24 WG3 Summary: Evaluating the role of forest management and forest products in the carbon cycle

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INTRODUCTION

Decisions on land-use and forest management can have a significant effect on the global carbon (C) budget. In order to evaluate the effect of land use and forest management decisions on the global C balance, or to assess the potential for positive change, we need not only to evaluate the current and near-term status of forests, but also to understand the processes and sectors, both ecological and industrial, that are affected by forest management decisions.

Forestry policy and management can change the area of forested land and the C content of forest ecosystems. In combination with wider economic and energy policy they can influence the mean life-span of wood products and energy efficiency. At the regional and operational level, a system for evaluating the C sequestration potential of specific forest management options needs to be able to account for all such impacts on the C budget, depending on what has been postulated. The system thus needs to evaluate impacts on forest ecosystems, forest products, wood processing technology and energy supply and consumption.

Many writers have suggested that forest ecosystems and forest products can be managed in order to slow down the accumulation of carbon dioxide in the atmosphere (see for example Marland 1988; Sedjo 1989; Thompson and Matthews 1989). It is difficult, however, to synthesise from the literature a consensus on the role which forests and the forestry sector can play in sequestering C (Chapter 19). The apparent lack of agreement in the literature can be attributed in part to progressive changes of opinion following the gradual improvement in our understanding of forests in the C cycle, and of what is technically, economically and socially possible in terms of forest management and wood processing. It is also the case that some of the divergences of opinion are more apparent than real, in that some authors and reviewers do not distinguish between an inventory of the current status of forests, and an assessment of the larger impacts that can occur when a decision is made to influence that inventory. On the other hand, conflicting viewpoints have also arisen directly from differences in the scope of individual case studies, and in the methodologies adopted by different research groups. Nabuurs (Chapter 20) has argued that efforts should be made to devise an agreed, standard procedure for the estimation of the C sequestration potential of forest management options.

This overview paper sets out some suggestions for guidelines for procedures for evaluating C sequestration potential, and for the presentation of results for specific forestry schemes. Special consideration is given to the role of wood products, and to the likely impacts of alternative methods of forest management and wood use on C sequestration potential. The

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paper draws heavily on material presented in the plenary sessions of the Workshop, and on the discussions involving members of Working Group 3.

PROCEDURES FOR EVALUATING CARBON SEQUESTRATION POTENTIAL

The apparent disagreement in the literature over the potential impacts of forest management on C sequestration may be the result of the adoption of inconsistent methodologies or definitions of the forestry sector for the estimation of C budgets by different research groups. Confusion may also arise from inconsistent styles of presentation, e.g., published statistics on C sequestration potential often consist of a mixture of results for both stocks and fluxes, which can be difficult to interpret. Carbon budgeting is also a relatively new and untried technique, and we are only beginning to appreciate the possibilities and pitfalls. At this early stage of development, it is especially important that analyses make absolutely clear what is and what is not being included.

Much confusion may be avoided if guidelines for the modelling and presentation of C budgets can be formulated and broadly accepted by the scientific community. The specification of such a standard is beyond the scope of this paper, and perhaps beyond current understanding of the problem, but we propose the following five criteria as central to any standard:

1. The procedure should account for impacts on C stocks and fluxes associated with all relevant C pools:

   - Above- and below- ground biomass;
   - 'Necromass' (or 'mortmass') including coarse woody debris, litter, soil organic matter and peat;
   - Wood products;
   - Fossil fuels (including potential savings through direct and indirect substitution).

   It may not always be possible to compute a budget which accounts for impacts on the stocks and fluxes associated with all relevant C pools, and we acknowledge that there is insufficient information for the construction of complete models in all cases. In such cases the omissions should be stated clearly, and the implications discussed.

2. The procedure should account for initial C stocks and expected fluxes in all C pools prior to implementation of any proposed forestry scheme or change in forest management, as well as final conditions.
3. The procedure should assess both the absolute and the marginal C benefits and costs of any proposed forestry scheme or change in forest management.

   The absolute benefits and costs for a given forestry scheme, presented in isolation from alternative options, may appear to overstate the impact of the proposed scheme. For example, a proposed afforestation programme on a certain area of land may be shown to have significant C sequestration benefits in absolute terms, but the marginal benefits of the programme may be small when compared to the alternative of leaving the land area unmanaged and permitting natural forest succession to take place. It is highly desirable, therefore, to compute marginal benefits and costs relative to both non-intervention, and to alternative strategies for intervention. The estimation of initial C stocks (criterion 2 above) is a prerequisite for calculating marginal benefits and costs.
4. The procedure should compute the C budget and present results for a period of at least 100 years from the proposed time of implementation of any forest management scheme.

5. A full and readily understandable description of the procedure should be published. The basic data on which calculations rely should always be included or referenced and be verifiable.

Procedures conforming to the above criteria still encompass a wide range of possible modelling approaches, all of which are equally valid. For example, the procedure could be implemented by carrying out direct measurement of C stocks and fluxes for all C pools, or by constructing an empirical 'book-keeping' model of C pools, stocks and fluxes, or by developing a physically- and physiologically-based model of the forest sector system. Even highly sophisticated procedures may not meet the criteria specified above, thus complexity does not guarantee correct nor consistent results.

The Intergovernmental Panel on Climate Change and Organisation for Economic Co-operation and Development have made an attempt to define a procedure for the estimation and reporting of national statistics on emissions of greenhouse gases, including emissions and/or sequestration attributable to agriculture, forestry and changes in land use (IPCC/OECD 1994).

The IPCC/OECD procedure for the 'forestry sector' concentrates on the estimation of changes in C stocks in the forest biomass and soil pools, with incomplete consideration of the wood products C pool, and no account being taken of links to consumption of fossil fuels. A separate, unrelated procedure for the 'energy sector' is used to monitor emissions resulting from burning of fossil fuels. The purpose of splitting up the overall procedure across a number of discrete sectors of human activity is to reduce the risks of double-counting of C stocks and fluxes in the calculation of national statistics. The importance of a simple methodology is also emphasised, permitting the same procedure to be applied consistently by different nations with widely varying resources and data at their disposal. However, while the IPCC/OECD methodology may provide a useful beginning for national inventories, it does not adequately quantify the impact of certain forestry schemes on the C balance.

Although it might be possible to use the methodology in the role of a 'global carbon tracking system' (Chapter 17), it fails to meet any of the five criteria specified above. Most importantly, the inability of the procedure to account for linkages between forest management and fossil fuel consumption renders it inappropriate for assessing the potential impacts of alternative forest management schemes and policies.

DATA FOR ASSESSMENT OF CARBON SEQUESTRATION POTENTIAL

At the global scale, considerable research effort has been directed towards quantifying stocks and fluxes of C in forest ecosystems. The most recent global estimates are those of Dixon et al. (1994) who estimate 1146 Pg C in the biomass, necromass and soil of forests, and an estimated flux for the year 1990 of 0.9 ±0.2 Pg C to the atmosphere, primarily due to deforestation. Compared to forest ecosystems, little work has been done on the assessment of global C stocks and fluxes associated with the wood products pool, hence estimates are less certain. Estimates of C stocks and fluxes attributable to forest ecosystems and forest management are derived using procedures to quantify the contributions of vegetation and soils, and to evaluate the effects of land-use pressures, management, manufacture of forest products and bioenergy utilization, on the forest C budgets within specific geographic regions. Such regional assessments must be founded on reliable data, which include:

1. Data on areas and C densities of forest ecosystems (biomass, necromass and soil), and changes in areas and C densities associated with forest growth, succession and management.

2. Data on the fate of harvested wood and the impact of harvesting methods and wood utilisation on the size of the wood products C pool.
3. Data on the impacts of different methods of forest management, wood processing and wood use in terms of consumption of fossil fuels.

Data on carbon in forest ecosystems

Forest inventory data provide extensive and detailed information on forest composition, structure and productivity, vital for assessing current and future levels of biomass. A variety of inventory methodologies are in use, based on either direct survey or remote sensing systems. Methods which include the use of yield tables and models have the important advantage that future growth and timber production can be predicted readily. Forest inventory techniques based on remote sensing methods, including the interpretation of satellite images, are currently under development but must still be translated with the help of traditional forest inventory data or models. Forest inventory data must often be adapted or extrapolated to estimate C stocks in forest biomass. Typically, estimates of timber volume have to be expressed in terms of biomass and then inflated to allow for other forest ecosystem components using 'total-to-merchantable ratios'.

Data on soils, ecosystem types, forest health and past disturbances have been collected for some regions of the world, but for many areas data are unreliable, unrepresentative or simply not available. Global databases on soils and ecosystem distribution have been compiled (e.g., Olson et al. 1983; Zinke et al. 1986), although these are necessarily of coarse spatial resolution. Data on soil organic C content, classified according to soil, ecosystem and land use type, are critical to the assessment of the impact of land-use change and forest management on soil C content. Great care needs to be taken to evaluate changes in soil C content where there is reason to suspect that this is not stable. When assessing the impacts of changes in management on soil C content, data are required at the process level on rates of soil organic matter accumulation, decomposition, turnover rates and humification rates, for use in conjunction with models of soil C dynamics.

Forest health or 'condition' data provide information on a range of phenomena that can affect the long term productivity of forests, for example attacks by pathogens or insects, site degradation and incidence of fire or pollution. These data are essential for predicting long-term future C sequestration by forests under different systems of management. It may not always be straightforward to infer the impacts of natural disturbances on C pools from data which may merely indicate the area of land affected. Data on the severity of damage to an ecosystem by fire and subsequent recovery, for example, are difficult to find and usually only apply to specific case studies.

Data on carbon in wood products

Several global estimates of C stocks in this pool were proposed at the Workshop. Birdsey (USDA Forest Service, Portland, 1994, pers. comm.) extrapolated calculations for the USA (from Heath et al., Chapter 22) to the global level, to arrive at an estimate of 4 Pg C in long-lived wood products (greater than 1 year life-span). Houghton (Woods Hole Research Center, Woods Hole MA, 1994, pers. comm.) proposed a global estimate of 15 Pg C in both short-lived and long-lived products. Kurz (ESSA Technologies Ltd, Vancouver, 1994, pers. comm.) noted that estimates for Canada suggested that the C stored in long-lived products constituted approximately 25% of the total stored in all wood products, a result which appears consistent with those of Birdsey and Houghton. Our own calculations, based on Food and

Agriculture Organisation statistics on global wood harvesting, and decay curves for wood products used by Harmon et al. (1990), suggest that global C stocks in long-lived products lie in the range 2–8 Pg C, which encompasses Birdsey's estimate. Comparison of Houghton's estimate with that of Dixon et al. (1994) for forest ecosystem C, suggests that C in wood products amounts to 1.3% of that in forest ecosystems. Similar calculations based on estimates of C in forest ecosystems and in home-grown wood products in Britain (Matthews, Forestry Commission Research Division, Farnham, UK, 1994, pers. comm.) suggests a ratio of about 1.8% for that country. The ratio for Britain might be expected to be higher than the global value, given that 90% of the forest area in Britain is commercially productive. The above estimates are the best currently available, and suggest that C stocks in the wood products pool are small compared to stocks in forest ecosystems.

In many countries it is quite possible to obtain adequate data for the determination of the quantity of C flowing into the wood products pool, broken down by product categories. In contrast, it is very difficult technically to calculate the quantity of C flowing out of the wood products pool. Different research groups use similar methods to estimate the rate of C loss to the atmosphere due to decay or destruction of wood products (see for example Thompson and Matthews 1989; Dewar 1990; Harmon et al. 1990; Marland and Marland 1992; Nabuurs and Mohren 1993; Fischlin and Bugmann 1994; Karjalainen et al. 1994). Curves are constructed, often by guesswork, for estimating the fraction of C remaining in different categories of wood products since time of manufacture. An assumption may then be made that the shapes of these 'decay curves' for different products have not changed over time; given this assumption, releases of C from the wood products pool will reflect the current and previous inputs, allowing changes in the quantity of C in the wood products pool to be estimated. The robustness of such an assumption is unclear, however; for example the 'half-life' of houses built in 1900 is unlikely to be the same as that for houses built in 1994. Houses are often not demolished so much as renovated, and it is difficult to determine the subsequent fate of wood products as they fall out of use and are re-used, burned or otherwise disposed of. For those products that are dumped in landfills, the rate of decay is dependent upon the product type, local climate and other site factors.

Data on wood products and fossil fuel consumption

The relative magnitudes of the global estimates of C stocks for forest ecosystems and wood products might suggest that wood products make an insignificant contribution to the C budgets of forest ecosystems, and offer limited potential for C sequestration. Nevertheless, at the regional and local scale, and for certain types of forests and systems of management and wood use, C sequestered in wood products could over time exceed C sequestered in forest biomass (see for example Thompson and Matthews 1989). Furthermore, in many cases, carbon dioxide emissions saved through direct and indirect substitution by wood products could constitute the single most important element of the C budget of a forestry scheme (see for example Marland and Marland 1992; Chapters 18 and 19). This important component is, however, the least well understood, few supporting data are available and it is not clear how to proceed with calculations.

There are in particular, methodological difficulties in interpreting data on energy and materials consumption for calculating the quantity of C attributable to indirect substitution. Different materials are used in different quantities for the manufacture of the same good, and have different life cycles and life times. For example, per unit mass manufactured wood is less energy-consuming than steel, but a wooden bridge will need a much larger volume of wood than of steel to achieve the same strength. Furthermore, the wooden bridge may not last as long as the steel one (although if well designed it could last longer). Finally, the materials used to make either the wooden or steel bridge may be recycled or re-used in different ways when the bridge is replaced.

Although direct and indirect substitution could potentially constitute the most significant elements of the C budgets for certain forestry schemes, the actual quantity of fossil fuel displaced by wood fuel and energy-efficient wood products often would not be under control in practice but would be determined largely by market forces. In some instances, for example, it could be argued that making additional energy available through efficient use of biomass fuels would simply increase the total supply of primary fuels without actually substituting for current fossil fuel consumption; on the other hand, this fuel would serve to improve lifestyles and must in the long term meet a demand for energy services that would eventually otherwise be met by fossil fuels. Clearly there is a need for more data on the ways in which wood products are used, and on the materials for which they substitute.

POTENTIAL POSITIVE IMPACTS OF FOREST MANAGEMENT ON CARBON SEQUESTRATION

Following on from the discussion of methodologies above, we have reviewed a range of options for changing forest management and forest policy, and have attempted to identify those options with the most potential for increased C sequestration. We must stress, however, that the following discussion is concerned with the impact of various forestry options in terms of C sequestration only, thus excluding wider discussion of social, environmental and economic impacts. It is also important to recognise that the applicability and benefits of the various options may be very site-specific, and that the most appropriate management decision for any given land area will depend on site-specific characteristics such as productivity, the potential efficiency of harvest, and current land use.

Preservation and protection of existing forests

This was considered one of the most important options, not least because of the significant contribution to atmospheric C estimated to be made by deforestation. Clear-cutting of primary forest continues across the boreal, temperate and tropical zones of the world. Where clear-cutting of long-established virgin forest is followed by the establishment of commercial plantation forests or agroforestry systems, it is doubtful that the C released to the atmosphere will ever be fully recovered within the ecosystem. This may not necessarily be the case, however, for forests that are subjected to frequent disturbances, such as interventions by fire (for a specific example see Chapter 23). Marland and Marland (1992) have shown that for sites with large, mature trees and low productivity, it can take many years after harvest to return to the original state in terms of net C sequestered from the atmosphere. In many areas where deforestation is followed by major land degradation, protection of existing forests may be the most significant action that can be taken to maintain and enhance C sequestration potential (P Fearnside, National Institute for Research in the Amazon, Manaus, 1994, pers. comm.).

Afforestation

On many sites, notably certain lands previously denuded of trees or degraded by exploitation for agriculture, afforestation is a significant option for achieving C sequestration. Afforestation can take the form of tree planting or natural succession or some combination of the two. The impact of afforestation is highly site-specific, however. For example, large-scale afforestation for C sequestration is likely to be inappropriate on sites of low potential productivity with an existing high soil C content, notably peatlands, where site preparation and tree planting are likely to result in a significant loss of C from such soils.

Other options

In addition to forest protection and afforestation, there are a number of forest management tools which could also be applied to existing forests and are worthy of consideration as part of a strategy for C sequestration:

- Improved utilisation of wood harvesting and processing residues (e.g., for biomass fuel). This option is only viable if site productivity is not compromised by increased removals of biomass. Purpose-grown wood fuel crops could also be established on ex-agricultural sites. This option is only viable if excessive energy consumption is avoided in fuel processing and fertiliser applications to maintain productivity.
- Longer rotation ages for managed stands of trees ('elevation of standing crops'; Fischlin and Bugmann 1994). The prime objective of this option is to increase the total quantity of C on the forested site. This could involve simply retaining even-aged stands for longer between clear-cuts (Chapter 21), or could involve the introduction of 'continuous-cover' management methods or conversion of coppice to high forest.
- Site preparation for forest establishment, provided that care is taken not to consume excessive fossil-fuel energy in the process nor to disturb existing stocks of C at the site. Some site preparation techniques may produce benefits extending for several rotations.
- Improving site productivity and C density by means such as fertilisation, provided that the fossil fuel energy consumed to make the fertiliser does not negate increased productivity.
- Matching of tree species for planting to site types to achieve optimum productivity and C density.
- Tree breeding to improve productivity and C density.
- Silviculture to increase the proportion of harvested wood in high-value product categories (e.g., thinning, pruning). High value wood products are more likely to be long-lived, thus it may be possible to enhance the accumulation of C in the wood products pool. Perhaps more importantly, high value sawnwood is among the least energy-intensive of materials and can substitute for steel, concrete, aluminium and other materials with resultant energy savings and reductions in consumption of fossil fuel. The manufacture of wood products is often made more energy-efficient by using scrap wood as a fuel source for the manufacturing process.
- Urban forestry. Besides the stored C, trees in urban areas usually improve the city climate and may contribute to reduced consumption of fossil fuels for air conditioning or heating of buildings.

The evaluation of the relative importance of the above options, in terms of their potential for sustaining or increasing C sequestration, requires information not only on the relative effectiveness of each option per unit of land area, but also on areas of land over which each option can be appropriately applied. Not all of this information is currently available but it is apparent from the diversity of ecosystems and types of land use around the globe that there are no blanket prescriptions for forest management and forest policy to achieve an enhancement of C sequestration by forests.

WIDER IMPACTS OF FOREST MANAGEMENT TO ENHANCE CARBON SEQUESTRATION

The wider impacts discussed below are of peripheral relevance to a consideration of methodologies for the estimation of the C sequestration potential of forests and forestry schemes and a more thorough discussion may be found in Duinker et al. (Chapter 32). Nevertheless, it is in this wider context that our results, conclusions and recommendations will be judged and acted on by policy-makers, forest managers and the general public. When evaluating afforestation schemes or other proposals for forest management for their C sequestration potential, there is a risk that the consequences for other benefits accruing from the forest may be neglected. Concentrating on C sequestration alone can be useful for purely analytical purposes, but we have to keep in mind that both negative and positive side effects can occur. In certain circumstances, for example, trying to maximise on-site or off-site C stocks through intensive management of a forest ecosystem could reduce ecological diversity. On the other hand, ecological diversity could be increased if such management was implemented on lands previously managed in marginal agriculture or in other degraded states. If not too much emphasis is put on C sequestration, then it should be possible to reap the traditional benefits of the forest at the same time. A local community in the Sahel region may benefit from shelterbelts as being sources of fuelwood or urban climate may improve because street-side trees have been planted.

In fact, there are a number of socio-economic issues that bear importantly on the use of forests, wood products and biofuels for mitigating the increase of CO_2 in the atmosphere. Perhaps most important is the fact that forest lands serve a variety of public and private purposes including habitation, recreation, aesthetics, protection of watersheds, protecting biodiversity, and so on. There is widespread public sentiment attached to the preservation of forests. It is frequently envisioned that using forests to mitigate atmospheric CO_2 is synonymous with increasing the extent and C density of forests and people do not easily perceive that this goal is often best served by careful and efficient harvest and utilisation of forest resources.

Conflict may arise between short-term and long-term objectives in that, for example, early net losses of C to the atmosphere may be followed by increased sequestration later. To select the forest management strategies that will most effectively serve long-term goals may require planning horizons longer than those generally used in the political process and achieved by setting short-term goals. Long-term planning of forest strategies may also bear on world timber markets and world trade in timber and exploitation of forest resources. The point is that the way forests are managed in one area will have an impact upon forest management in other areas as well. For example, protecting forests in one area may simply hasten their destruction elsewhere and increasing wood production in one area may depress markets elsewhere.

Ultimately, we can expect that any C policy-driven efforts aimed at achieving an increase in forest area or forest products to mitigate increases in atmospheric CO_2 will be strongly influenced by the perceived value of forest land and the demand for forest products. Forest expansion can be stimulated if incentives are offered to encourage displacement of energy-intensive materials by wood products or if a market for wood is generated in the energy sector or if tax or other public policy creates incentives for storing C in forest lands.

Normally, forest policy and forest management are determined primarily by economic considerations, for example an afforestation project may be justified in terms of a cost-benefit analysis. Having demonstrated the apparent viability of a particular forestry project in purely financial terms, the analysis may be supplemented by a consideration of other costs and benefits, including C sequestration. Of course, analysis of the potential damages from climate change may lead us to conclude that there is great economic benefit in using forest land to mitigate net emissions of C to the atmosphere and to adopt public policies that give greater value to this objective.

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