbon stock changes in LULUCF/AFOLU would capture management, all disturbances, indirect anthropogenic effects and natural processes, and the IPCC guidelines provides appropriate details on how to estimate these stock changes. However, although the effects of particular factors may be estimated, because of interactions it is less clear if it is possible to apportion the total carbon stock change uniquely to individual drivers (e.g. possible biomass increases or decreases driven by differing management regimes, age distribution of forests, natural disturbances, CO_2 and nitrogen fertilisation etc.).

Therefore the IPCC guidelines recommend using emissions and removals from managed land as a proxy for anthropogenic emissions and removals:

> *Anthropogenic emissions and removals means that greenhouse gas emissions and removals included in national inventories are a result of human activities. The distinction between natural and anthropogenic emissions and removals follows straightforwardly from the data used to quantify human activity. In the Agriculture, Forestry and Other Land Use (AFOLU) Sector, emissions and removals on managed land are taken as a proxy for anthropogenic emissions and removals, and interannual variations in natural background emissions and removals, though these can be significant, are assumed to average out over time.*[5]
>
> *2006 Guidelines Vol. 1 Ch. 1 Page 1.4* (4),

Thus, inventory compilers should report all emissions and removals that occur on managed land. Managed land in this context is given a broad definition:

> *Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions.*
>
> *Ibid. Page 1.5* (4),

The rationale behind the managed land proxy is explained in volume 4 of the 2006 Guidelines:

> *The key rationale for this approach is that the preponderance of anthropogenic effects occurs on managed lands. By definition, all direct human-induced effects on greenhouse gas emissions and removals occur on managed lands only. While it is recognized that no area of the Earth's surface is entirely free of human influence (e.g., CO_2 fertilization), many indirect human influences on greenhouse gases (e.g., increased N deposition, accidental fire) will be manifested predominately on managed lands, where human activities are concentrated. Finally, while local and short-term variability in emissions and removals due to natural causes can be substantial (e.g., emissions from fire, see footnote 1), the natural 'background' of greenhouse gas emissions and removals by sinks tends to average out over time and space. This leaves the greenhouse gas emissions and removals from managed lands as the dominant result of human activity.*
>
> *Ibid. Page 1.5 (4),*

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[5] The 2003 Good Practice guidance allows that

> *If methods are applied that do not capture removals by regrowth after natural disturbances, then it is not necessary to report the CO_2 emissions associated with natural disturbance events.*
>
> (page 3.49)

but the 2006 Guidelines was more specific and does not assume the re-growth will balance the emissions from the disturbance:

> *Equivalence (synchrony) of CO2 emissions and removals: CO2 net emissions should be reported where the CO2 emissions and removals for the biomass pool are not equivalent in the inventory year. For grassland biomass burning and burning of agriculture residues, the assumption of equivalence is generally reasonable. However, woody vegetation may also burn in these land categories, and greenhouse gas emissions from those sources should be reported using a higher Tier method. Further, in many parts of the world, grazing is the predominant land use in Forest Land that are regularly burnt (e.g., grazed woodlands and savannas), and care must be taken before assuming synchrony in such systems. For Forest Land, synchrony is unlikely if significant woody biomass is killed (i.e., losses represent several years of growth and C accumulation), and the net emissions should be reported. Examples include: clearing of native forest and conversion to agriculture and/or plantations and wildfires in Forest Land.*
>
> *(page 2.41)*

The key assumptions behind the managed land construct are listed below and a discussion about the validity of these assumptions follows in section 3 of the report:

- all direct human-induced effects on greenhouse gas emissions and removals occur on managed lands only: natural processes (e.g. wildfire, pest outbreaks, drought impacts, etc.) are assumed to contribute only a small proportion of the emissions and removals on managed land
- indirect human influences are manifested predominantly on managed lands
- the substantial natural, short-term and local variability averages out over time.

3.1. Direct and Indirect Anthropogenic Effects

Indirect anthropogenic effects are second order impacts of human activities on emissions by sources or removals by sinks. They include effects such as:

- Impacts of climate change induced changes in temperature, precipitation, and length of growing season.
- Climate change induced inter-annual and inter-decadal variability in such environmental factors.
- Changes in ambient CO_2 concentrations (i.e. CO_2 fertilisation).
- Human-induced increases in nitrogen availability (e.g. increased N deposition).
- Impact of local and regional air pollution (e.g. ozone, particulates).
- Changes in disturbances regimes, including extreme events (e.g. climate change can alter scale, intensity and frequency of fire, pest attack, windthrow, flooding etc.).

While management activities used in forestry and agriculture and their effect over long time scales (e.g., age structure and past practices; woody encroachment) are a direct effect some possible accounting for emissions and removals aim to factor-out the impact of these activities prior to a pre-defined reference year (e.g. the Kyoto Protocol).

The methods in all the IPCC emission inventory guidance aim to estimate all the greenhouse gas emissions to, and removals from, the atmosphere on the lands to which they are applied and so include both direct and indirect effects. The IPCC guidelines state that all emissions and removals from managed lands should be reported as anthropogenic emissions. The UNFCCC asks for "A national inventory of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol" (Art 12, Para. 1) and makes no distinction between direct and indirect anthropogenic emissions.

The Kyoto Protocol does state that "The net changes in greenhouse gas emissions by sources and removals by sinks resulting from *direct human-induced* land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period, shall be used to meet the commitments under this Article of each Party included in Annex I." (Article 3 Para 3)[6].

Subsequently, in the Marrakesh Accords decision on Land Use, Land-Use Change and Forestry (LULUCF) the Conference of Parties to the UNFCCC invited the IPCC

> *To develop practicable methodologies to factor out direct human-induced changes in carbon stocks and greenhouse gas emissions by sources and removals by sinks from changes in carbon stocks and greenhouse gas emissions by sources and removals by sinks due to indirect human-induced and natural effects (such as those from carbon dioxide fertilization and nitrogen deposition), and effects due to past practices in forests (pre-reference year), to be*

[6] UNFCCC decision for the Kiyoto Protocol 16/CMP 1, article 1, *Affirms that the following principles govern the treatment of land use, land-use change and forestry activities: … (h) That accounting excludes removals resulting from: (i) elevated carbon dioxide concentrations above their pre-industrial level; (ii) indirect nitrogen deposition; and (iii) the dynamic effects of age structure resulting from activities and practices before the reference year*

submitted to the Conference of the Parties at its tenth session;

(UNFCCC 11/CP.7, para 3)

However, as noted above, in 2003 the IPCC said that:

The scientific community cannot currently provide a practicable methodology that would factor out direct human-induced effects from indirect human-induced and natural effects for any broad range of LULUCF activities and circumstances. Research efforts are addressing some particular effects, such as CO_2 fertilization, over a range of spatial scales and are providing information relevant to the separability and attribution of different effects at specific sites where good historical information is available and intensive measurements are being carried out. Such efforts are expected to provide an increasing understanding of the feasibility and practicability of a broadly based approach to the issues of separability and attribution.

(IPCC 2003b)

3.2. IPCC Guidelines Treatment of Time Series and Annual Estimates

Some participants noted that for a few Parties to the UNFCCC following the IPCC Guidelines leads to estimates of fluxes of greenhouse gases dominated by inter-annual changes, driven largely by natural cause (Kurz W. A. 2009; Richards G. 2009). The 2006 IPCC guidelines give clear guidance on the treatment of annual emissions:

Inventory year and time series

National inventories contain estimates for the calendar year during which the emissions to (or removals from) the atmosphere occur. Where suitable data to follow this principle are missing, emissions/removals may be estimated using data from other years applying appropriate methods such as averaging, interpolation and extrapolation. A sequence of annual greenhouse gas inventory estimates (e.g., each year from 1990 to 2000) is called a time series. Because of the importance of tracking emissions trends over time, countries should ensure that a time series of estimates is as consistent as possible.

2006 GL, Vol. 1 Ch. 1 Page 1.4 (4),

And

Multi-year averaging: *Countries should report annual inventory estimates that are based on best estimates for actual emissions and removals in that year. Generally, single year estimates provide the best approximation of real emissions/removals and a time series of single year estimates prepared according to good practice can be considered consistent. Countries should, where possible, avoid using multi-year averaging of data that would result in over- or under-estimates of emissions over time, increased uncertainty, or reduced transparency, comparability or time-series consistency of the estimates. However, in some specific cases that are described for specific sectors in Volume 2-5, multi-year averaging may be the best or even the only way to estimate data for a single year. In the case of high or uncertain annual variability – as in the growth of various tree species in a year – and where there is higher confidence in the average annual growth rate over a period of years then multi-year averaging can improve the quality of the overall estimate.*

2006 GL, Vol. 1 Ch. 2 Page 2.11 (4),

Here the guidelines do allow some averaging of multi-year data. However this is in the context of empirical input data where a measurement in one year, if used for other years, may be subject to large errors due to this inter-annual variability and a value averaged over many years may be more reliable and subject to smaller errors. It is important to note that the guidelines do NOT allow for averaging of emission estimates in order to disguise large real inter-annual variability. This also has the effect that Tier 1 methods may not be able to estimate the total inter-annual variability which should be evident in higher tier methods.

While inter-annual variability may largely be driven by climate variability and natural disturbances, estimation of the impacts of these factors is complicated by:

- Need for historical activity and climate data, which can be difficult to obtain.
- Impacts of past land management practices, which occur when prior conditions affect the impact of current management practices, such as the long-term effect of past practices on soil organic matter and nitrogen contents, forest age-class structure and soil organic matter decay.

The meeting noted that the aim of emission inventories is to provide a best estimate of the emissions and removals in a given year and thus do not try to remove or reduce the impact of inter-annual variations on anthropogenic emissions (e.g. those caused by climate effects on forestry, agriculture or energy production). The meeting further noted that subsequent accounting (such as that of a future climate agreement) could agree to average out this variability in a transparent manner if desired.

4. Assessment of the managed land proxy

In São José dos Campos, meeting participants examined the use of the managed land proxy and its underlying assumptions.

4.1. Assumption 1 – Direct Effects

all direct human-induced effects on greenhouse gas emissions and removals occur on managed lands only. [7]

2006 GL, Vol. 4 Ch. 1 Page 1.5,

Implicitly, natural processes are assumed to contribute only a small proportion of the emissions and removals on managed land. However, some direct human-induced effects can spread into unmanaged lands and some natural effects occur within managed lands. The relative importance of these exceptions differs between countries and over time. For example prescribed fires may spread from managed lands onto unmanaged lands and natural wildfires occur within managed lands. Nutrients (e.g. fertiliser) and dissolved GHG (e.g. N2O, (Clough T.J. 2007)) may flow from managed lands to unmanaged lands which can affect growth and emissions and removals on those unmanaged lands or wetlands, lakes and rivers. While the magnitude of these effects is not clear and methodologies to quantify the effects of nutrient flows are not yet available, it is likely that the impacts of these factors are generally much smaller than the direct effect on managed land or the impacts of natural disturbances on managed land, and the consequence of fire on unmanaged land may be more related to fuel load than to the cause of ignition.

4.2. Assumption 2 – Indirect Effects

many indirect human influences on greenhouse gases (e.g., increased N deposition, accidental fire) will be manifested predominately on managed lands, where human activities are concentrated..

Ibid

By virtue of their location managed lands are often more exposed to indirect effects such as pollutants and nutrient deposition. However other indirect and natural effects, such as CO_2 fertilization, the influence of a changing climate, and disturbances of natural origin largely occur indifferently on managed and unmanaged lands. However, unmanaged lands are likely to respond more strongly to N deposition per unit N deposited than fertilized managed lands where nitrogen is the limiting factor for vegetation growth. Often emissions with a natural origin are largely determined by direct and indirect anthropogenic effects. For example, an ongoing insect outbreak in forests in western North America has a natural origin but the geographic extent is largely determined by warmer winters (an indirect effect of anthropogenic climate change) and the magnitude of the emissions is affected by past management (fire suppression and not harvesting pine forests) and current harvesting decisions (salvage logging of dead trees) (Kurz W. A. 2008a; Richards G. 2009)

4.3. Assumption 3 - Variability

while local and short-term variability in emissions and removals due to natural causes can be substantial … the natural 'background' of greenhouse gas emissions and removals by sinks tends to average out over time and space.

Ibid

Two presentations highlighted the importance of inter-annual variability generated by indirect and natural effects, such as climatic variations (Richards G. 2009), and large scale disturbances (Kurz W. A. 2008b) and a further presentation demonstrated the inter-annual variability due to disturbances (mortality), age class distribution and site distribution, using a model that was designed to simulate carbon stock changes and fluxes (Somogyi Z. 2009). The effect of climate variability

[7] Note that, according the the Guidelines, if there is a direct human induced activity in a land that previously was unmanaged, that land immediately becomes managed land.

is also occasionally observed in other inventory sectors, e.g. the energy sector where hydro-electric power generation and energy use for heating and air conditioning can vary annually with climatic variations.

Such effects may be more clearly identifiable where higher-tier methodologies have been applied to estimate development The inter-annual variability driven by climate variability and extreme events is not reflected in the inventories when the inventory compilers, usually using lower tier methods, averaged input data over multiple years. The climatic component of the inter-annual variability will only show up when estimates based on process models or additional high frequency observations are used.

The signal of the impact of direct human-induced emissions and removals, or the impact of mitigation measures, may not be discernible when confounded by large inter-annual variations. The ability to discern the signal of the mitigation from the noise of the inter-annual variability is important when inventory estimates are used for monitoring the impacts of mitigation measures.

The assumption of a neutral balance of greenhouse gas emissions and removals of pristine lands was first stated in the 1996 Guidelines. However the residual uptake of carbon (the "missing sink") estimated in the IPCC Fourth Assessment Report (IPCC 2007) (6) to amount to a sink of 2.6 Gt/yr in the 1990s (with a range of 0.9 to 4.3 Gt/yr) indicates that natural effects will not average to zero during a decade. In addition, the total area disturbed (e.g. burnt) may vary considerably over time (Mouillot F. 2005). Natural and indirect effects may not average to zero in forests on managed land, either (Somogyi Z. 2009).

Thus, although these background emissions and removals may average out over the long run for carbon, it may be on a time scale much greater than one year. Emissions of CH_4 and N_2O are never balanced by removals of these gases. The use of annual greenhouse gas inventories should take this into account, noting that year-to-year changes may be due to these causes and not part of a trend.

4.4. Natural Effects and the Managed Land Proxy

Consideration of the three assumptions (above) imply that emissions and removals reported using the managed land proxy may generally be predominantly of anthropogenic origin (both direct and indirect) and that the contribution from natural causes is negligible over time. In some countries natural disturbances occurring within the managed forest (wildfires, pest outbreaks, windthrow due to storms) can contribute large and highly variable emissions to the GHG balance reported using the managed land proxy (Kurz W. A. 2008b), and the background uptake may be significant, although accounting methods which take account of this in all years may be relatively insensitive to it, and where new forests are established any increase in uptake due to background effects may perhaps be thought of as direct anthropogenic. It is important to acknowledge that this proportion of natural and indirect contribution to the managed land proxy fluxes can be large and highly variable in some countries.

5. Sectoral considerations

The meeting considered the use of the managed land proxy for each of the six broad land use categories defined in the IPCC Guidelines. The main issues identified were associated with wetlands and forests.

5.1. Cropland and Settlements

All cropland and settlements are managed. The meeting concluded that the managed land proxy is a good approach for estimating anthropogenic emissions and removals from these lands. Measurement-based estimates of C stock changes on cropland soils will always capture a combination of natural, direct and indirect anthropogenic effects.

Potential, future, improvements to inventory methodologies are needed before it is possible to assess the impact of cropland or settlement management practices on adjacent un-managed as well as other managed lands (for example through run-off or erosion) which are not subject to rigorous inventory estimation, especially on wetlands and water bodies.

5.2. Grassland

Not all grassland is managed. For example, extensive areas of tundra can be considered un-managed grassland. The meeting concluded that the managed land proxy is a good approach for estimating direct and indirect anthropogenic emissions and removals from managed grasslands.

Managed grassland experience disturbances, namely fires, but these tend to be associated with management practices rather than natural events and are therefore mainly anthropogenic emissions or removals and reported as such using the managed land proxy.

5.3. Wetlands

Pristine wetlands naturally emit and remove GHG, providing a background of natural fluxes against which the direct human impact can be difficult to assess. Wetlands (notably peat lands) contain significant stocks of carbon (Tarnocai C. 2009) which could be released through the impact of indirect human-induced impacts (climate change) with fluxes potentially greater than those resulting from direct human activities. Wetlands differ from other lands in that the greenhouse gas fluxes appear to be significantly affected by lateral fluxes of water, carbon and nutrients from adjacent lands. For this reason, wetlands affect, and are affected by, processes and activities that are taking place on adjacent lands which can alter greenhouse gas emissions and removals. One example is the correlation between greenhouse gas emissions from water bodies (lakes, reservoirs) and land use or land management activities on the watershed (Worrall F. 2003; Bastviken D. 2004; Kortelainen P. 2006; Juutinen S. 2009). Another is the eutrophication of water bodies that disrupt the greenhouse gas dynamics in un-managed water bodies that are not included in managed land proxy (enhancing emissions or removals; (Huttunen J.T. 2003a; Huttunen J.T. 2003b; Huttunen J.T. 2003c). Care needs to be taken to ensure that estimation of these processes does not lead to double-counting.

Experience shows the challenges in monitoring different types of wetlands, notably managed wetlands that have been abandoned, because although area information may be available, the status of the wetlands in a transition phase is so diverse that emissions and removals cannot be robustly quantified by a land category approach (Myllys M. 1996). The IPCC AR4 emphasized the uncertainty in the global carbon cycle due to lack of proper knowledge on soil carbon (of which peatlands would constitute a significant proportion) (IPCC 2007). Further, there are significant challenges in monitoring at the appropriate spatial and temporal scales, some of the important controls (eg depth of the water table and growing season precipitation) over the emissions and removals of different greenhouse gases from wetlands (Lafleur 2007; Strack M. 2007). Small scale studies have shown that these different processes and effects can be quantified but the scientific tools that have been developed are not operational at the national scale or applicable for lower tier methods. Similarly, small-scale studies have demonstrated the relatively important inter-annual variability in the GHG budget of peatlands (Bubier J.L. 2003; Bubier J. 2005); again the measurements that have been collected and tools that were developed cannot at this point be generalised for large-scale applications.

Estimating all emissions and removals on peatlands on the time scale relevant to reporting may not always reflect their true contribution to radiative forcing. For example, northern peatlands have contributed to long-term cooling the climate by sequestering CO_2; nevertheless, their current annual GHG budget could be calculated as a source (of CH_4) in total CO2eq. (Frolking S. 2006; Frolking S. 2007). This could be true for other types of wetlands with significant long-term carbon sequestration potential.

Due to the complex climate and landscape factors affecting the GHG budget of wetlands, and the lack of broadly applicable methodologies to quantify anthropogenic emissions and removals, the current guidance continues to be, while incomplete, the most practicable, with its focus on human activities (e.g. drainage of peatland and flooding) whose impacts are clear. Rapid improvements in the scientific understanding may warrant re-visiting the current guidance in the mid-term.

Due to incomplete scientific understanding and the lack of comprehensive and widely applicable approaches, the IPCC guidance focuses on human activities that directly and significantly impact wetlands, namely drainage of peatland and flooding. Meeting participants concluded that this approach is helpful in quantifying anthropogenic emissions and removals from wetlands.

5.4. Forest Lands

Forests can be either managed or unmanaged and there are extensive boreal and tropical unmanaged forests. Both managed temperate and tropical managed and unmanaged forests currently appear to be a significant carbon sink (Stephens B. B. 2007; Le Quere C. 2009).

While the use of the managed land proxy captures most direct and indirect anthropogenic effects on forest lands some issues were raised:

- Some management activities (e.g. prescribed fires) have the potential to spread to unmanaged lands.
- Natural wildfires that are ignited and burn on managed land can lead to a large proportion of the emissions from managed forests (Kurz W. A. 2008b). In Russian forests, the frequency of fires outside intact forests is higher than in intact forests suggesting a direct human impact on the number of wildfires (Mollicone D. 2006). The extent and intensity (not the occurrence) of disturbances (windthrow, pest outbreaks, fires) in managed forests is necessarily related to past and present management because past and present management determine the amount of available carbon, vulnerability and resilience of forests. Natural wildfires can start in the managed forest or spread into it from adjacent unmanaged areas. The emissions are directly related to fire intensity (which is a result of weather conditions prior to and during the fire) and fuel consumption (which is a result of fuel loads and stand history).
- There was concern that by designating areas, currently unmanaged, for activities that do not impact the carbon stock (such as conservation) it would be possible to include significant carbon sinks that are occurring without direct human intervention thus obscuring the impact of direct human activities. This is the case in Brazil where large protected areas in Amazonia (e.g. national forests, conservation units, indigenous peoples land) have the potential to offset the real deforestation emissions (Krug T. 2009).
- Some natural disturbances can cause significant changes in carbon fluxes (e.g. pest outbreaks) that cannot be controlled. The actual size of the flux is determined by a combination of the original natural cause and direct and indirect effects that control the spread and development of the disturbance (such as past management and climate changes)

Thus the ability to attribute changes in fluxes of greenhouse gases to natural or anthropogenic factors would increase the understanding of anthropogenic emissions.

5.5. Other Lands

This category includes bare soil, rock, ice, and all unmanaged land areas that do not fall into any of the other five categories. The other lands category is assumed not to be a significant carbon pool. Hence significant greenhouse gas emissions do not occur in this category except if land changes to or from this category from or to another category. Therefore the issue of separating anthropogenic from natural emissions is not relevant here.

6. Discussion on the methodological options

It is clear that carbon stock change estimates capture management, disturbances, indirect anthropogenic effects and natural processes – both current and past factors. However, the challenges remain in apportioning the total carbon stock change and non-CO2 GHG emissions and removals to individual drivers (e.g. anthropogenic changes to wetlands, differing management regimes, age class distribution of forest stands, disturbances, possible biomass increases or decreases driven by climate change, CO_2 fertilisation etc.).

Meeting participants recognised methodological developments in recent years and the further need to improve the separation of anthropogenic from non-anthropogenic fluxes and their expression in the inventory time series and in some cases direct from indirect effects. A number of methodological options were considered in a preliminary fashion and are further elaborated below. Note that these options are not necessarily mutually exclusive.

1. Maintenance of the managed land proxy
2. Component separation (quantify the influence of different drivers and then identify which drivers contribute to anthropogenic emissions)

3. Comparison of two time series (that represent two different levels of human activities, e.g. current management and no management, or improved management vs. business as usual management)

4. Default factors and optimal fingerprinting (without quantifying the relative contributions, apply a default factor which indicates the impact of the human activity)

5. Activity based approach (estimate emissions by different activities and sum up anthropogenic contributions))

The meeting considered that these options are worth further investigation. However before they can be widely used they will need to be assessed with regard to the science, methodological implications, data requirements (e.g. Tier 1, 2 and 3 variations), and consistency with the general principles of inventory guidelines. Thus the managed land proxy remains for the time being the approach for distinguishing between anthropogenic and non-anthropogenic emissions and removals adopted by the IPCC emission inventory guidelines.

All the proposed refinements to the managed land proxy are based on modelling frameworks that can spatially integrate the interactions between human activities and natural drivers, and their combined long and short-term effects; this knowledge is mostly site-specific and not currently available at the global scale. If these models are used they will have considerable data and information needs and there will need to be careful consideration of how to present the methods, assumptions and results transparently.

6.1. Managed land proxy

The managed land proxy (described above) is a first approach for distinguishing between anthropogenic and non-anthropogenic emissions and removals and is the approach in existing IPCC guidance, including the 2006 Guidelines.

While the methods described in the other options (below) may help us assess the extent to which this approach separates non-anthropogenic and anthropogenic emissions and removals, the managed land proxy remains the only applicable approach approved by the IPCC.

6.2. Component separation

This is an approach which seeks to quantify the contribution of the following:

- Past management and legacies (e.g. age class legacy) e.g. species distribution, distribution of forest area by site, and suppression of natural disturbances

- CO_2 fertilisation, N fertilisation, climate (both inter-annual and long term trends), etc

- The effects of recent anthropogenic activities on managed land and on areas outside the managed land (e.g. planting, regeneration, harvesting.)

- The effects of natural and anthropogenic disturbances (e.g. wildfires, accidental fires, pest outbreaks, floods, windthrow) on managed land (and on unmanaged lands)

- Other environmental factors (e.g. precipitation, temperature trends)

For each factor it is necessary to estimate its impact on the fluxes of greenhouse gases and so apportion the total flux between the different factors. This assumes that the impacts of each factor can be added linearly – if there are cross-factor effects this leads to added complications in the approach (e.g. the impact of CO_2 fertilisation may depend on past management legacies). There are scientific methods that can be used to identify these components (8) but their usefulness and global applicability still need to be assessed.

6.3. Comparison between two time series

A comparison of two time series of net GHG balance estimates could be used to determine the impacts of two levels of human activities. For example, a Tier 3 model could be used to represent current management (i.e. the estimated actual emissions and removals) and compare these to a model run with no direct human activities. Alternatively current levels of management activities could be compared to business-as-usual management activities to account for impacts of changes in human activities (similar to the approaches used for project-level accounting).

A comparison between the actual time series (a model of fluxes that actually occurred including natural, indirect and direct effects) and a second time series in which the fluxes from the known anthropogenic factors that drive the emissions are removed (the factors removed include all harvesting and human-caused fires). The difference in between these two resulting estimates can be attributed to human activities as the impacts of natural and indirect effects occur in both time series and therefore cancel each other out. The direct anthropogenic impacts on removals must also be assessed and taken out of the baseline. Identification of direct human impacts on removals can be difficult in cases such as large-scale fire suppression where it is difficult to know how much fire would have occurred in the absence of fire suppression efforts.

This approach requires identification of all the anthropogenic factors involved, to model accurately the anthropogenic drivers of emissions and removals and to accurately represent the actual outcomes. This can be achieved with Tier 3 models that simulate forest dynamics with and without management such as harvesting or planting. However, this approach may be able to separate out anthropogenic emissions and removals in a more accurate way than the managed land proxy without completely representing all the factors involved. The comparison approach also requires that the interaction between anthropogenic factors and disturbance can be quantified. (Böttcher H. 2008)

6.4. Default factors and Optimal Fingerprinting

Another approach is to develop and apply default factors to attribute impacts of anthropogenic and natural effects on fluxes of greenhouse gases. .

Detailed understanding of the processes involved could lead to quantification of Tier 1 factors that could be used by countries to remove non-anthropogenic effects. More confident attribution to different anthropogenic and natural factors of changes in ecosystems has been developed in the last few years. (Tett S.F.B. 2002; Tett S.F.B. et al. 2002; Smith J.U. 2005; Gedney N. 2006; Nabuurs G.J. 2006; Smith P. 2006; Betts R.A. 2007; Eggers J. 2008; Gillett N.P. 2008; Schelhaas M.J. Submitted). Smith J.U and Smith P. et al for example, both used an ecosystem model to attribute future changes in soil carbon to changes resulting from direct impacts of climate on soils, indirect effects via changes in productivity, changes in land use, and improved management / technology (Smith J.U. 2005; Smith P. 2006; Smith P. 2007). Tett and Gedney et al both used ecosystem models and optimal fingerprinting statistical techniques to attribute observed changes to different potential causes (Tett S.F.B. 2002; Gedney N. 2006).

The approach has been used widely to separate out direct anthropogenic effects. This approach is essentially involved in existing Tier 1 factors for cropland management since those factors were derived from multiple comparisons of C difference between different management systems at the same physical locations. Therefore, indirect and natural effects are similar for both systems so the factor is primarily capturing direct anthropogenic effects. However, by cancelling out much the indirect and natural effects, the existing Tier 1 factors do not report those emissions and removals that the atmosphere sees. Canada has used this approach with Century model for Tier 2 factors (e.g. (Smith W.N. 2001; Kurz W. A. 2008b)) that are used to estimate C change on cropland for reporting under the UNFCCC. While these methods are already used to develop default factors that vary over space, time and changes in management practices, their use to develop default emission factors would require further elaboration and application to a wider range of national circumstances, followed by formal adoption by the IPCC.

Optimal fingerprinting is a formal detection and attribution technique developed to isolate the causes of observed change. In short, the models are run with all factors included, and allowed to vary within set ranges. The models are then run again, fixing one potential driver at a time. By comparing the model outputs to the observations, the distinct spatio-temporal patterns of the response serve as 'fingerprints' that allow the observed change to be separated into contributions from each factor (Gedney N. 2006). These formal detection and attribution techniques can be further developed and used to attribute annual to decadal variability of carbon and GHG budgets in managed ecosystems to human and natural driving processes.

These methods can potentially be used to develop default factors that would vary over space and/or time and management practices. This would require further elaboration and assessment by the IPCC. While the development and use of these factors would greatly simplify the attribution of fluxes to the various factors, the approach will need careful validation and documentation to provide credible results.

6.5. Activity based approach

In this approach, as a first step, specific human activities and their impact on emissions and removals are identified and estimated. The approach then sums up the impacts of the individual activities, and accounts only for their contribution to emissions and removals but excludes indirect and natural effects that are currently included in the managed land proxy.

Estimating the impact of specific human activities on emissions and removals requires assumptions about a "background" or "baseline" scenario without these activities. Currently there is no scientific consensus about how to construct such a scenario. Generic studies have developed a basis for developing the activity based approach (Böttcher H. 2008) but decisions on what constitutes the “background” or “baseline” scenario and the "anthropogenic" contributions should result from a science-policy dialogue.

In order for this approach to be effective it would be necessary to correctly identify all the human activities driving the greenhouse gas fluxes and to be able to accurately model each of the factors and how they interact. Currently this may be applicable in specific situations but there is insufficient scientific knowledge at present to apply this approach everywhere. Applying this approach at a national scale will need considerable data and information and probably will be difficult to apply transparently.

7. Conclusions

1. Despite valid concerns, the managed land proxy remains a globally applicable, assessed and approved method for separating anthropogenic emissions and removals.

   The meeting noted that the managed land proxy is a first approach for distinguishing between anthropogenic and non-anthropogenic emissions and removals, and is the current approach in the 2003 Good Practice Guidance for Land Use, Land-use Change and Forestry and the 2006 Guidelines for National Greenhouse Gas Inventories. Refinements are being developed that so far can only be implemented with higher tier methodologies

2. The meeting recognised that the managed land proxy has several shortcomings and that for some national circumstances (for example Canada and Australia) natural disturbances can play a significant role in fluxes from managed land. The managed land proxy makes a number of assumptions, none of which is universally true: direct effects spill over onto unmanaged land; natural effects occur in managed lands; indirect effects may not occur mainly on managed land; and natural effects on managed land may not average out to zero over reasonable time scales. For some countries and circumstances, use of the managed land proxy may lead to emission and removal estimates dominated by natural effects occurring on managed land and this would need to be recognised where inventory estimates were used in estimates of anthropogenic or management effects. In addition, inter-annual variations in fluxes (driven by natural effects) may swamp the changes in fluxes due to mitigation efforts and there may be significant background uptakes.

3. Tier 1 and Tier 2 approaches may not result in emission and removal estimates with significant inter-annual variability as input data may be averaged. However moving to Tier 3 can result in significant inter-annual variability where annual climatic effects and annual area disturbed are more correctly represented or measured.

4. The meeting noted progress with the development of methods for separating anthropogenic from non-anthropogenic emissions and removals, and the possibility for comparison between these methods. The methods considered by the meeting were:

   - Maintenance of the managed land proxy
   - Component separation (quantify the influence of different drivers and then identify which drivers contribute to anthropogenic emissions)
   - Comparison of two time series (that represent two different levels of human activities, e.g. current management and no management, or improved management vs. business as usual management)
   - Default factors and optimal fingerprinting (without quantifying the relative contributions, apply a default factor which indicates the impact of the human activity)
   - Activity based approach (estimate emissions by different activities and sum up anthropogenic contributions))

   The participants recognized that these methods, which largely involve Tier 3 representation of ecosystem dynamics, could potentially refine the estimation of anthropogenic emissions and removals but considered that they needed further work; in particular: with regard to the science; methodological implications; data requirements, Tier 1 – 3 variations, and consistency with the general principles of inventory guidelines. The meeting hoped that further work by the scientific community will result in more mature approaches which can be assessed at a later date.

5. The meeting noted that the aim of emission inventories is to provide a best, while pragmatic, estimate of the emissions and removals in a given year and thus do not try to remove or reduce the impact of inter-annual variations (e.g. those caused by climate effects). The meeting further noted

that subsequent accounting can average out this variability in a transparent manner if so desired.

While the meeting agreed that annual emission inventories should estimate the actual emissions in the inventory year, it was also noted that there is also a requirement to be able to identify the impact of mitigation and management efforts even where these are overwhelmed by the impacts of natural processes (e.g. natural disturbances) or where these are obscured by inter-annual variations in greenhouse gas fluxes.

6. A clearer common understanding of anthropogenic is needed particularly in relation to the distinction between direct, indirect and natural effects, and how to classify effects that have a range of natural and direct influences, for example where there is a natural origin but the emission is mainly determined by direct anthropogenic factors or where there is an anthropogenic origin (e.g. fire ignition) but the magnitude of the emissions is affected by natural causes (e.g. extreme drought or high fuel loading due to tree mortality from pest outbreaks or windthrow). One issue that will need to be addressed is how to deal with areas with significant natural fluxes, so that emissions estimated using the current IPCC guidelines do not reflect the changes seen by the atmosphere. This situation occurs in other sectors but is particularly acute in the wetland sector.

7. Guidance for wetlands will need development in the future. Currently, scientific understanding, and the ability to translate it into practical methods, is immature. With increasing impacts of climate change the relative contribution of natural and indirect human-induced fluxes to the total is expected to increase (thus making the managed land proxy increasingly inappropriate as a proxy of fluxes due to direct human activities). Therefore research needs to continue to quantify the contribution of indirect human and natural causes of emissions and removals to develop methods for factoring out direct human impacts from all others.

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Annex 2. Co-Chairs Summary

Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals

5 -7 May, INPE, São José dos Campos, Sao Paulo, BRAZIL

Co-Chairs Summary

- Anthropogenic emissions and removals affect the level of greenhouse gases in the atmosphere. The IPCC has grouped these emissions and removals under the headings: energy; industrial processes and product use; agriculture, forestry and other land use; and waste.

- IPCC inventory methods for forestry and land use estimate greenhouse gas emissions and removals from the atmosphere.

- IPCC's advice in the 2006 Guidelines is that the anthropogenic component of emissions and removals from forestry and land use is the component which occurs on managed land. This is the managed land proxy.

- The experts noted the managed land proxy is a first approach for distinguishing between anthropogenic and non-anthropogenic emissions and removals, and is the current approach in the 2003 Good Practice Guidance for Land Use, Land-use Change and Forestry and the 2006 Guidelines for National Greenhouse Gas Inventories.

- The experts noted progress with the development of methods for separating anthropogenic from non-anthropogenic emissions and removals, and the possibility for comparison between these methods.

- The experts noted that these methods include component separation, detailed modelling grounded in empirical observation, comparison of time series, and fingerprinting. They noted that some of these methods had been outlined in presentations made during plenary sessions of the meeting, and considered that these methods could be helpful in improving estimates. Some of these methods could be the basis for Tier 1 approaches.

- The experts noted that where these methods are used to help estimate anthropogenic emissions and removals, it is important that the methods and estimates are fully described and transparently documented; are applied in accordance with time series consistency; and follow good practice.

- The experts noted that the outcome of the meeting will be summarised in a report to the IPCC Plenary.

TFI Co-Chairs, Saõ José dos Campos, 7th May 2009

Annex 3. Background Papers

Invited Background paper

Carbon Fluxes of Boreal and Temperate Forests

Richard Birdsey and Yude Pan, (U.S. Forest Service), Jingyun Fang, (Peking University)

Introduction

Here we report recently published estimates of average annual change in carbon stocks for boreal and temperate forests of the northern hemisphere. Estimates are shown for regions or large countries, which are generally categorized as boreal or temperate depending on the dominant proportion of forest area falling into the category boreal or temperate. The approximate time period is the decade 1995-2005, though there is significant variation in the reported estimates depending on the source of information. The most likely causes of observed sources and sinks are identified to the extent possible. Significant trends are noted and as well as the magnitude of interannual variability, if this information is evident in the literature. Estimates are based on peer-reviewed literature. Some of the estimates include carbon changes in harvested wood products. There are differences in the treatment of some carbon pools such as soils, and in the definition of what constitutes a forest.

For the most part, estimates are based on the inventory approach, meaning that the estimates are calculated from forest inventory data which is converted to carbon using one of several approaches. This is the generally accepted method for international greenhouse gas inventory reporting, but there can some variability in estimating biomass carbon according to method if the approach involves converting volume to carbon (Linder and Karjalainen 2007). This problem is avoided in the U.S. because the inventory approach involves direct calculation of biomass from individual tree measurements without requiring the intermediate step of making a volume estimate (Jenkins et al. 2003). Some of the estimates presented are based on ecosystem models or other approaches that combine inventory data, models and atmospheric inversions.

Summary Table: Average annual change in carbon stocks by selected regions and countries, approximate years 1995-2005. Estimates are from country- or region-specific studies so the separation of boreal from temperate is approximate. Causes of sink or source and trends are identified where known.

Region and country	*Boreal forests* ($TgCyr^{-1}$)	*Temperate forests* ($TgCyr^{-1}$)	*Trend and interannual variability (if known)*	*Significant causal factors*[1]
North America	38	138	-Probably decreasing -Interannual variability moderate but increasing	-Varies by country (see below)
Canada	28		-Probably decreasing -High interannual variability	-Age class -Harvesting -Natural disturbance
USA		190	-No significant trend. -Low interannual variability.	-Age class -Harvesting -Natural disturbance -CO2 and N dep.
USA (Alaska)	10		-Trend unknown -High interannual variability	-Natural disturbance -Climate variability -CO_2
Mexico		-52	-Trend unknown -Low interannual variability	-Land cover change -Natural disturbance
Northern Eurasia	240	455	-possibly increasing -variability depends on country	-Varies by country (see below)
Russia	240		-Trend unknown -High interannual variability	-Age class -Harvesting -Natural disturbance
China		92	-Increasing -Decadal variability	-Land cover change -Age-class effects -CO2
Europe		363	-No significant trend -Low interannual variability	-Land cover change -Age-class effects -CO_2
Total of North America and Northern Eurasia	278	593	-see above	-see above

[1]Land cover change, age-class effects, harvesting or management, natural disturbance, climate variability, CO_2 and N deposition, other factors.

Brief Description for Each Region or Country

North America

Between 1990 and 2004, Canada's forests were a net sink of 17 $TgCyr^{-1}$ but annual estimates ranged from a sink of more than 40 $TgCyr^{-1}$ to a source of 40 $TgCyr^{-1}$ (Environment Canada 2006). In a given year, boreal forests of Canada may be sources or sinks for carbon depending largely on wildfire and insect activity (Kurz et al. 2008). The most recent estimates point toward a more persistent source of CO_2 from forests, as mountain pine beetle and other insect outbreaks increase. Projections suggest that Canada's forests will remain a source of CO_2 for several decades (Kurz et al. 2008). This projected source does not include the effects of increasing CO_2 or climate variability, factors that may offset some of the CO_2 release from natural disturbances (Balshi et al. 2007; Chen et al. 2006).

Temperate forests and wood products of the USA have been a stable sink of about 190 $TgCyr^{-1}$ for several decades according to estimates based on forest inventories (Birdsey et al. 2006; Smith and Heath 2008). Interannual variability is low, in the range of + or – 25% of the long-term average primarily because of wildfire and insects. The main causes of the stable carbon sink are historic harvesting and land-cover changes which have produced an age-class distribution favorable for high ecosystem productivity, and a steady rate of harvesting for wood products followed by regeneration. Other approaches to estimating the size of the USA temperate carbon sink, such as inverse modeling and satellite-driven ecosystem produce similar but more variable results (Pacala et al. 2001). There is some concern that increasing tree mortality caused by drought, wildfire and insect outbreaks, may reduce the magnitude of the carbon sink in future decades (van Mantgem et al. 2008).

Boreal forests of Alaska have sequestered approximately 10 $TgCyr^{-1}$ (Yarie and Billings 2002; McGuire et al. 2004). Because of highly variable fire frequency, it is likely that Alaska boreal forests occasionally release sufficient C during the highest fire years to be a net source of C to the atmosphere (Tan et al. 2004). Because of the lack of active management of much of Alaska's boreal forest, climate change, natural disturbance rates and CO_2 fertilization are likely to be dominant factors now and in the future. Among these factors, CO_2 fertilization may have the dominant effect on ecosystem carbon flux (Balshi et al. 2007).

Temperate forests of Mexico were a net source of about 52 $TgCyr^{-1}$ to the atmosphere during the 1990's, primarily as a result of deforestation and forest degradation, but also reflecting insect outbreaks, wildfire, and other damages (De Jong et al. 2000; Masera et al. 1997). Reductions in carbon stocks are partially offset by recovery of degraded forests and establishment of industrial wood plantations. The trend is not known, but implementation of afforestation programs and potential adoption of a strategy to reduce deforestation and degradation could reduce or reverse the historical and persistent source of atmospheric CO_2 (Masera et al. 2001).

Northern Eurasia

Estimates of carbon flux for Russian forests are highly variable. One recent estimate suggests a forest carbon sink of 240 $TgCyr^{-1}$ (Kudeyarov et al. 2007) and another older estimate is 406 $TgC\ yr^{-1}$ (Nilsson et al. 2003). Yet another recent study concluded that land-cover and land-use change in northern Eurasian boreal ecosystems resulted in a net source of CO_2 to the atmosphere of 45 TgC yr^{-1} primarily from fire and climate (Hayes et al. 2009). Factors influencing the current carbon sink in Russia's forests include harvesting, age-class distribution, and natural disturbances, which also contribute to a high interannual variability especially from fire (Balshi et al. 2007). In the future, climate variability and CO_2 fertilization will likely become increasingly important leading to some significant uncertainty about whether the current rate of sequestration can be maintained, or will increase or decrease.

Between recent forest inventory periods, China's forests sequestered about 92 TgCyr^{-1} (Piao et al. 2009). Age-class structure is driving large periodic changes in the size of the carbon sink, a reflection of rates of forest recovery primarily from tree planting (Fang et al. 2007; Pan et al. 2004). Since China continues to implement an aggressive tree planting effort, it is expected that the current rate of C sequestration will continue to be high or even increase for many decades because the increasing area of young forests will maintain the relatively young age-class distribution (Ju et al. 2007). Another important factor besides age class is likely to be CO_2 fertilization, at least for several decades according to process model simulations (Ju et al. 2007).

In Europe, biomass stocks have been increasing for decades, with the current forest sink estimated to be approximately 363 TgCyr^{-1} (Janssens et al. 2003). The main causes of this persistent C sink appear to be an excess of growth over harvest, a favorable age-class distribution resulting from increasing forest area, low levels of natural disturbance, reductions in damage from air pollution, and CO_2 fertilization (Ciais et al. 2008). Another important factor may be nitrogen deposition, though it has been difficult to separate this from other factors (Churkina et al. 2007; Magnani et al. 2007). It is likely that forest biomass in Europe will continue to increase at least for several decades since current biomass is still significantly less than the potential maximum, assuming that the current levels of harvest and disturbance remain constant (Ciais et al. 2008).

Summary and Conclusions

This brief review estimated that northern temperate and boreal forests sequestered nearly 0.9 PcCyr^{-1} over the approximate period of 1995-2005. Temperate forests were responsible for two-thirds of this total. In general, the trend in boreal forest estimates seems to suggest a smaller and highly variable sink in the near future because of natural disturbances, though the prospective impact of climate variability and increasing CO_2 may alter this conclusion. The trend in temperate forests is difficult to assess because the circumstances of individual countries are highly variable, depending on land use, management, and air pollution much more than boreal regions.

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Invited Background Paper

Background Paper to the IPCC Expert Meeting Revisiting the use of Managed Land as a Proxy for Estimating Anthropogenic Emissions and Removals

Dr Gary Richards

Introduction

Article 4(1a) of the United Nations Framework Convention on Climate Change calls for the Parties to:

> *(a) Develop, periodically update, publish and make available to the Conference of the Parties, in accordance with Article 12, national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties;*

In most non-land based reporting sectors (those other than *Agriculture* and *Land Use, Land Use Change and Forestry*) anthropogenic emissions are readily separated from other indirect or naturally caused emissions. Typically, the emissions in these sectors are point-source, a direct result of human activity and instantaneous in response to human action.

In the land sectors this separation of anthropogenic and natural emissions is not so readily achieved. As pointed out in the *IPCC 2006 Guidelines*, *"The factors governing emissions and removals can be both natural and anthropogenic (direct or indirect) and it can be difficult to clearly distinguish between causal factors".*

Beyond the difficulty in directly attributing the 'cause' to either anthropogenic or natural source, there is the added complexity that variability in climate will have a large effect on the scale of emissions from the same action over time.

To deal with these difficult separation issues it is necessary to look beyond simple attribution of cause to find an approach that comprehensively deals with the interrelated impacts of:

factoring out natural, indirect and legacy effects;

stabilising interannual variability, and

the overarching need to retain symmetry in accounting while dealing with these impacts.

The Managed Lands Proxy

Moving from the activity based approaches that focussed on attribution of cause as characterised by the early IPCC deliberations on this issue (see the Rockhampton meeting, September 1997, *Expert group Meeting on biomass burning and land-use change and forestry in dealing with fires*) approaches have followed the general trend LULUCF inventory method to focus on a land use rather a than causal activity.

Under this land use approach, first seen in the *2003 Good Practice Guidance* and furthered in the *2006 IPCC AFOLU Guidelines*, lands are separated into managed and unmanaged. Pragmatically, emissions from unmanaged lands are considered to be natural in origin, and emissions from managed land, anthropogenic. The effect of this on the reporting of anthropogenic emissions is that naturally caused emissions (e.g., from natural disturbances) on managed lands are reported as anthropogenic.

The test of this pragmatic approach is how much the reporting of natural emissions on managed land as being anthropogenic would, in both absolute quantum and trend, add to truly anthropogenic (caused) emissions.

If the impact of including them is significant, there is then the question of how emissions from natural disturbances may be factored out of the emissions estimation on managed lands.

A second issue that arises with the inclusion of emissions from natural disturbances on managed lands is that they are often episodic in nature. Emissions tend to be instantaneous, while recovery may occur over decades. This gives rise to concerns that the managed land proxy may, by accepting natural emissions on managed land, introduce a scale of interannual variability that corrupts any understanding of trends in truly anthropogenic emissions.

A further challenge in implementing the managed land construct is the clarity of the definitional approach to the separation of managed and unmanaged land, and its ability to be consistently applied across national inventories.

The *2003 Good Practice Guidance* did not provide an explicit definition for managed lands, noting *"Managed land may be distinguished from that unmanaged by fulfilling not only the production, but also ecological and social functions".* That managed lands were a proxy for anthropogenic emissions was not explicitly stated, but given effect through guidance and methods.

The *2006 IPCC Guidelines* were more explicit on the use of managed lands as a proxy for anthropogenic emissions. The *2006 IPCC Guidelines* state *"For the AFOLU Sector anthropogenic greenhouse gas emissions and removals by sinks are defined as all those occurring on 'managed land'. Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions".*

The scale at which emissions from natural disturbances and legacy effects add to anthropogenic emissions, and the extent to which interannual variability is exacerbated, will in part depend on how narrowly or broadly the definition of managed land is applied. The broader the interpretation, the larger, in both absolute scale and proportion of reported emissions, amount of non-anthropogenic emissions that will be included in inventory estimates. One test of the consistency in these interpretations is to look at the definitions and their impacts in recent inventories compiled under the *2003 Good Practice Guidance* as discussed later in this paper.

Testing the Effectiveness of the Proxy

From the previous discussion, the appropriateness of using managed land as a proxy for anthropogenic emissions can be tested by:

- evaluating how clear and how consistently applied the definition of managed land is;
- assessing whether the introduction of non-anthropogenic emissions is of an acceptable scale (while accepting that to do a strict identification of anthropogeicity by cause is not possible and that this will lead to use of a proxy, and the pragmatism inevitably induced). These non-anthropogenic emissions come from:
- natural disturbances;

- indirect effects; and,
- legacy (e.g., forest age class structure).
- assessing whether the additional interannual variability caused by the inclusion as anthropogenic the emissions of natural disturbances, indirect effects and legacy effects beyond those from natural fluctuations (e.g., from climate) acceptable?

Given that attempts to attribute emissions to either natural or anthropogenic causes have not worked in the past and that accounting has moved to a land use basis, there is an inherent logic in dismissing unmanaged land from accounts. There is the potential that even if one or more of the tests outlined above raises question over the use of managed land as the singular proxy for anthropogenic emissions, there may also be the potential to provide some secondary treatments on managed land that limit these problems.

A second phase of tests can then be applied to determine whether it is possible to treat these problems, to an acceptable level, within managed land. Provisions contained within the *1996 IPCC Guidelines* and *2003 Good Practice Guidance* that attempted to do this include:

- the symmetrical removal of both sources and removals by subsequent sinks on lands affected by natural disturbances; and,
- multi-year rolling averages to smooth trends given interannual variability.
- Treatments in the rules and modalities for the Kyoto Protocol to factor out legacy and indirect effects include:
- use of activity cut-off dates to identify lands brought into the accounting (e.g., afforestation, reforestation and deforestation only after 1990); and,
- net-net accounting and caps on gross emissions.

Beyond these approaches that have already been applied to inventories, there is the potential to factor out age-based legacy effects and to use process-driven (i.e., including climate legacy effects) models to factor out the effects of climate variability.

Should the use of managed land prove unacceptable as the singular means of separating natural and anthropogenic emissions, then the options outlined above, and others, may be applied on managed lands to derive an acceptable outcome.

How clear is the definition?

Although the *2003 Good Practice Guidance* and *2006 IPCC Guidelines* definitions of managed land differ, they contain similar elements that could be presumed to lead to the same outcome when applied nationally. Both definitions seek some form of human benefit around social, ecological and production functions from managed land.

The key difference between the two that could lead to a divergence in application is that the *2006 IPCC Guidelines* talk about *"...human interventions and practices..."* which infers that a direct, physical human activity is required to bring land into a managed condition. The *2003 Good Practice Guidance* is more ambiguous, not specifying human actions or interventions, but of fulfilling *"...not only the production, but also ecological and social functions".* It is possible that a national definition under the *2003 Good Practice Guidance* could include broad land areas, such as wilderness that are protected from human intervention, in order to serve an ecological function, but that would not meet the test of *"... human interventions or practices..."* under the *2006 IPCC Guidelines*.

As the *2003 Good Practice Guidance* provides support for the currently applied guidelines, it is possible to look at the range of national definitional treatments in the production of current inventories. Two examples of contrasting approaches are for Australia and Canada. As the *2003 Good Practice Guidance* requires coverage of land for purposes of social and ecological function and given the range of legislative provisions that cover the entirety of the national land area, Australia took the decision that there was no immediate basis for excising land. For forests, this has been the practice of most countries. In applying the *2003 IPCC Good Practice Guidance*, Canada identified areas of forest that fell outside of the managed land definitions.

Due to the divergence in application and uncertainty in the eventual definition, the *2003 Good Practice* or *2006 IPCC Guidelines,* variants point to a need to further consider the construct and intent of the managed land definitions. This does not directly question the use of managed land as a proxy for anthropogenic emissions, but points to a need for more clarity and certainty in the definitions if it is to consistently serve this purpose. Key in this will be determining the inclusiveness of the definition and this will directly impact on the appropriateness of the proxy. Decisions cannot be taken in isolation of other potential treatments of natural emissions, legacy effects and interannual variability on managed land.

Scale of non-anthropogenic emissions entering the accounting

Natural Disturbances

The scale of non-anthropogenic emissions from natural disturbances will be affected by both national circumstance and the inclusiveness of land into the national managed land definition. For a country like Australia, with episodic extreme fire events, this is very large - conceivably representing in the order of over a quarter of the national inventory for all sectors in any one year.

Here again, changes between the *2003 Good Practice Guidance* and the *2006 IPCC Guidelines* are germane. The *2003 Good Practice Guidance* contained provisions that state*"If methods are applied that do not capture removals by regrowth after natural disturbances, then it is not necessary to report the* CO_2 *emissions associated with natural disturbance events"*. The effect of the symmetrical inclusion or exclusion of natural emissions from disturbances is to either respectively include or exclude the affected land area from accounting. If the occurrence of natural disturbances was stable over time and if the span of accounting covered a full disturbance and recovery cycle, then the net result of either approach would be the same. Presumably, there would be few instances where the reporting period was this long, and where there was no interannual variability in scale of natural disturbances.

Under the *2006 IPCC Guidelines*, the provisions for exclusion of natural disturbances were removed, enforcing the potential for the entry of a significant scale of natural emissions to the accounting. This also meant the interannual variability in emissions was also large.

The impact of the change from the application in the *2003 Good Practice Guidance* to the removal of these provisions in the *2006 IPCC Guidelines* clearly has an impact on the appropriateness of the use of the managed land proxy. In national circumstances, where natural emissions caused by natural disturbance on managed land are large and variable, the inability to excise those emissions and subsequent removals (effectively by excising those lands where the natural emissions dominate), reduces the appropriateness of the use of managed land as a proxy for anthropogenic emissions.

Indirect effects

Indirect effects include emissions and removals induced by climate change, CO_2 fertilisation and enhanced atmospheric nitrogen deposition.

The question on indirect effects starts with whether they should be considered as anthropogenic (and factored into anthropogenic accounting), anthropogenic but not directly human induced (and therefore although anthropogenic are not deliberate or additional and should be factored out of accounting), or considered a source of natural emissions. Subsequent scientific questions, that may or may not need to be addressed depending on accounting treatment, are the net direction of overall effects (sinks or source) and the persistence of any effect.

Independent of both of these considerations is the nature of the lands to which they are applied. If their effect is limited to managed lands (land where there is human intervention and implementation of management practice is applied), then presumably any effect will be overwhelmed by the emissions and removals affected by the management. Therefore, scale is unlikely to be a problem.

For inventories prepared using methods that are sensitive to climate variability, there is the potential for exacerbated variability (particularly extremes) arising from climate change to disrupt inventory trends. Presuming that the emissions are to be included in accounting, the issues of trend disruption is then a matter of scale. If small in scale, then inventory trends will not be affected, and this will be the case for many countries. However, for many countries the scale and therefore the trend disruption will be significant.

The *1996 IPCC (Revised) Guidelines* applied 'smoothing by rolling to means moderate this effect and the *2003 Good Practice Guidance* did not explicitly remove those provisions. However, these provisions were removed in the *2006 IPCC Guidelines*. The effect of the removal of these smoothing provisions meant that there will be a significant effect of interannual variability from indirect effects that is not moderated by the use of the managed land proxy for countries that:

- have a large area;
- adopt an inclusive approach to defining managed lands;
- use estimation methods sensitive to climate variability; and,
- have variable climates.
- However, large or small, this moderation by the managed land proxy may not fully compensate for the removal of the smoothing provisions.

Legacy effects

Legacy effects are an accounting issue that has multiple dimensions, but is assisted by the managed land proxy. Legacy effects can be human or natural in source. Presumably legacy effects on unmanaged land are natural emissions and removals and are therefore rightly excised from accounting. Legacy effects from both natural and anthropogenic causes can occur on managed land. Depending on the treatment of natural disturbances (excision or inclusion on managed land), natural emissions (if excluded) should not be significant, where the principles applied to current reporting are reapplied to past events that have a legacy (lagged effect) into the inventory reporting period. If not, then the legacy effect will be a windfall gain from ongoing removals from historic natural disturbances.

For legacy effects from human activity, the question is one of accounting policy and is independent of the effects of the managed land proxy. It could be taken that where there was a legacy effect from a human activity, the land would be defined as managed (the managed land definition making no reference to the human activity or practice being within the accounting and reporting period). In this case, decisions on inclusion or exclusion of these emissions is unaffected by the proxy.

Interannual Variability

The acceptability of the scale of interannual variability entering national accounts depends on many factors:

- the national circumstance (land area, climate variability etc);
- the estimation method (targets whether recognising climate variability or not, or on annual or mulit-year periods);
- the inclusiveness of the managed land definition; and,
- the inclusion or exclusion of natural disturbances.

The main concerns with interannual variability are not of anthropogenicity, although the more natural emissions included the larger and more likely variability, but are in the accounting construct. Short base and reporting periods (e.g., 1990 against commitment period years) have the capacity to be unduly influenced by variability that diverges from trend. This is particularly for the one year 1990 where the variability is magnified by five to account for comparison to the five commitment period years under the Kyoto Protocol.

The provisions for smoothing annual estimates of emissions, as previously applied in the *1996 IPCC Guidelines* provided one approach. Current recommendations are to apply multi-year measurement of average input data to the estimation process. The different effects of smoothing outputs and inputs should be carefully tested. Nevertheless, this will only apply to measurement based inventories where repeat measurement intervals are over many years. For model-based inventories where time-series are usually monthly, , annual estimates are reported.

Conclusion

On the basis of the previous discussions, it is worth reframing the question about whether managed land is proxy for anthropogenic emissions. If proxy is to be taken as the sole and singular treatment to separate anthropogenic and natural emissions, then managed land is a very questionable proxy.

If the question is reframed, to ask whether the managed land construct assists in separating anthropogenic emissions then the answer is certainly yes. However, subsequent treatments of a technical nature (removal of emissions from natural disturbance), and of a policy nature (removal of any legacy effect and smoothing of interannual variability) should be applied in support.

What would a decision to go down this path mean for the *2006 IPCC AFOLU Guidelines?* In regard to the AFOLU chapter, and in fact the *Guidelines* more fully, the additional provisions to support the managed land approach have existed in previous (currently applied) *Guidelines*, and *Good Practice Guidence.* A decision to move to the use of the *2006 IPCC Guidelines* by Parties could simply contain text that enabled the carry forward of averaging provisions and the potential to excise emissions and removals from natural disturbances as contained in the currently adopted *Guidelines*. The qualifications on the definition of managed land in the *2006 IPCC Guidelines* to require *"...human intervention or managed practices..."* would seem to address ambiguity in the *2003 Good Practice Guidance* definition.

Recalling that the UNFCCC calls for inventories of anthropogenic emissions only, the ramifications for the *2006 AFOLU Guidelines* would be almost negligible if provisions were added to make the use of managed land an acceptable proxy for separating anthropogenic emissions from natural emissions.

Invited Background Paper

Fingerprinting as a technique for attributing direct and indirect human induced effects (including changes in C stocks in crop & grasslands caused by climate change)

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The attribution of changes in carbon stocks and in greenhouse gas (GHG) emissions came to prominence when the Kyoto Protocol was signed in 1997 (http://unfccc.int/kyoto_protocol/items/2830.php). Article 3.3 of the Kyoto Protocol states that "net changes in greenhouse gas emissions by sources and removals by sinks resulting from *direct human-induced* land-use change and forestry activities" need to be accounted for, and Article 3.4 states that "*additional human-induced activities*" could also be considered. This wording thrust the science of attribution of observed ecosystem changes to a) direct human induced factors (e.g. land use and land management change), b) indirect human induced factors (e.g. climate change and N deposition) or to c) natural factors (e.g. natural climate variability). Working group I of the Intergovernmental Panel on Climate Change (IPCC) were charged with examining the potential to factor out natural from direct and indirect human induced ecosystem carbon and GHG changes (IPCC, 2003). In considering the use of split plot multi-factorial experiments and ecosystem models to attribute changes in C stocks and GHG emissions to natural and direct, and indirect human-induced factors, the IPCC concluded at the time that "these methods provide only limited potential to separate direct and indirect effects, since differences in carbon stocks and greenhouse gas emissions and removals between plots result not only from direct human-induced effects but also from the interactions with indirect human-induced effects, natural effects and past" (IPCC, 2003).

Very recently, advances in modelling and in attribution methodology have allowed the more confident attribution of changes in ecosystems to different anthropogenic and natural factors (Tett et al., 2002; Smith et al., 2005; Smith et al., 2006; Gedney et al., 2006; Betts et al., 2007; Gillet et al., 2008, Eggers et al 2008, Nabuurs et al. 2006, 2008, Schelhaas et al. subm). Smith et al. (2005), Smith et al. (2006) and Smith et al. (2007), for example, used an ecosystem model to attribute future changes in soil carbon to changes resulting from direct impacts of climate on soils, indirect effects via changes in productivity, changes in land use, and improved management / technology. Tett et al. (2002) and Gedney et al. (2006) used ecosystem models and optimal fingerprinting statistical techniques to attribute observed changes to different potential causes. This is a formal detection and attribution technique developed to isolate the causes of observed change. In short, the models are run with all factors included, and allowed to vary within set ranges. The models are then run again, fixing one potential driver at a time. By comparing the model outputs to the observations, the distinct spatio-temporal patterns of the response serve as 'fingerprints' that allow the observed change to be separated into contributions from each factor (Gedney et al., 2006). These formal detection and attribution techniques can be further developed and used to attribute annual to decadal variability of carbon and GHG budgets in managed European ecosystems to human and natural driving processes.

In this presentation I will show how these techniques are already used in climate science, and I will show examples of how models and data have been used to examine how much observed or modelled change in soil carbon can be attributed to climate change, and how much can only be explained by other factors. I will finish by presenting an economic analysis of the agricultural mitigation options to show how vitally important it is, both environmentally and economically, to develop robust methods that allow human induced indirect and direct climate effects to be disentangled to allow robust accounting in the land based sector. I will end with examples of Tier III national accounting systems already in use for carbon / GHG accounting that have the potential to factor out various causes of observed change on managed land, and consider if tier I equivalents are possible.

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Invited Background Paper

Large inter-annual variations in carbon emissions and removals

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Background

The underlying assumption of the “managed land proxy” is that for the land use, land-use change and forestry (LULUCF) sector, the emissions and removals from managed lands are primarily due to anthropogenic activities. This proxy is currently used for the reporting of national greenhouse gas (GHG) budgets because there is no agreed-upon methodology to separate direct-human induced emissions and removals from those emissions and removals that are attributable to natural or indirect human-induced causes.

Forests are under varying degrees of direct human influences. In some large countries not all regions are accessible, populated or otherwise affected by direct human influences. The managed land proxy therefore provides a crude first approximation to distinguish between direct-human and other causes by stratifying the land area into managed and unmanaged components. While the managed land proxy has been useful in enabling the initial development of national greenhouse gas inventories for the LUCUCF sector, data now available raise several concerns. Here we focus on concerns for the managed forest.

First, in large countries with low population density (such as Canada, Russia, Australia and others) the contribution of natural and indirect-human induced processes to the net greenhouse gas balance of the managed forest can be very large and confound the contribution of anthropogenic activities.

Second, the interannual variability of the net GHG balance can be very large as a result of interannual variability in climatic conditions, and (in part as a consequence of this variability) in natural disturbances, including fires, insects, windthrow and drought.

Third, the predicted impacts of climate change include increases in natural disturbance rates and other extreme events, as well as increasing mal-adaptation of existing forest to the new climatic conditions. These climate change impacts are projected to increase the influence of indirect-human and natural processes on the net GHG balance in the managed forest. This will render the managed land proxy increasingly inaccurate and inappropriate as a means for reporting emissions and removals from anthropogenic activities.

Here we will briefly describe the factors contributing to large interannual variations in reported GHG net balances for the managed forest, and discuss ways in which these might be addressed such that anthropogenic emissions and removals are separated from those caused by natural and indirect-human processes.

Summary of Disturbance Impacts on Emissions and Removals

Natural disturbances (such as wildfires, insect outbreaks, and windthrow) differ in several ways with regard to their impacts on greenhouse gas emissions and removals: these include the magnitude and timing of emissions in the year of the disturbance and thereafter, as well as the temporal variability in the occurrence of the disturbances.

Impacts on GHG emissions and removals

Fires cause large emissions in the year of disturbance from the consumption and oxidation of biomass and dead organic matter in the litter, fine and coarse woody debris pools. Fires also contribute large quantities of non-CO_2 greenhouse gas emissions in the form of CH_4 and N_2O. Crown fires are typically stand replacing and kill a large proportion of the live tree biomass, while ground fires result in no or partial tree mortality. In Canada, the average amount of carbon transferred annually from live biomass to dead organic matter pools through wildfire exceeds the amount of carbon emitted directly to the atmosphere during the fire. Fire-killed biomass added to dead organic matter decomposes in the years after the burn. Fires therefore affect post-disturbance carbon dynamics with burned stands acting as net carbon sources for several yeas post fire until, following regeneration and stand establishment, the regrowing forest contributes a larger sink than areas that were not affected by fire.

Insects cause negligible direct emissions in the year of the outbreak. The primary impact of defoliating insects is initially a reduction in tree growth (and therefore net carbon uptake). Repeated defoliation events can lead to increasing tree mortality. Bark beetles can cause significant mortality rates in the first year of stand attack. Depending on the proportion of host tree species in the stand, the amount of mortality caused by the insect, and the response of the surviving trees, forests can be turned into net carbon sources for one or more years after the insect outbreak.

Windthrow reduces C uptake immediately after the event, and like insects, does not cause (material) increased emissions in the year of the event. In the years after the event stands affected by windthrow will be net sources of greenhouse gases but will eventually turn back into sinks.

The carbon dynamics after all types of natural disturbances is further affected by salvage logging which removes carbon that would otherwise be released through decomposition and transfers some of it to harvested wood products or bioenergy uses. Rates of carbon uptake can further be affected by human activities aimed at accelerating forest regrowth including planting, vegetation management or other activities aimed at accelerating the establishment of a forest.

The implication of the temporal responses of emissions and removals following different types of disturbance is that the direct emissions from wildfire are strongly correlated with area disturbed. But for all other disturbances and for post-fire emissions, the impacts on the emissions and removal balance occurs in the years after the disturbance, contributing to greater emissions during the initial years after the disturbance and to greater removals in later years. Quantification of the temporal dynamics of post-disturbance carbon dynamics is necessary if impacts from natural disturbances were to be separated from anthropogenic contributions.

Temporal variability

Fires are characterized by large regional variations in the proportion of the forest area annually burned. Area burned also displays high inter-annual variability, with minimum and maximum area burned differing by as much as an order of magnitude. Area annually burned can also exhibit high interdecadal variability, with decadal averages in area burned differing by factors of two or more (Mouillot and Field 2005). Long-term trends in annual area burned, both increasing and decreasing have been observed in different regions of the world over the last century (Mouillot and Field 2005).

Insect outbreaks are characterized by multi-year cycles of high insect impacts followed by multi-year periods of low impact levels. In some regions such cycles have been observed over centuries (e.g. Esper et al. 2007, Swetnam and Lynch 1993). Climate change impacts (and other factors) have contributed to an unprecedented outbreak of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins) on the greenhouse gas balance of the managed forest in British Columbia, Canada (Kurz et al. 2008a), and other regions of western North America. Other insect species are also expected to increase in range and impact, while others are expected to continue their outbreak cycles.

Windthrow, like fires, is characterized by large interannual variability, with many years of no or little windthrow punctuated by occasional extreme events. Several storms in Europe caused tree mortality in excess of annual harvest.

The implications of the temporal variability in disturbance regimes for the managed land proxy are twofold. First, the contribution of emissions from wildfires as proportion of total emissions in the managed forest varies greatly between years, and while it can be estimated (once the area burned in known) it is not predictable. Second, even decadal (or longer) averages of disturbance impacts vary considerably, as a result of processes affecting regional area burned such as the Pacific Decadal Oscillation (Balshi et al. 2008, Calkin et al. 2005) or regional-scale outbreaks of insects. Thus, lengthening the accounting period for emissions and removals is by itself not sufficient to address temporal variability in natural disturbance regimes.

Long-term trends

It is well established that changes in forest disturbance regimes are associated with changes in emissions and removals (Kurz and Apps 1999, Hurtt et al. 2002, Birdsey et al. 2006). The predicted impacts of global change on forests include, among others, forecasts of changes in natural disturbance regimes, in particular increases in the area annually burned (Balshi et al. 2008, Amiro et al. 2009).

Increases in the areas affected by natural disturbances, will however, also increase the contribution of non-anthropogenic process to the emissions and removals reported for the managed forest. This will further diminish the suitability of the managed land proxy as an estimate of human-induced emissions and removals in the future.

Relationship between interannual variability and choice of reporting method

The IPCC Guidelines for LULUCF (and AFOLU) reporting provide parties with choices regarding the methods used to prepare estimates of GHG emissions and removals from managed forests. National circumstances, such as the availability of forest inventories, remote sensing programs and modeling tools have contributed to parties' methodological choices. The magnitude of interannual variability of emissions and removals reported for the managed forest is, however, strongly affected by the choice of methods.

IPCC guidelines describe two approaches: (1) The default method which calculates stock changes as the difference between gains and losses and (2) the stock change method which estimates the difference between stocks at two points in time (IPCC 2003, IPCC 2006).

Stock change approach
Estimating carbon emissions and removals from the difference in carbon stocks over a period, e.g. two forest inventories compiled 10 years apart, yields the average stock change from all causes over the 10-year period. Unless auxiliary information is used to annualize the periodic change, there is no interannual variability in the estimate.

In practice, parties rarely conduct complete inventories in a single year but measure a proportion of all inventory plots every year. More complex statistical methods are required to annualize such a continuous inventory and the results will show greater interannual variability. However, because natural disturbance impacts from the past year are only observed in the subset of plots remeasured this year, interannual variability tends to be "dampened". Moreover, in times of increasing natural disturbance rates, the impacts of disturbances can be underestimated in the most recent year(s), while in times of decreasing disturbances disturbance impacts in the most recent year(s) can be overestimated.

One inventory plus change
The second approach to estimating emissions and removals in the managed forest is typically implemented using detailed data plus models. Parties that implement this approach usually track annual area disturbed by wildfire and other disturbances and their impacts result in much larger interannual variability in reported emissions and removals. The choice of model further affects the magnitude of interannual variability.

No climate variability
Parties that use empirically driven models, i.e. those in which forest growth rates are specified by yield tables or other forms of yield models that are not sensitive to variations in annual climate, will not report that component of removals that is associated with annual variability in tree growth rates due to climate variability. Unless there are long-term trends in climate (or other factors not captured in the empirical yield tables) the yield tables are expected to average growth rates over a period. It is good practice to confirm from time to time that the yield tables adequately represent growth rates.

Estimates of emissions associated with heterotrophic respiration (decomposition) are typically derived from process models (e.g. Kurz et al. 2009). Parties have the choice, however, to estimate decomposition rates using either average climate conditions or to account for interannual variability in climate. To be consistent with the representation of tree growth, the Canadian estimation methods currently use average climate to estimate decomposition rates. Using annual climate parameters would increase interannual variability in emissions from decomposition.

But even with the impacts of natural disturbances alone, interannual variability in the time series of emissions and removals in Canada's managed forest between 1990 and 2007 spans 300 Mt CO_2e, equivalent to about 40 % of the emissions in all of Canada (excluding the LULUCF sector). The predicted variability in the 5-year average of the net GHG balance of Canada's managed forest for the first commitment period covered a range of about 200 Mt CO_2e due to the large variability in natural disturbances (Kurz et al. 2008b).

With climate variability
Parties that use climate-sensitive process models to estimate emissions and removals in the managed forest will report high interannual variation in emissions and removals because their estimates are affected by both, variations in climate and variations in natural disturbances. In this case, the annual

estimates of anthropogenic emissions and removals in the managed forest are substantially confounded with the impacts of natural disturbances, weather variability and long-term climate trends.

The implications of the choice of estimation method for the interannual variation in reported emissions and removals in the managed forest proxy can be substantial. It is important to note that the choice of estimation method affects both the proportion and the timing of the emissions and removals that are included in the reporting.

Factoring out Processes that Contribute to Interannual Variability

Four methodological options to factor out processes that contribute interannual variability in the emissions and removals are discussed briefly. All involve model simulations and comparisons between two sets of estimates and all require that the "actual" emission and removals be calculated using the actual human activities, natural disturbances and climate (in the case of models in which climate variability contributes to emissions and removals). The options differ with regard to the reference against which these actual values are compared and consequently, how the results of the comparison need to be interpreted.

Option 1: compare to a scenario with average climate and no disturbances
The first option involves comparing the estimates of actual emissions and removals against the results of a second simulation with long-term average climate and no natural disturbances. The difference in the resulting estimates of emissions and removals can be attributed to natural disturbances and variations in climate from the average.

Option 2: compare to a scenario with average climate and average disturbances
A variation of the first option would be to use average climate and average disturbance rates for the comparison against the actual. The difference in the resulting estimates is then attributed to deviations in climate and disturbances from long-term averages. It would be difficult, however, to determine the long-term average disturbance rates in periods of change.

Option 3: compare to a scenario with BAU human activity
The third option involves comparing actual estimates against a simulation with the same data on natural disturbances and climate, except this second simulation uses a "business-as-usual" level of human activities. The difference in the resulting estimates can be attributed to changes in human activities between the baseline and the actual. The impacts of natural disturbances and indirect human effects are the same in both simulations and therefore cancel each other out.

Option 4: compare to a scenario with no human activity
A fourth option is to compare actual estimates against a simulation in which all anthropogenic impacts that cause emissions, including all harvesting and human-caused fires are removed. The difference in the resulting estimates can be attributed to all human activities between the baseline and the actual. This approach would be more difficult to implement because in this approach the direct anthropogenic impacts on removals must also be assessed and taken out of the baseline.

For example, if fire suppression efforts are practiced, then how large would the area annually burned be in the absence of such efforts? Note that in many countries less than 5% of the number of fires cause well over 90% of the area burned (Stocks et al. 2002, Calkin et al. 2005). So even a small increase in the number of fires that are not contained could trigger large increases in area burned. Similarly, where efforts to suppress insect outbreaks are practiced, these will contribute towards maintaining or increasing forest carbon stocks. It is difficult to predict what the insect impacts would have been, had humans not implemented control activities.

The carbon dynamics of a forest region can be simulated with and without a natural disturbance event. For example, the difference in emissions and removals between simulations with and without the current Mountain Pine Beetle outbreak in British Columbia, Canada, was 990 Mt CO_2e over the 20-year outbreak period (Kurz et al. 2008a). Thus quantification of the natural disturbance impact is possible. More difficult, however, is the question whether an insect outbreak is entirely a “natural” disturbance or whether anthropogenic actions have contributed to it. An unknown fraction of the fires 80 to 120 years ago could have been caused by human activities. While the pine stands regenerated naturally after these fires, management decisions, some made decades ago, to suppress fires or to protect stands from harvesting contributed to today’s host conditions. While the insect outbreak has reached its current scale because of warmer climatic conditions that contributed to higher winter survival rates and range expansions northward and to higher elevations, a small but unquantifiable contribution of past anthropogenic activities cannot be ruled out.

Similarly, catastrophic, large-scale windthrow events that recently affected European countries are clearly caused by the extreme natural events. But did silvicultural decisions over past decades that affected species choices and stand structure, contribute to the magnitude of the impact of the natural events? Lastly, fire protection efforts and fuel management can both affect the future area burned by wildfire.

While the question of complete attribution of natural disturbance events to natural and anthropogenic causes may be of scientific interest, it greatly complicates any attempts to factor out the direct-human impacts on interannual variability from other factors.

If the intent of national GHG inventories is to report the impacts of current anthropogenic activities then the complications arising from the interactions of past human activities and natural disturbances can perhaps be ignored?

Conclusions

The two primary sources of interannual variability in GHG emissions and removals in the LULUCF sector are natural disturbances (such as fire, insects, windthrow, and ice storms) and climate variability (e.g., weather, drought, and cold or hot extremes). Natural disturbances have large impacts per hectare in the areas where they occur, while climate variability typically causes small changes per hectare but over large areas.

The impact of disturbances on emissions and removals is not limited to the year of the disturbance. The ratio of direct emissions and post-disturbance emission differs between disturbance types: fires cause large direct emissions in the year of the fire, and also considerable post-fire emissions from trees killed in the fire. Insects and windthrow cause very small or no immediate emissions but contribute to large post-disturbance emissions (and reduced removals).

Fires and windthrow are highly episodic with very large interannual variability. Large interdecadal variability has also been documented for fires. Insects typically occur in outbreak cycles that can last from several years to a decade or more – these outbreak cycles contribute to interdecadal variability.

Using the “managed land” proxy to account for direct human effects yields estimates of emissions and removals that are to varying degrees confounded with the impacts of natural disturbances and climate variability.

Factoring out direct human impacts from the impacts of natural disturbances and direct human-induced effects is at least partly possible and four examples have been provided here. All involve the comparison between two runs of the same simulation model, but they differ in their approach to which factors are included or excluded in the pair of simulations used in the comparisons.

Complex issues arise when trying to assess the effects of human activities on the suppression of natural disturbances because it is difficult to determine what natural disturbances would have occurred in the absence of suppression and control efforts.

With climate change impacts predicted to cause significant increases in the area annually burned and the associated emissions in many regions of the world (e.g. Balshi et al. 2008, Amiro et al. 2009), finding ways to separate direct-human impacts on emissions and removals from natural and indirect impacts will be increasingly important. This is recognized by the international community and is the subject of ongoing climate negotiations and scientific research.

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Annex 4. Presentations

All presentations are available on the IPCC TFI website http://www.ipcc-nggip.iges.or.jp/

Simon Eggleston – **Introduction**

María Sanz- Sánchez- **Treatment of LULUCF Inventories under UNFCCC**

Nalin Srivastava - **Treatment of Anthropogenic Emissions/Removals in IPCC GHG Inventory Guidelines**

Jim Penman - **Scoping of meeting including summary of previous IPCC meetings and overall issues**

Jennifer Jenkins - **Overview of earlier IPCC and other Activities**

Gary Richards – **The Use of Tier 3 Systems to Factor Out Non-Anthropogenic Emissions and Removals on Managed Land** (presented by Annemarie Watt)

Luiz Gylvan Meira Filho – **Climate Change and Carbon in the Biosphere**

Werner Kurz – **Large inter-annual variations in carbon emissions and removals**

Zucong Cai – **Methane and Nitrous Oxide emissions from rice fields**

Pete Smith – **Fingerprinting as a technique for attributing direct and indirect human induced effects**

Richard Birdsey & Yude Pan – **Carbon Fluxes of Boreal and Temperate Forests**

Dominique Blain – **Managed Land and GHG Emissions/Removals in Wetlands**

Joel Goldenfum – **Emissions from Freshwater Reservoirs**

Zoltan Somogyi – **Using the carbon accounting model CASMOFOR to separate the effect of disturbances ("mortality"), age class distributionand site distribution: need and feasibility**

Devendra Pandey – **National Forest Inventory and Assessment of Forest Biomass Carbon Stock of India's Forests**

Annex 5. Agenda

Tuesday 5th May	09:30 – 10:00	Welcome,	Hosts and Co-Chairs
		Introductory Remarks	Taka Hiraishi
	10:00 – 12:30	**Plenary 1 – Invited Background Papers**	
		Background: Aims and Objectives	Simon Eggleston
		Treatment of LULUCF Inventories and anthropogenic emissions/removals required by UNFCCC	UNFCCC
		Treatment of "Anthropogenic Emissions/Removals" in IPCC GHG Inventory Guidelines	Nalin Srivastava
		Scoping of meeting including summary of previous IPCC meetings and overall issues	Jim Penman (UK)
		Overview of earlier IPCC and other Activites	Jennifer Jenkins (USA)
		Discussion	
	12:30-14:00	LUNCH	
	14:00 – 16:00	Existing modelling approaches to LULUCF/AFOLU emissions/removals – how do they treat direct and indirect contributions to carbon fluxes?	Gary Richards (Australia)
		Forest Carbon Sink	Luiz-Gylvan Meira-Filho (Brazil)
		Large Inter-annual variations in emissions/removals	Werner Kurz (Canada)
		Methane and Nitrous Oxide Emissions from Soils	Zucong Cai (China)
		Fingerprinting as a technique for attributing direct and indirect effects (including changes in C stocks in crop & grasslands caused by climate change)	Pete Smith (UK)
		Wetlands – including peatlands	Dominique Blain (Canada)
		Discussion	
	17:00 - 17:30	Introduction to Break Out Groups	TSU

Wednesday 6th May	09:30 – 12:30	**2 Breakout Groups (Forest and All Other Lands)**
	12:30-14:00	LUNCH
	14:00 – 14:30	**Plenary 2** Reports from BOGS and Discussion Decide BOG focus for afternoon
	14:30 – 17:30	BOG discussions continue

Thursday 7th May	09:30 – 11:00	**Plenary 3 – Reports from BOGS and Discussion**.
	11:00 – 12:30	**BOGs draft outline of meeting report**
	12:30-14:00	LUNCH
	14:00 – 15:30	**Plenary 4 Agree Draft Outline and Co-Chairs Statement**

Annex 6. Participants List

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